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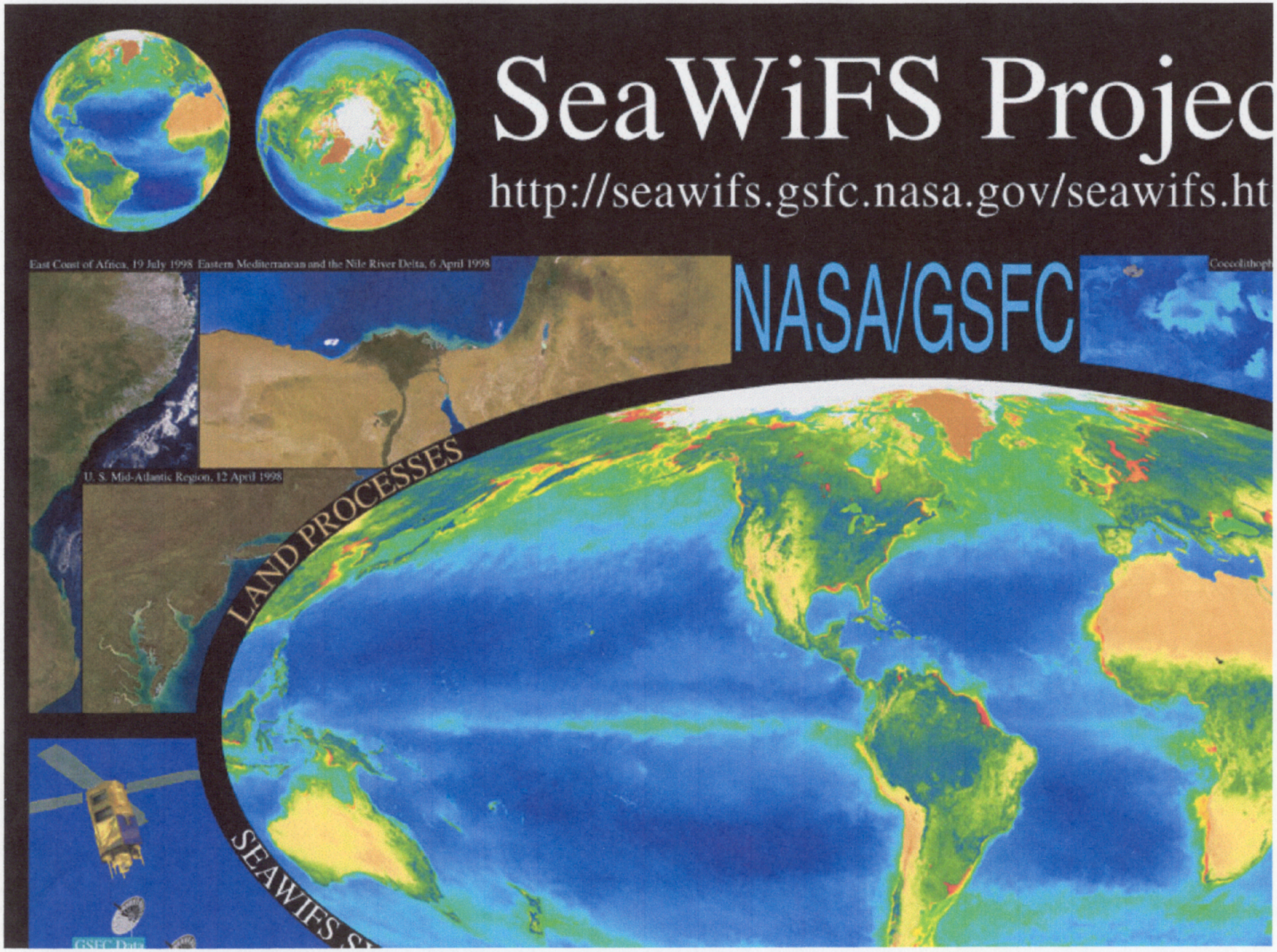
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GSFC Data

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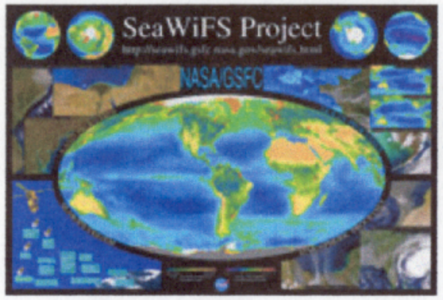

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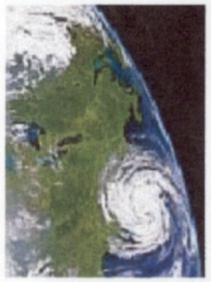
Poster - print quality (4MB jpeg) or web quality (425 kB jpeg).
Teaching Supplement - available from the Goddard DAAC.



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Lesson Plans for K-12

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Educational Brief

SeaWiFS Poster Teaching Supplement

Introduction

Welcome to the SeaWiFS Poster Teaching Supplement, a collaborative effort of the Goddard Earth Sciences Distributed Active Archive Center, the SeaWiFS Project, and the Education Department of the University of Maryland—Baltimore Country.

An image of the Earth that is obtained by a scientific remote sensing instrument carried on board a satellite is more than a picture; it is a multidimensional representation of a multitude of environmental processes. Remote sensing data is a vital tool in our investigation and understanding of the Earth's geophysical processes, but in order to be of greatest use, both the advantages and disadvantages of remote sensing data should be well understood. Not all images derived from remote sensing data describe what is really "there," because the data can be analyzed to provide considerably more information than is originally apparent.

The goal of the SeaWiFS Poster Teaching Supplement is to augment the superb remote sensing images displayed on the poster with succinct and descriptive summaries of the variety of geophysical phenomena that can be seen in each image. These summaries can be used in the classroom to supplement lessons, to answer student questions, and to provide starting points for independent student investigations. Teachers can use the information in the supplement to complement other classroom resources. College-level science students can utilize it as reference material.

As the name of the instrument implies, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) was originally conceived as an instrument for the study of the oceans; specifically, the accurate measurement of ocean color. When incoming sunlight is reflected back from the ocean surface toward space, it is affected by whatever is present in the water, such as living and nonliving particles, and dissolved substances. This interaction imparts a specific color to the light radiating toward space, and this light can be detected and analyzed to provide information about the characteristics of ocean surface waters. SeaWiFS was intended to be the first instrument that would observe the global oceans continuously. The original instrument design was actually improved before launch, increasing the accuracy of the data and also making the instrument into a true "global" sensor, capable of observing both land and sea.

SeaWiFS data therefore provide a remarkable view of the ever-changing surface of the Earth, affected by the seasons and by phenomena such as El Niño, whose effects can linger for years and be felt over wide areas of the Earth. Indeed, the daily imaging capability of SeaWiFS provides the opportunity to view global environmental connections, such as dust storms that can cross immense expanses of ocean and affect the environment a great distance from their origin.

For each of the image sections, the goal is to provide a complete description of the primary phenomena shown in the image, as well as to include some auxiliary information about other features that can be seen. Frequently these other features are volcanic or tectonic. The multidimensional aspect of Earth's environment is well illustrated by the combination of features that are seen in these images. For example, the Bering Sea would not be a uniquely isolated Arctic environment if it were not for the tectonic forces that have created the Aleutian Island arc and the Aleutian Trench.

While it is not necessary to understand the technical aspects of the SeaWiFS Project to use the information provided about the images, the final descriptive section of the supplement explains the SeaWiFS Project Operations Diagram in detail. This section may be used to introduce the concept of Earth remote sensing if the curriculum permits. The supplement also contains a glossary of terms and instructions on how to access the "SeaWiFS Poster Teaching Supplement Information and Links" Web page hosted at the GES DAAC. For those classrooms and schools that have access to the World Wide Web, the Web links listed on this page provide additional information or images related to poster and supplement topics. This list is updated every 6 months to insure that most of the links are active, and also to provide new and interesting links. The PDF version of the supplement is also available on this site.

This teaching supplement would not have been possible without the considerable work of a number of persons. Space does not permit a description of their vital contributions, so this listing only suffices to acknowledge their invaluable efforts: Dr. John Marra, Ocean Biogeochemistry Program, NASA Headquarters: Irene Antonenko, Norman Kuring, Dr. Charles McClain and Dr. Gene Feldman of the SeaWiFS Project; Dr. Robin Williams, Dr. George Serafino, and Dr. Steve Kempler of the GES DAAC; and Assistant Professor Dr. Susan Blunck, undergraduate assistant Ms. Melissa King, and secondary teacher candidates of the University of Maryland—Baltimore County (UMBC) Department of Education.

We all hope that the SeaWiFS Poster Teaching Supplement will be a valuable resource for you and your students.

Dr. James Acker, GES DAAC Ocean Color Data Support Team

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IMAGE: The Global Biosphere (central image and four hemispheric projections)

IMAGE DESCRIPTION: The Global Biosphere image is a global Level 3 image, showing ocean chlorophyll concentrations using the SeaWiFS chlorophyll concentration color palette. Four hemispheric projections are shown at the top of the poster, featuring the Atlantic Ocean, polar projections of the Arctic and Antarctic, and the Pacific Ocean. Land areas are shown using the Normalized Differential Vegetation Index (NDVI) color palette, where dark green indicates maximum vegetation cover and light or medium brown indicate minimum vegetation cover. (Some of the terms used above and in the following Phenomenon Description are explained in the "SeaWiFS Project Operations Diagram" section, page 12.)

TOPIC AREAS: Ecological interrelationships / Global carbon cycle / Land surface features / Ocean basins / Ocean currents / Oceanic productivity / Coastal processes

PHENOMENON DESCRIPTION: This is the crown jewel of the SeaWiFS Project, an image of the entire Earth showing the patterns of productivity in the world ocean. SeaWiFS was the first remote sensing mission to obtain an image like this, with an unprecedented degree of accuracy; SeaWiFS has obtained views like this routinely since the beginning of the mission. Remarkable images like this one allow scientists to see the "big picture." Oceanographers can now observe biological patterns at the scale of entire oceans, rather than the view from a ship to the horizon, which is all that was available for much of the history of oceanography. Though not originally designed for such a purpose, SeaWiFS also produces high-quality land surface data, as a result of instrument modifications that were introduced during the development stage. Biologists can now observe biological patterns at the scale of continents. The Normalized Differential Vegetation Index (NDVI), which was originally created for the remote sensing data of the Advanced Very High Resolution Radiometer (AVHRR), is now used by SeaWiFS to show the distribution of vegetation on all the continents of the Earth. Thus, this image shows biological patterns over the entire Earth, ocean and land. This image shows the Earth's *biosphere*.

One of the most important processes in the biosphere is the production of carbon by photosynthesis, which is called *primary productivity*. The presence of chlorophyll, in the green leaves of land plants or in the microscopic cells of ocean phytoplankton, generally indicates where primary productivity is occurring.

On land, major features are immediately evident: dense forests in South America and Siberia, arid deserts in Africa and Australia. In the ocean, there are similar patterns: large areas of the ocean where biological productivity is very low; bands of higher productivity near the Equator, and somewhat higher productivity in the northern and southern reaches of the Atlantic and Pacific Oceans. Moving closer, bright red regions are found in coastal areas and shallow seas, indicating that the highest productivity waters are found only in small and special areas of the ocean. (Not all the bright reds exclusively indicate highly productive waters, but in many areas they do. Turbidity can cause difficulty in the data analysis, which is discussed below.)

