NASA Facts

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These articles consider Earth's many dynamic processes and their interactions.

Biosphere

Traditional Approaches to Climate Modeling

Traditional approaches by climate modelers to predicting climate change have not considered the interactions between the atmosphere and the plant and animal life that occupy the land surfaces and the oceans. With the development of more-sophisticated mathematical models of the processes going on within the atmosphere, scientists have realized that air/land interactions and air/sea interactions must be taken into account if there is to be progress in predicting climate change. These biospheric interactions are important both on a large scale, where the predictions are for the Earth as a whole, and on a regional scale, where the nature of the changes may be more significant to humankind.

The prediction of climate change due to human activities can be said to have begun with the Swedish chemist, Svante Arrhenius, in 1896. He took note of the industrial revolution then getting under way and realized that the amount of carbon dioxide being released into the atmosphere was increasing and would continue to increase as the world's consumption of fossil fuels, particularly coal, increased ever more rapidly. His understanding of the role of carbon dioxide in heating the Earth, even at that early date, led him to predict the effects of a doubling of atmospheric carbon dioxide on warming the Earth. He said that the Earth would become several degrees warmer. At that time, little attention was paid to what must have been seen to be a rather far-out prediction of no particular consequence to people living at that time.

Now, we who are living in the late twentieth century have become aware that carbon dioxide in the atmosphere is increasing with the likelihood that it will double by the middle of the next century from what Arrhenius saw toward the end of the last century. The monthly average atmospheric carbon dioxide concentration has been measured continuously at Mauna Loa,

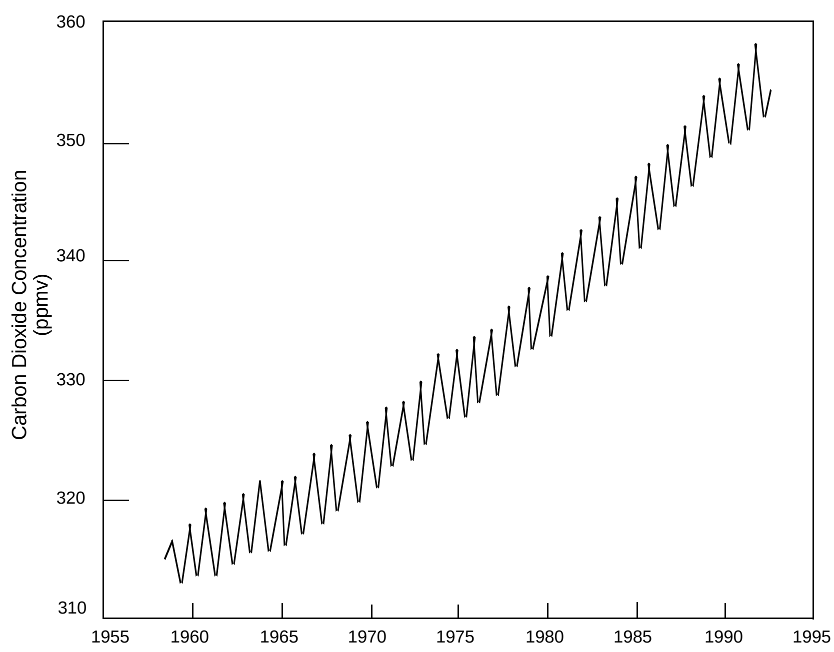

Figure 1. Atmospheric Concentration of Carbon Dioxide (Mauna Loa Data)

Hawaii since 1958 and is shown in Figure 1. The concentration of 315 ppmv (parts per million by volume of dry air) in 1958 increased more than 10% in just 30 years. (The seasonal variations are due primarily to the withdrawal and production of carbon dioxide by the terrestrial and oceanic biota.) Indeed, the current concentration of about 353 ppmv is 26% greater than the pre-industrial concentration of about 280 ppmv in the late eighteenth century.

