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Airborne Measurement of Snow Cover Properties using the Polarimetric Scanning Radiometer during the Cold Land Processes Experiments (CLPX02-03)

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***Abstract*—Multispectral polarimetric microwave brightness temperature maps of snowpack in the Colorado Rocky Mountains were obtained using the NOAA Polarimetric Scanning Radiometer (PSR) during three Cold Land Processes Experiments (CLPX) in February 2002, February 2003, and March 2003. The PSR CLPX data offers unique high-resolution information about snow extent, polarimetric emissivity, and snow water equivalent at scales commensurate with natural inhomogeneities in terrain and precipitation patterns. The data is being used for several purposes including snowpack and snowmelt hydrology, calibration and validation of the AMSR-E sensor, cryospheric satellite sensor design, wideband snow emissivity modeling, and snowpack change detection. Initial results from CLPX02 using the PSR/A scanhead are presented showing brightness temperature, emissivity, and estimated snow water equivalent (SWE) maps.**

I. INTRODUCTION

The Cold Land Processes Experiment (CLPX) program is sponsored by the NASA Terrestrial Hydrology and the Earth Observing System Programs to study means of remote sensing of properties of the terrestrial cryosphere. Cold land regions play an important role in the Earth's hydrologic cycle and have a significant impact on global weather and climate through their modulation of the Earth's radiation budget. Freeze/thaw events in cold regions also modulate the flux of organic carbon, and water stores within cold regions form important natural resources. The goals of CLPX are thus to understand the formation and evolution of snow and to better observe transitions between snow and water in the cold regions [1]. A specific goal is the development of a spaceborne cryospheric sensor for the improvement of spring snowmelt forecasting. Passive microwave remote sensing plays a key role in CLPX due to the wealth of information contained in the polarimetric microwave emission spectrum from snow in its various forms.

The NOAA Polarimetric Scanning Radiometer (PSR) is the first airborne multi-band conical-scanned imaging radiometer system. The PSR was designed for a variety of high-resolution environmental remote sensing purposes, including ocean wind imaging, sea ice imaging, soil moisture mapping, and rain and cloud water imaging [2]. It is also uniquely suited for CLPX studies. The most recent PSR hardware improvement permits simultaneous use of two PSR scanheads on a single aircraft to provide imagery at all of the EOS NASDA AMSR-E imaging bands (Table 1).

Frequency (GHz)	Scanhead	Polarization	Beamwidth[1] (°)	ΔT_{rms}^2 (K)
5.8-7.5 GHz	PSR/CX	v,h,U,V	10	0.2
10.6-10.8	PSR/CX PSR/A	v,h,U,V	7 8	0.4 0.6
18.6-18.8	PSR/A	v,h,U,V	8	0.3
21.4-21.7 (H_2O)	PSR/A	v,h	8	0.4
36-38	PSR/A	v,h	2.3	0.5
86-92	PSR/A	v,h,U	2.3	0.6
10 μm (IR)	PSR/A	unpolarized	7	0.2

[1] Half-power beamwidth.
[2] 18 msec equivalent integration time, v & h

Table 1. Polarimetric Scanning Radiometer system parameters.

We present here initial results from three separate CLPX experiments, including one where the PSR/A was flown aboard the NASA DC-8 in February 2002 during the CLPX02 mission and two on the NASA P-3 in February and March 2003 for the CLPX03A and CLPX03B missions (respectively).

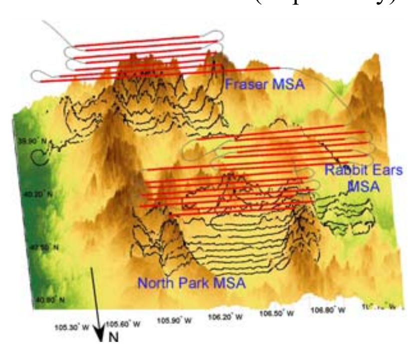

Figure 1. 3D view of the CLPX Mesoscale Study Areas (MSA) that were sampled during February 2002, February 2003 and March 2003. Flight lines (red), flight lines projection onto the ground (black).