This is an "annual" image compiled by averaging data acquired over an entire year (1998), so seasonal variability is not visible, but regions that are seasonally productive are apparent. The higher chlorophyll concentrations (yellow and green) seen in the North Atlantic Ocean only occur in the spring, during the North Atlantic Bloom. The global image shows a contrast because adjacent waters have low productivity over the entire year. The term *phytoplankton bloom* refers to a drastic increase in phytoplankton population occurring over a short time period due to an increase in nutrients, sunlight, or both. In the case of the spring North Atlantic Bloom, phytoplankton utilize increasing sunlight and nutrient levels, refreshed over the winter, to grow rapidly. This increase in production progresses from mid-latitudes to high latitudes during spring, so most of the North Atlantic appears to have elevated chlorophyll concentrations.

Another seasonal change that is observed in the image occurs in the Arabian Sea, between India and Africa. For part of the year, the Arabian Sea has low productivity. But when the monsoon winds blow, nutrients are brought to the surface, causing an explosion of productivity. SeaWiFS provides the opportunity to watch these events as they unfold over weeks and months.

There are several areas that are productive over the entire year, and these are where some of the highest chlorophyll concentrations are found. Two specific examples are on the coast of Peru in South America, and on the western coast of southern Africa. In these regions, the interaction of wind-driven surface ocean currents brings cold, nutrient-rich water to the surface (*upwelling*), where the nutrients are utilized by phytoplankton to maintain very high levels of productivity. It is not a coincidence that these are also some of the most productive fishing regions in the world.

Major ocean currents provide moving boundaries between different sections of the world ocean. Two examples of this are the Gulf Stream in the Atlantic Ocean and the Kuroshio Current in the Pacific Ocean, both of which are found in the Northern Hemisphere. Though the actual path of these currents cannot be seen in the globally averaged image, their approximate location marks the transition zone between very low productivity waters in the central Pacific and central Atlantic and higher productivity waters to the north.

One of the world's largest currents is found in the Southern Ocean. As its name implies, the Antarctic Circumpolar Current flows entirely around the polar land mass. Interactions between the Circumpolar Current and the sea bottom, or other currents in these areas, help to bring nutrients to the surface. These nutrients nourish the phytoplankton, which are eaten by krill, the shrimplike zooplankton preferred by whales and penguins. As a result, productivity in these waters is fairly high. In either the global biosphere image or the Antarctic polar projection, this band of productivity encircling Antarctica is obvious. Zones of higher productivity, such as where the current gets squeezed between the Antarctic Peninsula and the tip of South America, or where it runs directly into the Agulhas Current flowing southwest off the southeastern edge of Africa, can also be seen.

To the north, there is no unifying current system. The Gulf Stream sends its warmth over the British Isles and Europe, keeping them warmer than equivalent latitudes in North America or Asia. In the Arctic Ocean, complex currents emerge from under the arctic ice, making the Bering Sea an unusual body of water. There, the high productivity shallow waters allow the existence of extensive fisheries and a rich community of fauna on the bottom. Whales, coming to Alaskan waters in the summer to feed, actually dive into the bottom, gouging out holes of mud which they filter through baleen to derive their nutritional needs.

The most prominent feature in the Pacific Ocean is the Equatorial Upwelling Zone. This productive region is created by interaction between currents flowing in opposite directions along the Equator. Though not as productive in any one place as coastal upwelling zones, the huge size of the Equatorial Upwelling Zone makes it a vital part of the Earth's ecosystem. The Equatorial Upwelling Zone can be drastically affected by the phenomenon called El Niño, which will be discussed in the next section.

Rivers are a vital component of the biosphere, affecting the ecosystem of the land around them. Many major rivers can be identified in the global biosphere image by the signature of their effluents, which show up as bright red, indicating a large amount of suspended sediments in the water (and also the presence of dissolved nutrients, which augments phytoplankton growth at the river mouth). The Amazon River (on the Atlantic coast of South America), the Mississippi River (on the Gulf of Mexico coast of North America), the Ganges River (in the Bay of Bengal, east of the Indian subcontinent), and the Yangtze and Yellow Rivers (in northern China) all can be located by the bright red color found at the mouths. Note also how the Baltic Sea and Great Lakes show up as red. This is due to the presence of turbid water, which affects the corrections for atmospheric effects in the data analysis. Algorithm modifications will improve the data analysis for inland waters such as these.

Researchers who study the optical properties of the ocean have devised two divisions of ocean optical properties, Case 1 waters and Case 2 waters. In Case 1 waters, the water is very clear, and any absorption or scattering of light is due largely to the presence of phytoplankton. These are typically open ocean conditions, and the analysis of Case 1 waters is fairly simple. On the other hand, Case 2 waters have a variety of substances present, such as sediments or colored organic matter in addition to phytoplankton, all of which can scatter and absorb light. Analysis of Case 2 waters is much more difficult. Therefore, when the colors in SeaWiFS images are yellow and red near the coast, this can indicate high chlorophyll concentrations, but it might just be "muddy" water. Extracting the absorption of light due to chlorophyll in Case 2 waters and separating it from the influence of other substances or particles in the water is a major research effort for oceanographers analyzing SeaWiFS data.

The formation of ice in the Arctic depends in part on the flow of fresh water from large Siberian rivers. It also depends on the global climate, as recent studies of arctic sea ice indicate that it covers a smaller area every winter. Such a change in sea ice cover, which may be partly natural and partly due to global warming caused by the input of carbon dioxide (CO_2) and other gases into the atmosphere by humans, could have profound effects on the global ecosystem. One of the primary goals of the SeaWiFS mission is to better quantify the role of the oceans in the global carbon cycle. High productivity regions are the ocean's "forests," using sunlight and CO_2 to produce organic carbon. It is a straightforward process to map the occurrence of forests and changes in their coverage on land. The oceans, however, change much more quickly. They are in constant motion, and phytoplankton blooms can appear in days and disappear just as quickly. Phytoplankton are the photosynthetic base of the oceanic food web, so their productivity is a fundamental indicator of the health of the oceans. Because phytoplankton use CO_2 for photosynthesis, their activity has a direct bearing on the concentration of CO_2 in the atmosphere.

While the oceans are the primary focus of the SeaWiFS mission, SeaWiFS also provides important views of processes on land. SeaWiFS data can be used in combination with other data to determine how the area of desert regions is changing, and whether or not it is increasing. SeaWiFS also has provided dramatic images of weather- and climate-related land surface phenomena, such as the large fires in Mexico and Indonesia that were promoted by the dry conditions induced by El Niño (discussed in subsequent sections), and the huge amounts of sediment carried off the coast of North Carolina into the Gulf Stream following the strong winds and floods of Hurricane Floyd.

RELATED IMAGES: Pacific Ocean Image Pair: December 1997–February 1998 & June 1998–August 1998

IMAGE: Pacific Ocean Image Pair: December 1997–February 1998 & June 1998–August 1998

IMAGE DESCRIPTION: Two SeaWiFS Level 3 regional/seasonal binned images of the Pacific Ocean; one for the winter of 1997–1998 when the El Niño condition was at near-maximum, and one for summer 1998 when the El Niño condition in the Pacific Ocean had ended (right side of poster).

TOPIC AREAS: El Niño / Regional climate / Global climate / Oceanic productivity

PHENOMENON DESCRIPTION: One of the largest interannual changes in the world climate, and certainly the largest change in the Pacific Ocean basin, is the El Niño/La Niña phenomenon, also known as the El Niño–Southern Oscillation (ENSO) phenomenon. (Southern Oscillation describes a broader class of event, centered on the warm Pacific waters north of Australia.) The phenomenon was named for the occurrence of rain on the arid coast of Peru near Christmastime, so El Niño stands for "Christ child." Rain on the coast indicated that the waters offshore had warmed, which meant that the anchovy fishermen, who fished the normally rich waters of the Peru upwelling zone, would have a meager catch.

For most of the century, El Niño, while not exactly predictable, behaved in a fairly well-known fashion. Warm waters appeared off Peru, reducing the upwelling of nutrients and causing fish to stay deeper in the water column. The phenomenon occurred every five to seven years and lasted over the winter. Rainfall and snowfall patterns in North America may have been somewhat different, but not markedly so.

As the technological capabilities for ocean monitoring and observation improved, the underlying causes of El Niño were perceived. The normally strong and continuous winds, which push warm water to the west in the southern Pacific Ocean, decrease in intensity, allowing a succession of waves of warm water to move eastward, then spread north and south along the Pacific coast of Central and South America. This warm water would cause the thermocline (the temperature boundary between surface waters and deep waters) to become deeper. What is still unclear, however, is why the winds begin to lessen in intensity at the beginning of an El Niño occurrence.

In 1983, an El Niño took place that was unprecedented in size and scope. Warm waters extended as far north as the coast of Washington in the United States. Island seabird populations, dependent on surface fish near the Galapagos Islands, disappeared. Massive storms pummeled the Pacific Coast of North America and Mexico. The Coastal Zone Color Scanner (CZCS) satellite sensor, in operation at the time, observed the disruption of the Galapagos Upwelling Zone, an area of high productivity normally extending far to the west of the Galapagos Islands. CZCS observations showed that this area of high productivity was much reduced in size, and at times even extended to the east due to the disruption of the equatorial current system.

In an unusual coincidence, the launch of SeaWiFS in 1997 occurred at about the same time as the commencement of the largest El Niño event since the 1983 occurrence. SeaWiFS, therefore, initially observed a Pacific Ocean with very low productivity, unlike the "normal" condition present in most years, where the ocean is dominated by the Equatorial Upwelling band. As in 1983, the Galapagos Upwelling Zone was virtually absent. As storms once again rolled into the Pacific coasts of North, Central, and South America (causing widespread flooding), oceanographers watched the slow changes in temperature, both at the ocean surface and deep into the water column. While oceanographic instruments indicated that the El Niño was ending, SeaWiFS observed dramatic changes in oceanic productivity occurring in only a matter of weeks. The Equatorial Upwelling Zone suddenly reappeared, and the Galapagos Upwelling Zone swelled and intensified abruptly. The rate at which the changes occurred was surprising to many oceanographers.

This image pair of the Pacific Ocean shows binned data for 2 three-month periods, at the height of the El Niño winter, and for the following summer when the situation reversed. The most noticeable feature in the summer image is the Equatorial Upwelling Zone, which is nearly absent in the winter image. A closer look shows the Galapagos Upwelling Zone as a bright yellow spot to the west of Peru in the summer image, and an increase in the area of the Peruvian Upwelling Zone is also apparent.

The condition that sometimes follows El Niño, called La Niña, is marked by colder-than-normal surface waters. La Niña can also influence the climate, though not quite as markedly as the warm waters of El Niño.

The changing colors of the seasons on land, increasingly green in the spring and summer, more brown and darker in the fall and winter, can also be observed in this image pair. The most notable changes are in Southeast Asia and in the South American rain forest. Subtle changes can be seen in southeastern Australia and the southern United States. SeaWiFS seasonal imagery of land areas shows the ebb and flow of the seasons quite clearly.

