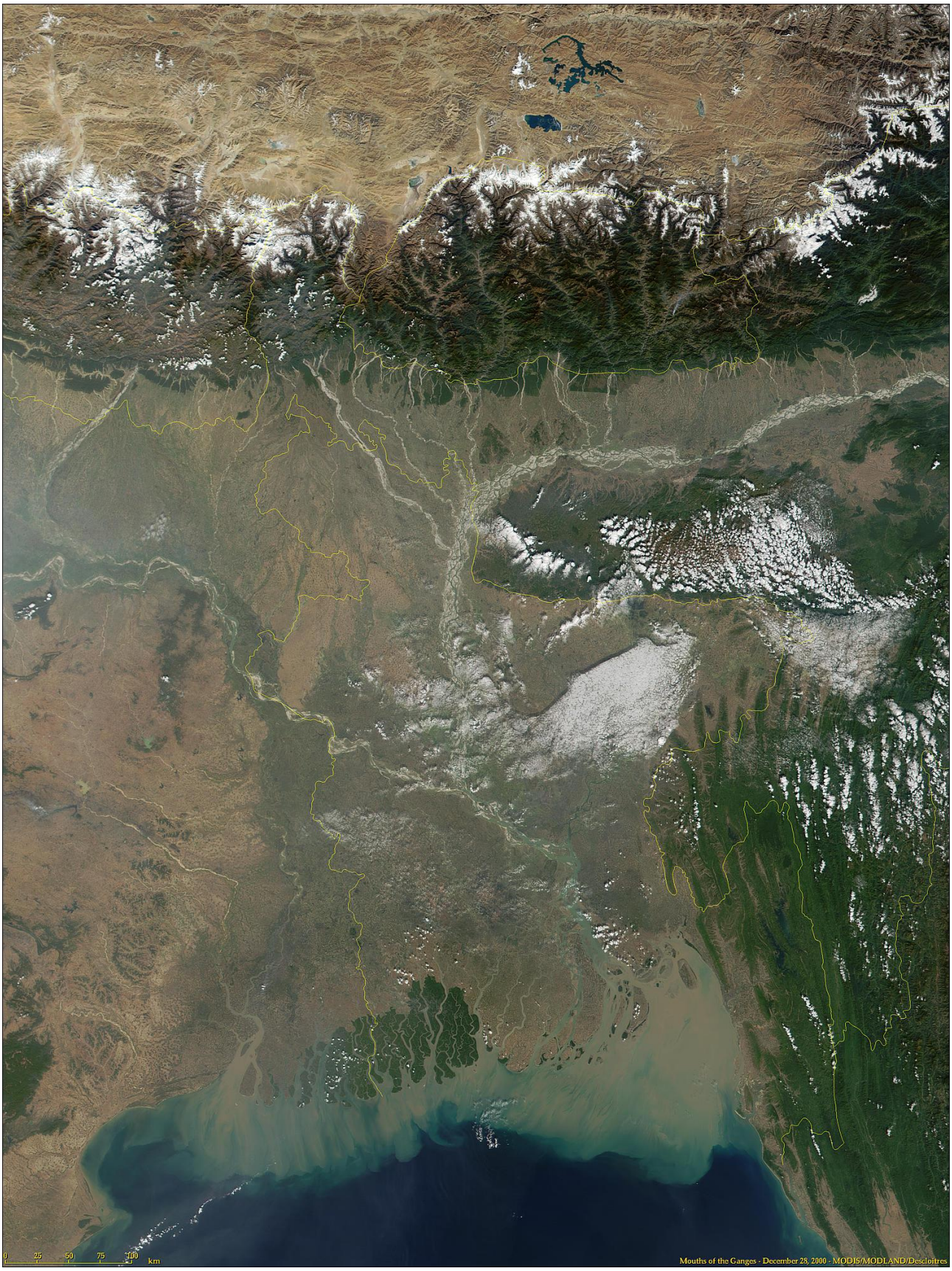
SCIENCE FOCUS: Ocean Sediments

Sedimentia

Image of the Ganges River delta and the Bay of Bengal acquired by the Moderate Resolution Imaging Spectroradiometer (MODIS). This image shows the massive amount of sediments delivered to the Bay of Bengal by the Ganges River, sediments that are derived from erosion of the Himalayan mountain range to the north. On the next page is a larger version that includes the Himalayan range. Mt. Everest, the highest point in the world, is located in the upper right corner of the high-resolution image.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Mouths of the Ganges - December 28, 2000 - MODIS/MODLAND/Descloitres

No, it doesn't mean we're crazy about sediments. On the contrary, most of the time sediments make life more difficult for the analysis of remotely-sensed ocean color data. Some aspects of this subject have been covered in *Turbidity—Through A Water Column, Darkly*, another *Science Focus!* article. That article primarily dealt with the reasons that sediments can be a problem for accurate analysis of chlorophyll concentrations, particularly in coastal regions.

