A study of the Rain Impact Model (RIM) under different wind speed conditions

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Abstract

When rain falls over the ocean, it produces a vertical salinity profile that is fresher at the surface. This fresh water will be mixed downward by turbulent diffusion through gravity waves and the wind stress, which dissipates over a few hours until the upper layer (1-5 m depth) becomes well mixed. Therefore, there will be a transient bias between the bulk salinity, measured by in-situ instruments, and the satellite-measured SSS (representative of the first cm of the ocean depth). Based on observations of Aquarius (AQ) SSS under rain conditions, a rain impact model (RIM) was developed to estimate the change in SSS due to the accumulation of precipitation previous to the time of the satellite observation. RIM uses ocean surface salinities, from the HYCOM (Hybrid Coordinate Ocean Model) and the NOAA global rainfall product CMORPH, to model transient changes in the near-surface salinity profile. Also, the RIM analysis has been applied to SMOS (Soil Moisture and Ocean Salinity) and SMAP (Soil Moisture Active Passive), with similar results observed. The original version of RIM assumes a constant vertical diffusivity and neglects the effects of wind and wave mixing. However, it has been shown that the persistence of rain-induced salinity gradients depends on wind speed, with freshening due to rain during weak winds (less than 2 m/s) persisting for 8 hours or more. Moreover, the mechanical mixing of the ocean caused by wind and waves rapidly reduces the salinity stratification caused by rain. Also, previous results using RIM, in the presence of moderate/high wind speeds, show that the model overestimates the effect of rain on the SSS, which suggests that for RIM to accurately model the near-surface salinity stratification, the effect of wind needs to be included in the model. To address this issue, this paper will focus on an improved RIM-2 that parameterizes the effects of wind on the vertical diffusivity (Kz). Results will be presented that compare RIM and RIM-2 calculations at different depths for several Kz parametrizations. Also, comparisons, between RIM-2 at depths of several meters with measurements from in-situ salinity instruments, will be presented.

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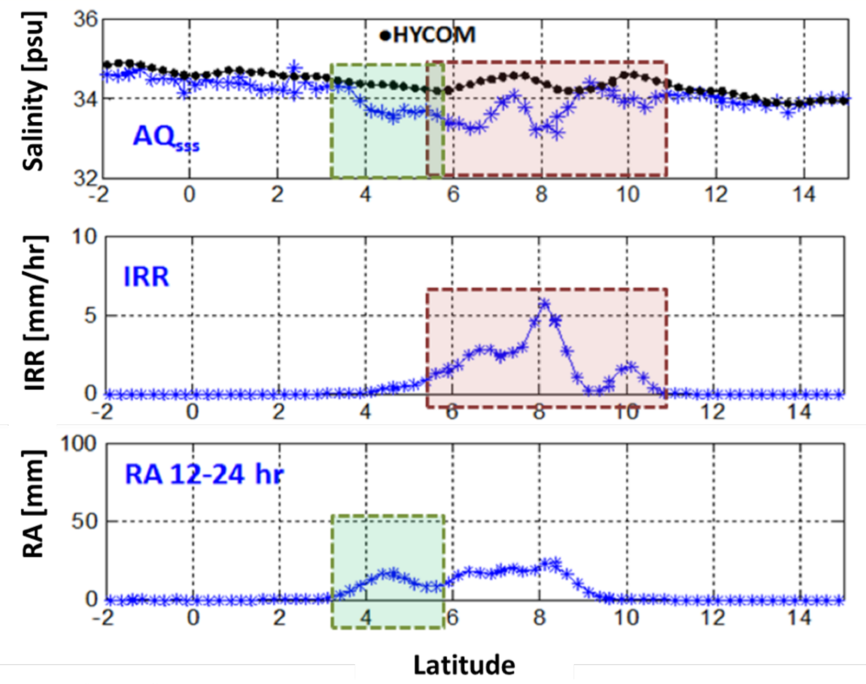
OBSERVATIONS DURING RAIN



Motivation:

During rain, AQ measures fresher SSS compared to HYCOM

Hypothesis:

