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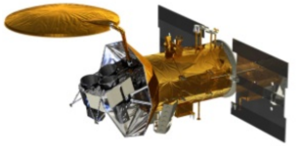

The effect of rain-induced stratification and surface roughness on Aquarius SSS retrieval

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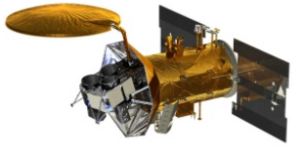
Outline



- **Objective:** To develop a rain roughness correction to reduce the uncertainty of Aquarius SSS retrieved under rainy conditions
- **Introduction:** Rain signature observed in L-band measurements and why rain roughness correction is difficult but needed
- **New approach:** Built upon recent progresses in understanding near surface salinity stratification under the influence of rain
- **Results**
  - **Rain free GMF and roughness correction**
  - **SSS retrieved under rainy conditions**
  - **Comparison with drifters and moorings**

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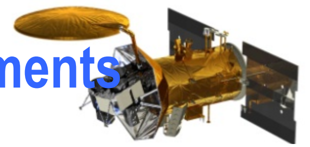
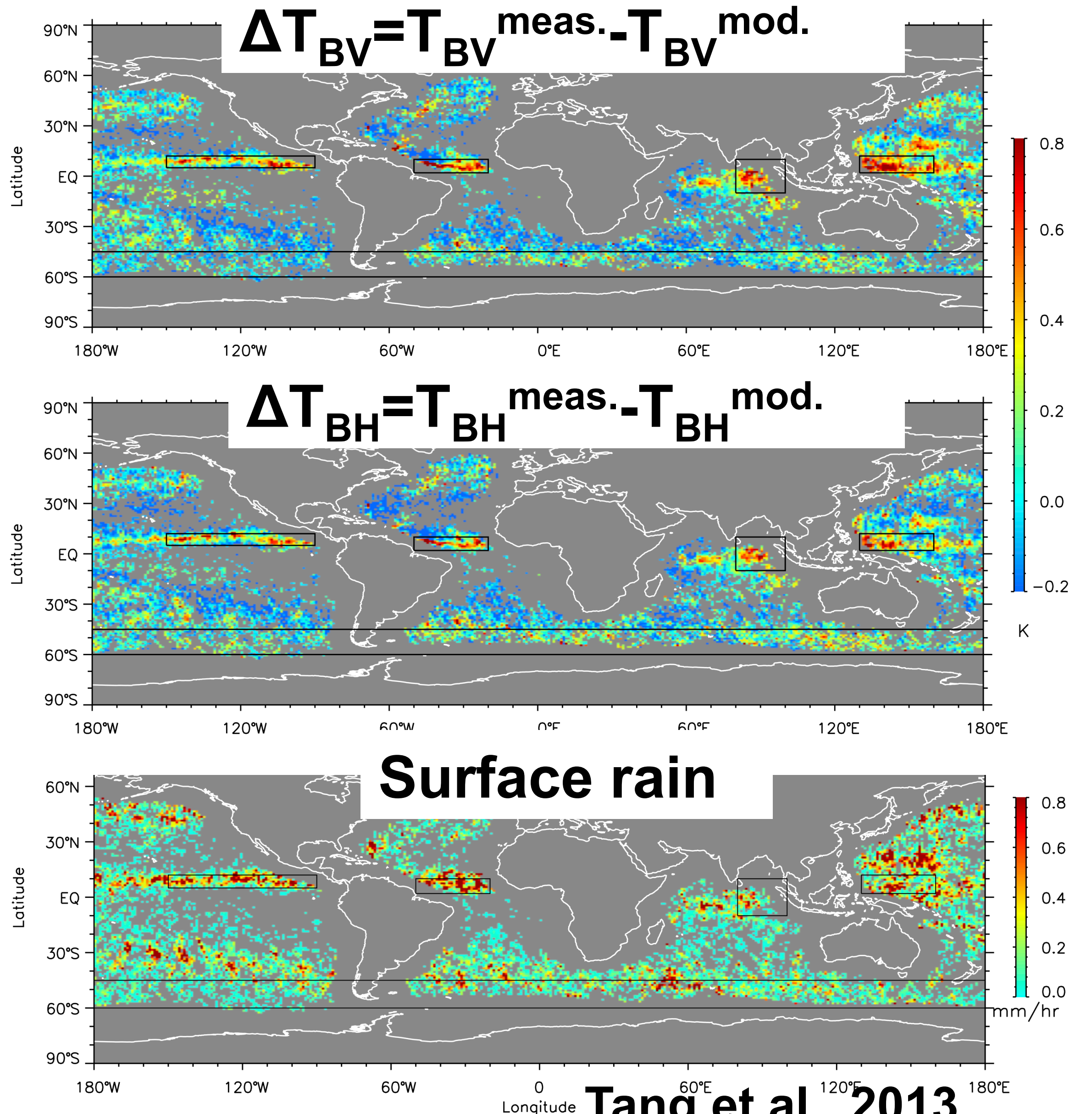
Rain signature observed in L-band measurements

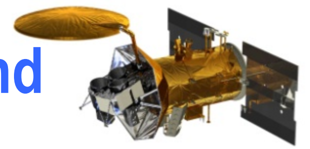


- **Aquarius measured T_B is higher than forward model prediction under rainy conditions**
- **Surface freshening associated with rain cause salinity decrease which corresponds to higher T_B for given SST**
- **Raindrops splashing on surface also increase surface roughness which, if not accurately accounted for, will result false low SSS in satellite retrieval**



Tang et al., 2013

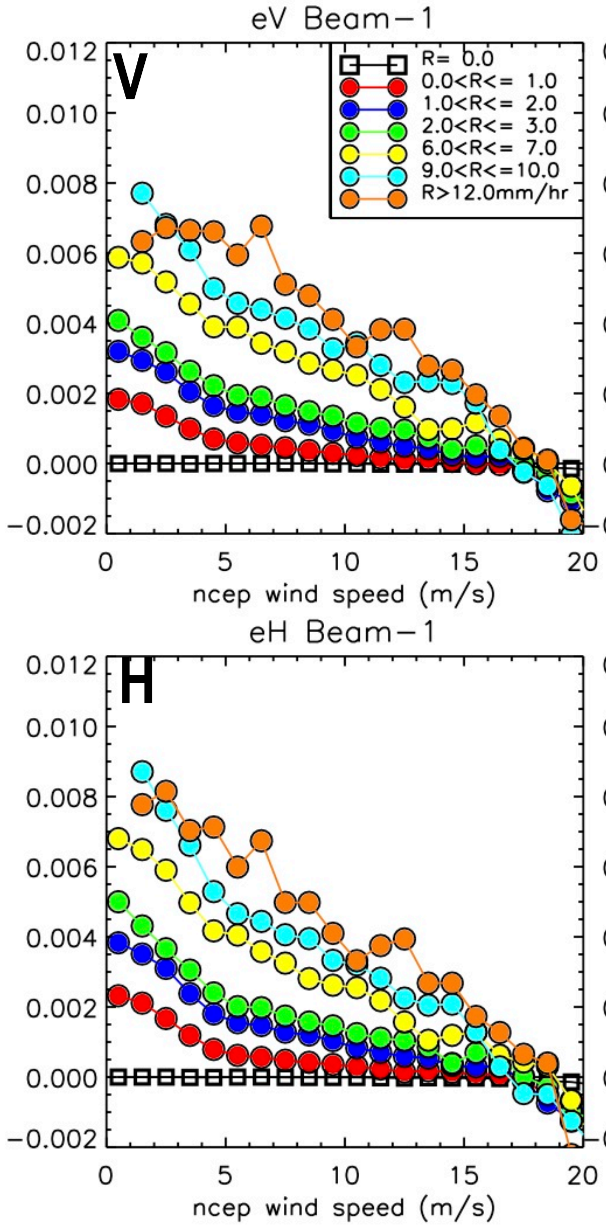
Residual analysis: ΔT_B vs. rain and wind



