Recent progress in using CYGNSS to investigate relationships between wind-driven surface fluxes and tropical oceanic convection

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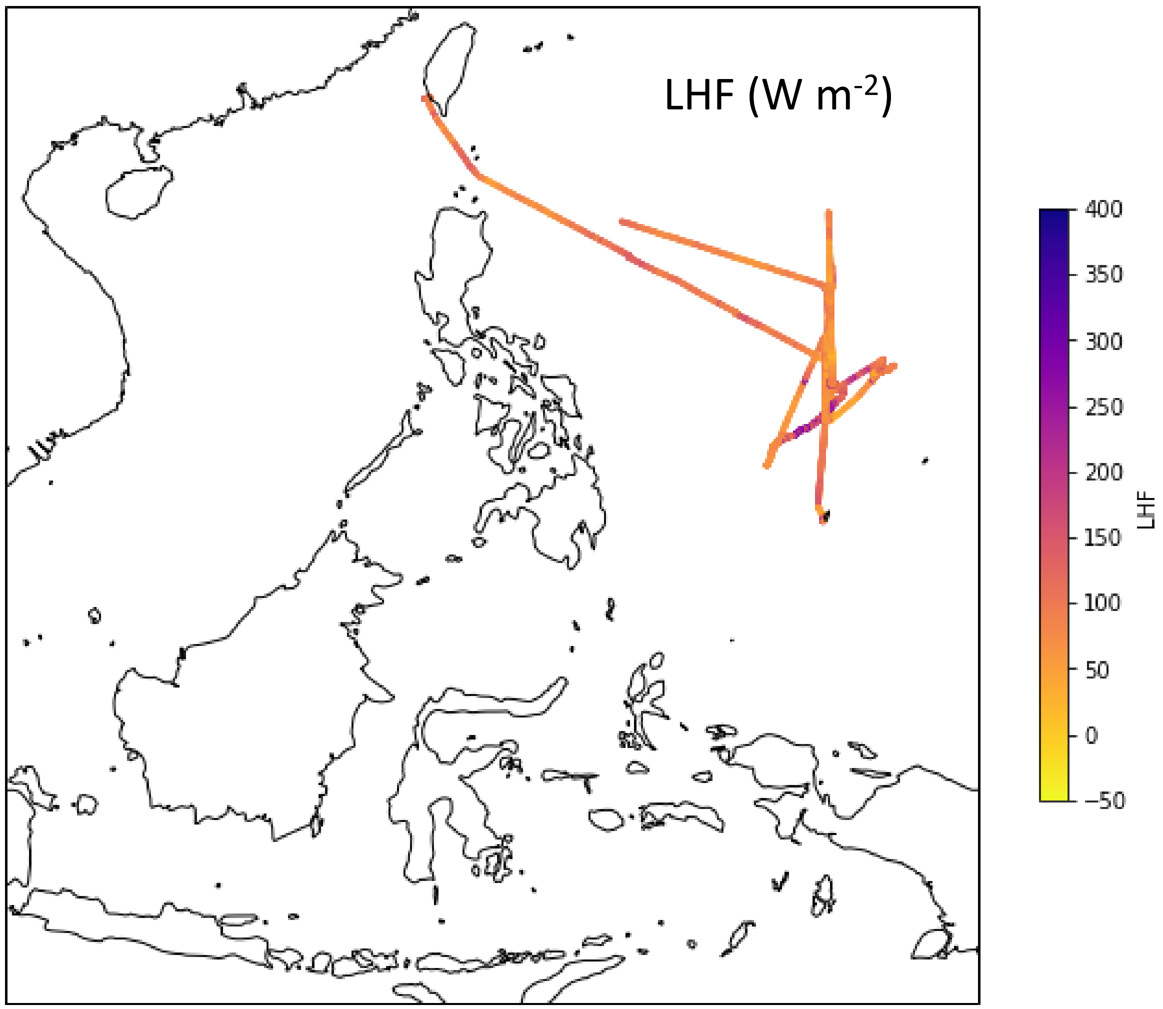
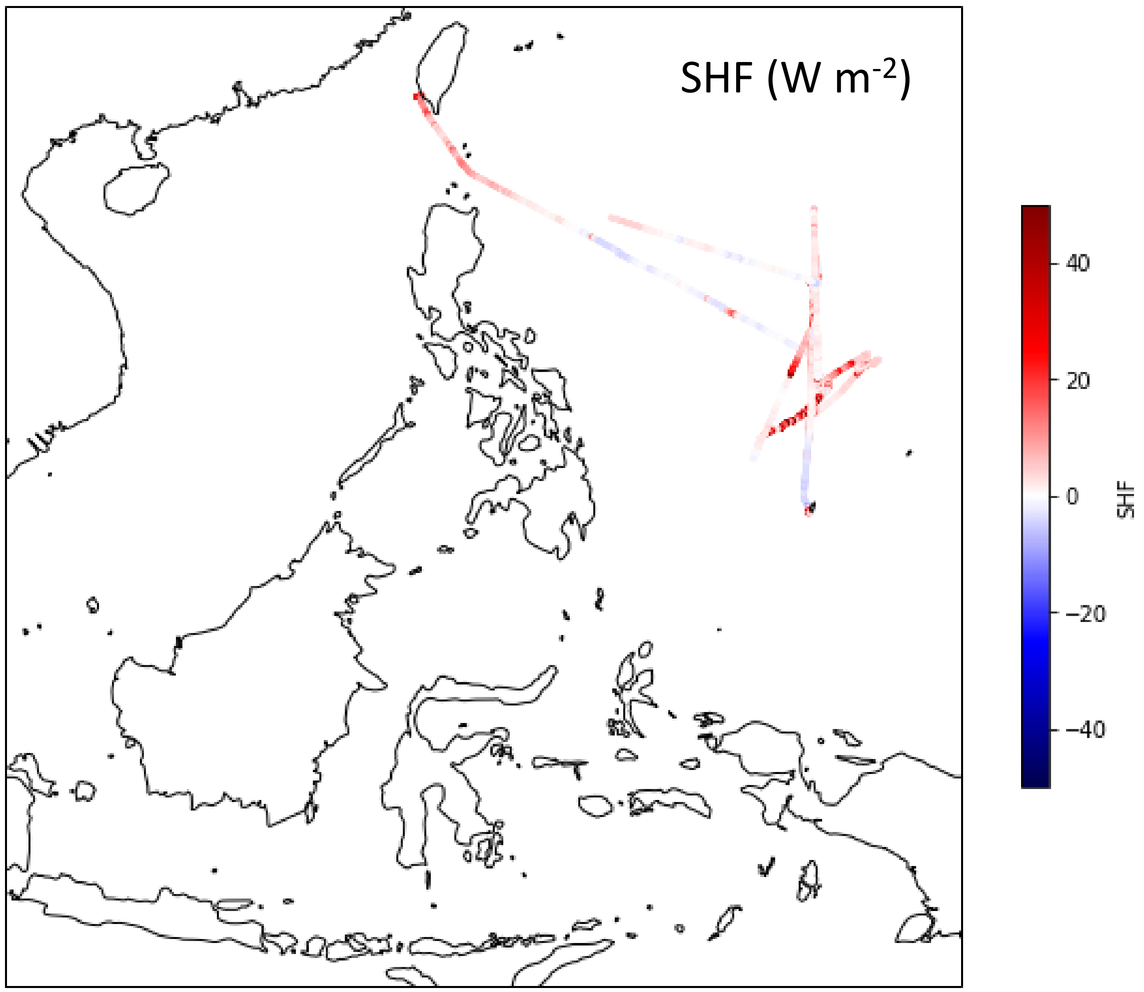
Presentation Overview

