Passive and Active L-Band System and Observations during the 2007 CLASIC Campaign

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ABSTRACT

This article describes the upgraded PALS instrument and the characteristics of data acquired from the Cloud Land Atmospheric Interaction Campaign (CLASIC) 2007. The data acquired over lake passes were used to remove the radiometer calibration bias. The calibrated radiometer data showed significant consistency with the L-band land emission model for soil surfaces published in the literature. We observed significant temporal (days) changes of a few dB in the radar data. The change of radar backscatter appeared to correlate well with the change of in-situ soil moisture or the soil moisture data derived from the PALS dual-polarized brightness temperatures. The radar vegetation index also correlated well with the vegetation opacity estimated from the radiometer data. The preliminary analyses suggest complementary information contained in the surface emissivity and backscatter signatures for the retrieval of soil moisture and vegetation water content.

Index Terms— Soil moisture, radar, radiometer

1. INTRODUCTION

To investigate the benefits of combining passive and active microwave sensors for soil moisture remote sensing, the Jet Propulsion Laboratory (JPL), with NASA support, designed, built and tested a precision Passive/Active L-band System (PALS) instrument to support soil moisture and ocean salinity field campaigns [1]. From 1999 to 2002, PALS together with a large conical horn antenna was deployed on the NCAR C-130 aircraft to support three ocean campaigns, the Southern Great Plains 1999 experiment (SGP99), and the Soil Moisture Experiment in 2002 (SMEX02). The PALS data from these campaigns have been used to illustrate first attempts at joint passive and active soil moisture change detection [2].

Since 2003, several upgrades have been included in the PALS instrument to support future experiments. From June 8 through July 6, 2007, the upgraded PALS system was flown on the Twin Otter to support the CLASIC conducted in Oklahoma. A key objective of the 2007 CLASIC was to explore the interaction of soil moisture and precipitation over the Southern Great Plains. In addition, we included test sites with tree canopies to acquire L-band microwave data for the development of active/passive algorithms for soil moisture retrieval under the influence of significant vegetation biomass. A total of 15 aircraft flights were completed. For each flight, there were flight tracks over lakes to acquire data to validate the radiometric calibration of the PALS radiometer. The results of detailed science analysis are provided in a companion IGARSS paper [3].

2. PALS INSTRUMENT CHARACTERISTICS

The radiometer products from PALS include the vertically polarized (V) brightness temperature (Tb_V) and horizontally polarized (H) brightness temperature (Tb_H). The PALS radar provides the normalized radar backscatter cross-section (σ_0) for V- transmit/V-receive (σ_{0VV}), V-transmit/H-receive (σ_{0HV}), H-transmit/H-receive (σ_{0HH}), and H-transmit/V-receive (σ_{0VH}). The PALS instrument electronics have recently been upgraded to perform the polarimetric third Stokes parameter measurement for the radiometer and the complex correlation between any two of the polarized radar echoes (VV, HH, HV and VH). Table 1 provides the key characteristics of PALS.

Table 1. Characteristics of PALS

Passive	Frequency	1.413 GHz
	Polarization	V, H, +45, -45
	Half Power Beamwidth	20 degrees
Active	Frequency	1.26 GHz
	Polarization	VV, HH, VH, and HV
	Half Power Beamwidth	20 degrees
Antenna	Microstrip antenna with >30 dB polarization isolation	
Aircraft platform	Twin Otter, P-3, C-130	

A key limitation of the previous PALS (PALS-I) system is the use of a conical horn for the antenna [2]. The conical horn is large (about 3 meters long), prohibiting operation on P3- and smaller aircrafts. For the new PALS, a flat-panel antenna array has been developed under the support of the NASA Earth Science Technology Office Advanced

