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THE POTENTIAL OF SPACEBORNE SYNTHETIC APERTURE RADAR FOR OCEANOGRAPHY

BACKGROUND

In the summer of 1978, NASA launched Seasat, the experimental oceanographic satellite. Seasat contained active and passive microwave instruments designed to probe various large-scale oceanic and atmospheric processes. One of the active instruments, the synthetic aperture radar (SAR), was able to penetrate cloud cover to form high resolution imagery of the ocean. Typically, the SAR collected imagery with cross-track swaths of 100 km and spatial resolution of 25 m.

On March 25 and 26, 1980, APL hosted a symposium to explore some of the scientific implications of the Seasat SAR imagery that was collected in the western North Atlantic area during summer and fall of 1978. Although only about 20 such passes (out of a total of about 500 during the 100 day mission) have received intensive study, oceanic and atmospheric processes on many scales were evident in much of the imagery. The major goals of the symposium were (a) to review the pertinent ocean physics responsible for the SAR imagery, (b) to review our ability to monitor winds, waves, and oceanic circulation from other sources (both remote and *in situ*), (c) to examine Seasat SAR data that are pertinent to each of these three areas, and (d) to discuss the potential of the SAR as a new tool to advance our knowledge of oceanic and atmospheric processes.

The Seasat SAR sensed only the spatial distribution of short (30 to 40 cm) gravity waves on the ocean surface by means of a Bragg-type resonance of the radar emission with the ocean. However, the distribution of these short waves appears to be correlated with a number of significant larger-scale phenomena, including local wind structure, long gravity waves, current shear boundaries, and surface tension. Ideally, each of these larger-scale phenomena, through its influence on the small-scale waves, would produce a unique temporal or spatial signature. In reality, of course, each of the larger-scale effects is somewhat dependent on all the others, usually in a nonlinear way. Consequently, the large-scale effects are not always separable.

PRESENTATION SUMMARY

The symposium was structured along four main themes, with a concluding panel discussion. Brief summaries of the presentations and highlights of the panel discussion are given here.

Air-Sea Interactions and the SAR

One of the major keys to understanding how SAR works is contained in the behavior of the short gravity waves — how they are generated and influenced by wind, long waves, and currents. Owen Phillips and Sergei Kitaigorodskii, both of The Johns Hopkins University, addressed this topic from both the theoretical and empirical points of view. Phillips stressed the classical hydrodynamics associated with strong interactions, emphasizing some of the nonlinear coupling mechanisms that are responsible for the short-wave modulations. Kitaigorodskii described some recent experiments performed in the USSR using a circular wind tank to create unlimited fetch (the distance over which a wind does work on the ocean). Even at wavelengths longer than 30 cm, there was a wind-dependent saturation regime. Such wind dependence potentially enables the SAR to be used for wind monitoring but simultaneously interferes with its ability to sense other phenomena.

Robert Harger of the University of Maryland discussed models to explain how the SAR accomplishes coherent imaging of the large-scale ocean features through resonance with the moving small-scale scatterers. Successful imaging, he believes, requires a favorable set of circumstances. The probability of randomly obtaining favorable circumstances is not known, but it is almost certainly a function of the radar wavelength. John Apel of the Pacific Marine Environmental Laboratory of the National Oceanic and Atmospheric Administration (NOAA) described the various classes of atmospheric and oceanic phenomena that appear to be observable with SAR. He showed a dramatic example of bathymetric expressions or signatures seen by the SAR over Nantucket Shoals (Fig. 1), contrasting it with Skylab imagery over the same

