Atmospheric Corrections for Improved Satellite Passive Microwave Snow Cover Retrievals over the Tibet Plateau

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C23A-0942

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Introduction

Since 1978, satellite passive microwave data have been used to derive hemispheric-scale snow cover maps. The seasonal and inter-annual variability of the microwave snow maps compares reasonably well with simultaneous maps of snow cover derived from satellite-based, visible-wavelength sensors. In general, the microwave-derived maps tend to underestimate snow extent during fall and early winter, due to a weak signal from shallow and intermittent snow cover. The Tibet Plateau is the only large geographic region where microwave retrievals tend to consistently overestimate snow-covered area compared to the visible data. The microwave overestimate is also clearly evident in multi-year monthly climatologies.

Current microwave algorithms used to derive snow cover are based on ground or aircraft measurements that are later fine-tuned for satellite use. In this way, the algorithms have implicitly accounted for the presence of an atmosphere, because the brightness temperatures used in the algorithms have already passed through the atmosphere when measured at the satellite sensor. These methods are reasonably accurate when applied as a global algorithm to most snow-covered regions. However, a thinner atmosphere between the surface and satellite is likely the source of the consistent microwave snow extent overestimate on the Tibet Plateau, where elevations range from 3,200 to over 5,000 m.

We present a methodology to adjust satellite-based microwave brightness temperatures as a function of the observed surface elevation, thereby reducing the microwave snow cover overestimate on the Tibet Plateau. We include comparisons to snow maps derived from selected visible-wavelength products. We estimate that the adjusted microwave algorithm reduces the Tibet Plateau area of disagreement with the NOAA snow charts by approximately 17% (468,000 km2) over the snow season.

Motivation

The Tibet Plateau is the only large geographic region in the Northern Hemisphere where the microwave retrievals tend to consistently overestimate snow-covered area compared to visible data. This was noted in limited case studies at the time of the initial comparisons of visible and microwave data. The microwave overestimate is also persistent over time, as demonstrated by the multi-year climatologies[3] (Figure 4).

Figure 1 (below) illustrates the typical spatial pattern of microwave overmeasure (green) in the high elevation regions of the Tibet Plateau. During Decembers for the period of record, the figure shows regions where both visible and microwave detect snow (gray), only visible methods detect snow (orange) or only microwave detects snow (green). Elevation contours are included, with elevations of 3200 m and higher in red, demarcating the region where we will apply high elevation adjustments.

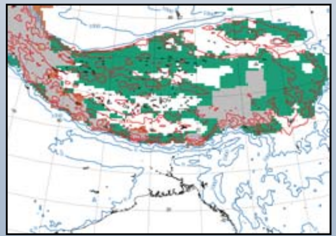

Figure 1: Tibet Plateau December snow-covered area difference climatology, 1987-2007, with elevation contours, showing microwave overmeasure (green) at high elevation locations. Visible data are derived from NOAA snow charts. Passive microwave snow cover is derived from SSM/I. The area shown is the subset box outlined in the upper right image of Figure 4.

Proposed Adjustments

Since we suspect the reduced atmosphere over the Tibet Plateau leads to the over-measure of passive microwave snow, we model the effects of adding back atmosphere to adjust the measured brightness temperatures.

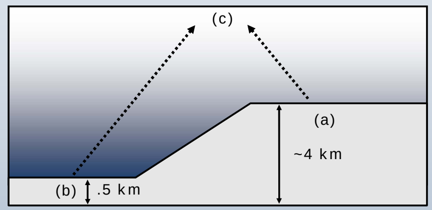

Figure 2 is a cartoon diagram of the situation.

Imagine the case of a snow-covered surface at high elevation (a).
•A satellite sensor observes the surface through a thin atmosphere, (a) to (c).
•Using a representative sounding of the atmosphere between (a) and (c) and radiative transfer equations, we estimate the physical properties of the surface (a).
•Next we figuratively move the surface to a lower reference elevation (b).
•Using the inverse radiative transfer equation with representative soundings from (b) to (c), we estimate what the sensor would have measured, had it observed the identical surface through a thicker atmosphere, more typical of the regions where the algorithms were first validated.

The paper detailing this adjustment is in preparation.[4]

Seasonal Application

To test the adjustments, we compute the passive microwave snow algorithm with and without adjusted brightness temperatures for a single snow season and compare with visible-derived snow cover maps derived from NOAA IMS[5] and MOD10C1.[6]

For the comparison, we examine grid cells where both sensors have valid data and the surface elevation is at least 3200 m. We define a Failure Index as the percent of examined grid cells where passive microwave and visible algorithms yield different snow cover values.

