Sea Surface Radiometric Observations At L-Band: Wind Speed Sensitivity Derived From WISE 2000 And 2001

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Abstract— The WISE campaigns were sponsored by the European Space Agency (ESA) to gather experimental data to improve the knowledge of the L-band brightness temperature dependence with wind speed at different incidence angles and azimuth angles. The goal is to help the development of sea surface salinity retrieval algorithms for ESA's SMOS Earth Explorer Mission. The UPC L-band AUtomatic RAdiometer (LAURA) plus other sensors to characterize the sea surface state were installed at the Casablanca oil rig (Spain) during approximately 2 months in 2000 and 2001. The derived wind speed sensitivity at vertical and horizontal polarizations and different incidence angles is presented.

1. INTRODUCTION: DESCRIPTION OF THE CAMPAIGN

Knowledge of the distribution of salt in the global ocean and its annual and inter-annual variability, are crucial in understanding the role of the ocean in the climate system. The measurement of sea surface salinity (SSS) is one of the challenges of ESA's SMOS Earth Explorer Opportunity mission. The dielectric constant for seawater is determined, among other variables, by salinity. Therefore, in principle it is possible to retrieve SSS from passive microwave measurements as long as the variables influencing the brightness temperature (T_B) signal (sea surface temperature, roughness and foam) can be accounted for at different viewing angles, polarizations and frequencies. The sensitivity of T_B to SSS is maximum at low microwave frequencies and good conditions for salinity retrieval are found at L-band (1.4 GHz). However, even at this frequency, the sensitivity of T_B to SSS is low (0.5 K per psu for an SST of 20°C, decreasing to 0.25 K per psu for an SST of 0°), comparable to that to wind speed (~0.2 K per m/s at nadir). It places demanding requirements on both the performance of the instrument, and the geo-physical modeling of the emissivity.

In the SMOS mission, the range of incidence angles varies from 0º to approximately 60º, which translates into a T_B range at vertical and horizontal polarizations from 50 to 150 K. The SSS retrieval algorithms must then include: 1) the variation of the local incidence angle as a pixel appears in consecutive snap-shots, and eventually 2) the sea emission azimuthal signature. Additionally, if these algorithms are stated in terms of series of T_h and T_v measurements, they must account for 3) the polarization mixing due to Faraday and geometric rotations across the field of view. Alternatively, if they are formulated in terms of the first Stokes parameter $I = T_v + T_h$, which is invariant to rotations, these two effects do not need to be corrected for [1,2]. The first two points require an accurate modeling of the sea surface emissivity at L-band. However, to date, experimental data is very scarce and different models predict quite different emissivities: there are uncertainties in the sea surface parametrization (spectrum, swell), in the dielectric constant [3,4], the foam emissivity at L-band has not been measured etc.

The goal of the WISE campaigns was the determination of the T_B sensitivity to wind speed. The following instrumentation was installed in the Casablanca oil rig (Repsol petrol company), 40 km away from the Ebro river mouth: a fully polarimetric L-band radiometer from UPC (Fig. 1), a fully polarimetric Ka-band radiometer from UMass (only in WISE 2000), four oceanographic and meteorological buoys from ICM and LODYC, a portable meteorological

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station from UPC, a stereo-camera from CETP that provided sea surface topography and foam coverage, a video camera from UPC mounted on the antenna pedestal, and an infrared radiometer from UV to provide SST estimates. Additionally, satellite imagery and water samples where acquired.

The radiometers were placed in the North-West corner of the platform at about 32 m above the sea level pointing in the direction of the dominant winds and avoiding Sun glint effects (except in the evening when the radiometer was pointed to the North-East). The oceanographic buoys were moored in the North and West sides of the platform. WISE 2000 data acquisition spanned from 25/11/2000 to 18/12/2000 and from 8/1/2001 to 15/1/2001, and WISE 2001 from 23/10/2001 to 22/11/2001. Three types of radiometric measurement sequences were carried out:

1) Constant incidence and azimuth angles during 1 hour once a day early in the morning at 44° incidence angle and azimuth ϕ=90° West (field of view common with that of the stereo-camera). Measurement mode designed to analyze the dependence of T_B with of sea state.

2) Elevation scan from 25° to 65° incidence angle in 10° steps at fixed azimuth angle (ϕ=90° West, to minimize RFI from Tarragona city). During the afternoon-evenings, to avoid sun glint, elevation scans were performed from 25° to 65° incidence angle in 5° steps at fixed azimuth angle (ϕ=20º East). This is the normal mode of operation, designed to acquire as much data as possible to determine the T_B sensitivity to wind speed.

