3.1 IMPROVING WESTERN UNITED STATES SNOW WATER EQUIVALENT (SWE) ESTIMATES FROM PASSIVE MICROWAVE SENSORS

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1. INTRODUCTION

Passive microwave data have been used to estimate snow water equivalent (SWE). Snow water equivalent is measured as the depth of the equivalent amount of liquid water in mm. Brightness temperatures from the sensors are converted to SWE using a regression approach (Chang et al., 1987). However, such methods underestimate tend to underestimate actual SWE when dense vegetation is present, when the snow is melting, and when the snowpack is shallow or patchy (Chang et al., 1996; Robinson and Frei, 2000). For very deep snow, passive microwave SWE estimation is limited because brightness temperature no longer varies as a function of depth (Armstrong et. al. 1993). The purpose of this research is to improve the satellite-derived SWE estimates over selected regions in the western United States.

2. APPROACH

The overall approach is to use ground-based measurements of SWE to calibrate the satellite-derived estimates of SWE. For this purpose, we use station data from the Natural Resources Conservation Service (NRCS) Snowpack Telemetry sites (SNOTEL) from water years 1981–1999. Satellite-derived SWE data come from the Scanning Multichannel Microwave Radiometer (SMMR; 1981- 1987) and the Special Sensor Microwave/Imager (SSM/I; 1987-1999). Weekly satellite-derived SWE values were provided by Armstrong and Brodzik (2000). Two regions are examined: the Pacific Northwest and Colorado. SNOTEL station data area aggregated for each region and the mean weekly SWE value is computed. Every fourth week is removed from each of these two periods and set aside as a validation data set. The remaining values are used to develop the relationship between the SNOTEL and satellite SWE values. In order to preserve the mean and variance of the "ground truth" data and to avoid negative values that can result with a regression approach, we use a distribution swapping approach (Panofsky and Brier, 1963). The data in the calibration period are ranked. The SNOTEL SWE value is substituted for the microwave SWE value of equal rank. The relationship is tested using the validation data.

We also explore how vegetation cover affects the relationship between SNOTEL SWE and microwave SWE. For this, we use a gridded data set of percent vegetation cover and cover type (DeFries et al., 1999).

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3. RESULTS

For the calibration data sets, the microwave SWE time series have significantly different means and variances with the microwave data underestimating SWE (Figures 1 and 2). In Figs 1 and 2, the microwave SWE has been multiplied by 4 so for visual comparison with the SNOTEL. Correlation coefficients between microwave and SNOTEL SWE for the calibration period are .51 (SMMR) and .52 (SSMI) for the Pacific Northwest and 0.64 (SMMR) and 0.66 (SSMI) for Colorado. The Pacific Northwest usually receives higher snowfall than Colorado.

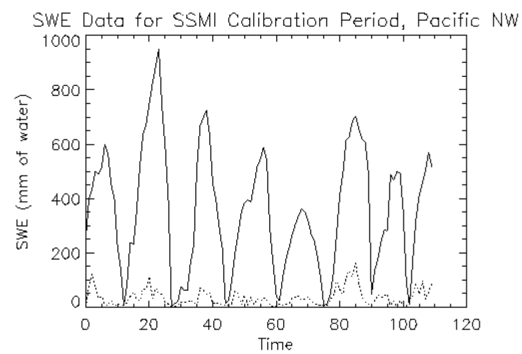

Figure 1. SSM/I period (1988-1999) calibration SWE for the Pacific Northwest. SNOTEL are indicated by the solid line and microwave data (multiplied by 4) by the dotted line.

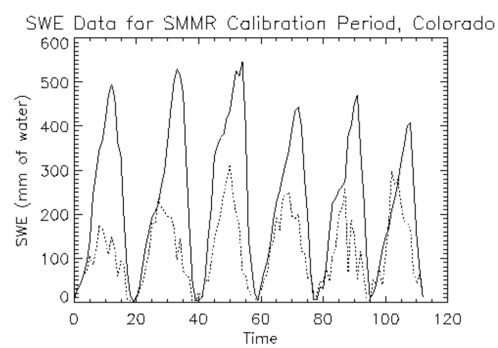

Figure 2. SMMR period (1981- 1987) calibration SWE data for Colorado. SNOTEL are indicated by the solid line and microwave data (multiplied by 4) by the dotted line.