RELATED IMAGES: Fires and Smoke Plumes over Mexico, 5 June 1998 & Coccolithophorid Bloom, Bering Sea, 25 April 1998

IMAGE: Coccolithophorid bloom, Bay of Biscay, Celtic Sea, 18 May 1998

IMAGE DESCRIPTION: The Level 1A (true color) image shows bright patches near the British Isles, corresponding to blooms of coccolithophores, a type of planktonic organism.

TOPIC AREAS: Phytoplankton and phytoplankton blooms / Carbon cycle / Oceanic sediments (specifically carbonate sediments) / Fossil sediment deposits / Interaction of the biosphere and atmosphere

PHENOMENON DESCRIPTION: Coccolithophorids are a class of phytoplankton that create calcareous (calcium carbonate, or $CaCO_3$) hard parts. A "coccolith" is actually a microscopic disk of calcium carbonate. These disks are cemented around the organism to form a "coccosphere." Because the coccospheres are bright white, when a bloom of coccolithophorids takes place, the millions of phytoplankton create an unmistakable turquoise-blue to blue-white coloration of the ocean surface. This brightly-colored area is easily observed by SeaWiFS.

Coccoliths are formed by the process of *calcification*, which takes place inside the cells of the coccolithophorid. Bicarbonate ions and calcium ions from seawater are combined to produce calcium carbonate, carbon dioxide, and water according to the following reaction:

$$2HCO_3 + Ca^{2+} \rightarrow CaCO_3 + CO_2 + H_2O$$

The production of CO_2 by this process may improve the ability of the coccolithophorid to produce carbon by photosynthesis.

The cause of coccolithophorid blooms is still unknown. One thing that is known is that when they occur, they can affect the lives of numerous other creatures of the sea. Because the bloom obscures the clarity of the water, birds that feed on fish can't see the fish below the surface, and they may starve. Whales appear to avoid entering a bloom as well. When a coccolithophorid bloom finally ends, the coccospheres disintegrate, and the coccoliths sink to the bottom, forming carbonate sediments.

Fossil carbonate sediments containing coccoliths may be as close as the chalkboard in the classroom (if the classroom still has one), because fossil coccoliths are mainly found as chalk. England's "white cliffs of Dover," on the English Channel, are composed almost entirely of coccoliths that were once deposited on the sea floor.

However, not all coccoliths end up on the sea floor. In some parts of the ocean, coccoliths will dissolve after they reach the bottom. This dissolution process is one of the ways that oceans neutralize the CO_2 that is absorbed from the atmosphere. Over thousands of years, this process helps maintain a balance in the Earth's carbon cycle.

Coccolithophorids, interestingly enough, may also influence the atmosphere more directly. One by-product of their metabolism is a chemical called dimethyl sulphide (DMS). A coccolithophorid bloom can release large quantities of DMS, which can influence the atmosphere two ways: 1) the chemical can be broken down by sunlight to create a sulfur aerosol that blocks incoming radiation from the Sun, and 2) DMS itself can act as a "seed" for the formation of the tiny water droplets that form clouds. DMS is not normally present in high enough concentrations to be particularly harmful, but it is possible that climate change could lead to more coccolithophorid blooms, which would cause more cloud cover over the oceans, which can reflect more sunlight back into space and thus help cool the Earth. This is an example of "negative feedback" in the Earth's ecosystem.

Suggested demonstration: Dissolution of calcium carbonate in vinegar

Allow students to put samples of calcium carbonate in vinegar and to observe the production of carbon dioxide. Question: If the dissolution of calcium carbonate produces carbon dioxide, how does the dissolution of calcium carbonate in the ocean neutralize carbon dioxide that has been absorbed from the atmosphere? Answer: It's due to the reverse of the calcification reaction shown above! This is a subtle point: the reaction of calcium carbonate and an acid is not the same reaction as the neutralization of CO_2 in the oceans.

RELATED IMAGES: Global Biosphere (high nutrient upwelling areas) & Coccolithophorid Bloom, Bering Sea, 25 April 1998

IMAGE: Coccolithophorid Bloom, Bering Sea, 25 April 1998

IMAGE DESCRIPTION: The Level 1A (true color) image shows aquamarine waters in the Bering Sea west of Alaska, indicating a coccolithophore bloom. Several land surface features related to plate tectonics (the Alaska Peninsula and volcanic islands) and glaciated regions of Alaska are visible in this image. Cook Inlet is also visible.

TOPIC AREAS: Phytoplankton and phytoplankton blooms / Climate / Carbon cycle / Oceanic sediments / Marine food chain interdependency / Plate tectonics / Volcanoes / Tides

PHENOMENON DESCRIPTION: In 1997, just as the SeaWiFS mission was beginning, one of the first noteworthy observations the instrument made was of a bright blue-green area of water in the Bering Sea. The highly reflective waters were characteristic of coccolithophore blooms, but such a widespread bloom had not been observed before in the Bering Sea. The bloom conditions persisted in 1998 and 1999, and may have reappeared in the early spring of 2000. Researchers surmise that the bloom indicates a significant shift in the water conditions of the Bering Sea, potentially caused by a long-term regional climate shift or associated with the strong El Niño event which took place in the winter of 1997–98. One of the apparent causes of the bloom was an increase in the amount of radiation from the Sun that reached the sea surface (*insolation*), as a result of less cloud cover than normal.

The effect of this bloom on the Bering Sea ecosystem has been profound. Birds that hunt fish by sighting them from the air and then diving on them were unable to see fish below the surface. They began starving by the thousands. Whales were sighted at the edges of the bloom but did not penetrate it. The bloom may potentially have kept them away from areas where food sources were rich. The normal salmon run in Bristol Bay, Alaska was virtually absent. It is likely that the reduced salmon numbers also affected the populations of seals and walrus in the Bering Sea.

This SeaWiFS image highlights the coccolithophore bloom in the Bering Sea, but there are other interesting geophysical features in this image. The Alaska Peninsula extends from mainland Alaska in a southwest curve, leading to the Aleutian Islands. Both the Aleutians and the Alaska Peninsula have numerous active volcanoes, because the Aleutian Island arc is formed at a convergent plate margin. Just south of the Aleutian Islands lies the Aleutian Trench, one of the deepest trench systems in the world. Where the Alaska Peninsula meets mainland Alaska, the snowfields of Katmai National Park can be seen. In 1912, Katmai was the site of the largest volcanic eruption of the 20th century. The eruption caused a caldera to form where the summit of Mt. Katmai collapsed, and filled an adjacent valley with rhyolitic volcanic deposits. When the valley was discovered after the eruption, it was called "The Valley of Ten Thousand Smokes" due to the numerous fumaroles (steam vents) in the cooling deposit. (This convergent plate margin was also the site of one of the largest earthquakes of the 20th century, on 27 March 1964, which measured 8.4 on the Richter scale.)

Another active volcano in this region is Augustine Island. This small island can be seen in Cook Inlet, the narrow body of water on the right side of the image. Plumes of ash from Augustine Island (as well as Redoubt Volcano a few miles further north on the mainland) have menaced aircraft flying the northern route to Asia, and have caused the airport in Anchorage to close.

Cook Inlet is an interesting body of water due to its long and narrow shape, which, like the Bay of Fundy in Nova Scotia, amplifies the tidal cycle. In fact, the tide heights in Cook Inlet are only exceeded by the tides in the Bay of Fundy. When tides are particularly strong, the inflowing tide is so powerful that it forms a tidal

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bore, a wave of water moving inland. The tidal bore is commonly seen in Turnagain Arm at the head of Cook Inlet.

RELATED IMAGES: Coccolithophorid Bloom, Bay of Biscay, Celtic Sea, 18 May 1998 & Global Biosphere, Arctic Polar Hemispheric Projection (second from left)

IMAGE: Saharan Dust over the Canary Islands, 6 March 1998

IMAGE DESCRIPTION: The Level 1A (true color) image shows wind-blown plumes of dust, from the Sahara Desert, passing over the adjacent Canary Islands in the Atlantic Ocean.

TOPIC AREAS: Atmospheric aerosols / Land surface features / Ecosystem interdependency / Phytoplankton and phytoplankton blooms / Climate / Carbon cycle / Volcanism / Plate tectonics

PHENOMENON DESCRIPTION: The Sahara Desert is the largest desert in the world. It exerts a profound influence on the climate of adjacent regions due to the heat and dry air that are generated over the desert sands. As shown in the image, plumes of desert sand and dust are frequently carried off the desert and over the adjacent ocean. Large plumes of Saharan dust can even cross the entire Atlantic Ocean and cause hazy conditions on the East Coast of the United States, particularly in Florida.

Suspended particles in the atmosphere are called "aerosols." This image shows that aerosols can obscure the view of the Earth's surface from space. They can also affect the amount of solar radiation that reaches the Earth's surface, and thus help to cool the Earth. (The desert can actually cause cooler conditions in other areas.) As discussed in the SeaWiFS Project operations diagram, one of the main functions of data processing is to remove the influence of light scattering in the atmosphere, so that the correct surface radiances (particularly water-leaving radiances) can be determined. Atmospheric aerosols, such as the sand and dust seen here (or the smoke discussed in the Yucatan Peninsula section), significantly complicate these calculations.

Saharan dust in the atmosphere can obviously reduce the amount of solar radiation reaching the sea surface. It has also been shown that this dust has far-ranging ecological effects. One significant question for researchers studying the rain forest is how vegetation in the canopy (such as *epiphytes,* organisms that grow on the trees without roots in the ground) obtains vital nutrients. Research showed that for much of the rain forests in Central and South America, and on some Caribbean islands, nutrients for the canopy vegetation are supplied by the deposition of Saharan dust.

The oceans receive a similar nutrient contribution from dust. In many areas of the ocean, the growth of phytoplankton is limited by the availability of iron dissolved in the water. Iron is only slightly soluble in water, yet phytoplankton require it as a nutrient and need a fairly constant input of iron for growth. Because iron has such low solubility, a constant input of iron is required. Near the shore, this iron is supplied primarily by sediments and input from rivers (iron is slightly more soluble in fresh water than seawater). In the open ocean, the main source of iron is from desert aerosols (the Sahara for the Atlantic, China's Gobi Desert for the western Pacific, and to a lesser extent deserts in Peru, Chile, and Australia for other regions of the Pacific). In fact, Earth's ancient climate cycles may have been partly controlled by the input of iron to the oceans and its effect on phytoplankton growth and photosynthesis. If more iron is added to the oceans, increased photosynthesis will reduce the amount of CO_2 in the atmosphere, affecting the global temperature and climate.

Also worth noting in this image are the Canary Islands. The Canary Islands are volcanic islands, somewhat similar in appearance to the Hawaiian Islands. Yet these two island chains were formed by different mechanisms. The Hawaiian Islands are formed by a plume of hot magma, which originates deep within the Earth's mantle. As the ocean plate moves slowly across the plume (or "hot spot"), the center of volcanic activity is shifted progressively from one volcanic center to the next, creating a chain of progressively younger volcanoes. "Hot spot" volcanoes are characterized by hotter, more fluid lava than margin volcanoes. In contrast, the Canary Islands appear to have formed along a large fault in the African Plate. Here, the recent volcanic activity has not been isolated to one volcano at the end of the island chain. Even though the most recent eruption, in 1971, was on La Palma Island, near the end of the chain, eruptions on other Canary Islands have occurred during the past century. Large fault zones on the ocean floor are also a consequence of plate motion.

