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Retrieval of precipitable water using Special Sensor Microwave/Temperature-2 (SSM/T-2) millimeter-wave radiometric measurements

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[1] Four years of Special Sensor Microwave/Temperature-2 (SSM/T-2) measurements over the high-latitude regions of both the Northern and Southern Hemispheres are used to retrieve precipitable water $W < 0.8$ cm. The retrieved W values compare well with several thousand near-concurrent radiosonde-derived estimates of W. Additionally, very good agreement is found between the retrieved SSM/T-2 W values and continuous ground-based radiometer-derived estimates of W during a couple of extended time periods. A bias (0.03–0.06 cm) exists between the W values retrieved from the SSM/T-2 and the values derived from the radiosonde/radiometer observations. This bias is caused primarily by the assumption of equivalent surface emissivity across the 150–183 GHz frequency range that is made during the development of the retrieval algorithm. The spatial distribution of the SSM/T-2-retrieved winter mean W values is examined together with digital elevation models for both the Greenland and Antarctic ice sheets. This detailed comparison conveys expected climatological characteristics that are quite sensible when the combined effects of the surface elevation and the general atmospheric circulation patterns near and over the ice sheets are considered in unison. The SSM/T-2 W retrieval presented provides accurate W information with a high sampling rate for the potentially climate change-sensitive polar regions of the Northern and Southern Hemispheres. *INDEX TERMS:* 1836 Hydrology: Hydrologic budget (1655); 1878 Hydrology: Water/energy interactions; 1655 Global Change: Water cycles (1836); 1694 Global Change: Instruments and techniques; 3360 Meteorology and Atmospheric Dynamics: Remote sensing; *KEYWORDS:* millimeter-wave, radiometry, remote sensing, precipitable water, water vapor, polar meteorology

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1. Introduction

[2] Although high-latitude regions receive much less incoming solar radiation than the equatorial regions, the high-latitude contribution to the outgoing longwave radiation budget is substantial [*Salby*, 1996]. Atmospheric water vapor is an important source of energy that feeds the development of weather systems while also being a strong absorber of infrared radiation with a significant impact on the planetary greenhouse effect. Therefore water vapor in these regions is linked through its local influence on the longwave radiation budget to global energy balance and climate.

[3] When assessing the polar surface radiation budget, uncertainties in the estimation of atmospheric water vapor can create errors in satellite-derived estimates of surface temperature [*Key and Haefliger*, 1992] as well as surface albedo [*Rossow et al.*, 1989]. Therefore accurate knowledge of seasonal and regional variations of precipitable water for the high-latitude regions should help

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improve the accuracy of these important retrievals. Additionally, there are numerous passive microwave radiometer retrieval techniques used at high latitudes that could potentially benefit from quantifying the effect of water vapor. For instance, *Abdulati and Steffen* [1997] note that none of the passive microwave methods used to detect snowmelt over ice sheets has included any quantification of the variability in the input brightness temperatures that can be caused by changing atmospheric conditions. *Steffen et al.* [1992] make the same statement in reference to several passive microwave sea ice retrieval algorithms. Other passive microwave retrievals such as surface temperature [*Shuman et al.*, 1996] and snow depth [*Foster et al.*, 1997] could also benefit from quantifying the effect of water vapor. The amount of improvement would likely be small for most retrieval cases; however, a recent study demonstrates that the effects should not be ignored, especially when the retrieval method uses frequencies $\geq$37 GHz [*Wang and Manning*, 2003a].

[4] Until a few years ago, satellite microwave measurements of precipitable water W were limited to the ocean areas where the cold ocean surface microwave emission can be accurately characterized [e.g., *Alishouse et al.*, 1990; *Manning*, 1997]; the retrieval technique is based on multichannel measurements near the weak water vapor absorption line of 22.235 GHz and nearby window regions. Recently, algorithms using measurements near the stronger water vapor line of 183.31 GHz have been developed to retrieve low $W < 0.8$ cm over Antarctica [*Conlee*, 1994; *Moore*, 1997; *Miao*, 1998; *Miao et al.*, 2001]. *Miao et al.* [2001] validated an independently derived Special Sensor Microwave/Temperature-2 (SSM/T-2) W retrieval method over Antarctica using 1 month of numerical model data while also demonstrating the retrieval method's capability of showing seasonal variations of water vapor over Antarctica. They further asserted that the retrieval method's high sensitivity to water vapor and low sensitivity to surface emissivity characteristics and clouds make the proposed method especially useful in polar regions where atmospheric water vapor measurements are temporally and spatially sparse.

[5] The regression approach of *Miao et al.* [2001] is straightforward and was utilized by *Wang et al.* [2001, 2002] in their analysis of the airborne Millimeter-wave Imaging Radiometer (MIR) measurements over the Arctic and midwest regions; more specific details related to the algorithm are provided in section 2.2. *Wang and Manning* [2003b] further extended the analysis to cover a few days of near-concurrent MIR and SSM/T-2 data over these regions and discussed the error sources caused by variations of surface temperature T_s and emissivity $\xi(\nu)$ (at frequency ν). The approach proved to be quite robust after these errors were adequately corrected within the retrieval procedure.

[6] The same regression approach [*Wang and Manning*, 2003b] is applied to the Defense Meteorological Satellite Platform (DMSP) SSM/T-2 data set over the midlatitude and high-latitude regions of the Northern and Southern Hemispheres, and the output is compared directly with instantaneous radiosonde- and radiometer-derived point measurements of W where applicable. The primary objective of this study is to thoroughly examine the instantaneous performance of the SSM/T-2 W retrieval procedure in an effort to more completely assess the quality of the product generated.

6. Conclusions

[30] The radiometric measurements from the 150 and 183 GHz channels of the SSM/T-2 on board the DMSP F12, F14, and F15 satellites are used to retrieve precipitable water W in the high-latitude regions of both the Northern and Southern Hemispheres for the period 1998–2001. The retrieval results are validated with those derived from near-concurrent radiosonde and ground-based microwave radiometer observations; good agreement is shown between the SSM/T-2 W retrievals and both validation groups. The retrieved W values, on average, are higher than the radiosonde-derived values by 0.008 cm in the Southern Hemisphere and by 0.05 cm in the Northern Hemisphere. This bias is mostly attributable to the assumption of frequency-independent surface emissivity $\xi(\nu)$ across 150–183 GHz in the development of the retrieval algorithm. On the basis of the comparison cases where $W \leq 0.2$ cm and the retrievals using the three 183.31 GHz channels are applicable the average differences of $\xi(150)-\xi(183)$ are estimated to be -0.011 and -0.037 for the Southern Hemisphere and Northern Hemisphere radiosonde station locations, respectively. Therefore the observed biases between the retrieved and radiosonde-derived W values are consistent with the magnitude of the emissivity differences shown by *Wang and Manning* [2003b]. Correction to this emissivity-induced error is a nontrivial problem based on the currently available channels of SSM/T-2 measurements.

[31] The large-scale general circulation features revealed by the SSM/T-2 W retrieval results agree well with the atmospheric water vapor characteristics described by *Serreze and Barry* [1995] for the area around 70°N. Furthermore, the spatial distribution of the SSM/T-2-retrieved winter mean W values corresponds well with recently derived digital elevation models for both the Greenland and Antarctic ice sheets. Collectively, the comparisons of the SSM/T-2 W retrieval product with other data sources strongly suggest that the retrieval procedure presented provides accurate W information with a high sampling rate for the potentially climate change-sensitive polar regions of the Northern and Southern Hemispheres.