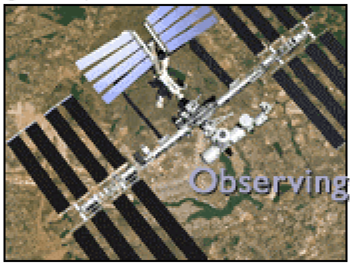

Astronaut Photography: Observing the Earth from the International Space Station

by Julie Robinson & Cindy Evans • design by Robert Simmon

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With much of their time committed to constructing the International Space Station, astronauts and cosmonauts are also beginning their first scientific studies. The Destiny Laboratory just joined to the International Space Station includes the best optical quality window ever flown on a human-occupied spacecraft. The window will eventually host a number of remote sensing experiments mounted on a special rack system, the Window Observational Research Facility or WORF, for mechanical and electrical support (Eppler et al. 1996). Until the WORF is complete in June 2002, astronauts are photographing the Earth's surface as part of an early project, called Crew Earth Observations.

Artist's rendering of the International Space Station (ISS) after installation of the U.S. Laboratory Destiny and its nadir-viewing optical quality window during Space Shuttle Mission STS-98/Station Mission 5A in February 2001 (Image JSC2001e00360

Since early space missions in the 1960s, astronauts have photographed the Earth below–observing the world's geography and documenting transient events like storms, floods, fires, and volcanic eruptions. The early photography formed a foundation for Landsat and other Earth observing satellites (Lowman

1999). Even as such satellites have become the most common way for scientists to collect data from orbit, humans have continued to look out the windows of spacecraft and to record what they see with cameras. For the early Space Station expeditions, astronauts will use 70- and 35-mm film cameras and electronic still cameras to capture images of the Earth.

Astronauts' photos document human impacts on the Earth–such as city growth, agricultural expansion, and reservoir construction. Today, images of the world spanning more than 30 years provide valuable insight into Earth processes and the effects of human activities on the planet. Photographic images taken by astronauts serve as both primary data on the state of the Earth and as secondary data to be combined with images from other satellites in orbit. Through their photography of the Earth, International Space Station astronauts will build on the time series of imagery started 35 years ago, ensuring that this continuous record of Earth remains unbroken.


A frame captured from the attached Space Shuttle showing the U.S. Laboratory Destiny and the position of the WORF window port (arrow). The external cover of the port is currently closed to protect the window. Space Shuttle remote cameras captured the video on February 15, 2001, while Space Shuttle Atlantis was still docked.

As a formal project or "payload" on the International Space Station, Crew Earth Observations will focus on some of the most dramatic examples of change on the Earth's surface. An interdisciplinary group of scientists selected some of the most dynamic regions of the Earth as their initial target sites that could be observed under the tight time constraints of the early phases of Space Station construction. These sites include major deltas in south and east Asia, coral reefs, major cities, smog over industrial regions, areas that typically experience floods or droughts triggered by El Niño cycles, alpine glaciers, tectonic structures, and features on Earth, such as impact craters, that are analogs to structures on other planets.


The WORF window from inside the Destiny Laboratory.

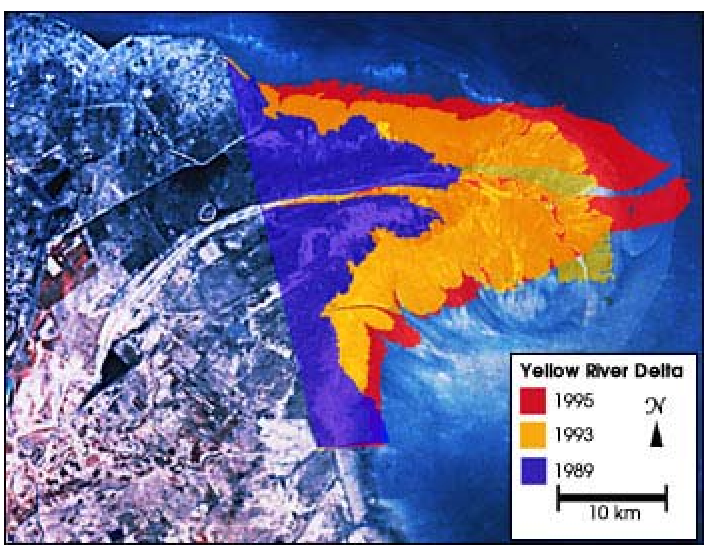
Deltas

Humans are transforming coastlines around the world. Some of the ongoing coastal modifications include building structures that regulate water and sediments (dams, seawalls, and jetties), ground water extraction leading to subsidence, and sea level rise induced by global warming. The increasing populations and development in coastal zones drive many of these changes. One example of a dynamic coastal zone selected for the Crew Earth Observations project is the Chinese coastline along the Gulf of Bohai. Here a combination of human and natural changes can be observed.

