Error characterization of SSS products using Triple Collocation Analysis

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Hoareau et al., 2018 (TGRS)

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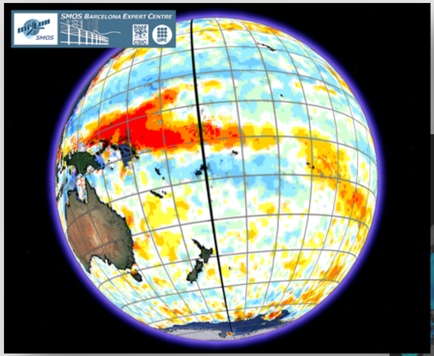
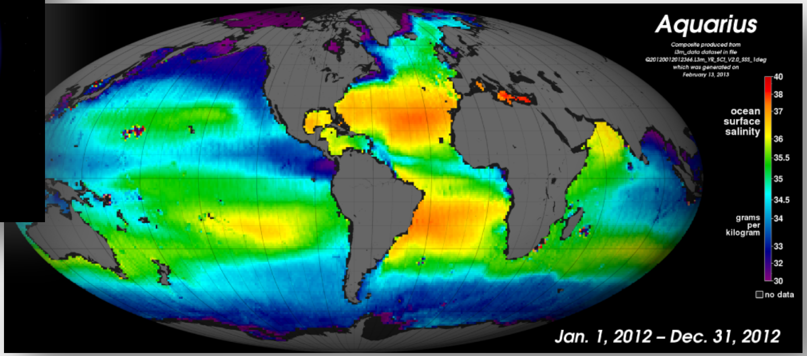
Sea Surface Salinity (SSS): Essential Climate Variable





More than **9 years of** remote sensing SSS data are available, thanks to **satellite passive L-band missions.**

Satellite salinity measurements provide unprecedented spatio-temporal resolution/coverage as compared to any other observation system (Argo, CTD, TSG, moored buoys, etc.).

⇒ **Need for a comprehensive error characterization** of the available SSS products.

In this study, we focus on the validation of **SMOS-BEC** and **Aquarius v.4 Level 3** products.

Limitations of direct comparison validation approach

Spatial and temporal representation when comparing satellite gridded product versus in situ data:

- Vertical representation: first cm / ~5m
- Spatial representation: 0.25^0/ point measurement
- Temporal representation: ~weekly / instantaneous (Argo)

=> The different spatial & temporal representation of the data will impact the direct comparisons and therefore needs to be accounted for during the validation process => ***representativeness error***

In direct comparisons, *in situ* data are assumed to be true or perfect at satellite scales
=> only the **relative error** is estimated.

Absolute error estimation requires at least **3 independent** measurement systems.

=> Use of *Triple collocation Analysis*.

Triple Collocation (Stoffelen, 1998)

- **Triple collocation** (TC) was conceived as a tool for **intercalibration** and **individual error assessment** of three different collocated WIND data sets (Stoffelen, 1998).

- Given 3 measurement systems with different spatial resolution (buoy, satellite, model), s_i , $i=1,2,3$, the measurement and its error are modelled by the following linear equation:

