2nd Meeting of the
Scientific Steering Committee
for the
Analysis, Integration and Modeling of the Earth System
(AIMES) Core Project

Joint Meeting with WCRP/WGCM: 27 September, 2006
AIMES SSC Meeting: 28-29 September, 2006
Victoria, BC Canada

Agenda and Working Papers
An IGBP Core Project
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2006 Participant List

Ayako Abe-Ouchi
Center for Climate System Research (CCSR)
The University of Tokyo
4-6-1, Komaba, Meguro
Tokyo, 153- 8904 JAPAN
+81-3 5453 3955,
abeouchi@ccsr.u-tokyo.ac.jp

Laurent Bopp
LSCe
Institut Pierre Simon Laplace
CE/Saclay, Orme des Merisiers, Bât. 709;
F-91191 Gif-sur-Yvette Cedex FRANCE
bopp@lsc.e-saclay.cea.fr

Julie Brigham-Grette (PAGES CHAIR)
Dept of Geosciences
611 N. Pleasant Street
Morrill Science Building
University of Massachusetts
Amherst, MA 01003, USA
+1 413-545-4840
juliebg@geo.umass.edu

Jérôme Chappellaz
Laboratoire de Glaciologie et Geophysique de l’Environnement
UMR 5183 CNRS-UJF
54 rue Molière - Domaine Universitaire - BP 96
FR-38402 St Martin d’Hères Cedex FRANCE
+33 4 76 82 42 64
jerome@lpg.leg.grenoble.fr

Susan Chavez
NCAR
PO Box 3000
Boulder, CO 80303 USA
+1 303.497.1611
chavez@ucar.edu

Robert Costanza
Gund Institute of Ecological Economics
The University of Vermont
590 Main Street
Burlington, VT 05405-1708 USA
+1-802 656 2774
rcostanz@uvm.edu

Carole Crumley
Department of Anthropology
University of North Carolina
301 Alumni Building; Chapel Hill, N. C.
27599-3115 USA
+1 919 962-5527
crumley@unc.edu
Pierre Friedlingstein
IPSL/LSCE
CEA/Saclay
Orme des Merisiers, Bât. 701
FR-91191 Gif sur Yvette FRANCE
(33-1) 6908 8730
pierre.friedlingstein@cea.fr

Congbin Fu
Institute of Atmospheric Physics
Chinese Academy of Sciences
P.O. Box 9804; Qi Jia Huo Zi, De Sheng
Men Wai Street
Chao Yang District
Beijing 100029 CHINA
+86 10 6204 1317
fcb@tea.ac.cn

Claire Granier
Service d'Aéologie/IPSL
University of Paris
6 Boite 102 75005 Paris FRANCE
+33 (0) 1 44 27 84 21
claire.granier@aero.jussieu.fr

Kathy Hibbard
NCAR
Box 3000
Boulder, CO 80303 USA
+1 303.497.1706
kathyh@ucar.edu

Suzi Kerr
Motu Economic and Public Policy Research
Level 1, 93 Cuba Mall, P.O. Box 24390,
Wellington, New Zealand
+64-4-939-4250
suzi.kerr@motu.org.nz
Natalie Mahowald  
National Center for Atmospheric Research  
Climate and Global Dynamics Division  
PO Box 3000  
Boulder, co 80307-3000 USA  
+1-303 497 1719  
mahowald@ncar.ucar.edu

Luiz Martinelli  
Centro de Energía Nuclear na Agricultura (CENA)  
Universidade de Sao Paulo  
Av. Centenário, 303;  
13416-000 Piracicaba; Sao Paulo BRAZIL  
+55 19 3429 4674  
zebu@cen.sp.br

Kevin Noone  
IGBP Secretariat  
Executive Director  
Stockholm, Sweden  
+ 46-8 166 448  
kevin@igbp.kva.se

I.C. Prentice  
QUEST - Earth Sciences  
University of Bristol  
Wills Memorial Building  
Queens Road  
Bristol BS8 1RJ  
Colin.Prentice@bristol.ac.uk

David Schimel  
NCAR  
Box 3000  
Boulder, CO 80303 USA  
+1 303.497.1610  
schimel@ucar.edu

Anond Snidvongs  
Southeast Asia START Regional Center and Department of Marine Science  
Chulalongkorn University  
Old SWU Building No. 5, Henri Dunant Rd.  
Bangkok THAILAND  
+66 2 218 9464  
anond@start.or.th

Mat Williams  
School of GeoSciences  
Institute of Atmospheric and Environmental Sciences; University of  
Edinburgh  
Mayfield Rd, Edinburgh  
EH9 3JU UK  
+0131 650 7776  
mat.williams@ed.ac.uk

Apologies From:

Paul Falkowski  
Jonathon Foley  
Diana Liverman  
Denise Mauzerall  
Carlos Nobre
Transportation from the Airport
Both taxis and an airport shuttle are available on arrival. Estimated cab fare from the airport to downtown Victoria is $50.00 CDN. The airport shuttle costs $14.00 CDN and provides daily half-hour service to and from the airport to all hotels and motels in Greater Victoria. There are also a number of car rental companies on site.

The venue for the meeting is:
The meeting rooms are booked.

**Hotel reservations**
A block of hotel rooms is reserved for the majority of the participants.
Room Booking: to book a room, individuals should call the Reservations Department at 1-800-667-4677 or email: vic.reservations@deltahotels.com
Callers must identify themselves as being with the “WCRP/WGCM/AIMES Group”.
Deadline for reservations is 24 August 2006.
Room rate: CDN$ 179.00 single/double per night plus 17% tax

A small block of more economical rooms are reserved at the:
Queen Victoria Hotel and Suites: [http://queenvictoriainn.com/](http://queenvictoriainn.com/)
Room Booking: to book a room, individuals should contact the Reservation Department at one of the following numbers/email:
Toll Free: 1-800-663-7007
Direct: 1-(250)-386-1312
Email: reservations@qvhotel.com
In order to obtain the preferred room rate individuals must identify themselves as being with either the Group Name: WCRP/WGCM/AIMES or Group Number: 6284
Deadline for reservations must is 24 August 2006.
Room rate: CDN$ 125.00 CDN per night plus 17% tax

A complimentary shuttle service is provided by the Queen Victoria Hotel. Delegates staying there can schedule a daily shuttle to take them to the meeting site at the Delta Victoria Ocean Pointe. Otherwise, the meeting venue is a comfortable distance away for those who prefer to walk. There are also small harbour ferries to shuttle the delegates back and forth between the Delta Ocean Pointe Hotel and the Inner Harbour (these are small distances). Please see information at: [http://www.harbourferry.com/](http://www.harbourferry.com/)

**Banquet**
The banquet will be held in the Delta Ocean Pointe Hotel dining room - named the "Lure". A private section, slightly elevated from the surrounding diners with a view of the Inner Harbour, is reserved for your group the evening of Wednesday, 27 September 2006. The menu will be fixed with a selection of two or three choices of entrée. The specifics of the soup, salad, entrée and dessert choices are still under discussion.

Information on Victoria
Tourism Victoria
The City of Victoria
[http://www.city.victoria.bc.ca/common/index.shtml](http://www.city.victoria.bc.ca/common/index.shtml)
Draft agenda

DAY 1  Wednesday, September 27

JOINT SESSION: WGCM-AIMES

0845-0900  Welcome and outline of joint WGCM-AIMES session (J.Mitchell, D.Schimel)
0900-1230  Session: G.Meehl to lead
0900-1000
  ▪ Overview/summary of Aspen Workshop
  ▪ Response/discussion from non-Aspen participants
1000-1030  Discussion
1030-1100  Coffee break
1100-1200  Review of modelling group responses to survey regarding near-future modelling plans
1200-1230  Discussion
1230-1400  Lunch break
1400-1500  Session: D.Schimel to lead
  Revisit experimental design from Aspen Workshop: Not only for scientific credibility but also for a design that allows people to evaluate, in some scaleable way, the consequences of mitigation options
1500-1530  Coffee break
1530-1700  Session led by J.Mitchell
  ▪ Discussion and formulate conclusions for white paper
  ▪ Next meeting of WGCM-AIMES
1700  Closure of the session
1800  Joint AIMES/WGCM Banquet
DAY 2  
Thursday, September 28

**ASSESSMENT, REPORTS AND EARTH SYSTEM MODELING**

0845-0900  Welcome, approval of 2005 minutes, outline of meeting structure (D. Schimel, I.C. Prentice)
0900-1030  Aspen AR5 White Paper: Discussion and Strategy (K. Hibbard, D. Schimel)
1030-1100  **Coffee break**
1030-1100  IHOPE (Costanza/Crumley)
1100-1130  Young Scientists Network (N. Mahowald)
1130-1200  GEIA: update and proposed assessment activity (C. Granier)
1200-1230  Regional/Global Interactions: MAIRS (C. Fu, A. Snidvongs)
1230-1400  **Lunch break**
1400-1530  *Earth System Modeling: Carbon Cycle Feedbacks* (P. Friedlingstein)

Implementation of ‘core’ carbon cycle components in ESM’s: status, reality checks. Next C4MIP meeting, …

1530-1600  **Coffee break**
1600-1700  *Discussion: Future Directions in ESM’s: Applied Earth System Modeling / C4MIP to CxMIP*

Carbon-Climate Chemistry, Aerosols, Ecosystem Services,…

1800  AIMES Dinner
## Future Strategies: Modeling, Integrating Human Dimensions and Capacity Building

**Friday, September 29**

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<tr>
<td>0900-1000</td>
<td>Discussion of AIMES and the WCRP/COPES/WMP activities <em>(D. Schimel)</em></td>
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<td>Review of COPES and WMP, AIMES as an official partner with WCRP and COPES strategy, AIMES Terms of Reference and the WCRP</td>
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<td>1000-1030</td>
<td>Applied Earth System Science: Template for an IGBP Strategy <em>(D. Schimel, K. Hibbard)</em></td>
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<td>1030-1100</td>
<td>Coffee break</td>
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<td>1100-1130</td>
<td>Development of Simple Integrated Models <em>(S. Kerr)</em></td>
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<td>1130-1200</td>
<td>Modeling Ecosystem Services in the Earth System <em>(R. Costanza)</em></td>
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<td>1230-1400</td>
<td>Lunch break</td>
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<td>1400-1430</td>
<td>Proposal for Capacity Building Institute with START: Latin America and Earth System Modeling: a mini-IPCC <em>(Hibbard)</em></td>
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<td>1600-1700</td>
<td>AIMES Open Science Meeting, SSC Rotation, Next AIMES SSC</td>
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<tr>
<td>1700</td>
<td>Close of Meeting</td>
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Earth System Models: The Next Generation
Report from Aspen Global Change Institute session, July 30-August 5, 2006
Gerald A. Meehl and Kathy Hibbard (and session participants—see list at end)
September 20, 2006

We are now on the threshold of including Earth system model (ESM) components in “standard”
global coupled climate models used for climate change projections. At present, these standard
models (referred to generically as atmosphere-ocean general circulation models, or AOGCMs)
include components of atmosphere, ocean, land and sea ice. Some modeling centers have
incorporated simple carbon cycle models into AOGCM’s (e.g., Cox et al. 2000, Friedlingstein et
al. 2006), and additional candidate components include aerosols, chemistry, and dynamic
vegetation, as discussed below.

Assuming the Intergovernmental Panel for Climate Change (IPCC) Fifth Assessment Report
(AR5) publication date is early 2013, modeling groups are making decisions this year (2006) on
what form their next generation models will take (to be used for climate change projections).
New emission scenarios have been and continue to be developed by the integrated assessment
community and others (e.g. mitigation/adaptation, also referred to as stabilization). Many of
these scenarios reflect the recommendations of the 25th IPCC Session (April 2006) that the
following four elements should be addressed in the development of new scenarios: (1) Consistency
between scenarios used for studying climate change, climate change impacts and
adaptation and mitigation, (2) Comparability of scenarios by using comparable definitions and
assumptions (the content of the definitions and assumptions should be entirely defined by the
scientific community itself), (3) Transparency and openness of the development process; and (4)
Substantive involvement of experts from developing countries and economies in transition in the
scenario development process. However, the climate modeling community does not have the
expertise to evaluate scenarios in order to choose a subset to run in emerging ESMs. The
experimental design proposed in this report takes this into account, and also addresses the first
three recommendations (see below), with an extra effort needed towards the fourth. The new
scenarios will come to bear on climate change projections for assessment in the IPCC AR5 with
the new emerging Earth system models.

Thus, there has been a confluence of activities in model development and scenario development
that must be communicated and coordinated across various groups and scientific communities
this year. To this end, a session of the Aspen Global Change Institute was convened from July
30-August 5, 2006, to address five major objectives:

1. Identify new components that are currently under implementation or will be ready in the
next six months for inclusion in AOGCMs

2. Establish communication through WCRP, IGDP, IPCC, the climate impacts community,
and integrated assessment (IA) modeling teams to coordinate activities in preparation for
cclimate change simulations that will be performed with this next generation of climate
system models for the IPCC AR5

3. Propose an experimental design for 21st century climate change experiments with these
models (near term and longer term time frames)
4. Specify the requirements for these new models in terms of time series of constituents from new stabilization scenarios (particularly with regard to impacts, mitigation, and adaptation).

Updates regarding current status of four new components for earth system models were discussed, along with scientific issues involved with coupling these components into emerging ESMs. Summary points for the status of carbon cycle and dynamic vegetation to be incorporated in AOGCMs included:

- Empirical evidence indicates that the carbon cycle responds to climate change, and first generation coupled carbon cycle models indicate the possibility of a large positive carbon cycle feedback to global change (Cox et al. 2000, Fung et al., 2005, Friedlingstein et al. 2006). This makes the challenge of achieving any particular stabilization target more difficult to achieve. Therefore, the community is moving towards including aspects of the carbon cycle and dynamic vegetation in emerging Earth system models.

- Some models already include a closed carbon cycle, but none have yet consistently included the impacts of land use change, land management, and wildland fires. These dynamics are under development in some groups and will be a priority for models to be used for the AR5.

- We also expect some models to include a simple representation of ocean biology for the AR5.

- Although all models won’t include other potentially important processes such as micronutrient limitations on ocean ecosystems, ocean bottom chemistry, nutrient limitations on terrestrial ecosystems (e.g., nitrogen), impact of anthropogenic management on fires and increases in tropospheric ozone, it is anticipated that some models may be implementing some or all of these.

- Modeling groups are also implementing various strategies for biogeography and successional processes.

Summary points for aerosols and chemistry to be incorporated in AOGCMs included:

- Aerosols and chemistry need to be considered in Earth system models for a number of reasons, including aerosol composition, effect of pollution on the biosphere and air quality. Indeed, a new consideration for IPCC is the ability of the ESM to provide insight into air quality trends, for use by impacts and scenario communities.

- For the AR5, most models will have a representation of the indirect effect of aerosols. However, mixed phase and ice phase cloud-aerosol interactions are likely to be handled rather crudely in the AR5 simulations and are a subject of ongoing research.

- The representation of aerosols and chemistry is likely to be more comprehensive for near-term (2005-2030) than for long term (2100 and beyond) experiments partly due to
computational resource limitations and computing demands. In addition, the climate effects of aerosols and chemistry are expected to be particularly important over the near-term time frame.

Taking into account the state-of-the-art of these new components, session participants (who represented relevant communities involved with WCRP, IGBP, the former Task Group on New Emissions Scenarios (TGNES), and IPCC Working Groups I, II and III). An experimental design for community coordinated climate change projection experiments was proposed for the next IPCC AR5 assessment. These fell into two timescales involving different scientific problems, policy considerations, scenario issues, and model configurations.

**Proposed AR5 Experimental Design for Coordinated Climate Change Projections**

1. **Near term (2005-2030)**

The primary goal of projections for the next 25 years is to provide better guidance as to the likelihood of changes in extremes on the regional scale. To produce such regional scale predictions will require finer resolution models (at least ½ to 1 degree in the atmosphere, but other resolutions are possible, as well as increased vertical resolution and domain) with the inclusion of simple chemistry, aerosols, and dynamic vegetation, but an interactive carbon cycle is not required on this timescale. Both improved process representation and higher resolution are important and compromises will be required to make the simulations computationally feasible.

To determine the significance of regional changes, especially those of extremes, will require numerous simulations in an ensemble approach. Given that scenarios of long-lived greenhouse gases do not differ substantially prior to 2030, a single, mid-range scenario is anticipated to be used in model predictions. For this time frame the relatively small magnitude of climate change will make signal to noise discrimination even more difficult. A single, base-case scenario for the well-mixed gases along with several air pollution estimates (i.e., aerosol and short-lived gas emissions) both low and high is proposed. The number of ensemble simulations to be performed is somewhat uncertain, but a minimum of 10 ensemble members for each case should be performed and discriminating changes in hydrologic extremes may require even more.

Two optional scenarios were identified: (1) A number of scenarios for pollutants (aerosols and short-lived gases) to study their effects on weather could be provided for low, medium and high emission projections as perturbations around the standard scenario, and (2) Testing geo-engineering hypotheses (e.g., injecting sulfur into either the stratosphere or troposphere) with model experiments to mitigate climate change. Interactions and feedbacks to the climate system would nevertheless need to be explored with ESMs to try and ascertain unintended consequences on other Earth System model components such as ecosystems and atmospheric chemistry.

Near-term simulations will also require accurate reconstruction of ocean salinity data and soil moisture initializations which are currently problematic due to sparse observations. Improved initialization datasets incorporating observed soil conditions and sea ice may be required. To incorporate past climate forcings, for model verification, and for the coupled
assimilation/initialization process, simulations should start during the latter half of the 20th century.

2. **Long term (2005-2100 and beyond)**

The goal for longer term projections is to quantify the various feedbacks in the climate system involving earth system components related to climate outcomes for different scenarios that could be affected by various socio-economic and policy considerations (e.g., stabilization). Therefore, coupled initialization is not required for long term runs (e.g., 1850-2100/2300) as the model initial conditions for 1850 are from equilibrium runs. A lower resolution AOGCM (roughly 2 degree) could be used with a more conventional pre-industrial spin-up, followed by a 20th century experiment with natural and anthropogenic forcings (at least 10 member ensembles would be required for detection/attrition studies), leading to an A1B-type mid-range 21st century experiment as a single member. This set-up would correspond to what was done for the IPCC AR4 and would provide a reference to earlier experiments, as well as supply a multi-model ensemble of a mid-range scenario for analysis. Two benchmark stabilization scenario experiments would then be performed:

1. high forcing, perhaps A2-type stabilization scenario
2. low forcing, perhaps B1-type stabilization scenario

At least one ensemble member would be run for each, with carbon cycle and biogeography active, and chemistry and aerosols prescribed and time-evolving. Initially the experiments would be run to 2100, then concentrations stabilized after 2100, and the models run out to 2300. Two experiments from 2005 to 2100 would be run for each scenario:

**Experiment 1**: Both AOGCM and AOGCMs coupled to the carbon cycle (ESMs) run with a time series scenario of prescribed CO₂ concentrations. In this run, the climate system is allowed to respond to prescribed CO₂ concentrations. Coupled carbon cycle-climate ESMs produce time series of CO₂ fluxes from the land-atmosphere and ocean-atmosphere that do not enter the atmosphere or impact the climate system response. The internally calculated land/ocean CO₂ fluxes plus the prescribed increase in atmospheric CO₂ produce an implied CO₂ emission rate (F(t)) and are provided to WG3 and IA modeling groups to derive mitigation policies to achieve those allowed emissions. Non-ESM groups (standard AOGCMs) without a carbon cycle component can also run this experiment to derive climate system response to changing CO₂ concentrations as occurred in the AR4.

**Experiment 2**: The second experiment is similar to Experiment 1, with the exception that the atmospheric CO₂ concentrations are held constant at pre-industrial levels for radiative calculations but not for other ESM components. The derived emissions from Experiment 2 represent no carbon cycle-climate feedback to the prescribed atmospheric CO₂ concentrations. Comparing Experiments 1 and 2 provides an indicator of the magnitude of the carbon cycle feedback in terms of different emissions.

**Experiment 3 (optional)**: A third experiment is proposed to quantify the climate response with an active carbon cycle. This experiment uses the implied emissions from Experiment 2, but with

Comment [01]: Maybe a smoother emission pathway towards stabilization could be used instead of a sudden stabilization in 2100 if WG3 can suggest something better.
active carbon cycle feedbacks that can change the atmospheric CO2 concentrations. The difference between experiments 1 and 3 gives the magnitude of the carbon cycle feedback in terms of the climate response (e.g. temperature).

This experimental design has a number of desirable features as well as requirements:

- Different timescales of climate change projections require different approaches in terms of model configurations and scientific and policy problems of interest.

- Relatively few future climate projection simulations would be required of the ESMs using two new benchmark stabilization scenarios (for high and low forcing). For the AR4 there were three future climate projection simulations. For the proposed new coordinated experiments, there are four for groups with ESMs (and two optional experiments), and two for groups with AOGCMs.

- Non-ESM results can be directly compared with the ESM results for the physical climate system (i.e. modeling groups without new earth system-type components (e.g. no carbon cycle) can still participate by running either the near-term projection, the longer term projection (just Experiment 1, or both).

- Using benchmark stabilization concentration scenarios allows the WG3 community to provide these scenarios to the WG1 community in a timely manner without the WG1 community having to evaluate and choose individual scenarios, this being outside their area of expertise. The development of a complete new set of scenarios would take several years and WG3 have assessed revised SRES and some new scenarios (from the literature) that are available immediately. Based on these revised SRES and corresponding stabilization scenarios, WG1 supplies emission time series back to WG3 scientists, who derive socio-economic constraints to achieve those emissions stabilization pathways. This is the reverse of what has typically been done up to now (i.e. with socio-economics as the starting point, generating emissions, concentrations, climate response, impacts analysis). Impacts are analyzed from the climate response experiments as before. WG3 will therefore evaluate socio-economic assumptions to achieve stabilization.

- The process involved with this experimental design establishes pathways for necessary interactions between WG1 and WG3 communities. Community groups that can coordinate activities across their respective communities (e.g. the WCRP Working Group on Coupled Models (WGCM) for the AOGCMs, the IGBP Analysis, Integration and Modeling of the Earth System (AIMES) for biogeochemistry) need to be formed for WG2 and WG3 to allow better overall coordination of these types of activities.

**Overall Recommendations:**

- An integrated effort is needed to produce past/current/future emissions of aerosols and ozone precursors that would ensure the use of consistent and documented data relevant to climate/carbon cycle/aerosol/chemistry communities.
• To assess regional climate change effects will require gridded emission data for aerosols and short-lived trace gases. A concerted effort will be necessary to produce these datasets.

• In order to use more up to date model projections for impacts results reported in IPCC WG2 assessment, model simulations need to be made available to impacts modelers several years before the production of the WG2 report. This could be done by either staggering the WG1 and WG2 reports or by producing new climate change simulations as soon as possible (about 2009-2010).

• There is a need for a PCMDI-equivalent for WG2 and WG3 communities where relevant climate model output can be collected, archived, and tailored for use by scientists in these communities. This could include an expanded role for the IPCC Data Distribution Center. A WGCM-type community organization mechanism is also needed for the WG2 and WG3 communities.

• WG2 and WG3 scientists need to have input to the selection of fields to be archived for analysis in the new integrations for the AR5, in particular a list of fields related to the carbon cycle.

1. Introduction

In IPCC Fourth Assessment Report (AR4), a common or core set of integrations was performed by a number of climate modeling groups (about 17). These integrations allowed the assessment of model response uncertainty to changes in the radiative forcing. The simulation of past climate changes led to identification of model errors in the simulation of present day climate and improved estimates of the human impact on climate. The future climate projections sampled the range of uncertainty associated with the various scenarios used to drive the climate models, and the uncertainty associated with the model response to the imposed forcing changes.

In the AR4 common set of integrations, three future scenarios were used by most modeling groups: the draft or marker SRES A2, A1B and B1 scenarios. More than 20 different climate models were used to make the future climate projections. The range of model responses for a given scenario represents a measure of the model response uncertainty.

An Earth System Model (ESM) simulates processes in the climate system involving the major components of atmosphere, ocean, land and sea ice, and also includes forcings and feedbacks involving the biosphere, and composition and chemistry of the atmosphere and ocean of potential importance to the physical climate (e.g. carbon cycle, aerosols, chemistry, and dynamic vegetation). Such ESMs can be used as tools to study climate impacts which are dependent on climate change, to inform climate mitigation strategies such as avoiding dangerous climate change (e.g. Amazon dieback) or verifying plausibility and providing consistency with scenarios (e.g. air quality control policy, food production, biofuels, and costs of adaptation). The ultimate ESM would include every known process in the physical and biogeochemical earth system.
Clearly at this stage we are not yet at that point, so we will be discussing ESM-type configurations with simplified biogeochemical components. For simplicity, we will refer to these types of models as “ESMs”.

The current status of modelling the Earth System is characterized by sophisticated global coupled climate models of the physical climate system including components of atmosphere, ocean, land surface and sea ice (Fig. 1, upper left). These are often referred to simply as atmosphere-ocean general circulation models or AOGCMs. The climate modelling community is now considering expanding these already complex models to encompass chemical and biological aspects of the Earth System. In particular, AOGCMs are now beginning to implement detailed sub-models, or components, of atmospheric chemistry, the carbon cycle, aerosols, and dynamic vegetation (Fig. 1, lower left). Currently, output from AOGCMs can either used to produce information on climate change impacts on line if the impact is dependent on the weather that is being simulated (e.g. heat waves), or if the impact feeds back on climate (e.g. soil moisture changes). If the impact is just dependent on the climate being simulated, the impacts can be determined separately or offline using various types of impact models or methodologies (Fig. 1, right). These can include models directly using AOGCM or ESM output (e.g. crop models) or, if higher resolution information is required, statistical downscaling or embedded regional models driven by output from the AOGM can be employed.

Earth System Models of Intermediate Complexity (EMICs) offer a complementary approach for long-term simulations. EMICs span a wide range of a hierarchy of more simplified models, but usually include coupled processes in a reduced domain (e.g. two dimensional), and can capture some of the essential feedbacks while using far less computer resources than a typical AOGCM or ESM. EMICs can therefore be used to run many more scenarios for much longer time periods than typical AOGCMs or ESMs, and can provide first order information on global temperature and sea level response (but not information on changes of variability or extremes). More holistic, exploratory models are being developed for the investigation of the interaction of human societies with the other components of the Earth System.
Scientists working in these fields as well as members of a number of international panels representing these various communities met in July 2006 at an Aspen Global Change Institute (AGCI) session. Participants represented the Working Group on Coupled Models (WGCM) and Stratospheric Processes and their Role in Climate (SPARC) from the World Climate Research Program (WCRP), and Analysis, Integration and Modeling of the Earth System (AIMES) and the International Global Atmospheric Chemistry program (IGAC) from the International Geosphere-Biosphere Program (IGBP). In addition, representatives from the emissions scenario (IPCC WG3 and the Task Group on Next Emission Scenarios (TGNES)), climate change impacts (IPCC WG2, and Task Group on Data and Scenario Support for Impact and Climate Analysis (TGICA)), and the integrated assessment communities were present. The purpose of this workshop was to define a roadmap to accelerate progress in ESMs at the international level. Several scientific issues were considered at this workshop, for example, aerosol/ cloud/ climate coupling, and vegetation/ ocean/ biogeochemistry/ climate feedbacks. The central question for the workshop was: what should be the strategy to improve our ability to model with more certainty these processes, what form will these processes take in the next generation of earth system-type models, and what would be an experimental design to address future climate change in these models with new scenarios?

The outcomes and recommendations from the joint AGCI session will provide fuel for discussion at the joint WGCM/AIMES meeting in September 2006 as well as the Earth System Science Partnership (ESSP) Open Science Conference in Beijing in November 2006. The objective of the workshop was to establish a coherent approach through WCRP and IGBP (jointly), and to "distribute" the responsibilities and tasks between the different IGBP and WCRP Projects in preparation for climate change simulations that would be performed by this next generation of models for the IPCC AR5. The workshop had four general objectives:

1) Identify what new components are ready now or will be ready in the next six months for inclusion in AOGCMs to be used in the IPCC AR5
2) Establish communication through WCRP, IGBP and TGNES to coordinate activities in preparation for climate change simulations that will be performed with this next generation of models for the IPCC AR5
3) Propose an experimental design for 21st climate change experiments with these models (near term and longer term time frames)
4) Specify the requirements for these new models in terms of time series of constituents from new stabilization scenarios (particularly with regard to impacts, mitigation, and adaptation).
This report outlines the new AOGCM/ESM modeling components in terms of aerosols/atmospheric chemistry and carbon cycle/dynamic vegetation components that are under development and implementation in ESMs, followed by a proposed experimental design that integrates impacts and scenarios (represented in IPCC WG2 and WG3, respectively) and physical climate science (WG1) for the next Assessment Report. We summarize with a suite of recommendations for the joint WGCM, AIMES and IPCC communities.

2. New components for inclusion in AOGCMs to make ESM-type models

**Aerosols and Chemistry**

Aerosols are important to the climate system for many reasons. They have a direct effect on heating and photolysis rates in the atmosphere by scattering and absorbing radiation. They influence the climate system indirectly by modulating cloud drop size, cloud lifetime, and precipitation, and there are other processes such as the “semi-direct” effect involving subtle modulations of the dynamical and physical processes of the atmosphere. Aerosols also act on other components of the climate system by reducing energy reaching the surface, and by transporting nutrients from one place to another. There are well documented changes in aerosol distributions due to mankind during the last few hundred years and some more changes are anticipated in the future.

There are also many photochemical processes taking place in the atmosphere which are affected by mankind. These processes influence aerosol formation and properties, and affect the climate system directly. The changes in the chemistry of the troposphere are of concern for a variety of reasons. Air quality near the Earth’s surface affects humans and ecosystems. Many aerosols are formed or influenced by chemistry (the oxidation of precursor gases to sulfate, nitrate, and secondary organic aerosols is an obvious example).

Simulating the chemistry of the atmosphere, the interactions with aerosols, and the interactions of these components with other components of the climate system are enormously complex, and computationally very costly. These components cannot be represented comprehensively in today’s AOGCMs. Simplifications must be made, and many aspects of their interactions must be ignored to be able to include them in the emerging ESM-type models. We recognize that complexity could be different for short- (up to 2030) and long-term simulations (to 2100 and beyond). In this section, we discuss some of the properties of aerosols and chemistry of the climate system which we believe are needed for the next generation of ESMs, and identify the simplifications that are appropriate in their treatment.

1. The radiative forcing by tropospheric ozone is believed to be globally small, however, it is not negligible regionally. Some representation for this effect should be employed. One way to implement this is through “time slice” photochemistry, where a reasonably comprehensive photochemical model is occasionally employed off line (e.g. a one year simulation performed once every 10 years). There may be other alternative efficient methods of producing photochemical information in the model.

2. One simplification to represent tropospheric O3 that is frequently used in today’s ESMs is the use of prescribed oxidant distributions (OH and O3 for example in the oxidation of SO2 to sulfates). Alternatively, extreme simplifications to the photochemistry can be employed (the chemistry of peroxides in the oxidation of SO2 to SO4 in clouds). While
limited treatment of most aerosols can be achieved though the use of these off-line oxidants, it is clear that an improved treatment may be required for the formation of secondary organic aerosols.

3. A number of climate feedbacks should be explored more thoroughly for the climate change problem including, but not limited to:
   - Temperature => isoprene emission => ozone => temperature
   - Temperature => monoterpenes emission => SOA => temperature
   - Climate change => DMS => sulfates => temperature
   - Climate change => lightning, fires, wetlands => O3, CH4, aerosols
   - Climate change => vegetation cover => dust emissions => climate
   - Preliminary studies indicate however that these feedbacks are likely to be not very strong; but many are positive and may add up to something larger.

4. Aerosols and some reactive chemical species (mostly ozone, carbon monoxide and nitrogen oxides) are important for impact assessments of air quality as they have a large impact on human health and crop (and more generally vegetation) yield. The occurrence of ozone episodes and nitrogen deposition can strongly impact the carbon cycle. These species should be considered in this context in the next climate assessment.

5. Interactive modeling of stratospheric ozone would alleviate the current difficulties of merging independent characterizations of ozone from tropospheric and stratospheric chemistry at the tropopause.

6. It is estimated that air quality controls may result in additional heating over the next two or three decades (because of the removal of cooling aerosols). These controls may also have an impact on precipitation over the same time scales. Feedbacks involving the vegetation (mostly ozone poisoning and nitrogen deposition) operate over multi-decadal to century timescales. Overall, the consideration of aerosol and chemistry in the next IPCC simulations will require more interaction with the integrated assessment modeling community. For this effort to be successful, consistency with assumptions made in emission scenarios (including land use) will also be required.

a. Representing aerosols and chemistry in the near- and longer-term
   In many climate modeling centers, the capability for simulating aerosols exists but the computational cost of additional tracers and processes is an issue that limits their applicability to climate assessment exercises. This is becoming even more an issue when more complex aerosol formulations are being considered. Furthermore, it is important to keep in mind that the knowledge of driving inputs (e.g., characterizing the number of primary aerosol particles emitted, individual VOC species emissions, and the vertical profiles of emissions) might be insufficient to run the most complex versions over the historical or future periods. It is unclear at this point if the full complexity is required for IPCC-type simulations. Therefore simplified versions are currently under investigation. For instance (1) bulk versus modal approach for aerosols, (2) simplified versus comprehensive gas-phase chemistry, and (3) asynchronous versus full reactive chemistry coupling.
An evaluation of these different alternatives is well underway through the participation of the various modeling groups who are involved in intercomparison exercises such as AEROCOM, CCMval, ACCENT, and the new Atmospheric Chemistry and Climate (AC&C) initiative under the auspices of SPARC and IGAC. However, it is recognized that there is a need for more coordinated intercomparison studies and common diagnostics. This should lead to more insight into what should be included in the next generation of ESMs.

The following table summarizes the status of the developments planned within the various groups represented at the workshop with respect to the aerosol and chemistry packages that will most likely be included in the core version of their climate models to be used for IPCC AR5.

<table>
<thead>
<tr>
<th>Model Center/Aerosols</th>
<th>Chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Within about 1 year</strong></td>
<td>Cost is under evaluation for all groups.</td>
</tr>
<tr>
<td>(ready to run for next IPCC)</td>
<td>At least snapshots / asynchronous coupling will be done with full chemistry (tropospheric and stratospheric) with a coupling every 5/10/20 years?</td>
</tr>
<tr>
<td>GISS: Sulfate / BC / OC / dust / sea-salt</td>
<td></td>
</tr>
<tr>
<td>Hadley: bulk, sulfate /BC / OC / dust driven from DGVM / sea-salt / SOA climatology</td>
<td></td>
</tr>
<tr>
<td>NCAR: Both bulk and modal approaches are available and being considered</td>
<td></td>
</tr>
<tr>
<td>MPI: A seven-category modal approach predicting total number and species mass in each category (M7)</td>
<td></td>
</tr>
<tr>
<td>Limited ability to represent aerosol indirect effect processes, especially in mixed phase, ice and convective clouds.</td>
<td></td>
</tr>
<tr>
<td><strong>Beyond AR 5</strong></td>
<td>Full chemistry</td>
</tr>
<tr>
<td>Full aerosol scheme</td>
<td></td>
</tr>
<tr>
<td>Comprehensive mixed and ice phase cloud microphysics</td>
<td></td>
</tr>
</tbody>
</table>

In summary, for AR5, most models will have a representation of the indirect effect of aerosols and the considered aerosol schemes will be much more comprehensive than in AR4, including more species, and treating their temporal change from past to the future. The representation of chemistry has to be more comprehensive for the near-term (2005-2030) than for the long-term (2100 and beyond) experiments. Beyond AR5, it is expected that all modeling centers will have access to enough computer power to be able to have a full representation of aerosols (for both mass and number) and gas-phase chemistry.

b. Aerosol and chemistry considerations for an experimental design
For the simulation of aerosols and chemistry, a critical item is the knowledge of historical and future emissions, which have to be consistent. In particular, because of the developments in the simulation of aerosols, it is necessary to build and assess historical emissions beyond sulfur.
These include black carbon and primary organic carbon (with some information on size if possible) and ozone precursors. The more comprehensive chemistry schemes will also require the development of a detailed speciation of volatile organic compounds (VOC) emissions. For both gaseous species and aerosols, the knowledge of emissions for different sectors is needed as emission factors and speciation depend on the emission type. In all cases, the knowledge of injection heights (smoke stacks, airplanes, biomass burning, etc.) is an important additional piece of information.

Recent studies of the carbon cycle indicate that, as a result of fire suppression policies, large areas of the western US and Canada (and possibly other parts of the world) have experienced a large decrease in fires and open burning, in contradiction with the usual assumption of an increasing number of fires over the industrial period made in previous studies. The negative trend in fire emissions at mid-latitudes could have very significant impact on the present estimate of the radiative forcing of ozone and biomass burning over the pre-industrial to present-day period. In addition, the knowledge of historical and future land use (incl. ecosystem knowledge) is necessary for the representation of past dust and biogenic emissions.

Because of the existence of a variety of historical emissions, it is unclear what the appropriate level of guidance could or should be for defining whether a single set of emissions should be used and, if so, which one. In order to minimize the amount of simulations of interest to a variety of communities (IPCC, CLRTAP), a strong effort will be required to ensure consistency in the used past/present/future emissions.

There is a strong and urgent need for an increased dialogue and collaboration between the observation, measurement, modeling and scenarios communities that utilise past and current emissions relevant to gas-phase chemistry, aerosols and carbon cycle (e.g., GEIA and IGAC). An integrated assessment or a synthesis document discussing these emissions and providing expert evaluations would be extremely useful. Such a process should be coordinated at the highest level (IPCC, IGBP, WCRP, IHDP, CLRTAP), which would ensure the existence of a consistent set of input data usable by all the communities interested in climate change science and impacts over the historical and future periods.

c. Computer cost

Very rough estimates of the additional cost (with the atmospheric model using the same model resolution serving as a reference) of a fairly simple aerosol scheme amount 30% (Hadley Center) to 100% (NCAR). For tropospheric chemistry the overhead ranges from a 50% (for simple chemistry version of the GISS model) up to a factor of 3 (NCAR) or 4 (Hadley) increase compared to the atmosphere model. It is clear that computer cost depends on how the atmospheric model is optimized and on the type of platform. In the case of NCAR, it has been estimated that, for transport only and ignoring other costs, there is an additional cost of 2-3% per added tracer.

d. Recommendations for implementing aerosols and chemistry components

- Aerosols and chemistry need to be considered in ESMs for a number of reasons. A new consideration for IPCC is the ability of the ESM to study air quality trends, and to be used by the impact (WG2) and the scenarios (WG3) communities.
• For AR5, most models will have a representation of the indirect effect of aerosols using more comprehensive schemes than in AR4, and will treat their temporal change from past to the future.
• The representation of aerosols and chemistry is likely to be more comprehensive for the near-term (2005-2030) than for the long-term (2100 and beyond) experiments partly due to computational limitations.
• The expectation is that effects from aerosols and chemistry would be particularly important over this near-term time frame.
• Mixed phase and ice phase cloud-aerosol interactions are likely to be handled rather crudely in AR5 simulations. This is a subject of on-going research.
• An integrated effort to produce past/current/future emissions of aerosols and ozone precursors would ensure the use of consistent and documented data relevant to climate/carbon cycle/aerosols/chemistry communities.

