ESSE 21 MODULE – EARTH SYSTEMS SCIENCE
Overview

- Earth Systems Science is multi-disciplinary, in that it encompasses all of the basic fields of science (Biology, Chemistry, and Physics).
- This module includes discussions of the following major topics:
  - Earth and the Solar System
  - Origins: The Creation of Earth and our Solar System
  - Introduction to Remote Sensing
  - The Solid Earth: Geology
  - Earth's Biosphere
  - Origin of Life and Evolution
  - Earth's Water and Ice: Hydrosphere and Cryosphere
  - Earth's Atmosphere, Weather, and Near-Earth Space Environment
  - Effects of Human Activity on the Earth Systems

INTRODUCTION TO EARTH & EARTH SYSTEMS SCIENCE
Objectives

- The primary objective of this module is to provide an introduction to Earth and Earth Systems Science, for college students majoring in science or engineering, or as background for teaching these or related subjects to pre-college students.
- Other objectives include:
  - Providing background for more advanced courses in Atmospheric Science, Geology, Oceanography, Ecology, and other sub-fields of Earth & Earth Systems Science, or related areas of engineering
  - Introducing other educational resources, including books and periodicals, videos, CD-ROMs, and relevant World Wide Web sites.
  - Introducing Earth System Science, and its component topics and significance, to pre-college school students and the general public, by way of informal presentations and media.

ESSE 21 MODULE – EARTH SYSTEMS SCIENCE

- The current version is at the highest level, which is for college students majoring in science or engineering, and for teachers of science at the high school level.
- Other versions planned to be produced include ones for:
  - College students not majoring in science or engineering
  - General public and high school presentations
- Because the fields of Earth & Space Science are rapidly changing with time, computer media (such as PowerPoint presentations, which can be easily updated with time) are preferable to, and less expensive than, printed textbooks.

MAJOR AREAS OF EARTH & EARTH SYSTEMS SCIENCE

- The “classical” fields of Earth Science include the following:
  - **Geology,** the study of the solid Earth
  - **Oceanography,** the study of the oceans and other water bodies
  - **Atmospheric Science**, the study of the atmosphere and its variations (includes meteorology and aeronomy)
  - **Ecology,** the study of the life forms that inhabit Earth, their history, and their interactions with the above.
- More recently, it has been realized that all of these interact with each other, in such a manner that we must consider them all as constituents of the **Earth System**.
- Therefore, we must utilize the processes of **Systems Science**, in order to fully understand the Earth System and its variations as a whole.

INTRODUCTION TO EARTH SYSTEMS SCIENCE

- **Earth Systems Science** is truly an interdisciplinary field of science. It is based on all three of the “basic” sciences, **biology, chemistry, and physics**, but also includes the relatively new field of **systems science.**
- Therefore, the Earth & Earth Systems Science module must also introduce or review many of the basic concepts of Biology, Chemistry, Physics, and Systems Science, as well as the relevant specialties within Earth Science.
- Like in most other fields of science and engineering, **mathematics** and **computer science** are also essential components.
- Earth **Systems** science also includes study of how all of the above **interact with each other.**

WHAT IS EARTH *SYSTEMS* SCIENCE?

- The relatively new topic of Earth Systems Science includes not only the many specialties and topic areas in traditional Earth science, but also *how the different processes interact with each other* to change the Earth system as a whole.
- Examples include the effects of human, as well as natural, processes that affect the composition and temperature of Earth's atmosphere, the temperature and volume of the hydrosphere and cryosphere, and effects on other life forms.
- Earth systems science, in general, includes both positive and negative feedbacks that result from changes (man-made or natural) that affect one or more parts of the Earth system.
  - A **positive** feedback is due to an event or process that, when increased, causes an increase in a natural system (such as atmospheric temperature, which is **increased** by an increase in greenhouse gas content of the atmosphere).
  - A **negative** feedback is due to an event or process that, when increased, causes a **decrease** in a natural system (such as polar ice cap volume and extent, which is **reduced** by increased greenhouse gas content of the atmosphere).

EARTH SYSTEMS SCIENCE

- An example of Earth Systems Science is given by **Darwin's Law of Evolution**, in which those life forms best suited to the environment in which they live are the most likely to survive and multiply.
- Another, simple example is given in the textbook, **The Earth System,** by Lee R. Kump, James F. Kasting, and Robert G. Crane (Pearson Prentice Hall, 2004):
  - A hypothetical planet, Daisyworld, is black in color but partially covered by white daisies.
  - If the planet's sun decreases in brightness, the white daisies do not grow and multiply as rapidly, and begin to cover a smaller area of the planet, which in turn becomes darker in overall color and absorbs a larger portion of the heat and light from the star, hence moderating the decrease in temperature.
  - If the planet's sun increases in brightness, the white daisies multiply and cover a larger proportion of the planet's surface, causing it to reflect more light, and hence moderating the increase in temperature.
  - However, this latter process cannot continue indefinitely, as a point is reached in which it is too hot, even with nearly complete coverage of the planet's surface by the white daisies, for the daisies to survive.
  - This latter stage is the type of scenario which might eventually apply to Earth, resulting from global warming due to increased greenhouse gases!

