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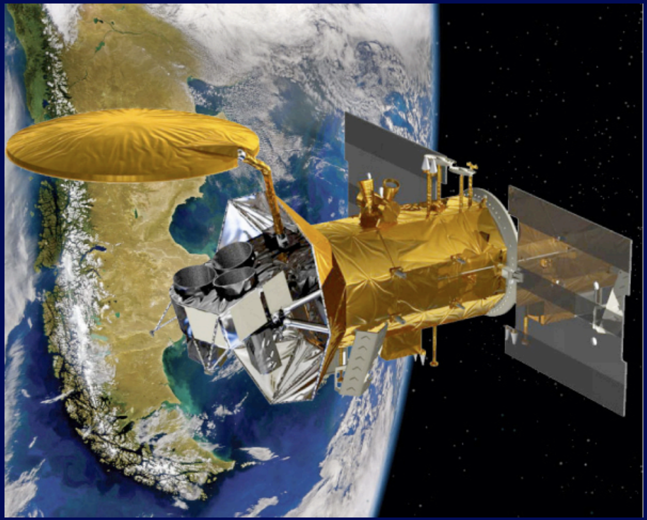
Estimate of Uncertainties in the Aquarius Salinity Retrievals

T. Meissner + F. Wentz, *Remote Sensing Systems*

G. Lagerloef, *Earth and Space Research*



Aquarius/SAC-D Science Team Meeting
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Outline

1. Motivation + Philosophy
2. Algorithm for Assessing Formal Uncertainties
    - Level 2
    - Level 3
3. Physical Error Model
    - Description of Major Components
4. Results
5. Formal versus Empirical Uncertainties
6. Summary

Uncertainty Estimates
Motivation + Goals

- Any meaningful physical measurement has a value and an uncertainty (error bar).
  - Has becomes standard requirement for data sets and scientific studies.
  - Not easy. Not straightforward.
  - Very few satellite data sets have reliable error estimates.
- Important for ocean modeling who use Aquarius salinity as input in their model.
  - Determines relative weight of observation in assimilation.
- Identifying degraded conditions.
- Uncertainty estimates are needed for both Level 2 and Level 3.
  - Need to address error propagation from Level 2 to Level 3.
- Aquarius has only few channels and essentially only one observation (salinity).
- But it also has lots of error sources that need to be considered!

Uncertainty Estimates

Formal Method in a Nutshell (1)

- Formal parameter in the physical salinity retrieval algorithm: λ.
  - NEDT, SST auxiliary field, wind speed (roughness correction), galaxy, moon, land, RFI, …
  - Independent.
- Physical model for uncertainty Δλ.
  - Physical retrieval has physical error.
  - Scene dependent.
  - Requires realistic error model for all relevant parameters λ.
  - Not always straightforward and unequivocal.
  - Some components of the error model are based on SSS input from ground truth (HYCOM).

Uncertainty Estimates

Formal Method in a Nutshell (2)

- Run perturbed retrieval for Level 2 salinity S
  - Done separately for each parameter λ.
  - Calculate derivative: $\partial S/\partial\lambda = \left[S(\lambda+\epsilon) - S(\lambda-\varepsilon)\right]/2\epsilon$.
  - Depends on scene: SST, wind speed, wind direction, ….

- Uncertainty in S due to error in λ:

$$\Delta S_{\lambda} = \left|\partial S/\partial\lambda \cdot \Delta\lambda\right|$$

- Total uncertainty: $(\Delta S)^2 = \sum_{\lambda} (\Delta S_{\lambda})^2$

Error Propagation + Correlations

Level 2

- Independent errors are added as RMS

$$(\Delta S)^2 = \sum_{\lambda} (\Delta S_{\lambda})^2 \quad .$$

- Correlations need to be taken into account in perturbed retrievals. For example:
  - NEDT: V-pol and H-pol independent. When performing the perturbed retrieval, they are treated as two separate parameters λ and perturbed independently.
  - Error in galaxy: V-pol and H-pol are not independent. When performing the perturbed retrieval, only the V-pol gets perturbed and the H-pol is calculated from the perturbed V-pol.

Error Propagation
Spatial and Temporal Averaging

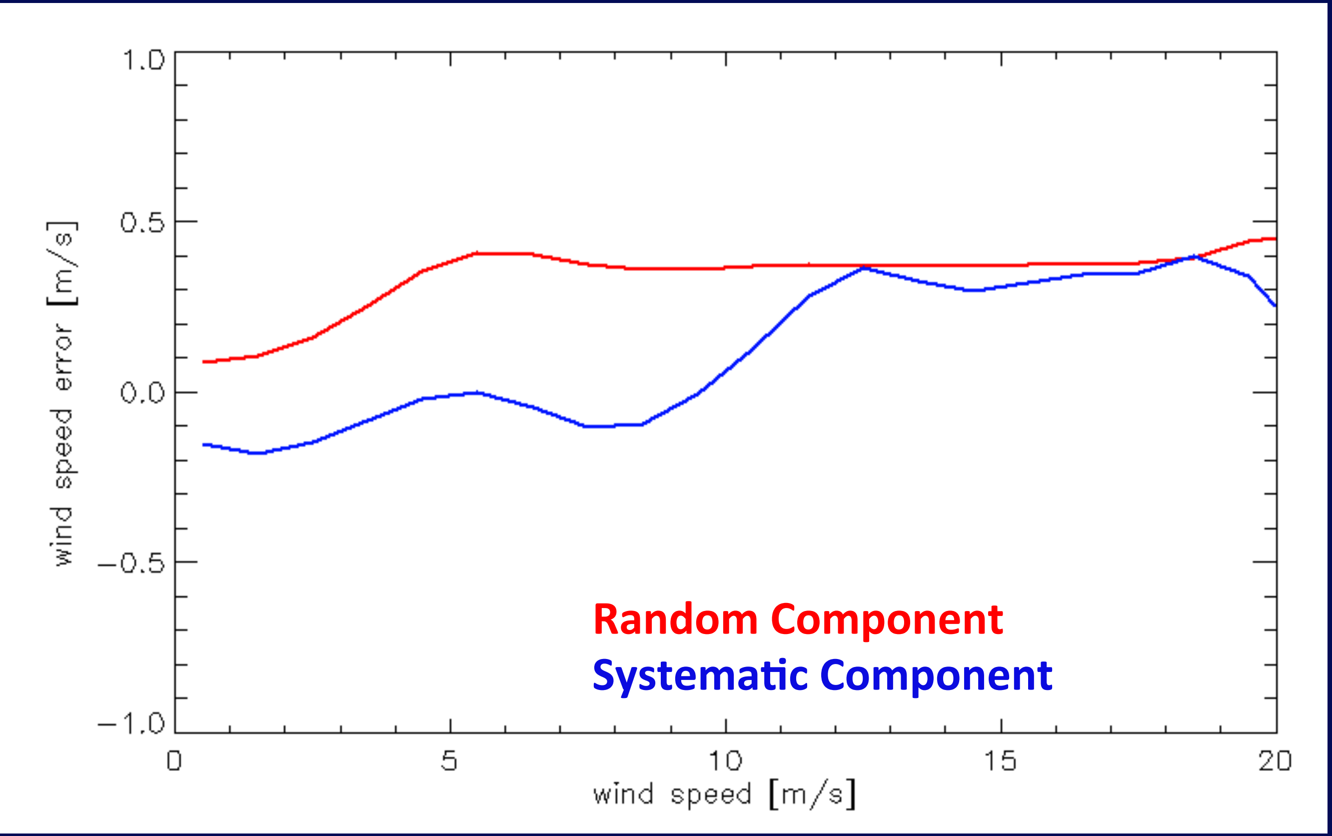
- Need to distinguish between random and (quasi -) systematic errors.
- Taking average over N SSS retrievals:
  - Random errors: Get reduced by $1/\sqrt{N}$.
  - Quasi-systematic errors: Stay constant over time scales of 1 week – 3 months and within 100 – 150 km.
- Important for going from Level 2 to Level 3 products.

