REMOTE SENSING APPLICATIONS IN SNOW HYDROLOGY – PAST, PRESENT AND FUTURE

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By

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INTRODUCTION

Recent advances of remote sensing systems provide new information needed for retrieval of important snow hydrology variables. Considerable research efforts and associated significant results have been reported. These activities have taken advantage of certain general characteristics of remote sensing data such as synoptic viewing, repetitive coverage, relative low cost and real time data acquisition. The Landsat and NOAA environmental satellite systems have provided many observations that are proving to have utility in monitoring snow-covered area. Airborne gamma-ray techniques are useful for monitoring snow water equivalent from low altitude along index lines over large open areas. Research being carried out now also suggests that microwave observations from a variety of observing platforms may be able to monitor snow cover and water equivalent as well as other fundamental snow hydrology variables needed by water resource managers.

PAST

The most definite snowpack feature that can be extracted from spacecraft or aircraft is the area of a drainage basin covered by snow. The extraction of snow-covered area from satellite observations was first performed on the Indus River above Attock, Pakistan and later on the Kabul River above Nowshera, Pakistan (Rango, et al., 1977). Low resolution, meteorological satellite data and International Hydrological Decade stream-gauge records for the period of 1967 to 1973 were used in this study. The average area covered by snow near the beginning of April was related in a simple regression analysis to runoff occurring from 1 April to 31 July. The regression relation on the Kabul River was significant at the 99% level with the coefficient of determination (r^2) = 0.89. Subsequent examination of the shorter term, but higher spatial resolution, Landsat data in the Wind River Mountains of Wyoming indicated that similar relationships existed on watersheds as small as 200km (Rango, et al., 1975). Despite the significant relationships, when forecasting seasonal flow for a new year was attempted, it was apparent that not enough years of record existed in order to provide a narrow confidence interval around the forecasted volume. Aerial snow-cover observations made on several watersheds in the southern Sierra Nevada Mountains were combined with Landsat snow-covered area to form approximately 25 years of record. A method to update seasonal forecasts every 15 days after April 1 throughout the snowmelt season was developed on the Kings and Kern Rivers. The results showed that such updating of forecast volumes was possible and that significant improvement in forecast accuracy was likely on basins which were not adequately instrumented or had highly varying watershed parameters (Rango, et al., 1979).

Because of the promising aspects of satellite snow-cover mapping, a cooperative demonstration project was conducted to deal with the operational applications of satellite snow-cover observations. Six Federal agencies and three state agencies were among those who tried to incorporate the satellite data into their operational procedures. The studies employed hydrologic modeling, regression analysis, low altitude aircraft flights, calculation of melting snow areas, and the Landsat data collection system in addition to basic photo interpretation. Results and cost/benefit analyses from this project have been fully documented (Rango, 1981; Schumann, 1981; Brown and Hannaford, 1981; Shafer, et al., 1981; Dillard, 1981; Schneider, 1981; Castruccio, et al., 1981; and Bowley, et al., 1981).

In all of these primarily empirical tests of the snow-cover data, it became apparent that a more efficient way to use the new information was to provide inputs to numerical snowmelt runoff models. A snowmelt-runoff model (SRM) compatible with remotely-sensed snow-cover data was developed by Martinec (1975) on small experimental and representative mountain basins (with significant elevation differences) in Czechoslovakia (Modry Dul, 2.65km) and Switzerland (Dischma, 43.3km). Using Landsat data the model was first applied to two basins in the Wind River Mountains of Wyoming, Dinwoody Creek (228km) and Bull Lake Creek (484km). Next, the model was applied to the South Fork (559km) and Conejos River (730km) basins in the Rocky Mountains of Colorado. The results of these applications are well documented (Rango and Martinec, 1979; Rango, 1980; Jones, et al., 1981; and Shafer, et al., 1981). More recently SRM has been tested on much larger basins, namely the Upper Rio Grande River (3419km) in Colorado and the Kings River (3999km) in the Sierra Nevada Mountains of southern California. In each of the basins cited, the model was found to successfully simulate the snowmelt discharge from the basin using Landsat data with only a slight decrease in simulation accuracy as the basin size increases. This approach seems to be an effective way to employ the satellite snow-cover for operational water resources applications.

