# Roughness Corrections for Aquarius SSS Retrieval

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**10/11/12**

**SMOS-MODE**

# L-Band Combined Active/Passive Aquarius

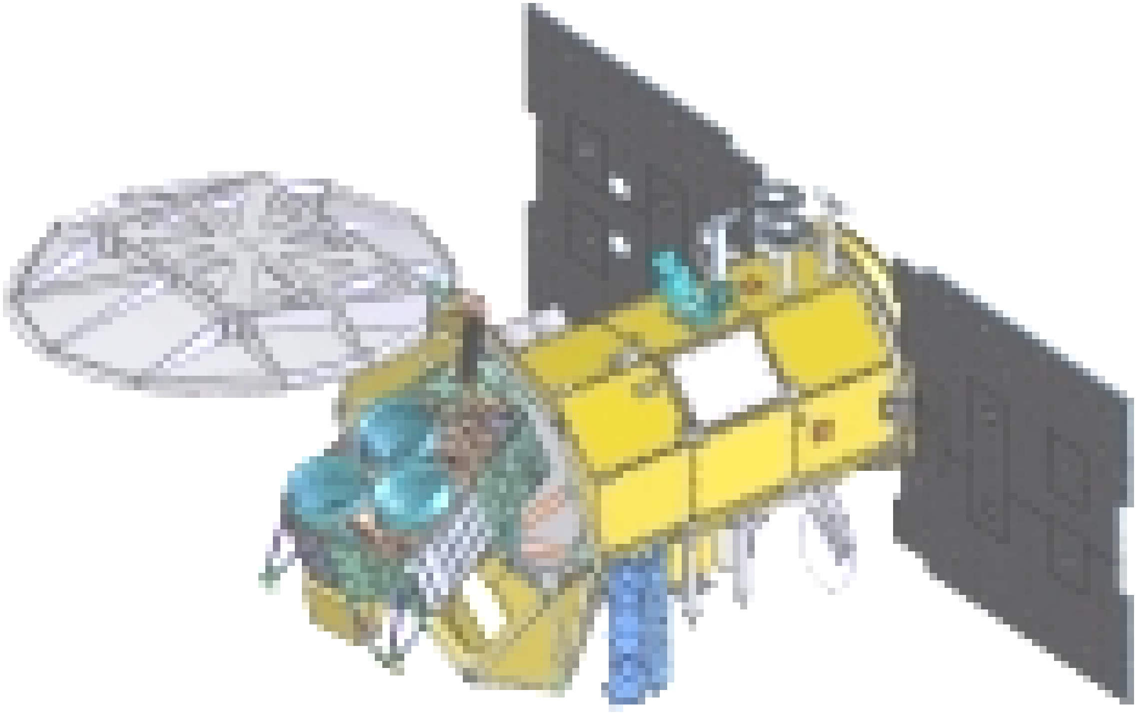
**Aquarius (Sea Surface Salinity)**

**L-band radiometer and scatteroemter**

**Push-broom (single look) with three feeds**

**<0.1 K for radiometer**

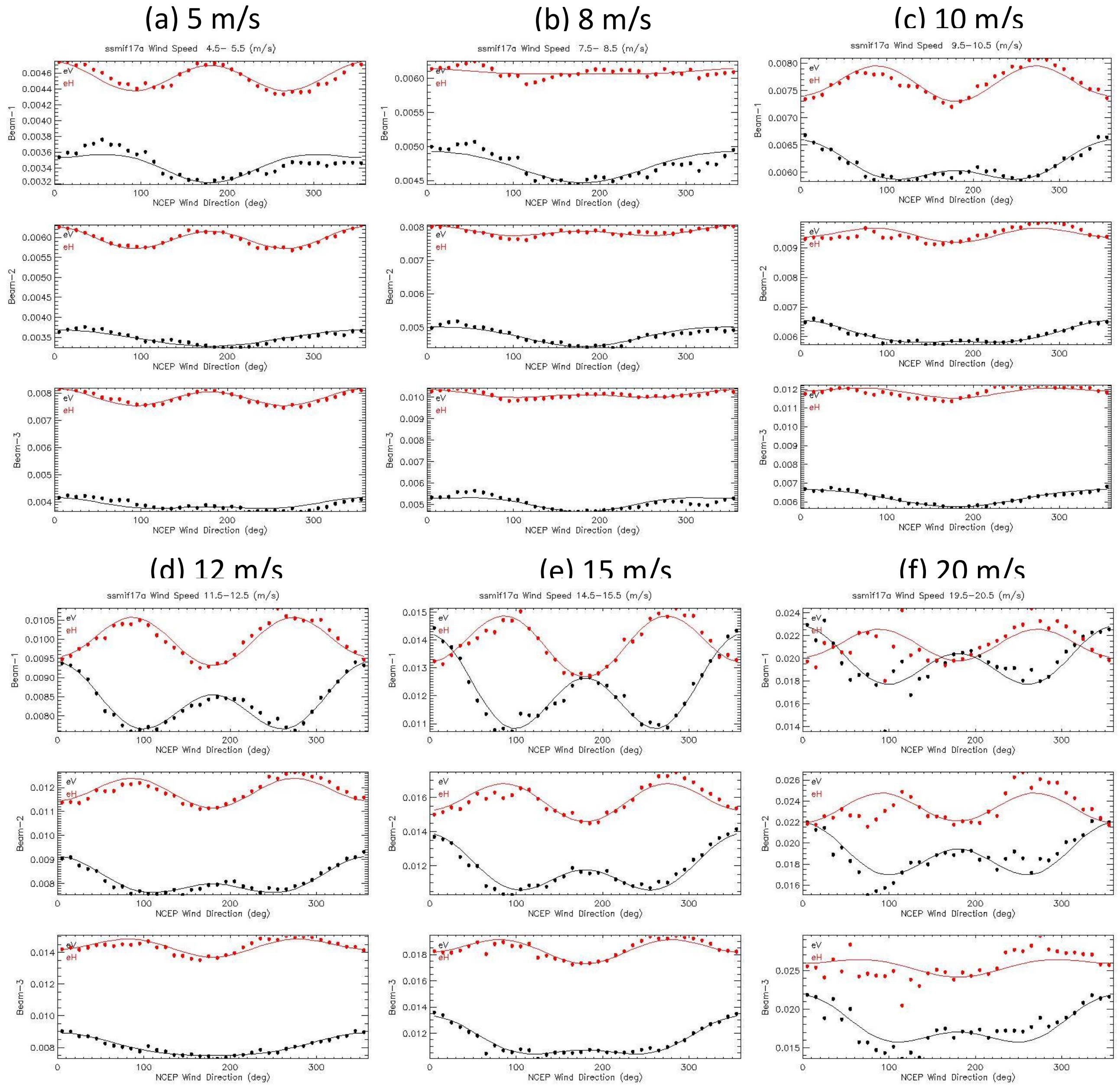
**<0.1 dB for scatterometer**



# Approach

- Test different roughness correction methods
  - Matchup Aquarius TB and sigma0 with NCEP wind and NOAA WW3 SWH, develop the roughness GMF for TB and sigma0, and use CAP algorithm
  - NCEP vs. Radar for wind correction
  - Correction for SWH
- Assess the galactic reflection correction
  - Derive effective wave slope
  - Use CAP retrieval algorithm

# L-band Passive Microwave TB vs. Wind



# Aquarius Radiometer Model

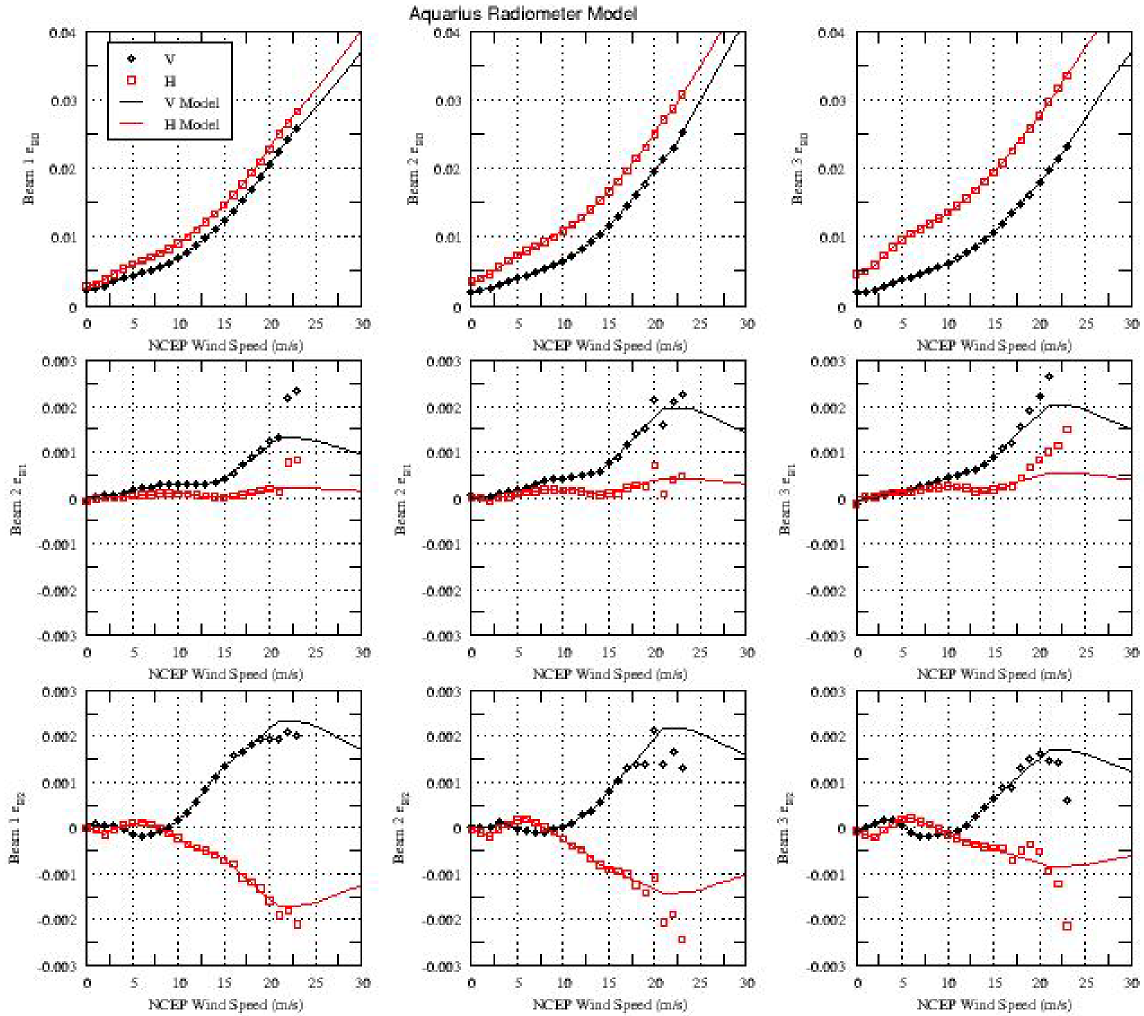
- TBH is more sensitive to wind speed
- TBV has  a larger upwind-downwind asymmetry.

$$\Delta e(w,\phi) = e_0(w) + e_1(w)\cos\phi + e_2(w)\cos 2\phi$$

e0

e1

e2



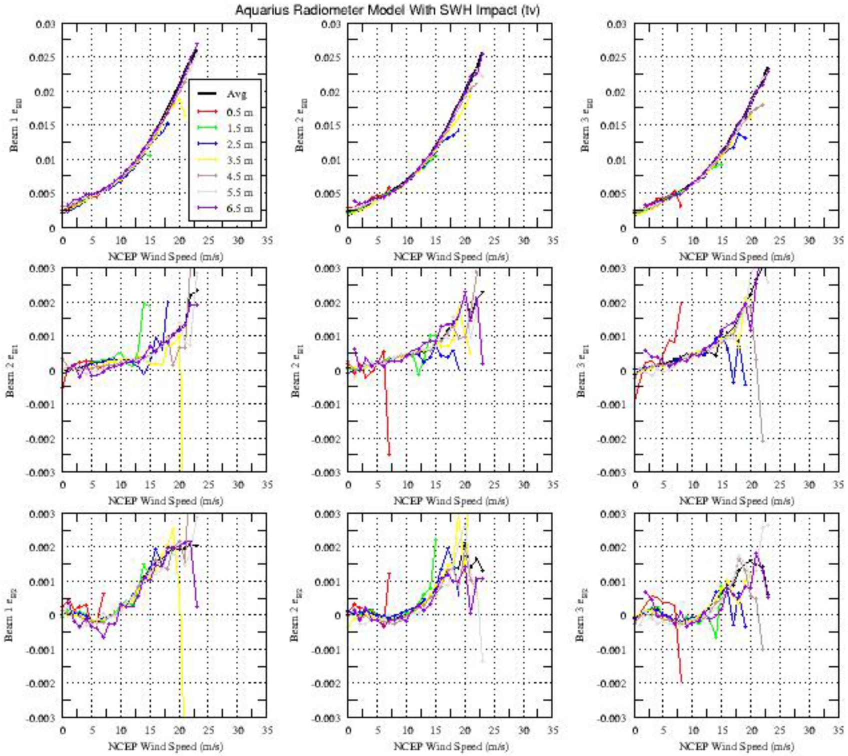

e2 changes phase at about 3 and 8 m/s

Similar to active Non-Bragg?