Error Model
Parameters Included

λ	Type (ran/sys)
NEDT (V, H, S3)	ran
Pointing	ran
wind speed / roughness correction	ran + sys
wind direction (auxiliary)	ran
SST (auxiliary)	sys
non-linear IU coupling	sys
galactic reflection	sys
lunar reflection	sys
land contamination	sys
sea ice contamination	sys
RFI	sys

Error Model

Wind Speed / Roughness Correction



1. Random component: Estimated from running perturbed Aquarius wind speed retrievals. Dominated by scatterometer noise (Kp), radiometer noise (NEDT), wind direction error (NCEP).
2. Systematic component: Estimated form Aquarius HHH – WindSat wind speed.

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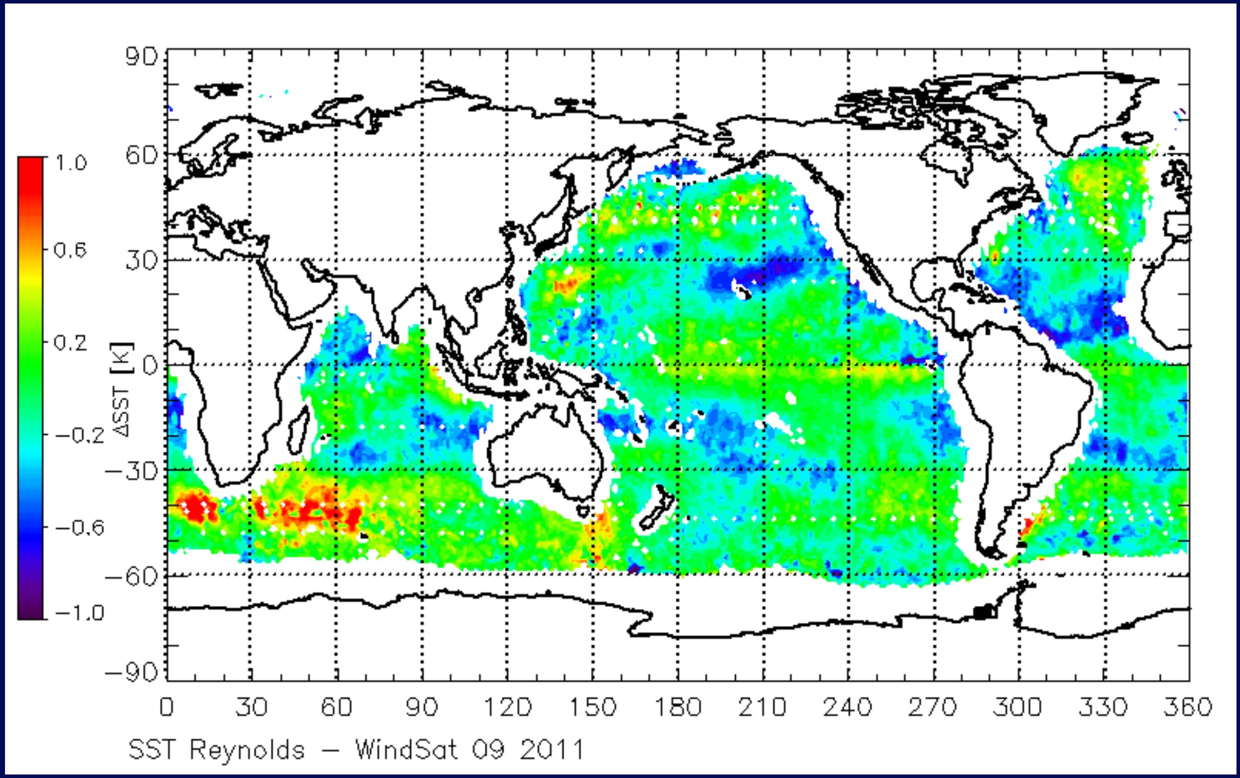
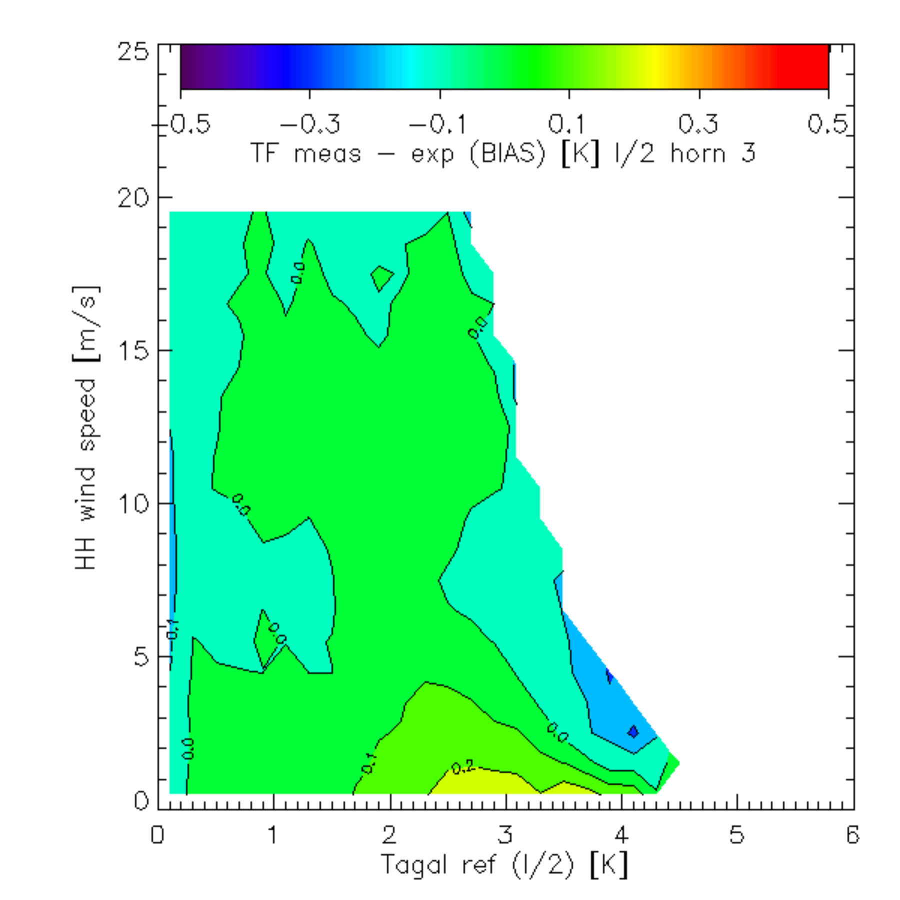
Error Model
Auxiliary SST



