Predictability (***Timing***) of tropical freshwater lenses due to convective and stratiform rain during SPURS-2

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Motivating freshwater lens research from a weather and climate predictability perspective

- Salinity stratification by rain contributes to amplified SST heating rates and lateral SST gradients.

  Vershinksy 1982, Soloviev and Lukas 1997, Wijesekera et al. 1999, Woolnough et al. 2000, Lau and Waliser 2005, Thompson et al. in prep

- In the tropics, the magnitude and lateral gradients of SST impact local precipitation intensity and timing by heating/ moistening/deepening the atmospheric boundary layer, which invigorates thermals that reside within it, which vertically advect moist static energy into the free troposphere… as well as SST-driven wind convergence, and convective instability.

  Lindzen and Nigam 1987, Fairall et al. 1996a, Soloviev and Lukas 1997, Woolnough et al. 2000, 2001, Costa et al. 2001, Back and Bretherton et al. 2009a,b, Bellenger et al. 2010, Li and Carbone 2012, Clayson and Bogdanoff 2013, Seo et al. 2014, de Szoeke et al. 2014, Ruppert and Johnson 2015, Carbone and Li 2015

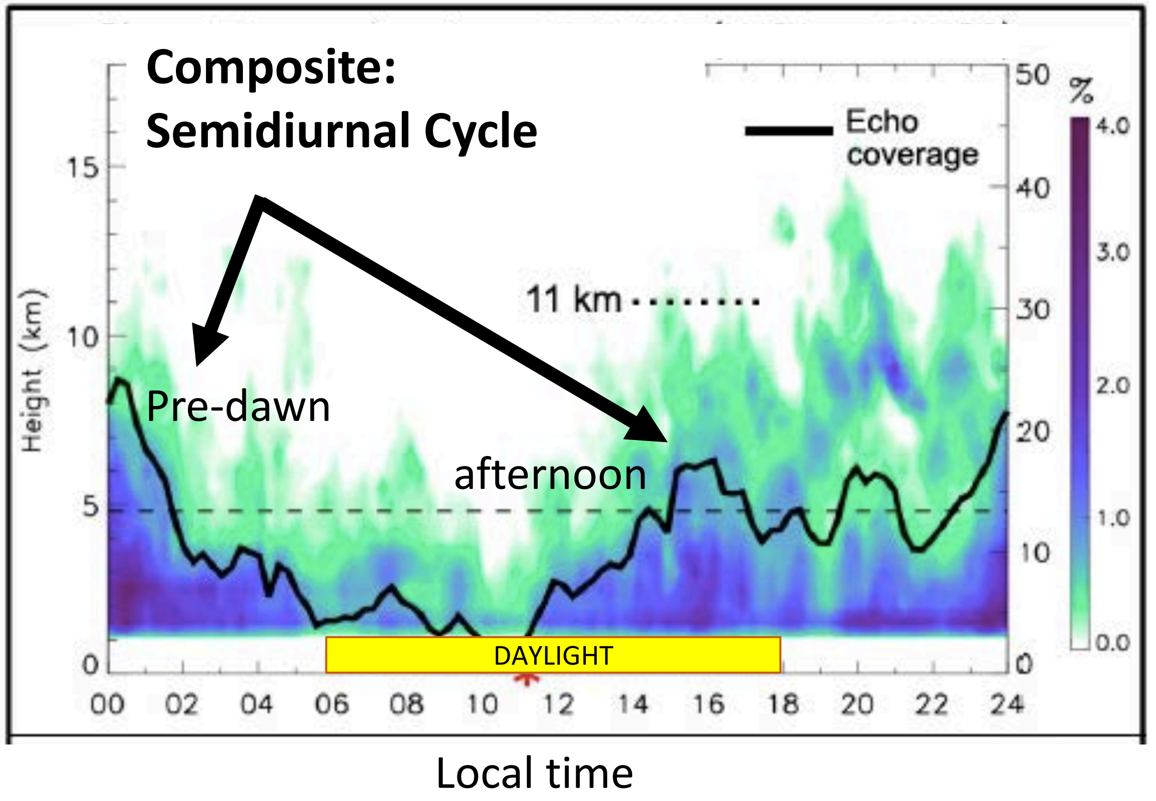
- Diurnal SST-driven precipitation and clouds reduce large-scale subsidence in the atmosphere, which encourages deeper atmospheric convection to follow.

  Ruppert and Johnson 2015, 2016, Ruppert 2016

- Diurnal SST variability also works to reduce wind-driven fluxes and support on-equator convection… leading to more realistic MJO propagation… and global weather/climate predictability

  Bernie et al. 2005, 2007, 2008, Stan et al. 2010, Klingaman et al. 2011, Klingaman and Woolnough 2014, Seo et al. 2014, DeMott et al. 2014, 2015, 2016

Tropical Oceanic Cloud Top Height PDF (from radar)



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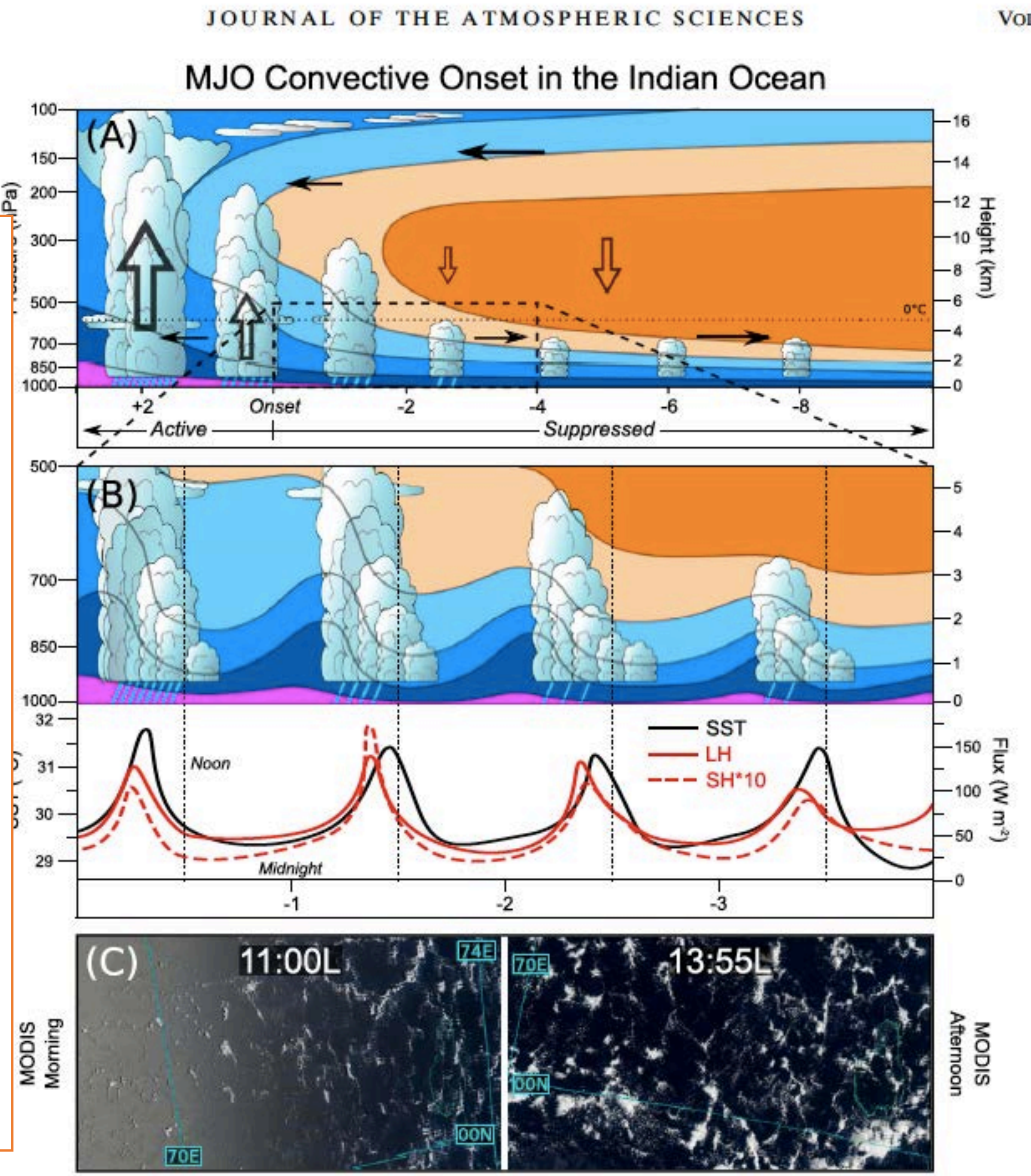

