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# INTERPRETATION OF CAROLS L-BAND MEASUREMENTS IN THE GULF OF BISCAY

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## ABSTRACT

In order to validate and improve models used in the SMOS data processing for salinity retrieval, L-band airborne CAROLS campaigns have been conducted in the Gulf of Biscay. The radiometer (CAROLS) is mounted onboard the French research ATR42 airplane. *In situ* measurements were gathered during the campaigns. We analyse here a coastal flight (20 May 2009) characterized by strong SSS gradients. Thanks to the TRAP simulation software which integrates the CAROLS antenna lobes geometry and physical models used in the SMOS data processing over the ocean, we retrieve the salinity for each antenna and each polarisation using the sensitivity of  $T_b$  to SSS. Results are in good agreement with *in situ* measurements especially for the first part of the flight where correlation between retrieved and *in situ* SSS is up to 0.88. Then we estimate the possible error sources as the extrapolation, the spatio-temporal wind speed variability or RFI. Future work will be based on the analysis of the sea roughness using CAROLS and the STORM scatterometer measurements during other flights.

Key words: SSS; salinity; SMOS; inversion.

## 1. INTRODUCTION

Sea surface salinity (SSS) is a key component of the global earth water cycle and of the ocean circulation.

The Soil Moisture and Ocean Salinity (SMOS) mission uses a very innovative interferometric technology. It has been successfully launched on the 2<sup>th</sup> November 2010. It provides for the first time information on the SSS at the global scale.

However, a precise determination of the SSS from L-band radiometry requires a very good knowledge of the influence of the other parameters that affect the L-band measured signal.

Our study is part of the validation and improvement of

models used in the SMOS data processing for salinity retrieval, of airborne measurements of L-band Brightness Temperature ( $T_b$ ) and associated *in situ* salinity, sea surface temperature and wind speed measurements.

We interpret in this study data of a coastal flight with a high salinity variability. We study the influence of the high spatio-temporal frequency variability of the Sea Surface Salinity (SSS) and of the roughness parameterised as a function of wind speed.

In section 2, we present the radiometric data acquisition, using the L-band Cooperative Airborne Radiometer for Ocean and Land Studies (CAROLS), the sea surface parameters. Then we describe the methods used to simulate Brightness Temperatures and to retrieve the sea surface salinity (SSS).

Then, in section 3, we expose results on the retrieved sea surface salinity using CAROLS and compare them to *in situ* measurements.

Key results from these tests are summarized and discussed in section 4, where we will investigate possible sources of the error originating from wind and SSS variability.

## 2. DATA & METHODS

### 2.1. Data

#### 2.1.1. CAROLS Radiometric Data

The L-band Cooperative Airborne Radiometer for Ocean and Land Studies (CAROLS) radiometer (Zribi et al. (2008)) flew seven times over the Gulf of Biscay between May 04 and May 26, 2009 around 20 UTC. These flights followed two other airborne campaigns with the same instrument in September 2007 and November 2008 always in the Gulf of Biscay which is characterized by strong SSS contrast (Gironde plume).

Brightness temperatures ( $T_b$ ) of the surface were measured by a nadir antenna and an antenna looking at  $33^\circ$  (referred to the  $30^\circ$  antenna in the following) on the right hand side of the aircraft (french research ATR42 airplane). The two antennas measure the four stokes parameters. Raw data are corrected for cable attenuation and reflexion and a kurtosis filter criteria is applied (2.9–3.1) to reject the main part of the Radio-Frequency Interferences (RFI).

### 2.1.2. Sea Surface Conditions

The salinity along the plane track was extrapolated using a nearest neighbor method applied to measurements taken onboard:

- the R/V Antea (20 May 17h to 21 May 18h) which sailed from the south to the north and followed most of the plane track;
- the Investigator ship from AZTI which made CTD near the track flight northeast branch between the 19 May 13h45 and the 20 May 01h UTC (Fig. 1(a)).

Salinity from a microcat mooring (45.56 N; 1.83 W) and water samples (18h and 19h50 the 20 May) from Arcadino Campaign were used for validation .

As seen on the sea surface conditions deduced from extrapolated measurements, the plane track (North to South) remains within the continental shelf in the Gulf of Biscay characterized by strong salinity contrast (Fig. 1).

QuickScat satellite recorded wind speed between 6 and 7 m/s at 18h36 along the plane track in agreement with the wind speed measured at the same time by the Antea ship. During the flight over the ocean, the Antea ship measures a wind speed varying between 5 and 10 m/s (Fig. 1(b)) which indicates possible variation of wind speed during the flight. When the ship crossed the plane track (20h28, 44.89 N; 1.69 W) a strong gradient both in wind speed (Fig. 1(b)) and in salinity was measured by the R/V Antea.