Dynamic Vegetation and the Carbon Cycle
a. Model Strategies
“Core” components of the carbon cycle in ESMs for AR5
The majority of major global models are expected to include several additional components into their carbon cycle modeling strategy. Taken together, these components “close” the global carbon cycle (i.e. allow calculation of the net land-atmosphere and ocean-atmosphere exchanges of CO₂ online within the ESM):
• Ocean biogeochemistry including simple ocean ecosystem models (e.g. NPZD: nutrient, phytoplankton, zooplankton, detritus).
• Terrestrial carbon cycle model (typically without nitrogen limitations) that simulates the water, energy, and carbon fluxes at the land surface.
• Vegetation dynamics – re-growth following disturbance including age class succession with limited Plant Functional Types (5-15 PFTs) and in some cases dynamic biogeography (i.e. the ability to change the geographical distribution of PFTs).
• Anthropogenic land-use change (transient) with corresponding translation into net carbon fluxes including wood harvest.
• Land management – agricultural activity on cropland (e.g. irrigation, tilling), pasture and forestry.
• Fire - wildfire including affects on vegetation and carbon stocks.

It is important to stress that the response (and sensitivity) of the terrestrial carbon cycle depends heavily on the simulated precipitation and temperature of the climate model. A short set of climate metrics that need to be met in order for a meaningful simulation of the carbon cycle to be possible should (and in some cases have already) be identified and delivered to developers of the physical model as early in the model development cycle as possible. The Köppen and/or Holdridge classifications may be useful diagnostic tools to help identify inconsistencies between the simulated temperature and precipitation regimes and the expected vegetation class. In the case where a solution to a temperature or precipitation bias that is detrimental to the vegetation distribution simulation cannot be found, it is preferable to avoid tuning the land or dynamic vegetation model to get the correct vegetation types (e.g. rainforest in the Amazon) and consider the resulting problems during analyses.
While many groups have already implemented, or are developing the above model components, there are technical and philosophical challenges when it comes to integrating the components. Coupling of the components should also occur relatively early in the development cycle to identify and counter unforeseen problems (e.g. bugs or model instabilities).

Not all modeling groups will incorporate all of the DGVM and carbon cycle components in time for AR5. We may therefore wish to provide prescribed fields (e.g. of the CO$_2$ fluxes from land-use change), that will allow these models to participate in an intercomparison. Careful design of the model experiments is critical in this respect (see text on “Experimental Design for AR5 ESM runs”).

**“Vanguard” components of the carbon cycle in ESMs by the time of IPCC AR5**

The following “vanguard” elements are not likely to be incorporated into the majority of carbon cycle models but may be present in some models, and will therefore be used in “research-type” model experiments:

- Nitrogen cycling and nitrogen limitations on the terrestrial carbon cycle.
- Anthropogenic impacts on fire (including ignitions, suppression).
- More sophisticated ocean ecosystem models, with resolution of more phyto- and zoo-plankton functional groups.
- River biogeochemistry (especially DOC fluxes from land-to-ocean).
- Micronutrient limits (Fe) on ocean biogeochemistry.
- Ocean bottom carbon chemistry, calcite formation (only important on 300-1000 yr timeframe, e.g. for stabilization scenarios)
- Interactive biogenic fluxes of methane, VOCs etc. (for coupling to atmospheric chemistry).
- Advanced vegetation dynamics with improved succession based-on more PFTs and possibly explicit dispersal mechanisms (the latter is only applicable in high-resolution ESMs).
- Multiple agriculture crop x management types
- Transient urban fractional cover.
- Improved spatial resolution of the land-surface based on either a higher resolution regular-grid (and/or an irregular land-grid defined by river-catchments).
- Impact of tropospheric ozone on vegetation.
- Improved treatment of organic soils including carbon dynamics and links to thermal and hydraulic impacts of peatlands.

**Coupling frequency**

The land-atmosphere carbon fluxes need to be determined at every land-model timestep (typically 30 minutes) to ensure consistency with energy and water fluxes. Ocean-atmosphere fluxes will typically be calculated on the timestep of the ocean model and increment atmospheric CO$_2$ (in runs with prescribed emissions) on every ocean-atmosphere coupling period (typically 1 hour to 1 day). The terrestrial and ocean carbon cycle models will therefore be coupled.
synchronously, although a hierarchy of timescales are often used within the DGVM component (daily to weekly for phenology, monthly to yearly for dynamic biogeography).

**Timescale of feedback**
Although global carbon cycle feedbacks may not be readily apparent for 30 or so years, the biophysical response (e.g., albedo) to disturbances (fire, drought, timber harvest, etc) is detectable on much shorter timescales, e.g. annual, timescales.

**b. Computer resources**
The cost of adding the terrestrial carbon cycle may be around 20% of the atmosphere-land model (as low as 3-5% GFDL, as high as 30% CCSM), with most of this associated with the calculation of CO₂ fluxes on each timestep of the land model. By contrast, vegetation dynamics will be computationally cheap because it only needs to be updated fairly infrequently (monthly to yearly). Storage requirements for the land model increase significantly due to large increase in number of prognostic variables, but this increase is likely to be fairly insignificant in the context of the ESM as a whole.

Ocean biogeochemistry is likely to require a 2- to 5-fold increase to the computational cost of the ocean model due to a large increase in the number of tracers. Storage requirements will also increase considerably.

It is important to note that to bring the carbon cycle into equilibrium, computational requirements for a coupled carbon cycle model development and spin-up will significantly increase over those for a standard AOGCM.

**c. Scenarios requirements and new requirements from the atmosphere model**
- Global mean CO₂ concentrations for 1850-2100 (for runs with prescribed CO₂ but diagnosed anthropogenic emissions, see “Experimental Design for AR5 ESM runs”).
- Global anthropogenic CO₂ emissions from fossil fuel burning plus cement production for 1850-2100 (for runs with interactive CO₂).
- Global net CO₂ emissions from land-use change for 1850-2100 (for runs with interactive CO₂ in models that do not calculate land-use fluxes internally).
- Grided land-use and land management information, including consistent disturbance history and future disturbance. It is critically important that the history and scenarios of land-use are consistent (i.e. without a discontinuity in going from past to future!).
- Grided fire history reconstruction including area burned (disturbance) and emissions to the atmosphere from fires.
- National-level CO₂ emissions for the carbon cycle validation period (say 1960-2000). These emissions will be used in the coupled climate-carbon cycle models to assess their ability to reproduce seasonal changes and latitudinal gradients of atmospheric CO₂ concentration.
- Grided nitrogen deposition fields for 1850-2100.
- Grided near-surface ozone concentration fields for 1850-2100.

**d. Validation and Model Improvements**
A number of missing observational datasets can be readily identified that would speed-up and augment the carbon cycle model development. These include satellite measurements of column integrated CO₂, soil moisture, and vegetation structure as well as a general increase in the
Southern hemisphere data (e.g. carbon stocks, land use/management, surface ocean-atmosphere CO₂ fluxes).

The representation of agriculture (crop types, crop phenology, management including irrigation and tiling) and fire can clearly be identified as a weak point of many current models and requires more development.

Historical reconstructions of globally gridded land-use change including crop, pasture, shifting cultivation, and wood harvest have recently been completed for use in this class of models. A major need is the development of future global gridded-land use change products that are consistent with both the gridded historical reconstructions, and the future scenarios developed by scenario teams.

More constraints on the simulated carbon cycle are required to validate the models. These constraints could include observations or other methods (e.g. the Tracer Transport Model (TRANSCOM) and Ocean Carbon Model Intercomprison Project (OCMIP) modeling activities).

Ocean flux of CO₂ at the air-sea interface is likely to improve as eddies are resolved or as eddy mixing parameterizations are improved (e.g., through the use of ARGO float density, salinity and temperature information to validate models). In general, and as noted above, it is critical that the carbon cycle modelers identify critical aspects of the physical models that require further attention before realistic carbon cycle simulation can be achieved.

3. A Proposed Experimental Design for the AR5

The pathways of model development over the next ten years are not parallel across groups. There are specific questions that will require high-resolution (in space, time, complexity) model runs and those that will need to address longer-term questions with regard to impacts and mitigation. Therefore, we propose an experimental design that leverages near-term and longer-term model runs with appropriate model resolution and hypotheses.

I. Near-Term Experimental Design – Climate Change to 2030

a. Scientific Questions and Relevant Models

It is anticipated that model capability is now sufficient to provide some regional guidance as to the effects of climate change out to 2030. Of particular interest are regional changes in water availability (soil moisture), affected by changes in precipitation, evaporation and melting of the snow pack. Also of interest are local daily and seasonal temperature changes. With regard to societal impacts, it is the changes in extremes in both of these categories - floods, droughts, extended heat waves, hurricane frequency and intensity are primary concerns. Effects of climate change on human health, through alterations in air pollution (aerosols, ozone) or the migration and adaptation of disease vectors (e.g., carried by insects) could have significant societal impact. Many of these changes have ramifications for agriculture; in addition, climate change will also impact fishery industries. Stratospheric ozone recovery from chlorine loading will be affecting climate during this time frame. In addition, an assessment of historical and near-term aerosol forcing, compared with on-going aerosol and temperature observations, may allow us to better understand aerosol climate forcing, and hence climate sensitivity.
Both AOGCM and ESM models will be useful for near-term simulations, although development of each requires significant computational and manpower resources. How to divide those resources remains an issue.

At one extreme, AOGCMs run at very fine resolution (on the order of 0.5° for latitude and longitude) would allow for a better regional assessment of climate change, although additional downscaling to even finer resolution might be required for some climate change impact studies. Most AOGCMs currently have about 2° resolution (at best). An increase of spatial resolution by a factor of 4 would increase computational time by close to a factor of 60. Additional increases in the vertical resolution, to optimize the dynamical advantages of the finer horizontal resolution, would bring the computational burden to greater than 100 times (i.e., two orders of magnitude). Such an approach would strongly inhibit the inclusion of additional physics to explore alternate aspects of the earth system, some of which (aerosols, ozone, vegetation health) would be having direct effects on regional climate that would be omitted.

At the other extreme, ESMs could be run at close to the current resolution but with expanded physics packages for aerosol, atmospheric chemistry and dynamic vegetation. These additions likewise require significant computing time - aerosol and atmospheric chemistry calculations can each double the computational time or add even more, depending on the sophistication of the routine. Simulations of stratospheric ozone chemistry could require greater resolution in the stratosphere and a higher top of the model. Their inclusion would allow for a more complete assessment of the physics of climate change, but would not provide more regional discrimination.

As a compromise approach, it is suggested that models for this time period utilize a somewhat finer horizontal resolution (on the order of ½° to 1° latitude x longitude) along with simplified aerosol and chemistry packages. Dynamic vegetation would be included to assess the health of the vegetation and possible in-place succession. Other longer-time scale processes, such as ocean biogeochemistry, land ice and ecosystem migration would be omitted or performed off-line. A crude estimate is that for the various simulations suggested, even this model version would require some 4 dedicated computer-years using current computer capabilities. And developing models on finer resolution is itself a non-trivial task. While the Japanese experience has been that their model parameterizations did not have to be changed (just tuned), and climate sensitivity was relatively invariant when going to significantly finer horizontal resolution, this has not been the experience of, say, GFDL, and may not be true with much finer vertical resolution. Developing this new model may require significant time and resources prior to its use in these proposed experiments.

b. Relevant Emission Scenarios
Given that the different scenarios for well-mixed gases do not vary greatly prior to 2030, it is suggested that only one such scenario be employed. For aerosols and short-lived gases, several emission scenarios (including a low and a high estimate) should be provided. For example, consistent global, gridded data for reactive gases (CH₄, NOₓ, major classes of NMVOCs, CO, NH₃), aerosol precursors (SO₂), and aerosols (BC, OC) are needed. The ideal emissions input data set would:

1. Extend continuously from historical to future projection years
2. Be gridded at the finest resolution being considered (e.g. 0.5 degrees)
3. Exhibit appropriate spatial changes over time
4. Resolve appropriate injection heights (ground, 100m, aircraft)
5. Resolve large seasonal effects (biomass burning in particular)

Decisions on exactly what emissions are required will need to be made by the Earth-System modelers, and providing these emissions will be the responsibility of Integrated Assessment modelers.

Some shorter term projections (e.g. GAINS, RAINS, Streets et al.) produce emissions at a temporal and spatial scale that may be consistent with most of the ideal requirements listed. The integrated assessment models (IAMs) used to produce long-term emissions scenarios (up to 2100) generally produce emissions at a large spatial scale. The SRES exercise produced long-term emissions that were gridded at a level of four meta-regions, with a fixed pattern within each meta-region.

However, in general, producing consistent and globally gridded historical, near-term, and long-term input data sets is not a capability that exists at present. A first step toward this capability would be to conduct a census of available inventories and projections, their characteristics, and level of detailed data availability. Using this information, the actions and capabilities that would be needed to produce the necessary emissions data sets could be detailed.

The next generation of ESMs will also require scenarios of anthropogenic land use changes as input data. Gridded input data sets of land-use conversions (changes from one category to another) and anthropogenic management (agriculture, perhaps specific crops or classes of crops, forestry, pasture, etc.) will be needed. Methodologies to convert the output of IAMs to land-use change data sets that are consistent with the historical land-use change data sets used in the ESMs will also need to be developed. Ideally, biogenic emissions of VOCs would be produced by the ecosystem component of the ESM. In this manner, the effect of anthropogenic land-use and vegetation changes would be reflected in biogenic emissions. The same is true for methane, although this will likely remain in the research domain for the near future.

Additional experiments could be done to investigate suggested geoengineering attempts at mitigating climate warming. For this time frame, one option being discussed is that of injecting sulfur into the atmosphere, either into the stratosphere or troposphere, to help cool the climate. The climate consequences of such injections could be explored in ESMs; unintended consequences might be harder to ascertain.

c. Experimental Design and Ensembling/Scenario Simulations
Assuming the 'compromise' modeling approach is adopted, the attempt would be to provide the most realistic predictions possible for the regional scale. While the predictions would extend from the present to 2030, climate change over this time period is affected by what has happened in the past. The past decades will also provide the possibility of validating the model for regional scale predictions. These simulations will be affected by the initial conditions at the start of the experiment, particularly in the ocean (temperature, salinity) but also on land (soil moisture, ground temperature). Ocean initial conditions could conceivably be provided by ocean data assimilation exercises currently underway, but salinity reconstructions remain a significant
problem. There is no direct way to provide soil moisture or ground conditions at this time. The potential errors induced by incorrect initial conditions should become less important in later years but could still be evident through the course of these simulations. If model simulations are started prior to the availability of the ocean initial conditions, the model ocean would have to be 'nudged' toward the observed values; how strongly this should be done, and what it implies about energy conservation are research issues that will have to be explored.

In addition, as noted above, gridded emission data for aerosols and short-lived gases would need to be provided on this same fine regional scale, for both the historical times of concern as well as future projections. The "natural forcings" would be handled conservatively. The total solar irradiance for this time period would be unchanged, possibly having just the observed 11-year cycle superimposed. The mean value for volcanic aerosol loading over the past 25 years could be employed, or a stochastic occurrence of major volcanoes, based on the last 100 years of data might be added. It is not anticipated that these choices will play a determining role in the climate simulation results.

To determine the significance of regional changes, especially those of extremes, will require numerous simulations in an ensemble approach. For this time frame the relatively small magnitude of climate change will make signal to noise discrimination even more difficult. We therefore propose that there be one base-case scenario for the well-mixed gases along with low, medium, and high air pollution estimates (i.e., aerosol and short-lived gas emissions). The number of simulations to be performed is somewhat uncertain, but it should be 10-15 for the base case in order to discriminate changes in hydrologic extremes.

d. Initialization and Model Spinup Considerations

While historical simulations for spin-up and model validation are necessary, there are conflicting influences concerning the starting date for these runs. The atmosphere is in better radiative balance starting in 1950 than at later times. Ocean data initialization is currently being done from 1970 onward, although it is better in more recent years due to a larger number of observations; and emissions data improves greatly after 1980. However, the earlier the start time, the greater the computational burden being assumed. This may already be a problem (even without considering the longer-term simulations anticipated), and so the starting time may have to be 1980 for practical considerations.

II. Longer-Term Experimental Design – 2100 and Beyond

Longer-term runs provide an opportunity to contribute a policy perspective on avoiding the consequences of climate change. In addition, experiments would provide a basis for evaluating the feedbacks and contributions of the carbon cycle to the climate system. The recommended experimental design indicates that WG1 and WG3 be staggered in time. The long-term simulations would be with lower resolution AOGCM and ESM’s (roughly 2°) with a pre-industrial spinup including a 20th century forced experiment that consists of natural and anthropogenic forcings. Two, possibly three greenhouse gas (GHG) and aerosol concentration scenarios to be supplied by WG3: (1) a high radiative forcing stabilization (e.g., A2-type), (2) a low radiative forcing stabilization (e.g., B1-type); and possibly (3) mid-range scenario (A1B-type) to provide a swath of possible outcomes. At least one ensemble member for each scenario would be considered, and the models would include as core, the terrestrial and ocean carbon cycle, biogeography and successional processes as implemented, chemistry and aerosols would
be prescribed to 2100 and stabilized after 2100 until 2300, although a few models may run interactive aerosols and chemistry as well. The first two experiments are considered ‘core’ for all groups to participate in, with a third, optional experiment. WG3 would provide time series of concentrations of GHGs for these experiments.

- **Forward approach: start with socio-economic variables**

![Diagram](image1.png)

- **Reverse approach: start with stabilization scenario concentrations**

![Diagram](image2.png)

**Fig. 2:** Schematic of traditional forward approach starting with socio-economic variables to derive emissions, concentrations and then temperature and other climate changes from climate models (top), and new proposed methodology where the starting point is concentrations run in climate models, that are used to derive emissions and then socio-economic factors to achieve those emissions.

As noted in Fig. 2, using benchmark concentration scenarios as the starting point is different from the more traditional starting point of socio-economic variables. However, by using benchmark concentration scenarios that are then applied to derive emissions and then socio-economic factors to achieve them, WG1 does not have to evaluate socio-economics before running scenarios in climate models, and WG3, who have expertise in socio-economics, can determine the factors that would produce the emissions from the concentrations that have an associated climate change outcome. There will be multiple socio-economic pathways leading to the concentrations resulting in a rich ensemble of WG3 scenarios.

It is important that any proposed set of integrations be easily integrated by non-ESM (AOGCM) models. This will allow groups who do not have an ESM to participate in AR5. The number of proposed integrations is also important. Due to the large amount of computer resources required to time integrate ESMs, it is important to prescribe only a few required integrations. Groups are
always free to integrate other scenarios and other models, but these would be for research and not part of the common set.

A second type of constraint involves the scenarios used to drive the ESMs. Policymakers are increasingly focused on stabilization scenarios and the ways to achieve climate stabilization. All the scenarios proposed are stabilization scenarios. To implement this strategy, two experiments are proposed, each of which uses a given benchmark concentration scenario, and each representing a high and a low radiative forcing. There is also an optional third scenario which lies between the high and the low scenario:

**Experiment 1**: An AOGCM or ESM is run with time series of specified benchmark concentrations provided by WG3. The idea is to use prescribed concentrations of the GHG and aerosols (Note: Aerosol concentrations will depend on spatial emissions patterns, these will have to be specified for the scenarios, as was the case in SRES. Who/How these are developed needs to be determined; In the case of SRES this was a joint WG1 and WG3 effort). Each scenario would also include the prescribed changes in the future land use in accordance with the scenario characteristics. The ESMs would be initialized in a manner similar to what was used in AR4. After the model is developed, the radiative forcing constituents are set to “pre-industrial” (usually mid-1800s) conditions. The model is allowed to come into a quasi-equilibrium state with those radiative conditions (usually after several centuries of integration – See Stouffer et al. 2004). At some point in this integration, the start of the pre-industrial control is declared (i.e. year 1 of the pre-industrial control). One evaluation criterion to be used in AR5 for the fidelity of the carbon components will be the rate of drift of the carbon system in this control (e.g. some modelling groups insist that the long-term mean land-atmosphere and ocean-atmosphere fluxes of CO₂ should be within 0.2 GtC/yr of zero net flux). However, the 10% of the current sink is not totally relevant here. The main point is that the long term mean of the sum of land and ocean fluxes should be close to zero (0.1 to 0.2 GtC/yr). The sum is what really matters for 2 reasons: a) in the real world, there is a net CO₂ flux from the land to the ocean through rivers, this means that the net atm-land flux is a sink and the net atm-ocean is a source, but the sum of the two is zero; b) emissions will be function of the sum of the ocean and land fluxes, and any long term imbalance in the land+ocean flux will translate into a non-zero emission. As in the AR4 exercise, it would be good to have a long control run from the ESMs in order to estimate the carbon drift, and remove it from the inferred emissions for a given scenario if necessary.

The climate system only responds to benchmark concentrations, and temperature changes accordingly. As the model runs, the carbon cycle component produces a time-series of CO₂ fluxes that are saved. Note: – these CO₂ fluxes do not enter the atmosphere to change the climate system response to the specified concentration time series. The computed CO₂ fluxes from this experiment (e.g., land/ocean CO₂) are returned to WG3 where inverse calculations of these fluxes are used to derive corresponding emissions, and then mitigation policies to achieve those derived emissions. Emissions can be calculated when the CO₂ fluxes and the CO₂ concentration time series are known.

At various points in the pre-industrial control, historical integrations can be started to generate an ensemble. This ensemble is useful for detection/attribution studies and other comparisons to the observed climate changes. The inputs needed for this type of integration are the time series of
GHG and aerosol concentrations and land use changes. This is similar to what was needed for the AR4 common integrations.

The future projections start from the end of the historical integrations. The concentrations of GHG (including CO2) and aerosols and the future land use changes are prescribed according to the input scenario (see below for details). Even though the ESM model can predict changes in atmospheric CO2 concentrations, the CO2 concentrations are prescribed. The prescribed atmospheric CO2 concentration is used in the radiation calculation and to compute the carbon fluxes from the land and ocean. This prescription allows non-ESM models to be forced in a manner similar to the ESMs and allows for easier intercomparison of the physical climate response among all the models in the AR5 common set.

The ESMs that include an interactive carbon cycle will calculate land and ocean CO2 sinks which are consistent with the prescribed CO2 concentration scenario and the climate change predicted by the component AOGCM. These fluxes can be used to calculate the “permissible CO2 emissions” profile consistent with the prescribed CO2 stabilization scenario, using an approach already adopted applied to some first generation coupled climate-carbon cycle models (Jones et al., 2006):

\[ E(t) = \frac{dCO_2}{dt} + F_{A-o} + F_{A-l} \]

where \( E(t) \) is the profile of anthropogenic emissions consistent with the prescribed rate of carbon dioxide increase \( \frac{dCO_2}{dt} \), and the modelled atmosphere-land and atmosphere-ocean fluxes of CO2 are \( F_{A-o} \) and \( F_{A-l} \) respectively. This applies to models not computing land use change fluxes, so, e.g. carbon fluxes from deforestation would be lumped in with those from fossil fuel burning. Other models that could estimate carbon fluxes from imposed land use changes as part of the last term on the right, and the residual would be only from fossil fuel. The profile of permissible emissions diagnosed from each ESM can be used by IPCC WG3 to determine the policy measures consistent with the prescribed concentration scenario and the particular model projection. In some cases the permissible emissions may not be feasible, or could be inconsistent with the assumptions implicit in the concentration scenario (e.g. by assuming land-use changes that are inconsistent with the implied net CO2 emissions). Here a WGIII-WGI-WGIII iteration (from one IPCC assessment to the next) will be required to derive achievable stabilization scenarios. Related guidance on the realism or otherwise of stabilization scenarios will be very useful information for policymakers.

That is, the rate of change of CO2 concentration (which is prescribed) is \( \frac{dCO_2}{dt} = F_{\text{emissions}} - F_{o-a} - F_{l-a} \), or, the change in CO2 with time = emissions minus CO2 fluxes from the ocean-atmosphere and land-atmosphere. The WG3 scenarios group would also provide prescribed concentrations for other gasses as well as aerosols that would be interactive within the models.
Experiment #1:
Carbon Cycle sees increasing CO2 Concentrations and ΔT;
Land/Ocean CO2 fluxes saved to derive emissions for WG3

Land/Ocean CO2 fluxes are NOT interactive with atmosphere

Experiment 2: A second integration to evaluate the impact of the climate changes on the carbon cycle response. For this experiment, atmospheric CO2 is fixed for the radiation code in the atmospheric model only. That is, the atmosphere sees a constant CO2 concentration throughout the experiment. Therefore, no climate change occurs, and the temperature will remain about the same throughout (except for internal climate variability). However, the CO2 concentrations from Experiment 1 are given to the carbon cycle component, and the resulting CO2 fluxes are saved as they were in Experiment 1, but the carbon cycle only responds to the increasing CO2 since the temperature remains about the same. Consequently, the CO2 fluxes in experiments 1 and 2 from the carbon cycle can be used to derive emissions (added to the derived emissions from the specified time series of concentrations), and the difference between the two derived time series is a measure of the carbon cycle feedback on emissions (emissions consistent with a given concentrations scenario). The CO2 concentrations from Experiment 1 are very important, since the impact of emissions on stabilization at a given level for a given benchmark scenario provides WG3 with information regarding which socio-economic options would be required to reach that level of stabilization. The derived emissions will be noisy, and WG3 will have to fit, or smooth the time series of emission pathways.
**Experiment #2:**

Carbon Cycle sees CO₂ Concentrations from Experiment #1; atmospheric CO₂ and T are constant; Land/Ocean CO₂ fluxes saved to derive emissions for WG3

Two scenarios are required to be integrated by the AR5 models: a high and a low case. As noted above, both are GHG stabilization scenarios. The high case could stabilize near 700 ppm CO₂ (or about 950 ppm in terms of equivalent CO₂) concentration in the atmosphere corresponding to about 6.5 W/m² radiative forcing relative to present day. The low case could stabilize near 400 ppm CO₂ (or about 500 ppm equivalent CO₂) concentration corresponding to about 3 W/m².

Each scenario would be based on land use changes changes (and other driving forces) consistent with the GHG emission profiles.

**Experiment 3 (optional):** In order to determine the magnitude of a carbon cycle feedback in terms of temperature from the climate models, the derived emissions from Experiment 2 (derived surface carbon cycle emissions without climate system feedback added to the derived emissions from the specified concentrations) can be run with a fully interactive carbon cycle. Since in this experiment CO₂ fluxes from the carbon cycle will be allowed to enter the atmosphere to supplement the prescribed CO₂ concentrations from a given scenario, CO₂ will evolve differently from the original prescribed CO₂ scenario (of Experiment 1), and will thus produce a different temperature response in the model. The climate system response difference between experiments 1 and 3 defines the magnitude of the carbon cycle feedback.
**Experiment #3 (optional):** Derived emissions in the absence of climate change from Experiment #2 are used to drive carbon cycle-climate model from Experiment #1.

These experiments are designed to be community-coordinated, and do not rule out different experiments with different scenarios and different model formulations that could be run by individual modeling groups. This experimental design allows an AOGCM to diagnose the feedback from Experiments 1 and 2, and Experiment 3 explores whether there are differences in climate change for a given scenario due to the inclusion of the carbon cycle feedback. If a modeling group only has an AOGCM (i.e. not carbon cycle), Experiment 1 could still be run to obtain a climate change outcome, thus widening the participation. This experimental design also provides consistent analyses across models such that caveats of model-specific inputs will not have to be documented later.
Advantages of a three-phase approach include:

1. Relatively few future climate projections required of the ESMs. In AR4, three future integrations were integrated by most groups. The two required benchmark integrations per scenario with two required scenarios yielding four future integrations. Modeling groups that do not have an ESM would have only two future required future integrations.

2. Non-ESMs results can be directly compared with ESM results for the physical climate system as in AR4.

3. Using benchmark scenarios allows the WGIII community to supply new scenarios to the WGI community in a timely manner. The development of a complete new set of scenarios would take several years. At the same time, WGII and III can use the climate outcomes of benchmark scenarios to better assess the resulting impacts and possible mitigation and adaptation measures and policies. All of this together can help improve the integrated assessment models.

4. The process involved with this experimental design establishes pathways for the necessary interactions between the WGI, WGII and WGIII communities and drastically shortens the time frame required for developing new scenarios and climate projections.

3. Overall Recommendations

- The development of Earth System Models (ESMs) requires new common integrations to be developed for the Fifth IPCC Assessment (AR5). Here we view this generation of ESM to include components of the terrestrial and ocean biology to close the carbon cycle. The ESM may include other components such as atmospheric chemistry or sophisticated aerosol components, but they will be optional. The input scenarios should supply information (emissions or concentrations) so that models of varying sophistication can be integrated. Gridded land use changes must also be incorporated.

- An integrated effort is needed to produce past/current/future emissions of aerosols and ozone precursors to ensure the use of consistent and documented data relevant to climate/carbon cycle/aerosol/chemistry communities.

- To assess regional effects in short-term predictions will also require gridded emission data for aerosols and short-lived trace gases as well as land use. A concerted effort will be necessary to produce these datasets.

- For longer-term runs, WG2 and WG3 IPCC reports need to be lagged about 2 years behind a WG1 report. At present, the WG2 and WG3 reports use relatively outdated (up to six years) model simulations from the previous assessment while WG1 uses relatively outdated emissions scenarios. It would be more desirable if all three working groups are using as close to current generation model projections as possible. An alternative would be for the modeling groups to make new climate change projection simulations and
scenarios as soon as possible (about the 2009-2010 timeframe), and delay the next full assessment by about 2 years (to 2015).

- There is a need for a PCMDI equivalent for WG2 and WG3 communities, or an expanded role for the IPCC DDC, and a WGCM-type community organizing mechanism for WG2 and WG3.

- WG2 and WG3 need to have input to selection of fields to be archived for analysis in the new integrations for AR5, in particular a list of fields related to the carbon cycle.

References


Participants
Dave Bader, PCMDI, Livermore, CA
Olivier Boucher, Hadley Centre, Exeter, U.K.
Guy Brasseur, NCAR, Boulder, CO
Peter Cox, Exeter University, U.K.
Peter Gent, NCAR, Boulder, CO
Claire Granier, CNRS, Paris, France
Kathy Hibbard, NCAR, Boulder, CO
George Hurtt, Univ. of New Hampshire
Michio Kawamiya, Frontier Research Center for Global Change, Yokohama, Japan
David Kicklighter, Woods Hole, MA
Masahide Kimoto, Univ. of Tokyo, Japan
Jean-Francois Lamarque, NCAR, Boulder, CO
Dave Lawrence, NCAR, Boulder, CO
Norm McFarlane, Univ. of Toronto, Toronto, Canada
Linda Mearns, NCAR, Boulder, CO
Gerald Meehl, NCAR, Boulder, CO
Richard Moss, UN Foundation and Univ. of Maryland, College Park, MD
Nebojsa Nakicenovic, Vienna University of Technology and IIASA, Vienna and Laxenburg, Laxenburg, Austria
Phil Rasch, NCAR, Boulder, CO
David Rind, NASA Goddard Institute for Space Studies, New York, NY
Steve Smith, PNNL and Univ. of Maryland, College Park, MD
Ron Stouffer, GFDL, Princeton, NJ
**ESSP Input to SBSTA25 on Research Gaps and Needs for the UNFCCC**

(21 September 2006)

**I. Background**
The letter to all parties from Haldur Thorgeirsson, Deputy Executive Secretary of UNFCCC’s SBSTA dated 8 June, refers to the draft conclusions from SBSTA24 on its agenda item 5 (see FCCC/SBSTA/2006/L.7) dated 23 May 2006 which state *inter alia*:

> Following the Special Side Event hosted by SBSTA in Bonn on 19 May “the SBSTA invited these programmes to provide, together or separately, to the SBSTA, before its twenty-fifth session (November 2006), a short summary report or reports drawing on the above-mentioned special side event, including identification of any gaps in their research programmes with respect to the research needs of the Convention, as viewed by Parties, for example in document FCCC/SBSTA/2006/INF.2, and considering options for addressing these needs.”

The organisations that made presentations on 19 May were: WCRP, IHDP, IGBP, START, IAI and the ESSP Joint Project on Global Carbon, and some regional and national contributors. These presentations are available on the UNFCCC web site.

In this document, the Earth System Science Partnership (ESSP) has tried to gather together all their views i.e. to reply to SBSTA “together” rather than “separately”. Of course this does not preclude any organisation from making separate input to SBSTA prior to SBSTA25 in November 2006.

**II. Gaps in Research Programmes With Respect to the Need of the Convention as Viewed by the Parties**

i) **FCCC/SBSTA/2006/INF.2** gathers research needs into a summary (pages 13-15) as follows:

- Parties to the UNFCCC noted that, although progress has been made since 2002, work needs to continue on improving:
  - Quantifying of the anthropogenic component of observed changes in climate and estimates of natural influences and natural variability;
  - Understanding the mechanisms and factors, both anthropogenic and natural, leading to changes in radiative forcing, and reducing uncertainties;
  - Climate related systematic observation and, in particular, a global climate observing system for climate related research.

The United States also observed that the representation of developing countries in international climate change research would be enhanced by improving observation systems, by the efforts of more developing countries to share their climate data and through encouragement and incorporation of such research into their sustainable development planning.

Parties have also noted several specific subjects where more work is needed to meet the needs of the Convention. These subjects include:

- Improvement of methods to quantify uncertainties of climate projections and scenarios, including long-term ensemble simulations using complex models;
- Improvements in the integrated hierarchy of global and regional climate models with a focus on the simulation of climate variability, regional climate changes and extreme events;
- More effective links between models of the physical climate and the biogeochemical system, and incorporating the consideration of the human dimension into climate change research.

In order to coordinate activities in climate change monitoring, advanced climate modelling, and impact and adaptation studies, Japan indicated the necessity of the establishment of a database system where data obtained from observations, climate change projection models, and impact and adaptation studies are integrated so that information from different research areas can be made accessible and more applicable to mitigation policies.

International and regional research programmes attempted to identify remaining gaps in research and observations and specify directions in the research to address these gaps.

ii) **FCCC/SBSTA/2006/MISC.3** contains summary statements of research needs from some nations as proposed prior to the SBSTA24. These include (from the EU):
Strengthening of the dialogue between scientists and the policy community to better use scientific results in the development of policies on both mitigation and adaptation; and

Initiating an international programme or framework that would:

a) assess global and regional impacts and risks associated with various greenhouse gas stabilization levels and emission pathways, taking into account adaptation. This should also include better estimates of thresholds and probabilities for abrupt, or irreversible, events and assessment of the risk of the possible amplification (or amelioration) of anthropogenic climate change; and

b) assess the economic, environmental and social costs and benefits associated with different stabilization levels and emission pathways and the technological and adaptation scenarios associated with each, including improved understanding of factors affecting resistance to change and learning processes.

The EU also noted that the G8 science academies and those of China, India and Brazil in a statement issued in July 2005 had recommended that governments should be urged to ‘launch an international study to explore scientifically informed targets for atmospheric greenhouse gas concentrations, and their associated emissions scenarios, that will enable nations to avoid impacts deemed unacceptable’ (e.g. Royal Society http://www.royalsoc.ac.uk/).

In this regard the EU encourages the Earth System Science Partnership (http://www.essp.org/about_essp.html) to take appropriate steps towards such integrated global research essential to tackling climate change.

III. ESSP Views of Gaps in Research Programmes With Respect to the Needs of the Convention

The Earth System Science Partnership (ESSP) responds to the SBSTA request to identify research needs for the UNFCCC in the framework established by the SBSTA; issues of anthropogenic climate change and of improved sharing and understanding followed by more specific proposals.

i) Climate Change

The ESSP considers the following research tasks as particularly important:

- Improving climate observations, especially the consolidation of the efforts of the various global observation entities (e.g. GEO, IGOS, CEOS, GCOS, GTOS, GOOS...), and a better link to international research programmes.

- Improving the understanding of radiative forcing and coupling including that of GHG concentration changes (presumably via radiative forcing and other associated processes, e.g. CO2 feedbacks on oceans and the terrestrial biosphere) because this forcing is the basis of greenhouse warming.

- Improving the understanding of feedbacks between climate and major biogeochemical cycles, especially carbon (e.g. vulnerabilities of presently stable carbon pools to release under climate change). Likewise, greater understanding is needed about feedbacks between climate and the hydrological cycle. To accomplish this, it is important to embed better descriptions of the major elemental cycles (e.g. C, N, S) and the hydrological cycle, together with their interactions, into climate models.

- Improving the treatment in climate models of the dynamics of aerosols and clouds, and their consequences for the Earth's radiation balance and hydrological cycle. Related to this is the use of palaeo-data to test climate models.

- Improving the descriptions of human activities in climate models so that they begin to represent true “earth system models”. For this, the natural and social science communities must begin to work together more intensively. It is particularly important to understand and model trends in human energy use, urbanisation and land use, and their interactions with climate and biogeochemical cycles. ESSP is working actively on these trans-disciplinary questions
through its joint projects, including the Global Carbon Project.

ii) Improved Understanding and Capacity Building
ESSP Programmes and Projects mandate that ESSP has a geographical distribution of members on its governing boards. This is one means of enabling developing countries to be engaged in its activities. One of the central activities of the ESSP – “START” – is a major effort to build capacity for understanding and acting on climate change and its impacts.

Specifically, the ESSP offers detailed proposals in response to FCCC/SBSTA/2006/INF.2, p. 4-9 grouped by the three IPCC Working Groups.

iii) Modelling Vulnerability
The climate system is so complex and the scientific and computational requirements for providing societally-beneficial regional climate forecasts are so enormous that the nations of the world should create an international research and computational facility dedicated to the ‘grand challenge’ of climate prediction.

Climate feedbacks involve highly complex non-linear interactions in both space and time and, therefore, climate models must be run at sufficiently high space and time resolutions to be able to understand and resolve, for example, the climate processes involving deep convective cloud systems. Climate research and climate prediction during the past 30 years has been done by models with space resolution of about 100-300 km, which were adequate to resolve cyclones. We now must advance from cyclone resolving models to cloud system resolving models with resolutions of about 2-5 km. This will require petaflop computers and a critical mass of hundreds of scientists working together to build the next generation of climate prediction models.

The scientific expertise to revolutionise climate prediction of the physical-biogeochemical Earth system and its interactions with the global socio-economic systems resides in no one nation or scientific discipline. An international joint effort is required to make very necessary advances in the 21st century. Immediate beneficiaries of such a multi-national joint effort focussed on the ‘grand challenge’ of climate prediction will include Parties to the UNFCCC and others to ‘environmental’ UN Conventions wishing to develop vulnerability assessments and adaptation policies.

iv) Impacts, Vulnerability and Adaptation
ESSP believes that delivery of climate information on regional scales underpins all efforts in this category. ESSP is pleased to be able to point to its efforts in this area, especially highlighting the ESSP Integrated Regional Study approach, and particularly the impressive success of the Global Environmental Change And Food Security (GECAFS) regional case study approach.