Yet sediments, despite all the disparaging comments that might be directed at them by remote-sensing scientists, are an important aspect of the marine realm, and they can be geophysically significant for several different reasons. One reason is that sediment particles can be composed of materials that are highly reactive in the marine environment. Some rivers deliver sediments that are rich in organic matter into estuaries and the open ocean, providing a food source for bacteria and zooplankton. Other sediments (more on this below) are reactive in seawater and are important players in the marine carbon and carbonate cycles. Sediments also carry important materials on them: both clay particles and organic particulates can adsorb dissolved metal ions on their surfaces. This process of adsorption may quickly transport metals that could be harmful to the sea floor, where they may be buried, or digested by opportunistic bacteria—but that's not always a good thing.

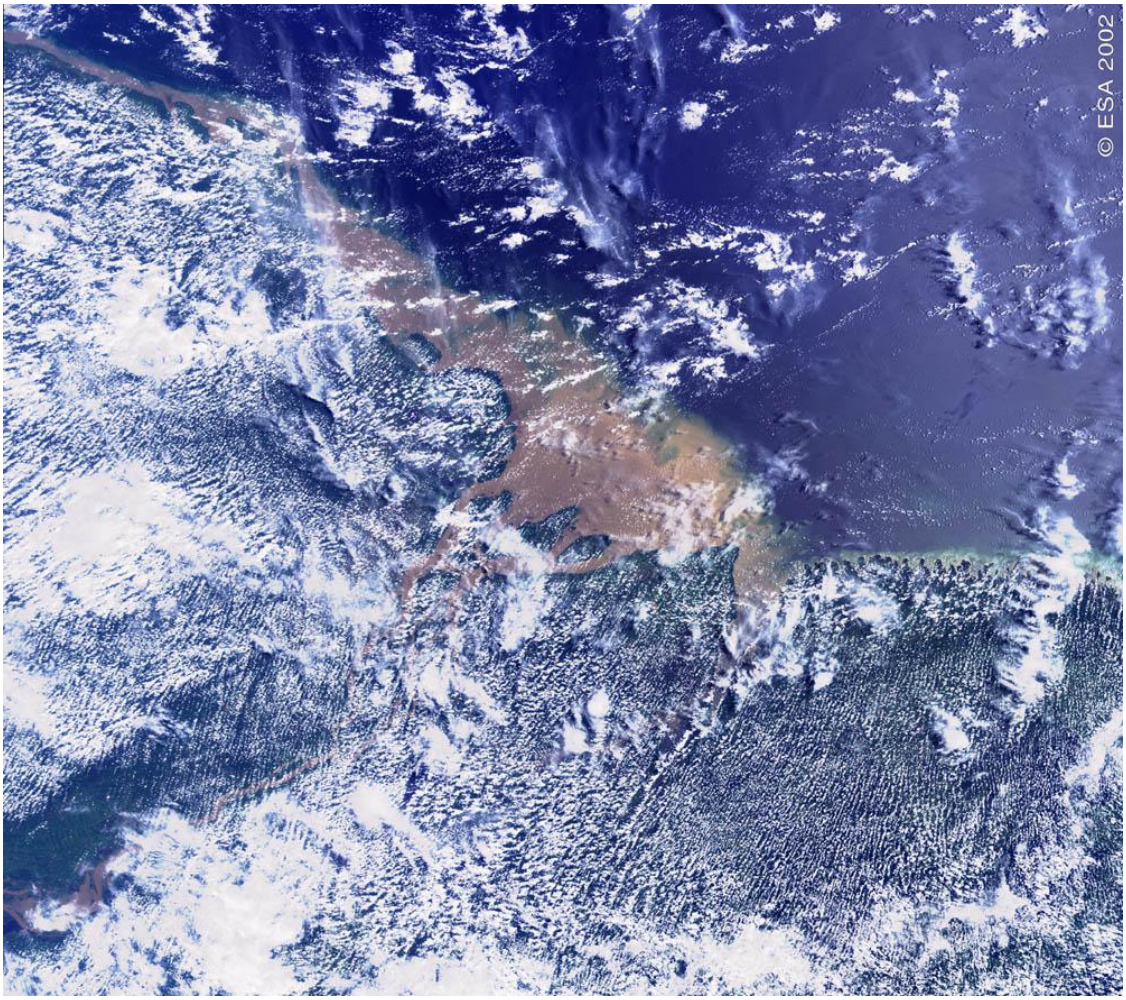
Furthermore, sediments are the source of one of mankind's favorite recreational sites—the beach! Sediments move around, of course, and while they can move and pile up to make beaches, they can also move and directly affect the sea floor environment.

