Toward a wind speed dependent Rain Impact Model

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The Rain Impact Model (RIM) was developed at UCF to quantify the vertical salinity gradients generated by rain.

Salinity profile during/after rain:

Rain generates near-surface freshening → vertical salinity gradients in the upper few meters of the ocean.

Satellite validation: Satellites measure salinity at ~1 cm depth, in situ platforms used to validate satellite salinity measure at ~1-5 m depth.

Hydrological cycle: e.g., understanding water cycle changes, estimating rainfall from satellite SSS.
RIM predicts near-surface freshening from satellite rain measurements using a diffusion model

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

- \( S(z, t) \): salinity at depth \( z \), time \( t \)
- \( S_0 \): initial bulk salinity (from HYCOM)
- \( d_0 \): characteristic mixing depth
- \( RIF \): “rain impulse function” = rain accumulation (\( R \), from CMORPH) integrated over \( d_0 \)
- \( K_z \): vertical eddy diffusivity coefficient

- \( K_z \) estimated from in situ measurements of \( O(1-10) \) km scale rain events
- \( K_z \) assumed to be constant in RIM: \( 1 \times 10^{-4} \) m\(^2\)/s

Santos-Garcia et al., 2014, based on Asher et al., 2014
RIM works well in many cases
RIM predictions of SSS are included in the Aquarius V5 product

Santos-Garcia et al., 2014
... but RIM often over-predicts freshening

![Graph showing HYCOM, Aquarius, and RIM data]

- **Low wind**: RIM works
- **Rain rate**
- **Wind speed**
- **High wind**: RIM too fresh

**RIM output example**

Count (concatenated data)
... but RIM often over-predicts freshening

HYCOM vs Aquarius

RIM vs Aquarius

HYCOM is too salty

RIM is too fresh

* Stats for Pacific ITCZ data, 2012, rain rate > 0.5 mm/hr only
RIM works at wind speeds < 5 m/s
Because it is tuned for low/moderate winds, so it doesn’t mix away freshwater in higher wind cases

Distribution of $\Delta S$: all cases

Distribution of $\Delta S$: winds < 5 m/s

This motivates developing a wind-dependent version of RIM

RIM fresh bias
Median $\Delta S_{\text{RIM-Aquarius}}$ is $-0.25$ psu

Low winds: no bias
Median $\Delta S_{\text{RIM-Aquarius}}$ is $-0.06$ psu

* Stats for Pacific ITCZ data, 2012, rain rate > 0.5 mm/hr only
Our goal: improve RIM by introducing a wind- and rain-dependent vertical diffusivity ($K_z$)

**Step 1:** Determine $K_z$ for different wind speeds & rain rates from idealized modeling using the Generalized Ocean Turbulence Model (Burchard 2001, Drushka et al 2016)

**Forcing:**
Use a range of rain accumulation and wind speed values

**Salinity response:**
estimate $K_z(R,U,t)$ by fitting a diffusion model

Rain accum. 0 to 5mm

Wind speed: 0 to 10 m/s

$S(z)$

depth

Time 1
Time 2
Time 3

time
$K_z$ is strongly dependent on wind speed, weakly dependent on rain rate, and also varies with time.

Parameterized $K_z$:  
$$\ln(K_z) = (a_0 + a_1 U + a_2 U^2)(b_1 R_0^{b_2 U} + b_3)$$

- $U$ = wind speed
- $R = $ rain accum.
- $a_i, b_i =$ time-varying coefficients from fits to model output

**Left Panel:**
- Constant $K_z$ used in original RIM
- Color: rain accum.
- Time: 1 hour after rainfall

**Right Panel:**
- Color: wind speed
- Rain accum.: 2 mm

**Graphs:**
- Wind speed, m/s vs. $K_z$, m$^2$/s
- Time, hours since rain vs. $K_z$, m$^2$/s
Parameterized $K_z$ implemented into RIM (called “PRIM”)

Not enough freshening (PRIM looks too much like HYCOM)

**HYCOM vs Aquarius**

**PRIM vs Aquarius**

Rain rate, mm/hr

* Stats for Pacific ITCZ data, 2012, rain rate > 0.5 mm/hr only

**Count (concatenated data)**
PRIM under-predicts freshening. Why?

\[ S(z, t) = S_0 \left( 1 + \frac{R}{\sqrt{K_z t}} \right)^{-1} \]

- This term is too small
- \( K_z \) too large?
- \( R \) (rain accumulation) too small?

\( K_z \) parameterization was developed using a 1-d model that is consistent with small-scale rain events having scale \( O(1-10) \) km

- How well does it represent the large scales (25 – 100 km) measured by satellites used in RIM?
- How is salinity mixing on “in situ” and satellite scales related?

Satellite rain products represent scales \( >O(100) \) km, 60-90 min averages

- \( R \) observed over a satellite footprint << \( R \) at a point
Can tweaking $K_z$ in PRIM teach us about scales of salinity mixing?

PRIM with $K_z = K_z \times 0.01$

Too much freshening

Some improvement: PRIM looks more like Aquarius

PRIM with $K_z = K_z \times 0.1$

Rain rate, mm/hr

Salinity, PSU

HYCOM

Aquarius

PRIM

Rain rate, mm/hr

Salinity, PSU

HYCOM

Aquarius

PRIM
Can tweaking $K_z$ in PRIM teach us about scales of salinity mixing?

Scaling $K_z$ by a factor of between 0.1 and 0.01 will make RIM “work”.

This is consistent with the ratio of scale at which $K_z$ was developed (1-10 km) & scale of satellite rain (100 km).
Summary

1. RIM **over-predicts rain freshening** at winds > 5 m/s
   - RIM has no wind speed dependence

2. We developed parameterized RIM (PRIM):
   - PRIM parameterizes $K_z$ based on wind (and rain, time)
   - PRIM **under-predicts freshening**
   - Adjusting $K_z$ suggests that the rain we observe/model on scales of individual rain events is mixed away 10-100x faster than rain observed by satellites, consistent with their relative size (1-10 km versus ~100 km)

Future work

- Further refinement of RIM (using IMERG rain, Argo instead of HYCOM)
- Exploration of $K_z$ scaling relationships
- A PRIM product for SMAP? OSST suggestions?