Overview of results from the SIR- C/X-SAR mission

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ABSTRACT

The US Space Transportation System, or Shuttle, has shown itself to be a useful platform from which to evaluate remote sensing instrumentation for later usc in a free-f}ying satellite. Such flights have also produced significant science on their own. The Spaceborne imaging Radar (SIR) program, consisting of Shuttle flights in 1981, 1984 and 1994, has both matured the state of the art of synthetic aperture radar (SAR) imaging and proven the capability of such systems to extend our knowledge of Earth. The latest of the SIR series, SIR-C, consists of both L- and C- band polarimetric SARs. SIR-C has been combined with X-SAR, an X-band VV-polarized SAR, and MA1'S, an air pollution measuring device, to form the Spaceborne Radar lab (S1<1,), which flew aboard Shuttle in April 1994 and at this writing is to fly again as S1<1.-2 in October. "J'bus, with multiple passes over each site, SRL should produce multi-temporal data from its targets at multiple look angles, multiple wavelengths, and (at two wavelengths) across the full spectrum of polarizations. Temporal changes should be assessible over time periods of both days and months. With such a deep data set, more extensive and longer lived missions can limit their efforts to the diversity required to address specific issues.

2. MISSION DESCRIPTION

As an advance in remote sensing research, SIR-C/X-SAR seeks to provide information about land and ocean surfaces and vegetation cover that is unique or complementary to measurements made by sensors operating in other portions of the spectrum. SAR has the obvious advantage of providing its own illumination and of penetrating through clouds. It is thus a more efficient mapping device. This same characteristic makes it possible to explore regions that are not accessible either directly or using other remote instrumentation. Because its interaction with the surface is fundamentally different from optical sensors, SAR data can also be used to infer surface moisture, vegetation biomass, and enhance topography. in targets such as vegetation, ice, and dry alluvial or aeolian soils, radar can provide additional information about subsurface or ciccp-target geometry as well.

3. SCIENTIFIC RESULTS

Scientifically, SRL responds to 51 investigators whose investigations arc organized around 19 "supersites" worldwide, most of which have extensive pre-flight ground truth and arc heavily instrumented during the flights. Central themes of the investigations arc the global carbon cycle, the hydrologic cycle, paleoclimate and geologic processes, ocean circulation and air-sea interactions, and advanced technology. An important goal is to feed the development of invertable models which produce maps of bio- or geophysical parameters such as soil moisture, biomass surface roughness, etc.

The April flight was superbly successful. instrument operation, accomplished from the. Payload operations Control Center in Texas (USA), was able to respond to investigators in the field and to capture several unique opportunities including a cyclone and a major flooding event. instrument stability and calibration were completely nominal, as observed from telemetry and from field sites in Oberpfaffenhofen (Germany), Italy, Japan, Australia, and various sites in the United States. Preliminary results from analysis of the data indicate that SRI. has expanded the abilities of SAR as a mapping tool, and that derived quantities match well with field measurements. For example, a forested supersite near the town of Raco in northern Michigan (USA) is composed of several distinct tree species. Multi-wavelength SAR coverage at this site was obtained by S1{1.-1 and was input to an algorithm developed to derive vegetation type maps. Quantitative measurements of biomass were inferred using a similar algorithm, and both have been cross-checked against field measurements[1,2] both at Race, Duke Forest (North Carolina, USA) and Landes (France). optimum incidence angles for biomass estimation have been determined to be 30 to 40 degrees. Similarly, at the Chickashea (Oklahoma, USA), supersite, soil moisture estimates have been produced. in this latter case, a rainstorm early in the S1<1.-1 flight produced a dry-down condition that was accurately monitored as the flight progressed. Further, with the additional capabilities of polarimetric SAR, the effects of surface roughness and soil moisture can be effectively separated; quantitative measurements of the accuracy with which the individual effects can be measured ,are now avail able[3]. in addition, observation of soils and vegetation at the Orgeval (France) test site were used to test various algorithms based on multi-parameter radar data to estimate soil surface water content and roughness.