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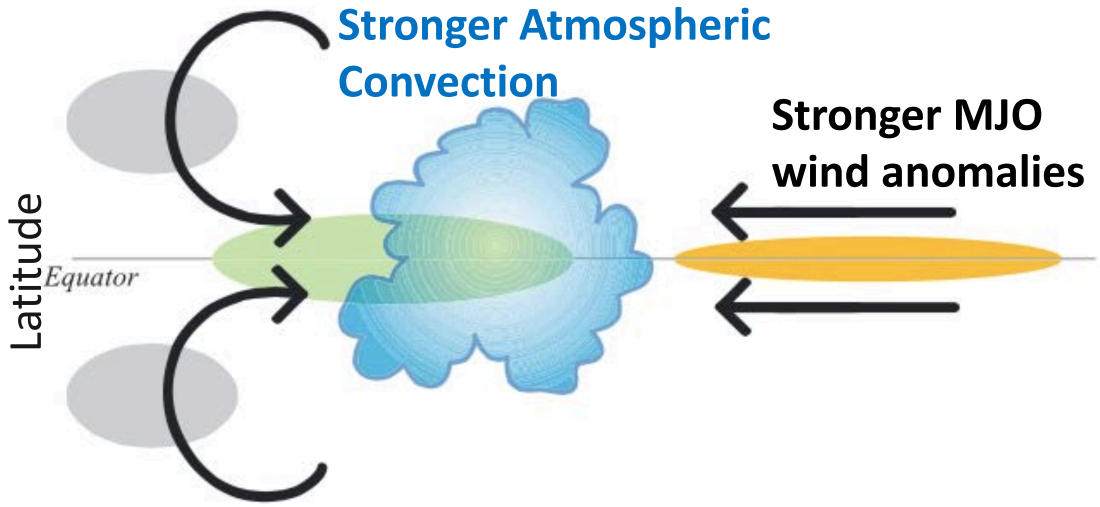
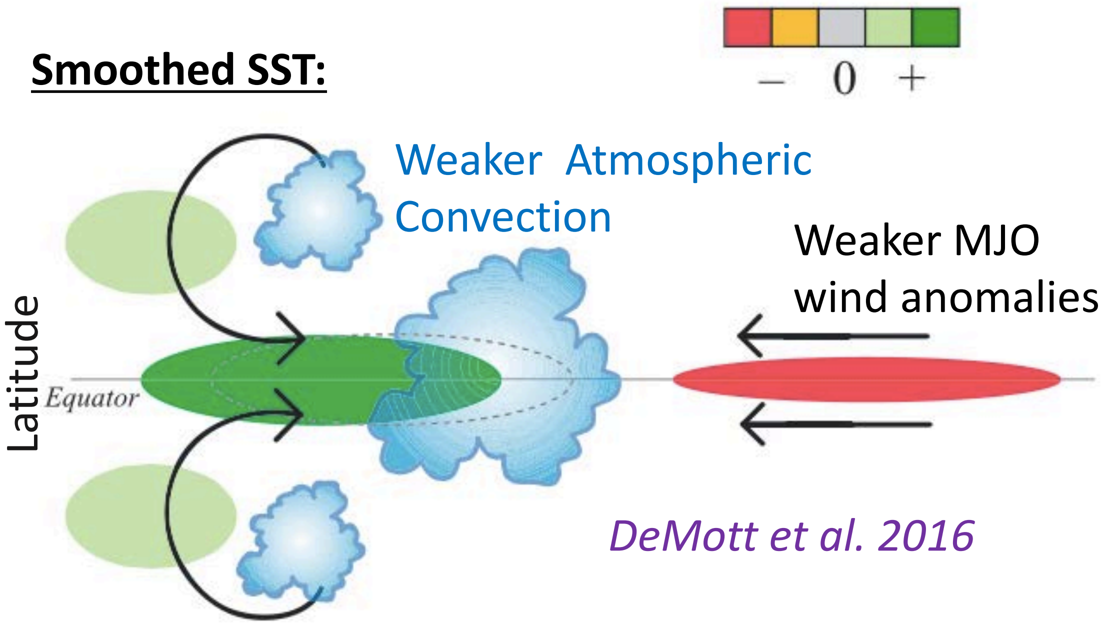
Realistically varying SST:



Smoothed SST:



DeMott et al. 2016

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Sunny conditions can occur just after and just before tropical rain.
It is important to understand freshwater lens timing
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Quantitatively, what is known about freshwater lens timing?

Wijesekera et al. 1999, Asher et al. 2014, Drushka et al. 2016, Thompson et al. in prep

Buoyancy Flux: $B = kg\rho_W{}^{-1}\left[SSS\beta(P-E) - \frac{\alpha}{c_P}(LHF + SHF + Solar_{NET} + IR_{NET}) + \alpha\delta TP\right]$

Mixed layer depth : $z = \frac{U_*{}^3}{B}$

<u>Rain does not always produce stable salinity (density) stratification because:</u>

- R < 5 mm h^{-1} does not appear to provide enough buoyancy flux to overcome mixing by turbulence and net surface cooling
- Upper wind limit of fresh lenses: 9 m s^{-1} for R = 50 mm h^{-1}, or 6 m s^{-1} for R = 10 mm h^{-1}. Sub-surface turbulence can also prevent rain stratification.
- The rain cooling effect has an order of magnitude lower impact on ocean surface buoyancy than freshening
- dS/dz in stable fresh lens is linearly related to maximum rain rate R once wind speed is taken into account

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Objectives of this SPURS-2 study

- Understand the physical mechanisms that influence the timing and creation of individual fresh water lenses … Are stratiform or convective rainfall more efficient or effective at creating or sustaining freshwater lens?

  … which requires quickly-updating, high-accuracy rain observations

  … as well as ocean stratification observations at high vertical & temporal resolution

The Surface Salinity Profiler (SSP)

Asher et al. 2014

0-1 m ΔS for 1/3 of cruise

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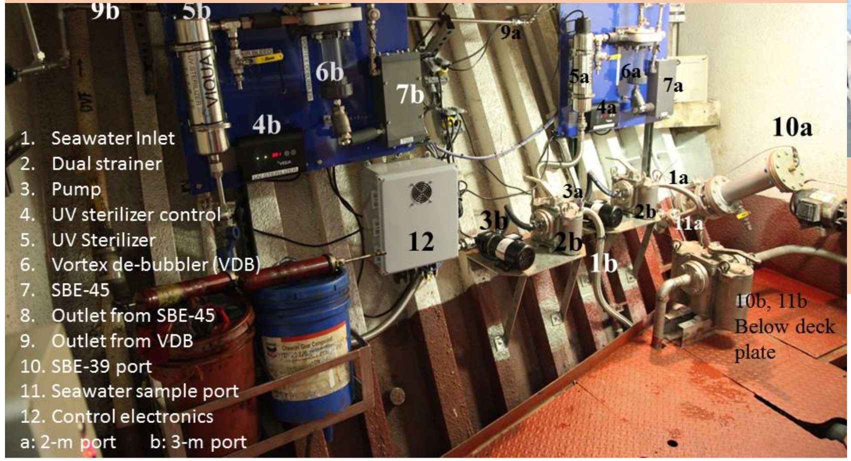
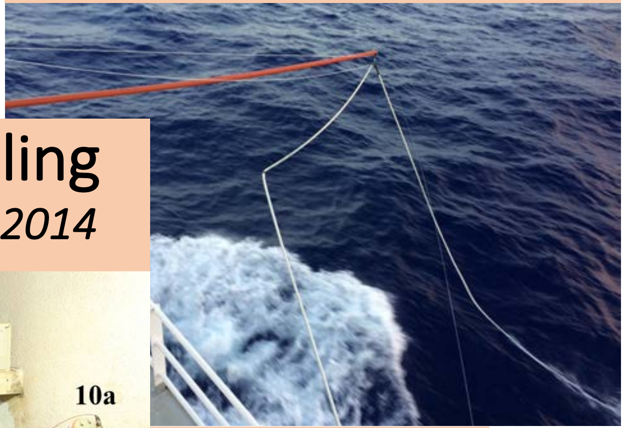
Underway Salinity Profiling System (USPS) *Asher et al. 2014*