3) Azimuth scans at fixed incidence angle, starting at an azimuth angle approximately ϕ=110º West and ending at an azimuth angle approximately ϕ=20º East in 30º angular steps. Measurement mode designed to find out is there is a T_B azimuthal signature, although this point is specifically addressed by the LOSAC campaign, carried out by the Technical University of Denmark and sponsored by ESA.

a) b) c) d)

Fig. 1. LAURA (L-band AUtomatic Radiometer, Universitat Politècnica de Catalunya):
a) location in the North side of the platform, b) pointing to the sea during an azimuth scan, c) pointing to the sky for cold load calibration, d) out of service during the November 16th storm (wind: speed sustained >100 km/h, peak >140 km/h at 69 m height)

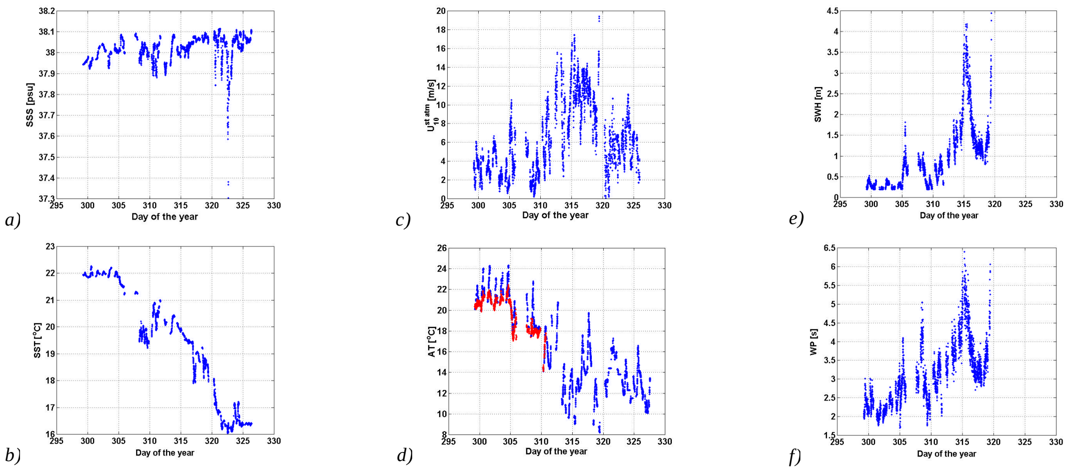

Fig. 2. Main oceanographic and atmospheric parameters measured during WISE 2001:
a) Sea surface salinity (SSS) [psu], b) Sea surface temperature (SST) [ºC],
c) Wind speed at 10 m height (U_{10}) (computed from data at 2.6 m and 69 m height assuming stable atmosphere),
d) Air temperature (AT): in red at 2.6 m height from buoy and in blue at 32 m height from portable meteorological station,
e) Significant wave height (SWH) defined as H1/3 the average of the highest third of the waves [m], f) Wave period (WP) [s].

During WISE 2000 wind conditions were low to moderate, but during WISE 2001, the meteorological and oceanographic conditions were the most extreme ones registered on the platform during the last 20 years. Figures 2a-2f show the main oceanographic and atmospheric parameters measured during WISE 2001. As it can be appreciated, during more than one third of the campaign winds well exceed 10 m/s, reaching 20 m/s (at 10 m height), when the strongest storms happened. Measured sea surface salinity was very stable around 38 psu, except on November 18th due to an intense rain event. Sea surface temperature evolution shows the start of the cooling from the warm summer value. The high difference between sea surface temperature and air temperature on days around 315 and 320 (November 10th and 15th), about 10°C shows two clear events of unstable atmosphere, coincident with the two strong storms.

2. DISCUSSION OF L-BAND RADIOMETRIC DATA

LAURA is an L-band fully polarimetric radiometer consisting of two Dicke-type radiometers for the vertical and horizontal polarizations (T_v and T_h), and a correlation radiometer for the third and fourth Stokes parameters (U and V). Calibration measurements are performed at the beginning and at the end of each measurement cycle (usually < 100 min). Calibration of the Dicke radiometers is performed by looking to a microwave absorber at known temperature (hot load) and the sky (cold load). The cold load "temperature" is computed taking into account the atmospheric, cosmic and galactic noise contributions, the geographic position of the platform, the date and time, the antenna pattern and its orientation. Calibration of correlator's offsets and local oscillator leakage and so on is performed by injecting uncorrelated noise, while phase is calibrating injecting know correlated noise. Radiometric, temperature, position and orientation data is acquired together with meteorological and video data for further processing, which includes RFI screening, antenna oscillations due to strong winds, and antenna finite beamwidth effects.

