IGBP Report 59

Developing an Integrated History and Future of People on Earth (IHOPE): Research Plan

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IHOPE is led by the international project Analysis, Integration and Modelling of the Earth System (AIMES). AIMES is a core project of the International Geosphere-Biosphere Programme. IHOPE is co-sponsored by PAGES and IHDP.

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Lead Contributing Authors:

K. A. Hibbard, R. Costanza, C. Crumley, S. van der Leeuw, and S. Aulenbach, J. Dearing, J. Morais, W. Steffen, Y. Yasuda.

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Box 50005
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Ph: +46 8 16 64 48
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IHOPE International Project office
Stockholm Resilience Centre
Stockholm University
Kräftriket 2B
SE-106 91 Stockholm, Sweden
Ph: +46 8 674 70 00

Web: www.stockholmresilience.org/ihope

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Background

Historical narratives are traditionally cast in terms of wars, the rise and fall of civilisations and specific human achievements, leaving out the important ecological and climate contexts that shaped and accompanied such events. It is now widely recognised that current Earth system changes are strongly associated with changes in the coupled human-environment system, making the integration of human history and Earth system history a timely and important task. Until recently, however, there have been few attempts to integrate historical information across fields of study, and separate methods of investigating and describing these histories have emerged due to a lack of interaction between academic communities. Bridging these communities and their findings will be an essential step towards understanding the factors contributing to global change and towards developing coping and adaptation strategies for the future. (Fig. 1)

The overarching goal of the *Integrated History and future Of People on Earth* (IHOPE) project is a rich understanding of the interactions between environmental and human processes over the past hundred or so millennia on Earth. Our main objective is to use new and existing data sources to produce an integrated historical account of changes in climate, atmospheric chemistry and composition, ecosystem distribution, material and water cycles, species extinctions, land-use systems, human settlement patterns, technologies, patterns of disease, patterns of language and institutions, conflicts and alliances, and other variables. To achieve this ambitious goal, it will be necessary to create a framework that can be used to integrate perspectives, theories, tools and knowledge from a variety of disciplines spanning the full spectrum of social and natural sciences and the humanities.

A key step toward the development of such an integrated history took place in June 2005 at the IHOPE-Dahlem conference in Berlin, Germany. IHOPE-Dahlem assembled an interdisciplinary group

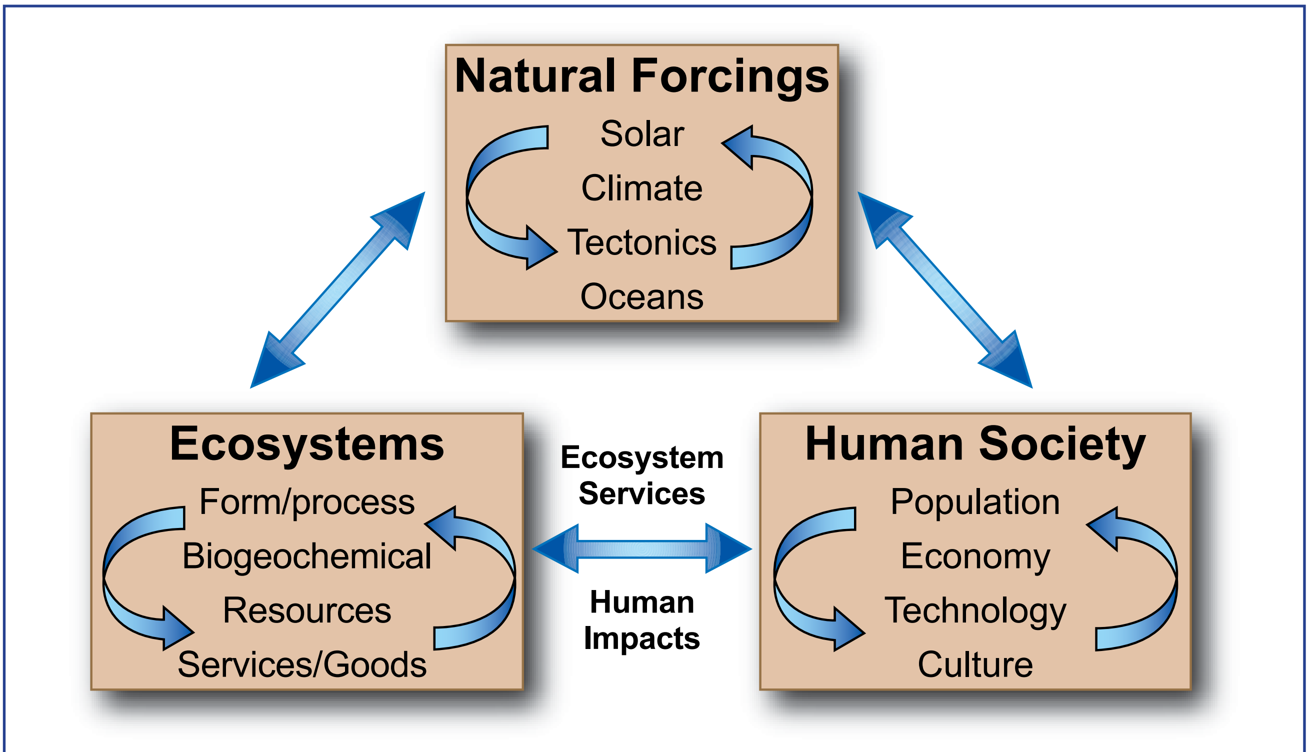

Figure 1. Integrating research across a broad range of disciplines and communities is an essential step towards understanding the factors contributing to global change and towards developing an integrated history. Reprinted from Dearinget *al.*, (2006)

of 40 top researchers from a range of natural and social science disciplines, with the goals of identifying how humans have responded to and impacted their environments over millennial, centennial and decadal scales, as well as providing a glimpse of the future of the global human-environment system. Results from IHOPE-Dahlem are now published in a book, *Sustainability or Collapse? An Integrated History and Future of People on Earth*, from MIT Press (Costanza *et al.*, 2007) (Fig. 2). The overall conclusion from IHOPE-Dahlem was that human societies respond to environmental (e.g., climate) signals in a variety of ways, including coping, adaptation, collapse or failure, migration and creative invention through discovery. Extreme drought, for instance, has likely triggered both social collapse and the development of ingenious water management and irrigation systems.

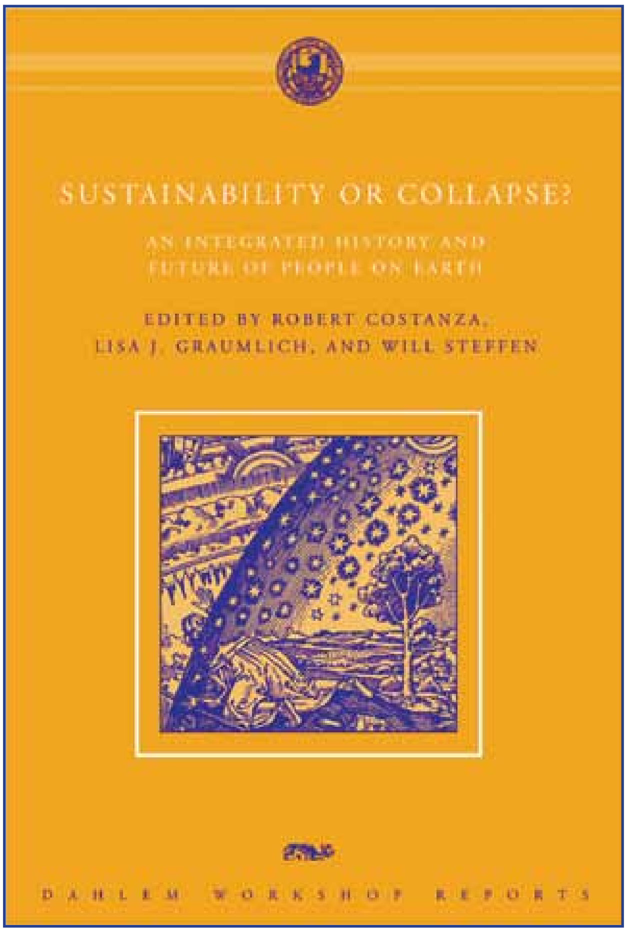

Figure 2. Book cover of “Sustainability or Collapse? An Integrated History and future Of People on Earth”, by R. Costanza, L. Graumlich, and W. Steffen (eds.), published by The MIT Press (2007).

Following the IHOPE-Dahlem Conference, an international symposium on the Sustainability of Islands and Resource-Recycling Societies was sponsored by the Japanese Ministry of Environment and Technology in October 2005 through the Environment, Economies, Civilization and Global Change Program (EECGP). The participants explored sustainability challenges to Mayan, Monsoon Asia, Pacific Island and Atlantic Island civilisations, future models for sustainable living and potential technologies for resource recycling. Several participants from IHOPE-Dahlem, as well as experts in island-nation archaeology from Europe, India, the US and Asia contributed to this symposium.

Finally, this research plan is the product of several IHOPE participants who convened at the Swedish Academy of Sciences in Stockholm (participants listed at the end of this document). Long-term goals as well as overarching research questions and an implementation strategy were mapped out with further contributions solicited from a broader community including the international programmes (e.g., the International Human Dimensions Programme (IHDP) and the Past Global Changes (PAGES) project of the International Geosphere-Biosphere Programme (IGBP).

Long-Term Goals of the IHOPE Project

The IHOPE project identifies three long-term goals:

1. **Map the Earth's integrated record of biophysical and human system changes over the past millennia.** Higher temporal and spatial resolution will be possible in more recent periods of analyses (e.g., 100–2000 years before present (YBP)). The range for longer-term analyses will depend on the region. For example, Australian history might include the past 60,000 years, and in southern Europe, the past 20,000 years could cover colonisation since the Last Glacial Maximum (LGM). (Fig. 3, Table 1)

2. **Test human-environment system models against the integrated history to better understand the socio-ecological dynamics of human history**. How well do various models of the

Figure 3. Mulga woodlands of Australia can exist in a grass-rich state that supports sheep herding (left), or a shrub-dominated state of no value for sheep grazing (right). Either state can be resilient depending upon management. From Folke *et al.*, (2002). Photos: D. Tongway

Ecosystem type	Alternative state 1	Alternative state 2
Freshwater systems	Clear water Benthic vegetation Olgotrophic macrophytes and algae Game fish abundant	Turbid water Blue-green algae Cattails and blue-green algae Game fish absent
Marine systems	Hard coral Kelp forests Seagrass beds Fish stock abundant	Fleshy algae Urchin dominance Algae and muddy water Fish stock depleted
Rangelands	Grass structure	Shrub structure
Forests	Pest outbreak Pine trees dominate Birch-spruce succession	No pest Hardwood plants dominate Pine dominance
Arctic systems	Grass dominated	Moss dominated

Table 1. Examples of documented shifts in states in different kinds of ecosystems. Adapted from Folke *et al.* (2002).

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 described by global biogeochemistry?

3. **Project, with more confidence and skill, options for the future of humanity and Earth systems.** These projections will be based on models that have been tested against the integrated history and with contributions from the full range of participants. (Fig. 4)