Assessment of impacts, vulnerabilities and adaptation to climate change is so complex that it is difficult to prioritize research needs. However, the ESSP identifies issues of great importance as being:
- Multi-scale analysis of climate change impacts and mitigation responses including economic costing of climate change. Assessment of climate impacts at different greenhouse gas stabilisation levels.
- Assessment of impacts from abrupt and/or irreversible climate changes.
- Study and analysis of adaptation strategies and their links to sustainable development i.e. “climate proofing”.
- Assessment of the second-order impacts of adaptation strategies.

v) Mitigation
There is now no reasonable doubt that human-caused climate change is occurring. While ESSP believes that some degree of climate change is unavoidable, it also believes that all efforts should be made to lessen the intensity and speed of climate change and its impacts through concerted mitigation and adaptation measures.

To be attractive to policy makers, it is essential to identify mitigation costs, effectiveness of strategies and barriers to accepting them. ESSP believes that holistic analyses of energy and land use options, including demand management and enhancing innovation in GHG abatement technologies, are essential now. We note that ESSP already has significant research efforts in the areas of bio-sequestration potential through Land Use, Land Use Change and Forestry (LULUCF) – especially through accounting and reporting.
It is also of great importance to identify different future “portfolios” of renewable energy that would maximize their benefits to climate mitigation and other sectors and minimize their undesired impacts.

While the ESSP takes no position on geo-engineering as a mitigation approach, we believe that the feasibility and consequences of various proposals should be scientifically studied.

IV. Making ESSP Research More Relevant to the UNFCCC

The ESSP mandate calls for ESSP research to be relevant to important policy issues of society. With this in mind, the ESSP will initiate a discussion within our community about making our work more immediately relevant to the UNFCCC. This includes:

- Considering playing a role in the development of scientific scenarios related to the UNFCCC (emission scenarios, climate scenarios, integrated scenarios);
- Sending ESSP representatives to SBSTA meetings;
- Establishing a reporting system so that ESSP results are directly reported to the SBSTA;
- Beginning an ongoing “dialogue” with SBSTA, which opens the possibility that ESSP re-orient its research to give special priority to key policy-relevant questions defined by the SBSTA.

Already an initial comparison of research needs of the SBSTA and ESSP shows that research interests are converging. Topics of common interest include:

- Ensuring the quality of the climate observing system, in particular improving monitoring of extreme events;
- Improving the exploitation of the available hierarchy of global and regional climate models to focus more strongly on predicting climate variability, regional climate changes and extreme events;
- Improving the quantification of uncertainties in climate projections and scenarios, including using ensembles of long-term simulations and using multiple models;
- Increasing the links between models of the physical climate, the biogeochemical system and the world hydrological cycle, and incorporating the consideration of the human dimension into climate change research;
- Linking social as well as natural sciences, and the interaction between the two, in responding to the research needs arising from the assessment reports of the IPCC (section C, paragraph 31, point b) - something ESSP is designed and mandated to do.

Finally, ESSP wishes to stress the need for a forum for an ongoing and lasting dialogue with the UNFCCC/SBSTA community. ESSP and its partners hope that SBSTA considers our May 2006 meeting as only the first in a set of regular meetings between ESSP and the UNFCCC SBSTA (a recognised “stakeholder” for all the ESSP Programmes and Joint Projects). We would like to use these meetings to establish common priorities and to allow the ESSP and our Programmes to be able to respond to the needs of the UNFCCC through the SBSTA.

Prepared and approved by the ESSP Task Team on UN Conventions
Contact details:
Chair of ESSP Task Team: Ann Henderson-Sellers
Director, World Climate Research Programme
c/o WMO, 7bis Avenue de la Paix
Case Postale No 2300, CH-1211 Geneva
Ph: +41 (0)22 730 8246
Fx: +41 (0)22 730 8036
Email: AHenderson-Sellers@wmo.int

Martin Rice, ESSP Coordinator
c/o DIVERSITAS
51 Bd de Montmorency
75016 Paris, France
Tel: +33 1 45 25 67 04 (Direct)
Tel: +33 1 45 25 95 25 (Secretariat)
Fax: +33 1 42 88 94 31
Email: mrice@essp.org
Website: www.essp.org
AIMES SCIENTIFIC STEERING COMMITTEE AGENDA ITEMS
PARTICIPANTS
AIMES SSC MEMBERS:

<table>
<thead>
<tr>
<th>Name</th>
<th>Country</th>
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<tbody>
<tr>
<td>Ayako Abe-Ouchi</td>
<td>Japan</td>
</tr>
<tr>
<td>Jérôme Chappellaz</td>
<td>France</td>
</tr>
<tr>
<td>Bob Costanza</td>
<td>USA</td>
</tr>
<tr>
<td>Jon Foley</td>
<td>USA</td>
</tr>
<tr>
<td>Pierre Friedlingstein</td>
<td>France</td>
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<tr>
<td>Suzi Kerr</td>
<td>New Zealand</td>
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<tr>
<td>Laurent Bopp</td>
<td>France</td>
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<tr>
<td>Denise Mauzerall</td>
<td>USA</td>
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<tr>
<td>Natalie Mahowald</td>
<td>USA</td>
</tr>
<tr>
<td>Carole Crumley</td>
<td>USA</td>
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<tr>
<td>Luiz Martinelli</td>
<td>Brazil</td>
</tr>
<tr>
<td>Claire Granier</td>
<td>France</td>
</tr>
<tr>
<td>Kathy Hibbard</td>
<td>USA</td>
</tr>
<tr>
<td>David Schimel</td>
<td>USA</td>
</tr>
<tr>
<td>Colin Prentice</td>
<td>UK</td>
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NON-SSC MEMBERS

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<thead>
<tr>
<th>Name</th>
<th>Project</th>
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<tbody>
<tr>
<td>Mike Apps</td>
<td>Global Carbon Project (GCP)</td>
</tr>
<tr>
<td>Mingkui Cao</td>
<td>Global Carbon Project (GCP)</td>
</tr>
<tr>
<td>Marcel Endejan</td>
<td>Global Water System Project (GWSP)</td>
</tr>
<tr>
<td>Julie Hall</td>
<td>Integrated Marine Biogeochemistry &amp; Ecosystem Research (IMBER)</td>
</tr>
<tr>
<td>Dennis Ojima</td>
<td>Global Land Project (GLP)</td>
</tr>
<tr>
<td>Richard Aspinal</td>
<td>Global Land Project (GLP)</td>
</tr>
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<td>Jim Hurrell</td>
<td>Global Ocean Ecosystem Dynamics (GLOBEC)</td>
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<td>Phil Rasch</td>
<td>International Global Atmospheric Chemistry (IGAC)</td>
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<td>Andi Andreae</td>
<td>Integrated Land Ecosystem-Atmosphere Process Study (iLEAPS)</td>
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<td>Jeff Hare</td>
<td>Surface Ocean Lower Atmosphere (SOLAS)</td>
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<td>Nancy Rabalais</td>
<td>Land-Ocean Interactions in the Coastal Zone (LOICZ)</td>
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<td>Jerry Meehl</td>
<td>World Climate Research Programme/Working Group on Coupled Models (WCRP/WGCM)</td>
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<td>Guy Brasseur</td>
<td>International Geosphere/Biosphere Programme (IGBP)</td>
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<td>Kevin Noone</td>
<td>International Geosphere/Biosphere Programme (IGBP)</td>
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Invited but did not attend:
With regrets, Congin Fu (China), Paul Falkowski (USA), Anond Snidvongs (Indonesia) and Diana Liverman (UK) of the AIMES SSC were unable to attend. Sander vander Leeuw (International Human Dimensions Programme; IHDP) was unable to attend.
Thursday: 17 November, 05
Dave Schimel greeted the group and suggested the new AIMES project of the IGBP operate as an ACTIVIES program, rather than advisory – he suggested three interaction templates for collaborating with the IGBP Core and ESSP Projects:

1. **Process and parameterization**: AIMES has global models that need observations and process models for global model evaluation, testing and parameterization. Datasets and process knowledge need not be localized, they can be global networks of data. Trade-off is the global context for regional processes.

2. **Regional-global interaction** – e.g., rapid rates of human development trigger changes in the atmosphere or biosphere; obvious development in Asia, Rapid changes locally and regionally that have global consequences. Impacts and feedbacks within a region and between global system.

3. **Applied Earth System Science**: ambition of challenging basic science to solutions to real-world problems: Dave suggested the International Nitrogen Initiative (INI) as an ongoing activity representative of this template.

Colin Prentice presented a history of AIMES predecessor, the Global Analysis and Integration of Models (GAIM) Task Force. He presented some of the early GAIM projects, the history of the 23 Hilbertian questions and how new projects have rolled into AIMES. Early GAIM was successful in securing funding for post-doctoral scholars and Colin would like to see this improved in the current AIMES project.

Kathy Hibbard presented an overview of ongoing AIMES activities and introduced the idea of a high latitudes integrated regional study. Activities reported included GEIA, IHOPE, the Young Scientists’ Network and planned collaborations with the Global Carbon Project, including a carbon vulnerabilities to drought and disturbance conference and a jointly sponsored Carbon and Urbanization Conference with GLP, GCP and AIMES. Further details of ongoing activities (GEIA, YSN, IHOPE) were presented by their respective leaders and are summarized below. Kathy discussed ongoing collaborations with the Global Carbon Project: (1) AIMES and the GCP are collaborating on a workshop on Earth System Feedbacks: Vulnerability of the Carbon Cycle to Drought and Fire to be held in Canberra, Australia, 5-8 June, 2006. The scope of the workshop is to explore the interactions of energy, water and carbon in the Earth System caused by drought and variability of the water cycle and its effects on carbon exchange, ecosystem respiration on disturbance frequency and emissions. Four themes are under development:

*Theme 1: Observations of Climate Change, Variability and the Carbon Cycle*
*Theme 2: Processes and Controls of Coupled Carbon-Water Cycles*
*Theme 3: Modeling Present and Future Interactions of Carbon and Hydrological Cycles*
*Theme 4: Vulnerability and Ecosystem Services of Carbon-Water Cycles*

In addition, AIMES and the GCP are collaborating on a peatland and permafrost vulnerability activity that will be part of a high-latitude integrated study. The purpose of a high latitude study is not to repeat other numerous research programs that are ongoing or under development, but to facilitate improvements to global models derived from regional process studies. AIMES’ charge is the global modeling and global results. For the regional studies, the payoff is being able to
quantify the global significance of the regional feedbacks and interactions, as well as have global drivers for regional models. The high latitudes are indisputably responding to global change in at least four ways:

- Carbon storage and sequestration (OM, CH₄, clathrates, CO₂)
- Hydrology: precipitation: evapotranspiration ratios: runoff, sediment transport, salinity gradients, permafrost, etc.
- Changes in the thermohaline circulation with implications towards warming, altered ocean CO₂ uptake
- Wide range of human activities: e.g., altered fossil fuel reserves and changes in shipping paths
- Changes in high latitude albedo, biophysical properties
- Extreme events: disturbance, storms
- Changes in coastal zone/marine ecosystem structure

AIMES is very much interested in participating with the core projects in a regional terrestrial/aquatic/marine high latitude activity; this is a region that is dramatically forced by "global change" and has significant global feedbacks to the physical, biological and human dimensions of Earth System science.

AIMES is also collaborating with NCAR and GLOBEC on an integrative climate and marine ecosystems activity. There was a planning meeting in early November, 2005 to explore pilot studies with respect to climate interactions and marine ecosystems. Climate models, modes and marine ecosystem variability and fisheries were discussed in terms of regime shifts, coupled variability in global climate models and links to policy. A larger, international workshop is proposed for the summer 2006 at NCAR and a summer institute using Earth System models to explore marine ecosystem interactions with climate, perhaps in 2007, 2008.

**Ongoing AIMES Activity Reports:**

**Claire Granier and the Global Emissions Inventory Activity (GEIA)**

Claire provided a short history of GEIA as an activity initially sponsored by IGAC in 1990. The goal was to provide a global inventory by chemical species. Current activities include the addition of new inventories including regional, global and time-dependent. In addition, model/data and model intercomparisons and evaluations are ongoing with the identification of major uncertainties and problems with inventories. The identification and prioritization of measurements in collaboration with other IGBP activities are primary goals towards the development of databases of driving variables. Evaluation and compilation of emission factors, emission algorithms and other driving variables will be used for emission estimates. GEIA will use chemical exchange models that have been evaluated with March 2004 observations. GEIA is co-sponsored by the European network, Atmospheric Composition Change (ACCENT) linked to IGAC. The ACCENT network includes up to 43 EU institutions with ca. 120 institutions from the US, Canada and Japan as partners.

It was suggested that a forum for discussion through a data portal, perhaps through the GEIA and ACCENT websites be developed. GEIA also hopes to include fires, vegetation and humans as
eventual vectors for emissions in future databases. There will be a GEIA meeting in December, 2005 and next year. GEIA currently hosts a website maintained through NASA grant, and the ACCENT network funds 0.5 person for the data portal. There are limited funds for ACCENT meetings, and support is needed for a steering committee meeting in 2006.

GEIA would also like to promote a summer school on emissions and Earth system modeling. The product would be a book published in summer/fall 2007. GEIA is in contact with SOLAS and iLEAPS.

**Bob Costanza and the Integrated History of People On Earth (HOPE):**
Bob presented perspectives on HOPE and emphasized that an integrated modeling and complex systems aspects would be a key features. It will be important for the next workshop to translate narrative data into numerical analyses, possibly by incorporating human processes and models. There was some discussion about possibly creating a model of the system and using the model as a game and as an experimental device to understand/quantify human behaviour. Under the hood of GEIA there are some potentially very good mutual constraints and tests of GEIA and HOPE.

If, as Ruddiman suggests, man has influenced the climate system for the last 8,000 years through increasing greenhouse gas emissions (e.g., methane) through widespread rice cultivation, the linkages between HOPE and the Earth System (e.g., C4MIP) models can test and/or reject such hypotheses. Additionally, Pleistocene extinctions, metallurgy and deforestation in the early Bronze Age can contribute to quantifying and understanding human interactions with the climate system. The Global Land Project (GLP) is very supportive of this activity and hopes to contribute and interact. There is also the possibility of future links to DIVERSITAS (not represented at this SSC meeting).

Bob also presented a new Internet Service Provider (ISP) - the Earth Portal as a peer reviewed portal that may be useful for AIMES, HOPE, GEIA, and the ATLAS. The Earth Portal will compete with AOL, etc, but will utilise part of the revenue from their ISP to fund the portal.

**Colin Prentice and the ATLAS:**
This is a project that has been ongoing since GAIM and is led by Colin Prentice and Dork Sahagian. Sahagian has funds for a 2-year position as director at Lehigh University in Pennsylvania, USA; a search is currently underway. The ATLAS hopes to introduce peer-review status and a journal type format to create a product, however, development has been slow. An actual user-interface exists; it can be found through google and ‘Earth System Atlas’. The graphic interface to the ATLAS was derived from the University of New Hampshire Arctic Rims project.

The group mentioned a comparable ocean biogeography information system out of New Zealand and Flanders. The ATLAS project is admittedly moving slowly forward and could use some momentum in the process. Biggest bottleneck are the people in charge are too busy and there is not yet a project manager hired, however, a candidate is on the table. Jonathon Foley suggested that the ATLAS take advantage of wiki datasets and many of the global datasets that already exist and/or are under development.
**Jim Galloway: International Nitrogen Initiative (INI;http://www.initrogen.org/)**

The INI was a fast-track initiative (FTI) initiated in January 2003 in GAIM and was co-sponsored with SCOPE. A book in the SCOPE series was published in 2005 entitled Agriculture and the nitrogen cycle. At the IGBP SC meeting in Beijing, 2005, it was agreed that INI was complete as an IGBP fast track and was moving from quantifying and understanding N processes in agricultural systems to a global assessment activity. The IGBP SC agreed that AIMES was the appropriate integrating project to manage INI.

Jim started with an overview of reactive nitrogen; deposition, transformation and creation. Synthetic N was first manufactured in the early 20th century. He discussed regional and temporal changes in nitrogen deposition. The overall goal of the INI is to optimize nitrogen's beneficial role in sustainable food production and minimize nitrogen's negative effects on human health and the environment resulting from food and energy production. The INI operates in three phases, that do not necessarily have to occur in sequence:

1. Assessment and Knowledge
2. Identification of Solutions
3. Implementation of Solutions

There are 5 INI Regional Centers: North America (USA), Europe (The Netherlands), Asia (China), Latin America (Brazil) and Africa (Uganda). INI activities, both past and planned include:

- Nitrogen Fertilizer Rapid Assessment Project (NFRAP) Workshop: Kampala,Uganda; January 2004
- Denitrification Workshop: Woods Hole, MA, USA; May 2004
- Third International Nitrogen Conference: Nanjing, China; October 2004
- Policy Approaches to Nitrogen Management: France; January 2006
- *Impact of Anthropogenic N on Open Ocean: Norwich, England, November 2006; INI and SOLAS*
- *Fourth International Nitrogen Conference: Salvador, Brazil; October 2007*

The INI wrote a draft Preliminary Assessment of what is known and unknown about the impact of humans on the nitrogen cycle, and the resulting impacts on ecosystems and people. It is an INI goal to continue the assessment process in support of the linked goals of identifying solutions, and best-practice methods for implementation.

**Colin Prentice and the Fire Fast Track Initiative**

Fire was also initiated as an FTI in GAIM in 2003, however, the Fire FTI got off to a rather slow start after its inauguration. Now, FIRE it has momentum, but realistically the time frame for completion of the activities defined at a recent Exeter workshop is the end of 2006. A short summary of the Exeter workshop was an excellent two days in terms of information exchange between the different communities. Colin was particularly impressed with the achievements of people working with satellite data, CO-based inversions, and palaeodata. In terms of products, the idea was suggested to go ahead with three activities, each of which will have one more (small, focused, "working") workshop and soon after that lead to a final written product. These three activities are:
1. A high-profile synthesis article on the role of fire in the earth system, involving at least Colin, Sandra Lavorel and Mike (Flannigan) plus a few carefully selected others
2. A consensus statement and "user guide" produced by the community sensing fires from space, providing information about the potential uses and reliability of different global products. Steven Plummer to lead.
3. A worldwide synthesis of the available data on changes in fire regime over the period LGM to present.

While FTI’s are expected to last 2-3 years, but Colin suggested that it would make sense for this FTI to take 4 years (early 2003 - end 2006) at which time there will be several solid products which can be labeled as IGBP products. Colin did not request continuation in the long term under an IGBP umbrella (that might be something to think about, or not, later on), but specifically to be allowed to continue trading as "IGBP Fire FTI" through 2006. This request does not *necessarily* imply a requirement that IGBP continue to fund the workshops, although such funding would be useful.

In addition, the workshop in Exeter came out with a strong conclusion that the time is now ripe -- in a way that it wasn't, even as recently as five years ago -- to develop the next generation of Dynamic Global Vegetation Models (DGVMs) with an *evidence-based* representation of plant functional types (PFTs) and traits (as opposed to the largely arbitrary or anecdotal basis for PFTs and their parameter values found in the present generation of models.) The two keys to this are (a) recent developments in whole-plant physiology, such as the growing understanding of the fundamental role played by plant hydraulics, and (b) the accumulation of data at the species level showing systematic interrelationships among traits. Both are areas of science that got a strong push through the previous IGBP project, Global Change and Terrestrial Ecosystems (GCTE; now evolved to the Global Land Project (GLP) co-sponsored with the IHDP). It was also mentioned DIVERSITAS has the potential to play a strong role here as well as GLP.

**Summary Discussion**

The first day’s talks led to a discussion on how to engage stakeholders and with what kinds of activities? This kind of scientific strategy is exciting to the AIMES SSC. Colin suggested a nice way to reinvent C”MIP; instead of using academically derived scenarios from an academic process, go to energy and technology sectors and ask THEM what might happen. Each project would have a different constituency. He also suggested that every project that AIMES is involved with should have stakeholder involvement, but the G8 question: to what extent is what we do provide useful input or information that governments are clamoring for? If we approached from this perspective, we might well have different suite of projects altogether.

The group suggested that perhaps AIMES start with Nitrogen as a pathfinder? Develop IHOPe with timelines of human interactions with nitrogen. How would a mass balance of N and economic balance next to each other? Whose problems are we concerned with? Our science should be focused on society’s problems. The concepts of geo-technologies and interactions, impacts on biogeochemical cycles – what will the extreme events will be? What does this mean for society?
People are concerned about the quality of life – certainly a function of climate. IHOPE could also have a positive impact in this. How did we get here, what is our history? We can re-cast our questions starting at societal level. How to understand developing countries and the. distribution of wealth The environment is a luxury good (in the eyes of the public) when it comes to food, water, etc. (e.g., lack of water and difficulty of farming to produce food in Africa).

Luiz warned the group to be careful when we say society. We need to be mindful of solutions that are appropriate for different situations. There are different problems in different parts of the world with different solutions. An analytical framework to assess problems would be useful. Luiz gave the example of a big drought in the Amazon; there may still be a lot of water, but the water is not distributed easily. The topic of fishing pressure, marine ecosystems and subsequent climate impacts was raised. AIMES could integrate case studies on food, supplies; integrated chemistry, biogeochemistry and relevant boundary conditions.

Friday: 18 November 2005
Dave Schimel summarized the previous day’s discussion for the newly incoming Core and ESSP Project representatives. He emphasized that integration as KEY to AIMES philosophy and that the AIMES SSC should function in an activist rather than solely advisory role. He restated the three interaction templates introduced the day before, and the group agreed to a fourth that emerged from discussions later in the afternoon of the 18th:

1. **Process and Paramaterization**: improving global representation of process mechanisms in Earth System Models by speeding the transfer of local and regional process understanding to global models.
2. **Regional to Global**: Dave suggested three types of regional to global interactions:
   1. When rapid change in a human system triggers a global response: either directly through transport or indirectly through teleconnections in the climate system. In order to understand the significance of the regional study, it has to be embedded in a global context. This is where the global remit of AIMES can collaborate with one or more of the core projects
   2. Another global changes trigger rapid changes in a region with subsequent global feedbacks; poster child for this kind of interaction is in the northern high latitudes. The emphasis would be not so much on the human causation, but the human consequences.
   3. A third type of regional-global: regional impacts of global change need to be understood at high resolution. An ES approach to downscaling: if we know the broad gc’s how do we understand the regional effects; more on changes in human behaviour.
3. **Applied Earth Systems**: Information about global change to a specific region is known; translating those regional responses in the context of global understanding to avoid adverse consequences would be the goal of this interaction template. The integrative models that are a GAIM hallmark can produce a tremendous amount of information on ecosystem services globally. This appears to be a very clear direction that members of our SSC are interested in tackling. Most clearly in the INI Development and transfer of solutions to the problems. In the case of the INI, nitrogen is such a multi-scaled global problem. A disconnect at multiple scales re: decision making that requires a clear cross-cutting decision making process. Any single scale solution optimizes may magnify the
severity of the problem at other scales. This kind of integrative problem-solving activity can be achieved by harnessing the energy of the whole programme (e.g., IGBP) through AIMES.

4. **Integrative Earth System Modeling:** Coupled models of the climate biogeochemistry, ecology and human dimensions, beginning with incremental problem-focused additions to today's coupled models leading to a greater capability to understand human-environment interactions and coupled behavior of the biogosphere. An example program that would develop and use such increasingly integrative tools is "Envision the future". Methods for “Envisioning” could include, for instance, gaming, focus groups, video presentations. Integrative modeling should be a component of any Applied activity (see template 3, above).

**General AIMES Discussion**

Guy suggested that if this meeting could identify a region and a problem and start something new. He cited that Japan and their Ministry of Environment is interested in contributing to a meeting to manage large environmental problems that Asia is facing from China to Japan. Air quality, degradation of soils, modification of hydrological cycle. This falls in line with the AIMES regional global studies as coupled to IGBP Integrated Regional Studies (IRS). Andi proposed the high latitudes as a candidate region as well. Colin: if we’re talking about a link from global information and global projections that are understandable there are perhaps some reasonable solutions. Dennis: related to the 3rd interaction template: especially at the regional scale: crafting a strategy that very directly and very immediate in the sense of the development of the project that you engage the decisions makers and local expertise from the outset. Getting the appropriate communities together from the onset of an activity is the most useful. The role that AIMES can play then, how can we develop a common framework so a global analysis can use these regional studies both in the human, social, biophysical, climate systems. Need to get engaged with stakeholders should be carefully thought out. Addressing problems at multiple scales will be critical. The YSN really discussed development and climate across scales. They perceived that solutions in urbanization and air quality intrinsically lie at cutting the scales. AIMES can initiate these kinds of activities and clearly, these are not AIMES standalone activities.

Colin reminded the group that the precursor to AIMES, GAIM and it’s overarching role for key biophysical and carbon cycle global models became mainstream. As we move into AIMES, the SSC should be thinking about new frontiers and new areas. Four challenges: 1st climate/carbon chemistry, 2nd human/physical interface 3rd human dimensions 4th; providing information to society.

The group agreed that a major shift from GAIM to AIMES would be to engage stakeholders. It will be important to learn how to ask and ANSWER the correct questions. Colin discussed an EU project (A-Team) that involved stakeholders from inception to completion. Scale and objectives would be the first vector for finding the correct stakeholder. Government, NGO, business, industry, public local, state, national, federal level. Which to cross? Maybe invite chairs or coordinators of an MIT forum to next AIMES SSC to make links? Carole
cautioned the need for a few generalized guidelines to teach us a bit on how to establish connection to maintain credibility. There’s an economy that needs to be balanced; on the research side, need to maintain credibility; packaging is important. On the other hand, need to be cognizant and design research to fit into what decision makers and managers need, but that can’t be only driver to research. AIMES will have to caucus and come up with some principles.

**Phil Rasch and IGAC: Climate Chemistry Coupling**
Phil discussed opportunities for SPARC, IGAC and AIMES. SPARC traditionally works with a middle atmosphere focus and IGAC with troposphere. There are, however, many areas of common ground, the upper troposphere for example. The projects focus on more than chemistry, but also on climate aspects. Common themes include aerosols and water sources. IGAC is primarily focused on non-modeling activities; and is organized around tasks, or, particular projects with a theme. The projects collaborate on an Atmospheric Brown Cloud (ABC) and PolarCat activities. SPARC contributes a strong modeling component, IGAC a field and observation component. There are obvious connections with AIMES as well. There is also some talk at the programmatic level about integrating activities and perhaps to combine SPARC and IGAC explicitly rather than to share. Claire Granier mentioned a model validation activity at the last SPARC meeting discussed.

**Discussion**: Climate-chemistry models are running in coupled mode but are very expensive. EMICs are doing this now (referred to MIT). Time slices to integrate on fully coupled models might be an idea to start (until we get better computers) chemistry of evolution of climate system from an AIMES perspective outside the chemistry community. Questions posed by members from outside the community could add new perspectives. Also, (Phil) suggested that AIMES contributions to understanding how to cross scales would be helpful. Important to recognize strengths and deficiencies of current understanding and models. For instance, with respect to aerosols and indirect forcing addition of aerosols to clouds one of the effects is the albrecht effect: cloud drops are smaller, they don’t precipitate as easily and they last longer. These very detailed simulations indicate that you change the dynamics of the clouds and the clouds evaporate more rapidly and you have fewer clouds. Atmospheric chemistry models can handle this, but more general Earth System Models of Intermediate Complexity (EMICs) can’t handle any aspect of this. It was suggested that there is the need to monitor the uncertainties and the range of models. This is EXACTLY the kind of issue to address through a process-parameterization template that accelerates integration from process understanding to global implementation.

**Natalie Mahawold and YSN**
Natalie presented an overview of the new AIMES Young Scientist’s Network. The goal is to foster global collaborations among young scientists on integrative research to better understand the role of humans in perturbing biogeochemistry and climate. The organizational committee is Natalie Mahawole, Marko Scholze, Kathy Hibbard, Rik Leemans, Peter Rayner, Richard Dawson and Ahmed Balogun.
As background information, GAIM had discussed a postdoctoral network on Earth System Science in a broad manner. In 2004, AIMES decided to plan a first workshop at NCAR, with NCAR support and adjacent to the CCSM workshop. Planning is underway for a 2006
meeting and several participants will be present at the AGU meeting in December, 2005 with plans for a future EGS meetings.

The first meeting was held in Breckenridge, Colorado, 2005, alongside NCAR’s annual Community Climate System Model (CCSM) workshop and was funded by AIMES, NCAR’s SERE and ASP divisions, the National Science Foundation, the Max Planck Institute and participant organizations. More information can be found at http://www.asp.ucar.edu/ess. A workshop report is in press to EOS transactions, led by Marko Scholze. In summary, the first workshop 52 young scientists from 18 countries: Argentina, Australia, Bangladesh, Brazil, Canada, France, Germany, Ghana, India, Italy, Nigeria, Poland, Portugal, Russia Switzerland, UK, USA and Zimbabwe. Most were natural scientists (chemical, biological, physical), with about 25% representing human decision making communities. Thirty three of the YSN participants also attended the CCSM workshop. There were 83 applications to attend the YSN workshop, therefore the criteria for acceptance included:

1. The organizing committee felt it was important to fund at least 10 developing country applicants. There were ~50 applicants and chose most integrative earth system science postdoctoral scholars. There was a conscious attempt to balance geographic range,
2. Young scientists representing human dimensions were encouraged to apply,
3. Applicants working on integrative earth system science were encouraged to apply; and
4. Any other appropriate young scientist who could be self-supporting was accepted.

Feedback from workshop was positive and informative. There was strong enthusiasm from participants: both scientific collaboration and networking were well-received. It was suggested that the YSN meet with formal workshops every year or alternate years and perhaps include tutorials. It was agreed that social and/or working meetings at existing meeting (e.g. Fall AGU, EGS) would encourage communication and collaboration. The YSN participants also suggested the development of a web page, with a swiki interactive interface to encourage interactions. Ideas for improving the workshop included more interactions between participants, more time for poster sessions and discussion, to include more time for keynote speakers to interact with the young scientists.

Urbanization impacts on biogeochemistry and climate was agreed as a future topic for interaction and discussion. To that end, AIMES is collaborating with the Global Carbon Project (GCP) on a Carbon Management at Urban and Regional Levels Conference in Mexico city in September, 2006. The goal of an AIMES YSN contribution would be to write up state of research and prioritization of research questions on urbanization interactions with biogeochemistry and climate. Current status is that we have ~$25K USD from NCAR and the Quantification and Understanding of the Earth System (QUEST) in the UK as startup funds. Proposals have been submitted to the Interdisciplinary Science in the Americas (IAI) and NSF for participant support. In addition, AIMES is hoping to support members of the YSN that do not participate in the Urbanization workshop at the Earth System Science Partnership Open Science Conference and START’s Second International Young Scientists’ Global Change Conference in November, 2006, Beijing.
Jerry Meehl and WGCM interactions with AIMES:

In collaboration with IHDP and WCRP, AIMES will contribute to integrating emissions, land use through GEIA, IHOPE. The timeline is short with limited planning, funding, model and development time. New models for the Fifth Assessment Report (5AR) will require ca. 25X more computing power. Issues for 1st generation Earth System Models include:

1. Coupled Carbon Cycle capability (inc. marine and terrestrial ecosystems)
2. Coupled climate-photochemistry (esp O3 and chemical lifetimes with related emission modeling issues
3. Aerosols and radiation (indirect effect w/ links to chemistry, dust, etc.)
4. Dynamic vegetation (w/links to biophysical climate and trace gas emissions.

An Aspen Global Change Institute (AGCI) workshop has been proposed for the summer of 2006. Participants to include members from the WCRP’s Working Group on Coupled Models (WGCM) and the Stratospheric Processes and their Role on Climate (SPARC) projects, the IGBP’s International Global Atmospheric Chemistry (IGAC) and AIMES representatives as well as representatives from the emissions scenarios community. The strategy of the workshop will be to improve our ability to model the processes with more certainty and the form those processes take in the next generation of Earth System Models.

In addition, the next AIMES SSC will next meet jointly with the WGCM JSC, tentatively scheduled for the last week in September, 2006 in Victoria, BC, Canada. It was suggested to perhaps invite emission scenario people to the joint meeting. Jerry suggested that perhaps SRES not the best tract for scenario building.

Standard runs that are likely from all groups with conventional Atmosphere-Ocean Global Climate Models (AOGCM’s) for the AR5:

1. Equilibrium mixed layer 2XCO2 runs (for climate sensitivity)
2. 1% CO2 increase run for TCR with model with atmosphere-ocean, land-sea ice
3. “All forcings” for 20th century climate
4. One SRES scenario for 21th century climate (perhaps use the mid-range scenario, A1B).

For the few groups with Earth System type AOGCM’s: adaptation/mitigation experiments requiring new emission scenarios.

Jim Hurrell and GLOBEC: Jim talked about a new activity that is primarily linking GLOBEC and NCAR, but will also include an AIMES perspective on linking Earth System modeling with marine ecosystem dynamics. It has long been understood that fisheries and marine ecosystems respond strongly to environmental and climatic factors. With GLOBEC in a synthesis phase, the time is proper for marine ecosystem scientists to interact with the global climate modeling community. An internal grant from NCAR supported a small working group to discuss possible pilot projects for interactions between the NCAR CCSM and marine ecosystem models. The grand challenge of the project will be to understand and be able to project the effects of global climate variability and change on ecosystems, the goods and services ecosystems provide, the drivers and consequences of human responses to ecosystem variability and change, and ecosystem links to the climate system. The goals of the funded proposal are to:
• Identify and enhance collaborative opportunities between climate, ecosystem and climate impact scientists
• Use and link tools such as the CCSM, high-resolution ocean models and marine ecosystem and foodweb models
• Trace the linkages from variations in modes of climate variability to changes in the physical ocean and changes in marine nutrients, primary producers and the higher trophic levels that support human fisheries
• Ultimately to assess possible impacts on the characteristics and dynamics of those fisheries Position NCAR as a major resource for the marine ecological and fishery management communities.

Potential linkages include:
• Connection between NCAR and GLOBEC modeling efforts
  • Flexibility of CCSM
  • GLOBEC models as alternative modules to existing CCSM ocean models
  • Continued progress on embedding regional scales models

• Analysis of observational and model data to further document and understand modal variability and the associated ecological responses
  • Simulation of major modes of variability an emphasis of CCSM
  • IPCC FAR runs of interest to both climate and marine ecosystem communities

• Reanalysis of long records from fisheries in light of recent knowledge gained on climate modes and their role in climate change
  • Synergism between retrospective analyses of GLOBEC data and climate analysis research

• Analysis of the utility of CCSM and GLOBEC model results for managers, policy makers and economists, e.g.
  • Can the assessment of fisheries stocks be improved with such model results?
  • Can fishery managers design their decision making, monitoring and enforcement processes to promote socially beneficial use of such information?

Goals of the initial planning meeting included:
• Produce a list of prioritized challenges that can be best (and perhaps only) be addressed through such collaborative efforts
• Identify a (short) list of potential pilot projects that would demonstrate why this effort should be continued and expanded
  ▪ Internal ecosystem dynamics
  ▪ North Atlantic basin scale
  ▪ Pacific
    • Warm and cold epochs
    • ENSO
  ▪ Tuna (end-to-end approach)
Coral Reefs

- Short white papers under development include:
  - Science to be addressed, including necessity of linking climate, ecosystem science and management
  - Tools (models, datasets)
  - Research plan

Goals for a larger international workshop, to be held in the late summer or fall of 2006 at NCAR in Boulder, Colorado were identified as:

- **Build bridges from physical climate through to marine resource policy**
- **Identify the role of coupled modeling and coupled climate-ecosystem models in building those bridges**
- **Identify goals for improved coupled (climate-marine ecosystem) models**
- **Provide a focused activity linking the physical, biological and social science communities together**
- **Set the stage for an ASP colloquium in 2007**
  - Graduate and post-doctoral students
  - Tutorials in using CCSM

Discussion included the response of ecosystems to modal variability, and that indices of climate modes summarize a whole suite of environmental variables. It was queried whether the GLOBEC models use historical data, or economic modeling and what is their scale? For instance, are there any global GLOBEC models? They are end-to-end with respect to trophic dynamics, but not global in scale. GLOBEC does not deal extensively or comprehensively with economic modeling, partially because the uncertainties regarding climate change and marine bio-resources is such that economists have not been as engaging in this topic as economists working on food and agricultural issues. However, we have recently worked on a number of projects that are both global and regional, such as:

  - Comparative impacts of a reduction in pelagic fish production in three Asian countries with different economies
  - Global modelling of the fishmeal market, including regional interactions and supply-demand markets at different scales
  - Management adaptations, at national level, for resources suffering from regime shifts, etc.

Several of these case studies will appear in a special GLOBEC book to be printed by Elgar Publishers in February 2006. GLOBEC is currently correcting proofs. There are also plans to address economic issues related to tuna fisheries and climate change. Kathleen Miller from NCAR is in the planning team. In addition, GLOBEC’s Focus 4 working group has been dealing with social-ecosystem interactions, particularly in relation to the so called Livelyhoods approach to resource management. There is some information in GLOBEC Newsletters and on the web at www.globec.org -go to Structure, Focus 4-.
The project with GLOBEC as a model for how we might work on ecosystem services in the third template. A takeaway concern is the link with other communities; data structures will constrain our analyses. Need to be careful to not exclude historical and other datasets.

**Coupled Carbon Cycle-Climate Model Intercomparison Project (C4MIP)**

Pierre Friedlingstein presented recent results from the C4MIP activity and emphasized the need for proper and more extensive model evaluation (validation). C4MIP results agree qualitatively with all models simulating positive feedbacks, primarily from tropical land surfaces. Uncertainties exist, however in the coupled simulations with regard to validation and model bias and drifts.

Most of the C4MIP models are poorly evaluated relative to climate or carbon cycle data. Typical comparisons are limited to global atmospheric CO2 trend and mean carbon budget. Pierre compared the IPSL model results with the flask dataset (e.g., Mauna Loa) and also against the ocean inventory of anthropogenic CO2 penetration, however. He suggested additional comparisons with the TransCom model results, the satellite NDVI and chlorophyll datasets to evaluate seasonal, interannual variability and trends. This should be done systematically by the C4MIP modeling groups. Issues still remain with regard to model improvement, particularly in the representation of existing processes (e.g., clouds, thermohaline circulation, soil respiration) and missing processes such as aerosols, DMS and land use before moving into a C4MIP. Also, Pierre showed that climate biases can have a large impact on the simulated carbon cycle and feedback. The inclusion of more components of the Earth System such as carbon, methane, chemistry will put a strong pressure on the development of next generation climate models.

Discussion included the concept of working backwards to identify key observable processes that control C4MIP models responses and testing models ability to represent them. Discussions also mentioned methane feedback as the next uncertainty, and the need to include global methane model treating wetlands and permafrost in Earth System Models. Several of the C4MIP groups are already working on a methane component. In addition, they understand that tropical carbon biomass is largely driven by humans; whereas the story in high latitudes is largely driven by climate change. C4MIP is led by Pierre Friedlingstein (AIMES SSC).

The group has been talking at length about stakeholders. What about say, if you have a wind-energy system, will the winds destroy the windmills in the next 20 years? This gets to extreme events – the hard stuff in models. Talking to industry representatives would help improve this dialogue. Perhaps discussions on what other kinds of variables (e.g., other than mean temperature, etc) they expect. For instance, how many days without rain is more important than increase of mean temperatures. There exists a disconnect between impacts (interested in extremes) and the climate community (reporting averages). Has a rational been discussed on moving the climate models to Earth System models? This is what we’re facing right now. Jim mentioned that US CLIVAR is making an effort to specifically reach out to the stakeholder community. Rather than a mega model, the WCRP/COPES strategy is thinking of an Earth System modeling framework that utilize different pieces from different models, or a modular theme.
**Jonathon Foley: Really Putting People in the Biosphere**

Jon presented a conceptual framework to integrate human actions and processes into terrestrial and coastal ecosystem modeling. He emphasized the need to go beyond, say, cropping systems for land use database development: how much water, fertilizer, how often are crops rotated are really what drive agricultural practices. The links between the atmospheric and terrestrial systems through environmental goods and services channel into human welfare and actions. One of the biggest uncertainties in deforestation is through the reporting, and observations. He presented a strong visual mapping of IGBP projects, Earth System Models and cross cutting themes across his framework.