Estimated from SST difference between NOAA OI SST (used in Aquarius SSS retrievals) versus WindSat SST.
Treated as systematic error.

Error Model

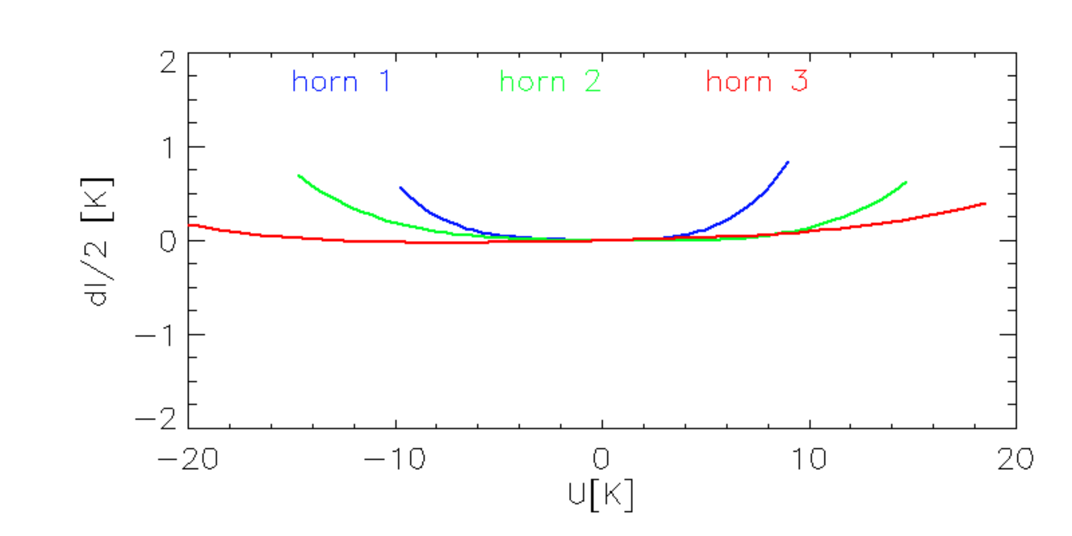
Reflected Galaxy



2- dimensional lookup table for TA measured – expected.
Depends on reflected galactic TA and wind speed. Treated as systematic error.
V/H –pols are correlated in perturbed retrievals.

Error Model
Non-Linear IU Coupling

horn 1 **horn 2** **horn 3**
TB measured – expected



Non-linear relation. Can NOT be absorbed in IU coupling of antenna pattern correction.
An empirical correction is done in V4.
It is also included in error model.