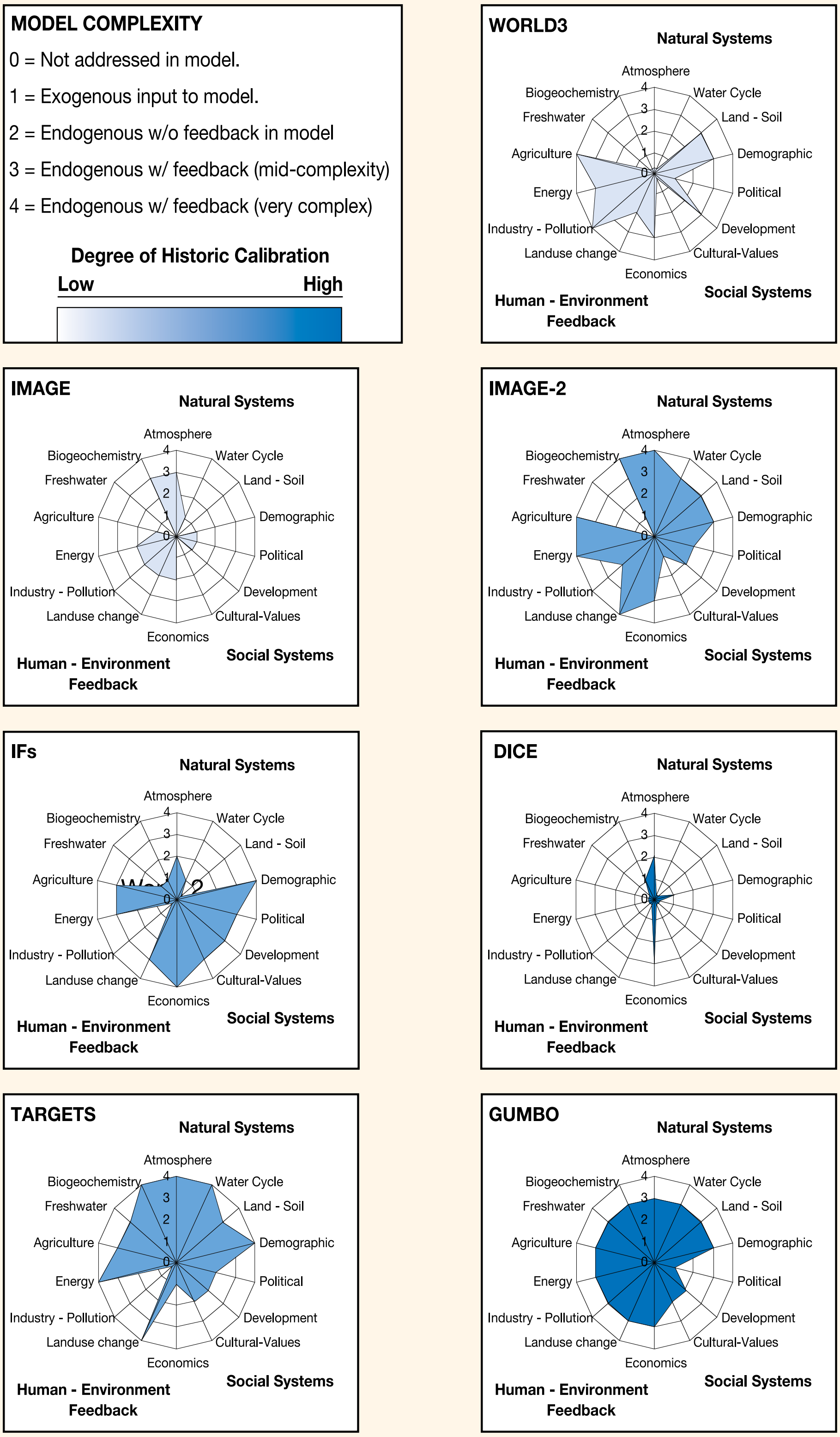

Figure 4. Amoeba diagram of complexity with which Integrated Global Models (IGMs) capture socio-economic systems, natural systems, and feedbacks.

Figure reprinted from Costanza, R., Leemans, R. Boumans, R. and Gaddis, E. Integrated global models. p 417-446 in R. Costanza, L. Graumlich, and W. Steffen (eds.), Sustainability or Collapse? An Integrated History and Future of People on Earth, MIT Press (2007).

IHOPE in the Global Change Community

IHOPE has strong links with the international global environmental change community, and in particular with different projects of IGBP and IHDP, such as AIMES, PAGES, and the Global Land Project (GLP). The Analysis, Integration and Modelling of the Earth System (AIMES) project is improving understanding and quantification of biogeochemistry and biophysical processes in global climate system models, and integrating human processes into a new generation of coupled human-in-environment Earth system models (Fig. 5). AIMES is currently hosting the administrative function for IHOPE, with co-sponsorship from PAGES and IHDP, through an International Project Office (IPO) based in Stockholm, Sweden. (www.stockholmresilience.org/ihope)

PAGES, an IGBP core project, focuses on regional-scale climate variability of the past 2000 years and beyond (e.g. PAGES Focus 2: Regional climates and modes of variability) and addresses the long-term interactions between past climate, other ecological processes and human activities in Focus 4 (Past Human-Climate-Ecosystem Interactions). An emphasis of this PAGES component lies in comparing regional-scale reconstructions of ecological and climatic processes, from natural archives, documentary and instrumental data, with evidence on past human activity derived from historical and archaeological records.

Strong connections also exist with the Global Land Project co-sponsored by both IGBP and IHDP, and with themes of the entire IHDP programme itself. IHOPE will work to maximise the synergies with these and other global change projects. IHOPE is thus an activity of the entire global environmental change (GEC) community, including the Earth Systems Science Partnership. In addition to the existing global environmental change communities, IHOPE reaches out to several additional research communities, including environmental historians, archaeologists, sociologists, psychologists and others, which have not thus far been involved in GEC research. Thus, the broad range of IHOPE 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), presenting an exciting opportunity for IHOPE be a shared activity of the entire global change community.

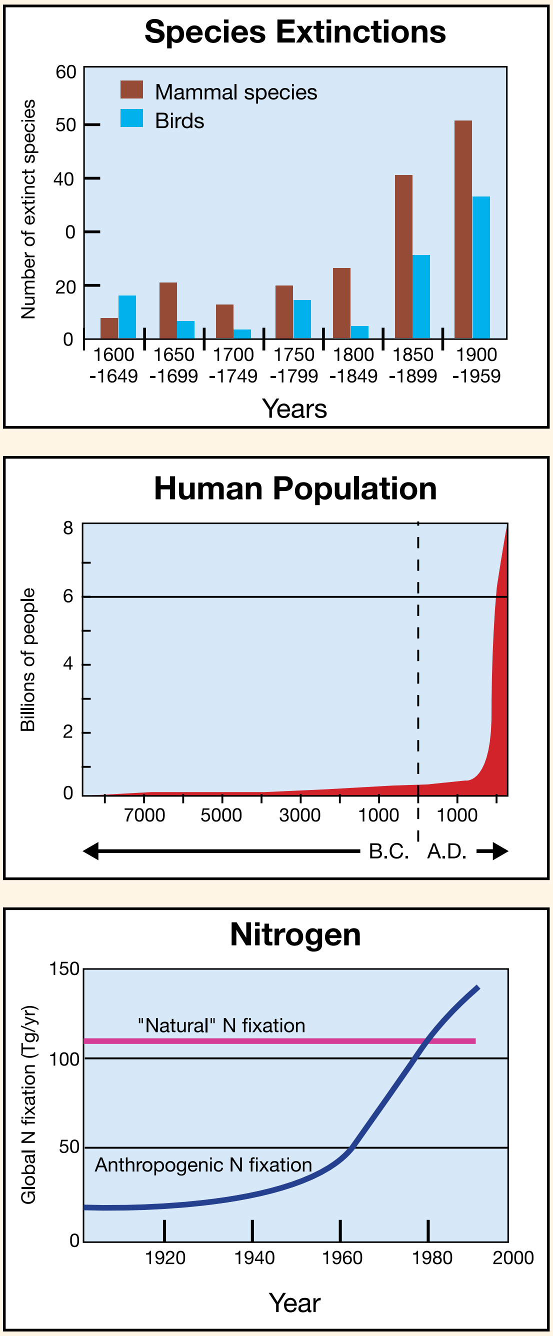

Figure 5. The challenge: sustainable management of an ever-changing planet. Figures adapted from Millennium Ecosystem Assessment, 2005

The Research Need

Human systems and Earth systems are intimately linked in ways that we are only beginning to appreciate (van der Leeuw, 1998; Redman, 1999; Steffen *et al.*, 2004; Diamond, 2005; Kirch 2005). An integrated history from IHOPE will provide a rich picture of how (and why) the planet and human societies have changed over time (Fig. 6). IHOPE seeks to unravel Earth system changes to understand, in one direction, the importance

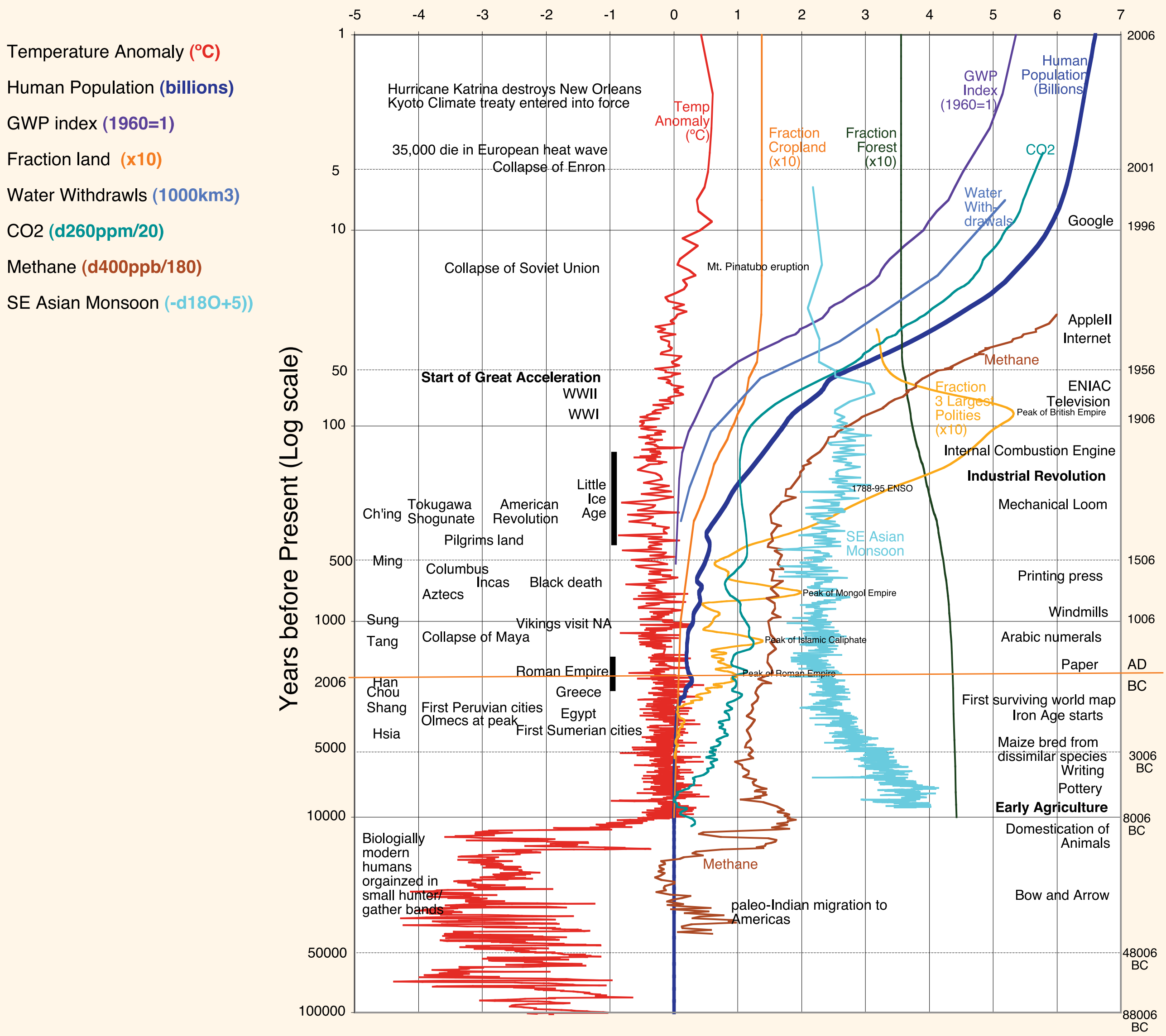

Figure 6. Human and environmental change/interactions have always occurred together and some of these parallel developments are illustrated in the figure (independent datasets; causation is not specifically discussed). The figure shows that the development of civilisation has occurred against a background of constant environmental variability. The environment and its dynamic processes are always a factor in human decision making and the evolution of societies. The challenge for IHOPE is drawing the correct conclusions about the reciprocal impacts of the evolution of human and environmental systems from the historical and palaeo environmental narrative.

Reprinted from Costanza R, Graumlich LJ, Steffen W, Crumley C, Dearing J, Hibbard K, Leemans R, Redman C, and Schimel D. (2007) Sustainability or Collapse: What Can We Learn from Integrating the History of Humans and the Rest of Nature? AMBIO: *A Journal of the Human Environment*: 36:522-527.

