Microwave Signatures of Snow on Sea Ice: Observations

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***Abstract*—Part of the Earth Observing Sysytem Aqua Advanced Microwave Scanning Radiometer (AMSR-E) Arctic sea ice validation campaign in March 2003 was dedicated to the validation of snow depth on sea ice and ice temperature products. The difficulty with validating these two variables is that neither can currently be measured other than *in situ*. For this reason, two aircraft flights on March 13 and 19, 2003, were dedicated to these products, and flight lines were coordinated with *in situ* measurements of snow and sea ice physical properties. One flight was in the vicinity of Barrow, AK, covering Elson Lagoon and the adjacent Chukchi and Beaufort Seas. The other flight was farther north in the Beaufort Sea (about 73° N, 147.5° W) and was coordinated with a Navy ice camp. The results confirm the AMSR-E snow depth algorithm and its coefficients for first-year ice when it is relatively smooth. For rough first-year ice and for multiyear ice, there is still a relationship between the spectral gradient ratio of 19 and 37 GHz, but a different set of algorithm coefficients is necessary. Comparisons using other AMSR-E channels did not provide a clear signature of sea ice characteristics and, hence, could not provide guidance for the choice of algorithm coefficients. The limited comparison of *in situ* snow–ice interface and surface temperatures with 6-GHz brightness temperatures, which are used for the retrieval of ice temperature, shows that the 6-GHz temperature is correlated with the snow–ice interface temperature to only a limited extent. For strong temperature gradients within the snow layer, it is clear that the 6-GHz temperature is a weighted average of the entire snow layer.**

***Index Terms*—Advanced Microwave Scanning Radiometer (AMSR), passive microwave, sea ice, snow on sea ice, validation.**

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I. Introduction

SNOW depth on sea ice is a standard product of the Earth Observing System Aqua Advanced Microwave Scanning Radiometer (AMSR-E) instrument [3]. The algorithm was developed through the comparison of *in situ* snow depth measurements with Special Sensor Microwave/Imager brightness temperatures of Southern Ocean sea ice [8]. Currently, the same algorithm coefficients are applied to the Arctic, although there are significant physical and corresponding radiometric differences between the ice and snow in the Arctic and the Antarctic. The most important difference is the presence of multiyear sea ice in the Arctic. Multiyear ice is flagged in the Arctic, and no snow depth is retrieved over this sea ice type because of the ambiguity between the radiometric signals of multiyear ice and deep snow. Other complications such as salinity variability and the presence of a slush layer at the snow–ice interface also influence the retrieval of snow depth, but the lack of validation data, particularly over Arctic first-year sea ice, has prohibited a refinement of algorithm coefficients. The data collected during this aircraft campaign are a first effort to evaluate the algorithm coefficients for the Arctic.

Similar to the retrieval of snow water equivalent on land (e.g., [2] and [7]) the algorithm for snow depth on sea ice makes use of the difference in scattering by snow between the 19- and 37-GHz frequencies. Explicitly, snow depth h_s is calculated using the spectral gradient ratio of 37 and 19 GHz at vertical polarization, i.e.,

$$h_s = a + b \times GR = a + b \times \frac{TB_{37\mathrm{V}}(\mathrm{ice}) - TB_{19\mathrm{V}}(\mathrm{ice})}{TB_{37\mathrm{V}}(\mathrm{ice}) + TB_{19\mathrm{V}}(\mathrm{ice})} \quad (1)$$

where, for AMSR-E, $a = 2.9$ and $b = -782.4$ are regression coefficients (in centimeters) and $TB_{37\mathrm{V}}(\mathrm{ice})$ and $TB_{19\mathrm{V}}(\mathrm{ice})$ are brightness temperatures that have been corrected for the open water fraction within each pixel using passive microwave ice concentration estimates [9]. First-year sea ice has a high emissivity (about 0.95) for both the 19V and 37V channels. Thus, the difference between $TB_{37\mathrm{V}}$ and $TB_{19\mathrm{V}}$, or GR, is close to zero for no snow. With increasing snow depth, the radiation emitted by the sea ice is increasingly scattered. This scattering is greater at 37 GHz than at 19 GHz so that increasing snow depth results in relatively greater brightness temperatures at 19 GHz compared to 37 GHz and, thus, more negative GRs.