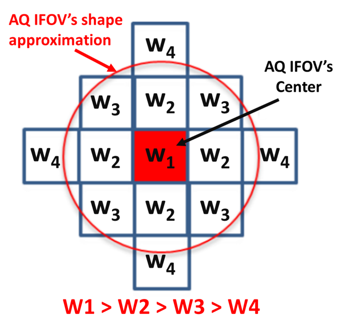
- Rainfall reduces SSS and causes salinity stratification
- Following rain event, turbulent diffusion and wave mixing reduce salinity over a period of several hours
- AQ SSS in the presence of rain can be significantly fresher than the bulk salinity at > 1 m depth

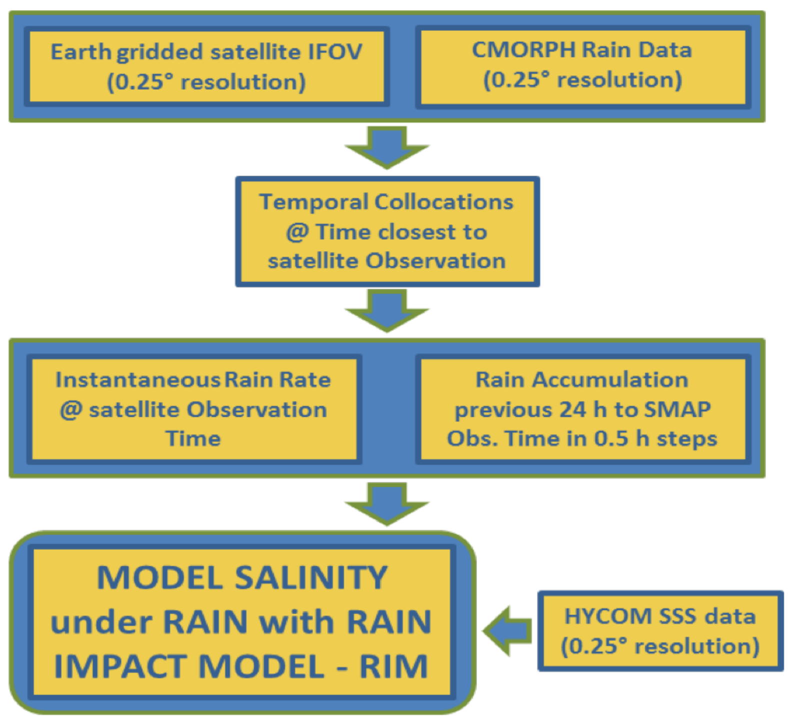
RIM Model

- Estimates SSS under rainy conditions at different depths

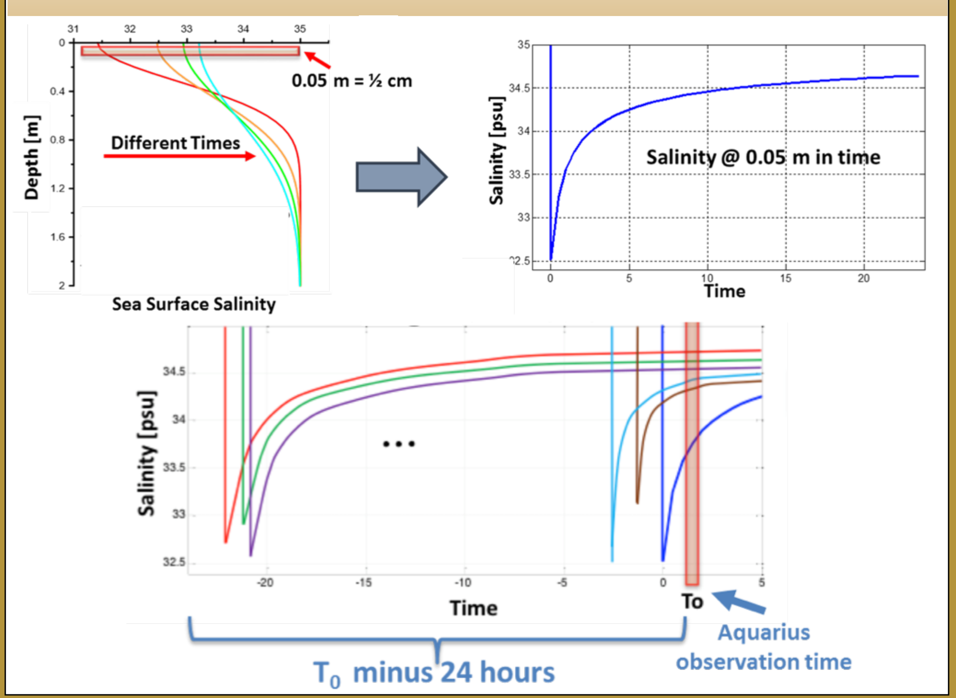
METHODOLOGY

- Rain Accumulation based on NOAA CMORPH Rain data
  - Global coverage between ±60°lat
- Spatial integration over AQ IFOV
  - Assumes circular footprint of 100 km
  - Uses 13 x 0.25° boxes
  - Weighted average based on antenna beam efficiency