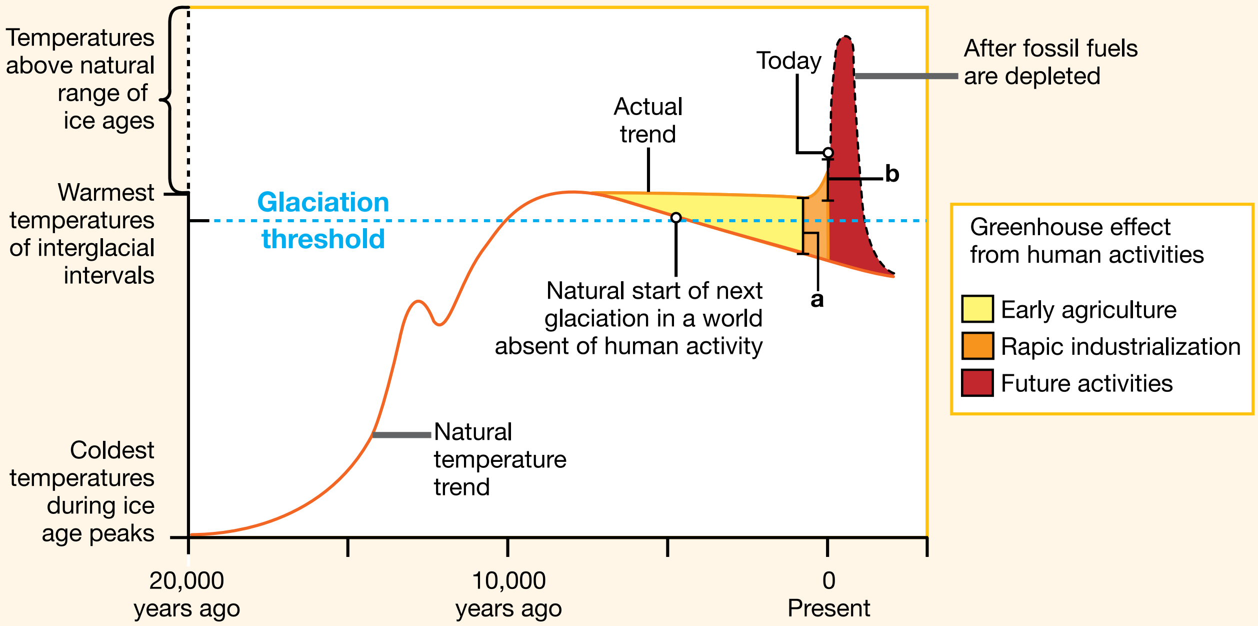

Figure 7. Greenhouse effect from human activities may have warded off a glaciation that otherwise would have begun about 5000 years ago. Early human agricultural activities produced enough greenhouse gases to offset most of the natural cooling trend during pre-industrial times (yellow), warming the planet by an average of almost 0.8 degrees Celsius. That early warming effect (a) rivals the 0.6 degrees Celsius (b) warming measured in the past century of rapid industrialisation (orange). Once most fossil fuels are depleted and the temperature rise caused by greenhouse gases peaks, the Earth will cool toward the next glaciation - now thousands of years overdue. Ruddiman (2005).

Figure credit: Lucy Reading-Ikkanda for *Scientific American* Magazine

of environmental dynamics on human life and the evolution of society and, in the other direction, how human activities contribute to the observed changes in Earth system dynamics (e.g., chemical, physical, biological) as seen in the geological record. 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. Other palaeoscientists argue against Ruddiman by challenging the analogy with data from previous interglacials and through carbon cycle budgeting and modelling work (e.g., Joos *et al.*, 2004; Broecker and Stocker, 2006). The insight, data and models generated from the IHOPE activity by environmental historians, archaeologists, ecologists, modellers and palaeo-environmental and palaeo-climate scientists 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. (Fig. 7)

On the following pages, we have summarised a list of general and 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.

Overarching Questions for IHOPE

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

1. What are the key socio-ecological interactions from an integrated history that provide insight into future options?

2. What are the complex and multiple interacting processes and scales that steer the emergence, resilience, sustainability or collapse of coupled socio-ecological systems? A part of this question is to understand, derive and quantify the relative contributions of humans as causal agents.

3. What is needed to evaluate alternative explanatory frameworks, specific explanations and models (including complex systems models) against observations of highly variable quality and coverage?

Specific Questions for IHOPE

Building on these overarching questions, several specific questions are outlined below to serve as examples of the kinds of questions that could be addressed through IHOPE.

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

Resilience is the capacity to absorb change, reorganise and continue to develop. In a resilient social-ecological system, disturbance, change, uncertainty and surprise can be handled through mechanisms that buffer the system from collapse. Resilient human systems, partly as a function of their "social memory," have the capacity 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 and regional scales (Scheffer *et al.*, 2001; Folke *et al.*, 2005). In addition, recent work has begun to elucidate interrelationships between the social and the ecological, involving 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). (Fig. 8) The interactions between variables operating at different speeds and spatial scales, and their implications

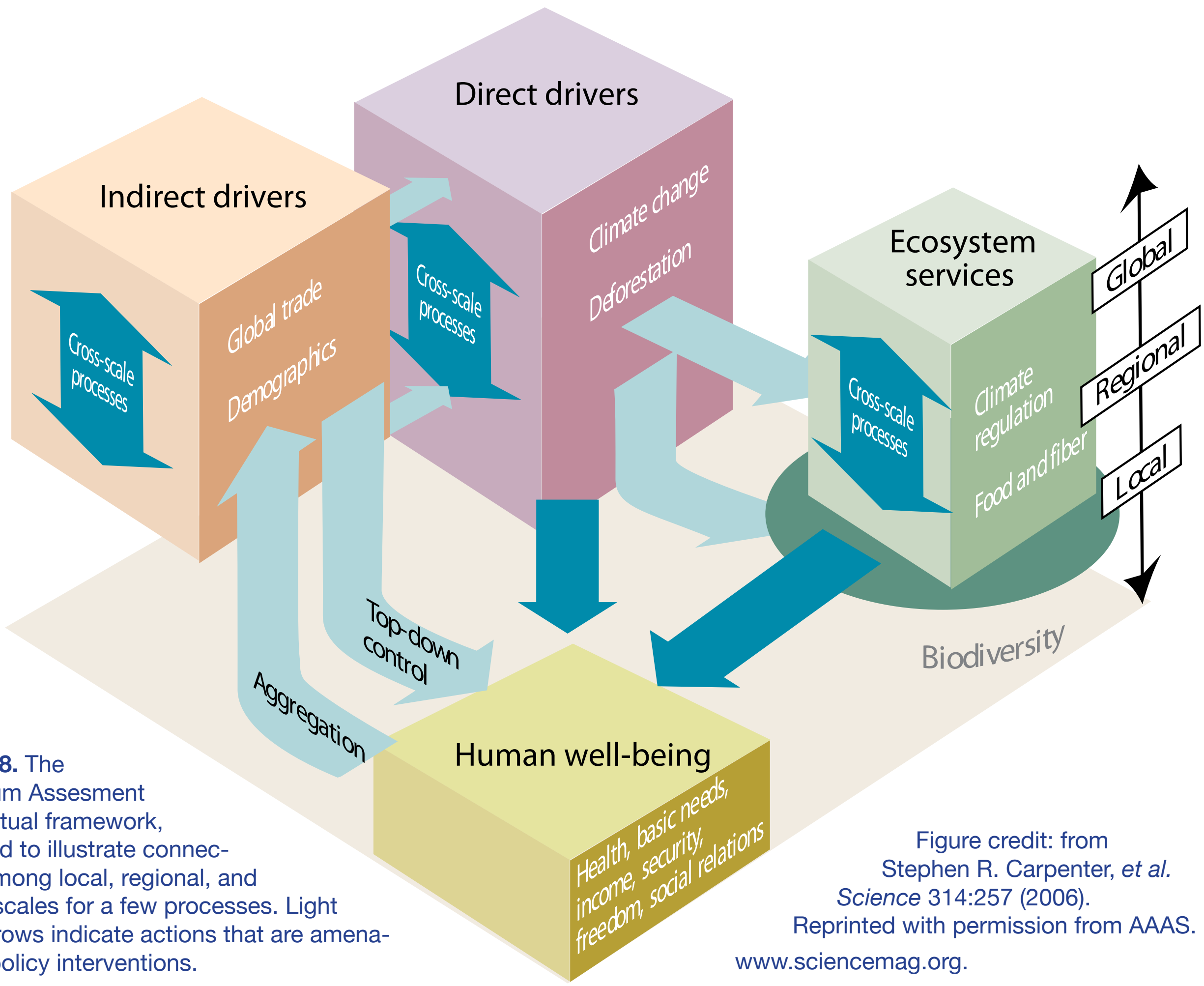

Figure 8. The Millenium Assesment conceptual framework, modified to illustrate connections among local, regional, and global scales for a few processes. Light blue arrows indicate actions that are amenable to policy interventions.

Figure credit: from Stephen R. Carpenter, *et al.* *Science* 314:257 (2006). Reprinted with permission from AAAS. www.sciencemag.org.

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), 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 organisational 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).

To date, these insights related to resilience are predominantly based on observations spanning the past 10–50 years. A decadal-scale focus will miss trends requiring a larger temporal window, so-called creeping changes, and the acceleration of system dynamics. There are huge gaps and a lack of coherent observations of relevant features in societies over historical time. One key question is whether or not multi-level governance becomes too slow to respond to the speed, frequency and unpredictability of environmental signals. Such shifts or changes in the biophysical environment change human perceptions of environmental dynamics and therefore social responses. Homogenisation of the environment alongside increasingly complex societies enhances the vulnerability on both sides.

One possibility is that societies tend to lose resilience (or become "brittle") as they expand in space or become more complex in structure. The same environmental stress that could be handled easily in earlier, less complex stages of a society's development can thus become sufficient to cause collapse if the society has become brittle. IHOPE will assemble data to test this hypothesis.

2. How do societies respond to resource limitations? Can technology create new frontiers indefinitely?

A common characteristic of human-in-environment development is extraction and consumption of natural resources. A typical response to the exhaustion of these resources has been to move to new regions where continued extraction and consumption is possible. These migrations have led to colonisation of new areas, conflict and displacement of indigenous populations, introduction of new species, and so on. 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 that are used to overcome local constraints of resource availability.

When used properly, advances in technology can meet human needs while also allowing for restoration and conservation of ecosystem services. That is, technologies intended for the advancement of sustainable use can provide new methods for increased extraction of limited resources, opening of new sources of resources, and recycling of resources. For example, some recent technological developments are 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. Integrated data from IHOPE can be used to address the hypothesis that technologies are a long-term solution to overcoming resource constraints.

3. What is the role and path of technology 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) in a wider sense. Technological innovations often impact the environment, but they also affect socio-environmental-cultural spheres and directly influence the techniques (in the narrow sense) used by a society. Moreover, impacts of technology often cascade forward in time through direct and indirect effects (2nd, 3rd, 4th order, and so on). Capturing these effects in space and time will be a significant challenge.

The following factors will be key in guiding the IHOPE community toward an integrated view of the interplay between technology, society and environment:

1. 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.
2. In particular, it is important (and often neglected) to study the role of society's ***institutions*** and how they operate. Institutions that have a direct impact on the specific technologies used, or on environmental dynamics must be given more attention.
3. All technological changes trigger – or are triggered by – ***changes in know-how***. Such changes have their own (cognitive) dynamic, driven by the interactions between problems, observations, and inventions. To truly understand the evolution of a technology, these components and their interactions have to be analysed.
4. 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 these 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 study the behaviour of such models under different circumstances (institutional, environmental, etc.). This involves the study of materials and other resources, the constraints and opportunities they offer, the feedbacks and feed-forwards that constitute "technological systems", and their impact on the environment and society at large.

4. What causes socio-ecological systems to be more or less successful in 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 those that are more erratic. Since environmental stresses have different degrees of predictability, a crucial question is the extent to which reduced predictability leads to problems in adaptation or to collapse.

We are currently facing the challenge raised by a slow, almost imperceptible change to an environmental variable (atmospheric carbon in the case of climate change), which upon reaching a certain threshold may lead to rapid changes that are dramatically out of proportion to the rate of change of the driving force. In such cases, it is ultimately the society's ability 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 recognised 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, coastlines and landforms were exposed, water bodies and wetlands were formed, and ecosystems moved across landscapes. Plants and animals were re-dispersed over these landforms. Evidence of these changing landforms and biotic assemblages is reflected in regional and global biogeochemical cycles and Earth system dynamics captured in sediments, ice and other natural archives.

