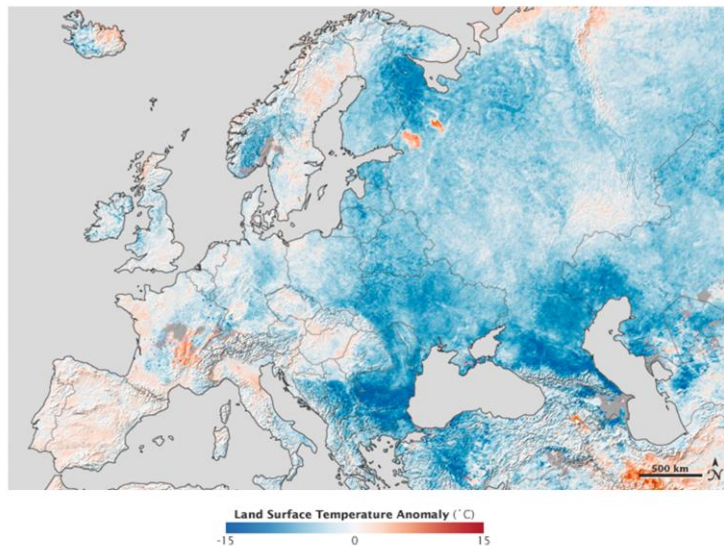


Temperature anomalies for Europe and western Russia from January 25 to February 1, 2012 compared to same dates, 2001-2011.



MODIS on Terra

1

Rare snowstorms in Rome and Tripoli and mounting death tolls from exposure were among the consequences of a severe cold snap in Europe in late January and early February 2012. Meteorologist Jeff Masters described it as Europe's worst stretch of cold weather since February 1991.

This map above shows temperature anomalies for Europe and western Russia from January 25 to February 1, 2012, compared to temperatures for the same dates from 2001 to 2011. The anomalies are based on land surface temperatures observed by the Moderate Resolution Imaging Spectroradiometer ([MODIS](#)) on NASA's [Terra](#) satellite. Areas with above-average temperatures appear in red and orange, and areas with below-average temperatures appear in shades of blue. Oceans and lakes appear in gray.

Blue dominates this image, with most regions experiencing temperatures well below normal. Some of the most severe temperature anomalies occur in northwestern Russia and around the Black Sea.

Masters explains that the unusual cold is a product of the [jet stream](#). Jet streams are bands of strong, upper-atmospheric winds that blow from west to east around the globe. These bands roughly separate colder air at higher latitudes from warmer air at middle to low latitudes, and they generally blow straight west to east. "But this winter, the jet has had a highly convoluted shape, with unusually large excursions to the north and south," Masters states. "When the jet bulges southwards, it allows cold air to spill in behind it, and that is what has happened

to Europe over the past two weeks.” When the jet stream adheres to a convoluted pattern for long enough, extreme weather can result.

The [Arctic Oscillation \(AO\) Index](#) provides an indication of whether the jet stream has formed an unusual bulge. When the AO is strongly negative, jet stream winds are comparatively weak, meaning it has drooped southward over Europe, dragging frigid air with it. A negative AO also often means unusual cold and snow over North America, but due to other factors, much of the United States has experienced [below average snowfall](#).

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Simeonova, D. (Agence France-Presse). (2012, February 7). [Floods add to Europe's cold to claim more lives.](#) Google News. Accessed February 9, 2012.

NASA Earth Observatory image created by Jesse Allen, using data provided courtesy of the Land Processes Data Active Archive Center (LPDAAC). Caption by Michon Scott.

Instrument: Terra - MODIS

Water in the Landscape Chapter 12, 7, 8, 9

Rivers, lakes, and ocean color

Water color, turbidity,
ice, snow (7)

Ocean satellites: SeaWiFS

Surface hydrology, drainage

Evapotranspiration

“Water is the world’s most valuable
resource”

Without water it’s all just chemistry.

Add water and you get biology.

-- Felix Franks, Cambridge

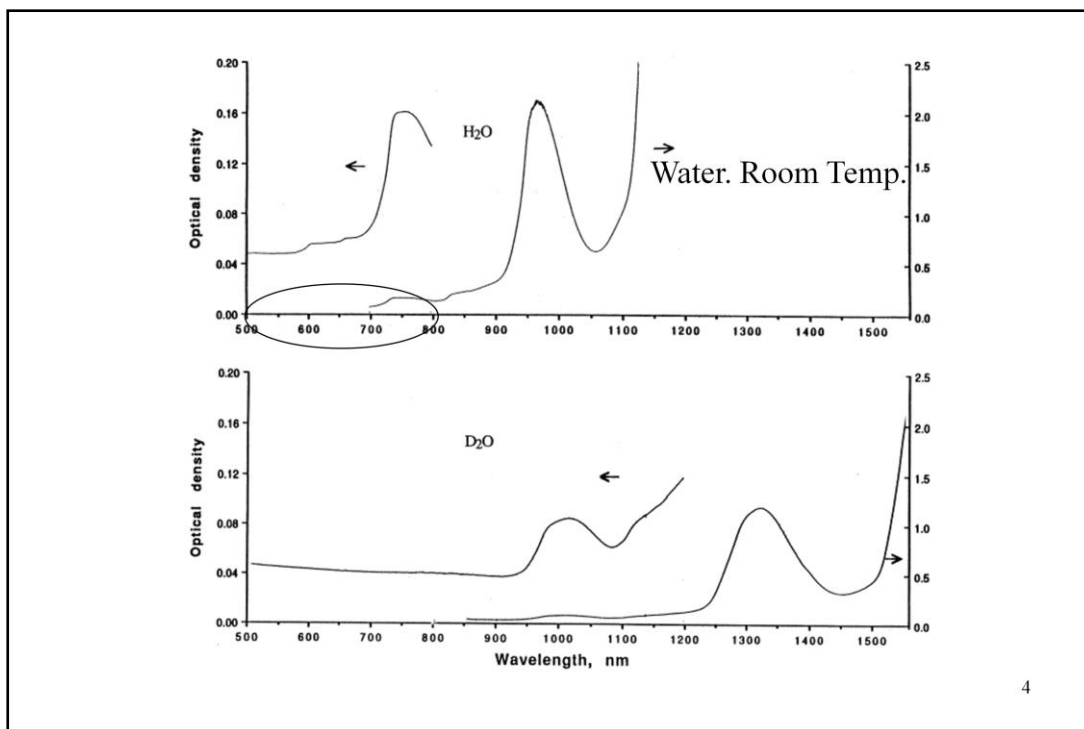


Towards the Himalayan Plateau, from
Chengdu, Sichuan Province China

Why is Water Blue?



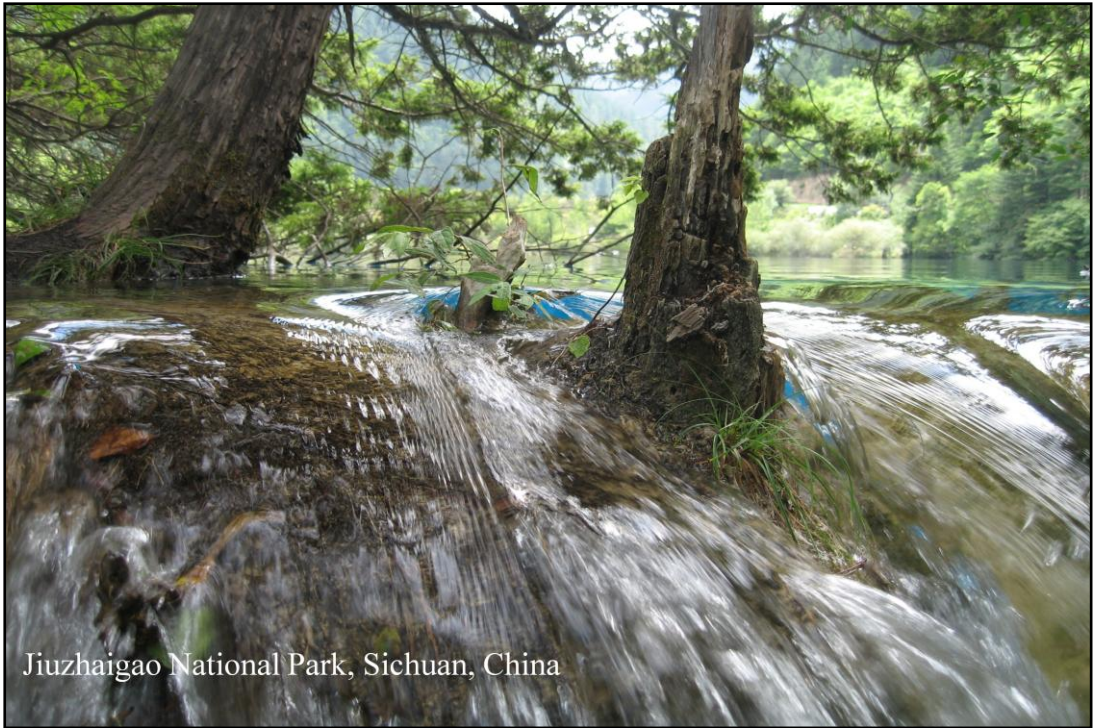
No Pigments



4

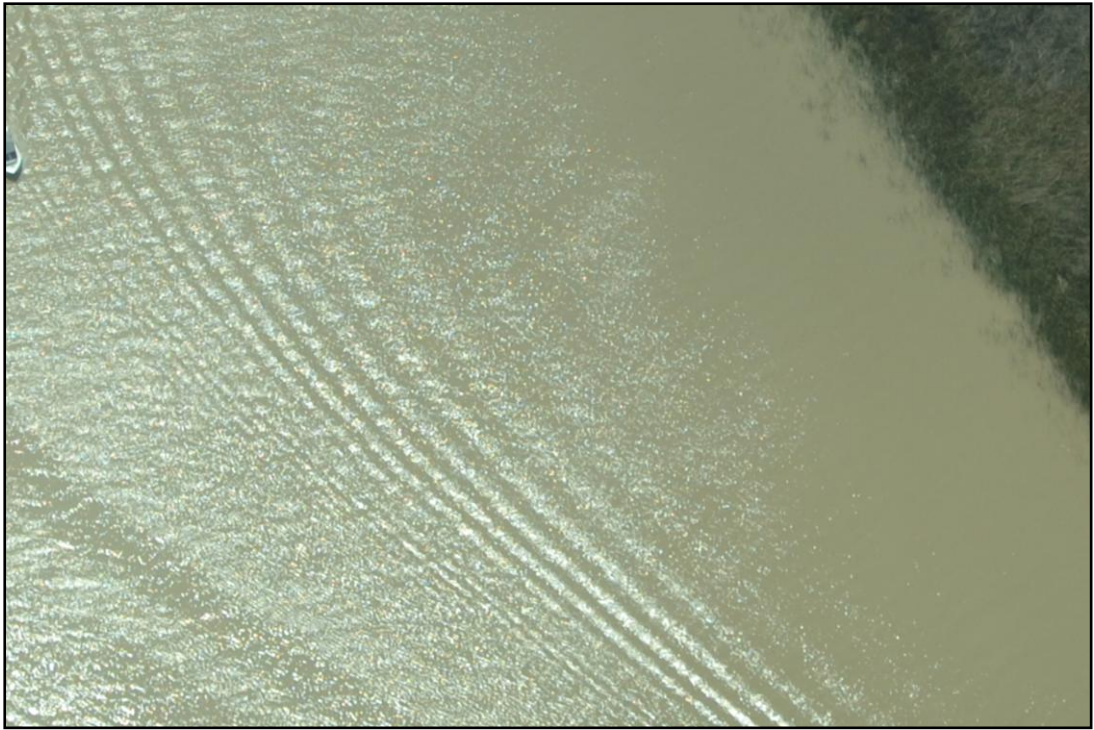
On the short wavelength tail of the 760 nm absorption, there are small absorptions at 605 and 660 nm (red) caused by vibration of the water molecule. This small absorption in red causes water to reflect at green and blue. Some blue light comes from reflected sky light which is enriched in blue wavelengths relative to longer wavelengths.

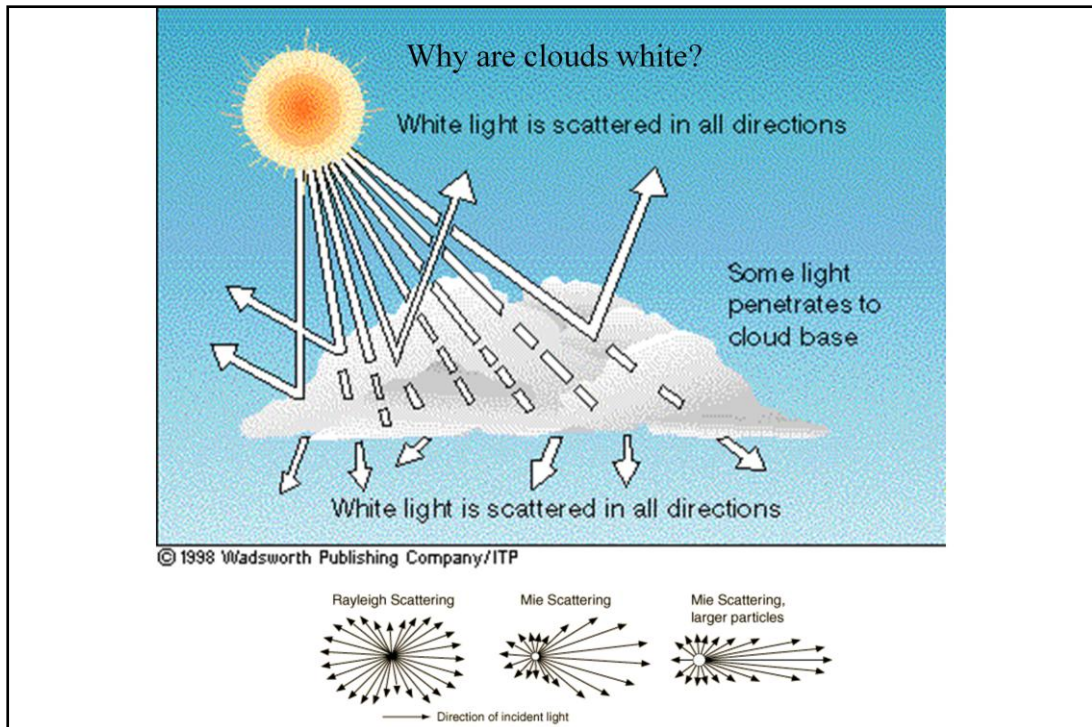
The upper spectrum is that for liquid H₂O in a 10 cm cell at room temperature; the lower spectrum is for D₂O under the same conditions. No cell was used in the reference beam of the spectrophotometer so that the "baseline" absorbance of approximately 0.04 originates in cell reflections.



Jiuzhaigao National Park, Sichuan, China







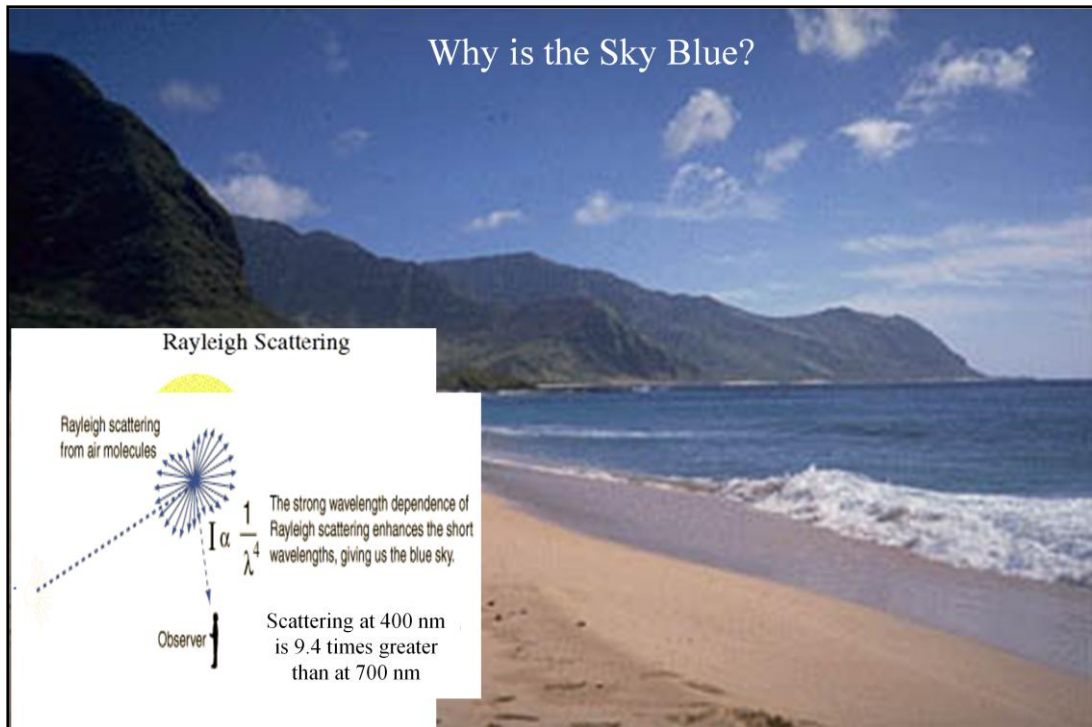
Mie Scattering When large particles in the atmosphere scatter all wavelengths of white light nearly equally.

this is why clouds appear white.... Fog appears white.

