

EARTH SYSTEM HISTORY REVIEW PANEL
November 11, 2006

The Review Panel met on October 16 and 17, 2006, to assess the quality and effectiveness of NSF's Earth System History Program and its role in fostering cross-disciplinary cooperation.

In fulfilling its charge, the Panel addressed:

Program accomplishments and impacts:

- What are the key accomplishments of the ESH program? Have transformational discoveries resulted from ESH awards?
- Has ESH produced significant cross-divisional/interdisciplinary research efforts that might not otherwise have occurred? What new approaches, techniques, and/or insights have resulted?
- Were the goals of the ESH program met? How? Are there any unmet goals?
- Has ESH had significant impacts on other areas of science nationally and/or internationally?
- Was the existence of a focused research program/solicitation critical to ESH scientific advances?

Relevance of the ESH program goals to current science priorities:

- Are the goals of the ESH program still a high priority for the geosciences?
- Do ESH scientific advances suggest new directions/activities/goals for NSF to pursue? If so, what would be the most effective ways to move forward?

A) Key accomplishments of ESH.

The study of Earth system history can contribute substantially to climate and global change research through its unique ability to address five major challenges. The ESH program has promoted accomplishment in each of these areas:

(1) Is the warming of the past several decades unique? To what extent can these changes be attributed to either anthropogenic or natural forcing?

ESH has been invaluable in developing a broad range of data sets from a variety of indicators (tree rings, corals, lake and marine sediments, ice cores, etc.). These data sets, and ESH funding, have enabled a synthesis of climate information for the last 1000 years and beyond that is of fundamental importance for separating anthropogenic and natural forcing. As one key piece of evidence, the NAS (Surface Temperature Reconstruction for the Last 2,000 Years; 2006) report recently concluded that the synthesis records of the last millennia that describe a "hockey stick" shape to global temperatures are largely robust.

(2) How does the climate system respond abruptly to internal and external forcing?

ESH projects are of critical importance in demonstrating the potential for significant climate changes on time scales of decades or less, in ocean or

atmosphere circulation and sea ice, or possibly even associated with ice sheet instabilities. Through combined data and modeling approaches, ESH has also contributed substantially to the exploration of different plausible mechanisms that could result in abrupt change during future warming. This research is of fundamental importance to our understanding of future climate change and comprises some of the most highly visible contributions of ESH.

(3) *How will regional and temporal climate variability change in response to global change?*

ESH plays an important role in examining climate variability and regional changes. ESH contributions are in important areas such as characterizing drought variability, determining the nature and impacts of past ENSO events, examining the response of mountain glaciers to warming, and deciphering the variability of the monsoon system. For example, ESH researchers are addressing the important question of how El Niño responds under different climate conditions, and specifically whether El Niño responses during past warm climates provide analogues for future climate change.

(4) *What is the nature of climate sensitivity to internal and external forcing? Can we increase our confidence in the sensitivity of climate models used to predict the future?*

ESH has supported a more limited set of projects that have served to isolate the importance of specific forcing factors (e.g. insolation, solar variability or volcanic eruptions) in influencing the climate system. Less emphasis is evident in the assessment of uncertainties in internal forcing associated with coupled systems (e.g. attributed to ocean-atmosphere interaction or land biosphere-atmosphere interaction) and in the assessment of the degree to which climate models have realistic sensitivity to a variety of climate forcing factors, including greenhouse gases.

(5) *How sensitive are the climate features of most significance to human populations (e.g. extreme weather events) to changes in forcing?*

ESH has supported a limited set of projects that address specific climate elements of major significance to human populations (e.g. persistent mega-droughts, typhoon landfalls), or that have attempted to assess how human populations have responded to past climate changes (e.g. the rise and fall of the Mayan civilization).

B) Promoting cross-division and interdisciplinary research.

The fact that EAR, ATM, and OCE all support ESH is noteworthy, and in itself sends a strong signal that the Geosciences Directorate is serious about creating the linkages necessary to support interdisciplinary research. The strong and dedicated leadership of GEO Program Directors has been pivotal in ensuring the success of ESH and the extra effort to co-fund proposals is to be applauded. In particular, Dave Verardo has provided strong and dedicated leadership to the program that has ensured its success. The value of

strong leadership cannot be overstated. The Panel notes many cases in which ESH research crosses disciplines and divisions, and where funded collaborations involve multiple institutions and diverse areas of expertise. However, the data were not available to demonstrate the extent to which shared funding or the diversity of investigators were actually unique or even well outside the norm. The Panel believes that the investment in ESH has created the conditions (i.e. the maturity of discovery in both data sets and mechanisms) that support and enable interdisciplinary research. For example, there is substantially greater synergism between the paleoclimate community and the dynamics community. There is little evidence, however, that specific teams representing different disciplines are being funded by ESH. There remains much potential benefit in promoting both cross-division and interdisciplinary research involving the Earth system.

C) Have the goals of ESH been met?