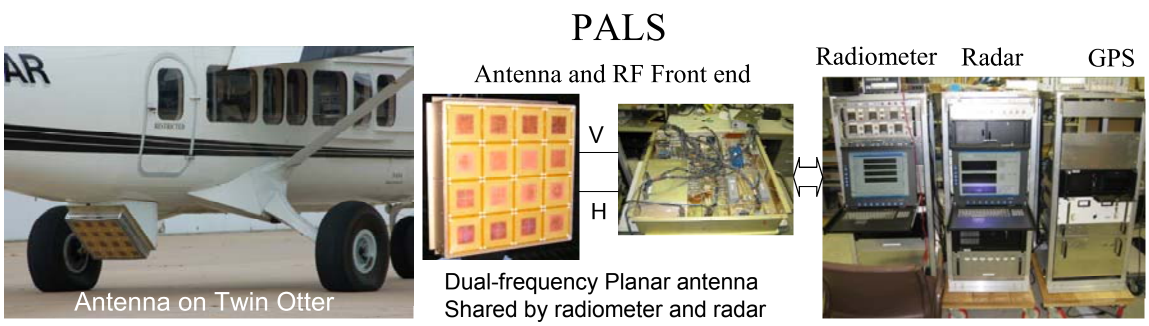

Figure 1. PALS antenna installation and equipment racks for the Twin Otter.

Component (ACT) program [4]. The planar antenna consists of 16 stacked-patch microstrip elements arranged in a four-by-four array configuration (Fig. 1). Each stacked-patch element uses a honeycomb structure with extremely low dielectric loss at L-band to support the ground plane and radiating patches. The measured antenna pattern shows better than 33 dB polarization isolation, far exceeding the need for the polarimetric measurement capability. This compact, lightweight antenna has enabled PALS to transition from operation on C-130 to small aircraft, such as the Twin Otter (Fig. 1) or UAV, for long-term, low-cost field deployment.

3. PALS PASSIVE OBSERVATIONS

To obtain retrieval from PALS passive data, we adopted the following dual-channel land emission model [2] to solve for soil moisture m_v and vegetation opacity τ iteratively:

$$T_{B_p} = T_s[(1 - r_{s_p})e^{-\tau} + (1 - \omega_p)(1 - e^{-\tau})(1 + r_{s_p}e^{-\tau})]$$

$$r_{s_v} = [(1 - Q)r_{o_v} + Qr_{o_h}]e^{-h}$$

$$r_{s_h} = [(1 - Q)r_{o_h} + Qr_{o_v}]e^{-h}$$

where p denotes H or V polarization, r_{oh} and r_{ov} are Fresnel reflectivities at their respective polarizations, and T_s is the land surface temperature. As a first-order approximation we further assumed $h = 0.1$ cm, $\omega_h = \omega_v = 0.1$, and $Q = 0.0$ in the above parameterization. The resulting time-sequence mapping of the retrieved soil moisture, after bias correction, at the Little Washita watershed is shown in Fig. 2.

As evident in the figure, the retrieved soil moisture is persistently greater than 20% cm^3/cm^3 throughout much of the region, an observation consistent with the observed wet conditions that permeated throughout the field campaign. Furthermore, on or shortly before July 4 the retrieved soil moisture indicates an event that results in widespread soil wetness in excess of 35% cm^3/cm^3 on the east side of the region. This observation is in good agreement with the occurrence of a major rainfall event (with 2.3-inch precipitation) on July 2 recorded by the Oklahoma Mesonet station at Chickasha.

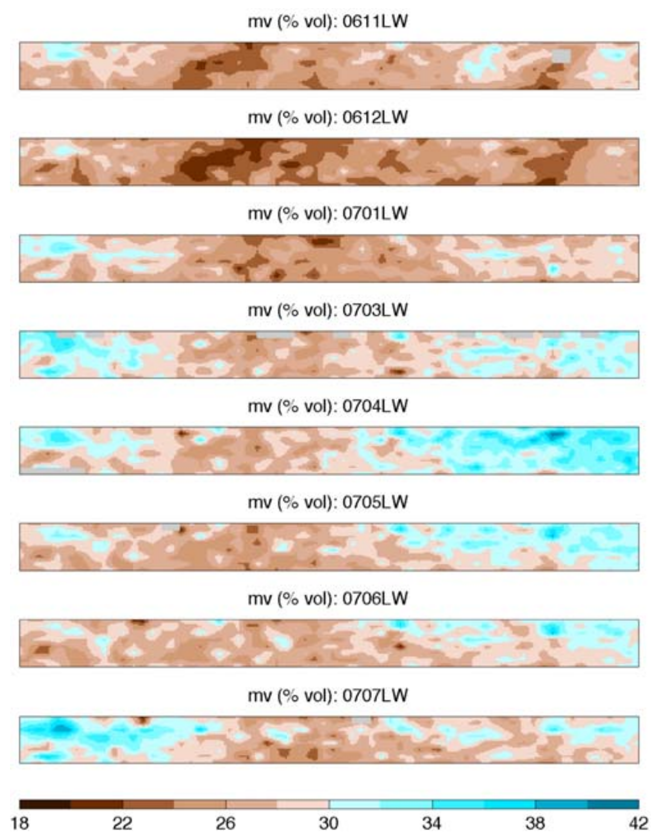

Figure 2. Volumetric soil moisture derived from a two-channel land emission model. The temporal variability coincides with an actual major rainfall event observed at the Oklahoma Mesonet station at Chickasha.