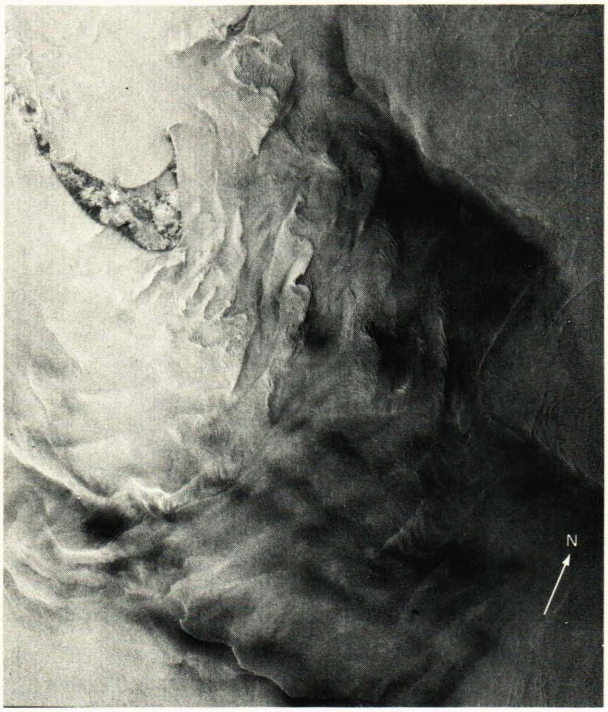

Fig. 1—100 km square image of Nantucket Shoals pro- vides a dramatic illustration of bathymetric expressions occasionally evident over large areas. Most of the area included in this image is less than 40 m deep, much of it is less than 20 m deep, and portions are less than 2 m deep. Bathymetric expressions were discussed by Apel and Shuchman. (JPL digital product, pass 880)

Fig. 2—Complex radar backscatter patterns in a nearly calm 100 km square region of the ocean located just outside the mouth of Chesapeake Bay. The dark regions generally correspond to low surface winds (less than 2 m/s), but the patterns also indicate a wide variety of current-generated interactions having only indirect relationship to the wind. Wind and current interactions were discussed by Ross, Delnore, and Boicourt. (JPL digital product, pass 1339)

area. Clearly, the SAR's limitation in sensing only surface phenomena does not exclude it from appearing to penetrate the surface, since internal phenomena often generate surface expressions.

Wind

Willard Pierson of the City University of New York summarized the state of knowledge of the variability of the winds over the ocean. Unfortunately, such knowledge is extremely sparse. Wind sensors used to provide the data for forecast models typically grossly undersample the real wind field. Microwave remote sensing (the Seasat scatterometer in particular) promises to extend our knowledge of the wind field spectrum into the mesoscale region, which is presently little understood.

Duncan Ross of the NOAA Sea-Air Interaction Laboratory used simultaneously collected aircraft and spacecraft measurements to show an apparent functional relationship between the frictional wind velocity, u^*, and the normalized Seasat SAR backscatter, σ°. If the u^* versus σ° relationship is unique, the value of the SAR for measuring the fine-scale and mesoscale wind structure described by Pierson would be advanced considerably. Ross's data indicated that such a relationship definitely exists, with radar backscatter monotonically increasing over a range of surface winds from 2 to 11 m/s. The scatter in the data was large, probably because of uncertainties in u^*, but the relationship appears to be stronger for low winds than for high winds (see Fig. 2).

Building on the existence of the u^* versus σ° relationship, Victor Delnore of the NASA Langley Research Center investigated the small-scale structure of the wind as measured by the SAR. Using a one-dimensional cut nearly normal to the prevailing wind direction, the SAR appeared to be sensitive to the microstructure of the wind field. Delnore also presented evidence to indicate that the microwave backscatter is nearly isotropic at the SAR operating wavelength.

Wind-Generated Waves

Wave hindcast models are used to determine wave conditions for many types of applications, particularly in the design of ocean structures. Similar models are used for wave forecasts. Marshall Earle of Marine Environments Corp. gave a historical review of the various hindcast models of waves, describing their relative complexities, inherent assumptions, and relative value. He stressed that one major limitation to the accuracy of existing models is the lack of measured wave data for model development and verification, especially long-term data and directional data. Data are also needed for modeling shallow water effects and wave-current interactions. The SAR, of course, can collect these needed data on a global basis if ocean waves can be reliably sensed.

Robert Beal of APL described one particularly well-documented case where the SAR was able to detect and track a low-energy ocean swell system with a height of about 1 m (Fig. 3) from deep