APPROACH



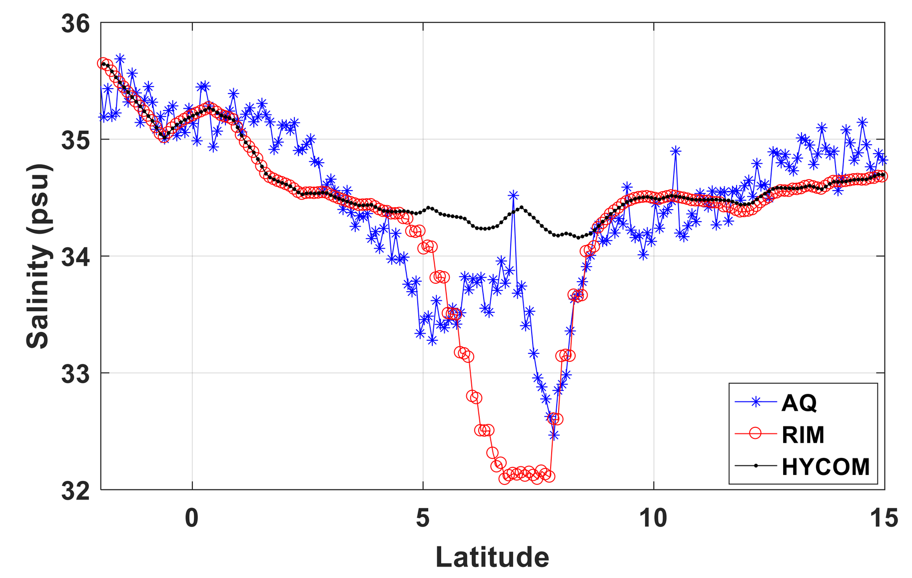
RIM FORMULATION

$$RIM_{SSS} = S_0\left(\prod_{i=1}^{48}\left[d_{0i} + \frac{R_{1i}}{\sqrt{K_{zi} * t_i}} e^{-z^2/4K_{zi}t_i}\right] * \left[d_0 + \frac{R}{\sqrt{K_z * t}} e^{-z^2/4K_z t}\right]\right)^{-1}$$

S_0 = HYCOM Salinity (psu)	K_z = vertical eddy diffusivity (m²/s)
z = depth (m)	R = rain impulse function (m) = f(RR)
t = time (s)	d_0 = mixing depth(m)

