NASA EARTH SCIENCE ENTERPRISE: A NEW WINDOW ON OUR WORLD

G.R. Asrar, G.J. Williams and P. Morel
NASA Headquarters, Washington, D.C., USA

Keywords: Earth system, feedback, satellite remote sensing, interactions

Contents

1. Introduction
2. A Scientific Vision—The Earth as a System
3. A View From Above—Characterizing the Earth System
3.1. Biosphere–Atmosphere Interactions
3.2. Ocean–Atmosphere Interactions
3.3. Climate–Chemistry Interactions
3.4. Polar Regions–Atmosphere Interactions
4. Taking It All In—Understanding the Earth System
5. Getting There From Here—Predicting Earth System Change
6. Conclusion
Acknowledgements
Bibliography
Biographical Sketches

Summary

The view from space made possible by satellite remote sensing technologies has enabled researchers to study the interactions among continents, oceans, atmosphere, ice, and life. As a result, they have come to view the earth as a dynamic system, and to turn their attention to the interactions among these major components. The new, interdisciplinary field of Earth system science was created. Early results from this research are already showing benefits in weather, climate, and natural hazard prediction. It is envisioned that the promising nature of this research will motivate development of an intelligent constellation of satellites for research and practical applications of Earth system science.

1. Introduction

Earth is the only planet in our solar system where highly diversified life is thriving. Why is that? The reason (or the necessary condition) for this unique feature is that the Earth system has maintained essentially constant global-mean climatic conditions (within a few degrees of global mean temperature) for a period in excess of three billion years up to the present era, despite considerable changes in the arrangement of oceans and continents and significant increase in the brightness of the sun. This remarkable property cannot be the result of chance: the Earth's climate system, alone among other planets, constitutes a thermostat of cosmic proportion. We know now that the operation of this thermostatic mechanism is based on external forces such as the solar energy we receive from the sun and a set of complex interactions that take place among the atmosphere, oceans, continents, and life on Earth. For example, the two physico-chemical cycles: the carbon cycle through the Earth atmosphere, ocean, and the lithosphere on the one hand, and the water cycle between the atmosphere, rivers and land, and the oceans play a major role in the operation of Earth's climate thermostat. Both cycles are responsible for removing carbon dioxide from the atmosphere.

Carbon dioxide (actually carbonic acid) dissolved in rain water slowly but relentlessly attacks rocks through the process of "weathering." The resulting carbonates find their way through rivers to the oceans and the ocean floor, where they slowly accumulate and constitute enormous limestone deposits. Except for the activity of the Earth interior and the constant recycling of the lithosphere (i.e. Earth's crust), carbon would have long disappeared from the atmosphere and oceans, thus making the earth forever sterile for life as we know it. As far as we know, this is what happened on Mars. Earth has active plate tectonics that constantly recycle the lithosphere: no piece of the ocean floor is older than 200 million years.

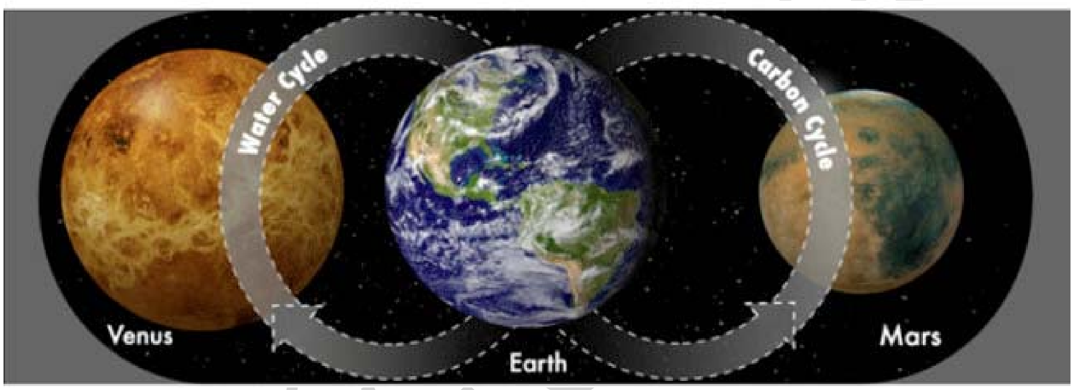

Figure 1. In contrast with its nearest neighbors, Earth hosts highly diversified life (*Source*: NASA)

The result of this recycling is constant outgassing of carbon dioxide into the atmosphere, thus replenishing the carbon supply for life to thrive on. However, had the water cycle failed to control the ongoing accumulation of carbon dioxide, the Earth atmosphere would have suffered a runaway greenhouse effect and made conditions unlivable at the surface of the planet. Such apparently was the fate of Venus.

Thus, it happened that life on Earth depends critically upon the harmonious interplay of both external and internal forces. Should Earth's climate become too cold, for example, the water cycle would be sluggish and removal of carbon dioxide from the atmosphere would slow down to the point it would not compensate accumulation due to outgasssing from the Earth's interior.

Under these circumstances, the amount of carbon dioxide would increase in the atmosphere and give rise to an enhanced greenhouse effect, thus warming planetary climate (and conversely if climate was too warm). Thus, we have a powerful negative feedback mechanism that has been effective in maintaining stable Earth climate on timescales of millions of years.

