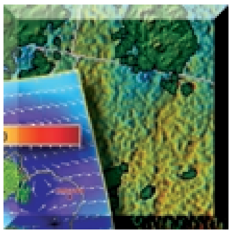

SAR Symposium Keynote Address*

Robert S. Winokur

Spaceborne synthetic aperture radar (SAR) can provide a perspective of the Earth's surface that is nearly unique in scientific remote sensing studies. From the 1978 Seasat (which provided the first intriguing images of ocean features) to present systems, spaceborne SAR has demonstrated the capability to image the Earth's ocean and land features over broad areas, day and night, and under most weather conditions. Civil research has included studies of ocean dynamics, marine meteorology, and sea ice monitoring; terrestrial research has included agriculture, mapping and charting, and resource management. But is SAR ready to make the transition from a scientific research tool to an operational sensor? To be truly operational, a SAR system must have continuity of observations, timeliness of data delivery, and usable products. (Keywords: Environmental satellites, Operational applications, Synthetic aperture radar.)

For those of you who are not familiar with NESDIS [the U.S. National Environmental Satellite, Data, and Information Service], our responsibilities include the management and operation of the nation's operational environmental/weather satellite program. Although you may not be aware of it, I think most of you are familiar with what we do. When you turn on the TV and you see the latest hurricane image of the day, it comes from a NOAA [U.S. National Oceanic and Atmospheric Administration] satellite operated by NESDIS. I will not mention all the satellites we fly, because the focus here today will be synthetic aperture radar [SAR]. I have put together a variety of activities that in my view help to point out where we've been, where we are today, and where, hopefully, we can go in a coordinated manner in the future. Although NESDIS does not operate a SAR, I will leave it to you to think about if and how SAR fits into our future.

Figure 1 shows a timeline of the major spaceborne SAR platforms from 1978 through 2004. Most of you are familiar with these platforms, particularly those of you who have been involved routinely with SAR. It is a timeline that takes us out to about 2004, the early part of the next century. Let me make a couple of observations. It is noteworthy that we just celebrated the 20th anniversary of Seasat, which flew in 1978; however, it is just as noteworthy that since then the U.S. has had only a few Space Shuttle SAR missions. But even then, there was a big gap. There was not much going on for a long time—some 10 years. The question in my mind has always been, why? Why didn't the U.S., while other nations were committing to SAR, not do so? I have some of my own opinions, but I won't go into them here. Other than the Space Shuttle missions, SIR-A,

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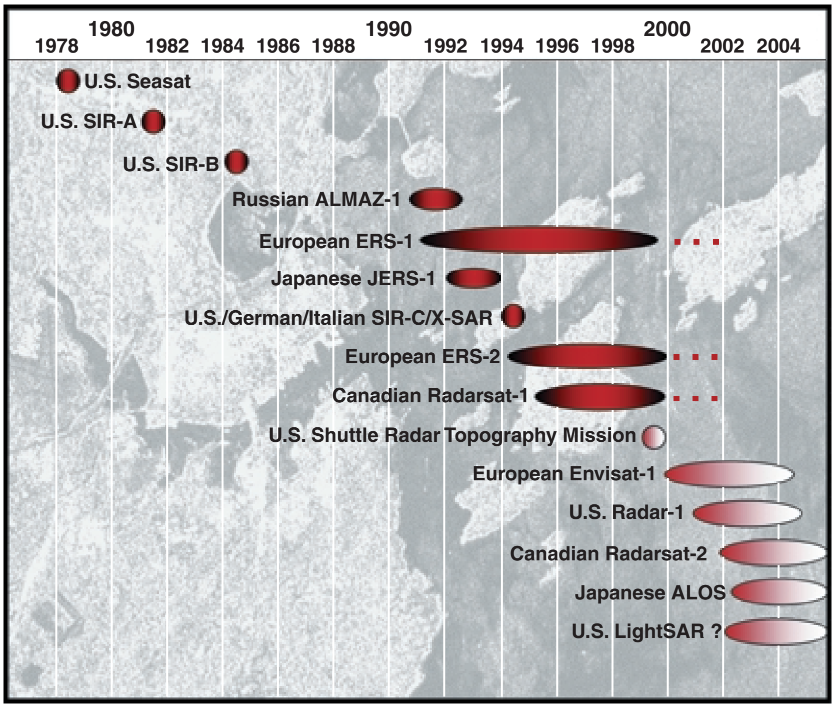

Figure 1. Timeline showing spaceborne SARs from 1978 through 2004. Dates are approximate. (SIR = Shuttle Imaging Radar Experiment, ALMAZ = translated from the Russian as "diamond in the rough," ERS = European Remote Sensing satellites, JERS = Japanese Environmental Resources Satellite, ALOS = Advanced Land Observing Satellite.)