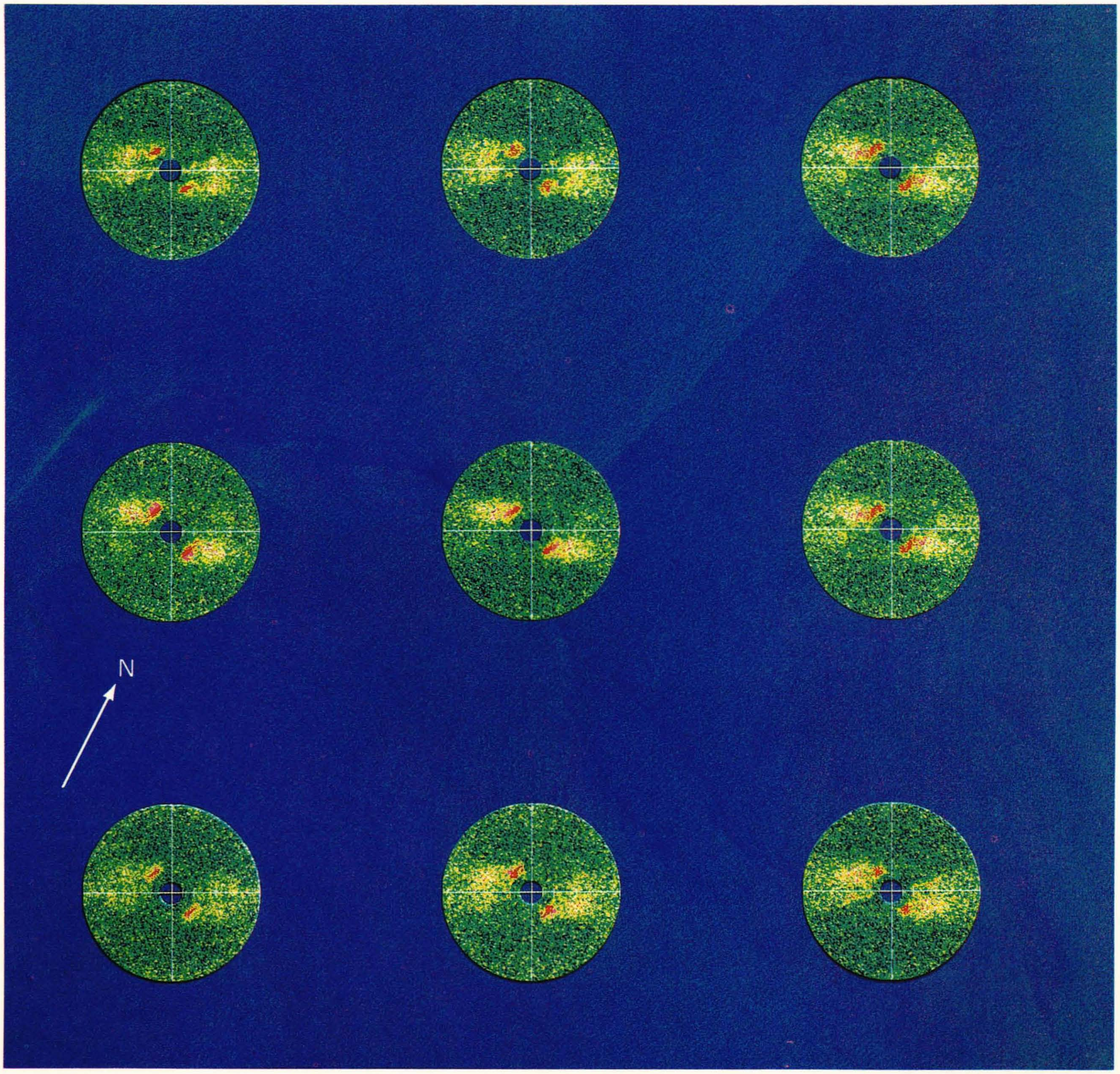

Fig. 3—A matrix of ocean wave spectra superimposed on the original 40 km square SAR imagery. Spectra show a well organized (200 m) swell system and a shorter, evolving, and less organized (≈ 100 m) swell system. Radial distances on the spectra are linearly proportional to reciprocal ocean wavelength, from 400 m (inner radius) to 50 m (outer radius). Ocean wave spectra were discussed by Beal, Shuchman, and J. Hayes. (MacDonald-Dettwiler & Assoc. digital product, pass 1339; transformed and enhanced by D. Tilley of APL)

water across the Gulf Stream and the Continental Shelf into shallow water. The swell system, with a wavelength of 200 m, was detected over a range of wind speeds from 2 to 11 m/s and exhibited wavelength and direction changes consistent with the local bathymetry.

Hurricane Ella, which generated some well-developed swell in the Cape Hatteras area, was the subject of two papers. John Hayes of Environmental Research and Technology investigated the SAR potential for mapping ocean surface currents and gravity waves by examining the wave diffraction patterns around Cape Hatteras in the wake of Ella. A shallow-water wave model that incorporated ocean current refraction was invoked to explain the patterns. Robert Shuchman of the Environmental Research Institute of Michigan, again using the Cape Hatteras data set following Ella, analyzed a large number of wave transformations to predict local depth. The resulting high correlation verified in a statistical sense that the SAR was indeed observing waves with sufficient clarity to sense refraction in shallow water. The technique was proposed as a potential method for estimating depths in coastal regions.