- **ΔT_B (R,W) using SSS_{HYCOM} as model input,**

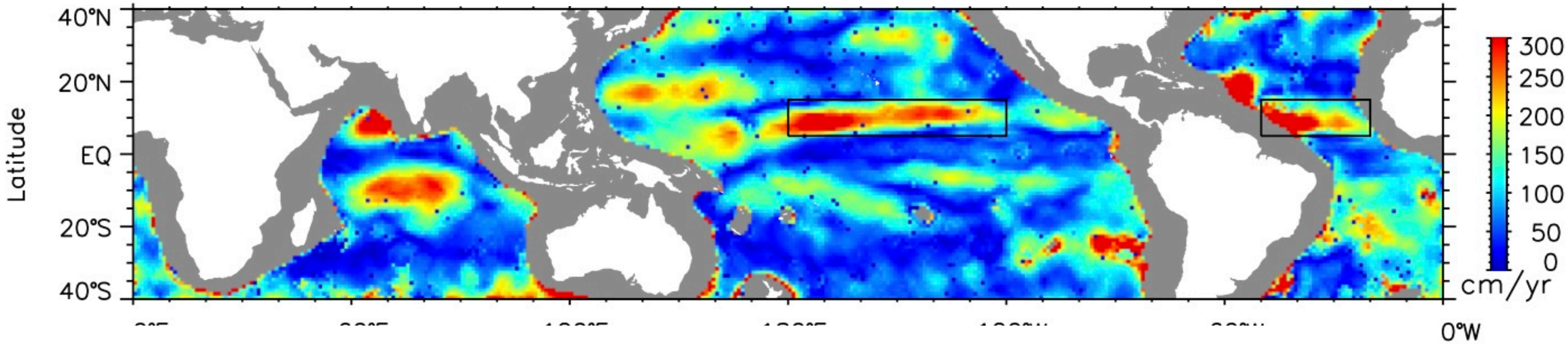
$$\Delta T_B = T_B^{meas.} - T_B^{flat}(SSS,SST) - SST*\Delta e^{\mathrm{mod}}(W,\phi,SWH)$$

- **If the calibration reference correctly represents the salinity at L-band measuring depth (1-2 cm) under rain, ΔT_B obtained by this empirical residual analysis could be a good approximation of rain-induced surface roughness.**
- **However, when rain presents persistently, one expects SSS_{HYCOM} biases higher compared with SSS because the rain freshening effect is much diluted in a few meters down from the surface.**
- **ΔT_B represents the combined effects of rain-induced freshening and roughening. Applying the rain-free GMF directly to SSS retrieval under rain may overestimate the freshening effect; while correct GMF with ΔT_B likely overestimate the roughness.**

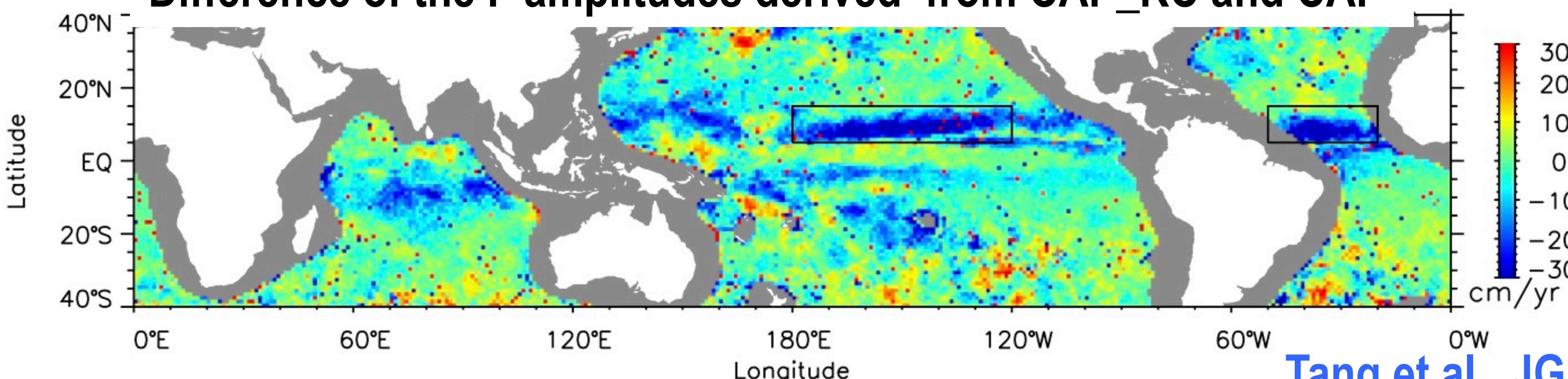


AQUARIUS/SAC-D Reduce the uncertainty of SSS under rain?