Human expansion occurred during this same time period, and the impact of human activities increased in intensity during the past 10,000 years. As human activity intensified resource use and domestication of animals, the impact on Earth system cycles became increasingly apparent and was captured in natural archives around the world. The superimposed signals of past human activities and natural environmental variations complicate the isolation of one component. However, studies that integrate multiple evidences, methods and regions can distinguish between natural and human perturbations. The attribution of human and environmental changes that affect the Earth system can be carried out for the past 10,000-year period, 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 behaviour, 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., mycotoxogenic 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., airplane technology has 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 the application of theory and the development of appropriate models over long timescales are still 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. (Fig. 9, Table 2)

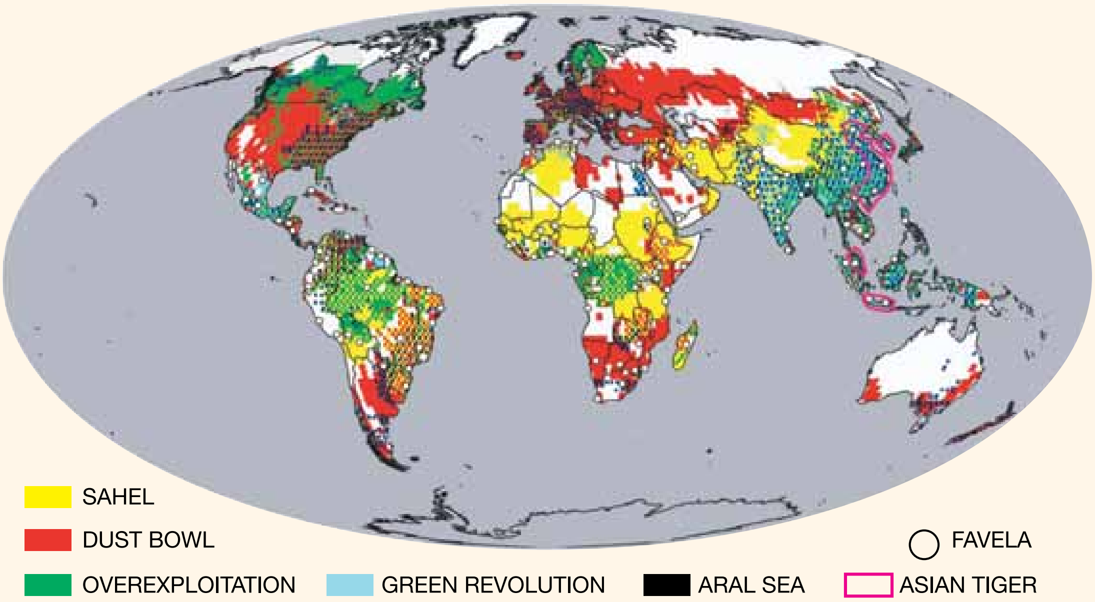

Figure 9. Global distribution of seven syndromes. Syndrome names are given in the legend. Simultaneous occurrence of more than one syndrome in a spatial map unit (2 degrees of latitude by 2 degrees of longitude) is symbolised by a chequered pattern combining the colours of the syndromes involved (the finest original resolution for a single syndrome is 0.5 by 0.5 degrees). The light grey land areas are either syndrome-free with respect to the seven investigated syndromes, or potential syndromes could not be identified because of significant gaps in data availability. While the indication of the Dust Bowl, the Green Revolution and the Asian Tiger Syndromes has global coverage, some gaps exist for the other four syndromes due to absent or unreliable data. This refers, for example, to all four syndromes with respect to Russia, to the Aral Sea and Sahel Syndromes in some regions of Africa and the Overexploitation Syndrome in parts of Central America. Reprinted from Lüdeke *et al.* (2004)

Syndrome name (abbreviation)	Underlying functional pattern	Syndrome description	Disposition factors
SAHEL (S)	Reproduction-oriented smallholder agriculture.	Downward spiral by mutual reinforcement of resource degradation and impoverishment	Marginal land (Sd1); no alternative income sources (Sd2).
DUST BOWL (D)	Profit-oriented capital-intensive agriculture.	Soil and environmental degradation due to capital-intensive, profit-oriented overuse and extensive application of chemicals; decreasing labour intensity and/or induced land pressure on small holders.	Profitable soil or pasture conditions (Dd1); accessibility by train/road/ship (Dd2).
GREEN REVOLUTION (G)	Ensuring food self-sufficiency in developing countries.	Environmental degradation and growing socio-economic disparities due to non-adapted agricultural techniques (high-yielding varieties) introduced by governments.	Malnutrition (Gd1); cereals a relevant fraction of national diet (Gd2).
OVER-EXPLOITATION (O)	Extraction of renewable resources.	Vegetation and soil degradation due to profit-oriented overuse of renewable resources, mainly forests; policy failures with regard to stopping or regulating the exploitation.	Accessibility and usability of forests (Od1). National dependency on wood export (Od2).
ARAL SEA (A)	Centrally planned large-scale water schemes.	Environmental degradation, Socio-economic problems, and (international) conflicts caused by dams and irrigation schemes.	Tendency towards top-down project planning and purely technological solutions
ASIAN TIGER (T)	Rapid economic growth in developing or newly industrialising countries.	Severe pollution and health problems due to rapid industrialisation without regard for environmental standards	World market accessibility (Td1); pronounced work ethic.
FAVELA (F)	Unplanned urbanisation in developing countries.	Pollution and health problems in rapidly growing urban areas due to lacking infrastructure development.	Absence of rural development.

Table 2. Seven syndromes of global change, along with their respective underlying functional patterns of human-nature interaction and their disposition factors (conditions under which the respective syndrome occurs).

At certain spatial scales, such applications are also hampered by a 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 query the IHOPE databases in novel ways, such as analysing world regions and ranking them according to long-term vulnerability to soil erosion or overuse of water. One might also apply the socio-ecological syndrome approach at regional and sub-national scales, or 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.*, 2000) for a single region. (Fig. 10)

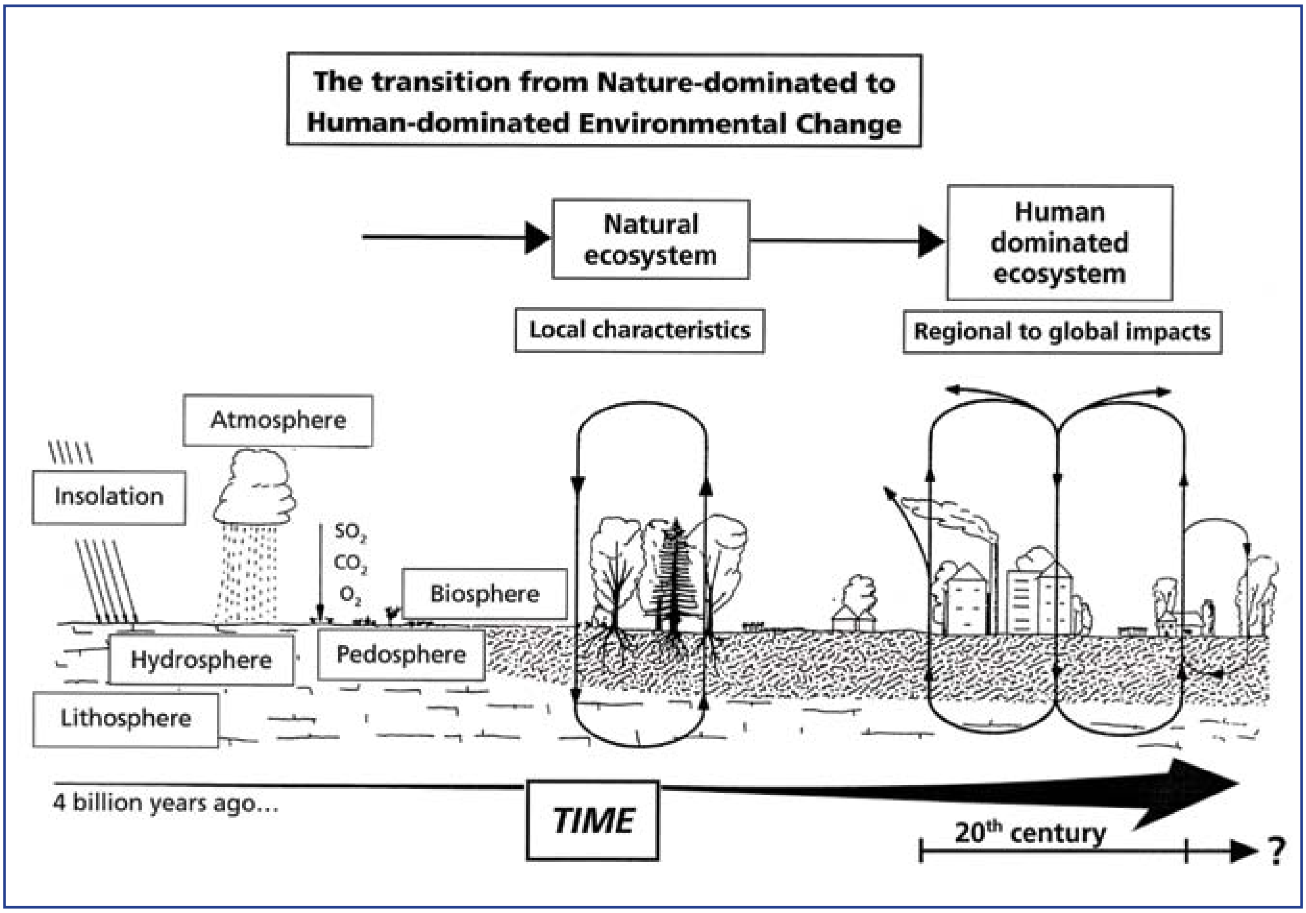

Figure 10. The time-line of environmental changes (Ganssen, 1965: Schreiber, 1980, Messerlli, 1986): natural ecosystems are characterised mainly by locally adapted and integrated processes in contrast to "urban-industrialised ecosystems", which have a growing and far-reaching impact on air, water and soil on a regional to global level.

Reprinted from *Quaternary Science Reviews,* Vol 19, Bruno Messerli, Martin Grosjean, Thomas Hofer, Lautaro Núñez and Christian Pfister, "From nature-dominated to human-dominated environmental changes", p.460, Copyright (2000), with permission from Elsevier.

Operating Principles

Given the unique goals of IHOPE and the general and specific questions listed above, we believe that there are certain general operating principles that are particularly relevant to this project.

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 modelling. IHOPE syntheses will seek to identify and model cross-scale interactions in time and space. Spatio-temporal scale analyses in IHOPE will embrace the entire long-term record of human environmental interactions with an emphasis on the last glacial cycle (120,000 YBP). As the resolution of archaeological, anthropological and historical records increases with biophysical and environmental proxies, the IHOPE lens will zoom in on human activities since the Holocene. In essence, IHOPE endeavours to embrace timescales of human interactions with the environment since early societies began modifying their environment.

IHOPE will develop a special focus on regional analyses and changes since the Holocene (11,600 YBP) through to the present and into the future. For the near past (e.g., 100–200 YBP) and contemporary time domains, a regional focus maps onto the geographical scale of the majority of human activities, governance and decision-making through history (e.g., globalised networks and international treaties). A regional focus will incorporate and require up-scaling of many local case-studies and will allow subsequent translation to the global level to produce global time series and input into the modelling 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.

Approaches to Evaluate Alternative Explanatory Frameworks (AEFs)

IHOPE studies need to adopt a range of alternative explanatory frameworks (AEFs), 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 utilise 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

Several potential obstacles to implementing IHOPE are listed below along with potential mechanisms to meet their challenges.

World View Perspectives

To develop an integrated history of the human and Earth system, various disciplinary perspectives will require careful reconciliation. This includes resolving differences between quantitative and qualitative information, and among knowledge sets from different disciplines. IHOPE will be challenged to create a framework and shared conventions to interconnect these diverse views and to harmonise different perspectives to achieve the integrated history of human-environmental systems.

The IHOPE community will develop shared conventions between the biophysical and social science communities. To determine what factors and principles jointly affect coupled human-environment system dynamics, IHOPE studies will involve resolving scale issues of time and space (as mentioned in the previous section), conciliation of impacts and drivers among different components of the coupled system, and alternate views of the analytical framework. Recent examples of resolving these challenges can be found in the Millennium Ecosystem Assessment and sustainability science.

Data: An IHOPE Research Information System (IRIS)

IHOPE will develop a community-driven, distributed research information system to advance its goals.(Table 3) The IHOPE Research Information System (IRIS) will provide a flexible structure that allows input, visualisation, analyses and interpretation from a wide breadth of scholarly and scientific cultures. Recognising the need for both simultaneous, long-term collaboration

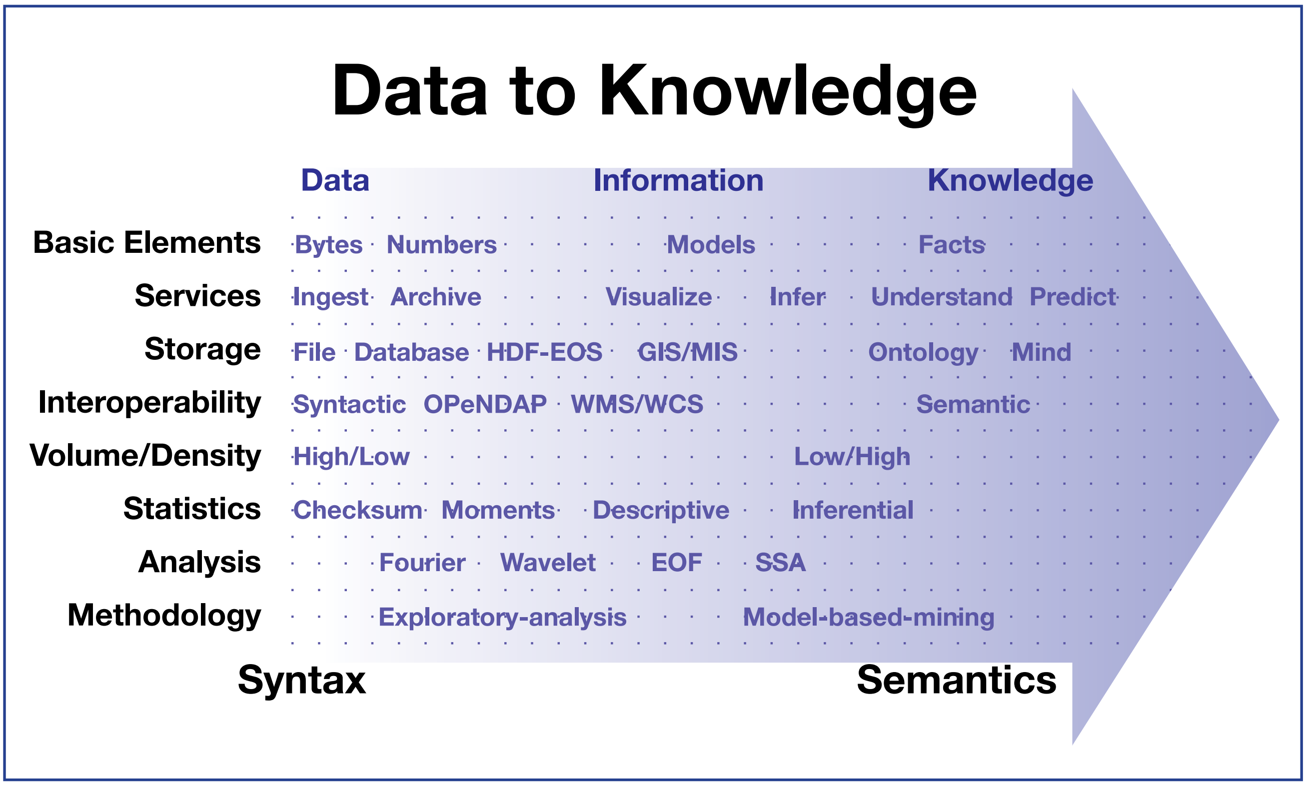

Table 3. The progression from data to knowledge across a range of aspects of computer systems.
Rob Raskin, NASA JPL, OPeNDAP Developers Meeting, February 2007. Figure courtesy of S. Aulenbach.

and exploratory independent research, IRIS will facilitate multiple points of entry and levels of participation within the IHOPE community. Lacking a single point of political control, the community's information system will encourage self-management when desired but still facilitate group participation and long-term curation of the varied data resources that IHOPE will produce. The goal for IRIS is a data system that provides multiple paths for data analysis and interpretation.