SIR-B, and SIR-C/X-SAR [Shuttle Imaging Radar Experiments], the U.S. has not made a national commitment to flying an operational SAR mission. One good aspect of the Space Shuttle work, other than getting a variety of researchers involved in the program, is that at least we do have a limited-duration operational mission coming up in about a year: the Shuttle Radar Topography Mission. Nevertheless, one key observation is that there are significant gaps in SAR missions in the U.S. and in the foreseeable future.

In 1983, I met some of the people who are here in this room, who taught me about SAR. Since then I have been convinced of the potential of SAR for a variety of applications and committed to pursuing SAR application programs. I think it's tremendous technology that we just really haven't taken advantage of, for reasons that aren't totally obvious. I think one of the reasons is that we are still learning what to do with it, particularly those of us in the ocean community. But we certainly have done that over the last few years, in particular as we have taken advantage of ERS-1 and ERS-2 [European Remote Sensing satellites], JERS-1 [Japanese Environmental Resources Satellite], and the Canadian Radarsat. These systems were key events in the evolution of SAR missions. We have reason to expect more activity as we go into the next century, with planned missions well under way. Envisat is under way in Europe, and Canada has Radarsat-2 planned. As we look further in time (but it remains to be seen), we have the Japanese ALOS [Advanced Land Observing Satellite], and the U.S. LightSAR still being considered by NASA [the National Aeronautics and Space Administration]. [In August 1999, NASA announced that it does not intend to pursue the LightSAR program.]

That is a brief history of SAR missions, but as you get past 2006, this chart [Fig. 1] really ends. We had Seasat, then a big gap, and then a flurry of activity. The question is: What happens after about 2006? I think that is an important question. In contrast, for example, consider the corresponding timeline of NOAA satellites shown in Fig. 2. This is not to advertise NOAA satellites, but rather to point out the contrast between the previous chart and this one. On this chart, you see the U.S. geostationary weather satellites that take us out to 2010. In addition, we are currently working on the next generation beyond that. As for the polar orbiters, the "NOAA" series of satellites, NOAA-14 and NOAA-15, are currently on orbit with plans for continuous launches until the last satellite in this series in about 2008. Then we go into our next generation of polar orbiters that takes us out to about 2020. These are operational programs; the key element in an operational program is continuity, continuity, continuity. That's what I get paid to do—minimize risk, maximize continuity. You see [in Fig. 2] an operational program that actually takes us well into the next century at least to 2020.

There is a marked contrast between these operational programs and the SAR programs that, to a very large extent, have been research-oriented missions. What have we learned since Seasat, 20 years ago? I will show you a few examples from my own perspective. Many of you will be able to add your own.

Several important applications have emerged recently, particularly since ERS-1, ERS-2, JERS-1, and Radarsat data have been available. Our ability to process the data has improved greatly. We can process SAR data relatively rapidly now and get it into the hands of the user. That was not the case when I first became involved with SAR back in the early 1980s. We've come a long way on the processing side, and there are commercial processors available that you can buy today that will enable you to do the job.