Amplitude of the mixed-layer salt storage tendency (F) $F = h(\partial S / \partial t) / S$



Difference of the F amplitudes derived from CAP_RC and CAP



Tang et al., JGR, 2014

- **The uncertainty of SSS retrieved under rainy conditions causes about 10% difference in the amplitude of mixed-layer salt storage tendency (F), or 50 cm/year.**
- **The key to reduce this uncertainty is to find a way to separate rain-induced surface roughness from freshening.**

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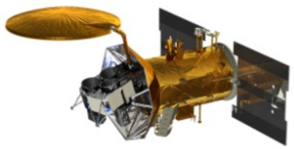
adjusting HYCOM SSS with RIM



- **Asher et al. (JGR, 2014) analyzed the salinity gradients in top ocean (0.1-2m) measured by a towed profiler. They found the relation between salinity measured at different depths and surface rain rate can fit well to a one-dimensional turbulent diffusion model,**

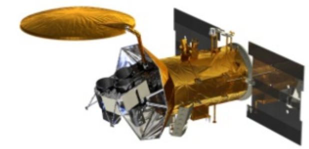
$$S(z,t) = S_0 d_0 \left(d_0 + \frac{A}{\sqrt{K_z t}} e^{-\frac{z^2}{4K_z t}}\right)^{-1}$$

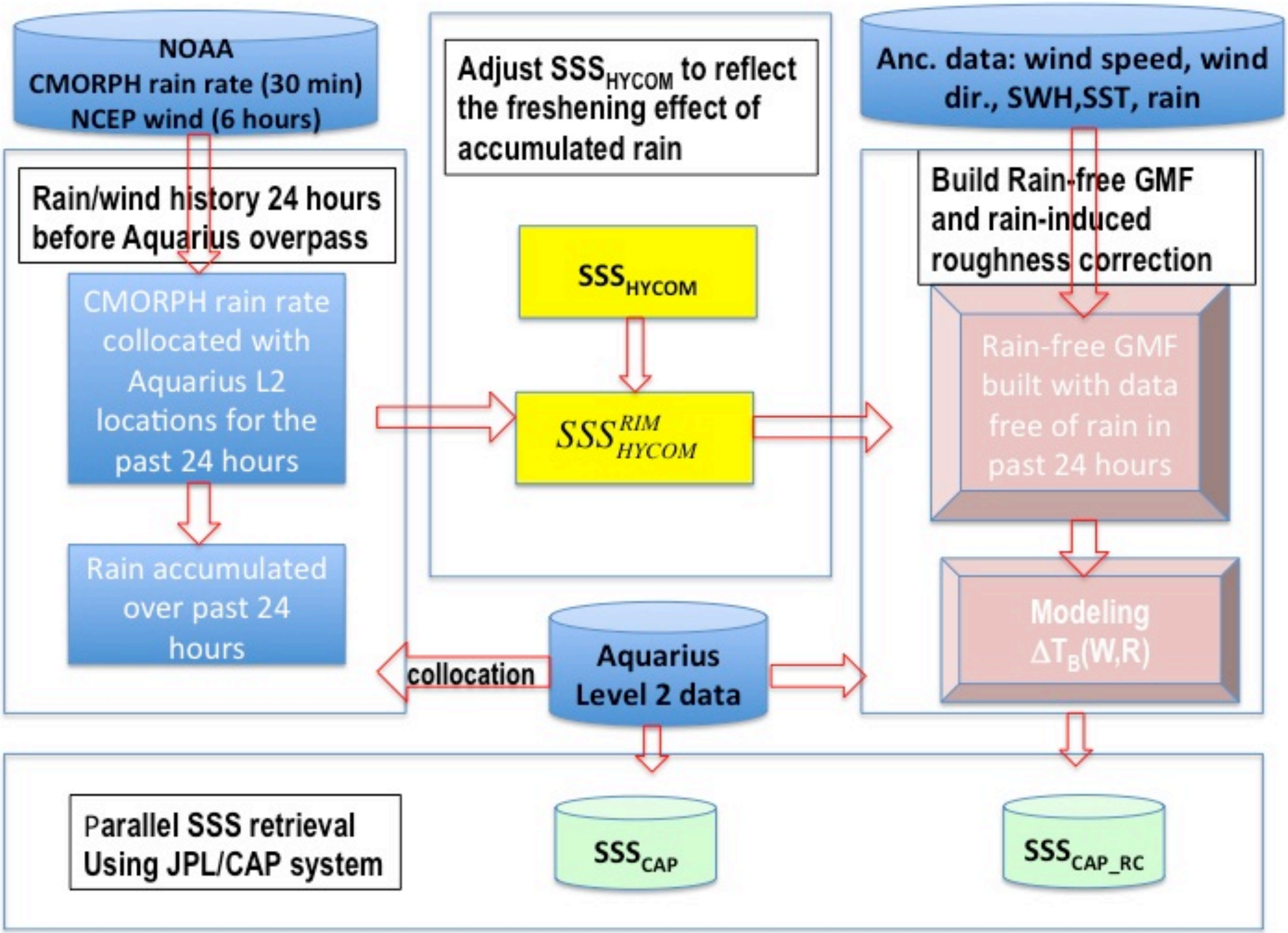
where S_0 is the bulk salinity, d_0 is a characteristic mixing depth, and K_z is the vertical eddy diffusivity.

- **Santos-Garsia et al. (JGR, 2014) applied Asher's formula on a series of rain events and developed a rain impact model (RIM) which predicts salinity at depth z in terms of rain accumulated over 24 hours before T_0, assuming initial bulk salinity $S_0=SSS_{HYCOM}$ (PSU).**

- **Assuming the rain-induced stratification can be determined by rain history prior Aquarius overpass, we propose to develop a rain roughness correction scheme for SSS retrieval by adjusting the calibration reference SSS_{HYCOM} to reflect the impact of rain.**