INTRODUCTION TO EARTH & EARTH SYSTEMS SCIENCE

- **Earth Science** is now considered to be only a specialized area in the broader space science field of **Planetary Science**, particularly in their physical science-related aspects. (However, the emerging sub-field of **astrobiology** has further increased the commonality between the two fields.)
- In addition, the technologies for Earth observations from space have much in common with those for similar observations of other planets and their satellites, asteroids, and comets.
- Recently, NASA has integrated its Office of Space Science and its Office of Earth Science into a single Office of Science, in recognition of these facts.
- Our module, therefore, also includes an introduction to our Solar System, and its origins, of which our Earth is an average member in many characteristics (but unique in others) relative to the other planets.

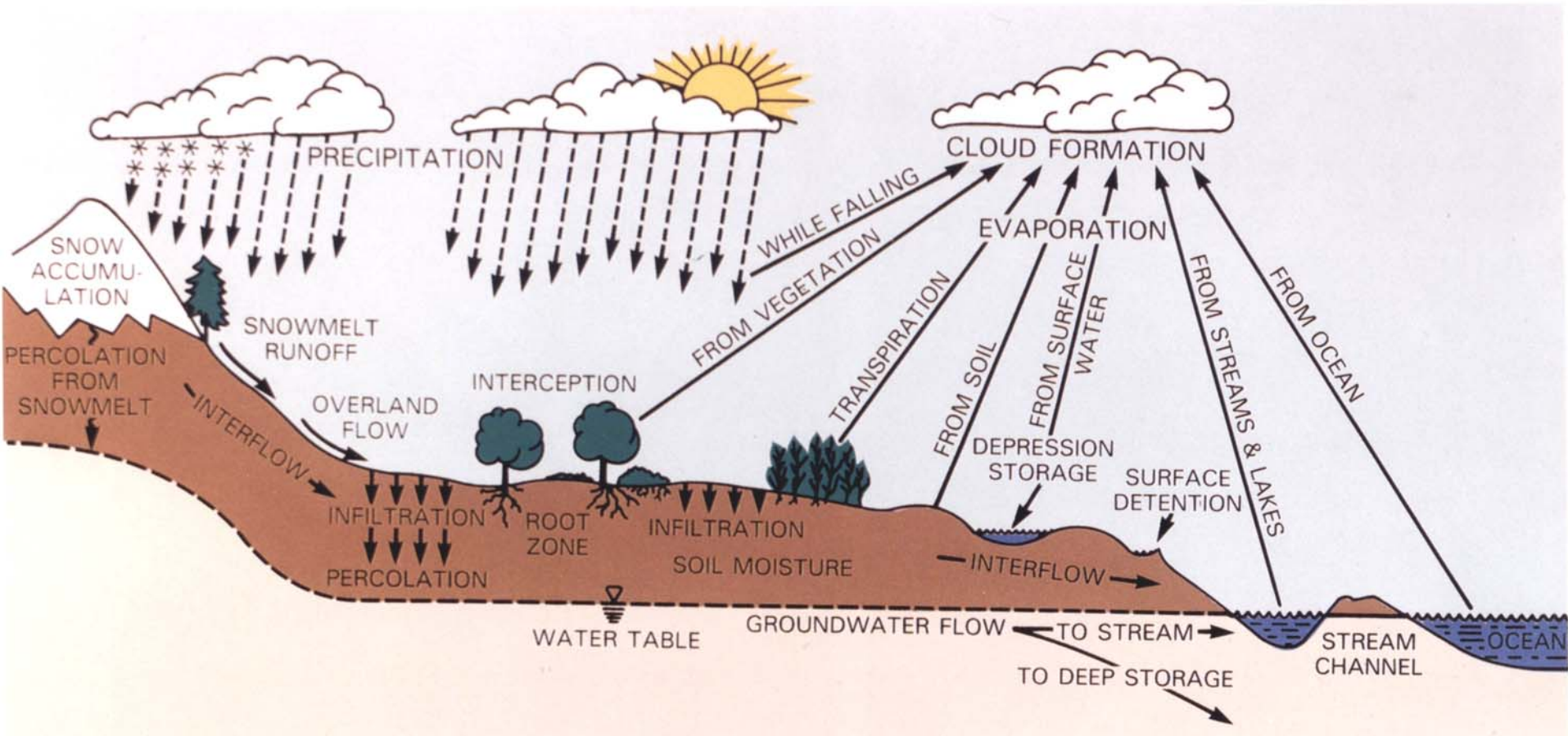
GEOLOGICAL AND GEOCHEMICAL CYCLES

- The Earth system, consisting of the solid Earth, its atmosphere, and its hydrosphere, constitute (for all practical purposes) a **closed system.**
- Therefore, although the chemical and physical states of the elements constituting the Earth can be interchanged between various physical and chemical states, **the total amount of any element or non-reactive compound is fixed.**
- Examples of **geologic cycles** of practical importance include:
  - The **Hydrologic Cycle** (the interchange of water between gaseous, liquid, and solid phases)
  - The **Carbon Cycle** (the interchange of carbon between various chemical compounds and states, such as methane (CH_4), carbon dioxide (CO_2), and calcium carbonate ($CaCO_3$)).
  - The **Rock Cycle,** in which igneous rocks are weathered by water and CO_2 to form sedimentary rocks, which can be subducted (by plate tectonics) into the mantle, and be converted back to igneous rocks.

