A yearlong comparison of plot-scale and satellite footprint-scale 19 and 37 GHz brightness of the Alaskan North Slope

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[1] Subpixel heterogeneity remains a key issue in the estimation of land parameters using satellite passive microwave sensors; the scales of spatial variability on land are typically much smaller than sensor footprints (tens of km). Disaggregation is a necessary component of any successful assimilation or retrieval scheme attempting to exploit satellite passive microwave observations to estimate parameters at the local scale. This paper quantifies the similarity between ground-based brightness and satellite brightness observations at 19 and 37 GHz for Arctic tundra on the North Slope of Alaska, identifying and quantifying sources of the differences. To the extent that this very homogeneous area represents a limiting case, the impact of subpixel heterogeneity in less homogeneous areas may be gauged. The ground-based radiobrightness observations were collected during the Radiobrightness Energy Balance Experiment 3 (REBEX-3) conducted on the North Slope in 1994–1995. A comparison was made of 381 days of brightness observations from a tower-mounted Special Sensor Microwave Imager (SSM/I) simulator representing the full range of annual conditions with coincident satellite SSM/I observations. Issues such as instrument stability, the effects of atmospheric radiative transfer, and consistency of satellite pixel locations are considered. Linear correlations between tower-based and SSM/I brightness observations of 0.93, 0.94, 0.93, and 0.92 were observed for the 19V, 19H, 37V, and 37H channels, respectively. Footprint sizes were 2 × 4 m for the tower-based observations and 43 × 69 km for the resampled SSM/I observations. Atmospheric, topographic, and time-of-observation effects can account for the differences between the best fit lines and the 1:1 lines, with calibration errors accounting for the residual differences. *INDEX TERMS:* 1823 Hydrology: Frozen ground; 1863 Hydrology: Snow and ice (1827); 3360 Meteorology and Atmospheric Dynamics: Remote sensing; 6969 Radio Science: Remote sensing; 9315 Information Related to Geographic Region: Arctic region; *KEYWORDS:* remote sensing, microwaves, radiometry, Arctic, tundra, land surface

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1. Background

[2] The Arctic is a key component of both atmospheric and oceanic general circulations, through which Arctic processes interact with global processes. Several climate warming scenarios have predicted that the largest changes will occur at high latitudes [*Houghton et al.*, 1996]. For example, doubled-CO_2 atmospheric general circulation model simulations predict increases in the global mean surface air temperature of 1°–4.5°C by the year 2100 [*Houghton et al.*, 1996], with even greater warming expected in certain parts of the Arctic [*Manabe et al.*, 1991].

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[3] Both short-term and long-term warming trends have already been observed in the Arctic [*Chapman and Walsh*, 1993; *Hansen and Lebedeff*, 1987]. Decadal or longer-term warming of permafrost is apparent in borehole temperature profiles [*Osterkamp and Romanovsky*, 1999; *Lachenbruch and Marshall*, 1986]; this has resulted in a loss of permafrost [*Williams and Smith*, 1989; *Houghton et al.*, 1996] and will result in changes in the regional ecosystems [*Oechel et al.*, 2000; *Michaelson et al.*, 1996]. Warming promotes thawing of the permafrost, which affects the surface hydrology of the Arctic through a deeper active layer (the upper portion of the tundra and permafrost which thaws during the summer), increased soil moisture storage, warmer soil temperatures, and increased evaporation [*Hinzman and Kane*, 1992].

4. Conclusions and Implications for Lower-Frequency Observations

[63] REBEX-3 was undertaken from September 1994 through September 1995 on the North Slope of Alaska. One of its purposes was to determine how well passive microwave satellite observations might be used to estimate surface conditions in tundra/permafrost areas. Specifically, we sought to explore the scaling issue associated with large satellite radiometer footprints by determining how well ground-based radiobrightness observations would match satellite radiobrightness observations, to identify sources of any differences, and to begin to understand how they could affect estimates of surface conditions.

[64] The TMRS2 instrument system was developed for this project and was designed to collect the ground-based microwave observations (collocated with micrometeorological observations for use in future modeling and assimilation studies). The radiometers formed an SSM/I simulator hardened for extended ground-based deployment and capable of long-duration remote operation without frequent absolute calibration. The system robustness was demonstrated over the course of 500 deployed days during REBEX-3 and subsequent experiments.

