The Earth Science Vision for 2025: A NASA Perspective

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ABSTRACT

The NASA Earth Sciences Vision defines a future paradigm of scientific understanding and prediction capability for 20 years hence. Under this new paradigm, the ever-changing Earth system and its major facets—the climate system, weather, the biosphere, and the solid earth—will be accurately observed, and understood well enough to make predictions of climate change, severe weather, ecosystems changes as well as limited predictions of earthquakes and volcanoes.

1. BACKGROUND

Climate, weather and other Earth processes strongly affect human activities. In the United States alone, average annual weather-related damage exceeded $17 billion per year during 1991-1995, with about 500 fatalities per year. Other changes in the Earth system, both natural and anthropogenic, have profound economic impacts. Human activities in many areas of the world are considerably more sensitive than the United States to changes in climate, weather, and other natural hazards.

As the human population grows and as the demand for food and natural resources grows, the Earth system and human activities have an increasingly intermingled relationship. For example, fresh water, once abundant, is becoming an increasingly critical resource due to the multiple and often conflicting societal demands, such as agriculture, urban sprawl, preservation of natural areas and biodiversity, or recreation.

The NASA Earth Science Enterprise addresses high priority science process studies, presently including: the carbon cycle, climate and weather, the hydrologic cycle, atmospheric chemistry, ocean surface characteristics, bio-ecosystems and human-biosphere interactions, solid Earth processes, many other process studies, plus alteration of Earth processes in response to climatic changes. Due to the long lead time for space technology development, it can take ten years or more to develop the science and the spaceborne observing capability, and, following that, to transition new measurements systems and technology to operational centers. The planning outlook for the NASA Earth Science Enterprise is therefore most strongly directed towards the one to ten year time frame. The technology development in support of these decadal priorities includes the following instrumentation initiatives such as the Earth Observing System (EOS) and other research missions, plans to transition to the NPOESS Preparatory Project (NPP) and then on to NPOESS, and to future geostationary Earth sensing satellite systems.

The NASA Earth Sciences Vision (ESV) planning activity seeks to identify the outlook beyond the current decadal horizon for Earth science planning. The ESV activity identifies the far-reaching science goals that will fundamentally change the understanding of Earth system processes, and consequently the ability to forecast changes in the Earth system and the relationships between the Earth system and life on Earth. The initial steps of the Earth Science Vision process have been to identify key science issues and the new observational and numerical modeling capabilities required to support the science. Following this step comes the definition of candidate technologies—novel new observing strategies more capable and flexible computing capabilities, and efficient product delivery, etc.—that will be required to meet the needs of society.

To address these broad Earth Science Vision issues, science working groups have identified far-reaching goals for new science understandings of the Earth system. These working groups addressed the following:

- long term climatic trends, which can occur over many years,
- monthly to seasonal climatic variability, which can result in major floods and droughts which can change whole ecosystems,
- extreme weather events such as hurricanes and severe storm systems,
- ecological forecasting that can result from climate and weather changes and can affect food supplies,
- solid Earth changes, such as earthquakes, volcanoes and sea level rise.

The scientific issues and some technological responses to these issues are discussed briefly herein, and more completely in the papers that follow in the Earth Science Vision Sessions at IGARSS-2002.

In future years, this long-term, Earth Science Vision planning process will continue in concert with shorter range planning for new science missions and new technologies. This will occur as the NASA science plans are updated, science knowledge and capabilities increase, and new science priorities emerge.

2. Identified Research Topics

The five Earth Science Vision work groups each identified important areas for breakthroughs in science knowledge that would serve as goals for new capabilities and applications in 2025.

The five science areas identified as highest priority for new Earth science capability include the following:

- the availability of water under the stress of long term climate changes,
- development of the conceptual basis for understanding intra-seasonal to seasonal weather and climate variability; there is currently no theoretical basis that adequately explains major changes in weather on these scales,
- understanding the factors that affect predictability of tropical storm (hurricane) track and intensities,
- ecological species forecasting, and
- understanding the linkages between sea level and changes in climate and other aspects of the Earth system.

Additional science topics with high priority were also defined by the work groups, and include the following:

- the ability to understand, measure and forecast the hydrologic cycle under the effects of the changing climate,
- ecosystem health including biodiversity changes and invasive species,
- severe storm systems such as tornado, hail, winter snow and ice storms, and
- earthquakes, and volcanoes.

3. Improvement in Observational and Modeling Capabilities

Improvements in scientific understanding generally evolve, first from new abilities to observe how nature operates, and then from new theories that provide explanations for the measurements. Finally, as the observations and the interpretative theories are confirmed, predictive models can be developed that provide the ability to foresee future changes or the effects of changed forcing. For each of the Earth system research goals, the ESV work groups therefore addressed the needed improvements in observational capabilities that would be required to achieve the new level of understanding, plus the types of new modeling capabilities that would be required to evaluate theoretical explanations of the observations.

