The Earth Science Vision: An Intelligent Web of Sensors

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Abstract— In this vision of the future a globally responsive web of space-based sensors, processing networks, and distribution systems will create and deliver information products to users throughout the world. Great leaps forward in the ability to predict earth systems behavior and response will be its hallmark. One challenge is that a greater scientific understanding of basic phenomenology is required and is essential in the evolution of this vision. The second challenge is that key technical capabilities are needed to implement these systems. Revolutionary advancements are required in many scientific and technical areas. A computer-generated video will illustrate concepts of how the sensorweb may evolve and operate. Realization will require participation on a grand scale—national; international; and commercial partnering. A long-term commitment among all stakeholders and constituents will be essential to make it work. The payoffs on a global scale can be significant both economically and societal.

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Introduction

The mission of NASA's Earth Science Enterprise (ESE) is to develop a scientific understanding of the Earth system and its response to natural and human-induced changes to enable improved prediction of climate, weather, and natural hazards for present and future generations.

Currently more than 40% of the U.S. economy is sensitive to weather and climate. Between 1991 and 1995, the average annual weather-related damage in the U.S. was in excess of $17 billion per year, accompanying a death rate of 500 persons per year. Much of the world is even more sensitive to weather, climate and natural hazards than is the U.S.[1]

By the year 2020, the planet Earth will have undergone profound human-induced changes[2]. The population of the earth will be increase to in excess of 7 billion people. The coastal populations will have increased by a factor of 2 to 3. Extensive areas of the tropical rainforests may have been burned for agricultural usage by 2020. Food and fresh water shortages may become common. The impacts from climate, weather, and natural hazards will further strain our economic and natural resources. As more people and assets in the U.S. move to the coasts, and as nations around the world seek to increase living standards for their growing populations, the need for a proactive Earth system prediction capable of providing for economic, ecological and societal benefits will be essential.

NASA's ESE is planning to revolutionize our understanding of and predictive capability of the Earth's environment and climate in the 2020 timeframe, through a remarkable new Earth observing and analysis paradigm known collectively as the "Earth Science Vision."

The Earth Science Vision Initiative[2]

The Earth Science Vision Initiative (ESVI) began in late 1998. NASA Headquarters requested that NASA's Goddard Space Flight Center (GSFC) lead an agency wide effort to look the role of NASA's Earth Science Enterprise in the 2020 time frame. The ESVI was established to develop the Earth Science Vision (ESV), a series of key science and application targets to be achieved in the 2020 time frame and beyond.

Three of the guiding principles[1] for the development of ESV were:

- To fundamentally improve the predictive capability of Earth system models, including climate, weather, pollution transport, biological and atmospheric change, and other physical processes, on both a short and long-term basis;

- To develop better monitoring systems for Earth processes, including provision of integrated ground and space-based sensor networks (operated jointly with partner agencies) to provide both near real-time monitoring of global events and continuous, long-term data sets for scientific research;

- For NASA to enhance current and to establish new partnerships with other agencies to support the implementation of fundamentally improved Earth monitoring, hazard avoidance and disaster relief programs with new technologies and data products for use by its partners.

EARTH SCIENCE VISION

The ESVI set forth to layout a roadmap for a future where a proactive Earth system prediction capability enables a richer relationship of people with our home planet. This includes all the means and benefits of climate, weather, and natural hazard prediction, such as:

- 10 year climate forecasts
- 15-20 month El Nino / La Nina prediction
- 12 month regional rainfall rates
- 5 day hurricane track prediction to +/- 30 Km
- 2 day air quality notification
- 1 hour volcano and earthquake warning
- 30 minute tornado warning.

To support this, NASA has developed a twenty-five year ESV of future capabilities to observe, understand and forecast the state of the Earth in the interests of mankind.