PRESENT

Further testing of the SRM model is required to evaluate its performance in a variety of snowmelt situations and modifications must be made to convert it for automatic operation in the forecast mode. Additional tests are being conducted on several international basins as part of a World Meteorological Organization project on an intercomparison of models of snowmelt-runoff. The modifications for forecast purposes are being carried out and testing is taking place using the Rio Grande River basin. The results of these tests should permit operation of the model for both short-term and long-term forecasts. For the long-term seasonal forecasts, however, empirical techniques may be preferred by certain water agencies. In such a case, it is recommended that the satellite snow-cover data continue to be collected and be used in combination with conventional data in a multiparameter approach to reducing seasonal streamflow forecast errors.

For snow water equivalent measurement, low altitude gamma-ray flights can currently be used over flat regions. Although the program is operational, the delivery and analysis of the data are still in an informal mode and very much limited to a particular region of the country. Conventional snow water equivalent data are relayed in real time when needed by satellites as well as by meteor-burst systems and are becoming an extremely important tool in snow surveying that, along with the remote sensing information, will eventually change the predominant types of forecast techniques employed by operational agencies. These new kinds of data should cause a major shift from empirical to model-based forecasts.

In order to permit remote sensing to be more fully utilized, the capability for sensing snow-cover extent must be extended to all-weather situations and coupled with a complementary capability for measurement of areal snow water equivalent. To realize this goal, extensive research activities are now concentrated on using microwave wavelengths in sensing the properties of snowpacks. Microwaves, with wavelengths of 1 cm to 1 m can penetrate a snowpack up to several meters in depth. In addition, microwave radiation usually is not affected by cloud cover. The attenuation and scattering of the electromagnetic radiation by the snow crystals and internal structure of the snowpack provides the needed information in retrieving the important snow properties. The snow water equivalent retrieved from airborne and truck-mounted radiometer systems compared favorably with the model predictions (Figure 1). Figure 2 shows that the microwave brightness temperatures measured by Nimbus-7 SMMR over the Eurasia area correlated well with snow depth observations (Chang, et al., 1982).

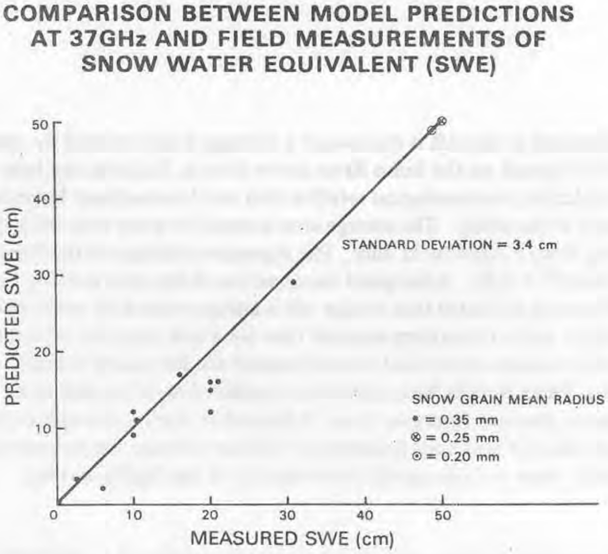
COMPARISON BETWEEN MODEL PREDICTIONS AT 37GHz AND FIELD MEASUREMENTS OF SNOW WATER EQUIVALENT (SWE)

Figure 1

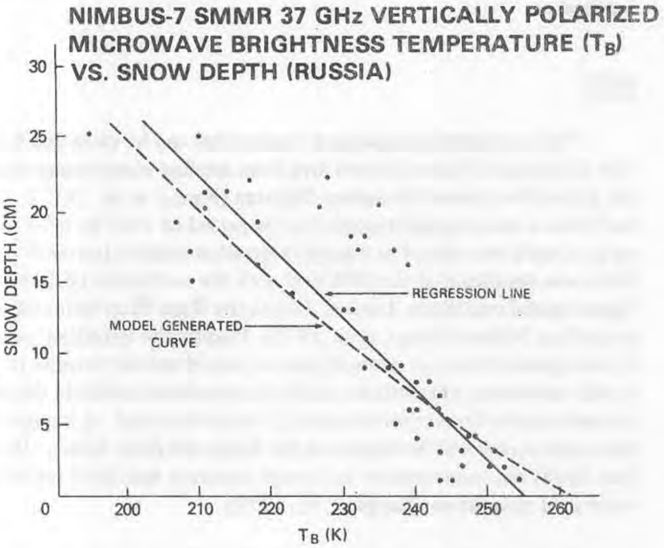
NIMBUS-7 SMMR 37 GHz VERTICALLY POLARIZED MICROWAVE BRIGHTNESS TEMPERATURE (T_B) VS. SNOW DEPTH (RUSSIA)