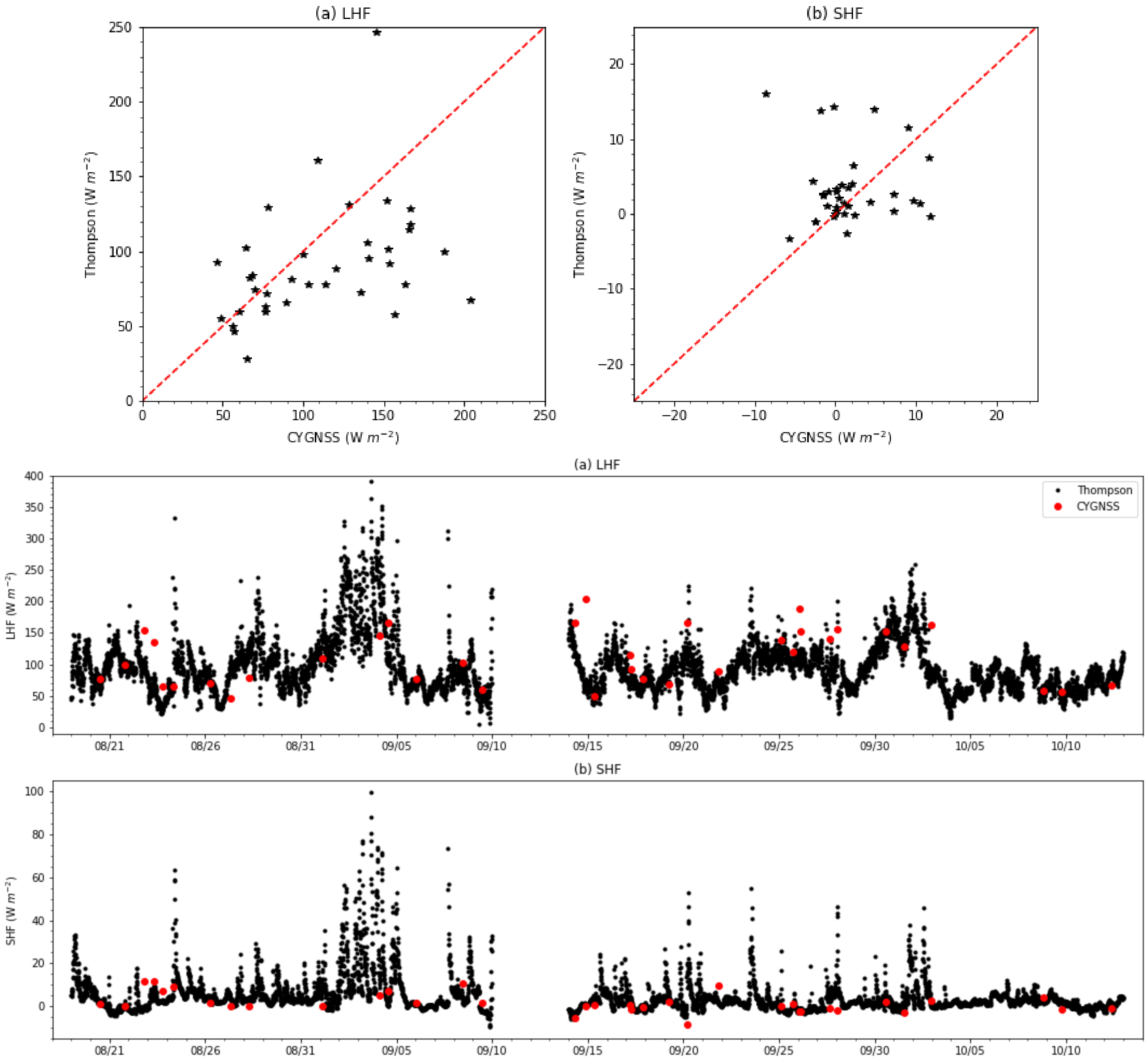
- Comparisons between CYGNSS and PISTON observations
- CYGNSS and MERRA-2 Kalman filter analysis
- CYGNSS tropical convection data assimilation experiments

