Progress in Aquarius Level 2 Algorithm: From V2 to V3

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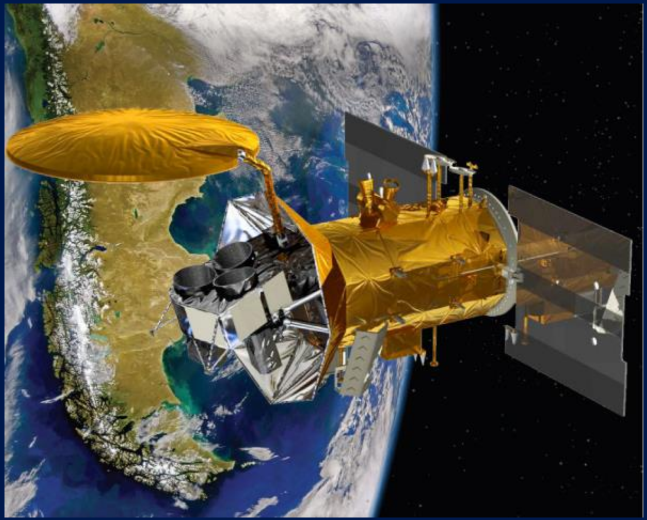

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Outline: Major Steps from V2.0 to V3.0 in the order of importance

1. **Improved Surface Roughness Correction**
   - Use of Aquarius L-band scatterometer
   - HHH wind speeds
2. **Empirical Correction to Reflected Galactic Radiation**
   - Swath symmetrization (ascending/descending)
   - Reducing ascending – descending biases
3. **Quality Control (Q/C)**
   - Q/C flagging / masking
4. **Adjustment of Antenna Pattern**
   - Spillover (cold space field of view fraction) lowered by 1.5%
   - Improved biases over land scenes / cold space maneuver
   - Improved biased for 3rd Stokes parameter
   - Very little – no effect for ocean salinity

Algorithm Development and Processing

- ADPS L2 algorithm is developed by Remote Sensing Systems (RSS) with input from the Aquarius cal/val team
- Front runner: RSS Testbed version (V4)
  - Contains RSS MWR L2 products (cloud water absorption, rain, wind, vapor) collocated to Aquarius L2 swath.
  - Available to anyone interested.
  - Contact and support: meissner@remss.com (Algorithm), brewer@remss.com (FTP access).
- L2 and L3 processing is done at the Aquarius Data Processing System (ADPS) at Goddard Space Flight Center
- Delivered to PO.DAAC
- Current: V2.0
- V3.0 to be officially released in January 2014

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Aquarius Level 2 Algorithm

Aquarius Radiometer Counts
Earth + Calibration View

↓

Radiometer Calibration Algorithm

↓

Total Antenna Temperature

↓

Remove Space Contributions: Galaxy, Sun, Moon, CS

↓

Earth Antenna Temperature

↓

Remove the Antenna Pattern Effect

↓

Earth Brightness Temperature

↓

Correct for Faraday Rotation

↓

Top of the Atmosphere Brightness Temperature

→

Remove Atmospheric Contribution

↓

Sea-Surface Brightness Temperature

↓

Remove Surface Roughness Effects

↓

Specular Brightness Temperature

↓

Find Salinity for which emissivity of Meissner-Wentz 2012 dielectric model matches specular TB

↓

Salinity

Surface Roughness Correction
Wind Speeds

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Roughness Correction in V3.0 (1)

Important: 1 m/s error in wind speed means 0.7 psu error in salinity.

- T. Meissner + F. Wentz:
  A geophysical model for the emission and scattering of L-band microwave radiation from rough ocean surfaces.
  - Submitted to JGR Oceans Special Issue.
  - **Roughness model for V3.0.**
- **Use scatterometer HH to derive wind speed.**
  - V2.0 uses NCEP wind speed and combined it with scatterometer VV-pol in roughness correction.
- Combine with radiometer TB H-pol: **AQ HHH wind**.
  - HH backscatter looses sensitivity at cross-pol observations and at high wind speeds (> 20 m/s).

Aquarius Wind Speeds (1)

RMS [m/s] Evaluated against WindSat, 1 hour, rain-free			
AQ HHH	AQ HH	NCEP	MWR
0.77	0.86	1.24	2.10

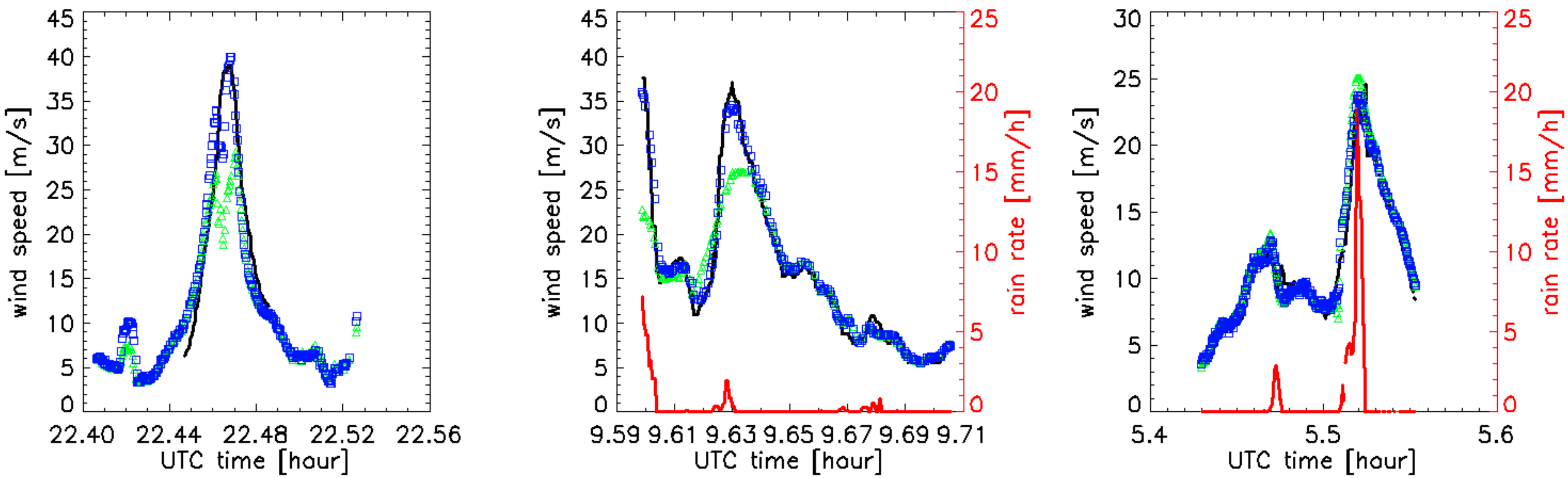
- Estimated AQ HHH accuracy: 0.54 m/s
  - Same quality as other microwave satellite winds (WindSat, SSM/I, QuikSCAT, ASCAT)
- MWR: NOT suited for use in Aquarius surface roughness correction