By co-locating PALS observations and *in-situ* soil moisture measurements within a space-time window of 300m and ±1 hr, we illustrated in Fig. 3 an intercomparison between the radiometer-derived soil moisture and *in-situ* soil moisture.

Table 2. Small calibration adjustments in the original calibrated T_B observations could lead to improvements (boxes marked with "√") in RMSE, bias, correlation level, or all three, as indicated by +1K offset in the H channel and −1K offset in the V channel. Offsets of this magnitude are within the calibration budget of the PALS data.

H offset	V offset	RMSE	Bias	Corr
0K	0K	6.5%	+4.6%	0.77
0K	-1K	5.5% (√)	-3.3% (√)	0.76
1K	0K	6.2% (√)	-3.9% (√)	0.77
1K	-1K	4.3% (√)	-2.5% (√)	0.81 (√)

Despite a root-mean-square error (RMSE) of 6.5% cm^3/cm^3 and a bias of 4.6% cm^3/cm^3 in magnitude, the decent correlation level (+0.77) suggests that the dual-channel land emission model is able to provide a reasonably accurate description of the actual radiative processes. In an attempt to further improve the fit (in terms of smaller RMSE, smaller bias, *and* higher correlation), it is common to proceed in two ways: (a) add model parameters that are previously ignored and/or fine-tune some of the existing model parameters, or (b) introduce artificial offsets to the original calibrated T_B observations. The former is motivated by the belief that an improved fit can be attained by more accurate modeling whereas the latter by more accurate calibration in the original T_B observations. To determine how much an improved fit can be attributed to each mechanism, we first tried out different values for h, ω, and Q and then different offsets for T_{Bh} and T_{Bv}. Based on the T_B observations and ground truth we analyzed in this study, we found that fine-tuning existing model parameters alone is not sufficient to produce an improved fit. On the other hand, offsetting the original calibrated T_B observations by as little as 1K seems to be quite effective in bringing forth simultaneous improvements in RMSE, bias, and correlation level, as indicated in Table 2.

By artificially adding offsets of +1K and −1K to T_{Bh} and T_{Bv}, the RMSE was reduced from 6.5% to 4.3%, bias magnitude from 4.6% to 2.5%, and correlation increased from 0.77 to 0.81. The simultaneous improvements resulting from these adjustments suggest that the current retrieval results could be further improved by using the existing dual-channel land emission model along with small calibration adjustments in PALS calibrated T_B observations.

4. PALS ACTIVE OBSERVATIONS

In the previous section, we described the use of a dual-channel land emission model in simultaneous retrieval of soil moisture m_v and vegetation opacity τ. While the

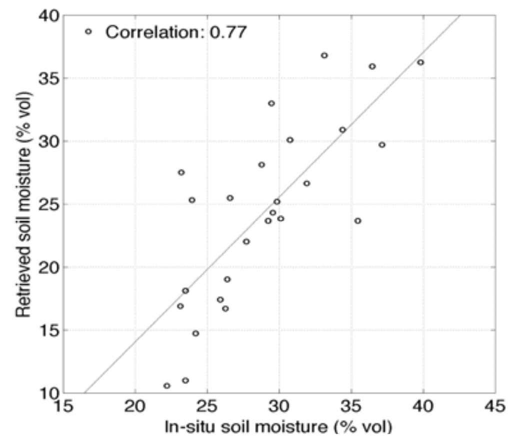

Figure 3. Intercomparison between retrieved soil moisture and *in-situ* soil moisture. It shows that there exists a bias between the two quantities. The least-square fit line has a slope of 1.18.

