Estimation of Seasonal Flow in the Ob River Using Passive Microwave Snow Water Equivalent Data

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Abstract

A passive microwave snow algorithm, produced using data from the AMSR sensor on the Aqua satellite, has been used to estimate snow depth and snow water equivalent (SWE) for the Ob River Basin in western Siberia. Because there are very few places in the world where spatially dense networks of ground measurements exist, it is important to validate satellite-derived estimates of SWE and snow depth using other approaches. One way to do this is to look at water balance measurements – discharge versus basin-wide snow water equivalent. In this study, snowmelt runoff for the entire Ob Basin, for 2002-2003 and 2003-2004, was compared with basin-wide SWE. Results demonstrate that the AMSR-derived values of SWE corresponded favorably with the Ob discharge parameters for this admittedly very limited data set. Nevertheless, there is a possibility that these space-borne measurements can be used to predict basin-wide discharge before the onset of snowmelt.

1.0 Introduction

Currently, there is a combined heritage of more than 25 years of global, daily observations of snow cover (SC) and snow water equivalent (SWE) using space-borne passive microwave instrumentation. Passive microwave instruments have been found to be effective for SWE and snow depth estimation (see Chang at al., 1987, Foster et al., 1997 and Kelly at al., 2003), especially in terrain characterized by non-complex topography and low stand, homogeneous vegetation (Derksen et al., 2002). However, practical uncertainties related to the retrieval process persist, particularly in mountainous and forested regions. These uncertainties are largely caused by the relatively coarse spatial resolutions of the relevant wavebands of these instruments and can be partially reduced by increasing spatial resolution.

The Advanced Microwave Scanning Radiometer – EOS (AMSR-E) instrument aboard the Aqua spacecraft (launched in 2002) is an example of an advanced Earth observing technology that has improved spatial resolution compared with previous passive microwave instruments, such as the Scanning Multichannel Microwave Radiometer (SMMR – operating from 1978-1987)) and the Special Sensor Microwave Imager (SSM/I – operating from 1987-present). Potentially, AMSR-E can provide improved accuracy estimates of snow depth or SWE at both the regional and global scales.

The purpose of this paper is to assess the accuracy of the AMSR-E estimates of snow water equivalent (SWE) and snow cover (SC) of the Ob Basin compared to basin-wide discharge of the Ob River system – for the period 2002/03-2004-05. In essence, basin-wide SWE is regressed against peak daily discharge, peak monthly discharge and total seasonal discharge to determine whether or not these parameters have utility in forecasting streamflow in large Arctic basins**.** Where available, independent snow depth data, measured at a wide variety of locations within the Ob Basin, having different snow, terrain and vegetation characteristics, were also compared with the AMSR-derived estimates.

2.0 Passive Microwave Snow Algorithm

The microwave brightness temperature of snow observed by spaceborne sensors originates from radiation from the underlying ground surface, the snowpack, and the atmosphere. Snow crystals within the pack are effective at scattering upwelling microwave radiation and the microwave signature of the snow depends on both the number of scatterers in the snow and their scattering efficiency. The degree of scattering is frequency dependent with higher frequency (shorter wavelengths) radiation scattered more than lower frequency (longer wavelengths) radiation.

If a snowpack is not too shallow (> 5 cm or contains more than about 10 mm SWE), scattering of naturally emitted microwave radiation by snow crystals occurs and can be detected at frequencies greater than about 25 GHz. By comparing brightness temperatures detected at an antenna at frequencies greater than 25 GHz (typically scattering dominated) with those brightness temperatures detected at frequencies less than 25 GHz (typically emission dominated), it is possible to identify scattering surfaces. Generally, the strength of scattering signal is proportional to the SWE, and it is this relationship that forms the basis for estimating the water equivalent (or thickness) of a snow pack (Chang et al., 1987; Josberger et al., 1993; Pulliainen and Hallikainen, 1999; Tsang et al., 2000; Kelly et al., 2003).

To derive snow depth, SWE is simply divided by the snow density. It has been determined that in general, a snow density value of 300 kg/m^3 is representative of mature mid winter snow packs in North America (Foster et al., 1997).

The data are projected into a 25 km x 25 km Equal Area Scaleable Earth grid (EASE grid). Overlapping data in cells from separate orbits are averaged to give a single brightness temperature, assumed to be located at the center of the cell (Armstrong and Brodzik, 1995.

In this paper, the algorithm used to estimate snow depth is the baseline algorithm currently in production for the AMSR-E Level 3 snow product. To summarize, snow depth (*SD*) is calculated from:

$$SD = a\,(Tb18H - Tb36H) / (1 - 0.2\,ff) \quad [\mathrm{cm}] \qquad (1)$$

where *Tb18H* and *Tb36H* are the horizontally polarized brightness temperatures (K) at 18 and 36 GHz respectively, and the coefficient *a* is 1.6 cm K^{-1} and was originally calibrated to represent a snowpack with an average snow grain radius of 0.30 mm and density 0.3 g cm^{-1} (Chang et al., 1987). *Ff* is the fractional forest cover within each 25 x 25 km area and is obtained from MODIS land cover data.