This *Science Focus!* article will feature brief stops around the world where sediments have been observed by SeaWiFS and MODIS (and MERIS), and will finish with a phenomenon that may be an important facet of the marine carbon cycle.

The first stop is the northern Adriatic Sea in Europe. In the northern Adriatic, the Po River discharges a large amount of sediments derived from erosion in the Alps, and this sediment underlies the historic city of Venice. It also forms the famed Lido Beach. The Po River "plume" was actually observed by the Coastal Zone Color Scanner and astronauts on the Space Shuttle on the same day, as described and illustrated in **Classic CZCS Scenes** *Chapter 10: River Plumes and Estuaries*. SeaWiFS has occasionally viewed the Po River plume, as seen in the image on the next page. However, pervasive haze and pollution in the Po River valley frequently obscures observations of the northern Adriatic.

SeaWiFS image of Italy and the Adriatic Sea. The Balkans to the west and the snow-covered Alps to the north are also visible. The Po River valley is the hazy brown area just south of the Alps. The plume of sediments carried by the Po River is seen on the western side of the far northern Adriatic Sea.

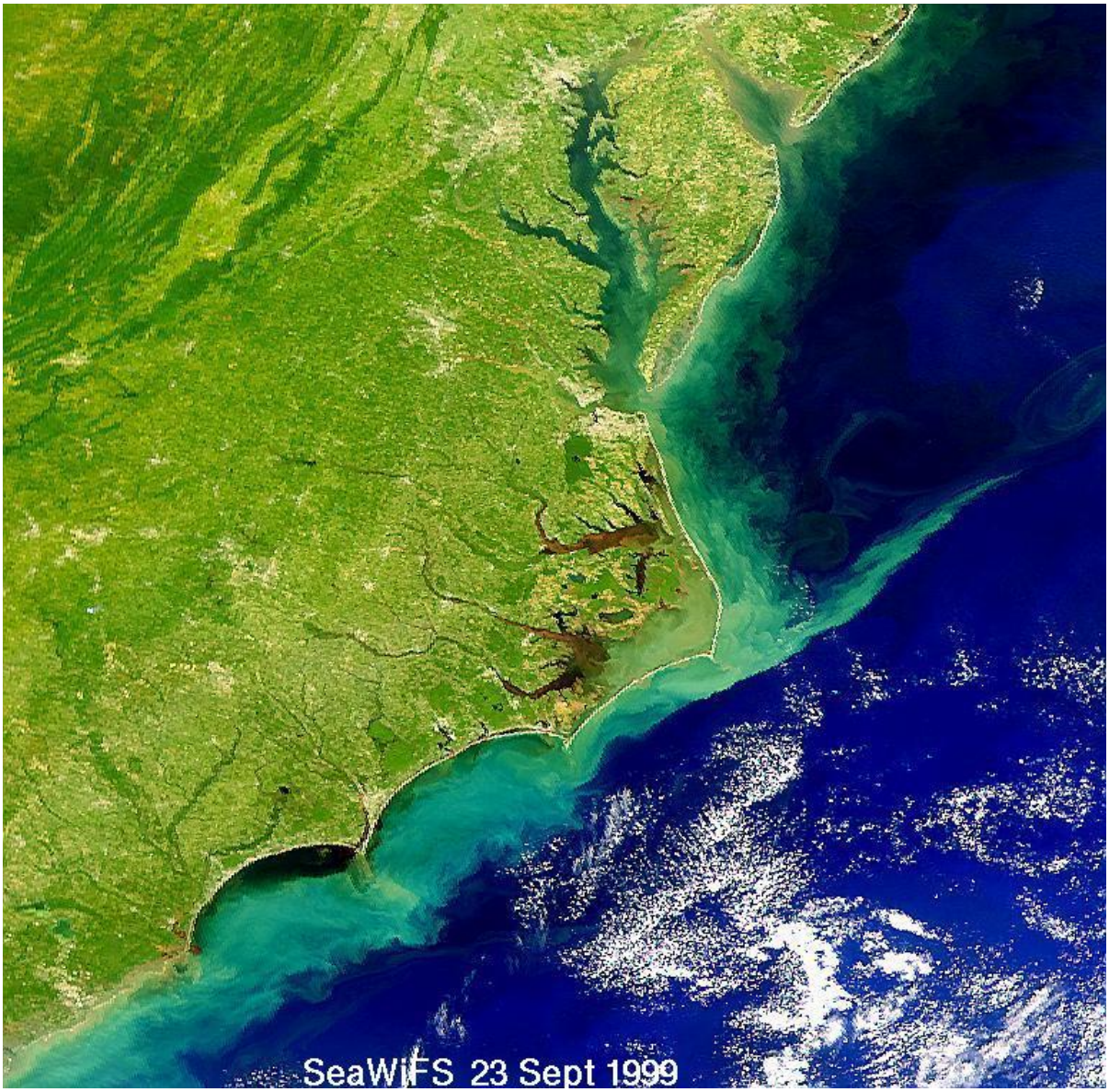
Next, we look at the mightiest river on Earth, the Amazon, with one of the newest instruments in orbit: MERIS, the Medium Resolution Imaging Spectrometer carried on ENVISAT. MERIS captured this view of the mouth of the Amazon River on March 25, 2002. The large mass of sediments delivered by the Amazon to the Atlantic Ocean is carried by currents up the coast into the Caribbean Sea.