Jon presented the need to improve the status of global datasets through two examples: the lack of global agricultural practices – while there exists global satellite data, there is little practical information associated with these types of datasets (limited process and mechanism inference). Another example are global deforestation rates: we don’t really understand the baselines or extents as there are various reporting mechanisms (e.g., FAO, 8km AVHRR, TRES, etc). He suggested a solution through blending local and global/biophysical and social datasets. He reminded the group that it won’t be quite that simple however, as there are disparate methods and scales of data products. Jon presented some recent and upcoming products from his Center for sustainability and the Global Environment (SAGE) program, and highlighted the need to blend social and biophysical data that are geospatially consistent and include rich thematic information from census’. Also, to blend local and global datasets and the need for cross-scale collaboration and consistency. He suggested the need for connecting local knowledge to global challenges through networking and using wiki’s for collaboration. This all leads to a proposed “Earth Collaboratory” that would be a web-based integration of the different kinds of knowledge from a changing world. The collaboratory (http://earthcollaboratory.org) would provide information to scientists, stakeholders and practitioners as well as local citizenry. He provided existing example prototypes through a Global Rivers and Land System (http://www.sage.wisc.edu/riverdata; http://www.sage.wisc.edu/iamdata) and his Atlas of the biosphere (http://www.sage.wisc.edu/atlas). Current status of the collaboratory is that they still need to finish the prototype software and are seeking a small amount of seed funding. They are exploring partnerships with industry and thinking through links to regional networks including NGO’s, etc.

How to link to AIMES: Jon proposed that rather than adding another AIMES project, the Collaboratory is already going to happen and involves a significant community, but, perhaps to contribute to existing AIMES projects, e.g., IHOPE, a new DGVM activity that improves the dynamic plant functional type strategy into Dynamic Global Land Models (DGLM) and the Atlas. The collaboratory could also contribute to GEIA and C4MIP.

**IGBP Programmatic and overall strategy for AIMES:**

*Science Plan*
Timeline for Science Plan: We’ll circulate draft Science Plan to group in early part of the year. Comments turned around couple weeks before the IGBP SC. Writing assignments to AIMES SSC will provide the bulk of the AIMES Science Plan.

Meetings
Discussion of meetings; PAGES would like to have a joint SSC with AIMES, perhaps a topical joint session at the Congress; There appears to be many aspects of the new PAGES proposal that link well to the CXMIP and AIMES through paleo climate, the paleoclimate and humans, it would be good to foster some kind of integration activity. There appears at the present, a disconnect between paleo biogeochemistry and PAGES. Need a more formal and stronger link between PAGES and AIMES on paleo biogeochemistry. Developing a joint activity may be the way forward. How to develop joint projects and broader collaborations is an important path that needs to be forged. Next 3-6 years think about a joint PAGES/AIMES meeting.

Open Science Conference (OSC) for AIMES; What should an integrative core projects’ OSC look like? Perhaps in the second 3-year term (early on) would be good. Perhaps to coincide with end of IPY in 2009. IF QUEST were to be a part of the meeting; the meeting could be in the UK, at the latest in 2009.
The ESSP OSC in November, 2006, Beijing is an opportunity to showcase the exciting things (e.g., IHOPE, Collaboratory) and some discomfort of a model for the future international programmatic. It was agreed that the AIMES OSC would be around 2009 – Clearly there is broad overlap between AIMES and GCP, PAGES, and QUEST agendas. End to end understanding (from forcing to response to policy to mitigation) of biogeochemical cycles.

The group also agreed to highlight AIMES INI activities in the 2007 INI conference.

AIMES Modeling Workshops Dave and Colin gave the SSC some history on the GAIM modeling workshops. There was one in South America and one in Africa. It was agreed that AIMES should follow up on the interactions with START through the YSN to provide bulk of faculty. Hassan suggested as true summer institutes on the order of 4 weeks. The model we envision is that we would be willing to develop the proposal, curriculum, id a faculty, but we expect them to coordinate the fundraising as they’re much more entrained in the proper channels. These institutes cost on the order of $200-250,000. The real cost goes way beyond the travel costs – software development, etc. Perhaps turn over the planning and choice of a model. Opportunities in SE Asia, perhaps also Africa. Should really be an AIMES/START partnership. A suggested model was perhaps an institute or workshop where the participants can go away able to teach the class.

Miscellaneous
IGBP working on a letter to circulate to initiate an institutional network.
Kathy Hibbard to poll core projects for nitrogen projects and co-author with all a newsletter article for IGBP on a nitrogen theme in IGBP.

Writing Assignments for SSC to draft a Science Plan:
Natalie YSN and tutorials (modeling outreach; institutes)
<table>
<thead>
<tr>
<th>Name</th>
<th>Project/Task</th>
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<tbody>
<tr>
<td>Pierre*</td>
<td>C4MIP -&gt; CXMIP (Chemistry; Management; PC4MIP)</td>
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<td>Bob/Carole</td>
<td>IHOPE</td>
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<td>Jim</td>
<td>INI</td>
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<td>Claire</td>
<td>GEIA</td>
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<td>Colin</td>
<td>Atlas</td>
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<td>Colin/Kath</td>
<td>FTI’s in general + fire as a case study</td>
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<td>Kathy</td>
<td>WGCM interactions</td>
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**New Projects**

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<th>Name</th>
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<tr>
<td>Bob/Jon</td>
<td>Modeling Ecosystem Services</td>
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<tr>
<td>Denise, Suzi, Laurent, Diana</td>
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<tr>
<td>Bob/Suzi/Diana</td>
<td>Envisioning the Future</td>
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<tr>
<td>Luiz</td>
<td>N impacts assessment</td>
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<tr>
<td>Mat</td>
<td>Northern Hemisphere High-latitude IRGS (+ input on paleo?)</td>
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<tr>
<td>Denise/Fu/Anond</td>
<td>Asia-Pacific IRGS (+ input on paleo?)</td>
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<tr>
<td>Dave</td>
<td>LBA process analysis (+ paleo opportunity)</td>
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**Other Elements**

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<td>Jon</td>
<td>Collaboratory</td>
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* + Ayako, Jerome, Laurent, Paul Falkowski, Natalie
Developing an Integrated History and future Of People on Earth (IHOPE):
Draft Science Plan as of 9/25/06

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Background

Human history has traditionally been cast in terms of the rise and fall of great civilizations, wars, and specific human achievements. This history leaves out the important ecological and climate contexts that shaped and mediated these events. Human history and earth system history have traditionally been developed independently, with little interaction among the academic communities. Therefore, separate methods of describing these histories have been developed, and there have been few attempts to integrate these histories and information across these fields of study. Recent recognition that current earth system changes are strongly associated with the changes in the coupled human-environment system make the integration of human history and earth system history an important step in understanding the factors leading to global change and in developing coping and adaptation strategies for the future.

The capability to integrate human history with the natural history of the earth now exists. The goal of the Integrated History and future Of People on Earth (IHOPE) project is to understand the interactions of the environmental and human process over the past several ten to hundred millennia to determine how human and biophysical changes have contributed to Earth system dynamics. In order to reach this goal, our objective is to produce an integrated history of the climate, atmospheric chemistry and composition, material and water cycles, ecosystem distribution, species extinctions, land use systems, human settlement patterns, technological changes, patterns of disease, patterns of language and institutions, wars and alliances, and other variables on earth from many new and existing data sources in a spatially and temporally consistent framework.

Human-environment systems are intimately linked in ways that we are only beginning to appreciate (van der Leeuw 1998, Redman 2000, Steffen et al. 2004, Diamond 2005, Kirch 2005). To achieve the ambitious goals of IHOPE there are multiple scientific challenges that must be met. In order to fully understand the history of the Earth it is necessary to integrate the different perspectives, theories, tools, and knowledge of multiple disciplines across the full spectrum of social and natural sciences and the humanities.

A step towards the development of such an integrated history took place at an IHOPE-Dahlem conference in Berlin, Germany; June, 2005. IHOPE-Dahlem assembled an interdisciplinary group of 40 top researchers from a range of natural and social science disciplines with the goal of identifying mechanisms and generalizations of how humans have responded to, and impacted their environment over millennial, centennial and decadal scales, as well as providing a glimpse of the future of the human-environment system. The overall conclusion from IHOPE-Dahlem was that human societies respond to environmental (e.g., climate) signals through multiple pathways including coping, adaptation, collapse or failure, migration, and creative invention through discovery. Extreme drought, for instance, has likely triggered both social collapse and ingenious management of water through irrigation. Future response and feedbacks between the human and environmental components of the Earth system will depend on our understanding of the past and adaptation to future surprises. Results from IHOPE-Dahlem will be published in a book from MIT press in 2006.

Following the IHOPE Dahlem Conference, an international symposium was sponsored by the Japanese Ministry of Environment and Technology in October 2005 through the Environment, Economics, Civilization and Global Change Program (EECGP) on the theme of Sustainability of Islands and Resource-Recycling Societies. This symposium discussed sustainability and failure of past and present Mayan, Monsoon Asia, Pacific Island and Atlantic
Island civilizations as well as future models for sustainability and technologies for future resource recycling. Several participants from IHOPE-Dahlem as well as experts in island-nation archeology from Europe, India, the US and Asia contributed to this symposium. The EECGP symposium was a precursor to a larger, Asian IHOPE conference to be held at the International Center for Japanese Studies, University of Kyoto, Japan in spring, 2007.

A third IHOPE meeting with 18 participants (list attached) was held at the Swedish Academy of Sciences in Stockholm on Jan. 12-13, 2006. The purpose of this meeting was to review final draft chapters from the Dahlem workshop, integrate IHOPE activities with the Global Change community, and draft a science plan for IHOPE. This draft science plan is the product of the Stockholm workshop.

**Long-Term Goals of the IHOPE Project**

Three major long-term goals have been identified for the IHOPE project:

1. **Map the integrated record of biophysical and human system change on the Earth over the last one hundred thousand years, with higher temporal and spatial resolution in the last 1000 and the last 100 years.** The long-term timeframe of analysis will depend on the region. For example, Australian history might cover up to the last 60,000 years, and in southern Europe, the last 20,000 years would capture initial colonization since the Last Glacial Maximum (LGM).

2. **Understand the connections and dynamics of human and Earth history by testing humans-in-environment systems models against the integrated history.** For example, how well do various models of the relationships between climate, agriculture, technology, disease, language, culture, war and other variables explain the historical patterns of human settlement, population, energy use, and earth system cycles such as global biogeochemistry?

3. **Project with much more confidence and skill options for the future of humanity and earth system dynamics, based on models and understanding that has been tested against the integrated history and with participation from the full range of stakeholders.**

**IHOPE in the Global Change Community**

Coupling the human-environment system with Earth System models is a primary objective of the Analysis, Integration and Modeling of the Earth System (AIMES) project of the International Geosphere/Biosphere Programme (IGBP). AIMES ([http://www.aimes.ucar.edu](http://www.aimes.ucar.edu)) is charged with not only contributing to improving process understanding of biogeochemistry and biophysical processes in global climate system models, but also with integrating human processes into a new generation of coupled human-in-environment Earth System models. AIMES is thus a logical administrative host for the IHOPE activity and AIMES has committed to perform this function. But IHOPE intersects with several other global change projects and communities and the intention is that IHOPE be a shared activity of the entire global change community. Particularly strong connections exist, for instance, with the Past Global Changes (PAGES) and the Global Land Project (GLP) of IGBP and IHDP and IHOPE will work to maximize the synergies with these and other global change projects. In spirit, IHOPE is thus an activity of the entire Earth System Science Partnership (ESSP) community. In addition, IHOPE
will connect to important activities being performed by communities not now part of the global change research community, including environmental historians, archeologists, sociologists, psychologists, and others. The broad range of IHOPE also implies that many different approaches to science, data, and knowledge will have to be integrated, and the inherent normative features of this problem will have to be acknowledged and dealt with (cf. Costanza 2001).

The Research Need

An integrated history from IHOPE will provide a rich picture of how (and why) the planet and human societies have changed in historical times. IHOPE seeks to unravel Earth system changes through analysis of the coupled human-environmental system to understand, in one direction, the importance of environmental dynamics on the evolution of society, and, in the other direction, in how the local to integrated suite of human activities contribute to the observed changes in Earth system dynamics (e.g., chemical, physical, biological) as recorded in geological records. Initial development of IHOPE histories will begin with local and regional scale interactions between humans and their environment and lead up to global scale issues. The integrated history will be used initially as input for analysis of the impact that the coupled human-environment interactions have had on regional and global dynamics. It will also be used as a core data set to test integrated models of humans in natural systems at multiple time and space scales, from regional to global.

The IHOPE activity will provide a mechanism to test a broad range of hypotheses about human-environment interactions. For example, Ruddiman (2005) suggested that departures from average methane concentrations in the Vostok Ice Core (Petit et al. 1999) since the most recent interglacial period were anomalous when compared to previous interglacial periods and were primarily the consequence of the rapid increase in global rice cultivation. The paleo science community has argued against Ruddiman through solar forcing and other modeling work (e.g., see Joos et al. 2004, Broecker and Stocker 2006). The insight, data and models generated from the IHOPE activity by environmental historians, archeologists, ecologists, modelers and paleo-environmental and paleoclimate communities will allow the testing of such hypotheses. It will also allow the calibration and testing of integrated global earth system models that contain a range of embedded hypotheses about human-environment interactions. We have summarized below a list of general and more specific questions that IHOPE intends to address. This is followed by a set of operating principles, strategies to address the questions, existing barriers to the activity and methods for overcoming the barriers.

General Questions

Consistent with the long-term goals mentioned above, three overarching questions have been identified for the IHOPE project.

- How do we best use an integrated history of socio-ecological interactions to inform us about options for the future
- How do we understand the complex reasons for the emergence, resilience, sustainability or collapse of coupled socio-ecological systems? A part of this is understanding the relative contributions of humans as causal agents in the systems.
• How do we evaluate alternative explanatory frameworks and specific explanations and models (including complex systems models) against observations of highly variable quality and coverage?

Specific questions

Below is a list of six more specific questions building on the three general questions above, intended as examples of the kinds of questions that might be addressed in the IHOPE initiative.

1. What are the resilience characteristics of socio-ecological systems that lead to either sustainability or collapse? – what makes socio-ecological systems resilient or brittle at various points in their evolution?

Resilience is the capacity to absorb change, reorganize and continue to develop. In a resilient social-ecological system, social mechanisms have emerged that can handle disturbance, change, uncertainty and surprise without the collapse of society. It has the capacity and legacies (e.g. social memory) to make use of change for renewing and evolving (Gunderson and Holling 2002, Berkes et al. 2003).

The mechanisms and processes of resilience in the ecological domain are fairly well understood at local to regional scales (Scheffer et al. 2001, Folke et al. 2004). There are also insights on feedbacks between the social and the ecological, like the role of knowledge systems, technologies, institutional responses to environmental change, and adaptive capacity (Costanza et al. 1993, 2001, Berkes et al. 2000, Carpenter et al. 2001, Adger et al. 2005). The interactions between variables operating at different speeds and spatial scales, and their implications for failures and successes in resource and ecosystem management have also been highlighted (Holling and Meffe 1996, Fraser 2003, Allison and Hobbs 2004).

Research is advancing concerning the role of structural features and governance regimes of different societies in relation to resilience. There are insights emerging on cross-scale interactions (Holling and Meffe 1996, Cash 2006), on the dynamics of social and economic drivers of change (Lambin et al. 2001, Cinner 2005) and on governance systems that allow for learning and responding to environmental feedback and change (Dietz et al. 2003). The interplay between the individual (e.g. leadership), the emergence of organizational structure, institutional dynamics, and the power relations glued together in dynamic social networks are examples of features that seem critical in governance that allows for ecosystem management and for responding to environmental feedback (Folke et al. 2005).

The insights generated above are predominantly based on decadal to half a century observations. A decadal time scale focus will miss larger temporal and spatial scales, so-called creeping changes, and the acceleration of system dynamics. There are huge gaps and lack of coherent observations on such features in societies over historical time. Issues that need to be addressed include whether or not multi-level organization of society becomes too slow to respond to the, speed, frequency, and unpredictability of environmental feedbacks. Such shifts change the perception of the environmental dynamics and therefore the responses. Homogenization of the environment alongside increasingly complex societies enhances the vulnerability on both sides.

One hypothesis based on the above is that societies tend to lose resilience (or become “brittle”) as they become more extended in space or more complex in structure. The same environmental stress that could be easily handled in earlier, less complex stages of a societies
development can thus become sufficient to cause collapse if it occurs when the society has become brittle. IHOPE can assemble data to test this hypothesis.

2. **How do societies respond to the closing of frontiers? Can technology create new frontiers indefinitely?**

   A common characteristic of human-in-environment development is extraction and consumption of natural resources. The typical response to the exhaustion of these resources has been to move to new regions where possible. These migrations potentially have led to colonization of new areas, conflict and displacement of indigenous populations, introduction of new species, etc. Only quite recently in human history has the ability to occupy new lands become limited by geopolitical constraints. New frontiers are now associated with technological advances which overcome local constraints of resource availability.

   Technology advances take on a number of different dimensions to maintain and further extract resources for human use and to allow for restoration and conservation of ecosystem services. These technological developments provide new methods for increased extraction of limited resources, development of new sources of resources, and recycling of resources. These developments may come about from harmonization of economic and nature for sustainable use; use of new technologies; bio-cycling to increase efficiencies; “bio-mimicry” (using examples from nature) to provide solutions to reduce pollution and degradation of resources; nanotechnology; and blending traditional techniques in novel ways to improve modern technologies.

   One hypothesis following from the above is that new technologies will always be able to overcome resource constraints and keep moving the frontier outward? Integrated historical data from IHOPE can be used to address this hypothesis.

3. **What is the role and path of technology and substitution in the evolution of socio-ecological systems?**

   Never before in history has a good understanding of the nature, shape and role of human impact upon the natural processes of the planet, and vice-versa, been of greater importance. And among the factors governing the dynamics of this interplay between society and the environment, technology is key.

   Technology is not a homogeneous ‘entity’ or ‘process’. It consists of a suite of activities, practices and capabilities that cover the technical realm in the narrow sense (e.g. tools, machines, knowledge systems), but also social arrangements (such as institutions, legal frameworks, economic incentives, etc.) in a wider sense. All these forms of technology have impacts in the environmental realm, but they also feed back onto changes in the socio-environmental-cultural spheres, and directly into the techniques (in the narrow sense) used by a society. Moreover, impacts of technology are cascading forward in time through direct and indirect (2\(^{nd}\), 3\(^{rd}\), 4\(^{th}\), etc. order) effects, depending to some degree on the nature of the technology under discussion. Capturing these effects in space and time will be a significant challenge.

   Key issues in reflecting on these things are among others:
- The context of the trajectories of the technological systems (or part-systems) involved. These contexts depend on a variety of external societal and environmental factors, all acting as historically defined constraints on the system’s dynamics.
- In particular, it is important (and often neglected) to study the role of society’s institutions and how they operate. Especially institutions that have a direct impact on the specific technologies used, or on environmental dynamics have to be given more attention,
- All technological changes trigger – or are triggered by – changes in know-how. Such changes have their own (cognitive) dynamic, driven by the interaction between problems, observations, and inventions. To truly understand the evolution of a technology, these components and their interactions have to be analyzed.
- In the course of a trajectory there occur sudden shifts in the use of resources (substitution), but also societal changes that create new conditions for (among other things) technology. Thus, the evolution of technologies, and their impact on the environment, is ‘path dependent’. Unfortunately, it is not always possible to understand or predict such sudden changes, and they may be predicated on systemic ‘choices’ that involve very complex sets of interactions on multiple spatio-temporal scales.

To successfully study the interactions between these different aspects of technological dynamics, one needs to create dynamic models of the relationships between problems and solutions involved, and then to study the behavior of such models under different circumstances (institutional, environmental, etc.). This involves the study of the materials and other resources, their constraints and the opportunities they offer, but also of the feedbacks and feed-forwards that constitute the ‘technological systems’, as well as its impact on the environment and society at large.

4. What causes socio-ecological systems to be more or less successful in perceiving and adapting to decadal and longer changes (e.g., land use, climate, disease)? Are some types of environmental stress inherently more likely to cause collapse than others?

This question focuses on the nature of environmental stresses, and on the ways in which societies perceive change, and deal with it. For example, it is often assumed that societies are better able to adapt to environmental stresses that are predictable than to stresses that are more chaotic. However, environmental stresses have different degrees of predictability, and a crucial question is the extent to which reduced predictability leads to problems in adaptation or to collapse. A second issue is the challenge raised by a slow, almost imperceptible change to an underlying trend in an environmental variable, which leads to a rapid and unexpected increase in the number and intensity of extreme events, or even to a threshold and then a sudden change, out of all proportion to the rate of change of the driving force. In such cases, it is ultimately the ability of societies to perceive the nature and time scale of the environmental stress that determines whether successful adaptation can be implemented. Exploring the nature of environmental stresses that have caused societies to collapse in the past, and the nature of stresses that societies have recognized and coped with, may give important clues as to how modern societies may (or may not) be able to deal effectively with climate change and other changes to the global environment.
5. **What might have been the long-term human contributions to changes in the rates and composition of Earth processes?**

During the post-glacial period of the past 10,000 years, environmental and human systems have changed radically. With the retreat of the ice-sheets, coast lines and landforms were exposed, water bodies and wetlands were formed, and ecosystems moved across landscapes. Plants and animals were re-dispersed over these landforms. The evidence of these changing landforms and biotic assemblages is reflected in the global signatures of biogeochemical cycles and earth system dynamics captured in sediments and ice cores.

Human expansion occurred during this same time period and the impact of human activities increased in intensity during the past 10,000 years. The ability to pick up the signal of human activities is confounded by natural responses to post-glacial environmental conditions. However, as human activities intensified resource use and domestication of animals, their impact on earth system cycles has become more apparent and was captured in ice and sediment cores around the world. Regional and global indicators of natural and human perturbations can be distinguished from earth system indicators. The attribution of human and environmental changes that affect the earth system can be carried out for the past 10,000 years and this ability to partition the differential effects of human and natural perturbations will provide greater understanding of the coupled system.

6. **Historically, what are the effects of humans on the dispersal of other species (i.e. diseases, invasive species) and vice-versa?**

Many species interact and have direct or indirect effects on each other. Because of the distinctive features of human behavior, cultural practices and movement patterns, as a species we have had a disproportionate role in modifying global patterns of interactions between other species. For example, through agricultural practices involving the domestication and cultivation of plants and animals, humans have altered vast regions of the world.

These alterations have directly affected land cover and indirectly impacted soils, hydrology and historical biodiversity. Similarly, humans have purposely or inadvertently transplanted species into regions where they had not previously existed or have caused species to go extinct. Often these transplantations had little or no effect, but in some cases the impacts have profoundly changed ecosystem processes, to the extent that local biotic systems have been displaced to alternative stable states. Conversely, many organisms have significantly affected the dispersal of human populations, including diseases that predominate in certain regions (e.g., tropics) or under certain circumstances (e.g., mycotoxigenic fungi in stored foods). In some cases, these interactions have affected the evolution of cultural practices that deal with the harmful properties of pathogens. Settlement patterns of humans can also be disrupted by predation, either directly on humans or on their prey items or livestock. The nature and scope of these reciprocal interactions exhibit patterns that have explicit contexts in space (from local habitats to continental scales) and time (e.g., as technology accelerated mobility). The intersection of these associations has had profound effects on humans and their role in the biosphere.

7. **How can we use our understanding of past socio-ecological interactions to help map modern spatial variations in resilience, system trajectory and sustainability**
worldwide, thus allowing classification and ranking of the state of world systems at different scales?
Integrating past social and ecological records will provide the means for understanding the nature of change that underlies modern environments. In some instances, the methods required for this are already available. But in other situations and scales the application of theory over long timescales and the development of appropriate models are at an early stage. For example, theoretical constructs such as socio-ecological ‘syndromes’ (Lüdeke et al. 2004) and ‘resilience theory’ (Gunderson and Holling 2002) have been applied to modern systems and their recent pasts, but not over long timescales. At certain spatial scales, such applications are also hampered by the lack of data. IHOPE will provide the databases of socio-ecological information that will allow the extension of such theories to longer timescales and over a wider range of spatial scales. In the future, we would expect to interrogate the IHOPE databases in novel ways. For example, to produce an analysis of world regions, at some given scale, ranked according to long term vulnerability to soil erosion or overuse of water; or to apply the socio-ecological syndrome approach to regional and sub-national scales; and for a single region, to identify the pace and position of the socio-ecological system on an ‘adaptive cycle’ (Gunderson and Holling 2002) or ‘trajectory of vulnerability’ (Messerli et al. 2002).

Principles
Given the unique goals of IHOPE and the general and specific questions listed above, are there general operating principles that are relevant? We believe that there are and list some of them below.

Multiple time and space scales
IHOPE acknowledges that the interpretation of socio-ecological interactions and changes through time is in part dependent upon the scales of observation and study. A major issue is therefore to appreciate the role of scale in determining socio-ecological interaction through comparative studies and modeling. IHOPE syntheses will seek to identify and model cross-scale interactions in time and space.

IHOPE deals with spatio-temporal scales on Earth in the Holocene period. There is however a special focus on regional spatial scales and changes over the past 10,000 years and into the future years. Notwithstanding globalised networks and international treaties, a regional focus maps most realistically onto the geographical scale of the majority of human activities, governance and decision-making through history. A regional focus will require the upscaling of many local case-studies but it also allows subsequent upscaling to the global level to produce global time-series and input into the modeling of global dynamics.

Complexity and causality
IHOPE acknowledges that socio-ecological systems are complex and the concept and identification of causation may prove problematic. Complex systems may exhibit multiple interactions between apparent drivers and responses where the direction and strength of interaction are not necessarily explicable in terms of simple, direct and linear causative links; there may be internal dynamics that drive system changes. IHOPE studies therefore encourage the use of concepts from complexity science, including linear and nonlinear dynamics, feedback, thresholds, emergence, historical contingency and path dependence, and the application of
nonlinear simulation tools, spatially explicit and agent based models to simulate relevant phenomena.

**Multiple approaches to evaluate Alternative Explanatory Frameworks (AEFs)**

IHOPE studies need to adopt a range of alternative explanatory frameworks, embracing conventional scientific positivist approaches as well as discipline-specific protocols. However, a key issue for IHOPE is the evaluation of explanations and the realistic appreciation of uncertainty. The type and range of data sources, the different disciplinary conventions and the nature of conceptual and predictive models used imply that there is no single method to determine the quality and certainty of explanations. In some contexts, it may be possible to utilize a hypothesis-testing approach, but in others the ability to falsify hypotheses may be severely restricted. In many historical studies, the use of approaches that argue from the perspective of mutual internal consistency or weight of evidence may be more appropriate. For some disciplines, it may be necessary to construct an agreed set of interpretative protocols for IHOPE studies.

**Challenges to Implementation**

There are several potential barriers to implementing IHOPE. These are listed below along with potential ways to overcome them.

**Language/World View**

A challenge to development of an integrated history of the human and earth system is the reconciliation of the various disciplinary perspectives on representing history and events. Resolving differences between quantitative and qualitative information, and between knowledge sets from different disciplines is a necessary step in successful development of interdisciplinary studies. Development of a framework and shared conventions to interconnect these diverse views and to provide a mechanism to harmonize different perspectives will be needed to achieve the integrated history of human-environmental systems.

The IHOPE community will work toward the development of shared conventions between the biophysical and social science communities. Resolving issues related to understanding what factors or principles jointly affect coupled human-environment system dynamics is fundamental to the progress of the IHOPE studies. This will involve resolving scale issues of time and space (as mentioned in the previous section), conciliation of impacts and drivers between different components of the coupled system, and alternate views of the structure of the analytical framework. Recent examples of resolving these challenges can be found in the Millennium Ecosystem Assessment and sustainability science.

**Data**

The constellation of data sets that support IHOPE will serve as a central resource for studies from various perspectives of the earth’s history and possible futures. The integrated history itself will also be used as a core data set to test integrated models of humans in natural systems at multiple time and space scales, from regional to global.

As such, IHOPE is a comprehensive and complex intellectual endeavor that will require a commensurate cyber infrastructure. The culture of information sharing across the disciplines and
among the participants must complement the technological capabilities. This necessitates a set of basic principles that parallel the IHOPE science goals. These include:

- An IHOPE culture of sharing data, with data freely exchanged among scientists, practitioners and the public. The IHOPE effort should be based on the notion of sharing data and should be facilitated by the notion of using emerging technology as appropriate.
- The preservation and long term curation of the harvested data is in the spirit of the IHOPE project and an essential element of its success and continued use as a freely available scientific resource.
- The recognition that the data will be dispersed and profoundly heterogeneous in nature, from numerical to narrative.
- Awareness that this may require distinctive and unique uses of information including negative results and surrogates.
- High standards of data quality assessment. “IHOPE will require the integration and synthesis of data from a huge range of sources of highly variable quality. While experts in a field of study usually have a good working understanding of the quality constraints on their data, this understanding is not often or easily communicated across fields. What we need for the IHOPE effort is a system to communicate the full range of data quality - from statistically valid estimates to informed guesses – from historical narratives to the results of computer simulations. Communicating data quality is a prerequisite to effectively integrating the full range of information we hope to assemble.” (Costanza 2006)

The IHOPE data system must reflect these basic principles in its design and use by the community.

**Different Approaches to Analysis, Synthesis, and Modeling**

One of the hallmarks of IHOPE will be to use a wide variety of datasets, tools and information. For instance, utilization of multiple lines of evidence to cross-check and test hypotheses can be performed with a complementary suite of models and observations. However, we must recognize that many of the disciplines employ models that represent very different views of historical information and operate on significantly temporal and spatial scales. Conflicting goals across disciplines will have to be addressed to develop creative solutions to the appropriate interpretation and analyses of disparate observations and model solutions. For instance, both human and environmental observations mirror unique snapshots of space and time relevant to specific questions and different disciplines have various means of tracking time. Archaeologists have mutually agreed-upon methods (e.g., erosion signals, sediment burial) applied within discrete temporal windows, whereas the atmospheric and palaeoenvironmental communities utilise a wide range of archives, which are often spatially restricted (e.g. lakes) but temporally continuous (e.g., ice-cores).

There are at least 5 constituent communities that will be involved with IHOPE that all have such very different cultures with regard to data collection, modeling, analysis, storage, archival and formatting strategies:

1. Archeologists who know what happened to human societies;
2. Anthropologists who know how the structure of societies change;
3. Quaternary scientists (including palaeoecologists) who know what happened to the physical environment (e.g. Dearing et al 2006a and b);
4. Geographers who manage analyzed data over various temporal and spatial scales; and
5. Earth System scientists who are interested in derived products that can be used as inputs to dynamic models that evaluate impacts on say, hydrologic processes, carbon cycle, etc.

The analysis and interpretation of the observations and modeled data will have an open and collaborative philosophy to facilitate the participation of various communities. To this end, IHOPE will encourage the development of regional centers for data collection, modeling and analysis where local experts will have control over regional analyses and contribute to the global synthesis activities.

Institutional Issues

A major issue in implementing inter- and transdisciplinary research is the disciplinary structure and reward system built into the current academic enterprise. Scholars are often given credit in promotion and tenure decisions only for work in their academic discipline, and often only for work for which they are the first author. This reward structure runs exactly counter to the goals of IHOPE, which require broad interdisciplinary collaboration, group work, data sharing, and research in interstitial areas not covered by any academic discipline. However, there is a counter trend in academia of developing interdisciplinary schools, centers, and networks, and thus implementing alternative reward structures more consistent with IHOPE’s agenda. These are discussed further on.

Implementation Strategies

Several short-term and longer-term strategies and projects have been identified to implement the IHOPE project. Below we identify three such strategies that could be implemented in the near term.

Authentic engagement with range of communities

The kind of approaches needed to make IHOPE a success strongly depend on multidisciplinary, interdisciplinary and transdisciplinary efforts. This means that different scientific cultures, biases, jargons and methodologies have to be bridged and connected. This is a major challenge. There are many successful examples of such integration, and many of these focused on developing models.

A recent example of a successful integration across disciplines is the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2003, Reid et al. 2005). Here economists, ecologists, together with other natural and social scientists made an assessment of the past, current and future state of species, ecosystems, ecosystem services and human well-being. The main objective was to provide guidance to national governments, NGOs, the private sector and the international conventions on how to respond to the merging threats. The assessment started in 2000 and was completed in 2005. Early on in the process, two important factors were recognized, that could limit the relevance of the assessment. First, a continuous adjustment to the evolving user needs was considered essential. This was established through a formal consultation process with representatives of the users and the relevant conventions and resulted, for example, in a detailed assessment of the Millennium Development Goals that were adopted at the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002. Second, a common
conceptual framework and acceptable terminology seemed needed because at the earliest design meetings many were confused by the width of the assessment and all the different perspectives that had to be included. This led to a smaller working group that developed a highly aggregated conceptual framework (CF) that depicted the relationships between drivers and responses, and species, ecosystems, ecosystem services and human well-being. The CF made the linkages between different scales and actors explicit. Together with state-of-the-art multidisciplinary review of major concepts (e.g. ecosystem services, human well-being, ecosystem valuation, drivers and scale) the CF was published (Millennium Ecosystem Assessment 2003) and provided essential guidance throughout the whole assessment process.

One of the important lessons learned for the Millennium Assessment is not to design a detailed rigid framework, but one that is general enough to allow the incorporation of new insights and approaches. The relevance of developing and documenting a CF is that mutual exchange and learning between disciplines is facilitated.

Within IHOPE a similar interdisciplinary process has to be established. The first attempts were made at the Dahlem Conference in 2005 (Costanza et al. 2006) but still many gaps remain. Additional workshops should be organized that, for example, focus on how to integrate the different spatial, temporal and societal dimensions of the various natural, social and economic drivers of change. At the same time common and distinctive properties of the human-environment system have to be defined. These can, for example, be based on demographic, economic, ecological and physical variables, specific indicator values or series of aggregated indicators.

**Integrated Human-Environment Time Lines**

As one of the first steps in the IHOPE Project, we propose to assemble carefully selected chronologies of indicators that describe human numbers and activities in concert with indicators of environmental variation at continental scales. Our overall objective in this task is to observe synchrony, or lack thereof, to pose better questions and to generate refined hypotheses regarding human-environment interactions. In the past decade, important research questions regarding the workings of the Earth system were generated when time series of global biogeochemistry, land cover and climate were compared (EPICA 2004). Similarly, time lines depicting the rise over the past several hundred years in a suite of indicators of human impacts on the earth system have argued powerfully for the recognition that we have entered a new geological era, the Anthropocene (Crutzen, Steffen refs). The timing and nature of human perturbations to the Earth system is less well known as we go back in time, yet it is critical to our understanding of the nature of human-environment interactions (e.g., Ruddiman). In developing timelines of human and environmental events and variability on time scales ranging from decades to millennia, this task will contribute to overall IHOPE goals by assessing availability of data key variables describing the state of human-environment interactions during the past and projecting these into the future, developing strategies for integrating human and environment data in way that produces researchable questions.

This IHOPE activity builds on recent progress in developing global indicators of human and environmental variability over the Holocene (Crutzen, Steffen and McNeil in prep). Such global-scale analyses will play a key role in characterizing the human imprint on natural variability during the Holocene.

In the next phase of IHOPE activity, we propose to examine co-variation of the human-environment system at continental scales. Theses analyses will allow us to assess data
availability and quality at a regional scale, to enhance our understanding of the reliability of chronological data, including the quality of chronological control.

We propose to assemble the following times series by integrating modeling with existing databases (e.g., see below in “Spatially Explicit Global Data Bases” for representative activities):

**Biophysical**
- Land cover (ecosystem and landscape characteristics related to vegetation cover, snow and ice extent, wetland, and water body distribution)
- Evidence for changes in land-surface and oceanic conditions that point to environmental proxies
- Fire and dust events (and associated geological markers)
- snow and ice extent
- coast line delineation
- Atmospheric composition
- Indicator(s) of coastal processes and structure

**Human and Societal**
- Land use (type and intensity)
- population -- number and distribution (e.g., urbanism)
- economic activity
- longevity of coherent culture in a specific place (long-lived groups perceive environmental threats based on long-term history and memory, but what about newly arrived groups, or groups that emerge after collapse)
- energy (source, distribution, capabilities)
- major technological change (e.g., internal combust engine, technology for warfare, public health)
- Major human events (e.g., significant wars, disease pandemics, etc.)

We are aware of the care that should be taken in interpreting a collection of human and environment chronologies, knowing that such time lines could generate misconceptions as well as insights. In particular, correlation does not imply causation and leads and lags may represent system dynamics or artifacts of the choice of variables. In consultation with experts that generate the primary data, we anticipate that the observed synchrony and lack of synchrony will yield researchable questions for the IHOPE project. For example, a lack of synchrony may imply that human dynamics dominate the system and the culture is resilient to environmental disturbances.

The significance of this activity is to generate more specific opportunities to address dynamics and questions tests usefulness of continental scale aggregation

**Spatially Explicit Global Data Bases**

Recent advances in Earth system models have incorporated aspects of terrestrial interactions with the climate system, primarily through the carbon cycle. Components of the land dynamics include processes of production, respiration and decomposition as well as disturbances such as fire. Human contributions to Earth system dynamics such as deforestation, cropping, management of systems (e.g., through fire), etc. are not represented in global models except through prescribed land cover or fire parameterizations (CCSM, IPSL, Hadley).
Similarly, many ecosystem models contain detailed components of biogeochemical cycles or changes in plant functional types (e.g., CENTURY, LPJ, MC1) due to disturbance, but, evaluation of these models (for spinup and historic reconstruction) has been difficult, except for recently observed events. The paleo climate community has a rich history of combining paleo climate and dynamic vegetation models through the Paleo Model Intercomparison Project (e.g., Harrison 1999; http://www-lsce.cea.fr/pmip/). Development of spatially explicit global paleo climate, archeological, anthropological and ecological databases by IHOPE will provide the modeling community with a reference for both model development and testing biophysical and linked socio-ecological hypotheses.