Light is scattered.....redirected in many directions (with preferential forward scattering)

If a cloud is optically thick then little light will penetrate through the cloud. When only a little light penetrates to a particular location in a cloud, such as cloud base, how will it look?????

Why is the Sky Blue?



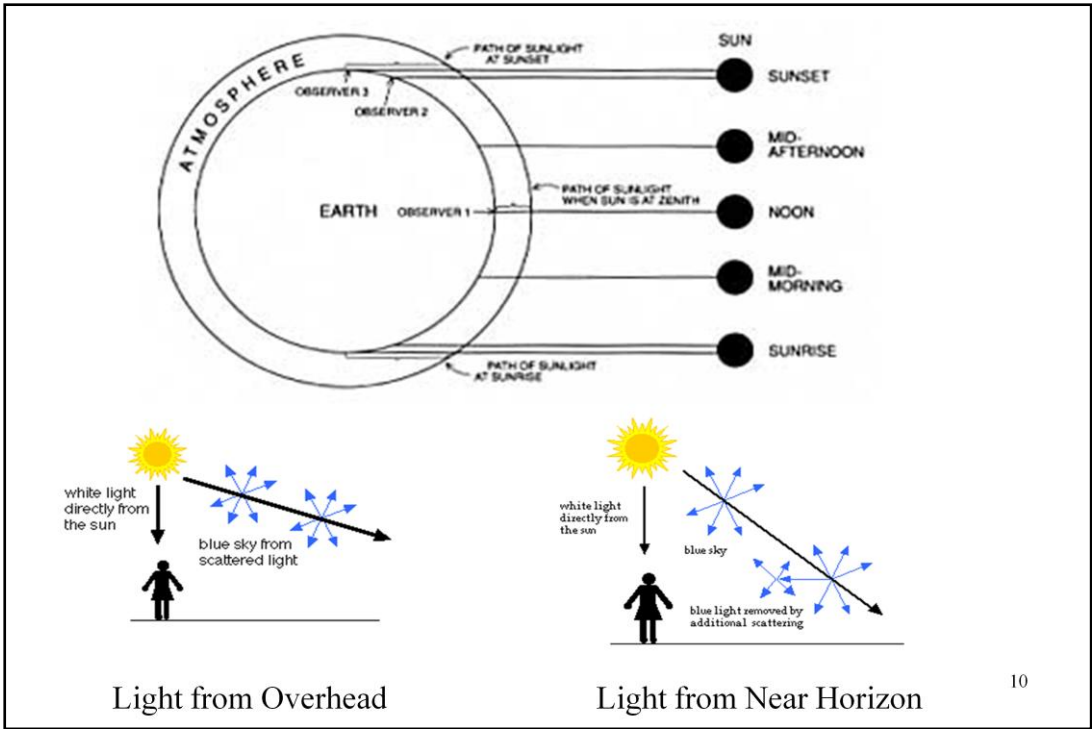
Rayleigh Scattering Is the selective scattering of shorter wavelengths of visible light (predominantly violet and blue) by atmospheric gases.

Rayleigh scattering scatters nearly equally in all directions (diffuse)

Note that Rayleigh scattering involves much smaller scattering particles than Mie scattering

if there were no atmosphere, what color would the sun look like?

Note that the blue of the sky is more **saturated** when you look further from the sun. The almost white scattering near the sun is attributed to Mie scattering, which is not very wavelength dependent.



Atmospheric Scattering

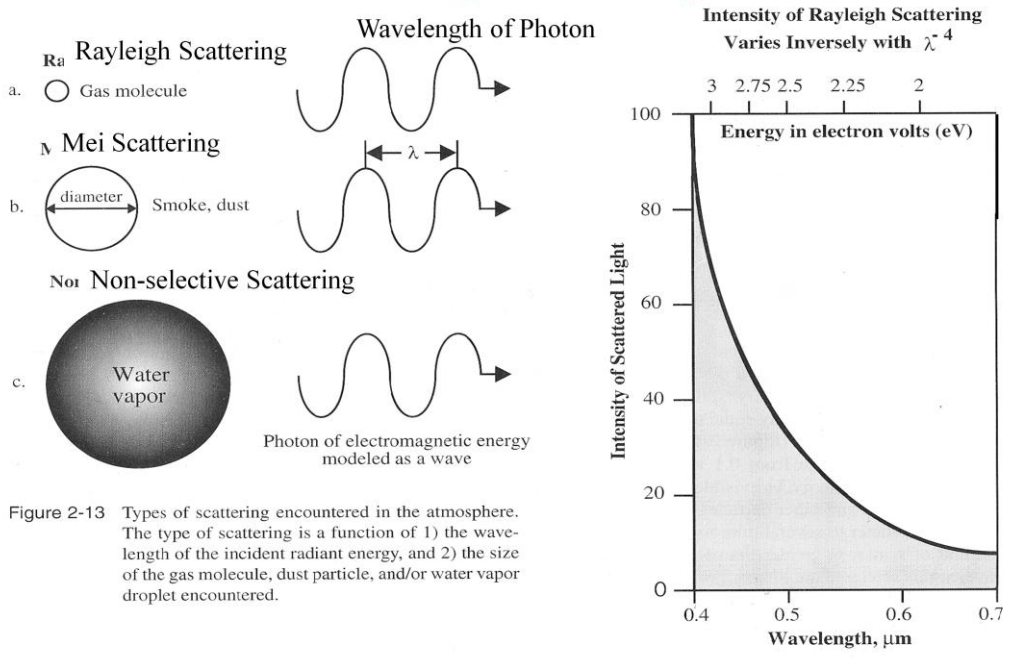
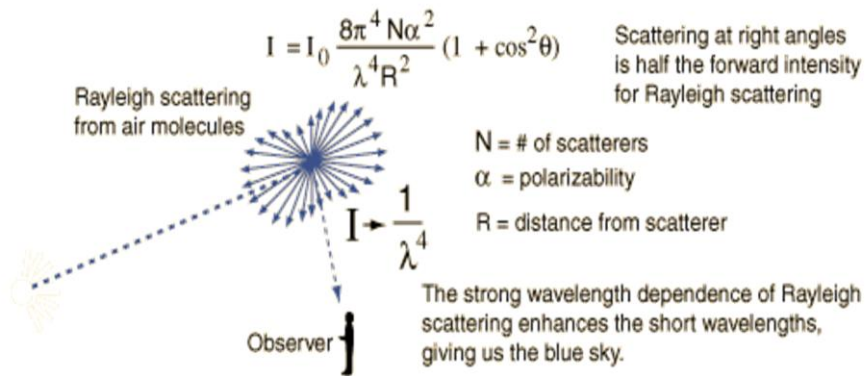


Figure 2-13 Types of scattering encountered in the atmosphere. The type of scattering is a function of 1) the wavelength of the incident radiant energy, and 2) the size of the gas molecule, dust particle, and/or water vapor droplet encountered.

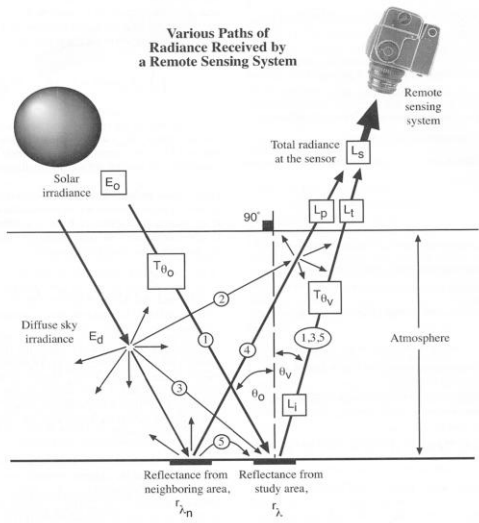
Rayleigh Scattering



12

Rayleigh scattering refers to the scattering of light off of the molecules of the air, and can be extended to scattering from particles up to about a tenth of the wavelength of the light. It is Rayleigh scattering off the molecules of the air which gives us the blue sky.

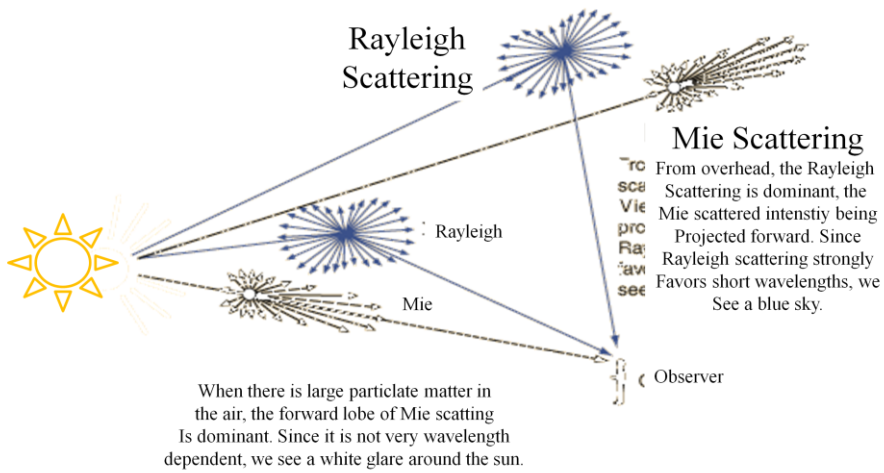
Rayleigh scattering can be considered to be elastic scattering since the photon energies of the scattered photons is not changed.

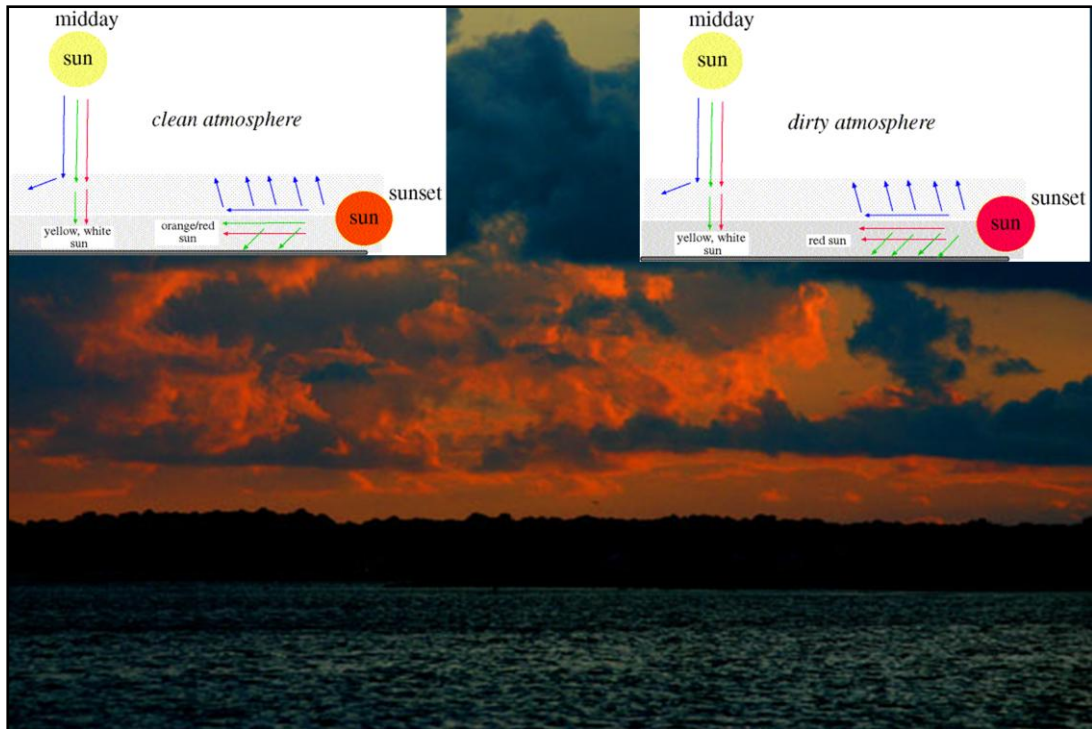


1. Direct Beam Radiation
2. Atmospheric Scattering (sky light)
3. Forward scattering from sky to Ground
4. Scattering from Surroundings to sensor
5. Scattering from Surroundings onto Target

Figure 2-20 Radiance (L_s) from paths 1, 3, and 5 contains intrinsic valuable spectral information about the target of interest. Conversely, the path radiance (L_p) from paths 2 and 4 includes diffuse sky irradiance or radiance from neighboring areas on the ground. This path radiance generally introduces unwanted radiometric noise in the remotely sensed data and complicates the image interpretation process.

Why is the sky lighter toward the horizon?





Orange/red sunsets in a clean atmosphere

At midday the sky color is dominated by rayleigh scattering, only the shorter wavelengths of visible light are scattered since the radiation passes through a short distance (path length) in the atmosphere.

At sunset, the radiation must pass through a much thicker layer of the atmosphere.

When the sun is at an angle only slightly (e.g., 4°) above the horizon, the atmospheric path length is up to 12 times thicker than at midday. Much more blue light and some green light is scattered relative to red light and therefore, the sun appears to look orange/red.

orange/red sunsets in a dirty atmosphere

When pollution (aerosols, dust, etc.) is present, the atmosphere contains more large particles with larger diameters than the atmospheric gases. Hence, more of the intermediate wavelengths of visible light such as yellow and green are scattered in addition to the blue and green light. What largely remains is red light...., Hence the sun and the sky appear red, especially at sunset.

Why do clouds also appear red near sunset?????

Rayleigh Scattering:

- molecule diameters less than 0.1 to less than $10^{-3} \lambda$
 - particle is small compared to wavelength
 - insensitive to particle shape

Mie Scattering:

- range of 0.1 - 50 times λ
- wavelength and particle size is similar
- radiation interacts strongly with particle
 - often strong absorption

Non-selective scattering:

- greater than 50x wavelength
- spheres are large relative to the wavelength
 - shape matters

Can you think of a case where the molecules would have different shapes? How about snowflakes? Or dust/smoke or aerosol particles in atmosphere?