PISTON Surface Flux Measurements

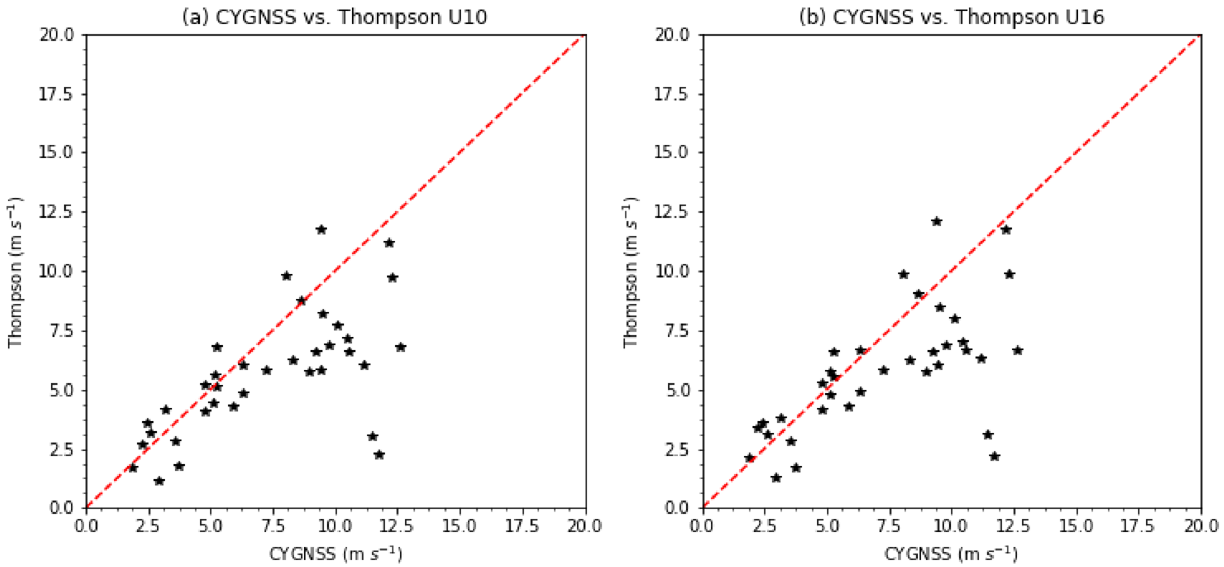


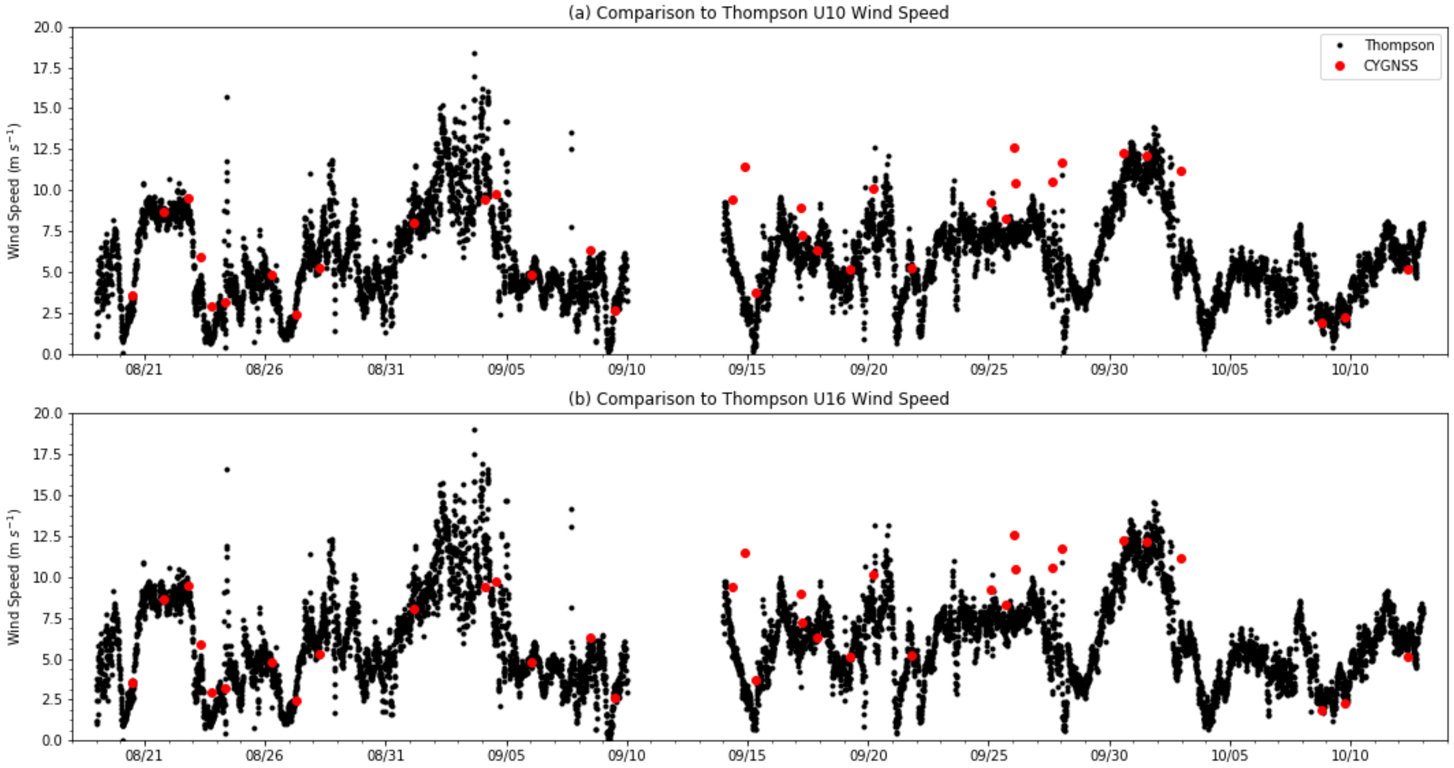


Flux data courtesy of Chris Fairall, NOAA



- Hourly averaged observations bookending overpasses within 25 km of ship
- 36 data points
- RMSDs of 50 W m^{-2} for LHF and 7 W m^{-2} for SHF
- CYGNSS bias is +20 W m^{-2} and -2 W m^{-2}, respectively.