An IRIS framework will help build trust among the many interacting groups of data users and providers. For instance, data providers will be able to annotate data sets or flag suspect relationships between variables (e.g., although water withdrawals may be correlated with human disease, water use does not uniquely cause disease). The provider will also be able to provide expert insight into variable relationships (a log and blog concept) and, if desired, be available as a potential collaborator. (Fig. 11)

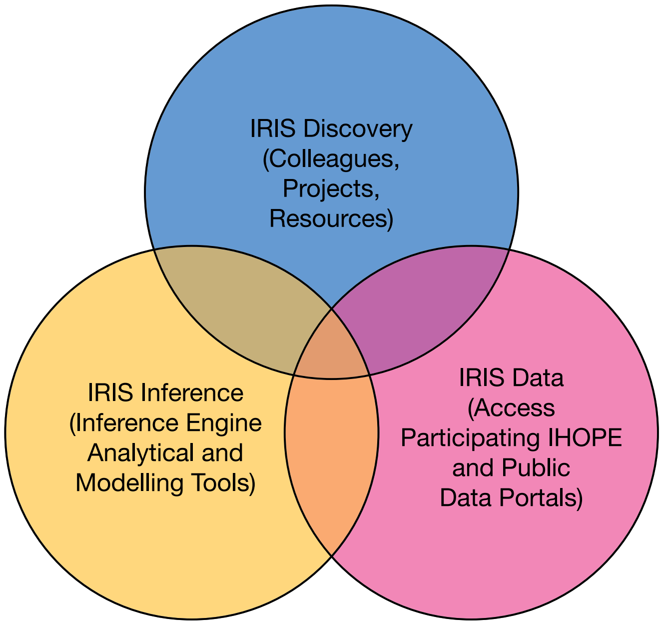

Figure 11. IRIS facilitates integration of data access, discovery, and inference. Figure courtesy of S. Aulenbach.

Through the IRIS, tools such as data flags and annotations, providers will be able to document caveats to proper data usage, and users can thus be forewarned about non-supported hypotheses or important factual considerations involved in testing new hypotheses. The intent is to build trust between data providers and users by rewarding data providers for their participation and contribution of their data, and giving future users a solid understanding and appreciation of their colleagues' contributions. Data providers will be credited and their insight will translate into data attribution and provenance.

Designed to be an interactive community resource, IRIS will also serve to guide and integrate IHOPE research, providing appropriate academic checks and restrictions on user communities. (Fig. 12) IRIS will not be hosted or controlled by a single domain, but will be a distributed data system with individual investigators maintaining full control over data visibility. Initial establishment of IRIS has been initiated through the National Center for Atmospheric Research (NCAR), however, it is anticipated that NCAR will serve simply as a conduit for scholars and scientists to post, browse and query IHOPE data. The IRIS data system would be flexible enough to allow data providers to vet new datasets for internal peer review as well as promote them to wider communities. This way, scholars and scientists could communicate with the data provider, oftentimes supplying an additional pair of eyes or "reality check" on work-in-progress. In addition, by providing variably mature datasets, the providers are able to augment their own research through contributions from outside usual disciplinary channels.

IRIS will preserve, curate and archive harvested data streams and ensure continued use of data as a freely available resource. Much of the data will be sparse in time and space and heterogeneous in nature (from narratives to numerical), requiring distinct and unique data interpretation. As such, IRIS will provide an open forum where negative or unfounded interpretation of data will generate lively community discussion and the development of data proxies and/or surrogates. As mentioned earlier, experts in a field of study have a strong working understanding of the quality constraints on their data and this understanding is not often or easily communicated across disciplines. The IRIS system will communicate the full range of data quality – from statistically valid estimates to informed guesses – in a variety of formats, from historical narratives to computer simulations.

In summary, an IRIS will provide an infrastructure to host data, allowing multiple distribution points. However, it will be organised so that providers can control how their data is used and who can use it. Providers will have the option to manage their own datasets or to use readily available community resources. (Fig. 12)

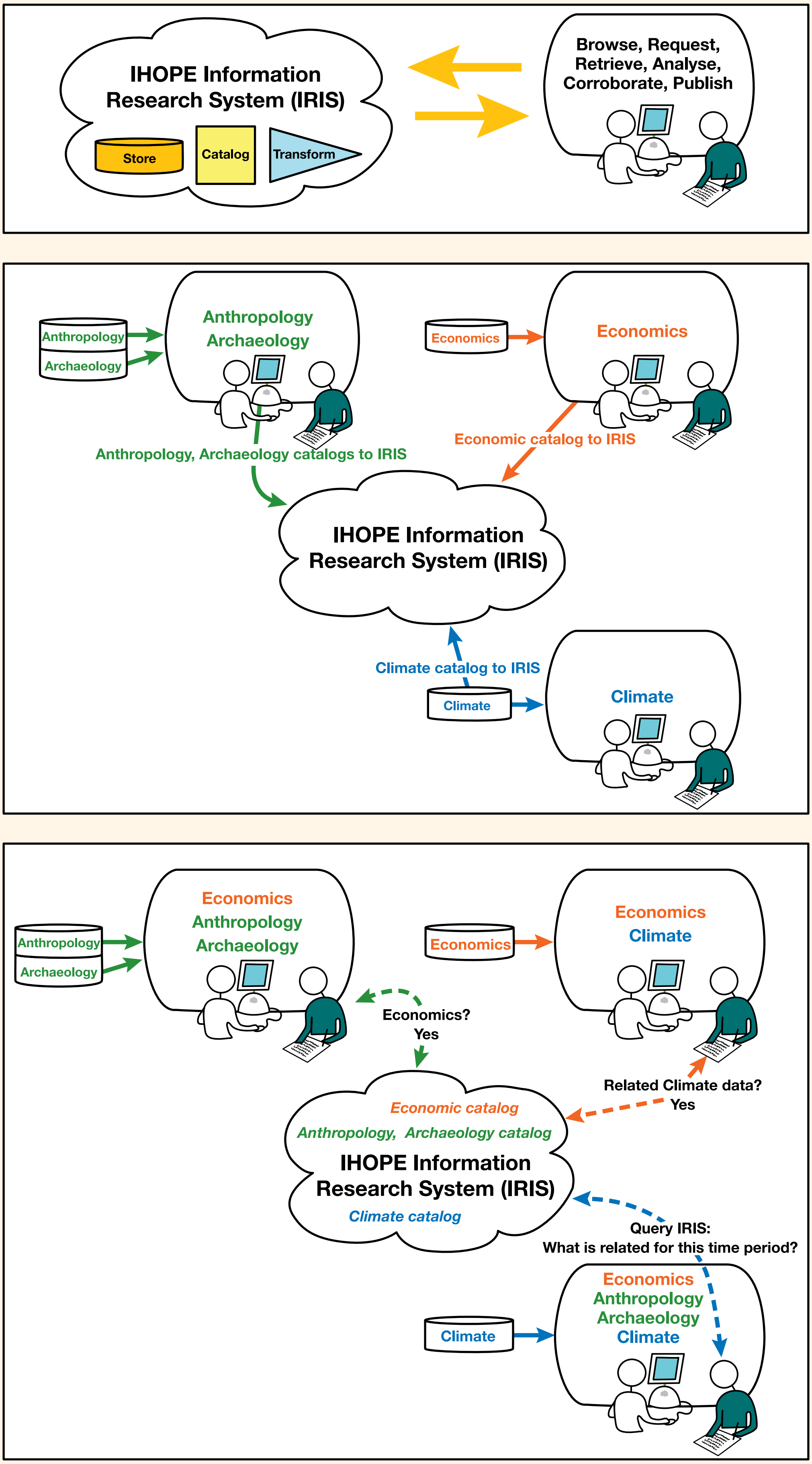

Figure 12. IRIS facilitates integration across disciplines and communities. Figures courtesy of S. Aulenbach.

Multidisciplinary Approaches to Analysis, Synthesis and Modelling

One of the central aims of IHOPE is to use a wide variety of datasets, tools and information. Cross-checking and testing hypotheses using multiple lines of evidence can be performed with a complementary suite of models and observations. However, various disciplines use models that represent differing views of historical information and operate on different temporal and spatial scales. Conflicting goals across disciplines must be addressed to appropriately interpret and analyse disparate observations and to effectively model solutions. For instance, 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 palaeo-environmental communities use a wide range of archives, which are often spatially restricted (e.g., lakes, glaciers) but temporally continuous (e.g., sediment cores, ice cores). IHOPE collaborators would have a unique opportunity to generate creative solutions to the challenge of synthesising interdisciplinary datasets. (Fig.13)

Creating consistency across disparate data sets is an essential and non-trivial challenge for IHOPE. Data and historical narratives will be contributed in non-uniform and often incomplete formats because of the breadth of communities contributing to the effort. Consistency across palaeological records and proxies as well as historical, archaeological and anthropological records, will require careful methodologies for visualisation and analysis. In particular, generating scenarios or meta-analyses based on simple correlation and causation methods will often be misleading.

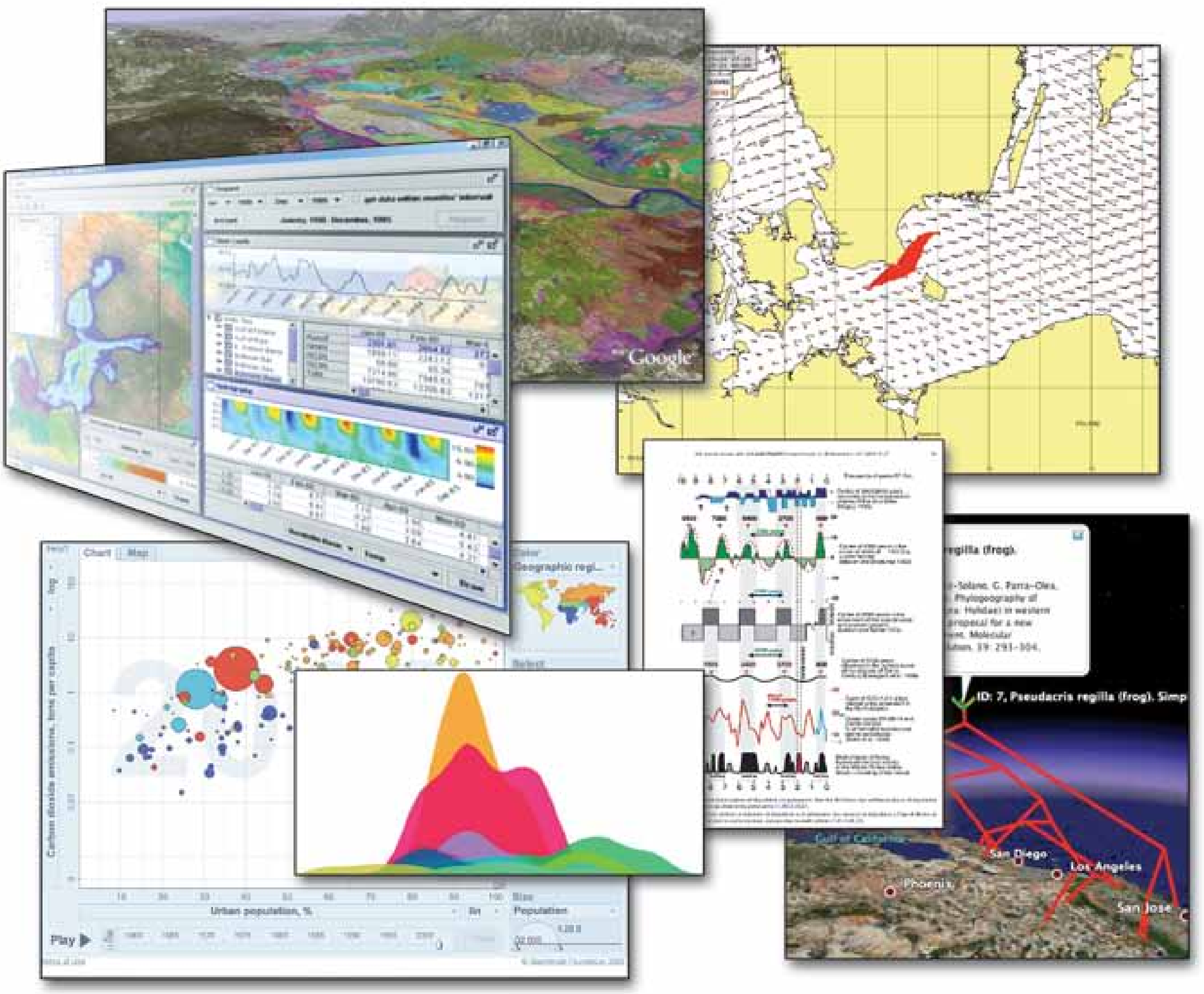

Figure 13. IHOPE will combine data that comes in many different forms, varies in quality, and comes from many different sources. Figures courtesy of S. Aulenbach.