GMF development and data processing





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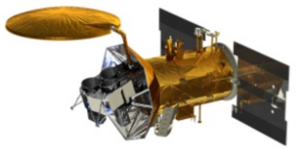
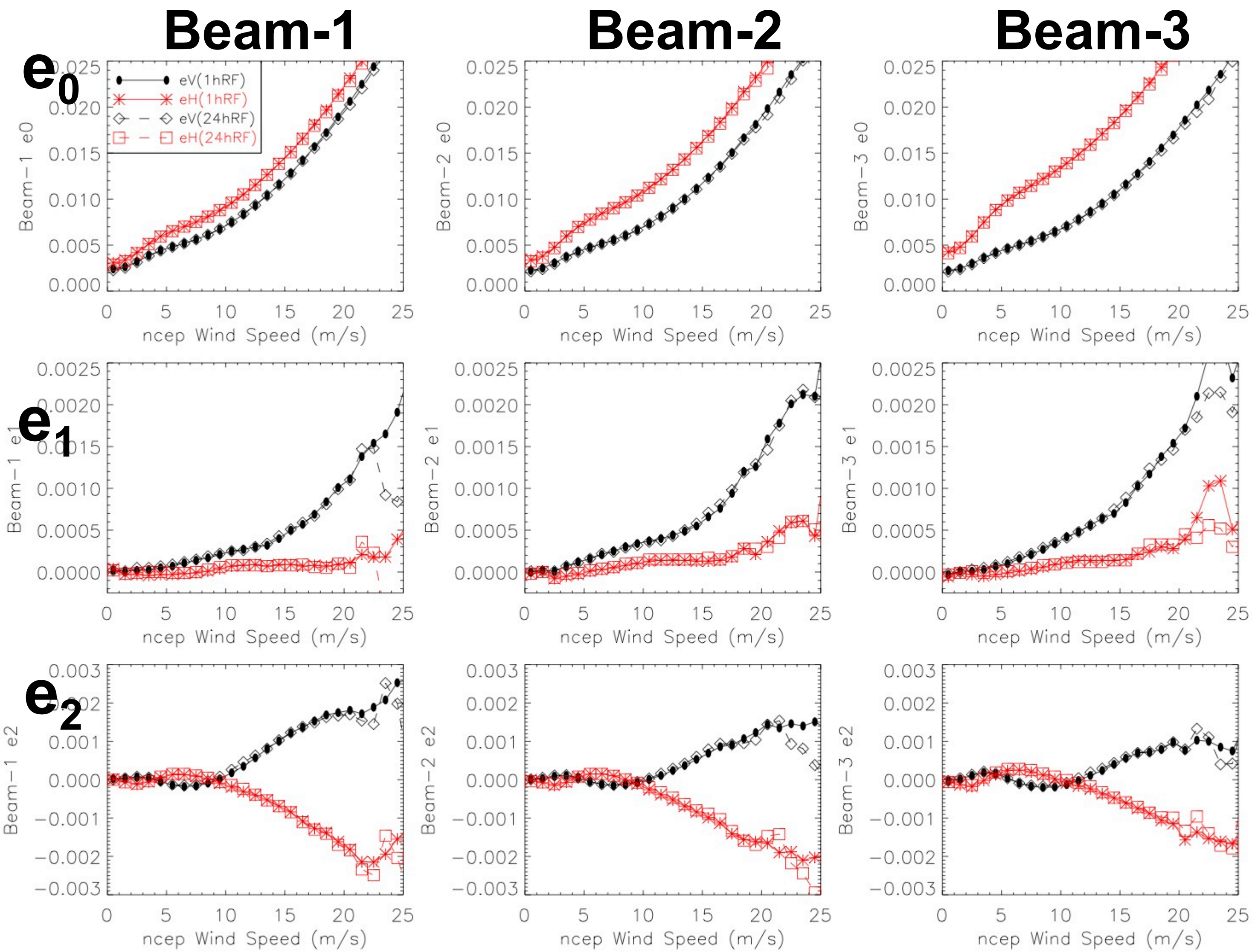
Rain free Radiometer GMF





Base rain-free GMF not sensitive to rain history; difference at high wind likely caused by different samplings.

$$\Delta e_p(w,\emptyset,\mathrm{SWH},\mathrm{R}) = e_{0,p}(w,SWH)+\delta e_{0,p}(w,R) + e_{1,p}(w)cos\phi + e_{2,p}(w)cos2\phi$$

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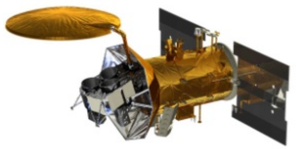
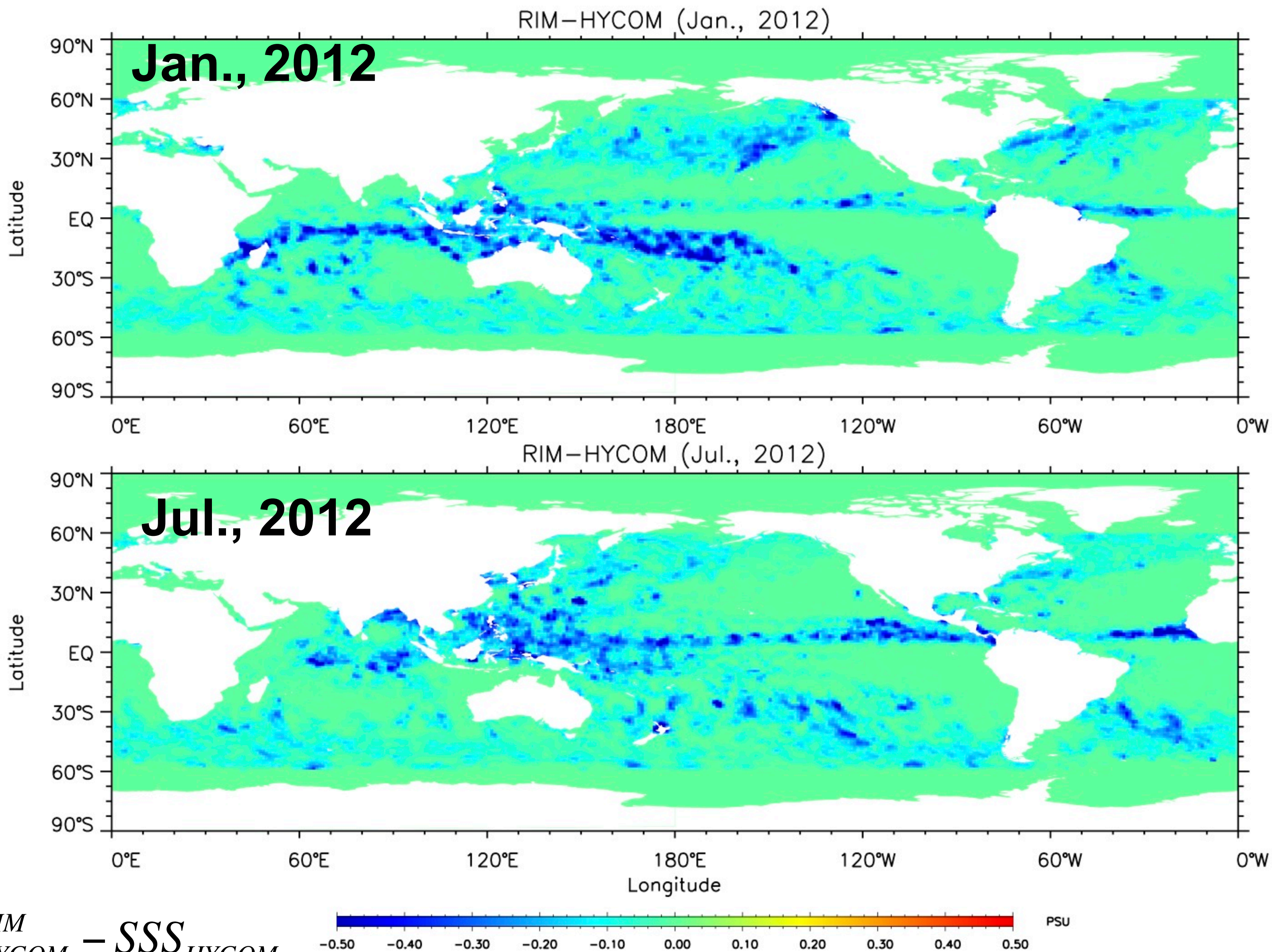
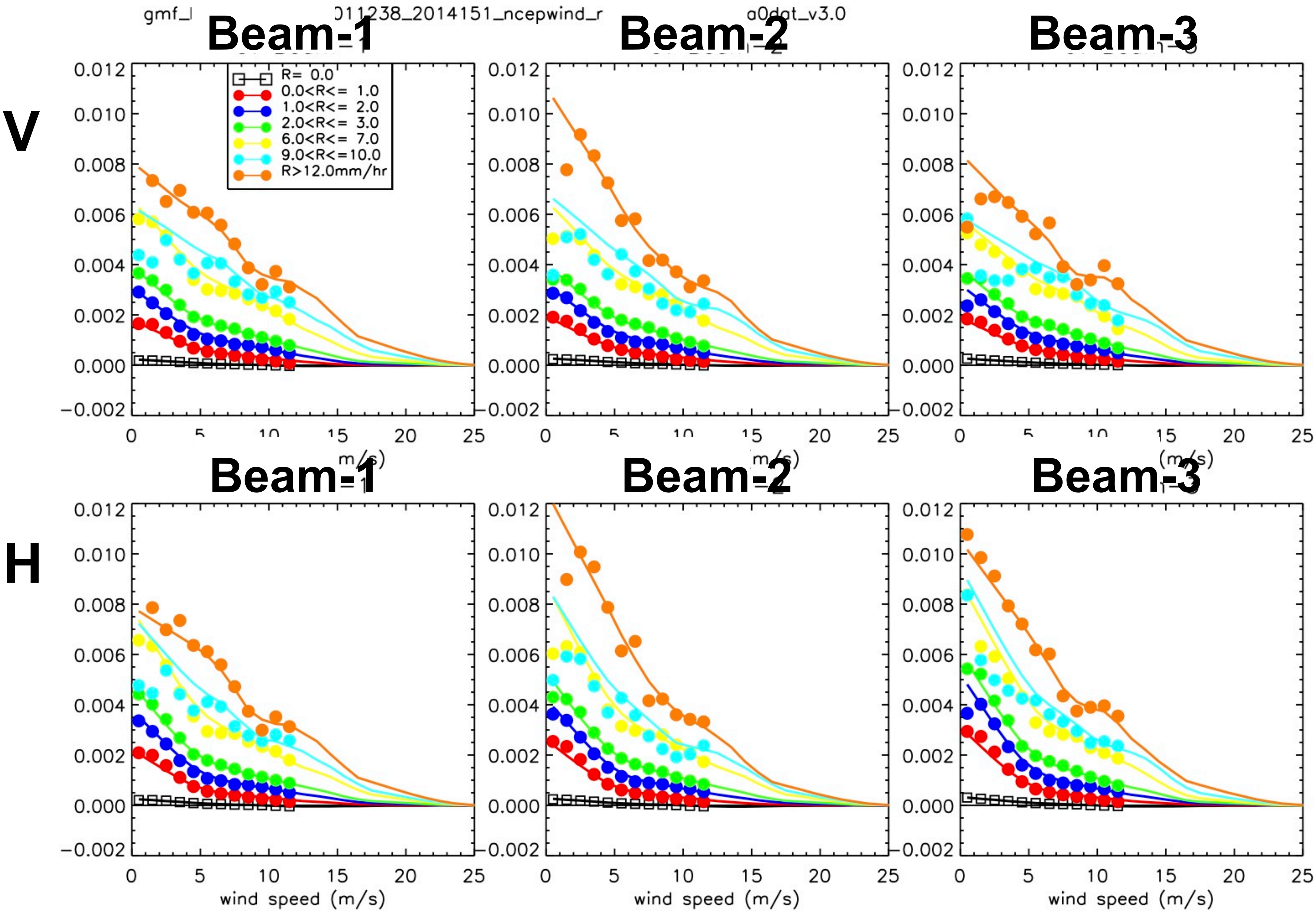
The effect of RIM adjustment