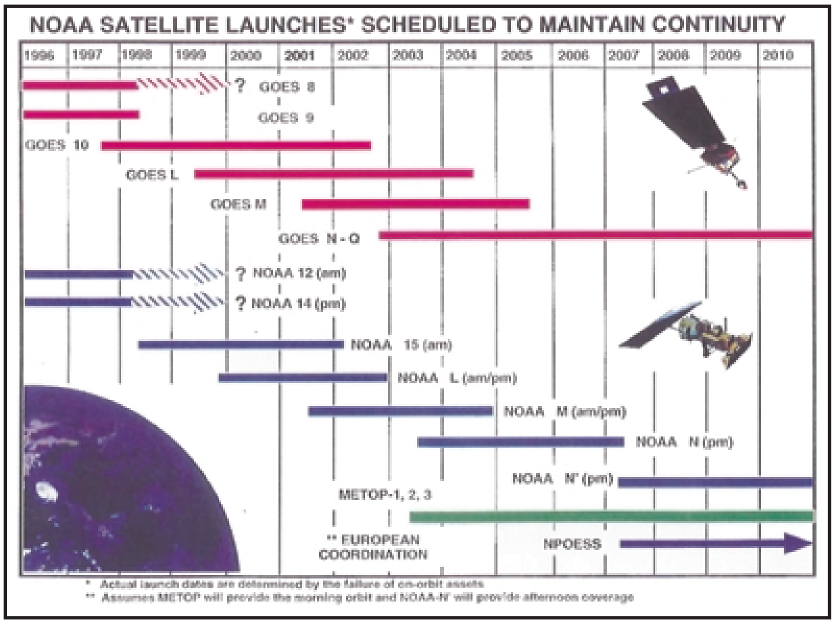

Figure 2. Continuity in NOAA Environmental Satellite System operations. (GOES = Geostationary Orbiting Environmental Satellite, METOP = Meteorological Operational satellite, NPOESS = National Polar-Orbiting Operational Environmental Satellite System.)

Here in the U.S. we still have no consensus on what our role should be with respect to operational SAR. We are working with our European, Japanese, and Canadian colleagues, as well as the emerging commercial sector. What will happen in the future? From the perspective of the operational community, assured continuity is essential once imagery is being used routinely. Will it be there when I need it, well into the future, as I invest in the use of the data? It has to be available in a timely manner, not just processing, but access to the data. And the application has to be cost-effective. These are all very critical issues that have to be dealt with in any operational system.

What have we learned about SAR over the past few years? I will show a few examples of applications that I've used through the years and some of the work that we at NOAA and other people are doing.

In the area of sea ice applications of SAR, we have become operational. In other applications we continue to experiment to see how to best use the data. We know we can use SAR for oil spills and for some natural hazards. Again, it becomes an issue of access and how we get the data. Some key questions as we begin to use these systems that are coming down the pike are: How can we use SAR for ship detection, for high-resolution surface winds, and for other applications related to the surface roughness signature?

Let me quickly go through just a few images. Figure 3 happens to be one of my favorite images. I first saw it at the Norwegian Defense Research Establishment, probably about 10 years ago, when they were working on a detection system to be used in their coastal waters to take advantage of ERS-1 at that time. This particular image shows a lot of things; in particular, some kind of spill in the ocean, oil spill, or some ship pumping its bilge. If you look closely you can see ships represented by dots, and you see ship wakes. Also, you can see internal waves breaking over the shelf. This one image shows clearly what SAR is capable of and a variety of applications.

We have been looking in NOAA over the last few years at how best to use the SAR in an operational or quasi-operational mode. Figure 4 shows an oil spill that took place up in Portland, Maine, a couple of years ago, when an oil tanker crashed into a bridge—the result, a major oil spill. Key questions are: How do we use these data? How do we get it into the hands of the people who have to do the cleanup of this spill—the HAZMAT folks, if you will, not just the people who do that at NOAA, but the local and state emergency management organizations?

Another of the emerging application examples, of which I have a number of images, is ship detection and fisheries management. Figure 5 shows a collection of ships, on the left with the ocean in the picture, and on

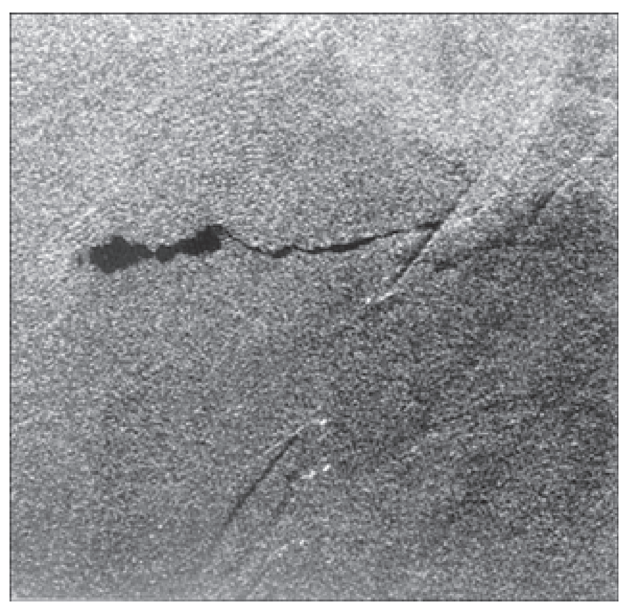

Figure 3. ERS-1 SAR oil spill detection off the Norwegian coast.

