Earth surface change as viewed by the Spaceborne Imaging Radar-C, X-Band Synthetic Aperture Radar (SIR-C / X-SAW and Shuttle Hand-Held Photographs

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The Spaceborne Imaging Radar-C, X-Band Synthetic Aperture Radar (SIR-C/X-SAR) was launched on space shuttle Endeavour at 7:05 AM EDT, Saturday, April 9, 1994 as part of the Space Radar Lab (SRL-1), Soon after launch, the radars were activated and began around the clock operations which lasted for the next 10 days. Endeavour landed at approximately 1:05 pm EDT, Wednesday April 20 at the Dryden Night Research Center at Edwards Air Force Base facility in California. The second flight of SIR-C/X-SAR is scheduled for August 18, 1994, again on space shuttle Endeavour. Radar images and astronaut Hand-Held Photos (HHPs) from these missions will be used by the international science community to better understand the global environment and how it is changing (Evans et al., 1993, 1994).

SIR-C /X-SAR is a cooperative experiment between NASA, the German Space Agency (DARA), and the Italian Space Agency (ASI). The SIR-C instrument and Ground Data Processor were developed by NASA's Jet l'repulsion Laboratory (JPL). SIR-C provides increased capability over earlier orbital radar systems (Seasat, SIR-A, and SIR-B, and the European ERS-1 and Japanese JERS-1) by acquiring digital images simultaneously at two microwave wavelengths (lambda): 1.- band (wavelength=24 cm) and C-band (wavelength=6 cm) (e.g. Evans et al., 1993). Vertically and horizontally polarized transmitted waves are received on two separate channels, so that SIR-C provides images of the magnitude of radar backscatter for four polarization combinations: HH (Horizontally transmitted, Horizontally received), VV Vertically transmitted, Vertically received), VH, ancl HV; and also data on the relative phase difference between the 1111, VV, VH and HV returns.

X-SAR was developed by the Dornier and Alenia Spazio companies with the Deutsche Forschungsanstalt fuer Luft und Raumfahrt e.v. (DLR), as a major partner in science, operations and data processing. X-SAR operates at X-band (wavelength=3 cm) with VV polarization, resulting in a three-frequency capability for the total SIR-C/X-SAR system. Because radar backscatter is most strongly influenced by objects comparable in size to the radar wavelength, this multifrequency capability provides information about the Earth's surface over a wide range of scales not discernible with previous single-frequency experiments or with optical sensors.

A major goal of the SIR-C/X-SAR missions is to validate radar's ability to extract key environmental information about the earth's surface and cover through darkness and cloud cover, under a variety of seasonal and meteorological conditions: e.g. rain, snow cover, dust storms, sea ice, and flooding. To aid in this proof-of-concept, Endeavour's crew exposed over 14,000 frames of film during the 1 l-day SRL-1 mission, a record for shuttle flights, Visual observations provide an important perspective for the interpretation of the radar data since astronaut observations and photographs cover a much broader area than the radar swath, providing a context from which the radar data can be interpreted. The photographic record, available in digital form, will also permit radar investigators to verify the actual surface conditions at the majority of radar study sites where ground truth was not available. The visible imagery, along with verbal reports from the crew during the mission, has already proven key to interpreting anomalies seen in the radar imagery, such as heavy precipitation over rain forest targets in the Amazon basin.

These HHPs, along with a similar data set collected on SRL-2 in August of 1994, also serve to expand the documentary record of environmental change captured on previous shuttle missions. Collected in a band girdling the planet between 57 deg. N and S latitude, the visible imagery includes synoptic views of geology and vegetation cover, and close-ups of dynamic phenomena like storm systems and volcanic events, all of high interest for validation of the radar processing algorithms intended for a permanent environmental monitoring system. Access to astronaut photography in digital form is discussed in Lulla et al. (1993).

The unique perspective of space and the rnultiparameter capabilities of SIR-C/X-SAR allow us to explore our planet in a way that has *never* before been possible. For example, ecology investigations being carried out by science team members are focussed on mapping deforestation, and wetlands and flooding under forest canopies (e.g. Hess et al., 1990); and validating models to determine vegetation type, seasonal freeze/thaw transitions, and biomass (e.g. Dobson et al., 1992; Le Toan et al., 1992). These measurements are essential to our understanding of carbon dioxide increase and global warming because we need to know how much carbon is being taken up by forests compared to how much carbon is being release to the atmosphere through clear cutting and burning of fossil fuels.