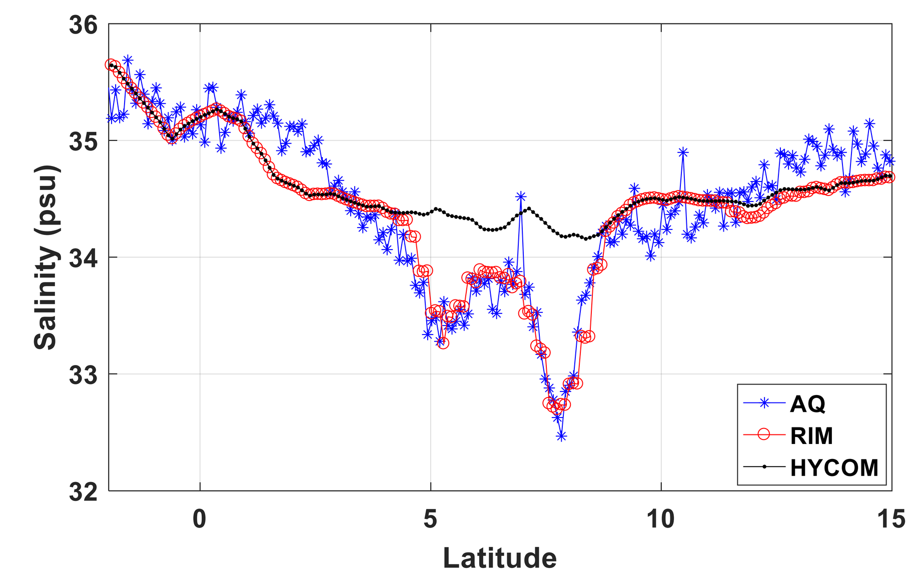
RIM V1.0 - CONSTANT WS

Without Rain Weighting

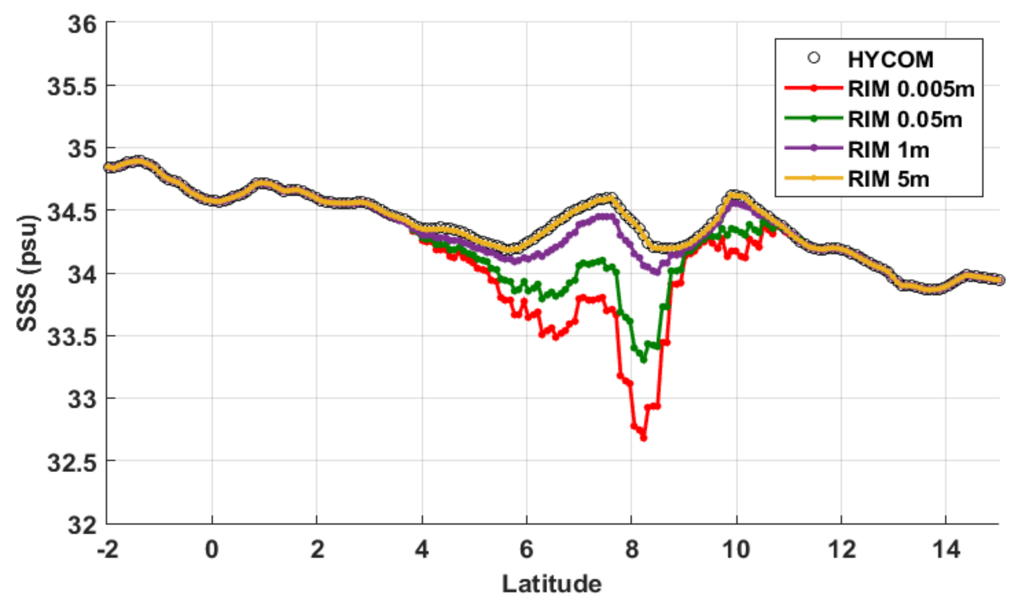


With Rain Weighting

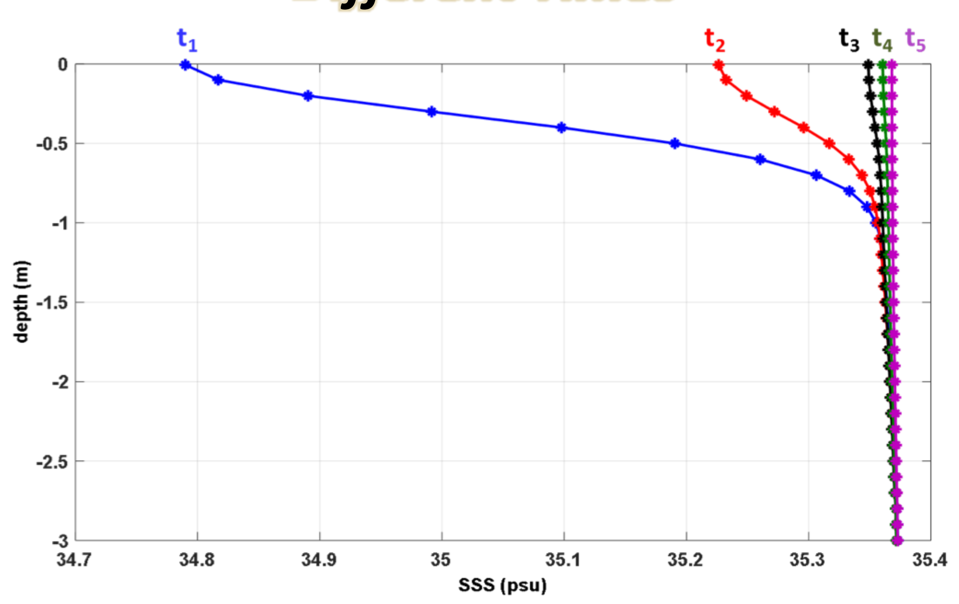
$R_{1i} = c_1 * f(RR_i)$	$R_2 = c_2 * f(IRR)$	c1, c2 = empirically derived