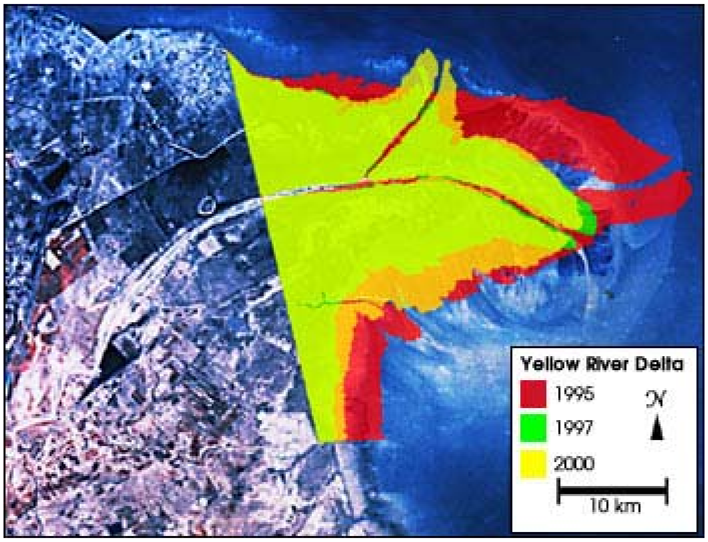
The delta of the Yellow River is the fastest changing coast on the Earth's surface. The lower river channel silts up rapidly, resulting in frequent river course changes. The river has been engineered for millennia, but recent water demands and water diversions (amplified by several years of drought in the 1990s) have resulted in little or no water reaching the coast.

This image of the Yellow River delta was taken from the Space Shuttle in February 2000 using an electronic still camera as part of the EarthKAM Project Image # STS099.ESC.04093647

Between 1989 and 2000, astronauts on the Space Shuttle documented dramatic changes in the tip of the Yellow River delta. Over this time, several hundred square kilometers have accreted to and been eroded from the coast. The delta grew nearly 400 square km between 1989 and 1995, and then began eroding back. In 1997 a new channel was cut near the tip of the delta, providing the water and sediment a shorter route to the sea. Between 1995 and 1997, the delta area eroded back about 250 square km. From 1997 to February 2000, the delta tip again grew nearly 100 square km.



From 1989 to 1995 the Yellow River delta accreted (grew in area). Each of these outlines of the above-surface delta was measured from an astronaut photograph mapped to the common base.



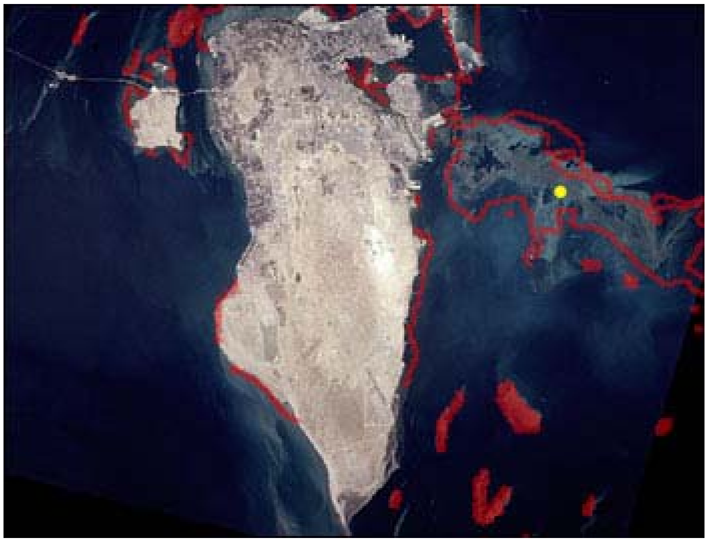
From 1995 to 2000 the Yellow River delta eroded (shrank in area). Each of these outlines of the above-surface delta was measured from an astronaut photograph mapped to the common base.