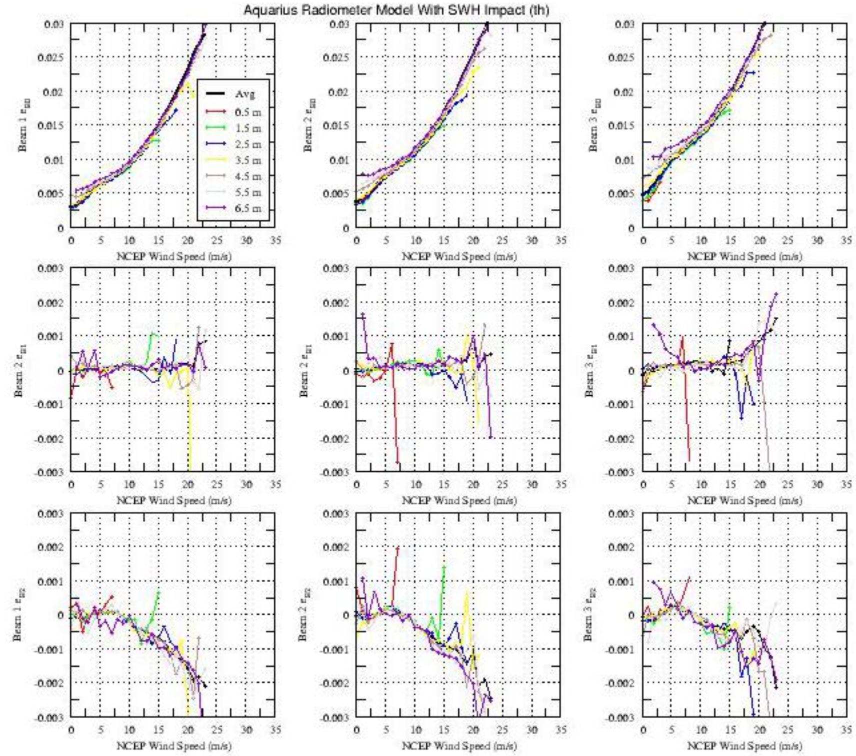
# Aquarius Radiometer Model with Wave Effects

- e1 and e2 have no obvious dependence on SWH

**V-pol**



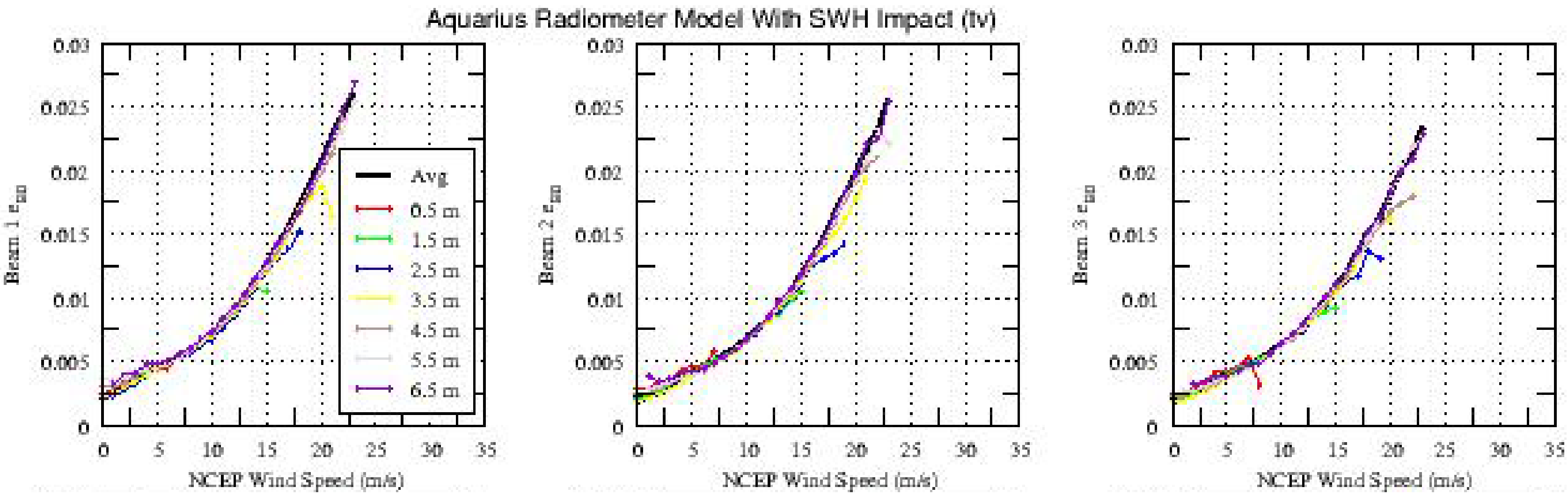

**H-pol**



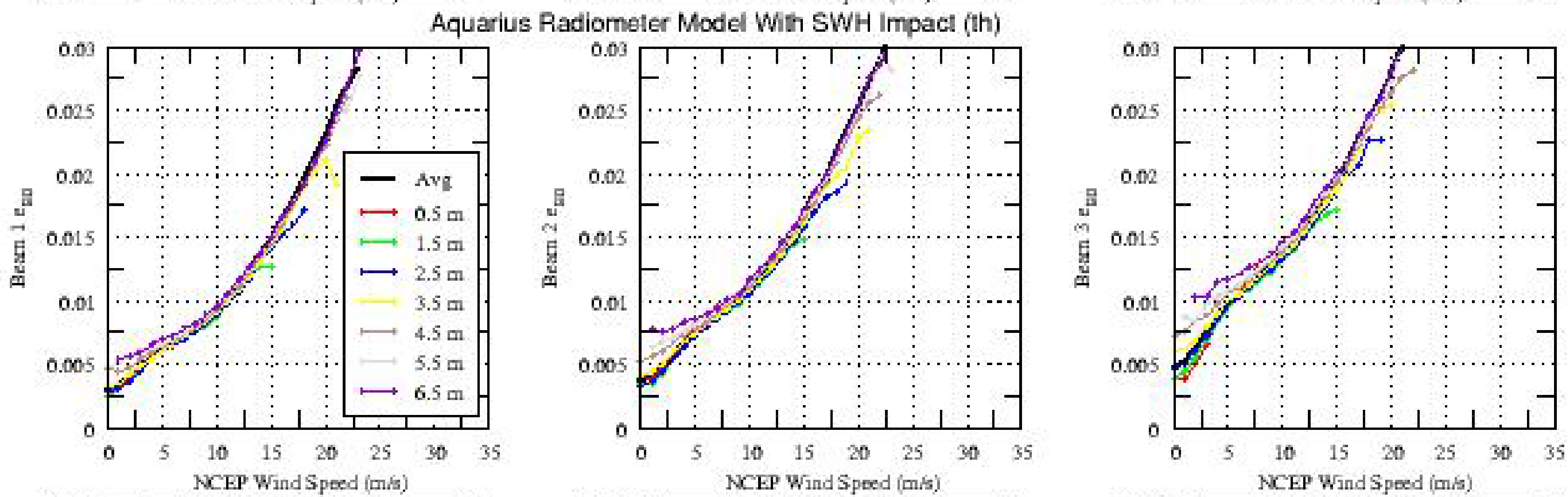
# Radiometer Model with Wave Effects

- TH at low winds is more sensitive to the effects of SWH.

**V-pol e0**



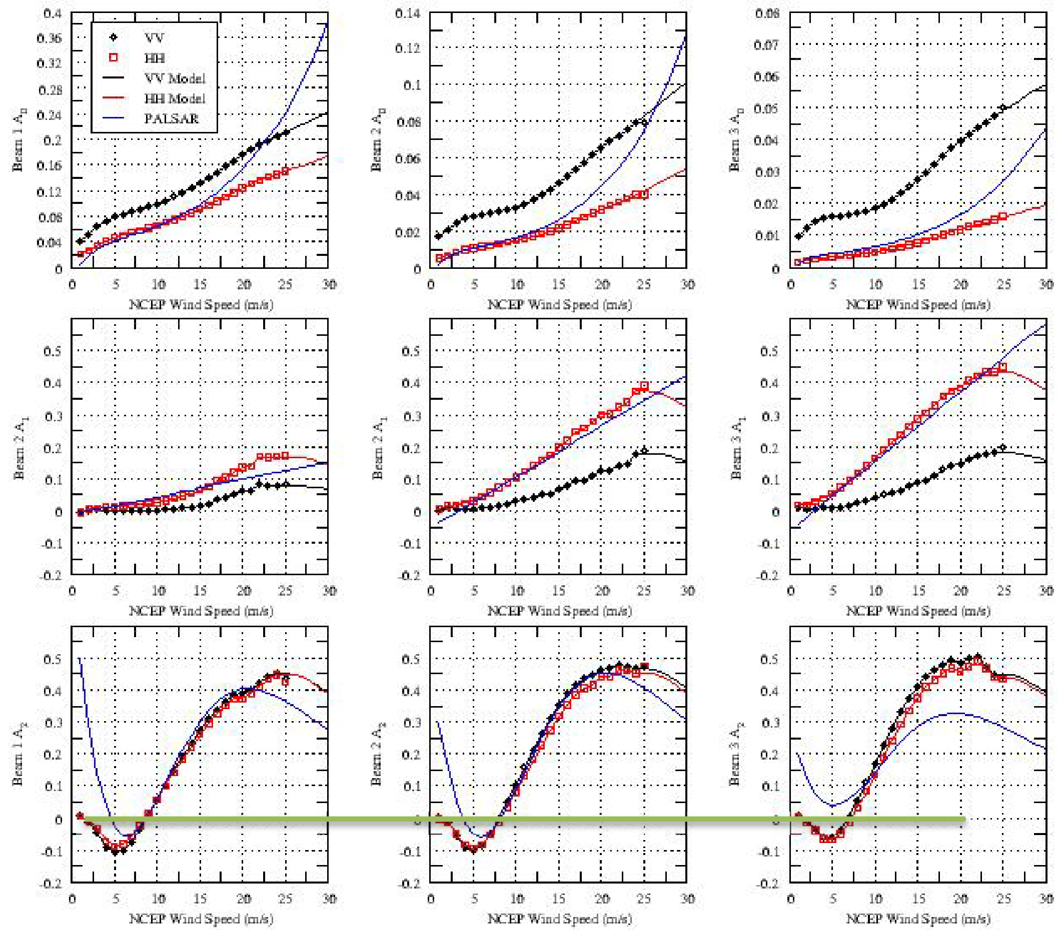

**H-pol e0**



# Aquarius Scatterometer Model

- Sigma0 model $\sigma_0(w,\phi) = A_0(w)[1 + A_1(w)\cos\phi + A_2(w)\cos 2\phi]$

Negative A2 from 3 to 8 m/s Non-Bragg?

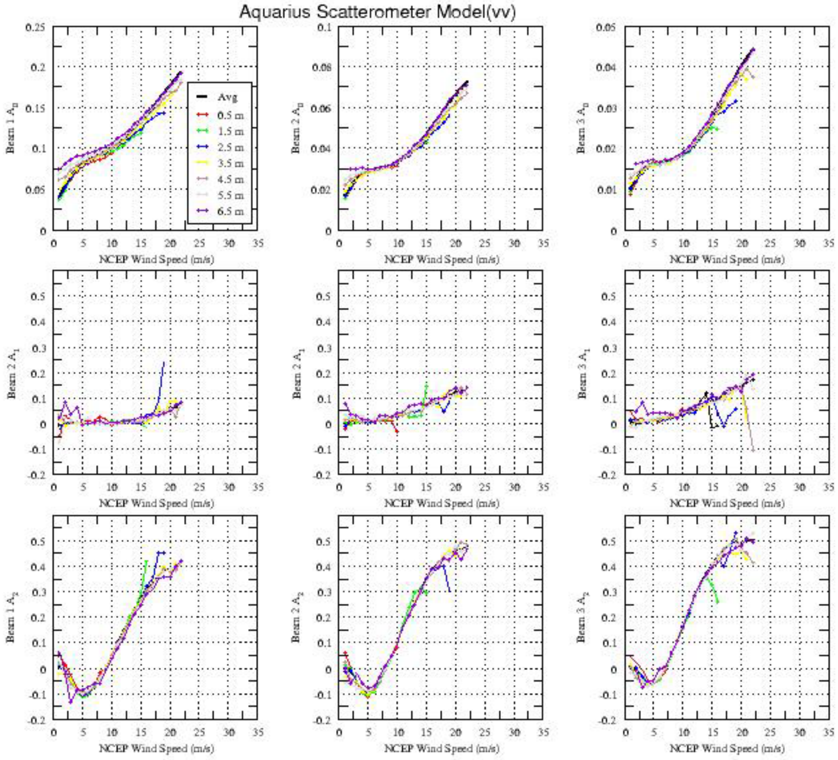



- Aquarius GMF for HH agrees well with the Japanese PALSAR GMF (Osamu Isoguchi and Masanobu Shimada, IEEE TGRS, 2009.

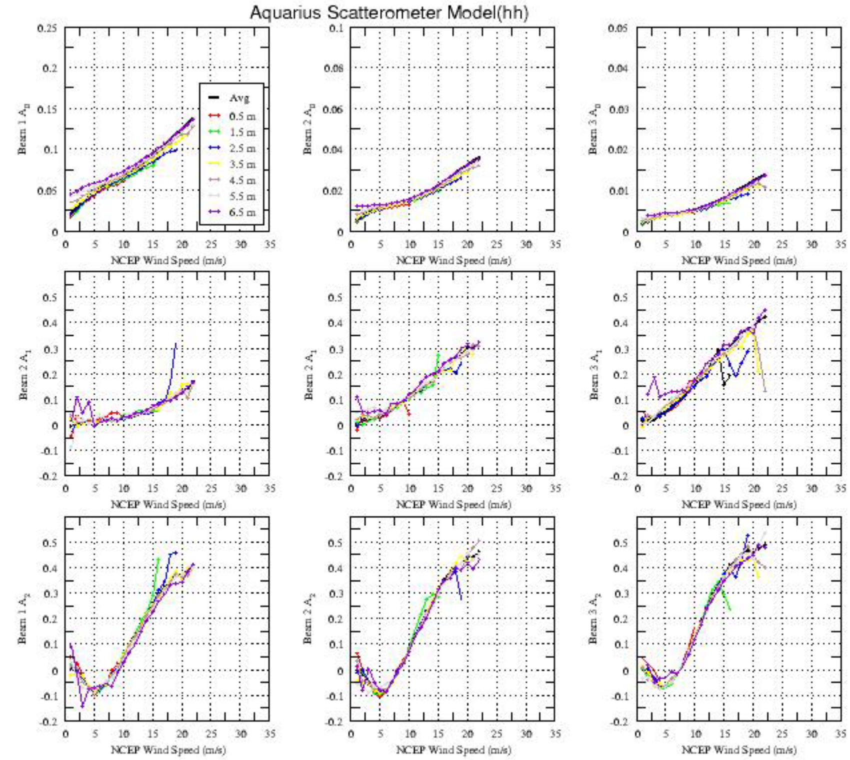
# Aquarius Scatterometer Model with Wave Effects

- HH is more sensitive to the effects of SWH.