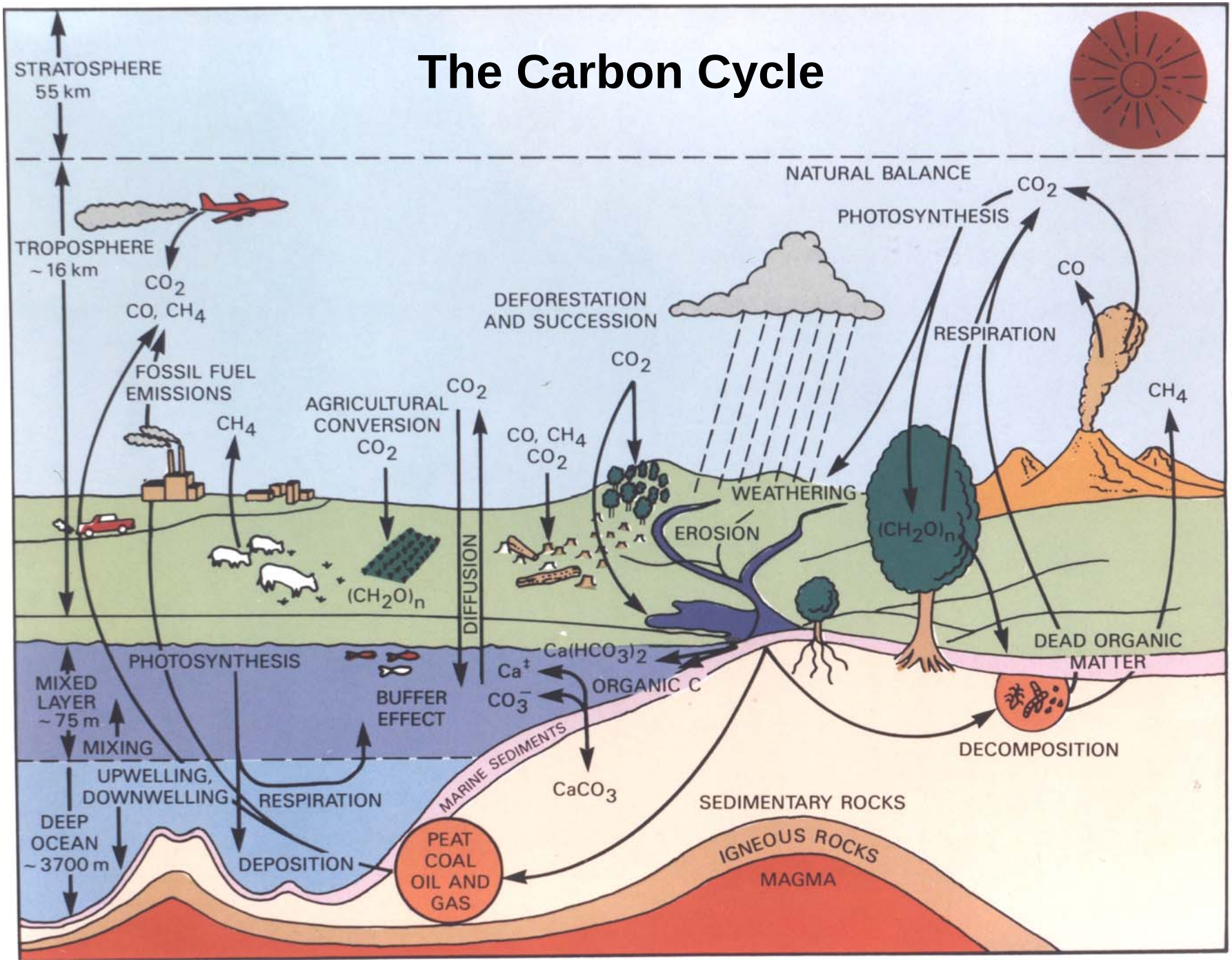
GEOLOGICAL AND GEOCHEMICAL CYCLES

- The **Hydrologic Cycle** is responsible for precipitation (rain and snow) and resulting erosion of land areas
- The **Carbon Cycle** is responsible for the recycling of carbon between the oxidized states (such as CO_2) and the reduced states (such as living organisms and fossil fuels).
- Both of these cycles are of great practical importance to humans and other inhabitants of Earth, but can potentially be altered in undesirable manners by human activities.
- Other cycles include the **Rock Cycle**, which is the means by which the original (igneous) rocks of Earth interact with Earth's hydrosphere and atmosphere to create sedimentary rocks, but also has had major effects (throughout Earth's history) on the atmosphere and hydrosphere, as well.
- An important area of current research in Earth & Space Science is to determine the actual and potential effects of both natural phenomena and human activities on these cycles, and of these cycles on each other, constituting the new field of **Earth Systems Science**.
- This includes two subsystems, **physical climate** and **bio-geochemical cycles**, which are linked by the global hydrologic cycle.