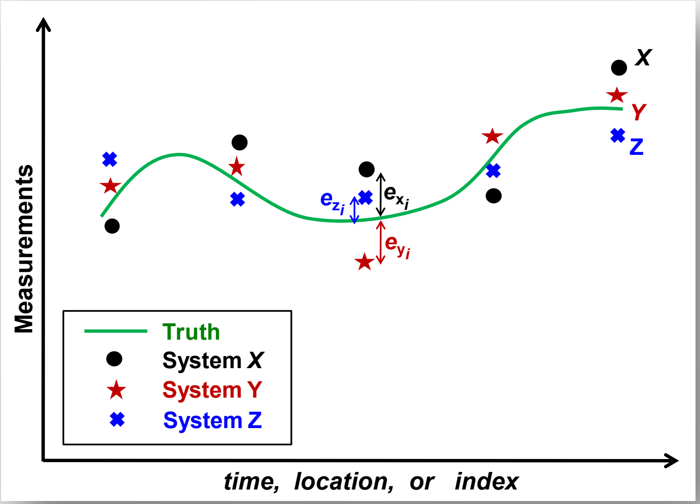
scaling *calibration coef.*

random measurement ***error*** *(Gaussian)*

$$s_i = a_i S + b_i + \delta_i$$

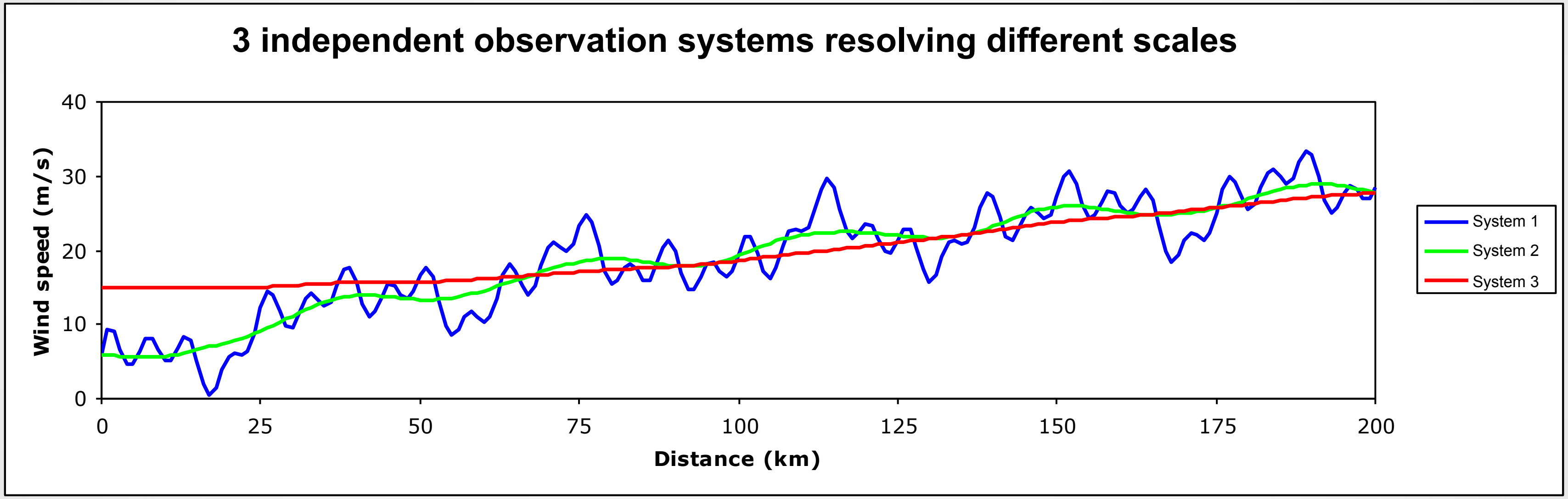
bias *calibration coef.*

Truth *at the scales commonly resolved by all 3 data sources*

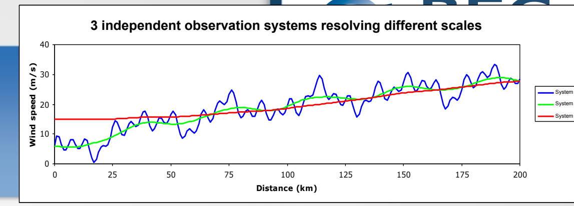


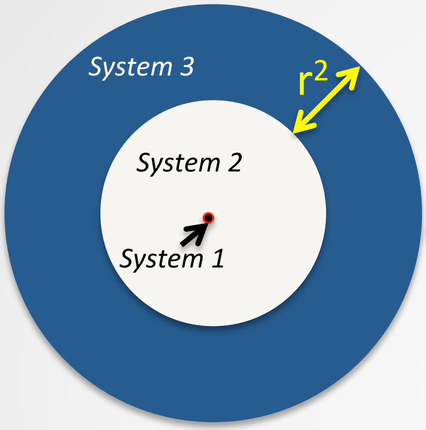
<u>TC model assumptions</u>:
- errors are additive
- error distributions are close to Gaussian
- the collocated data sources are independent

Triple Collocation (Stoffelen, 1998)
Representativeness error



Triple Collocation (Stoffelen, 1998)
Representativeness error





Suppose system 1 and 2 resolve **smaller turbulent** scales than system 3.

The true variance common to these smaller scales is:

$$\boxed{r^2 = \langle \delta_1 \delta_2 \rangle}$$

which is part of the measurement errors δ_1 and δ_2.
=> r^2 is the **correlated part** of the errors of s_1 and s_2.

Assuming that, since s_3 does not include these smaller scales, its measurement error δ_3 is independent of δ_1 and δ_2, and:

$$\boxed{\langle \delta_1 \delta_3 \rangle = \langle \delta_2 \delta_3 \rangle = 0}$$

Representativeness error (r^2) corresponds to the **common true variance** of Systems 1 and 2, not resolved by system 3.