NASA's Earth observing satellites and related research have led scientists to view the Earth as a system—as a complex dynamic set of interactions among the land surface, atmosphere, oceans and ice caps, and the Earth's interior. Human activities long apparent at the local level, are now seen as causing global-scale impacts, first in stratospheric ozone depletion and now perhaps in changing climate. Our planet continues to offer disruptions of its own in the form of earthquakes, volcanic eruptions, and severe weather[3]. These profound realizations have given rise to the birth of the new interdisciplinary field of Earth System Science. This way of studying the Earth is critical to understanding how global climate responds to the forces and feedbacks acting on it.

Researchers have constructed computer models to simulate the Earth system, and to explore the possible outcomes of potential changes they introduce in the models. This way of looking at the Earth as a system is a powerful means of understanding changes we see around us.

That has two implications for Earth Science. First, we need to characterize (that is, identify and measure) the forces acting on the Earth system and its responses. Second, we have to peer inside the system to understand the source of internal variability: the complex interplay among components that comprise the system. Earth system changes are global phenomena.

Historically Earth remote sensing has consisted primarily of a single spacecraft with multiple instruments in a classic "stove-pipe" campaign. The science collected by each campaign tended to be focus on one particular focused area or science discipline (such as land cover) and not interrelated to other science disciplines. Each individual mission or campaign was operated independently of other science missions. Typically there is no real time sharing of information between sensors, other spacecraft or investigators. We would fly over a particular area, image or sense the area and re-visit the same area sometime in the future (e.g., Landsat has a 14 day revisit period.) Earth remote sensing was effectively remote monitoring.

In the vision (2020) timeframe, we envision a system where: A million miles from Earth, deep space sentinels provide interferometric characterization of our atmosphere day and night, feeding cloud and temperature data to scientists' models to produce a ten year forecast of climate variability. Closer to Earth, observations from satellites and buoys enable a 15 month advance warning of the next El Nino event. Regionally-specific, seasonal forecasts of precipitation are updated, allowing farmers in the southeastern U.S. to select between drought and flood-resistant crops, and Forest Service officials to redistribute fire fighting resources based on adjusted fire potential indices. Meanwhile, a combination of sensors measuring wind vectors and precipitation rates drives a 3-D model of the structure of Hurricane Hattie, enabling the U.S. Hurricane Center to nail the landfall prediction and minimize the evacuation area.

CONCLUSION

By the year 2020 we plan to revolutionize our understanding of the Earth's environment and climate, through radical, new paradigm. Rather than simply monitor and response to changes in the Earth's environment, we will heavily involved in actively modeling and forecasting changes in our environment. Rather than just detecting changes and natural hazards after they have occurred, we will be anticipating these changes and natural hazards before they begin. We will be able to offer the public 5-day hurricane track prediction,
1 hour earthquake warnings, and 30 minute tornado warnings routinely.

To accomplish this, by the year 2020, we envision a world where a global, intelligent web of space-based, air-based, and insitu sensors coordinate observations and collaboratively gather relevant data. Where networks of computers co-operatively collected and processing the vast qualities of data. Where distribution systems will create and deliver information products directly to the users throughout the world.

Two major areas of challenges do exist. Both of which are being worked;

- One challenge is that a greater scientific understanding of basic phenomenology is required. Our current set of EOS are providing us extensive insight into the phenomenology.
- The second set of challenges are the key technical capabilities needed to implement these systems.

While some of these challenges may seem far-reaching, there is work already in progress within NASA, other agencies and the private sector which when developed, will facilitate many elements of this vision. Already the Earth Science Constellation (ESC) is one of the first step toward developing our web of sensors in space. ESE is striving to coordinate and identify coincident imaging among it's EOS missions. To achieve this, the operational coordination of the entire Sun-synchronous ESC will be viewed as a whole system. (This planned constellation currently consists of at least 9 identified missions, four (LANDSAT-7, EO-1, SAC-C and TERRA) with AM node crossings (morning train) and five (Aqua, PICASSO-CENA, CloudSat, Aura and Parasol) with PM node crossings (afternoon train).) Even this recent accomplishment is showing great promise in improving our understanding of our environment.

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