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# APPLICATIONS OF ISES FOR SNOW, ICE, AND SEA STATE*

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## Snow and Ice

There will be six facility instruments on the NASA NPOP-1 and NPOP-2 and additional instruments on the Japanese and European satellites. Also, there are the 24 selected NASA instruments that may be flown on one of the platforms. Many of these instruments can provide data that could be very useful for real-time data studies in the snow and ice area. This paper will not address any one instrument in particular, but will be concerned about what is potentially possible using the capabilities of some of these instruments.

In the snow area, we are mainly concerned with detecting seasonal snow and glaciers, while in the ice area we are concerned with sea ice, river and lake ice and also ice sheets. Over the years, the seasonal snow covering has averaged about 40 million square kilometers. Figure 1 shows one of the snow maps produced using Defense Meterology Satellite Program Special Sensor Microwave Imager (DMSP) SSM/I data. The SSM/I is a passive microwave radiometer with 19-, 22-, 37- and 85-GHz channels. It was launched in 1987, and the image shown here is a false color plot constructed from 19- and 37-GHz data. The resolution of the 19-GHz channel is about 60 km and that of the 37-GHz channel is about 30 km.

With this resolution we have a low data rate, and it is certainly reasonable to consider doing this in real time. We are using kilobit data rates, and there should be no problem at all doing any global type of study.

To arrive at the algorithm used here we mounted a radiometer on top of a truck and measured brightness temperatures over various snow fields. By combining these measurements with snow field and climatology data in a modeling program, we were able to generate this simple relationship between snow depth and brightness temperature. This algorithm depends on the radiative transfer in layers of snow crystals. In Figure 2 we show the effect of varying the snow crystal radius. One curve is for 0.3-mm crystal size data and the other is for the 0.5-mm size. The dominant effect of crystal size variation is in the 37-GHz data. Since the 18-GHz radiation basically does not scatter by snow crystal at all, it serves as a reference point to normalize the physical temperature.

This algorithm has worked pretty well over open areas like the prairies of Russia, but we know that in mountainous areas or regions with trees this simple algorithm is not going to work. The United States Geological Survey (USGS), United States Department of Agriculture (USDA) and NASA initiated a cooperative program over the Colorado River basin following the 1983 flood, and we are still working on these problems and getting close to a solution. We probably will not be using a simple relation like the one just given. Different regions of the world may require different algorithms. That will complicate the data retrieval a little, but it still shouldn't be too difficult.

Historically, horizontally (H) polarized data have been used in these applications because the H channel of a similar instrument on Nimbus 7 was better behaved than the vertical (V) channel. Although the H polarized data from the DMSP satellite was used above, both V and H polarization were available and they should give about the same results for future applications.

The only microwave radiometer that has been currently selected for the Eos project is the AMSR, a Japanese instrument that weighs around 900 kgm. This may be too heavy for inclusion on NPOP-1 or

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*The snow and ice section is by Dr. Chang and the sea state section is by Dr. Delnore.

-2, so it is still not definite what the final channel selections will be or which instrument will be flown. However, it is reasonably certain that an 18- or 19-GHz channel and a 37-GHz channel will be available.

Using the given algorithm we can retrieve two parameters (the snow cover area and the amount of snow storage). The snow coverage has been derived by NOAA and the Air Force for a long time. NOAA is using visible data to come up with a weekly product. The Air Force uses ground measurements and models and comes up with a daily product. These two products do not always match each other; they sometimes differ by millions of square kilometers in area. We thought that more things could be done in this area; therefore, we are using microwave data for the snow depth estimates because that's the only sensor that can provide this information. Of course, we will probably use visible sensors for the area coverage because of the higher resolution, but there is still the cloud cover problem.

Radar altimeters can penetrate snow and give a different altitude than optical altimeters; thus, it is possible to get the snow depth in this manner. However, the dielectric constants of snow and ice are quite different, so when the temperature rises, microwave instruments can tell right away whether the snow is melting or not. Whereas snow storage will be more of a long-term type of measurement, snow melting will have more real-time importance.