$$SSS_{HYCOM}^{RIM} - SSS_{HYCOM}$$

calibrated to SSS_{HYCOM}



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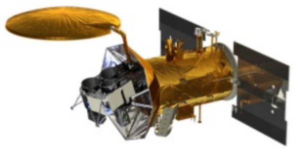
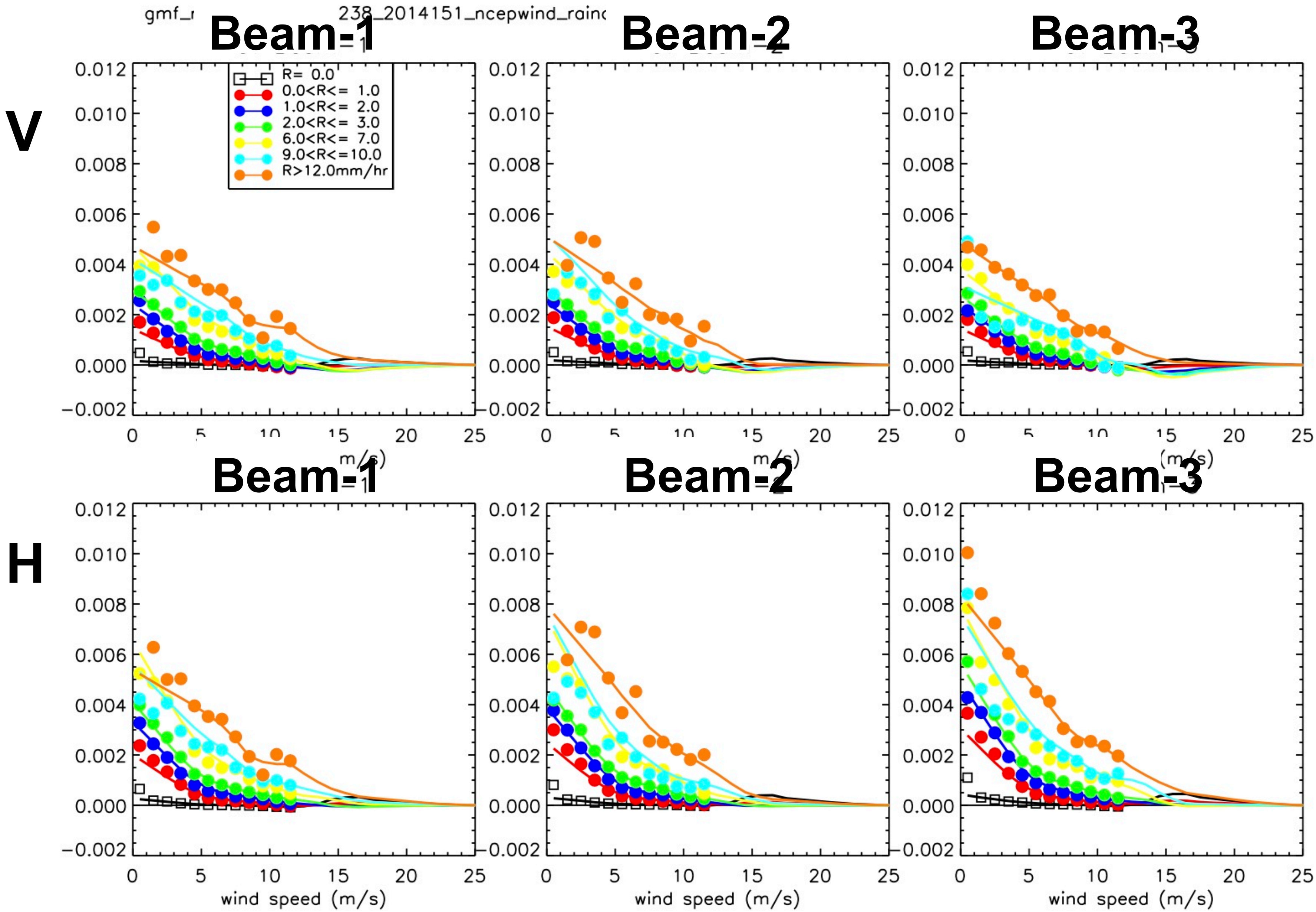
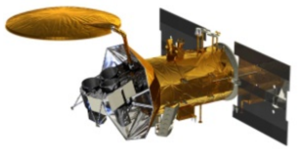
calibrated to RIM adjusted SSS_{HYCOM}