MERIS image of the mouth of the Amazon River and sediments on the coast of Brazil. Image credit: European Space Agency (ESA).

The Ganges River in India, along with the Yellow and Yangtze River in China and the Mekong River in Vietnam and Cambodia, carries some of the heaviest mass of sediments of any river in the world. The sediments of the Ganges are derived from erosion of the Himalaya mountain range. The MODIS image at the beginning of this article shows the delta region of the Ganges and the massive amount of sediments entering the Bay of Bengal.

Rivers, then, are obviously one of the primary sources of sediments to the marine environment. However, many rivers do not carry a large amount of sediments to the ocean except under special conditions, specifically floods. On September 23, 1999, SeaWiFS acquired a remarkable view of the North Carolina coast one week after the passage of Hurricane Floyd. The rain-swollen rivers of North Carolina delivered an immense amount of sediment into the Atlantic Ocean, which was then carried into the open ocean by the Gulf Stream.



SeaWiFS image of the U.S. East Coast acquired one week after the passage of Hurricane Floyd (see image below). The sediments generated by the flood waters of rivers in North Carolina are seen entering the Gulf Stream off of Cape Hatteras. Also note the increased turbidity in the sounds and river estuaries and persistent sediment suspension southward along the coast.

Hurricane Floyd was interesting for another reason, which is the concluding topic of this article. The sediments carried by rivers can be classified as riverine, predominantly inorganic sediments, because they are usually composed of mineral grains that have been eroded from the land surface. Another form of sediments which is found primarily in the ocean are *biogenic* sediments, which means that they are composed of minerals formed by organisms. The main two mineral forms of this type that are found in the ocean are calcium carbonate ($CaCO_3$) and silica (SiO_2). Calcium carbonate is formed by numerous organisms: coccolithophorids, foraminifera, pteropods, corals, and coralline algae, to name a few. Silica is predominantly formed by diatoms.

$CaCO_3$ is important to the marine carbon cycle because this mineral can dissolve in seawater, if the seawater chemistry is <u>undersaturated</u> with respect to the mineral. Seawater contains ions of calcium (Ca^{2+}), which doesn't vary much in concentration in seawater, and both bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}), which do vary considerably, particularly with depth. Seawater is usually oversaturated with respect to $CaCO_3$ at the surface of the ocean, and undersaturated deep in the ocean. The depth at which $CaCO_3$ will start to dissolve, the <u>saturation horizon</u>, varies. It can be nearly 3000 meters deep in the Atlantic Ocean, and as little as 150 meters deep in the northern Pacific Ocean.

Another factor is that $CaCO_3$ can exist in a variety of mineral forms. Calcite, formed by coccolithophorids and foraminifera, is the least soluble in seawater. Aragonite, formed by pteropods, is more soluble than calcite. And corals and coralline algae form calcite that contains a considerable amount of magnesium (Mg), which makes this "high-Mg" calcite the most soluble form of biogenic calcium carbonate.

