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WindSat Polarimetric View of Greenland

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Introduction: WindSat is the first spaceborne microwave polarimetric radiometer that measures all four elements of the Stokes vector, the brightness temperatures at vertical and horizontal polarizations (T_V and T_H), and the real and imaginary parts of the cross-correlation of the vertical and horizontal polarization known as the third and fourth Stokes parameters (T_U and T_F).[1] WindSat was developed by NRL and had been in operation since January 2003. The polarimetric signatures of the third and fourth Stokes measurements are mostly related to the asymmetric structures of the ocean-wind-driven surface roughness. Prior to the launch of WindSat, it was a common belief that land polarimetric signatures at satellite footprint scales would be below the instrument noise level and would not carry any useful geophysical information. However, postlaunch data processing reveals significant land signals in the T_U and T_F, particularly over Greenland and the Antarctic ice sheets, which are the most environmentally sensitive Earth media, playing a significant role in global sea level and climate changes. Understanding this polarimetric signature, uniquely afforded by WindSat, and its relation with the snow properties and microstructures will have a profound impact on climate study.

Methodology: By observing the changes in the microwave signature, one can infer temporal and spatial variations in the physical properties of the ice sheet. A simple and effective way to represent the microwave signature is to construct an empirical observation model that can describe and separate different effects in the measurements using a small number of model parameters.[2] Over Greenland, it is well-known that T_V and T_H respond mostly to the dielectric properties of the snow,[2] ice and firn. WindSat data now show that T_U and T_F respond most strongly to the asymmetric structure of the snowpack and can be strong functions of the observation geometry, including the azimuth look angle. Therefore we examine the azimuthal modulations of T_U and T_F to separate observation geometry effects from environmental variations. The temporal and spatial variations of these azimuthal modulation coefficients can provide insight about the microwave scattering mechanism and its related geophysical processes.

Results: Figure 8 depicts T_U (left panel) and T_F (right panel) Stokes measurements at 10.7 GHz over the North Hemisphere for the period 1-10 February 2004. T_U shows coherent large-scale signals varying between ±2.5 K over the ocean and about 0.5 to 1 K signals over ice-free land. The variation for T_F over ocean and land is much smaller, less than ±1 K. However, over Greenland, both parameters show variations up to eight times larger than the ocean
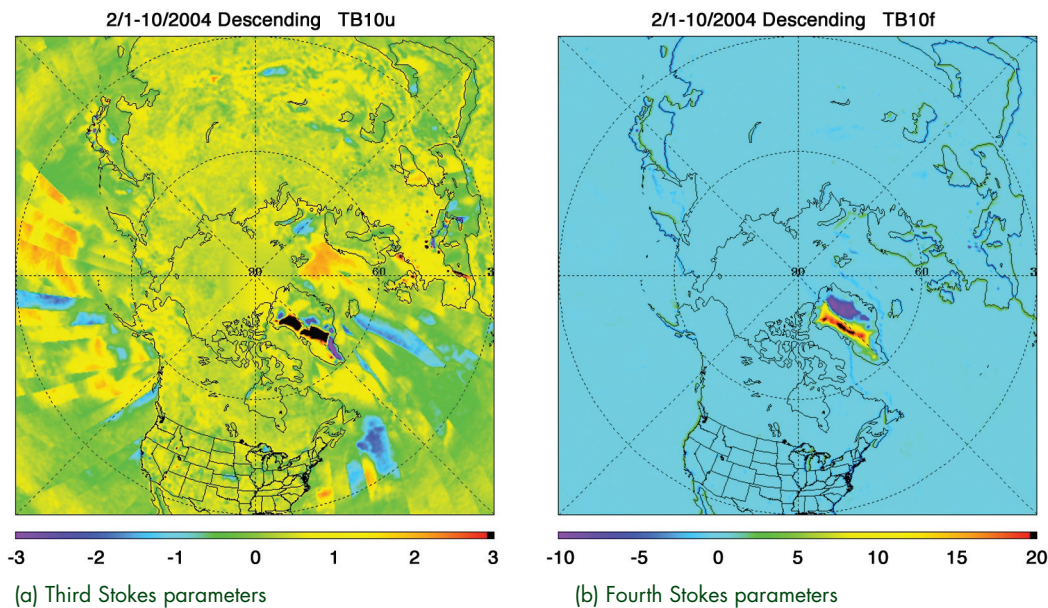

2/1-10/2004 Descending   TB10u

2/1-10/2004 Descending   TB10f

(a) Third Stokes parameters

(b) Fourth Stokes parameters

FIGURE 8
Composite WindSat polarimetric measurements at 10.7 GHz. The descending pass data were collected by WindSat during 1–10 February 2004.

signature, where T_U varies between ±10 K and T_F from −10 to +20 K. Such large polarimetric signatures can be attributed mostly to the volume scattering by the porous Greenland snow media. Figure 9 illustrates the azimuthal dependence of polarimetric data extracted from the WindSat data at a location on the Summit of the Greenland ice sheet for April 2003. The two clusters of points are from ascending (near 210°) and descending (near 340°) revs. T_U and T_F are plotted for 10.7, 18.7, and 37 GHz, and all clearly show very well-defined azimuthal dependences. The solid lines represent the empirical model expressed as second-order harmonic functions, suggesting an excellent model fit to the data.