[65] A custom EASE-Grid software processor was used to generate a data set containing gridded SSM/I satellite brightness observations covering the state of Alaska for the REBEX-3 period. The processor uses the same Backus-Gilbert interpolation routines as the National Snow and Ice Data Center (NSIDC) standard processor. This processor also extracted pixels from all overflights of the REBEX-3 site, including pixels which would have been discarded by the standard processor due to swath overlap.

[66] Very strong linear correlations ($R^2 > 0.92$) between SSM/I EASE-Grid and ground-based brightness observations were found for the 19 and 37 GHz V- and H-polarized channels over the 380 day REBEX-3 period before adjusting for any atmospheric or topographic effects or calibration-related errors. The spread of the points about the best fit line in scatter plots (Figure 9) is consistent with differences in the exact satellite and ground-based observation times during times of day when the microwave brightness changes rapidly. Topographic and atmospheric effects were shown to be small. The residual differences were attributable to errors in the cold calibration of the ground-based observations.

[67] The strength of this linear correlation despite the 4-order-of-magnitude difference in footprint sizes suggests that tundra areas such as the North Slope of Alaska may be well-suited for using the relatively low-resolution satellite microwave brightness observations without disaggregation to estimate surface conditions. This, in turn, is encouraging for a region considered to be a sensitive indicator of climate change as well as for the monitoring of land surface conditions in general.

[68] The comparisons presented in this section were conducted at the 19 and 37 GHz SSM/I frequencies and polarizations because those were the only passive microwave satellite observations available for REBEX-3. Lower-frequency observations with their greater ability to sense through snow and vegetation and into the soil are likely to be more useful for tundra soil-vegetation-atmosphere transfer modeling studies.

[69] Lower-frequency satellite sensors are likely to have a spatial resolution no better than SSM/I, so the gridded REBEX-3 SSM/I data set can give an indication of horizontal homogeneity at the SSM/I sensing depths under various conditions. Also, along with ancillary information on land cover characteristics, this could assist in assessing the effects of subpixel variability at the typically deeper sensing depths of the lower frequencies.

[70] Atmospheric absorption and self-emission, scattering by cloud liquid water droplets and ice crystals, and attenuation and scattering by vegetation would all be less significant at lower microwave frequencies, while at the same time, effective emission depths would be greater. So there would be greater sensitivity to soil conditions at lower frequencies. Atmospheric considerations aside, observations at lower and higher microwave frequencies would provide complementary information about conditions within snow-covered or snow-free soil-vegetation columns simply based on the different effective emission depths.

Appendix A: EASE-Grid Processing Details

[71] In the EASE-Grid implementation, actual SSM/I antenna patterns were used to generate the weighting coefficients for combining swath pixel brightnesses to form interpolated brightnesses. Coefficients were tabulated for interpolation points that form a grid with a density 16 times that of the original swath pixel spacing in the swath reference frame (i.e., a grid spacing of 6.25 km for the 19, 22, and 37 GHz channels and 3.125 km for the 85 GHz channels).

[72] From this densified array the brightness value of the point closest to the center of the desired EASE-Grid cell is reregistered to that EASE-Grid cell location and is used as the brightness value for that cell. This method of assigning interpolated values has two notable features. First, the original swath data are not temporally or spatially averaged as is the case with the "drop-in-the-bucket" method used in another SSM/I gridded product (the "DMSP SSM/I brightness temperature grids" [*Comiso*, 1990], which cover only polar regions and use 24 hour averaged data). This was a design requirement of the EASE-Grid in order to preserve temporal and spatial fidelity [*Armstrong and Brodzik*, 1995]. Second, the use of a finite-spacing densified grid (rather than interpolating exactly to each EASE-Grid point) provides significant computational efficiencies. The weighting coefficients need be computed only once since the basic SSM/I scan geometry is consistent. The current EASE-Grid processors rely on pretabulated values. For a densified grid spacing of 6.25 km a nominal maximum reregistration distance is $\sim\sqrt{2}/2\times 6.25 = 4.4$ km or 10% of the 19 GHz effective field of view and less than the 10 km maximum geolocation error for swath pixels cited by *Wentz* [1991].