NEW GOALS FOR SNOW MONITORING BY SATELLITE

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ABSTRACT

The success of the snow mapping ASVT program has encouraged me to contemplate what new research and operational goals we hydrologists ought to be setting for ourselves. Short-term research goals should include: 1) testing of a snow/cloud discrimination satellite sensor; 2) field studies in situ of spectral reflectance of snow under diverse conditions; 3) development of techniques to estimate albedo of snow from satellite sensors; 4) determination of the effects of physical properties and substrate on snow spectral reflectance; and 5) determination of the effect of atmospheric attenuation on snow spectral response.

Achievement of these short-term goals ought to lead us to our long-term goals: 1) estimation of density and/or water equivalent of snow; 2) an understanding of spectral reflectance and albedo of snow throughout seasonal metamorphosis.

Short-term operational goals must be: 1) to reduce the time required for receipt of satellite data; 2) to optimize the MSS type sensors for snow studies; 3) to test empirical models relating snow-covered area to runoff; 4) to understand the snowmelt process well enough to model it with satellite data input; 5) to develop a digitized automated snowmapping program; 6) to revamp existing models to accept satellite data; and 7) to deposit snow-cover data in existing international repositories.

Achievement of these short-term goals should result in approaching our long-term operational goals: 1) a near-real-time, semi-automated computerized preparation of snowmelt-runoff calculations; 2) accurate seasonal hydrologic forecasts of basin water supply based on snow-runoff data.

INTRODUCTION

Every ending is also a beginning. The end of the Applications Systems Verification and Transfer (ASVT) program in snow-cover observations is the appropriate time for us to look ahead and plan ahead. The success of the ASVT program will certainly engender new efforts in snow monitoring. The fact that NASA had invited me to speak to this select audience on a subject of great personal interest is appreciated, especially as I have been an unreimbursed but very interested observer and a strong supporter of the ASVT effort.

I would not quarrel with those who might say that this paper is a profound statement of the obvious. Nontheless, statements need to be made, and the obvious is not always obvious to everyone. The purpose of the paper is to present my point of view on the relative merits of future research and operational efforts that involve snow monitoring by satellite. If the goals here stated encourage only one graduate student to attack an unsolved snow monitoring problem, the paper would, in my view, have some redeeming research value.

OPERATIONAL GOALS

Table 1 shows both the short- and long-term operational goals, and Table 2 lists the research goals. These lists are certainly not complete. However, achievement of any of the goals represents a noteworthy milestone in the progress of satellite snow studies.

Table 1--Operational Goals

Short-Term

1. Reduce the lag time for receipt of data.
2. Optimize MSS-type sensors for snow studies.
3. Test empirical models relating snow-cover area to runoff.
4. Understand the snowmelt process well enough to model it with satellite-data input.
5. Develop a digitized automated snow mapping program.
6. Revamp existing models to accept satellite data.
7. Deposition of data in international data repositories.

Short-Term

1. Near-real-time, semi-automated computerized preparation

of snow melt-runoff calculations or forecasts.

2. Accurate seasonal hydrological forecasts of basin water supply based on snow-runoff data.

Table 2--Research Goals

Short-Term

1. Test a snow/cloud discrimination sensor.

2. Field (*in-situ*) studies of spectral reflectance of snow under diverse conditions.

3. Develop techniques to estimate albedo of snow from satellite sensors.

4. Determine effect of physical properties of snow and substrate on spectral reflectance.

5. Determine effects of atmospheric attenuation of snow spectral response.

Long-Term

1. Estimation of density and/or water equivalent of snow.

2. An understanding of spectral reflectance and albedo of snow throughout seasonal metamorphosis.

Short-Term Operational Goals

1. Reduce the lag time for receipt of data.

This long-standing goal was mentioned as an original objective of the ASVT (Rango, 1975). If NOAA and NASA are serious about providing coverage for operational hydrologic studies, they *must* insure timely delivery of their products. Snow hydrology is simply too dynamic to do otherwise. Although NOAA/NESS has a system of image receipt and dissemination that is rapid, NASA has not always been successful in getting Landsat images to operational snow mappers in time to be used in forecasts.

2. Optimize MSS-type sensors for snow studies

What is the best spectral band to observe snow? What advantages do multiband data provide for snow studies? Are currently used bands optimum? I have difficulty with these questions.

Landsat's MSS-5 (0.6-0.7μm) provides the best contrast between snow-covered and snow-free terrain (Barnes and Bowley, 1974). The NOAA VHRR sensor utilized the same band. However, measured snow-covered area is a function of the spectral band (Schneider and McGinnis, 1976). It is also a function of spatial resolution. Results from pixel-count digital classification techniques can be rather different from those from photo-interpretive techniques (Table 3).