Error Model

Land + Sea Ice Contamination

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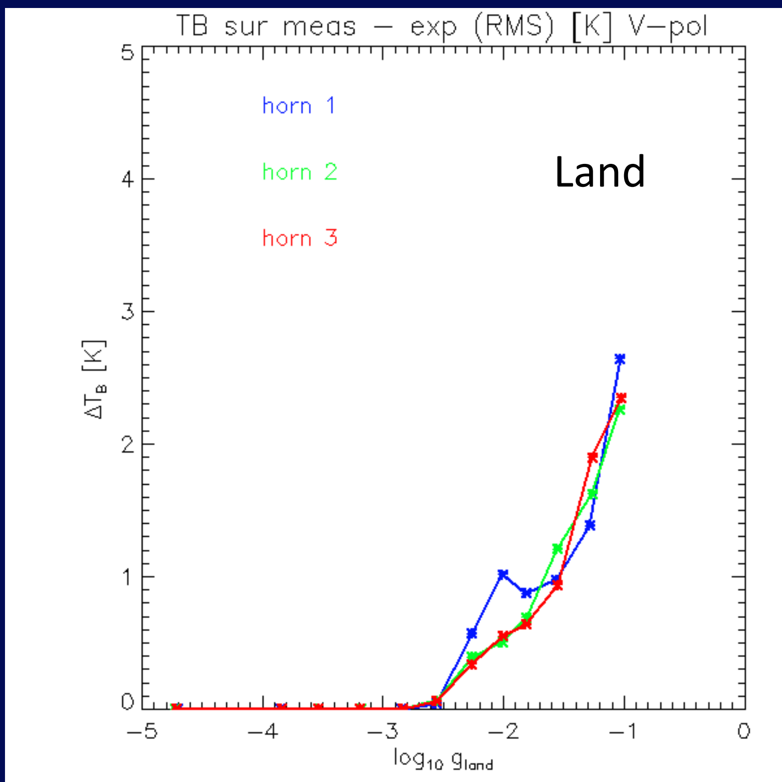
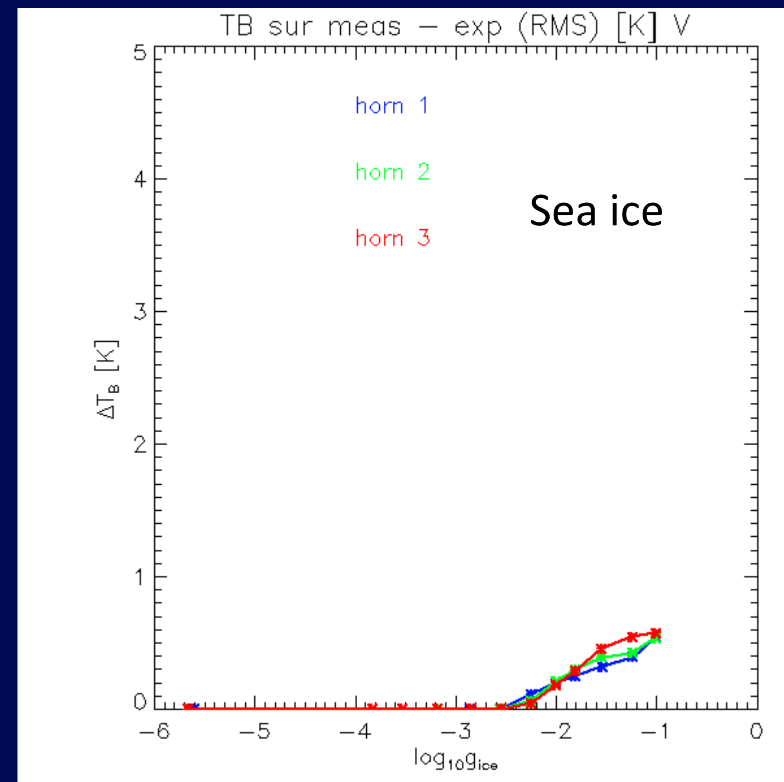
horn 1 **horn 2** **horn 3**





Lookup table for RMS of TB measured – expected as function of antenna gain weighted land fraction g_{land} or sea ice fraction g_{ice}. Treated as systematic error.
V/H –pols are correlated in perturbed retrievals.

Error Model
Estimated Undetected RFI

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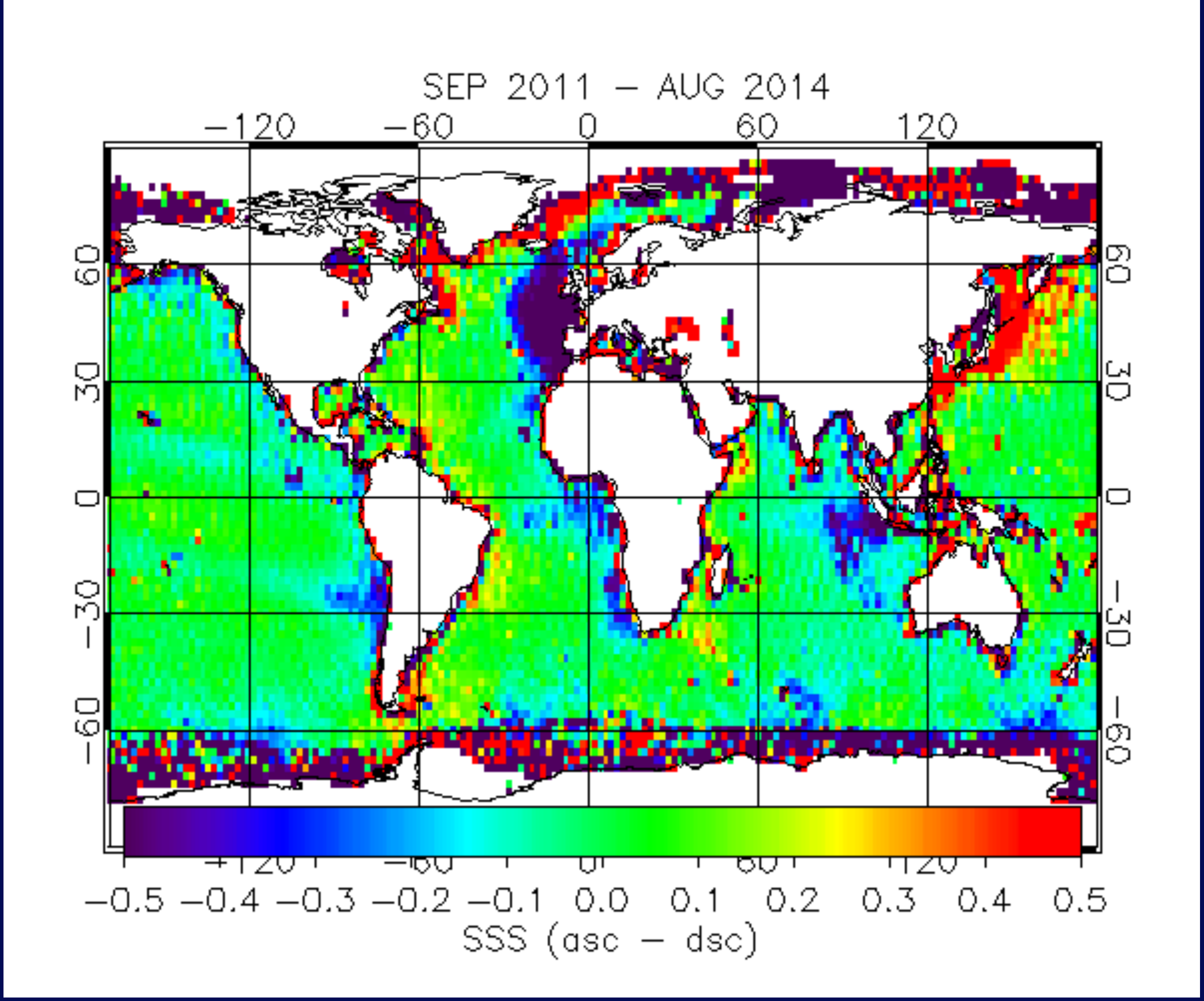