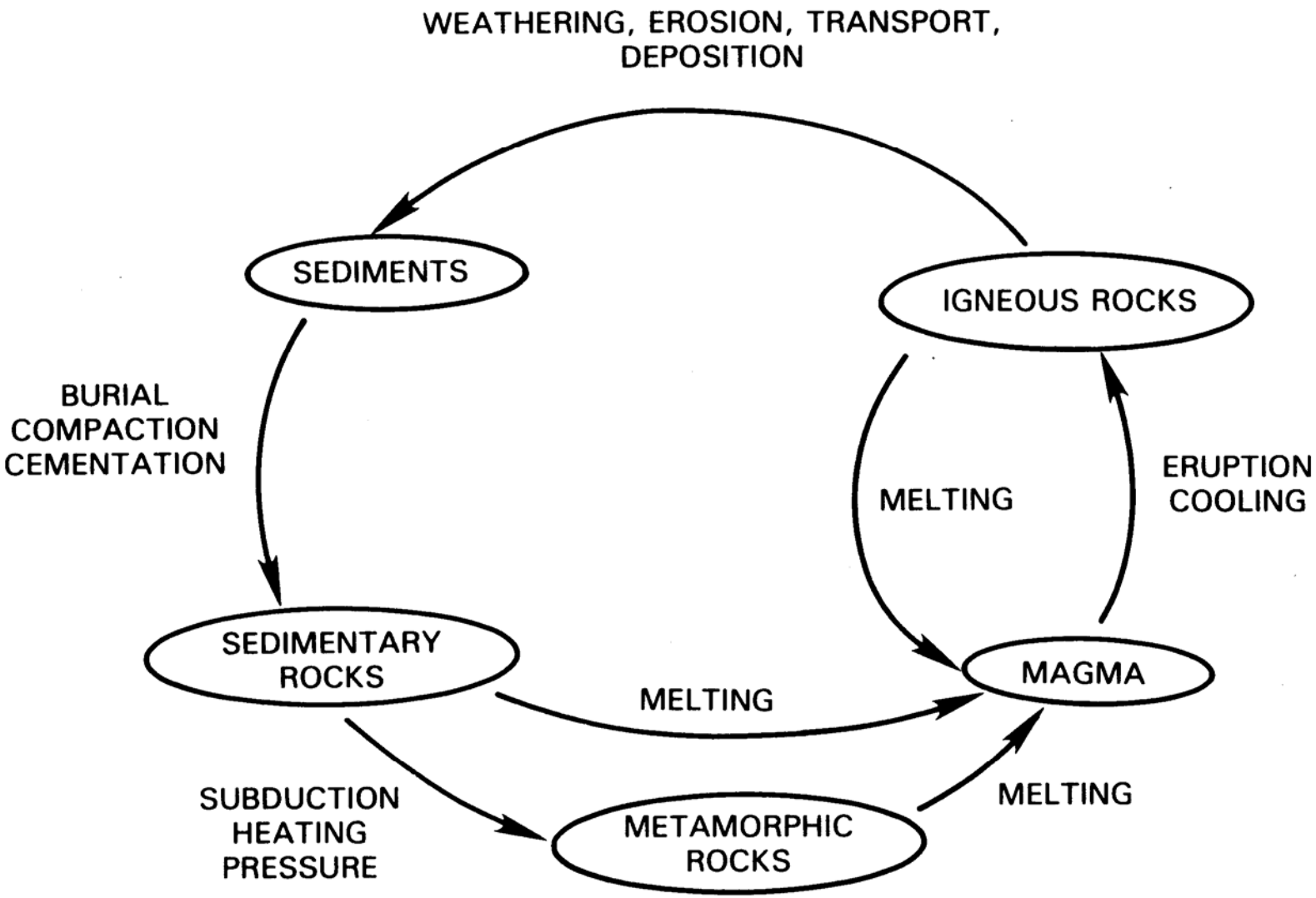
The Hydrologic Cycle



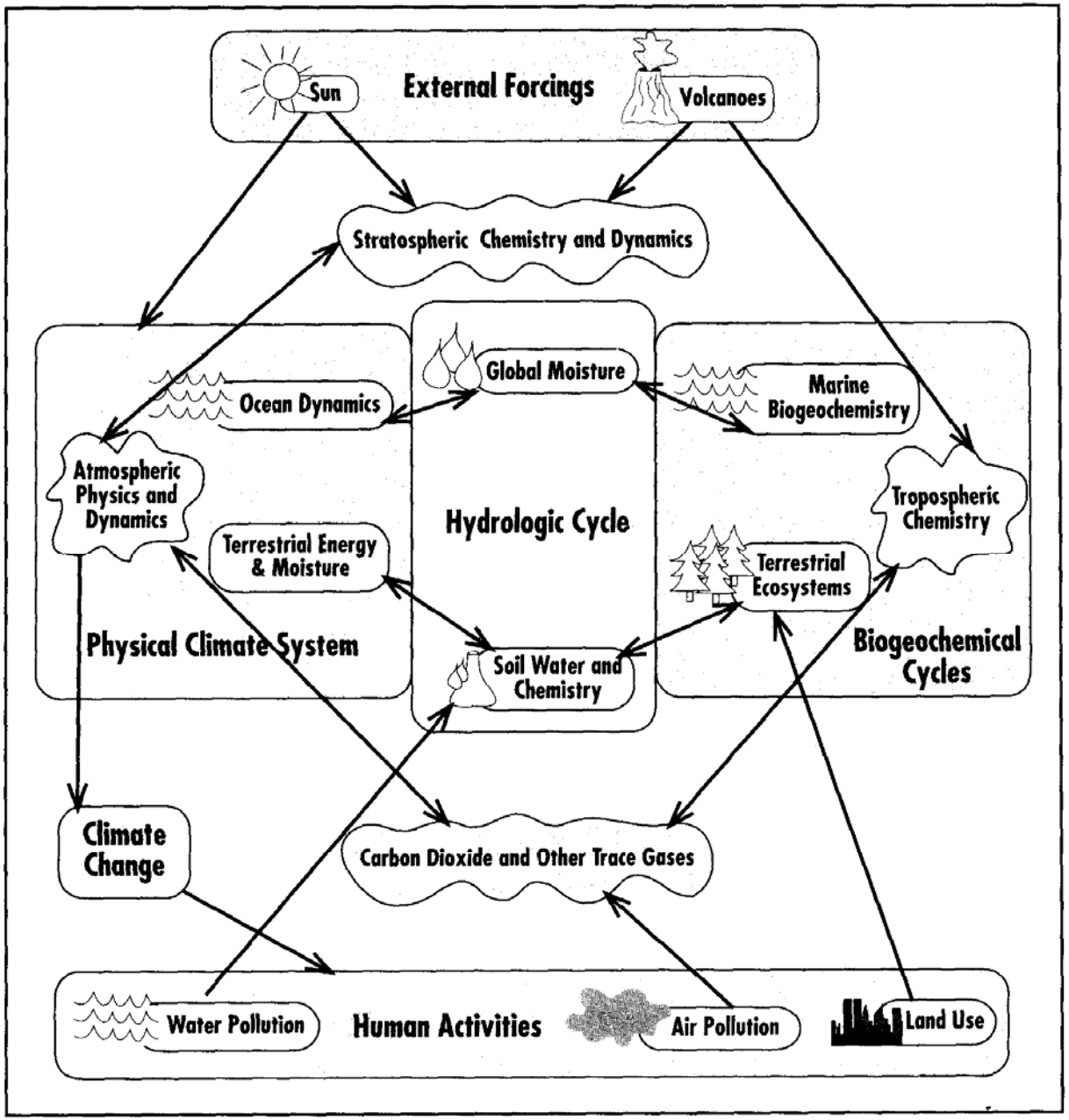
The Carbon Cycle



The Geologic Rock Cycle



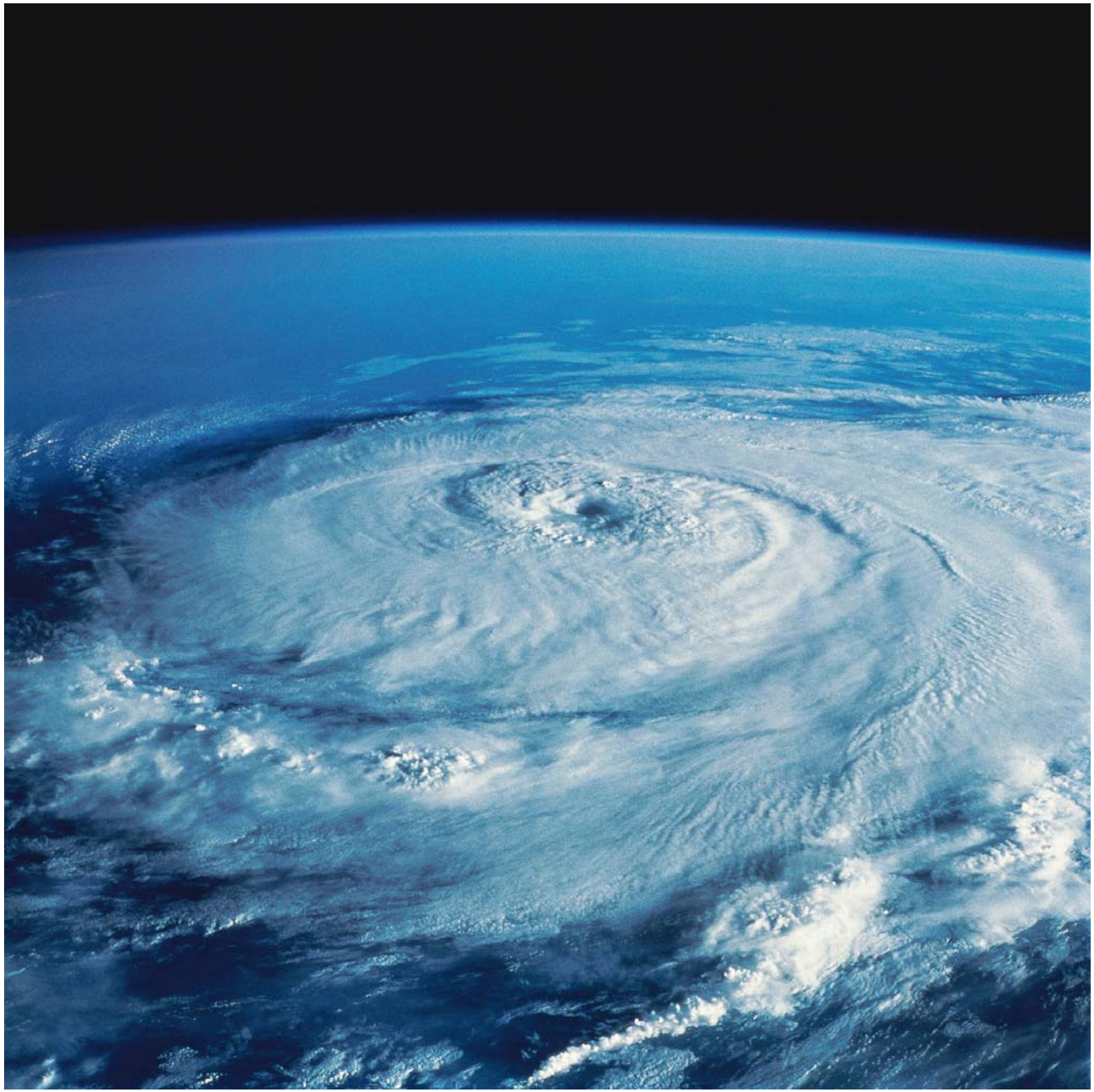
THE EARTH SYSTEM



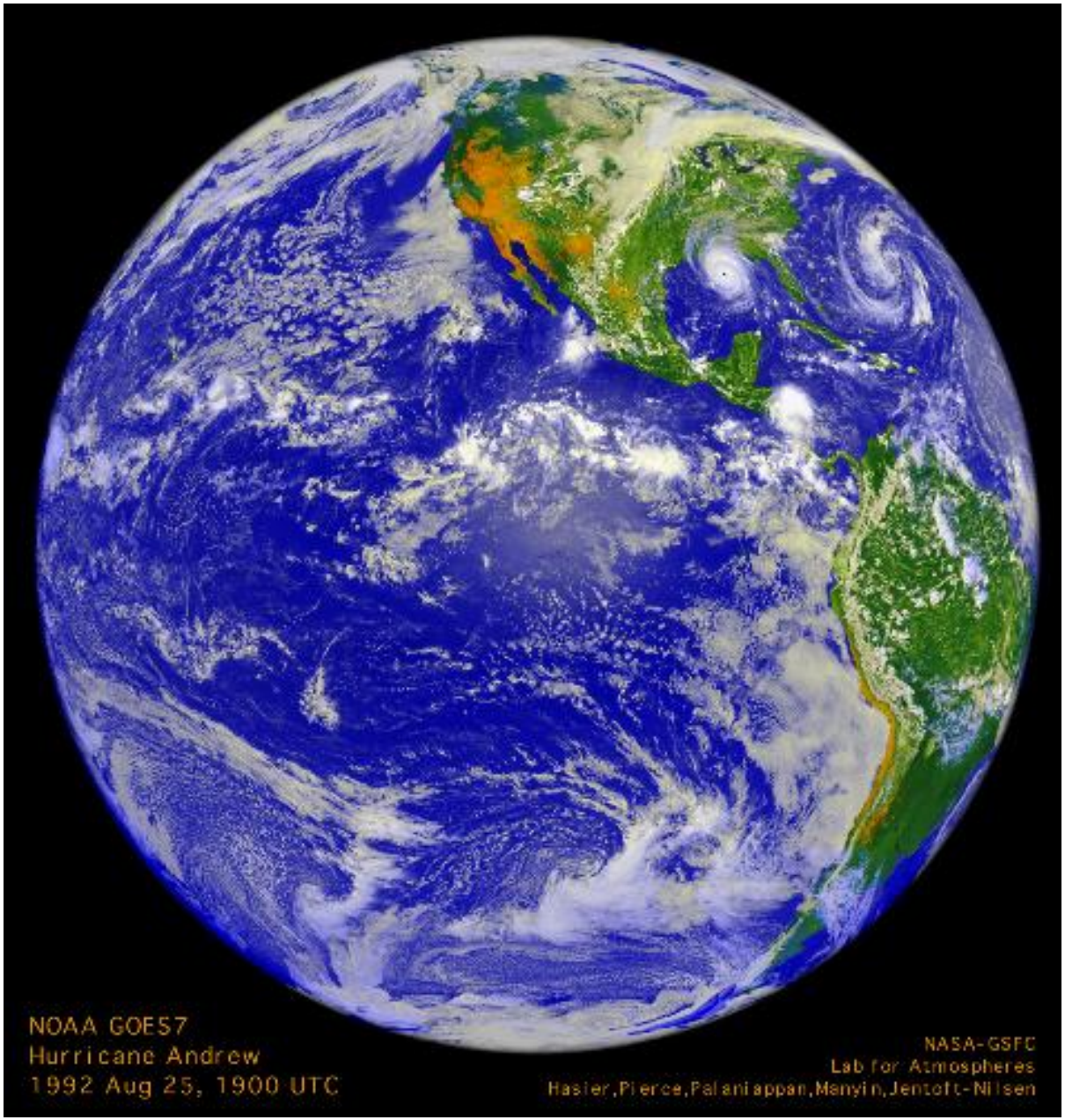
EARTH SCIENCE FROM SPACE

- Advantages of a space-based location for **Earth science** measurements include the following:
  - A satellite in orbit around Earth can provide **global coverage and monitoring** which would be difficult or impossible with aircraft, ship, or ground-based platforms. **Weather satellites** are an important practical application.
  - A satellite in near-Earth space can make remote-sensing measurements of Earth's upper atmosphere, in **ultraviolet, X-ray, and infrared wavelengths** which do not penetrate the lower atmosphere and hence cannot be studied from the ground.
  - A spacecraft in near-Earth space can also make **in-situ measurements** of the very high altitude regions of the atmosphere and the near-Earth space environment, and the effects of the Sun (and time variations) thereof.
- Recent and current Earth science missions include the *LandSat* series of satellites; and the currently operational *Terra, Aqua,* and *Aura* research satellites, which are major parts of NASA's *Earth Observing System* (EOS).

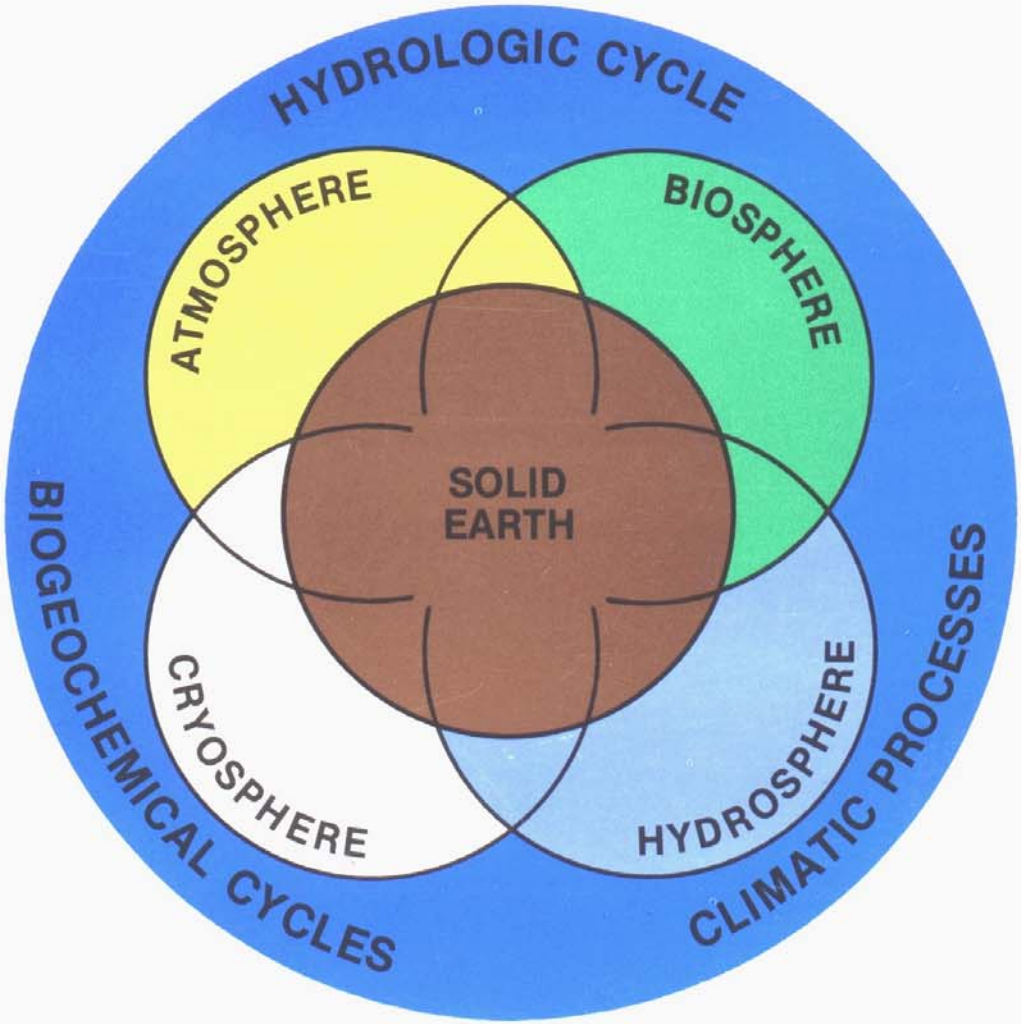
View of a Hurricane from Low Earth Orbit