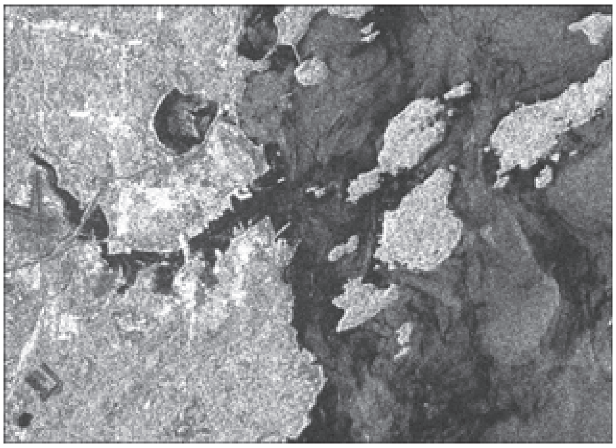

Figure 4. Portland, Maine, oil spill.

the right with the ocean removed. The ships are clear enough. If we are looking for fishing vessels or trying to assess or measure the stresses on the environment created either by pleasure ships or commercial vessels, SAR is certainly one way to do that. In Fig. 6 you can also see some kind of a discharge, or slick, on the surface of the ocean. In this instance, we believe that the vessels, while they are processing their catch, are discharging fish oil. Most likely, that is what the image shows. It is not an oil spill, but it is, in fact, an indicator of fishing activity and fish processing. In an enlarged view, you can see where all the fishing vessels are, and all of the discharge from onboard processing.

Another example in fisheries management is shown in Fig. 7, a Radarsat image of Dutch Harbor, Alaska. Once again, it is possible to see the location of fishing vessels, which provides an indication of the stress on a particular fishery. When fisheries are open at certain times of the year, fisheries management officials would like to know how many vessels are out there and what is the intensity of activity with respect to that period of fishing for an individual fishery. This provides a potential indicator—a snapshot of the stress on that particular fishery.

Another application for SAR imagery is not only for vessel detection, but also the ability to monitor sea surface ice cover. Fishermen tend to be very aggressive, since this is how they make their living. It is very important that they know where the ice is relative to where they are. It's also very important for activities on shore, the National Weather Service, for example, to

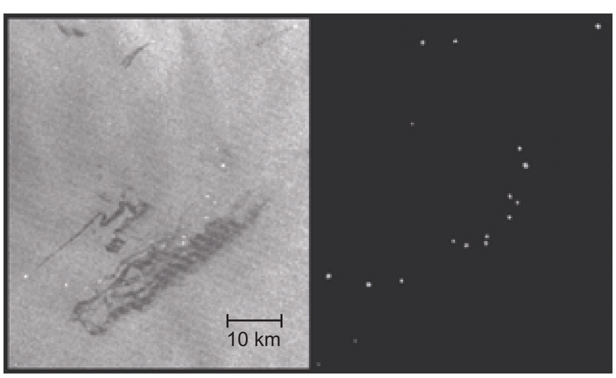

Figure 5. SAR ship detection, with (left) and without (right) ocean background.

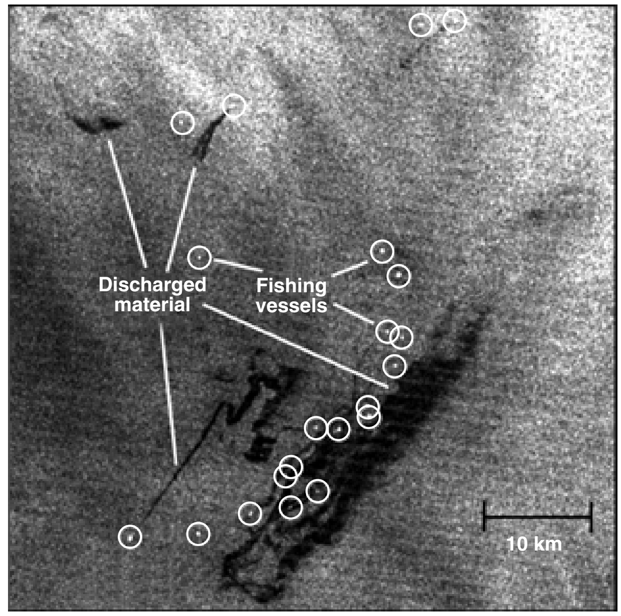

Figure 6. Fisheries monitoring with SAR.

