Science for Society: Delivering Earth System Science Knowledge for Decision Support in the Year 2025

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Abstract – **The Earth Science Enterprise Applications Program mission is as follows: Expand and accelerate the realization of societal and economic benefits from Earth science, information, and technology. The Applications Program serves its mission, the Earth Science Enterprise and the Nation by benchmarking practical uses of NASA sponsored observations from remote sensing systems and predictions from scientific research for decision makers. This mission in 2003 will still need to be accomplished in 2025 as the understanding of Earth system science increases and as new and/or continuing challenges face the citizens of the home planet. The ESE Applications Strategy builds on the strategies and results of the ESE Research Program and of the ESE Technology Program. Therefore, as these programs develop a vision for the future, it is important for the Applications Program to consider the vision of NASA for 2025 and have its own vision for how the decision makers of 2025 may use the visionary observation and prediction products to serve society. This paper will propose an architecture for an Earth Resources Management Infrastructure to serve decision makers in the Year 2025.**

I. INTRODUCTION

At the writing of this paper, the U.S. Census Bureau's POPClock reports that the United States population is estimated to be 290,646,612 and the world's population to be 6,284,624,834. Three years ago (June 1999) the number of people on Earth reached 6 billion. In just three years, the population of the world has increased by an amount equivalent to that of the entire United States. The world's population is projected to exceed 8 billion by the year 2025.

With Earth's human population growing at such meteoric rates, it is not surprising that demands on the planet's natural resources are being stretched to their limits. For example, fresh water is becoming an increasingly critical natural resource to manage due to the multiple, and often conflicting, societal demands for water use. Water withdrawal for irrigation, industry, and municipal use are placing significant burdens on this finite resource. In contrast to the 50 million hectares irrigated at the beginning of the 20th century, nearly 250 million hectares are now under irrigation for agricultural use (a 500 percent increase). The increases in world food production that we have enjoyed over the last century have been enabled by this 500 percent increase in water for irrigation. In addition to the irrigation demands for agriculture, industrial and municipal water demands will increase in many countries due to urbanization, and increases in income and population. In fact, by the year 2025 the Earth's water cycle is projected to be stressed more from population growth and development than from climate change [1]. Finally, demand for all non-irrigation use of water is estimated to rise by 62 percent between 1995 and 2025 [2]. Since water is required to sustain the world food supply to serve the projected populations, there is a need for water management policies that optimize the use of water amongst its various end uses.

As it turns out, those who manage resources in the United States may bear the greatest responsibility compared to others around the world. That's because the global resource use per capita per year in the United States exceeds the rest of the world in every category and the United States population is only 4.6% of the total world's population.

Can the Earth system keep up with such great demands on water management and food production to accommodate future generations? Studies report the inherent difficulties associated with funding the growth in the Earth's physical infrastructure (transportation networks, desalination facilities, etc.) to maintain pace with the population expansion. The challenge is to establish an approach based on the capacity of Earth science information to support decision makers in establishing policies and management solutions to better utilize Earth's resources (food, water, energy, etc.) for the good of the global society. A component of the challenge is to develop an Earth resources management infrastructure. The Earth science and engineering communities have the opportunity to build the infrastructure to use the observations, the computational models, and the knowledge about Earth system science to enable decision support to be used globally, nationally, regionally, and locally.

In an effort to address challenges of managing the Earth's resources to meet the basic needs of increasing populations while preserving the environment, a series of international meetings have taken place over the last decade. These include the Rio Earth Summit in 1992, the Johannesburg World Summit on Sustainable Development in 2002, and the annual UN Framework Climate Convention (UNFCCC) Conference of the Parties (COP). An objective of this paper is to recognize a challenge for the information systems communities (computational, science, engineering) to address the need to build an Earth resources management infrastructure that will assist the decision and policy makers in meeting the needs of the Earth's burgeoning population. Decision support tools that are based on scientific knowledge of Earth system processes benefit policy makers in evaluating scenarios to optimize the balance of Earth resources and economic stewardship in developing and evolving global and regional policies and resolutions. If it is not practical to expand the world's physical infrastructure at a rate required to keep pace with the needs of projected population growth, then is the solution to develop an effective global information infrastructure?