Aquarius Wind Speeds (2)

Hurricane KATIA
SEP 09 2011

extratropical cyclone
NOV 30 2012

extratropical cyclone
APR 12 2012



NOAA HRD wind
(ground truth)

RSS WindSat all-weather wind
(ground truth)

AQ HHH wind **AQ HH wind** **WindSat Rain rate**

- **Good capabilities even in big storms: Very high winds, rain.**
- **Scatterometer only wind (HH) looses sensitivity > 25 m/s.**

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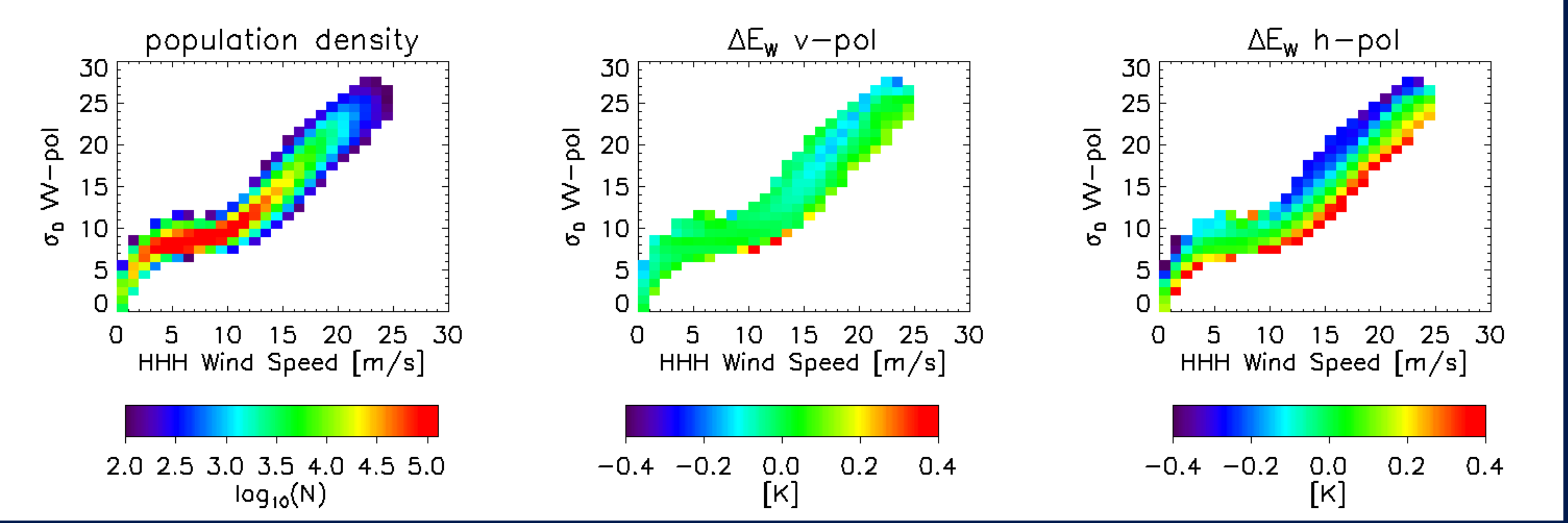
Roughness Correction in V3.0 (2)

$$\Delta E_W = A_0(W_{HHH}) + r_1(W_{HHH}, \sigma_{0\,VV}) + r_2(W_{HHH}, SWH) + \Delta E_\varphi(W_{HHH}, \varphi_{rel})$$

residual roughness 1st order — residual roughness 2nd order — wind direction signal

Residual r_1 as function of W_{HHH} and σ'_{0VV}



Color scale: +/-0.4 K

Performance of Roughness Correction

Parameters used	1V	1H	2V	2H	3V	3H
NCEP W	0.395	0.413	0.397	0.426	0.383	0.473
NCEP W σ_{0VV} (V2.0)	**0.316**	**0.341**	**0.334**	**0.357**	**0.334**	**0.388**
HHH W	0.283	0.269	0.300	0.255	0.295	0.252
HHH W σ_{0VV}	0.269	0.222	0.289	0.211	0.294	0.206
HHH W σ_{0VV} SWH (V3.0)	**0.264**	**0.220**	**0.282**	**0.210**	**0.288**	**0.205**

Standard deviation of TB_{surf} (measured – RTM) [Kelvin]