VV

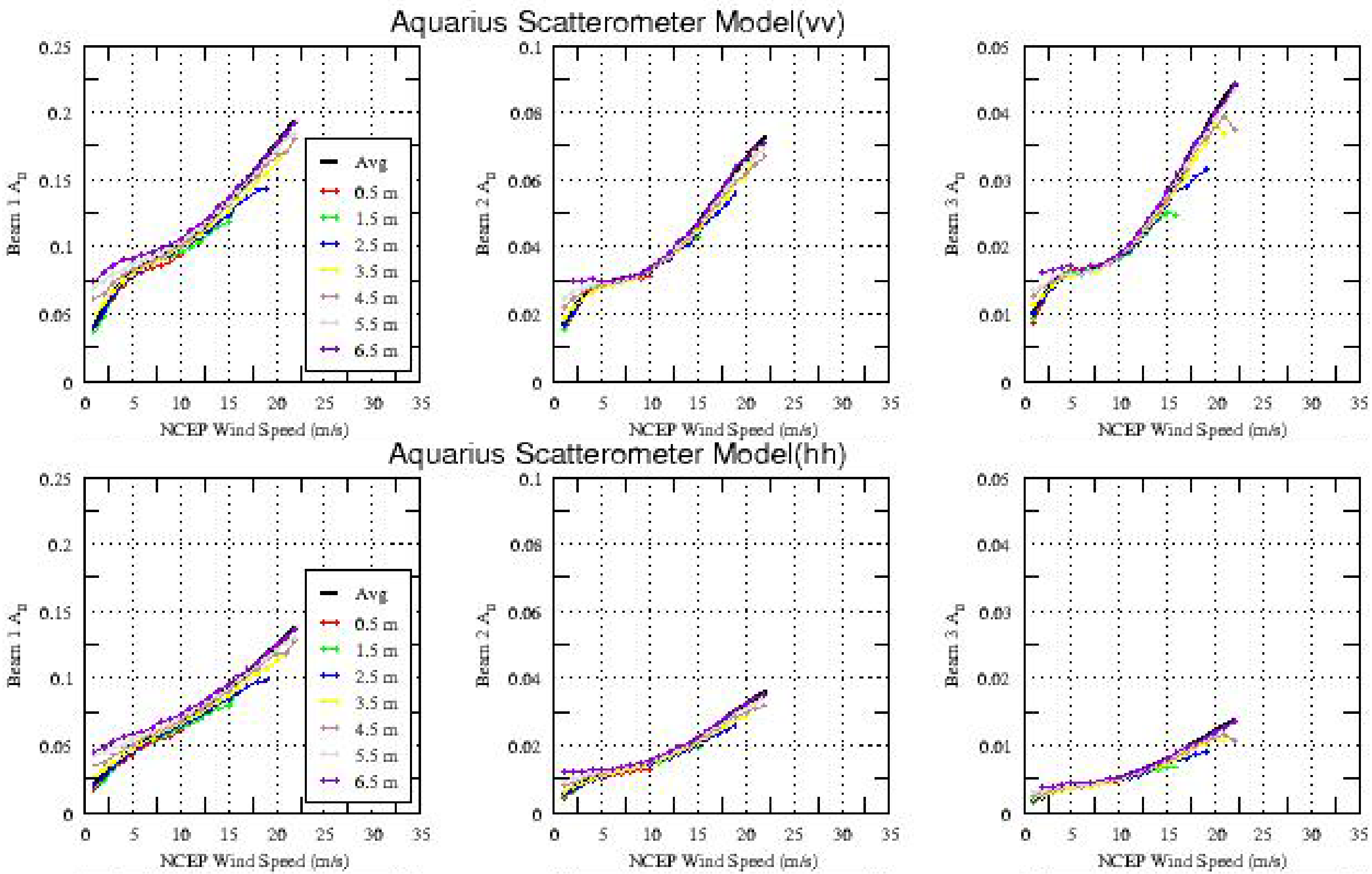



HH



# Aquarius Scatterometer Model with Wave Effects

- Beam 1 is more sensitive to the effects of SWH.



# Active-Passive Algorithms for Aquarius SSS and Wind Retrievals

- Combined Active-Passive (CAP) Algorithm
  - Retrieve SSS, Wind Speed and Direction Using Combined Passive and Active Data
  - Do not use NCEP winds for TB correction

$$F_{pol}(SSS,W,\phi) = \frac{(I - I_m)^2}{2\Delta T^2} + \frac{(\sqrt{Q^2 + U^2} - \sqrt{Q_m^2 + U_m^2})^2}{2\Delta T^2} + \frac{(\sigma_{0VV} - \sigma_{0VVm})^2}{(k_p \sigma_{0VV})^2} + \frac{(\sigma_{0HH} - \sigma_{0HHm})^2}{(k_p \sigma_{0HH})^2}$$

$$I = T_{BV} + T_{BH}$$

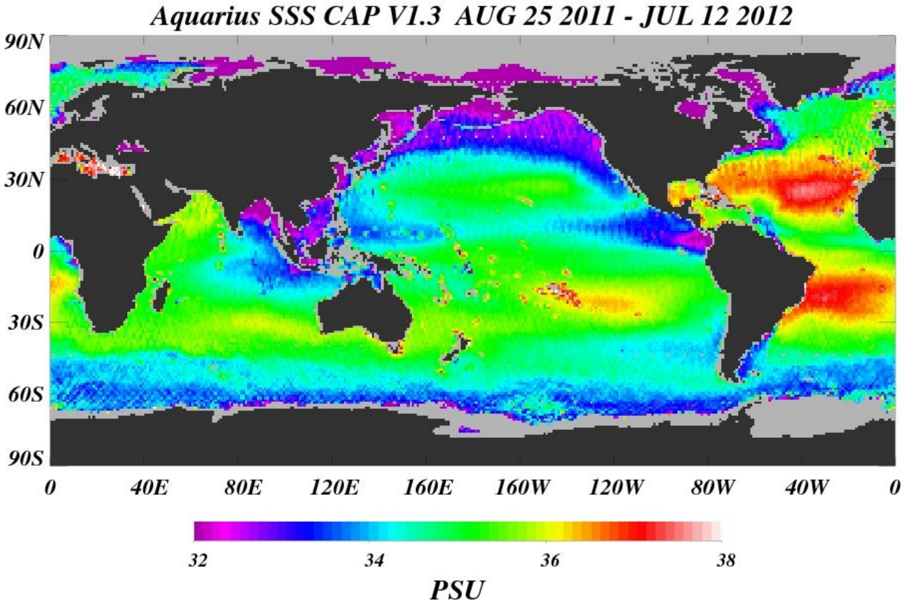
$$Q = T_{BV} - T_{BH}$$

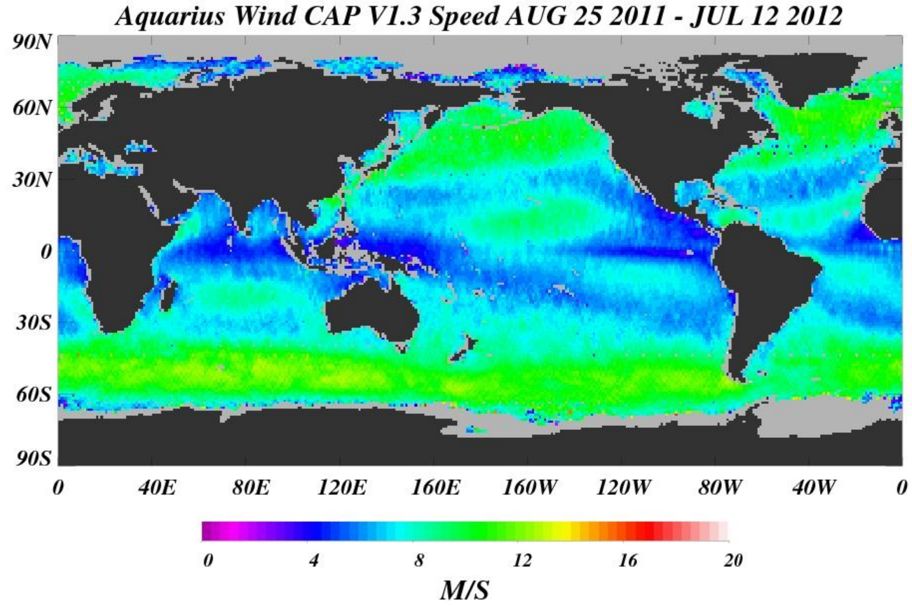
Yueh and Chaubell, IEEE TGRS, April 2012

- $TB_m = TB_m(W, \phi, SST)$
- $\sigma_m = \sigma_m(W, \phi)$
- Ancillary input: Reynolds SST

# Aquarius CAP Wind and SSS Composites

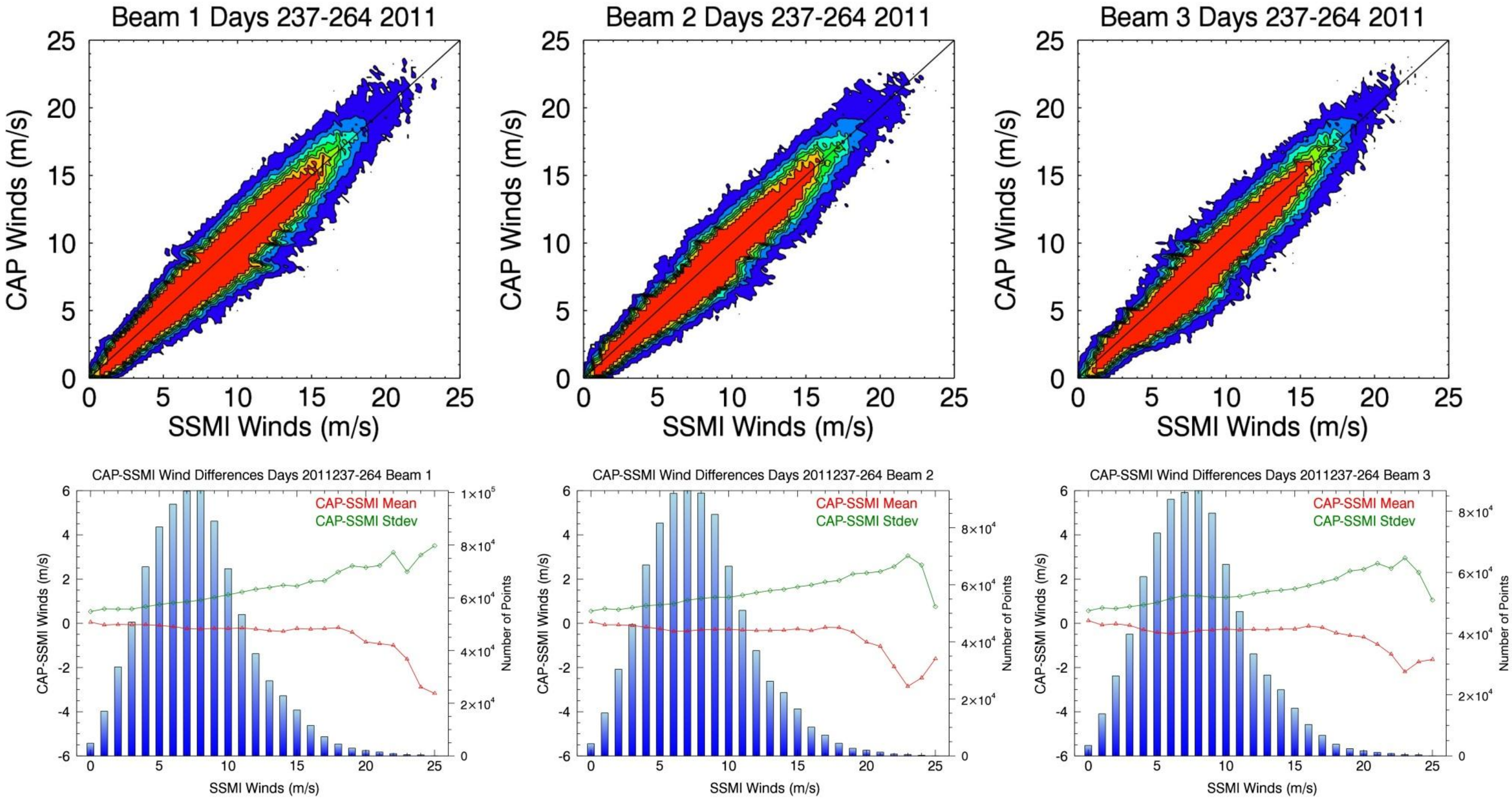
**Aquarius CAP SSS and Wind from Aug 25, 2011 to July 12, 2012**



# CAP Wind Speed comparison with SSM/I

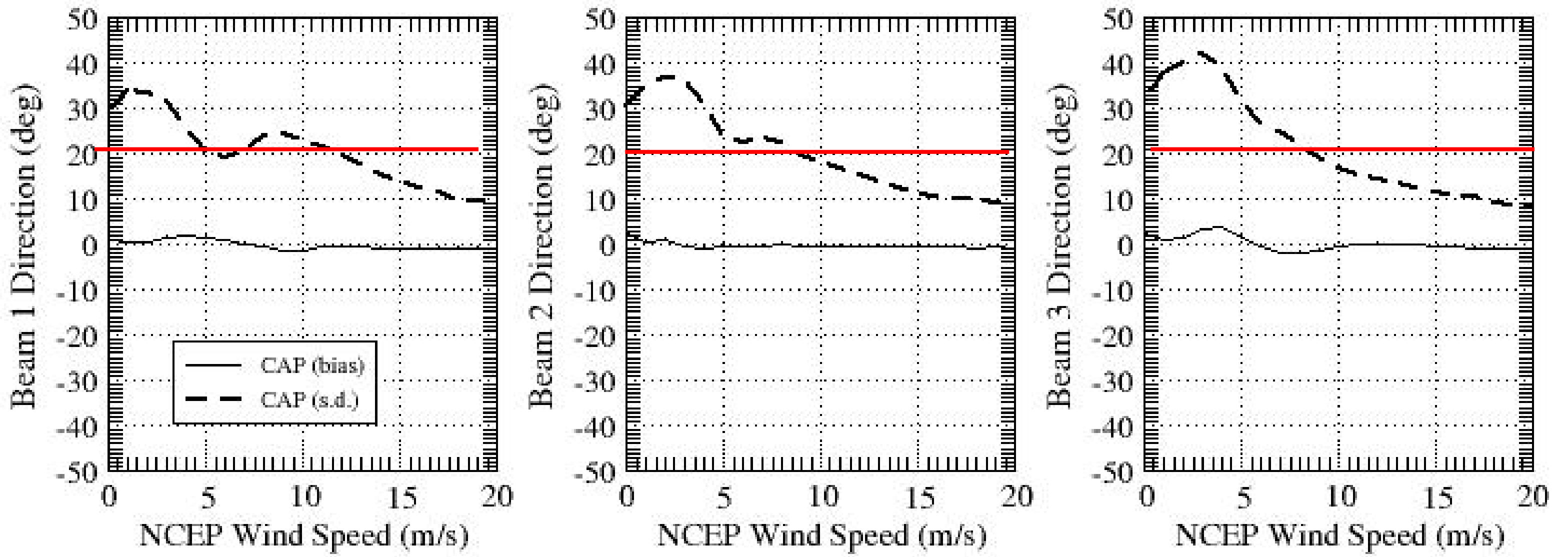
- Aquarius CAP winds agree well with SSM/I
  - standard deviation of speed difference < 1.5 m/s for 0-15 m/s