3.0 The Ob Basin

The Ob River is the largest Russian river with respect to its watershed area (2, 975, 000 km^2) and the 3rd largest contributor of fresh water to the Arctic Ocean – a mean flow of 412 km^3/year. The Ob originates in the Altai Mountains and flows northward across the vast West Siberian lowland towards the Arctic Ocean. The majority of the snow cover is contained in the lowlands rather than in mountainous regions and persists for six months or more. During the snow season, surface air temperatures are very cold, averaging less than -15 C at Omsk and below –25 C at Salekhard, for example. Therefore, the combination of cold, dry snow and large areas of uniform topography is well suited for snowpack extent and water equivalent retrievals from passive microwave observations. Tundra is found in the northern portions of the Ob basin, and the lack of forest cover again facilitates microwave snow mapping. Taiga covers only the basins midsection, while the southwestern part of the watershed is primarily steppe.

Snowmelt typically begins in April in the southern reaches of the basin but not until June near the mouth of the Ob. Maximum flows usually occur in May when the south-north flood wave finally compromises the ice cover. The only large reservoir on the Ob is located near Novosibirsk, at the southeastern end of the basin, but this diversion is rather small and has little impact on the total flow entering the Arctic Ocean (Grippa et al., in press).

4.0 Results and Analysis

4.1 River Discharge and AMSR Data

In 2003, the peak daily flow was observed on May 25 (40,800 m^3s^{-1}), and daily flows remained over 30,000 m^3s^{-1} until late July. The average monthly maximum discharge was noted in the month of June (1,031,190 m^3s^{-1}), and the total seasonal flow was approximately 4,574,592 m^3s^{-1}. A maximum stage height of 4.944 m was reported in early June. In 2004, the daily peak flow was recorded on June 6 (37,400 m^3s^{-1}), and flows over 30,000 m^3s^{-1}were maintained for just one month. The average monthly maximum also occurred in June (1,035,870 m^3s^{-1}), and the total seasonal flow was approximately 4,025,071 m^3s^{-1}. Ob discharge data and AMSR snow data for the years 2002/03 and, 2003/04 are presented in Figure 1.

4.2 Analysis

With only 2 years of data, very little can be said in regards to how river discharge for the Ob basin relates to basin-wide snow depth and SWE. However, the correspondence between maximum basin-wide SWE, in late winter, during 2003 and 2004 and peak daily discharge, maximum monthly discharge and total seasonal discharge is worth noting. The peak date of maximum basin-wide SWE in both 2002/03 and 2003/04 occurred on March 13. In 2003, the total SWE in $m^3$was approximately 2.4×10^{15}, whereas in 2004, the total SWE was approximately 1.7×10^{15}. About 98% of the Ob basin was snow covered on March 13 in both of these years. As can be seen in Figure 1, while peak daily flow was slightly higher in 2004 than in 2003, peak monthly flow and peak seasonal flow for 2003 and 2004 were in accord with AMSR-derived basin wide SWE estimates. Figure 2 lends credence to the validity of the AMSR SWE estimates inasmuch as data from meteorological stations, in general, is in agreement with the satellite-derived snow depth.

5.0 Discussion

In an earlier study (Mognard et. al, 2004), AMSR-E estimates compared favorably with integrated ground measurements of snow depth in western Siberia using data from the World Meteorological Organization global surface summary. For example, the average daily basin-wide snow depth error for the winter of 2002-2003 was 5.4 cm (Figure 2). Chang et al. (2005) show that when using ground point measurements, within a 1 x 1 degree grid, at least 10 point measurements are required to obtain an estimation of the snow depth to within 5 cm or better. Fewer points increase the uncertainty of representation. This is important because there are relatively few locations in the world where spatially dense networks of ground measurements exist. Thus, space-borne observations are required to both augment the ground data, where and when available, and as a sole source of snow data in unpopulated regions.

Where the surface conditions affect snowmelt runoff, in permafrost areas for instance, relating SWE to discharge can be problematic. In addition, ice jamming on north flowing rivers can seriously impact runoff reaching the river channel. Recognizing these difficulties here we attempted to assess the efficacy of using SWE estimated for one of the largest basins in Eurasia with basin-wide discharge. Because of the limited data, terms such as "corresponds favorably" must be used rather than "highly correlated." Several more years of AMSR and river discharge data are needed to further refine these statistics, including confidence levels and error bars, are available. For this investigation recent discharge data from sub basins was not yet available, in the near future, SWE for individual watersheds (greater than about 5,000 km^2) can be compared with discharge from these smaller units. Results in this case are expected to be more meaningful since streamflow emanating from a sub basin of the Ob, rather than from the entire Ob basin, is much more likely to reflect the observed snow conditions found within that sub unit, where the sub climate, physical hydrology and vegetation characteristics are more similar.