Figure 10 shows the time-series of first- and second-order harmonic coefficients of empirical observation model for T_U and T_F at 10.7, 18.7, and 37 GHz channels at the Greenland Summit. The first harmonic coefficients describe the scattering signatures that are related to the asymmetric structure of the snowpack, possibly induced by the surface slope or skewness of the snow dune. The second harmonic coefficients describe asymmetric features of the snowpack in direc-

tions parallel and orthogonal to the dune direction. The T_F signals are stronger than those from T_U over Greenland. This is a striking contrast to relatively weak polarimetric signatures generated by ocean surface scattering and indicates significant volume scattering contributions to the polarimetric signals. All harmonic coefficients peak in late winter to early spring when the snow metamorphism is most intense, and are weak in the middle summer when the penetration depth is dramatically reduced. This again highlights the importance of volume scattering in the polarimetric signals.

Summary: WindSat polarimetric data exhibit distinct geophysical and observation geometry signatures over Greenland that are correlated with geophysical variations, including snow microstructure, melting, and metamorphism. Therefore, WindSat provides an unprecedented and unique dataset for environmental and climate studies in the polar region. Furthermore, these results demonstrate how future polarimetric microwave radiometer missions can be exploited for climate studies.
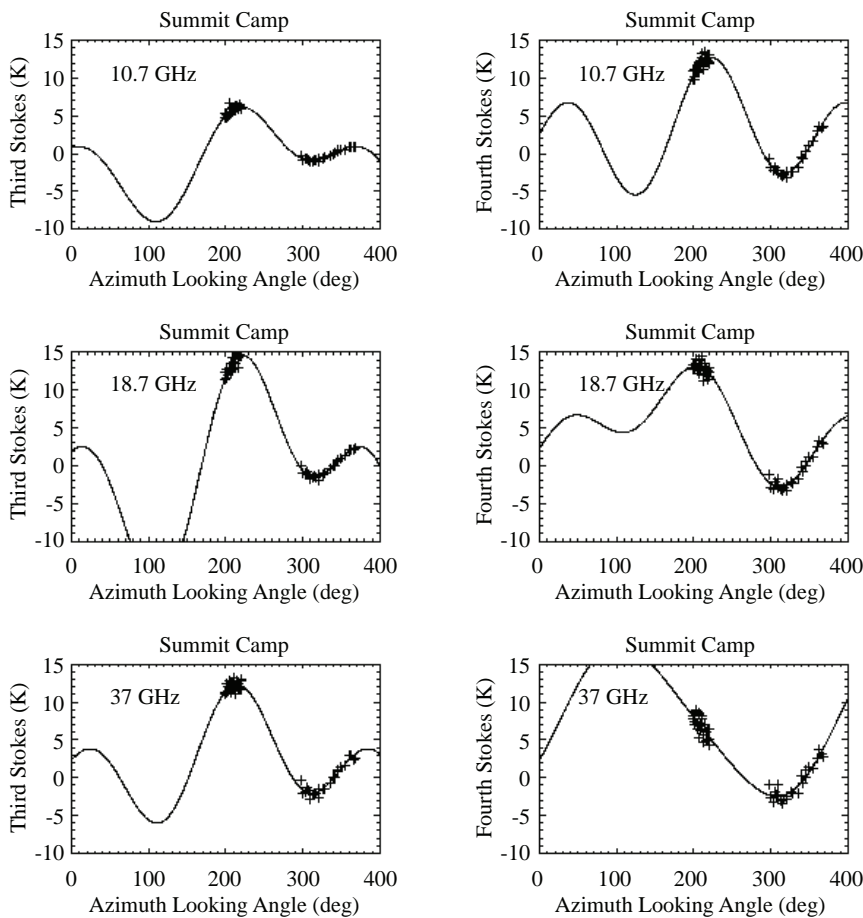

