On a Scientific Assessment for a Third Flight of the Shuttle Radar Laboratory: Letter Report

Committee on Earth Studies, National Research Council

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Space Studies Board

On a Scientific Assessment for a Third Flight of the Shuttle Radar Laboratory

On April 24, 1995, the Committee on Earth Studies Chair John H. McElroy and Space Studies Board Chair Claude R. Canizares sent the following letter to Dr. Charles Kennel, associate administrator for NASA's Office on Mission to Planet Earth.

The Committee on Earth Studies of the Space Studies Board held a workshop at the Beckman Center from January 9th to January 11th to begin the study of spaceborne synthetic aperture radar (SAR) systems that you requested. The workshop was preceded by an extensive data-gathering phase that your staff performed with guidance from us as to our needs. It proved convenient to divide the data gathering into the categories of ecology, ice sheets and glaciers, oceanography, hydrology, solid earth, and technology. Your staff enthusiastically took on a difficult task in a compressed time frame, and they are certainly to be commended. You have also requested an early scientific assessment prior to the completion of the overall study to guide your decisions and/or planning for a third flight of the Shuttle Radar Laboratory (SRL); this letter provides that assessment.

Beyond this brief science assessment, the overall results of the study you have requested of spaceborne radar systems must await the completion of the final report at the end of the study. We begin with a few general comments.

Overview Comments

The use of SAR for civil research and operational applications has been advanced by the series of Shuttle-based SAR flights (SIR-A, SIR-B, and the U.S.-Germany-Italy SIR-C/X-SAR) and the European Space Agency's ERS-1. Some contributions have also been made by the Russian Almaz-1 and Japan's JERS-1. NASA's aircraft-based experimental system, AIRSAR, has played a vital role in complementing and enhancing the understanding of the space-based measurements, as have systems developed in Germany (E-SAR) and the Netherlands (PHARUS). The accompanying research and analysis (R&A) program has also played an indispensable role in advancing the utility of this technology.

In spite of these commendable advances, there is no doubt that SAR systems remain less familiar and are less frequently employed than are more conventional electro-optical sensing systems. While both kinds of systems can be used to produce images of the Earth, the interpretation of the images is necessarily quite different between the two. As a result, the research and operational user communities have had a lengthier period to go through in learning how to use SAR data, and a major part of the learning has involved significant research in determining what the data show. That research continues. The moisture and frequency-dependent variable surface and vegetation penetration of microwaves, for example, certainly requires a reorientation of the thinking of image analysts. The problems of layover and shadowing also pose challenges in the interpretation of radar data. Lastly, until some of these issues are better understood, the research community cannot effectively include SAR data in processing algorithms that link near, short-wave, and long-wave infrared information.

At the same time, however, the additional learning the community has undergone can pay dividends. Electro-optic sensors, as powerful as they have become, are inherently limited by cloud-cover, fog, and dust--all of which may be persistent phenomena in some regions of the world, or which may be expected to accompany natural disasters. Indeed, in most regions of the world, one cannot rely on being able to obtain a surface image from an electro-optical sensor at the time the image is most needed. Because of their day-night, all-weather capability, microwave systems may represent the only reliable approach to collecting data on a given region at a particular time. In addition, unlike electro-optical systems, the signals returned by radar systems are sensitive to the physical structure and moisture content of the surface being sensed and may offer avenues to obtaining results that are important for research and applications but are not otherwise obtainable.

For all of the above reasons, there are some who believe with possible justification that, while radar imaging systems today play a secondary role to the electro-optical sensing systems, the role will be reversed in the future. Whether this "bullish" view proves to be correct or not is less important than is the acknowledgment that active microwave systems are demonstrating their worth, and that room exists for still further technological enhancement of their capabilities. Thus, although it is understandable why active microwave sensors have not occupied a more prominent role in the early development of the planning for the Mission to Planet Earth, it should be expected that they will become increasingly important in the future—and likely be indispensable in some applications.

Putting aside for the moment the committee's generally favorable view of the long-term potential of SAR measurements for the Mission to Planet Earth, the committee recognizes that a major immediate issue that you are facing is deciding whether or not to seek a third flight of the Shuttle Radar Laboratory (SRL-3). Based only on scientific considerations, it is the committee's judgment that such a flight would produce good scientific results, if the current instrumentation were simply reflown, but that it would produce especially worthwhile results if it were modified for dual-antenna interferometric measurements of topography. Support for that view is provided below.

It is important, however, to note that the committee has no view or expertise on the cost of a third flight, the feasibility of modifying the instrumentation to add a dual-antenna capability within a given schedule, or the realism of gaining a third flight in the Shuttle manifest. Your staff has provided us with some information on these matters, but the committee has no basis on which to evaluate trade-offs.