retrieved soil moisture was shown to display consistent dynamic range and temporal variability at Little Washita during the observation period, the retrieved vegetation opacity had not been subject to similar rigor of consistency check as of this publication. As a first step, we computed from PALS active data (expressed in linear scale) the radar vegetation index (RVI) [6]:

$$RVI = \frac{8\sigma_{HV}}{\sigma_{VV} + \sigma_{HH} + 2\sigma_{HV}}$$

and plotted it against the retrieved vegetation opacity. This result is shown in Fig. 4, in which the RVI shows an upward trend as vegetation opacity (and hence the level of vegetation water content) increases. This response of RVI to increasing vegetation content is consistent with a previous study [7]. The high correlation (+0.90) between RVI and vegetation opacity indicates that at L-band frequencies active data could be useful for vegetation water content estimation. In a future combined passive-active retrieval algorithm, for example, the additional independent information on vegetation water content enabled by active data could potentially lead to more accurate retrieved soil moisture.

In addition to its sensitivity to vegetation water content variation, the PALS radar also shows decent sensitivity to soil moisture variation. From Jul 1 to Jul 7 at the LW29 sampling site (standing winter wheat), there were 5 PALS/*in-situ* data pairs co-locatable within a space-time window of 300m and ±1 hr. The corresponding variation in PALS radar backscatter and *in-situ* soil moisture is shown in Fig. 5. By designating the data pair (July 5) with the lowest soil moisture as the baseline, it is clear from the figure that the change of observed VV radar return is strongly correlated (r = +0.91) with the change of soil wetness over a relatively short time span, provided that the vegetation growth is negligible during the period, as in this particular

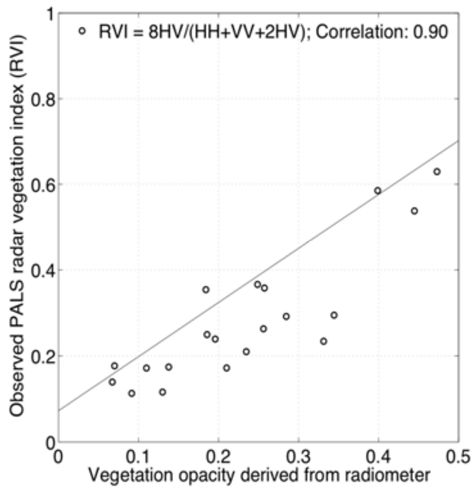

Figure 4. The observed radar vegetation index correlates strongly with vegetation opacity derived from PALS passive data. For a vegetation opacity coefficient b of 0.1 and incidence angle θ of 41°, the observed RVI shows a sensitivity of $b \times \Delta$RVI / (cos $\theta \times \Delta\tau$), or 0.16 per kg/m^2 of vegetation water content.

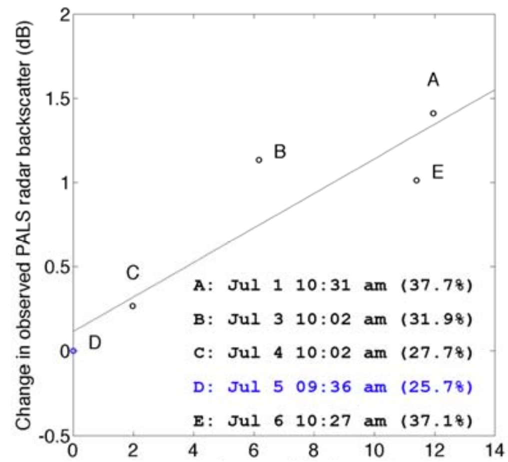

Figure 5. The observed change of PALS radar return is strongly correlated with the change of soil wetness over a relatively short time span (~ days) at LW29. The strong correlation illustrates the potential of change-detection techniques in radar-based retrieval algorithm development.

case at LW29. At a sensitivity of ~ 0.1 dB/% a typical dry-wet transition will result in a 4 dB change in the VV radar return, which is in good agreement with prior L-band active data observed in the SGP99 field campaign [2].

5. SUMMARY

The characteristics of the PALS/CLASIC data compared well with the *in-situ* soil moisture measurements and lent support to the existing radiometric model of soil moisture. The preliminary analyses of radar signal changes and radar vegetation index also support the development of combined passive and active retrieval algorithm for soil moisture under the influence of vegetation cover.

6. ACKNOWLEDGEMENTS

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