RELATED IMAGES: Fires and Smoke Plumes over Mexico, 5 June 1998 (atmospheric aerosols) & Coccolithophorid Bloom, Bering Sea, 25 April 1998 (plate margin volcanoes)

IMAGE: Fires and Smoke Plumes over Mexico, 5 June 1998

IMAGE DESCRIPTION: The Level 1A (true color) image shows plumes of smoke from fires burning in the rain forests of southern Mexico and the Yucatan Peninsula.

TOPIC AREAS: Climate / El Niño / Land surface features / Atmospheric aerosols / Interaction of the biosphere and atmosphere / Human influence / Prehistoric climate events

PHENOMENON DESCRIPTION: One surprising feature of SeaWiFS land surface data has been the clear visibility and prevalence of smoke plumes from ground fires. This means that phenomena such as forest fires and the use of slash-and-burn agricultural practices can be detected. It also provides another method of observing the effects of El Niño. The shifts in ocean temperature that are associated with El Niño can have a significant effect on rainfall patterns, which can in turn influence the distribution of forest fires around the world.

The strong El Niño event that occurred in 1997–1998 had profound global consequences. As noted in the Pacific Ocean Image Pair section, the shift of warm-pool water from the western Pacific to the eastern Pacific greatly affected rainfall patterns. Areas that are normally arid, such as the Peruvian coast of South America (where the name El Niño originated) received large amounts of rainfall, causing flooding, coastal erosion, and destruction of coastal property and homes. Areas such as Mexico and Indonesia, which normally experience the heavy amounts of rainfall associated with the rain forest environment, were deprived of this vital resource.

In Mexico, lightning from sporadic thunderstorms touched off fires in remote and pristine rain forest areas. The fires burned on the trees and on the forest floor, creating a choking, hazy plume of smoke that spread northward and caused suffering in Texas, the Gulf Coast, and Florida. Ecologists estimated that it would take 50–100 years for the burned rain forests to recover completely.

In Indonesia, subsistence farmers use fire to clear plots of land. Normally, the common torrential thunderstorms would quench such fires in a day or two. In 1998, however, the rain was absent, and the fires spread over large areas of the island. The plume of smoke created an impenetrable haze that obscured SeaWiFS' view of the islands and adjacent ocean waters. Ordinarily, this is a very cloudy area of the world, so it would have been unusual to see the islands and adjacent waters. El Niño caused a reduction in cloud cover and rainfall in this area, but the cloudless skies were soon replaced by smoke and haze.

Also visible in this image are the fringing coral reefs of the Yucatan Peninsula, and an adjacent coral island. The Yucatan itself is an example of a *carbonate platform*, an area that is primarily made of carbonate rocks, deposited by calcifying phytoplankton and coral at some time in the past when the sea levels were higher and the region was underwater. The islands and banks of the Bahamas, Bermuda, and most of the state of Florida are other examples of carbonate platforms.

The Yucatan was also the site of a huge asteroid impact about 65 million years ago, at the end of the Cretaceous Period, which apparently contributed to the extinction of the dinosaurs. This event, called the Chicxulub impact, produced a large crater that was subsequently buried in carbonate sediments. The buried impact crater was first suspected to be located here because of ancient wells, called cenotes, that were used by the Mayan Indians. These wells were found to lie in a semicircular ring on the Yucatan Peninsula, suggesting a circular structure below the surface. The ring of wells resulted from the fact that water travels along the circular fractures that were created by this massive impact. Geological studies of the area by oil companies revealed the buried crater.

Some scientists believe that the impact event was a critical factor in causing the extinction of the dinosaurs and other organisms at the end of the Cretaceous period. An impact into the carbonate platform would have caused the carbonates and associated minerals, such as calcium sulfate (*gypsum*), to vaporize, producing large quantities of aerosols. The dust and sulfate aerosols ejected into the atmosphere would have caused the Earth's surface to cool significantly. This is what many scientists believe finished off the dinosaurs. (The Earth's climate had been slowly cooling before the impact, so the dinosaurs were already in decline, even before the Chicxulub impact event.)

RELATED IMAGES: Pacific Ocean El Niño Image Pair: December 1997–February 1998, June 1998–August 1998; Saharan Dust over the Canary Islands, 6 March 1998 & Hurricane Bonnie, 25 August 1998 (Bahamas Banks visible at lower right)

IMAGE: U.S. Mid-Atlantic Region, 12 April 1998

IMAGE DESCRIPTION: The Level 1A (true color) image shows the landforms and coastal features of the U.S. Mid-Atlantic Region. The Chesapeake and Delaware Bays, barrier islands on the New Jersey coast, the Appalachian Mountains, and the Hudson River Valley are prominent.

TOPIC AREAS: Estuaries / Rivers / Coastal features / Tectonic forces / Land surface changes / Human influence

PHENOMENON DESCRIPTION: The U.S. Mid-Atlantic region encompasses a variety of land and coastal surface features (and also a lot of U.S. history, of course). The most noticeable large features are the Chesapeake and Delaware Bays. Each of these bays is a prime example of an *estuary*. An estuary is characterized as an area where fresh water from rivers mixes with oceanic water. The extent of the mixing area in an estuary depends on geography (the size and shape of the estuary) and the amount of water being delivered from rivers into the estuary. The Chesapeake is so large that waters in the northern part of the bay are nearly fresh, while water at the mouth of the bay is essentially seawater, so the mixing zone is extensive. In other estuaries, the mixing zone is much smaller. Variability in the flow of rivers from year to year can affect the salinity of an estuary and the distribution of organisms living in it.

Estuaries are vital zones in the entire oceanic ecosystem. Though small in area, they usually have high productivity, due to several factors: shallow and usually clear water, a variety of bottom habitats (sea grasses, oyster beds, sand bars), and higher nutrient levels than the open ocean. Estuaries are sometimes called the "nurseries" of the sea, where the larval and juvenile forms of many species are born and grow. The degradation of estuarine habitat can, therefore, significantly affect the populations of many important marine species. Since estuaries are also attractive places for people to live and visit, estuaries around the world are under considerable environmental pressure. For example, increased nutrient levels and increased turbidity due to bottom destruction (disturbance of the bottom by dredging or dumping) cause less light to penetrate the water in an estuary. This leads to the die-off of sea grass beds, which are important habitats for juvenile fish and for prey animals, such as shrimp.

The New Jersey coast of Delaware Bay is protected by barrier islands, which are narrow strips of sand that form near coastal areas with low tidal influence. Barrier islands can serve to protect the main coast from the impact of storms, but they are ephemeral, because the sand that composes them is always moving. Building on barrier islands may cause changes in the normal patterns of sand deposition, leading to erosion and the gradual disappearance of the islands. The Delaware Bay islands are the site of a very interesting ecological dependency. Every spring, as horseshoe crabs mate and release eggs in the shallows, migratory shorebirds converge on the islands and gorge themselves on the eggs, replacing the fat reserves that allowed their long migration from the Caribbean and South America. Recent use of horseshoe crab meat for bait has reduced their populations, affecting the shorebird populations that depend on them.

Another prominent feature of this region is the Appalachian Mountain range, which shows up as a series of alternating brown bands across the northern part of this image. The Appalachians are a folded mountain belt. They were formed about 250 million years ago at a convergent plate margin. But unlike the Aleutian Islands, off the coast of Alaska, the Appalachians represent the collision of two continental plates. When continents collide, the rocks between them are squeezed, like putty in a vise; as a result, layers of flat sedimentary rock are tilted, folded, and deformed into very complex structures. In the Appalachians, many millions of years of erosion have removed the upper layers of rock, revealing these interior structures. In the western portion of this image, these can be seen as a jagged, orange and brown zigzag pattern.

Cutting across the Appalachian range, the north-to-south line of the Hudson River is easy to see near the top of the image. The Hudson River has been carving through this region for a long time. One reason that this is known is by the presence of the Hudson Canyon on the continental shelf margin, which cuts through the continental shelf edge to the floor of the abyssal Atlantic Ocean. The Hudson Canyon is connected to the present-day mouth of the Hudson River by an ancient underwater river channel that is filled with modern sediments. The Hudson Canyon was actually carved by undersea landslides ("turbidity currents") originating on the continental shelf. The presence of the ancient Hudson River channel indicates that sea level is much higher now than earlier in Earth's geologic history and that the Hudson River has been flowing in this area for thousands of years. Sea level was much lower during the periods of continental glaciation in the Pleistocene Era (the "Ice Ages"), because a great deal of water was frozen in the huge glacial sheets.

The Hudson River cuts through many geologic layers. One of these is a volcanic sill, formed when magma was intruded between existing layers of rock. When solidified, such intruded lavas often display a distinctive fracture pattern called columnar jointing. The Palisades Sill, just north of New York City, has some good examples of columnar jointing. Other places where columnar jointing can be seen are Devil's Tower and the Grand Canyon of the Yellowstone River in Wyoming, Devil's Postpile National Monument in California, and Giant's Causeway in Antrim, Scotland.

RELATED IMAGES: Eastern Mediterranean and the Nile River Delta, 6 April 1998; Global Biosphere (high productivity coastal regions) & Coccolithophorid Bloom, Bering Sea, 25 April 1998

IMAGE: Eastern Mediterranean and the Nile River Delta, 6 April 1998

IMAGE DESCRIPTION: Level 1A true-color image of the Nile River delta and eastern Mediterranean Sea.

TOPIC AREAS: River deltas / Oceanic productivity / Deserts / Saline lakes / Rift valleys / Tectonic spreading centers

PHENOMENON DESCRIPTION: The most prominent feature in this image is the Nile River delta. Deltas are found at the mouths of rivers that have both high sediment loads and shallow bottom topography, so not all rivers with high sediment loads will form deltas. Deltas have a prominent role in human history because the rich sediments, the constant supply of river water, and their proximity to the seacoast, made them vital areas for agriculture and commerce. Some examples of famous river deltas around the world: the Mississippi River delta on the Gulf of Mexico, United States; the Ganges/Brahmaputra delta in India; the Po River delta in the Adriatic Sea (the city of Venice is built on Po River sediments); the Danube River delta in the Black Sea; the Yellow River delta in China; and the Okavango River delta in Botswana. (The Okavango delta is a strange example, because the river ends right in the middle of a continent.) Many lakes and bays also have smaller deltas where rivers enter them. Not all rivers form deltas, because they require a fairly large region at the mouth of the river and a sufficient sediment supply.

The Nile River delta has a particularly important role in human history, because it (as well as the shores of the Nile River) provided rich agricultural resources to ancient Egyptian civilizations. Deltas are land forms that are very susceptible to changing climate conditions. Changes in the amount of water flowing to the delta, sea level rise and fall, and severe storms can all drastically alter the delta landscape, because deltas generally rise only a few feet above sea level. Deltaic sediments often show characteristic patterns of deposition that are related to such climate factors. Deltas depend on a constant supply of sediments, because the compaction of deposited sediments causes the land surface to slowly sink (*subsidence*). The construction of the Aswan High Dam in Egypt, which formed Lake Nasser, depleted the supply of sediments to the Nile River delta. This is another factor that is contributing to a loss of land in the delta.