Ocean Circulation

One might think there would be little chance for the SAR to monitor internal oceanic processes. However, Erik Mollo-Christensen of MIT laid the physical basis for surface signs of internal ocean dynamics. He described some of the mechanisms for distortion of the wave field by currents and by the wind-driven surface Ekman layer. There are many such examples of surface signs where remote sensing has played a central role, such as the map of the heat content of the upper mixed layer derived from Landsat data. Shelf-edge cold fronts, warm-and cold-core rings, and oblique internal waves are all examples of internal phenomena that have definite surface signatures.

William Boicourt of the Chesapeake Bay Institute discussed an example of the detection of internal processes by SAR in the interactions of currents outside the Chesapeake Bay. The region just north of the point where the Gulf Stream departs from the Continental Shelf is rich in surface expressions of currents and small-scale turbulence. SAR imagery appears to provide valuable information on the location of coastal fronts, both in the estuary and on the Continental Shelf. SAR imagery also reveals a rich surface layer structure whose origin is not presently understood.

The Gulf Stream, one of the most energetic current sources in the ocean, is usually clearly visible in SAR imagery. Richard Hayes of the Coast Guard examined the correlation of the Gulf Stream boundaries shown on SAR imagery with those found on aircraft and satellite infrared imagery. The semipermanent Gulf Stream meander that develops when the current passes over the Charleston Rise is clearly visible, with the linear features highly correlated with the shear zone of the current velocity.

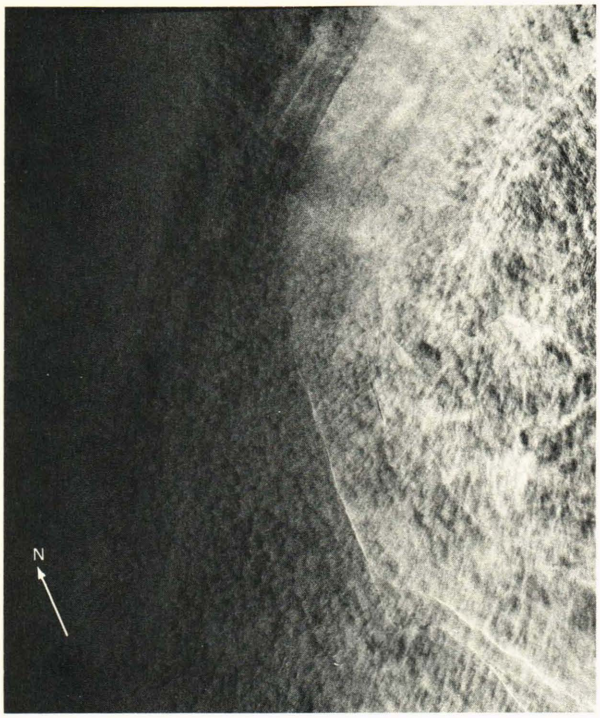

Fig. 4—100 km square image showing a clear expression of a warm water ring off the New Jersey coast. Warm rings are usually detectable in Seasat SAR imagery. Aspects of Gulf Stream circulation were discussed by R. Hayes, Cheney, and Lichy. (JPL digital product, pass 1318)

Cold-core rings that separate from the Gulf Stream as it heads across the North Atlantic are a particular challenge for remote detection. Robert Cheney of NASA's Goddard Space Flight Center tracked a number of these rings during the summer of 1978, initially with surface measurements and later by locating 10 to 50 cm depressions with the Seasat altimeter. He attempted to verify the ability of the SAR to detect surface expressions of cold rings by examining one SAR image that was known to pass directly over a ring. A weak surface expression in the proper location suggested the presence of a ring, but the swath was too narrow and the data were too sparse to draw a definite conclusion.

On the other hand, David Lichy of the Coastal Engineering Research Center presented conclusive evidence that, under low to moderate wind conditions, the SAR not only can track warm water rings over several weeks, but can distinguish current shears within the ring itself (Fig. 4). The ring and much of its central current structure are evident on five out of six passes. High winds may have been responsible for masking the radar signature on the sixth pass.