Clouds

**Water Droplet
Radius (μm)**

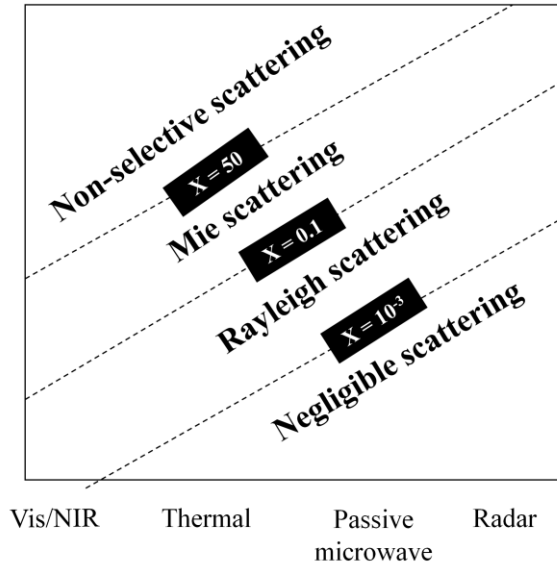
raindrops

drizzle

Cloud droplets

Smoke, dust

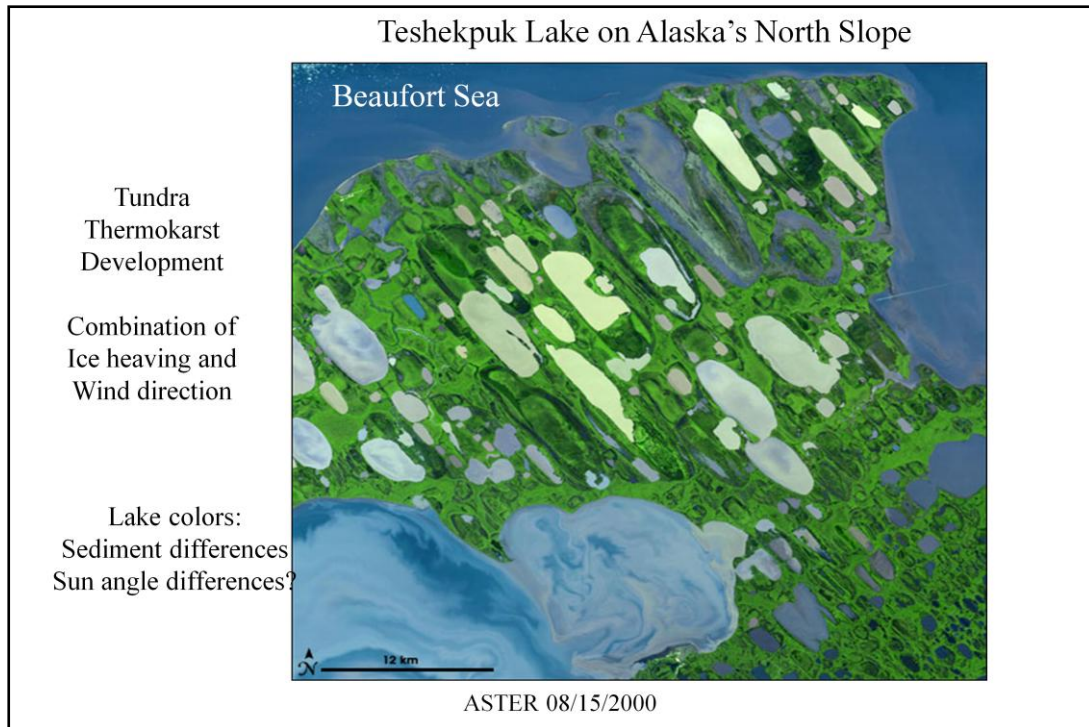
Air molecules



Wavelength Region

Remote Sensing of Glacial Landforms

Teshkepuk Lake on Alaska's North Slope



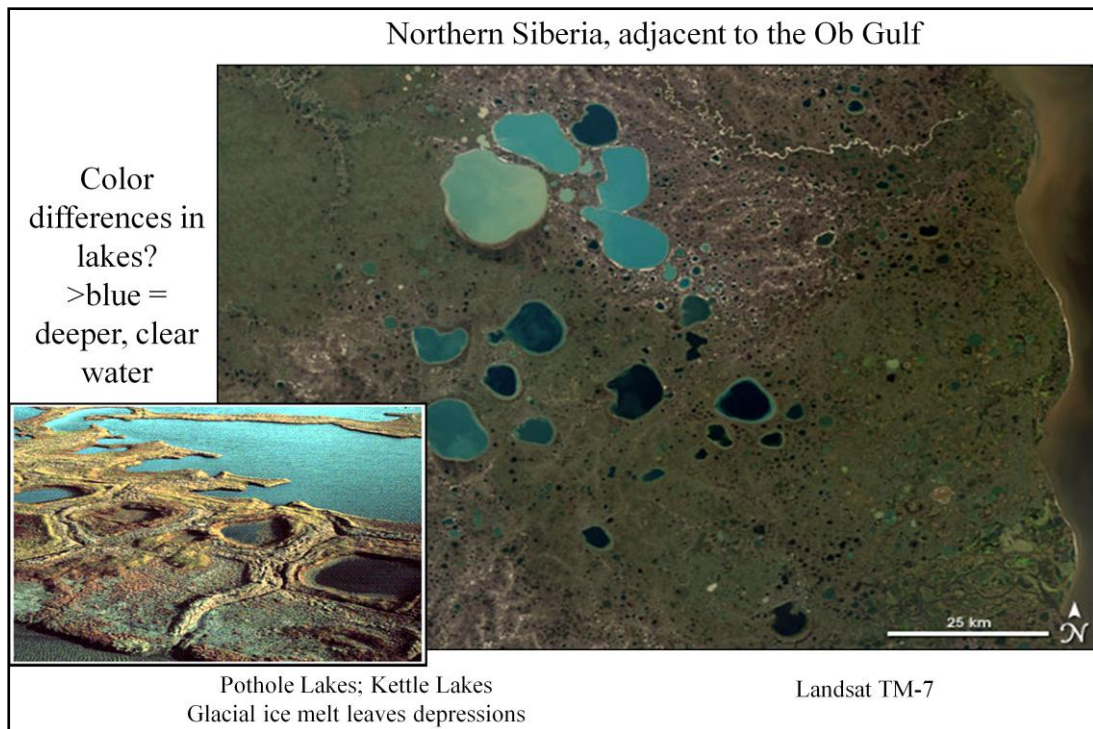
On January 11, 2006, the U.S. Department of the Interior (DOI) approved oil and gas drilling on approximately 500,000 acres of land in and around Teshkepuk Lake on Alaska's North Slope within the National Petroleum Reserve. Up to 90,000 geese nest in this area in the summertime, and up to 46,000 caribou use the area for both calving and migration. Some environmental groups contested the DOI decision to allow drilling. The DOI decision stipulated that no surface drilling would be allowed on land considered crucial for molting geese or caribou, and a maximum of 2,100 acres in seven different zones could be permanently disturbed on the surface.

The Advanced Spaceborne Thermal Emission and Reflection Radiometer ([ASTER](#)) on NASA's [Terra](#) satellite took this picture on August 15, 2000. In this image, green indicates vegetation and blue indicates water. Some bodies of water also appear in off-white or yellowish, probably due to different amounts of sediment in the water and/or the sun angle. The Beaufort Sea is at the top of the scene, while Teshkepuk Lake is at lower left. The land here is a lacy, lake-dotted expanse of tundra.

The large image covers an area of 58.7 by 89.9 kilometers, and is centered near 70.4 degrees North latitude, 153 degrees West longitude.

Image courtesy NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan ASTER Science Team

Northern Siberia, adjacent to the Ob Gulf



When the Pleistocene Ice Age reached its peak around 22,000 years ago, continent-spanning glaciers covered large sections of North America and Eurasia like a sheet. As the Ice Age waned, the glaciers retreated. Occasionally large chunks of ice broke off from the glacier and became surrounded or even buried by soil and rock debris deposited by the melting ice sheet. Eventually, the blocks of ice also melted, leaving behind a depression in the ground. These depressions are called kettles; when they are filled with water, they are called kettle lakes, or pothole lakes.

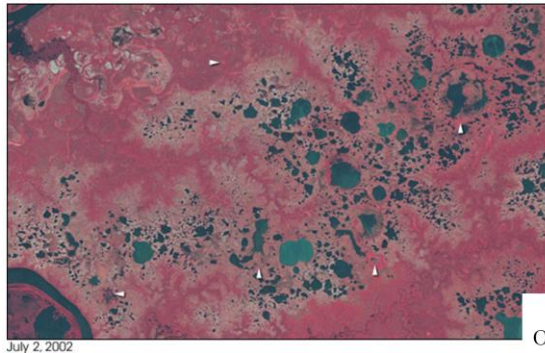
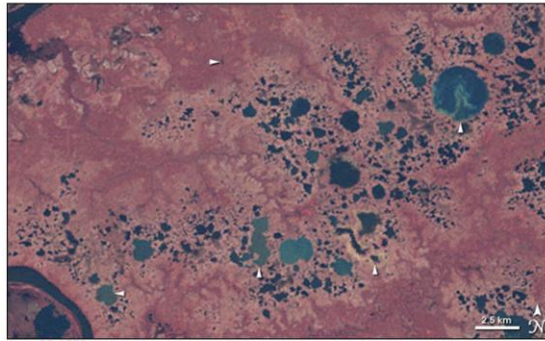
This natural-color Landsat 7 image shows blue and green pothole lakes in northern Siberia, adjacent to the Ob Gulf. The different colors of the lakes reflect different amounts of sediment or depth; the deeper or clearer the water, the bluer the lake. The arctic tundra in this area is permafrost: the top levels of the soil melt and warm in the summer, but the ground below is frozen solid year round. Rivers cut only shallowly into the hard, frozen ground, and they meander across the image like golden threads (upper right and lower left). The landscape is dominated by spongy peat bog, covered in shallow-growing vegetation such as moss that can survive the harsh winters.

Pothole lakes dot the landscape of the Northern Hemisphere in the American and Canadian prairies, the Russian steppes, and throughout northern Siberia. Scientists use satellite images of these glacial kettle lakes to [measure water clarity](#) and to make environmental assessments. These lakes are far from agricultural land and settled areas, so they have fairly clear and unpolluted waters. Scientists also monitor these lakes to study climate change. Researchers reported in *Science* that some glacial kettle lakes in northern Siberia [have drained](#) over the past 30 years as the region has warmed and the permafrost beneath the lakes has “cracked,” allowing lake water to drain out.

NASA image created by Jesse Allen, Earth Observatory, using data obtained courtesy of the University of Maryland’s [Global Land Cover Facility](#).

Monitoring Changing Hydrologic & Environmental Conditions

Loss of Siberian Lakes



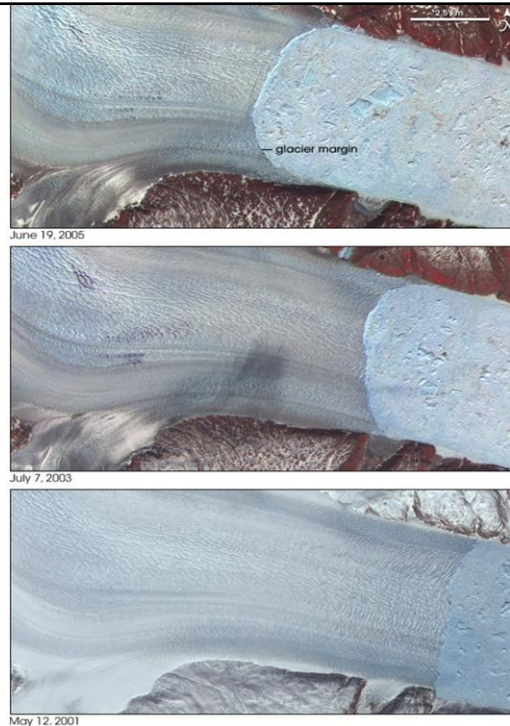
NASA Earth
Observatory: AVHRR

Satellites have been critical to monitoring changes in boreal environments, such as this example. Requires a long data record, which is only available from the weather satellite program (e.g., AVHRR on POES) or from the earliest Landsat MSS. Change detection requires consistent data across time or an ability to re-create data with the original characteristics (e.g., spectral bands, spatial resolution, time of day, etc.).

Glacial Retreat Rate of retreat

Helheim glacier (outlet from
Greenland Ice Sheet)

June 2005 (top),
July 2003 (middle),
and May 2001 (bottom).



Along the margin of the Greenland Ice Sheet, outlet glaciers flow as icy rivers through narrow fjords and out to sea. As long as the thickness of the glacier and the depth of the water allow the ice to remain grounded, it stays intact. Where the ice becomes too thin or the water too deep, the edge floats and rapidly crumbles into icebergs. Satellite observations of eastern Greenland's Helheim Glacier show that the position of the iceberg's calving front, or margin, has undergone rapid and dramatic change since 2001, and the glacier's flow to the sea has sped up as well.

These images from the Advanced Spaceborne Thermal Emission and Reflection Radiometer ([ASTER](#)) on NASA's [Terra](#) satellite show the Helheim glacier in June 2005 (top), July 2003 (middle), and May 2001 (bottom). The glacier occupies the left part of the images, while large and small icebergs pack the narrow fjord in the right part of the images. Bare ground appears brown or tan, while vegetation appears in shades of red.

From the 1970s until about 2001, the position of the glacier's margin changed little. But between 2001 and 2005, the margin retreated landward about 7.5 kilometers (4.7 miles), and its speed increased from 8 to 11 kilometers per year. Between 2001 and 2003, the glacier also thinned by up to 40 meters (about 131 feet). Scientists believe the retreat of the ice margin plays a big role in the glacier's acceleration. As the margin of the glacier retreats back toward land, the mass of grounded ice that once acted like a brake on the glacier's speed is released, allowing the glacier to speed up.

Overall, the margins of the Greenland Ice Sheet have been thinning by tens of meters over the last decade. At least part of the thinning is because warmer temperatures are causing the ice sheet to melt. But the other part of the thinning may be due to changes such as glacier acceleration like that seen at Helheim. Initial melting due to warming may set up a chain reaction that leads to further thinning: the edge of the glacier melts and thins, becomes ungrounded and rapidly disintegrates. The ice margin retreats, the glacier speeds up, and increased calving causes additional thinning. Understanding the dynamic interactions between temperature, glacier flow rates, and ice thickness is crucial for scientists trying to predict how the Greenland Ice Sheet will respond to continued climate change.

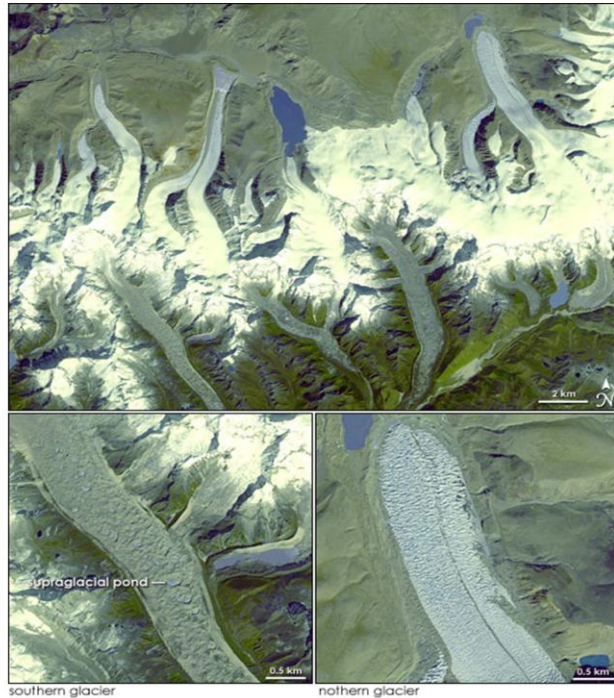
Reference Howat, I. M., I. Joughin, S. Tulaczyk, and S. Gogineni (2005). Rapid retreat and acceleration of Helheim Glacier, east Greenland. *Geophysical Research Letters*, 32, L22502, doi:10.1029/2005GL024737.

Bhutan
Located between India and
Tibetan Plateau

Himalayan mountains reaching
23000 ft (7 km)

Glaciers on south side move 10-
20 m/y compared to the north
side, that move 100-200 m/year

ASTER, Nov. 20, 2001



One of the highest mountain relief on Earth can be found in Bhutan. Sandwiched between eastern India and the Tibetan plateau, Bhutan hosts peaks that reach between 5,000 and 7,000 meters (16,000-23,000 feet) in height. These mountains are neighbors to Mount Everest, Earth's highest peak at 8,850 meters (29,035 feet). The impressive Bhutan Himalayas are permanently capped with snow, which extends down valleys in long glacier tongues. Because of weather patterns on each side of the Himalaya and differences in topography, the glaciers on each side of the mountain are distinctly different from one another and are likely to react very differently to climate change.

This image, taken by the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on November 20, 2001, is one of a series of images used to study the glaciers of the Bhutan Himalayas. By tracking the movement of surface features like crevasses and debris patterns, Andreas Kaab of the University of Zurich measures the speed at which glaciers flow down the mountain. He found that glaciers on the north side of the range move as much as ten times faster than glaciers on the south side.