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Triple Collocation algorithm

Initialization,

$n = 0, \quad i = [1,2,3]$

S_i^n = Collocated i-data set

$a_i^n = 1.0$

$b_i^n = 0.0$

r^2

TC model

$n = n+1 \qquad i = [2,3]$

$$M_{ij}^n = \langle S_i^n S_j^n \rangle$$

$$a_2^n = \frac{M_{23}^n}{M_{13}^n} \qquad a_3^n = \frac{M_{23}^n}{M_{12}^n - r^2}$$

$$b_2^n = \langle S_2^n \rangle - a_2^n \langle S_1^0 \rangle \qquad b_3^n = \langle S_3^n \rangle - a_3^n \langle S_1^0 \rangle$$

$$S_i^{n+1} = a_i^n S_i^n + b_i^n$$

No

$$\frac{|a_i^n - a_i^{n-1}|}{|a_i^{n-1}|} \leq 10^{-5}$$

$$\frac{|b_i^n - b_i^{n-1}|}{|b_i^{n-1}|} \leq 10^{-5}$$

Convergence ?

Yes

a_3 depends on r^2

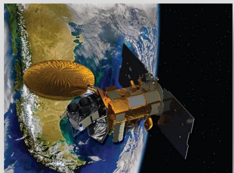
Errors estimated after convergence and for calibrated data

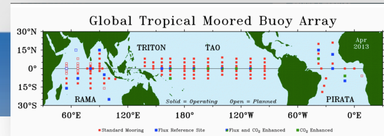
Error Estimation (SD)

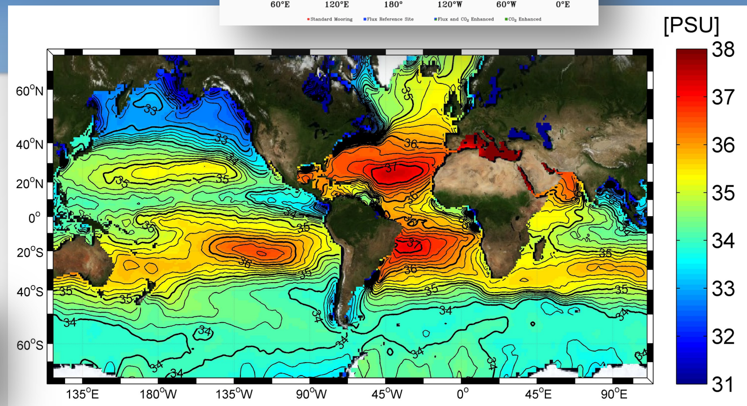
$$\varepsilon^2 = M_{12} - r^2 = M_{23} = M_{13}$$

$$\langle \delta_i^2 \rangle = M_{ii} - \varepsilon^2$$

SSS DATA







	Spatial Resolution	Temporal resolution
TAO	*Point*	*Daily average*
GLORYS2V3	*0.25°*	*Daily product*
AV4	*1°*	*7 days average*
SOA	*0.25°*	*9 days average*
WOA13	*0.25°*	*Daily interpolation from monthly product*
WOA09	*1°*	*Monthly product*

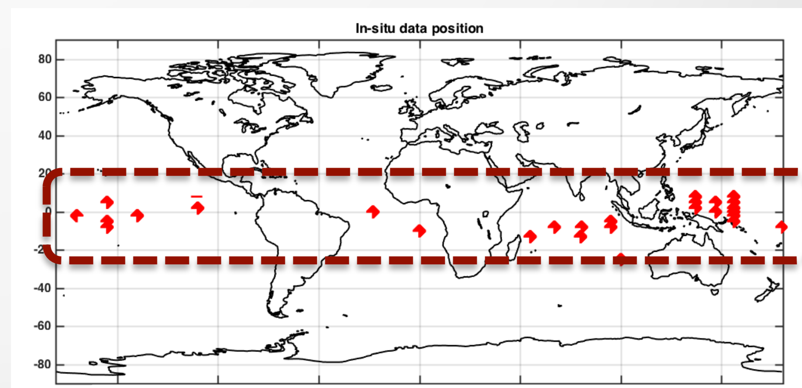
Period of study: **2013**

- all the SSS data sources are available at this period.
- 2013 is not influenced by strong events such as El Niño (2014-2015) or La Niña (2011-2012), which are known to be unresolved by the climatology, thus leading to strong biases in the latter.