PANEL DISCUSSION

At the conclusion of the formal papers, Isadore

Katz of APL led a panel discussion. The panel consisted of Phillips, Kitaigorodskii, Harger, Pierson, Earle, and Mollo-Christensen. Although they are all researchers in the fields of air-sea interactions or the SAR, none had been actively involved with the Seasat SAR so that their comments are relatively unbiased with respect to its utility. Katz posed the following questions to the panel: (a) From your own point of view, from your own discipline, what have we accomplished? (b) Where are we today with respect to SAR? (c) Can you think of any steps that we ought to take in the future in terms of experiments or theoretical developments? Highlights from the panelists' comments are presented below:

Owen Phillips:

"I've found this to be an extremely stimulating and enjoyable meeting. Some things I thought were fascinating, some were cute and pretty obvious, others we haven't seen before, and still others we could probably see much better in other ways. It is clear that we can sometimes see the Gulf Stream by means of SAR, but it is quite a strong current, giving rise to gross and coarse features. In some of these pictures the actual Gulf Stream line disappears. However, we can see features that we haven't seen before, such as the filamented structure in the Gulf Stream that is not always visible from thermal pictures. Obviously this is a structure that we don't understand too well.

"It is clear that we can see bathymetry, probably because of variations in the current patterns associated with the bottom topography. This is a very interesting and fascinating observation. But let me play the devil's advocate and express a personal view that there are other ways of measuring bathymetry that may be less expensive than flying a synthetic aperture radar. Bathymetric features do not change quickly, so that once they are measured, it's done for a year or so.

"We can see meteorological fronts and squall lines. We can see the swell. When we are thinking about the swell problems, might we not take advantage of one of the nuisance properties of the SAR, that is, that it smears a moving pattern and displaces its image in space? Might it not be conceivable or practical to measure the height of the swell by taking advantage of that smearing property? If the scatterers are the short waves that are propagating on the long waves, are they convected with not only their own propagation speed, but also with the orbital speed of the swell? The orbital speed of the swell and its wavelength can define the height of the swell. In some sense, the degree of smearing by these moving scatterers is some index of the height of the swell.

"The most interesting things to me are the new structures that we have seen, the weird and wonderful mottling on some of the imagery. Is it some sort of deep convection pattern of a kind that we have not observed before? If it is, it probably is a fairly deep one.

"In several pictures north of Cape Hatteras, one can see images that look superficially like the topographic SAR pictures of the area around Nantucket [Fig. 1]. Are they also topographic features reflected in surface waves, or are they an image of a small-scale ocean structure about which we do not know much? These scales of about 10 km or so must be responsible for a fair bit of the horizontal exchange processes in oceanography."

Sergei Kitaigorodskii:

"I was extremely impressed by the power of SAR. Owen Phillips has mentioned that one can see many phenomena at different scales. This is a great advantage. But I do think it is a disadvantage for SAR as well. I was impressed by the comments of Prof. Mollo-Christensen, who stated that you can see on these pictures the surface signs of internal ocean dynamics. Prof. Pierson emphasized the point that you can also see signs of atmospheric dynamics. So one must look at these pictures, using Prof. Pierson for one eye and Prof. Mollo-Christensen for the other. My problem was to find out if it is possible to distinguish between these two views.

"Because the backscatter is from the short gravity waves, one must, in effect, have a noticeable wind. The time constant of weak, nonlinear interactions for this range of scales is very small. The time constant of viscous dissipation of short gravity waves is about one minute. If there is no wind, this small-scale activity will simply disappear from the sea surface. If the activity is there, wind must be present.

"Experimentally, there is perfect correlation between the mean-square height of the short gravity waves and the frictional velocity or momentum flux. Consequently, with any model of the frequency or wave-number spectrum of short gravity waves (either in the Phillip's saturation regime or in a wind-dependent saturation regime), the mean-square height of the short waves will always be proportional to frictional velocity squared, and probably be some function of other parameters as well. I believe that the structure in these pictures is definitely related to the variability of total momentum flux in the atmosphere.

"The atmospheric variability of the pictures shows that there are atmospheric eddies of the order of several hundred meters, which are distributed in space and which influence the backscattering signal. If this is so, there must be a very strong influence of wind variability in the pictures.

"I would like to remove this atmospheric effect to look at the oceanic phenomena. To remove the effect, perhaps one must attempt to look more at scales of oceanic phenomena, which are different from atmospheric scales. Erik Mollo-Christensen has shown that when you go to a scale of about 100 km or more, one can attribute some features in the pictures to propagation of tidal internal waves and similar internal phenomena."

Robert Harger:

"I would like to join the consensus that we have seen some very interesting images. In fact, it appears that what one might call the 'biological stage of gathering phenomena' has been going on quite well and successfully. Perhaps the more quantitative aspects might be the next step. This will be a very difficult step with the SAR because its ability to image has always been problematic, ever since its use to form high-resolution imagery of the ocean was first considered.