It is important for IHOPE to juxtapose human history with environmental history. Reconstructions of the evolution of landforms since the Holocene, and their comparison with observations and modeled changes in climate, ice mass, coastal zones, and biogeochemistry are available from various sources such as the Cooperative Holocene Mapping Project (COHMAP). Other information that has been gathered and analyzed over the last 20 years has been largely motivated by the jointly sponsored IGBP/WCRP Past Global Changes (PAGES) and Climate Variability (CLIVAR) projects’ Paleo Model Intercomparison Project (PMIP; http://www-lsce.cea.fr/pmip/). Regional to global syntheses from ca 6,000-21,000 YA included the BIOME 6000 reconstruction of paleovegetation (Prentice and Webb 1998), the ICE-5G global ice sheet reconstruction (Peltier 2004), The Global Lake Status Data Base (GLSDB) activity that contains assessments of lake level or relative water depth (lake status) through time (30,000 yr B.P. to present; http://www.bridge.bris.ac.uk/projects/GLSDB), the Dust Indicators and Records of terrestrial and Marine Palaeoenvironments (DIRTMAP) database that contains records of dust accumulation rates and properties targeted from 150K years BP to present (Mahowald et al. 1999), Snowline reconstructions during the LGM from the tropics and sub-tropics (SNOWLINE; Mark et al. 2005) and a Multiproxy Approach for the Reconstruction of the Glacial Ocean surface sea surface temperatures (MARGO; Kucera et al. 2005). Ongoing and planned regional and global syntheses include changes in fire regimes through charcoal, wetland extent and improved vegetation. While these and other databases are spatially and temporally incomplete, changes in the areal extent of coastal zones, ice sheets and landforms through time need to be reconstructed in the same spatial resolution as the current global system models (e.g., 0.5 degrees) with various model formulations.

Historic and geologic observations of vegetation changes due to alterations in regional climate, in coastal and continental landforms, and disturbance patterns will help constrain models of the biogeochemistry of terrestrial and ocean ecosystems. Archeological observations of human distributions across the landscapes will provide information on the spatial distribution of local activities related to deforestation, fire, animal husbandry, cultivation, and other human activities. We can then begin to play out the interactions between human expansion and impacts on the terrestrial system and intensity of land use over the last several thousand years.

While complete global coverage of human activities such as land use and emissions is not immediately feasible, a short term product of a historic global database utilizing available observations of land use will enable both regional and global analyses and hind-casting.

For instance, strong data constraints on Earth system dynamics are imposed by the analyses of ice cores and global atmospheric methane and CO₂ concentrations (Petit et al. 1999, EPICA 2004). These types of data can be used to test, for example, the expansion of domestic ruminant livestock populations, cultivation of rice, and the importance of fire through modeling exercises. Other hypotheses can be tested to improve our understanding of the consequences of shifts in
climate (e.g., extreme drought), and the failure of societies (such as the Maya) to deal with them. Simple correlations, however, with climate events may be necessary but not sufficient to account for changes in human activities. Social and archeological disciplines provide insight into societies that may be undergoing political and institutional stresses. For instance, models that link social pressures with scenarios of extreme drought from the past (e.g., Maya, dust bowl of North America in the mid-20th century) will provide an opportunity for understanding how social and environmental systems may or not respond to future stress.

**Integrated History Regional Case Studies**

We have demonstrated that the rapid developments of the last few years in the area of distributed data management, data mining and modeling enable us to launch into the building of the kind of data system needed to achieve IHOPE’s goals. Intellectually, however, ensuring that (a) the relevant questions have been identified, (b) all the data to be collected are relevant to the questions investigated, and (c) they are in a form ready to be used are a priori necessary tasks for IHOPE. IHOPE will develop experimental designs to test data that have been collected at different spatial and temporal scales, within disciplines with different epistemologies, in response to different questions, using different metrics and with variable levels and degrees of detail.

Realization of IHOPE’s goals will be implemented through an analysis of regional case studies for which the data available are dense, the result of research in a wide range of disciplines, and representative of the many categories of data to be collected at the global scale. Regional case studies will be framed through the coupled process and transitions of the human-environment system, for example, the colonization of pristine landscapes by hunter gatherers in Australia, the colonization and abandonment of landscapes by hunter-gatherers in the Sahara during and since the Holocene, recolonization of early Man in Europe after the deglaciation, transitions to settled agriculture in the Middle East and the Viking Landnam colonization of inhabited regions. This will allow us to experiment with a range of AEF’s, designing and implementing the datasets required to enable each AEF to ask the project’s questions, experimenting with different metrics, trying out various kinds of model validation, etc.

At the same time, a study that compares the socio-environmental dynamics in these different areas will allow us to design the kind of meta-language about socio-environmental phenomena that will allow us to compare the systemic behaviors underlying different instantiations of socio-environmental interactions. Below we list several possible example case studies and why they would be appropriate for IHOPE.

**Australia**

A large amount of research has been carried out in Australia on the palaeo-environment and on the evolution of human society on the continent, including the abrupt transition from Indigenous to European-dominated cultures in many parts of the continent (Flannery 1994, 2006). Some attempts have been made to link human activities with past environments (e.g., mega–fauna extinctions), although there is not yet a consensus on these interpretations. Near-term climates are sufficiently predictable with ENSO forecasting for seasonal and interannual climate variability and is routinely used by farmers and ranchers in the region. On the longer term (e.g., millennial changes through the Holocene and last glacial), the maritime nature of the continent provides a muted response to climate change relative to for example, northern hemisphere regions. While Australian perceptions of human-landscape interactions on
archaeological timescales (e.g., the last 60,000 years) may be based on the assumption that humans have been particularly important (viz the Gurdip Singh hypothesis of aboriginal fire, which has been promulgated by Kershaw et al), however, the evidence may not support this. In particular, Geoff Hope has shown that similar fire and vegetation changes have occurred in New Caledonia (with no long history of humans) as on the mainland. Also, model simulations (with no humans!) can reproduce large-scale changes (1). In addition, the climatic history of Australia is primarily driven by the Australian monsoon, and the Antarctic cold reversal and not the northern hemisphere Younger Dryas characterize the period during ‘deglaciation’. Given the amount of existing information on the environmental, archaeological, and historical aspects of Australia, an initial synthesis would be useful in generating questions and hypotheses for further study.

Australia offers a good opportunity to study some unique aspects of socio-ecological systems because of its continental-scale cultural isolation from ca. 65,000 years ago to about 200 years ago. Australia has an uninterrupted culture that experienced the coldest periods of the last ice age, the (geologically) rapid transition to the Holocene, the temperature maximum at the mid-Holocene, and the slowly cooling climate since then (up to the 1700’s). Finally, the Australian continent has seen an abrupt transition from a hunter-gatherer culture to an industrialized European culture over the past 200 years.

The Mediterranean
The Mediterranean is one of the most studied regions on Earth. Over some 10,000 years, environmental, archaeological, written historical and instrumental data testify to the complex interactions between the atmosphere, the geosphere, the biosphere and a range of successive societies. The basin has been studied at different scales, from the local to the sub-regional to the regional, and by researchers in disciplines ranging from atmospheric studies to tectonics, geomorphology, biology, economics, and various social sciences to history and geography. Moreover, the area has been the theater of the emergence as well as the collapse of a number of social systems of various sizes and forms. It is therefore an ideal area to do a case study of the kind proposed here: multi-scale, multi-disciplinary and based on many different kinds of data.

What are the kinds of questions that can be approached in this area, rather than in the other ones? On the one hand, we have detailed, multi-scale and long-term data on the growing connectedness of the societal and the environmental dynamics, which leads to increasing disturbance-dependency of the environment on the society, and ultimately to societal control over the environment, and the “accident waiting to happen” that we are experiencing at present.

On the other hand, we have dense data on how this long-term process occurs in different ways in different areas – and therefore on which environments are more, or less, vulnerable to specific phases of the long-term dynamics, as well as on the different ways in which the societies in question shape their own environment, and their own fate. Hence, the area lends itself particularly well to a comparative study of the different ways people in the region have interacted with the same set of global environmental dynamics.

The Maya Area
Maybe the principal interest of the study of the Maya area in this context is the fact that here we have an instance of geographical shift of an important, highly complex, and relatively well-known civilization from one terrestrial environment (the mountains of Guatemala, Belize and
Chiapas) to another (the level, karstic area of lowland Yucatan). The climate is different from all other areas chosen (water is not the main constraint to the system), the chronology is well-established through the presence of many stelae with calendar dates that are known to modern researchers, and through the same stelae we have a developing sense of the political dynamics at the local/regional scale. It is assumed that the geographic shift from highlands to lowlands could be due to environmental degradation, but socio-political stresses may also have been important.

In particular, this area is expected to yield an important contribution to the IHOPE project, because it concerns a culture that is comparable in complexity to those of the Near East and the Mediterranean, but that has a completely different technology (no wheeled transportation), a different kind of agriculture (maize rather than wheat, barley and other such cereals), a different kind of social organization, and a different kind of (low-density) urbanism.

China

The historical record of China is rich in terms of its sources and detail. The vast documentary record of China’s environmental history is gradually being compiled and made accessible (eg. Elvin 2006). Palaeoenvironmental/archaeological studies continue to reconstruct regional climate (Wang et al 2005), local human activities (Yasuda 2002), vegetation change (Yu et al 2000) and catchment-scale interactions between human activities, climate and environmental processes (Shen et al 2006). We thus learn that China’s immense geographical scale, ranging from the sub-tropics to the northern cold deserts, has provided an unmatched level of ecological diversity within a more or less consistent polity. Its long and dynamic history of changing governance, war and technological development suggests that there is arguably an even greater diversity of past socio-ecological interactions. The earliest are perhaps described by archaeological studies in the middle Yangtze basin where rice phytoliths suggest a centre of cereal cultivation existing as early as 10000 cal BP (Yasuda 2002). Even on the relatively isolated Yunnan plateau, measurable effects of human activities on forest cover and hydrology are recorded from at least 7000 years ago. On the northern loess plateau, in the catchment of the Yellow River, the socio-ecological history of soil erosion over seven millennia encompasses early warfare, population migration, climate variability, the inner wars of the 1930s, the Cultural Revolution and recent soil conservation schemes (He et al 2006). Large scale hydraulic modification and linking of the natural waterways (eg, the Grand Canal) over at least 2000 years is probably unrivalled worldwide, and much of China’s agriculture has depended upon the successful management of irrigation systems, a situation that remains today (Elvin and Ts’ui-jung 1998). The link between China and IHOPE can thus be viewed from two perspectives. The historical archive of a country that, for much of antiquity, has represented 20-30% of the world’s population provides crucial input into both Asian and global analyses. But also, today’s population pressures, coupled with the tensions between the needs of subsistence agriculture and economic development, demand that environmental management in China is founded on the highest possible level of understanding of past, present and future socio-ecological interactions.

The US Southwest

Over the last 3000 years, the US Southwest has seen a succession of very different adaptations to the extreme climatic circumstances of the region. Initially, these were based on resilience that was due to the high degree of mobility of the populations (Nelson and Hegmon, 19XX). But, contrary to Australia, the population of this drought-ridden area did eventually settle down in
larger groups, and establish both dry- and irrigation-based farming. The range of adaptations to
the environment is therefore considerably wider than elsewhere.

The interest of this area for this part of IHOPE lies (1) in the particular (extreme)
environmental circumstances and the wide range of ways the regional societies have dealt with
them over the last 10,000 years, (2) in the dominance of water availability for the sustainability
of the regional human systems, so that in this case a single environmental factor comes to
dominate the whole socio-ecological system, (3) in the temporal precision with which the
dynamics can be monitored, thanks to the availability of long tree-ring sequences that allow us to
make detailed reconstructions of fluctuations in annual average precipitation and temperature, as
well as to assign very precise dates to the wealth of archaeological evidence, and (4) in the fact
that this area has thus far provided the best, and most detailed, dynamics (multi-agent) models of
socio-environmental interaction over thousands of years.

**Transdisciplinary Networks and Centers**

As regional case studies are developed, it will be useful to draw from the regional case studies to:

a. Quantify global population numbers and density through time;
b. Quantify and map area affected by specific settlements and/or populations;
c. Develop and apply objective schemes to assess ‘human impact’ on natural
   vegetation (extension of the ‘biomisation’ method (Prentice and Webb 1998);
d. Quantify and map timings of expansion, migration events;
e. Synthesis environmental data and reconstruction of regional changes covering the
   relevant periods of interest (e.g., Holocene, last 20,000 years, Late Quaternary)
f. Map the land-geography through time (NOTE Pat Barglein has been working on
   this but there is still a ways to go).

The implementation of the challenging IHOPE research agenda will require contributions
from scholars around the world. This Science Plan outlines the way forward with regard to
regional case studies and deliverables as described above. A networking approach will clearly
be essential for IHOPE’s success, and at least two types of networks can be envisaged. First,
there will need to be regionally based networks of scholars from a wide range of disciplines who
undertake the case studies in an integrated fashion. Complementing these will be more
disciplinary networks, both regional and global, who can further develop and test data and
information gathering methodologies for particular aspects of the IHOPE agenda and who can
develop specific simulation tools needed for the analysis and integration phases of the project.

As integration across disciplines is central to IHOPE, the growing number of interdisciplinarily
research centers around the world will provide an infrastructural underpinning to the IHOPE
effort. Examples of such centers include the Global Institute for Sustainability and the School for
Human Evolution and Social Change at Arizona State University, the Gund Institute for
Ecological Economics at the University of Vermont, the consortium of Stockholm-based society-
environment research units (Centre for Transdisciplinary Environmental Research/Stockholm
University/Stockholm Environment Institute/Beijer Institute for Ecological Economics),
the National Center for Ecological Analysis and Synthesis (NCEAS) in Santa Barbara, CA, and the
Centre for Resource and Environmental Studies, at the Australian National University.
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Participant List
IHOPE planning meeting, 12-13 Jan, 2006, The Royal Swedish Academy of Sciences, Stockholm, Sweden

Steve Aulenbach
National Center for Atmospheric Research
PO Box 3000
1850 Table Mesa Drive
Boulder, CO 80307-3000, USA
Phone: +1 303.497.1701
aulenbac@ucar.edu

Robert Costanza
The University of Vermont
Gund Institute of Ecological Economics
50 Main Street
Burlington, VT 05405-1708, USA
Tel: +1 802 656 2774
Robert.Costanza@uvm.edu

Carole Crumley
University of N. Carolina
Department of Anthropology
204-A/B Alumni Building
Chapel Hill, NC 27599-3115, USA
(1-919) 962 5527
crumley@unc.edu

John Dearing
Department of Geography
The University of Liverpool
Roxby Building
Liverpool L69 7TZ, UK
Tel: +44-151 794 2873
j.dearing@liverpool.ac.uk

Carl Folke
Beijer Institute
The Royal Swedish Academy of Sciences
Box 50005
SE-106 90 Stockholm
Sweden
Tel: (46-8) 673 9533
calle@system.ecology_su.se

Lisa Graumlich
Montana State University
Mountain Research Center
Dept. of Land Resources & Env. Sciences
PO Box 173490, 106 AJM Johnson Hall
Bozeman, MT 59717-3490
Tel: (406) 994 5178
lisa@montana.edu

Kathy A. Hibbard
IGBP/AIMES Executive Officer
Project Scientist II
Climate and Global Dynamics Division
National Center for Atmospheric Research
PO Box 3000
Boulder, CO 80307-3000, USA
Tel: +1 303.497.1706
kathyh@ucar.edu

Rik Leemans
Wageningen University and Research Center (WUR)
Environmental Systems Analysis Group
PO Box 8080
NL-6700 DD Wageningen
The Netherlands
Tel: (31-317) 484 919
rik.leemans@wur.nl

Sander van der Leeuw
Arizona State University
Director, School for Human Evolution and Social Change
Box 872402
Tempe, AZ 85287-2402, USA
Tel: +1 480 965 6213
Email: vanderle@asu.edu

Julia Lupp
Program Director/Serial Editor
Dahlem Konferenzen der Freien Universität Berlin
Thielallee 50, 14195 Berlin, Germany
Tel: +49 (30) 8385 6602/3
dahlem@zedat.fu-berlin.de

João Morais
IGBP
The Royal Swedish Academy of Sciences
Box 50005, Lilla Frescativägen 4
Se-104-04 Stockholm
Sweden
Tel: +46 8 673560
morais@igbp.kva.se

Dennis Ojima
Natural Resource Ecology Lab
Colorado State University
Campus Delivery 1499
Fort Collins, CO 80523-1499
Tel: +1 970 491 1796
dennis@cnr.colostate.edu

Jim Reichman
Dept. of Ecology, Evolution
NCEAS
Marine Biology
735 State St. Suite 300
U.C. Santa Barbara
Santa Barbara, CA 93101, USA
Tel: +1 (805) 892-2500
reichman@nceas.ucsb.edu

Will Steffen
Director, CRES and ANU Institute for Environment
Centre for Resource and Environmental Studies (CRES)
Australian National University
W.K. Hancock Building[43],
Biome Place
Canberra ACT 0200, Australia
Tel: 61 2 6125 4588
steffen@cres.anu.edu.au

Uno Svedin
FORMAS
Birger Jarls Torg 5, PO Box 1206
SE-111 82 Stockholm, Sweden
Tel: +46 8 775 4037
Email: uno.svedin@formas.se

Yoshinora Yasuda
International Research Center for Japanese Studies
Kyoto, Japan
TEL 81-75-335-2150
Email: Yasuda@nichibun.ac.jp
Sustainability or Collapse: 
What Can We Learn from Integrating the 
History of Humans and the Rest of Nature

Robert Costanza\textsuperscript{1}, Lisa Graumlich\textsuperscript{2}, Will Steffen\textsuperscript{3}, Carole 
Crumley\textsuperscript{4}, John Dearing\textsuperscript{5}, Kathy Hibbard\textsuperscript{6}, Rik 
Leemans\textsuperscript{7}, Charles Redman\textsuperscript{8}, and David Schimel\textsuperscript{6}

DRAFT as of 9/5/06  Do not cite or quote

1. Gund Institute of Ecological Economics, Rubenstein School of Environment and Natural Resources, 
University of Vermont, Burlington, VT
2. Big Sky Institute, Montana State University, Bozeman, MT
3. Centre for Resource and Environmental Studies, Australian National University
4. Department of Anthropology, University of North Carolina, Chapel Hill, NC
5. Department of Geography, University of Liverpool
6. Climate and Global Dynamics Division, National Center for Atmospheric Research, Boulder, CO
7. Environmental Systems Analysis Group, Wageningen University and Research Center (WUR), The 
Netherlands
8. Global Institute of Sustainability, Arizona State University, Tempe, AZ
Abstract
What is the most critical problem facing humanity at the beginning of the 21st century? Global pandemics, including AIDS? Global warming? Meeting global energy demands? World-wide financial collapse? International terrorism? The answer is all of these and more. We live in an increasingly global system in which our most critical problems surpass regional and national borders. But because humans can influence the future, we cannot fully predict it. However, if we can adequately understand the past, we can use that understanding to create a better, more sustainable and desirable future. An emerging consensus is that simple, deterministic relationships between environmental stress, (for example, a climatic event), and social change are inadequate. Extreme drought, for instance, has triggered both social collapse and ingenious management of water through irrigation. Human responses to change may in turn feedback to the climate and ecological systems, producing a complex web of multidirectional connections in time and space. Integrated records of the human-environment system over millennia are needed as a basis for understanding the past and forecasting future changes.

We live in an increasingly global system in which our most critical problems go well beyond regional and national borders. When past civilizations collapsed, they were relatively isolated from other parts of the world. Today, in our interconnected global system, massive social failure in one region threatens the entire system. Can the current global system adapt and survive the accumulating, highly interconnected problems it now faces? Or will it collapse like Easter Island, the Classic Maya, the Roman Empire and other past civilizations, but on a larger scale? What can we learn from these past civilizations (and especially the ones that did NOT collapse) to help guide our current global society toward sustainability? To answer this question requires a new, more integrated, transdisciplinary understanding of the history of how humans have interacted with the rest of nature, how we currently interact, and what the options are for future interactions. Our phrasing of the previous sentence is quite deliberate. “Humans and nature” implies that humans are separate from nature, while “humans and the rest of nature” implies that humans are a part of nature, not separate from it. We emphasize “history” because much discussion of human-environment interactions has lacked a temporal dimension and as such is unconstrained by knowledge of what has already occurred, at least in part because information about human-environment interactions in the historical past has not been well organized for this purpose. If we continue to operate in ignorance or denial of this integrated historical understanding, we run the very real risk of going the way of the Easter Islanders. But if we can adequately learn from our integrated history, we can create a sustainable and desirable future for our species.

Integrating Human and Natural History
Human history has traditionally been cast in terms of the rise and fall of great civilizations, wars, specific human achievements, and extreme natural disasters (e.g.
earthquakes, floods, plagues). This history tends to leave out, however, the important ecological and climate context and the less obvious interactions which shaped and mediated these events (Figure 1). The capability to integrate human history with new data about the natural history of the earth at global scales and over centuries to millennia has only recently become possible. This integrated history could not have been accomplished even 10 years ago, and is a critical missing link that is needed in order to provide a much richer picture of how (and why) the planet has changed in historical times. Such an integrated history will advance research from various perspectives of the earth’s history and possible futures and can be used as a critical shared data set to test integrated models of humans in natural systems.

Socio-ecological systems are intimately linked in ways that we are only beginning to appreciate (1-7). Furthering this research agenda poses great methodological challenges. Events can be plucked from the past to prove almost any theory of historical causation. While Figure 1 puts a range of environmental indicators and historical events together on the same graph, it can show only coincidence, not causation. The causal links are more complex and not evident in the figure. For example, water extraction is related to complex developments resulting from social organization, engineering and climate (see the Roman Empire period on Figure 1). While we use the timeline to illustrate the parallels between human and environmental change, the complex web of causation that resulted in the sequence of events depicted cannot be represented on such a graph. One challenge in linking human and environmental change is the development of a new integrated analytical modeling paradigm that reveals the complex web of causation, while allowing important emergent properties and generalities to rise above the details. Only with such a paradigm can we survey the past and test alternate explanations rigorously. To develop the integrated understanding we seek, a project of the global change research community has been initiated titled: “Integrated History and future of People On Earth (IHOPE)”.

**Long-term Goals of the IHOPE Project**

The IHOPE project has three long-term goals:

1. Map the integrated record of biophysical and human system change on the Earth over the last several thousand millennia, with higher temporal and spatial resolution in the last 1000 and the last 100 years.

2. Understand the socio-ecological dynamics of human history by testing human–environment system models against the integrated history.

3. Based on these historical insights, develop credible options for the future of humanity.

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1 A first step toward the development of such an integrated history and future took place at a Dahlem conference in Berlin, Germany; June, 2005. IHOPE-Dahlem assembled an interdisciplinary group of 40 top scholars from a range of natural and social science disciplines with the goal of identifying mechanisms and generalizations of how humans have responded to and impacted their environment over millennial (up to 10,000 years ago), centennial (up to 1000 years ago), and decadal (up to 100 years ago) time scales as well as a glimpse of the future of the human-environment system. The IHOPE Dahlem Workshop was the kickoff event for a series of coordinated interdisciplinary research projects around the world that will allow us to learn about the future from the past.
To achieve the ambitious goals of IHOPE multiple scientific challenges must be met. This includes linking disparate disciplinary approaches, cultures and models across the sciences and humanities, development of an appropriate information infrastructure to link such disparate information, and developing a common understanding and approach.

**Evolution of the Human-Environment Relationship**

Human societies respond to environmental (e.g., climate) signals through multiple pathways including collapse or failure, migration and creative invention through discovery. Extreme drought, for instance, has triggered both social collapse and ingenious management of water through irrigation. Human responses to change may in turn feedback to the climate and ecological systems, producing a complex web of multidirectional connections in time and space. Ensuring appropriate future responses and feedbacks within the human-environment system will depend on our understanding of this past web and how to adapt to future surprises. To develop that understanding, we need to look at multiple time and space scales (8-9).

At millennial timescales different cultural elements (social and political structure, traditional practices, and beliefs, to name a few) enable or constrain responses. Even global-scale events (climate change, major volcanic activity, etc.) do not affect all regions at precisely the same time or with the same intensity. Models (conceptual and computational) of how societal characteristics and environmental conditions affect the resilience of socio-ecological systems are needed. Processes important for the study of resilience or vulnerability include: the degree of rigidity of social, economic, and political networks; the diversity of biophysical resources and of human resourcefulness; the development of complexity, costliness and ineffectiveness in problem-solving; and the cyclical expansion/contraction and geographical shift in the centre of accumulation with periodic declines and “dark ages” when external limits to social reproduction are reached. Simple, deterministic relationships between environmental stress, (for example, a climatic event), and social change are inadequate. Organizational, technological and perceptual mechanisms mediate the responses of societies to environmental stress, and there are also time-delays to societal responses.

More recent changes in the human-environment relationship, such as accelerated globalization and global environmental change, have deep roots in humanity’s relationship with nature over the past millennium. While we often associate the term “global change” with the greenhouse gas warming evident in the last decade, changes of continental and global scales were put in motion over at least the past 1000 years (e.g. many European landscapes looked much like they do today far earlier than this). Important phenomena include a rise in human population, the strengthening of nation states, the global transfer of European inventions and values, the beginning of industrialization and the rise of global communications, and associated with these the dramatic modifications of land use and biodiversity, hydrological and energy flows, and key ecological processes.

The last 1000 years is also interesting because it’s a period when broad swings in temperature as well as clusters of extreme weather events arguably changed the trajectory of history. The fourteenth century in Europe saw the end of the Medieval Warm Period. Particularly during the period from 1315–1317 Western Europe witnessed a combination of rainy autumns, cold springs, and wet summers that led to crop failures and a dramatic slowdown in urban expansion. These early Europeans
were further subjected to the last major locust invasion (1338), the “millennium flood” (1342), and the coldest summer of the millennium in 1347. From 1347 to 1350 the “Black Death” devastated populations. The clustering of extreme events in the fourteenth century fundamentally undermined social order and was a key factor in a major wave of anti-Semitic pogroms and systematic discrimination. Many would argue that it also led to the end of the feudal system, improved land and employee rights and, through the enlightenment period, paved the way for the modern age. The Little Ice Age affected food availability in many parts of Europe, leading to the development of technological, economic and political strategies as ways to reduce vulnerability. The exceptional 1788-1795 ENSO event reverberated around the world in places as far afield as the first British colonial settlement in Australia, the Indian monsoon region, Mexico and western Europe.

The present nature and complexity of socio-ecological systems are heavily contingent on the past; we cannot fully understand the present condition without going back centuries or even millennia into the past. An important implication is that societal actions today will reverberate, in climatic and many other ways, for centuries into the future.

Turning to the more recent past, the 20th century witnessed several sharp changes in the evolution of socio-ecological systems, at both global (two world wars and the Great Depression) and regional (e.g. the failure of Soviet farming, its reliance on grain from the US, and subsequent collapse as a polity) discontinuities. Variations in the growth rate of CO2 in the atmosphere occur in response to both climatic controls over land-atmosphere-ocean fluxes (for example, CO2 increases more rapidly in El Niño years because of climate effects on terrestrial ecosystems) and political events (the growth rate slowed during the 1970s oil shock and after the breakup of the Soviet Union because of changes in fossil fuel use). The 20th century also marks the first period for which instrumental records of many environmental parameters have become available and for which detailed statistical records of many human activities have also been collected.

The most remarkable phenomenon on Earth in the 20th century was the “Great Acceleration,” the sharp increase in human population, economic activity, resource use, transport, communication and knowledge–science–technology that was triggered in many parts of the world (North America, Western Europe, Japan, and Australia/NZ) following World War II and which has continued into this century (10,11). Other parts of the world, especially the monsoon Asia region, are now also in the midst of the Great Acceleration. The tension between the modern nation-state and the emergence of multinational corporations and international political institutions is a strong feature of the changing human-environmental relationship. The “engine” of the Great Acceleration is an interlinked system consisting of population increase, rising consumption, abundant cheap energy, and liberalizing political economies.

Globalization, especially an exploding knowledge base and rapidly expanding connectivity and information flow, acts as a strong accelerator of the system. The environmental effects of the Great Acceleration are clearly visible at the global scale — changing atmospheric chemistry and climate, degradation of many ecosystem services (e.g., provision of freshwater, biological diversity, etc.), and homogenization of the biotic fabric of the planet. The Great Acceleration is arguably the most profound and rapid shift in the human–environment relationship that the Earth has experienced.
Towards the end of the 20th century, there were signs that the Great Acceleration could not continue in its present form without increasing the risk of crossing thresholds and triggering abrupt changes. Transitions to new energy systems will be required. There is a growing disparity between wealthy and poor, and, through modern communication, a growing awareness by the poor of this gap, leading to heightened material aspirations globally - a potentially explosive situation. Many of the ecosystem services upon which human well-being depends are depleted or degrading, with possible rapid changes when thresholds are crossed. The climate may be more sensitive to increases in carbon dioxide and may have more inertia than earlier thought, raising concerns of abrupt and irreversible changes in the planetary environment as a whole.

From the past, we know there are circumstances when a society is resilient to perturbations (e.g. climate change) and there are circumstances when a society is so vulnerable to perturbations that it will be unable to cope (1, 5). We need to construct a framework to help us understand the full range of human-environment interactions and how they affect societal development and resilience. We now have the capacity to develop this framework in the form of more comprehensive integrated models, combining approaches from geophysical, systems dynamics and agent-based models to implement approaches including simulation games and scenario analysis. Although the future will differ from the past, insights from modeling and analysis of the rich array of well-documented integrated historic events can be used to structure, test and further develop these models.

The fundamental question we ask is: how the history of human-environment systems generate useful insights about the future? In trying to gain insights from the past, tests of alternate models play a central role. While in the natural sciences, alternate models can be tested against numerical data sets, in testing models (conceptual and computational) of the human-environment system, we need both numerical data and historical narratives and the understanding of how to combine them. The extent to which we can (or cannot) reproduce historical behavior in socio-ecological systems determines the confidence we can place in future projections. An array of different modeling approaches, some focused strongly on the biophysical aspects of the Earth System (e.g., General Circulation Models of climate) and others centered on socio-economic aspects (e.g., models of the global economy) have been developed for projecting Earth System behavior into the future. Integrated models at various scales have also been developed (12, 13). Rather any single approach having intrinsic advantages, comparing, synthesizing and integrating the results from different modeling approaches is a more robust strategy, paralleling the use of multiple working hypotheses. Developing an integrated historical narrative and data base will allow testing of alternate models, more rapid evolution of paradigms, and better answers to questions about the degree to which the future is predictable vs. contingent.

It has been said that if one fails to understand the past, one is doomed to repeat it. IHOPE takes a much more “hopeful” and positive attitude. If we can really understand the past, we can create a better, more sustainable and desirable future.
References and Notes


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14. We thank H. J. Schellnhuber and Julia Lupp for their support and guidance in producing this paper and the Dahlem conference report on which it is based. We also thank the other participants in the Dahlem conference in June, 2005 and a follow-up meeting in Stockholm in January 2006 for their valuable contributions: Steve Aulenbach, Roelof Boumans, Paul J. Crutzen, Bert J. M. de Vries, Carl Folke, John Finningan, Richard Grove, Arnulf Grubler, Helmut Haberl, Fekri Hassan, Frank Hole, Eric F. Lambin, Diana Liverman, Nathan J. Mantua, John R. McNeill, Dennis Meadows, Bruno Messerli, João Morais, Dennis Ojima, Christian Pfister, Frank Riedel, Jim Reichman, Vernon L. Scarborough, Joseph A. Tainter, Peter Turchin, Sander van der Leeuw, Yoshinori Yasuda, Uno Svedin, Marianne N. Young, and Michael D. Young. Many of the ideas summarized in this paper are elaborated in the chapters in (9) by the authors listed above.
Figure 1. Selected indicators of environmental and human history (raw data and sources are given in supplementary information). While this depiction of past events
is integrative and suggestive of major patterns and developments in the human-environment interaction, it plots only coincidence, not causation, and must, of course, be supplemented with integrated models and narratives of causation. In this graph, time is plotted on the vertical axis on a log scale running from 100,000 years before present (BP) until now. Technological events are listed on the right side and cultural/political events are listed on the left. Biologically modern humans arose at least 40,000 yrs BP and probably more than 100,000 yrs BP, but agriculture did not start until the end of the last ice age and the dramatic warming and stabilization of climate that occurred around 10,000 yrs BP, at the Pleistocene/Holocene boundary. Northern Hemisphere temperature can be reconstructed for this entire period from ice core data, combined with the instrument record from 1850 until the present. Human population fluctuated globally at around 1 million until the advent of agriculture, after which it began to increase exponentially (with some declines as during the black death in Europe) to a current population of over 6 Billion. Gross World Product (GWP) followed with some lag as people tapped new energy sources such as wind and eventually fossil fuels. Atmospheric CO₂ and Methane closely track population, GWP and energy use for the last 150 years. The start of the “Great Acceleration” after WWII can be clearly seen in the GWP, population, and water withdrawal plots. The plot for “SE Asian Monsoons” shows the long-term variability in this important regional precipitation pattern. Patterns in land use are shown as the fraction of land in forest, cropland, and in the “three largest polities”. This area in large “polities” or sovereign political entities has increased over time, with significant peaks at the height of the Roman, Islamic Caliphate, Mongol, and British empires. Currently the three largest polities are Russia, Canada, and China, together covering about 32% of the land surface. At the peak of the British empire in 1925, the 3 largest were Britain, Russia, and France, together covering about 53% of the land surface before the independence of British and French colonies.
Supplementary Information (to be posted on the web site)

What do we need to know?

Several key questions and directions for further research emerge from this initial synthesis, including:

1. What are the long term trajectories extending into the future, and the strength of past and current interactions? The analysis of socio-ecological systems around a range of time scales from millennial through centennial and decadal and into the future provides a rich basis for a deeper understanding of human-environment interactions. For example, in the millennial timescale, humans move from hunter-gathers to agriculture and civilizations, developing a stronger ability to manipulate nature, at least at the local and regional level. But the reverse direction of the human-environment relationship – impacts of natural environmental variability and change on human societies – was stronger and, for the most part, dominated the relationship. By the centennial timescale, the two-way interactions between humans and the natural world, especially at larger spatial scales, had become more balanced. The imprint of humans at large regional scales was now clearer and the first signs of significant global impact were appearing. The Great Acceleration – the rapid expansion of human activities and impacts since about 1950 - carries this trend dramatically forward. We are now a global geophysical force that rivals the great forces of nature in many aspects. A feature of the Great Acceleration that points towards the future evolution of socio-ecological systems is the fundamental role of technology in mediating the interactions between humans and the rest of the natural world.

2. How connected are our activities? Another way of looking at these trends in the human-nature relationship is to contrast the connectivity of humans to nature with the size and power of the “human enterprise”. One end point is represented by hunter-gatherers, who are strongly connected to nature but are small in numbers and have a weak capacity to impact the natural world at large scales. Agrarian societies evolving into the early civilizations represent an interesting mid-point, in which the human enterprise had become large enough and active enough to significantly impact the natural world at more than local scales. On the other hand, early human civilizations still retained a strong connection to the natural world through their direct and visible reliance on ecosystem services for their success and well-being. The other end point is the current highly technological, globalizing society, which is less connected to nature than ever before but also more numerous and economically powerful than ever before. The human enterprise has grown to enormous size and strength. It can (and does) insulate people from both the direct knowledge and experience of the ecosystem services on which we all still ultimately depend and from the many global-scale impacts of the burgeoning human enterprise on the natural world.

3. What are the fast/slow controls on adaptive cycling? Insights can also be obtained from examining the evolution of socio-ecological systems from a particular time perspective, but in a broader context. For example, a particular strength of the millennial-scale analysis is that it addresses the importance of the long-term evolution of societies. The analysis is able to go beyond shorter-term historical cycles to multiple completed cycles of the rise, spread and eventual decline of civilizations.
This raises some intriguing questions that would not necessarily arise from examining shorter time scales. How do societies re-organize after a decline or collapse? What are some of the more important “slow processes” (c.f. resilience perspective in the next section) that are barely discernible at shorter time scales but can dramatically affect the success or failure of socio-ecological systems? Are there particular points in the evolution of socio-ecological systems at which slow processes flip from being adaptive to being destabilizing?

4. Given contingency, what are the key antecedent controls on modern and future system states? Finally, examining socio-ecological systems across multiple time scales can identify the antecedents further back in time of major phenomena that occur in a particular era or time. A good example is the Great Acceleration (ca. 1950 to the present). The phenomenon is well described from a decadal perspective but the antecedents, especially in the socio-economic sphere (e.g., globalization, fossil fuel use, increased information flow, etc.), go well back into the centennial timeframe. Examining the Great Acceleration from a longer time perspective also uncovers the still-born Great Acceleration of the late 19th and early 20th centuries. Most of the ingredients for an acceleration of the human enterprise were apparent, but the decline and collapse of many countries and regions in the 1915-1945 period due to economic depression and world wars delayed the phenomenon for a half-century. On the other hand, this could also be interpreted from a resilience perspective as two adaptive cycles of the modern, globalized socio-ecological system.

**Common themes across time scales**

Several common themes are also emerging from this initial synthesis, including:

1. There is a general movement away from simple causality or cause-effect paradigms as a credible explanatory framework. Multiple cases studies have revealed diverse social responses to similar climate changes. There is a strong consensus that we are dealing with complex, adaptive, integrated, socio-ecological systems that often defy simple cause-effect logic in their behavior. Complex systems may exhibit multiple interactions between apparent drivers and responses where the direction and strength of interaction are not necessarily explicable in terms of simple, direct and linear causative links; there may be internal dynamics that drive system changes. Studies therefore will need to encourage the use of concepts from complexity science, including linear and nonlinear dynamics, feedback, thresholds, emergence, historical contingency and path dependence, and the application of nonlinear simulation tools, spatially explicit and agent based models to simulate relevant phenomena (c.f. Young et al. 2006)

2. A dichotomy often arises between explanatory power and predictive success. Could anyone have predicted the collapse of the Classic Maya civilization a century before it occurred? Could anyone in 1900 have predicted the evolution of human societies, especially their relationship to the natural world, through the 20th century? In both of these (and other) cases, we have impressive explanatory power in describing what unfolded, but that does not yet translate into an ability to predict the future trajectories of complex socio-ecological systems. In fact, our increasing ability to influence the future makes it more difficult to predict it. A better way to look at it
is that we can use a deeper understanding of the past to help us create a better future, rather than to predict the future.

3. While human actions often succeed in reducing specific risks, these efforts also created qualitatively new risks at a larger spatial scale and/or a longer timeframe. The notion of “risk spirals” points to a dangerous positive feedback loop. As human societies become more complex and interconnected at every scale, it becomes more costly to deal with shocks from the natural world and, ironically, in the process of making themselves more complex, societies inadvertently and (often) unknowingly change their interaction with natural systems in ways that make these systems more vulnerable to abrupt changes or extreme events.

4. A critical aspect of any society is the trade-off between short-term production and long-term resilience or sustainability. These values are often in conflict. In general, there is a need to keep production systems well below theoretical carrying capacity to avoid a severe drop in resilience. Cultural traditions and social networks have played an important role in building long-term resilience by acting as a brake on short-term production that would damage or diminish resilience and long-term sustainability. During the Great Acceleration, many of these cultural traditions have faded and, due to competitive forces in almost all arenas of human activities, we may be adversely affecting resilience and long-term sustainability.

5. The role of feedback processes is crucial in complex socio-ecological systems (and a big reason why simple cause-effect paradigms often have little explanatory power). A potentially dangerous positive feedback loop (a “risk spiral”) was mentioned above. But are there counteracting negative feedback loops that can generate increased resilience in socio-ecological systems? For example, is there a general self-regulating feature in human civilizations that acts to lessen environmental stresses when they become apparent? Are the “decelerating trends” we see now in some aspects of the contemporary human enterprise part of a self-regulating feature that will slow the Great Acceleration?