Reflected Galactic Radiation
Ascending Descending Biases

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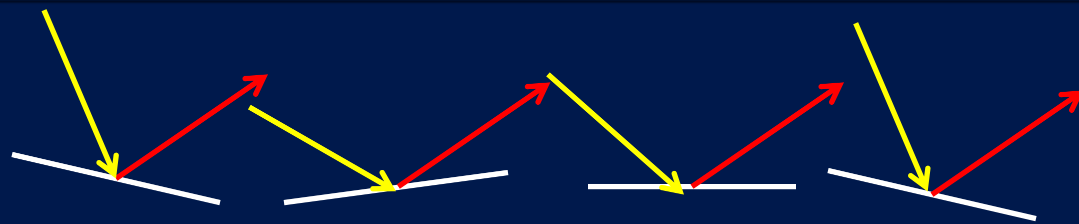
Causes of Ascending – Descending Biases
in the order of importance

- Residual errors in reflected galactic correction
- Undetected RFI
- Faraday Rotation / 3rd Stokes
  - Rotation of 2nd Stokes (V – H pol) in Earth ionosphere
  - Coupling from 3rd into 1st (V + H pol) and 2nd Stokes (V – H pol)
- Wind directional effects.
  - Wind direction signal was already implemented in V1.3
- Diurnal SST variations.
  - Reynolds SST is daily average
  - We have checked versus WindSat SST and found little difference
- Diurnal fresh water
  - Rain
  - Melting ice
  - Possibly real signal
- Residual errors in other celestial corrections
  - Direct galaxy, sun, moon
  - Signals are small compared to reflected galactic radiation.

Correction for Reflected Galactic Radiation
Geometric Optics Model (GO)



- Physical Model
- Modeling Galactic Radiation: A Tilted Facet (**G**eometric **O**ptics) Model.
  - **Yellow arrows** from Galaxy to Ocean: **Red arrows** from Ocean to Aquarius
  - Slope variance: 25 % of Cox-Munk value.
- Facet integration must be done for every ocean pixel seen by Aquarius antenna.

$$T_B(\mathbf{k}_s,\mathbf{P}_s)=\tau^2\iint dz_u dz_c T_B(\mathbf{k}_i)(\mathbf{k}_s\cdot\mathbf{n})\frac{P_z(z_u,z_c)}{(\mathbf{k}_s\cdot\mathbf{z})(\mathbf{n}\cdot\mathbf{z})}\Upsilon$$

- Computation is a 4-fold integral over rough surface (tilted facets) and antenna pattern.
- Overall effect is a smoothing of the galaxy map as winds increase.

Correction for Reflected Galactic Radiation

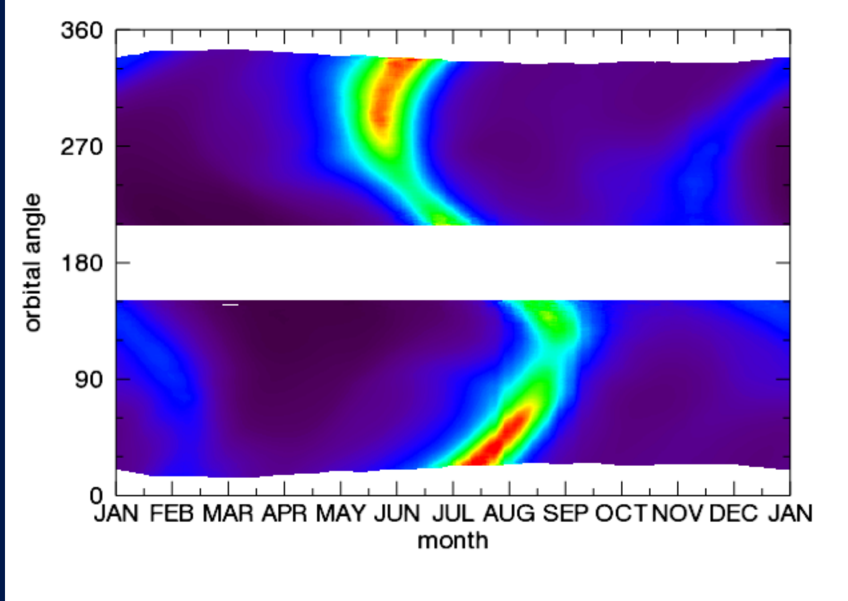
GO + Empirical Adjustment

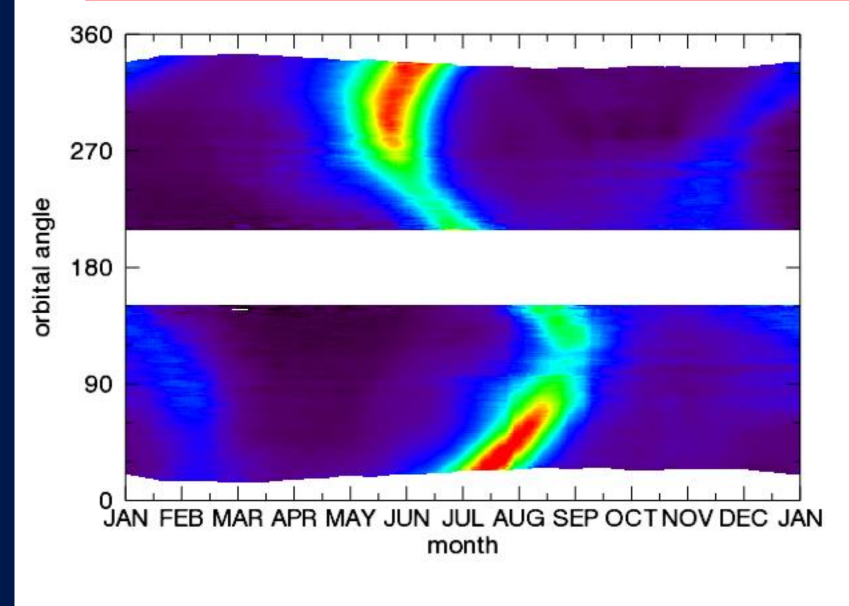
(V+H)/2

GO (V2.0)