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6.0 Conclusions

Results demonstrate that the AMSR-derived values of SWE corresponded favorably with the Ob discharge parameters for this admittedly very limited data set. There is a possibility that these space-borne measurements can be used to predict basin-wide discharge before the onset of snowmelt.

7.0 References

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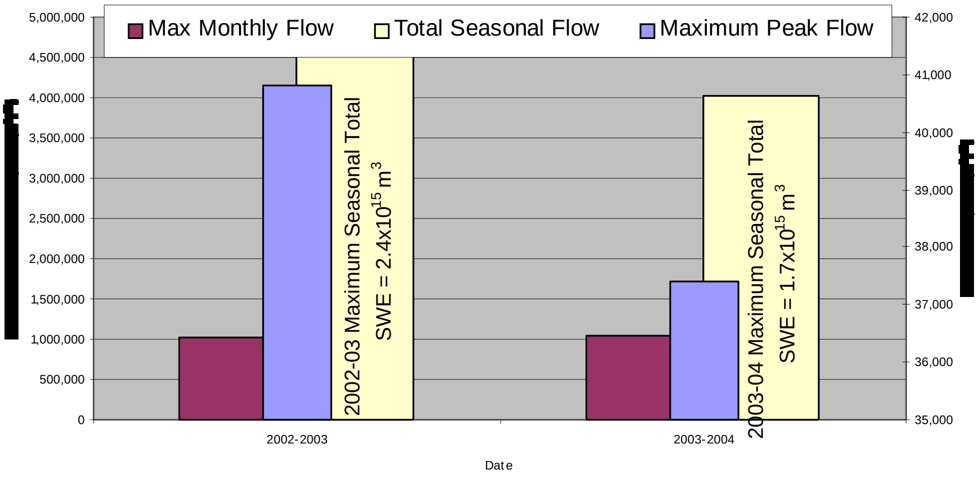

Figure 1– Chart showing discharge from the Ob Basin (Salekhard station near the mouth of the Ob River). Peak flow, maximum monthly flow, total seasonal flow, and maximum snow water equivalent derived from AMSR, for the entire Ob Basin are shown.

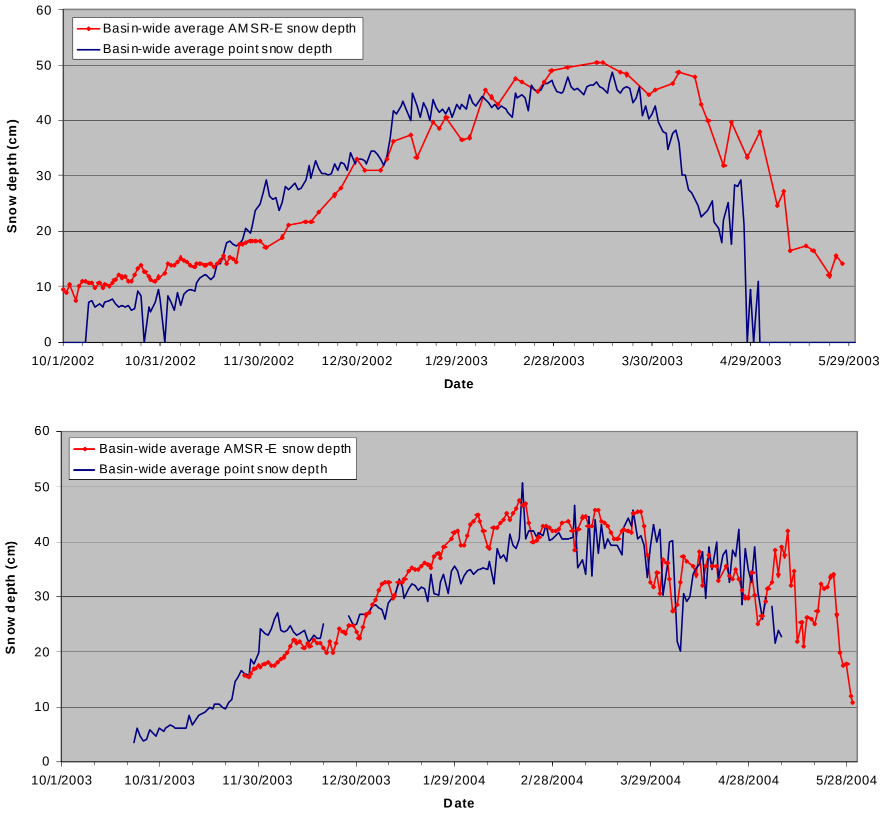

Figure 2 - Comparison of AMSR-derived snow depth with snow depth averaged from meteorological stations in the OB Basin (top, 2002-2003 and bottom, 2003-2004)