As the prospect of considerable change in the atmosphere has become more real and threatening, we are more interested in knowing how seriously to take predictions that go back to that of Arrhenius. New computer models are being applied to the problem. They take into account more of the natural processes that must be part of the whole picture to understand what could happen to the Earth's climate as the carbon dioxide increases. An important aspect of the newer models is their treatment of the "amplifier effect," in which changes in the moisture and clouds in the atmosphere occur in response to the changes in carbon dioxide. These changes can significantly alter the estimate of global temperature change.

The findings of some of the general circulation models that are now being applied to the problem of global warming indicate that there will be less precipitation during the summer months in the interiors of continents and that there may be more precipitation including snowfall in the interiors of the continents in the wintertime. For vegetation, these effects will not balance out because plants need the added moisture as they enter the growing season. These findings, however, are still regarded as highly uncertain.

The Role of Biology in Climate Modeling

The newer models are only beginning to take into account the role of vegetation, forests, grasslands, crops, and the marine biota in controlling the amount of carbon dioxide that will actually be in the atmosphere. Along with their role as "sinks" for carbon dioxide, the various types of vegetation in the biosphere have further climatic effects. They heat or cool the air around them (through the release of sensible heat—heated air—or through evaporation of water), interfere with the pattern of surface winds (remove momentum), and take up and release moisture into the air (thus contributing to the alteration of the hydrologic cycle). In turn, changes in climate will affect the patterns of growth of vegetation. For instance, forest stands that require relatively cool conditions would not be able to adjust to rapid warming of continental interiors. With slow warming, we would expect that the northern edges of North American forests would creep slowly

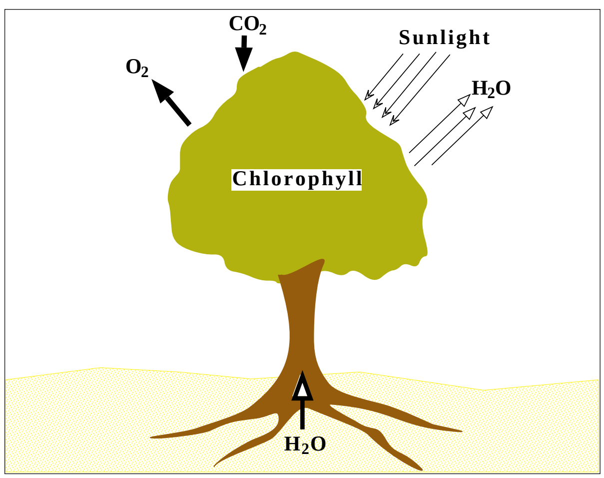

Figure 2a.
As plants and trees grow, photosynthesis — involving the interaction of sunlight, chlorophyll in green leaves, carbon dioxide (CO_2) and water (H_2O) — results in a net removal of CO_2 from the air and the release of oxygen (O_2) as a by-product. Also, moisture is released to the air through evapotranspiration.

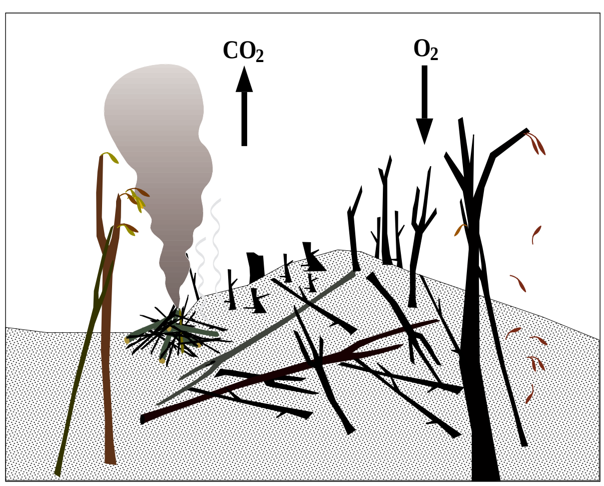

Figure 2b.
When forests die and decay, or are burned, the biomass is oxidized and CO_2 is returned to the air.

northward to more favorable conditions while the southern edges would give way to grasslands that are better suited to the warmer conditions. With unaccustomed warming rates, the loss at the southern edge would be more extreme, and the northern edge would not be able to move northward fast enough to make up for the loss at the southern edge.