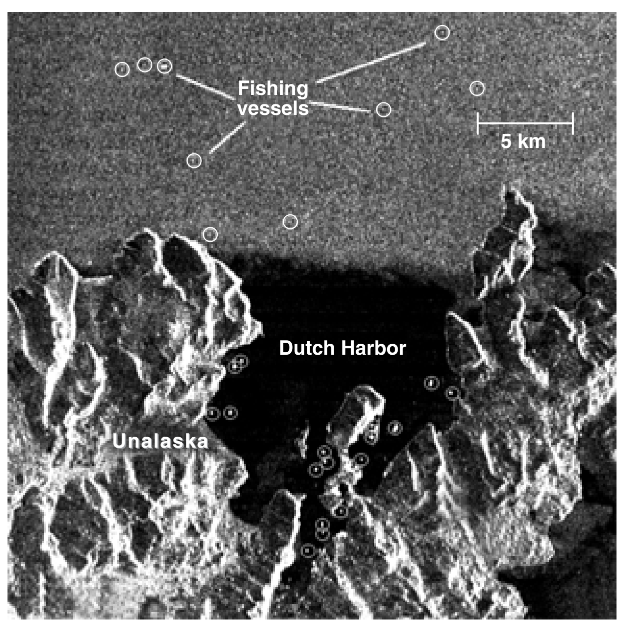

Figure 7. Fisheries management in Dutch Harbor, Alaska, with SAR. (© Canadian Space Agency, 1998.)

know where they are in case the weather changes rapidly. Some of these fishing vessels can easily get trapped or be put in harm's way, if you will, by the ice in the marginal ice zone.

Figure 8 shows an interesting image of an atmospheric front as seen by both a visible sensor and by a SAR. This is an example that we should be able to learn from. On the left is a GOES [Geostationary Orbiting Environmental Satellite] image, clearly indicating an atmospheric front. On the right, in the SAR image of the same area, you can see an even clearer manifestation of this intense front in the sea surface backscatter. What this actually translates into in terms of operational applications remains to be seen, but it is potentially significant.

A very important application for SAR, in my view, is in natural hazards and disasters. Many countries have serious problems with flooding. As an example, Fig. 9 is a 1993 image of Mississippi River flooding in the St. Louis area, superimposing information from both a SAR and a visible image. Here you can clearly see the area of inundation from the severe flooding event. How much of the city of St. Louis was under water? Emergency management officials, while they are on the ground, tend to know where the floods are, but this kind of imagery gives them that synoptic view that they can use in planning some of the recovery and relief activities. The information becomes even more valuable when you combine the imagery with a GIS [Geographical Information System], put the roads in, put the power plants in, put the hospitals in, and put the residences in. Then emergency management officials at the state and federal levels can see exactly what the impacts are, and start to plan ahead.

Over the last few years I have been involved with something called the Global Disaster Information Network, or GDIN. GDIN was a study for the Office of the Vice President to look at how we might use data and information from all available satellite systems to detect and monitor natural hazards in a wide variety of applications: flooding, earthquakes, wildfires, and severe weather events. In the U.S., the variety of natural hazards that we are subjected to includes wildfires, landslides, earthquakes, hurricanes, and floods. In the U.S., over the last 90 years, our ability to forecast landfall from hurricanes has improved remarkably, so that the number of deaths over that period has decreased dramatically. We saw an indication of that in 1998, for example, with some of the hurricanes that hit the U.S.: Bonnie, Danielle, and Georges. We were very lucky. On the other hand, hurricane Mitch had a devastating impact on lives and property in Central America, where approximately 10,000 people lost their lives or were missing. It will be years and years before Central America recovers from Hurricane Mitch.