In the Colorado River basin incident of 1983 there was an unusually hot week in May. Under normal conditions snow generally melts from the valleys toward the mountain peaks, but in this case it suddenly melted everywhere, from the bottom of the mountains all the way to the top, generating the big flood. This kind of event can probably be detected quickly in real time, and will be extremely important to the resource manager responsible for dams and reservoirs.

Now, water vapor is usually not a major factor. When it's cold there is not much water vapor in the air. It becomes a factor in the temperate regions, however, because sometimes there can be snow and rain mixed together. Since only the 37-GHz data are responding to the snow, it should be possible to determine the snow/rain mix during a storm. This will definitely be a real-time problem since it will affect traffic and snow removal. Another problem can be winter kill; this can be a big factor in the plains area if you don't have enough snow. Usually snow is a good insulator and can help prevent winter wheat kills. Real-time monitoring of conditions can help predict next year's crop conditions.

Another thing to consider is glacier movement. Glacier motion is on the order of about 70 meters per year. Although this is slow, according to Mark Myer's study the melting or receding of glaciers contributes significantly to the increase of the water level globally. This is obviously important for global change studies.

Sea ice has been extensively studied. In Figure 3 we see a large area in the northern hemisphere over Greenland and in the southern hemisphere over the boundary of Antarctica. What we can do now is determine its concentration. Figure 3 also shows the concentration and location of the sea ice. Global sea ice covers about 20 million square km. This large an area has an impact on the global energy balance, but the real-time usage of this data will be more for shipping. The traffic patterns are the important factor; where there is ice the ships cannot go through. The microwave instruments can tell the difference between frozen sea water and compacted snow over the land masses. Icebergs are a related problem but they must be detected using Synthetic Specture Radar (SAR) data.

At this moment, lake ice and river ice are not being studied with these same sensors because of the 25 to 50 km resolution. With improved resolution, however, it should be possible to monitor the beginning of melting and foresee the possibility of ice jams. These kinds of problems will obviously need real-time data.

It may be possible to use Geodynamics Laser Ranging System (GLRS) data or laser altimeter data to determine snow depths from year to year. These kinds of data will be very important in global energy models, hydrological cycles, and so on. Even though most of the global data is important, the real-time problems are not a sensitive issue in this area.

Figure 4 demonstrates some of the research we are currently doing with comparisons of aircraft and satellite data. The aircraft sensor was the same as that on the DMSP so that aircraft data could be used to interpret or validate the spacecraft data. In the future we will have to repeat these experiments because of different frequencies, resolutions, and other instrument parameters. Coverage is probably fairly easy to do, but determining the areal extent of leads is more difficult. Because the energy exchange between the atmosphere and the water surface is several orders of magnitude higher than when the water is covered with ice, if you have 20-percent open water, the energy exchange is quite different from solidly packed ice. That's why we need to understand the data better to make sure the retrieval is reasonable. It is very difficult to measure the ice concentration accurately except by using aircraft.

The distinguishing of water and ice on a daily monitoring basis in areas such as the Arctic Ocean is very important. This is a very dynamic region. There is the continual opening of pack ice and then within hours the ice sheets close up again, and some sheets wrap over other ice sheets. The ice edge is a part of this process also because the advancing and receding of the boundary has a significant effect on the energy exchange. Ships at sea want to know where the ice edge is to determine how far north they can go when taking a great circle route. Meteorologists want this information for their modeling programs.

This constant activity profoundly affects the climate in the Northern regions, which of course makes its way down to us in the Canadian Arctic front or polar express. What is happening at the poles then influences global climate and weather and needs to be monitored in real time. Right now SAR is the only instrument that can be used to determine the areal extent of leads in the ice packs. However, the large amount of data required is not practical. Visible sensors can help in the summer, but they are not very useful in the winter because of the low Sun angles in the polar regions. The Canadians and Norwegians have extensive aircraft programs to collect this vital information.

In summary, there are several areas in which real-time microwave radiometer data are needed, or would certainly be beneficial. They include the determination of the sea/ice boundary for ships at sea and for meteorological modeling; the determination of snow/rain mix in a storm as an aid to transportation, directing clean-up activities, and in crop management; and the determination of snow and ice melting locations and rates for flooding and reservoir management.