Remote sensing image analysis is an efficient strategy for examining regional changes that occur over large areas, and provides context for smaller-scale changes. The photographs collected by astronauts can be assembled in a time series of images that demonstrate both the scale and specific locations of coastal change. Change can be quantified when the images are referenced to standard maps. Such analyses can identify both natural and human-induced changes, lending some understanding of the processes involved in the coastline evolution.

Other Asian deltas that will be a focus of Crew Earth Observations are those of the Yangtze, Irrawaddy, Mekong, and Ganges Rivers.

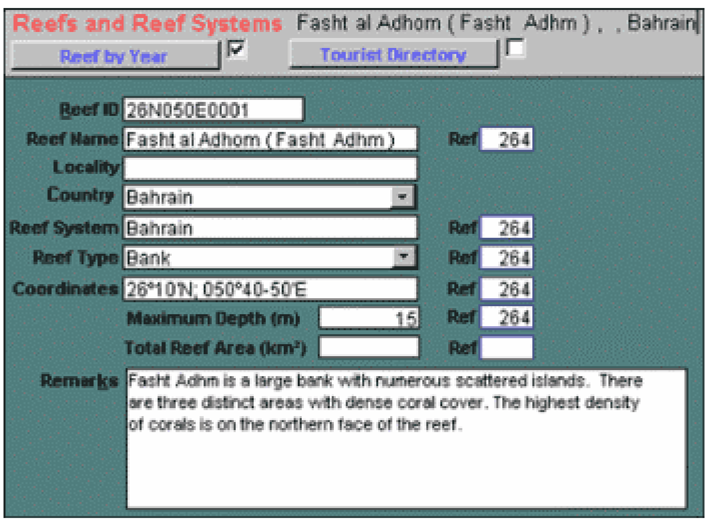
Coral Reefs

Healthy coral reefs sustain local and national economies through fisheries, coastal protection, and tourism. Despite these benefits, it has been estimated that 58 percent of coral reefs globally are threatened by human activities (Bryant et al. 1998). Scientists still lack basic data about the locations, spatial extent, and health of reefs. Major efforts are underway in the U.S. and around the world to improve the mapping information on coral reefs. Astronaut photographs are a unique data source for these efforts because photos of the reefs have been collected for many years, and the images are available in the public domain. Of particular value is the fact that the astronauts took advantage of opportunities when cloud cover was minimal to take the photographs. Astronaut photographs can be used as primary data for maps of the locations of reef crests and as supplemental data for use with other satellite images, especially when it is important to distinguish small clouds from reef areas.



Astronaut photograph of Bahrain (STS078-748-11 combined with ReefBase data (yellow dot) and World Conservation Monitoring Centre maps of the reef crest (transparent red).

Astronaut photographs are being used as base maps in an international compilation of information on coral reefs, known as ReefBase. Images have also been included in a prototype reef data distribution system that uses a global map based on 1.1-km data from the SeaWiFS satellite sensor as a backbone for links to georeferenced reef remote sensing data from a number of different satellites (Robinson et al. 2000b) Investigations comparing the level of detail that can be mapped from an astronaut photograph to that from other satellite data are nearing completion.



Reefs and Reef Systems Fasht al Adhom (Fasht Adhm) , , Bahrain

Reef by Year | Tourist Directory

Reef ID	26N050E0001		
Reef Name	Fasht al Adhom (Fasht Adhm)	Ref	264
Locality			
Country	Bahrain		
Reef System	Bahrain	Ref	264
Reef Type	Bank	Ref	264
Coordinates	26°10'N; 050°40-50'E	Ref	264
Maximum Depth (m)	15	Ref	264
Total Reef Area (km²)		Ref	

Remarks: Fasht Adhm is a large bank with numerous scattered islands. There are three distinct areas with dense coral cover. The highest density of corals is on the northern face of the reef.

ReefBase text data for Fasht al Adhom, Bahrain.

Images of the Tuamotu Archipelago, American Samoa, Malaysia, and the Philippines are targeted for acquisition during the Crew Earth Observations project, to provide additional data for these mapping investigations.