Different Depths



Different Times



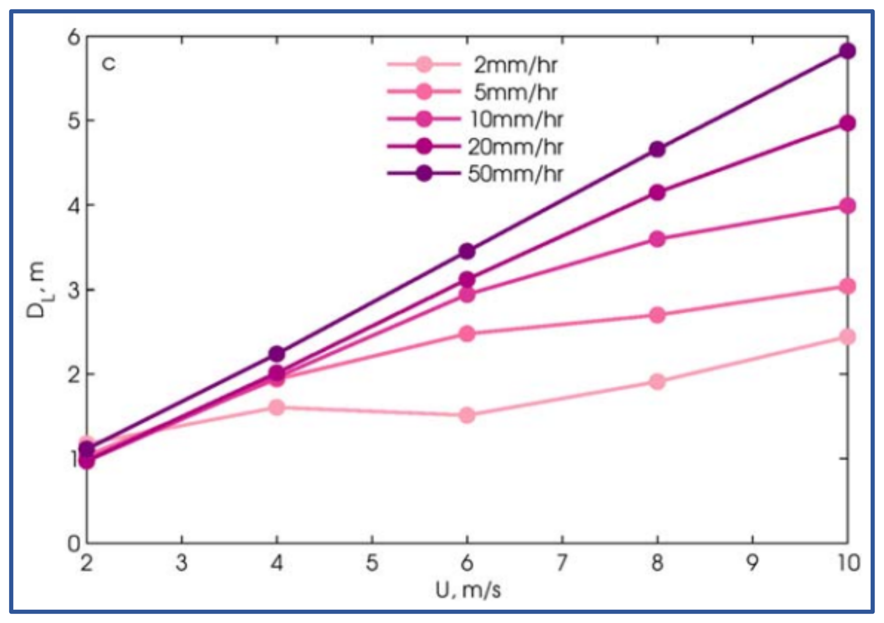
RIM V2.0 - VARIABLE WS

Vertical Diffusivity

$$K_z = 2.5 * 10^{-5} * ws^2 \; †$$

† Wenegrat, J. O., M. J. Mc Phaden, and R. C. Lien (2014), Wind Stress and Near-Surface Shear in the Equatorial Atlantic Ocean, Geophys. Res. Lett., 41, 1226-1261, doi: 10.1002/2013GL059149

Mixing Depth

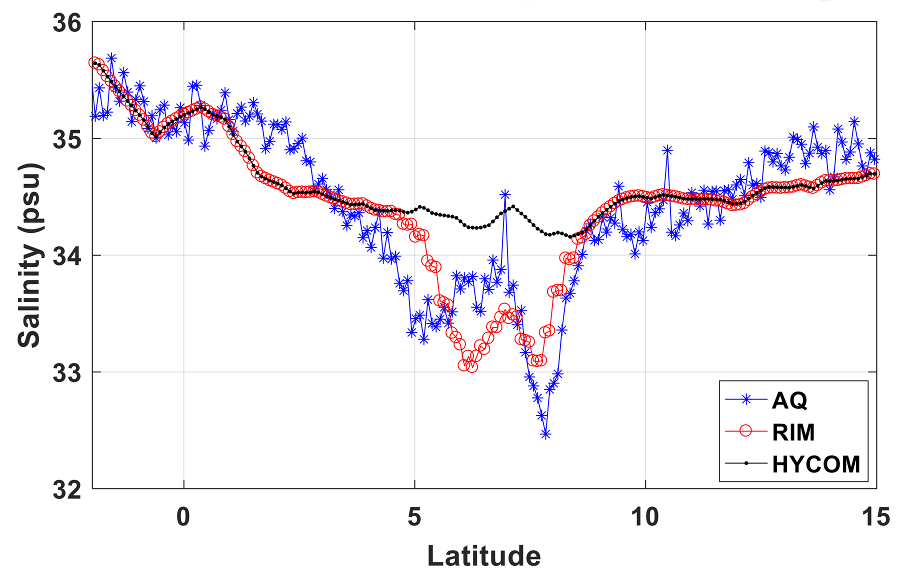


Drushka, K., W. E. Asher, B. Ward, and K. Walesby (2016), Understanding the formation and evolution of rain-formed fresh lenses at the ocean surface, J. Geophys. Res. Oceans, 121, 2673–2689, doi:10.1002/2015JC011527