II. FLIGHT DESCRIPTION AND DATA PROCESSING

Figure 1 depicts in a 3D view the flight lines used to obtain microwave snow images within the three Mesoscale Study Areas (MSAs): 1) North Park, with an average terrain height of 2780 m MSL and range of 2125 m, 2) Rabbit Ears, with an average height of 2540 m MSL and range of 1700 m, and 3) Fraser Meadows, with average height of 2770 m MSL and range of 2530 m. Imaging was performed over a ~40 x 110 km

Exper-iment Name	MSA	Date	Observation Times (UTC)	Tot. # of Flt. Lines	Flt. Alt. (km AGL)	Avg Resolution (m) @ 37, 89 / 10, 18, 21 GHz	T_{max} / T_{min} (°C)	TPW (cm)	Cloud/ Precipitation (T=trace)
CLPX02	RE	2/19/02	21:18-22:35	7	2.45	150 / 530	54 / 29	0.47	Clear / 0.06”
	FM	2/21/02	16:45-18:49	7	2.23	140 / 480	52 / 23	0.48	Clear / T
	NP	2/23/02	16:57-18:34	7	2.22	140 / 480	64 / 38	0.42	Clear / --
CLPX03 A	NP	2/22/03	18:35-20:35	7	4.22	260 / 900	50 / 23	0.52	Cloudy / T
	NP, RE, FM	2/23/03	17:35-21:37	21	2.30	140 / 470	47 / 6	0.37	Cloudy / 0.02”
	NP, RE	2/24/03	20:30-23:05	14	2.34	145 / 500	15 / -3	0.39	Cloudy / 0.05”
	NP, RE, FM	2/25/03	17:30-21:00	21	2.30	140 / 470	12 / 0	0.64	Cloudy / 0.02”
CLPX03 B	NP, RE, FM	3/25/03	17:50-22:05	21	2.30	140 / 470	40 / 30	1.15	Cloudy / 0.09”
	NP, RE, FM	3/30/03	18:10-22:30	21	2.30	140 / 470	37 / 26	0.70	Clear / T
	NP, RE, FM	3/31/03	17:50-21:50	21	2.30	140 / 470	58 / 38	0.90	Clear / --

Table 2. Summary of CLPX flight characteristics, including meteorological statistics during observations.