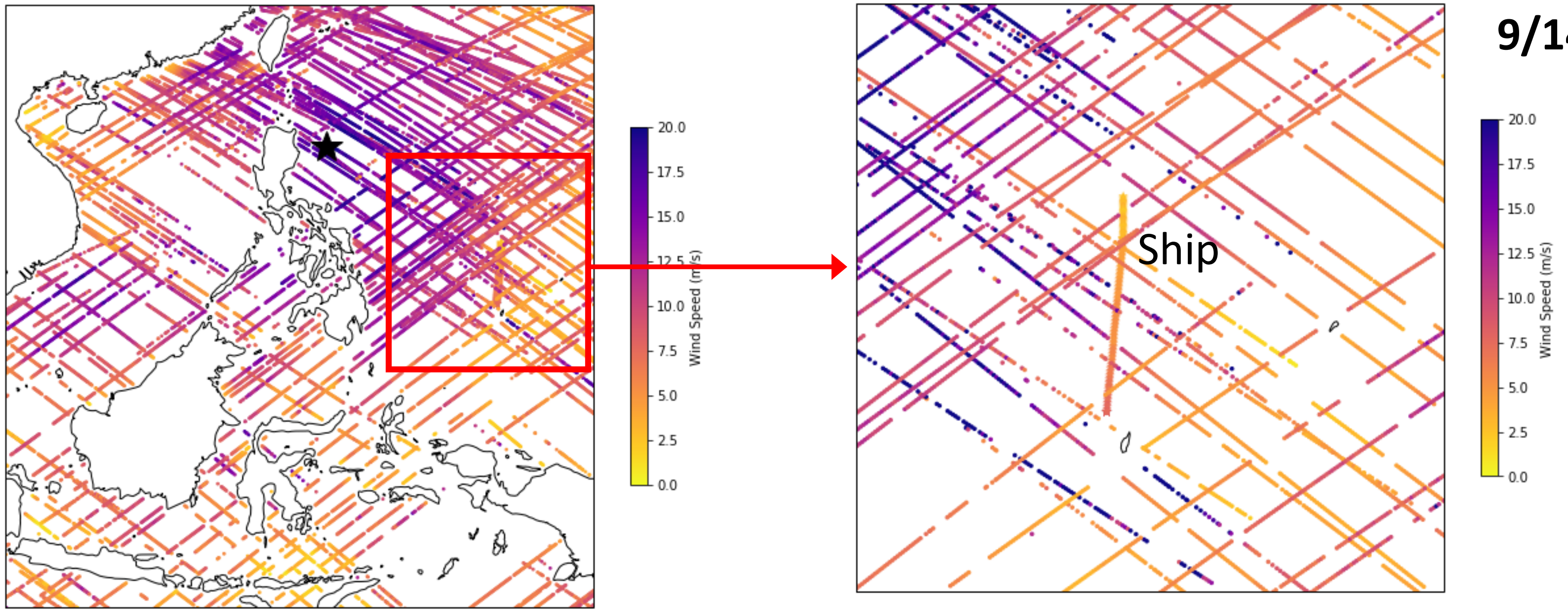




- 36 points for wind speed obs as well
- CYGNSS bias for U10 of +1.7 m/s and an RMSD of 3.1 m/s