We now have the ability to embark on the scientific grand challenge of understanding our complex home, Planet Earth, to answer questions of whether expanding our knowledge and increasing access to that knowledge may alleviate the pressures impacting our dynamic system.

II. AN APPROACH: UNDERSTANDING AND PROTECTING THE EARTH SYSTEM

Earth system science, the study of how the Earth works as a system of continents, oceans, atmosphere, ice, and life, is based on our ability to measure key parameters and integrate the knowledge into Earth system models. These parameters involve variables that are both holistic and interdependent.

In an effort to unravel the complicated phenomenon that make-up Earth's dynamic system, NASA has been pursuing a general research strategy of characterizing, understanding, and predicting the consequences of forcings (changes) on the Earth system. Earth science researchers worldwide are characterizing the Earth system and the interactions among its components with a network of space based, sub-orbital, and *in situ* sensors. Data from this network of sensors, or sensor web, are used to describe land cover change, ocean circulation, the cycling of water and carbon among the land, atmosphere, and oceans, and other key features of the dynamic Earth system. Earth science modelers use the resulting imagery, trend data, and flow depictions to understand the underlying processes to build computational models of the climate system, geophysical structure, biogeochemical processes, and the Earth's response to incoming solar energy. These models are refined over time, assimilated with satellite observations to define initial conditions, and employed in prediction of future variations.

The Earth system is driven by forcings from two sources – natural and anthropogenic. Examples of natural forcings are variations in the solar irradiance and volcanoes spewing ash into the atmosphere. Anthropogenic forcings on the system include deforestation and emissions, such as carbon dioxide from the burning of fossil fuels. Research indicates that carbon emissions from fossil fuels and other sources contribute to long-term climate change. An understanding of the mechanisms whereby carbon cycles amongst the land, atmosphere, and water is key to reliable predictions of future atmospheric concentrations of carbon in all of its forms, and hence, to understanding the contributions from anthropogenic sources. NASA's constellation of more than 20 Earth observing research satellites takes the pulse of the planet by examining the seasonal rhythm of terrestrial and marine ecosystems on a global scale. This view of the seasonal uptake and release of carbon allows new insights into the role of ecosystems in the carbon and water cycles. This research helps envision the impact of global change on food and fiber production and can serve as a component of the Earth resources management infrastructure.

To achieve the understanding of the Earth system that enables innovative approaches for decision support requires two fundamental inputs. Earth science observations are needed from an armada of *in situ*, sub-orbital, and space based sensors to serve operational solutions. These observations must be assimilated into computational models that describe the Earth system at unprecedented resolutions and accuracies.

III. A SOLUTION: AN EARTH RESOURCES MANAGEMENT DECISION SUPPORT SYSTEM

NASA researchers have posed a set of fundamental questions that will lead to our characterizing, understanding, and predicting the Earth system response to forcings. The scientific knowledge acquired through this line of inquiry about the Earth system will enable us to assess our planet's capacity to keep up with the rapid pace of population growth and the subsequent demands on its natural resources to accommodate our quality of life. Answers to these scientific questions will also serve as the basis for the creation of a viable management decision support system.

NASA's Earth Science Enterprise endeavors to understand and protect our home planet by advancing Earth system science to enable improved prediction of climate, weather and natural hazards using the vantage point of space. NASA is deploying and operating the first comprehensive constellation of Earth observing satellites designed to reveal the interactions among Earth's continents, atmosphere, oceans, ice, and life. These interactions produce the conditions that sustain life on Earth. Data and information from these Earth observing satellites enable researchers to understand the causes and consequences of global change and inform the myriad decisions taken by governments, businesses and citizens to improve our quality of life.

Implementing the Earth resources management infrastructure to realize societal and economic benefits requires NASA and its global partners to focus on solutions that are citizen-centered, results-oriented, and market-driven. To accomplish this objective it is necessary to provide a bridge between Earth system science research and the operational solutions manifested in the Earth resources management infrastructure. For example, the Tropical Rainfall Measuring Mission TRMM is a joint mission between NASA and the National Space Development Agency

(NASDA) of Japan to monitor and study tropical rainfall and the associated release of energy. Such precipitation processes help to power the global atmospheric circulation shaping both weather and climate around the globe, including catastrophic events, such as hurricanes and typhoons. In addition, to increasing our knowledge of the Earth's water cycle, TRMM data products may be used for decision support in such diverse areas as air quality, water management and conservation, public health, and invasive species management.