"The state of theoretical modelling for that kind of application is fairly pristine, but the amount that has been done would lead one to conclude that it will take a fairly fortuitous confluence of circumstances — local wind, the right kind of wave height, the right kind of wave-number combinations, and so forth — to get integral images. Furthermore, the images will sometimes contain misleading information — information that, if simply read out at face value, would be incorrect.

"The development of models has been relatively slow and laggardly all through the 1970's. There have been some simple models based on fairly elementary ideas about a cork following the orbital motion on a long wave. The problem with that approach is that there are many nonlinear effects going on. Such effects cannot be summed particularly well. Furthermore, it is not clear that the motion of that cork is important in this particular application. It is the Bragg-like scatter that is responsible for the radar return. Therefore, a local wind has to be present. It is possible that other things like white-capping can generate the right kind of small gravity wave structure, but I'll accept Prof. Kitaigorodskii's word that the most probable source is going to be the local wind. This is very difficult to work into any kind of analytic model.

"There are two kinds of interactions that I would stress. I am not sure that they are recognized as much as they should be. First of all, there is the 'nonlinear' electromagnetic interaction — the interaction of the large scale and the small scale in a nonlinear way. There is also the hydrodynamic wave-wave interaction. The fine-scale structure depends on the large-scale structure, and the intuitive models have been based on a cork moving around in accordance with a large-scale structure. This can lead to ideas such as finding the height of a wave, but it is very hard to see how one might do that. Perhaps the effects of the nonlinear electromagnetic interaction are even more obvious in an image than this nonlinear wave-wave interaction.

"The two-scale model itself, which is the main one that has been proposed, can be an appropriate description of the sea for a relatively small percentage of the time. As the waves build up, one passes through a regime where the model does not really describe what is going on. The appropriateness of the model also depends on the frequency that one chooses for the radar. If one wishes to choose the optimum radar frequency, the model is not too good for answering the question."

Marshall Earle:

"The most advanced models that we use for forecasting and hindcasting, whether they are hybrid in combining a parametric model with swell propagation, or discrete (such as those developed by Prof. Pierson and his coworkers), all involve the directional spectrum. However, we do not have good actual measurements of the directional spectrum. Ideally, we would like the two-dimensional spectrum with fine resolution. This is apparently rather difficult with the SAR; however, we can obtain the dominant period or frequency and the direction of the particular wave component.

"None of our existing wave models simultaneously and rigorously incorporate shallow water and wave current effects with the processes of wave generation and dissipation. These effects cannot be included without directional information, which has many applications. Since the SAR does not provide wave heights, the altimeter may be operated simultaneously with SAR to provide actual height information.

"With respect to currents and to the type of directional information obtained for wave directional spectra, we now need some initial information for interpreting SAR imagery. We need to know that a feature was there. In the future, we would like an estimate of the repeatability of various types of features that might be seen in the SAR image and some estimate of accuracy. I recognize that this is probably a long way off."

Erik Mollo-Christensen:

"Like everybody else, I have seen many phenomena and effects. But we are talking about air-sea interaction. From the meteorological and oceanographic viewpoint, most important air-sea interactions occur when the winds are very strong, which is not the usual situation. So we must guard against tuning an instrument and developing a system that works for average weather conditions, when we are concerned with unusual weather.

"Prof. Pierson presented a diagram showing that the drag coefficient was at first constant at slack wind, then had a variation, and then settled down at a linear slope again. Why was the slope linear, and why did things start behaving above 16 m/s or so? That is because there are very few data points over 16 m/s. Let us not believe that the variation stops right there.

"Furthermore, is there a drag coefficient? One would think the drag depends on the rate of wave generation. If there is equilibrium between the wind and the wave field, there is probably a drag coefficient. But if there is not equilibrium, the further away from equilibrium we are, the larger the drag coefficient. In fact, if the wave field is distorted by strains in a tidal estuary, you may find variations at tidal frequency — or at twice tidal frequency — in the frictional velocity. So you start believing the old fisherman's tale that now that the tide is changing, the wind should pick up a bit again.

"There has been much talk about wave spectra. We should ask the question: 'Why do we want them?' If we look at the practices of the classification societies such as Lloyds of London, and talk with the people operating equipment in the North Sea, wave spectra do not really turn them on any more, especially not the insurance companies. There is more and more talk about a need for setting wave-group tolerance criteria for ships and rigs, because a combination punch is what sinks or destroys things. One wave in a group gets the bow into the water so that the ship slows down. It slowly rises on the next wave, after which the next wave in the group arrives and washes over the stern. I do not want to imply that spectra are useless, but we have to think beyond spectra when we want to define what we really need to know in severe weather conditions."