6. “Collapse” is a central concept in developing an integrated understanding of the past, and probably the most critical question facing current society, but its use needs to be refined to reflect the variety of socio-ecological responses to environmental changes. We need to differentiate between radical environmental alterations, radical institutional changes, and radical demographic losses in a region. The first or second in isolation may be better thought of as a transformation, yet when combined with the third seems to fit the term collapse.

**Research challenges**

To address these issues there are a set of research challenges that will need to be met regardless of the time scale or particular aspect of interest. These include:

1. Data on the behavior of socio-ecological systems vary enormously in quality, selection, interpretation, resolution, dating/chronologies, and unevenness (c.f. Costanza 2006). The amount of data rises dramatically as we approach the present, and this could easily distort analyses.
2. There is an issue regarding the balance between social and environmental data. In the longer time frames there seems to be more information on societal characteristics and less on the nature of environmental change. This makes it difficult to explore the types or characteristics of environmental variability or change to which various societies are especially vulnerable.

3. There is often a dichotomy in research approaches – reductionist v. systems-oriented – that can lead to tension within research teams and thus pose major challenges to interdisciplinary research projects. Studies need to adopt a range of alternative explanatory frameworks, embracing conventional scientific positivist approaches as well as discipline-specific protocols. However, a key issue is the evaluation of explanations and the realistic appreciation of uncertainty. How we learn from the past takes different forms (c.f. Dearing 2006): the type and range of data sources, the different disciplinary conventions and the nature of conceptual and predictive models used imply that there is no single method to determine the quality and certainty of explanations. In some contexts, it may be possible to utilize a hypothesis-testing approach, but in others the ability to falsify hypotheses may be severely restricted. In many historical studies, the use of approaches that argue from the perspective of mutual internal consistency or weight of evidence may be more appropriate.

4. In analyzing socio-ecological systems or simulating their behavior into the future, biophysical laws governing aspects of nature can give an “envelope of regularities” in projections or analyses (but complex natural systems can also have strong nonlinearities). This broad envelope of regularities can define the “environmental space” within which human societies operate, but contingent events, which are difficult or impossible to predict, often determine the trajectories of socio-ecological systems within that space and are thus crucially important to how the future will actually unfold. We need to know what the range of possibilities are, as we continue to create the future.

5. Comprehensive models of the Integrated Earth System (or humans-in-nature) are still in their infancy and have a long way to go (c.f. Costanza et al 2006). Nearly all models begin with a strong emphasis on either the natural or the human part of socio-ecological systems. There is a strong need for more balanced, hybrid approaches that can take on the research challenges outlined above. The insight, data and models generated from the close collaboration of environmental historians, archeologists, ecologists, modelers and many others will allow the construction and testing of new ideas about humans’ relationship with the rest of nature. It will also allow the calibration and testing of a new generation of integrated global earth system models that contain a range of embedded hypotheses about human-environment interactions.

We are poised to address a number of critical research and policy questions affecting the life of all humans on earth. It is fitting at this point to conclude not with answers, but with questions. The big, general questions for the IHOPE activity (consistent with the long-term goals stated earlier) can be summarized as the following:
What are the complex and interacting mechanisms and processes resulting in the emergence, sustainability or collapse of socio-ecological systems?

What are the pathways to developing and evaluating alternative explanatory frameworks, specific explanations and models (including complex systems models) using observations of highly variable quality and coverage?

How do we use knowledge of the integrated history of the earth for understanding and creating the future?

References and Additional Reading


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Workshop report: YSN-Urbanization interactions with biogeochemistry and climate

September 9 and 10, 2006: Mexico City, Mexico

This document has three parts: summary, description of workshop, agenda, and results of the evaluation of the workshop by the participants.

Summary of results

Overall the workshop was a success (pending acceptance of resulting paper). Participants were very enthusiastic about the workshop, and hope to submit a paper to Science or Nature (or PNAS or Climatic Change) on the topic. The discussions were dynamic and cross disciplinary. There were some things we could do better in the future, most of which are related to the short time frame we had to do the final meeting planning after we were notified of funding: frame the question before the meeting better as a group and we lost 4 participants to visa issues. In addition, having four ‘senior’ scientists was probably too much, although all the ‘senior’ scientists were each individually wonderful. The model of having our meeting adjacent to another meeting on the topic is a good one, and one we should probably continue.

Description of pre-workshop and workshop process.

The workshop was focused on a particular topic: Urbanization interactions with biogeochemistry and climate, and proposed to produce a whitepaper. This narrow, but interdisciplinary focus, along with it being a working workshop is the result of comments from participants in last years meeting, and organizers’ positive experience with previous workshops in this format.

The workshop was conceived of in October/November of 2005, and put adjacent to the similar GCP/AIMES conference (short title Urban and Regional Carbon Management (URCM)), because of the similarity in the topics. During January 2006 we started planning, and submitted proposal to NSF for 3 years of funding for this workshop and 2 successive workshops. Applications to our meeting were originally due in March, but this was extended when the URCM meeting abstract deadline was extended until April 31. We had about 30 good quality applicants. We reviewed applications and selected 25 top-choice participants during May. Unfortunately we did not hear definitely on funding until July 7, 2006, and thus could not do the final planning until then. Due to the lateness of the funding decision, we lost 4 of our participants at the last minute due to not being able to get a visa into Mexico (3 from Nigeria (one residing in the US) and one from Bangladesh). In addition, this meant that the final writing assignments were also made late: we started iterating in earnest with the participants on the writing assignments in early July, and finalized writing assignments in early August, so participants had only 4 weeks to do the literature search and writing that we requested.

Despite the loss of 4 participants due to visas (and one more due to working visa issues associated with her next new job), we had a great diversity of countries represented: Uganda, Brazil, US, UK, Germany, Portugal/Russia, Poland, Belgium, Indonesia, Philippines/Japan, and Mexico. In addition, we had a diversity of
disciplines: ecology, energy analysis, urban planning, meteorology, policy analysis and climate. However, we need to keep recruiting social scientists, preferentially.

Participants were asked to use a provided framework to write about 3 different cities: (which they voted on) Sao Paolo, Shanghai and Phoenix. The goal was to look at urbanization and carbon/water cycle interactions in these cities, to better understand what processes were important for the coupling between urbanization and the carbon cycle, and how to include that into earth system models. Organizers designated ‘leaders’ for each city: these were participants that the organizing committee had met the previous year and felt could do a good job leading. This was more or less true in the different groups. However, the goal of the whitepaper could have better framed for the participants, since they were not earth system modelers, they did not understand the context very well. But on the whole they did a good job putting together a set of whitepapers and presentations on the topic.

In addition, we had 4 ‘senior’ speakers at the meeting, and gave them one hour each to talk about their work, and 15 minutes to talk about their personal biography. The four speakers we found were excellent, each with a different view, and very easy to talk to for the participants. In hindsight, this was too many ‘senior’ speakers, and they tended to dominate the discussion sessions, and senior presentation part of the workshop was too much of the total time—it would have better spent in discussion session, with only 2 ‘senior’ speakers.

At the end of the workshop, we had a fairly detailed outline, conceptual model and writing assignments for the resulting paper.

There were several improvements that the organizers felt could have been made to the workshop:
1. Should have included in the applicant process our ability to grab abstract submitters form the main conference that were young scientists to throw it into our pool of applicants. We tried to advertise to all applicants, but somehow this was missed. After we had made decisions, URCM organizers starting sending us very appropriate names, but too late.
2. We should have defined the science question more clearly via email. Maybe even have a pre-meeting conference call, since emails can be misunderstood? Have the participants involved in defining the science question.
3. We had too many seniors and senior talks—although they were wonderful, it ended up being too much of our time.
4. More time for participants to present—perhaps poster sessions with 2 minutes advertisements.
5. Need to work hard on recruiting social scientists. We should add a social scientist to the organizing committee.

The location of the workshop was quite problematic for NCAR in its organizational role—the hotel refused to answer calls and emails, and we had to go through local organizers. Local organizers were very helpful, but this cumbersome method led to much wasted time and energy (and grey hairs).

Agenda:
September 9:
9:00-9:30   Welcome, goals and introductions
9:30-9:45   White paper presentation: how natural scientists see the world
9:45-10:00  White paper presentation: how social scientists see the world
10:00-11:00 Roberto Sanchez on white paper
11:00-11:30 Coffee Break/informal discussion
11:30-11:45 Roberto Sanchez: short bio/career path discussion
11:45-12:15 Whitepaper presentation: Phoenix
12:15-12:30 Discussion
12:30-1:30  Lunch (groups with senior speakers)
1:30-2:30   Galena Churkina (“senior speaker” reflections on whitepaper)
2:30-2:45   Galena Churkina short bio/career path discussion
2:45-3:15   White paper: Shanghai
3:30-4:00   Coffee Break/informal discussion
4:00-5:30   Panel Discussion: 4 Senior speakers on the topic
6:30-8:30   Ice breaker

September 10:
9:00-10:00  Nancy Grimm (“senior speaker” reflections on white paper)
10:00-10:15 Nancy Grimm short bio career/path discussion
10:15-10:45 White paper presentation: Sao Paolo
10:45-11:15 Coffee Break/informal discussion
11:15-12:15 Kevin Gurney (“senior speaker” reflections on whitepaper)
12:15-12:30 Kevin Gurney short bio career path discussion
12:30-1:30  Lunch
1:30-3:00   Discussion
3:00-3:30   Coffee Break/Informal Discussion
3:30-5:00   Discussion: how to proceed, writing assignments.
5:00-6:00   Final group discussions.
6:00       Workshop adjourns

Results from evaluation: Text of the evaluation follows, summarized results in italics.

The goals of the meeting were:
1. Foster collaboration among young scientists between different disciplines and geographic locations
2. Foster work designed to improve our ability to include biogeochemistry and human interactions in earth system models
3. Write a white paper on Urbanization interactions with biogeochemistry and climate.

Comments on all questions are very welcome:

1. Overall how did you rate this workshop? (rate on a scale of 1 to 10, 10 is perfect)
   Average 8.8, comments were positive.
2. Do you think the workshop meet its goals? (rate on a scale of 1 to 10, 10 is perfect) How could this be improved? 8.5 or 8.8 (if paper is completed higher average)

3. Do you think this meeting is important for your scientific future (rate on a scale of 1 to 10, 10 is perfect) Average: 9.0 (one person abstained, but comments indicated that s/he didn’t think it was relevant to their own disciplinary work.)

4. Did you have enough chance to interact with your young scientist colleagues? (rate on a scale of 1 to 10, 10 is perfect) Average: 9.8

5. Did you have enough chance to interact with the senior scientists? (rate on a scale of 1 to 10, 10 is perfect) Average: 8.5

6. What improvements to the meeting would you suggest?
   Comments varied: More structure of pre-workshop work, tutorials in addition to workshop, organized outing, tiring with 5 day Urban-Regional Carbon Management Conference right before, others said needed to be longer, need to include stakeholders, perhaps local, and policymakers.

7. What was the best part of the workshop?
   Generally: discussion, working in groups, variety of people at the meeting.

8. What was the worst part of the workshop?
   Generally, logistical details, food, hotel, location where it was difficult to get visas, couple of comments on lack of direction in pre-workshop writing and senior domination of discussion.

9. What follow-up do you anticipate from this workshop (personal or as a group)?
   Generally what we proposed: paper, future workshops, interactions with individuals and groups on topic or individual research.
THE GLOBAL EMISSIONS INVENTORY ACTIVITY (GEIA)

The goal of the GEIA (Global Emissions Inventory Activity) of AIMES is to quantify the anthropogenic emissions and natural exchanges of trace gases and aerosols that drive Earth system changes. GEIA is currently chaired by Claire Granier (Service d’Aéronomie/ IPSL and CSD/ERSL/NOAA) and Alex Guenther (NCAR).

GEIA activities over the past year have focused on (1) the development of the web portal access to emissions inventories, (2) the organization of focused workshops, (3) the development of a database of driving variables and (4) the organization of the 2006 GEIA conference and of a summer school in 2007.

The GEIA activities are currently supported through small grants from NSF and NASA, which help develop and maintain the GEIA Center. The Center is directed by P. Middleton, who is responsible for the GEIA web site (http://www.geiacenter.org), and for the development and maintenance of the GEIA network, which currently includes over 600 people around the globe. Information on GEIA activities are sent regularly to all the members of the network.

In 2004, a network of scientific institutions called ACCENT (Atmospheric Composition Change: A European Network) was established by the European Commission. The network is coordinated by S. Fuzzi, who is also one of the two IGAC chairmen. The ACCENT network is funding the development of the web portal, and is providing partial travel funds for participants to the GEIA workshops. Details on the ACCENT network can be found on the http://www.accent-network.org webpage. It should be noted that several non-European institutions are associate members in the network.

Details of activities organized within GEIA are summarized below:

Development of the GEIA/ACCENT data portal

With the help of the ACCENT network, a GEIA/ACCENT data portal has been developed, and the first dataset was available for download in summer 2005. The 1st version of the GEIA inventory is also available from the portal. The currently available inventories are POET (1x1 degree, 1990 to 2000, gaseous species only), RETRO (0.5x0.5 degree, 1960 to 2000, gaseous species, as well as different types of aerosols) and AMAP-mercury (0.5x0.5 degree, 1995 and 2000, 3 vertical levels). We have also started to include regional inventories in the data portal: the first of these inventories is the so-called ABBI inventory, which provides biomass burning emissions for a large number of chemical species in Asia. Each dataset includes a detailed dataset description, i.e. abstract, references, contact details, spatial and temporal details, and details on the methodology used to construct the dataset. The data portal can be accessed through the GEIA web site (http://www.geiacenter.org), the ACCENT network website (http://www.accent-network.org), or directly through the portal website: http://www.aero.jussieu.fr/projet/ACCENT/database.php
The GEIA/ACCENT inventories are available for 2 formats, ASCII and NetCDF. Format transformation tools, and other tools to manipulate the data have been developed, and will be available soon on the data portal, as soon as the corresponding documentation are finalized. Other tools such as interactive graphics are being developed. Discussions are also under way with several groups, in order to include more emissions inventories on the portal.

Organization of focused workshops

Different workshops were organized in 2005-2006, which focused on the development of a database of driving variables (see next section), on the quantification of biomass burning emissions using satellite observations, and on emissions from combustion sources in non-OECD countries.

Workshop on biomass burning emissions

The title of this workshop, organized by C. Liousse (Laboratoire d’Aérologie, France) and J.M. Gregoire (Joint Research Center, Italy) was: “Biomass burning from satellite observations (BBSO)”. It was held in Toulouse, France on December 14-15, 2005. The program, list of participants, presentations and report are available on the ACCENT network web site, in the http://www.accent-network.org/portal/integration-tasks/access-to-emissions-data/Workshops-and-meetings page. Two joint initiatives have emerged as a result of the discussions:
- A compilation of the global and regional inventories for the determination of burnt biomass will be done, based on a questionnaire on available fire products. Burned areas, active fires and fire radiative energy measurements will be considered.
- An intercomparison exercise of emissions of particulate matter and carbon monoxide will be carried out. The reference year that has been chosen for this exercise is 2003. The goal of this activity is to understand the origin of the observed differences between estimates of biomass burning emissions, in terms of overall budgets and spatial/temporal distributions.

Workshop on emissions from combustion sources

The “Joint ACCENT/GEIA workshop on anthropogenic emissions for non-OECD countries in global inventories” took place in Vienna, Austria on February 8-10, 2006. It was organized by M. Amman (Institute for Applied Systems Analysis, Austria), J. Olivier (Environmental Assessment Agency, The Netherlands), and J. vanAardenne (Joint Research Center, Italy). The workshop focused on the following emission sectors: mobile (road and off-road) land-based sources, combustion in the power plant and industrial sectors, biofuel used in the residential sector and burning of agricultural waste. Different compounds were considered, greenhouse gases (CH₄ and N₂O), air pollutants (CO, NOₓ, NMVOCs, NH₃, SO₂) and primary aerosols (BC, OC, PM₂.₅ and PM₁₀). The participants reviewed the information contained in existing global and regional emissions inventories, and discussed appropriate improvements for key sectors in different world regions.
The program of the meeting and presentations can be obtained from the workshop web site: http://www.iiasa.ac.at/rains/meetings/ACCENT_GEIA/Accent-agenda.html.

Database of driving variables

The goal of this project is to provide the scientific users with ancillary data required to quantify the surface emissions of chemical species. These data will allow for example to improve existing inventories or to calculate emissions using either relatively simple algorithms or comprehensive models simulating emissions processes.

A workshop partially funded by the ACCENT network was held in Paris in April 2005, which helped define the database: the program, participants and presentations given at the workshop are available from the ACCENT-emissions workshops webpage: http://www.accent-network.org/portal/integration-tasks/access-to-emissions-data/Workshops-and-meetings. Pilot projects were identified, and a proposal, endorsed by AIMES and by IGBP, was sent to the French CNES, which was accepted in the summer of 2005. One person started to work on this project in October 2005, and the architecture of the database is now ready, together with graphical tools allowing interactive plots and statistical analyses of the data. The group in charge of this project has started to work on a protocol for the use of the data. It is expected that this database will be open to the scientific community at the end of the winter 2006. Links with the Atlas/AIMES project will also be formally established during the coming months.

GEIA 2006 Conference and 2007 summer school

The GEIA 2006 Open Conference will take place in Paris, France on November 29, 30 and December 1st. Four discussion themes are considered, (1) Emission trends: from the past to the future, (2) Integration of spatial and temporal scales, (3) Terrestrial ecosystems/biomass burning, and (4) Natural aerosols. About 60 abstracts have been received at the end of 2006, and it is expected that about 90 people will attend the conference. On November, 28th, both the GEIA and ACCENT-emissions steering committees will meet, and discussions on future activities and planning for the coming years will take place. During this joint meeting of the steering committees, discussions on collaborative projects within AIMES, and with other IGBP projects (IGAC, iLEAPS, SOLAS) are planned.

The organization of a summer school entitled “Surface emissions and prediction of atmospheric composition changes” has been proposed to different organizations. This idea has been welcomed by international organizations. A small budget has for now been allocated by the European Science Foundation to start the organization of the school, and several activities within the ACCENT network will help fund the school, which should be sufficient for the support of the European participants to the school. During 2007, other proposals will be submitted to help non-European students, post-docs and young scientists to attend the school.
Brief introduction of MAIRS, a new international research programme of the Earth System Science Program (ESSP)

MONSOON ASIA INTEGRATED REGIONAL STUDY (MAIRS) is the new international research programme of the Earth System Science Program (ESSP) that addresses coupled human and natural processes in the monsoon Asia region. The MAIRS programme is guided by a Scientific Steering Committee (SSC) and supported by an International Project Office (IPO).

Here is a brief introduction of the draft initial Science Plan of MAIRS which will be released in OSC of global change in November.

Almost all aspects of societal and economic activities in monsoon Asia are critically dependent on monsoon climate and its variability. On the other hand, there are indications that human activities, especially those associated with economic development may be having a detectable impact on the monsoon system.

Our understanding of the implications of major social transformations attributable to environmental changes has progressed substantially in the last decade. There is now real potential to address the broad question: Is the Asian monsoon system resilient to this human transformation of land, water and air? Changes in the monsoon could have profound impacts on social development, human well-being and health. At the same time rapid economic and social development, which drive environmental changes, may also be helping to reduce certain vulnerabilities. So the second overarching question is: Are societies in the region becoming more, or less, vulnerable to changes in the Asian monsoon? Environmental change in the monsoon Asia region is not independent of global changes, and vice versa. There is still little knowledge about how and how much the regional and global environmental systems are conjoined. The third key question is therefore: What are the likely consequences of changes in monsoon Asia on the global climate system? To start answering these questions, we have identified four vulnerable geographic zones and key integrated study themes for each zone. They are:

- Rapid transformation of land and marine resources in coastal zones.
- Multiple stresses on ecosystems and biophysical resources in high mountain zones.
- Vulnerability of ecosystems in semi-arid zones under changing climate and land use.
- Changes in resource use and emissions due to rapid urbanization in urban zones.

Compared to inland areas, coastal zones generally offer a more gentle terrain and fertile soil, are richer in freshwater and ocean resources and offer more efficient transportation and easier access to waste disposal — aside from milder weather and attraction for tourism and recreational activities. For these reasons, coastal zones are generally more prosperous than inland areas and impoverished people are consequently often drawn to the coast. The coastal zones of the monsoon Asia region are unique because they are subject to the strong influence of monsoons. Moreover, local anthropogenic drivers within the coastal zone itself as well as drivers from the catchments upstream of the coastal zone could act in concert with global atmospheric forces. The overarching question is: What affects rapid transformation of land and marine resources in the coastal zones in the context of global change? Four priority
research areas have been identified: Coastal Morphological Changes, Sustainability of Coastal Resources, Vulnerability of Coastal Society and Adaptation, Coastal Management.

The mountains of monsoon Asia and their role in the dynamics of the Asian monsoon have a profound effect on global weather and climate. The Initial Science Plan for this zone will take into account its climatological, hydrological, ecological and social features. The overarching research question is: What are the drivers and impacts of global environmental change on the fragile natural and human systems of the mountain zone of monsoon Asia? Six priority research areas have been identified and key research questions have been proposed for each area: hydrology and water availability; ecosystems and biodiversity; agriculture, forestry and food security; energy; natural disaster management; and air quality and human health.

The semi-arid region is a transitive zone between arid and humid monsoon regions; it is very sensitive to natural and human disturbances. Climatic and water cycle variations are highly correlated with the fluxes of the Asia monsoon system. This leads to the high frequency of extreme events and climatic anomalies. The overarching science question is: How will the semi-arid zone change over the next two to three decades in the context of changes in water availability, air quality, food production, provision of ecosystem goods and services as well as occurrence of natural extremes and hazards? Three priority areas for research are proposed: global warming–monsoon variability–increasing aridity; atmosphere–land–ecosystem interaction under changing land-use patterns; and dust aerosols–hydrological cycle–regional climate.

Urbanization is one component, and one lens through which to analyse the remarkable social development and environmental transformations of Asia in the past few decades and into the future. It is also potentially very important for policy because the process of change is still unfolding and could be redirected along more benign and safe pathways. There are also significant opportunities for the rest of the world to learn lessons about non-motorized transport, high density settlements and other aspects of urban form, function and transformation in the monsoon Asia region. The overarching research question is: Is urbanization contributing to changing, or altering the vulnerability of societies to potential changes in, the Asian monsoon? Three priority research areas have been identified: energy, emissions and urban air quality; urbanization, flood regimes and disaster management; urbanization and water security.

The Initial Science Plan also addresses a number of issues related to the implementation of integrated research studies: data acquisition, modeling, regional studies, capacity building, international linkages and contributions to sustainable development. In this context, we address the opportunities and challenges associated with the conduct of research across the Asian region, as well as the potential benefits of interaction with the broader research community and with policy-makers and other stakeholders. Several activities are planned over the next few years.

(prepared by Congbin Fu, chair of SSC-MAIRS)
Eleven coupled climate–carbon cycle models used a common protocol to study the coupling between climate change and the carbon cycle. The models were forced by historical emissions and the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) A2 anthropogenic emissions of CO₂ for the 1850–2100 time period. For each model, two simulations were performed in order to isolate the impact of climate change on the land and ocean carbon cycle, and therefore the climate feedback on the atmospheric CO₂ concentration growth rate. There was unanimous agreement among the models that future climate change will reduce the efficiency of the earth system to absorb the anthropogenic carbon perturbation. A larger fraction of anthropogenic CO₂ will stay airborne if climate change is accounted for. By the end of the twenty-first century, this additional CO₂ varied between 20 and 200 ppm for the two extreme models, the majority of the models lying between 50 and 100 ppm. The higher CO₂ levels led to an additional climate warming ranging between 0.1° and 1.5°C. All models simulated a negative sensitivity for both the land and the ocean carbon cycle to future climate (Figure 1). However, there was still a large uncertainty on the magnitude of these sensitivities. Eight models attributed most of the changes to the land, while three attributed it to the ocean. Also, a majority of the models located the reduction of land carbon uptake in the Tropics. However, the attribution of the land sensitivity to changes in net primary productivity versus changes in respiration is still subject to debate; no consensus emerged among the models.

FIG. 1. (a) Atmospheric CO$_2$ for the coupled simulations (ppm) as simulated by the HadCM3LC (solid black), IPSL-CM2C (solid red), IPSL-CM4-LOOP (solid yellow), CSM-1 (solid green), MPI (solid dark blue), LLNL (solid light blue), FRCGC (solid purple), UMD (dash black), UVic-2.7 (dash red), CLIMBER (dash green), and BERN-CC (dash blue). (b) Atmospheric CO$_2$ difference between the coupled and uncoupled simulations (ppm). (c) Land carbon fluxes for the coupled runs (GtC yr$^{-1}$). (d) Differences between coupled and uncoupled land carbon fluxes (GtC yr$^{-1}$). (e), (f) Same as (c), (d), respectively, for the ocean carbon fluxes.
APPLIED EARTH SYSTEM SCIENCE – AN IGBP STRATEGY

There are many examples of successful transitions from scientific understanding to application, including the Montreal Protocol, seasonal to interannual forecasting of El Nino Southern Oscillation (ENSO) events, satellite-based famine early warning systems, the IPCC. The transfer of daily-seasonal-interannual atmospheric carbon dioxide observations produced the international Kyoto Protocol and, as our understanding of the carbon cycle increases, carbon trading across nations now occurs. As such, the global community has responded in a significant manner to emerging scientific understanding. When the international Global Environmental Change (GEC) programmes first started in the early 1980’s, and in particular, for the World Climate Research Programme (WCRP), a clear client and collaborator was established with the World Meteorological Organization (WMO). That relationship has facilitated an operational component to WCRP that exists today.

When IGBP was in its formative years, one clear client, the United Nations (UN) (e.g., the UN Development Programme (UNDP), UN Environmental Programme (UNEP), and the Food and Agriculture Organization of the UN (FAO)) was rather dysfunctional and an alliance with them at this time would have likely ground IGBP science to a halt. As such, the IGBP proceeded to develop a programme that emphasizes question and hypothesis testing in the natural sciences across and within disciplinary themes (e.g., atmosphere, ocean, land). After ca. 20 years, IGBP has matured with an engaged and enthusiastic scientific community and the time is right to begin thinking about developing a pathway for communicating science findings to the assessment and decision support communities, or, increasing the scientific relevance of our research for immediate applications and advancement of knowledge (e.g., moving from Bohrs to Edison’s quadrant). Key questions to begin this dialogue include (1) what is the IGBP’s vision for applied earth system science, and (2) who are the sponsors (those who pay and don’t use), the customers (those who pay and use), and who are the users (those who don’t pay, but use) IGBP science?

There are several examples of Edison’s quadrant (see Stokes 1997) within core projects of the IGBP. For instance, GLOBEC transfers information on marine ecosystems to the fisheries industry and START emphasizes the transfer of IGBP science to capacity building in developing countries. There is no clear client, however, that the IGBP as a programme has partnered with.

The IGBP (particularly AIMES) is developing a strategy that transitions fundamental science into applications for policy, assessment and resource management communities. Since the 1980’s, the UN has also developed into a productive entity. It is timely, therefore, for the IGBP to consider a more formal engagement with the relevant organizations within the UN, perhaps the World Bank and others. The lessons learned from WCRP’s relationship with WMO suggest that the client-driven model may not be appropriate, however, for many of the fundamental research activities in the IGBP and care will be necessary towards forming a relationship with the UN. Jointly funded activities, however and collaborations with the UN and IPCC would provide a clear customer for applications-oriented activities.
The development of an IGBP applied Earth System Science program-level strategy, is therefore critical. The strategic interaction of basic and applied Earth System Science and the importance of user needs, for example, are highly visible at the top level of WCRP’s COPES document:

2.1 Societal needs and benefits: To facilitate analysis and prediction of Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society.

The IGBP vision statement addresses this issue, but in less specific terms:

The vision of IGBP is to provide scientific knowledge to improve the sustainability of the living Earth.

The challenge to IGBP is to create a new vision and strategy for Applied Earth system science bearing in mind that applied Earth system science should not be confused with research in human dimensions (e.g., not all Applied earth system science is human dimensions and much research in human dimensions is not applied. The failure to keep this straight has caused problems). Finally, a strategy that embraces applied Earth system science needs sponsors (funding agencies), customers (who pay for deliverables) and users (non-paying downloaders and readers).
Building a prototype for a new type of Earth System Model:
A Simple Integrated Model or SIM

The aim of a SIM would be to promote learning, interdisciplinary communication and end-user communication. It would not be an accurate predictive or simulation model. It could motivate later development of a more sophisticated integrated model but this would not be the primary goal. The goals would be to help researchers focused on individual components think about questions such as: ‘How would another modelling group use the outputs of your model as inputs?’ and ‘How can you use their outputs as inputs? ‘How do models link?’ ‘What are the really essential aspects of my model for exploring a specific policy question?’

If each very simple component were based on reasonably realistic basic data and parameters, SIMs would allow preliminary explorations of integrated results:

a. What are important linkages and feedbacks?
b. Where are non-linearities likely to be important?
c. What sorts of simulations would be useful for policy making?
d. When (in policy scenarios) will uncertainty propagate rather than wash out?
e. What are the really important drivers of uncertainty

Ideally SIMs will be run by different people to explore their potential and compare results.

Approach
Each SIM would be targeted at a particular problem rather than trying to meet all needs. A SIM would be much simpler than a model of intermediate complexity. SIMs could be run on a PC with available and simple software (e.g. MATLAB). To reduce data needs they would have low spatial and temporal resolution. To allow multiple researchers to work with them and comment on them, they would be based on common, publicly available datasets. The linkages between components would be minimised and use specific – two input and output variables? This will make the drivers of the simulations transparent. All components may be based on a wider range of underlying data, of which some will be common. Each component would be calibrated to produce ‘reasonable’ results in defined ranges of the input and output variables. The SIMs would have a modular structure so they could use different components from different underlying models as long as the input and output variables are the same.

The complex part of a SIM will be designing a simple integrated structure to address an interesting question and making appropriate simplifications for each component so the components can link and provide useful insight despite the extreme simplicity. This will need to be done collaboratively. It could be done through a series of workshops where the goals would be to:

a. Identify key input and output variables from each component that are consistent
b. Define functional forms that adequately represent processes that are critical for the integrated model
c. Discuss the interpretation of SIM results
The figure below gives an indication of how a SIM that considers the effects of policies that internalise the costs of GHG emissions from land use (e.g. an agricultural emissions tax / sequestration reward – but not limited to this) might look. This isn’t fully thought through but is hopefully still helpful. There would be common databases that all three components (land use; climate and policy) would use: e.g. GIS maps of existing land use/cover, geophysical conditions (topography etc.), and climate. The only linkages into the climate model are land use related GHG emissions going in and temperature and precipitation coming out.

Red variables are exogenous starting conditions. Green variables are intermediate and final outputs.
An important application of Earth system science is the communication and distribution of the Intergovernmental Panel on Climate Change (IPCC) process. Briefly, three working groups develop an assessment of the climate system from the scientific basis, impacts, and adaptation to climate change and mitigation perspectives. Historically, while there is some communication between the three working groups, there is little in-depth scientific understanding among them. As such, the IPCC process in itself is often a confusing and difficult medium for trans-disciplinary understanding and collaboration. Developing a platform for communication on how the basic science, impacts and mitigation options are connected and reinforced by each other would align the groups for improved climate assessment and reporting.

We propose to develop an (at least two, perhaps three week?) AIMES capacity-building institute for Latin America that would highlight faculty and participants from the IPCC process itself through simulation and actual communication between the working groups about what’s needed and real transfer of information between the working groups. Students could be organized around the IPCC WGs I, II, and III and would be tasked with the process and analyses relevant to Latin America. For instance, in many regions of the world (and certainly in Latin America), land use change is as important a process as global climate change. A land-use emphasis would task students in WG I to analyze projections of land use change in the context of climate change and their combined impacts on socioeconomic and ecosystem services. Students in WG II would assess land use impacts and adaptation strategies, and WG III would evaluate the economics and mitigation options for land use change.

There are a number of ways that climate scenarios could be generated, including low-resolution or 1-D General Circulation Model (GCM) or an Earth System Model of Intermediate Complexity (EMIC)s in WG I. Likewise, there are many possible outcomes for scaling these general low-resolution results to particular regions and the strategy would be decided as part of the planning process for the institute. WG I students would transfer the scaled regional climatology pattern to WGs II and III. As with the generation of regional climatology, a range of impact models, including indicator methods, integrated assessment or economic models that calculate, for instance, impacts from crop models or potential agricultural productivity would be used by students in WG II. Methodologies that examine technological and economic options and barriers, costing and decision making framework models by WG III students would be used to assess mitigation and geo-engineering options.

In addition to modeling exercises, joint sessions where the three groups discuss mutual needs and science/data transfer across working groups. Such discussions will push each WG to understand the needs and requirements across groups and promote WG alignment for a more efficient assessment and policy process. This institute will produce a cohort of young scientists that are better prepared to enter and contribute to the emerging trans-disciplinary community of climate change research.
Possible international global environmental change program partners include: START, GCP, IHDP, IGBP regional office, others?

Avenues for funding might include: IAI, NSF, NOAA?, Local (e.g., S. American) funding agencies?

This document is not intended to be definitive, but rather, to stimulate communication and collaboration across several disciplines.
NON-AGENDA ITEMS
EXECUTIVE SUMMARY

(To be written)

INTRODUCTION AND BACKGROUND

There is a growing recognition within the research community that global change must be studied in a more holistic and integrated way. Crucial to the emergence of this perspective is the increasing awareness of two aspects of Earth System functioning. First, that the Earth itself is a single system within which the biosphere is a dynamic component. Secondly, human activities are so pervasive and profound in their consequences that they affect the Earth at the global scale. This recognition calls for humans be considered both as external forcings in the consideration of alternative policies and as fully embedded players in the coupled, interactive human-environment system as a whole (Figure 1). This emerging perception is challenging the way in which research on the analysis and modelling of the Earth System is organized, from the level of individual research groups and institutions to the international global change research programs.

Figure 1. Understanding the Earth’s global system requires integration of the biological, physical and human sciences. The grand challenge for AIMES is to extend the Earth System
Modeling approach, in terms of physical-chemical-biological coupling and how these interact with human processes.

The challenge to address these integrative questions is the driving force of the International Geosphere/Biosphere Programme’s (IGBP) project, the Analysis, Integration and Modelling of the Earth System (AIMES). The AIMES challenge for integrating human processes into Earth System modelling and science is represented by the directional linkages depicted in Figure 1. The bi-directional understanding that is necessary for fully coupled Earth System science will require close collaboration and communication with other projects and Programmes in the international science community – in particular, with the members of the Earth System Science Partnership.

AIMES OBJECTIVES AND STRUCTURE

Models, observations and measurements contribute to understanding the natural Earth System dynamics on which anthropogenic perturbations are superimposed and the complex response of the Earth System to change in its external environment. The challenge for AIMES is to achieve a deeper and more quantitative understanding of the role of human perturbations to the biogeochemical cycles and their role in altering the coupled physical climate system, in both the present, past and future. The overarching goal is to understand and quantify the interactions and feedbacks between the biogeochemical and climate systems and the consequences of human activities and decisions.

AIMES is guided by a Scientific Steering Committee (SSC) that functions in an activist and participatory role to the project. Integration across scientific disciplines is key to the AIMES philosophy and the composition of the AIMES SSC necessarily includes scientists from the natural and social sciences. The execution of AIMES activities are facilitated by an International Project Office (IPO). The IPO is led by a senior scientist and the Executive Officer who collaborates with project leaders and key participants. The chairs and the SSC are responsible for strategy and planning; the IPO is responsible for logistics, fund-raising, and liaison with the institutes involved in the network. The SSC meets annually. Beginning in 2005, the IPO for
AIMES is located at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, USA.

**AIMES PRECURSOR: THE GAIM TASK FORCE**

The AIMES Core Project succeeds the IGBP Global Analysis and Modelling (GAIM) Task Force. A brief description outlining the history and legacy of GAIM follows. The GAIM Task Force had its initial meeting under the chairmanship of Professor Bert Bolin at the 1989 Hintzergarten Third International Conference on Analysis and Evaluation of Atmospheric CO$_2$ Data Past and Present with the goal to advance the study of the coupled dynamics of the Earth system using both data and numerical models. Regular (annual) meetings began in 1992 under the chairmanship of Berrien Moore who passed the reins to John Schellnhuber from 2000-2004. The overarching theme for GAIM was to understand the links between the global biogeochemical and climate systems. GAIM realized that to develop integrated models of the Earth system, it was necessary to accelerate the development of global biogeochemical model components suitable for coupling to the climate system. At that time, it was clear that modelling the carbon cycle was a major gap in climate system modelling and GAIM undertook a series of activities to fill that need. Other gaps that GAIM addressed included land-atmosphere interactions in the hydrological cycle, database development and modelling paleobiogeochemistry.

The evolution of GAIM can be summarized in three phases: (1) a strong focus on independent sub-systems of the biogeochemical cycles and physical interactions between climate and ecosystems (including the water cycle) from 1993-ca 2000, (e.g., the Regional Interactions of Climate and Ecosystems (RICE) and GAIM 6000 Years Before Present (BP) experiment) as well as several model intercomparison activities including the Potsdam Net Primary Productivity (PIK-NPP), Ocean Carbon Model Intercomparison Project (OCMIP), and the Atmospheric Tracer Transport Model intercomparison (TRANSCOM). The GAIM 6000 BP experiment led to the data synthesis activity (Global Palaeo Vegetation Project (BIOME-6000)) that was co-sponsored by the IGBP-Data Information System (DIS), Past Global ChangES (PAGES) and Global Change and Terrestrial Ecosystems (GCTE); (2) a transition period from ca. 2000 – 2003
where the original goals were re-visited and activities were initiated to develop broader Earth system questions, and the development of 23-questions outlining an integration strategy termed the “Waikiki Principles” (Schellnhuber 2001). The early 2000s saw the initial development of coupled carbon-climate models (e.g. the Coupled Carbon Cycle-Climate Model Intercomparison Project (C³MIP)); and (3) a new phase of GAIM, with a name change to Analysis and Integration of Models of the Earths System, or AIMES, to reflect the necessary steps towards the development of activities that link human-environment interactions with biogeoophysical Earth System analyses. The grand challenge for GAIM was to integrate biogeochemistry and land surface processes into the climate system leading to Earth System modelling (e.g., OCMIP, TRANSCOM, NPP, C³MIP). The grand challenge for AIMES in the 2000s and beyond is to extend the Earth System modelling approach to include human processes. Modelling activities from AIMES will test the sensitivity of tradeoffs in vulnerability and resilience in terms of economic and ecosystem consequences.

The AIMES Project will promote the development and integration of activities that couple the human and biophysical dimensions of the Earth System. In previous approaches, direct human impacts were normally prescribed (e.g. emissions (TransCom) or emission scenarios (C³MIP)) and were developed externally to actual GAIM research. New activities will revolve around the development of a hierarchy of coupled Earth System models that are driven by specific issues and scenarios of interdisciplinary human-biophysical dynamics of the Earth’s system.

RESEARCH APPROACHES

AIMES is seeking close interaction and collaboration with the projects and activities of IGBP and the Earth System Science Partnership (ESSP). AIMES will provide the global context for regional processes providing a reciprocal exchange of information and data sharing from local and regional studies. AIMES has adopted four interaction themes, or templates for interaction and collaboration with both individual research groups and the global environmental change (GEC) communities:
Theme 1: Process and Parameterisation. Earth System models require observations and process understanding for model development, parameterisation, testing and evaluation. Datasets and process knowledge for global model improvement and development need not be localised – they can include global data networks. This theme provides a mechanism, or template to improve global representations of process mechanisms in Earth System models by enhancing the transfer of local and regional process understanding to global models.