Figure 2

FUTURE

Research efforts in the future will concentrate on developing microwave capabilities for snow measurements that will complement existing visible and infrared approaches. The eventual applications of the remote sensing techniques will cover several areas, namely, hydrology, agriculture, and climate. In most cases, the major difference between the applications will only be a matter of scale. The same kind of measurements will be useful for snowmelt runoff forecasts, avalanche hazard prediction, crop water supply evaluation, winter kill estimates, crop yield prediction, and climate modelling inputs. Based on experience gained from snow surveys, snow hydrology research, and remote sensing studies, a combined system of remote sensing and conventional snow measurements seems to be the most promising approach in the future.

Conventional snow survey measurements will continue to be made with increasing automation of many sites. These conventional snow survey measurements will provide basic information for snow runoff forecasting and calibration of microwave snow water equivalent measurements. After comparison with the point measurements, remote sensing data will then be used to extrapolate the conventional data over large areas. New in-situ instruments for water equivalent measurements, snowpack density profiles and profiles of liquid water content presently under development will be adopted at the automatic sites. Such data will have direct pertinence for input to the real time forecast models as well as for improving the comparison between conventional data and the variety of snow characteristics that can be derived from the microwave data.

Low altitude gamma-ray flights will be concentrated over open and flat areas and permanent flight lines will be surveyed every year. Selected areas will be surveyed on an irregular basis depending on flooding potential. Only limited use of this method will take place in the mountainous west with helicopters playing a significant role.

Significant research efforts will be expected to specify the microwave snow interaction and to develop techniques for extracting snowpack information from the microwave data. Radiative transfer models will be used to describe the processes involved, remote sensing derived parameters will be input to the models, and snowpack parameters of interest will be output. In mountain areas, once the techniques have been perfected, multispectral microwave systems will be flown at several thousand feet to obtain water equivalent and liquid water data over small watersheds and pre-selected flight lines. These data will be used to extend the ground-based data. The aircraft-mounted microwave systems may also find applications in nonmountainous snow areas because of the capability for assessing the hydrologic condition of the underlying soil.

High resolution (approximately 500m), geosynchronous earth resources satellites with visible and infrared sensors will provide the potential for near continuous, operational coverage of snow-covered area with delivery of data to users in 48-72 hours. The processed data will most likely come from regional data centers where computer programs will convert the satellite data into watershed snow extent maps. The maps will be available to all water and energy agencies and will be verified and calibrated when necessary by a small number of aircraft flights in various regions of the country.

Synthetic aperture radar systems will eventually be mounted on polar orbiting satellites for coverage of western U.S. snowpack areas with resolutions of about 25-100m. This will permit measurements of the snowpack in clearings in heavily forested areas at numerous points across a watershed for translation to large area water equivalent and liquid water data. Ground data will be used to calibrate and quantify the satellite data. It is possible that a low resolution (1-5km) radiometer would also be flown on this polar orbiter to provide large area coverage of relatively flat snow-covered regions. The active and passive systems could then be used for monitoring the extent, volume, and dynamics of the alpine and continental snowpacks, respectively. The ability to do this in all-weather conditions illustrates the great advantage of the microwave systems.

In order to achieve the above mentioned goals for snow hydrology applications, a vigorous program of research, development and testing must be undertaken. New sensor systems utilizing multifrequency, multichannel techniques should be developed to accommodate the spectral feature response, spatial resolution and repeat cycle time requirements. Because hydrologic data are dynamic and variable, the data delivery times are especially critical in system design. By adhering to these procedures, remote sensing data will provide the needed information to improve decision making by water resource managers.

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