Through all the work groups, a common theme for the required measurements and modeling capabilities includes the ability to address temporal and spatial scales that extend from climate through weather, and the need to provide for the constancy and traceability of calibration across evolving instruments and theoretical realizations, and at the very long time scales that are suitable for climate research.

The new observational and numerical modeling requirements for improving most aspects of the climate and weather issues centered on some common needs:

- Precise measurement of atmospheric and oceanic circulation systems and the transport of heat at temporal and spatial scales appropriate to the physical processes. This includes profiles of atmospheric temperature, humidity, and winds; certain atmospheric chemical constituents and aerosol loading; ocean structure and circulation.

- Measurement of the full hydrologic cycle and how it responds to climate changes. This includes measuring precipitation and evaporation, clouds, cycling through ground and surface water flow, ground water storage, ocean circulation and salinity, ice and frozen surfaces.

- Measurement of the Earth's land and ocean surface, including surface characteristics such as temperature, humidity and roughness, boundary layer depth and fluxes in the atmosphere and ocean, plus ice and frozen surfaces.

- Development of four dimensional, ensemble models that enable assimilating the new measurements into a numerical framework within which new theories can be developed, tested and improved

- Improvements of basic atmospheric and ocean model physics and of sub-grid scale parameterizations of the hydrological, turbulent and air-sea/land-sea interaction.

The new observational and numerical modeling requirements for improving the ecosystem health and biodiversity research included:

- Development of the ability to model and map biological resources, including ecosystem biophysical structure, functional capacity, and physiological state;

- High-dimensionality, hybrid predictive models, scalable spatio-temporal models, and coupled ecosystem/climate/economic models;

- Development of remote sensing measurements to distinguish dominant communities, biodiversity "hotspots", and a reasonable ability to identify keystone species;

- Development of remote measurement of vegetation structure, topography, soils, and phenology;

- Measurement of the full hydrologic cycle and how it changes with climate changes. This includes measuring precipitation and evaporation, clouds, cycling through ground and surface water flow, ground water storage, ocean circulation and salinity, ice and frozen surfaces.

The new observational and numerical modeling requirements for improving the solid earth issues, including sea level rise, earthquakes and volcanoes, included:

- Measurement of Earth surface changes, including Earth surface characterization, post-glacial rebound and ground deformation effects;

- Measurement of the full hydrologic cycle and how it changes with climate changes. This includes measuring precipitation and evaporation, clouds, cycling through ground and surface water flow, ground water storage, ocean circulation and salinity, ice and frozen surfaces.

- Development of new numerical modeling capabilities that enable assimilation of these data into a predictive capability for solid Earth changes and effects.

An interesting aspect of this process was identification of some common high-priority science themes that extended between the research groups. Most obvious was the theme of observation and full scientific understanding of the hydrologic cycle. This relates closely to the issue of availability of water, and extends to climate, weather, ecosystems, the carbon cycle, biodiversity, and the quality of life.

A second common theme was precise measurement of atmospheric and oceanic circulation, at scales ranging from climate down to large weather systems, and including atmospheric and oceanic structures, heat transport, and chemistry. Although most closely related to the understanding and predictability of climate and weather, this topic had important links to ecological forecasting and to solid Earth.

The third major cross-cutting topic was the development of vastly improved, high resolution numerical modeling capabilities that can assimilate new measurements, providing a forum for evaluating new theoretical understandings of earth system processes.

Central to this whole enterprise is the science concept that everything on Earth is intimately linked to the rest of the system, and that perturbations that happen here, can be manifest by results far away. The requirement is therefore an understanding the Earth system as a whole so as to provide the needed linkages to understanding life on Earth, and predicting the impacts of changes in the Earth system. As we learn more and more about the Earth system, we continually become more aware that life on Earth is in continuing response to change.

The Role of NASA

The role of the NASA Earth Science Enterprise is to develop new approaches and technologies that enable improved scientific understandings of the Earth as a system. These activities have important application to understanding the interactions between Earth systems and life on Earth. The Earth Sciences Vision effort extends the outlook from current, high-priority science and technology development, to far future capabilities that will transform our understanding of the complex relationships between life and the Earth system. In addition to the developing new science knowledge and technology capabilities, the approaches to accessing and disseminating information will be greatly simplified as the information is made fully accessible to users. NASA, as the primary governmental agency for space-based Earth science and application, leads these activities, working in close concert with other government agencies and national and international principal partners. NASA focuses on new technologies which transform observing capabilities, and which are destined to be operated by other agencies and private enterprises. The goal is to provide innovative new knowledge, technology and applications that assist decision-makers through in providing new, more accurate and accessible information about the Earth and its support of life on Earth.