Correcting sea surface temperature spurious effects in salinity retrieved from spaceborne L-band Radiometer measurements

J. Boutin(1), J.L. Vergely(2), E. Dinnat (3), P. Waldteufel (4), Francesco D’Amico(5), N. Reul(6), A. Supply(1) and Clovis Thouvenin-Masson(1)

See more in Boutin et al., IEEE TGRSS, 2020
Background (1)

- Salinity dependency of L-band (1.4GHz) radiometer meas. $\Leftrightarrow$ dielectric constant:

\[ T_{b_{sea}} = e \left( SSS, SST \right) \cdot SST \]

\[ e_v = 1 - \left[ \frac{e_p \cos \theta - \sqrt{e_p} \sin^2 \theta}{e_p \cos \theta + \sqrt{e_p} \sin^2 \theta} \right]^2 \]

\[ e_h = 1 - \left| \frac{\cos \theta - \sqrt{e_p} \sin^2 \theta}{\cos \theta + \sqrt{e_p} \sin^2 \theta} \right|^2 \]

- $|\partial T_{b}/\partial SSS|$ small (1 to 0.2 K/pss)
  $\Rightarrow$ need very precise $\varepsilon_r$ to retrieve SSS with $\sim$0.1-0.2 pss uncertainty

- Various dielectric constant models used for processing satellite data today:
  - SMOS ESA: Klein & Swift (1977) (KS): model fitted to laboratory measurements
  - Aquarius/SMAP CAP JPL: intermediate between KS and MW
Background (2): SST residuals between satellite & in situ SSS

Both SMOS and Aquarius V3 roughness models depend on SST based on physical considerations (2-scale model for SMOS & geometric optics for Aquarius V3) =>

Could we resolve the SST residuals of satellite SSS without empirical SST adjustment of wind model?

Dinnat et al. 2019, Boutin et al. 2020

Boutin et al. Dielectric constant
Objective of the study:

• Minimize the SST dependency of residuals between satellite and co-localized in situ salinity while retaining as much as possible physical basis in the modelling of the various components of the radiative transfer model
  => Investigate a revision of dielectric constant model

Method:

• Adjust one parameter of the physical inspired dielectric constant model of Somaraju and Trumpf (2006) by comparing SMOS retrieved pseudo dielectric constant (Acard) with Acard derived from SMOS Tb and ECMWF IFS Temperature & In Situ Salinity
Existing models for the permittivity of saline water are empirical ones that best fit experimental data. We propose a physically realistic model, similar to the one used in plasma physics, for the variation of the dielectric constant of water with varying frequencies and salinities.

In addition to using the dielectric model of fresh water Ellison et al. [15], Stogryn et al. [11] and Meissner et al. [12], respectively, use 30, 13 and 12 parameters that are determined from experimental data to predict the variation of all the terms in (5) with temperature and salinity. In contrast, our model is not only physically realistic but also uses only two additional parameters to describe the dielectric behavior of seawater.

Total polarization of sea water described as the sum of:
- $P_b$, the polarization due to the displacement of bound charges in water molecules (i.e. induced and orientation polarization):
  number of water molecules that orient themselves around the dissolved ions proportional to the number of ions, $N_i$ => $\varepsilon_s$ decreases linearly with $S$.
- $P_f$, the polarization due to the displacement of ions inside water (i.e. atomic polarization).

$$
\varepsilon_r(\omega, T, S) = \varepsilon_\infty(T) + \frac{\varepsilon_s(T, S) - \varepsilon_1(T, S)}{1 + j\omega \tau_1(T, S)} + \frac{\varepsilon_1(T, S) - \varepsilon_\infty(T) + j\sigma(T, S)}{1 + j\omega \tau_2(T, S)} + \frac{1}{\epsilon_0 \omega} \sum_i \frac{c_i}{1 + j\omega \tau_{if}/\omega}.
$$


Somaraju and Trumpf 2006
Existing models for the permittivity of saline water are empirical ones that best fit experimental data. We propose a physically realistic model, similar to the one used in plasma physics, for the variation of the dielectric constant of water with varying frequencies and salinities.

At low frequency, only one unknown parameter in addition to pure water parameters and conductivity (they use pure water parameters of Stogryn 1995; at L-Band using pure water parameters of MW 2014 gives very similar results)

\[
\epsilon_r(\omega, T, S) = \epsilon_1(T) + \frac{\epsilon_\infty(T) - \epsilon_1(T)}{1 + j\omega\tau_1(T, S)} + \frac{\epsilon_1(T) - \epsilon_\infty(T)}{1 + j\omega\tau_2(T, S)} + j\frac{\sigma(T, S)}{\epsilon_0\omega}.
\]
Somaraju’s fits of $\text{Re}(\varepsilon)$ and $\text{Im}(\varepsilon)$ to various dielectric constant models, at various $S$, $T$ as function of frequencies (1-256GHz)

\[ \alpha(T) = 0.00314 \text{ ppt}^{-1} \]

consistent with degree of dissociation of NaCl
Tb (SSS, SST) at L-band

KS: Klein and Swift (1977)
MW: Meissner and Wentz (2004, 2012)
ST: Somaraju and Trumpf (2006)
Data and methods