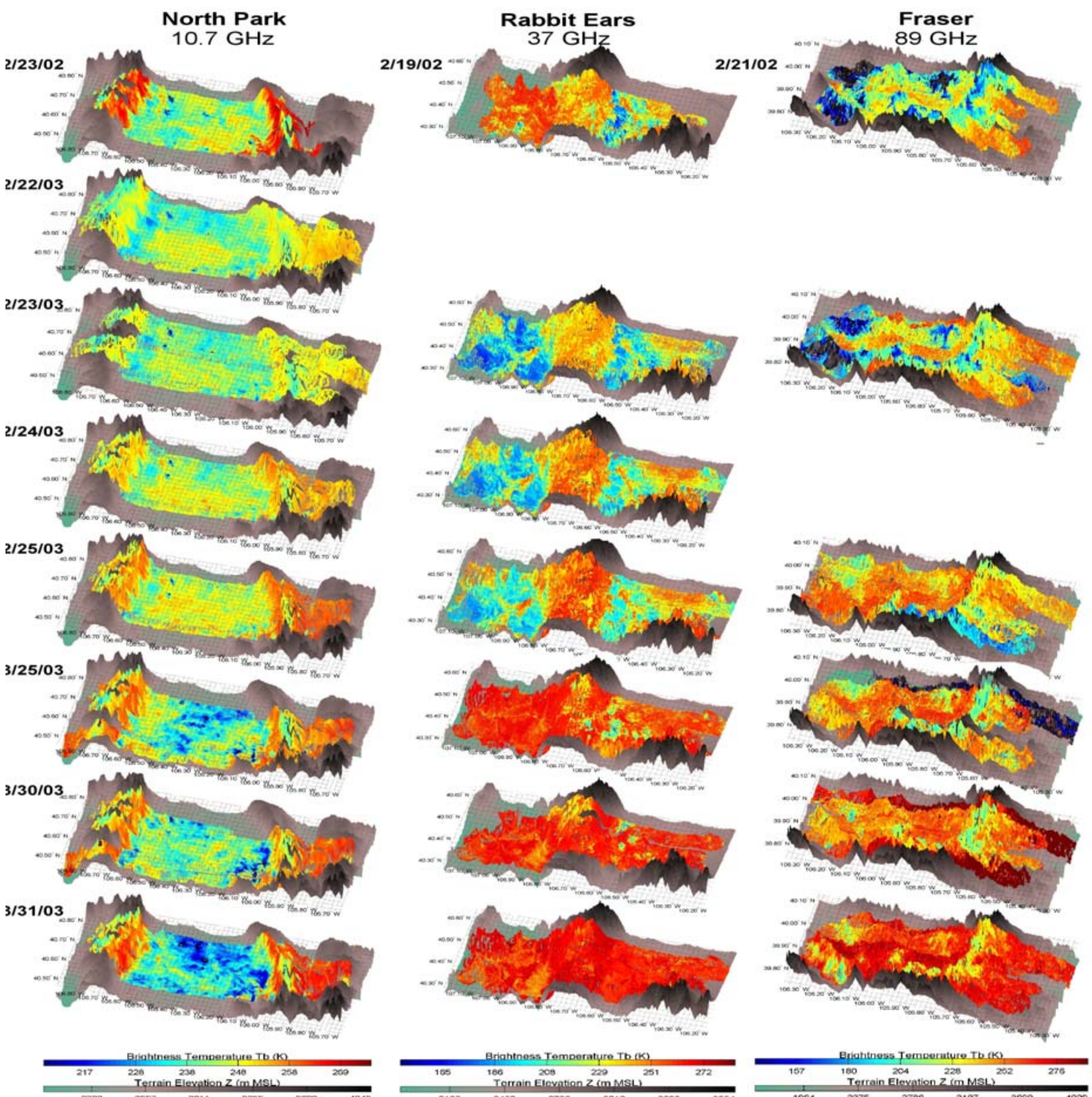

Figure 2. PSR/A observed horizontally-polarized brightness temperature time series for :(a) 10.7 GHz at North Park MSA, (b) 37 GHz at Rabbit Ears MSA, and (c) 89 GHz at Fraser MSA.

grid of seven parallel flight lines over each MSA. Most flight lines were flown at ~5000 m MSL (see Table 2). The MSAs collectively simulate a wide range of terrain characteristics from tundra and bare rock to irrigated grasslands and coniferous forests [1]. Consequently a wide range of snow characteristics and brightness signatures were observed.

Table 2 also lists pertinent meteorological statistics for each flight, including surface air temperature extremes, total precipitable water (TPW), and cloudiness. Overall, conditions during CLPX02 were fairly warm, clear, and dry with some fresh snowfall. CLPX03A was cold and cloudy with fresh snowfall almost daily. CLPX03B varied, the first day being cloudy, wet, and with abundant fresh snowfall, while the second and third days were clear with considerable sun glint from melting snow.

Figure 2 shows horizontally-polarized T_B images for the 10.7 GHz channel for all available sorties at North Park, 37 GHz images for all available sorties at Rabbit Ears, and 89 GHz images for all available sorties at Fraser. Because the MSAs are located in mountainous areas a ray-tracing geolocation procedure was used. The procedure used USGS 30-m resolution terrain data to locate points where PSR/A beams intersected the surface. A general radiometric cooling from CLPX02 to CLPX03A at North Park and Rabbit Ears in the 10.7 and 37 GHz channels suggests more widespread snow coverage in 2003 than 2002. The onset of snowmelt is also clearly seen in the opposite 10.7 and 37 GHz trends between CLPX03A and CLPX03B. Snowmelt signatures are less visible in the 89 GHz data since the emissivity varies significantly over diurnal freeze/thaw cycles.