GO + ADJUSTMENT (V3.0)

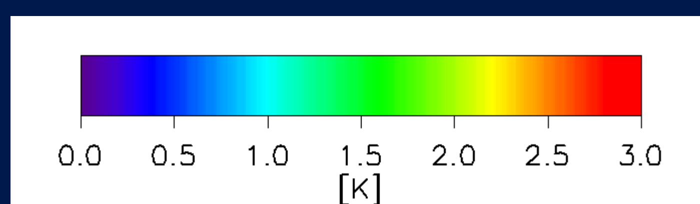
Adjustment is at the 10% level





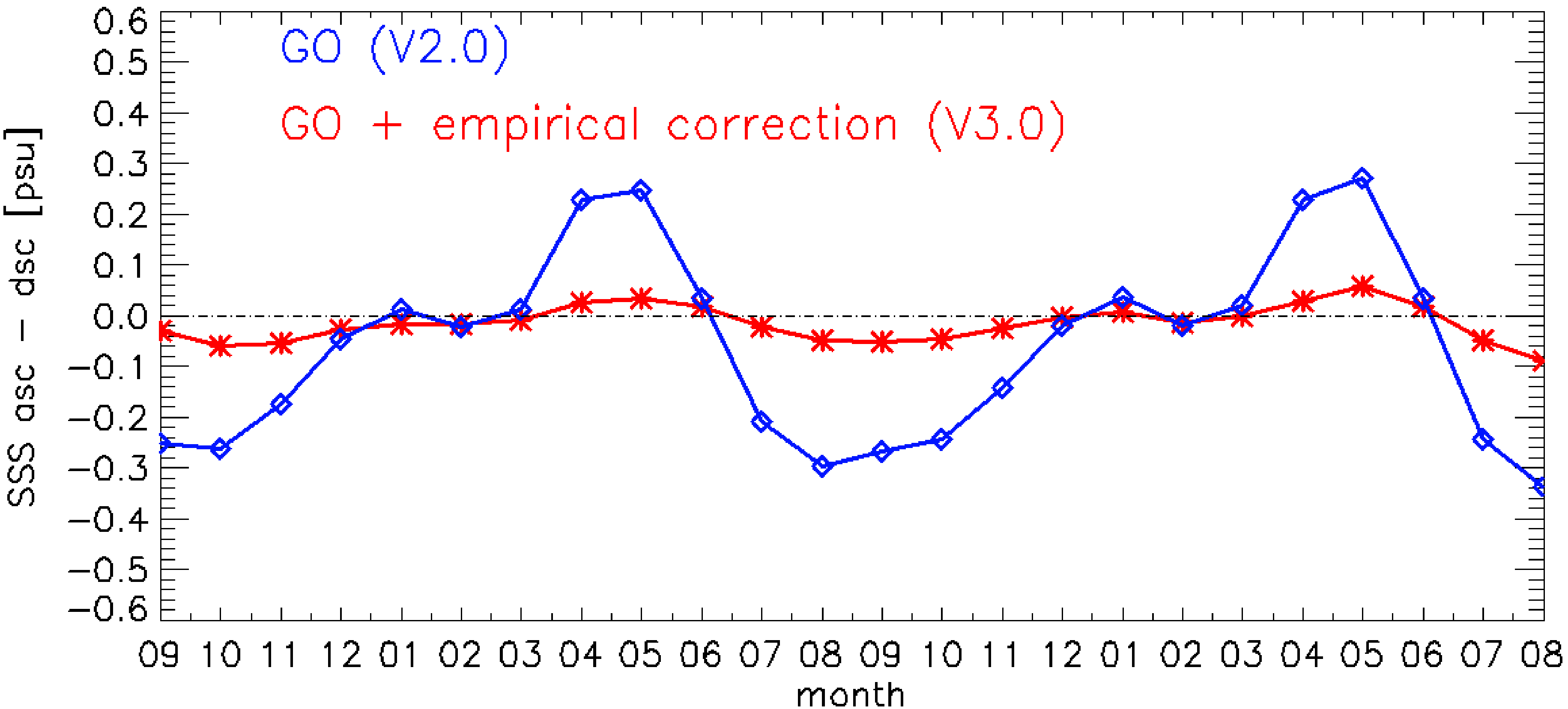
Orbit Position

Month



3 K TB signal = 6 psu SSS signal

Global Ascending - Descending Biases



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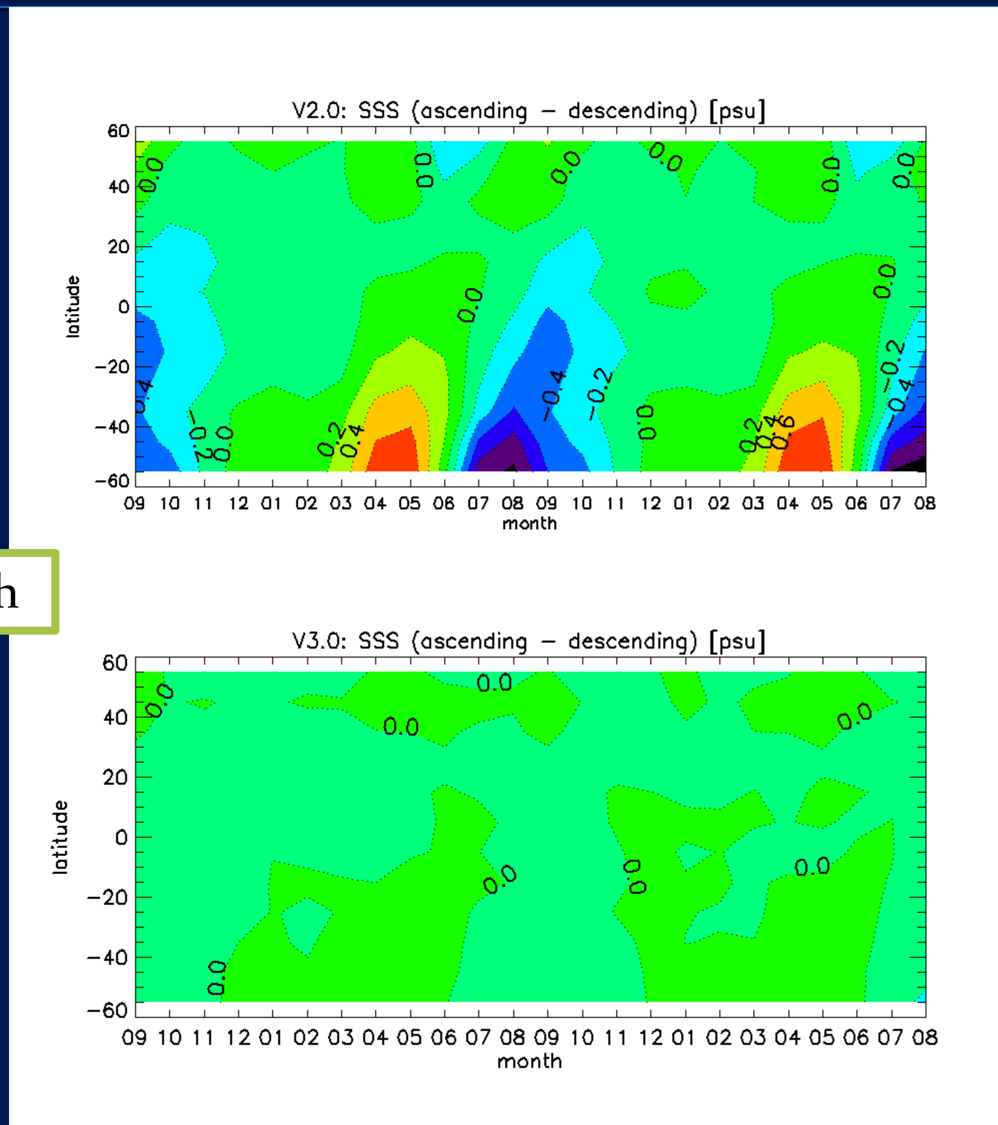
Zonal Ascending – Descending Biases



GO (V2.0)

GO + empirical adjustment (V3.0)

Latitude

Month

Probabilistic Model for Empirical Correction (1)

- Goal: Keep GO model
  - Physical
  - Works to about 90% and add a small (10%) static empirical correction.
- Basic Assumptions:

1. There are no zonal asc/dsc biases in ocean salinity on a time scale > 1 week.
2. All remaining zonal asc/dsc biases we see are caused by the galaxy.
3. The galaxy is either in the ascending or the descending swath.
4. The error is proportional to the strength of the reflected galactic radiation.
5. Repeatable each year.

- These assumptions are approximately fulfilled.