## Sea State

We have already touched on this subject in the active microwave paper "Radars in Space" presented in this document. Let's say you have an aircraft or spacecraft moving in a fixed direction. The wind is blowing in a certain direction, and a radar is looking in some arbitrary direction. The radar return depends upon the small-scale roughness of the surface of the ocean, which in turn depends upon the wind stress on the water. Also, the radar cross section is further influenced by the incidence angle with which the radar beam strikes and is reflected from the sea surface. Figure 5 shows the dependence of radar cross section on incidence angle. Now, for a given incidence angle, suppose you look at the ocean at different azimuths with respect to the upwind direction. It turns out that there is an additional modulation, a biharmonic function, and this is shown in Figure 6. We measure the roughness and know the incidence angles at two or more azimuths, but there is still an ambiguity, so we have to know something else to resolve the actual wind direction. The something else that is needed is an algorithm, or model function, to get from the radar measurements to the wind vector. This is the basis of scatterometry and how it is used to determine wind speed and wind direction; we have to make measurements of each surface area (or resolution cell) from two or more directions to resolve ambiguities in specifying the wind.

The accuracy in determining wind speed with a scatterometer is about 2 meters per second. As far as the wind direction goes, we are generally within 20 degrees. Both of these accuracies are usually much better than the in situ measurements. Now I don't know if you have spent any time on ships, but when the crew gets around to recording wind speed and direction, they are really very sloppy about it. We had some simultaneous reports from ships that were within a mile of each other, and they showed wildly different wind directions. For instance, there are anemometers, one on each side of the mast. You're supposed to use the reading from the windward one to avoid the lee of the mast, but often the crew forgets to do that and reports the wrong one.

In Figure 7 we see a comparison of satellite wind measurements with surface observations. Hundreds of readings went into this, and what we have is the wind speed from the scatterometer backed out through the algorithm versus what surface observations there were. It turned out that after this big verification program of Seasat data there was much more confidence in the scatterometer data than there was in the so-called ground truth that had been obtained from the ships and buoys at sea.

It is clear from the experience we had with the Seasat instrument that sea state can be determined probably more accurately from space than by surface measurements. This kind of information is certainly desired in near real time, and with recent improvements in signal processing and data reduction, real-time global wind field and sea state calculations are certainly feasible.

The next generation of spaceborne scatterometers and radar altimeters will make direct measurements of ocean wave spectra; then we'll get sea state statistics without recourse to a wind algorithm.

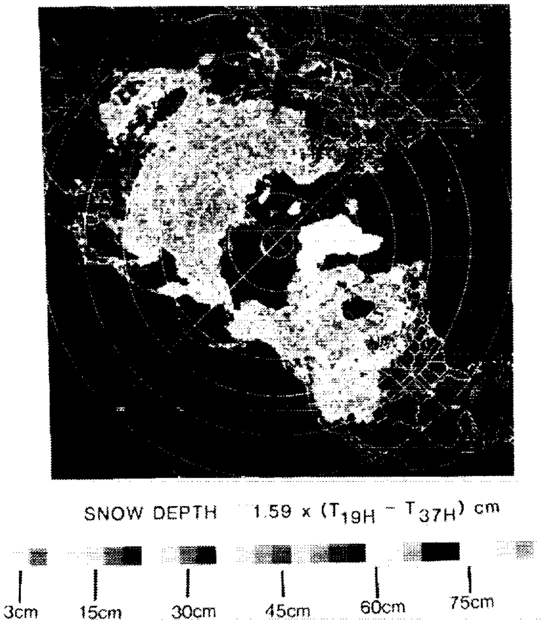

Figure 1. DMSP SSM/1 derived snow depth map, January 1988.