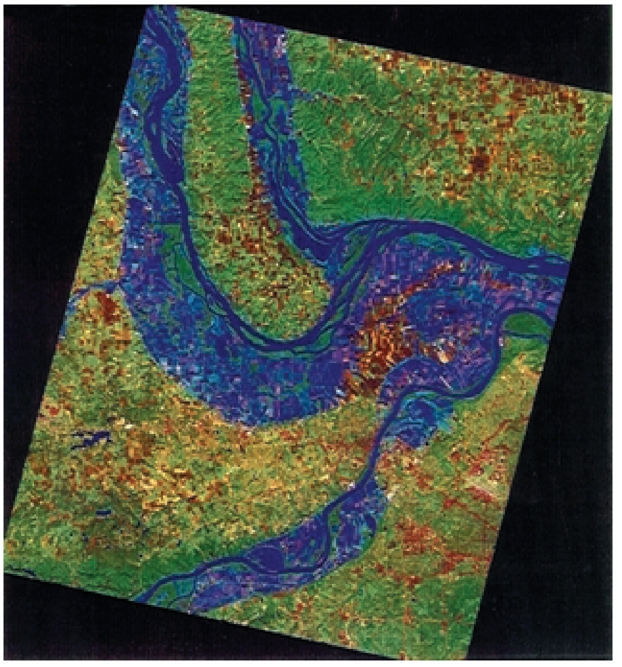

Figure 9. SAR image of a Mississippi River flood in 1993.

But while the number of deaths in the U.S. from natural hazards and disasters has gone down, the associated costs have gone up dramatically. It is estimated that it costs about $50 billion per year in the U.S. from all natural hazards and disasters. Consequently, we are assessing how to use satellite systems, including SAR, to minimize damage and establish a baseline for use in natural hazard disaster mitigation and response. Since we began looking at how best to use satellite technologies and how best to

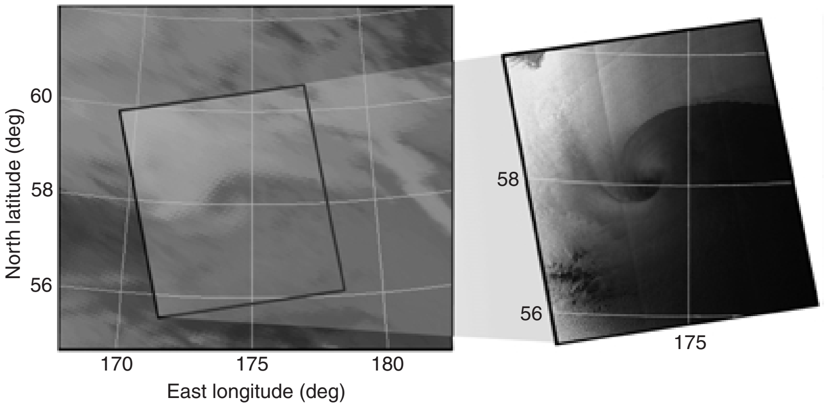

Figure 8. Synoptic weather imagery with GOES (left) at 06:00 UT on 5 February 1998 and Radarsat (right) showing a polar low. (Radarsat image © Canadian Space Agency, 1998.)

bring them to bear on natural hazards, a number of things have happened that indicate the time is now to apply space-based technology. Today there are about 240 sensors in different satellites that are downward looking. This was not the case in the 1980s. Also, with the emergence of the Internet, with all the government agencies using it, and with our ability to move data around, we now have in place all the necessary tools. All of us use the Internet, all the time. While there are still some issues to be resolved about using the Internet for a disaster information system, it has become a workhorse for all that we do. There are other systems and technologies that we can also use.

As part of the GDIN effort, we sponsored a meeting a couple of years ago that involved the user community, and asked them this question: What is it that you need, if we can put a satellite-oriented and -based disaster information system in place? The users came back with a number of reactions. For example, they need to know what is available; that is, what systems are out there. Is it a geostationary imaging system? Is it a polar-orbiting imaging system? Is it a synthetic aperture radar system? You need to know where to find the data, who has it. Is it on the Internet? Are there standards, formats, and protocols? How do you visualize it, combine it, and fuse it? Quality becomes very important. The data has to be flexible and scalable in such a way that you can actually use all of the information and fuse it together. These elements are key in any system that is established, a system that combines a variety of different sensors flown by different agencies in the U.S. and different nations, and [one] that incorporates different ways of accessing the data. Key factors are access and prioritization. It is essential to have access to data when and where you need it and not 3 or 4 days later, no matter what the system is. Finally, there is the need to use the appropriate communications technology and system, sized to the particular problem. All of these have to be factored in, but in my opinion synthetic aperture radar will be an important sensor in any disaster monitoring and information system.