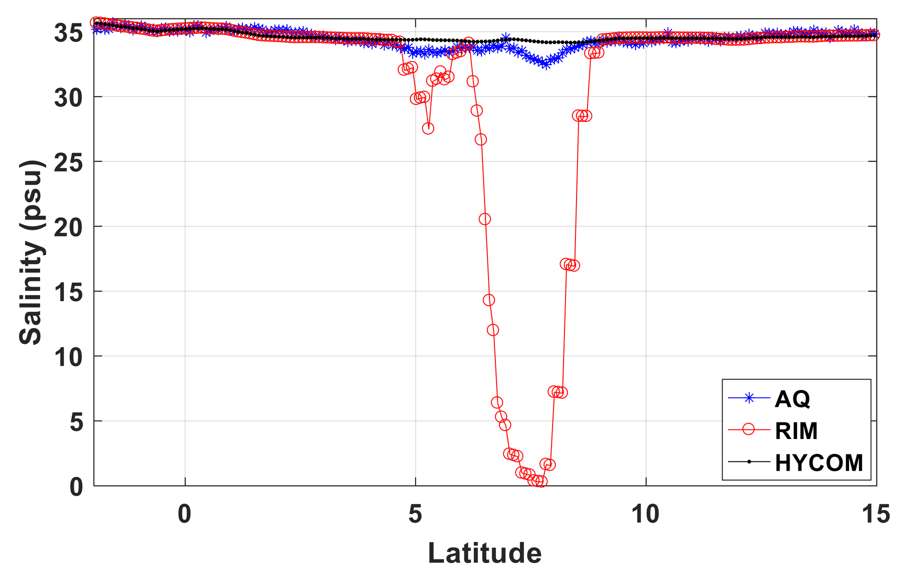
Wind Speed

AQ Scatterometer (Instantaneous)	NCEP (Wind Speed History)