Urban Areas

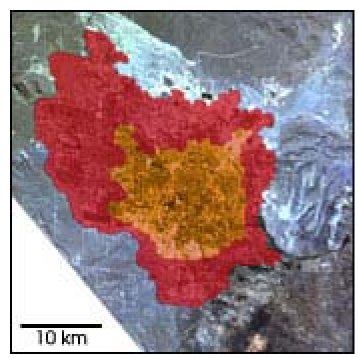
Megacities (cities with more than 10 million people) are increasing in number as the global human population continues to become more urban. By the end of 2030, three-fifths of the world population will be living in urban areas (Brennan

1999). Much of this urban growth occurs outside defined city boundaries and the resulting expansion of urban or "built-up" areas can be readily observed from orbit.

The database of astronaut photographs taken since the 1960s offers important baseline data for comparing and calculating the increases in urban areas (Robinson et al. 2000a).

Photograph of Las Vegas, Nevada, taken from the Skylab in 1973 (SL3-28-599).

Photograph of Las Vegas, Nevada, taken from the Mir Space Station in 1996 (NM22-725-34).



As measured from these two photographs, the built-up area around Las Vegas went from 206 square km in 1973 to 628 square km in 1996, an increase of 204 percent. The human population grew from 273,000 to 1.1 million during that time.

Crew Earth Observations on the Space Station will focus on documenting the growth of the largest and fastest growing cities around the world.

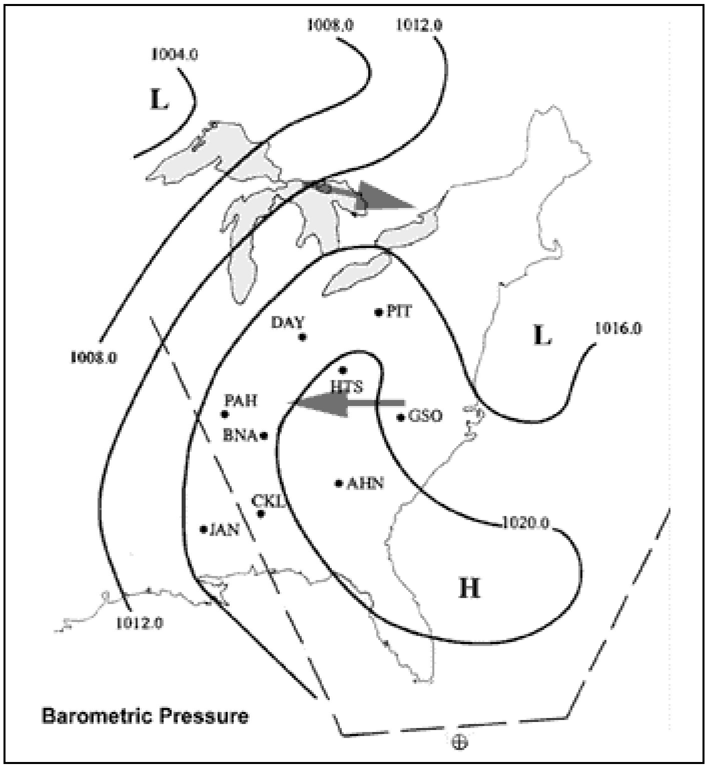
Smog

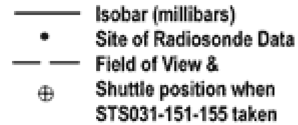
Dense smog blankets are light gray and reflect a small amount of the sun's energy back into space. This effect reduces the local degree of warming of the atmosphere by roughly 25 percent of the heating due to the greenhouse gases (Charleson and Wigley 1994). The location, size, movement, and duration of such smog blankets is of great interest to atmospheric scientists and climatologists.

According to atmospheric models, the greatest reflective cooling of this kind occurs over the major industrial regions of the world–Northwestern Europe, Northeastern North America, and East Asia. Thus, some models suggest that smog over industrial centers induces regional cooling, even though the greenhouse gases in the smog result in heating of other parts of the planet.

Photographs from the Space Station will be useful for visualizing the location, extent and rapid changes of smog palls over industrial regions (Wilkinson et al. 2000). Oblique viewing angles amplify the apparent density of the smog and make it easier to identify boundaries in handheld photographs than in satellite images.

The photograph (STS031-151-155) looks obliquely north up the east coast of the United States with the Florida peninsula in the foreground to the left. A smog pall from the northeastern U.S. industrial regions flows out into the Atlantic Ocean across the top of the view; it was thick enough on the day this photo was taken (26 April 1990) to obscure the coastline of the Mid-Atlantic states (top center).