At the edge of the delta, the greenish color indicates an outflow of sediment and possibly the presence of phytoplankton. The rest of the eastern Mediterranean has very clear water. Though humans have fished in the Mediterranean for thousands of years, the Mediterranean Sea, particularly the eastern regions, actually has very low productivity. Very few rivers supply nutrients to the coastal zone, particularly on the desert coasts, and the currents are slower and weaker than in the ocean, so nutrients in deeper water rarely rise to the surface.

It is well known that this is a very dry and arid part of the world. (Because humidity and haze levels—except during dust storms—are low, SeaWiFS frequently has very clear views of the region.) Thus, two river systems, the Nile and the Jordan, can be clearly seen in this image. These rivers have played crucial roles in the history of the region and are vital to the region today, because water supply is so critical in the desert. However, the two rivers are quite different. The Nile is the longest river in the world, and the Jordan is one of the shortest. The Nile flows northward, and the Jordan flows south, into the Dead Sea. The Nile has carved its own path in the African continent, terminating in the Mediterranean where it forms the delta. The Jordan, on the other hand, flows in a valley formed by tectonic forces and discharges into the Dead Sea, a terminal basin lake.

The Jordan Rift Valley is an extension of the spreading center in the Red Sea and the Great Rift Valley in Africa. The Red Sea is a place where tectonic forces have just begun to separate the land masses of Africa and Arabia, forming the narrow body of water. Deep in the sea, hot springs in this active spreading center create *brine pools*, pockets of very hot, very dense and highly saline water, where some very exotic minerals are formed. The presence of such brine pools indicates that this is an active tectonic rift.

The Dead Sea is a terminal basin lake, similar to the Great Salt Lake in Utah. A terminal basin lake has river water flowing into it, but no rivers flowing out of it. Therefore, dissolved ions in the river water become increasingly concentrated in the lake as the entering water evaporates under the hot desert sun. This process can increase the salinity of the water to much higher than that of seawater. (The term "basin" is used because these lakes occupy low areas in the Earth's surface, which is why rivers flow into them rather than flowing to the ocean. The surface of the Dead Sea is many feet below sea level.) The Caspian Sea and the Aral Sea are the largest examples of such lakes. The Aral Sea illustrates what happens if the water supply to these lakes is reduced: They dry up. The Aral Sea has been receding for decades due to diversion of water for irrigation in the surrounding region.

RELATED IMAGES: East Coast of Africa, 19 July 1998

IMAGE: East Coast of Africa, 19 July 1998

IMAGE DESCRIPTION: This Level 1A true color image shows the eastern coast of Africa (Mozambique) and the clear waters of the Agulhas Current in the Mozambique Channel.

TOPIC AREAS: Coral reefs / Land surface processes / River systems / Rift valleys / Plate tectonics

PHENOMENON DESCRIPTION: Clear, sunny skies and warm, clear, shallow water are two vital ingredients for the formation of coral reefs. The optical signature of coral reefs (bright blue-green water, caused by sunlight reflecting off the shallow bottom) can be seen in the southern portion of this SeaWiFS image of the east coast of Africa. (The image of Hurricane Bonnie also shows the blue-green waters of the Bahamas Banks.) The Agulhas Current, which is a warm surface current, flows southward through the Mozambique Channel in this region.

Corals are remarkable animals, because they derive energy in two different ways: 1) corals filter the water that passes over them, and 2) algae living inside the individual coral polyps create organic carbon by photosynthesis, which is shared with the coral in a *symbiotic* relationship. One of the by-products of energy production is calcium carbonate through the process of calcification, in the same manner as coccolithophorids. The buildup of calcium carbonate on the sea floor produces a *coral reef.* Coral reefs are unique and vital environments in the ocean. Their biological diversity is similar to rain forests on land.

Corals are also good indicators of the quality of the oceanic environment. Under stressful conditions, corals release the algae living inside of them, a process called "bleaching." Observations of bleaching around the world have been linked to rising water temperatures (although corals thrive in warm water, it can't get too warm) and lower water quality, which allows bacterial diseases and viruses to thrive. Corals are also susceptible to increased turbidity, which can result from increased concentrations of phytoplankton that are nourished by the higher nutrient levels, or from increased amounts of suspended sediments caused by changes in nearby land areas. The health of many coral reefs around the world is imperiled by the twin-pronged attack of warmer water and higher turbidity, both likely related to human activity.

SeaWiFS data are being used to map coral reef areas around the world. Even though the resolution of SeaWiFS is only 1 km, recurring observations allow these areas to be repeatedly observed over time. Furthermore, SeaWiFS provides vital information about potentially increasing phytoplankton concentrations.

Another visible feature in this image is the branching (*dendritic*) pattern of the Zambezi River as it enters the Indian Ocean near the center of the image. Not all rivers form sediment deltas such as the Nile River delta. The Zambezi does not carry a high sediment load, so there is very little turbidity visible at the river mouth

The image on the poster is notable for what it doesn't show. (The full image has been provided with this supplement, and is also available on the SeaWiFS Project web site.) Just to the west of the image border lies Lake Malawi (also called Lake Nyasa) the southernmost lake in the African Rift Valley, a spreading center on land. The African Rift Valley is a site where the African Plate appears to beginning to rift, the initial stage of formation of a new continental plate, which makes this a region of increased seismic and volcanic activity. Lake Malawi is very deep, almost 750 meters deep at its northern end. North of Lake Malawi, the Rift Valley creates two branches, the eastern and western branch. The western branch contains Lake Tanganyika and Lake Kivu.

There are several noteworthy volcanoes in or near both branches of the Rift Valley. On the eastern branch, the great size of famous Mount Kilimanjaro demonstrates how active volcanism has been in this region. Further to the north, Ol Doinyo Lengai volcano erupts a unique lava type, called nephelinite. This lava is rich in carbon, and is much cooler than the more familiar orange-red lava of basaltic volcanoes. In the western branch, Nyiragongo volcano is of interest because the crater was the site of an active lava lake for many years. Nyamuragira volcano, only 14 km northwest of Nyiragongo, is also frequently active, most recently in January and February 2000.

Intriguingly, the Rift Valley created several different micro-environments as climate changed 4–5 million years ago. These varied environments may have been critical to the evolution of humanity. The oldest hominid fossils are found in various locations in the Rift Valley area.

The other noticeable feature in the full image is the "Great Dike of Zimbabwe." It is visible as a thin black line dividing a mottled region of terrain. This is an area where igneous rock formed large intrusions, which is a form of volcanic activity occurring below the Earth's surface. The Great Dike of Zimbabwe is the solidified conduit of magma that supplied magma to several bodies of magma called *lopoliths*. This process occurred over 2.5 billion years ago, and since then, erosion has exposed the Great Dike and the lopoliths in this region.

RELATED IMAGES: Hurricane Bonnie, 25 August 1998

IMAGE: Hurricane Bonnie, 25 August 1999

IMAGE DESCRIPTION: Hurricane Bonnie approaching the southeast coast of the U.S. Note the Bahama Islands and Bahama Banks to the south of the hurricane, Great Smoky Mountains (southern Appalachians), and Tampa Bay and Lake Okeechobee in Florida.

TOPIC AREAS: Hurricane / Sea surface temperature / Convection / Cyclone / Coriolis effect / Latent heat / Buoyancy / Radar / ITCZ / TRMM

PHENOMENON DESCRIPTION: The hurricane is one of the most destructive natural weather phenomena known, and every year, several hurricanes occur in the tropical regions of the ocean. In the U.S., hurricanes may cause hundreds of millions of dollars worth of damage and take several lives. The word *hurricane* derives from "Huracan," the name of a Carib God of Evil. It is a violent cyclone that originates over tropical oceans, usually in the late summer or early fall. By definition a hurricane has a maximum sustained wind speed greater than 119 km (74 miles) per hour although winds in very intense hurricanes may top 250 km (155 miles) per hour.

The first sign that a hurricane may be forming is the appearance of an organized cluster of thunderclouds over tropical seas. If a center of low pressure is detectable at the surface, this region of convective (rising air) activity is labeled a tropical disturbance. Tropical disturbances are initiated in three ways: 1) a low-pressure system in the Intertropical Convergence Zone (ITCZ); 2) a trough in the westerlies intruding into the tropics from the mid-latitudes, or 3) by a wave, or a ripple, in the easterly trade winds (an easterly wave). The most intense hurricanes that threaten North America usually develop out of convective cloud clusters associated with easterly waves that continually track westward off the West African coast. Convergence on the east side of the wave helps to organize convective activity into a developing system. Storms originating in this way are referred to as Cape Verde-type hurricanes.

Only a small percentage of convective cloud clusters in the tropical Atlantic actually evolve into full-blown hurricanes. There are several reasons for this:

- Strong subsidence of air on the eastern flank of the Bermuda-Azores anti-cyclone and the associated trade-wind inversion inhibit deep convection.
- The vertical wind shear over the tropical Atlantic is usually too great for hurricane formation.
- The middle troposphere is usually too dry; low vapor pressure at these levels inhibits intensification of the system.

If conditions favorable to hurricane formation persist, cyclonic circulation develops (due to the Coriolis effect) and the surface air pressure begins to fall. A sea surface temperature of at least 26.5–27 degrees Celsius is required to drive the developing hurricane using the energy from *latent heat of evaporation*. When water vapor condenses within the storm, latent heat (stored when the water became water vapor) is released, heating the surrounding air and causing it to rise. As the air rises, it cools and expands, triggering more condensation, the release of more latent heat, and a further increase in buoyancy. Rising temperatures in the core of the storm, coupled with an anti-cyclonic outflow of air aloft, cause a sharp drop in air pressure which in turn induces more rapid convergence of air at the surface. The consequent uplift surrounding the developing eye leads to additional condensation and release of latent heat. (This is an excellent example of positive feedback.) Through these processes, the tropical disturbance intensifies and winds strengthen. If winds exceed 119 km (74 miles) per hour, the storm is officially designated a hurricane.

Hurricanes that threaten the Atlantic and Gulf coasts of the U.S. usually drift slowly westward with the trade winds across the tropical North Atlantic and into the Caribbean. At this stage in the storm's trajectory, it is not unusual for the storm to travel at a mere 10 to 20 km (6 to 12 miles) per hour and take a week to cross the Atlantic. Once over the western Atlantic, however, the storm usually speeds up and begins to curve northward as it is caught up in the mid-latitude westerlies. Precisely where this curvature takes place determines whether the hurricane enters the Gulf of Mexico and tracks up the Mississippi River Valley, moves up the Eastern Seaboard, or curves back out to sea. As the hurricane travels northward, it may begin to acquire extra-tropical (mid-latitude) characteristics at around 30 degrees N latitude. Colder air is drawn up into the circulation of the system and fronts develop. From then on, the storm follows a life cycle similar to that of any other mid-latitude cyclone and often ends by dissipating over the North Atlantic.

Hurricane Bonnie struck the southeast coast of the U.S. in late August 1998. It developed from a tropical wave, which rolled off the west coast of Africa on 16 August. The morning weather charts on that day showed this wave, and more significantly, a closed low-pressure isobar (low), which indicated a counterclockwise circulation of winds around the low. As the system moved westward with the prevailing winds, it encountered waters with temperatures in excess of 28 degrees Celsius. By the next day the wave had "deepened," a meteorological term meaning that the pressure in the center of the low had dropped, in this case to 1010 millibars. On this date, the wave was passing through the strongest part of a standing high-pressure zone in the southern Atlantic, and was becoming more organized.