Theme 2: Regional/Global Interactions. This theme focuses on the impacts and feedbacks in regions where rapid rates of human development trigger changes in the atmosphere or biosphere, and where rapid local and regional changes have global consequences. Regional to global interactions might include:

(A) When rapid change in a human system triggers a global response; either directly through transport, or indirectly through teleconnections in the climate system. In order to understand the significance of the regional study, it has to be embedded in a global context. This is where the global remit of AIMES can collaborate with one or more projects or activities.

(B) When global changes trigger rapid changes in a region with subsequent global feedbacks (for example, recent changes in the northern high latitudes). The emphasis here is not so much direct human causation within the high latitudes, but the consequences of human actions external to high latitudes (e.g., warming and subsequent feedbacks to albedo, hydrology, soils, human infrastructures).

(C) Regional impacts of global change need to be understood at increasing scales of resolution. This theme utilises an Earth System approach to downscaling: if global changes are recognised, this theme endeavours to understand the regional effects and feedbacks to changes in human behaviour.

Theme 3: Applied Earth System Science. This theme translates region- or process-specific global change into global understanding of assessment, mitigation and management. Integrative models will enable transfer of information to ecosystem services and integrative problem-solving. This theme addresses end-to-end problem solving across scales (e.g., spatial, temporal, management) from process-based research to implementation through mitigation or management.
**Theme 4: Integrative Earth System Science and Modelling.** Incremental, problem-focused additions to coupled models (of climate biogeochemistry, ecology and human dimensions) leads to a greater capability towards understanding human-environment interactions and coupled behaviour of the biogeoosphere. Integrative modelling is a component of all applied activities.

**PROJECT NETWORKING**

**The Young Scientist’s Network**
The GAIM Task Force discussed a postdoctoral network on Earth System Science in a broad manner. In 2004, AIMES expanded beyond a remit for post-doctoral scientists to include a broader cadre of young scientists. The goal of the Young Scientist’s Network (YSN) is to foster global collaborations among young scientists on integrative research to better understand the role of humans in perturbing biogeochemistry and climate. The first YSN meeting was held in Breckenridge, Colorado, 2005, alongside NCAR’s annual Community Climate System Model (CCSM) workshop and was funded by AIMES, NCAR’s SERE and ASP divisions, the National Science Foundation, the Max Planck Institute and participant organizations. More information can be found at [http://www.asp.ucar.edu/ess](http://www.asp.ucar.edu/ess) and a workshop report highlighting results can be found in Scholze et al. (2005). In summary, the first workshop supported 52 young scientists from 18 countries: Argentina, Australia, Bangladesh, Brazil, Canada, France, Germany, Ghana, India, Italy, Nigeria, Poland, Portugal, Russia Switzerland, UK, USA and Zimbabwe. Most were natural scientists (chemical, biological, physical), with about 25% representing human decision-making communities. Criteria for acceptance to the YSN include young scientists: (1) working on integrative earth system science, (2) geographic and disciplinary breadth is necessary, however, participation from developing countries is strongly encouraged; and (3) participation from human and social sciences are also given primary consideration.

The AIMES YSN has obtained funding from NSF for 3 future meetings (2006, 2007, 2008). The 2006 YSN meeting was held in Mexico City, in collaboration with the Global Carbon Projects’ Urban Regional Carbon Management Conference.

The YSN is co-led by Natalie Mahowald (AIMES SSC; NCAR), Marko Scholze (QUEST; UK), and Kathy Hibbard (AIMES SSC; NCAR) as well as Richard Dawson (UNUT, UK) and Ahmed Balogun (UMKC, USA), YSN participants from the first 2005 workshop.
AIMES and the International Global Environmental Change Programmes

As an integrative project, AIMES does not have any single theme, or focus (e.g., atmospheric chemistry, ocean biogeochemistry, carbon, etc.), but rather, is charged with quantifying and understanding the dynamics and coupled feedbacks in the Earth system. As an integrative project of the IGBP, AIMES serves as both lead and supporter for the more disciplinary activities and projects within the IGBP and ESSP.

AIMES and the Earth System Science Partnership (ESSP)

The Earth System Science Partnership (ESSP) is a joint initiative of the international global environmental change programmes (GECs): DIVERSITAS, IGBP, the International Human Dimensions Programme (IHDP) and the World Climate Research Programme (WCRP) (see Figure ESSP). There are currently four ESSP projects on global sustainability (carbon cycle, water resources, food systems and human health) that are each jointly co-sponsored by the GECs. An integrative approach to assess the influence and impacts of regional processes on Earth system function is investigated through ESSP co-sponsored Integrated Regional Studies (IRS). Regional capacity building and the development of regional networks are led through the ESSP SysTem for Analysis Research and Training (START) project. The ESSP provides a platform for bi-directional information and collaboration between AIMES and the interdisciplinary joint, regional and outreach projects. For instance, AIMES collaborates with ESSP projects on the development of assimilation models, carbon and hydrological cycle processes for Earth System models and contributes to the START capacity building through workshops and Young Scientist’s Networks (see section 6.1 above). For more information on the ESSP, see; http://www.essp.org/
Figure ESSP. Conceptual diagram of the relationship between the international global environmental change programmes and the joint projects on global sustainability within the Earth System Science Partnership (ESSP).

AIMES and IHDP, DIVERSITAS and WCRP

AIMES is formally sponsored by the IGBP and is actively engaged in ongoing dialogue and scientific collaboration with the IGBP Core Projects and the ESSP. As the Earth system modelling successor to the GAIM Task Force, AIMES is historically partnered with the WCRP, particularly with the Working Group on Coupled Models (WGCM). AIMES will seek partnerships with the IHDP and DIVERSITAS through strategic initiatives and activities. For instance, AIMES collaborated with the Global Carbon Project (GCP) and the new Urbanization Core Project of the IHDP through its Young Scientist’s Network (2006) at the Urban Regional Carbon Management Conference in Mexico City and the AIMES-IHOPE (see section 7.4.1) steering committee includes membership from both the IHDP and IGBP-PAGES project.

At the AIMES first Scientific Steering Committee (SSC) meeting held in November, 2005, several projects were proposed by the steering committee that could be of joint interest to AIMES and DIVERSITAS. Specifically, the AIMES SSC suggested an expansion of the AIMES horizon more towards how the physical, climate and biological systems interact with ecosystem services and end-to-end translation of science to management and policy communities.
One aim of DIVERSITAS is the development of predictive models of biodiversity change. This exploits the fact that dynamic bioclimatic-envelope modeling developments have improved our capacity to connect climate change with land-use, biodiversity distributions, and ecological functioning. This in turn makes it possible to evaluate the choice between adaptation and mitigation strategies in the management not just of Greenhouse Gasses (GHGs) but also in the conservation of biodiversity. The AIMES remit fits well with this aim, and collaborative workshops to identify an appropriate research agenda will be jointly planned and executed. DIVERSITAS is also interested in enhancing ecosystem components of Earth system models to produce more direct information about biodiversity in ecosystem services in changing climates. Therefore, there is indeed scope for collaboration in the development of models that will (a) aid prediction of climate induced biodiversity change, (b) enable us to evaluate the implications for land use, demographic patterns, human plant and animal health, and (c) evaluate alternative response strategies.

The AIMES scientific collaboration with the WCRP modelling strategy, the Coordinated Observation and Prediction of the Earth System (COPES) is facilitated through direct communication and joint participation in the WCRP Modelling Panel (WMP) which is charged to “facilitate analysis and prediction of the Earth system variability and change for use in an increasing range of practical applications of direct relevance, benefit and value to society.” Joint activities between AIMES and the COPES Strategic Framework provide the basis for understanding and modeling a fully integrated biogeochemical and coupled physical climate Earth system.

The AIMES SSC meets jointly with WCRP’s Working Group on Coupled Modelling (WGCM) every other year, following the legacy of GAIA. Other avenues for AIMES scientific collaboration with the GECs include a dynamic land surface model evaluation with the Integrated Land Ecosystem-Atmosphere Process Study (iLEAPS) and the WCRP Global Energy and Water Cycle Experiment’s (GEWEX) Global Land/Atmosphere System Study (GLASS); linking marine ecosystems (Global Ocean Ecosystem Dynamics; GLOBEC) and climate variability (Climate Variability and Predictability; CLIVAR) (see section 7.1.2 below), joint experimental design proposal on current Earth system modelling for the 5th Assessment Report.
to the Intergovernmental Panel on Climate Change (IPCC) with (i) the WCRP Stratospheric Processes and their Role in Climate (SPARC), (ii) the Working Group on Coupled Modelling (WGCM) projects, (iii) IGBP’s Integrated Global Atmospheric Chemistry (IGAC) project; and (iv) the IPCC’s Task Group on New Emission Scenarios (TGNES).

IMPLEMENTATION STRATEGY AND RESEARCH ACTIVITIES

Research activities within the AIMES project are both derived from ongoing GAIM and new initiatives incorporating human actions and their consequences to biogeochemical cycles of the Earth System. A representative suite of scientific activities and their current status are described below with regard to the AIMES interaction themes: the list below is not exhaustive, but rather, pathfinding and symbolic of the AIMES strategy. In particular, a growing synergism between the development of integrated activities and the advancement of fully coupled Earth system models will facilitate the inclusion of historical and contemporary human impacts improving uncertainties and sensitivity of the dynamic Earth system that will be useful in developing future scenarios.

Theme 1: Process and Parameterization

The Global Emissions Inventory Activity (GEIA)

The GEIA activity to date has been primarily a compilation of global emissions inventories. The development of accurate databases of human and natural emissions from surface (e.g. fossil fuel and the terrestrial biosphere) and atmospheric (e.g. aircraft and lightning) sources to drive global models of the Earth system requires updated inventories and data management for model implementation. GEIA follows the AIMES Theme II, Regional/Global Interactions, including activities with ongoing regional studies such as the Large Scale Biosphere-Atmosphere Experiment (LBA) in Amazonia to improve existing global emission estimates.

Specifically, GEIA will develop new emission inventories, facilitate model and data intercomparison and evaluation, prioritize observations, develop temporal datasets, and develop initialization schemes for chemical exchange models. The challenge of GEIA will be to develop databases for use in increasingly complex, integrated models. For this purpose, GEIA will work
directly with IGBP Integrated Global Atmospheric Chemistry (IGAC), Integrated Land Ecosystem-Atmosphere Processes Study (iLEAPS) and Surface Ocean – Lower Atmosphere Study (SOLAS) projects, as well as the WCRP Stratospheric Processes and Their Role in Climate (SPARC) projects and will establish formal links with the international Projects involved in ocean and human studies, building on existing connections between GEIA and these Projects

Integrating GEIA with AIMES will require an understanding of the complicated blend of models and observations that comprise the global emissions databases, as there are no readily available underlying databases for either global emissions or deposition fluxes. Gridded databases of driving variables will be provided by GEIA and AIMES to the community through workshops and ongoing research activities. For instance, information on emission source distributions, algorithms, and factors from biomass combustion, vegetation, human activities and other driving variables would be made available in a format suitable for a coupled modelling framework.

New information developed as part of GEIA and AIMES collaboration will continue to be organized, communicated and solicited through the existing and continually expanding NSF and NASA supported GEIA web site (www.geiacenter.org) and GEIA E-network (over 500 scientists worldwide). This work will continue to be done in collaboration with the ACCENT European Network (Atmospheric Composition Change: A European Network; http://www.accent-network.org/) whose web site is currently hosting the most recent GEIA databases.

To facilitate development of highest quality, most useful information and data on emissions and related human activities, a formal discussion forum dealing with integrated modelling and data needs will be developed through the GEIA and ACCENT websites. To establish a clear understanding of the current state of science to better guide the development of new data, GEIA, in collaboration with the Surface Ocean-Lower Atmosphere Study (SOLAS), iLEAPS and others, are promoting a summer school on emissions and Earth system modelling. This school would result in the development of a comprehensive book on current status and important next steps.
Claire Granier (AIMES SSC, Service d’Aéronomie/IPSL, France) and Alex Guenther (NCAR) are the scientific leads for GEIA.

Building Links Between the Climate and Marine Ecosystem Impact Research Communities

There is a growing appreciation that changes in the frequency and amplitude of modes of climate variability profoundly influence a variety of ecological processes and, consequently, temporal and spatial patterns of population and species abundance (e.g., Stenseth et al. 2003; Wang and Schimel 2003). These changing spatial patterns can have significant societal impacts, for example, by benefiting or harming different nations or groups of resource users, and by disrupting international agreements regarding the division of fishery benefits (Miller and Munro, 2004). Early studies of the influence of climate on ecological systems typically focused on local weather parameters such as temperature, precipitation and snow depth, and this approach is still common in ecology (Stenseth et al. 2005). Indices of large-scale climate modes, in contrast, provide an integrated measure of weather, and therefore can be linked more to the overall physical variability of the system than any individual, local variable. For instance, the North Atlantic Oscillation (NAO) infers information about temperature, storms and precipitation, cloudiness, hydrographic characteristics, mixed layer depths, and circulation patterns in the ocean that likely explain more of the observed variability of a species than just, for example, water temperature. Moreover, since oscillatory mode variations (e.g., ENSO, NAO) produce coherent variations in climate over large regions, they produce impacts on ecosystems at spatial scales that have major effects on society in many ways, including substantial control over Atlantic and Pacific fisheries, wildfire and other disturbances. Modal variability thus forms a natural subject in which investigators of climate, ecosystem and climate impact science can collaborate. This collaboration is also required to determine the most societally relevant effects of global change on ecosystems.

The goal of the Global Ocean Ecosystem Dynamics (GLOBEC) Core Project is to understand how physical processes influence marine ecosystem dynamics in order to predict the response of the ecosystem and the stability of its food web to climate change. Ultimately, GLOBEC aims to determine critical global change variables and produce an ecosystem description that couples observations and modelling, including the development of coupled biological/physical models.
Clearly, the interests and emphases of the GLOBEC community resonate with interests and emphases found within AIMES, including the development of Earth System Models.

David Schimel (AIMES SSC, NCAR), Cisco Werner (GLOBEC SSC; University of North Carolina) and Jim Hurrell (GLOBEC SSC; NCAR) are the scientific leads for this activity.

**Theme 2: Regional-Global Interactions**

**Regional Linkages of Human and Natural Processes to the Global System**

AIMES pursues a regional-global coupling strategy to link human and natural processes at local and regional scales to the Earth System. There are several reasons for this approach: 1) large scale regional changes can interact strongly with the global Earth System. For example, increasing Asian and use change and industrial/urban emissions are the subject of intense study and have the potential to affect the global climate and hydrological cycle, with possible additional feedbacks to the region. In order to understand the full implications of regional studies, a global context is required. Another example of this is the effect of climate change on Northern High Latitude (NHL) hydrology and carbon storage, where rapid regional changes resulting from climate may feedback again to the global system (see section 7.2.2 below). The former involves a large in situ human interaction, the latter, a less direct effect of humans in the NHL *per se*, but with impacts on human communities and resources. 2) The detail and process understanding from regional studies is precisely what is needed to advance the representation of process in global models, 3) This strategy will build an intrinsic close collaboration between AIMES and the other IGBP/ESSP projects.

AIMES collaborates with ongoing integrated regional studies (e.g., in Amazonia and Asia) through the Large scale Biosphere-Atmosphere (LBA), the ESSP and the IGBP Integrated Regional Studies (IRS) projects (e.g., the Monsoon Asia Integrated Regional Study (MAIRS)). The LBA project is an international research initiative led by Brazil and was designed to quantify the climatological, ecological, biogeochemical, and hydrological functioning of Amazonia, the impact of land use change on these functions, and the interactions between Amazonia and the Earth system. AIMES is working with the ESSP SysTem for Analysis, Research and Training (START) project and IGBP to link the MAIRS regional project with global systems. Workshops
to link the regional scientists with global process and climate system modellers will be developed in the initial phase of AIMES. Eventually, AIMES seeks to include coastal zone and marine couplings as well as the NHL. AIMES collaborations for linking regional to global process understanding lie with several IGBP Projects, including iLEAPS, IGAC, Land-Ocean Interactions in the Coastal Zone (LOICZ), Integrated Marine Biogeochemistry and Ecosystem Research (IMBER), SOLAS, Global Land Project (GLP), PAGES and ESSP projects such as START the Global Water Systems Project (GWSP) and the GCP (see Figure ESSP for context).

Northern high latitudes regional-global interactions: Quantifying and understanding connectivity between global change and the state of the Boreal and Arctic Regions

Background
There is strong palaeo-evidence that the Arctic and high-latitudes have responded strongly to external forcing and through internal feedbacks (vegetation, sea ice) in the past. Northern high latitudes are changing rapidly under both human pressures and the impacts of Global Change; the Arctic is predicted to warm faster and to a greater degree than any other part of the Earth. Because of significant biogeochemical, hydrological and energetic feedbacks between the Earth system and the northern high latitudes (NHL), the future state of the entire Earth system is strongly dependent on the response of the NHL to this warming. This potential for the northern high latitudes to amplify and accelerate global change has made them a focal point for research.

The importance of the NHL has resulted in a myriad of studies to quantify and understand the causes, impacts, interactions and feedbacks between and within terrestrial, ice, ocean, social and climate systems. Activities range from individual institutional investigations, national and regional campaigns, as well as the upcoming International Polar Year (IPY) in 2007-8. These investigations focus on issues central to IGBP, such as:

1. Changes in carbon storage and sequestration (including CO₂, CH₄ and methane clathrates), e.g., the vulnerability of the vast NHL soil carbon stocks to warming-induced mineralisation, which would accelerate CO₂ accumulation in the atmosphere and thus act as a positive feedback on warming;
2. Changes in albedo, e.g., the interactions between reduced sea ice and snow-cover, changing vegetation, and energy balance. Reductions in albedo associated with reduced snow and ice, and increased forest cover, will increase absorption of radiation and raise
temperatures, another positive feedback; while aerosols and their effect on haze and interactions with clouds are uncertain;

3. Changes in terrestrial hydrology, e.g., the implications of altered precipitation and evaporation ratios on terrestrial runoff with regard to permafrost dynamics and ocean salinity gradients. Freshwater loading to the Arctic Ocean from river discharge is important on controlling the thermohaline circulation, and so changes in discharge may affect deep-water formation.

4. Changes in ocean circulation, e.g. potential changes in thermohaline circulation through surface warming (see 2, above), changes to the salinity gradient (see 3, above) and altered CO\textsubscript{2} uptake (see 1, above), changes to ocean solubility and uptake rates, may feed back on global climate;

5. Changes in human behaviours: e.g., impacts on indigenous communities, changes in resource use, alterations in transport networks, including opening of new shipping routes.

An initial survey of various northern high latitude activities (past, present and planned) includes: International Polar Year (IPY; \url{http://www.ipy.org/}), 2007-8; Ecosystem Studies of Sub-Arctic Seas (ESSAS); through GLOBEC; Global Terrestrial Network on Permafrost (GTN-P); Northern Eurasian Earth Science Partnership Initiative (NEESPI); Boreal Ecosystem-Atmosphere Study (BOREAS); EuroSiberian Carbon Flux; NSF Arctic System Science (ARCSS); The International Tundra Experiment (ITEX); The Circumarctic Environmental Observatories Network (CEON); The Arctic regional climate model intercomparison (ARCMIP); Global implications of Arctic climate processes and feedbacks – (GLIMPSE); Arctic Ocean Model Intercomparison Project (AOMIP). These activities provide insight into local or regional processes, but we lack a coherent strategy to integrate the various process, observation and modelling studies in a global context, and to fully explore the regional-to-global interactions.

The Role of AIMES in a Northern High Latitudes Study

The AIMES core project of the IGBP provides a global context to disparate activities over multiple temporal and spatial scales. In a northern high latitude study, AIMES will focus
strongly on integrating across scales, linking regional-to-global templates in Earth System Modelling with global observations and datasets.

Earth System integration across scales and linkage among key processes in the northern high latitudes is needed to assess the likelihood of major or even de-stabilising feedbacks via arctic biophysical and biochemical pathways. The initial goal of AIMES, to assess human perturbations to the biogeochemical and climate systems, thus demands a focus on the northern high latitudes. AIMES will develop a collaboration and coordination among the northern high latitude studies (e.g., see above) as well as among the Earth System Science Partnership (ESSP) programmes in this region. Regional and global data and northern high latitude climate-relevant processes will be coupled to a global modelling framework, to facilitate analysis of potential sensitivities and feedbacks between humans, biogeochemistry and climate. No single model has strength in all of the requirements for simulating these high latitude feedbacks, such as simulation of frozen lands, peat-lands, wetlands or tundra-to-taiga vegetation dynamics. Thus, the specific goals of the AIMES integration will be to:

1. Develop close collaboration with a broad range of northern high latitude programmes and activities (see above), and other IGBP projects with a northern high latitude focus, including iLEAPS, LOICZ, SOLAS, GLP, PAGES, and ESSP projects such as GCP;

2. Use this collaboration to identify and improve representation of key northern high latitude processes in global coupled carbon cycle climate models (C4 models) using local-to-regional northern high latitude experimental and modelling outputs;

3. Use global C4MIP models to determine current uncertainties and key thresholds in Northern High Latitudes-Earth System climate-biogeochemical coupling.

Achieving these goals requires that AIMES facilitate linkages among the two key relevant groups; the scientists involved in regional, national and international northern high latitude activities listed above, and the global Earth system (e.g., C4MIP) modelling community.

At least two international workshops are required to bring the groups together. The first workshop will focus on agreeing the key issues in northern high latitude-global connectivity in Earth System Modelling, defining the problems in understanding these issues, building the key
partnerships and setting out a working strategy for achieving (2) and (3), with action items. AIMES will sponsor a website to publicise and promote northern high latitude programmes and research, and provide an interaction forum for continued discussion and sharing of expertise, data and ongoing model outputs. Then, a second workshop can bring participants together again to discuss the initial collaborative outputs related to goals 2 and 3, to identify key findings and attempt to generate a high profile publication, and solutions to any problems encountered. A longer term strategy will be developed, dependent on whether there is a requirement for further personnel exchanges, smaller focussed workshops, or another follow-up workshop after continuing work. The initial momentum provided by AIMES in collaboration with other projects and activities will become self-sustaining.

Theme 3: Applied Earth System Science

The applied Earth System science template will embrace two challenges: (1) integrating the increasingly complex coupled Earth System models into the assessment community and; (2) translating research understanding into useable science for management communities (e.g., resource managers) and decision makers (e.g., public and policy).

APPLICATIONS OF EARTH SYSTEM MODELS IN CLIMATE CHANGE ASSESSMENT

In collaboration with IHDP and WCRP, AIMES will contribute to integrating emissions and land use for assessment activities, including the Intergovernmental Panel on Climate Change (IPCC) assessment reports. From one assessment report to the next, timelines for model improvements are short with limited planning, funding, and model development time. Workshops to address linking assessment activities such as scenario development and deployment with modelling frameworks will address coupled carbon cycle capability for both marine and terrestrial ecosystems, coupled climate-photochemistry including O3 and chemical lifetimes with related emission modelling issues, coupling aerosols and radiation with their indirect effect and links to e.g., chemistry and dust, coupling dynamic vegetation to biophysical climate processes and trace gas emissions. A first workshop, co-sponsored by AIMES and the WCRP WGCM and the Aspen Institute for Global Change in 2006 began a dialogue for scenario development and model experimental design for the IPCC 5th Assessment Report (AR5). Outcomes from this workshop
include a white paper to be circulated to IPCC and the Atmosphere-Ocean Global Circulation Model/Earth system modelling communities.

The International Nitrogen Initiative (INI)

Over the past half century, growing human population and increasing human activities related to the production of food and energy have more than doubled the production rate of reactive nitrogen (Nr) on the land surface of the Earth (Galloway & Cowling, 2002; Galloway et al., 2004) and altered the nitrogen cycle globally more than that of any other element (Vitousek et al. 1997). Consequently, in many parts of the world the conversion of unreactive N\textsubscript{2} to reactive forms (nitrogen oxides plus other oxidized nitrogen species, NH\textsubscript{3}, NH\textsubscript{4}, and organic N) became controlled mainly by anthropogenic activities such as fertilizer production, combustion of fossil fuel, and biological fixation in agriculture, instead of being controlled by natural processes such as natural biological nitrogen fixation (BNF) and lightning (Smil, 2001; Galloway et al., 2004).

In mid 1990s, terrestrial BNF was responsible for the creation of ~110 million ton of N, while the sum of the major anthropogenic sources have created ~160 million ton of N. Approximately half of that total was due to the consumption of nitrogen fertilizers, almost 20% by combustion of fossil fuel, and a similar percentage by the cultivation of crops that fix nitrogen from the air.

Although estimates providing a global picture about the N use by mankind are important, they do not allow us to propose actions that would help mitigate the deleterious effects of N in the environment and for human health. Much more detailed spatial information on the creation and fate of Nr is needed in order to propose such actions. This is especially considering that, mainly
Figure INI. Creation of reactive Nitrogen by geopolitical region for the early 1990s, Tg N y⁻¹ (Galloway et al. 2004) due to human actions, the sources of nitrogen distribution are highly variable among the continents of the globe (Fig. INI).

There are several consequences of excess or lack of nitrogen to ecosystems and the human population. Lack of nitrogen to grow food led to food insecurity and land degradation especially in developing countries of Africa, Asia, and Latin America. In the developed countries of Europe and North America problems related to excess of nitrogen has caused major problems in the form of nitrogen pollution in the atmosphere, aquatic eutrophication and acidification and forest decline in terrestrial ecosystems. Thus the challenge is how to optimize the use of nitrogen to sustain life, and to minimize the negative impacts of nitrogen on the environment and human health. To address this challenge, the International Nitrogen Initiative was established in 2003 (http://initrogen.org)

The INI contains a three-pronged, interactive process to meet the challenge of nitrogen. One focus is the assessment of basic knowledge on the creation and distribution of reactive nitrogen: Where is there not enough nitrogen? Where is there too much? What are the effects of the decrease or increase in the abundance of nitrogen, relative to societies’ needs? The second focus consists of the development and identification of solutions for regions with an under- or over-abundance of nitrogen. The third focus is the implementation of scientific, engineering and policy tools to solve the identified problems. Policy makers at the governmental level must be involved in these steps, if the problems of nitrogen supply are to be reversed. Towards that end, the Third International Nitrogen Conference and the INI jointly developed the Nanjing Declaration, which lays out the major issues concerning nitrogen and sets the stage for the continued development of an integrated, global approach to meet the challenge of nitrogen.

There are several examples of where the problems of excess nitrogen have resulted in public policy to reduce nitrogen-related issues. In the US, the both the Clean Air Act and the Clean Water Act were passed to address, in part, N-related problems. In Europe Major sources of NOₓ emissions are transport, industry, and energy production. Work under the Convention on Long Range Transboundary Air Pollution has seen a reduction of emissions in Europe (Russia
excluded) by 21% between 1990 and 1998, mostly due to decreased industrial activity in Eastern Europe. Under the Convention’s new Gothenburg Protocol and new EC Directives, reduction is predicted to reach 50% of 1990 emissions by 2010 (Erisman et al. 2003; Howarth et al., 2006). The AIMES INI initiative represents end-to-end (research to management and policy) transmission of science to agricultural, ecosystem and policy management communities.

**Theme 4: Integrated Earth System Science and Modelling**

The ultimate goal of an ambitious project such as AIMES will be to understand the coupled human and environmental dynamics from the past and into the future. Two key activities within AIMES are pioneering this challenge and form a central core to AIMES scientific research. The first, the Integrated History and Future of People on Earth (IHOPE) endeavors to understand the interactions between humans and their environment over the last several millennia through to the present and future with the goal to develop the databases in human activities, their impact on the global environment and the consequences of global change on human societies. The second key activity, the ongoing Coupled Carbon Cycle-Climate Model Intercomparison Project (C4MIP) launched in the previous IGBP/GAIM Task Force are central to Earth system model development and the assessment process for the IPCC.

**INTEGRATED HISTORY AND FUTURE OF PEOPLE ON EARTH (IHOPE)**

The recent history of the earth has traditionally been cast in terms of the rise and fall of great civilizations, wars, and specific human achievements. This history leaves out the important ecological and climate contexts, which shaped and mediated these events. The capability to integrate human history with a fairly detailed and spatially explicit natural environmental history of the earth over the last several thousand years is now possible. Such an effort will provide a much richer picture of how (and why) the planet has changed in recent and distant past and possible futures for civilizations. The IHOPE dataset will be used as a core data set to test integrated models of humans in natural systems, Earth System Models of Intermediate Complexity (EMICs) through to Earth system models. The subset of models that exhibit skill in replicating the integrated history of humans on earth can then be used to make projections into the future with much higher confidence. The long-term goals of the IHOPE project are to:
• Map the integrated record of natural and human system change on the earth over the last several thousand millennia, with higher temporal and spatial resolution in the last 1000 and 100 years.

• Assess the impacts of historical human activity on the physical/biogeochemical and climate systems with data maps of human activities that are integrated with the Earth system (e.g., C4MIP) and EMIC models.

• Understand the connections and dynamics of human history by testing integrated human-in-environment-systems models against the integrated history

• Project with much more confidence and skill options for the future of humanity and Earth System dynamics, based on models and understanding that has been tested against the integrated history and with participation from the full range of stakeholders.

The IHOPE activity provides a mechanism to test a broad range of hypotheses about human-environment interactions. For example, Ruddiman (2005) suggested that departures from average methane concentrations in the Vostok Ice Core (Petit et al. 1999) since the most recent interglacial period were anomalous when compared to previous interglacial periods and were primarily the consequence of the rapid increase in global rice cultivation. The paleo science community has argued against Ruddiman through solar forcing and other modelling work (e.g., see Joos et al. 2004, Broecker and Stocker 2006). The insight, data and models generated from the IHOPE activity by environmental historians, archeologists, ecologists, modelers and paleo-environmental and paleoclimate communities will allow the testing of such hypotheses. It will also allow the calibration and testing of integrated global earth system models that contain a range of embedded hypotheses about human-environment interactions.

**IHOPE Science Questions**

Consistent with the long-term goals mentioned above, three overarching questions that implicitly incorporate the attribution of biophysical processes and/or specific events or cumulative human actions which have altered the Earth system have been identified for IHOPE:

1. How do we use integrated knowledge of human perceptions of and behaviors in the environment in the past for understanding the future?
2. How do we understand the complex reasons for the emergence, sustainability or collapse of coupled socio-ecological systems?
3. How do we evaluate alternative explanatory frameworks and specific explanations and models (including complex systems models) against observations of highly variable nature, quality and coverage?

Approaches to Analysis, Synthesis, and Modelling

IHOPE will use a wide variety of datasets, tools and information. For instance, utilization of multiple lines of evidence to cross-check and test hypotheses will be performed with a complementary suite of models and observations. However, IHOPE recognizes that many of the disciplines employ models that represent very different views of historical information and operate on significantly temporal and spatial scales. Conflicting goals across disciplines must be addressed to develop creative solutions to the appropriate interpretation and analyses of disparate observations and model solutions. There are at least 5 constituent communities that will be involved with IHOPE that all have such very different cultures with regard to data collection, modelling, analysis, storage, archival and formatting strategies: (1) archaeologists who study and interpret what has happened to human societies, (2) anthropologists who investigate how the structure of societies change, (3) quaternary scientists (including palaeoecologists) who study what happened to the physical environment, (4) geographers who manage analyzed data over various temporal and spatial scales; and (5) Earth System scientists who are interested in derived products that can be used as inputs to evaluate impacts on e.g., hydrologic processes and the carbon cycle.

Integrated History Regional Case Studies

Realization of IHOPE’s goals will initially be implemented through an analysis of regional case studies for which the data available are dense, the result of research in a wide range of disciplines, and representative of the many categories of data to be collected at the global scale. Regional case studies will be framed through the coupled process and transitions of the human-environment system, for example, the colonization of pristine landscapes by hunter gatherers in Australia, the colonization and abandonment of landscapes by hunter-gatherers in the Sahara
during and since the Holocene, recolonization of early Man in Europe after the deglaciation, transitions to settled agriculture in the Middle East and the Viking Landnam colonization of inhabited regions. This will allow IHOPE to experiment with a range of Alternative Explanatory Frameworks (AEFs), designing and implementing the datasets required to enable each AEF to ask the project’s questions, experimenting with different metrics, trying out various kinds of model validation, etc. As regional case studies are developed, it will be useful to draw from the regional case studies to; (a) quantify global population numbers and density through time, (b) quantify and map area affected by specific settlements and/or populations, (c) develop and apply objective schemes to assess ‘human impact’ on natural vegetation (extension of the ‘biomisation’ method (Prentice and Webb 1998), (d) quantify and map timings of expansion, migration events, (e) synthesis environmental data and reconstruction of regional changes covering the relevant periods of interest (e.g., Holocene, last 20,000 years, Late Quaternary); and (f) map the land-geography through time.

Transdisciplinary Networks and Centres
The implementation of the IHOPE research agenda will require contributions from scholars around the world and across many disciplines. A networking approach will clearly be essential for IHOPE’s success, and at least two types of networks are envisaged. First, there will need to be regionally based networks of scholars from a wide range of disciplines who undertake the case studies in an integrated fashion. Complementing these will be more disciplinary networks, both regional and global, who can further develop and test data and information gathering methodologies for particular aspects of the IHOPE agenda and who can develop specific simulation tools needed for the analysis and integration phases of the project.

THE COUPLED CARBON CYCLE-CLIMATE MODEL INTERCOMPARISON PROJECT (C³MIP)
At the October, 1998 meeting of the WCRP/WGCM, a Coupled Carbon Cycle-Climate Model Intercomparison Project (C³MIP) was proposed as a collaborative GAIM-WGCM project to analyze the interactions and feedbacks between the carbon cycle and climate in the presence of anthropogenic climate forcing. Feedbacks may be modulated by altered forcing of the ocean and terrestrial carbon cycles or by the impact of altered CO₂ concentrations in the atmosphere. The basic procedure is to include models of the terrestrial and ocean carbon cycles in existing
Ocean/Atmosphere Global Circulation Models (OAGCMs) and run the model with and without active feedbacks. Initial protocols included the consideration of carbon dioxide, radiative and biogeochemical (e.g. influence on plant function) forcing and used tracer CO₂ for diagnostic surface fluxes. We anticipate and will promote additional work in C⁴MIP that will bring in additional dimensions of human activity, possibly including additional land use/land management information and multiple trace gases, such as methane, CFCs, SF6, etc. mainly through collaboration with GEIA and IHOPE.

From C⁴MIP to CXMIP

Recent C⁴MIP simulations (Friedlingstein et al. 2006) demonstrate that coupled global models are generally in agreement (all show positive response) that future climate change will reduce the efficiency of the Earth system to absorb the anthropogenic carbon (Figure 2). Sensitivity analyses of the coupled models to future climate for the land and ocean uptake separately were consistently negative (Figure 3), however there are large uncertainties on the magnitude of these sensitivities. For the land, attribution of the sensitivity to changes in net primary productivity versus changes in respiration is still subject to debate; no consensus emerges among the models.

![Graph](image)

**Figure 2.** Difference in atmospheric CO₂ concentration between coupled and uncoupled carbon cycle-climate simulations (ppm) from Friedlingstein et al. (2006). Coupled models contain fully coupled and dynamic carbon cycle to existing Atmosphere/Ocean Global Circulation Models (AOGCM); uncoupled models do not include carbon cycle dynamics.
Figure 3. Coupled runs (GtC y$^{-1}$) for (a) land carbon uptake and (b) ocean carbon uptake (Friedlingstein et al. 2006).

Evolution of C$^{4}$MIP:

**The Palaeo Carbon Model Intercomparison Project (PCMIP)**

The ice core records, now extending up to 8 glacial cycles, demonstrate the remarkable covariation of climate and biogeochemical cycles such as carbon dioxide, methane and dust (Petit et al.1999, EPICA members 2004). There are also a growing number of marine and continental paleodata such as pollens and marine sediments that contribute to model development and evaluation. These data improved glacial climate simulations with the coupled physical climate models since the Last Glacial Maximum (LGM), or ca. 21,000 years. However, none of these models attempted to simulate the evolution of the biogeochemical cycles over these time scales. The observed 80 ppm change in CO$_2$ and 350 ppb change in CH$_4$ between glacial maxima and interglacial states are still unexplained. A next step for the C$^{4}$MIP community will be to address the “Vostok-EPICA challenge” using coupled carbon-climate models. The rationale will be first to simulate the LGM marine and continental carbon cycles, and second to use coupled climate-carbon cycle models to simulate the transient evolution of the Earth system from its glacial to interglacial states. In a second phase, using the upcoming
climate-carbon-chemistry models, C^4MIP plans to address the evolution of methane and dust over glacial cycles. If progress in the coupled carbon-climate-chemistry models allows, AIMES will consider the challenge of natural variations of nitrous oxide. However, evaluating model performance is crucially dependent on the existence of spatially-explicit data sets which can be compared with output from the model simulations. One goal of the Palaeoclimate Modelling Intercomparison Project (PMIP, supported by PAGES and the WCRP CLImate Variability and Predictability (CLIVAR) project) was to foster the creation of well-documented, spatially-explicit data sets explicitly designed for use in climate model evaluation. A similar effort will be encouraged through AIMES (as a joint investigation with PAGES), focusing on data sets relevant to the spatial and temporal evolution of sources and sinks of greenhouse gases, and trace gases (such as carbon monoxide, non-methane hydrocarbons or nitrogen oxides) having an indirect effect on the greenhouse gas palaeo-budgets.

CXMIP-Chemistry
The next phase of C^4MIP (C^5MIP) will integrate the fate of methane, nitrous oxide, aerosols, ozone and other important greenhouse gases (e.g., PFC’s, SF6) into the coupled carbon-chemistry-climate models. This will require the development of emission models and new data constraints of these species and their precursors both for the land and the ocean. This will require interactive chemistry in the atmosphere, linking strongly to the iLEAPS and IGAC scientific communities. The C^5MIP community will also investigate the interactions between climate-fire regimes and trace gas emissions from fire (including greenhouse gases such as CO_2, CH_4 and aerosols). The challenge is to quantify the feedback of these changes in chemistry on the climate system. This will require the development of emission models of these species and their precursors both for the land and the ocean. The GEIA activity (see Section 7.1.1 above) will contribute strongly to this activity. Emission models will have to be embedded in the ocean and land model components of the coupled models. Also, this will require interactive chemistry in the atmosphere, linking strongly to the iLEAPS and IGAC scientific communities. This will enable the community to investigate the feedback between climate and methane through the climate-induced changes in methane emissions from wetlands and permafrost. The fate of the oxidizing
capacity of the atmosphere and its control on the methane lifetime will also be addressed in CXMIP model experiments and tested against new tracers of past atmospheric chemistry.

Future CXMIP activities will investigate the interaction between climate- fire regimes and trace gases emissions from fire (including greenhouse gases such as CO₂ and CH₄ and aerosols). Climate may also induce changes in aerosol emissions (e.g., dust from changes in vegetation distribution, dimethyl sulfide (DMS) from change in ocean phytoplankton distribution, particulate organic aerosols from changes in fire regimes and changes in biogenic emissions). The challenge is to quantify the feedback of these changes in chemistry on the climate system. Results from the C⁴MIP AIMES/WGCM activity will also help to design the complexity of Earth System Models required to better simulate the future evolution of the climate system.