Once all data points were calibrated, the 5 minutes average T_B was computed and plotted at each polarization and incidence angle versus 10 m wind speed [5, Fig. 3]. It is found that around 55°, T_v is not sensitive to wind speed, and the derived wind-induced brightness temperature deviations $\Delta T_{B,p}$ are:

$$T_{B,p}(q) = \left[1 - \Gamma_p(e_r, q)\right] SST + \Delta T_{B,p}(q, U_{10}), \quad (1a)$$

$$\Delta T_h \approx 0.23\left(1 + q/70^\circ\right) U_{10}, \quad (1b)$$

$$\Delta T_v \approx 0.23\left(1 - q/50^\circ\right) U_{10}.$$

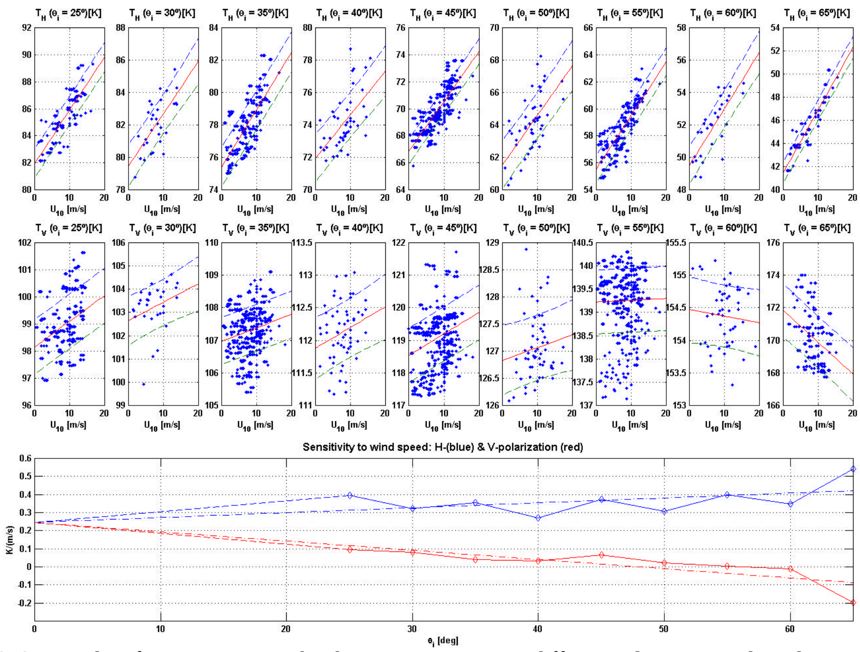

Fig. 3. Scatter plot of 5 minute average brightness temperatures at different polarization and incidence angle and derived brightness temperature sensitivity to wind speed. Wind speed at 10 m computed accounting for atmospheric instability.

However, from Figs. 2b and 2d, it is clear that in most cases the atmosphere was very unstable, with SST-AT exceeding 10°C. To analyze this effect, the 10 m wind speed was re-computed using [6]. Figure 4 shows the scatter plot U_{10} computed assuming stable atmosphere vs. U_{10} taking into account atmospheric instability: in general all wind speeds are increased, as compared to the stable case, except at some high wind speeds events.

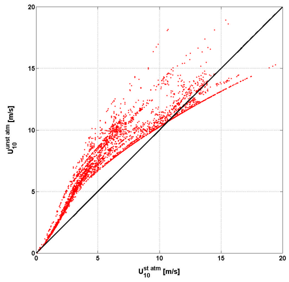

Fig. 4. U_{10} computed with atmospheric instability [5] vs. U_{10} computed assuming stable atmosphere.

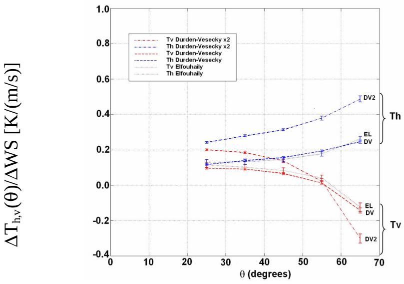

Fig. 5. Computed T_B sensitivities to wind speeds using a 2 scale model and different sea surface parametrizations.

From the slopes of the linear regressions of the clouds of points plotted for both H- and V- polarizations at different incident angles (Fig. 3, 18 upper plots, solid red lines: linear fit, dashed lines: ± percentile 50), the derived wind-induced brightness temperature deviations are now:

$$\Delta T_h \approx 0.25\left(1+q/94^\circ\right)U_{10},$$
$$\Delta T_v \approx 0.24\left(1-q/48^\circ\right)U_{10}. \quad (2)$$

Eqs. (1a) and (2) shown a quite similar behavior. It can be appreciated that the effect is negligible at V-polarization, but at H-polarization the brightness temperature increase tends to be slightly higher and exhibits a smaller incidence angle dependence. Both expressions are in agreement with the T_B sensitivities with wind speed computed by LODYC [1,2,7] using a two-scale model and the Durden and Vesecky spectrum [8] multiplied by two as illustrated by fig. 5 computed for the wind speed conditions encountered during WISE 2000.

3. CONCLUSIONS

This paper has presented the wind speed sensitivities derived from WISE campaigns. These results are in agreement with the very few measurements existing at L-band [9] and the simulation results. At H-polarization, the sensitivity to wind speed ranges from 0.23-0.25 K/(m/s) at nadir (depending on how the atmospheric stability is accounted for) to 0.54 K/(m/s) at 65°, and at V-polarization from 0.23-0.24 K/(m/s) at nadir to -0.2 K/(m/s) at 65°, being null around 55°. Further studies will be focused in the determination of the uncertainties in the sensitivities due to the uncertainties in the radiometric and wind speed data.

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