Weather charts from the National Climate Data Center on the date when the photograph was taken show that the Bermuda High pressure system was centered over the southeastern United States, its winds transporting the smog eastwards (upper arrow in line diagram) all the way to Bermuda (B on the photo), which is roughly 1500 km east of Cape Hatteras.

By combining photographs from the Space Station with other weather data, a greater understanding of movements of aerosols will be obtained. For example, the photograph above shows the leading edge of the pall (far right) curving back towards Florida, guided by the winds blowing around the high pressure system (arrows on line diagram). Within hours of this photo being taken, the smoggy air from the northeastern United States drifted across Miami from the sea (lower arrow in line diagram), an unexpected direction.

As part of the Crew Earth Observations project, astronauts will photograph accumulations of smog, with emphasis on the Northeastern United States, China, Sub-Saharan Africa, and Europe.

El Niño cycles

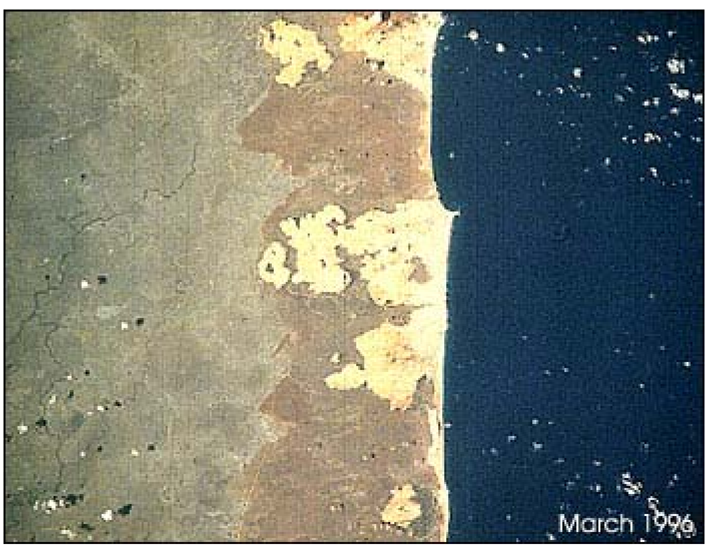
El Niño Southern Oscillation (ENSO) cycles occur every few years, disrupting weather patterns around the world. The human and economic tolls from extreme droughts and floods can be great (see the Earth Observatory Reference on ENSO). ENSO events affect rainfall patterns, leading to droughts in some places and extraordinary rainfall in others.

Astronauts track indicators of drought such as increased incidence of wildfires and lowered levels of lakes and reservoirs. Where rainfall increases, they observe floods and vegetation greening. The International Space Station crews will collect comparative photographs over parts of the world that were hardest hit by precipitation anomalies associated with the 1997-1998 El Niño. These new observations will build on the unprecedented data on El Niño-related floods and droughts that were collected by astronauts living on Mir (Evans et al.

2000).

Imagery from space provides regional context for local events like floods or fires. The presence of smoke, the boundaries of smoke palls, and lake level fluctuations can be compiled for a regional and global assessment of El Niño impact. Rising and falling water levels in lakes, reservoirs and rivers, and vegetation characteristics can be monitored repeatedly to determine responses and rates of response to extreme weather events.

Fires resulting from severe drought choke Indonesia during the beginning of the 1997-98 El Niño event. The photographs were taken from the Space Shuttle in September 1997 using an electronic still camera as part of the EarthKAM Project (STS086.ESC.00215701)



Heavy rainfall over the Horn of Africa resulted in flooding. This pair of images shows the remarkable greening of desert vegetation in Somalia. The first image, NM21-727-6was taken in March 1996.

The second image, NASA6-708-56],was taken in January 1998. The large light-colored patches on the coast are dune fields.

Other sites that are targeted for Crew Earth Observations include Lake Poopó, Bolivia; Lake Eyre Australia; Central California; Lake Nasser, Egypt (See Earth Observatory Image); and the lower Paraná River, Argentina.

Glaciers & Icepack

Changes in the extent of permanent and seasonal ice can serve as important indicators of short-term and long-term climate change. The volume of ice in the world's mountain glaciers is declining (see Earth Observatory feature on Glaciers).