FIGURE 9
Third and fourth Stokes parameters observed by WindSat over the Summit study site in Greenland during April 2003. The solid line is the fitted second-order harmonic model. The left column shows the third Stokes parameter while the right column shows the fourth Stokes parameter. The top row is 10.7 GHz, the center row is 18.7 GHz, and the bottom row is 37 GHz.
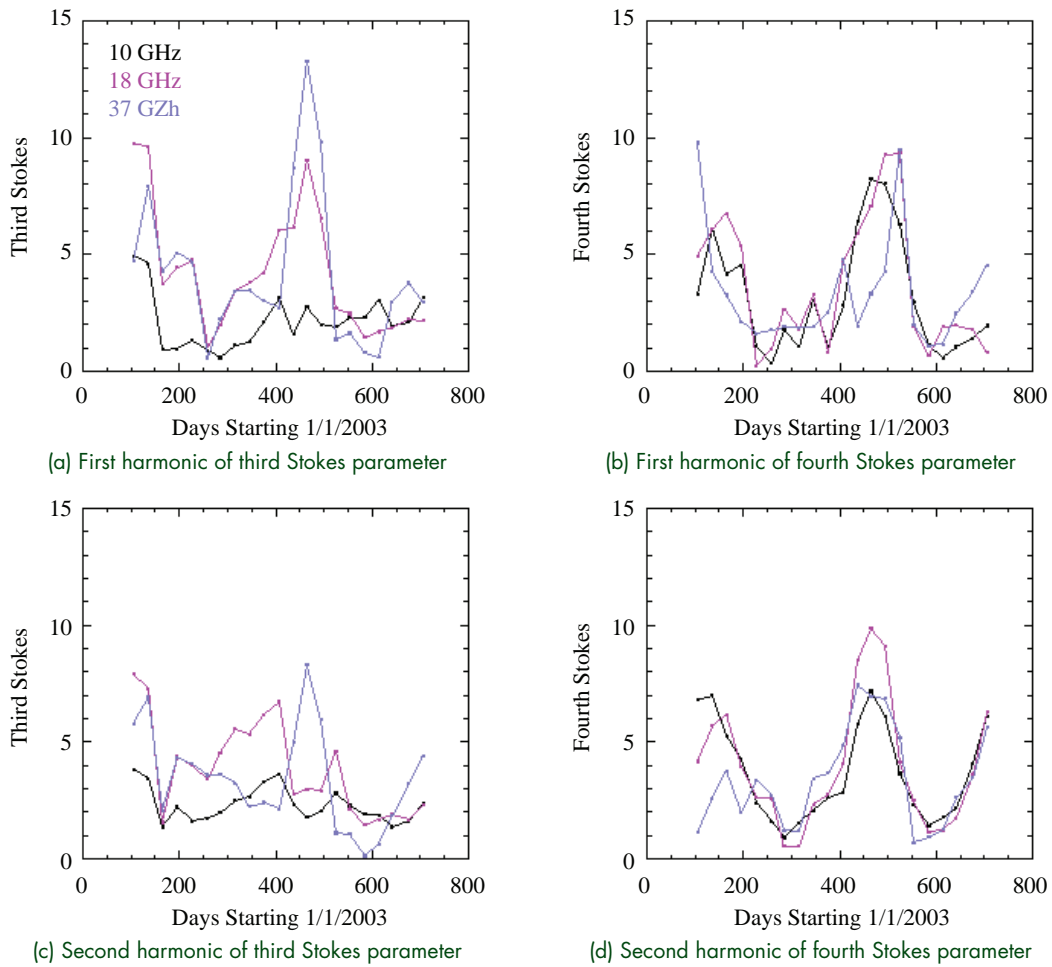
15

10 GHz
18 GHz
37 GZh

Third Stokes

10

5

0

0   200   400   600   800
Days Starting 1/1/2003

(a) First harmonic of third Stokes parameter

15

Fourth Stokes

10

5

0

0   200   400   600   800
Days Starting 1/1/2003

(b) First harmonic of fourth Stokes parameter

15

Third Stokes

10

5

0

0   200   400   600   800
Days Starting 1/1/2003

(c) Second harmonic of third Stokes parameter

15

Fourth Stokes

10

5

0

0   200   400   600   800
Days Starting 1/1/2003

(d) Second harmonic of fourth Stokes parameter

FIGURE 10
Time series of WindSat observations over the Greenland Summit study site from 1 April 2003 to 30 December 2004. The 10.7, 18.7, and 37.0 GHz data are color-coded with black, purple, and blue, respectively.

[Sponsored by ONR]

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[1] P.W. Gaiser, et al., "The WindSat Spaceborne Polarimetric Microwave Radiometer: Sensor Description and Early Orbit Performance," *IEEE Trans. Geosci. Rem. Sens.* **42**, 2347-2361, (2004).

[2] I.S. Ashcraft and D. Long, "Observation and Characterization of Radar Backscatter over Greenland," *IEEE Trans. Geosci. Rem. Sens.* **43**, pp. 225-237 (2005).

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