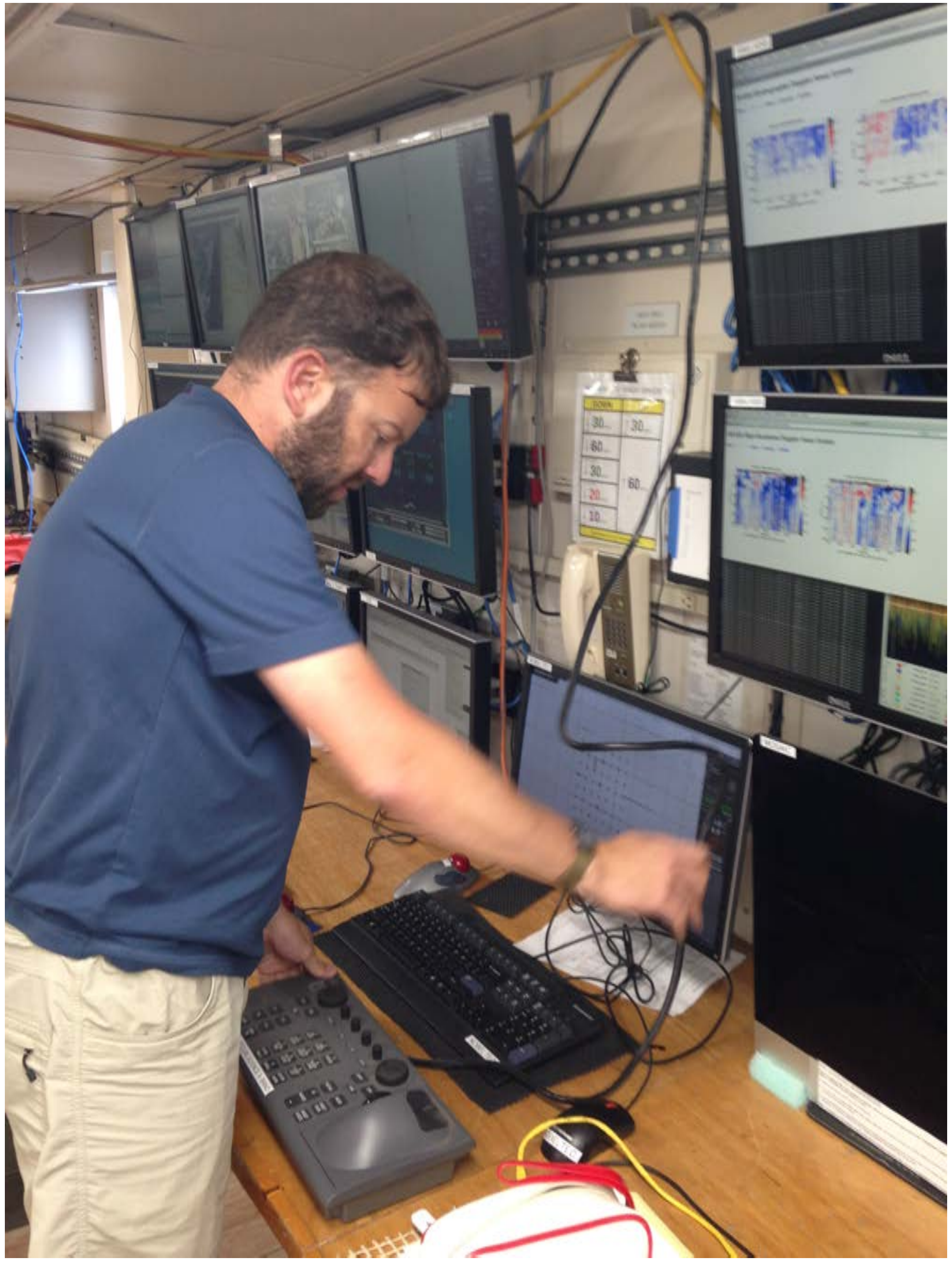


Sea Snake *(J. Schanze)*



0-5 m ΔS for entire cruise

A bonus rain radar dataset…



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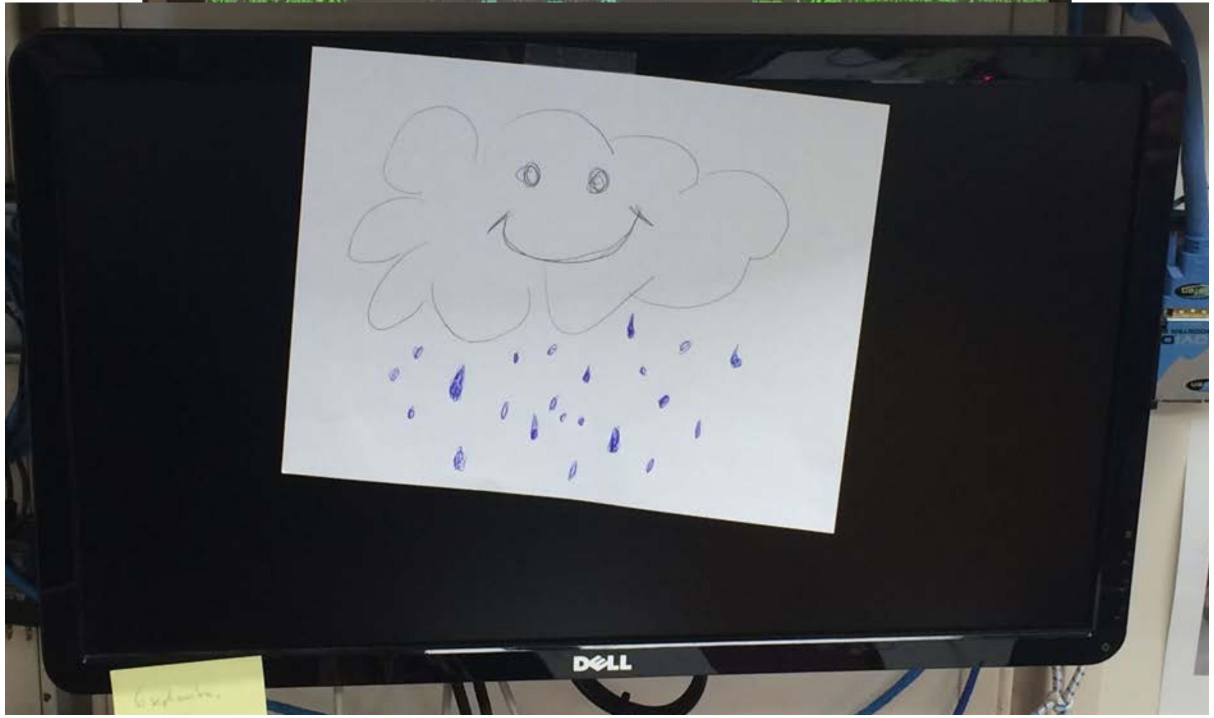