Several constituent communities will be involved with IHOPE, and all have very different cultures around data collection, modelling, analysis, storage, archival and formatting strategies. To name a few, these include:

1. Archaeologists, who study what happened to human societies;
2. Anthropologists, who study how the structure of societies change;
3. Scholars from the humanities (e.g., historians), who analyse written accounts of the past;
4. Palaeoscientists (including palaeo-ecologists), who study the climate and environment of the past (e.g., Dearing *et al.*, 2006a and b);
5. Geographers, who analyse environmental and societal data over various temporal and spatial scales;
6. Earth system scientists, who analyse how human and biological-physical processes interact;
7. Modellers-scientists-scholars in all of the above fields who seek to capture processes and interactions in quantitative frameworks that reflect the knowledge, theories, conventions and questions of their area

To facilitate the participation of various communities, IHOPE will foster an open and collaborative philosophy in the analysis and interpretation of data and support the development of regional centres for data collection, modelling and analysis. At these centres, local experts will oversee regional analyses and contribute to global synthesis activities.

Institutional Issues

A major issue in implementing inter- and transdisciplinary research is the 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 against the goals of IHOPE, which require broad interdisciplinary collaboration, group work, data sharing and research in interstitial areas not covered by any one academic discipline. However, there is a new trend in academia toward developing interdisciplinary schools, centres and networks, thus implementing alternative reward structures more consistent with IHOPE's agenda. These are discussed later.

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 applied in the near term.

Authentic Engagement Across Disciplines

The success of IHOPE will depend heavily on multi-disciplinary, interdisciplinary and transdisciplinary efforts. This means that different scientific cultures, biases, jargons and methodologies must be bridged and connected. This is a major challenge, but there are many successful examples of such integration, and many of these have focused on developing models.

A recent example of successful integration across disciplines is the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2003; Reid *et al.*, 2005). Here economists, ecologists and other natural and social scientists assessed 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, non-governmental organisations (NGOs), the private sector and international conventions on how to respond to emerging threats. The assessment began in 2000 and was completed in 2005. Early on in the process, the working group recognised two important ways to ensure the relevance of the assessment. First, 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 (CF) and acceptable terminology was needed because at the earliest design meetings many were confused by the breadth 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 CF depicting the relationships between drivers and responses, and among 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 through the Millennium Assessment was to avoid a rigid, detailed framework, but rather design one that is general enough to incorporate new insights and approaches. Developing and documenting a CF facilitates the mutual exchange and learning between disciplines.

Within IHOPE, a similar interdisciplinary process must be established. The first steps were taken at the Dahlem conference in 2005 (Costanza *et al.*, 2007) but many gaps remain. Additional workshops should be organised 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 Timelines

One of the first steps in the IHOPE project is 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 objectives in this task are 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 about the workings of the Earth system have been generated by comparing time series of global biogeochemistry, land cover and climate (e.g., EPICA, 2004) (Fig. 14). Similarly,

Comparison of EPICA Dome C data with other palaeoclimatic records.

a Insolation records.
Upper blue curve (left axis), mid-July insolation at 65° N; lower black curve (right axis), annual mean insolation at 75°S, the latitude of Dome C.

b ∂D from EPICA Dome C (3,000-yr averages). Vostok ∂D (red) is shown for comparison1 and some MIS stage numbers are indicated; the locations of the control windows (below 800-m depth) used to make the timescale are shown as diamonds on the x axis.

c Marine oxygen isotope record. The solid blue line is the tuned low latitude stack of site MD900963 and ODP6773; to indicate the uncertainties in the marine records we also show (dashed red line) another record, which is a stack of seven sites for the last 400 kyr but consisting only of ODP site 677 for the earlier period. Both records have been normalized to their long-term average.

d Dust from EPICA Dome C.

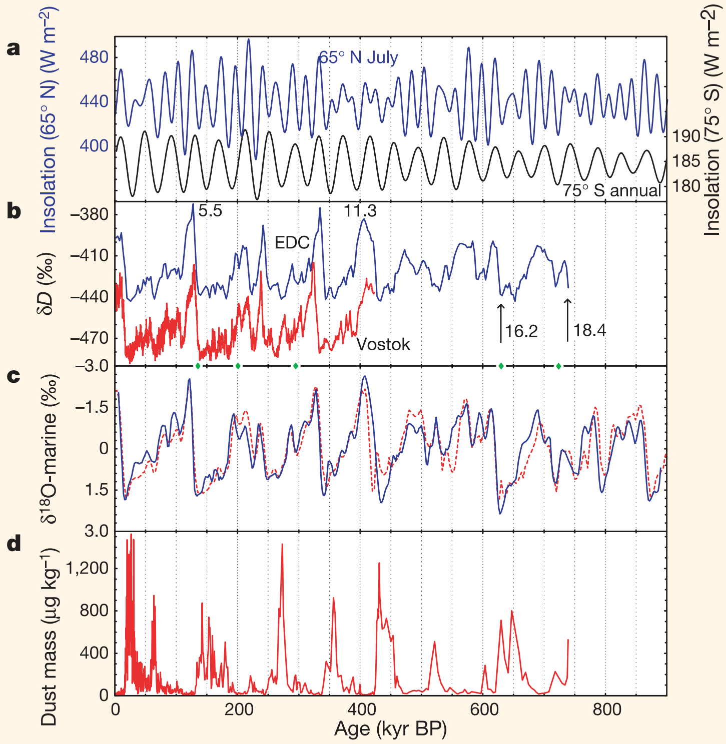

Figure 14. From EPICA Members 2004: timelines and global climate/biogeochemistry. Reprinted by permission from Macmillan Publishers Ltd: *Nature* Vol. 429 "Eight glacial cycles from an Antarctic ice core" EPICA community members, copyright 2004.

timelines depicting the increase over the past several hundred years in a suite of indicators of human impacts on the Earth system have argued powerfully that we have entered a new geological era, the Anthropocene (Crutzen and Stoermer, 2000; Steffen *et al.*, 2007). (Fig. 15, Table 4) The timing and nature of human perturbations to the Earth system are less well known as we look back in time, yet they are critical to our understanding of human-environment interactions (e.g., Ruddiman, 2005). Developing timelines of human and environmental events and variability on time scales ranging from decades to millennia will serve IHOPE goals by assessing the availability of data on key variables describing the state of human-environment interactions during the past and projecting these into the future.

The IHOPE activity builds on recent progress in developing global indicators of human and environmental variability over the Holocene (Steffen *et al.*, 2007). Such global-scale analyses will play a key role in characterising the human imprint on natural variability during the Holocene. Regional IHOPE analyses will examine co-variation of the human-environment system at continental scales. These analyses will allow us to assess data availability and quality at a regional scale, and enhance our understanding of the reliability of chronological data.

Care will be required when interpreting a collection of human and environment chronologies, as such timelines could generate misconceptions as well as insights (see Synchronization and Consistency under Challenges to Implementation above). In particular, correlation does not imply causation, and leads and lags may represent system dynamics or artefacts of the choice of variables. In consultation with experts who generate the primary data, it is anticipated that the observed synchrony and lack of synchrony between human and environmental data 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.

Spatially Explicit Global Databases

Recent advances in the development of Earth system models have incorporated aspects of terrestrial interactions with the climate system, primarily through the carbon cycle and dynamic vegetation. Components of the land dynamics include the processes of production, respiration and decomposition as well as disturbances such as fire. Human contributions to Earth system

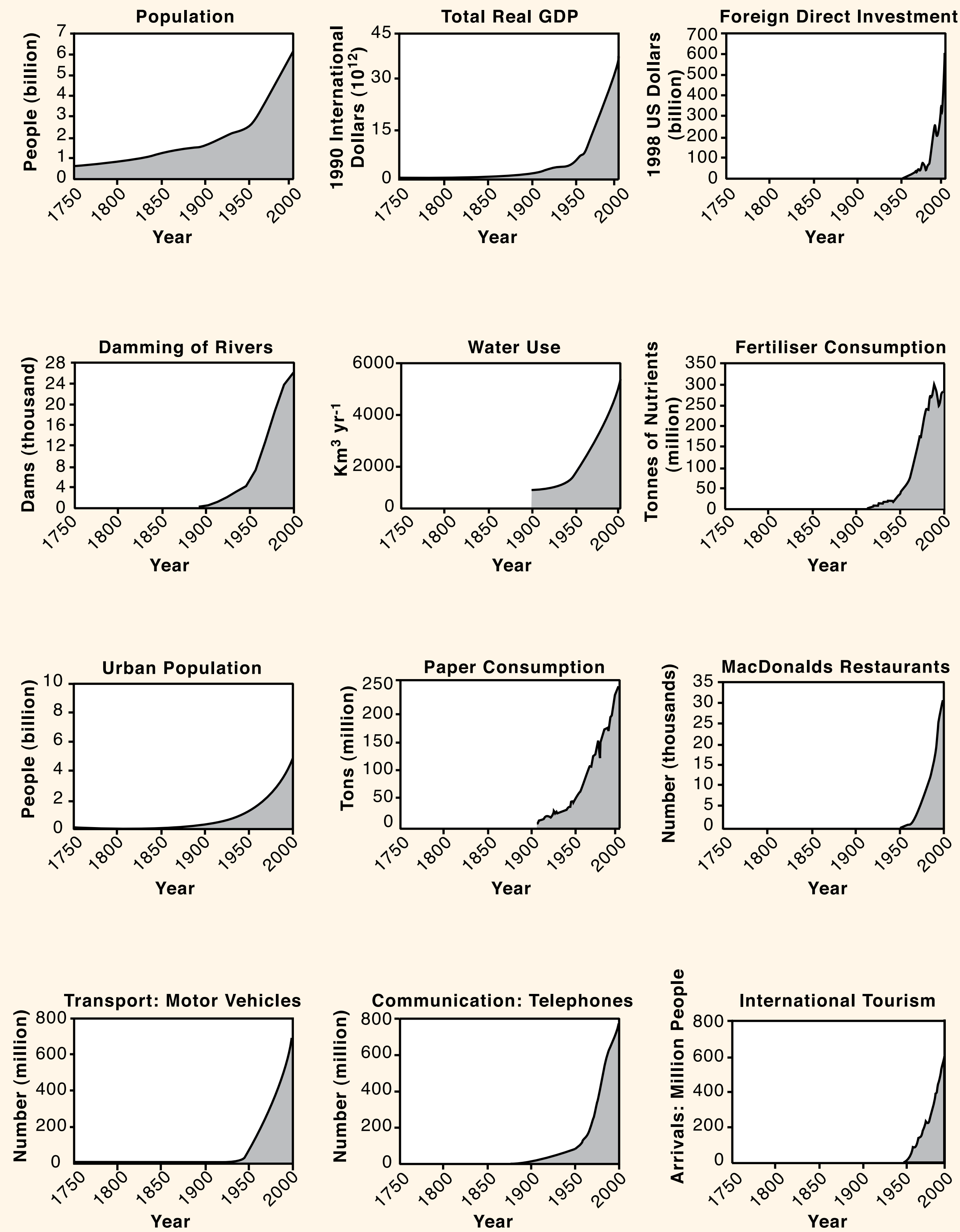

Figure 15. The change in the human enterprise from 1750 to 2000. The Great Acceleration is clearly shown in every component of the human enterprise included in the figure. Either the component was not present before 1950 (e.g., foreign direct investment) or its rate of change increased sharply after 1950 (e.g., population). From Steffen *et al.* 2007; Figure 2: Global indicators: Timelines. Reprinted from Steffen W, Crutzen PJ and McNeill JR (2007) *Ambio* 36(8), p. 617.