CAP retrieval



- CAP retrieves SSS and wind simultaneously by finding the best-fit solution to minimize the difference between the Aquarius data and model functions, i.e. the cost function

$$F_{ap}(SSS,w,\phi)=\frac{(T_{BV}-T_{BVm})^2}{\Delta T^2}+\frac{(T_{BH}-T_{BHm})^2}{\Delta T^2}+\frac{(\sigma_{VV}-\sigma_{VVm})^2}{{k_p}^2{\sigma_{VV}}^2}+\frac{(\sigma_{HH}-\sigma_{HHm})^2}{{k_p}^2{\sigma_{HH}}^2}+\frac{(w-w_{NCEP})^2}{\Delta w^2}+\frac{\sin^2((\phi-\phi_{NCEP})/2)}{\delta^2}$$

  Original form in Yueh and Chaubell, IEEE TGRS 2012
  Updated in Yueh et al, IEEE TGRS 2013

- CAP processing are run in parallel to assess the rain effect
  CAP: using radiometer/radar GMFs without rain correction
  CAP_RC: using radiometer/radar GMFs with rain correction

- Rain rate from SSMI/S (primary) and WindSAT (secondary) (from www.ssmi.com) are collocated with Aquarius footprints and used for rain correction. CAP and CAP_RC are identical when no rain, or no rain matchup data available

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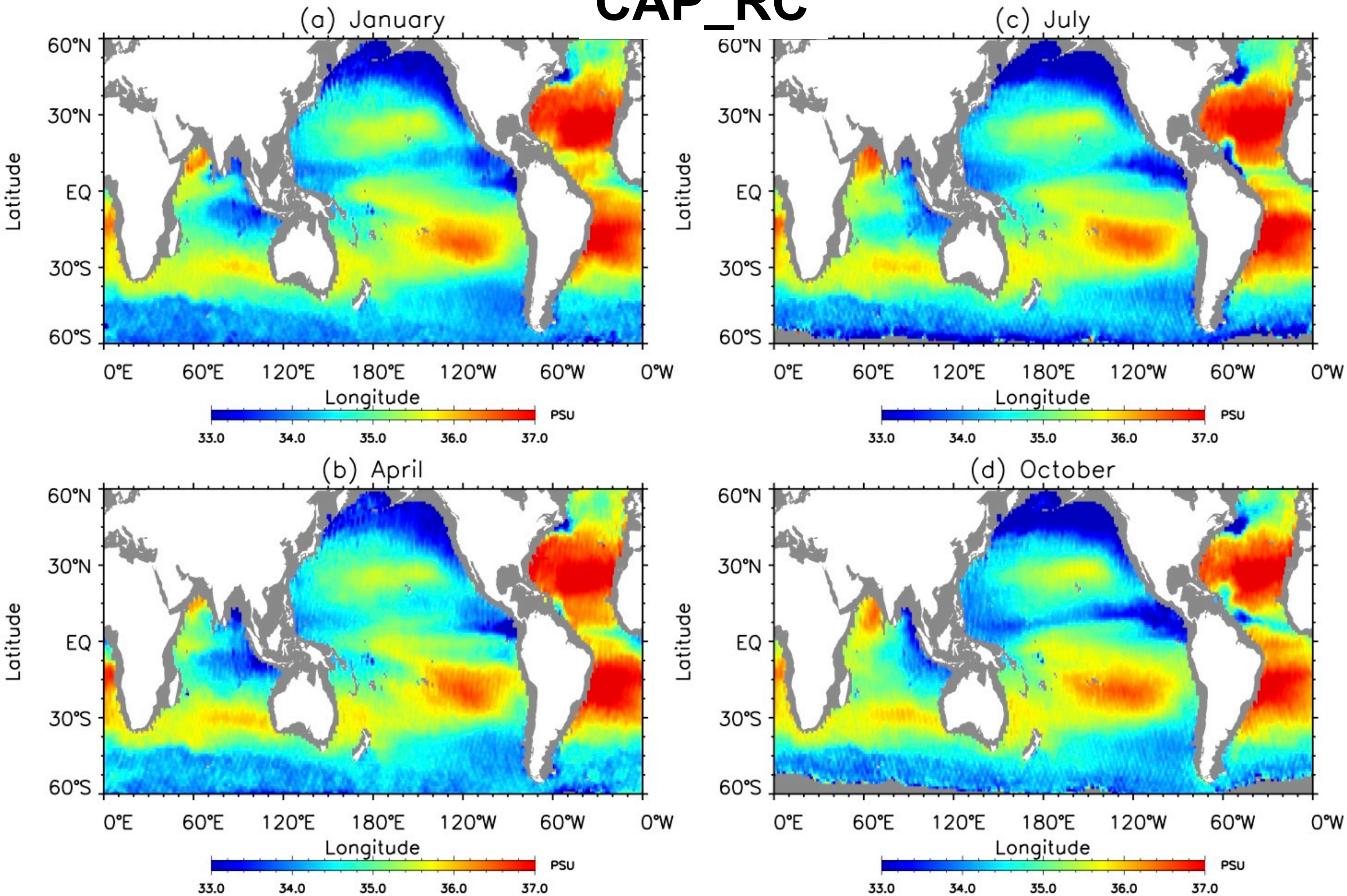
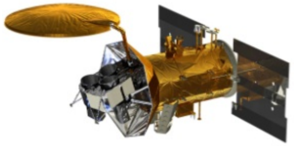
SSS retrieved with rain roughness correction