Collocation

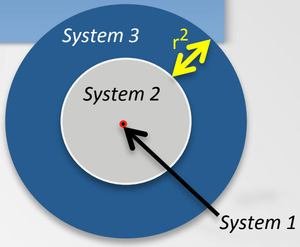
Spatial: The closest grid point to the in-situ location is used.
Temporal: Collocation to the central day of Aquarius product.

Total of 1456 collocations with the six products are obtained over the study period of 2013, in the **Tropical band**
=> Obtained sextuplets of TAO, SMOS, Aquarius, GLORYS2V3, WOA13, WOA09 collocated data.



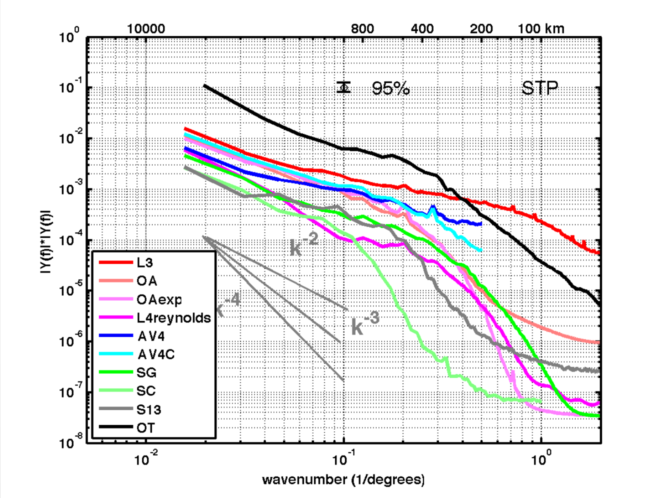
Location (red symbols) of the TAO, PIRATA, and RAMA buoys arrays used in this study.

Representativeness error
Estimation method



Until now, to estimate ***r²*** with sea surface wind data the methods have been based on:

- Integrating the difference between the scatterometer wind power density spectra (PDS) and those of the numerical model output (*Vogelzang et al. 2011*)
- Calculating the cumulative variance of scatterometer and model wind components (*Vogelzang et al. 2015*).



Problem: **SSS PDS spectral slopes** of the different products are **sensitive to the presence of noise** (*based on Hoareau et al., TGRS, 2018*).

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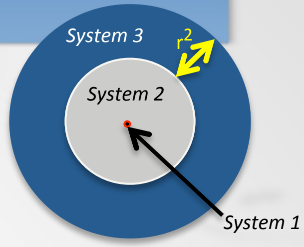
Representativeness error Estimation: method



Alternative approach based on TC intercalibration assumption
(*Lin et al., 2016*):

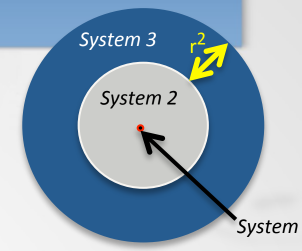
Assumption that a successful TC provides three data sets well intercalibrated.

⇒ ***TC calibration coefficient*** a_i, b_i, are related to the value of r^2
⇒ Setting a wrong r^2 leads to a miscalibrated system 3 with respect to systems 1 and 2.