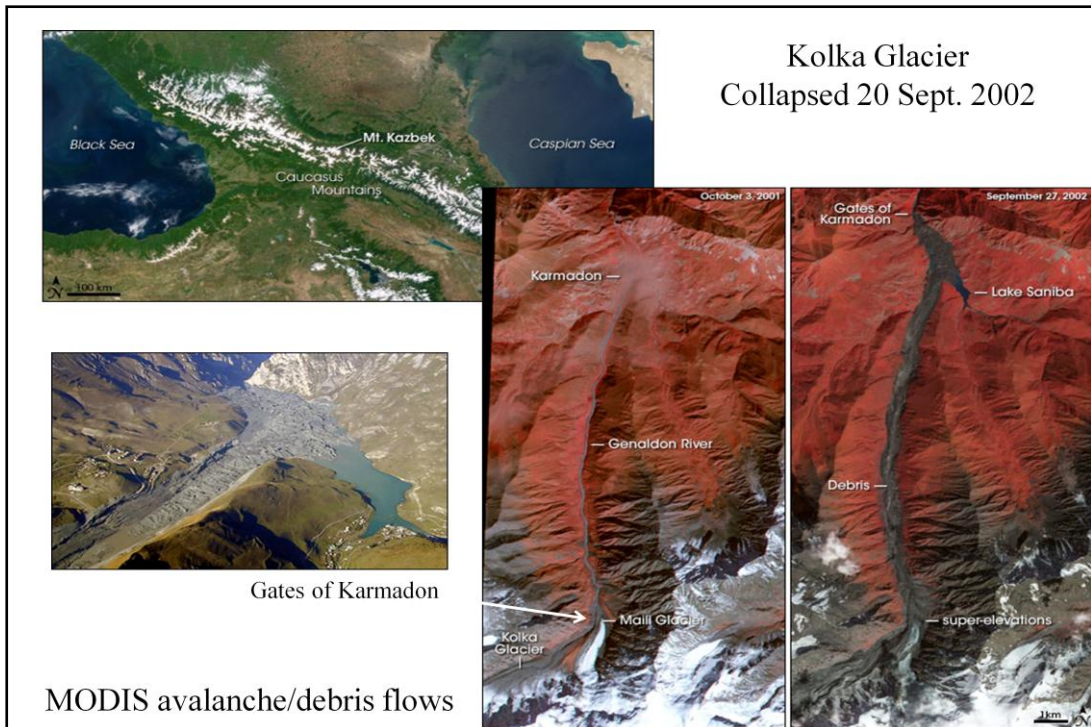
Glaciers move under their own weight. As more and more snow piles on the glacier, the ice compresses, deforms, and eventually begins to slide. One of the reasons the glaciers on the south side of the Bhutan Himalaya are moving so slowly—10-20 meters per year compared to 100-200 meters per year on the north — may be that their supply of ice is dwindling. Without new weight pressing on the glaciers, they are stagnating.

One reason the southern glaciers may be losing weight is the rock and gravel that rests on top of them. As this image clearly shows, the northern glaciers form in plateaus as high as 7,000 meters in elevation. The glaciers slide from the plateaus down the steep mountain side in long glacier tongues, which are white, tinted blue-gray where the snow is very compressed. The mountains are no less steep on the south side, but the glaciers have no plateaus on which to form. Instead, the glaciers cling to steep rock walls, which shower the glaciers with debris. The glaciers on the south are tinted gray-brown in this image because of the debris. Because the dark-colored debris absorbs energy from the Sun, the surface of the glacier is more susceptible to melting than it would be if its surface remained a reflective white. Indeed, the close view of a southern glacier, shown in the lower left image, shows pale blue ponds of liquid water, "supraglacial ponds" on the glacier's surface. The northern glacier, lower right, is free of both debris and ponds.

The difference between the glaciers on each side of the mountain could become more pronounced as global warming sets in. Eighty to ninety percent of new snow falls on the southern glaciers between March and October during the summer monsoon. As temperatures warm, not only will more snow melt, but precipitation will tend to fall as rain instead of snow. Without fresh snow to maintain their mass and movement, the glaciers will shrink in place, a process called "down wasting." By contrast, the northern glaciers are fed mostly by winter snow. Because temperatures are already cooler in the winter, the northern glaciers are more likely to get fresh snow every year, making them less sensitive to climate change. As temperatures warm, the fast-moving northern glaciers are most likely to adjust by retreating—shortening the length of the tongues that extend down into the valleys.

Understanding how glaciers may evolve is important because mountain glaciers are the proverbial "canary in the coal mine" when it comes to tracking global warming. Along with polar ice, they are the things most sensitive to warming temperatures. On top of being harbingers for climate change, melting glaciers can cause catastrophic floods, making it essential to monitor them regularly. Since most glaciers are remote and hard to get to, remote sensing is crucial to ongoing monitoring.

References: Kaab, A. (2005): "Combination of SRTM3 and repeat ASTER data for deriving alpine glacier flow velocities in the Bhutan Himalaya" *Remote Sensing of Environment*. 94 (4), 463–474.



Kolka Glacier
Collapsed 20 Sept. 2002

Gates of Karmadon

MODIS avalanche/debris flows

Between the Black and Caspian Seas, the Caucasus Mountains separate Russia (north) from Georgia (southwest) and Azerbaijan (southeast). Elevations reach 5,642 meters (18,511 feet), and glaciers accumulate from heavy snowfall in the steep mountain valleys. Around Mount Kazbek, a dormant volcano, glaciers intermittently collapse, burying the landscape below under rock and ice. (NASA Image by Jesse Allen and Robert Simmon based on MODIS data)

At the northern end of the depression, the churning mass of debris reached a choke point: the Gates of Karmadon, the narrow entrance to a steep-walled gorge. Gigantic blocks of ice and rock jammed into the narrow slot, and water and mud sluiced through. Trapped by the blockage, avalanche debris crashed like waves against the mountains and then finally cemented into a towering dam of dirty ice and rock. At least 125 people were lost beneath the ice.

When the Kolka Glacier collapsed in September 2002, ice, mud, and rocks partially filled the Karmadon Depression, destroying much of the village of Karmadon. The debris swept in through the Genaldon River Valley (lower left) and backed up at the entrance to a narrow gorge (top center). The debris acted as a dam, creating lakes upstream. This aerial photograph (looking north) was taken only 16 days after the disaster. (Photograph courtesy Igor Galushkin)

This pair of satellite images, taken before and after the collapse, shows the vast extent of the disaster. Debris and ice filled the Genaldon Valley from the Kolka Glacier Cirque to the Gates of Karmadon—a distance of about 18 kilometers (11 miles). (Images by Robert Simmon based on ASTER data)

Avalanche Running east to west across the narrow isthmus of land between the Caspian Sea to the east and the Black Sea to the west, the Caucasus Mountains make a physical barricade between southern Russia to the north and the countries of Georgia and Azerbaijan to the south. In their center, a series of 5,000-meter-plus summits (16,000-plus feet) stretch between two extinct volcanic giants: Mt. Elbrus at the western limit and Mt. Kazbek at the eastern. Volcanism fuels hot springs that steam in the alpine air. On the lower slopes, snow disappears in July and returns again in October. On the summit, winter is permanent. Glaciers cover peaks and steep-walled basins called cirques. The remote, sparsely populated area is popular with tourists and backpackers.

On the evening of September 20, 2002, in a cirque just west of Mt. Kazbek, chunks of rock and hanging glacier on the north face of Mt. Dzhimarai-Khokh tumbled onto the Kolka glacier below. Kolka shattered, setting off a massive avalanche of ice, snow, and rocks that poured into the Genaldon River valley. Hurtling downriver nearly 8 miles, the avalanche exploded into the Karmadon Depression, a small bowl of land between two mountain ridges, and swallowed the village of Nizhniy Karmadon and several other settlements.

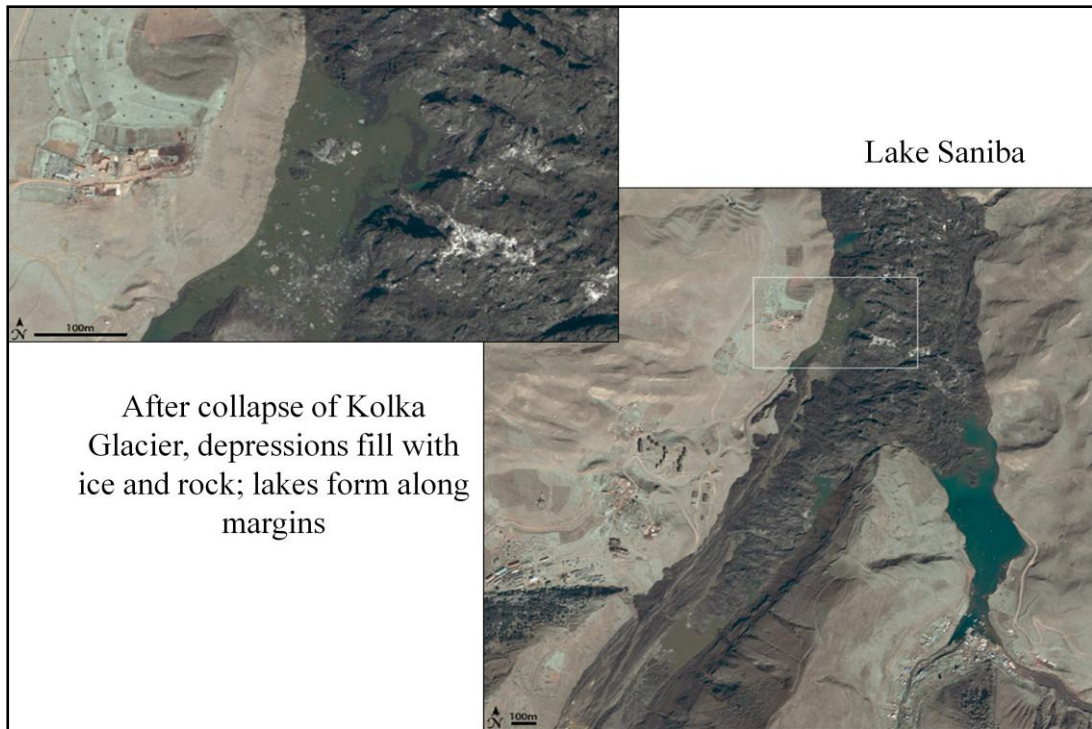
At the northern end of the depression, the churning mass of debris reached a choke point: the Gates of Karmadon, the narrow entrance to a steep-walled gorge. Gigantic blocks of ice and rock jammed into the narrow slot, and water and mud sluiced through. Trapped by the blockage, avalanche debris crashed like waves against the mountains and then finally cemented into a towering dam of dirty ice and rock. At least 125 people were lost beneath the ice.

Dmitry Petrakov, Sergey Chernomorets, and Olga Tutubalina have been returning to the site since the disaster. The three have been friends and colleagues for several years. Tutubalina and Petrakov are members of the Faculty of Geography at Moscow State University. She teaches and researches in the Laboratory of Aerospace Methods for the Department of Cartography and Geoinformatics, and he is a researcher in the Department of Cryolithology and Glaciology. Chernomorets is the General Director of the University Centre for Engineering Geodynamics and Monitoring

in Moscow. The combination of backgrounds made the team uniquely qualified to study the Kolka disaster. In the year following the event, they made five trips to the Russian Republic of Ossetia in the central Caucasus. They wanted to figure out exactly what had happened that day and to forecast what might happen in coming weeks, months, and years at the site. [A Dangerous Past](#)

This pair of satellite images, taken before and after the collapse, shows the vast extent of the disaster. Debris and ice filled the Genaldon Valley from the Kolka Glacier Cirque to the Gates of Karmadon—a distance of about 18 kilometers (11 miles). (Images by Robert Simmon based on [ASTER](#) data)

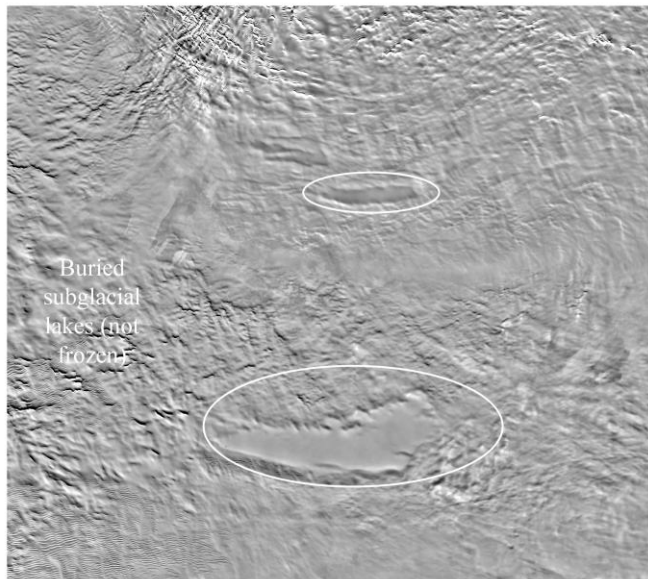
A Dangerous Past After the collapse, people speculated that something called a glacial surge had triggered the Kolka collapse. “In a surge,” explained Petrakov, “the leading edge of a glacier might slip a few hundred meters down slope very rapidly—perhaps in a day. A similar event happened at Kolka in 1969.” In 1902, a more significant collapse at Kolka Glacier had killed 32 people. Despite a history of disasters there, routine monitoring of the Kolka Glacier cirque ended shortly before the Soviet Union collapsed in 1991.



After collapse of Kolka
Glacier, depressions fill with
ice and rock; lakes form along
margins

After the Kolka Glacier collapsed, the Karmadon Depression filled with ice covered by black, pulverized rock. Water from dammed streams and melting ice formed lakes along the margins. The rapidly rising water was a continuing danger, threatening a sudden outburst that would cause flooding downstream. (Image copyright [Digital Globe](#))

East Antarctic Ice Sheet



In the coldest spot on the earth's coldest continent, Russian scientists have reached a freshwater lake the size of Lake Ontario after spending a decade drilling through more than two miles of solid ice, the scientists said Wednesday Feb. 8, 2012 (New York Times).

Water had been sealed for 15-34 M yrs

MODIS Terra and Aqua composite 11/20/2003 - 29/2004

Across the rippling, crevassed whitescape of the East Antarctic Ice Sheet, two unusual shapes appear in this grayscale satellite image of the frozen continent. The smooth, dark gray oval shapes are slight depressions in the surface of the ice sheet that trace out the shorelines of two lakes that are buried several thousand meters (more than 2 miles) deep in ice. Scientists recently published the first thorough description of the size, depth, and origin of these two large lakes, called 90° East Lake (for its longitude) and Sovetskaya Lake (for the Russian research station that was unknowingly built over top it many years ago).

The two lakes are close to Lake Vostok, thought to be the largest of Antarctica's 70 or more subglacial lakes. The water in the lakes is kept from freezing by warmth from the surface of the Earth and the insulation provided by the thick covering of ice. Scientists believe Vostok and the new lakes may contain unique ecosystems isolated from the outside world for tens of millions of years. The survival of life in these buried lakes could provide corroboration for the idea that life could exist in an ice-covered ocean that some scientists believe exists on Jupiter's moon Europa.

The image above is part of the satellite image collection called the "MODIS Mosaic of Antarctica," a map of the continent's surface made from 260 images acquired by the Moderate Resolution Imaging Spectroradiometer ([MODIS](#)) sensors on NASA's [Terra](#) and [Aqua](#) satellites between November 20, 2003, and February 29, 2004.

Reference Bell, R. E., M. Studinger, M. A. Fahnestock, and C. A. Shuman. (2006). Tectonically controlled subglacial lakes on the flanks of the Gamburtsev Subglacial Mountains, East Antarctica. *Geophysical Research Letters*, 33, L02504, doi:10.1029/2005GL025207.

Further Reading: [Two New Lakes Found Beneath Antarctic Ice Sheet](#), from the Earth Institute at Columbia University [Lake Vostok Fact Sheet](#) from the National Science Foundation [Europa](#) article entry in Wikipedia online encyclopedia

[MODIS mosaic of Antarctica](#) courtesy National Snow and Ice Data Center

New York Times Feb. 9, 2012. A statement by the chief of the Vostok Research Station, A. M. Yelagin, released by the director of the Russian Antarctic Expedition, Valery Lukin, said the drill made contact with the lake water at a

depth of 12,366 feet. As planned, lake water under pressure rushed up the bore hole 100 to 130 feet pushing drilling fluid up and away from the pristine water, Mr. Yelagin said, and forming a frozen plug that will prevent contamination. Next Antarctic season, the scientists will return to take samples of the water.

The first hint of contact with the lake was on Saturday, but it was not until Sunday that pressure sensors showed that the drill had fully entered the lake. Lake Vostok, named after the Russian research station above it, is the largest of more than 280 lakes under the miles-thick ice that covers most of the Antarctic continent, and the first one to have a drill bit break through to liquid water from the ice that has kept it sealed off from light and air for somewhere between 15 million and 34 million years.

There have been much-disputed hints that life might still exist there. If so, that would give a great boost to hopes of finding life in similar conditions in icy water on one of the moons of [Jupiter](#).

Dr. Lukin said it was a momentous, pioneering moment. “For me, the discovery of this lake is comparable with the first flight into space,” he told the Interfax news agency. “By technological complexity, by importance, by uniqueness. After reaching the water, the research team gathered by the drilling site for a [photograph](#).