Table 3--Comparison of Conventional Analysis vs. Computer-Generated Analysis (from McGinnis et al., in preparation; data from the American River basin, Calif.)

Date	Percent Snowcover Conventional Analysis (MSS 5)	Percent Snowcover Computer by GE Image 100	Ratio GE Image 100/ Conventional
8 May 1975	45	27	0.60
17 May 1975	40	20	0.50
13 Jun 1975	16	5	0.31
22 Jun 1975	12	2	0.17
1 Jul 1975	7	1	0.14
14 Apr 1976	41	21	0.51
23 Apr 1976	26	8	0.31
20 May 1976	7	1	0.14
29 May 1976	6	< 1	0.08

Mountain snowcover, especially during melt, includes elements of bare rock, shadows, forests, open water, roads, man-made structures, etc., all of which have an effect on the total spectral response from the area represented by a single pixel. Other workers (e.g., Itten, 1975), have reported similar difficulties when working at full pixel resolution and using various classifications of snow. Snow itself has a wide range of spectral response depending on not only its physical characteristics but also on the solar zenith angle. Polar-orbiting satellites cannot view the same pixel from pass to pass. However, as others will later demonstrate (Tarpley et al., 1979), geostationary satellites are more nearly able to view the same pixel from day to day.

The thematic mapper (TM) in Landsat D has two new spectral bands at 2.0-2.35μm and 1.55-1.75μm. They were designed to detect hydrothermal alteration of rocks. Both these bands should be investigated as possible indicators of snow physical properties. The 1.55-1.75μm band will permit cloud/snow discrimination (Barnes and Smallwood, 1975; Salomonson, 1978).

3. Test Empirical Models relating Snow-Covered Area to Runoff

Many readers would argue that this goal is (1) already attained for certain individual basins; and (2) should be a long-term goal, rather than a short-term goal. For some, the ultimate long-range goal is a universally accepted snowmelt runoff model based on snow-covered area. Whatever our individual goals, if we consider the field of satellite hydrology as a bona fide discipline, then we ought to strive for a whole new approach to hydrologic forecasting based on parameters that can be readily gathered by satellite. The work of Leaf (1975) and Martinec (1975) as well as Rango and Salomonson (1976) is noteworthy in that satellite-derived snow-covered area is used directly as an input in combination with conventional snow survey data for making residual volume streamflow forecasts.

4. Understand the Snowmelt Process well enough to Model it with satellite-data input

Many studies of snowmelt are carried out in areas of permanent snow packs or on glaciers. Studies of the transient snow of the temperate zones are less common. The physics of snowmelt is basically understood, but the challenge is to develop a technique from the perspective of the satellite. Thermal sensing provides a measure of temperatures, but the latent heat required for a change of state from solid to liquid makes zero-degree isotherm mapping less attractive. "Ripeness" of the snowpack is a term that is rather qualitative, but generally refers to an advanced state of metamorphosis in which the water-soaked snow is at or approaching zero degrees Celsius and is ready to contribute to runoff. If we could detect and identify this water-soaked "ripe" phase of the snowpack, perhaps we could relate time of runoff inception or water equivalent to it and thereby improve our hydrologic forecasts.

5. Develop a Digitized, Automated Snow-Mapping Program

The 1975 ASVT meeting referred to the desirability of digitized snow mapping (Itten, 1975; Algazi and Suk, 1975; Dallam and Foster, 1975; Luther et al., 1975; Bartolucci et al., 1975). Using DMSP data, the Air Force now produces a daily Northern Hemisphere 1:30,000,000 polar stereographic printout of snowcover. NOAA/NESS plans for digitized snow mapping from GOES are presented elsewhere in this volume by Schneider. Tomorrow, Ron Gird of NESS will discuss his latest efforts to develop the "automated digital snowcover map." Also this afternoon Prof. Haefner from Zurich will display examples of digital snow maps showing great detail, quite unlike the large-pixel GOES/VISSR data.

6. Revamp Existing Forecast Models to Accept Satellite Data

This goal is closely related to 3 and 4 above and need not be discussed again here.

7. Deposition of Data in International Data Repositories

World Glaciology Centre A is located in Boulder, Colorado. Its Director, Dr. Roger Barry, will now accept snow-covered-area measurements. Publications on river basin snowcover should be sent to this archive. His address is:

World Data Centre A for Glaciology
(Snow and Ice)
Institute of Arctic and Alpine Research
University of Colorado
Boulder, Colorado 80309 U.S.A.