Mapping of floodplain inundation in the Amazon has also been possible using S1<1.-1 data. Major floodplain vegetation types and hydrologic states on the central Amazon floodplain arc separable using multiple frequencies and polarizations, For example, L-band vertically-copol arized (LVV) data can separate flooded short grasses, water or fields from flooded tall grasses or forest, and these classes can be further divided using CIIH data to identify water, LHH to identify fields and 1.1 IV to separate flooded tall grasses from forests. Inundation maps can serve as the basis for regional methane emission estimation, for flood hazard assessment, as (demonstrated in Manaus (Brazil) and surrounding areas, and as inputs for regional hydrologic models. Preliminary analysis of SIR-C data confirms modeling predictions of canopy penetration at different wavelengths, Significant tempera] changes were also identified within the ten-day mission at several supersites, and seasonal changes were tracked against baselines provided by other SAR sensors. It is hoped that additional seasonal variations can be observed and quantified between the SRL- -1 and SRL-2 missions.

Multi-wavelength data taken over the East North Atlantic ocean has been used to investigate ocean currents and directional wave spectra, and both range- and azimuth-travelling swells have been tracked. Extensive datasets acquired in the extreme southern oceans south of Africa and South America allow tracking dominant waves for as much as 18 hours. Maps of wave vectors spanning more than 180 degrees of longitude have been prepared. in the North Sea and in Japan, artificially-inciuced slicks were monitored with S1<1.-1 data, and the question of using multiple radar wavelengths to distinguish between oceanic and atmospheric features is being addressed.

Mapping of geologic sites is another use for SAR, both because of its ability to penetrate clouds and its response to roughness and/or dielectric differences. Impact crater Chixalub on the Yucatan peninsula, thought to be the source of the K-'l' boundary iridium layer, has been mapped; and archeologic interests in the ancient city of Ubar have been aided by the discovery of trade routes in the vicinity, identifiable because of remnant roughness differences.

A major stated goal of SRL is to obtain a more complete regional view of the eruptive history for classical shield volcanoes. SRL data over study sites established at Lauea and Kilauea (Hawaii), Mt. Pinatubo (Philipines), and on the Galapagos islands have shown that cross-polarized SAR data are very good inputs for discrimination of lava flow units and the construction of lithologic maps; multiple incidence angle data show optimal incidence angles for mapping range from 35 to 50 degrees, Both C and L-band images arc helpful to discriminate different volcano lithologies, anti the signal-to-noise ratios offered by SIR-C make it superior for mapping. Previously unknown caldera features in the Andean volcanic arc have been identified using SIR-C/X-SAR-generated maps. Differential penetration was observed across the three wavelengths in the Safsaf (Egypt) site, and about 13% of the Sahara has been covered. Mapping of previously unseen terrain in desert areas has been termed "unprecedented" by researchers in that area, and future mapping missions to desert areas are now forseen. In the Kebir plateau, four different drainage patterns only dimly seen in Landsat images have been identified. in Italy, the Somma-Vesuvius complex was imaged, anti centrifugal drainage patterns on Mount Somma were seen emphasized in the radar; other geologic features identified include patterns at Roccamonfina, Avella-Partenio, Flysch del Cilento and alluvial deposits at the Volturno River. High look angles provided data suitable for structural mapping clue to the reduced amount of layover and foreshortening. in South America, mapping of glaciers in Patagonia provide new data on glacial advances in remote areas sensitive to climatic variability.

Another experiment involves the detection and measurement of rainfall using microwaves. Although it is well known that both C and X band microwaves arc absorbed by water droplets, no quantitative relationship existed which would allow measurement of rainfall rates or characterization of weather systems. Cloud systems surrounding the hurricane Odile system in the south Pacific Ocean were observed anti rainfall rates in the mm/hr range were estimated. in addition, intense thunderstorm signatures were detected over the Amazon, anti productive clouds were imaged in C, L, and X bands.

Snow properites can also be monitored using SAR. in Mammoth Lakes (California, USA) and Oetztal (Austria), extensive field measurement campaigns have been compared to C quad-pole and XVV band SRI. data to assist in the mapping of wet and dry snow. Preliminary results show that snow wetness can be measured to within 12% absolute error.

4. FUTURE PLANS FOR SIR-C/X-SAR

The second flight of SRI., delayed from August 1994 due to an overheating oxidizer pump in a Shuttle main engine, is now scheduled for October 1994. Repeat imaging of sites imaged in SRL- -1 where seasonal change is to be expected is of highest priority. In addition, experimental techniques in topographic mapping using interferometry will be investigated. These techniques show promise in producing meter-scale topography and, if successful, might lead to a more permanent interferometric mapping system that would have significant impact on many fields of terrestrial research.

5. ACKNOWLEDGEMENTS

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