- Avoid using auxiliary SSS field (HYCOM) to force zonal average.

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Probabilistic Model for Empirical Correction (2)

- This suggests to substitute the current empirical correction by a simple zonal symmetrization:
  - Asc swath z has no galaxy: p=1, q=0, Δ(z)=0.
  - Dsc swath (-z) has no galaxy: p=0, q=1, $\Delta(z)=\langle TB(-z)\rangle - \langle TB(z)\rangle$

$$T_B(z) \rightarrow T_B'(z) \equiv T_B(z) + \Delta(z)$$

$$\Delta(z) = \left[p \cdot \langle T_B(z) \rangle + q \cdot \langle T_B(-z) \rangle \right] - \langle T_B(z) \rangle$$

$$p = \frac{\langle T_{A,gal}(-z) \rangle}{\langle T_{A,gal}(z) \rangle + \langle T_{A,gal}(-z) \rangle}$$

$$q = \frac{\langle T_{A,gal}(z) \rangle}{\langle T_{A,gal}(z) \rangle + \langle T_{A,gal}(-z) \rangle}$$

$p + q = 1$ $\langle \; \rangle$: zonal average z:orbital angle

$$\langle T_B'(z) \rangle = \langle T_B'(-z) \rangle$$

$$\langle T_B'(z) \rangle + \langle T_B'(-z) \rangle = \langle T_B(z) \rangle + \langle T_B(-z) \rangle$$