John Priscu, a geologist specializing in Antarctica at Montana State University, who has kept in contact with scientists in Antarctica and in [Russia](#) as the drilling has progressed, said that the anticipation had grown in the past two weeks as the drilling team finally came close to the lake surface just as the Antarctic summer was ending and the weather worsening.

“It has been a suspenseful two weeks for me,” Dr. Priscu said. He is headed for Antarctica next season to drill to another buried lake, and he said he was delighted with the Russian achievement. “I applaud them,” he said. “I think they have done a great job.” Russian officials said the timing of the announcement was fitting because on Wednesday, Russia celebrated “Science Day,” commemorating the occasion in 1724 when Peter the Great signed an order establishing the St. Petersburg Academy of Sciences. And the drilling saga, like the expeditions of early explorers, has been years in the making and involves both scientific inquiry and national pride. In the early 1990s, an international team of researchers were drilling at the Vostok research station to obtain cores to study clues to past climate in ice that has been accumulating for millions of years. At a depth of more than two miles they reached a kind of ice different from the ice sheet and realized they had frozen lake water.

That a lake existed there was not a surprise, although its size and shape were not then known. What did raise scientific eyebrows was evidence that the lake ice contained microbes, said Robin Bell, of the Lamont-Doherty Earth Observatory at Columbia University, who has studied the lake extensively. But Dr. Bell said a consensus had never been reached on whether the evidence resulted from contamination from the drilling fluid.

Dr. Bell, who studies the behavior of ice sheets, designed surveys of the lake conducted in 2000 and 2001, using radar and other techniques, which showed its shape and location. Because it is such an unusual environment, there is always the possibility that it will provide other geological insights, she said, adding, "We could learn something absolutely unique."

The drilling project has been Russian, not international. And the difficulties of drilling through more than two miles of ice and keeping the roughly five-inch bore hole from freezing over have been extraordinary. The bore hole has had to be filled with kerosene to keep it from freezing over, and the researchers have had to work in what are difficult conditions, to say the least.

Dr. Priscu said the drillers, led by Dr. Lukin, had been racing against time to complete the project before the Antarctic summer ended and flights became impossible. Temperatures have dropped to lower than minus 45 already, and at minus 50 the difficulties for aircraft become extreme.

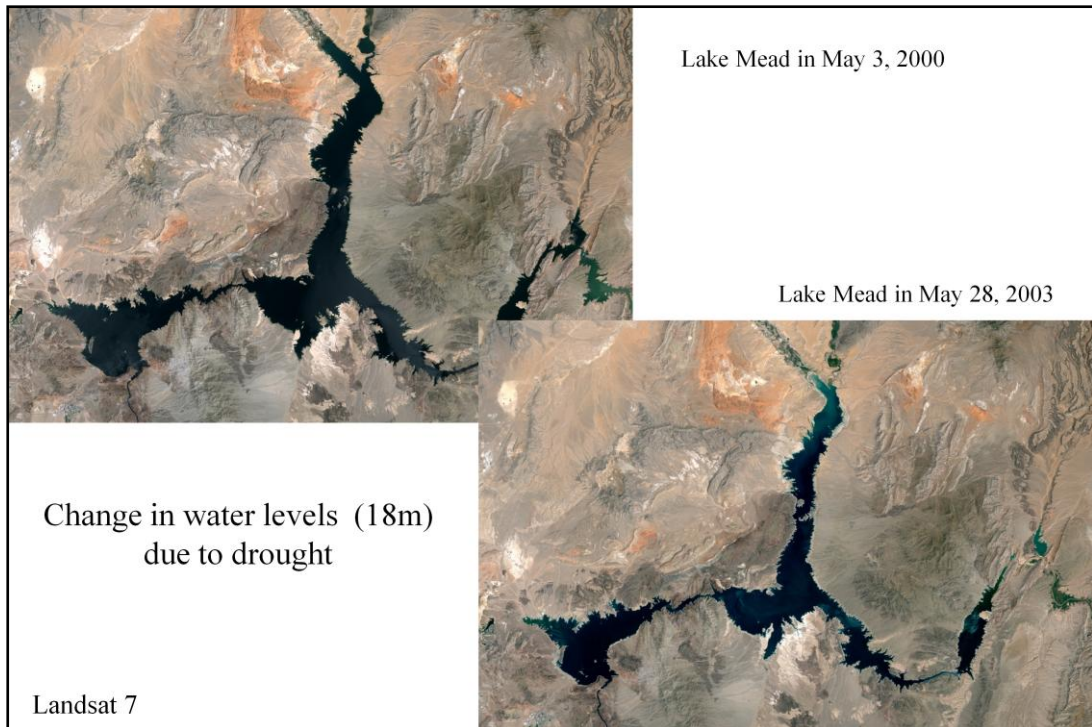
Nowhere does it get colder than at Vostok, in the middle of the East Antarctic ice sheet about 800 miles from the South Pole. The coldest documented temperature on earth was recorded at Vostok in July 1983, minus 128.6. Some environmentalists have raised objections to drilling to subglacial lakes because of the possibility of contamination. The Russian plan to prevent the drilling fluid from reaching the pristine lake water was to plug the bottom of the bore hole with an inert fluid, Freon, and to drill the final distance with a heated drill tip instead of a motorized drill. Enough kerosene would be removed to lessen the pressure in the bore hole so that when the lake was reached, lake water would flow up the bore hole, then freezing and forming an icy plug. That is exactly what happened, Russian scientists confirmed.

The need to prevent even the slightest contamination of the lake is acute. Its environment is comparable to conditions on the moons of Jupiter, which are among the candidates for extraterrestrial life. If life exists in Vostok, it may well exist on Europa, one of the moons of Jupiter, which has subsurface icy water. The water in Vostok stays liquid because of the pressure and the warmth of the earth below it.

Next season American and British expeditions will try to drill to other buried lakes, Dr. Priscu said. He is part of the American expedition that has targeted a lake in West Antarctica.

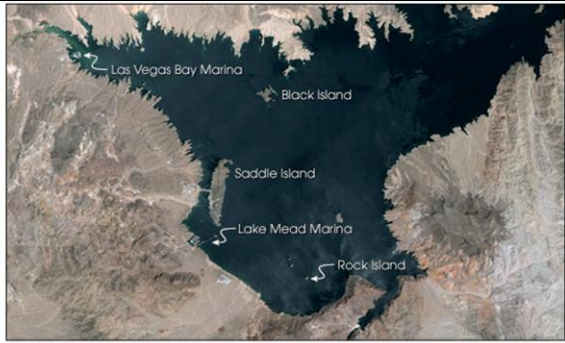
The specially designed drill that the American team will use, Dr. Priscu said, is being sent down to Antarctica by ship, and that journey has already begun. "The drill," he said, "is on its way to the ice." *David M. Herszenhorn reported from Moscow, and James Gorman from New York.*

**Remote Sensing of
Lake and Dune
Landforms**

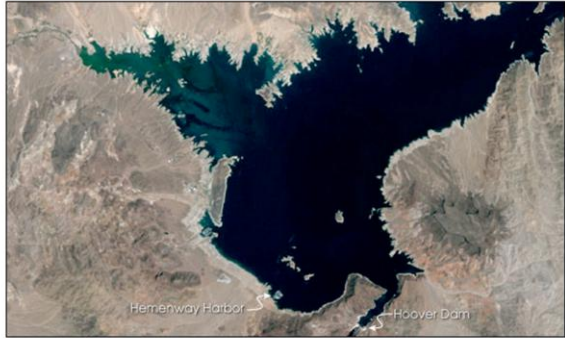


The image above, acquired by the Landsat satellite, shows the shoreline of Lake Mead in May 3, 2000. Place your cursor over the image to see the shoreline in May 28, 2003. Dramatic changes are quite evident in the three-year span between these images. Water levels in the lake between these images **dropped 18 meters**.

In the space of just three years, water levels in Lake Mead fell more than sixty feet due to sustained drought. Move your cursor over the image to compare the shoreline in 2000 to 2003. (Image by Jesse Allen, based on data provided by the [Landsat 7 Science Team](#))

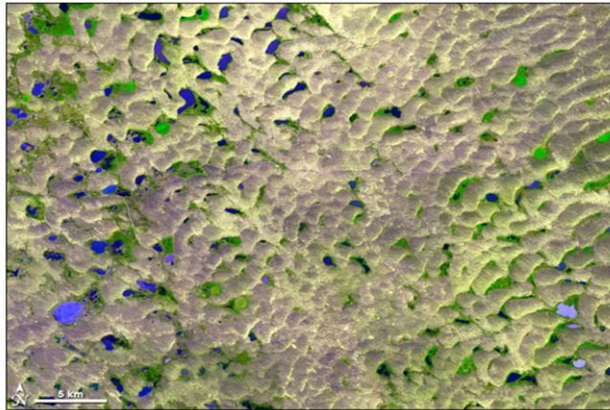


May 3, 2000



May 28, 2003

Sand Hills cover about 25% of Nebraska



Ancient (Pleistocene) Sand Dunes

Natural Color ASTER, 09/12/2001

The Sand Hills cover about a quarter of the U.S. Great Plains state Nebraska. These ancient sand dunes are from the Pleistocene Epoch (the geologic time period spanning about 1.8 to about 10,000 years ago). They are made of sediment eroded from the Rocky Mountains by the monumental Pleistocene glaciers, washed out into the plains, and now mostly stabilized by grassland vegetation. Covering an area of about 60,000 square kilometers in western Nebraska, the Sand Hills are the largest sand dune formation in America.

This simulated natural-color image from the Advanced Spaceborne Thermal Emission and Reflection Radiometer ([ASTER](#)) on NASA's [Terra](#) satellite shows a portion of the Sand Hills region, the landscape rippled by crowded yellow-tan and lavender-brown dunes. The area doesn't drain water very well, and so the hollows at the bases of dunes are filled with brilliantly blue lakes. In the large image it is easy to see that some of the emerald green vegetation is being cultivated, rather than growing naturally. Perfect circles of vegetation resulting from center-pivot irrigation appear in the scene, as well as fields with sharp angles and straight lines.

According to a [report on the Sand Hills](#) by the World Wildlife Fund, the soils of the Sand Hills aren't like any other soils in the Great Plains, and unique grasses and plants live there. The sandy soils were not attractive to farmers, and so the area was left largely unplowed by European settlers. As such, the area is one of the least disturbed remnants of the vast prairies that once filled the central United States. The area is an important habitat for migratory birds, such as the sandhill crane, one of only two species of crane native to North America.

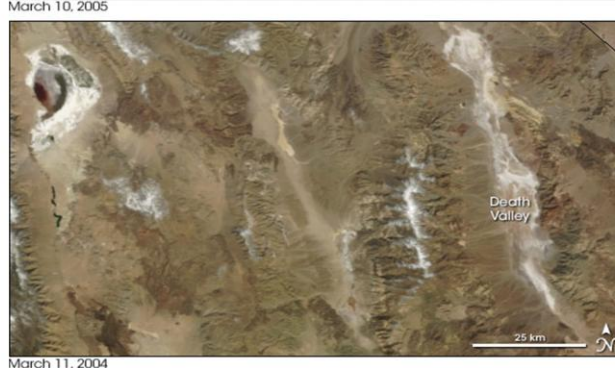
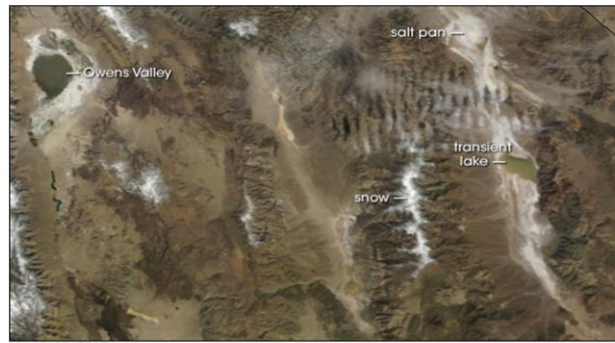
This ASTER image was acquired September 10, 2001, and the [large image](#) covers an area of about 57.9 by 61.6 kilometers. It is centered near 42.1 degrees North latitude, 102.2 degrees West longitude. Image courtesy NASA/GSFC/METI/ERSDAC/JAROS, and U.S./Japan [ASTER Science Team](#)

Death Valley:
Driest place in North
America

Ruminant of Pleistocene
Lake Manly (transient lake)
100mi long and 600 ft thick)
Owens valley –also
ruminant Lake

Salt pans

MODIS



Now the driest place in North America, Death Valley was once a verdant, water-filled haven. Between 128,000 and 186,000 years ago, ice covered the Sierra Nevada and rivers flowed into the long valley, feeding Lake Manly. At nearly 100 miles long and 600 feet deep, this massive lake filled Death Valley. To the west, on the other side of the Panamint Range (capped with snow in the top image), was the slightly smaller Panamint Lake. Though the lake and rivers dried as the ice retreated and the climate warmed, water has left its mark on the landscape. Evaporating water left a white salt pan in its place, so the beds of both lakes are clearly visible in these images, acquired by the Moderate Resolution Imaging Spectroradiometer ([MODIS](#)) on NASA's [Terra](#) satellite on March 10, 2005, (top) and March 11, 2004 (bottom).

Driven by a mild El Niño, winter 2005 was wet. Southern California was inundated with heavy rain from December through late February. The effects on the landscape hearken back to an earlier age when water was more prevalent. On March 10, 2005, water had pooled in the former Lake Manly and, less noticeably, in Lake Panamint. To the northwest, Owens Valley—another remnant of the last ice age—is also filling with water.

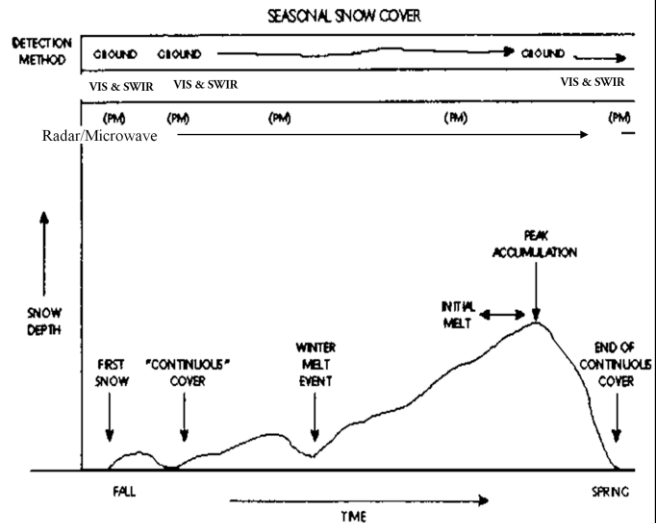
Aside from darkening the dry salt pans with water, the winter weather had another effect on the landscape. The mountains are darker and slightly greener with growing vegetation. On average, Death Valley receives less than two inches of rain per year. When the rain does fall, the desert springs to life, blossoming with flowers. This year, Death Valley National Park received over six inches of rain, and the result is a rainbow of wildflowers—one of the best blooms in modern history, the National Park Service reports. For daily wildflower updates, visit the [Death Valley National Park](#) home page. NASA images created by Jesse Allen, Earth Observatory, using data obtained courtesy of the [MODIS Rapid Response](#) team and the Goddard Earth Sciences DAAC.