Year/Period	Atmospheric CO_2 concentration (ppmv)[1]
250,000 – 12,000 years BP[2]	
Range during interglacial periods	262-287
Minimum during glacial periods	182
12,000 – 2,000 years BP	250-285
Holocene (current interglacial)	
1000	279
1500	282
1600	276
1700	277
1750	277
1775	279
(Anthropocene Stage I begins) 1800	283
1825	284
1850	285
1875	289
1900	296
1925	305
(Anthropocene Stage II begins) 1950	311
1975	331
2000	369
2005	379

[1] The CO_2 concentration data were obtained from: (a) http://cdiac.ornl.gov/trends/trends.htm for the 250,000 – 12,000 BP period and for the 1000 AD – 2005 AD period.

[2] The period 250,000 – 12,000 years BP encompasses two interglacial periods prior to the current interglacial (the Holocene) and two glacial periods. The values listed in the table are the maximum and minimum CO_2 concentration recorded over the two glacial periods. According to mtDNA evidence, the first appearance of fully modern humans was approximately 250,000 years BP.

Table 4. Atmospheric CO_2 concentration during the existence of fully modern humans on Earth. From Steffen *et al.* 2007; Table 1: Global indicators: Timelines. Reprinted from Steffen W, Crutzen PJ and McNeill JR (2007) *Ambio* 36(8), p. 617.

dynamics such as deforestation, cropping and management of ecosystems are not yet fully represented in global models except through prescribed land cover or fire parameterisations. Similarly, many ecosystem models contain detailed components of biogeochemical cycles or changes in plant functional types due to disturbance, but evaluation of these models (for spin-up and historic reconstruction) has been difficult, except for recently observed events. Through IHOPE, we plan to develop spatially explicit global palaeo-climate, archaeological, anthropological and ecological databases, providing modellers with a reference for both model development and testing of 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 modelled changes in climate, ice mass, coastal zones and biogeochemistry are available from various sources such as the Cooperative Holocene Mapping Project (COHMAP). Over the past 20 years, the palaeo-climate community has been combining palaeo-climate and dynamic vegetation models through the Paleoclimate Modelling Intercomparison Project (PMIP http://www-lsce.cea.fr/pmip/; Harrison, 2000), which is jointly sponsored by the PAGES and Climate Variability (CLIVAR) projects.

Regional to global syntheses of 6,000 – 21,000 YBP include the BIOME 6000 reconstruction of palaeovegetation (Prentice and Webb, 1998), the ICE-5G global ice sheet reconstruction (Peltier, 2004), the Global Lake Status Data Base (GLSDB), which contains assessments of lake level or relative water depth (lake status) through time (30,000 YBP to present), the Dust Indicators and Records of Terrestrial and Marine Palaeoenvironments (DIRTMAP) database, which contains records of dust accumulation rates and properties targeted from 150,000 YBP to present (Mahowald *et al.*, 1999), a database for snowline reconstructions during the LGM from the tropics and sub-tropics (Mark *et al.*, 2005) and a Multiproxy Approach for the Reconstruction of the Glacial Ocean surface (MARGO; Kucera *et al.*, 2005) (Fig. 16). 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 should ideally be reconstructed at the same spatial resolution as the current global system models (e.g., 0.5 degrees) with various model formulations. Although it is not possible in all regions, IHOPE will strive for dense spatial and temporal reconstructions.

Historic and geologic observations of vegetation changes due to alterations in regional climate, coastal and continental landforms, and disturbance patterns will help constrain models of the biogeochemistry of terrestrial and ocean ecosystems. Archaeological observations of human distributions across 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 tease out the interactions among human expansion, the intensity of land use and impacts on the terrestrial system over the past 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 using 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 recent analyses of ice cores and global atmospheric methane and CO_2 concentrations (Petit *et al.*, 1999; Indermühle *et al.*, 1999; Spahni *et al.*, 2005). 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 modelling exercises. Other hypotheses can be tested to improve our understanding of the consequences of shifts in climate (including 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 archaeological disciplines provide

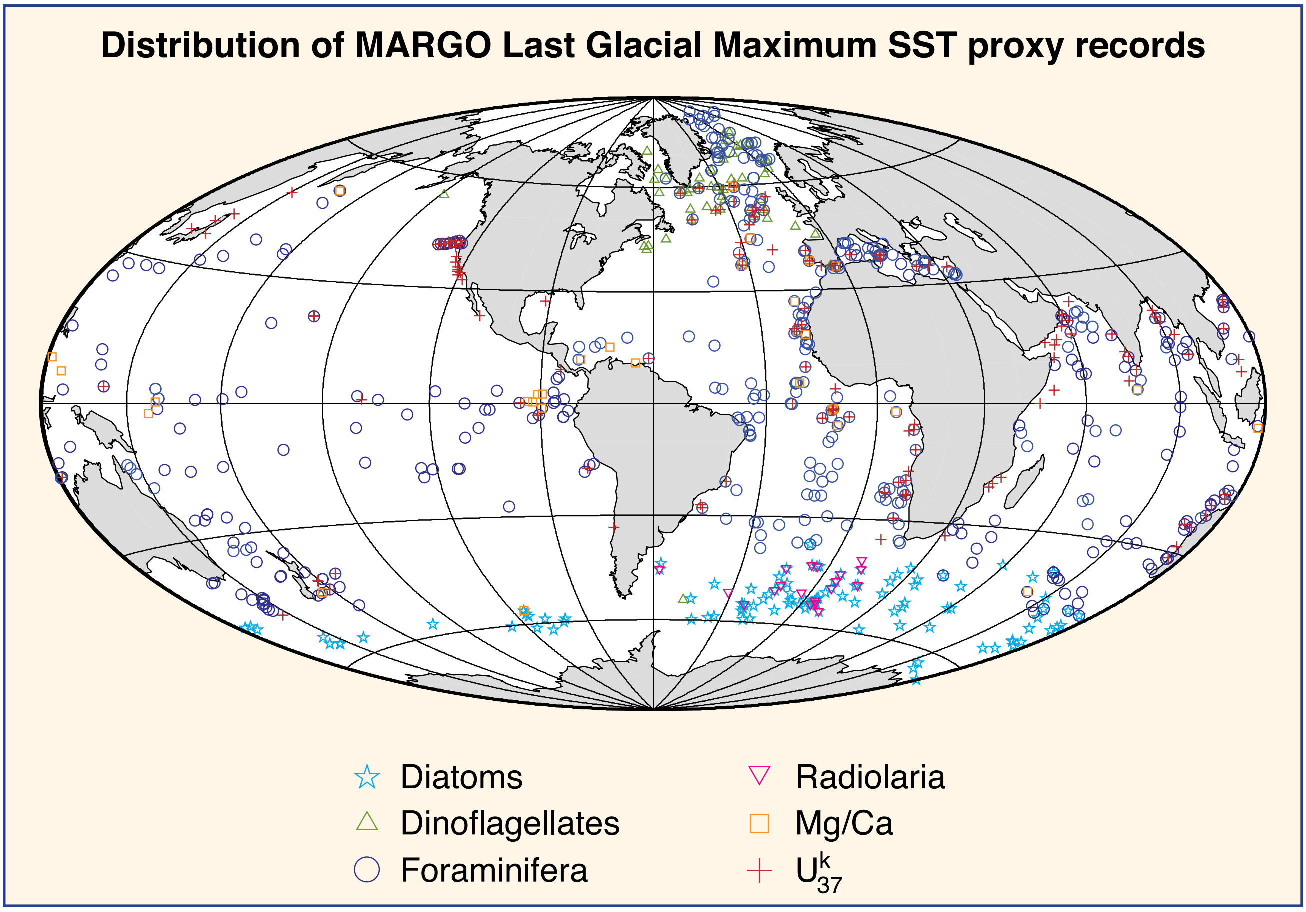

Figure 16. The location of proxy records of LGM SST included in the MARGO reconstructions. The alkenone data are from Roseli-Melé *et al.* (2004). Reprinted from Quaternary Science Reviews, Vol 24, Kucera M, Rosell-Melé A, Schneider R, Waelbroeck C and Weinelt M, Multiproxy approach for the reconstruction of the glacial ocean surface (MARGO), p.16, Copyright (2005), with permission from Elsevier.

insight into societies that may be undergoing political and institutional stresses. For instance, models that link social pressures with scenarios of extreme drought in the past (e.g., the Maya or the dust bowl of North America in the mid-20th century) will contribute to understanding and projecting how social and environmental systems may respond to future stress.

Regional Case Studies

Recent rapid developments in distributed data management, data mining and modelling enable us to build the kind of data system needed to achieve IHOPE's goals. Intellectually, however, IHOPE must ensure that (a) the relevant questions have been identified, (b) all the data to be collected are relevant to the questions investigated and (c) these data are in a form ready to be used. IHOPE will develop experimental designs to test data that have been collected at different spatial and temporal scales, and within disciplines with different epistemologies, in response to different questions, using different metrics and with variable levels and degrees of detail.

IHOPE's goals will be implemented through analyses of data from regional coordination activities. These data will result from research in various disciplines, and represent the diversity of data to be collected at the global scale. Regional analyses will be framed through the coupled processes and transitions of the human-environment system, for example, the colonisation of pristine landscapes by hunter-gatherers in Australia, the colonisation and abandonment of landscapes by hunter-gatherers in the Sahara during the Holocene, recolonisation of Europe by early humans after the deglaciation, transitions to settled agriculture in the Middle East and the Viking Landnam colonisation of inhabited regions. In this way, IHOPE can experiment with a range of Alternative Explanatory Frameworks (AEFs), design and implement the datasets required to enable each AEF to ask the relevant questions, experiment with different metrics, and try out various model validation and evaluation methods. At the same time, by comparing the socio-environmental dynamics in these different areas, we could design a meta-language about socio-environmental phenomena that will allow us to compare the systemic behaviours underlying different instantiations of socio-environmental interactions. Below we describe a few possible regional analyses for IHOPE.

Africa

Bordering the Mediterranean with a land bridge to Asia, Africa is a prominent continent in the history of humankind. Not only have the oldest human ancestors been discovered there, but there is also now clear evidence that our own species (*H. sapiens*) made its first appearance there (200,000–100,000 YBP), spreading subsequently to Asia and Europe. More recently (10,000 YBP), North Africa was one of two places in the world where cattle were domesticated. Cattle domestication was followed by pastoralism, which came to characterise the subsistence economy of many African countries. By 8,200 YBP, sheep and goats, along with wheat and barley, were introduced from South-west Asia to Egypt and from there to Eastern Africa. However, archaeological investigations in both East and West Africa reveal indigenous domestication of native cereal grasses and tubers.

These events were not independent from the influences of climatic changes and dramatic environmental transformations of the Africa landscape. Although North Africa is now a barren desert, palaeo-environmental investigation indicates that the desert was a lush savannah habitat before the Last Glacial Maximum when it became a hyper-arid zone, only to become less arid with increasing summer precipitation. Preliminary studies now suggest that a wet front associated with the Intertropical Convergence Zone (ITCZ) moved up to 800 km north of its present position. There are also indications of a retreat of the wet front beginning around 6,100 YBP. Abrupt climatic events seem likely to have forced populations to migrate, ideas to spread and innovations to emerge.

Retrieval of archaeological and palaeo-environmental and environmental data will make it possible to provide more appropriate models of how societies interact with environmental changes. These models would uncover how societal actions lead to significant ecological transformations, instead of providing superficial, synoptic grand narratives that fail to contend with regional specificity and the dynamics of social strategies during ecological stress or economic prosperity. Africa provides rich archaeological resources and an array of palaeo-environmental proxy-archives at different time scales. Deep and shallow lakes, accessible and well-exposed playa deposits, sequences of fluvial deposits, coastal deposits, faunal remains, well-preserved records of diatoms, ostracodes, pollen and spores, and tree records in different ecological settings from the Atlantic to the Red

Sea and from the Mediterranean to the Sahel provide a remarkable opportunity for detailed reconstructions of environmental history over the past 10,000 years. These will provide the basis for solid socio-dynamic interpretations of cultural developments that were significant in the history of humanity at large, such as the origins of Egyptian and other African civilisations.

Future work may proceed from hypotheses concerning specific "situations" that may have been triggered or facilitated by strong climatic signals. These include the initial domestication of cattle in response to frequent climatic fluctuations in the first phase of post-glacial warming, the spread of cattle and the emergence of pastoralism independently in the Sahara and East Africa from 8,200 to 4,200 YBP under the influence of abrupt climatic events, and the spread of domestication from South-west Asia in response to droughts. Additional situations involve the convergence of desert populations in the confined space of the Nile Valley from 7,800 to 6,100 YBP as conditions were becoming intolerable in the Sahara and the southern Levant, and the impact of climate-driven change in Nile floods on the course of Egyptian civilisation, especially at its formative stage and at 4,200 YBP, when centralised government collapsed after a period of stability that lasted nearly five centuries. The historical data over the past 1,300 years along with annual records of Nile floods would support a high-resolution examination of environmental change and social dynamics.