Other Feedback Effects

There are other feedback effects at work that must be considered. Under normal conditions, plant leaves take in carbon dioxide from the air and release moisture to the air as part of the photosynthetic process (see Figure 2a & 2b). The release of moisture, through evapotranspiration, causes a cooling of the air. With increasing atmospheric carbon dioxide, we can expect to see a change in plant carbon and water exchange rates. This may result in reduced evaporation rates, thus amplifying the summer continental warming. Without the plants, the ground and air would become still warmer.

A Sink for Carbon Dioxide

In recent years we have learned that the land biosphere may play a very significant role in taking up carbon dioxide released from the Earth's surface. Without this "sink" effect, the amount of carbon dioxide in the air would rise more rapidly, and the possibility of more-rapid global warming would be greater. The land biosphere may be responsible for taking up about one-third of all the carbon dioxide that is released into the atmosphere. Northern forests are believed to be the biggest sink of carbon dioxide. There is a concern that the ability to soak up the increasing carbon dioxide may be decreasing—there may be a saturation effect.

Marine Ecosystems

On time scales of decades or more, the carbon dioxide concentration of the atmosphere is controlled mainly by the exchange with the oceans. There is a continuous exchange of carbon dioxide in both directions between the atmosphere and oceans (see Figure 3). The exchange of carbon between the surface and deeper layers is accomplished mainly through transport by water motions. The top one kilometer or so is particularly important for the downward transport of anthropogenic carbon dioxide. The deep circulation is effective on time scales of 100-1000 years.

Climate change will probably affect ocean circulation and mixing patterns. These in turn control nutrient availability to the ocean's microscopic plants (phytoplankton) and their access to solar radiation that is required for photosynthesis. The photosynthesis by

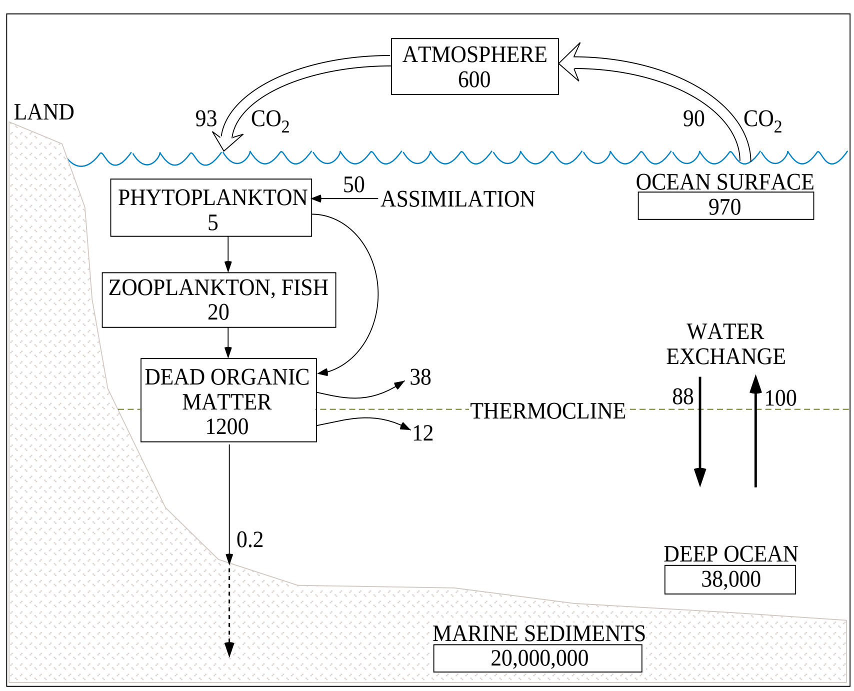

Figure 3. Estimate of the carbon exchange between the ocean and the atmosphere. The carbon cycle in the ocean is essentially self-contained in that phytoplankton assimilate the carbon dioxide dissolved in seawater and release oxygen back into solution. Zooplankton and fish consume the carbon fixed by the phytoplankton, using the dissolved oxygen for respiration. Eventually, the decomposition of organic matter replaces nearly all of the carbon dioxide assimilated by the phytoplankton. All quantities are in billions of metric tons (total carbon content in boxes; annual exchange beside arrows).