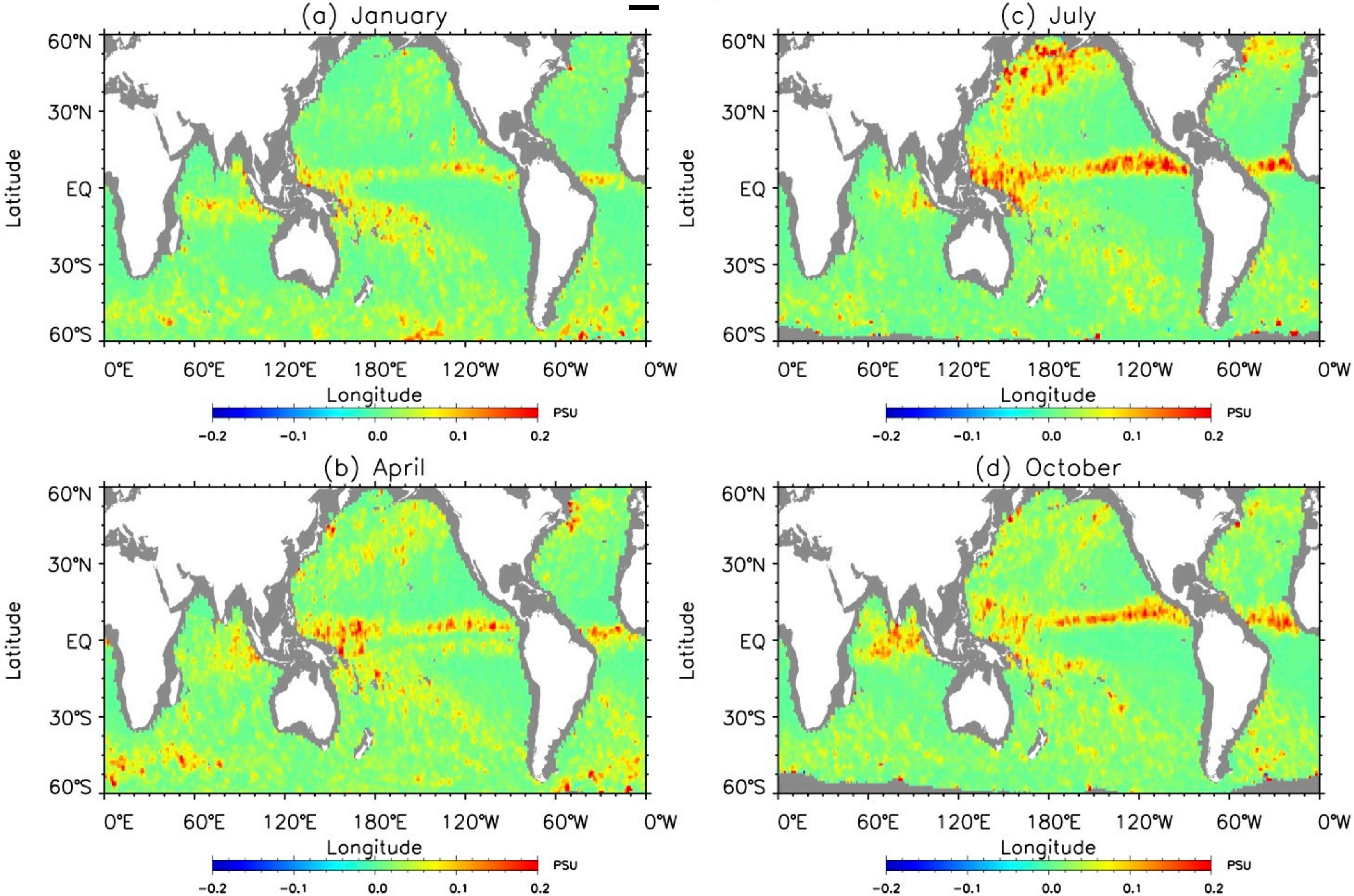
CAP_RC



Effect of rain roughness correction



CAP_RC - CAP



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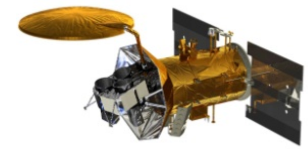
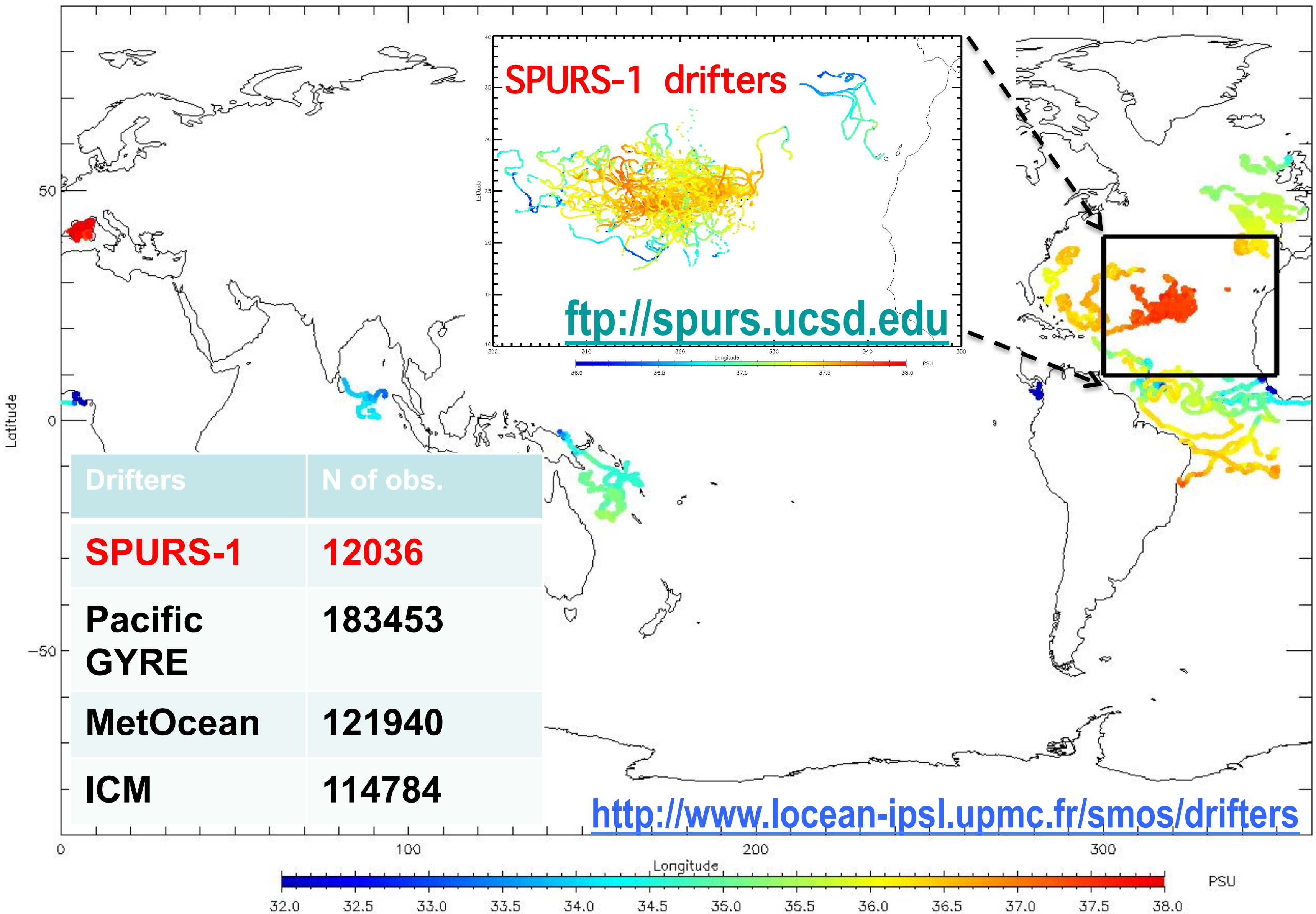
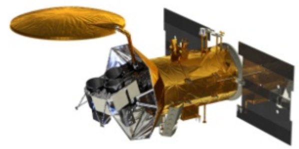
Comparison with drifters and moorings