**Remote Sensing of
Ice and Snow
Landforms**

Snow/Ice Observations of Sea Ice

Monitoring Ice and Snow:

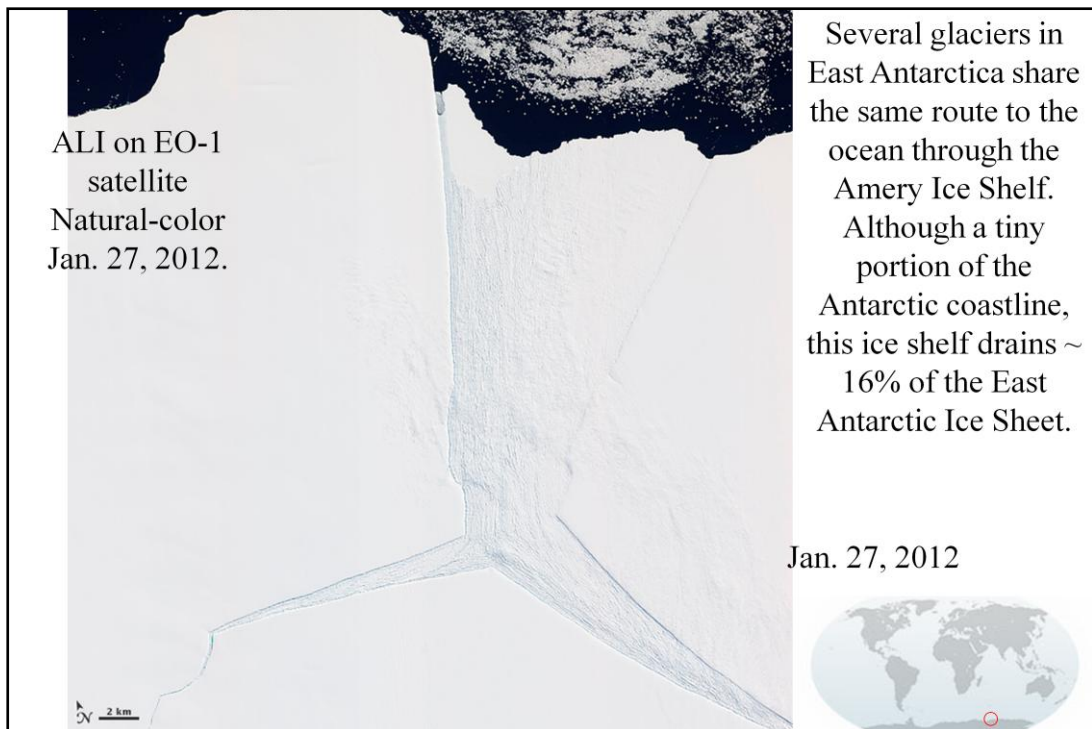
- Sea ice concentration/extent
- Sea ice motion
- Sea ice thickness
- Snow cover area
- Snow depth
- Snow water equivalent
- Ice sheet mass balance
- Ice sheet geometry
- Glaciers and ice caps
- Lake and river freeze-up & break-up (timing)
- Permafrost - active layer
- Permafrost - thermal state



33

List of examples where monitoring the extent and condition of snow and ice is essential. Continuous changes can be monitored from the ground but difficult from polar orbiting OPTICAL satellites (those measuring visible and reflected solar infrared) because of weather and low/no sun in arctic in winter.

Radar is essential for monitoring the changing conditions of snow (e.g., depth). Why?



Several glaciers in East Antarctica, including the Lambert Glacier, share the same route to the ocean through the Amery Ice Shelf. Although comprising just a tiny portion of the Antarctic coastline, this ice shelf drains roughly 16 percent of the East Antarctic Ice Sheet. The Amery deposits ice into the ocean through the natural, cyclical process of iceberg calving—a process that can take decades to complete.

The Advanced Land Imager (ALI) on NASA’s Earth Observing-1 ([EO-1](#)) satellite captured this natural-color image on January 27, 2012. It shows a portion of the Amery Ice Shelf, where three giant cracks, or rifts, meet. The largest rift runs in the same direction as the ice flow, and widens toward the edge of the ice shelf (image center). Smaller rifts extend toward the east and west, and the tip of the western rift narrows and curves significantly (image lower left).

These rifts lie along the western edge of a feature glaciologists have nicknamed Amery’s [“loose tooth.”](#) The tooth is a giant tabular iceberg that has been gradually loosening for more than a decade. The overall cycle of iceberg calving on the Amery Ice Shelf is slow, with the last major calving event occurring in the early 1960s. At that time, Amery released an ice island measuring roughly 140 by 70 kilometers.

Although slow calving of icebergs has been the norm for the ice shelf, a rapid retreat is possible. Although much smaller than Antarctica’s largest ice

shelves—the Ross and Filchner-Ronne—the Amery lies several degrees closer to the Equator. It also has some of the same traits as ice shelves that have retreated on the Antarctic Peninsula, such as extensive crevasses (cracks) and annual surface melt streams.

References

Averill, C., Diner, D.J., Fricker, H.A. (2002, October 17). [Amery Ice Shelf's "loose tooth" gets looser](#). NASA Earth Observatory. Accessed February 8, 2012.

Fricker, H.A., Coleman, R., Padman, L., Scambos, T.A., Bohlander, J., Brunt, K.M. (2009). [Mapping the grounding zone of the Amery Ice Shelf, East Antarctica using InSAR, MODIS and ICESat](#). *Antarctic Science*, 21(5), 515–532.

State of the Cryosphere. (2010, October 10). [Ice Shelves](#). National Snow and Ice Data Center. Accessed February 8, 2012.

NASA Earth Observatory image created by Jesse Allen and Robert Simmon, using EO-1 ALI data provided courtesy of [the NASA EO-1 team](#). Caption by Michon Scott, with information from Helen A. Fricker, Scripps Institution of Oceanography.

Instrument: EO-1 - ALI

Satellite Remote Sensing of Ice and Snow

- Satellites provide information in remote areas where conventional data are sparse or unavailable
 - 20-30+ yr data record for optical & Radar satellite-derived cryospheric information (sea ice, snow cover)
 - Multiple data sources: high repeat coverage of large regions (daily)
 - diurnal trends from multiple daytime passes
 - consistent spatial information using multiple data sources
 - Spatially resolved input & validation for models (climate, land surface process, hydrology, etc.)
- Requires additional development of retrieval techniques (algorithms) to develop snow and ice properties



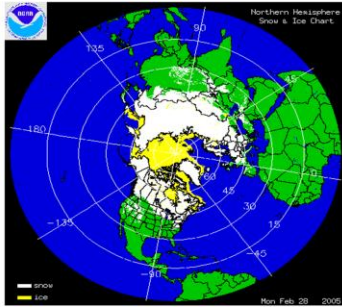
MODIS image - composite

Global mapping satellites (both optical and radar) provide the only consistent source of large scale (continental, global) data to monitor seasonal conditions and long-term (inter-annual) trends in snow/ice

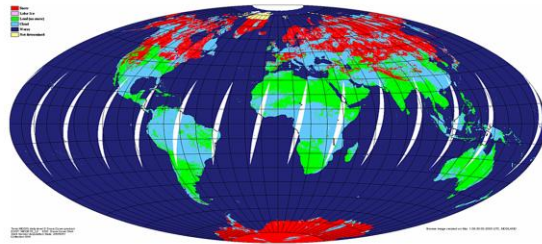
Snow: Remote Sensing/Satellite Capabilities

Snow Extent – Areal Coverage

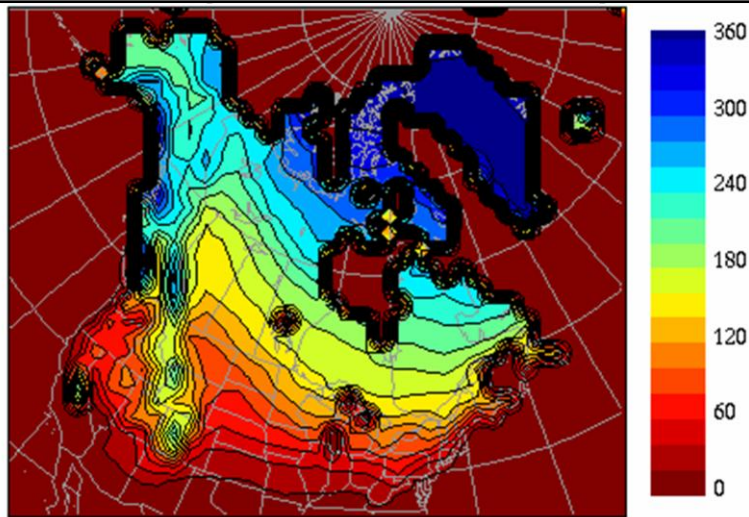
- optical (visible/infrared) –Landsat, AVHRR, MODIS, and VIIRS
- 30m to 1 km spatial information
- long history of standard snow products (NOAA snow charts back to 1960's)
- dependent on solar illumination, limited by cloud cover



NOAA daily IMS snow chart



*Global Daily Snow Cover from MODIS
(Red – snow, Blue – clouds)*



**Mean duration of snow cover (days) for 1972-94 period
computed from AVHRR satellite-derived maps of weekly snow cover
extent.**

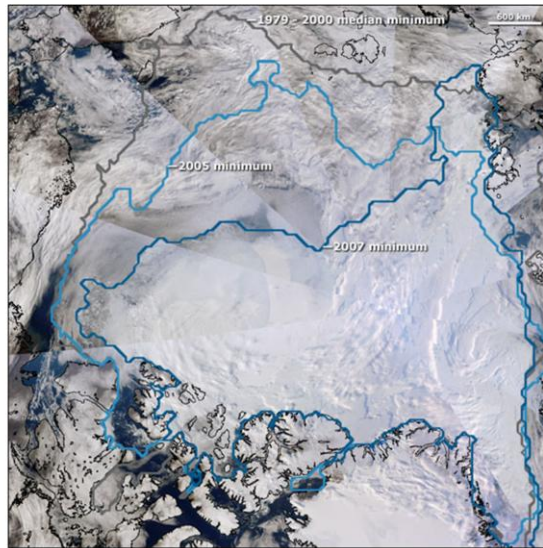
Source: R. Brown, Environment Canada (data supplied by D. Robinson, Rutgers University).

Snow cover is important because it represents the major store of water released in the spring melt period. Knowledge of how much water is contained in a snow cover (the Snow Water Equivalent, or *SWE*) and the rate at which it melts is critical information for flood forecasting, agriculture and for the optimal management of water resources.

Snow is an excellent insulator that prevents soil from freezing to great depths. For example, at Goose Bay, Labrador the mean January air temperature is -16.4°C , while the mean January soil temperature at 5 cm depth is only -2.1°C ---a difference of more than 14°C due to the insulating effect of snow.

Thirdly, because of the high surface reflectivity of snow (80-90% for new snow) and its insulation properties, snow cover has a major effect on energy exchange between the surface and the atmosphere. Numerous studies have shown that mean air temperatures are typically 5-10 degrees C colder when a snow cover is present.

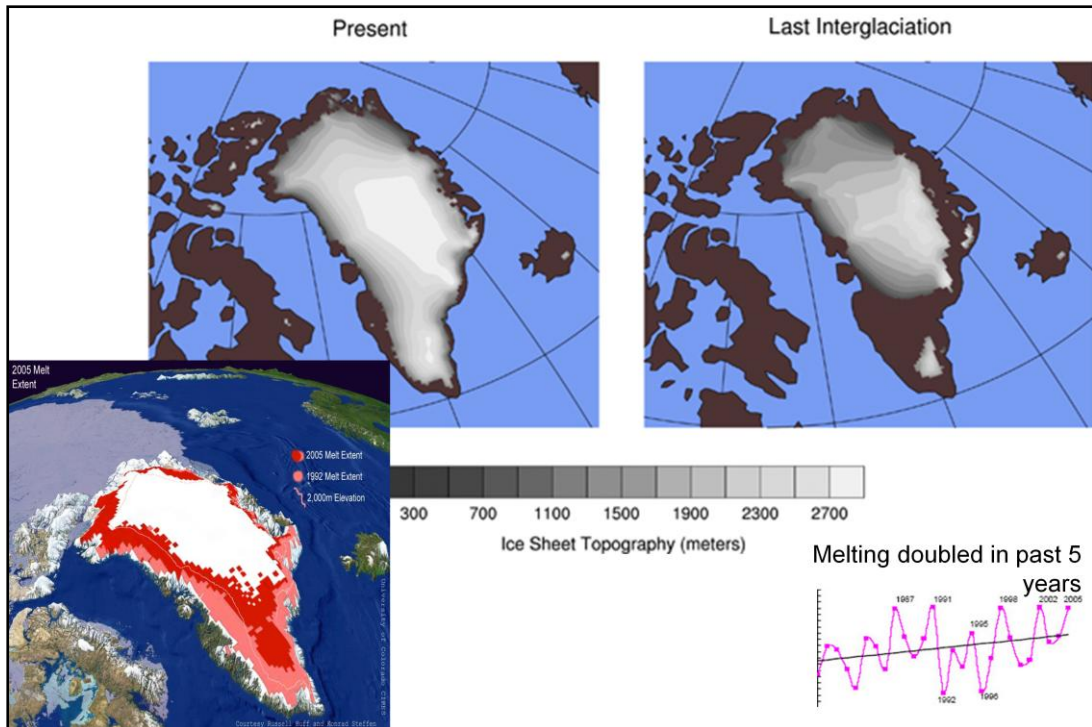
September 15-16, 2007, at the time of the Arctic sea ice minimum



The previous record low (2005, light blue), and the long-term average (1979-2000, gray) are overlaid.

On September 15-16, 2007, at the time of the Arctic sea ice minimum, relatively cloud-free skies enabled the Moderate Resolution Imaging Spectroradiometer ([MODIS](#)) on NASA's [Terra](#) to observe much of the sea ice and open ocean throughout the Arctic. Overlaid onto the image are sea ice minima from 2007 (medium blue), the previous record low from 2005 (light blue), and the long-term average from 1979-2000 (gray). The 2007 minimum, which correlates closely with the ice visible through clouds in this image, fell substantially below previous records. Image by Terry Haran, National Snow and Ice Data Center, University of Colorado, Boulder, using NASA MODIS data.

This image is also available as a [PNG file](#) (58.1 MB) at 500-meter resolution.

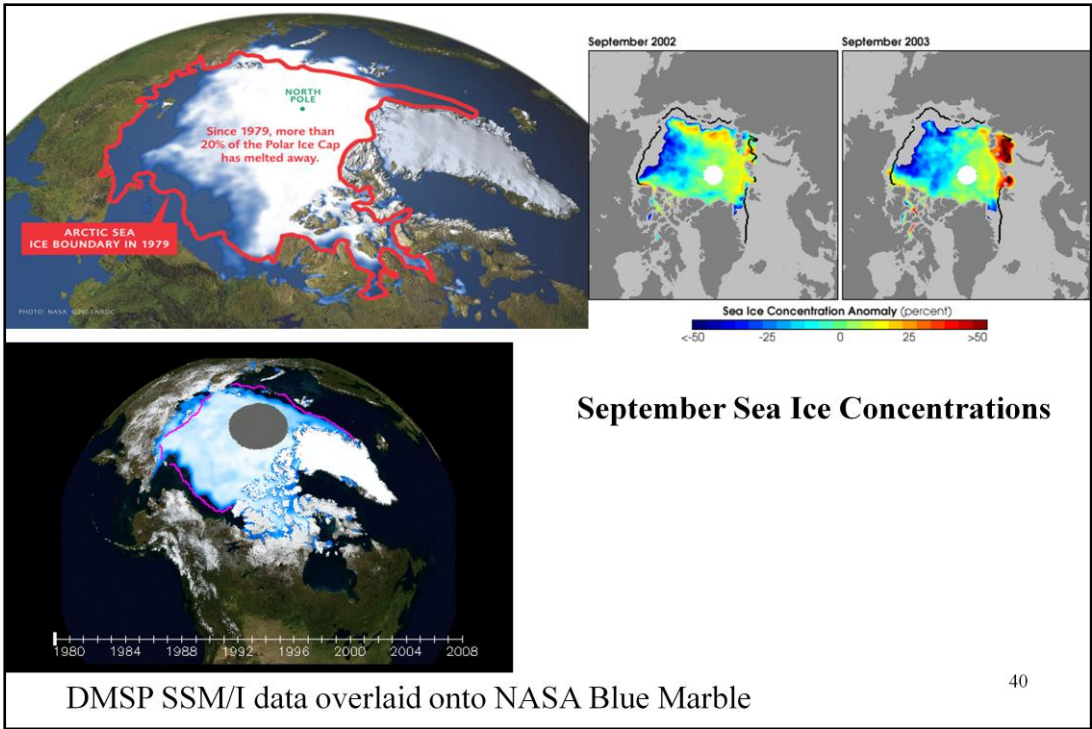


Ice sheets across both the Arctic and Antarctic could melt more quickly than expected this century, according to two studies that blend computer modeling with paleoclimate records. The studies, led by scientists at the National Center for Atmospheric Research (NCAR) and the University of Arizona, show that Arctic summers by 2100 may be as warm as they were nearly 130,000 years ago, when sea levels eventually rose up to 20 feet (6 meters) higher than today.

Otto-Bliesner and Overpeck base their findings on data from ancient coral reefs, ice cores, and other natural climate records, as well as output from the NCAR-based Community Climate System Model (CCSM), a powerful tool for simulating past, present, and future climates.