# Wind Direction Difference with Respect to NCEP

- RMS wind direction difference smaller than 20 degrees for mid to high winds

Day 240 2011 to Day 91 in 2012



# Results of Triple Collocation Analysis

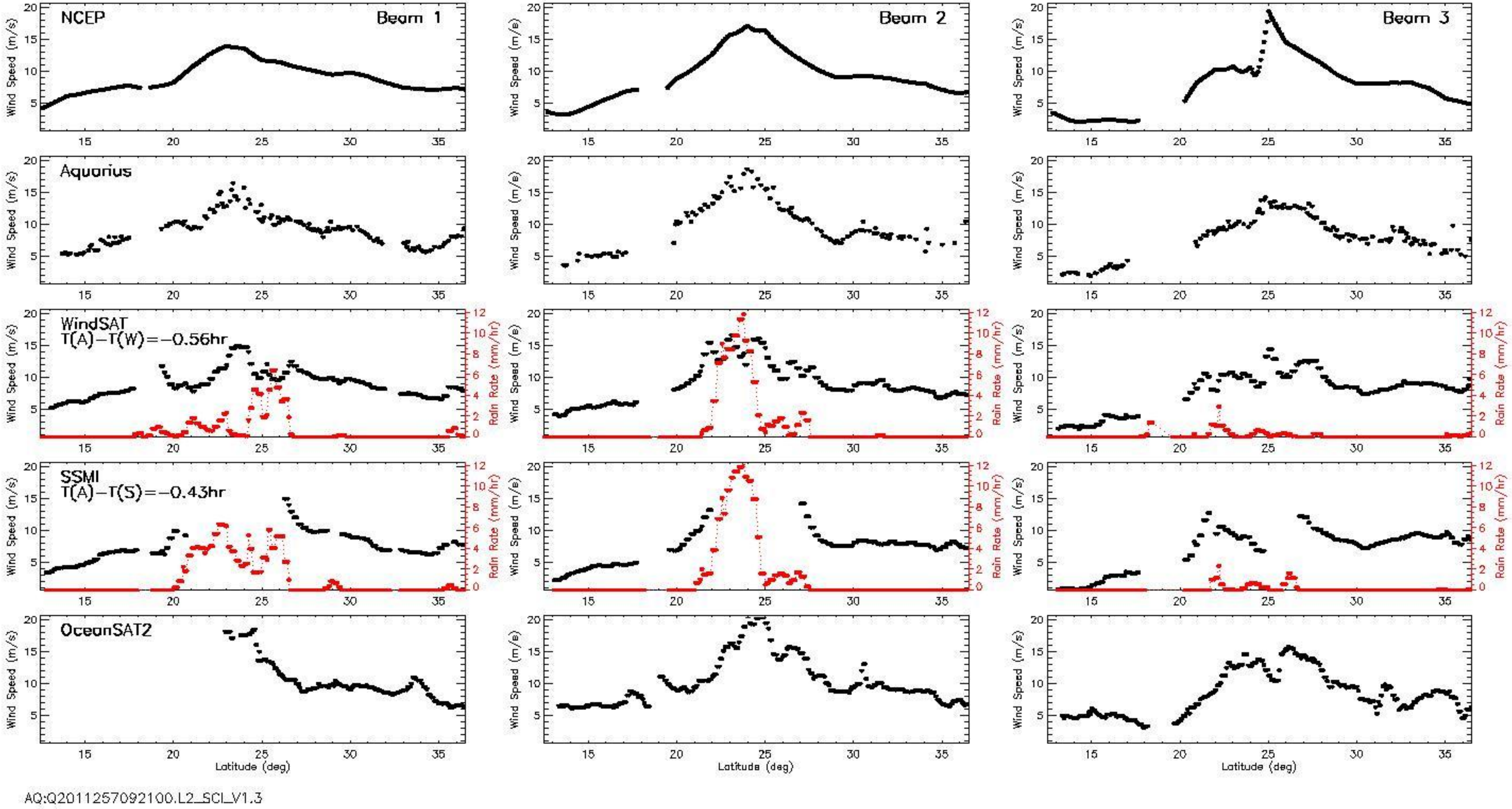
- Apply triple collocation method (Stoffelen, 1998)
- Aquarius RMS wind speed error about 0.76 m/s

| | SSM/I | NCEP | AQ-CAP |
|---|---|---|---|
| **Beam 1 Random Error (m/s)** | 0.77 | 1.08 | 0.77 |
| **Beam 2 Random Error (m/s)** | 0.75 | 1.07 | 0.73 |
| **Beam 3 Random Error (m/s)** | 0.80 | 1.03 | 0.78 |

| | SSM/I | NCEP | AQ-CAP |
|---|---|---|---|
| **Beam 1 Slope A** | 1 | 1.020 | 1.043 |
| **Beam 2 Slope A** | 1 | 1.021 | 1.042 |
| **Beam 3 Slope A** | 1 | 1.032 | 1.052 |
| **Beam 1 bias B ($m \bullet s^{-1}$)** | 0 | -0.19 | -0.31 |
| **Beam 2 bias B ($m \bullet s^{-1}$)** | 0 | -0.19 | -0.33 |
| **Beam 3 bias B ($m \bullet s^{-1}$)** | 0 | -0.27 | -0.43 |

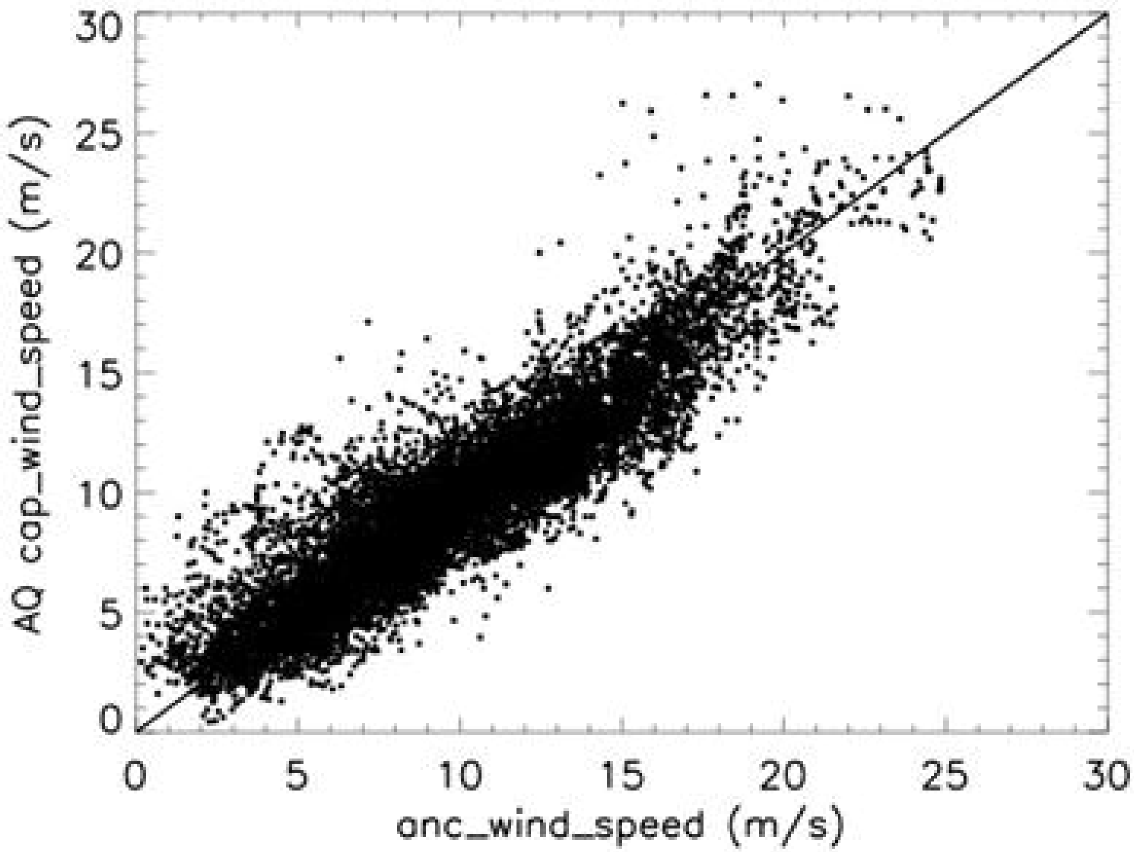
# Influence of Rain on AQ CAP Wind Speed Retrieval

- AQ CAP Wind Speed retrieval appear reasonable over areas with precipitation – where there were no SSM/I speed retrievals.
- Windsat AW speed retrievals could be problematic above 4-5 mm/h



# Comparison of AQ and NCEP Wind Speed under Rainy Conditions

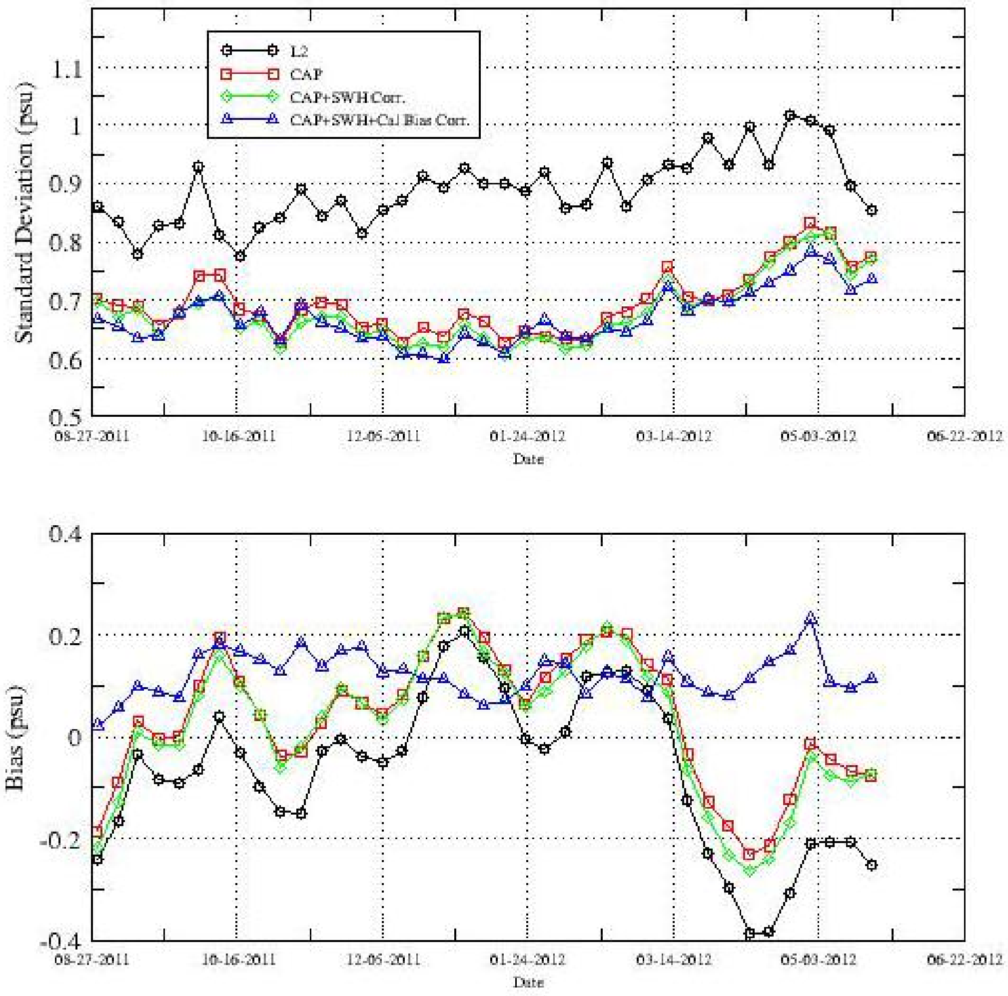
- Aquarius CAP wind speed appears unbiased with respect to NCEP when SSM/I rain rate > 0.



# NCEP vs Radar for Roughness Correction:

Aquarius SSS Comparison with Hycom for Each Satellite Pass

- Radar is far superior to NCEP for roughness correction: 0.9 psu (s.d.) vs. 0.7 psu




- Land and ice fractions < 0.0005
- All wind speed and SST

# Active-Passive Algorithms for Aquarius SSS and Wind Retrievals

with SWH Correction

- Combined Active-Passive (CAP) Algorithm
  - Retrieve SSS, Wind Speed and Direction Using Combined Passive and Active Data
  - Do not use NCEP winds for TB correction

$$F_{pol}(SSS,W,\phi)=\frac{(I-I_m)^2}{2\Delta T^2}+\frac{(\sqrt{Q^2+U^2}-\sqrt{Q_m^2+U_m^2})^2}{2\Delta T^2}+\frac{(\sigma_{0VV}-\sigma_{0VVm})^2}{(k_p\sigma_{0VV})^2}+\frac{(\sigma_{0HH}-\sigma_{0HHm})^2}{(k_p\sigma_{0HH})^2}$$

$$I=T_{BV}+T_{BH}$$

$$Q=T_{BV}-T_{BH}$$

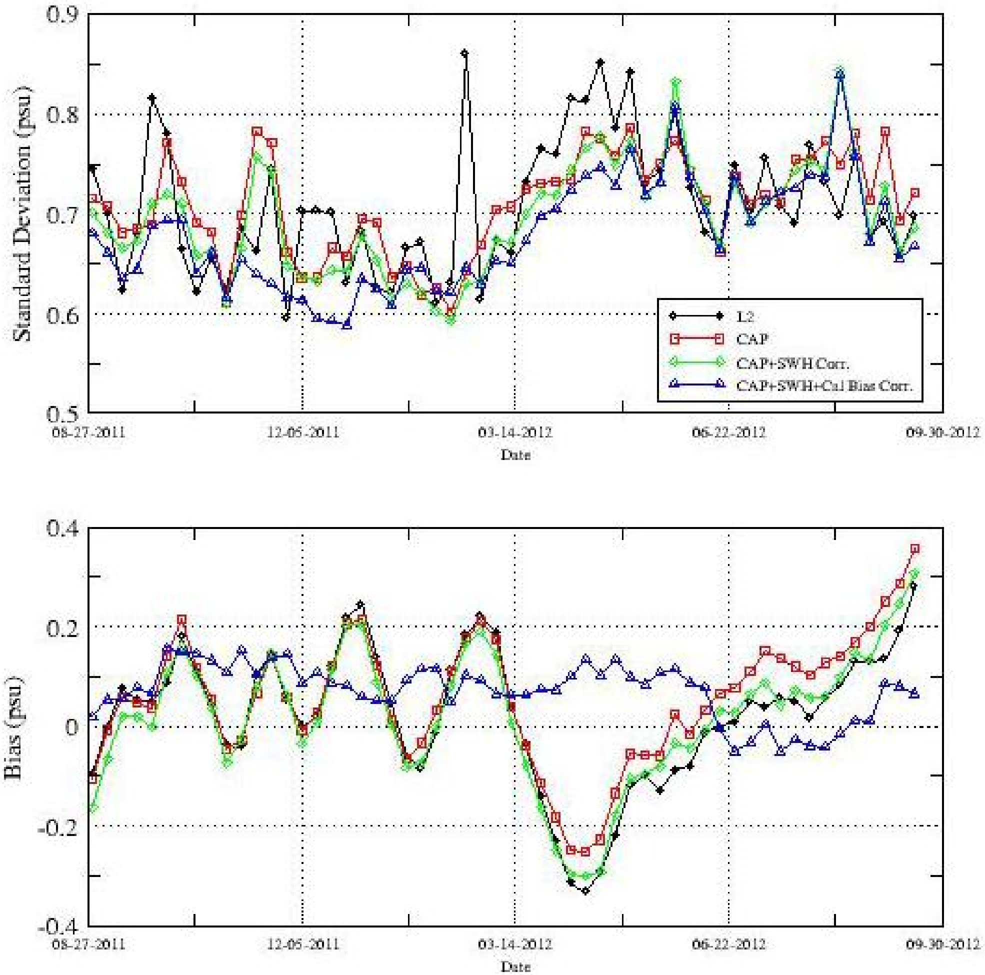
Yueh and Chaubell, IEEE TGRS, April 2012

- $TB_m=TB_m(W,\phi,SST,SWH)$
- $\sigma_m=\sigma_m(W,\phi,SWH)$
- Ancillary input: Reynolds SST and NOAA WW3 SWH