Even at this early stage in our deliberations, it is evident that the question of transitioning these results to an operational application is a complicated one, but also an important one. SAR is proving itself to be valuable; the community will not be content for it to remain in only a research status. In this regard, the committee has not yet examined the various orbit, coverage, and repeat-cycle issues that will be important in operational applications.

The next section of this letter addresses the individual scientific disciplines in slightly greater depth, with principal emphasis on what could be obtained from a third SRL flight.

Individual Disciplines

- Ecology

The committee notes that the data presented show that single-frequency, single-polarization SARs are sensitive to above-ground biomass differences in forests up to approximately 100 to 150 metric tons per hectare. Multichannel SAR systems that include low frequencies (L-band at 24-cm wavelength and P-band at 65-cm), and a higher frequency (C-band at 6-cm or X-band at 3-cm) can be used to estimate biomass levels up to 250 to 300 tons per hectare. This biomass range includes all forests except mature old-growth forests in temperate regions and some areas of tropical rain forests.

Because of their sensitivity to structural characteristics, multiparameter SAR systems offer a means to classify vegetation cover. It has been demonstrated that SAR data can be used to detect deforestation and forest regrowth and discriminate among up to ten distinct vegetation types in a region with accuracies comparable to data obtained with electro-optical remote sensing systems (i.e., approximately 89%). SAR is also sensitive to temporally dynamic factors such as moisture content and freeze/thaw status.

SAR appears particularly suited to detecting flooding in general and flooding under a wide range of vegetation cover in particular. For flooded forests, a lower-frequency (L- or P-band), HH-polarized SAR is required. For flooded herbaceous wetlands, a higher-frequency, HH- or VV-polarized SAR is better. The all-weather capabilities of SAR allow for repetitive coverage of flooded regions and provide a unique tool for use in disaster relief.

There remain a number of open questions. What temporally varying factors influence SAR signatures in the full range of vegetation and climatic regions worldwide? How sensitive is SAR to variations in the amounts of foliage in forests? What is the use of interferometric SAR in vegetated regions?

Were a mid-summer SRL-3 flight undertaken using the current equipment, it would enhance our understanding of the ability of multiparameter SAR to monitor Northern Hemisphere temperate crops and forests under full foliage conditions. The flight could enhance wetland delineation and mapping, and continue the analysis of forest regrowth. Collaboration with operational agencies could lead to an experimental test of the use of SAR in flood detection and relief planning.

Modifying the instrumentation to include the interferometer boom would allow the evaluation of the utility of mapping topography in vegetated terrains. It would offer an enhanced digital elevation model that could improve the mapping of vegetation cover and canopy characteristics in topographically complex terrains. The flight would also provide added information that could be used to explore whether additional data on land-surface characteristics are present in interferometric SAR data.

- Ice Sheets and Glaciers

Amplitude data alone permit the determination of snow facies, seasonal melt, surface morphology, ice velocity in rapidly moving regions, and iceberg production. The mapping of the snow facies of the Greenland ice sheet, for example, is a demonstrated capability that should be continued on an annual basis.

Multi-image complex data (amplitude and phase) add full spatial fields of ice velocity and surface topography. Interferometric SAR is the most important development for determining the surface velocity and topography of glaciers and ice sheets. Given suitable orbital parameters, interferometric SAR can provide a unique data set that cannot be obtained by any other means.

Single-frequency, single-polarization SAR will continue to contribute to research and operations. Multi-frequency SAR is required for probing the snowpack to different depths, but ascertaining the quantitative capabilities of these data requires further research. Snow-water equivalent cannot be measured for wet snow, because of the inability of the SAR signal to penetrate sufficiently into the snow. The snow-water equivalent of dry snow may be susceptible to measurement using multi-frequency polarimetric SAR, but this requires experimental verification.

An SRL-3 flight would expand the data set needed to answer many of the remaining questions regarding the utility of the L-band or X-band in multi-frequency and interferometric investigations of ice sheets and glaciers. However, the geographic coverage would not be large, as the 57° orbital inclination limitation does not permit measurements on the major ice sheets.

- Oceanography

In coastal oceanography, single-frequency single-polarization SARs have demonstrated the capability to observe internal waves, surface waves, bathymetric features, and the location of ocean fronts. In the open ocean, the frontal location of major currents such as the Gulf Stream and California Current can be measured. Multi-frequency, multi-polarization SAR has shown a capability to distinguish between oil spills and natural surfactants.