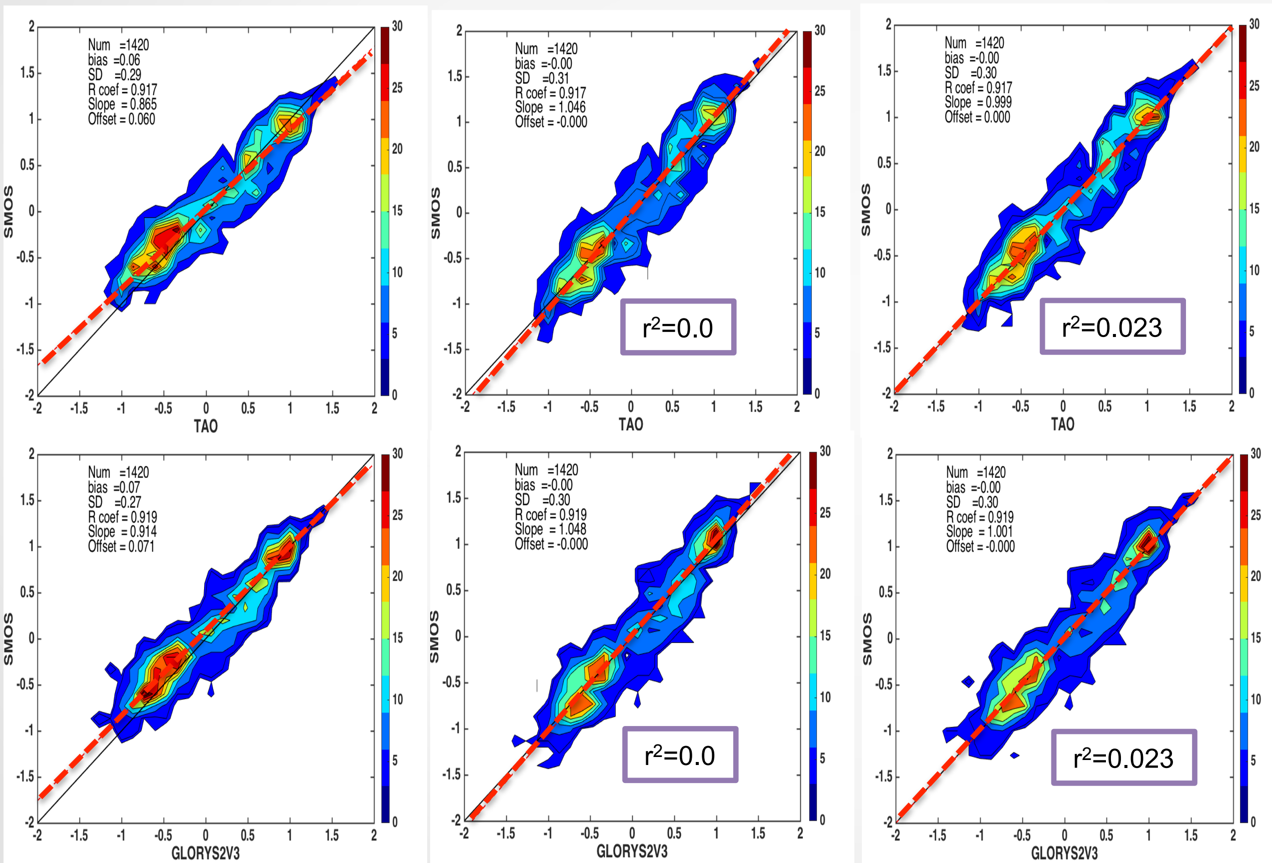
Therefore, an effective way of estimating r^2 is to repeat the TC analysis for different r^2 values until an optimal intercalibration of the different data sources is achieved.