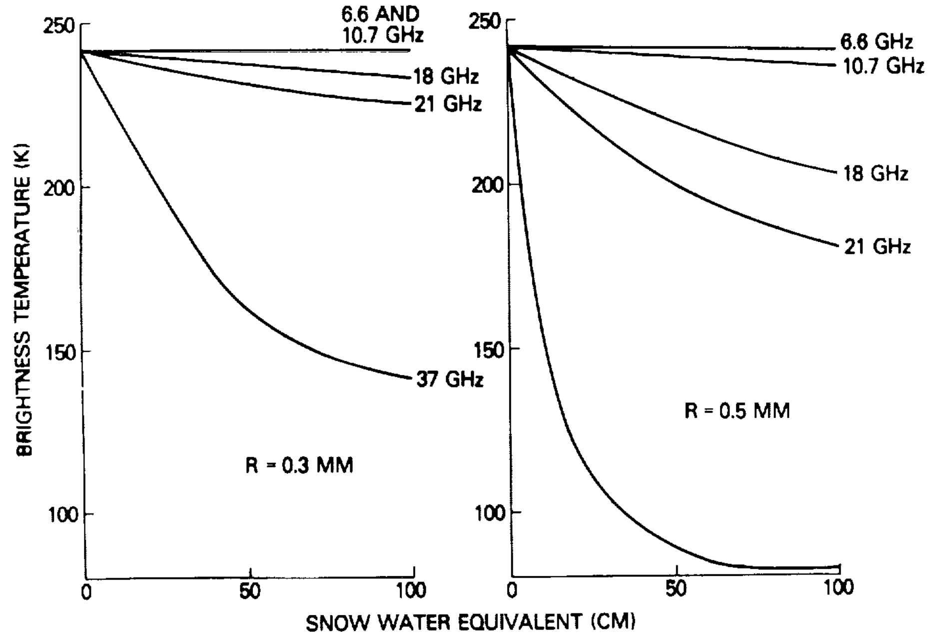

Figure 2. Calculated brightness temperature as function of snow water equivalent (horizontal polarization, $\theta = 50°$, frozen ground).

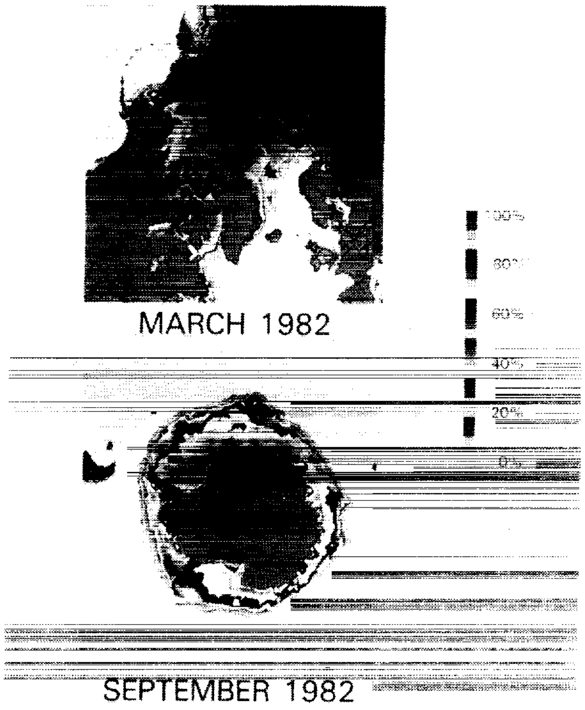

Figure 3. Winter sea-ice concentration from DMSP/1.