Australia

Much research has been carried out on Australia's palaeo-environment and on the evolution of human society in Australia, 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, Flannery, 1994), although there is not yet a consensus on these interpretations. Near-term climates are sufficiently predictable using El Niño Southern Oscillation (ENSO) forecasting of 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. 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 an outstanding opportunity to study some unique aspects of socio-ecological systems because of its continental-scale cultural isolation from roughly 65,000–200 YBP. It 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 1700s). Finally, the Australian continent has seen an abrupt transition from a hunter-gatherer culture to an industrialised European culture over the past 200 years.

The Mediterranean

The Mediterranean region has one of the best-studied human histories on Earth (e.g., van der Leeuw, 2005). Over some 10,000 years, environmental, archaeological, written historical and instrumental data testify to the complex interactions among the atmosphere, geosphere, biosphere and a range of successive societies. The basin has been studied at different scales, from local to sub-regional to regional, and by researchers in disciplines such as atmospheric studies, tectonics, geomorphology, biology and economics, and various social sciences such as history and geography. Moreover, social systems of various sizes and forms have both emerged and collapsed in this region. It is therefore ideal for a case study of the kind proposed here: multi-scalar, multi-disciplinary and based on many different kinds of data.

What kinds of questions can be uniquely approached in this area? On one hand, we have detailed, multi-scale and long-term data on the growing connectedness of societal and environmental dynamics, which leads to increasing disturbance-dependency of the environment on society. This is followed by societal control over the environment, and the "accident waiting to happen" that humans 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 process. This includes information on how the various societies in question shape their own environment, and their own fate. Hence, the Mediterranean region lends itself particularly well to a comparative study of the different ways people have interacted with the same set of global environmental dynamics.

The Maya Area

In the Maya area, an important, highly complex, and relatively well-known civilisation made a major geographical shift from one terrestrial environment (the mountains of Guatemala, Belize and Chiapas) to another (the level, karstic area of lowland Yucatán). The climate in this region is different from all other areas chosen, as water is not the main constraint to the system, and the chronology is well-established through the presence of many stelae with calendar dates that are known to modern researchers. Through these stelae, we have a developing sense of the political dynamics at the local/regional scale. The geographic shift from highlands to lowlands could have been 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 organisation, and a different kind of (low-density) urbanism.

China

The historical record of China is rich in sources and detail. The vast documentary record of China's environmental history is gradually being compiled and made accessible (Elvin, 2004). 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 among human activities, climate and environmental processes (Shen *et al.*, 2006). China's immense geographical scale, ranging from the subtropics 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 a great diversity of past socio-ecological interactions. Perhaps the earliest are described by archaeological studies in the middle Yangtze basin where rice phytoliths suggest a centre of cereal cultivation existing as early as 10,000 YBP (Yasuda, 2002). Even on the relatively isolated Yunnan plateau, measurable effects of human activities on forest cover and hydrology are recorded from at least 7,000 YBP.

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 (e.g., the Grand Canal) over at least 2,000 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 past 3,000 years, the US Southwest has seen a succession of very different adaptations to extreme climatic circumstances. Initially, these were based on resilience due to the high degree of mobility of its populations (Nelson and Hegmon, 2001). But, in contrast to Australia, the population of this drought-ridden area did eventually settle in larger groups and establish both dry and irrigation-based farming. The range of adaptations to the environment in this region is therefore considerably wider than elsewhere.

The relevance of this area to IHOPE efforts lies in (1) the particular (extreme) environmental circumstances and the diverse ways the regional societies have dealt with them over the last 10,000 years, (2) the dominance of water availability as the central factor in sustaining the regional human systems and in the socio-ecological system as a whole, (3) 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, and assign precise dates to the wealth of archaeological evidence, and (4) the fact that this area has thus far provided the best, and most detailed, dynamic (multi-agent) models of socio-environmental interaction over thousands of years.

The above regional case studies would lay a framework for many additional regional activities that IHOPE endeavors to embrace and are not meant to exhaustively represent past, present and future human and environmental interactions. As IHOPE develops and matures, global analyses will increasingly be generated through comprehensive regional studies.

Transdisciplinary Networks and Centres

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

a. Quantify global population numbers and density through time;

b. Quantify and map areas 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 and migration events;

e. Synthesise environmental reconstruction of regional changes covering the relevant periods of interest;

f. Map the land geography through time.

The implementation of the IHOPE research agenda will require contributions from scholars around the world. This research plan outlines a strategy with regard to regional studies and deliverables as described above. A networking approach will be essential for IHOPE's success, and we envision at least two types of networks. First, regionally based networks of scholars from a wide range of disciplines must undertake the case studies in an integrated fashion. Complementing these will be regional and global networks defined by discipline, which will further develop and test information-gathering methodologies for particular aspects of the IHOPE agenda and create specific simulation tools for the analysis and integration phases of the project. As integration across disciplines is central to IHOPE, the growing number of interdisciplinary research centres worldwide will provide an infrastructural underpinning to the effort. Examples of such centres 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, California, and the Centre for Resource and Environmental Studies at the Australian National University.

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Acronym List

AEF	Alternative Explanatory Framework
AIMES	Analysis, Integration and Modelling of the Earth System
CF	Conceptual Framework
CLIVAR	Climate Variability Project
COHMAP	Cooperative Holocene Mapping Project
DIRTMAP	Dust Indicators and Records of Terrestrial and Marine Palaeoenvironments
EECGP	Environment, Economies, Civilization and Global Change Program
ENSO	El Niño Southern Oscillation
EPICA	European Project for Ice Coring in Antarctica
ESSP	Earth System Science Partnership
GLP	Global Land Project
GLSDB	Global Lake Status Data Base
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Programme on Global Environmental Change
IRIS	IHOPE Research Information System
ITCZ	Intertropical Convergence Zone
MARGO	Multiproxy Approach for the Reconstruction of Glacial Ocean surface
NCAR	National Center for Atmospheric Research
NCEAS	National Center for Ecological Analysis and Synthesis
PAGES	Past Global Changes project
PMIP	Paleoclimate Modelling Intercomparison Project
WSSD	World Summit on Sustainable Development
YBP	Years Before Present

Participant List

IHOPE planning meeting, 12–13 January 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
Tel: +1 303.497.1701
E-mail: aulenbac@ucar.edu

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

Carole L. Crumley
Stockholm Resilience Centre
Stockholm University
SE-106 91, Stockholm, Sweden
Tel: +46 8 674 70 91
E-mail: carole.crumley@stockholmresil-ience.su.se

John Dearing
University of Southampton
School of Geography
Southampton SO17 1BJ
United Kingdom
Tel: (44-2380) 594 648
Fax: (44-2380) 593 295
E-mail: J.dearing@soton.ac.uk

Carl Folke
Beijer Institute
The Royal Swedish Academy of Sciences
Box 50005
SE-104 05, Stockholm, Sweden
Tel: +46 8 673 9533
E-mail: calle@system.ecology.su.se

Lisa Graumlich
Montana State University
Mountain Research Center
Dept. of Land Resources & Environmental Sciences
PO Box 173490, 106 AJM Johnson Hall
Bozeman, MT 59717-3490, USA
Tel: +1 406.994.5178
E-mail: lisa@montana.edu

Kathy A. Hibbard
IGBP/AIMES Executive Officer
National Center for Atmospheric Research
Current address:
Pacific Northwest National Laboratory
Atmospheric Sciences and Global Change Division
902 Battelle Way
Richland, WA 99354, USA
Tel: +1 509.371.6266
Fax: +1 509.372.6153
Blackberry: +1 509.554.0829
E-mail: kathy.hibbard@pnl.gov

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
E-mail: 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
E-mail: vanderle@asu.edu

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

João Morais
IGBP
The Royal Swedish Academy of Sciences
Box 50005
SE-104 05, Stockholm, Sweden
Tel: +46 8 673 9560
E-mail: morais@igbp.kva.se

Dennis Ojima
Professor, Department of Forestry, Rangelands, and Watershed Stewardship
Natural Resource Ecology Laboratory
Colorado State University
Fort Collins, CO 80523
Tel: +1 970 491 1976
E-mail: dojima@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
E-mail: 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], Biology Place
Canberra ACT 0200, Australia
Tel: +61 2 6125 4588
E-mail: steffen@cres10.anu.edu.au

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

Yoshinora Yasuda
International Research Center for Japanese Studies
Kyoto, Japan
Tel: +81 75 335 2150
E-mail: yasuda@nichibun.ac.jp

Governance

IHOPE focuses on the generation and synthesis of a broad range of ideas and datasets to provide new insights into human-environment relationships over long periods of time. IHOPE was initiated and is currently managed by the Analysis, Integration and Modelling of the Earth System (AIMES) Core Project of the International Geosphere-Biosphere Programme (IGBP). It now has its own International Project Office. It is co-sponsored by AIMES, the Past Global Changes (PAGES) Core Project of the IGBP, and the International Human Dimensions of Global Environmental Change Programme (IHDP). The responsibility of the cosponsors is to monitor the scientific progress of IHOPE. For this purpose, IHOPE will submit an identical annual report to all three co-sponsors.

Scientific Steering Committee

The IHOPE Scientific Steering Committee (SSC) is the governing body of IHOPE. It consists of 10-12 members that are selected to form a balanced representation with respect to discipline, geography, gender and age of the different communities involved in the activity. The members of the SSC are recommended by the IHOPE Executive Committee (IEC – see below) and approved by the co-sponsors. They serve 3 year, once renewable, staggered terms. The IHOPE SSC is not required to physically meet, but may do so when a convenient opportunity presents itself. Communication from the IHOPE Executive Committee to the SSC and within the SSC will be through regular tele conferences and/or videoconferences. The responsibility of the SSC include: (1) providing leadership and assistance into developing and implementing IHOPE activities; (2) helping with raising funds; (3) facilitating and coordinating activities in IHOPE regional nodes; (4) assisting in the development of an IHOPE Research Information System; and (5) ensuring that IHOPE functions in accordance with the guidelines of the sponsoring international programmes.

IHOPE Executive Committee

Daily activities of IHOPE are overseen by an IHOPE Executive Committee of 5 members, chosen from among the members of the SSC. They serve in an executive capacity for 3 years, with staggered terms (e.g., to ensure continuity, the entire Executive Committee does not rotate at the same time), renewable once. The IHOPE Executive Committee includes representatives from AIMES, PAGES, and IHDP, who are responsible for reporting IHOPE activities to these co-sponsors. The Executive Committee divides among its members the roles of Chair, 2 Vice-Chairs, Secretary and Treasurer as appropriate. It oversees the execution of the strategies outlined by the SSC, and is responsible for its activities to the latter.

Executive Officer

The Executive Officer of IHOPE is chosen by the Executive Committee, in consultation with the sponsors, and is appointed by the SSC. He/She serves a 3-year, renewable term, and is responsible for the execution of the strategies outlined by the SSC. The Executive Officer is an *ex- officio* member of the Executive Committee and SSC to ensure continuity of IHOPE goals, aspirations and legacy. The Executive Officer also has a research role in terms of facilitating, coordinating, and sometimes leading IHOPE research and synthesis activities.

Network and outreach

IHOPE includes institutional and individual partners and affiliates; their suitability is determined by the Executive Commmittee.

Institutional Partners and Affiliates

Institutional Partners to IHOPE are institutions that provide in-kind or financial support to IHOPE functions and/or infrastructure. In many instances, they will be the institutions that employ Principal Investigators of component research projects of IHOPE. In other instances, they will be institutions that provide support to the IHOPE infrastructure. Institutional Affiliates are those institutions that desire to be a part of IHOPE through relevant activities but do not contribute financial or in-kind support to IHOPE operations.

Individual Partners and Affiliates

Individual Partners to IHOPE are those individuals who are engaged in IHOPE activities and contribute to IHOPE operations through financial or in-kind support in ways that are not tied to their institutions. Individual Affiliates to IHOPE provide scientific contributions, data and leadership to IHOPE activities.

IHOPE

IHOPE is co-sponsored by the Analysis, Integration and Modelling of the Earth System (AIMES) project and the Past Global Changes (PAGES) project, both core projects of the International Geosphere-Biosphere Programme (IGBP) and The International Human Dimensions Programme on Global Environmental Change (IHDP). IGBP is an interdisciplinary body of the International Council for Science (ICSU).

More information on the project sponsors can be obtained from:

IGBP: www.igbp.net

AIMES: www.aimes.ucar.edu

PAGES: www.pages.unibe.ch

IHDP: www.ihdp.unu.edu/

ICSU: www.icsu.org

IHOPE

Developing an Integrated History and Future of People on Earth

ICSU
International Council for Science