In March 2003, seven aircraft flights over the Alaskan Arctic were carried out as part of the AMSR-E sea ice validation

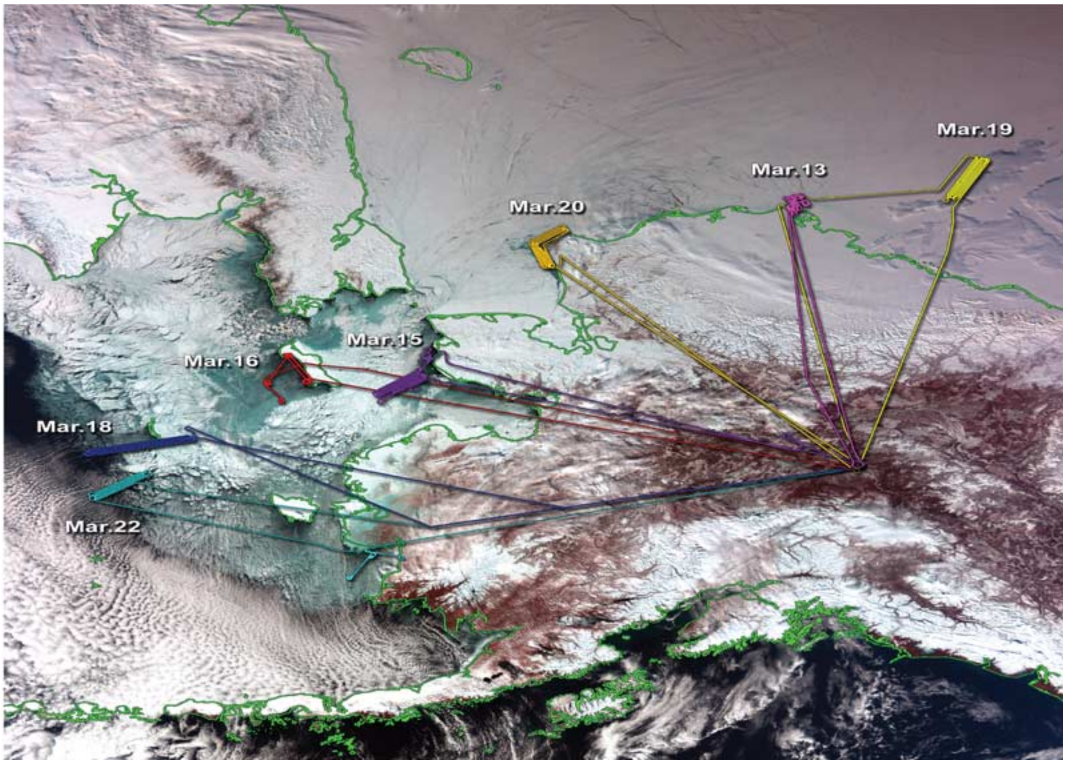

Fig. 1. Overview of PSR flights during the 2003 AMSR-E sea ice validation campaign over a Moderate Resolution Imaging Spectroradiometer (MODIS) image from March 20, 2003. The "true" color image was created using MODIS bands 2, 4, and 3.

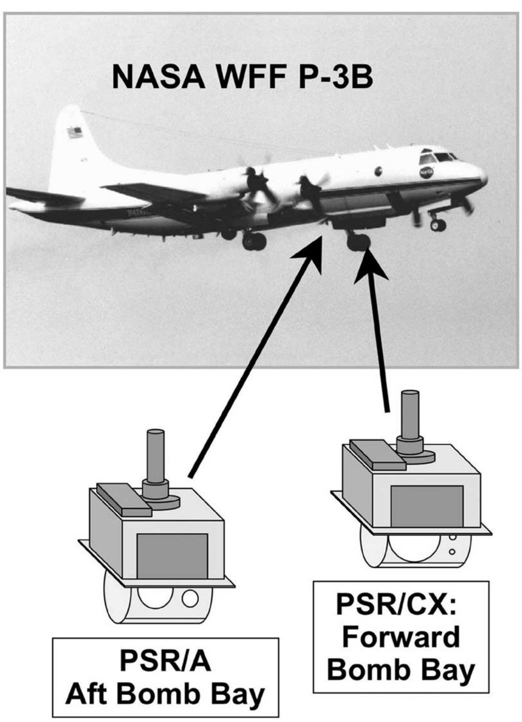

Fig. 2. Locations of the PSR onboard the NASA P-3 aircraft.

TABLE I
CHARACTERISTICS OF THE PSR SYSTEM

Instrument	Frequency band [GHz]	Polarization	Beam width
PSR/CX	5.80-6.20	V,H	10°
	6.30-6.70	V,H,	10°
	6.75-7.10	V,H	10°
	7.15-7.50	V,H	10°
	10.60-10.80	V,H	7°
	10.60-10.68	V,H	7°
	10.68-10.70	V,H	7°
	10.70-10.80	V,H	7°
PSR/A	10.6-10.8	V,H	8°
	18.6-18.8	V,H	8°
	21.4-21.7	V,H	8°
	36.0-38.0	V,H	2.3°
	86.0-92.0	V,H	2.3°

effort [1] (Fig. 1). The main instrument on the National Aeronautics and Space Administration's (NASA) P-3 airplane was the Polarimetic Scanning Radiometer (PSR) from the National Oceanographic and Atmospheric Administration's Environmental Technology Laboratory. Two PSR scanheads, namely 1) PSR/A and 2) PSR/CX, were integrated onto the P-3 in the plane's bomb bay (Fig. 2). These scanheads provide the same (and more) frequency coverage as the AMSR-E instrument (Table I).