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CAROLS SMOS CAL/VAL Campaigns

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Abstract— The CAROLS “Cooperative Airborne Radiometer for Ocean and Land Studies” L band radiometer was designed and built as a copy of the EMIRAD II radiometer constructed by the Technical University of Denmark team. It is a fully polarimetric and direct sampling correlation radiometer. CAROLS is installed on board a dedicated French ATR42 research aircraft, in conjunction with other airborne instruments. Following initial laboratory qualifications and other scientific campaigns, SMOS CAL/VAL campaigns involving 22 flights were carried out over South West France, the Valencia site and the Bay of Biscay (Atlantic Ocean) in spring 2010, in coordination with *in situ* field campaigns.

1. INTRODUCTION

Passive microwave remote sensing of Soil moisture and ocean salinity has been at the center of attention of many research programs, for several decades. SMOS satellite mission is based on an aperture synthesis L-band radiometer [1], designed and developed by the European Space Agency (ESA). In the context of the validation activity for the SMOS mission, the authors proposed to design, build and operate the CAROLS L-Band radiometer from an aircraft. Because the sensitivity of L-band brightness temperature to salinity is very small (-0.45 K/psu at a physical temperature equal to 105 K), it was necessary to build a very accurate, sensitive, and stable system. The radiometer was installed in the French research ATR-42 aircraft. In coordination with *in situ* field campaigns, it is used together with a suite of other airborne instruments: a scatterometer — or a C-Band radar — used to measure ocean roughness and winds, a GPS receiver to estimate ocean surface roughness, an infra-red radiometer to measure sea surface temperature, and a visible wavelength wide angle camera to provide a qualitative description of the surface.

This paper presents in Section 2 a detailed description of the CAROLS instrument with the other the instruments used in our campaigns. In Section 3, we describe the SMOS CAL/VAL campaigns. The CAROLS data quality and first results are discussed in Section 4. Our conclusions are given in Section 5.

2. CAROLS RADIOMETER AND AUXILARY INSTRUMENTS

2.1. Carols Radiometer

CAROLS is a total power radiometer and has a simple structure and high theoretical sensitivity. The receiver was developed as a copy of the EMIRADII radiometer [2], in collaboration between the TUD (Technical University of Denmark) and the LATMOS laboratory (Laboratoire Atmosphères, Milieux, Observations Spatiales). It is a fully polarimetric correlation radiometer using direct sampling [2]. The antenna system comprises two large, identical Potter horns and two bulky waveguide orthomode transducers (OMT). These provide dual-incidence measurements.

All of the analog components are placed inside a double insulated and thermally regulated box and their physical temperatures are recorded in real time by means of temperature sensors. The accuracy of the receiver is highly dependant on the stability of the noise source and other components used in the noise injection circuitry. Table 1 illustrates performance of CAROLS instrument.

Table 1: Main technical specifications of the CAROLS radiometer.

CAROLS: correlation radiometer with direct sampling	
Receiver type	Total power receiver
Operating frequency	[1.4–1.427 GHz]
Bandwidth	24 MHz @ –3 dB
Polarization	Vertical and Horizontal
Sampling rate	139.4 MHz
Integration time	1 ms and 1.8 s
Internal calibration	Load and noise diode
Sensitivity	0.1 K for 1 sec integration time
Stability	0.1 K
System noise temperature	150 K
Physical temperature of AFE	45°C
Physical temperature of DFE	90°C

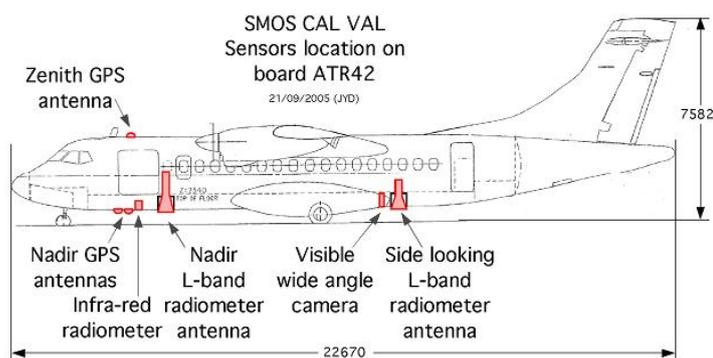


Figure 1: CAROLS instrument with two antennas (one slant and one nadir).