=> Check the data scatterplots after each intercalibration

Representativeness error estimation



Before TC | After TC | After TC



SSS data:
System 1 -> TAO
System 2 -> GLORYS2V3
System 3 -> SMOS

If wrong r^2
⇒ Not well calibrated

If correct r^2
=> Well calibrated

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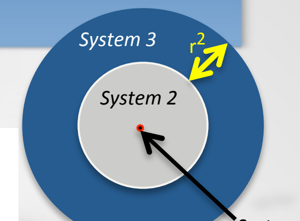
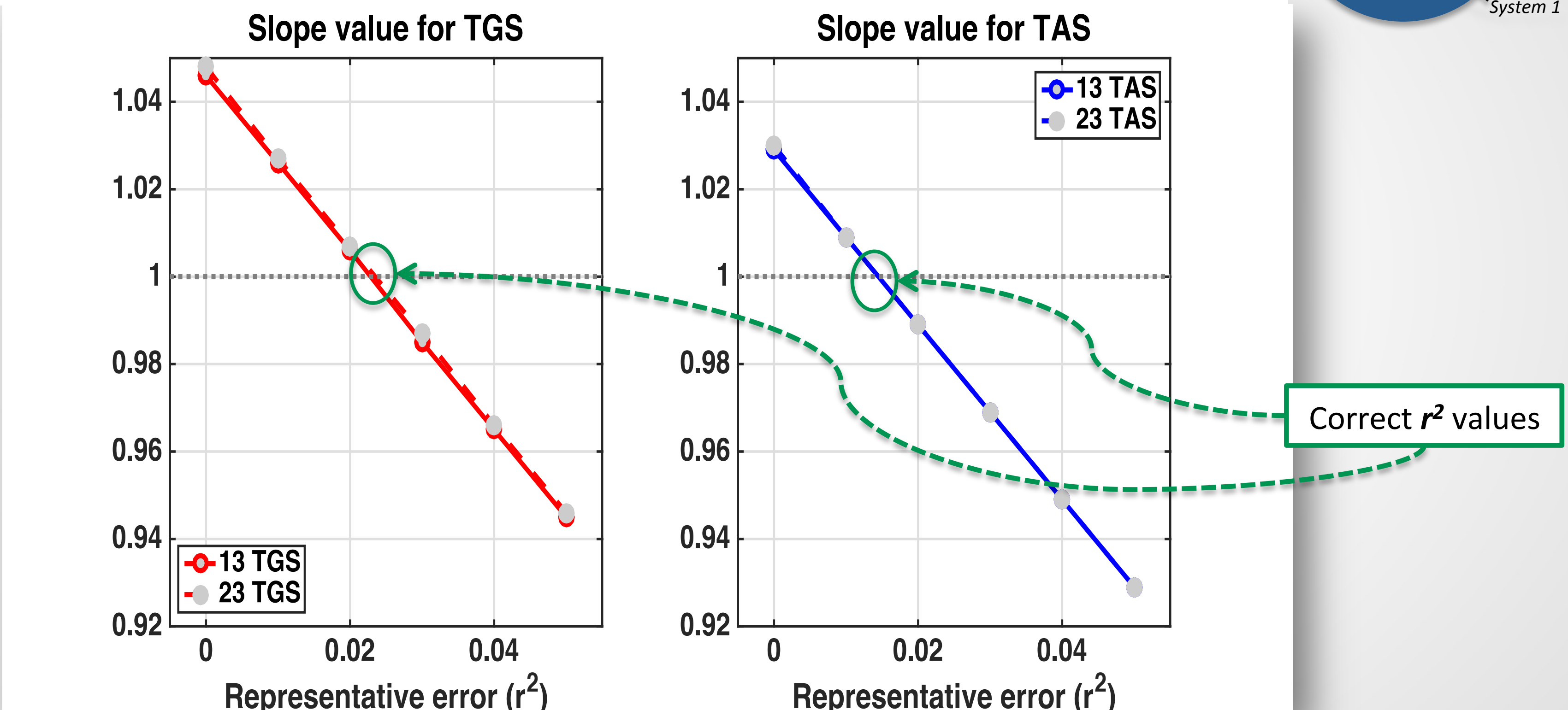
Representativeness error Estimation: Results



Slope values as a function of the representativeness error (r^2) for the triplets (Left) TAO-GLORYS-SMOS and (Right) TAO-AV4-SMOS.



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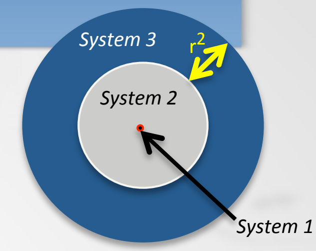
Representativeness error Estimation: Results



Acronyms:
T-> TAO in-situ
G-> GLORYS model
A-> Aquarius satellite
S-> SMOS satellite
13-> WOA 2013 climatology
09-> WOA 2009 climatology

r^2 estimation with sextuplets
=> robust TC analysis results

$$r^2_{TGS} = r^2_{TGA} + r^2_{TAS}$$

$$r^2_{TA13} = r^2_{TAS} + r^2_{TS13}$$

	TGA	***TGS***	***TA13***	***TS13***	***TA09***	***TS09***	***TAS***
r^2	0.009	0.023	0.027	0.011	0.034	0.020	0.015

Representativeness Error (r^2) for the different triplets of SSS data.

⇒ r^2 values help to identifies the systems having the finest and the coarsest effective spatiotemporal resolution: T<G<A<S<13<09

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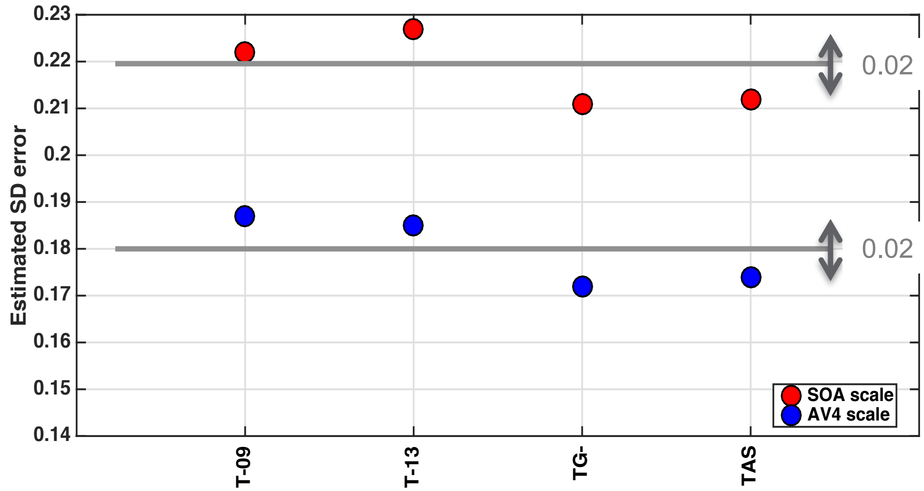
Random Error estimation at satellites resolved scales