3-year Aquarius SSS ascending - descending

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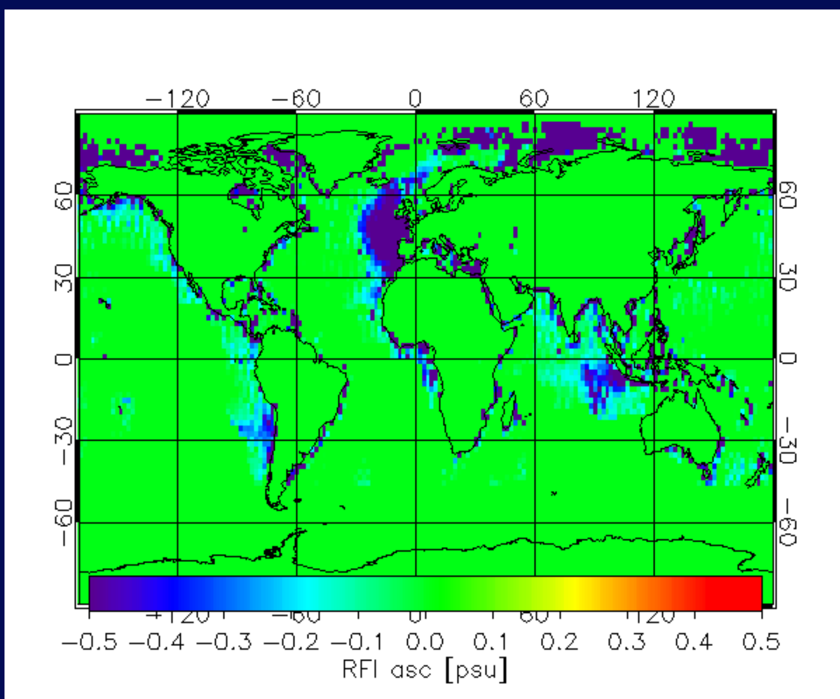
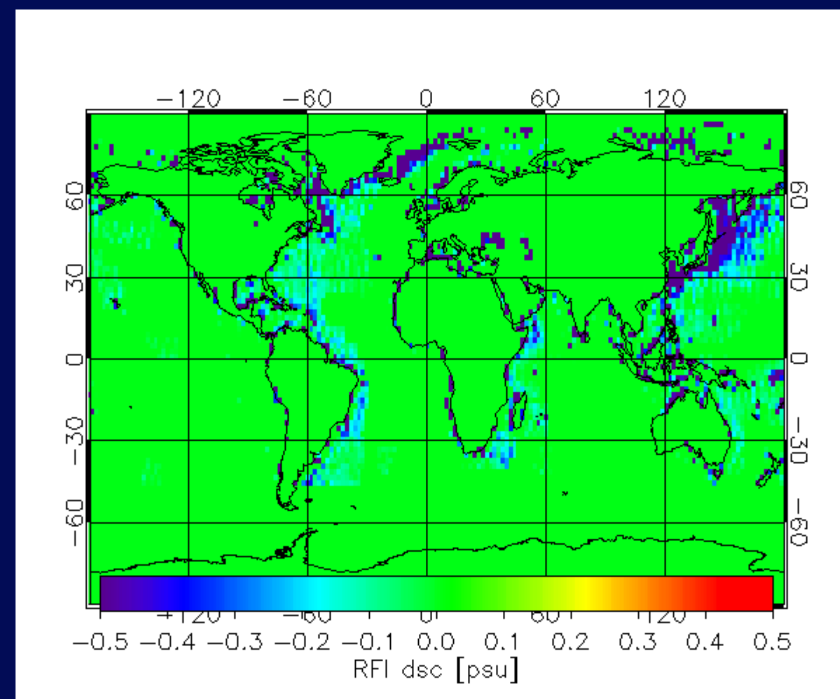
Error Model