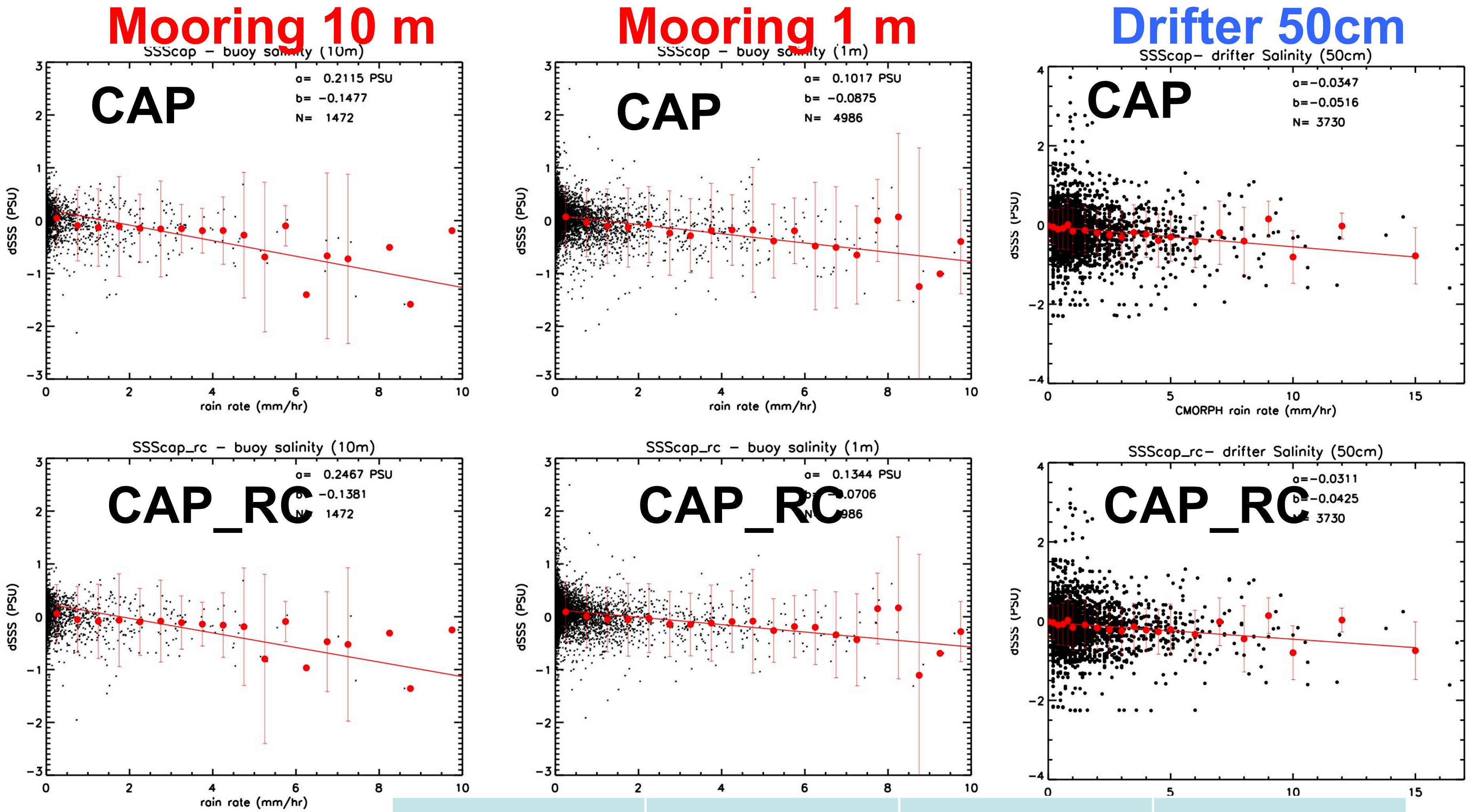




Drifters	N of obs.
SPURS-1	12036
Pacific GYRE	183453
MetOcean	121940
ICM	114784

Stratification reflected in ΔSSS





Slope (b)	S10m	S1m	S50cm
CAP	-0.1477	-0.0875	-0.0516
CAP_RC	-0.1381	-0.0706	-0.0425

$$\Delta SSS = a + bR$$

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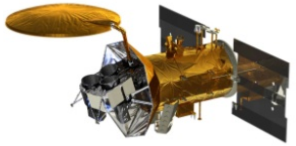
Summary



- The sensitivity of radiometer GMF to rain history based on CMORPH is tested. We found no significant difference between GMF built with data currently rain free or with data free of rain for the past 24 hours.

- A rain roughness correction is developed from empirical residual analysis, calibrated to the adjusted reference SSS^{RIM}_{HYCOM} which accounts for the stratification based on rain accumulated over 24 hours prior Aquarius measurements. Uncertainty of SSS retrieved under rainy conditions is reduced.

- SSS retrieved with rain roughness correction (SSS_{CAP_RC}) is validated with salinity measured by moorings and drifters at depths 10m, 1m, and 50cm respectively. The difference between satellite retrieval and in situ salinity increase with rain rate and depth. With rain-induced roughness accounted for, SSS_{CAP_RC} likely represents the surface stratification effects in terms of the negative slope of SSS_{CAP_RC}-S_{in_situ}(depth) vs. rain rate, which decreases with depth (towards the surface).