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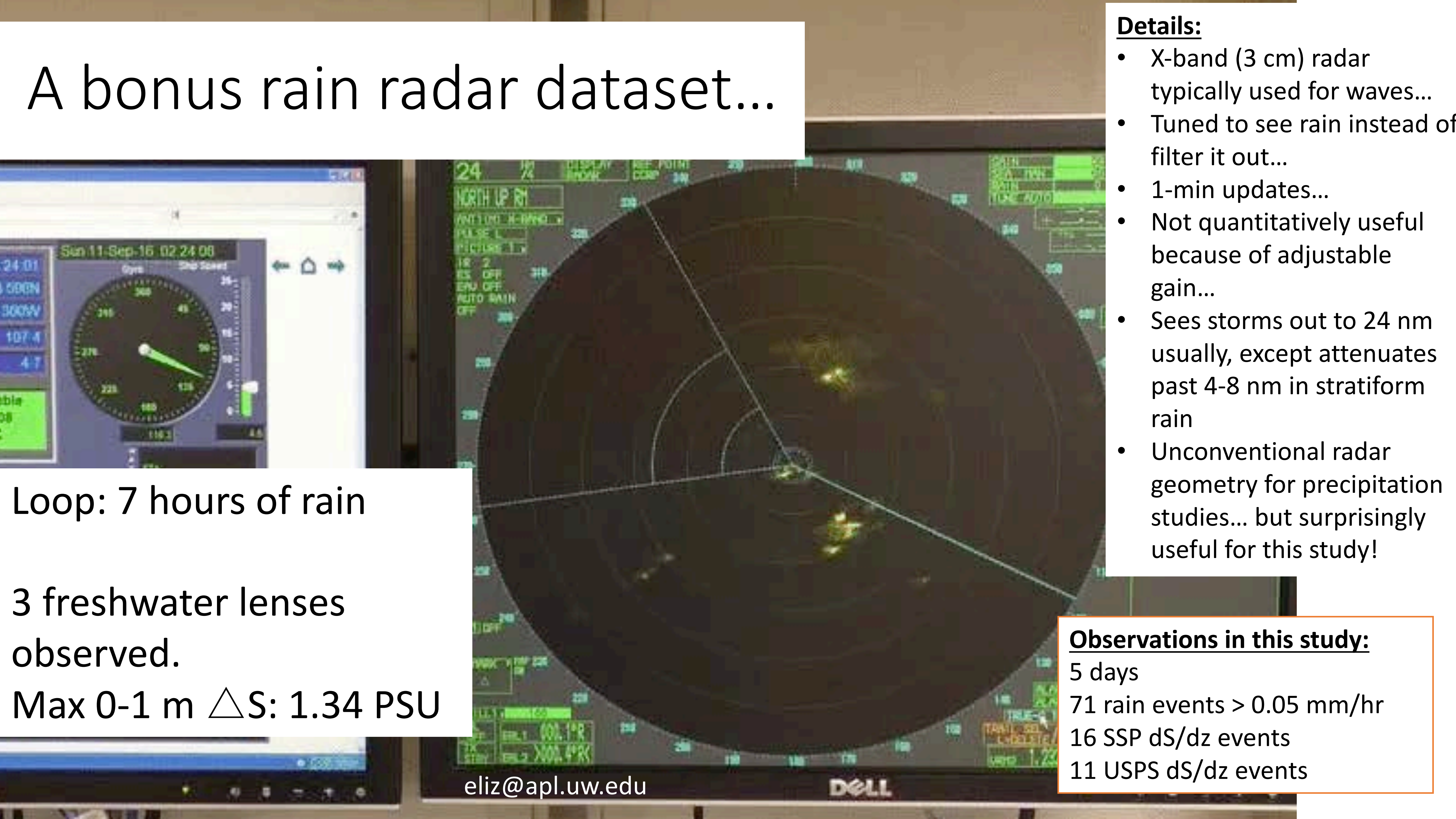

Details:

- X-band (3 cm) radar typically used for waves…
- Tuned to see rain instead of filter it out…
- 1-min updates…
- Not quantitatively useful because of adjustable gain…
- Sees storms out to 24 nm usually, except attenuates past 4-8 nm in stratiform rain
- Unconventional radar geometry for precipitation studies… but surprisingly useful for this study!

Loop: 7 hours of rain

3 freshwater lenses observed.

Max 0-1 m △S: 1.34 PSU

Observations in this study:

5 days

71 rain events > 0.05 mm/hr

16 SSP dS/dz events

11 USPS dS/dz events

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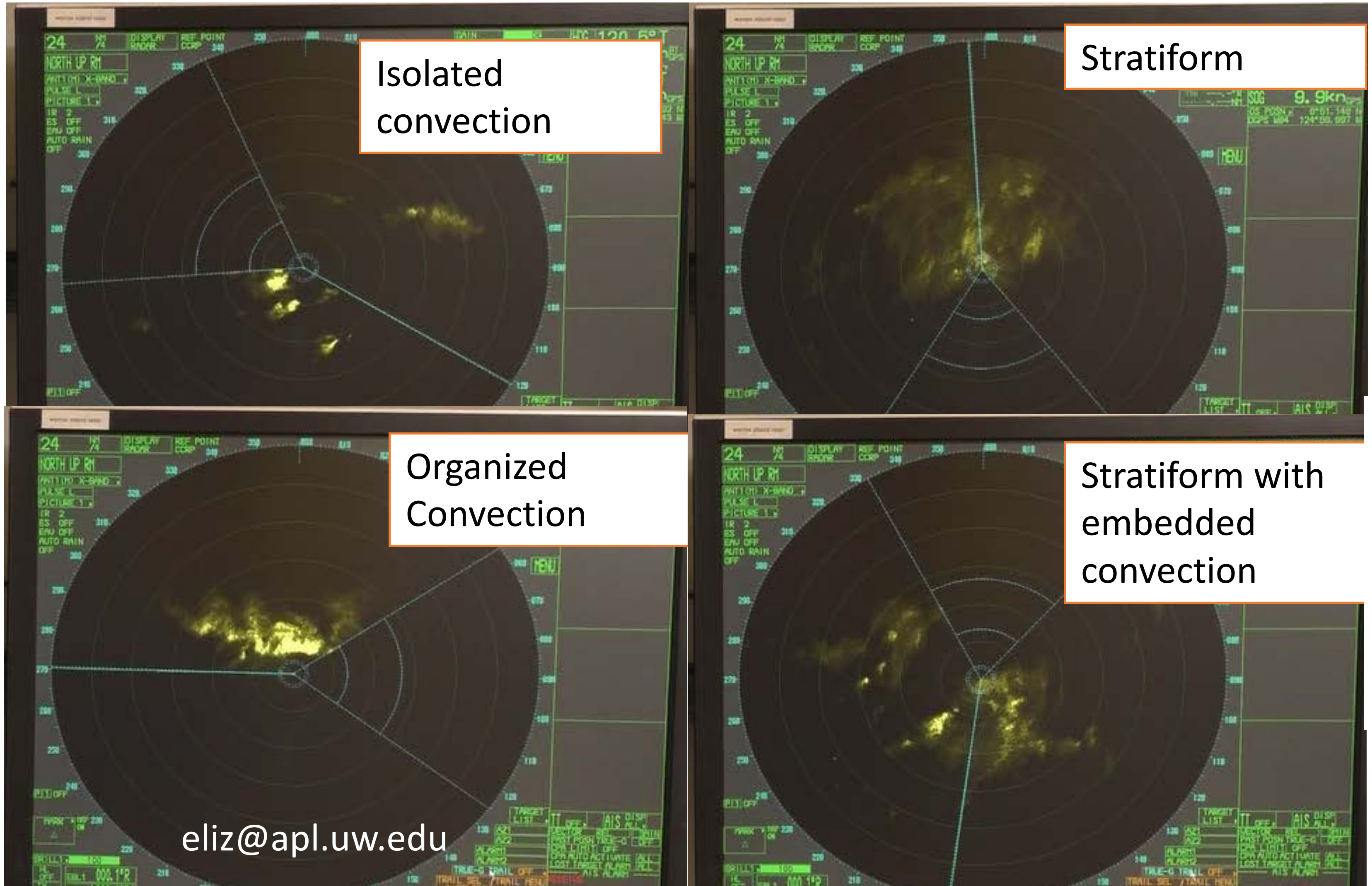
X-band radar qualitatively revealed stratiform and convective rain morphology on 1-min time scales