Landsat satellite images and tapes are archived routinely at the EROS Data Center, Sioux Falls, S.D., and NOAA satellite images and tapes are routinely archived at EDIS, Camp Springs, Md.

Long-Term Operational Goals

If satellite hydrology is to become a bona fide subdiscipline of hydrology, it seems to me that these two goals:

1. Near real time, semiautomated computerized preparation of snowmelt-runoff calculations, and

2. Accurate long-term seasonal hydrological forecasts of basin water supply based on snow-runoff data

represent worthwhile goals. I believe that satellite data will be needed to accomplish these goals in part or in full. Operational hydrologists will--properly--be chary of accepting new techniques unless they have been tried, tested, and proved. The first long-term goal stresses quickness; the second stresses "accuracy." My own work in examining continental and hemispheric snowcover variations leads me to believe that long-range seasonal hydrologic forecasts where snow is an important variable may be significantly improved as a result of the continued collection of snowcover data. Because many of these techniques of forecasting require a fairly large set of data for statistical analysis, it may take a decade or two before we can fully assess the impact satellite data collection is having on hydrologic forecasting.

RESEARCH GOALS

Short-Term Research Goals

1. Test a Snow/Cloud Discriminator Sensor

This goal will be achieved in 1982 when Landsat-D's mapper (TM) begins to transmit data. Dr. Salomonson's paper, which will be given tomorrow afternoon, will provide complete details on this significant, new sensor. As previously indicated the seven-band TM includes a 1.55-1.75μm band, which as Barnes and Smallwood (1975) have pointed out, has a low reflectance for snow but a high reflectance for clouds, thereby permitting snow/cloud discrimination.

2. Field (in-situ) Studies of Spectral Reflectance of Snow under Diverse Conditions

If there is a weakness in our efforts to advance the science of remote sensing of snow, it is in the lack of attention paid to advancing our knowledge of in-situ natural snow metamorphosis with respect to the spectral variations in irradiance under diverse atmospheric conditions, at diverse sun angles, with various substrates, and as a function of physical properties of the snow. The work of O'Brien and Munis (1975) and the newer microwave studies being done at the National Bureau of Standards and at NASA/GSFC under Dr. Rango's general supervision are notable exceptions. The often-cited capability of microwave sensors to penetrate cloud cover makes this sensor of enormous--yet presently potential--value.

3. Develop Techniques to Estimate Albedo of Snow from Satellite Sensors

NOAA/NESS prepares an experimental daily albedo estimate and prepares maps of albedo using an automated program from the scanning radiometer aboard NOAA polar-orbiting satellites. These values are mapped in a 2.5° latitude-longitude array. However, these values include cloud tops and thus are not useful for localized snow-covered river basins. Snow albedo estimates mapped for snowcover in river basins would materially aid the forecasting hydrologist.

4. Determine Effect of Physical Properties of Snow and Substrate on Spectral Reflectance

This goal follows naturally from controlled and uncontrolled lab and field studies of snow as discussed in goal 2. Research efforts in the microwave spectrum have been made (Meier and Edgerton, 1971) and continue to be made (Chang and Choudhury, 1978), but an attempt to study snow substrates at CRREL (funded by NOAA/NESS) has met with difficulties (Fig. 1).