While the relationship of glacier dynamics to regional climate is not well defined, scientists cite the worldwide recession of mountain glaciers during the last century as evidence for global warming. Mountain glaciers and small ice fields reflect changes in regional climate more quickly because their small size makes them sensitive to deviations from normal weather patterns. From the International Space Station, seasonal images of glaciers will provide valuable detailed information about the extent of glacial ice and surface snows (or equilibrium line) on the glaciers. Beyond the issues of global warming and rising sea levels, the retreat of glaciers and ice fields also has implications for current and future regional water resources. Astronauts are focusing on large ice and glacier fields in the Canadian Rockies, small glaciers atop high peaks in the equatorial regions (for example, Papua New Guinea and Mt. Kilimanjaro in Tanzania), and snowfields in the Andes, from Bolivia and Peru to Patagonia. The first photographs of glaciers have already been downlinked by Station crewmembers.

This photograph shows the glacial headwaters of the Rio de la Colonia in the Chilean Andes. The ranges here top 14,000 feet. The photograph, ISS001-ESC-5107 was taken in December 2000.

In this detail of the view above, note the shards of ice that have calved from the glaciers into the lakes on the left.

Sea ice can also serve as an important indicator of global climate change. Winter ice accumulation in the Gulf of St. Lawrence varies dramatically during El Niño events (Evans et al. 2000). Crewmembers will photograph limits of South Sandwich Islands pack ice as well.

Typical ice cover for the St. Lawrence Seaway as photographed from Mir in February 1997 (NM22-778-81). Newfoundland is in the foreground, and Nova Scotia is left of center. The arrow points to the Isles de la Madeleine.

Tectonic Processes

East Africa is of intense interest to geoscientists investigating the formation of ocean basins and the rifting of continental plates. Conditions in some areas, such as Ethiopia, have prevented the direct inspection of the area by western field scientists for more than a decade. The broken terrain has handicapped development of transportation, leaving extensive areas isolated and inaccessible to motor vehicles. Because of these limits to research, the East African Rift is a focus for Crew Earth Observations. Photographs taken from orbit permit observation and interpretation of both geological and environmental conditions in the region.

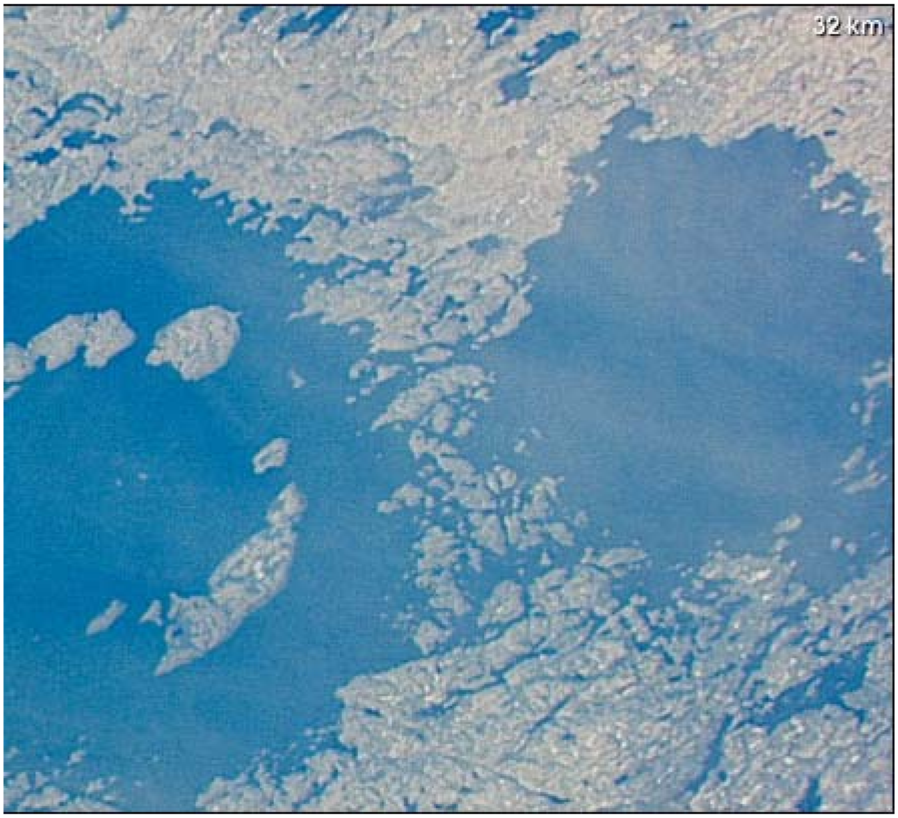
The Red Sea, Gulf of Aden, and Ethiopian rift systems originate in the Afar region of East Africa. Dark lava flows cut by long, straight faults characterize the terrain (STS41G-32-16). As the rifting continues over geologic time, Lake Assal will eventually become an extension of the Gulf of Aden.