24 nm range rings



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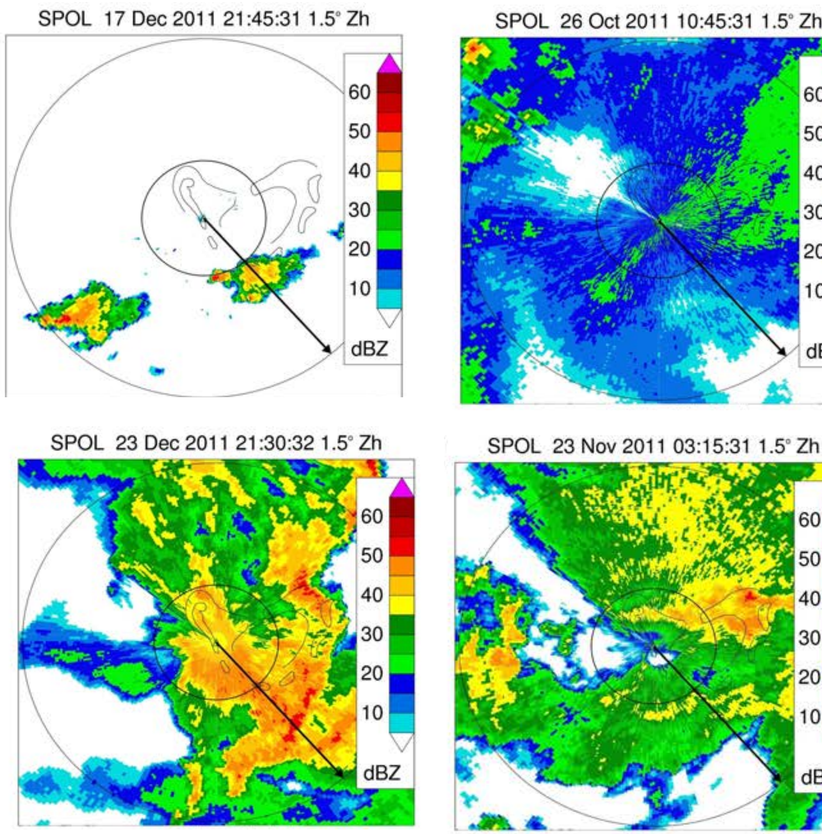
50 nm range rings



Thompson et al. 2015 JAS

Summary of Case Study Results:

Timing of beginning and maximum △S in the upper few meters of the ocean closely corresponded to R timing and R maximum on one-minute time scales.

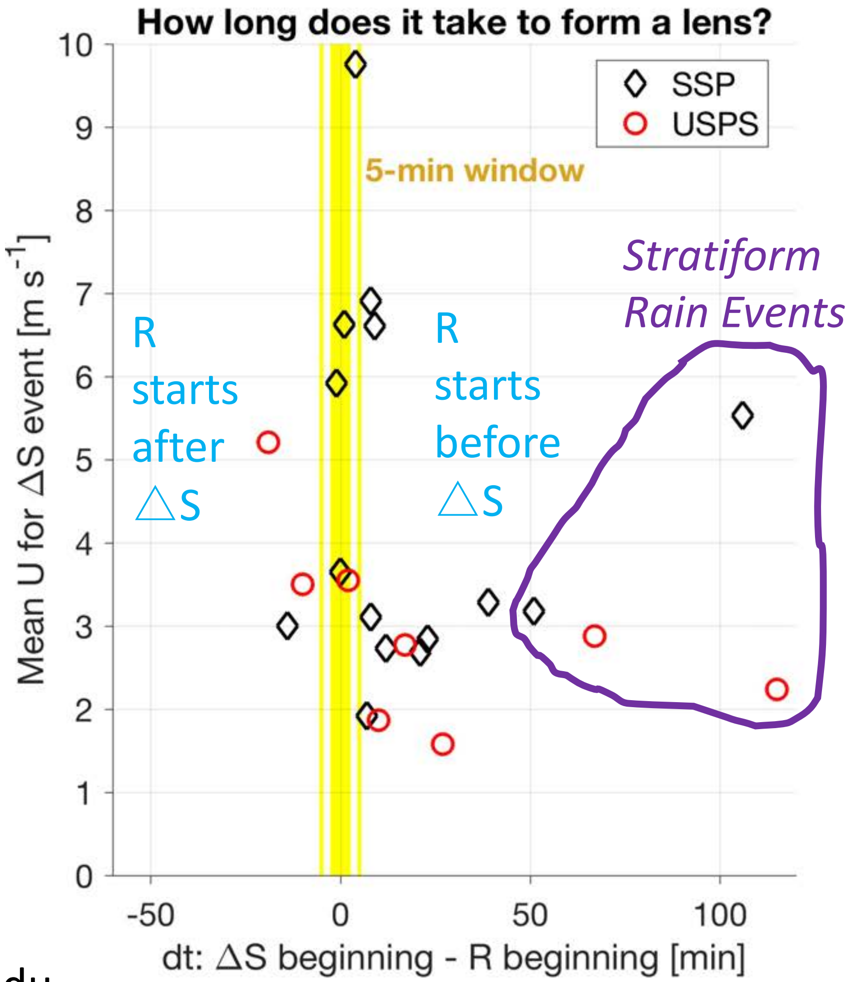
Observations in this study:

5 days

71 rain events > 0.05 mm h^{-1}

16 SSP △S events:0-1 m

11 USPS △S events: 0-3 m



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Summary of Case Study Results:

16/16 SSP △S events were associated with local rain.
2/11 USPS △S events occurred without local rain.

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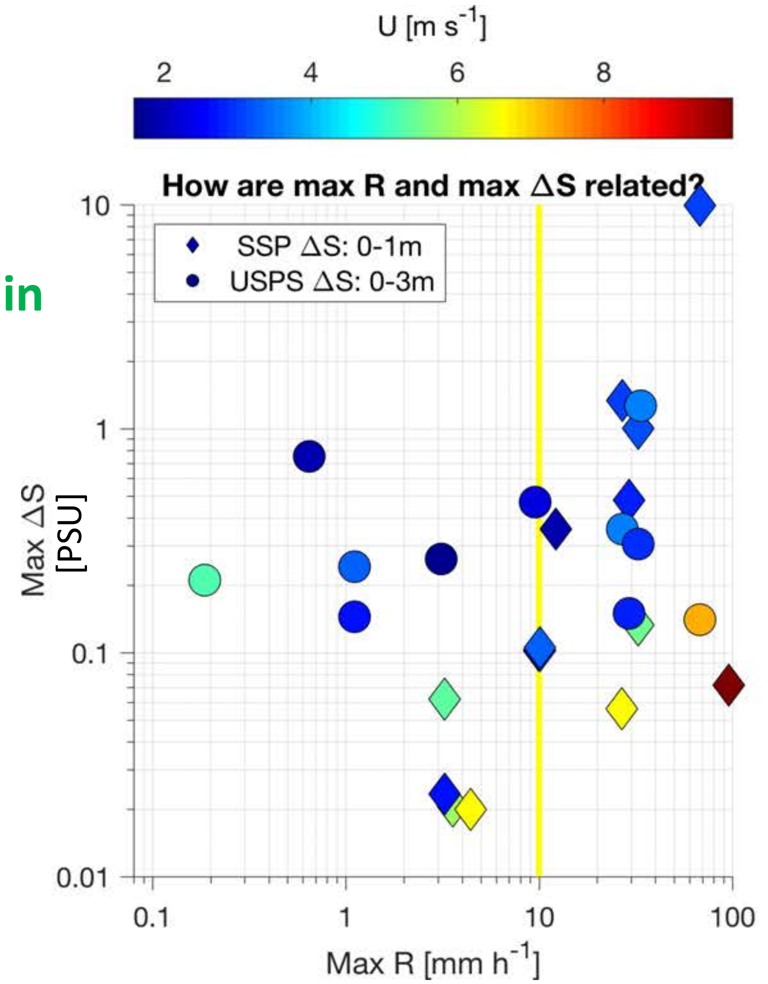
Ship rain gauge