$$\langle T_B(z) \rangle = \langle T_B(-z) \rangle \Rightarrow \Delta(z) = 0$$

Validation

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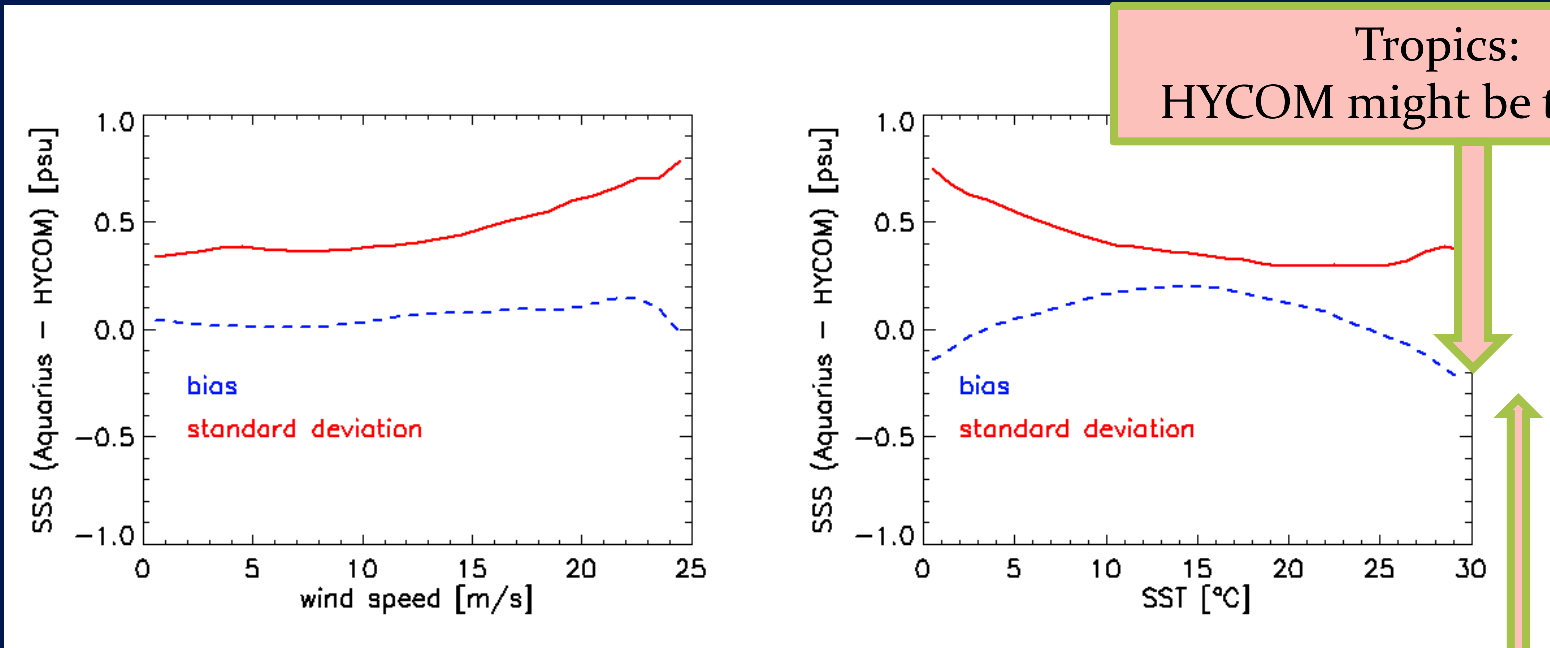
SSS Performance
Aquarius – HYCOM (global)



Tropics:
HYCOM might be too salty

SSS (Aquarius– HYCOM) [psu] $T_S > 5^oC$, W < 15 m/s	single cycle (1.44 sec)
V.2.0	0.54
V 3.0	**0.38** no difference between 3 horns

No systematic SST error in GMF (below required level)

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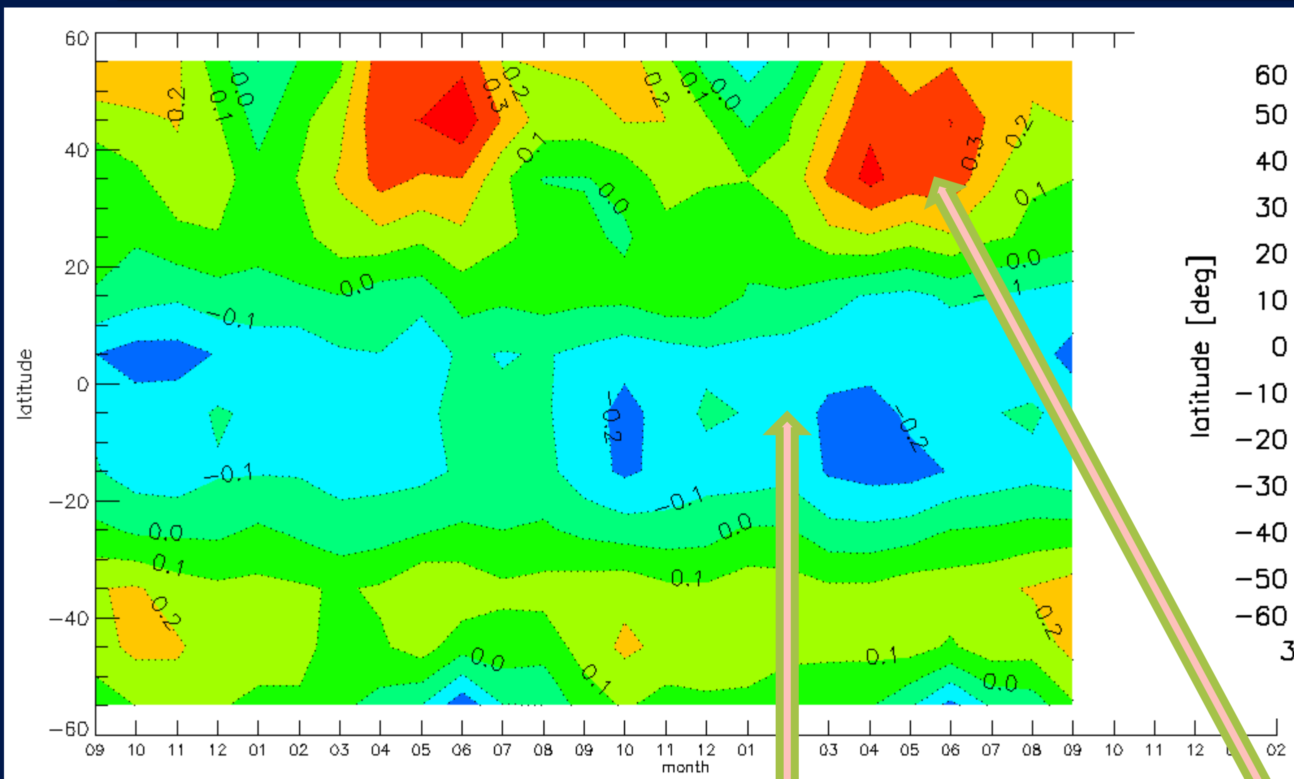
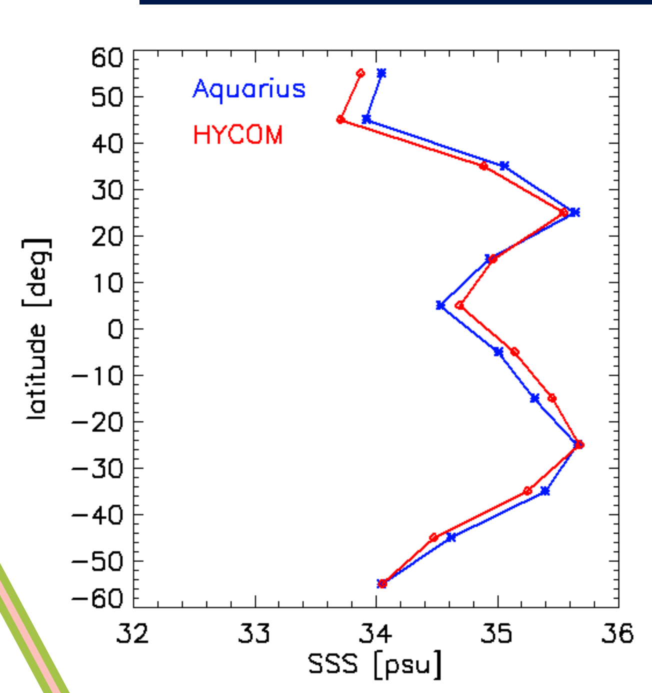
Zonal and Temporal Biases