Vegetation and biomass maps of the Raco Ml supersite were generated by investigators from the University of Michigan using SIR-C/X-SAR data. An example of clear cutting and regrowth, and the associated change in biomass was also generated for the Landes Forest in southwestern France. Regrowth after clearcutting and fires is important because regenerating vegetation accumulates carbon the most during the first 20 years after the disturbance, which makes this is a critical period for determining the global carbon budget. Understanding the length of the growing season is also important for studies of the carbon cycle as well as for agriculture. During the April mission we acquired data over several forested areas in the northern hemisphere as they underwent thawing. Seasonal data will be acquired over these same sites in August.

The focus of hydrology experiments is to improve our understanding of where moisture is stored and how it is redistributed (e.g. Wang et al., 1986; Rott and Mätzler, 1987). Understanding the hydrologic cycle is critical for adequately modelling the global climate, as well as for managing water resources. Using SIR-C data we have generated detailed soil moisture maps of the Chickasha, Oklahoma supersite showing how the area changed between April 12 (shortly after ~2 centimeters of rain) and April 15, following three days of drying. Such maps of soil moisture change are not only important for irrigation, they could provide insight into the recent flooding we've been experiencing. Model studies from the 1993 Midwestern floods have shown that high levels of soil moisture are essentially re-cycled back to the atmosphere and can result in severe rain storms. Thus, it may be possible to improve short term severe weather forecasting by using actual soil moisture information rather than estimated values.

Flooding can also be monitored with radar, as demonstrated during Flight 1 in both the Midwestern U.S. and in Germany. Real-time images of flood state can be assessed while clouds still obscure a flooding region. Flooding under vegetation canopies was also mapped in the Amazon flooding during the April mission and will also be imaged in August.

Other critical measurements for flood prevention and water resource management are snow wetness (free liquid water content in the snow pack) and snow water equivalency (amount of water stored in a snow pack). Using multipolarization data at C-band, investigators from the University of California at Santa Barbara generated a snow wetness map of Mammoth Mountain, Calif. Investigators plan to estimate snow water equivalence for this same period once they acquire a snow-free data set during the August flight. Similar data and HHPs were collected for the Oetztal glacier in Austria.

Data from SIR-C/X-SAR is being used by geologists in studies of volcanoes and tectonics, the history of past climate change; and soil degradation. We've obtained much of the data needed to map the paleo-rivers now covered under the Sahara sandsheet and will be filling in gaps during SRL-2. We've also demonstrated the ability to assess areas that are susceptible to sand and dust storms using surface texture maps generated from the radar data. We also have begun data collection for monitoring potentially hazardous volcanoes from the safe vantage point of space particularly in areas inaccessible on the ground. Examples of S1 R-C-/ X-SAR images and associated HHPs that were acquired and processed during the April and August flights include Mount Pinatubo volcano. SIR-C/X-SAR also revealed a previously unknown volcano in Colombia in imagery of the Andes volcanic arc.

Many population centers are located in proximity to potentially hazardous volcanoes such as Mt. Rainier, Mt. Vesuvius, and Popocatepetl. Many of these volcanoes represent a hazard long after they erupt, as sources of destructive mudflows or lahars. Mt. Pinatubo, imaged on the first flight of SIR-C /X-SAR, has presented a continuing danger to surrounding villages in the Phillipines since its eruption in 1991. The multiple polarizations and wavelengths of the SIR-C/X-SAR radar revealed, in surprising detail, the distribution of ash and other materials surrounding the volcano. During Flight 2, many hazardous volcanoes around the globe, including most of the volcanoes currently being studied as part of the United Nations International Decade for Natural Disaster Reduction will be imaged by SIR-C /X-SAR. The capability of the radar to discern the nature and state of surface units make it an ideal tool for long-term monitoring and hazard assessment.

Finally, the relatively low altitude of this shuttle mission is particularly advantageous for oceanography investigations since SIR-C /X-SAR data are more sensitive to ocean features than satellites in higher orbits. Oceanographers are using data from SIR-C/X-SAR to study surface and internal waves and wave/current interactions (e.g. Liu et al., 1994). In addition, extensive wave energy information was collected over the Southern

Ocean by an associated experiment provided by the Johns Hopkins Applied Physics Lab (Beal et al., 1986).