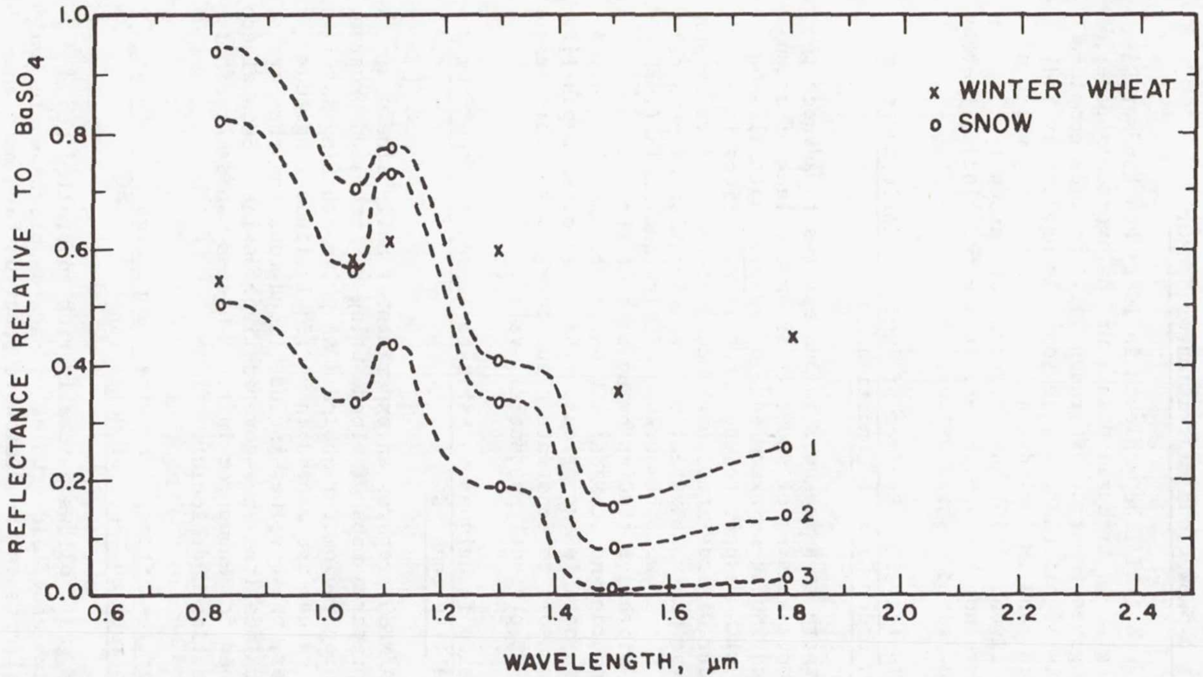

Figure 1. Spectral reflectance of snow melting <u>in situ</u> under solar irradiation. Curves are interpolated from data points. Curve 1 is based on measurements taken at 1040 LST, 11 April 1979, at Hanover, N.H., over 6.5 cm of snow that fell on 9 April 1979. Curve 2 is based on measurements taken at 1113, snow depth 5.5-6.0 cm; curve 3 is based on measurements taken at 1400 hours, snow depth 0.8-1.2 cm. The snow melted completely by 1445 hours. (Data from H. O'Brien, CRREL)

However, these efforts, under the direction of Mr. H. O'Brien, are continuing.

The Landsat-D TM bands, 1.55-1.75μm, and 2.08-2.35μm, ought to provide fresh insight into snow physical properties. Snow density, the presence of free water, grain size, hardness, and snow depth are parameters of interest.

5. Determine the Effects of Atmospheric Attenuation on the Spectral Response of the Snow

The superiority of band 5 (0.6-0.7μm) on Landsat-1 for snow mapping and general observation was quickly established, while band 4 was found to be obscured by haze and thin clouds. For serious research in multispectral investigations, atmospheric attenuation must be considered, especially where subtle differences in irradiance are presented as being definitive or diagnostic of snow types or metamorphic condition of the snow.

The most devastating attenuation of the spectral response of Landsat-obtained data was in fact not atmospheric but was bureaucratic. I refer to the arbitrary cutoff of high values of reflectance in Landsat MSS values in bands 4-6. This condition should be alleviated, but not completely cured by Landsat-D's Thematic Mapper (V. Salomonson, personal communication).

Long-Term Research Goals

1. Estimation of Density and/or Water Equivalent of Snow

Water balance equations are simply accounting procedures for keeping track of the water within the system and for determining the water in storage at any given time. The water equivalent of the snow is precisely the volumetric quantity that hydrologists need to know. If we could make an accurate daily assessment of water equivalent, snowmelt analysis problems would be virtually solved. No other quantity is more important in snow hydrology than water equivalent.

Is it realistic to expect that satellite sensors can give us this parameter? Depth, density and areal extent of snow are required. Spectral analysis may someday yield a density approximation. Snow depths can be averaged from ground stations with fair accuracy. Areal extent can indeed be obtained from satellite readings. In my opinion, snow density determinations will be made from Landsat-D's thematic mapper, if research continues at its present pace.

2. An Understanding of Spectral Reflectance and Albedo of Snow throughout Seasonal Metamorphosis

The goal of any research is ultimately to understand the phenomenon under study. The current textbook curves showing the spectral reflectance of snow are quite inadequate. The textbook curves relating snow albedo values to variation in time are not adequate for use with spectrally selective satellite sensors. This lack of basic physical measurements hampers the hydrologist as well as the remote-sensing specialist. Unless and until the problems cited here are given serious consideration our understanding of the basic physical relations governing snowmelt and its attendant radiometric effects on the snow surface will remain scant.

On one hand we are viewing the successful completion of a remarkable project: the verification of the need for and importance of snow-cover mapping in river basins for practical operational hydrology. On the other hand, we stand on the threshold of a new challenge: to add to our knowledge and understanding of the snowmelt process and to contribute toward development of improved hydrologic forecasts from the use of new sensors.

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