Coral reefs, and the shallow *carbonate banks* that are commonly located near them, are the most productive areas for biogenic $CaCO_3$ in the ocean. (Well-known examples of carbonate banks are the Bahamas islands and the island of Bermuda.) A small area of coral reef and carbonate bank can produce the same amount of $CaCO_3$ as hundreds of square kilometers on the surface of the open ocean.

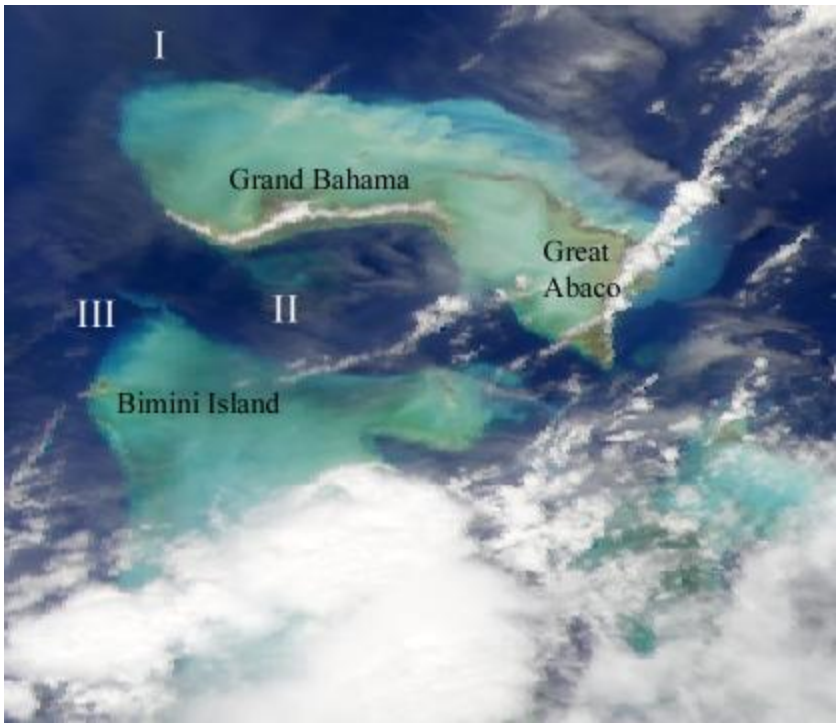
But there's a problem, which has been a research question for marine geologists and geochemists for many years and which is still very uncertain. Both the mechanisms by which this biogenic $CaCO_3$ is transferred from the shallow banks and reefs to the deep sea, and the amount of this material that is transported, are uncertain.

Remote sensing provides one way to clarify these questions. Because the sediments produced on carbonate banks are highly reflective, they are relatively easy to detect from space. Once these sediments reach the open ocean, however, they will begin sinking. So to be visible from space, a sufficient amount of sediments must be transported a sufficient distance from the islands.

There are several mechanisms that can move these sediments, and the most notable is hurricane-force winds. Before Hurricane Floyd moved inland over North Carolina and the states in the U.S. Northeast, it traveled directly over the Bahamas islands. On September 16, 1999, SeaWiFS captured the remarkable view of the U.S. East Coast shown below, with Hurricane Floyd's center near Washington, D.C. The path of Floyd carried it over the U.S. continental shelf, which is clearly visible due to the suspension of sediments on the sea floor.