Aquarius – HYCOM





Tropics:
Aquarius might see surface freshening

Salty bias in N hemisphere.
Strong seasonal variation.

Latitude

Month

Calibration constraint:
Aquarius is calibrated to HYCOM (global weekly average)

Moored Buoys

- **PMEL daily salinity**
  - TAO, TRITON, PIRATA, RAMA
  - Used default quality and above
  - Collocation radius of 75 km around the buoy
  - Observations from same day as satellite
  - Only used measurements at 1 m depth

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SSS Performance: Monthly Averages

AQUARIUS – HYCOM – PMEL Buoys

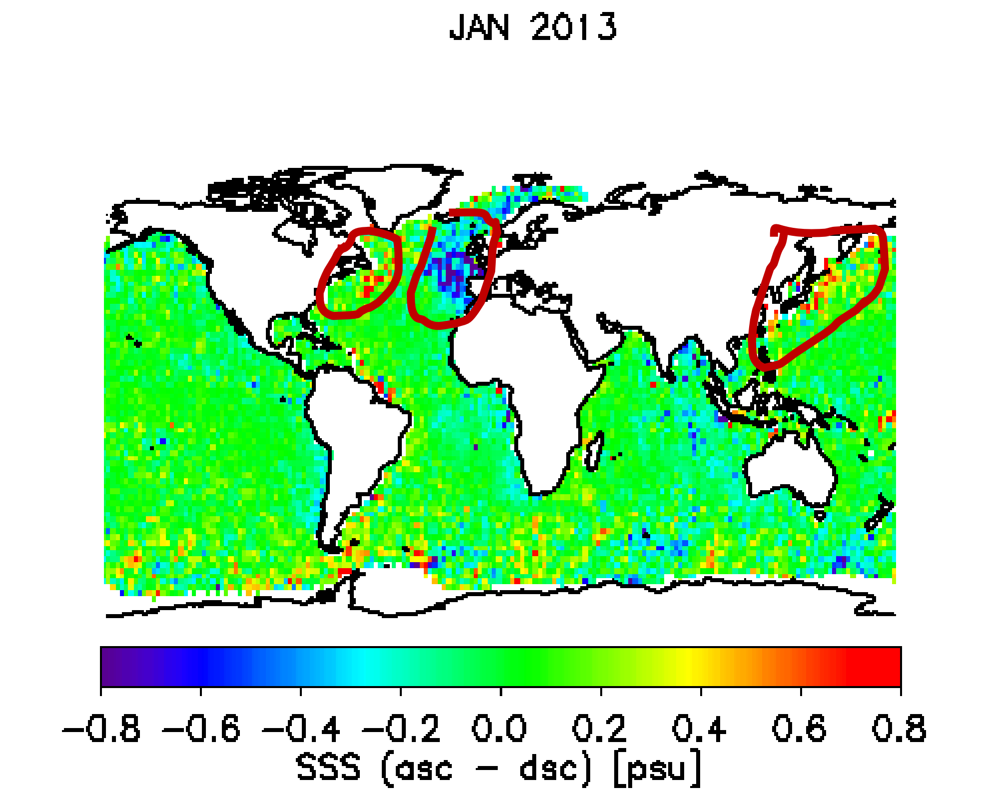
monthly 150 km average Bias / Standard Deviation [psu]	
AQ - HYCOM	- 0.129 / 0.228
AQ – BUOY	- 0.109 / 0.218
BUOY - HYCOM	- 0.020 / 0.276

monthly 150 km average triple collocation Standard Deviation [psu]	
AQ	0.108
HYCOM	0.201
BUOY	0.190