For the next two days the tropical wave intensified, wind speeds increased, and by midday on 20 August, Tropical Storm Bonnie was born. She was now located approximately 200 miles to the east of Puerto Rico, and moving toward the island. It was on this date that two NASA research aircraft were launched into the storm as part of the third Convective And Moisture Experiment (CAMEX3), based out of Patrick Air Force Base, near Cape Canaveral, Florida. Instrumentation on board the aircraft included LIDAR's, radars, particle samplers, and various temperature and humidity measuring instruments. Additionally, one aircraft had the capability to release dropsondes, weather packages that measure temperature, moisture and winds on descent to the ocean.

Two days later, on 23 August, surface wind speeds in Bonnie were in excess of 177 km (110 miles) per hour. She was just to the east of the Bahamas, heading toward the northwest at 19 km (12 miles) per hour right for the Georgia coast.

August 26 proved to be an incredibly busy day for the reconnaissance aircraft: at one point there were an unprecedented six aircraft in the eye of Bonnie! Data from the research instruments were extensive, and in many cases, unique. Not only airborne measurements were made. Shore- and satellite-based radar instruments saw structures and evolving patterns never before seen in hurricane research, such as the extremely high cloud tops observed by the radar instrument on the Tropical Rainfall Measuring Mission (TRMM) satellite. At one point, the eye of the hurricane expanded to an enormous 202 km (125 miles) after a smaller concentric eye-wall collapsed.

Bonnie finally made landfall near Wilmington, North Carolina. After hugging the Outer Banks for two more days, Bonnie moved off shore to the northeast, dissipating in the North Atlantic Ocean by 31 August.

Bonnie, in her 11-day life, traveled across the Atlantic from Africa, threatened the Caribbean Islands, and stopped at the North Carolina Coast for three days, dropping torrential rains on the Piedmont. She developed winds in excess of 161 km (100 miles) per hour for more than two-and-a-half days, and was responsible for three deaths in the U.S. She provided meteorologists a unique opportunity to examine the innermost workings of one of Earth's most awesome spectacles.

IMAGE: SeaWiFS Project Operations Diagram

IMAGE DESCRIPTION: The SeaWiFS Project Operations Diagram is the only item on the poster that is not an actual Earth remote sensing image. The operations diagram shows the basic connections in the project that allow the production and distribution of quality ocean color data. The diagram shows that many vital operations are necessary to produce accurate remote sensing data.

TOPIC AREAS: Remote sensing / Satellite remote sensing instruments / Data calibration / Data validation / Algorithms and data analysis / Image analysis

DESCRIPTION: The heart of the SeaWiFS Project is the instrument on board the Orbview-2 spacecraft, the Sea-viewing Wide Field-of-view Sensor, otherwise known as SeaWiFS. SeaWiFS was originally conceived during the latter part of the 8-year Coastal Zone Color Scanner (CZCS) mission, which took place from October 1978 to June 1986. CZCS demonstrated the feasibility and the usefulness of obtaining ocean color data from a satellite sensor. SeaWiFS was designed as the next mission, an instrument with improved optics that would carry out full-time observations of the Earth. CZCS was an instrument on the Nimbus-7 satellite, which carried other remote sensing instruments. The instruments shared the electrical power from the satellite's solar panels, so the CZCS was only operated on a part-time basis. SeaWiFS is the only sensor on board the Orbview-2 spacecraft, and so does not share power with other instruments and can be operated full time. The primary goal of the SeaWiFS mission was to provide continuous global coverage of the oceans, which the part-time operation of the CZCS could not accomplish.

Though SeaWiFS was first conceived in the 1980's, it took several years to obtain funding for the mission. SeaWiFS was made possible by a unique partnership with a private company, Orbital Sciences Corporation (OSC). OSC later created Orbimage, Inc. as an auxiliary business for remote sensing data. The National Aeronautics and Space Administration (NASA) specified the necessary data quality for the instrument, and then contracted with OSC to design the sensor and launch the satellite. In return, OSC would be allowed to sell the data for commercial applications, such as fisheries or even military applications. NASA specified the cost they would pay for data from the mission, if the mission were successful. Thus, SeaWiFS is called a "data-buy" mission.

OSC collaborated with the Santa Barbara Research Center (SBRC) to design and build SeaWiFS. The basic design of the instrument uses a rotating mirror that scans the Earth repeatedly as the satellite passes over it. Each rotation of the mirror provides one scan line of data. The light from the mirror is reflected through filters (called "bands") and then onto a light detector that measures light intensity. SeaWiFS has eight bands in the visible and near-infrared spectrum. The quantity that the detector measures is called *radiance*, sunlight that has been scattered, reflected, or partially absorbed by the land, ocean, and atmosphere, then bounced into space. For the oceans, this quantity is called *water-leaving radiance*. Data from the visible bands are the main remote sensing data from the satellite, while data from the near-infrared bands are used for atmospheric correction (described below). Instruments that measure radiance for specific spectral bands are called *radiometers*.

The speed and altitude of the satellite, the rotation speed of the mirror, and the size of the detector elements, determine the resolution of the resulting data. Resolution refers to the distance on the Earth's surface that each picture element (pixel) of the data represents. The best resolution that SeaWiFS achieves is 1 kilometer (km) directly below the satellite (at "nadir"). The total distance that each scan line covers is 2800 km, but the best data are in the middle 1500 km of the scan line, because the curvature of the Earth distorts features at the scan line's edges and the increasing light path length through the atmosphere reduces the optical quality.

Orbview-2 was launched on 1 August 1997 aboard a Pegasus XL rocket. Pegasus rockets are carried underneath an airplane to an altitude of about 30,000 ft, then dropped just before the rocket engine is fired. The rocket then delivers the payload (usually a satellite or satellites) into space. Following launch, the satellite was maneuvered into its proper orbit, and full-time data acquisition began on 18 September 1997. Orbview-2 orbits the Earth at a 450-km altitude, moving north-south over the sunlit hemisphere, a "descending node" orbit.

SeaWiFS data are transmitted to Earth in two different ways. The satellite broadcasts the data as soon as the sensor acquires it, and this signal can be picked up by any ground station close enough to the satellite to receive it. The ground stations are called High Resolution Picture Transmission (HRPT) stations. HRPT station data, also called Local Area Coverage (LAC) data, are the highest resolution data that can be obtained from SeaWiFS, because the satellite broadcasts all of the data it acquires. The satellite also records some data at a lower resolution, for later playback. A computer on the satellite "samples" the data to reduce data volume and improve data quality: the outer ends of each scan line are eliminated, leaving the central 1500-meter-wide swath, and then every 4th pixel in each scan line is recorded. These data, called Global Area Coverage (GAC) data, have a resolution of 4.5 km and are stored on the satellite computer until it passes near the U.S. East Coast, at either noon or midnight. Then the GAC data are transmitted to Goddard Space Flight Center (GSFC) in Maryland, the Wallops Flight Facility in Virginia, and Orbimage Inc. in Virginia. GSFC and Orbimage Inc. also receive data from the HRPT stations. Orbimage and the SeaWiFS Project collaborate in controlling the satellite functions through the Mission Operations Facility. Each GAC transmission has data for approximately 7.5 orbits, covering half the Earth.

Once the data are received, either from the satellite or from ground stations, the SeaWiFS data processing facility then begins to process the data. The data are checked for navigational accuracy, to make sure the Earth location of the data is precisely determined. This step produces *Level 1A data.* Then the scientific algorithms, which have been created by the SeaWiFS Project and by oceanographers around the world (the SeaWiFS Science Team), are applied to the data. The first calculation the algorithms perform removes the influence of light scattering in the atmosphere (*atmospheric correction*) using data from the near-infrared bands. The data are also corrected for the angle of the Sun. Ancillary data, including water vapor and ozone in the atmosphere, are also used in these algorithms. The algorithms are applied to the data to calculate important oceanographic quantities, such as the concentration of chlorophyll or the depth that light penetrates into the ocean. This is *Level 2 data.*

The next step that is performed by the data processing facility is the creation of global data products. The 4.5 km resolution data are combined and averaged (a process called "binning") over periods of one day, eight days, a month, and a year to provide images of the Earth with a resolution of about 9 km. Data binning has three purposes: to eliminate the influence of clouds, to provide averaged water-leaving radiance data (because single observations are not always reliable), and most importantly, to produce a <u>global</u> data product. The orbital altitude and scan line width on the Earth allow SeaWiFS a theoretical view of 90 percent of the Earth's surface every two days, but 90 percent of the surface is never visible, due to cloud cover. However, because clouds move, binning the data compiles more observations of the Earth's surface. Longer binning periods gradually eliminate the influence of clouds. This data processing procedure is the primary reason that the central image of the Earth on the SeaWiFS poster shows most of the Earth without clouds. The data produced by this process is called *Level 3 data*. (The "level" definitions are applicable to all remote sensing data and were defined early in the history of Earth remote sensing.)

Once the data have been processed, the data are tested using the Calibration and Validation process. Calibration is designed to insure that the light levels measured by the instrument remain accurate. Due to exposure in the harsh environment of space, the optics of the instrument degrade over time. SeaWiFS uses several methods, including viewing the Moon, to monitor the accuracy of the instrument. Necessary calibration corrections are applied to the data. Validation refers to the process of checking the calculated data against data obtained by researchers at the Earth's surface (*in situ*, *ground-truth*, or *sea-truth* data). Researchers determine the concentration of chlorophyll in the ocean, or measure the water-leaving radiance right at the ocean surface. A light-sensing buoy in the ocean near Hawaii also measures ocean optical conditions. Such ground-truth data sets are compared to the satellite data to evaluate how well the data analysis process is reproducing the actual conditions at the Earth's surface.

As researchers obtain additional data, they will modify the algorithms used to calculate the important oceanographic quantities that the SeaWiFS Project produces. Every year or so, the SeaWiFS Project uses improved algorithms to recalculate (*reprocess*) all of the data. As the mission progresses, the data should become increasingly accurate.

When the data are ready, data files are sent to the Goddard Earth Sciences Distributed Active Archive Center (DAAC). The DAAC stores the data in duplicate libraries, so that it will not be lost. Researchers obtain SeaWiFS data from the DAAC for use in their own oceanographic research.

The images that are created by the SeaWiFS Project come in three main varieties. "True-color" images use the calibrated light levels from three SeaWiFS bands to create images that are approximately the same color that the human eye would see from a low altitude. These are also called Level 1A images, because they have been derived from Level 1A data. Level 2 images are based on Level 2 data, and use a color palette created by the SeaWiFS Project to show the variation of chlorophyll concentration in the oceans. Images such as these, which use a color palette to emphasize features in the data, are called "false-color" images. The SeaWiFS chlorophyll palette uses blues and greens for low and medium chlorophyll concentrations, and yellow and red for high and very high chlorophyll concentrations. Other palettes are used on land, in some cases, to show vegetation cover. SeaWiFS Level 3 images comprise the global binned data products. (Note that remote sensing data of many types is commonly displayed using different color palettes specific to the data type.)