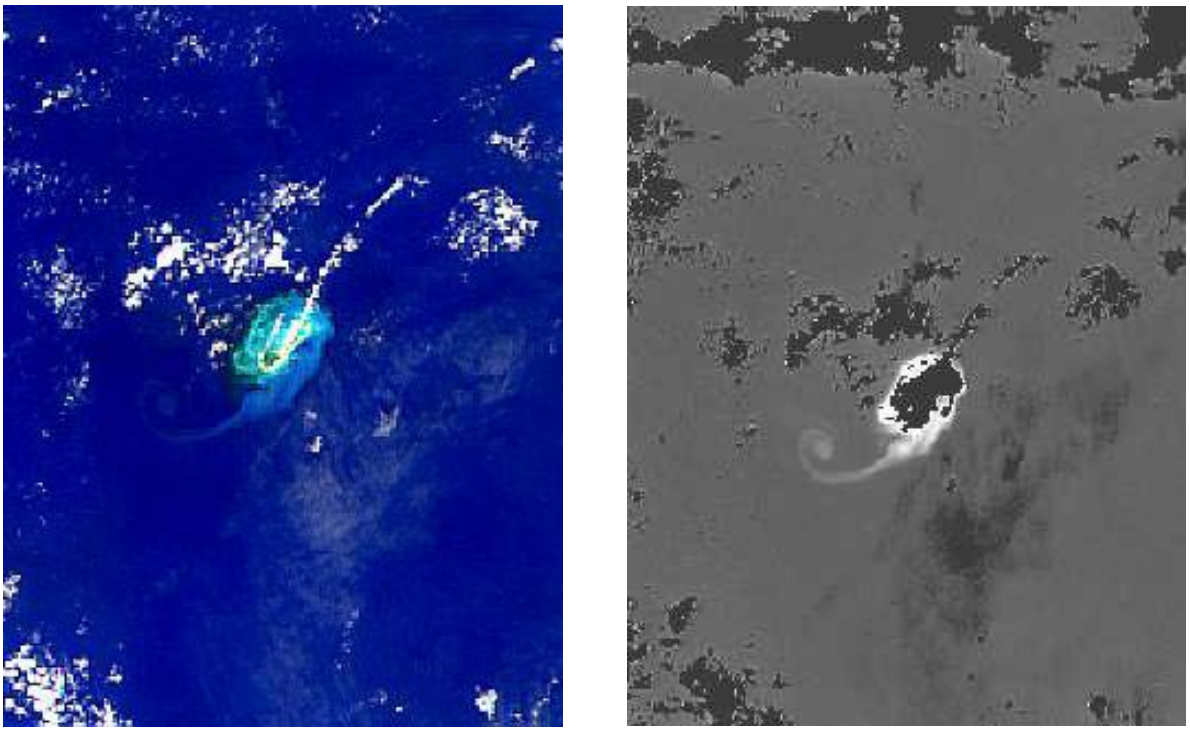
SeaWiFS image of Hurricane Floyd, the U.S. East Coast, and the Bahamas Banks, acquired on September 16, 1999. Sediment suspension along the U.S. continental shelf is prominent in this image.

Close examination of the Bahamas islands in this image revealed the presence of suspended carbonate sediments moving off the banks. This image shows several different plumes of sediment. The largest amount of sediments appears to be transported northeastward off the northern margin of Little Bahama Bank (north of Great Abaco Island). Other smaller plumes are visible on the northwestern corner of Little Bahama Bank and on the northeastern and northwestern sides of Great Bahama Bank to the south. Three of these plumes are labeled I, II, and III.



Magnified September 16 SeaWiFS image of the Bahamas Banks, showing several areas where carbonate sediments suspended by the winds of Hurricane Floyd are being transported off the banks.

However, it took the next hurricane of the 1999 season, Hurricane Gert, to provide the clearest image to that date of $CaCO_3$ sediments transported off a carbonate bank: in this case, the island of Bermuda. On September 25, just hours after Hurricane Gert had passed near the island, SeaWiFS captured an image of the island shown on the following page. The true-color image is on the left, and the image portraying normalized water-leaving radiance at 555 nanometers data, nLw(555), is on the right. The 555 nm band is particularly good at detecting the reflection of light from suspended sediments.



SeaWiFS images of Bermuda acquired on September 25, one day after the passage of Hurricane Gert. The plume of sediments generated by Gert is visible in both images. (Left) True-color image. (Right) Normalized water-leaving radiance at 555 nm image. Data processing has placed a mask over the bright land of the island of Bermuda and the shallow waters of the carbonate bank surrounding the island.

These two events provided a fairly clear indication of what suspended carbonate sediments transported from carbonate banks look like from space. The next step is to attempt to quantify the mass of sediments that is transported in such events. These sediments are particularly amenable to quantification because they are reflective, they are mainly composed of one mineral type, and because they are not associated with large amounts of organic matter. They therefore provide good "test cases" for algorithms that use remote-sensing data to quantify sediment concentrations. If these algorithms prove to be reliable, then the principles used in the algorithms may be applied to quantifying sediment concentrations for more complex conditions.

Links

Remote Sensing of Water Turbidity and Sedimentation in Florida Bay and Biscayne Bay

Water Colour and Suspended Sediments: Bays (Fisheries and Oceans, Canada)

Reference

James G. Acker, Christopher W. Brown, Albert C. Hine, Edward Armstrong, and Norman Kuring, 2002: Satellite remote sensing observations and aerial photography of storm-induced neritic carbonate transport from shallow carbonate banks. *International Journal of Remote Sensing,* **23(14),** 2853-2868.