2.2. GPS GOLD-RTR System

The GPS system was supplied by the IEEC (Institut d'Estudis Espacials de Catalunya or Institute for Space Studies of Catalonia) [3]. It is composed of 3 antennas and a GPS Open Loop Differential Real Time Receiver (GOLD-RT). The aim is to retrieve information concerning sea surface roughness, in the form of the effective Probability Density Function (PDF) of the sea surface slopes.

2.3. Infrared Radiometer (IRR)

The infrared radiometer is part of the standard equipment of the research ATR42. This instrument points to nadir, and has a 3° field of view. It measures the radiance and the brightness temperature of the Earth's surface in three channels, namely 8.7, 10.8 and $12\ \mu\text{m}$, and is used to provide surface temperature estimations.

3. DESCRIPTION OF THE CAROLS CAMPAIGNS

3.1. Description of the Interfaces with the Research ATR-42 Aircraft

The research ATR42 has been available for research experiments since early 2006 (<http://www.safire.fr>). It is an original ATR42-320, specifically modified for scientific use. Two configurations were proposed for the CAROLS campaign flights. In the first configuration, providing dual-incidence data, the CAROLS radiometer was operated with two antennas, one pointing to nadir for vertical measurements, and the other pointing to the right side of the aircraft (slant antenna), at an approximately 30° incidence angle (Figure 1).

3.2. Flight Descriptions

All measurements were made from altitudes ranging between 600 m and 3000 m. Different flight patterns were carried out during the oceanic flights, in addition to straight horizontal flight portions: wing wags with a $\pm 25^\circ$ roll; nose wags with a $\pm 5^\circ$ pitch; and circular flights with 15° positive and

negative roll angles. These movements are useful for the qualification of the instrument's behavior and validation.

3.3. Measurement Sites

We selected three different test sites for the CAROLS data acquisitions, over land and ocean surfaces. Simultaneously to the CAROLS measurements, different *in situ* measurements were acquired in order to qualify the CAROLS data, the direct emissivity models, and finally the inversion algorithms.

3.3.1. Bay of Biscay

The ocean measurements were made over the Bay of Biscay. In order to support the Airborne CAROLS experiment, ship campaigns were organized by the LOCEAN team for each CAROLS campaign, along the same track as that used by the aircraft. Measurements of SSS, sea surface temperature (SST), wind speed, foam, wave spectrum, heat and momentum flux were collected on the ship. Different drifters measuring SSS and SST were deployed.

3.3.2. SMOSMANIA Site

This site is situated in the South West of France. SMOSMANIA (Soil Moisture Observing System — Meteorological Automatic Network Integrated Application) determines soil moisture values, based on a portion of the Météo-France automatic ground station network (the RADOME network) [4].

3.3.3. Valencia Site

The Valencia Site is located in South East Spain, about 80 km inland, to the West of Valencia. Within the Valencia validation site, an area of 30 km × 50 km was selected for the experiment.

4. CAROLS AIRBORNE DATA ANALYSIS

4.1. Carols Calibration Data

During any given flight, periodic calibrations effectively decrease the influence of gain fluctuations, and increase the radiometer's sensitivity. For any calibration step, the gain and the receiver noise temperature can be estimated with help of two calibrated points (load and load+noise diode). In order to retrieve absolute values of natural emissions, absolute calibration of the measured brightness temperatures is needed. Absolute calibrations were carried out over the ocean. For the two antennas, the measurements were compared to calculated temperatures using the TRAP software [5]. For these comparisons, measurements recorded under conditions of only limited variations in roll and pitch, and also SSS, were used.