30% chance of creating △S for all rain, stratiform rain, and convective rain events

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Summary of Case Study Results:

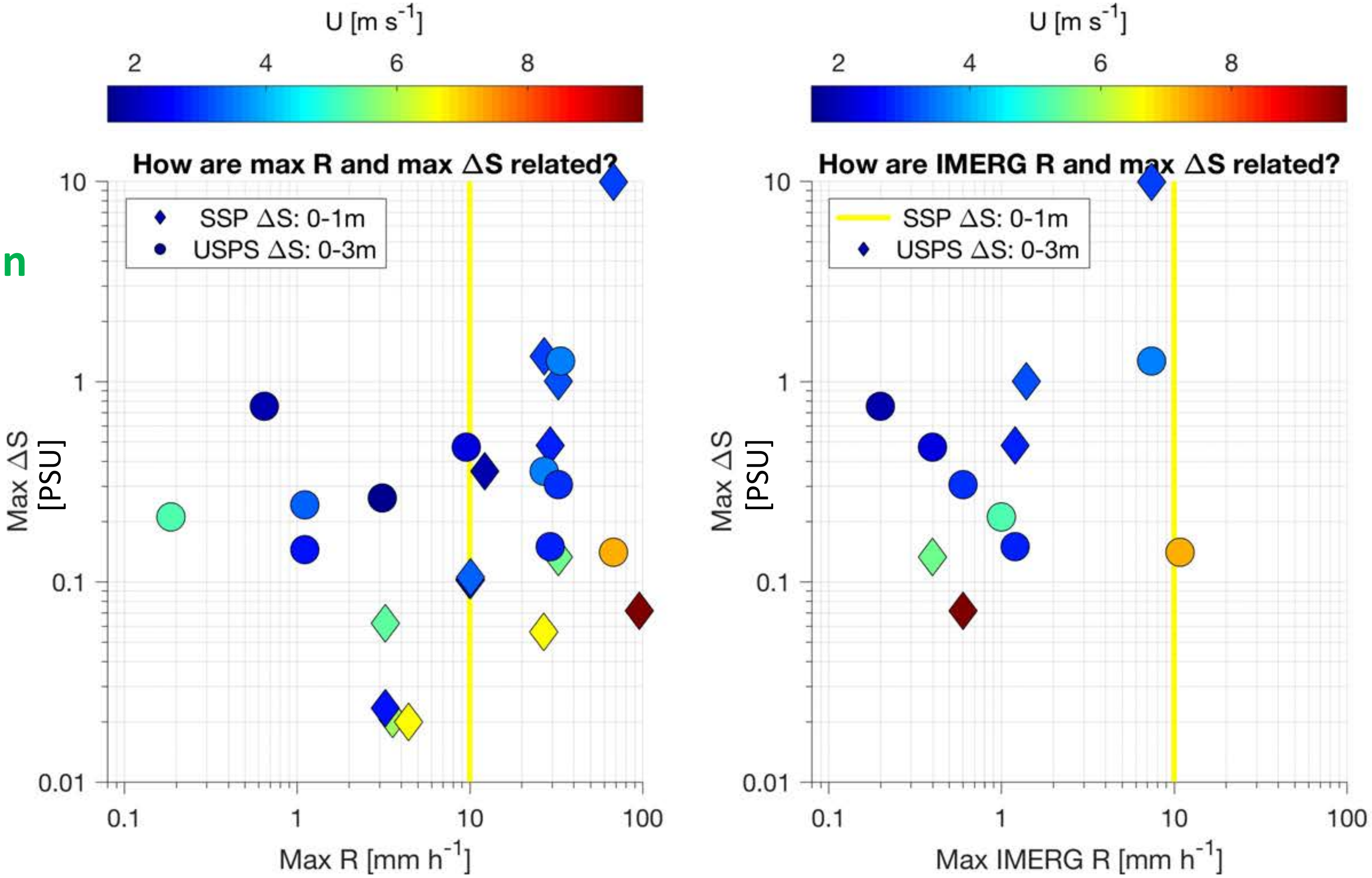
16/16 SSP △S events were associated with local rain.
2/11 USPS △S events occurred without local rain.
12/26 TOTAL △S events occurred without IMERG rain
… and the IMERG - △S event timing was less incoherent

Observations in this study:

5 days
71 rain events > 0.05 mm h^{-1}
16 SSP dS/dz events:0-1 m
11 USPS dS/dz events: 0-3 m

Ship rain gauge

Rainiest events are *not* more likely to be windy!