With regard to ESH goals set out in the 1990 planning document, the investment in some areas has probably exceeded the initial goals. In the case of the Holocene, the goals of ESH became more focused, with positive effect, as the science progressed (compared to the initial objectives of assessing the short-term record of variability in the initial ESH guidance). Some areas are characterized by slower progress (climate sensitivity, the broader analysis of spatial and temporal variability). Some goals were added because of growing interest (i.e. arctic climate change). Some goals are associated with little progress through ESH specifically (sea level change and carbon cycle research). The Panel's perspective is that the changes in focus or emphasis reflect a flexible history of funding that has changed in response to scientific discovery and recognized need. However, as stated above, the full set of original ESH goals and the science associated with all the major areas of contribution to climate and global change has made progress, but fruition has not yet been achieved.

D) Impacts on other areas of science, nationally and/or internationally.

There is no doubt that Earth system history research has had a significant impact on the full range of climate-related sciences from physical oceanography to atmospheric sciences to biology. In addition, some science questions in other disciplines have emerged or re-emerged because of ESH contributions (i.e. the role of climate in influencing human populations in the study of anthropology and archeology). ESH science has provided important guidance for international programs such as ocean drilling, promoted the development of high-resolution piston coring, and has contributed significantly to programs that are encompassed by PAGES (Past Global Changes) and to the intersection of PAGES and CLIVAR. The contributions to international programs such as PAGES as part of the current ESH program are not explicit. ESH contributions are highly evident in international research efforts, although there is some sense that international efforts in Earth system science are beginning to surpass(?) U.S. efforts. It is also interesting that Earth system history research and contributions in the international community appear to be outstripping US contributions. ESH has significantly influenced policy through such venues as the IPCC. ESH results are both highly visible and highly policy-relevant. The interest of policy-makers in ESH results is evident by the increasing

number of White House and Capital Hill briefings on research topics such whether the recent warming is unique compared to the last 1000 years.

E) Was a focused program necessary to the success of ESH?

The three key aspects of a focused ESH – the intellectual justification of ESH, driven by key questions of great importance to society, the signal that Geosciences is committed to science that is interdisciplinary, and the directed financial support - most certainly served to foster more rapid discovery and more advanced contributions to key science questions than would have been the case without a focused program. The importance of the research addressed by ESH suggests that this research would have eventually been accomplished even if ESH-related science was a part of the core divisions of the Geosciences Directorate, but the timeliness would not have matched the importance of the research to society.

F) Are ESH goals still a high priority?

The ESH goals remain a high priority for the Geosciences and for climate and global change research. The five major challenges outlined in (A) above are extraordinarily important to society and much research remains to be accomplished. In analyzing these challenges, science questions (1) and (2) are characterized by significant progress, but the research is far from complete. Significant questions remain – such as whether abrupt climate change is only a characteristic of climate states with significant land and sea ice. We have only begun to show the potential of ESH studies to elucidate the potential for significant changes in regional and temporal variability (science question 3). The assessment of climate sensitivity using Earth system history is in its infancy, as are the efforts to examine specific climate features of significance to human populations such as severe weather and extreme conditions. We need to develop models that are designed specifically to address ESH questions. Importantly, ESH has created the conditions that can promote truly interdisciplinary research, but that objective, and the fruits of this type of research, is far from achieved. There is much unrealized potential in joining the modeling and data communities in ESH.

It is significant to the Panel that the 2005 Working Group outlined six specific goals, each of which directly relates to the major challenges outlined in this review:

- I. Is the instrumental record of climate variability unusual in the context of the past several thousand years?
- II. What role do cryospheric feedbacks play in climate change?
- III. What is Earth's climate sensitivity to radiative forcing changes?
- IV. How do ENSO and/or other coupled modes respond to changes in forcing? How does ENSO respond to changes in mean climate state?
- V. Is there a link between changes in ocean circulation and climate?
- VI. What factors within the climate system are responsible for the observed correlation between climate change and solar forcing at shorter than-Milankovitch timescales?

(I) is a direct match to Challenge 1 as described under “Key Accomplishments” above. (II), (III), (V), and (VI) are of major importance in understanding climate sensitivity (Challenge 4). (II) is also directly applicable to understanding abrupt climate change (Challenge 2). (IV) is directly related to improved understanding of the nature of spatial and temporal variability (Challenge 3).

The overall challenges that ESH addresses remain as critical scientific needs, although the specific areas of focus within ESH have evolved with scientific discovery and recognized importance to society.

(G) New Directions and effective ways to move forward

An ESH-type program should continue primarily because of the critical nature of the problems that it addresses, and the obvious relevance to national and international policy debates on global warming. ESH is of major importance for advancing the pace of discovery. Further, it is clear that several key goals of ESH have only begun to bear significant results. Even in areas of fundamental and highly visible ESH contributions (e.g. the elucidation of trends over the last millennia), the research potential is still significant in terms of its contributions to our understanding of climate and global change. ESH has also not yet achieved its potential in terms of supporting interdisciplinary discovery.

The Panel can find no other effective way to move forward outside of a focused cross-division, interdisciplinary program. However, the opportunities for stronger contributions from other agencies, a stronger ESH program at NCAR, and more deliberate efforts to promote international collaboration would be beneficial.

Recommendations

- 1) A focused cross-divisional and interdisciplinary ESH program should remain as a priority for NSF and the Geosciences Directorate.
- 2) There are significant areas of unfulfilled potential in all of the major challenges of Earth System History and its contributions to understanding climate and global change research.
- 3) The program would benefit from stronger interagency support, international collaboration and connections to major centers, such as NCAR.

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