GLOBAL SNOW STUDIES UTILIZING MICROWAVE RADIOMETRY[1]

J. L. Foster, D. K. Hall and A. T. C. Chang[2]

Abstract.--A movie presentation has been prepared by the Hydrological Sciences Branch of NASA/Goddard Space Flight Center in order to increase awareness of the potential of microwave remote sensing for snow studies within the scientific community. This 12-minute movie offers some background information on snow hydrology and remote sensing of snow, and explains how passive microwave remote sensing is used to derive measurements of snow cover and snow depth. A three-year time series of monthly SMMR data is shown while the narrator discusses the observed brightness temperature patterns. Seeing the monthly microwave data in a time series allows the viewer to gain an appreciation of the large variability that is present in the Northern Hemisphere snowcovered area. Although more difficult to interpret, gross snow depth changes are also obvious in the film sequence. The compilation of microwave satellite imagery should complement the existing visible satellite data set and be a useful reference for climatological and energy balance studies.

INTRODUCTION

Snow can be the most variable feature of the Earth's surface. The snowcovered area in the Northern Hemisphere changes from less than 10 million km^2 in summer to about 50 million km^2 in winter. By means of sophisticated radio telescopes carried aboard artificial satellites, a view of our world as a planet can be obtained using a technique called passive microwave remote sensing, where the microwave region of the spectrum is taken to be the wavelength range from 1 mm to approximately 30 cm (1-300 GHz) (Schmugge, 1980). The unique vantage point of space provides the opportunity for global synoptic observations which are well suited for the study of many climatic data sets including snow cover. Monthly maps showing snow cover and snow depth variability for the Northern Hemisphere have been derived from Nimbus-7 SMMR data for 6 years (1979-1984). The microwave portion of the spectrum is advantageous for snow mapping because of the large differences in the dielectric constant of liquid and frozen water which causes a significant variation in the microwave signal when liquid water is present (Foster et al., 1984). Working in the microwave regions also permits remote observations of snow under nearly all weather and lighting conditions. Indeed, often the most dynamic areas are the most cloudy such as the boundaries of sea ice and snow cover (Campbell and Gudmansen, 1981).

MICROWAVE RADIOMETRY OF SNOW

The SMMR system on-board the Nimbus-7 is a dual polarized, five channel radiometer that measures radiation emitted by the scene under observation. The shortest wavelength (highest frequency) channel corresponds to 37 GHz (0.81 cm) and is best suited for mapping and measuring snow. This is because the longer the wavelength, the greater the depth of the emitted radiation, so shorter wavelengths sense more about the snowpack than do longer wavelengths which provide more information about the underlying soil. In addition, the dielectric constant for snow is usually lower than that of dry soil, and since scattering further reduces the brightness temperature, there is sufficient contrast in the brightness temperature range for snowfield

---

[1] Paper presented at the International Snow Science Workshop, Lake Tahoe, California, October 22-25, 1986.

[2] Al Chang, James Foster and Dorothy Hall are remote sensing scientists in the Hydrological Sciences Branch at NASA/Goddard Space Flight Center, Greenbelt, Maryland.

monitoring (Rango et al., 1979).

The intensity of microwave radiation emitted from a snowpack depends on the physical temperature, the grain size, the density, the wetness, and the underlying surface conditions of the snowpack (Hall et al., 1986). As an electromagnetic wave emitted from the underlying earth surface propagates through the snowpack, it is scattered by the randomly spaced snow particles into all directions. Consequently, when the wave emerges at the snow/air interface, its amplitude is generally attenuated. The dry snow absorbs very little energy from the wave and therefore, it also contributes very little in the form of self emission. When the snowpack grows deeper, the wave suffers more scattering loss, and the emission from the snowpack is further reduced (Shiue et al., 1984).

ALGORITHM DEVELOPMENT

Currently, several algorithms are available to evaluate and retrieve snow cover and snow depth parameters for specific regions and specific seasonal conditions. These algorithms have been derived from research using a combination of microwave sensors on-board satellites, aircraft and trucks as well as in-situ field studies. A straight-forward method to relate microwave radiometric data to snow cover and snow depth is to examine the differences between the brightness temperature observed for snow covered ground and that for snow free ground.