• SMOS ESA v662 retrieved pseudo dielectric constant (Acard) compared the one derived with *in situ* (Argo and ship) SSS measurements and ECMWF IFS SST

• Period: 2012-2015

• Thorough SMOS data sorting:
  • within +/-400 km away from the track, in order to avoid SMOS swath edges with fewer and noisier Tb measurements than in the central part of the swath,
  • further than 1000 km away from the coasts, in order to avoid land-sea contamination
  • wind speeds between 5 and 9 m s\(^{-1}\), to minimize uncertainties in wind corrections
  • latitudes south of 40\(^\circ\)N in order to avoid high northern latitudes possibly contaminated by remaining RFI, ice vicinity and solar contamination during the eclipse period [19],
  • latitudes north of 60\(^\circ\)S and 50\(^\circ\)S for descending and ascending orbits, respectively => minimize ice-sea contamination
Pseudo dielectric constant retrieved from SMOS Tb: Acard

Multiangular (θ ~ 0°- 60°) SMOS Tbs corrected from roughness, atmosphere, and galactic noise => Acard

Waldteufel et al. 2004

While it is not possible to retrieve real and imaginary part of dielectric constant separately, It is possible to derive a combination of them: Acard

\[ A_{\text{card}} = \frac{m_{\text{card}}^2}{(m_{\text{card}} + \varepsilon' - B_{\text{card}})} \]

with: \(m_{\text{card}} = ( (\varepsilon' - B_{\text{card}})^2 + \varepsilon''^2 )^{1/2}\)

with \(B_{\text{card}} = 0.8\)

Order of magnitudes:

\[ \frac{dA_{\text{card}}}{d\text{SSS}} = 1.1/\text{pss} \text{ @ 30°C} \]

\[ \frac{dA_{\text{card}}}{d\text{SSS}} = 0.3/\text{pss} \text{ @ 0°C} \]
SMOS SSS and Acard compared to in situ values

2012-2015 period

Wind Speed 5-9 m/s
SMOS SSS and Acard compared to in situ values

2012-2015 period

Wind Speed 5-9m/s

After filtering and correction for conditional sampling effect
Revision of $\alpha(T) \Rightarrow$ New $\varepsilon$ parametrisation (BV)

a) alpha(SST)

b) Acard comparison (median over the SSS), sigSST=0.6°C

ST value $= 3.14 \times 10^{-3}$
Validation (1):
SMOS SSS compared to Argo OI SSS

SMOS Tb obtained with v721 experimental reprocessing

Wind speed [3 12] m/s

Descending orbits 45°N - 60°S

Distance to coast > 1000 km

March to October 2016.

With $\varepsilon_{BV}$, SMOS SSS - Argo SSS: within +/-0.05 for SST > 7°C; [0.05 0.2] for SST < 7°C

(N.B. SMOS v7 Tb slightly different from SMOS v6 Tb used to adjust $\varepsilon_{BV}$ parametrisation)
Validation (2): Aquarius SSS compared to Argo SSS

With $\varepsilon_{BV}$, Aquarius V3 SSS - Argo SSS +/-0.1 pss for SST>2°C (Aquarius V3 without adjustment of SST-wind induced emissivity)
Conclusions and perspectives

• A temperature dependent parametrisation of $\alpha$ parameter in the Somaraju and Trumpf (2006) $\varepsilon_r$ model allows to deal with SST dependency of residuals between satellite and in situ salinity measurements while retaining much physical basis in the modelling of the other components of the radiative transfer model (RTM).

• When considering BV parametrisation, remaining SST-dependency of the satellite SSS residuals is:
  • SMOS : +/-0.05 for SST > 7°C; between 0.05 and 0.2 for SST< 7°C
  • Aquarius: +/-0.1pss for SST>2°C and with Aquarius V3 RTM or with SMOS RTM

• To go further :
  • Laboratory measurements of $\varepsilon_r$ are needed to validate $\varepsilon_r$ model independently of any assumption on other components of the RTM. A wide range of SSS and SST would be suitable to get more rigorous adjustments of $\varepsilon_r$ model parameters.
  • Study Somaraju and Trumpf (2006) model at higher frequency

• BV parametrisation implemented in ESA & CATDS SMOS L2OS processors; it will be used in SMOS v7 reprocessing (beginning 2021)

• Matlab code available on : https://owncloud.locean-ipsl.upmc.fr/index.php/s/ovhgqNazmMsEdna
Comparison with GWU 2020
FREQ=1.41GHz, EIA=40°, V-pol

MW2012
FASTEM5

BV2020
KS

- SST from 0°C to 30°C in steps of 1°C.
- SSS from 30 psu to 38 psu in steps of 1 psu.
- \( \Delta \text{TB surface} = \Delta \text{Emissivity} \cdot \text{SST (Kelvin)} \).
BV parametrisation leads to Tb intermediate between KS and MW

Tb with MW, BV, Zhou17 is lower than Tb with KS at low SST

$\Delta$Tb between 25°C and 30°C higher with MW, BV, Zhou than with KS

BV closer to KS between 5 and 25°C than MW, BV, Zhou