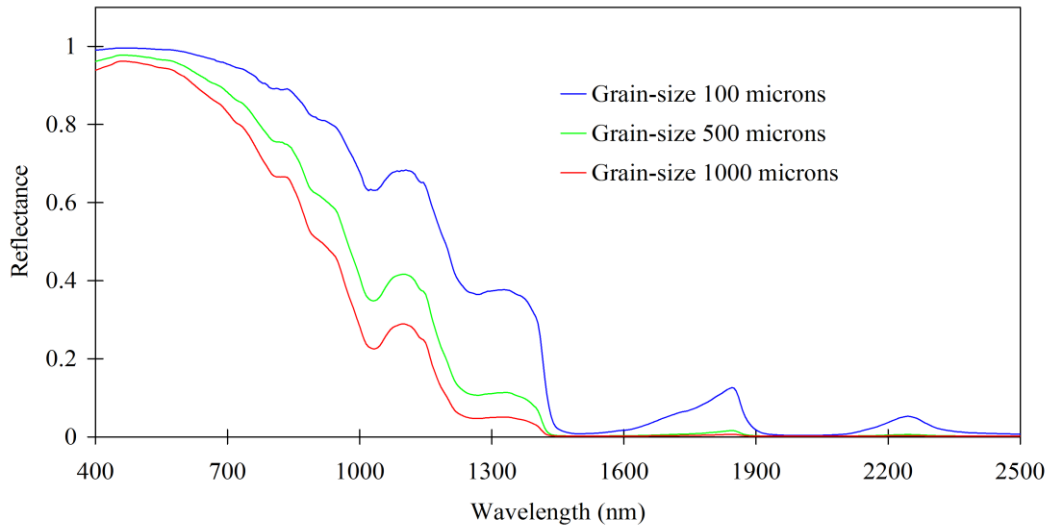
"Although the focus of our work is polar, the implications are global," says Otto-Bliesner. "These ice sheets have melted before and sea levels rose. The warmth needed isn't that much above present conditions."

The two studies show that greenhouse gas increases over the next century could warm the Arctic by 5-8°F (3-5°C) in summertime. This is roughly as warm as it was 130,000 years ago, between the most recent ice age and the previous one. The warm Arctic summers during the last interglacial period were caused by changes in Earth's tilt and orbit. The CCSM accurately captured that warming, which is mirrored in data from paleoclimate record



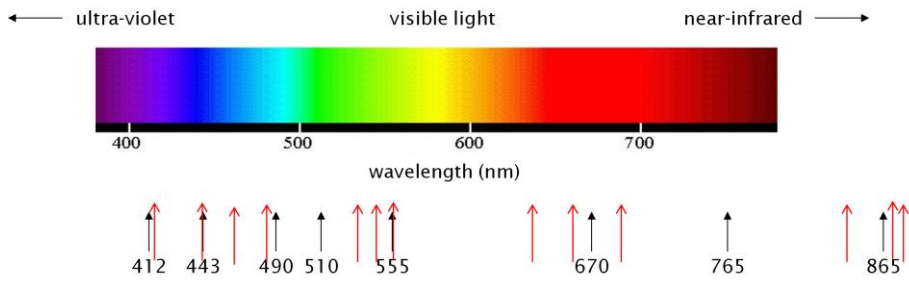
DMSP SSM/I data overlaid onto NASA Blue Marble

Effect of Grain Size on Snow Reflectance



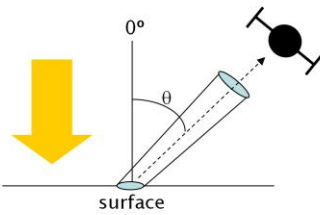
Remote Sensing of Ocean Color

Satellite ocean color



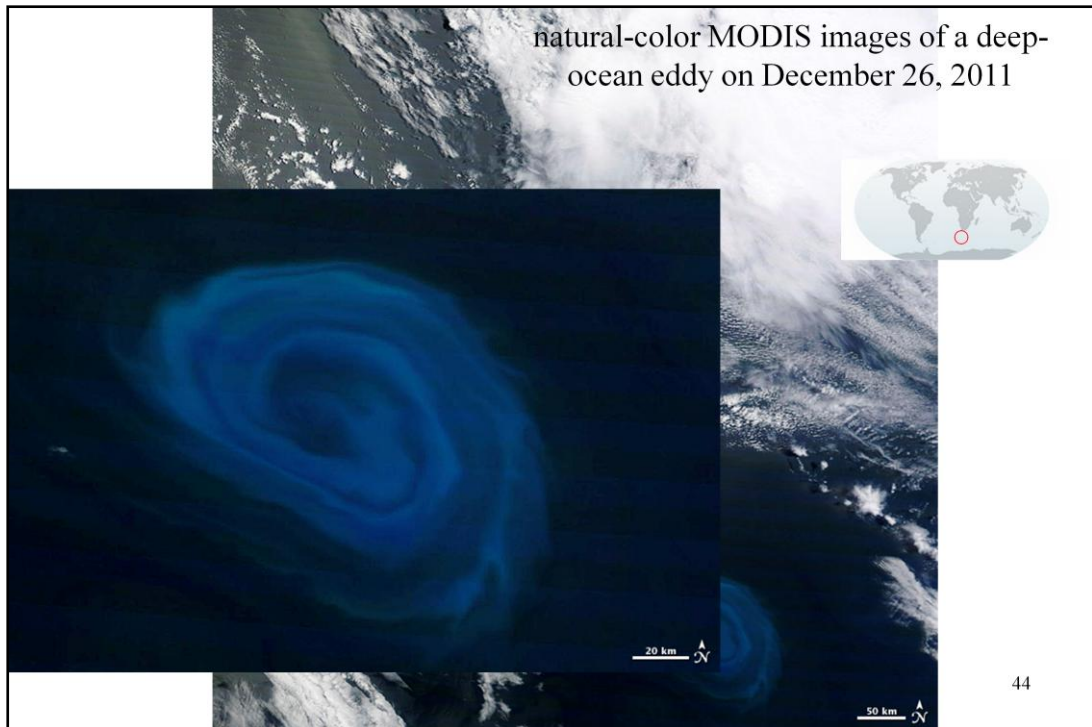
8 SeaWiFS channels

13 MODIS bands



radiance, L , in units of $\mu\text{W cm}^{-2} \text{nm}^{-1} \text{sr}^{-1}$

$$\text{reflectance, } R = \frac{L}{\text{incident irradiance, } E}$$



The ocean has storms and weather that rival the size and scale of tropical cyclones. But rather than destruction, these storms—better known as eddies—are more likely to bring life to the sea...and often in places that are otherwise barren.

The [Moderate Resolution Imaging Spectroradiometer](#) (MODIS) on NASA's [Terra](#) satellite captured these natural-color images of a deep-ocean eddy on December 26, 2011. The view shows the bloom and eddy in context, about 800 kilometers south of South Africa and 150km across in extent.

Eddies are huge masses of water spinning in a whirlpool pattern—either clockwise or counterclockwise—and they can stretch for hundreds of kilometers. Eddies often spin off from major ocean current systems and can last for months.

In the image above, the anti-cyclonic (counter-clockwise) eddy likely peeled off from the [Agulhas Current](#), which flows along the southeastern coast of Africa and around the tip of South Africa. Agulhas eddies, or “current rings,” tend to be among the largest in the world, transporting warm, salty water from the Indian Ocean to the South Atlantic.

Some eddies stir water masses in the ocean and draw nutrients from the deep, fertilizing the surface waters to create blooms of phytoplankton in the open ocean, which is relatively barren compared to coastal waters.

In satellite observations of sea surface height and in computer models, eddies appear as bumps or depressions in the ocean, indicating the upwelling or downwelling of water. They also can be distinguished by higher or lower surface temperatures.

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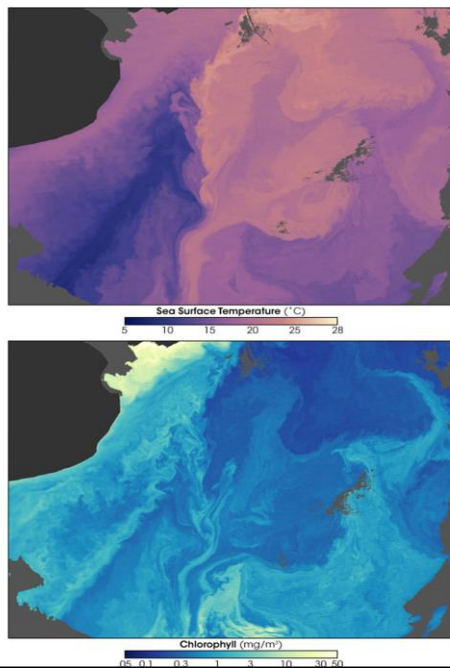
Cooperative Institute for Marine and Atmospheric Studies, University of Miami (n.d.) [Ocean Surface Currents: Agulhas](#). Accessed February 10, 2012.

Lehahn, Y., F. d'Ovidio, M. Lévy, Y. Amitai, and E. Heifetz (2011) [Long range transport of a quasi isolated chlorophyll patch by an Agulhas ring](#). *Geophysical Research Letters*, 38, L16610, doi:10.1029/2011GL048588.

McGillicuddy Jr., D.J et al. (2007, May 18) [Eddy/Wind Interactions Stimulate Extraordinary Mid-Ocean Plankton Blooms](#). *Science*, Vol. 316 no. 5827 pp. 1021-1026, DOI: 10.1126/science.1136256.

NASA Earth Observatory image created by Jesse Allen, using data obtained from the Land Atmosphere Near real-time Capability for EOS ([LANCE](#)). Caption by Michael Carlowicz.

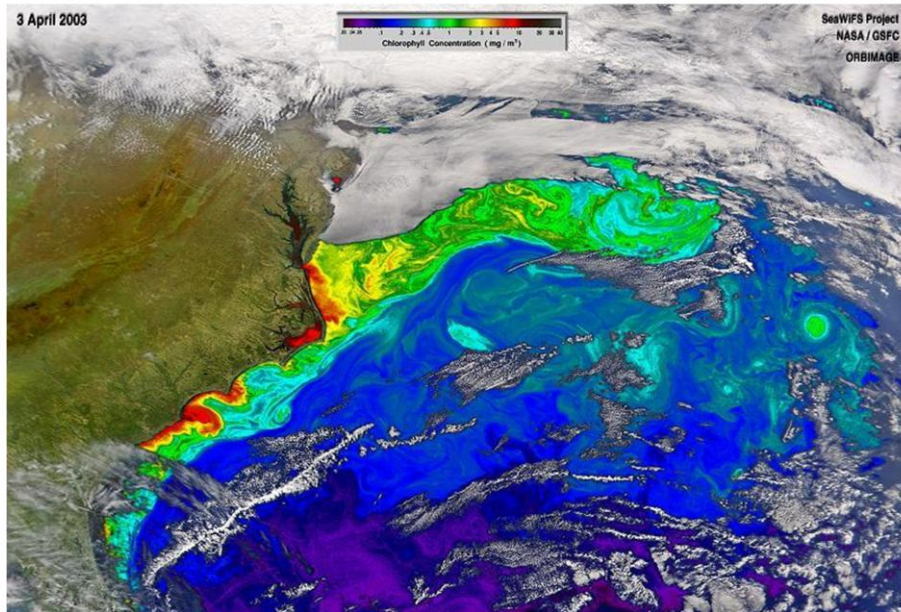
Instrument: Terra - MODIS



Malvinas Current reaches north into the warm South Atlantic Ocean until it encounters warm water from the Rio de la Plata between Argentina and Uruguay. MODIS May 2, 2005

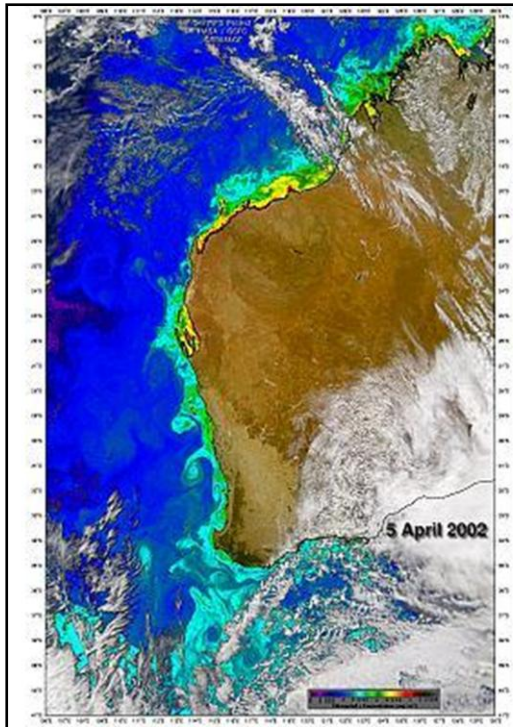
The dark blue icy finger of the Malvinas Current reaches north into the warm tub of South Atlantic Ocean in this sea surface temperature image. The current is an offshoot of the Circumpolar Current, the band of ocean water that circles Antarctica, and it carries frigid water north along the coast of South America until it encounters water pouring out of the Rio de la Plata between Argentina and Uruguay. Here, the cold Antarctic waters also meet the Brazil current carrying warm subtropical waters south, and the 20-degree boundary between the two currents forms a stark line in the top image. The image, and the chlorophyll concentration image that accompanies it, was acquired on May 2, 2005, by NASA's Moderate Resolution Imaging Spectroradiometer ([MODIS](#)). The lower image reveals the correlation between sea surface temperature and plant life. The cold, deep current stirs nutrients from the ocean depths and brings them to the surface, where plants thrive on them. By contrast, the warm current is shallow, and so the waters tend to be nutrient poor. The effect of the two currents on plant life is starkly clear where the two meet near the Rio de la Plata. In the lower image, which shows chlorophyll concentrations, the Malvinas Current is rich with plant life. The pattern of warm pink formed by the Brazil current in the top image matches the lifeless dark blue bulge where few plants are growing in the center of the lower image. Nutrient-rich waters such as those fed by the Malvinas Current also tend to support a diverse ecosystem. The tiny plants that grow on the surface of the ocean feed other ocean life. Off the coast of South America, fish teem in the waters of the Malvinas Current, and commercial fishing is an important industry in Argentina and Uruguay.

The Gulf Stream in the western North Atlantic Ocean



46

Probably the most dominant oceanographic feature of the western North Atlantic Ocean is the Gulf Stream. The northern edge of that current is clearly visible in the chlorophyll field measured by SeaWiFS today. As the Gulf Stream flows eastward it forms meanders that occasionally pinch off to form clockwise-rotating warm-core rings to the north and counterclockwise-rotating cold-core rings to the south. Cold-core rings generally have higher chlorophyll concentrations (and lower surface temperatures) than the surrounding water, and a few of them can be described in this image. Cold core rings tend to form in the east and then gradually migrate towards the southwest. Some have been reported to remain recognizable for up to two years.

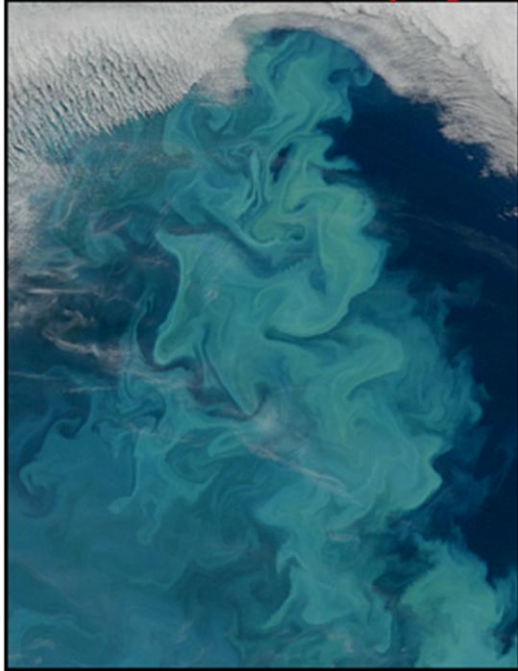


**True-color/chlorophyll
SeaWiFS image April 5, 2002**

Western Australia

This combined true-color/chlorophyll SeaWiFS image (collected on April 5, 2002) shows several eddies spinning off the western coast of Australia.