III. SNOW EMISSIVITY AND SNOW WATER EQUIVALLENT

Using 10 um IR surface temperatures and radiosonde-based atmospheric profiles we computed maps of the microwave surface emissivity for the clear air cases during CLPX02. The emissivity is given approximately by the ratio of measured T_B to the surface temperature. To estimate the atmospheric contribution to the observed brightness we used nearby NWS radiosonde temperature and water vapor profiles and the Microwave Radiative Transfer (MRT) model [3]. The MRT corrections included the angle of incidence of specular rays consistent with the local terrain slope. Figure 3a shows the derived 37 GHz horizontally-polarized snow emissivity for the Rabbit Ears MSA on 19 February 2002. The derived emissivity differs from the 37 GHz T_B measurements at the Rabbit Ears ridge where cooler surface temperatures and reduced atmospheric radiance contributions were present.

Snow cover is identified by the scattering of high frequency microwaves from ice particles and the fact that scattering reduces high frequency T_B measurements relative to the lower frequency measurements. This is used to compute the snow water equivalent (SWE, Figure 3b). We use the formula SWE = 4.8 ($T_{B18.7}$-T_{B37}) (mm) [4] to compute SWE for Rabbit Ears on 19 February 2002. Figure 3c shows an experimental SWE product from the NWS National Operational Hydrologic remote Sensing Center (NOHRSC) National Snow Analyses (NSA) model. The model is physically based and multi-layer, and operated at 1 km spatial resolution. Model snow pack characteristics are based on operationally available ground, airborne, and satellite observations. Comparing Figures 3b and 3c the two independent measurements are seen to be in the same general range, although PSR/A shows SWE variations from 8-100 mm with an eastern (leeward side) gradient. The NSA model results also show SWE values in the 25-100 mm range but do not show the high resolution variations nor the gradient seen in the PSR/A data.

CONCLUSIONS

The first high-resolution observations and retrievals of snow pack properties using the PSR multi-channel conically-scanned airborne microwave radiometer during CLPX have been presented. The results show promise for improved observation, understanding, and prediction of snow properties.

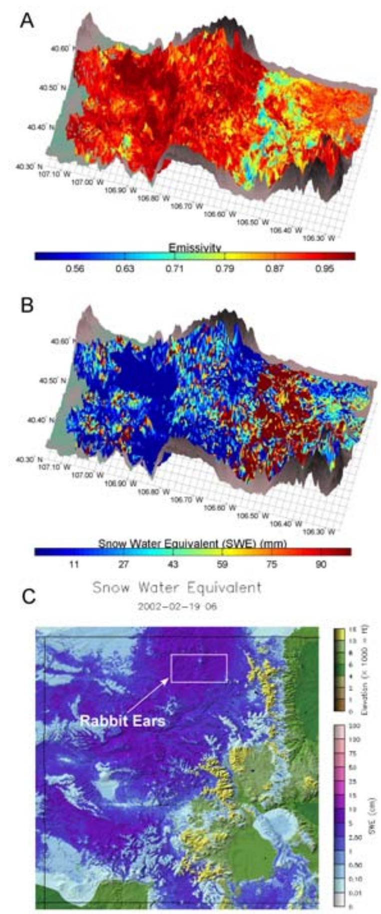

Figure 3. (a) Snow emissivity computed using the 37 GHz horizontal polarization and 10 µm IR observations, (b) SWE computed from 18.7 and 37 GHz horizontally-polarized T_B measurements on 19 February 2002, and (c) NWS/NOHRSC experimental SWE product for the same day.

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