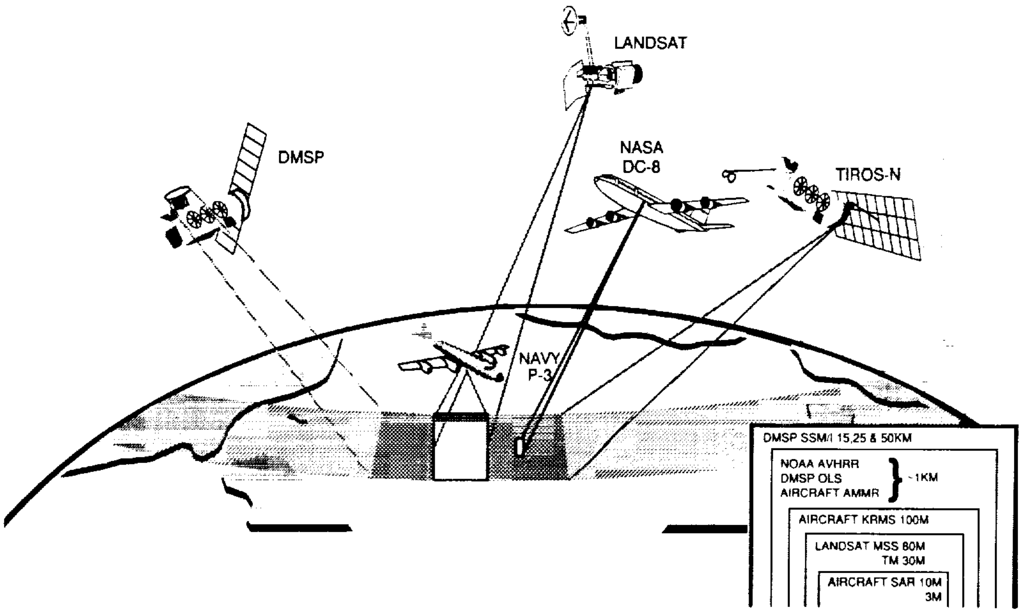

Figure 4. Multisensor/multispatial validation of sea-ice parameters.

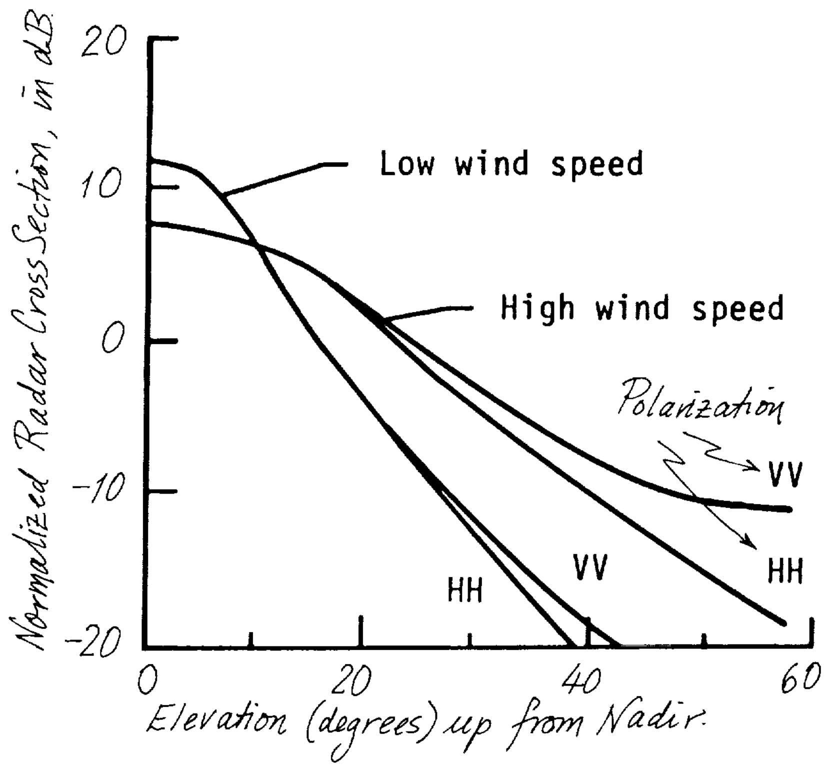

Figure 5. Dependence of normalized radar cross section on incidence angle for constant azimuth with respect to wind direction.