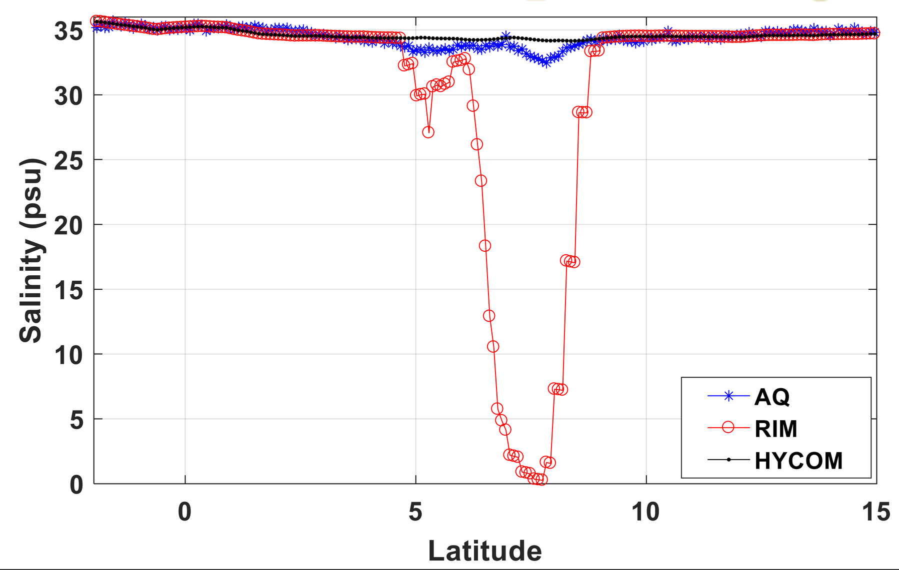
Case 1: Variable K_z, Constant d_0



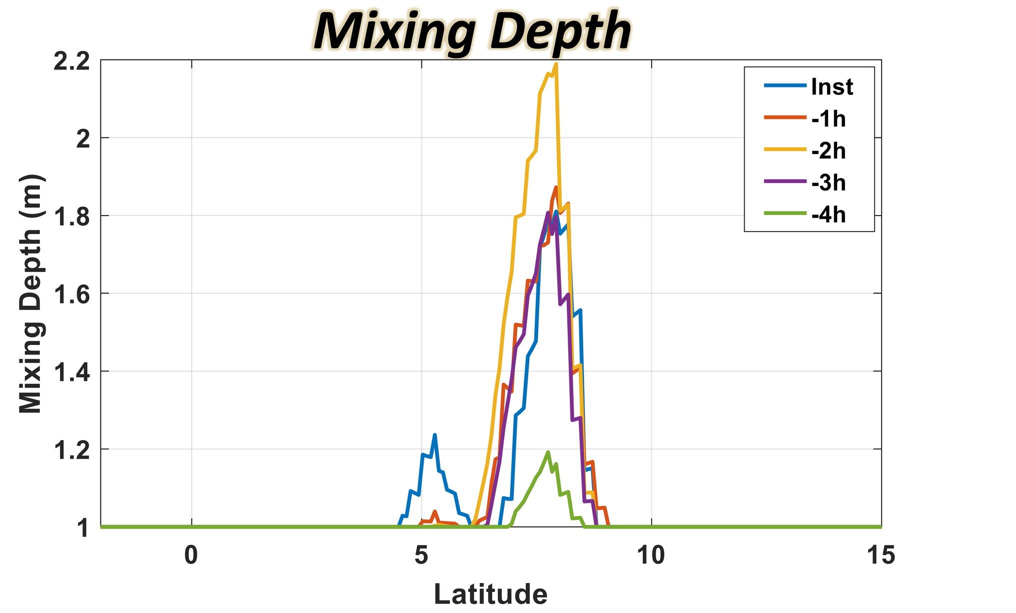
Case 2: Constant K_z, Variable d_0



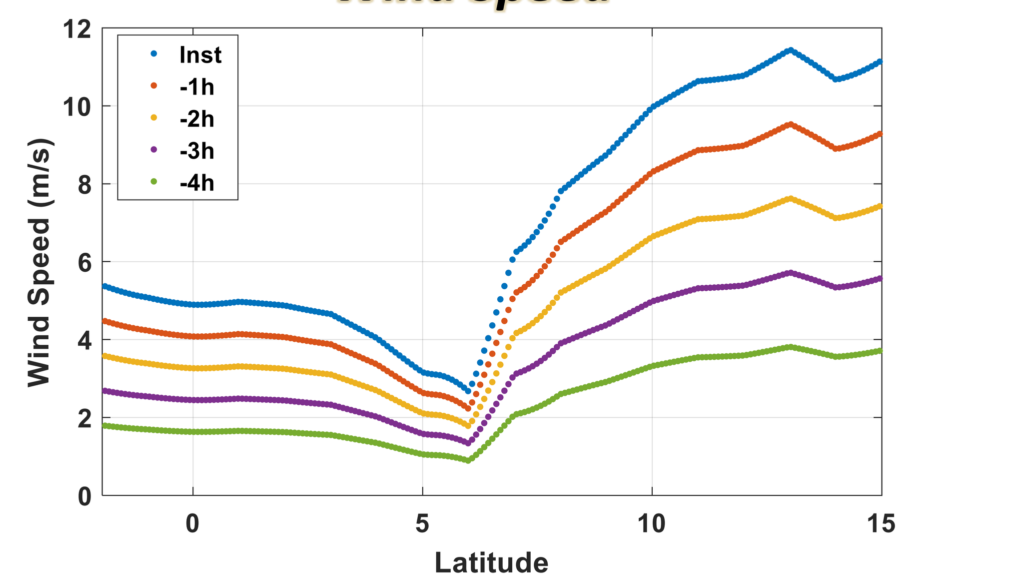
Case 3: Variable K_z, Variable d_0



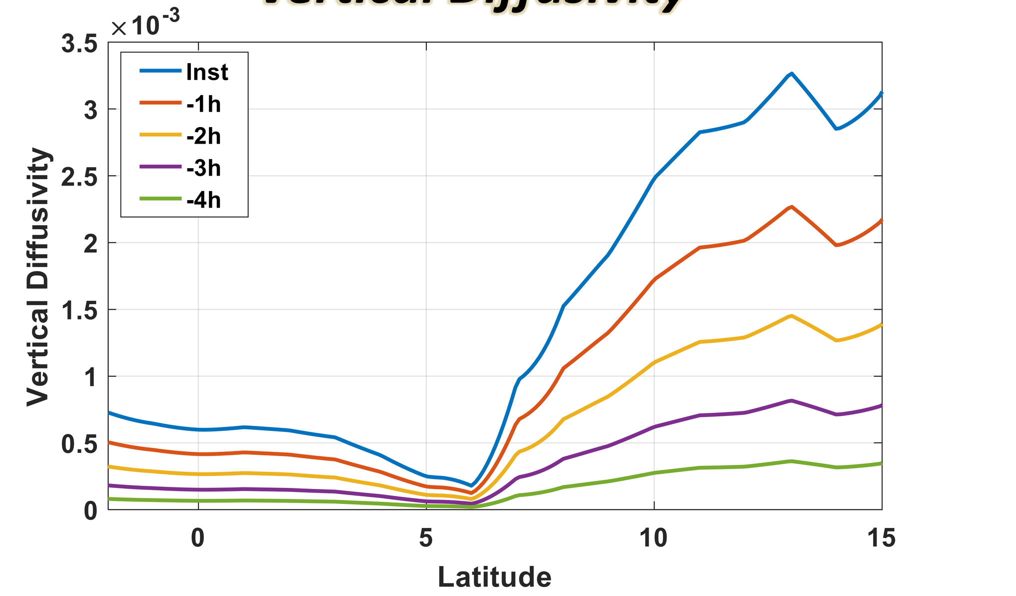
Mixing Depth



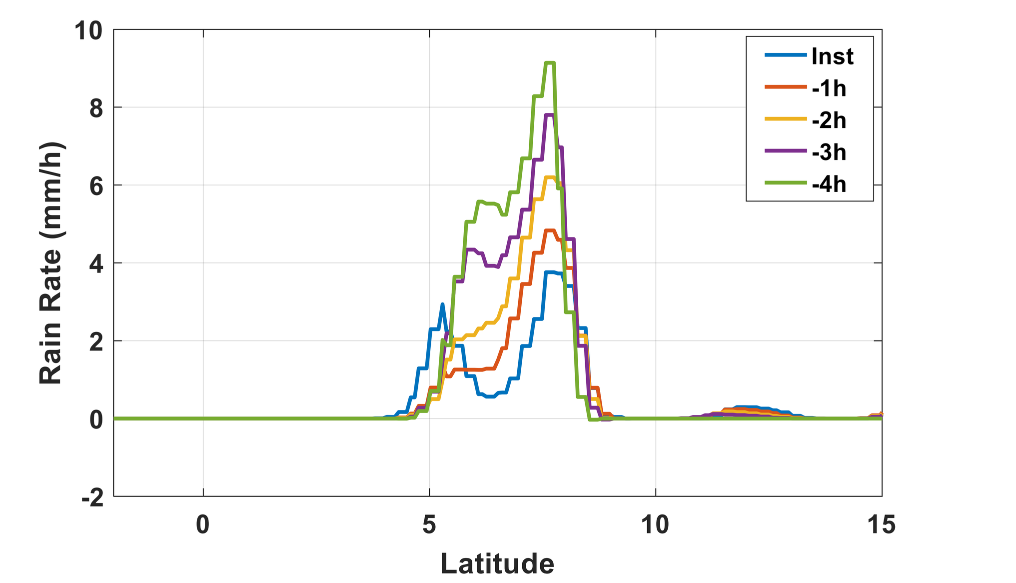
Wind Speed



Vertical Diffusivity



Rain Rate



SUMMARY

- Rain stratifies the ocean, creating a fresh layer near the ocean surface
  - This layer mixes laterally and vertically over a few hours
  - Satellite-measured salinities would be fresher than in-situ measurements (5 m - 10 m depth)
  - Therefore, knowledge of rain history is critical for accurately predicting rain effect
- RIM v1.0 has been demonstrated to work for Aquarius, SMAP & SMOS
  - RIM v1.0 provides a robust quality flag for identification of salinity stratification
- RIM v2.0 development seems to suggest that CMORPH doesn't provide an accurate description of rain field