Willard Pierson:

"Dr. Kitaigorodskii gave a nice explanation of why he thinks the SAR works the way it does with waves. It is roughly the same explanation for why the Seasat-A scatterometer works with waves, except that the Seasat-A scatterometer is working at a shorter wavelength, and things happen a lot more quickly. At those wavelengths, as far as we can tell, we are not dependent on what the swell and the other part of the gravity wave spectrum are doing. For example, the backscatter is independent of fetch. This simplifies our problem of interpreting radar data because all the activity is in the high frequency part of the spectrum.

"I am more pessimistic than some of the others about the ability of a SAR on a spacecraft to image waves usefully. For high waves, the effects of the Doppler shift is going to tear the image apart.

"We do not yet understand everything there is to understand about a SAR as compared to side-looking airborne radar or a moving target indicator. At a recent meeting at NORDA I said, 'Why don't we put the same three radars with the same overall antenna patterns, the same pulse repetition rates, and the same everything else on one airplane?' We could then image the waves simultaneously with a moving target indicator, a side-looking airborne radar, and a SAR. The moving target indicator would give the motion where you were looking, the side-looking airborne radar would give you the image that was there, in a sense, and the SAR would tell you where an image point has moved because of Doppler effects. With the three you could get a good picture of what was really going on. You would also need a very good comparison data set from other types of instruments to compare with these three different kinds of radar image.

"Prof. Mollo-Christensen talked about wave groups and the problems with using linear ship response. Until just a few years ago, naval architects have always been surprised at how well linear models have worked in naval architecture and in almost anything else that floats at sea. The kinds of events that he described and interpreted as highly nonlinear events are understandable and predictable for ship motions in waves, in terms of a linear response."

GUEST SPEAKERS

The two U.S. government agencies that would be the most probable users of future spaceborne SAR's for environmental monitoring over the oceans are NOAA and the Department of Defense. We were fortunate in having a leading spokesman of each agency: Dr. George Benton, Associate Administrator of NOAA, and Rear Admiral Ross Williams, Oceanographer of the Navy. The essence of their remarks is presented below.

George Benton:

"A great deal is happening in the field of remote sensing in Washington today. Much of it is very encouraging, and NOAA is closely involved in what is going on.

"Very early in his administration, President Carter initiated a major review of U.S. policy with regard to space activities. Perhaps the most important Presidential decision resulting from this review was announced in November 1979. This complex decision set forth a series of key policies with regard to our space effort. Several parts of it applied particularly to remote sensing. In the decision, NOAA was designated the federal agency that would be responsible for civil operational remote sensing from satellites. This decision of major importance will bring together within one agency the responsibilities for remote sensing of the atmosphere, the oceans, and the land.

"NOAA, of course, has been monitoring the atmosphere for many years with both polar-orbiting and geostationary satellites. In addition, NOAA is one of the three agencies that will develop the National Oceanic Satellite System (NOSS). The Presidential directive brought to NOAA an additional major responsibility: to develop for the civil sector an operational satellite system for land remote sensing. A major step forward has now been taken in bringing together these three responsibilities.

"Many of you have used or seen the products of NOAA's operational meteorological satellites. NOAA has acquired substantial experience with operational satellites both in their space aspect and in the ground processing of data, with its stringent requirement for reliable throughput almost in real time. This experience probably explains why NOAA was given broader responsibilities.

"Land remote sensing is new for NOAA. The problems are complex. NOAA must take an R&D land remote sensing system (which NASA calls Landsat) and convert it to a fully operational mode. This will be achieved in two steps. First, an interim system must be developed based on Landsat technology. This will be a series of satellites that will provide continuity of data beyond the planned launch of Landsat D and D′ now under construction. Second, a fully operational system must be developed, using new technology to improve the reliability of data collection, processing, and distribution. Such a fully operational system could come into being in the late 1980's. NOAA expects to devote a great deal of its creative energy to land remote sensing.

"Finally, I would like to say a few words about the NOSS, funding for which has been requested in the President's 1981 budget. If Congress approves his request, NOAA will move forward in cooperation with NASA and the Department of Defense. NOSS will be a tri-agency effort, with launch of the first satellite planned sometime in the second half of the 1980's. It will be an effort of major importance to oceanography.