The faults of the Red Sea system (trending North-Northwest), those of the Ethiopian rift (Northeast), and those of the Gulf of Aden (West-Southwest) originate in this region. The rift triple junction and the active volcanism in the area reflect stretching of the Earth's crust above a rising plume of hot mantle material. This rifting of continental crust is analogous to the process that separated the Americas from Eurasia and Africa to form the Atlantic Ocean.

East African rift zones that will be a focus of the Crew Earth Observations project include the Rukwa transform fault zone, Tanzania; Mt. Kilimanjaro, Kenya; and the rift triple junction in Ethiopia.

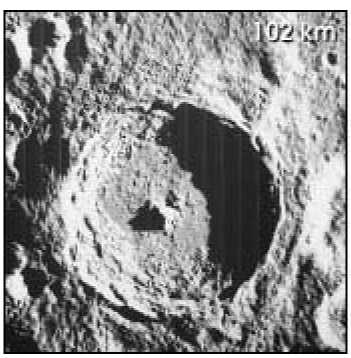
Analogous Features on Earth, Moon and Mars

Similar processes have produced volcanoes and impact craters on Earth, the Moon, and Mars. Others features on the different planetary bodies, such as dunes and canyons, may look alike but may not have formed by the same processes. Varying shapes and sizes of features can be due to differences in planetary density and diameter, presence or absence of an atmosphere, presence of water, and subsurface processes. Plate tectonics on Earth makes other processes more difficult to study because surface features are not preserved as well as they are on Mars or the Moon. Improved understanding of these features on the Moon and Mars will result in a fuller understanding of Earth.



Clearwater Lake W., Canada, photographed from the Space Shuttle (STS61A-35-86).

Terrestrial features for which there are morphological analogues on Earth's Moon and Mars are selected as Crew Earth Observations sites. These features include impact craters, volcanoes, dune fields, old shorelines, and expanses of layered rocks (see Canyons, Craters and Drifting Dunes).



far left: Tycho Crater, The Moon (Lunar Orbiter image V-125M).

left: Lowell Crater, Mars as seen by the Mars Orbital Camera.

By comparing detailed photos and high-resolution images of the Earth, Moon, and Mars, scientists can define the dominant processes that have shaped the landscapes of the three planetary bodies. Such analyses provide essential data for landing-site selection and for framing scientific objectives for robotic and human missions to Mars. They also aid in the identification of potentially troublesome environmental elements near proposed landing sites, such as persistent dust storms, steep slopes, or bouldered terrain.

Dynamic Events

A special advantage enjoyed by astronauts versus unmanned satellites is the ability to observe and record dynamic events on the Earth's surface. Opportunistic observations by astronauts on earlier space missions have provided unique views of volcanic eruptions, hurricanes, dust storms, and plankton blooms. Astronauts can scout and selectively photograph regions that lie off track and can interact with observers on the ground, providing a powerful and efficient way to observe such phenomena.

Rabaul volcano on the island of New Britain erupted unexpectedly in September 1994. The astronauts on board the STS-64 Space Shuttle mission first noted and then recorded the eruption using several camera systems. This image was taken near the peak of the eruption, and was later used by several scientists analyzing the dynamics of the eruption plume (STS064-116-64).

Future Earth Observing Payloads

All Earth Observation images recorded from the International Space Station are cataloged and added to the database maintained at the Johnson Space Center by the Earth Sciences and Image Analysis Laboratory. Through digital technologies and global networks, the collection of images is available to scientists, educators, and the public at theGateway to Astronaut Photography of Earth.

The Destiny window and WORF provide unprecedented opportunities for remote sensing of the Earth. Future payloads integrated into the WORF may be operated remotely and autonomously or may take advantage of the astronaut presence for operation, or real-time configuration changes and payload maintenance.

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