# Effects of SWH Roughness Correction:

Aquarius SSS Comparison with Hycom for Each Satellite Pass

- SWH correction improves the s.d. accuracy by about a few percent

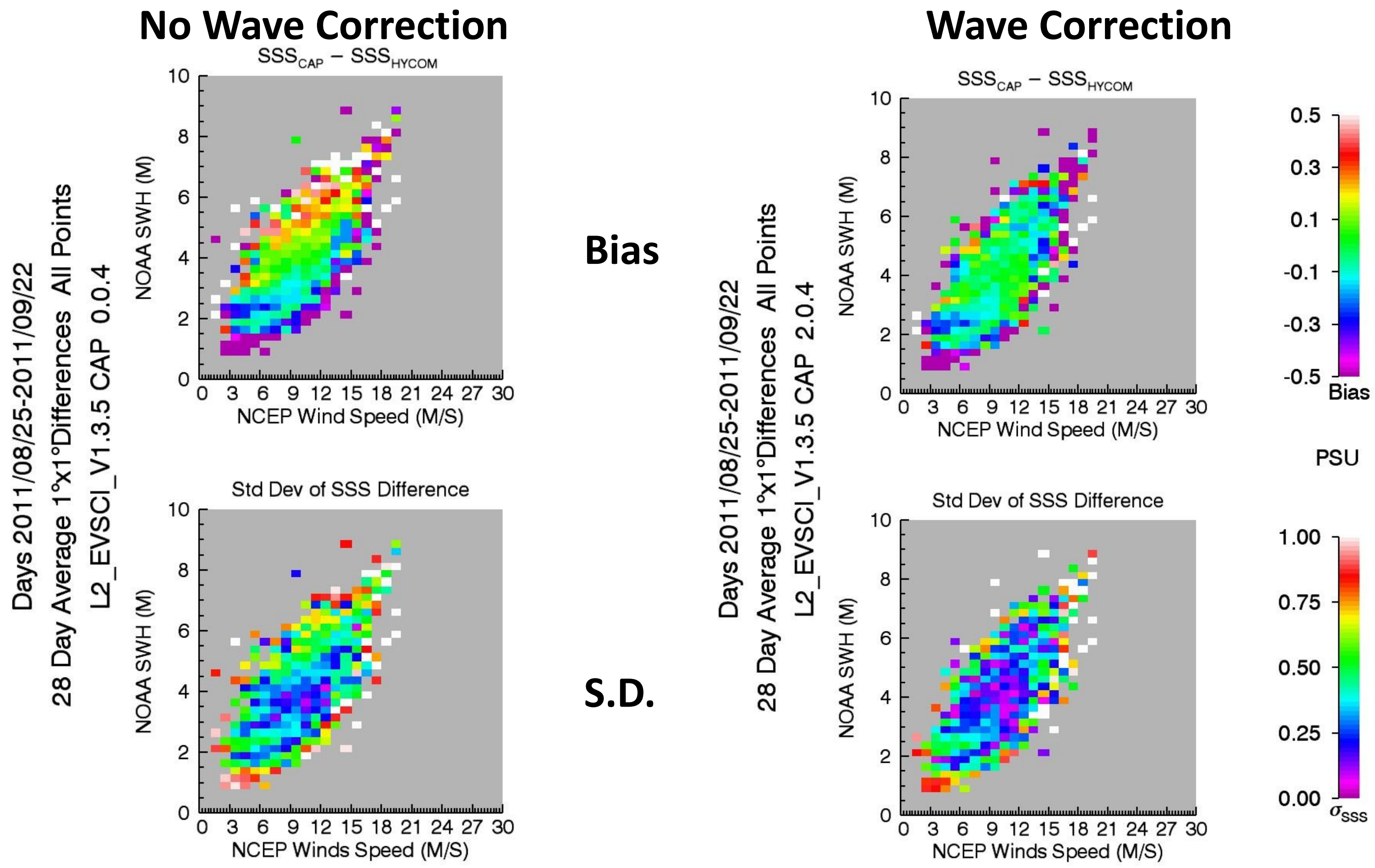



- Land and ice fractions < 0.0005
- All wind speed and SST

# Wave correction reduces the systematic bias and standard deviation

V1.3.5 Difference with HYCOM
8/25/11-9/22/11

- CAP retrievals w/o and with SWH correction



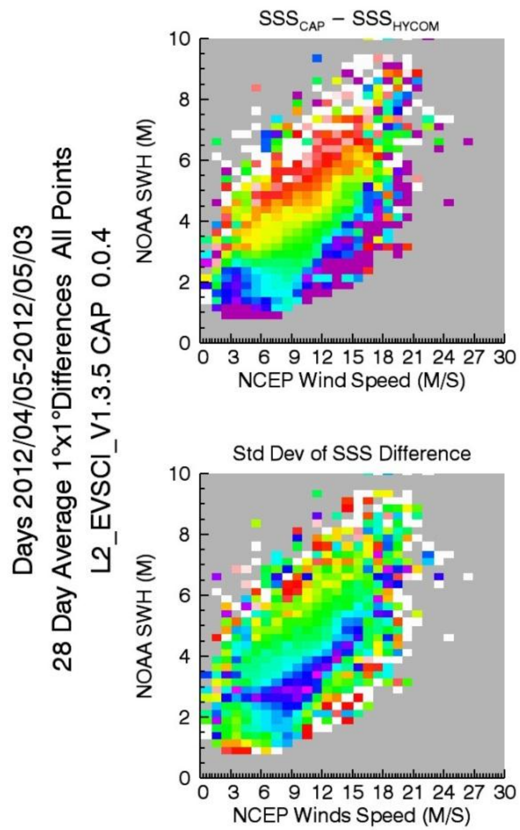
# Wave correction reduces the systematic bias and standard deviation

V1.3.5 Difference with HYCOM

4/5/12-5/3/12

- CAP retrievals w/o and with SWH correction

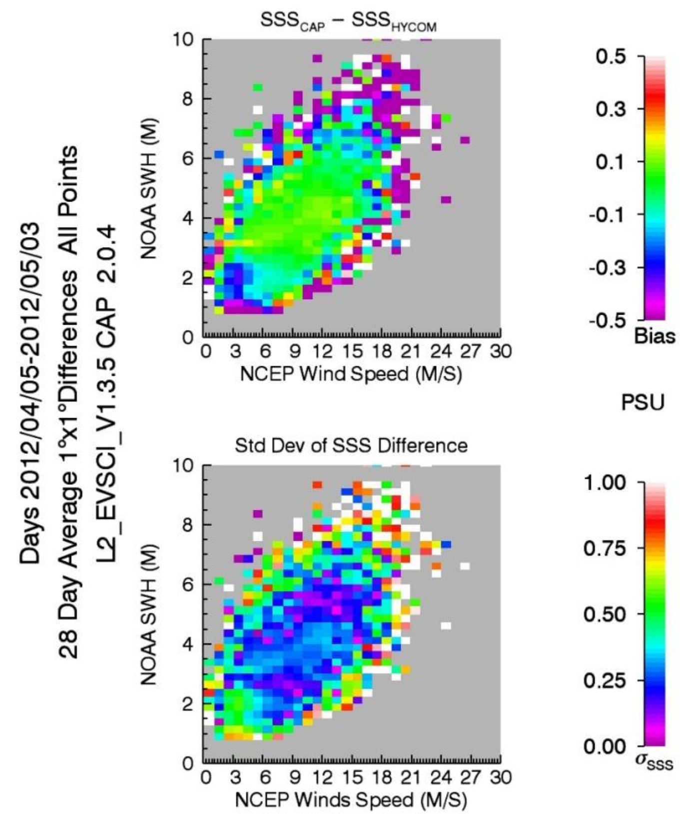
**No Wave Correction**




**Bias**

**S.D.**

**Wave Correction**



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V1.3.5 Difference with HYCOM

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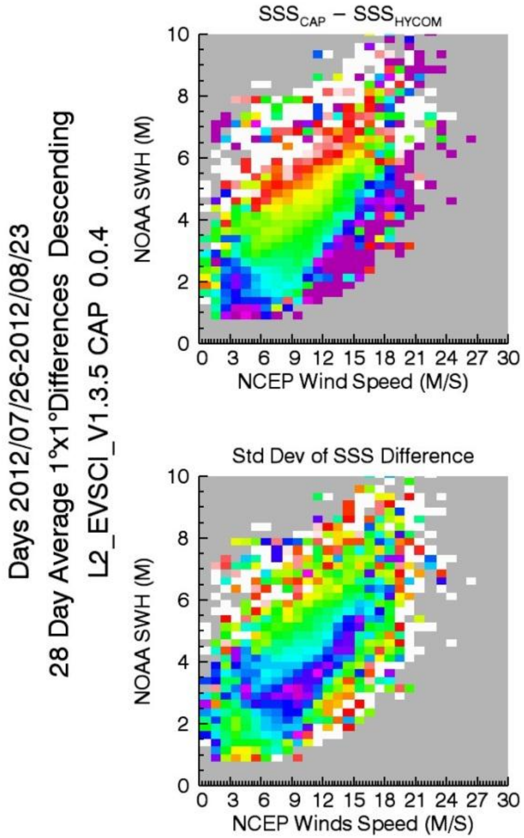
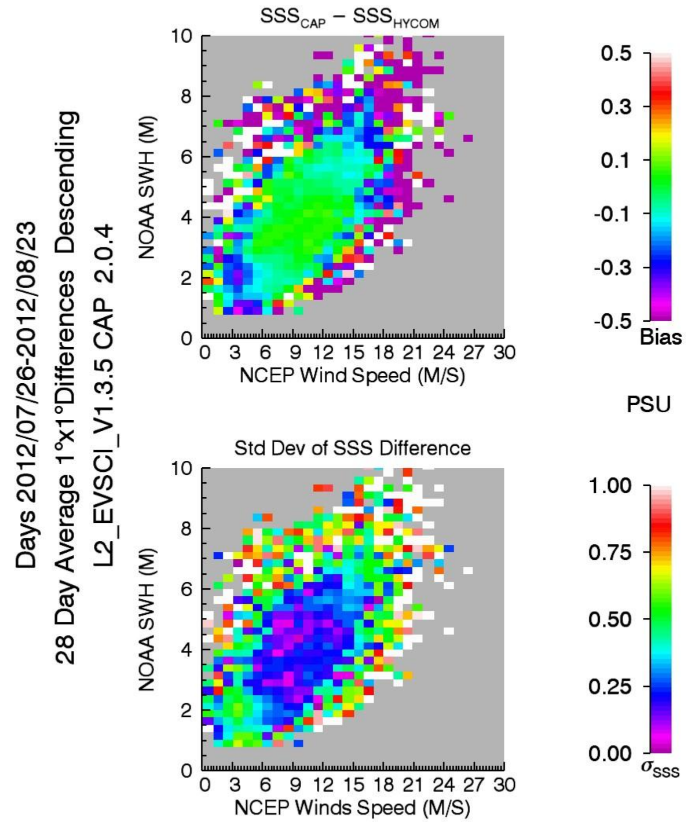



**Bias**

**S.D.**

**Wave Correction**



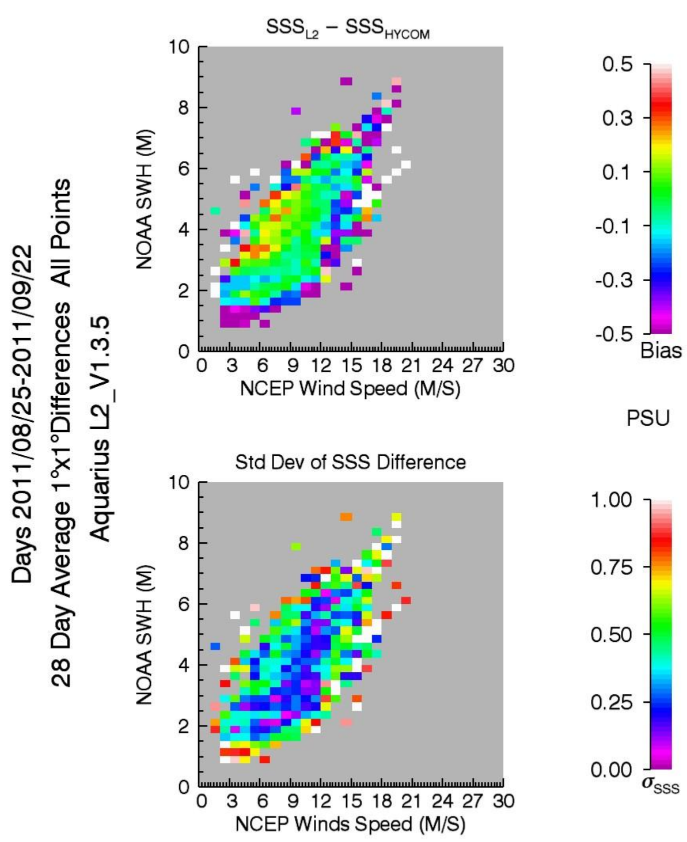
# Comparison with the Hybrid Algorithm for Aquarius V1.3.5

- Current V1.3 5 product uses the hybrid algorithm, which estimates an empirical TB correction for v-pol brightness from the NCEP wind speed, direction and radar VV sigma0
- The corrected V-pol TB is then used to retrieved SSS

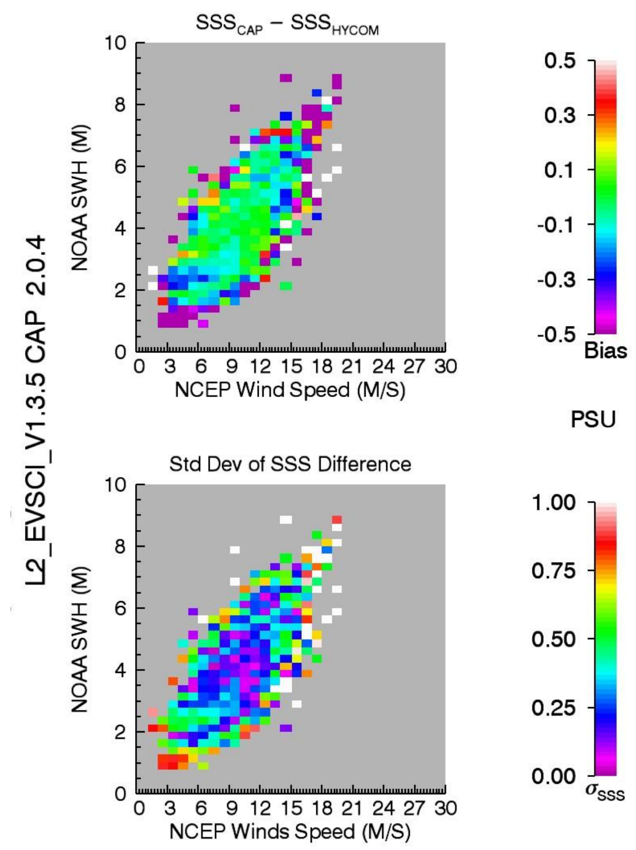
# CAP with SWH correction has smaller bias and standard deviation than the Hybrid Algorithm used for v1.3.5

V1.3.5 Difference with HYCOM
8/25/11-9/22/11

V1.3.5 (Hybrid)