Estimated TAO SD error (delta$_{TAO}$) estimated by the TC algorithm at both the ***SMOS*** *scale (red point) and the* ***Aquarius*** *scale (blue points) for different triplets.*



At system 2 resolution: $\delta_{TAO} = \sqrt{\delta_1 - r^2}$

At system 3 resolution: $\delta_{TAO} = \delta_1$

The **TAO error** variation gives an indication of the **uncertainty** of the proposed methodology: **about 0.01**

Estimated SD error of the different salinity measurements at the satellite scales

	TAO	*GLORYS2V3*	*AV4*	*SMOS*	*WOA13*	*WOA09*
Aquarius scale	0.18±0.01	0.18	0.17±0.01	0.24±0.01	0.29	0.31
SMOS scale	0.22±0.01	0.21	0.21±0.01	0.20±0.01	0.26	0.29

Conclusions

The **TC technique** consists of using 3 **independent**, **intercalibrated** and **collocated** data sources to provide an **estimate of their individual random error** (SD).

1) The analysis has been carried out **at the scales** resolved by the **two satellite** products: **SMOS** Objective Analysis and **Aquarius** v4 Level 3.

2) The **representative error** has been accounted for during the TC validation of **six different SSS** products along the tropical band for the year 2013 => **Sextuplets give robust TC analysis results**.

3) The r^2 **estimation method** is based on the analysis of the intercalibration results.

4) It has been found that the **representativeness error** (r^2) **contributes to 15% ~ 50%** of the error estimates.

5) r^2 values **help sorting the systems in terms of their effective spatiotemporal resolution**:

   TAO < GLORYS2V3 < Aquarius v.4 < SMOS OA < WOA13 < WOA09

6) The TC method developed here leads to **an uncertainty of about 0.01 in the SSS error estimates**.

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Conclusions

The validation has been carried out at the satellite-resolved spatiotemporal scales.

It has been found that the **TAO SD error** at the **Aquarius v4** and **SMOS OA** spatiotemporal scales is **0.18** and **0.22**, respectively.

=> **The error values include the contribution of the following representativeness errors:**

- the horizontal scale difference between the point-wise observation and the 0.25°-1° grid sizes of the satellite products
- the vertical mismatch between TAO measurement at 1-1.5m depth and the satellite at 1 cm depth
- the different temporal resolution of TAO (1 day) and satellite products (7-9 days).

The partition of these error contributions remains a research topic in oceanography.