Estimated Error due to Undetected RFI

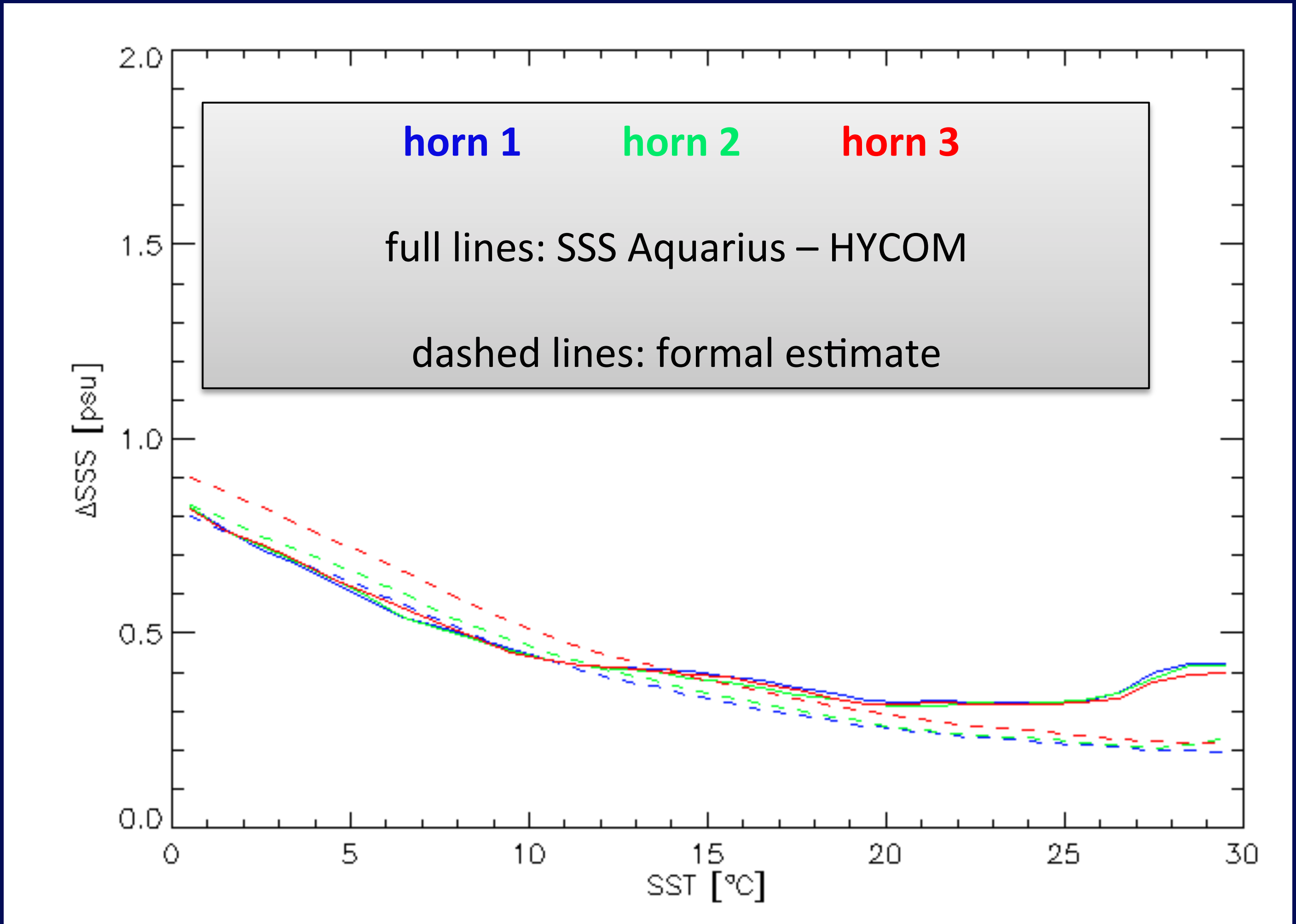
in vicinity of detected RFI (TF – TA)
SSS (asc – dsc) < 0: RFI in ascending swath
SSS (asc – dsc) > 0: RFI in descending swath
treated as systematic error for retrieved SSS





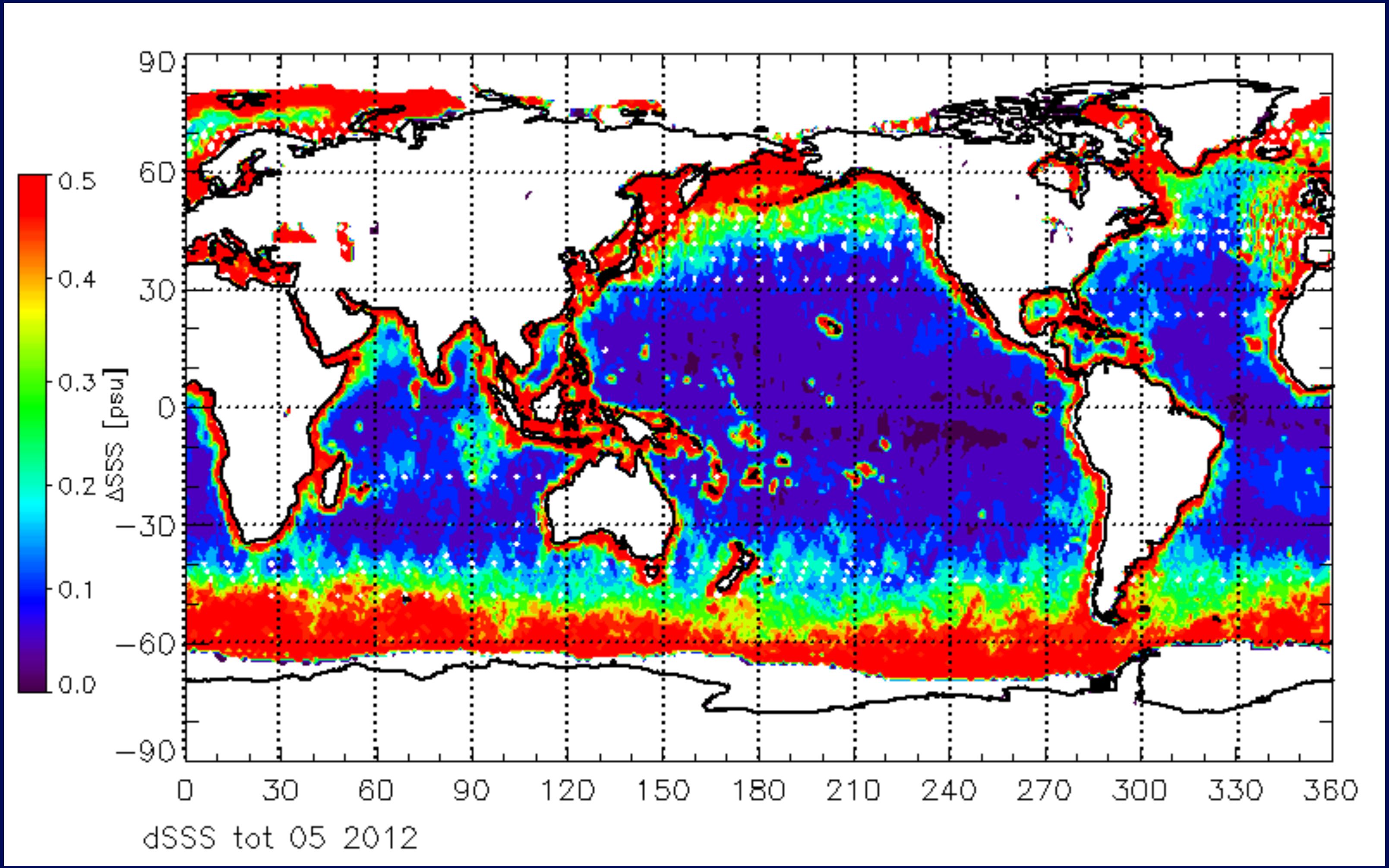
V3 had used this method to mask out undetected RFI.