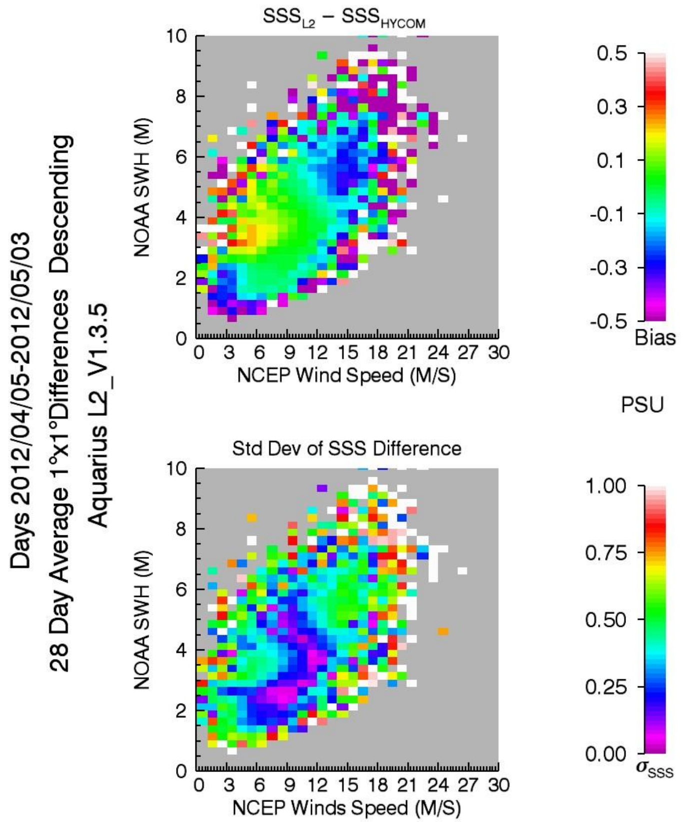

V1.3.5 CAP Wave Correction



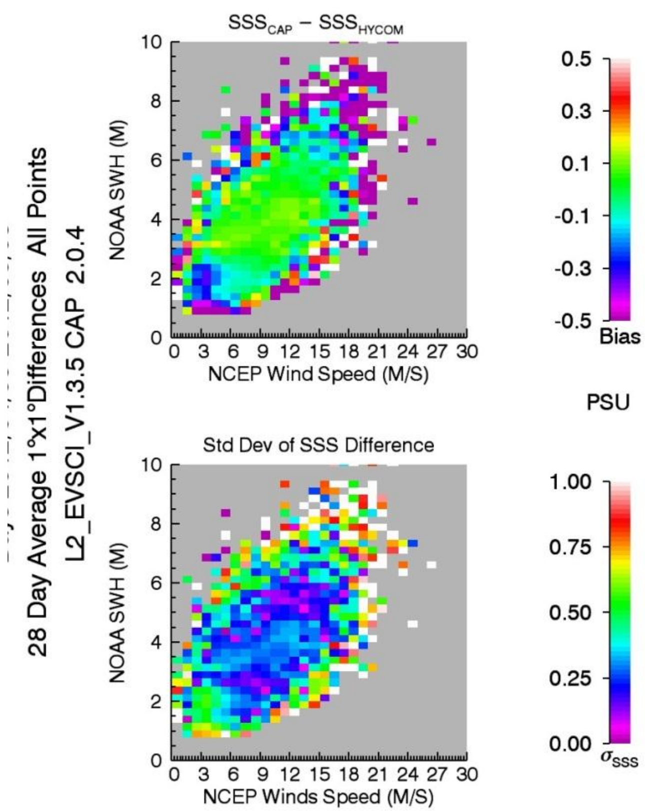
# CAP with SWH correction has smaller bias and standard deviation than the Hybrid Algorithm

V1.3.5 Difference with HYCOM
4/5/12-5/3/12

V1.3.5 (Hybrid)



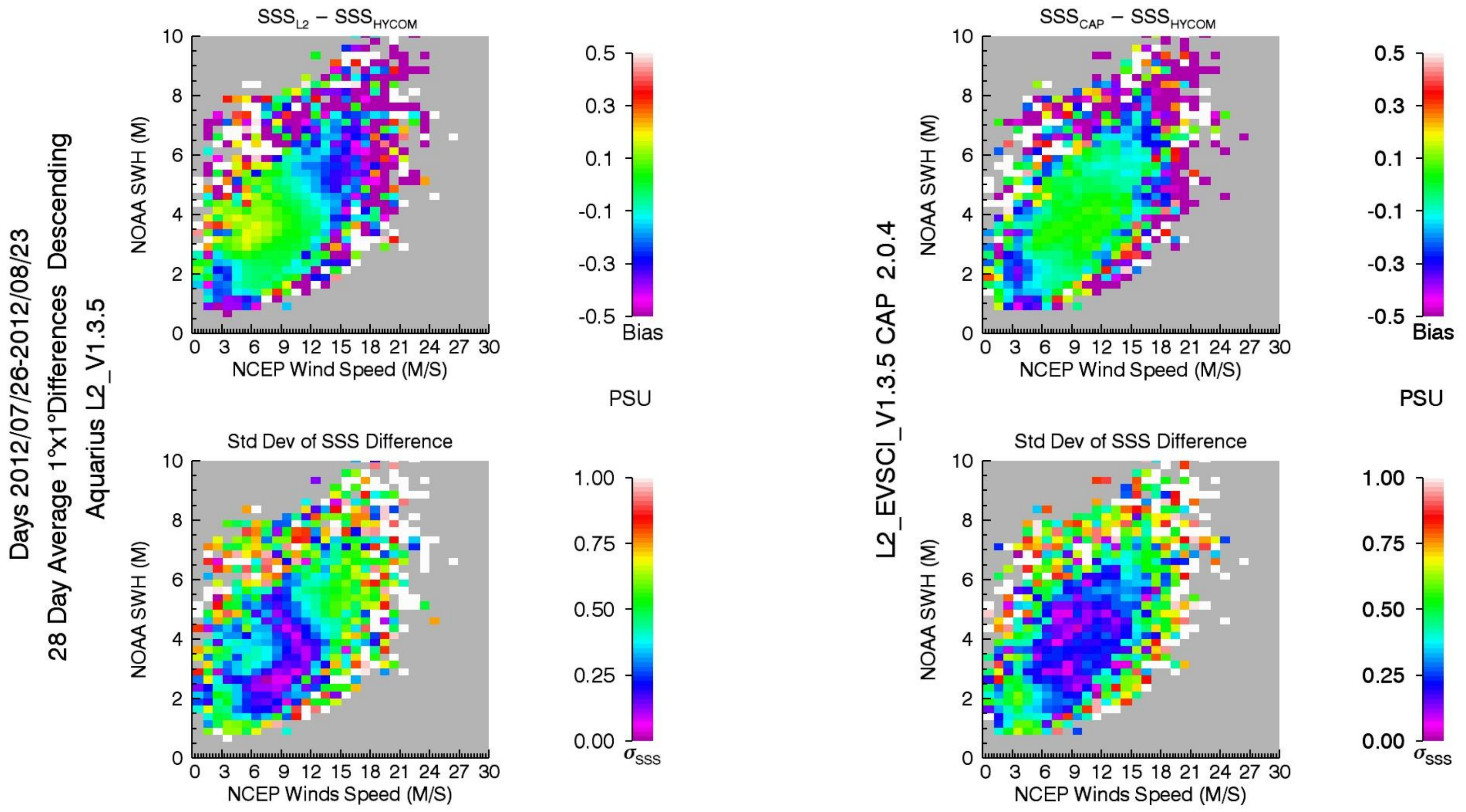

V1.3.5 CAP Wave Correction



# CAP with SWH correction has smaller bias and standard deviation than the Hybrid Algorithm

V1.3.5 Difference with HYCOM
7/26/12-8/23/12

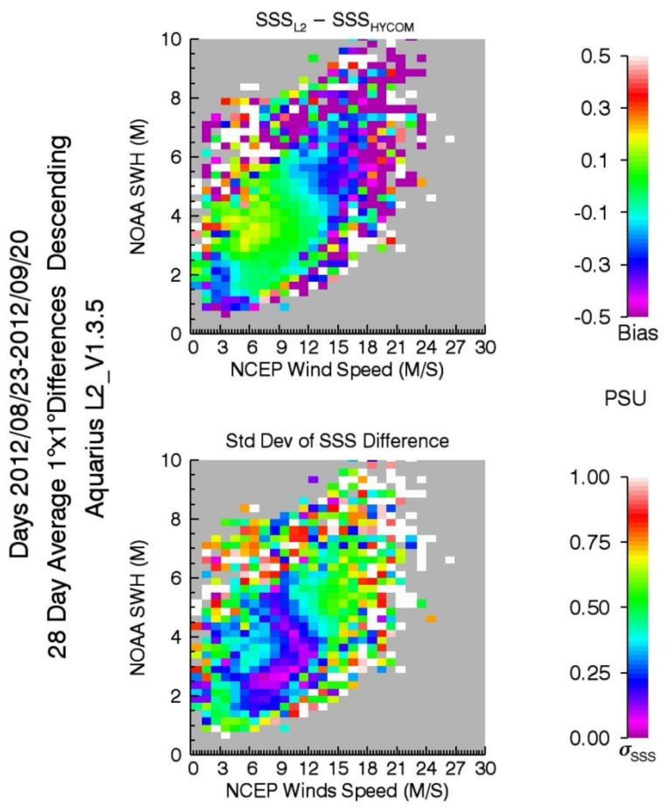
V1.3.5 (Hybrid) | V1.3.5 CAP Wave Correction



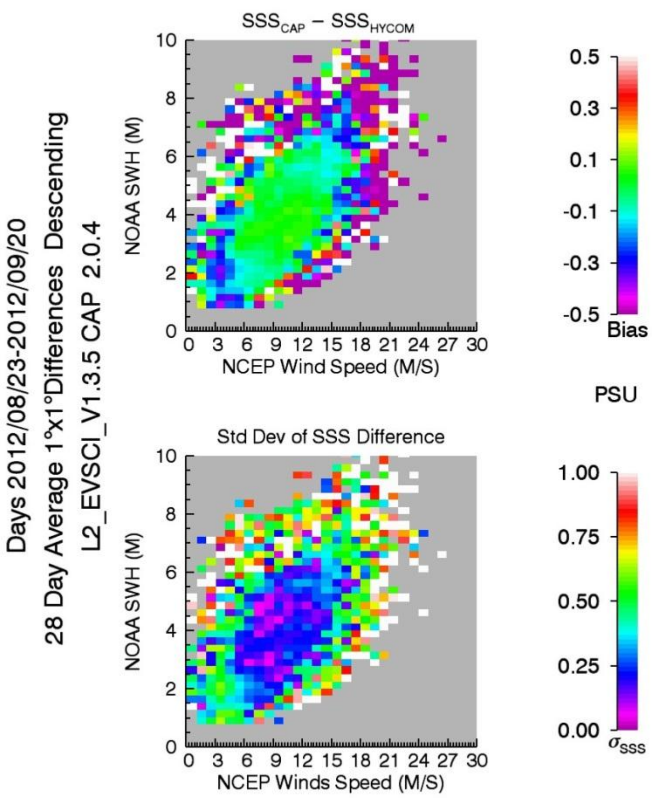
# CAP with SWH correction has smaller bias and standard deviation than the Hybrid Algorithm

V1.3.5 Difference with HYCOM
8/23/12-9/20/12

V1.3.5 (Hybrid)




V1.3.5 CAP Wave Correction



# Error Assessment of 28-day Average for v1.3.5cap

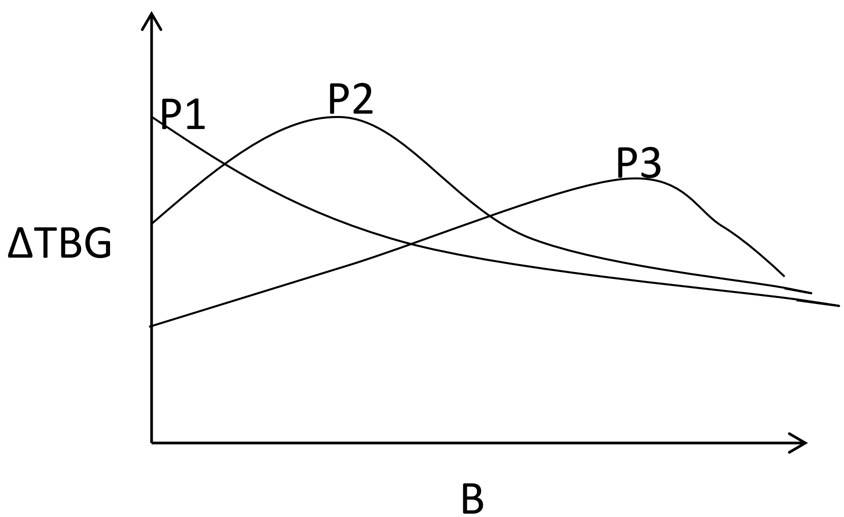
- Monthly average errors have reduced to about 0.36 psu for >5 deg C and < 15 m/s

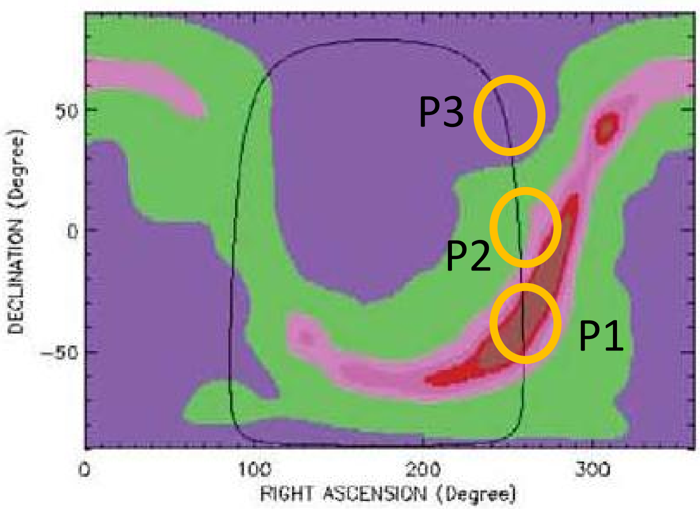
| Year | Period | All | All | >5 deg C and < 15 m/s | >5 deg C and < 15 m/s |
|---|---|---|---|---|---|
| | | No Wave Correction | After Wave Correction | No Wave Correction | After wave Correction |
| **2011** | 237-264 | 0.43 | 0.42 | 0.39 | 0.37 |
| | 265-292 | 0.46 | 0.43 | 0.43 | 0.40 |
| | 293-320 | 0.43 | 0.42 | 0.40 | 0.39 |
| | 321-348 | 0.43 | 0.41 | 0.38 | 0.37 |
| **2011/2012** | 349-011 | 0.41 | 0.40 | 0.35 | 0.34 |
| **2012** | 012-039 | 0.37 | 0.37 | 0.34 | 0.33 |
| | 040-067 | 0.37 | 0.38 | 0.36 | 0.35 |
| | 068-095 | 0.41 | 0.40 | 0.34 | 0.33 |
| | 096-123 | 0.43 | 0.44 | 0.35 | 0.35 |
| | 124-151 | 0.46 | 0.47 | 0.37 | 0.35 |
| | 152-179 | 0.47 | 0.49 | 0.36 | 0.36 |
| | 180-207 | 0.43 | 0.43 | 0.36 | 0.34 |
| | 208-235 | 0.45 | 0.46 | 0.37 | 0.41 |
| | 236-263 | 0.47 | 0.42 | 0.43 | 0.39 |

# Principle for Effective Ocean Wave Slope Estimate

$$\Delta T_{Bg} = R \int GP(\theta_x, \theta_y) T_{sky} d\theta_x d\theta_y$$

- ΔTBG varies with angular spread (or wave slope or wind speed) and position of beam in the galaxy
- For each Aquarius footprint, ΔTBG is evaluated for Gaussian beam width (B) of 5, 10, 15, 20, 25 and 30 degrees
- Use 3 months of Aquarius Beam 1 data for each wind speed range to find B(w) that minimizes the mean square difference.