2. A Scientific Vision—The Earth As a System

For much of human history, humankind labored to adapt itself to patterns and variability of the Earth system, most notably in response to climate. Over the past several centuries, the balance shifted toward humankind adapting the natural world for human purposes, most notably in food and fiber production, energy generation, and transportation. The circle is now closed: human activity is powerful enough to begin to affect planet Earth. Although the impacts of human activities have long been apparent at the local level, we are now witnessing global-scale impacts such as depletion of stratospheric ozone and perhaps changing climate.

We know that external natural and human-induced forces are acting upon the Earth system and result in a set of responses in Earth's environment. Natural forces include variation in the Sun's energy output that reaches Earth and volcanic eruptions that spew gases and ashes into the atmosphere and lava to the Earth's surface. Human forces include deforestation, emission of gases from automobiles and industrial activities, and other chemicals resulting from agricultural practices. Internal forces such as atmospheric water vapor and clouds also act upon the Earth system and introduce feedback that tends to either dampen or enhance the effects of internal/external forces acting upon Earth. We also know that Earth's climate demonstrates considerable internal variability (i.e. both short- and long-term changes and regionally specific impacts such as droughts and floods).

The view from above provided by NASA Earth Science Enterprise led to a new scientific vision: that of the Earth as a dynamic, integrated system of land, oceans, atmosphere, ice, and life. This vision has given rise to the new, interdisciplinary field of Earth system science, illustrated conceptually in Figure 2. NASA has sponsored the intellectual development of this exciting endeavor, and has stoked the flames of discovery with a series of satellites aimed at understanding the Earth system.

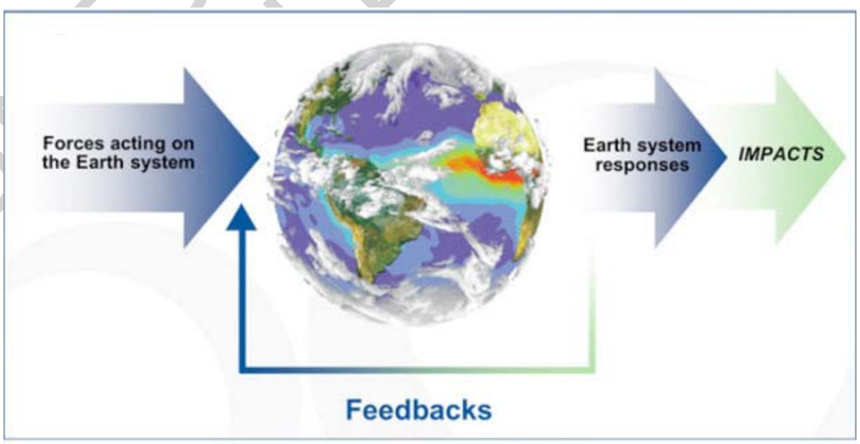

Figure 2. Earth system conceptual model
(*Source*: NASA)

To conduct Earth system science, the science community must: 1) characterize (that is identify and measure) the forces acting upon Earth and its responses; 2) understand (carry out scientific research on) the sources, causes, and magnitude of external and internal forces, feedback, and variability in Earth system; and 3) capture this knowledge in conceptual computer models to predict future changes in the Earth system.

Earth system changes are global phenomena, yet comprise many regional and local-scale processes and their manifestation being felt by humans. Thus, studying such changes requires a global view at regionally discerning scales. This is where NASA comes in, bringing the unique capability to study planet Earth from the vantage point of space. By combining observations, research, and powerful computer models we create a capability to mimic realistically the behavior of Earth system. As the Earth system models prove to be accurate in describing Earth system behavior we can use them to predict changes in Earth's environment months and years in advance to support key policy decisions on food and fiber production, energy and transportation, commerce and tourism, etc. In short, NASA is focusing the spirit of space exploration on our home planet to provide the necessary understanding and decision support system for the current and future inhabitants of Earth.

Investment in applications of remote sensing to practical problems is expanding the utility of Earth science in the broader economy. Extended weather forecasts, evaluations of forest and crop health, infrastructure layout of utilities and transportation systems for emerging megacities, and objective bases for economic investment and policy choices are all outcomes of NASA's research in Earth science. These outcomes are achieved through applications demonstration projects conducted and implemented by NASA and its partners in academia, industry, and abroad. The commercial remote sensing industry's current annual revenues are nearly US$4 billion today, and are expected to grow to US$10 billion by 2010.

-
-
-

Bibliography

NASA (2000). *Understanding Earth System Change. NASA's Earth Science Enterprise. Research Strategy for 2000–2010*. Washington, D.C.: NASA Headquarters Office of Earth Science. Available on the Internet at: http://www.earth.nasa.gov/visions/researchstrat/Research_Strategy.htm

NASA (1999). *EOS Reference Handbook*. Washington, D.C.: NASA Goddard Space Flight Center EOS Project Science Office. Available on the Internet at: http://eospso.gsfc.nasa.gov/eos_homepage/for_scientists/index.php

Biographical Sketches

Ghassem R. Asrar currently serves as the associate administrator for Earth science at the U.S. National Aeronautics and Space Administration. He has led scientific planning and managed deployment of the

Earth Observing System, and is now doing the same for the next generation of satellite observing capabilities. His scientific interests are in global change and the application of Earth system science to practical societal challenges.

Gregory J. Williams is the senior policy analyst for the Office of Earth Science at NASA Headquarters, with responsibility for development of strategic plans for Earth science at NASA.

Pierre Morel is professor emeritus from the University Pierre and Marie Curie, Paris, and currently part-time faculty at the University of Maryland, Baltimore County. His scientific interests are in geophysical fluid dynamics, meteorology and climate science, and Earth observation from space.