"Three Presidential decisions taken together (concentration of an earth remote sensing responsibility in a single agency, approval in principle of an operational land remote sensing system, and decision to begin to fund NOSS) promise substantial development in the field of earth remote sensing during the 1980's. Looking ahead to the 1990's, one can envision the development of a single comprehensive earth remote sensing system that will include many satellites in various orbits. The choice of satellite for a given sensor will depend on orbital requirements rather than on whether a satellite is labelled 'meteorological,' 'oceanic,' or 'land remote sensing.' Obviously, I do not know for certain whether such an integrated earth sensing system will materialize, but it would seem to be a logical outgrowth of present trends. As we look at the earth remote sensing needs for the atmosphere, the oceans, and the land, it would make good sense to consider how we might best put together an integrated system for the benefit of all users. The long-term prospects for earth remote sensing are bright; our government is now approaching the subject in a careful and rational way."

Ross Williams:

"I am not a scientist, but rather an operator in the business of providing environmental products of all descriptions to the Fleet. We have been trying to gear up to use oceanographic satellites in our environmental prediction business. This includes not only atmospheric but also oceanographic predictions, in order to provide long-range surveillance systems; that is, to give ships with long range sonars more of an advantage, so that they will understand what they are seeing in their instruments and how the environment is affecting the weapons system.

"I would like to relate an example. Many years ago, in the days of sail, masters took their ships to sea. They knew the environment. They had to, or they could not get from point A to point B. The range of their weapons was so short and the inaccuracies were so large that, as far as the weapons system itself was concerned, the environment was irrelevant. As we developed more sophisticated propulsion systems and weapons systems, we thought we could do anything, any time we wanted. We were fooled. We lost ships; we lost men. One of the prime examples of our ignoring the environment, or not understanding it enough, was a typhoon in the latter days of World War II. In the fall of 1944, we lost 790 lives from one task force. Three destroyers were lost; the bow of the carrier *USS Bennington* was severely damaged. Essentially all of its aircraft were destroyed in the hangar. The *USS Pittsburgh* lost its bow. That fighting force was ineffective after the typhoon. Some people think such a thing cannot happen today. This is not true.

"As recently as last year we had an example, when our operational forecasts continually predicted the 24- and 48-hour forecast positions of typhoon Bess as being south of the track of a major ship that was crossing the Pacific. The forecast was as good as we could provide. But on the 21st of March, 1979, the *USS Dubuque* rendezvoused with typhoon Bess. Fortunately the typhoon had not increased enough in intensity or built up enough to damage the ship. Had it been a super typhoon, it could have been disastrous.

"We need remote sensing information of all types. I was delighted with some of the remarks I heard about the multisensor, multiplatform, multispectral approach to the environment. That is the answer, and we have been working feverishly to try to get ready for the oceanographic satellites, to get information into the models so that we can provide better data to the Fleet.

"I was asked if I would comment on a policy question. I have been involved in Seasat, and before Seasat in GEOS-3. Even before the launch of Seasat, we started working on a Seasat-B, which has become a part of NOSS. The policy question has to do with interagency disputes but, more specifically, whether we can have classified and unclassified efforts going on in a single program. I was also asked whether the SAR had been dropped from NOSS because of its cost, because the agencies cannot work together, or because SAR has no scientific value.

"This symposium has been addressing the science question. The instrument cost was definitely a strong factor. In the original NOSS concept two to two and a half years ago, we did have a synthetic aperture radar, a Seasat-class radar that, if we had retained it, would have operated on perhaps a 25% duty cycle. Our colleagues in the Executive Office of the President, in the Office of Management and Budget, were very critical of our proposal for a FY80 start on NOSS (which included the SAR) because of its high cost. The present NOSS program (without SAR) is designed as a limited operational demonstration. It has been an extremely successful program, even though we are only at the stage of asking Congress for funds.

"The Office of Management and Budget has 'urged' DoD to contribute not the share that we had previously agreed to, but 50% of the total NOSS cost. Previously our plan was that NOAA and the DoD would share in the development of the ground segment of the system and in the data distribution. Now, the division of labor is a little fuzzier. However, NASA does have the responsibility for the development of the space segment, and will be the lead agency at least in the early stages. If the program is approved, NOAA and the DoD would be the lead agencies in the operational aspects and the data distribution.

"We are in every respect trying to get ready to provide a continuous stream of data for the oceanographers, the meteorologists, and others in the operational or research community who wish to use the data."

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