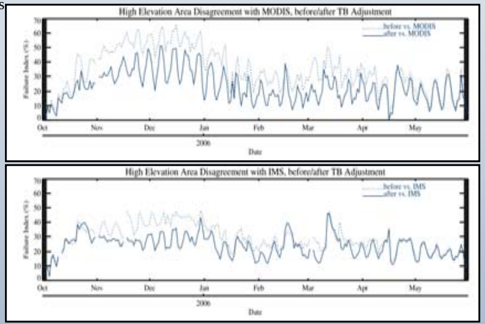

Figure 3. Time series of daily microwave algorithm performance compared to (top) NOAA IMS and (bottom) MOD10C1 snow cover, before/after (dotted/solid lines respectively) high elevation adjustment, winter season, 2005-2006. Periodicity in plots is due to precession of the area of missing microwave observations across the Plateau. Note the reduction in disagreement after applying the adjustment.

The adjusted algorithm (solid line) reduces the failure index in both comparisons. For the season shown, the adjustment reduces the failure index compared with IMS (MOD10C1) on average from 29% to 24% (34% to 23%).

Climatological Results

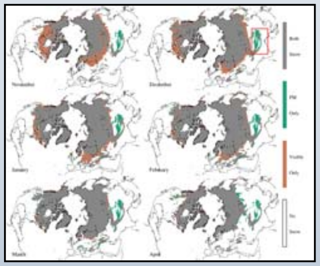

Figure 4 shows unadjusted difference climatologies. Large, consistent passive microwave overmeasure is evident on the Tibet Plateau throughout the season (green areas). The red box indicates the subset region shown in Figure 1.

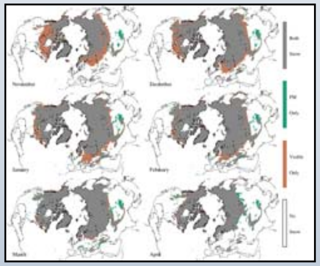

Figure 5 shows difference climatologies where our proposed adjustments have been applied to the brightness temperatures (above 3200 m) before use in the algorithm. Note the reduction in overmeasure.

Figures 4 and 5 show the Northern Hemisphere monthly snow-covered area difference climatologies, 1987-2007. Visible maps are derived from NOAA snow charts. Passive microwave (PM) snow cover is derived from SSM/I[3]. Compare before and after adjustments and it is apparent that the climatological results for the corrected passive microwave methods show less disagreement with the visible (less green area on the Tibet Plateau).

Considering only high elevation grid cells, on average over the period of record we see an 11% (303,000 km2) improvement in misclassified grid cells. During the heavy snow cover months(October through April) we see that the total incorrectly categorized area improves on average 17% (468,000 km2).

Conclusions

We do not imply that the Tibet Plateau is the only region where atmospheric adjustment could be made, but rather that it is a unique region where the atmospheric adjustment must be made in order for the snow-covered area derived from passive microwave to be reasonably accurate. There are other regions of the world with snow cover at elevations above 3200 m but these are limited in area. In the Northern Hemisphere, less that 1% of the grid cells above 3200 m are outside of the Tibet Plateau.

We have derived a method to adjust brightness temperature for observations over high elevation surfaces. When used in our passive microwave snow algorithm, the adjustments reduce the overall climatological disagreement with NOAA snow maps by 11% (303,000 km2) for the period 1987-2007 and 17% (468,000 km2) during the snow season (October through April).

References

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References:

3 Armstrong, R. L. and M. J. Brodzik. 2001. Recent Northern Hemisphere snow extent: A comparison of data derived from visible and microwave satellite sensors. Geophysical Research Letters, 28(19):3673-3676.

4 Savoie, M. H., Wang, J., Brodzik, M. J. and Armstrong, R. L., Atmospheric Corrections for Improved Satellite Passive Microwave Snow Cover Retrievals over the Tibet Plateau, in preparation 2008.

5 IMS Daily Northern Hemisphere Snow and Ice Analysis at 4 km and 24 km Resolution (http://nsidc.org/data/docs/noaa/g02156_ims_snow_ice_analysis/index.html)

6 MODIS/Terra Snow Cover Daily L3 Global 0.05Deg CMG (http://nsidc.org/data/mod10c1.html)

Funding for this work has been provided by NASA Research Grant NNG04GN38G. For more details on snow and ice data sets, please refer to our Web site at http://nsidc.org.