Efforts have been made by several investigators to produce a reliable global snow algorithm using theoretical calculations. Chang et al. (1986) have developed an algorithm that assumes a snow density of .30 and a snow grain size of .3 mm for the entire snowpack. The difference between the SMMR 37 GHz and 18 GHz channels is used to derive a snow depth/brightness temperature relationship for a uniform snow field and is expressed as follows

$$SD = (1.59)(T_B\ (18_H) - T_B\ (37_H))$$

where SD is snow depth in cm, 1.59 is a constant used to obtain a linear fit of the difference between the 18 GHz and 37 GHz frequencies, and H denotes horizontal polarization and T_B is brightness temperature. If the 18 GHz value is less than the 37 GHz value, the snow depth is then zero and so no snow cover is assumed.

This algorithm is presently being tested in several different regions in the Northern Hemisphere in order to verify the microwave response of varying snow conditions. One such region is in the western U.S., the Colorado River Basin (289,600 km^2), which includes rugged terrain and heavy vegetation cover. This basin presents a greater challenge in developing snowpack parameter retrieval techniques than do flat, homogeneous prairie areas.

Extensive validation of the SMMR-derived data on snow cover and snow depth is essential and will lead to the development of more accurate and reliable algorithms. The next step is to invert the algorithms that have been developed to model microwave emission, in order to calculate snow cover and snow depth from the microwave T_B. This appears to be possible in areas for which the relevant properties of the snowpack are well established.

COMPARISON OF SMMR AND NOAA DATA

Results describing seasonal and annual snow cover variability have been produced from SMMR microwave data as well as NOAA visible data. In order to compare the SMMR and NOAA snow map products and evaluate their accuracy snow depth and snow cover as reported by climatological stations in the United States was used as the reference or baseline measure. A subjective analysis was performed whereby SMMR and NOAA derived snow cover maps for January and February of 1983 were overlaid onto the climatological snow charts.

In general, the snow maps agree fairly well with each other although there appears to be a bias towards lower estimates of snow cover extent using the SMMR maps because of a lack of sensitivity to shallow snow (less than a few centimeters), and because dense vegetation complicated the microwave signature. For January and February of 1983 the SMMR derived snow maps indicate about 10 percent less snow for the entire U.S. than do the NOAA maps (Chang et al., 1986). The threshold for snow/no snow discrimination is being adjusted in the algorithm used to generate the SMMR snow maps in order to more accurately portray observed snow conditions.

CONCLUSION

Snow is a major component of the global energy balance. Currently, the causes and effects of observed variations in the snow-covered area are not well understood. Improved understanding of the climatic significance of the observed changes requires better knowledge of the physical processes involved as well as an accurate long-term record of ice and snow conditions. Progress in climate research will depend on the availability of a variety of geophysical data sets that describe the boundary conditions and forcings of the climate system. A compilation of microwave satellite imagery on snow cover for the years 1979-1984 has now been assembled which should complement the existing visible satellite data set. It is thought that this information will be a useful reference for climatological and energy balance studies.

LITERATURE CITED

Campbell, W.J., and P. Gudmansen. 1981. The Application of Microwave Remote Sensing for Snow and Ice Research. IEEE International Geoscience and Remote Sensing Symposium Digest, edited by K. Carver, pp. 951-957, Institute of Electrical and Electronics Engineers, New York.

Chang, A., J. Foster, and D. Hall. 1986. Nimbus 7 Derived Global Snow Cover Parameters. International Glaciological Society, Annals of Glaciology, Vol. 9, Cambridge, England, September 1986.

Foster, J., D.K. Hall, A.T.C. Chang, and A. Rango. 1984. An Overview of Passive Microwave Snow Research and Results. Reviews of Geophysics and Space Physics, 22, No. 2, pp. 195-208.

Hall, D.K., A.T.C. Chang, and J.L. Foster. 1986. Detection of the Depth Hoar Layer in the Snowpack of the Arctic Coastal Plain of Alaska Using Satellite Data. Journal of Glaciology, Vol. 32, pp. 87-94.

Rango, A., A.T.C. Chang, and J.L. Foster. 1979. The Utilization of Spaceborne Microwave Radiometers for Monitoring Snowpack Properties. Nord. Hydrol., 10, pp. 25-40.

Schmugge, T. 1980. Techniques and Applications of Microwave Radiometry. In Remote Sensing in Geology, edited by B.S. Siegal and A.R. Gillespie, chap. 11, pp. 337-352, John Wiley, New York.

Shiue, J.C., R. Shin, A. Chang, J. Fuchs, F. Lin, and H. Greenan. 1984. Observations of Passive Microwave Emission from Snowpacks. Proceedings of the 41st Annual Eastern Snow Conference, Washington, D.C., pp. 75-85.