Human activities are increasing the amount of carbon dioxide in the atmosphere, and ocean uptake represents a significant ultimate sink of that carbon dioxide. Currently, uncertainties in the global carbon budget are about the same as the net annual ocean uptake. A primary goal of Earth Observing System (EOS) ocean research is to better define the role of the ocean biosphere in the global carbon cycle.

phytoplankton leads to carbon fixation and, ultimately, long-term storage by the ocean of organic carbon.

Observing Climate Change

While biologists working with atmospheric scientists have come to understand the interplay between biologic actions and atmospheric phenomena, their knowledge of the relevant phenomena tends to be limited to instances that are studied intensively in fairly small areas. Only through satellite observations will the ability to map out aspects of climatic regimes throughout the world and relate them to the types of vegetation that thrive or suffer in these regimes be possible. As this global understanding develops, better predictions of the effects of climate change on vegetation and the effects of vegetation change on climate will be possible. Satellites are needed to measure the presence, amount, and distribution of chlorophyll (as an indicator of vegetation health) and water vapor globally.

NASA Missions to Study Biology and Climate

Over the years, several NASA missions have studied various aspects of biology and climate. These studies have been augmented by data from operational satellites of the National Oceanic and Atmospheric Administration (NOAA).

The Landsat series of satellites, beginning in 1972, carried sensors that differentiated between soil and vegetation, determined the health of vegetation, surveyed the type and extent of biomass, and mapped coastal waters.

The launch of the Advanced Very High Resolution Radiometer (AVHRR) on TIROS-N in 1978 and on subsequent NOAA operational satellites permitted the global mapping of sea surface temperature and of vegetation. The launch of the Coastal Zone Color Scanner (CZCS) on Nimbus-7, also in 1978, made mapping oceanic chlorophyll and phytoplankton possible. Scientists at NASA's Goddard Space Flight Center produced the "First-Picture of the Global Biosphere" using 15,000 images from the NOAA-7/AVHRR (land biomass) and 20,000 images from the Nimbus-7/CZCS (oceanic phytoplankton pigment concentration).

The OrbView-2 mission, launched in August 1997, acquires ocean color data to study the role of the oceans in the global carbon cycle, fluxes of trace gases at the air-sea interface, and ocean primary productivity (rate of carbon fixation from the atmosphere).

With the launch of the EOS satellites starting in 1998, NASA will extend the measurements of ocean color and land biomass with advanced instruments. The resulting accurate, self-consistent, and long-term data sets are expected to lead to major advances in our understanding of the role of the global biosphere in climate change.

Earth Science Enterprise

Selected Missions Related to the Study of Biology and Climate

Mission	Launch	Scientific Objective
Landsat	1972-1998	Soil/vegetation differentiation, mapping of healthy vegetation, biomass surveys, coastal mapping
TIROS/NOAA	1978-1998	Daily global sea-surface temperature mapping, global mapping of vegetation using the Normalized Difference Vegetation Index (from AVHRR)
Nimbus-7	1978	Mapping of oceanic chlorophyll and phytoplankton (from CZCS)
OrbView-2	1997	Role of oceans in the global carbon cycle, fluxes of trace gases at the air-sea interface, ocean primary productivity (from SeaWiFS)
Earth Observing System (EOS)	1998-	Role of the land, oceans, atmosphere, and biosphere in the global carbon and hydrologic cycles (particularly from advanced instruments on the EOS AM, PM, and Chemistry missions)