Although oceanography will be a significant element in the committee's overall SAR study, the committee could not make a compelling argument for it being a driver for the reflight of the SIR-C/X-SAR equipment on an SRL-3. Even adding the interferometric capability does not offer a great deal to oceanography in the form that the interferometer is usually conceived. If it were feasible to rotate one of a pair of interferometer antennas by 45°, then the SRL-3 flight could be used to test the concept of ocean surface velocity determination and surface wind velocity determination. Were these latter capabilities to prove successful, then the oceanographic community could become a stronger driver for future advanced SAR missions.

- Hydrology

Snow hydrology has already been discussed above. Soil moisture is a key variable in both research and operational applications. Aircraft, truck-mounted, and ERS-1 measurements have shown that surface soil moisture is correlated with radar backscatter. However, the nature of the correlation is strongly affected by surface roughness and slope and vegetation cover. The instrument responds to soil moisture in the top few centimeters, not the deeper soil moisture.

The earlier SRL flights did not provide the data necessary to assess the utility and desired parameters for a multiparameter SAR system to measure soil moisture on a routine basis. The previous flights took place during seasons when the soil moisture was evenly distributed. A midsummer flight would offer the opportunity to continue the investigations at a more favorable time. Obviously, hydrology would be a major beneficiary of a modification of the SRL to produce a topographic map within its latitudes of coverage.

- Solid Earth

SAR has demonstrated its utility as an all-weather, geologic mapping tool that offers high spatial resolution. A steerable antenna provides rapid site revisit. Multi-frequency SAR is required for precision measurements to remove the effects of variable ionospheric delays. Even with multi-frequencies, however, the removal of artifacts due to the variable wet tropospheric delays requires ancillary ground-based observations (e.g., Global Positioning System (GPS) observations). Multi-polarization data may facilitate lithologic discrimination, but their quantitative use has not been established.

The most compelling uses of SAR for solid earth studies involve interferometric

SAR. A major achievement would be the construction of a global digital elevation model that is referred to a single, global geodetic reference system. Interferometric SAR has demonstrated the capability to image surface deformation at the millimeter level on regional scales. This capability would permit the measurement of large-scale topographic changes associated with earthquake cycles, small-scale topographic changes due to volcanic inflation/deflation, lava flows, erosion, human activities, migration of mobile geologic features (e.g., sand dunes and glaciers), and incipient landslides. However, the role of multi-polarization, multi-frequency SAR in this application is unclear at this time.

Regarding your question about the complementary nature of SAR and the GPS, detection of motion with SAR is complementary to GPS observations at point locations in several ways. One is the obvious continuous spatial imaging provided by SAR as opposed to the point positions obtained with the GPS. The second is that the GPS can provide full three-dimensional vector motion determinations, while SAR gives only displacements along the line of sight. A third is the continuous monitoring capability of the GPS, which permits the resolution of temporal variations of crustal motions in earthquake or volcanic eruption cycles.

An SRL-3 would allow the continuation of experiments to test the above possibilities. In its present form, the SIR-C/X-SAR equipment does not appear likely to add greatly to the science base. If the orbit is not an exact repeat of SRL-2, the value would be that of obtaining data from some new regions. If an exact repeat orbit is attained, there may be the opportunity for limited interferometric analyses using data from the two missions. On the other hand, modifying the mission to provide continuous interferometry would provide the digital elevation map mentioned above for the region from 57o N to 57o S latitude. In the opinion of key members of our committee, this could be one of the most useful NASA missions ever flown for geology and land-use studies.

Final Comments

The committee hopes that these initial observations are of assistance to you. In summary, the unmodified SRL equipment would permit useful, but nevertheless incremental, extensions of the previous results, while the addition of an interferometer boom would produce a new set of important data.

Please pass on to your staff our appreciation for their responsiveness and professionalism. The preparations for the workshop were exceedingly well done and greatly eased our task.

Participant List

Committee on Earth Studies Meeting
January 9-11, 1995
Irvine, CA

CES Members

John McElroy, University of Texas, Arlington, *Chair*
William Bonner, University Corporation for Atmospheric Research
George Born, University of Colorado, Boulder
Janet Campbell, Institute for the Study of Earth, Oceans, and Space
Dudley Chelton, Jr., Oregon State University
John Evans, COMSAT Laboratories
Elaine Hansen, University of Colorado, Boulder
Roy Jenne, National Center for Atmospheric Research
Edward Kanemasu, University of Georgia
Conway Leovy, University of Washington
Pamela Mack, Clemson University
Peter Norris, Santa Barbara Research Center
Clark Wilson, University of Texas, Austin

Guests

John Apel, Apel Associates
William M. Brown, Environmental Institute of Michigan
Jeff Dozier, University of California, Santa Barbara
Eric Kasischke, Environmental Institute of Michigan
Kenneth Jezek, Byrd Polar Research Center
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