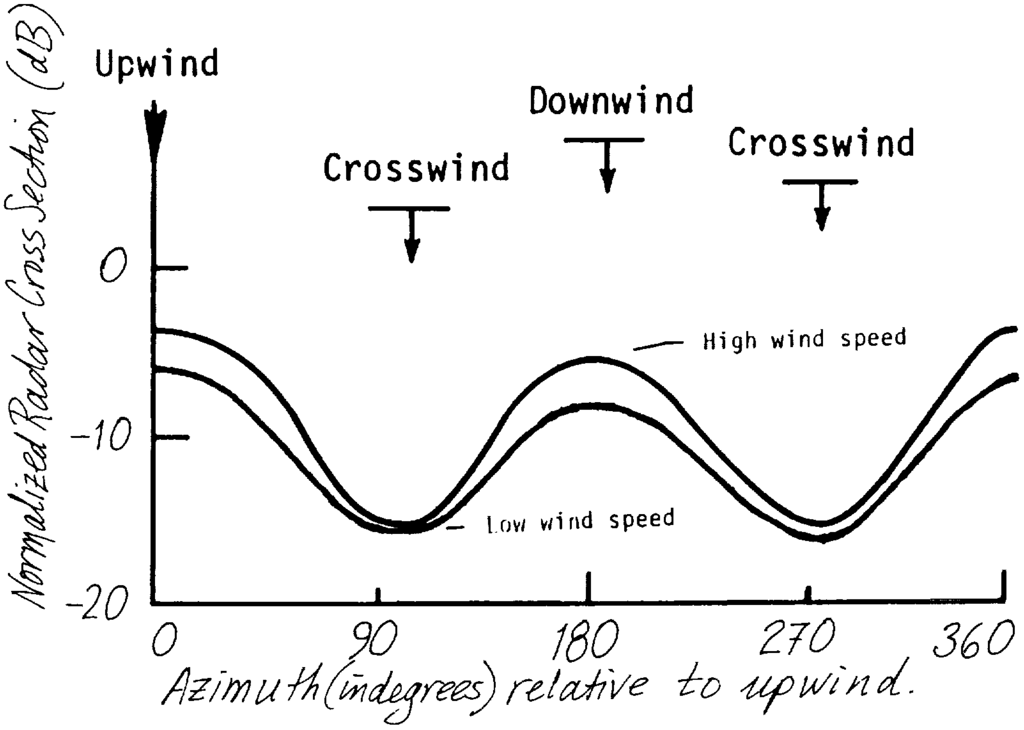

Figure 6. Biharmonic dependence of normalized radar cross section of sea surface on wind aspect for constant incidence angle.

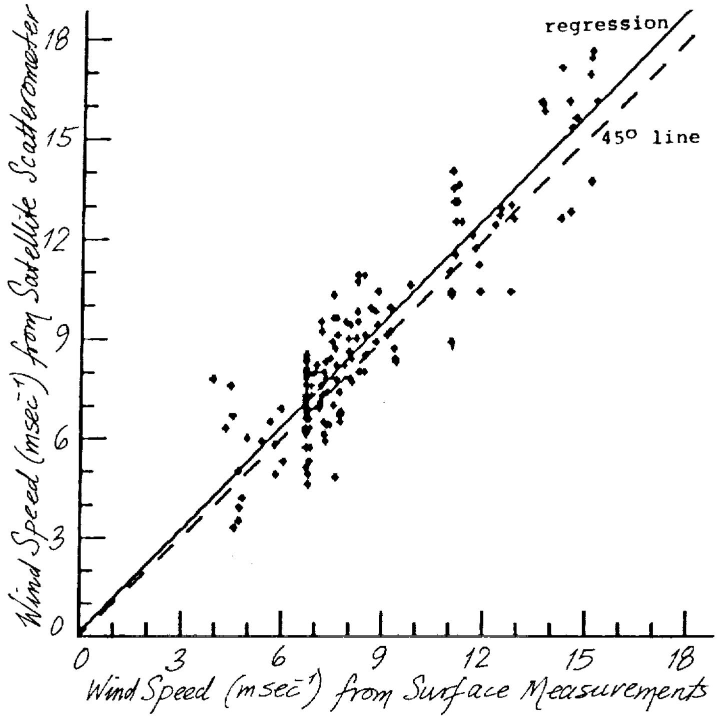

Figure 7. Comparison of satellite scatterometer (SEASAT) wind measurements with simultaneous sea surface wind measurements.