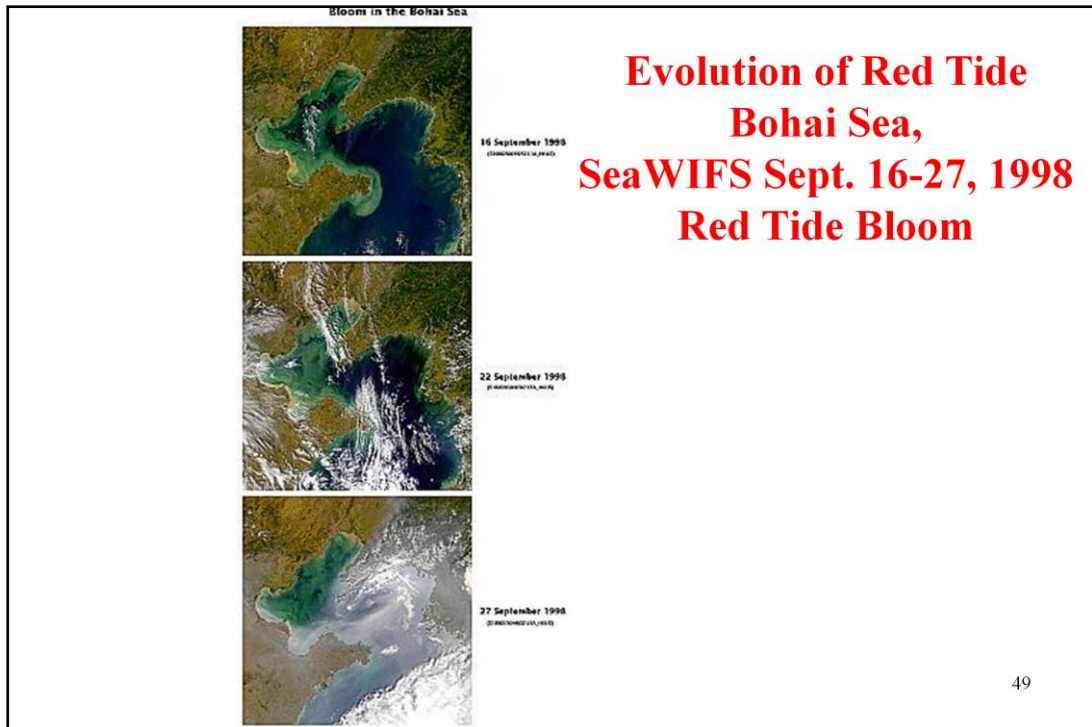
Phytoplankton Bloom in the Barents Sea



Coccolithophore blooms off Newfoundland in the western Atlantic.

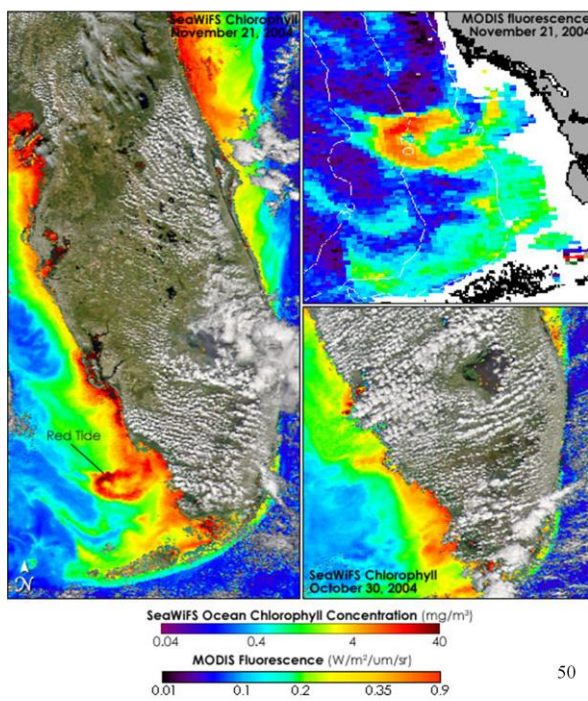
A break in the clouds over the Barents Sea on August 1, 2007 revealed a large, dense phytoplankton bloom to the orbiting MODIS aboard the Terra satellite. The bright aquamarine hues suggest that this is likely a [coccolithophore](#) bloom. The visible portion of this bloom covers about 150,000 square kilometers (57,000 square miles) or roughly the [area of Wisconsin](#).

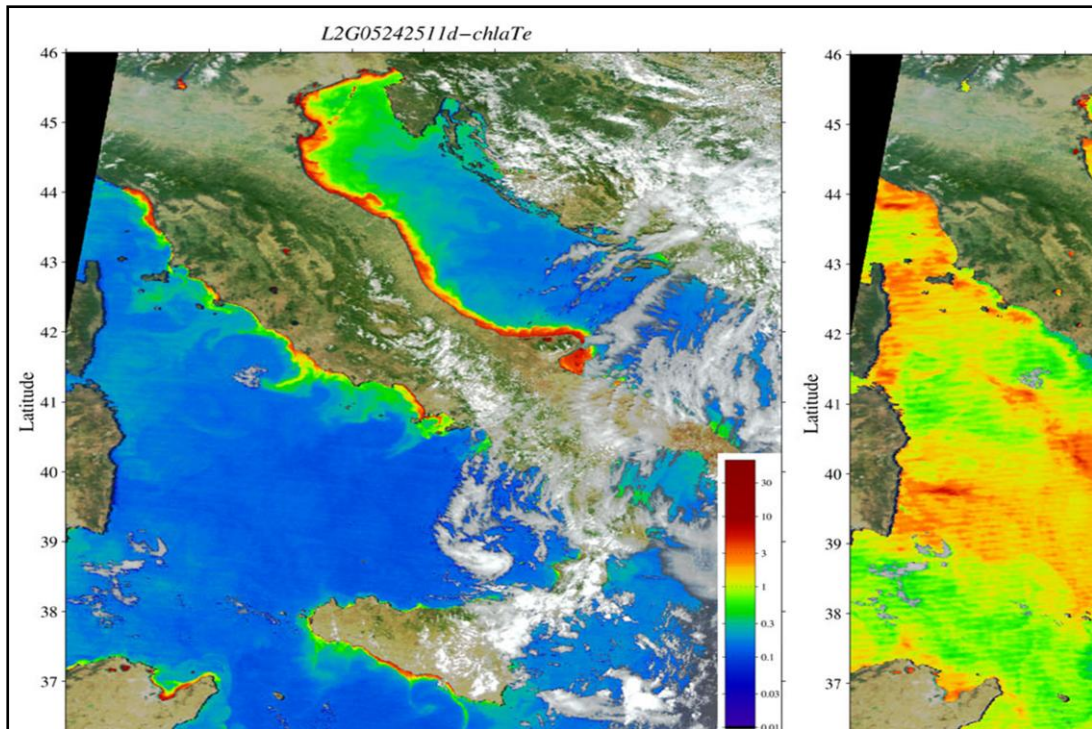
Coccolithophores are tiny organisms that generate very thin plates of calcium carbonate known as coccoliths, which reflect light to turn the color of the water into a bright, milky aquamarine during intense blooms, which can be seen from space.



In this sequence of SeaWiFS images from Sept. 16-27, 1998, the evolution of a red tide bloom in the Bohai Sea can be traced.

SeaWiFS Captures Red Tide Off Florida Coast





Observational Date: 2003/05/24

GLI chlorophyll-a concentration and sea surface temperature around Italia

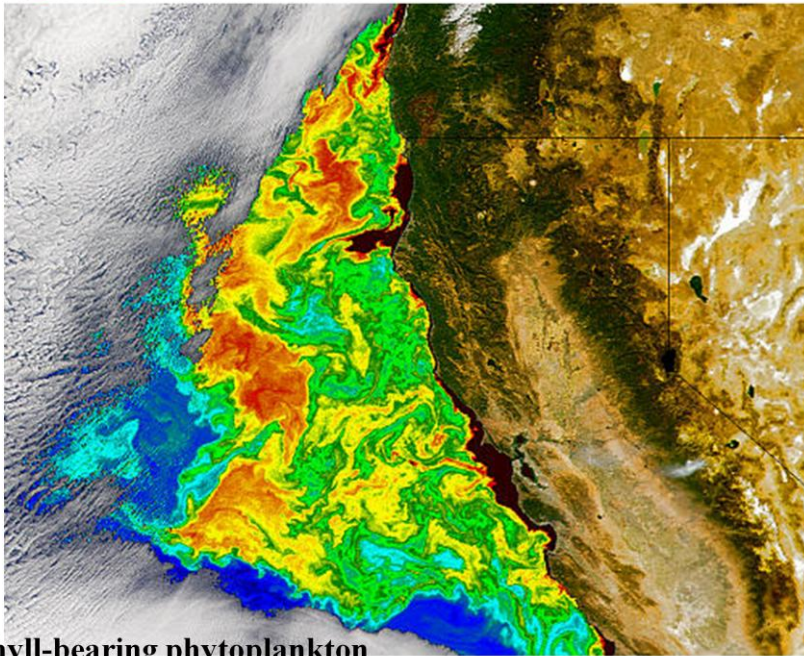
Above figures show chlorophyll-a concentration and sea surface temperature by the Global Imager (GLI) aboard Midori-II (ADEOS-II) on May 24, 2003.

1400 x 795 - 358k - jpg - suzaku.eorc.jaxa.jp/.../Italia_200305242511.jpg

Image may be subject to copyright.

Below is the image at: suzaku.eorc.jaxa.jp/.../20031104006/index.html

Upwelling along the northern and central California coast, SeaWiFS 6 Oct. 2002



chlorophyll-bearing phytoplankton

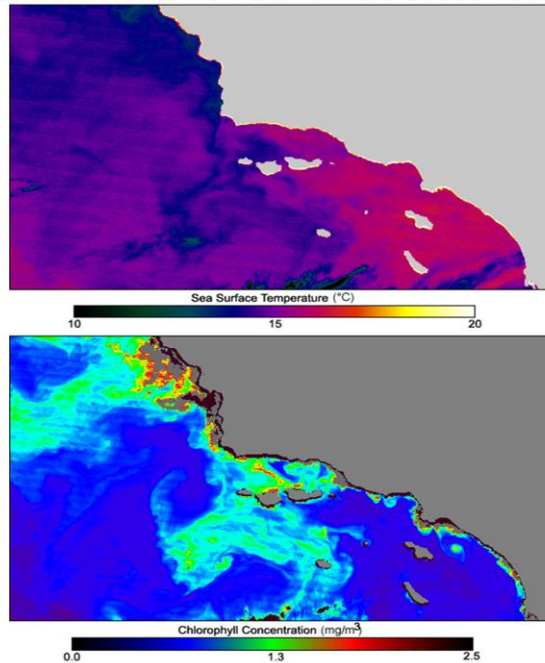
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Winds blowing southward along the west coast of the United States -- because of friction and the effects of Earth's rotation -- cause the surface layer of the ocean to move away from the coast. As the surface water moves offshore, cold, nutrient-rich water upwells from below to replace it. This upwelling fuels the growth of marine phytoplankton which, along with larger seaweeds, in turn nourish the incredible diversity of creatures found along the northern and central California coast.

Sensors such as SeaWiFS can "see" the effects of this upwelling-related productivity because the chlorophyll-bearing phytoplankton reflect predominantly green light back into space as opposed to the water itself which reflects predominantly blue wavelengths back to space.

The ocean areas of the above image (collected on 6 October 2002) are color coded to show chlorophyll concentrations. Land and cloud portions of the image are presented in quasi-natural color.

Phytoplankton Bloom off California's Channel Islands



The two false-color images above show the relationship that is sometimes apparent between sea surface temperature and biological activity in the ocean. The top scene shows sea surface temperature around California's Channel Islands, ranging from 10 - 20 degrees Celsius. The bottom scene shows concentrations of chlorophyll in the surface waters for the same region, ranging from zero to 2.5 milligrams per cubic meter. Both images were produced using data collected on February 3, 2003, by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra satellite. In these images, the land is colored gray and areas representing "no data" are black.

There is often a direct relationship between sea surface temperature and biological activity in the ocean. This relationship becomes evident just by comparing the patterns you see in both images. Warm surface waters typically block deeper, colder currents from rising to the surface. But where the surface waters are colder, the deep, nutrient-rich currents can "upwell" bringing nourishment needed to support life. Where nutrients (such as iron) are plentiful in the ocean, so too are blooms of the microscopic plants and animals that form the foundation of the marine food chain. Given ample nutrients, the tiny plants, known as phytoplankton, can quickly "bloom" into very dense populations producing colorful patterns on the ocean's surface. Satellites help us observe this direct relationship between sea surface temperature and biological activity.

By measuring the color variations of the ocean, scientists can determine where concentrations of phytoplankton are floating at the sea's surface. Like land-based plants, phytoplankton contain the pigment chlorophyll — used for photosynthesis — that gives them their greenish color. Chlorophyll absorbs red and blue wavelengths of light and reflects green light. From outer space, MODIS can distinguish even slight variations in ocean color that our eyes cannot detect. To MODIS, ocean water with high concentrations of chlorophyll will appear as blue-green or green, depending upon the type and density of the phytoplankton population there. This allows scientists to produce false-color maps showing where there are high and low concentrations of chlorophyll.

To learn more about the relationship between sea surface temperature and life in the ocean, check out the [Channel Islands](#) lesson.



Sediment runoff in South America's Rio de la Plata from May 2000.



Sediment plume flowing down western edge of Lagoa dos Patos, Uruguay, Aug. 18, 2000



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Right: A large sediment plume can be seen flowing down the western edge of Lagoa dos Patos and out to sea through the inlet by Rio Grande in southernmost Brazil. Phytoplankton blooms seen offshore may be partly supported by nutrients contained in the turbid runoff. Also visible are Lagoa Mirim, Lagoa Mangueira, and Laguna Negra (in Uruguay). This image was captured on Aug. 18, 2000

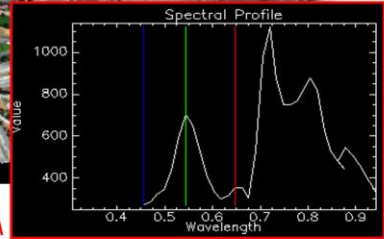
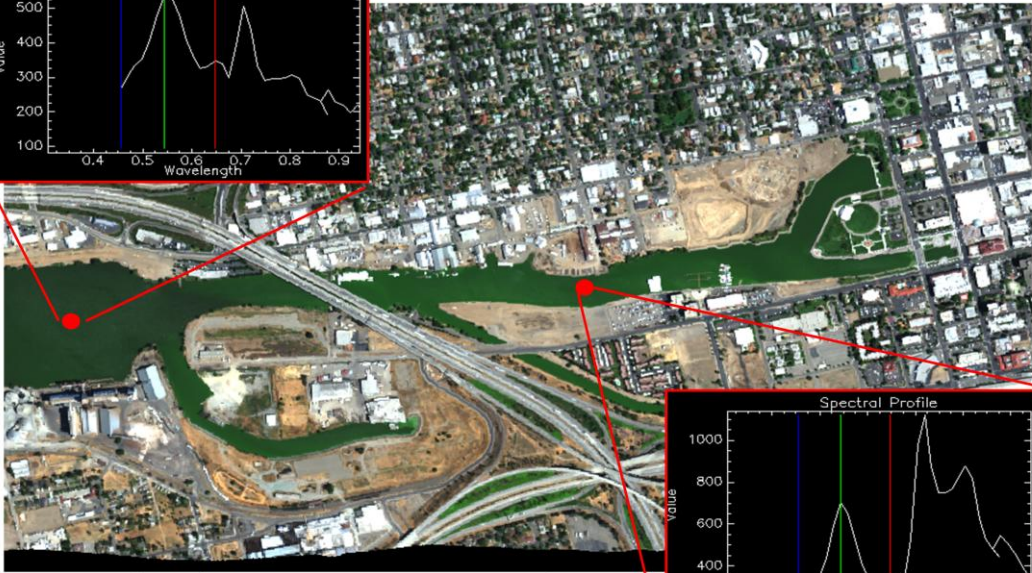
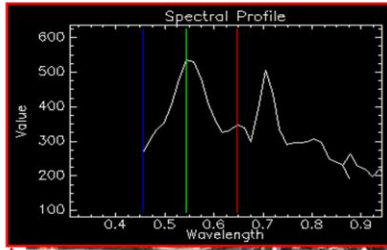
Louisiana Coast suspended sediments, organic matter and phytoplankton. March 15, 1999



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Louisiana coast and the dynamic coastal region showing the suspended sediments, organic matter and phytoplankton. March 15, 1999

Toxic Algae: Microcystis bloom



HyMap imaging spectrometer true-color
Port of Stockton, May 2, 2004

Lecture 12: Remote Sensing of water and water properties in the landscape and ocean: what you should know.

1. Optical properties are used to detect snow, ice and liquid water: applications drought detection, floods, storms, climate change.
2. Snow extent, depth, and snow water equivalent are important properties to monitor. Be able to explain how they are measured.
3. Monitoring changes in distribution of winter snow and ice and timing of melt.
4. What we didn't talk about: precipitation and soil moisture. These are best measured with radar instruments, which we will talk about later.
5. Ocean color for sediment observation, chlorophyll, phytoplankton, red tides.