IMERG

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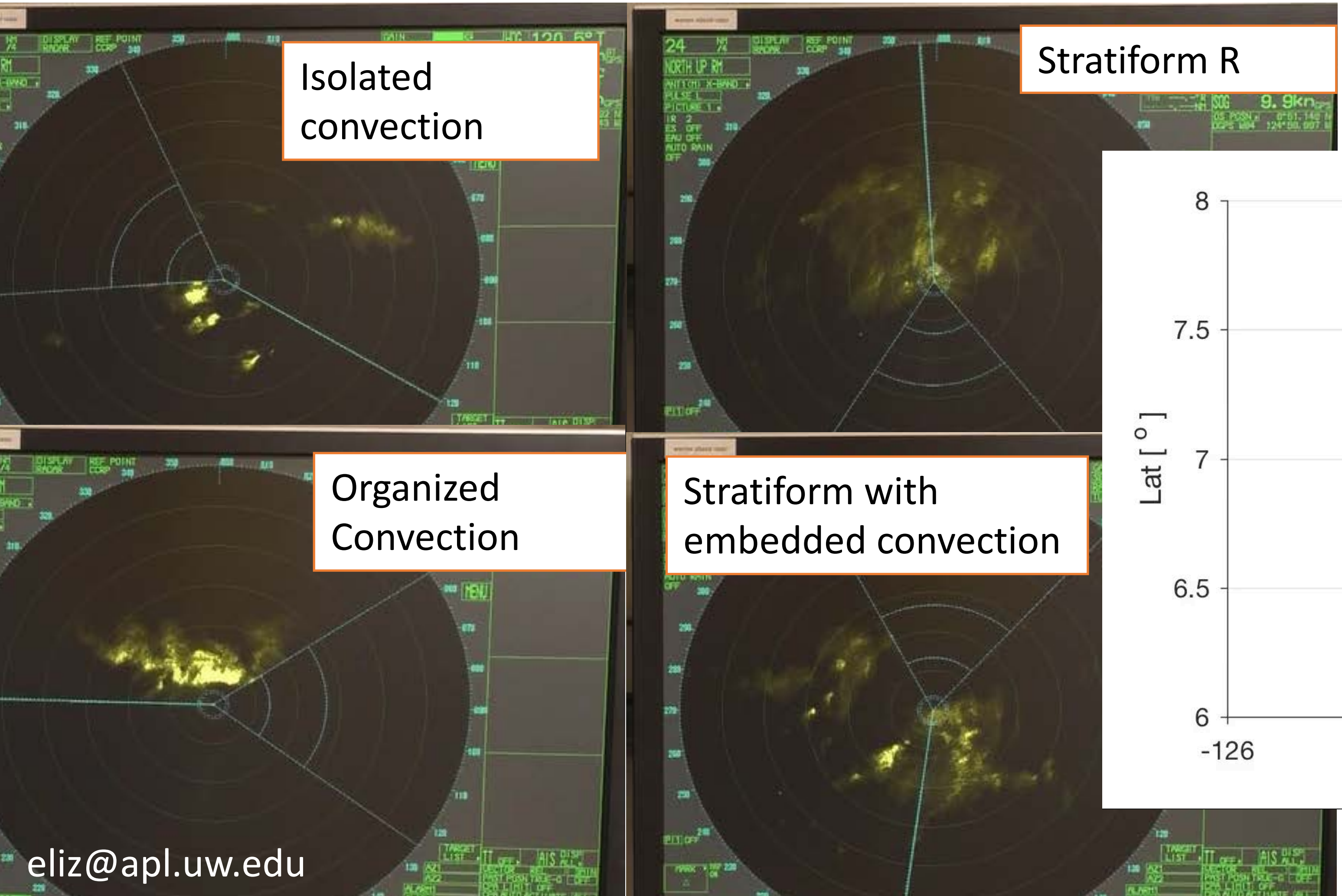
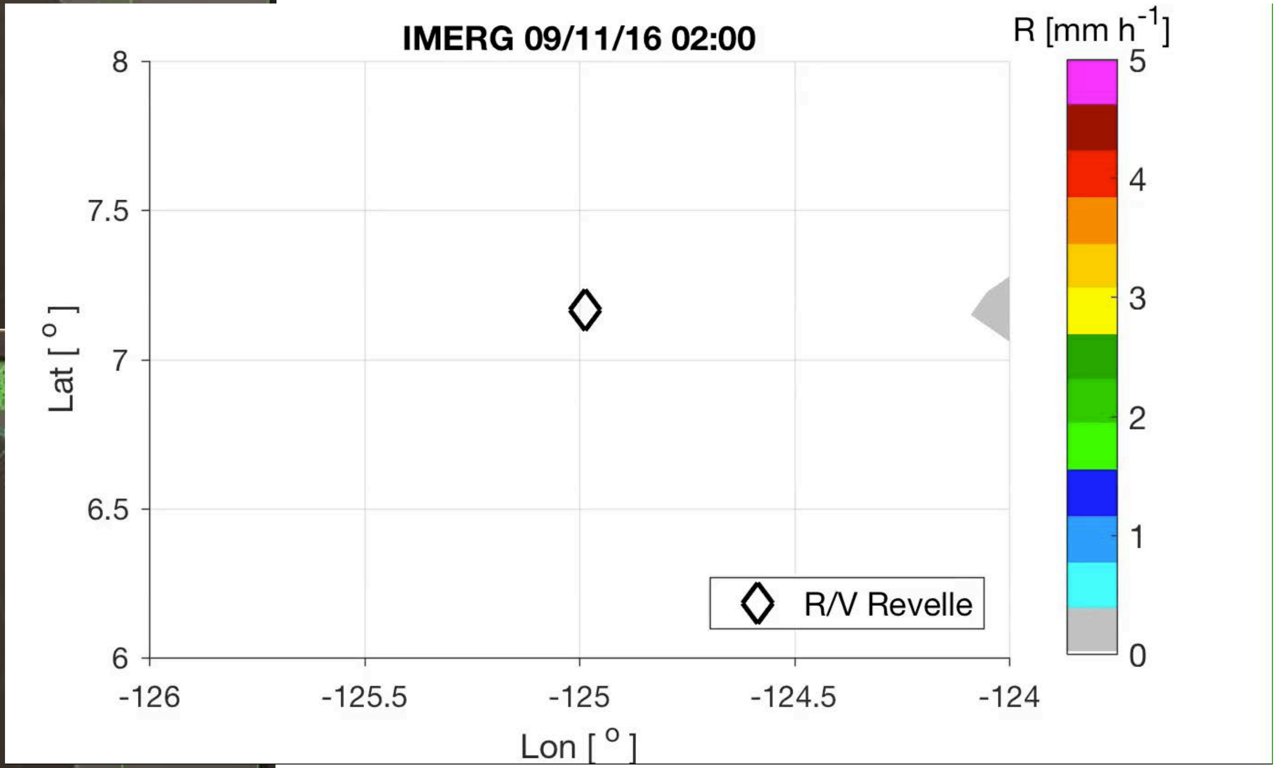
NASA GPM IMERG rain rate fails to capture mesoscale storm structure revealed by radar

24 nm range rings



120 nm x 120 nm Area



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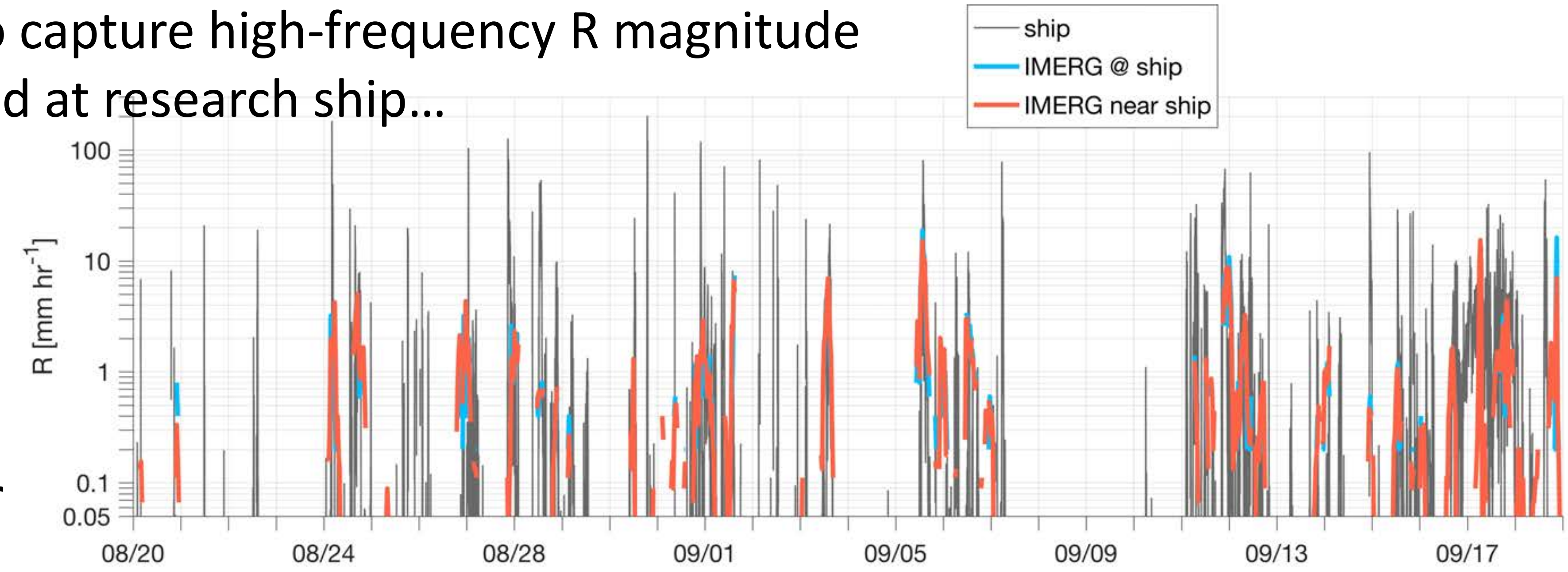
IMERG also fails to capture high-frequency R magnitude variability observed at research ship...



IMERG vs. ship rain gauge

IMERG R_{MAX} lower by order of magnitude and ΣR underestimated by 50%.

Most rain events lasting > 3 hr are captured by IMERG... But not all of them.