In addition to these global change studies there are many other applications for SIR-C/X-SAR data including topographic mapping, comparative planetology studies and archeology. An experiment to measure the Earth's topography with high accuracy will be performed on SRL-2. The use of radar to produce Digital Elevation Models (DEMs) and measure surface deformation has been demonstrated with ERS-1(refs). SIR-C/X-SAR will be the first spaceborne attempt to produce multiple frequency interferometric fringes, from which digital elevation models can be derived. The shuttle will be flown in a near-repeat orbit, collecting long data swaths across North and South America, Africa and Asia. An on-board GPS receiver will be used as an aid in determining where the orbits most closely repeat, and therefore where DEMs could be produced. The combination of digital topography and radar images to assess regions of volcanic or flooding hazards is a potentially powerful tool in hazard mitigation and assessment.

SIR-C/X-SAR data is also useful in comparative planetology studies. Radar data of Venus obtained by the Magellan spacecraft has provided an extremely detailed look at a planet that has been shaped by many of the same processes that affect the Earth (Head et al., 1992; Solomon et al., 1992). Comparisons between tectonic and volcanic features on Venus and Earth allow scientists to better understand the basic physics that govern processes such as mountain-building, volcanic flow emplacement, and impact cratering. A SIR-C image was acquired of the buried Chicxulub impact crater in the Yucatan Peninsula, Mexico, which was formed by an asteroid or comet impacting the Earth more than 65 million years ago and is thought to be linked to the extinction of dinosaurs. The 180 to 300-kilometer-diameter crater is buried by 300 to 1,000 meters of limestone, However the fracture patterns and wetland hydrology in this region are controlled by the structure of the buried crater, and it may be possible to use SIR-C data to help determine the size of the crater which is a topic of considerable debate.

Finally, several images of archeologic interest were acquired by SIR-C /X-SAR. For example, a SIR-C image of the region around the site of the lost city of Ubar in southern Oman, on the Arabian Peninsula was acquired during the April flight. The ancient city was discovered in 1992 with the aid of remote sensing data. Archeologists believe Ubar existed from about 2800 B.C. to about 300 A.D. and was a remote desert outpost where caravans were assembled for the transport of frankincense across the desert. The actual site of the fortress of the lost city of Ubar, currently under excavation, is too small to be detected in the image. However, tracks leading to the site, and surrounding tracks, appear as prominent, but diffuse, streaks. Since tracks such as these were key to recognizing the site as Ubar in 1992, they are of intense interest and are currently being field checked as to their archeological import ante.

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Suggested Figures

General

Picture of SIR-C/X-SAR in the Shuttle payload bay
Coverage maps for Flight 1 and 2 of S1 R-C/X-SAR

Ecology

Biomass maps(Raco, MI*; Landes Forest, Prance)
Seasonal change (Prince Albert, Canada; Raco Ml)
Canadian lake country in winter and summer
Snow line and ice cover across Siberia in winter near Lake Balkash or Baikal;
Oberpfaffenhofen agriculture and clouds (Radar image* and HHPs)

Hydrology

Soil moisture maps of Chickasha, OK*
Snow wetness map of Mammoth Mountain, Calif.*
Manaus flooding (Radar image* and HHPs)
Oetztal glacier in Austria (Radar image" and HHPs)

Volcanoes / Hazards

Mount Pinatubo on April 13, 1994* and August TBD, 1994 and HHPs.
Mt Rainier from August flight (other Decade Volcanoes) and HH 11'.
Colombia volcano*
Any ash flows or eruptive differences we can see on volcanoes

oceanography

Ice cover in Sea of Okhotsk and Great Lakes vs. summertime appearance

Comparative planetology targets

Magellan comparisons
- volcano on Venus and Kilauea image
- crater on Venus and Chicxulub

Archeology

Ubar*

Silk route

Fires (carbon cycle and hazard)

Galapagos fires vs. aftermath of fire scars
Canadian, Chinese, and Siberian fire scars
Active forest fires in April and August -- N. America, S. America, Australia, Asia
Clear Amazon basin and smoke-pall covered rain forest just 5 months later

*available through MOSAIC or jplinfo.jpl.nasa. gov