After the distribution swapping, we see a great improvement in the agreement between SNOTEL and microwave SWE values. For the Pacific Northwest, the correlation coefficients increase to .56 (SMMR) and .59 (SSMI) and for Colorado they rise to .72 (SMMR) and .61 (SSMI). The mean and variances are captured very well for both regions, for both the SMMR and SSMI time periods. Figure 3 shows the SMMR period validation results for the

Pacific Northwest region. The means and variances are not significantly different as shown by Student's T tests of means and F-tests of variances. The SSM/I data are more effectively modeled than the SMMR data for this region. These tests show that the data are adequately modeled by the distribution swapping technique. Results from Colorado indicate that the adjusted SWE values (Fig. 4) capture the magnitude of the peak SWE reasonably well. Root mean squared error (RMSE) values were computed for the difference between SNOTEL and satellite SWE for both regions. RMSE values for the Pacific Northwest were 246.3 and 200.1 mm of water for SMMR and SSMI, respectively. RMSE values for Colorado were 123.5 and 121.7 mm of water for SMMR and SSMI, respectively. In all cases, the microwave estimated peak occurs about 3 weeks prior to the SNOTEL peak SWE.

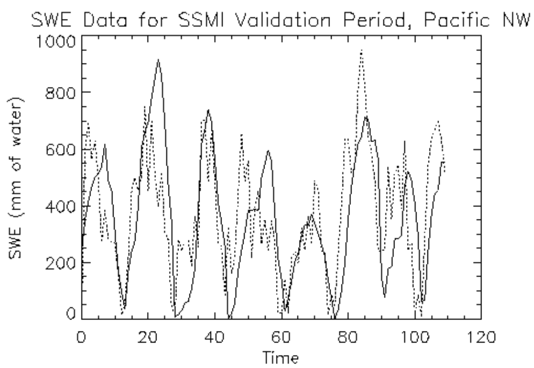

Figure 3. SSM/I validation for region 1, Pacific Northwest showing the estimated SWE (dotted line) and the SNOTEL SWE (solid line).

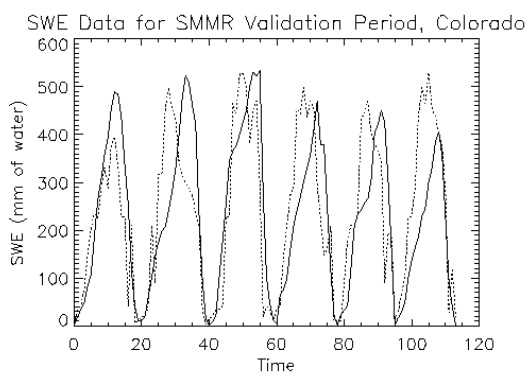

Figure 4. SMMR validation for Colorado showing estimated SWE (dotted line) and SNOTEL SWE (solid line).

3. DISCUSSION

A consistent pattern in the results is of an offset in the peak SWE values between SNOTEL data and satellite data. The peaks occur later in the SNOTEL because the stations are typically located at high elevations that receive much snow while the microwave is averaging over a 625-km^2 area over which the snow cover is more spatially variable.

The results show that Colorado, is more accurately modeled than the Pacific Northwest. The RMSE is lower and Figure 4 shows that the variability is better captured in this region. An explanation lies in differences in vegetation cover type and densities for the two regions. Mean percent vegetation cover for the regions obtained from the AVHRR are examined and compared to the mean microwave SWE value for the region. The Pacific Northwest region is highly vegetated with evergreen needleleaf trees while the Colorado region has much a much lower mean percent evergreen needleleaf tree cover. Pearson's rank correlation values indicate high negative correlation between vegetation cover and SWE for the Pacific Northwest, while in Colorado, there was no such correlation. Clearly, vegetation plays a role in the ability of the microwave sensor to estimate SWE. In areas of high vegetation, the sensor significantly underestimates snowcover.

4. CONCLUSIONS

Satellite-derived SWE estimates over Colorado and the Pacific Northwest regions are improved using a distribution swapping technique where data from SNOTEL stations are used as ground truth. The peaks of the SNOTEL data are delayed in comparison to the microwave due to the positioning of the SNOTEL station sites in high elevation, high snow cover region and because the microwave is biased towards lower snow because of spatial disagreement. Colorado, is better modeled than the Pacific Northwest and this can be explained by the effect of vegetation on the sensors' ability to estimate SWE. Further work will examine relationships between SNOTEL and microwave SWE for other regions in the western United States.

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