## 2.2. Methods

### 2.2.1. Brightness temperature simulations

Radiometer measurements in the antenna frame are compared with simulations conducted with the Terrestrial Radiometry Analysis Package (TRAP) software developed at IFREMER (Reul et al. (2008)). We used it to simulate airborne measurements. It takes into account, the CAROLS antenna lobes geometry, and the variability coming from geophysical parameters using the models implemented in the SMOS data processing of the ocean salinity:

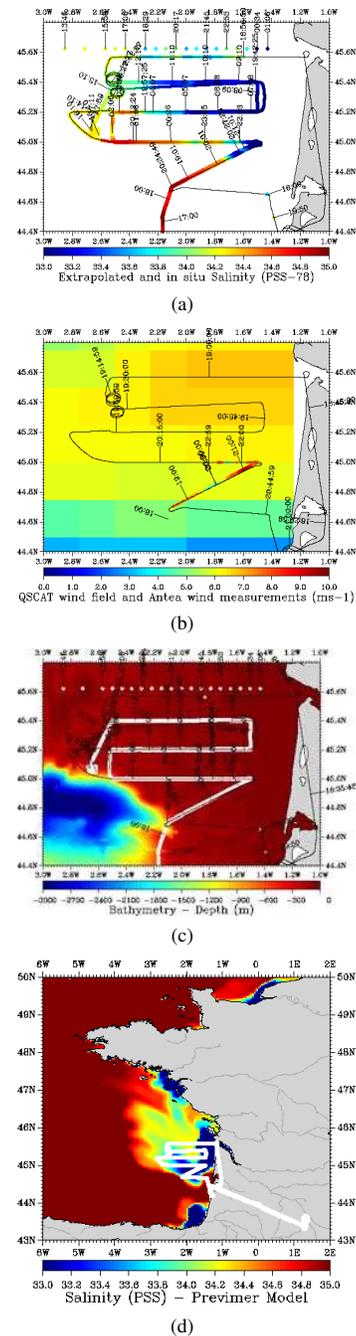


Figure 1. Sea surface conditions for the coastal flight of the 20<sup>th</sup> May 2009 around 20 UTC. (a) Extrapolated and in situ salinity (ps-78); 1(b) QuickScat Wind Speed field (18h36) and Antea in situ wind measurements in (ms<sup>-1</sup>); (c) local bathymetry (meter), the plane track in black and in situ measurements in white; and (d) Sea Surface Salinity from the Previmor model taken the 20<sup>th</sup> May 2009 at 20h UTC (Lazure & Jégou (1998)) with the plane track superimposed in white.

- the atmospheric emissivity and absorption from Liebe et al. (1993),
- the sea surface emissivity for a flat surface from Klein & Swift (1977),
- the contribution of the roughness to the sea surface emissivity according to a two-scale model using the Durden and Vesecky  $\times 2$  wave spectrum (Dinnat et al. (2003))
- the scattering of galactic noise by the sea surface according to Tenerelli et al. (2008).

At the ship/plane crossing we compared radiometric measurements and simulations using *in situ* parameters measured by the ship. The differences are respectively of (+0.39; +0.49; -0.55; -0.36) K for (Nadir-V; Nadir-H; 30°-V; 30°-H). They are adjusted in the rest of our analysis.

### 2.2.2. Sea Surface Salinity (SSS) Retrieval

The sea surface salinity from each polarisation on each antenna is retrieved using the sensitivity of  $T_b$  to SSS as follows:

$$\Delta T_b = T_{b \text{ meas}} - T_{b \text{ model}}(U_{QSCAT}, SST_{ship}, SSS_{34psu}),$$

$$SSS = 34 + \frac{dSSS}{dT_b} \cdot \Delta T_b.$$

where  $T_{b \text{ model}}$  is simulated with TRAP and  $\frac{dSSS}{dT_b}$  is estimated at  $SST = 15.6^\circ\text{C}$  and  $SSS = 34$  pss-78.

## 3. RESULTS

### 3.1. Sea Surface Salinity

Four salinity are retrieved using the two polarisations on the two antennas. They agree quite well with *in situ* measurements especially before 20h.

At the very beginning of the flight (until 19h), the plane flew over the Gironde plume. No *in situ* measurements were recorded there, but there is a very good agreement with the Previmer model salinity (Lazure & Jégou (1998)) especially in the V-polarisation (Fig. 2(a)).

After 20h, SSS retrieved from H-polarisation are too low both on the nadir and the side antenna which suggest Radio-Frequency Interferences (RFI). To assess this hypothesis we plot measured SSS vs. retrieved SSS for the first part of the flight and for the whole flight (Fig. 3(a) and 3(b)). In Fig. 3(a) we observe an accuracy of 0.3 pss-78 on retrieved SSS whatever the polarisation and antenna (Cf Table 3.1 which gives statistic for this figure). Fig. 3(b) shows a set of under-estimated salinities possibly linked to RFI although a Kurtosis criteria filter (2.9–3.1) has been applied on the raw data.