**CXMIP and Ecosystem services**

The C⁴MIP models have an extremely crude representation of human managed ecosystems. Land cover change such as tropical deforestation and crop management (irrigation, harvesting) have an impact on the climate system and therefore should be included in global models for simulating the climate of the 20th and 21st century. Ecosystem services such as crop yield, food and fiber production and fisheries may be affected in the future by climate change and change in biogeochemistry (e.g., atmospheric CO₂, NOx deposition, surface ozone concentration).

Within the decadal lifetime of AIMES, the C⁴MIP modelling community will endeavor to improve the representation of these “ecosystem services” in the coupled climate-biogeochemical models towards a C⁵MIP Earth Systems models. The primary emphasis will be on having a more realistic representation of crops, pastures and managed forests but also including grazing, cattle, food and fiber trade, and ecosystem carbon sequestration. These components will be added by linking with other international projects to include additional anthropogenic drivers such as fisheries, fertilizer and irrigation level, crop selection, harvesting and logging decisions, soil tilling, etc.

The AIMES IPO at NCAR will provide infrastructure and leadership for this activity to move forward. Current C⁴MIP leadership is with Pierre Friedlingstein (AIMES SSC, Laboratoire des
AIMES: NEAR AND LONG-TERM VISION

The success of AIMES will depend not only on practical advances in Earth System model development and application but also, to take the lead from the previous GAIM Task Force in visionary thinking towards the future and contributing to IGBP fast-track and other Global Environmental Change programme activities. Many of AIMES goals to understand and quantify the coupled human-environment systems will require ‘out-of-the-box’ thinking and foresight. Realisation of the coupled system will require a strategy of envisioning, modelling and integration.

Integrating Economic and Earth System Models

The roles of economics in integrated Earth system modelling

The ultimate value of integrating economics into Earth System Models is the insights it can produce for policymaking. It can provide one route to translate purely scientific results into information that assists policy makers to develop effective policy responses. Integrating economics allows us primarily to address issues of adaptation and mitigation: what drives them and how they can affect the earth system.

Economic modelling has some key differences from the existing models of natural earth systems. Not only are human actions uncertain, but the structure of the societies and economies that drive those actions are continuously evolving. Because humans are rational beings (at least to some extent!), they can behave strategically and their behaviour will change in response to new policies and situations.

This makes quantitative predictions inherently uncertain and potentially misleading. Using economics as part of a grand complex prediction model is one potential use but not the only one, and potentially not the most important one.
Instead, economic models can be used to generate insight into types of relationships, directions of effects and forms of interaction, and their relative importance. Integrated models can be built strategically to respond to specific policy questions rather than using one complex model for all needs. The very process of creating these simple integrated models is likely to identify new science needs for policy making. These policy specific models can explore questions such as the relative effects of different policies, unexpected effects of policies, the effects of different levels of policy stringency and the distribution of the costs of policies among countries and sectors. The national level is the highest level at which agents respond directly to the earth system, so as much as possible, results need to be made relevant to these agents.

The role of economics could be divided into four areas. Each involves different types of economist:

1. National (or sub-national) models of supply and demand: These could contribute to understanding the drivers of emissions (e.g. from fossil fuel or land use), predicting adaptation responses, and estimating the economic cost / value of these actions.

2. Global economic models of trade and migration: These allow exploration of how behaviour in one country affects other countries and imposes consistency on a global scale so that global resources are fully but not over utilised.

3. Use of economic theory to design policies that create appropriate incentives within and between countries: This component does not directly contribute to integrated modelling but it should motivate the model simulations and contribute to their interpretation.

4. Policy evaluation (ex-ante and ex-post): Ex-ante evaluations essentially involve simulations from quantitative integrated models that draw on (1) and (2) and also natural science input (See Figure 1 for a general model structure). Both the policies evaluated and the effects and side effects explored would be motivated by the theory in (3). These
evaluations may require custom designed integrated models (or at least components). They may raise questions that require new model components or new scientific input.

Ex post evaluation provides a real-life check on the value of the models. It allows quantitative predictions to be assessed and can also identify unexpected side effects that were not built into the policy design model. Evaluations involve a combination of qualitative assessment and econometric modelling. The latter is obviously easier to do if the evaluation has been anticipated and systematic data have been collected. Ex post evaluation can explore both the effectiveness of policy and the distributional effects.

Figure 4. An Integrated Earth System Model
The results of these evaluations should feed back into (3) but also into the basic modelling of (1) and (2) and the science components to create better policies and more useful policy evaluation models in the next round. Considerable work has been done on (1) through (3) above but less on (4). There are successful models of economic/natural science integration especially with regard to energy, but there could be much more. AIMES will examine three approaches to promote more and better integrated modelling.

**Economic Community Logistics: Data and natural science model availability**

The economics profession is a very individualistic one. The best economists including top graduate students mostly drive their own research agendas rather than joining existing teams. Large groups working jointly are extremely unusual. Papers usually have one or two authors. Professional rewards are mostly for new ideas and innovative methodology rather than model building or dataset development. Post Docs are rare in economics so most good young researchers go straight from a PhD to an assistant professorship. Thus young researchers who are probably our best target, ideally need to be able to take a research idea from start to finish more or less on their own in 2-3 years to fit with PhD and tenure review deadlines. Thus the key research questions combined with data and simple science models need to be made available to a wide range of potential users in an easily accessible form so they can choose to pick them up.

If well-documented datasets that can be manipulated on a PC and contain enough variables to explore a range of research questions are readily accessible to young economic researchers, they will be used. There are excellent examples of this in other economic sub-fields. Similarly, if simple natural science models that an economist can understand and use (non-scientist oriented documentation, accessible software) are available, they will use those to create simple integrated models that have an economic focus. Currently they often create their own ‘science’ components to avoid the perceived cost and risk (in terms of time) of working collaboratively with natural scientists.

**Actively promote communication between earth system modellers and key economists**
The aims here would be to build trust and respect among key researchers in economics and earth system modelling and establish strong communication channels; and identify potential integrated projects and what these would require. This would build on existing collaborations and learn from them.

A series of short carefully engineered workshops focused on specific sub groups of the economics community and targeted at particular aspects of model building kicks-off implementation of this activity. For example one workshop focusing on global trade modelling and its current and potential connections with earth system modelling; another workshop to investigate issues of urbanisation; another to examine the interactions of poverty and earth systems. The workshops would be small (10-20 people) and include well-regarded researchers from representative communities with strong interpersonal skills. Results of these workshops would provide linkages into wider scientific communities.

**A New Type of Earth System Model: Simple Integrated Models (SIM)**

The aim of a Simple Integrated Model (SIM) is to promote learning, interdisciplinary communication and end-user communication. The goal is not to be an accurate predictive or simulation model, but rather, to motivate the modelling, social and natural science communities towards further development of a more sophisticated integrated model. The goals would foster research questions that examine individual components and questions such as: ‘How would another modelling group use the outputs of your model as inputs?’ and ‘How can you use their inputs as outputs? ‘How do models link?’ ‘What are the really essential aspects of my model for exploring a specific policy question?’

If each very simple component were based on reasonably realistic basic data and parameters, SIMs would allow preliminary explorations of integrated results:

1. What are important linkages and feedbacks?
2. Where are non-linearities likely to be important?
3. What sorts of simulations would be useful for policy making?
4. When (in policy scenarios) will uncertainty propagate rather than wash out?
5. What are the really important drivers of uncertainty?
Ideally SIMs will be run by several scientific groups and institutions to explore their relative potential and compare results.

**Approach**

Each SIM would be targeted at a particular problem rather than trying to meet all needs. A SIM would be much simpler than a model of intermediate complexity. SIMs could be run on a PC with available and simple software (e.g. MATLAB). To reduce data needs they would have low spatial and temporal resolution. To allow multiple researchers to work with them and comment on them, they would be based on common, publicly available datasets. The linkages between components would be minimised and use a limited number of specific input and output variables. This will make the drivers of the simulations transparent. All components may be based on a wider range of underlying data, of which some will be common. Each component would be calibrated to produce ‘reasonable’ results in defined ranges of the input and output variables. The SIMs would have a modular structure so they could use different components from different underlying models as long as the input and output variables are the same.

The complex part of a SIM will be designing a simple integrated structure to address hypotheses and develop the appropriate simplifications for each component to facilitate model linking and provide useful insight despite model extreme simplicity. This can be achieved with multi-disciplinary collaboration through a series of workshops where the goals would be to:

1. Identify key input and output variables from each component that are consistent
2. Define functional forms that adequately represent processes that are critical for the integrated model
3. Interpreting SIM results

*Comment [dim6]: The idea of a super simplified integrated model worries me. I don’t think it’s possible to simplify as much as this section suggests and still have results that are meaningful.*
Figure 5 gives an indication of how a SIM that considers the effects of policies that internalise the costs of Greenhouse Gas (GHG) emissions from land use (e.g., an agricultural emissions tax / sequestration reward) might look. This example would include common databases that all three components (land use; climate and policy) would use: e.g., GIS maps of existing land use/cover, geophysical conditions (topography etc.), and climate. The only linkages into the climate model are land use related GHG emissions going in and temperature and precipitation coming out.

Figure 5. Conceptual Simple Integration Model (SIM). Policy and Red variables are exogenous starting conditions. Green variables represent intermediate and final outputs.

**Modelling Ecosystem Services**

**Background**

As part of the AIMES strategy, the building blocks for developing integrated models of human-environmental interactions will be developed through applied Earth system Science activities such as the International Nitrogen Initiative (see Section 7.3.1) and activities generated from the Regional/Global theme (see Section 7.2) and IHOPE. Implementing applied Earth system and...
regional analyses can be realized through modelling ecosystem services. Ecosystem services are defined as those functions of ecosystems that support (directly or indirectly) human welfare (Costanza et al. 1997, Mooney and Ehrlich 1997). Ecosystem services occur at multiple scales, from climate regulation and carbon sequestration at the global scale, to flood protection, soil formation, and nutrient cycling at the local and regional scales (e.g., see Costanza et al. 1997). They also span a range of degree of connection to human welfare, with services like climate regulation being less directly connected, and recreational opportunities being more directly connected.

The Science Needs and Questions
AIMES will develop a modelling approach that provides a more sophisticated and transferable system for resource and ecosystem managers to quickly understand the dynamics of ecosystem services in their area, how these services are linked to human welfare, and how their function and value might change under various management scenarios. Modelled management options will provide information on the dependence of various ecosystem services including the: (1) functioning of ecosystems; (2) spatial pattern of land use; and (3) transfer of information on local ecosystem services to the watershed, national, and global scales. These strategies require an overarching dynamic computer modelling framework to synthesize information and extrapolate results to areas not well covered by direct observations. As Palmer et al. (2004) put it: “New spatial, analytical, and other quantitative approaches will be needed to understand how ecological responses depend on space and time.”

Questions integral to a modelling ecosystem services activity include:

1. How are ecosystem functions linked to ecosystem services in time and space?
2. How can we best value ecosystem services in various circumstances?
3. **How do we value and measure biodiversity?**
4. How can we communicate information about the dynamics and value of ecosystem services to decision makers and the broader public?

Implementation
AIMES will require an intensive program of participatory modelling, data collection, valuation, and outreach that will take the study of ecosystem services to the next level and allow the results
to be effectively used in a number of critical environmental management contexts. Models and their supporting data bases can be produced using participatory, “mediated modelling” workshops, involving key ecosystem scientists, ecological economists, ecosystem managers, and students (c.f. Higgins et al. 1997, Costanza and Ruth 1998, van den Belt 2004). Task groups will produce, calibrate and test unit models for each of the major ecosystem types, including: (1) Forests; (2) Grasslands; (3) Wetlands; (4) Lakes/Rivers; (5) Cropland; (6) Urban; (7) Open Ocean; and (8) Coastal Ocean.

Unit models can be linked with remote sensing data and a GIS database, allowing model initialization and parameterization for any location on the planet. The spatial proximity of particular patches of an ecosystem relative to other systems is an important characteristic in determining its functioning and value. The proposed system would allow (for the first time) adequate consideration of this effect in ecosystem services modelling and valuation. The activity would also tie in to the ongoing NSF funded LTER (Long Term Ecological Research) network and other sites rich in ecological data to help calibrate and test the models. Integrated historical data will provide baseline conditions and aid in model calibration. The models can also be linked into spatial arrays allowing spatially explicit landscape models to be constructed (cf. Costanza et al. 2002, Costanza and Voinov 2003) from the watershed up to the global scale (Boumans et al. 2004), enabling the concept of ecosystem services and their value to humanity to be effectively used in a number of decision contexts. For example, the results of this project will provide critical input to systems of payment for ecosystem services, like the one used in Costa Rica.

**Envisioning the Future: Need and Science**

There is a tendency in thinking about the future to simply extrapolate past trends, however, one of the lessons of history is that trends do not continue smoothly. There are turning points, thresholds and discontinuities that are impossible to predict from past trends. For instance, the dissolution of the Soviet Union, the Berlin Wall coming down, and the development of the Antarctic ozone hole are three examples.

What society has learned about the change process in various kinds of organizations and communities is that a necessary ingredient to move change in a particular direction is to have a
clear vision of a desired goal that is also shared by the members of the organization or community (Senge 1990, Wiesbord 1992, Wiesbord and Janoff 1995). The challenge for the current generation is to develop a shared vision that is both desirable to the vast majority of humanity is ecologically and economically sustainable. Within AIMES, this need for envisioning is great, since AIMES will directly address integrated analysis and modelling of the Earth System.

The development and vision of the C^4MIP activity will contribute towards understanding present and future impacts from existing and ongoing development of Earth System models (ESMs). The goal of an envisioning activity is to build upon appropriate ESMs to postulate plausible alternative futures (PAFs). These futures can be generated as the result of simulation modelling exercises, gaming, interactive discussions, or simply brainstorming. The plausible alternative futures that arise from such exercises can provide increasingly informed choices about goals for an organization or community. Historically, PAFs have been presented in narrative form in order to communicate with a broad audience (e.g., Costanza 2000). They also play a key role in integrative modelling by helping to structure scenarios to be run with the models (Boumans et al. 2002). Key questions for an AIMES envisioning component are:

1. What are some plausible alternative futures (PAFs) for the integrated Earth system with particular regard to interactions between the climate system and human welfare?
2. How do we assess the relative preference of PAFs to various segments of society?
3. How can PAFs be incorporated with integrated Earth system models?

Within AIMES, envisioning and the development of PAFs will be implemented in a number of ways, including (a) building envisioning into integrated Earth system modelling, (b) holding stand-alone workshops focused on generating a range of plausible futures or development of particular future visions; and (c) utilizing integrative tools such as gaming and new internet capabilities to test specific envisioning hypotheses within prototype Earth System Models (e.g., Digital Earth, Google Earth, Earth Portal, TimeMaP, etc).
We need a section that summarizes the key objectives of AIMES and how we plan to accomplish them. I’d like to see a section devoted to the impacts of climate change, increased air pollution and ecosystem impoverishment. This would precede and feed into the economic modelling component.

AIMES PROJECT ORGANIZATION AND MANAGEMENT

Organizational Structure of AIMES

Scientific Steering Committee
The AIMES Scientific Steering Committee (SSC) is responsible for providing scientific guidance to, and actively overseeing the development, planning and implementation of the AIMES project, including communication of ongoing AIMES activities and fostering the publication and dissemination of AIMES results. The AIMES SSC will encourage national governments, and regional and international funding agencies to support the implementation of core research and the achievements of AIMES goals through the provision of adequate support at national, regional and international levels. The SSC will also encourage collaboration between AIMES research and relevant activities of the sponsors and others, including integration with adjacent IGBP, WCRP, IHDP and ESSP projects.

International Project Office
The International Project Office (IPO) serves as the secretariat for AIMES, and administers the project on a day to day basis. The IPO is responsible for assisting the SSC in all aspects of its work, and collates and communicates information related to national and international AIMES research. The IPO works with the IGBP to secure resources for AIMES as an umbrella organization. It also ensures effective coordination with other activities of the IGBP and supports a data management and archiving system for the project. The IPO will also keep a record of AIMES products, specifically:

- Syntheses and review papers
- Workshop reports
- Books and book chapters
- Special journal editions
Data and model output

These will be made freely available on the AIMES website, wherever possible. The IPO is located in the USA and is funded by the National Science Foundation.

Implementation

Implementation of much of the research activities described in this Plan will be overseen by an activist and member-responsible SSC, together with the IPO. Lead SSC members establish steering groups on relevant topics for which there is a clear need for international coordination. They will often be established jointly with other projects to allow the full scope of the topic to be covered.

Recognition of Research by AIMES

The goal of AIMES is to provide a framework to encourage the fullest participation and collaboration of multi-national, regional and national efforts in its scientific activities. It does not impose a rigid template on the nature of these efforts. However, some recognition procedure (often called ‘endorsement’) is necessary so that (1) the AIMES SSC knows what research is being conducted under the AIMES label, (2) research carrying the AIMES label is within the science areas defined in the AIMES Science Plan and Implementation Strategy, and (3) such research conforms to the scientific principles and ideals outlined in this Plan.

Principle Investigators and national/regional groups can submit their projects for approval by the AIMES SSC through the IPO.

Flowing from recognition as an AIMES project are the following benefits and responsibilities; the following are only intended as a guide and are not a set of regulations. They have been adapted from the practice of the GLOBEC and SOLAS SSC.

Benefits

- Provides the opportunity for participation in the development, planning and implementation of a collaborative international science programme.
- Adds to the scientific value of planned work by providing complementary information; for example, by widening the range of studies and extending their spatial and temporal coverage.
- Promotes rapid communication of ideas and results through meetings and publications.
• Makes available modelled and measured/observed datasets and develops a common data policy.
• Enables close working links with other relevant international programmes and studies.
• Gives the opportunity for participation in model and model-data fusion, development and intercomparison activities.

Responsibilities
• Acceptance of general principles and goals outlined in the AIMES Science Plan.
• Carry out a programme in general accordance with the relevant aspects of the AIMES Science.
• Participation in the activities of the programme through its management bodies, and by assisting in its planning and development as a whole.
• Make (model and observed) data collected within the programme available to the wider community.
• Acknowledge links with AIMES in the products of the project (e.g., acknowledgement in scientific papers).

Links to Related Programmes and Activities
AIMES is presently sponsored by IGBP and develops cooperative activities to take advantage of the unique expertise of the different core projects as well as ESSP projects to avoid unnecessary duplication. AIMES will collaborate with other projects, using an integrative approach to Earth system analyses and modeling that focuses on the five primary themes outlined in Section 7 of this Plan.

For process and parameterization implementation and development activities, AIMES will coordinate with the appropriate activities of IGAC, iLEAPS, GLOBEC, SOLAS, IMBER and GLP. It will also contribute to, and initiate IGBP Fast Track Initiatives (e.g., on Fire). In aspects of regional/global interactions, AIMES will collaborate with Integrated Research Studies (e.g., MAIRS) and other projects as appropriate. AIMES will also initiate activities in regional/global interactions (e.g., an integrated study in northern high latitudes) in collaboration with iLEAPS, GLP, LOICZ, GLOBEC, GCP, PAGES and regional projects (e.g., NEESPI). For applied Earth
system Science activities, AIMES is collaborating with the WCRP/WGCM and IPCC on the next generation Earth system models, as well as the INI. Applied Earth system science will be strongly focused on utilizing scientific understanding from end to end (e.g., from process to management applications). AIMES will collaborate with several institutions (e.g., MISTRA) to promote Integrated Earth System Science and Modeling. Integrated Earth system modeling will remain the fore-front of AIMES activities, following the lead from GAIM for activities including C\textsuperscript{3}MIP and GEIA. Finally, AIMES may form joint activities with related projects and activities of the IGBP, IHDP or WCRP and others to support implementation of AIMES research.

**Communication**

Communication within the AIMES scientific community to other groups, both scientific and beyond will be important aspects of AIMES. The AIMES website (http://www.aimes.ucar.edu) will be a central source of information, including the Science Plan and Implementation Strategy, science highlights, publications, contacts, internal AIMES documentation and details of activities. The site will also be a gateway to other data centers and activities. Communication within the international AIMES community and interested scientists will be facilitated through email bulletins and e-newsletters.

Planning, implementation and synthesis of AIMES research will be carried out through workshops, focused scientific conferences and symposia worldwide. The philosophy of AIMES is to encourage broad national and international representation in all activities, and to hold its meetings within the regions that contribute to AIMES, to encourage wide participation. The results of AIMES will primarily be published as scientific papers in international journals. In addition to the scientific literature, synthesis documents, including visually rich, easy to understand reports, will be produced periodically and widely distributed. Thus, AIMES research output will be accessible to a broad audience, in particular the policy and resource management communities, as well as to interested members of the public. Other outreach activities (e.g., press releases, publications in the popular press, contributions to the public understanding of science, educational activities, etc.) will be encouraged.
Education and Capacity Building

As noted earlier in the document, AIMES has a particular educational role to play (particularly with regards to the Young Scientist’s Network; see section 6.1 above) and not only brings together a range of academic disciplines (e.g., biology, chemistry, physics, social theory, etc) but must also involve scientists working in atmospheric, oceanic, terrestrial and human dimensions domains in integrated studies. Such multi-interdisciplinarity provides large educational challenges. The communication strategy outlined above will play an important role in this educational process.

Capacity building will be initiated in developing regions through a variety of workshops, both actual and virtual. The AIMES SSC will strongly encourage intensive courses and institutes for graduate students and other younger workers, taught by world experts and held worldwide. Specific initiatives such as a follow-on modelling institute, in collaboration with START are under discussion. It is intended for Ph.D. students from any country working on specialised topics of AIMES science, with the aim of providing a comprehensive overview of Earth system modelling, particularly with regard to the interactions between biogeochemistry, climate and human systems. This kind of institute will enable the young scientists to appreciate how their doctoral and post-doctoral work fits into the larger canvas of AIMES, and indeed, international global change science. We will collaborate with START, IAI and APN, so that their Fellowship schemes and other mechanisms can be used for capacity development, as well as with similar programmes.

Funding will be sought from a wide range of international sources to maximise participation from across the globe in these activities.
LITERATURE CITED


THE EARTH SYSTEM ATLAS

Provided by
Stephen J. Reid & Dork Sahagian
Lehigh University

Introduction
After several years of discussion and planning, the Earth System Atlas is finally taking the next steps beyond the initial prototype. With a newly formed editorial board, contacts with several funding sources and prospects for short and long-term funding, there is finally some hope that the Atlas will soon be paving the way of a new mode of data publication, melding data archiving and journal publication to give a data community a bone fide publication outlet, while enhancing the reliability and utility of existing data sets.

A Director for the Atlas
This June, Stephen Reid became the founding director of the Earth System Atlas. Reid has spent most of his career manipulating and analyzing data. Since being awarded his Ph.D. in Atmospheric Physics in 1994, he has worked at the Norwegian Institute for Air Research managing their NADIR data base used to collect and display data from a number EU-supported European experiments, and at the NOAA Aeronomy Laboratory in Boulder Colorado where he performed research on NASA airborne data sets and satellite data. From 2002 – 2005, he served as an Associate Program Director in the NSF’s Division of Atmospheric Sciences, assisting in the Climate Dynamics, Paleoclimate and Atmospheric Chemistry Programs.

Initial stages
Members of the community have now been approached to serve either as members of the Atlas Steering Committee, or as a member of the Editorial Board which will be responsible for selecting suitable reviewers for the data sets included in the Atlas.

The following individuals have been approached:

Steering Committee
Warren Washington, NCAR, U.S.A.
Mario Molina, MIT, U.S.A.
Ann Henderson-Sellers, WCRP, Switzerland
Ruth DeFries, UM, College Park, U.S.A.
Wolfgang Cramer, Potsdam, Germany
Jon Foley, UW-Madison, U.S.A.
Ferris Webster, U. Delaware, U.S.A.
Michael Mann, Penn State, U.S.A.
Diane Liverman, Oxford University, U.K.
Keith Alverson, GOOS, U.S.A.
Michel Meybeck, Université P.M. Curie , France
Robert Scholes, CSIR, South Africa
Colin Prentice, University of Bristol, U.K.
Dork Sahagian, Lehigh University, U.S.A.
Ken Caldeira, LLNL, USA
Larry Mayer, UNH, USA

Editorial Board (incomplete)
Claire Granier, CNRS, France
Bob Costanza, UVM, USA
Navin Ramankutty, U. Wisconsin – Madison,
Ruth DeFries, UM, College Park, U.S.A.
Sandy Harrison, University of Bristol, U.K.
Inez Fung, Berkeley, U.S.A.
Charles Vorosmarty, UNH, U.S.A.
Martin Jacobson,
George Kiladis, NOAA, U.S.A.
Darin Toohey, U. Colorado, U.S.A.
Natalie Mahowald, NCAR, U.S.A.
An initial batch of data sets (between 10 and 20 in number) are already being collected from various disciplines to test the peer-review process, and to serve as a demonstration of the Atlas’ graphical interface. Each data set is accompanied by a document describing the history of each data set (i.e., observational or model output, post-processing, known issues with data, etc.), which will aid the reviewers in their tasks. This will also provide the basis for the targeted explanation that will accompany each data set when it becomes available to the end user.

The existing Atlas prototype interface, currently handling only a few initial data sets, is to be expanded to incorporate the recent data acquisitions. While the initial prototype now available on line shows some of the power of the Atlas, the ultimate design of the web-browser interface is envisioned to be more along the lines of Google Earth; this will provide a highly versatile tool for visualizing and manipulating peer-reviewed scientific data sets, something that neither Google Earth nor anyone else can offer. An example of how Google Earth software may be applied to scientific analysis is being explored in the U.K. by the University of Bristol (http://lovejoy.nerc-essc.ac.uk:8080/Godiva2/#). Rather than reinventing technical wheels, the Atlas will build on capabilities already available.

**Summary of Unique Features**

We have identified some unique features to help us market the Earth System Atlas and attract funding from Federal agencies and other sources.

1. *All data sets will be peer-reviewed*
   
   Review process: all data sets to be included in the Atlas will be peer reviewed to ensure data quality, documentation of collection methodology, and assessment of comparable related data sets. The user will know why a particular data set was selected, how the data were collected, for what applications the data would be appropriate, and what other alternative data sets are available. This aspect of the Atlas renders I more like a journal than merely a whiz-bang data viewing technology, and provides scientific credibility to the Atlas contents, while giving the data community a proper publication outlet for data sets themselves, a current lacking in the literature.

2. *Citation of Data in the Atlas*
   
   The Earth System Atlas will be the first formal means for publishing data sets in a citable format in the United States. Data sets will have DOI designations and will be searchable in GEOREF, Web of Science, and other indices, and will serve just like a publication in any other journal. The difference is that data sets will be publishable in their own right rather than just appended to a scientific paper. Publishing a data set in the Atlas will count as a real publication, and we will encourage publication of additional scientific papers based on those data in disciplinary journals. It will give the data community a much appreciated formal publication outlet for their data results. By using the Atlas, not only will the data contributors benefit, but the entire community will gain new insights from the juxtaposition of their own and other data sets through the various data manipulation tools provided in the Atlas. These should lead to additional publications that would not have otherwise been possible.

3. *Targeted explanations*
   
   Each data set (and the maps to be generated from each) will have explanatory text included that is tailored to the needs of the target audience, making the language and content suitable for the scientific community, the lay public, policy makers, and K-12 school children. These explanations will be written by appropriate experts in each field.

4. *Data manipulation and display*
   
   The software which delivers the Atlas to the world will provide to a large array of statistical algorithms, enabling the user to process and combine data sets in a wide variety of ways, and then display the results.
with a high degree of graphical freedom. This will make the Atlas a scientific tool which may be employed for serious exploratory research, helping to trigger new ideas. The Atlas will also help to identify gaps in existing data sets and point the way for future observational and modeling activities.

The First Year
We are currently in the final negotiation phase for a small grant for exploratory research (SGER) from the National Science Foundation. Using this, we envisage that during the first year of Atlas operation, in order to produce a “proof of concept” important to funding agencies as well as electronic journal databases, we will:

- Appoint a steering committee and a team of data reviewers with combined expertise spanning the full range of the earth systems (already underway).
- Assemble an Editorial Board to handle selection of reviewers for the initial 10-20 existing data sets to be included in the Atlas (essentially a test of procedures) (already underway)
- Develop a comprehensive table of contents for the Atlas;
- Compile and assess an inventory of existing data sets for the prototype phase;
- Write and produce explanatory text for each data set in consultation with primary authors and data providers. Four versions will ultimately be customized for the scientific, lay public, policy, and K-12 educational communities;
- Develop derivative attributes for each data set as appropriate;
- Write explanatory text for initial Atlas products;
- Compile reference list for displayed products;
- Develop initial set of web-based Atlas data interface tools, including presentation, navigation, superposition/comparison;
- Begin to work with the relevant research communities to promote research to fill gaps in data records.
- Publish paper on initial Atlas development.
- Secure long-term funding by demonstrating not only the technical power of the Atlas, but also the process of peer review that sets it apart from any other data visualization platform.

Longer-Term Goals
Once the beta version of the Atlas is operational and we have secured a longer-term commitment for funding in order to expand the Atlas into a fully-fledged data repository and visualization tool, we will add full-time staff for data coordination, web tools and interface design, and science writing/education and outreach. At that point, additional means of financial support will be explored, including ads (value based on hit count), foundations, and other public and private sources.

Agriculture, Development, and Nitrogen

_A problem of too little or too much_

**Introduction**

The last 40 years have seen an extraordinary change in the global nitrogen cycle. As recently as the 1960s, nitrogen availability on Earth was controlled by natural processes, but the human creation of synthetic nitrogen fertilizer and the release of nitrogen from fossil-fuel combustion now match the natural rate of formation of reactive nitrogen on the planet’s landscape. While the fossil-fuel source is important in many industrial regions, agriculture is the major driver of change globally. Synthetic nitrogen fertilizer has been an essential component of the Green Revolution. Most of the human population is now absolutely dependent on this fertilizer for food sustenance, and 70% of the protein in the average person on Earth is composed of nitrogen from synthetic fertilizer. Nitrogen fertilizer and the Green Revolution it has fueled have greatly reduced hunger on the planet, particularly in Asia. The rate of change is incredible, and half of the synthetic nitrogen fertilizer ever used on Earth has been used in the past 15 years.

Two major challenges now face human society. First, much of the planet has still not seen the benefits of nitrogen fertilizer and the Green Revolution. And second, nowhere on Earth is nitrogen yet used in a sustainable way, and this is the “Achilles’ Heel” of the Green Revolution. The use of nitrogen is imbalanced, with industrialized countries suffering pollution problems from too much nitrogen and low-income countries having a shortage of nitrogen that constrains food production. The goal of the N2007 Symposium is to address these two challenges in an integrated manner. The meeting will bring together some of the world’s best nitrogen scientists with development experts to build a vision for revising the Green Revolution and discuss new trends in the global agriculture such as organic production and genetically modified products into a more sustainable process while bringing it to the most needy populations.

_Motivation_  

**Too Little Nitrogen:** Almost one billion people, or 15% of the world’s population, suffer from hunger and malnutrition. Nearly 6 million children die each year as a result: 10 children every minute. The State of Food Insecurity in the World (2005) reports “many of these children die from a handful of treatable infectious diseases including diarrhea, pneumonia, malaria and measles. They would survive if their bodies and immune systems had not been weakened by hunger and malnutrition.” Hunger contributes greatly not only to mortality but also poverty, illiteracy and disease in low-income countries of the world. The prevalence of widespread hunger and malnutrition is due to a number of factors. An important one (and one that can be addressed) is that the lack of nitrogen to enable food demand to be met by food production. This focus on nitrogen-limitations related to food production is in support of the first of the Millennium Development Goals: to eradicate extreme poverty and hunger by reducing by half the proportion of people living on less than a dollar a day, and the proportion of people who suffer from hunger.

Nitrogen is one of the prime factors limiting agricultural production, and so these goals cannot be met without bringing more synthetic nitrogen fertilizer into the world’s less affluent countries. To date, these countries – particularly the least developed ones – have not benefited from the Green Revolution. Per-capita use of nitrogen fertilizer in the world’s low-income countries averages only one-fourth of that of industrial nations. In the least developed countries, per-capita use of nitrogen is 3.5-fold less than in the average low-income nation and 12-fold less than in the industrial world.
Nitrogen is an essential component of any plan for reducing world hunger, poverty, and disease. However, the global experiment with increasing the supply of nitrogen is a recent phenomenon, and the industrialized nations and developing nations have not yet developed sustainable approaches for nitrogen use. When used in excess, nitrogen becomes an important pollutant. This duality is one of the major challenges that humanity has to face now and in the future if we want to ensure environmental sustainability, another of the stated Millennium Development goals. In concert with bringing more nitrogen to the world’s poorest regions, we must develop approaches for using nitrogen with less environmental harm throughout the world.


Too Much Nitrogen: In some regions of the world, particularly in industrialized countries of the Northern Hemisphere, there is an excess of nitrogen that results in a cascading series of effects on both ecosystem and human health. The First, Second and Third International Nitrogen Conferences devoted substantial attention to these issues. While the science underpinning these effects will be updated, the focus on nitrogen-excess regions will be on what policy tools/approaches have been successful in decreasing the negative impacts of anthropogenic nitrogen in the environment, what policy tools have not been effective, and how this knowledge can be used to help the development of sustainable nitrogen use in nitrogen-deficient areas. Nitrogen pollution also is major threat to human health. Tropospheric ozone production that nitrogen gases catalyze aggravates asthma and many other respiratory diseases; in the United States alone, this leads to an estimated 20,000 premature deaths each year. Fine nitrogen particles in air lead to both cardiovascular and respiratory diseases. Nitrate in drinking water is a carcinogen and also affects reproduction and development. In addition, nitrogen pollution may have a series of indirect health effects, by for example increasing pollen production and therefore allergies, or by increasing the populations of insects that are disease vectors.

Nitrogen in Tropical Systems: Besides the social and economic aspect, nitrogen also plays a central role in natural systems, since as an often-limiting nutrient it regulates productivity and carbon acquisition and the composition of plant and animal communities. Most of the studies regarding nitrogen dynamics in natural ecosystems were developed in temperate regions of the
world. Conclusions from these temperate systems may not apply in tropical ecosystems, mainly because tropical ecosystems often are much less limited by nitrogen than temperate systems. This may make the tropical systems much leakier and less retentive of nitrogen. Understanding the differences in nitrogen cycling between temperate and tropical ecosystems is essential if we are to better manage nitrogen in the tropics. Since so many of the low-income nations of the world are in the tropics, this context is a critical background element of N2007.

Another complexity of the nitrogen issue is that while low-income countries have a shortage of nitrogen for food production, they also at the same time have a lack of proper sanitation for human wastes, so water bodies in these countries are being enriched in nitrogen, jeopardizing even more their limited water supplies.

Goals and Agenda for N-2007
The complex problems of nitrogen cannot be tackled individually, but rather the solutions must engage a large community that encompasses a broad spectrum of professionals. For N2007, we will invite not only participants that are concerned with particular aspects of nitrogen cycling but participants from the policy, development, and engineering communities that can share their expertise to help build a sustainable future. The N2007 meeting is the perfect venue to discuss these issues and to find common ground to begin to find answers and solutions to alleviate world hunger with minimal environmental harm. N-2007 will build an agenda for how to better manage nitrogen across our planet. We will develop some specific goals to reach by 2025, set in the context of the goals of the United Nations Millennium Development Program.

To achieve these goals, we will use a mixture of plenary lectures, short workshops, and poster sessions. The plenary lectures will be used to inspire and challenge the meeting participants. Detailed scientific presentations will be given in a series of concurrent workshops. Posters will be equally important in the N2007 conference and will be grouped by topic area and with plenty of time for interaction among the presenters. The workshops will be the prime focus of the meeting, with participants interacting across disciplinary lines to consider approaches for closing the loop on agriculture, development, biogeochemistry and nitrogen. Some examples of potential workshop topics include:

- Understanding differences between N biogeochemistry in tropical and temperate systems
- Nitrogen biological fixation in natural and agricultural systems
- Nitrogen and carbon sequestration
- Nitrogen in aquatic systems and eutrophication
- Getting nitrogen into agriculture in low-income countries
- Reducing nitrogen losses from agricultural systems
- Developing appropriate sewage technologies for low-income countries
- Applying technologies for reducing nitrogen pollution from animal wastes
- Nitrogen and biofuel production
- Nitrogen and human health
- Global food trade and nitrogen

Conference Products
We will publish workshops results, general conclusions, and statements in the web site of the International Nitrogen Initiative, which guarantees free global access, with much less delay than has traditionally been possible. Selected presentations well be invited to submit their material
to a peer-review journal. Indefinite future access to these materials will be provided by posting them to D-space publication space at Cornell University.

**Intended Audience**
Overtime, the attendance at the International Nitrogen Conferences has grown increasingly diverse in terms of professional discipline. N-2007 will be no different. We expect a strong representation from both the energy and food production industries, as well as from NGOs, and United Nations agencies (FAO, UNEP, WHO). This broad-based attendance will help insure that post-conference distribution of conference products will also be extensive.

**Venue**
The conference will be held October 1-5, 2007 in the Costa do Sauípe complex, which is located 110 km north from the city of Salvador, capital of the State of Bahia. Brazil was chosen because it is an important country in terms of both food/feed production (soybean, beef) and because of the large extent of intact natural ecosystems. The State of Bahia, which is the capital of Salvador was chosen because this is one of the most beautiful coast of Brazil, but it is also a typical poor region of Brazil with low-nitrogen input.

**The Scientific Committee**
- Amy Austin (University of Buenos Aires and IFEVA-CONICET, Argentina)
- Carlos Nobre (IGBP, Brasil)
- Cliff Duke (Ecological Society of America, EUA)
- Ernesto Medina (Instituto Venezolano de Investigaciones Científicas, Venezuela)
- James N. Galloway (University of Virginia, EUA)
- Jan Willem Erisman (Energy Research Center of the Netherlands)
- Jerry Melillo (Woods Hole Marine Laboratory, EUA)
- Julio Baisre (Ministerio de la Industria Pesquera, Cuba)
- Kilaparti Ramakrishna (UNEP, Kenya)
- Luc Maene (International Fertilizer Association, França)
- Luiz Antonio Martinelli (General Coordinator- University of São Paulo, Brasil)
- Mateete Bekunda (Makerere University, Uganda)
- Reynaldo Luiz Victoria (University of São Paulo, Brasil)
- Robert Howarth (Cornell University, EUA)
- Vinicius Moreira (Louisiana State University, EUA)
- Zucong Cai (Chinese Academy of Sciences, China)

**The Local Committee**
- Epaminondas S. B. Ferraz – CENA/USP ([epferraz@cena.usp.br](mailto:epferraz@cena.usp.br))
- Jean Pierre H.B. Ometto - IGBP ([jpmetto@cena.usp.br](mailto:jpmetto@cena.usp.br))
- Luiz Antonio Martinelli – CENA/USP ([martinelli@cena.usp.br](mailto:martinelli@cena.usp.br))
- Plínio B de Camargo – CENA/USP ([pcmargo@cena.usp.br](mailto:pcmargo@cena.usp.br))