As we move ahead, we must also look at policy and organizational implications. How do we get everyone involved—the users, the providers, public and private resources—not only government-funded systems, but also the commercial systems that will be flying shortly, SAR, and other imaging systems? How can we put these resources together into a partnership, at the same time improving the environment for interagency and international cooperation?

I would like to briefly mention another activity that we are involved with because SAR fits into that one as well. I have the distinction of being the chairman of an international committee or partnership to develop an implementation strategy for a global observation system. This is a space-based activity right now, but we want and need to include an *in situ* component as well. At the present time we are working on a strategy with a view, in my opinion, that IGOS [Integrated Global Observing Strategy] will become a system. One of the goals in IGOS is to identify gaps and eliminate redundancy. If we have 10 SARs planned, do we really need all 10, or can nations get together and possibly trade a SAR for something else, or trade an imager for a SAR? I pointed out earlier that, at least beyond 2006, there really are no plans for SAR that I am aware of, so that as we go well into the next century, can we trade off an imaging system for a SAR system? While this *ad hoc* international group can identify actions required, negotiation will naturally take place at the national level. The essential question is: Can we fill gaps and eliminate redundancy, while hopefully saving money and meeting user-defined mission requirements and national needs? Any nation that participates in this arrangement has to do it voluntarily. In addition, in the long term, we will also need to expand this effort to include international public–private partnerships.

We have a number of demonstration projects that have been established and are just getting organized. The projects are just a means to an end and not the end in themselves. We have included a variety of different projects that bring to bear different kinds of sensors and that address different issues that I mentioned: to fill in gaps, to reduce redundancy. For example, the Global Ocean Data Assimilation Experiment, called GODAE, is an ongoing activity that would look at how we fuse space-based data with *in situ* data and assimilate it into operational forecasting models. Continuous ozone monitoring is another example; it is a critical problem in climate change impact. Two projects involve SAR: the global observation of forest cover and deforestation monitoring. One of the questions is: How do we use SAR data—along with Landsat and other high-resolution data—to assess forest cover, focusing on one or two areas to see if we can monitor them over a long term? The disaster monitoring and management support is a demonstration where we utilize a number of space-based sensors operated by different nations to see how we can better coordinate international activities using our combined space assets.

During the 2008–2020 time period, we will be transitioning to a new suite of satellites, NPOESS [National Polar-Orbiting Operational Environmental Satellite System]. We will be flying out our current systems. The Defense Meteorological Satellite System [DMSP], and the NOAA polar orbiters [POES] will both be replaced by NPOESS. The midmorning overpass by NOAA polar orbiters will also be replaced by METOP [Meteorological Operational satellite] from our European partner Eumetsat [the European meteorological satellite organization]. Potentially, NASA will fly the NPOESS Preparatory Project, which will provide the opportunity for risk reduction in some of the NPOESS sensors. It will also provide an early opportunity for an operational demonstration of sensors and a chance to view data-processing algorithms.

As we look at all these instruments, we see that synthetic aperture radar is missing. The planners made a conscious decision here in the U.S., as we go forward to build our next generation of polar-orbiting satellites, that we will NOT have a synthetic aperture radar. Clearly, we have not articulated the requirements for a SAR. Consequently, it is not there. That is one of the challenges I think we have to deal with in this nation. Do we want to have an operational SAR system, or do we want to rely on partnerships with other nations, or with the commercial sector? I am not giving you an answer; I am just saying this was a conscious decision as this program was put together. On the other hand, an interagency committee also produced a report a couple of years ago entitled *Operational Use of Civilian Space-Based Synthetic Aperture Radar* [Report 96-16, JPL, Pasadena, CA (Jul 1996)]. It points out some of the potential operational applications of synthetic aperture radar. It also points out that there is an operational need. So how do we put that need in place?

To conclude, the key and final question is: What can we reasonably expect in the future? I don't know the answer to that. But I do know that we have learned a lot since Seasat. We have come a long way over the last few years, particularly as we have learned about emerging applications. The technology has come a long way. We know how to process the data rapidly now. We know how to get our hands on the data. But we need continuity of operations if we are going to move into the operational world, and get out of the research and demonstration mode that we've been in for these last 20 years.

THE SPEAKER

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