Estimated L2 Uncertainties
stratified with SST



Estimated Uncertainty

Level 3: Monthly Average Map



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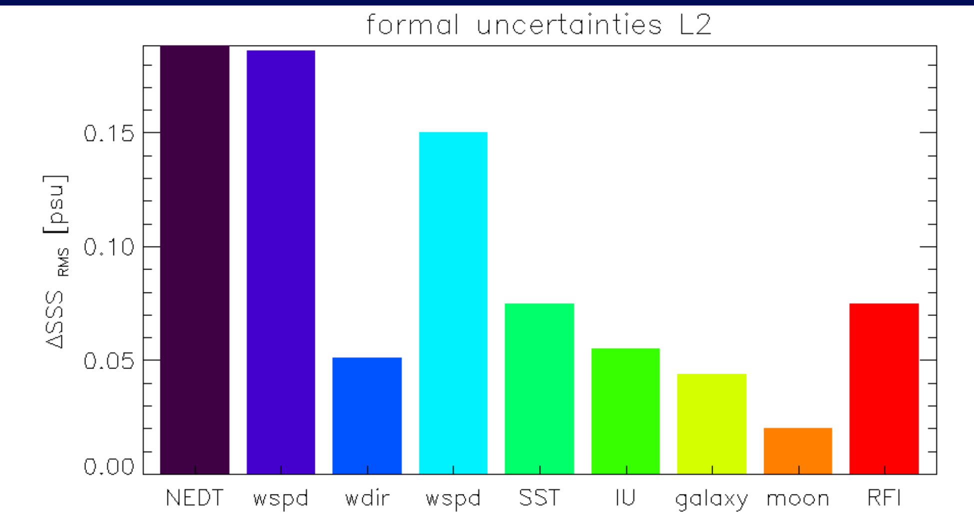
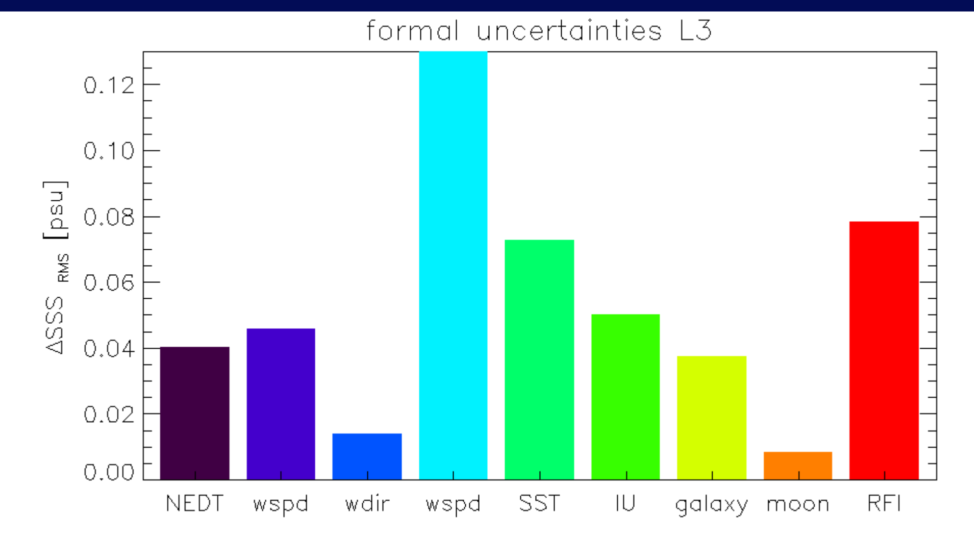
Formal Uncertainty Budgets



random

systematic

Level 2 1.44 seconds.
random components (NEDT, surface roughness) dominate



Level 3 Monthly 1° averages
random components suppressed.
Systematic components (surface roughness, SST, RFI, …) dominate.

Empirical Uncertainty Estimate

- Basis: Triple Collocation Analysis
  - Triple point collocations:
    SSS from Aquarius – ARGO – HYCOM
- Assuming that the 3 errors are independent the error (RMS) in the 3 different SSS can be determined from the RMS of the mutual differences

$$\mathrm{Var}(\mathrm{AQ}) = \frac{1}{2}\left[\mathrm{Var(AQ - HYCOM) + Var(AQ - ARGO) - Var(ARGO - HYCOM)}\right]$$

$$\mathrm{Var}(\mathrm{ARGO}) = \frac{1}{2}\left[\mathrm{Var(ARGO - HYCOM) + Var(AQ - ARGO) - Var(AQ - HYCOM)}\right]$$

$$\mathrm{Var}(\mathrm{HYCOM}) = \frac{1}{2}\left[\mathrm{Var(ARGO - HYCOM) + Var(AQ - HYCOM) - Var(AQ - ARGO}\right]$$