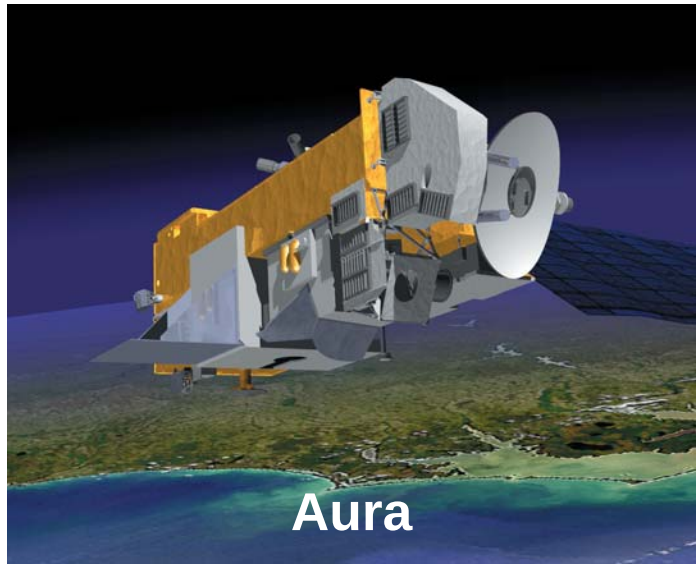
View of Earth from a Geosynchronous Orbiting Satellite

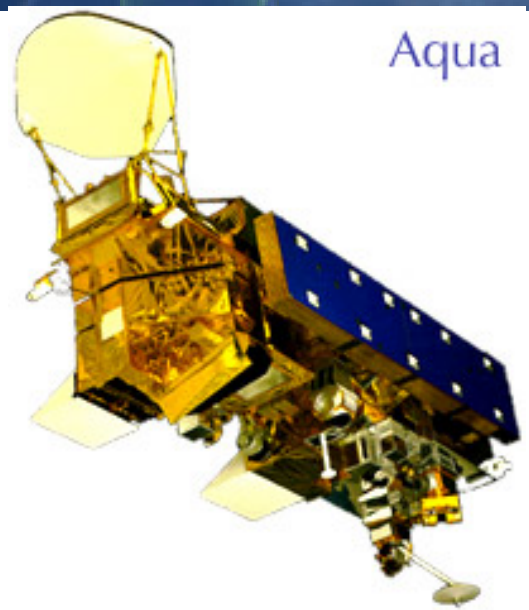


EARTH OBSERVING SYSTEM



NASA'S *EARTH OBSERVING SYSTEM* SATELLITES





The three EOS satellites travel in the same near-polar Earth orbit (the "A-Train"), but each concentrates on one of the three Earth observation specialties (study of the land, water, or atmosphere, respectively). However, there is also a significant degree of overlap among the three satellites' capabilities, to provide a degree of redundancy and increased capability.

EARTH & EARTH SYSTEMS SCIENCE
Reference Texts

- **Earth**, 3rd Edition, by Frank Press and Raymond Siever, W. H. Freeman & Co., San Francisco, 1982
- **Earth System Science: A Closer View**, Earth System Sciences Committee, NASA Advisory Council, 1988
- **Earth and Life through Time**, 2nd Edition, by Steven M. Stanley, W. H. Freeman & Co., New York, 1989
- **The Earth's Dynamic Systems**, 5th Edition, by W. Kenneth Hamblin, MacMillan Publishing Co., New York, 1989
- **The History of Earth**, by William K. Hartmann and Ron Miller, Workman Publishing Co., New York, 1991
- **The Earth System**, 2nd Edition, by Lee R. Kump, James F. Kasting, and Robert G. Crane, Pearson-Prentice Hall, Upper Saddle River, New Jersey, 2004