Q/C: Flagging and Masking

- Q/C flags: Level 2
- Indicate degraded conditions for algorithm performance
  - Contamination by land, sea ice
  - Undetected RFI
  - High intrusion of galaxy, sun, moon, …
  - Low SST (decreased sensitivity)
  - Very high wind speeds
- Important to be used by the user as designed by the algorithm team
  - Comparing performances between different algorithms need to employ the same Q/C
- Some L2 flags become exclusion masks in L3 processing
- Not yet fully implemented in V2.0
- Will be implemented in V3.0

Major Remaining Problem: Undetected RFI



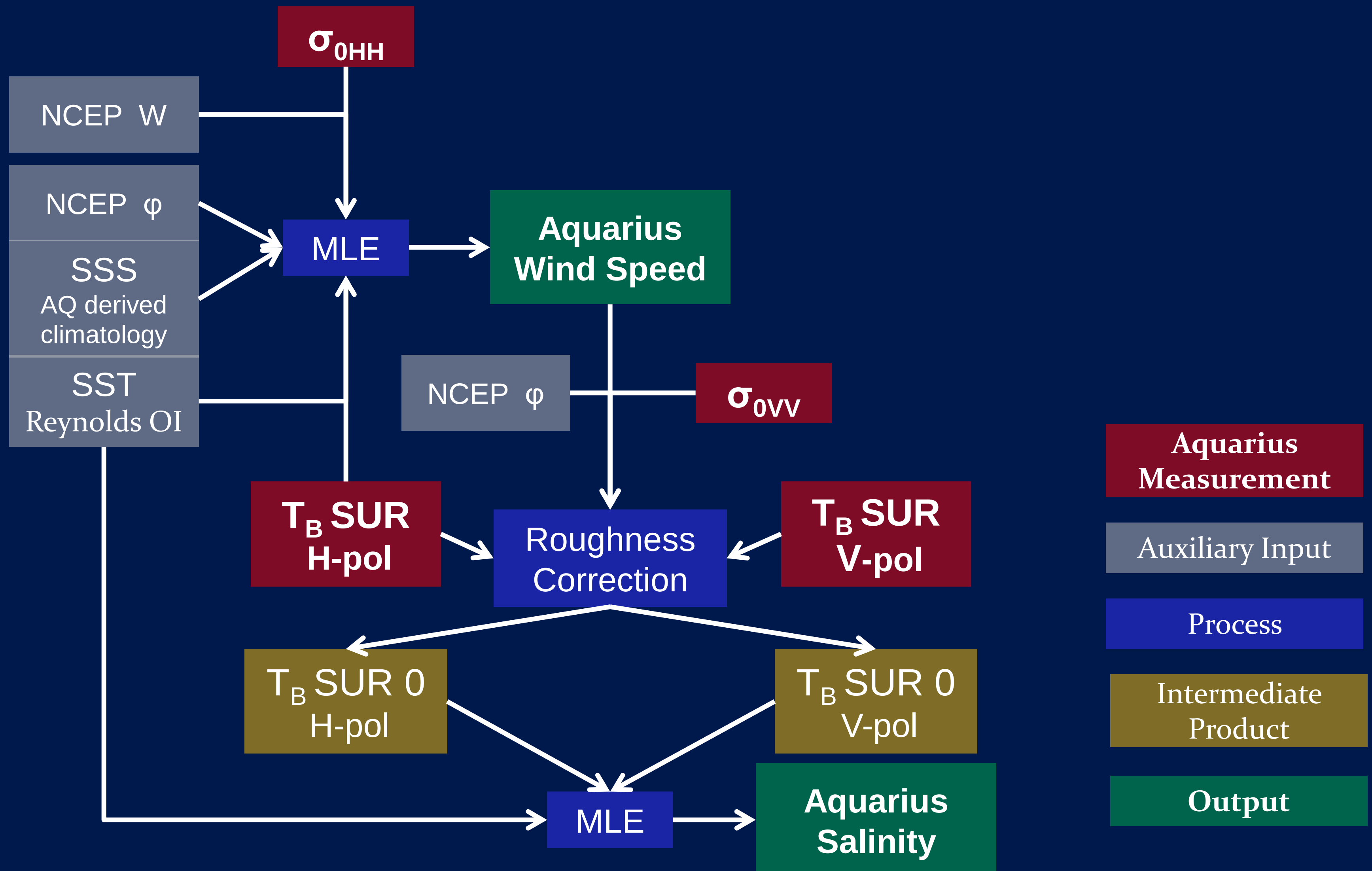
RFI shows as local ascending – descending bias

Summary and Conclusions

- Major Algorithm Performance Improvement from V2.0 to V3.0.
- Improved surface roughness correction:
  - Scatterometer essential
  - HHH wind speeds
- Empirical adjustment of correction for reflected galactic radiation.
  - GO (physical): 90%. Rest: 10%.
  - Swath symmetrization.
  - Reduction of ascending – descending biases
- Q/C flagging + masking: **Use it!**
  - **Do not take bad data from which you have been told that they are bad**
- Major remaining problem: Undetected RFI
  - Need further improvement in RFI filter algorithm
  - Flagging

Backup

Surface Roughness Correction
Algorithm Flow



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Triple Collocation Statistics

AQUARIUS – HYCOM – PMEL Buoys

single cycle (1.44s) Bias / Standard Deviation [psu]	
AQ - HYCOM	- 0.129 / 0.336
AQ – BUOY	- 0.109 / 0.337
BUOY - HYCOM	+ 0.020 / 0.332

single cycle (1.44s) triple collocation Standard Deviation[psu]	
AQ	0.225
HYCOM	0.249
BUOY	0.249

monthly 150 km average Standard Deviation [psu]	
AQ - HYCOM	0.228
AQ – BUOY	0.218
BUOY - HYCOM	0.276

monthly 150 km average triple collocation Standard Deviation [psu]	
AQ	0.108
HYCOM	0.201
BUOY	0.190