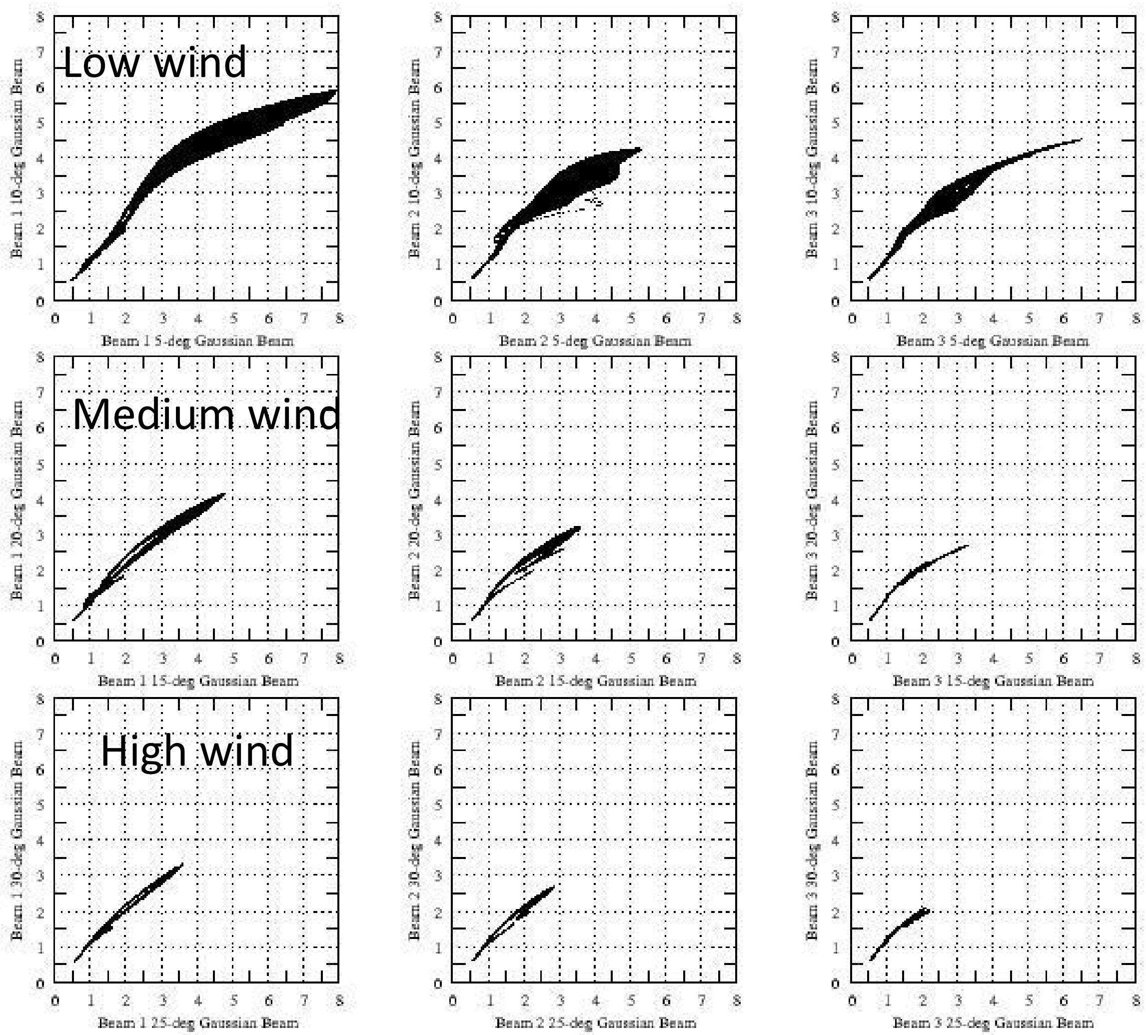



Background figure from LeVine and Abraham, 2004

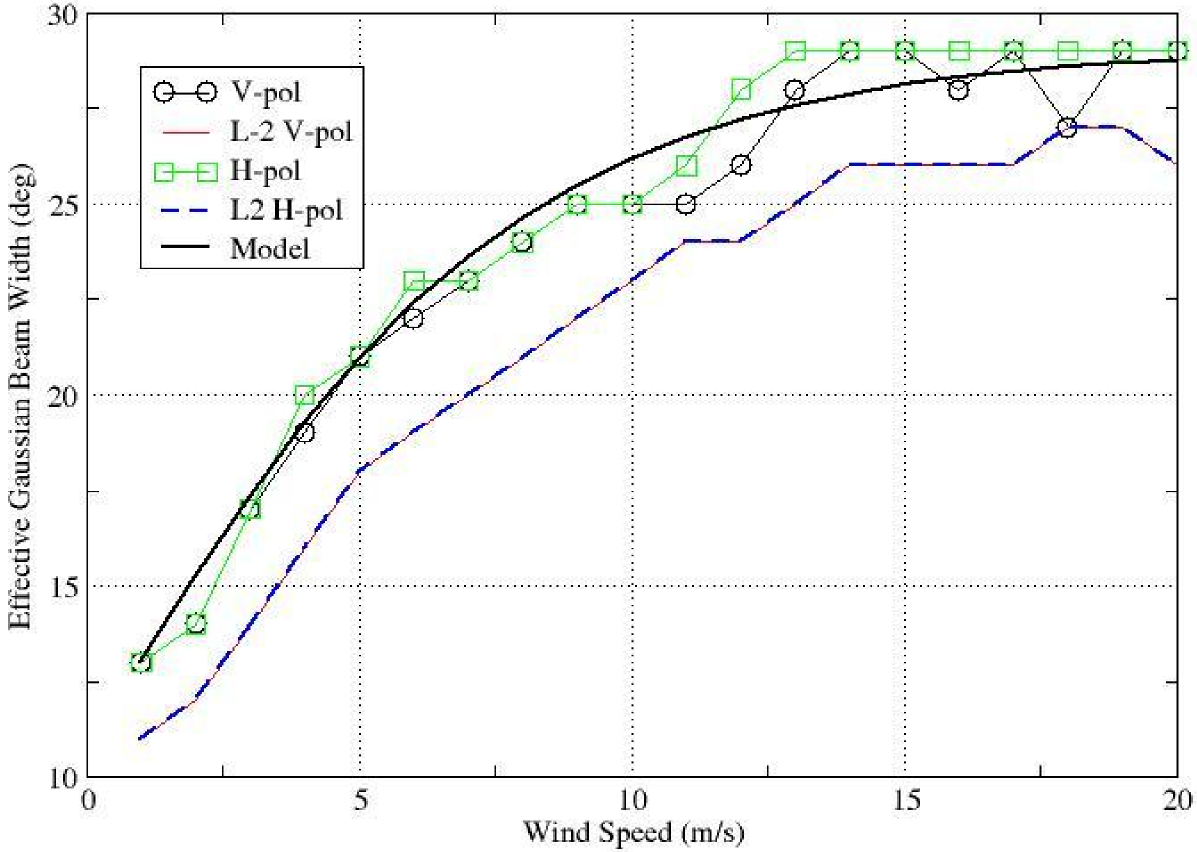
# Sensitivity of TBG to B

- ΔTBG has more variations for low B (low wind speed) near galactic plane



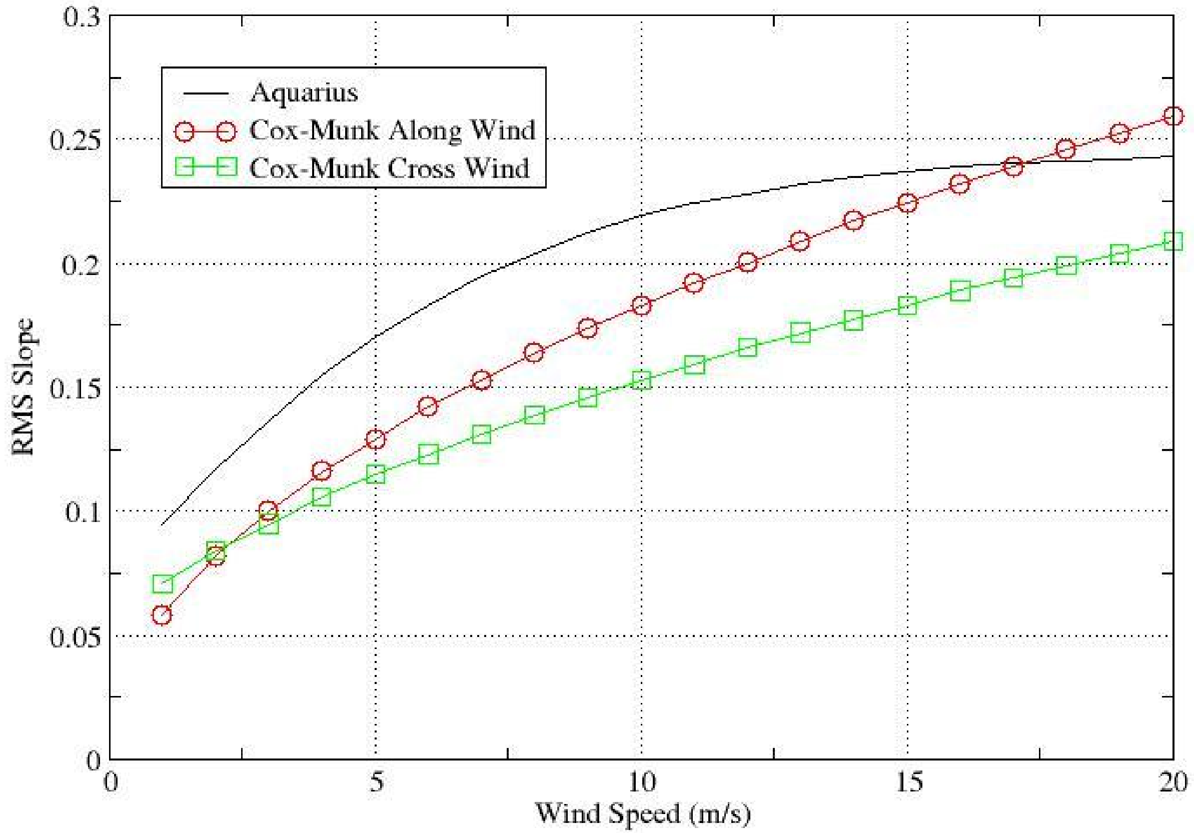
# Aquarius B vs. Wind Speed

- B(w) estimated from v-pol and H-pol agree with each other



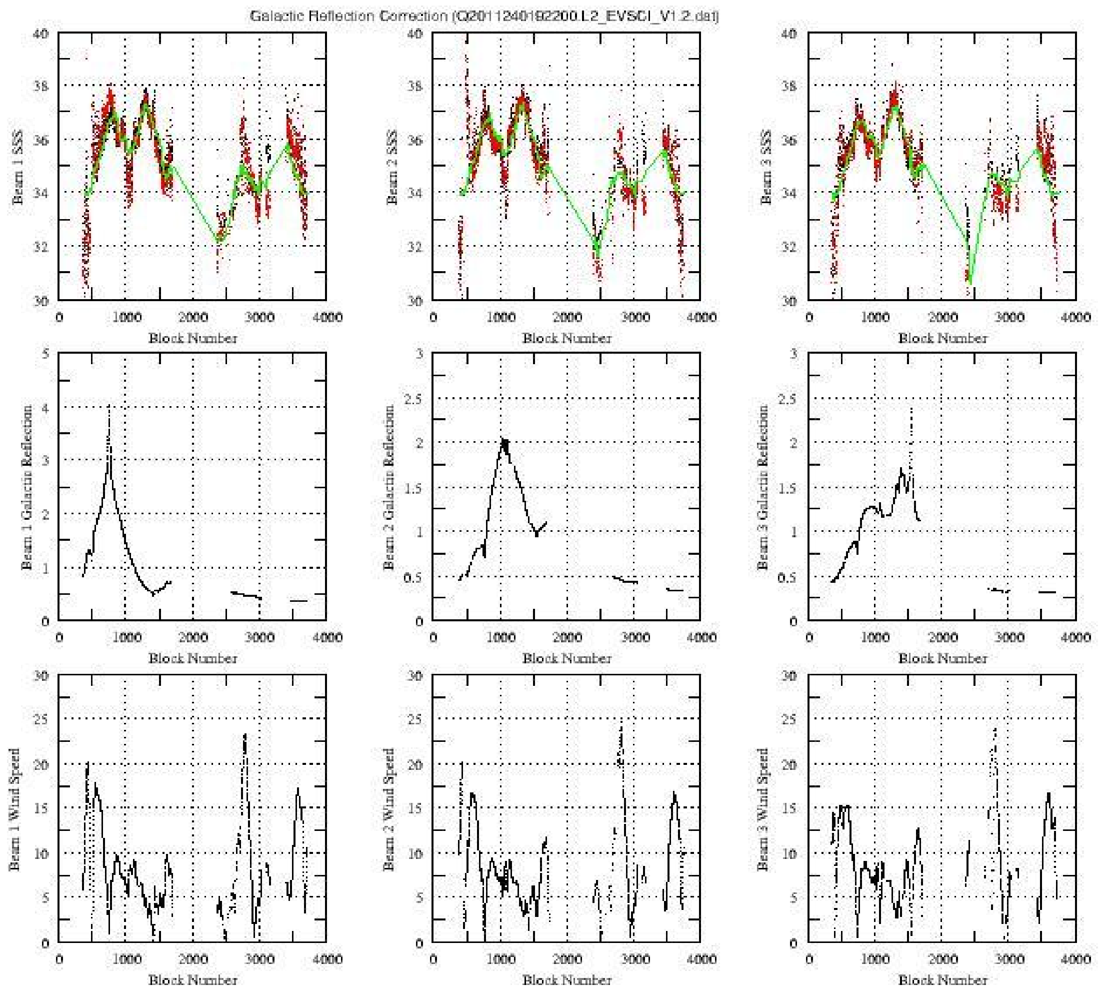
# Slope Model Comparison

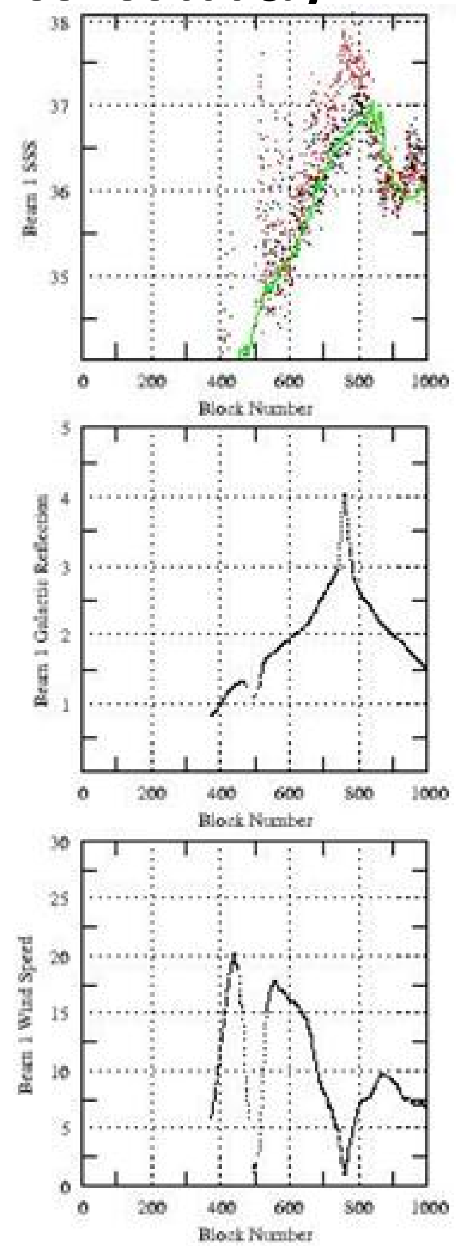
- Larger than Cox-Munk – could this be caused by swell or long wave?