These operational solutions and applications that benefit the public are enabled by systematically relating appropriate results from measurements and applied research in weather, global climate change, and natural hazards. Applied research, in turn, is enabled by basic research and technology developments in Earth system science. The relationship among basic research and development, applied research, and operational solutions is dynamic and iterative and a systematic approach to bridge the gaps between the research and operational domains is required.

The goal of NASA's Earth Science Applications Program is to *"expand and accelerate the realization of societal and economic benefits from Earth science, information, and technology*." In fulfilling this goal the Earth Science Applications Program has developed a systems engineering approach to benchmarking practical uses of NASA-sponsored observations from remote sensing systems and predictions from scientific research and modeling. The approach is designed to enable the assimilation of Earth science model predictions and measurements from research missions to serve as inputs to decision support systems. In this architecture NASA Earth Science Enterprise (ESE) outputs are information products, predictions, observations, and data products. NASA's partners, who have the mandate to serve society, maintain and operate the decision support resources that are enhanced by NASA ESE research results.

Figure 1 shows a proposed architecture for an Earth resources management infrastructure that is based on NASA's proven approach. The infrastructure consists of observations, model outputs, climate data records, and various others types of data as inputs. These comprehensive datasets and model outputs are synthesized with domain knowledge to create outcomes that are used to impact policies for managing the Earth's natural resources by the global society, and providing the decision support tools for Earth resources stewardship for this and future generations.

NASA is working towards providing decision makers with the data and understanding to help create a powerful system to aid present and future decision makers in managing Earth's natural resources. NASA is working today with organizations that have the appropriate information infrastructure to apply Earth science results. NASA's models, technology, observations and knowledge of the Earth system can be harnessed to enhance predictive capability in fields such as energy forecasting, food production, carbon management, water resource management, along with water and air quality management. The potential worldwide socioeconomic benefits of this predictive capability are significant.

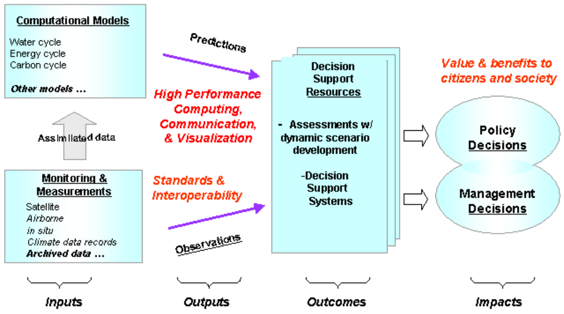

Figure 1 Architecture for an Earth Resources Management Infrastructure to serve decision makers.

Improving life here on planet Earth is foremost in NASA's vision, and in the larger purpose of NASA's Earth Science Enterprise. The vantage point of space yields information about Earth's land, atmosphere, ice, oceans and life that is obtainable in no other way. Global-scale changes require global-scale observations and models, and many regional and local changes are only truly understood when seen in this larger context. It is also true that the challenge of managing the Earth's natural resources can only be answered within the global context. Therefore, as we use the vantage point of space to increase our understanding of our home planet, we can use the same models, technologies, and observations to manage Earth's natural resources. The challenge proposed to the computational science and engineering community is to develop the observations and predictions that may be used to impact policies for managing the Earth's natural resources by the global society, and provide the decision support tools for Earth resources stewardship for this and future generations.

IV. REFERENCES

1. Vörösmarty, C.J., P. Green, J. Salisbury, and R. Lammers. 2000. Global water resources: Vulnerability from climate change and population growth. *Science* vol. 289: pp. 284-288.
2. Mark W. Rosegrant, Ximing Cai, and Sarah A. Cline, *Water and Food to 2025: Averting an Impending Crisis*, International Food Policy Research Institute and International Water Management Institute, www.ifpri.org, 2002.
3. Thomas E. Graedel and Paul J. Crutzen, Atmosphere, Climate, and Change, Scientific American Library, 1995.