Ant.-Polar.	Bias <sup>a</sup>	Std <sup>b</sup>	R <sup>c</sup>
Nadir – V	-0.49	0.36	0.83
Nadir – H	-0.23	0.73	0.54
30° – V	-0.19	0.31	0.89
30° – H	-0.22	0.76	0.62

Table 1. Statistic for the whole flight (a: Average Bias pss-78; b: Standard Deviation; c: Correlation)

Ant.-Polar.	Bias <sup>a</sup>	Std <sup>b</sup>	R <sup>c</sup>
Nadir – V	-0.46	0.31	0.77
Nadir – H	0.01	0.31	0.76
30° – V	-0.19	0.29	0.88
30° – H	-0.05	0.41	0.67

Table 2. Statistic on the first period of the flight:  $\Rightarrow 19\text{h}59$

## 4. DISCUSSION

Although measurements were corrected for the bias observed with respect to model at the ship/plane crossing, a bias remains in the retrieved SSS over the whole flight. This could be due to large variability in wind speed at ship/plane crossing and suspected RFI.

We used the sea surface salinity fields simulated by Previmer model every hour (Lazure & Jégou (1998)), to estimate the error coming from our extrapolation method. We extract Previmer SSS corresponding to time and location of ship measurements and then we extrapolate them under the plane track using a nearest neighbor method. We then compare these extrapolated SSS with the Previmer SSS extracted at the time and location of the plane track. The estimated error on our extrapolation method is in most cases less than 0.2 pss.

We looked at possible effect of the spatio-temporal variability of wind speed and its resulting error of wind speed on derived salinity, in two studies:

One of the possible effect is the variability of wind speed at spatial resolution lower than 25 km by using high resolution QuickScat wind speed from Owen & Long (2009) at 2.5 km. But as we can see in Table 4, no improvement is observed possibly because of the temporal variation of the wind since the satellite pass at 18h36.

In order to estimate an error on wind speed possibly responsible for the error on SSS, we retrieved WS (Fig. 4)

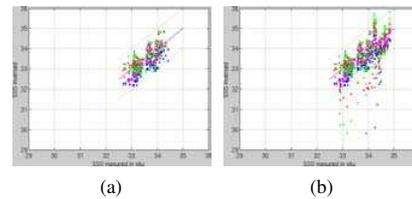


Figure 3. Scatter plot of (a) the first period of the flight: before 19h59 and (b) of the whole flight.

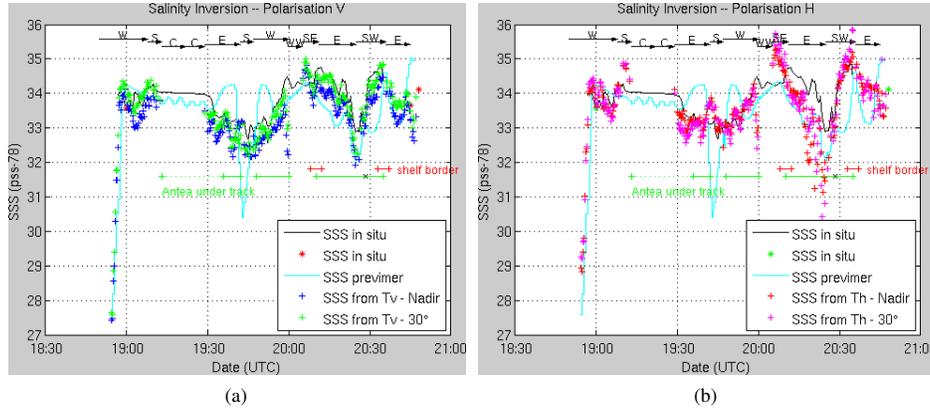


Figure 2. Sea surface salinity retrieved for the two antenna (a) in V-polarisation and (b) in H-polarisation. W, S, E represents the cardinal points and C and WW respectively Circle flights and Wing-wags movements. In situ extrapolated measurements under the plane track is plotted in black. Samples and microcat mooring are represented with a star.

from  $T_b$  and *in situ* SSS, using the same method as the SSS retrieval presents in section 2.2.2. Differences up to  $2\text{ms}^{-1}$  relative to QSCAT wind speed are found but they are not consistent between the 2 antennas and polarisations.

Ant.-Polar.	Bias <sup>a</sup>	Std <sup>b</sup>	R <sup>c</sup>
Nadir – V	-0.46	0.42	0.80
Nadir – H	-0.16	0.80	0.54
30° – V	-0.18	0.34	0.89
30° – H	-0.13	0.88	0.61

Table 3. Statistic of the whole flight with High Resolution QSCAT wind speed

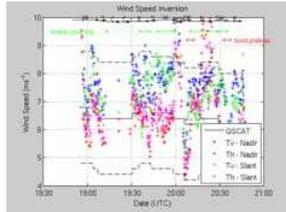


Figure 4. Wind Speed to retrieve the *in situ* salinity

## 5. CONCLUSIONS

We observe a good agreement between *in situ* measurements and retrieved salinity whereas we have a poor knowledge of the spatio-temporal wind speed in this area.

We suspect presence of RFI on the second part of the flight which affect H-polarisation of both antennas.

In the future, we plan to test a multiparameter retrieval (wind speed and sea surface salinity) and to analyse the sea surface roughness using CAROLS and the STORM

scatterometer which were simultaneously used on other flights.

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