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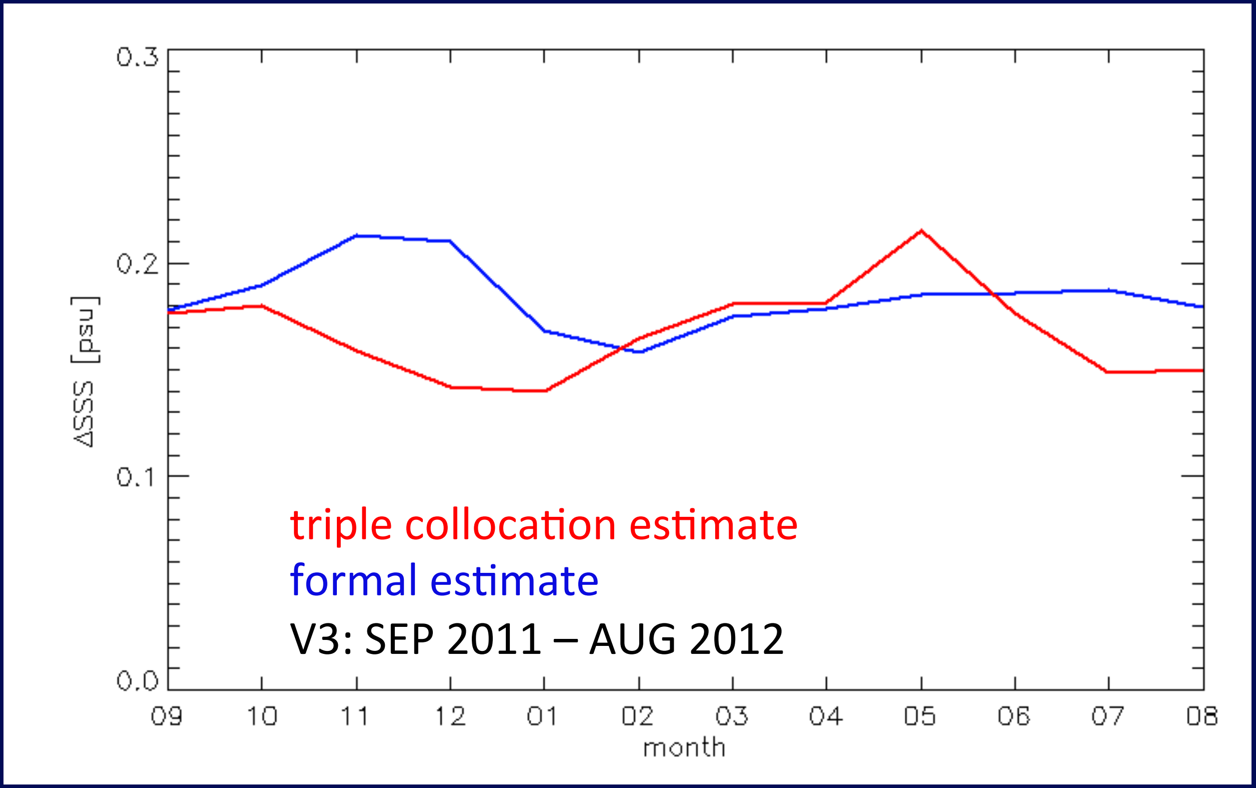
Formal versus Empirical Uncertainty
Time Series



Ensemble for triple collocation: Time series of monthly maps

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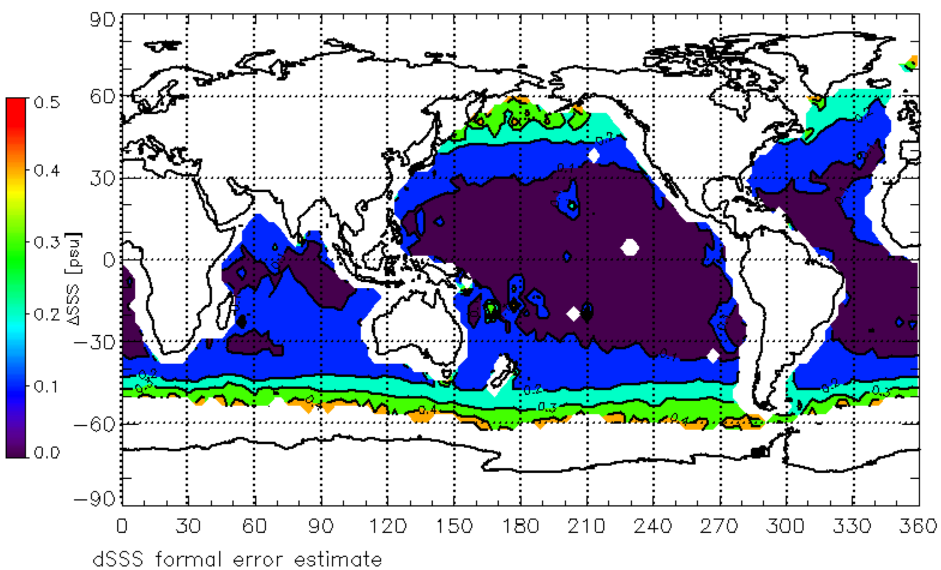
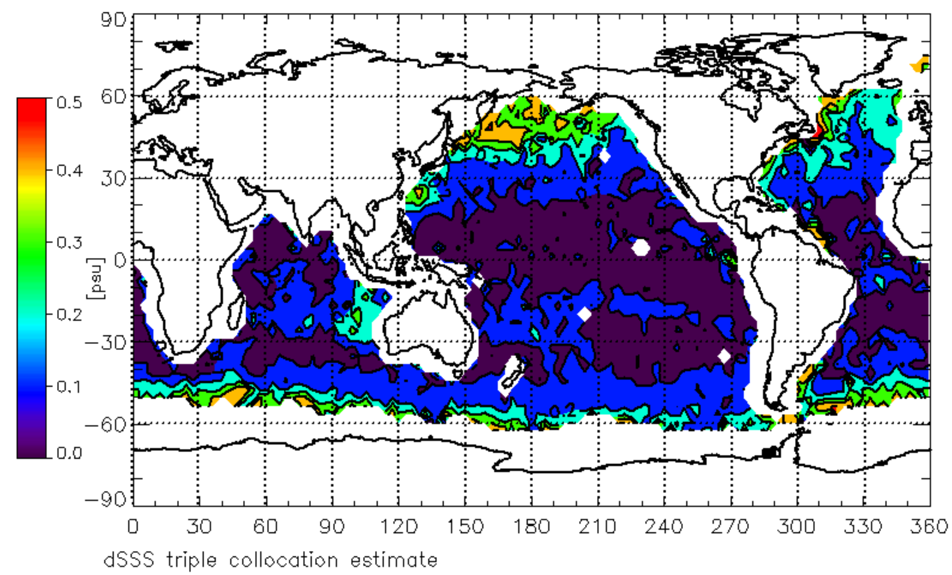
Formal versus Empirical Uncertainty
Global Map

Formal



Triple Collocation



Ensemble for triple collocation: Map where each cell is a 3-year time series (SEP 2011 – AUG 2014)

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Summary

- We have derived an algorithm for estimating formal uncertainties to our physical Aquarius salinity retrieval algorithm.
- Two components:
    1. Physical error model for each component of the salinity retrieval.
    2. Running perturbed retrievals: sensitivity of SSS to the various parameters.
- The physical error model is tied to physical components of retrieval algorithm.
- It is essential to separate random and systematic uncertainties.
    - Propagate differently when forming spatial and temporal averages of L2 observations.
    - Random components (NEDT, wind) dominate L2 product (1.44 sec).
    - Systematic components dominate the monthly 150 km averages.
- Formal uncertainty estimates and error estimates from triple point analysis compare well.
- Uncertainty estimates are implemented in V4 release.