4.2. CAROLS Measurements over Ocean

Figure 2 shows the data collected over the ocean, influenced by wing wag movements with strongly varying incidence angles, for both antennas. The results indicate a strong degree of coherence between the data collected by the two antennas. The upper TB values are for the X polarization, whereas the lower values correspond to the Y polarization. The nadir antenna data is plotted in red, and that with the slant antenna is plotted in black. For the same incidence angle, the variations

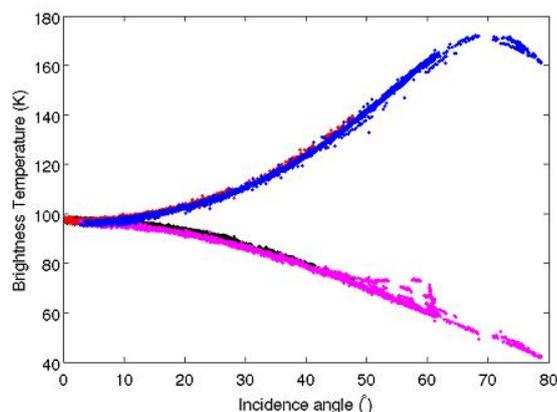


Figure 2: Tb (K) measured for the X and Y polarizations, for both nadir (red) and slant (black) antennas, as a function of incidence angle.

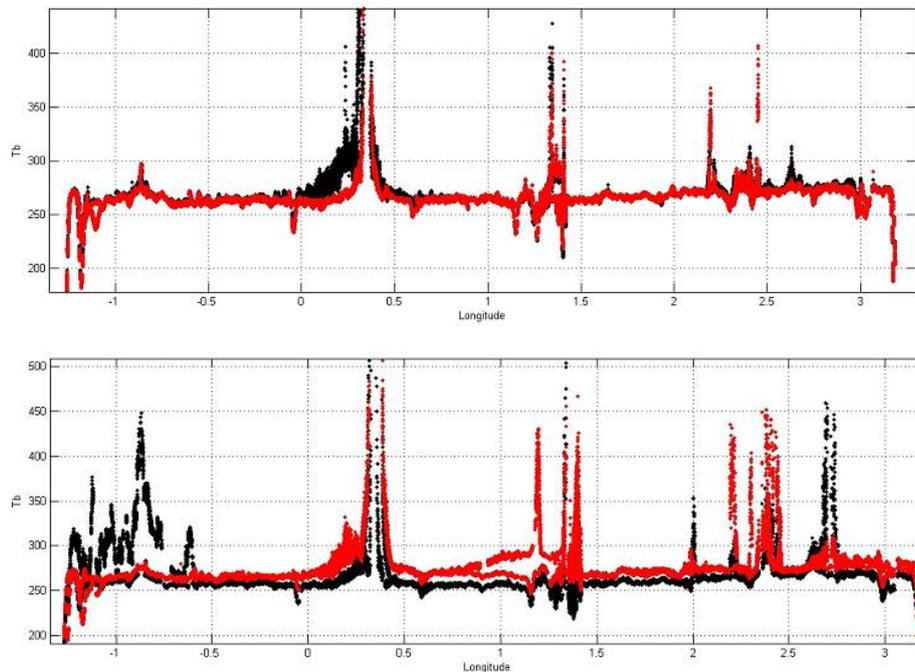


Figure 3: Time variations of T_b during the SMOSmania transect, in 2010, for the Nadir antenna (upper figure, red and black lines respectively for the X and Y polarizations), and Slant antenna (lower figure, red and black lines respectively for the X and Y polarizations). A mixed Kurtosis and thresholds to the T_b standard deviation algorithm [6] was applied for the data used here.

between the nadir and slant antenna measurements are less than 0.2K for the X polarization and less than 1 K for the Y polarization.

4.3. CAROLS Measurements over Land

Figure 3 shows the measured temperatures recorded over the SMOSMANIA site, acquired with both the nadir and slant antennas after RFI elimination [6]. For the nadir antenna, we find a good agreement between the T_x and T_y measurements. For the slant antenna, we verify that the T_x (close to T_V) values are higher than the T_Y (close to T_H) values. For CAROLS measurements, we qualitatively validate the agreement between Brightness temperatures and ground moisture measurements, with an increasing value of T_B on the driest flight days. The detailed inversion results will be published in the near future.

5. CONCLUSION

In the context of the SMOS mission, the CAROLS L-Band radiometric instrument has been built and tested. A large database was acquired during SMOS CAL/VAL campaigns over three studied sites (SMOSMANIA, VAS and the Gulf of Biscay). The retrieved brightness temperatures are found to be in good agreement and coherence with the simulated values over ocean. These measurement campaigns have been successful, and the detailed science results will be published in the near future.

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