# Improvement on Salinity Retrieval Case Study 1 (High TBG and low wind)

- Use CAP algorithm to retrieve SSS using existing (red) and modified (black) TBG corrections
- Hycom SSS in green

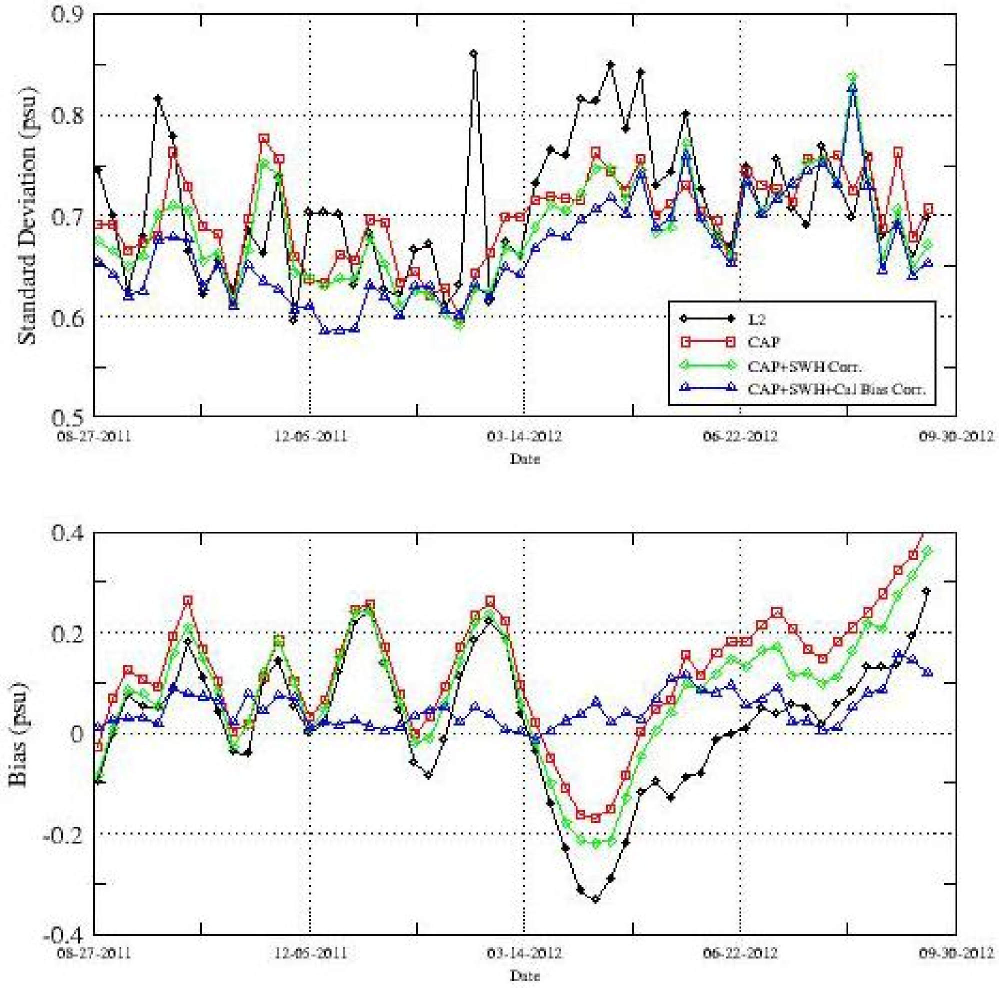


# Effects of Galactic Reflection Correction:

Aquarius SSS Comparison with Hycom for Each Satellite Pass

- Modified galactic reflection correction slightly improves the s.d. accuracy
- Galactic reflection has not been fully corrected.



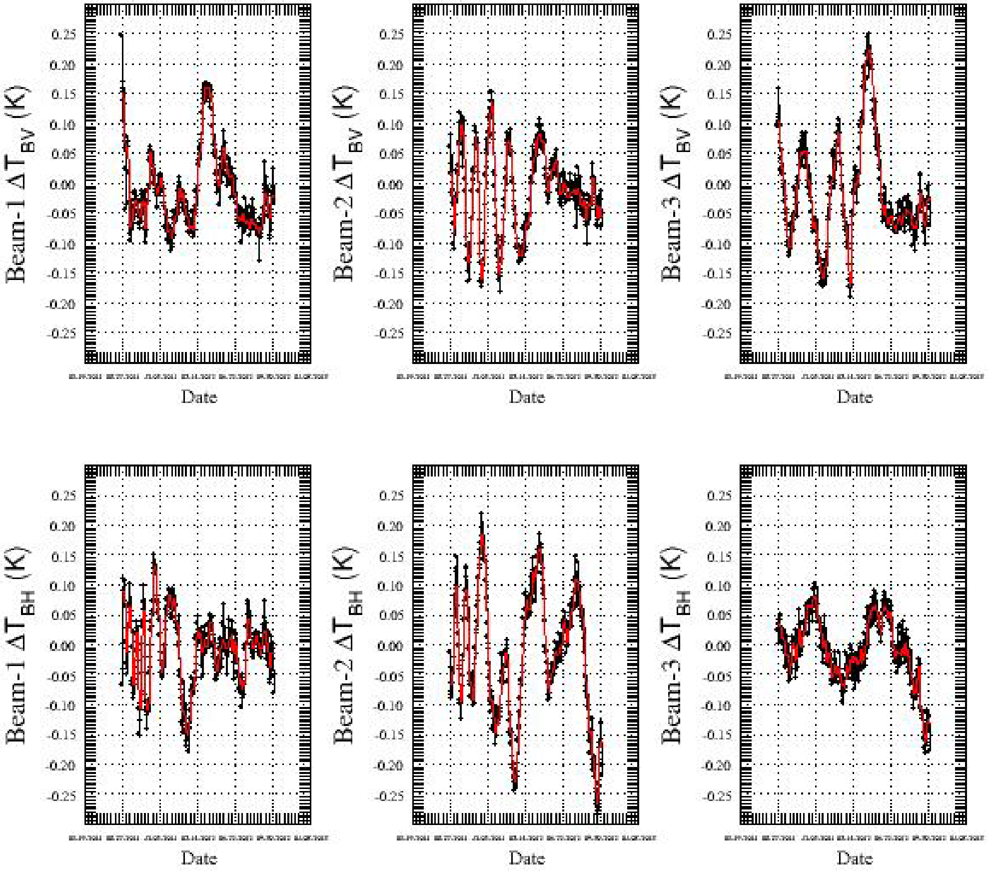

- Land and ice fractions < 0.0005
- All wind speed and SST

# Summary

- Aquarius radar sigma0 is much more effective than NCEP wind speed for roughness correction – about 30 percent better
- Wave correction using NOAA WW3 SWH allows the removal of systematic bias dependent on wind speed and SWH. Wave correction also improves the accuracy over a broader range of wind speed and SWH.
- The effective wave slope derived from the Aquarius data improves SSS retrieval.
  - The improvement did not provide much reduction for global averaged SSS error.
- Current monthly averaged accuracy is
  - About 0.36 psu for > 5 deg C and < 15 m/s
  - About 0.4 psu for all conditions.
- Ascending/descending bias not yet removed.

# Delta TB estimate

- Compute the difference between model and observed TBs.
  - An exponential drift of the noise diode TB has been removed from v1.3.5
- Perform daily average of the differences for each channel
- V-pol channels appear quite stable lately, but H-pol channels are going through some steep drop.

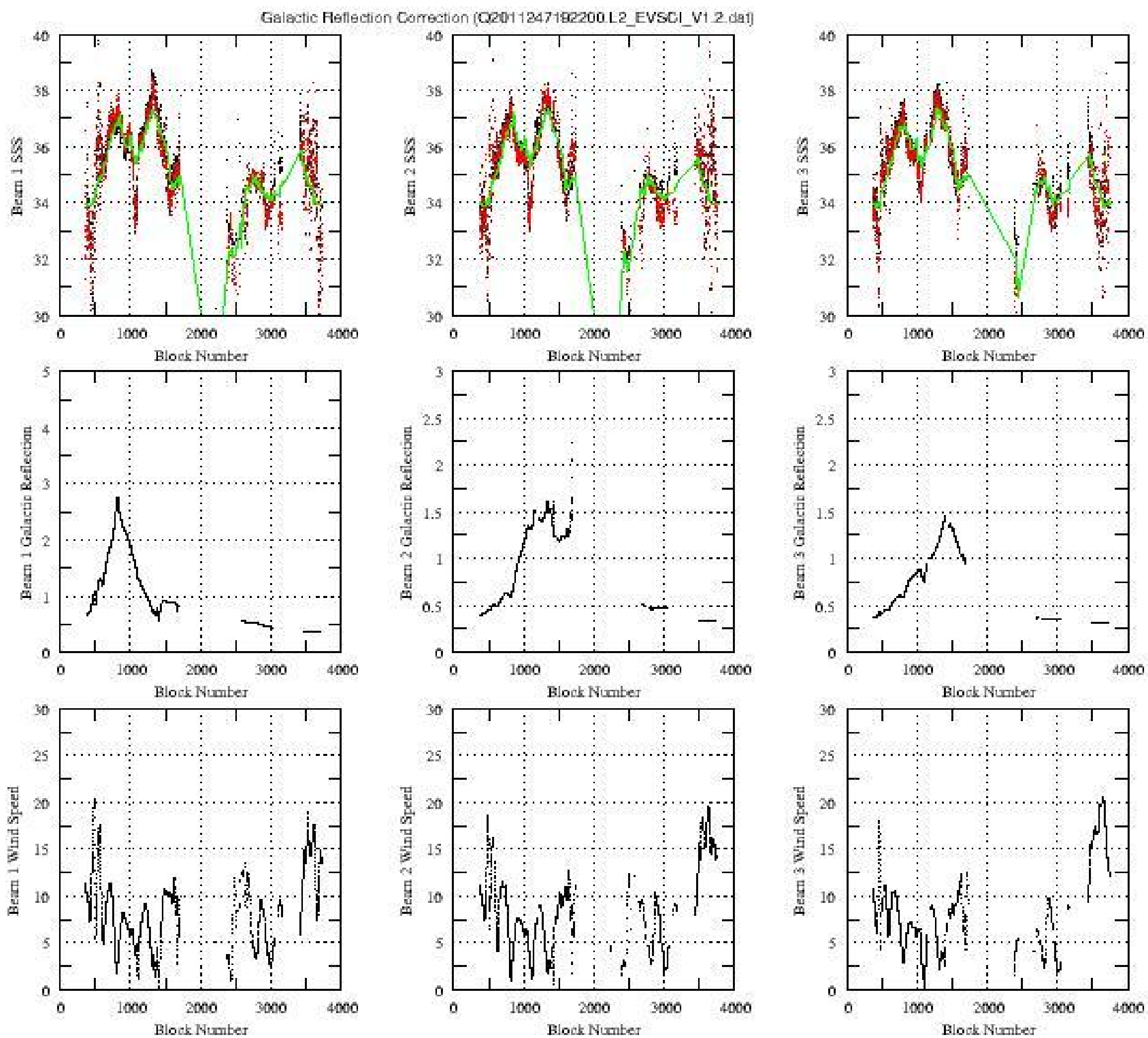


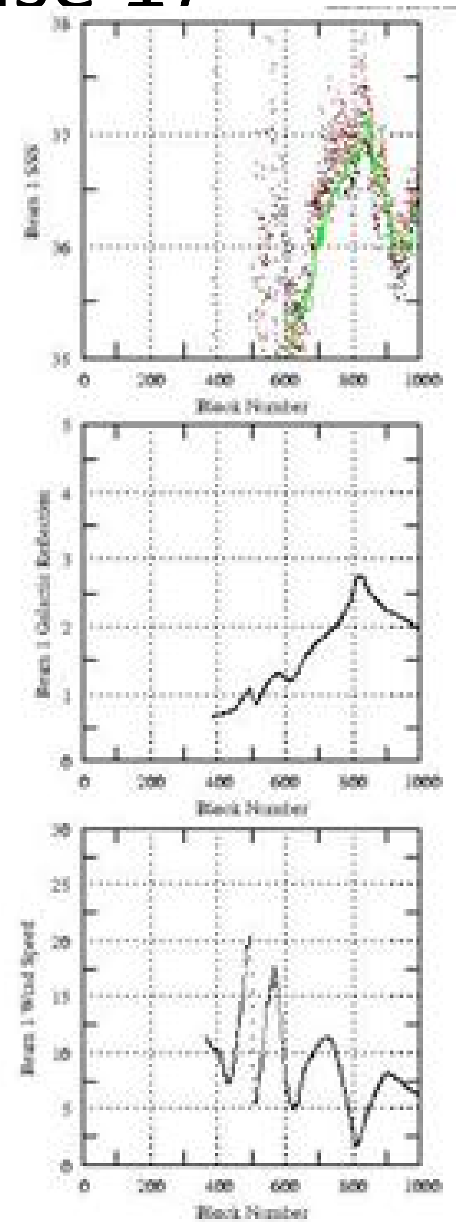
# Error Analysis - Triple Collocation Method

- 3 wind speed datasets: SSMI, NCEP, Aquarius retrieval.
  - $w_{ssmi} = w + r_{ssmi}$
  - $w_{ncep} = a_{ncep} + b_{ncep}w + r_{ncep}$
  - $w_{scat} = a_{scat} + b_{scat}w + r_{scat}$
- a, b are bias and scale factors, r is random error, w is true wind speed.
- Apply triple collocation method (Stoffelen, 1998) to determine a, b, and r for each.
- Assumptions:
  - $\langle r_{ssmi} r_{ncep} \rangle = \langle r_{ssmi} r_{scat} \rangle = \langle r_{ncep} r_{scat} \rangle = 0$ (all errors uncorrelated)
  - SSMI has no bias and no scale offset from true winds.
  - $\langle r_{ssmi} w \rangle = \langle r_{ncep} w \rangle = \langle r_{scat} w \rangle = 0$ (errors not correlated with true winds).

# Improvement on Salinity Retrieval
# Case Study 2 (Repeat case 1)

- Use CAP algorithm to retrieve SSS using existing (red) and modified (black) TBG corrections



# Improvement on Salinity Retrieval Case Study 3

- Use CAP algorithm to retrieve SSS using existing (red) and modified (black) TBG corrections