This description of the SeaWiFS instrument and Project provides an idea of the effort required to produce accurate remote sensing data. However, despite the work of numerous scientists, remote sensing is still very difficult. The SeaWiFS Project has initiated several different programs designed to improve the accuracy of the optical and biological data collected by oceanographers. New instruments have been created that allowed different research groups to calibrate their instruments in the exact same way. An entire database of optical and biological measurements has been created to allow researchers to compare SeaWiFS data to sea-truth measurements for a given region. Researchers have conducted cruises in various oceanic regions to collect data at the same moment that SeaWiFS was passing overhead, allowing direct comparison of the sea-truth data to the instrument measurements. All of these programs contribute to the SeaWiFS Project's success in producing ocean color data of unprecedented accuracy.

SeaWiFS and NASA's Earth Science Enterprise

The Earth remote sensing observations performed by many NASA satellite missions are part of NASA's Earth Science Enterprise (ESE). The primary objective of the ESE is to define and quantify the interconnections of Earth's climate system, and to use this information to discern both natural change and anthropogenic (human-related) alterations of Earth's climate and environment. Satellite remote sensing data provide scientists with information that is truly global in scope, rather than isolated to areas or regions, and thus allow integration of the processes occurring in the atmosphere, on land, in the oceans, and in the frozen areas of the globe. These processes are intricately connected to the ebb and flow of biological patterns on Earth's surface.

SeaWiFS is a pioneering mission in the study of Earth's biological patterns. By providing the first truly continuous view of biological variability in the oceans and on land, SeaWiFS has allowed scientists to observe changes in the biosphere and to calculate how a phenomenon such as El Niño affects the Earth's carbon cycle. In addition, SeaWiFS data allow a much more detailed view in time and space of the interactions of physical processes (such as wind and ocean currents) with the biology of the oceans. SeaWiFS has also observed unique events whose true size and impact might have been unsuspected, such as immense blooms of coccolithophores in the Bering Sea, and huge dust storms which travel across entire oceans, perhaps carrying nutrients such as iron and even bacteria that can attack coral reef organisms. SeaWiFS has therefore provided an initial look at the total Earth environment, a look that will be improved and focused by subsequent satellite missions of NASA's Earth Science Enterprise.

Glossary

Advanced Very High Resolution Radiometer: an instrument carried on polar-orbiting satellites operated by the National Oceanic and Atmospheric Administration (NOAA). AVHRR measurements include sea surface temperature and land surface coverage data.

aerosol: a suspension of liquid or solid particles in a gas

algae: aquatic plants that produce carbon by photosynthesis. Algae can range from microscopic to very large, such as kelp, which can be tens of meters in length.

algorithm: a systematic calculation process applied to input data to produce a derived value

atmospheric correction: the analytical process which removes the effects of light scattering in the atmosphere from remote sensing data

AVHRR: acronym for *Advanced Very High Resolution Radiometer*

band: a range of the electromagnetic spectrum that is sensed by a detector

barrier island: an elongate coastal island, usually composed primarily of sand, separated from the mainland by a marsh or lagoon

biosphere: the living organisms on the Earth

binning: the statistical process of combining data from repetitive remote sensing observations into a single value representing the mean value of the data for a given area and time period

bloom: rapid growth and proliferation of phytoplankton

brine pool: a local concentration of highly concentrated salt water

buoyancy: the upward force exerted on a body of lesser density immersed in a fluid of greater density

calcification: the production of calcium carbonate by organisms

calibration: the process of insuring that a measurement is accurate relative to an absolute standard

carbon cycle: the processes by which carbon in various forms is transferred between the atmosphere, ocean, and geologic formations on the Earth

carbonate sediments: oceanic sediments composed of calcium carbonate

carbonate platform/carbonate shelf: a geological formation composed of sedimentary calcium carbonate. Carbonate shelves are located along the coast (examples are the Florida and Yucatan peninsulas). Carbonate platforms are isolated shallow water areas which may include islands (examples are Bermuda and the Bahamas).

Case 1 Water: clear, open ocean water whose optical properties are primarily determined by the concentration of phytoplankton

Case 2 Water: turbid, coastal water whose optical properties are determined by the combined effects of phytoplankton, suspended particulates, and dissolved substances

cenote: a large circular deep well found in the Yucatan peninsula of Mexico

Coastal Zone Color Scanner: the first satellite-borne remote sensing instrument designed to measure ocean color

coccolith: a microscopic disk of biogenic calcium carbonate

coccolithophorid: a form of phytoplankton that creates coccoliths and coccospheres

coccosphere: a microscopic sphere composed of coccoliths

convection: vertical movement in a fluid medium due to heating, which results in heat transfer

coral: Anthozoa, bottom-dwelling attached marine organisms which produce skeletal calcium carbonate and which contain symbiotic algae

coral reef: a moundlike or ridgelike formation composed of corals and associated organisms

Coriolis effect: the apparent deflection of a body moving with respect to the Earth as viewed by an Earthbound observer, caused by the rotation of the Earth

Cretaceous Period: the final period of the Mesozoic Era, 135-65 million years ago

CZCS: acronym for *Coastal Zone Color Scanner*

delta: a sedimentary deposit of gravel, sand, silt, or clay, formed where a river enters a body of water

descending node: the point in a satellite's orbit at which it crosses the equatorial plane from north to south. A descending node orbit has the satellite moving north-south over the illuminated hemisphere.

dropsonde: an instrument attached to a parachute that is dropped from an aircraft and transmits measurements of atmospheric conditions as it descends

estuary: the area at the mouth of a river where fresh water mixes with seawater

evaporation: the process where liquid water becomes water vapor

extratropical: originating outside the tropics. Extratropical storms have different characteristics than tropical systems, and a tropical system can transform into an extratropical system as it moves poleward.

eye wall: the wall surrounding the eye of a hurricane, where windspeed is greatest

false color: the use of a range of colors (color palette) to enhance visualization of remote sensing data

GAC: acronym for *Global Area Coverage*

Global Area Coverage: remote sensing data stored at reduced resolution, suitable for global projections. Originally applied to AVHRR data.

ground truth data: data gathered at the Earth's surface, used to validate remote sensing data

Gulf Stream: the western boundary current originating in the Gulf of Mexico, which flows northward along the southern coast of the United States and then turns westward toward Europe

High Resolution Picture Transmission: a type of receiving station for satellite remote sensing data. This term also refers to 1 km resolution data transmitted continuously from a satellite remote sensing instrument, and was originally applied to AVHRR data.

HRPT: acronym for *High Resolution Picture Transmission*

hurricane: a tropical cyclone with wind speeds greater than 64 knots (74 miles per hour, 118 km per hour) or greater

in situ data: data collected "in place," i.e., data that has been collected by direct methods

insolation: the amount of direct solar radiation per unit of horizontal surface

Intertropical Convergence Zone: a region in the Earth's atmosphere located near the Equator where counter-rotating circulation in the Northern and Southern hemispheres results in an area of rising air currents, leading to the formation of convective storms

isobar: a line connecting points of equal pressure

ITCZ: acronym for *Intertropical Convergence Zone*

LAC: acronym for *Local Area Coverage*

Laser Infrared Detection and Ranging: detector system using lasers to detect atmospheric particles and water vapor

latent heat: heat change associated with a change of state or phase. Latent heat, also called *heat of transformation*, is the heat given up or absorbed by a unit mass of a substance as it changes phase (i.e., solid, liquid, or gas).

Level 1 Data: remote sensing data as measured by a satellite sensor, i.e. *raw* data

Level 2 Data: remote sensing data that has been processed and analyzed to produce accurate geophysical values

Level 3 Data: remote sensing data that has been statistically processed to produce global analyses

LIDAR: acronym for *Laser Infrared Detection and Ranging*

light scattering: deflection of light, without absorption, as a result of its interactions with particles (including molecules of air or water)

Local Area Coverage: data at the highest possible resolution of a satellite sensor (1 km resolution for SeaWiFS). This term originally applied to AVHRR data.

low-pressure system: an area of low pressure in the atmosphere, which may be associated with storm formation

nephelinite: a volcanic lava composed of sodium carbonate

NDVI: acronym for *Normalized Difference Vegetation Index*

Normalized Difference Vegetation Index: AVHRR visible (VIS) and near infrared (NIR) channel data used to generate a variable which indicates vegetation health and land coverage according to the formula (NIR - VIS)/(NIR + VIS). NDVI increases with increasing vegetation cover.

ocean color: the light which is reflected out of the ocean, where the color is determined by the interactions of incident light (sunlight) with substances or particles present in the water

particle sampler: airborne instrument that collects particles suspended in the atmosphere

phytoplankton: free-floating microscopic unicellular photosynthetic plants

plate tectonics: the movement of the Earth's crustal plates, which results in the apparent motion of the continents and gives rise to volcanic and seismic phenomena

radar: a device or system consisting usually of a synchronized radio transmitter and receiver that emits radio waves (microwaves) and processes their reflections for display

radiance: electromagnetic energy per unit time, area, solid area and spectral band, i.e., electromagnetic energy radiating in a given direction

radiometer: an instrument that measures radiances

resolution: in a spatial sense, the size of the smallest feature recognizable by a given detector

salinity: the concentration of dissolved elements in seawater

sea truth data: data gathered at the sea surface, used to validate remote sensing data

sediments: particulates in rivers, freshwater bodies, or seawater. *Suspended sediments* refers to particles that are in the water column; *sediments* usually refers to unconsolidated particles on the lake or sea floor.

subsidence: the downward settling or movement of material with little horizontal movement. Subsidence is usually caused by the removal of material beneath the subsiding mass.

symbiosis: biologically, a situation where two dissimilar organisms coexist in a mutually beneficial relationship

thermocline: a relatively sharp boundary between cold and warm waters in the water column of a lake or ocean

terminal basin lake: a lake located geologically such that there is no outlet

tidal bore: a wave in a river or estuary caused by the rapid influx of tidally-driven water

trade winds: winds that affect tropical and subtropical regions. In the Northern Hemisphere, the trade winds blow east to northeasterly in direction. In the Southern Hemisphere, they blow east to southeasterly. This means that in both hemispheres, they tend to blow from the east to the west and towards the equator. The *trade winds* were named because they were reliable winds for sailing ships in the ocean.

tropical storm: a tropical cyclone system with wind speeds between 34 to 63 knots (38 to 73 miles per hour, 61 to 118 km per hour)

true color: remotely sensed data that has been processed to appear similar to what the human eye would see

turbidity: influence on light reflection and scattering due to particles or dissolved substances in the water column

upwelling: an oceanic process that brings deep ocean water to the surface

volcano: a geological formation where molten rock (magma) from below the Earth's surface is released at the Earth's surface

water-leaving radiance: light which radiates upward from the sea surface, due to the reflection and scattering of sunlight incident on the sea surface

vertical wind shear: a change in wind direction with altitude

SeaWiFS Poster Teaching Supplement Information and Links

The Goddard Earth Sciences Distributed Active Archive Center (GES DAAC) maintains a Web page dedicated to the SeaWiFS Poster Teaching Supplement. This Web page allows access to the current PDF version of the Supplement, and has active, updated (every six months) Web links to sites with additional information related to the images on the poster and the topics presented in the Supplement. The URL for this Web page is:

http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/OCDST/poster_supplement.html

It is possible that this URL may change. To navigate to the SeaWiFS Poster Teaching Supplement site, follow these steps:

Access the GES DAAC home page, **http://daac.gsfc.nasa.gov/**

Click on the "Ocean Color" heading

Click "Educational Resources" on the Ocean Color Data Web Site page

Click on the link for the "SeaWiFS Poster Teaching Supplement Information and Links"

Enhancing Scientific Literacy with *The SeaWiFS Poster Teaching Supplement*

Imagine examining biological patterns on a global scale alongside scientific researchers. Would you like to know more about satellite remote sensing and image analysis? Are you intrigued with becoming an expert on El Niño, patterns of productivity in the oceans, or seasonal changes in the Pacific Ocean? These opportunities are just a mouse click away for you and your students as you begin to learn more about the SeaWiFS mission and *The SeaWiFS Poster Teaching Supplement.*

As teachers, we are always searching for authentic and developmentally appropriate technology-based resources to use in our classrooms. Scientifically literate students understand key scientific concepts in real-world contexts and are able to collect, critically analyze, and validate data. *The SeaWiFS Poster Teaching Supplement* is designed to help you learn more about a variety of Earth systems processes for the purpose of enhancing students' scientific understandings and process skills. The supplement is designed for you and your students to explore together. There are a number of sound reasons, rooted in the latest research on effective teaching, for using this resource with your students.