IMERG: zero false alarm rate

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IMERG also fails to capture high-frequency R magnitude variability observed at research ship…

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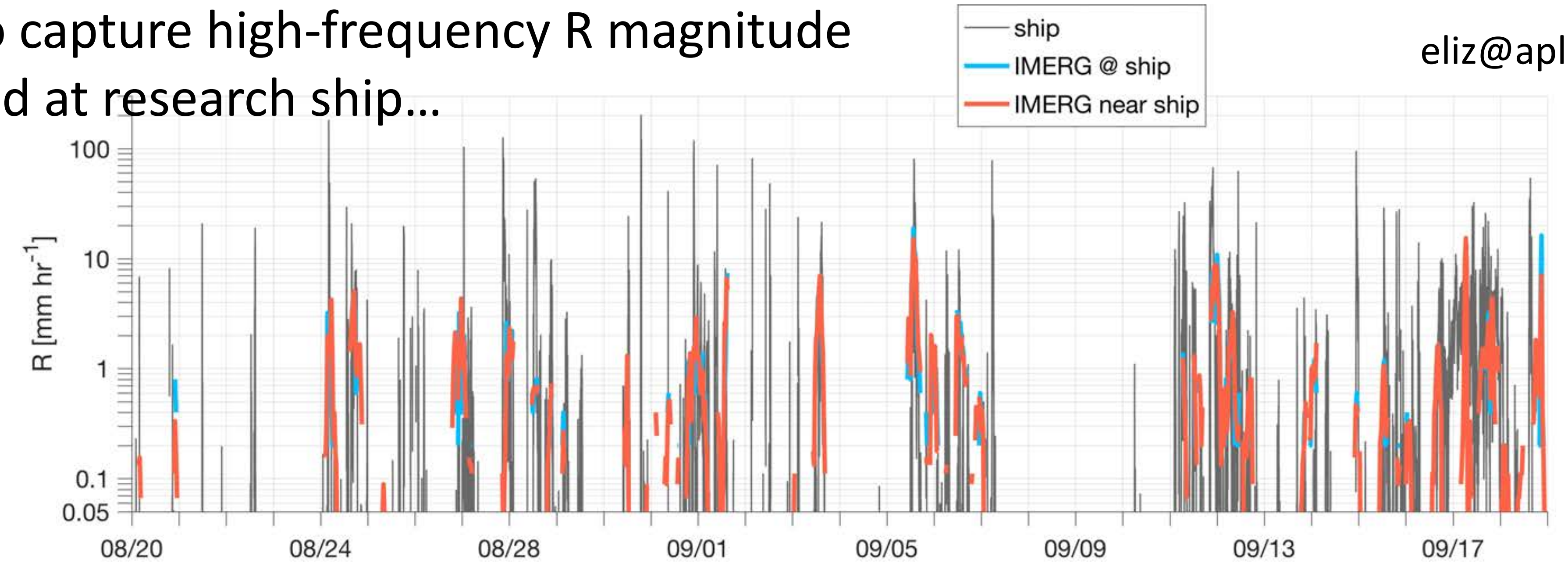
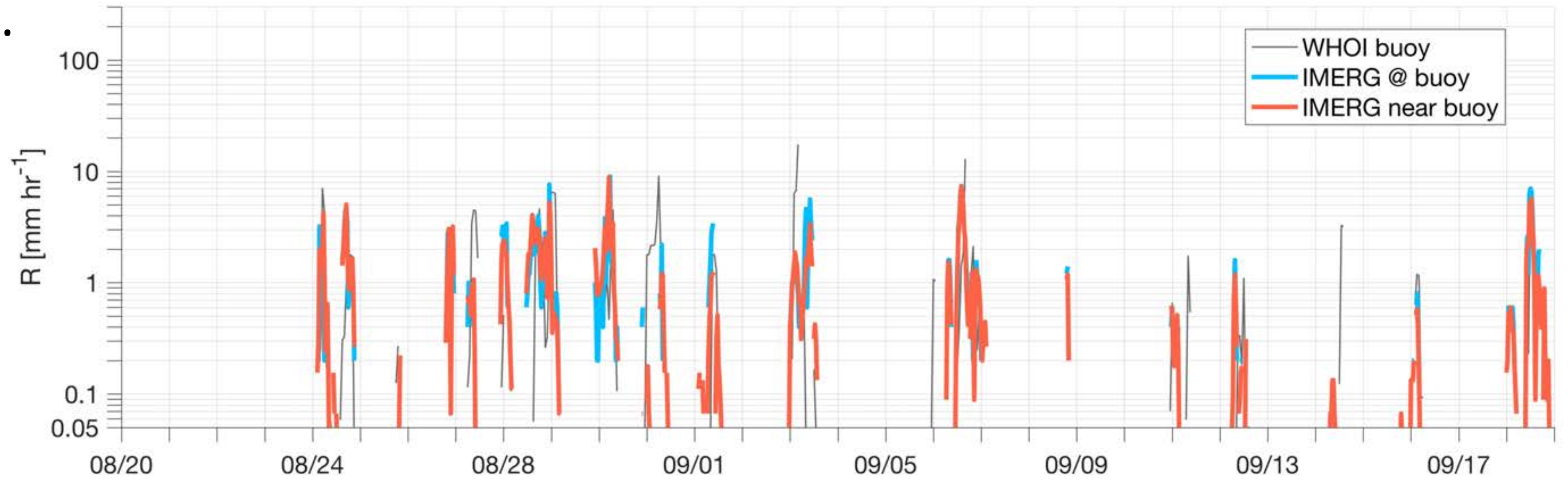
IMERG vs. ship rain gauge



However, (half-hourly) IMERG R exhibits remarkable agreement with WHOI central mooring R (hourly).

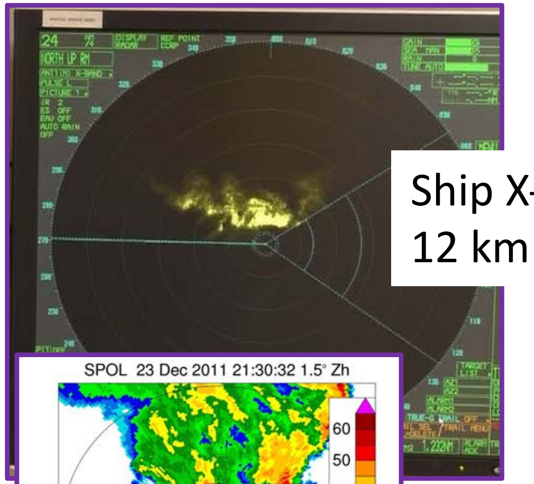
IMERG vs. central mooring

Similar R_{MAX} and ΣR

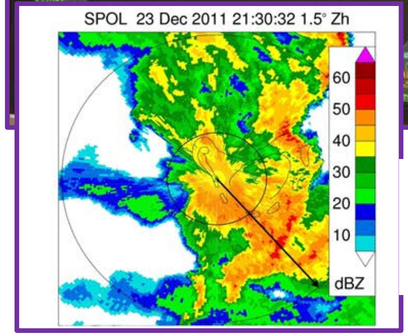


Therefore, IMERG R appears well-suited for ***hourly-average*** scales of precipitation.

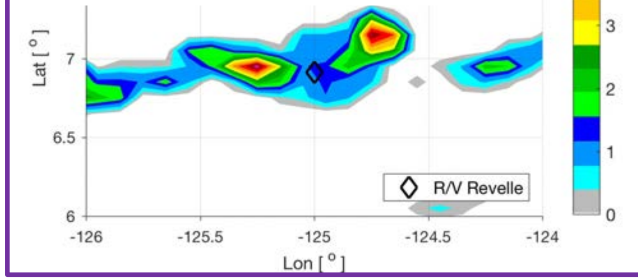
Summary: Freshwater lens timing, predictability, and detection



Ship X-band
12 km scale



Ship C-band
25 km scale



IMERG: Microwave + IR
220 km scale

- All rain events appear to have a 30% chance of creating a freshwater lens
  - convection is more common, but commonly too weak to produce a lens
  - stratiform rain implies a larger storm area, which implies different fresh lens evolution
- The timing and magnitude of dS/dz in the upper few meters is very closely linked to storm-scale precipitation processes on the order of minutes.
- IMERG is an upgrade from TRMM 3B42. It does not resolve storm-scale precipitation processes, but demonstrates great potential at one hour+ scales
- Our ability to connect these two scales will determine freshwater lenses predictability and detectability.
  - This will be attempted with SEA-POL C-band dual-polarization rain radar
    - 150 km range; 1 km horizontal and 3 min temporal resolution)
  - Radar will help develop a method to bridge the in-situ and satellite scales with through-hull port, gliders, drifter, and underway-CTD ocean measurements

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