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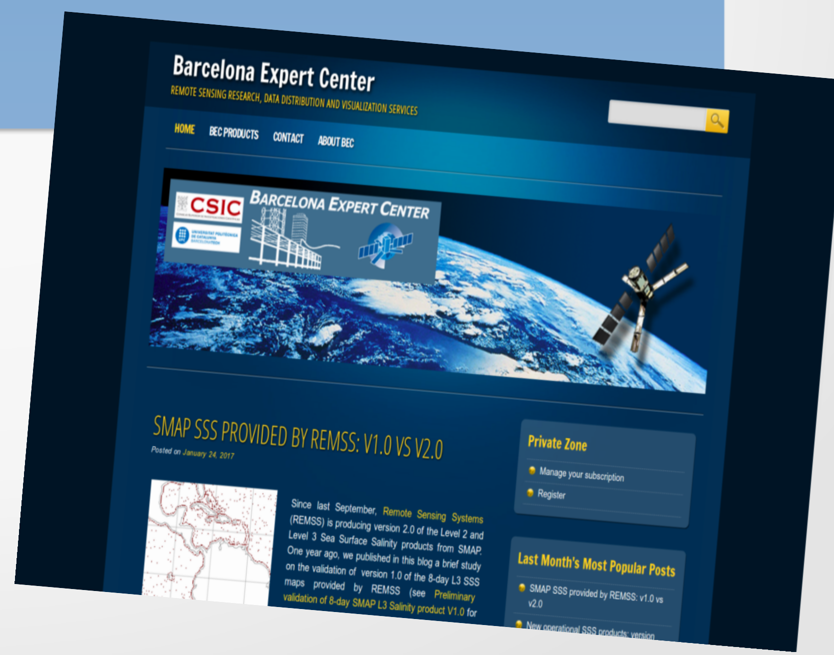
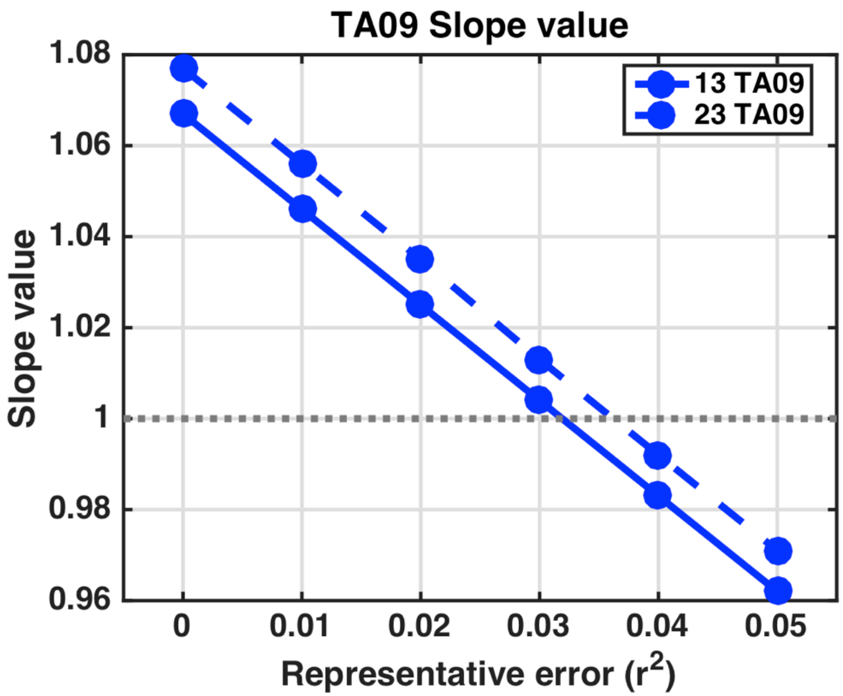


Results



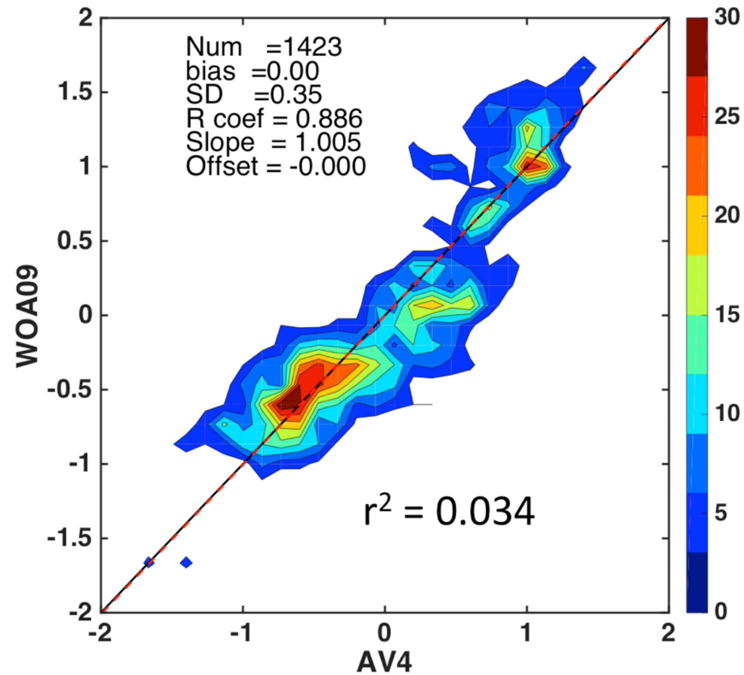


Figure 4: (Left) Slope values as a function of representativeness error (r^2) for the triplet TAO-AV4-WOA09 (TA09). Blue solid (dashed) line: slope values of the scatterplot TAO/WOA09 (AV4/WOA09). (Right) Scatterplot of AV4 versus WOA09 after TC, using a representativeness error, r^2, of 0.034.