Reasons to Explore *The SeaWiFS Poster Teaching Supplement*

1) Scientifically literate students know how and where to access up-to-date science information and data. *The SeaWiFS Poster Teaching Supplement* is a gateway providing personal access to a vast array of scientifically accurate and up-to-date information related to the global biosphere and Earth systems.

2) Scientifically literate students have the skills to analyze the information they access. The SeaWiFS mission employs cutting-edge satellite remote sensing to produce dynamic Earth images. Such images, and the data they represent, stimulate visual discrimination and critical thinking skills in students.

3) Scientifically literate students inquire into and investigate real-world situations, issues, and problems. The SeaWiFS mission is centered on collecting real-time information on the global biosphere. Students are able to question, predict, examine and analyze what is happening on a day-to-day, month-to-month, year-to-year basis.

4) Scientifically literate students have true understandings of how scientific research proceeds. The SeaWiFS mission can connect students to scientists and their research as it is happening, providing real-time, authentic science experiences allowing students to experience the dynamic complexities of scientific research.

5) Scientifically literate students use technology to enhance their understandings. *The SeaWiFS Poster Teaching Supplement* provides students with opportunities to use the World Wide Web for very specific and authentic purposes as they strive to understand interactions in the global biosphere.

6) Scientifically literate students have teachers who are partners in the learning process. The SeaWiFS Project and the Goddard Earth Sciences DAAC are concerned with providing teachers and students with the support they need to begin exploring the possibilities SeaWiFS has to offer. *The SeaWiFS Poster Teaching Supplement* is the tool that will help you and your students become partners in the learning process.

Possibilities for Exploring *The SeaWiFS Poster Teaching Supplement*

The ideas listed in this section are designed to stir your imagination and help you think about the many ways that SeaWiFS and Earth science can come alive in your classroom. As you read through *The SeaWiFS Poster Teaching Supplement*, you will find other activities and ideas. Remember, as teachers we don't need to understand all the information contained in a resource before we begin using it with students. Here are ideas to help you get started exploring the possibilities that SeaWIFS has to offer.

While doing long-range instructional planning, search for the places where the various SeaWiFS topics could be integrated into your curriculum. The SeaWiFS topics are designed to work together or to be embedded in your existing curriculum frameworks. Use the SeaWiFS information in creative ways to meet the needs and interest of your students.

SeaWiFS sleuthing is always exciting. Point your students to an interesting SeaWIFS image (or they can find the images on their own) and have them develop research questions to investigate by examining/comparing other SeaWIFS images or data. Your students might uncover a new process or phenomena. Inquiries like this serve as authentic and relevant student challenges.

Form SeaWiFS student research teams. Teams of students choose one of the SeaWiFS topics and explore the WWW connections and supplemental information independently. After the teams have completed their research they make presentations to the class on their findings, or create pages of information on their topic for a school web site or newsletter. At the end of the semester, hold a research symposium where students can do poster sessions, similar to a real scientific research conference.

It may also be possible to collect student ideas on how the topics on the poster can be integrated into classroom instruction. Students can review the information in the supplement and the related WWW links, and provide feedback to the teacher on topics that they would like to learn more about, or topics they would like to investigate via individual or group research for eventual presentation to the rest of the class. This challenge could serve as an authentic assessment for students in Earth science or environmental science courses.

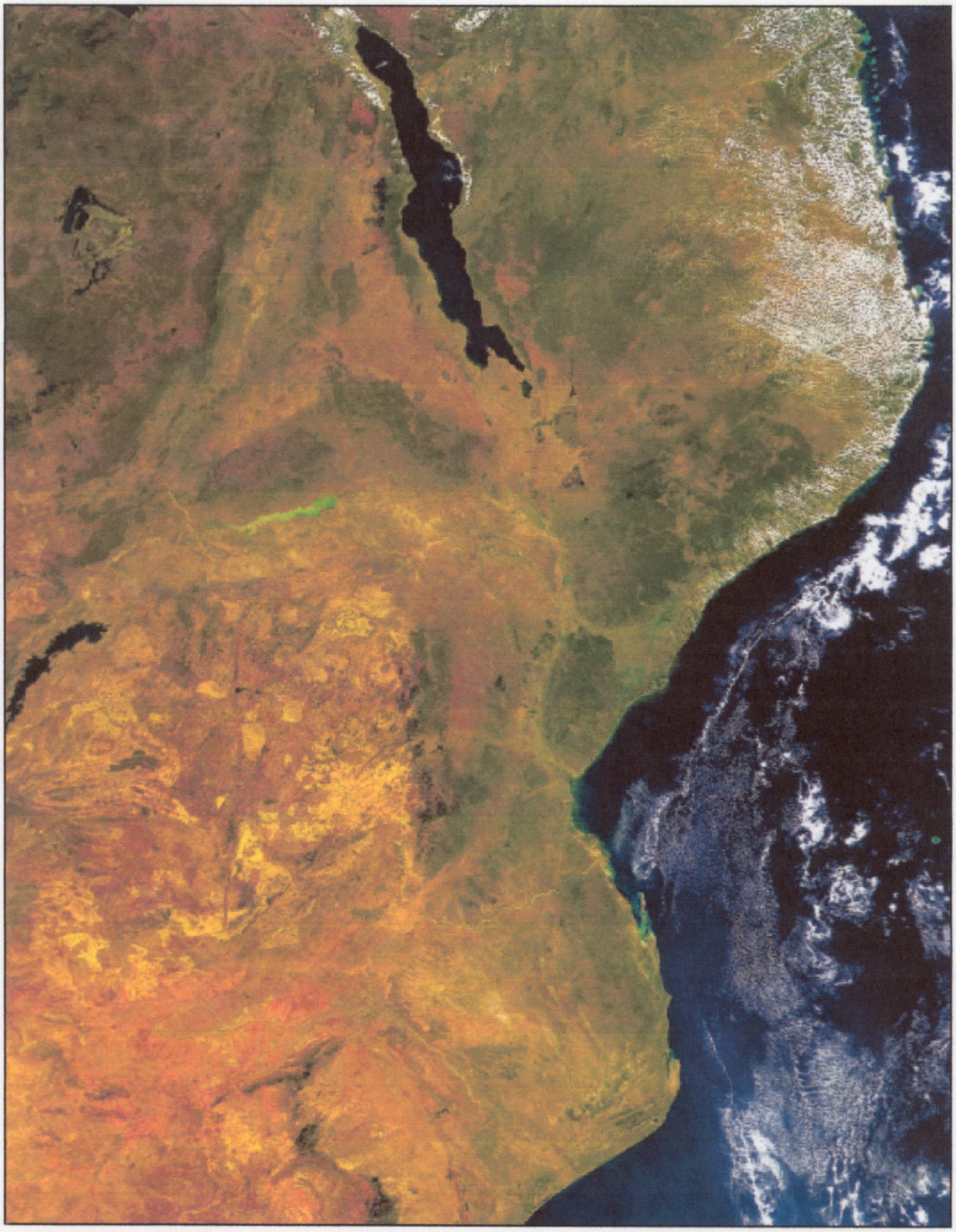
Have students use the information in *The SeaWiFS Poster Teaching Supplement* and the WWW components to develop a lesson they could teach on a specific SeaWIFS topic. Challenge the students to do more than verbal and written reports in the lesson. Have the students think of activities to illustrate the key concepts and processes they are trying to teach.

Encourage the students to e-mail SeaWiFS scientists with their questions and make sure that students share the results of any research with scientists as well. Students must develop effective communication skills to succeed in science. If local scientists are available to come in and interact with your students, bring them in to help students develop research questions or judge presentations or research posters.

Dr. Susan M. Blunck, Assistant Professor, University of Maryland—Baltimore Country (UMBC) Department of Education

Please take a moment to evaluate this product at **http://ehb2.gsfc.nasa.gov/edcats/educational_brief**

Your evaluation and suggestions are vital to continually improving NASA educational materials. Thank you.



SeaWiFS Image of the East Coast of Africa and the Great Rift Valley acquired July 19, 1998. This image features Lake Malawi (top center), the Zambezi River and delta, the Great Dike of Zimbabwe (center left), and coral reefs on the coast of Tanzania.

SeaWiFS Image of the East Coast of Africa and the Great Rift Valley acquired July 19, 1998

This image is the complete image of the "East Coast of Africa, 19 July 1998" image that appears on the left side of the SeaWiFS Poster. It features several geological features of interest. Conspicuous in the upper center of the image is Lake Malawi (also called Lake Nyasa), the southernmost of the Great Rift Valley Lakes. Malawi is very deep, nearly 750 meters in its northern end. North of the lake, the Great Rift Valley splits into the eastern and western branches. Some of the noteworthy geological features of the eastern and western branches of the Great Rift Valley are described in the supplement.

The body of water at the center left edge of the image is Lake Kariba. Victoria Falls would lie just out of the image to the west. The Zambezi River flows northeastward from Lake Kariba, then turns south-east to the delta region on the coast.

The highly conspicuous dark line in the center of the mottled light brown terrain is the "Great Dike of Zimbabwe." This is an area where igneous rock formed large intrusions, which is a form of volcanic activity occurring below the Earth's surface. The Great Dike of Zimbabwe is the solidified conduit of magma which supplied magma to several bodies of magma called *lopoliths*. This process occurred over 2.5 billion years ago, and since then, erosion has exposed the Great Dike and the lopoliths in this region.

Accompanying URLs (these are also listed in the Supplement)

http://daac.gsfc.nasa.gov/DAAC_DOCS/geomorphology/GEO_2/GEO_PLATE_T-35.HTML

http://daac.gsfc.nasa.gov/DAAC_DOCS/geomorphology/GEO_2/GEO_PLATE_T-34.HTML

http://www.geo.wvu.edu/~geol351/Spring98/12/default.htm

http://images.jsc.nasa.gov/images/pao/STS32/10063457.htm

http://www.mc.maricopa.edu/anthro/exploratorium/hominid_journey/earlyasian/Larick-2.html

http://www.africaonline.com/AfricaOnline/travel/zimbabwe/vic_falls.html

Related "Classroom of the Future" links:

Rift Valley Fever:
http://www.cotf.edu/ete/modules/rift/rvsituation.html

Teacher Page:
http://www.cotf.edu/ete/modules/rift/rift.html

EP-2000-9-003-GSFC