- U16 comparison is +1.5 & 3.0 m/s, respectively

Examination of two wind speed overestimates

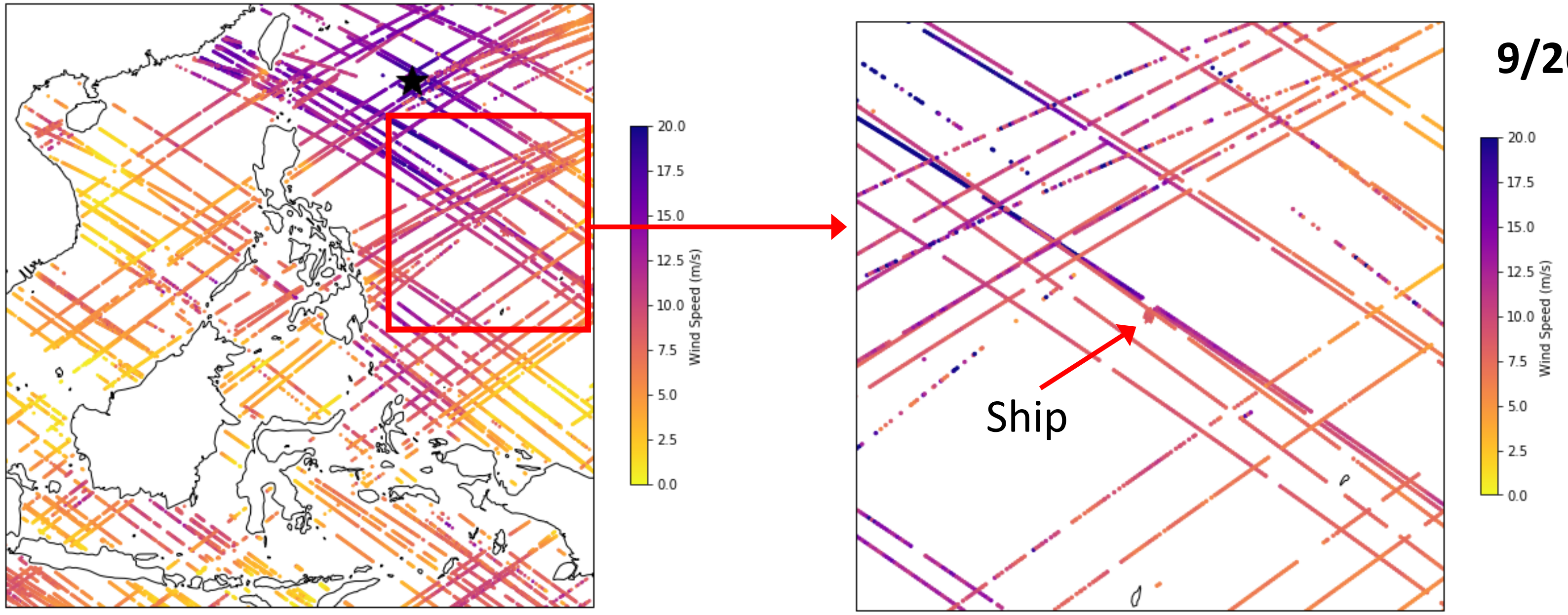
9/14/2018



Context

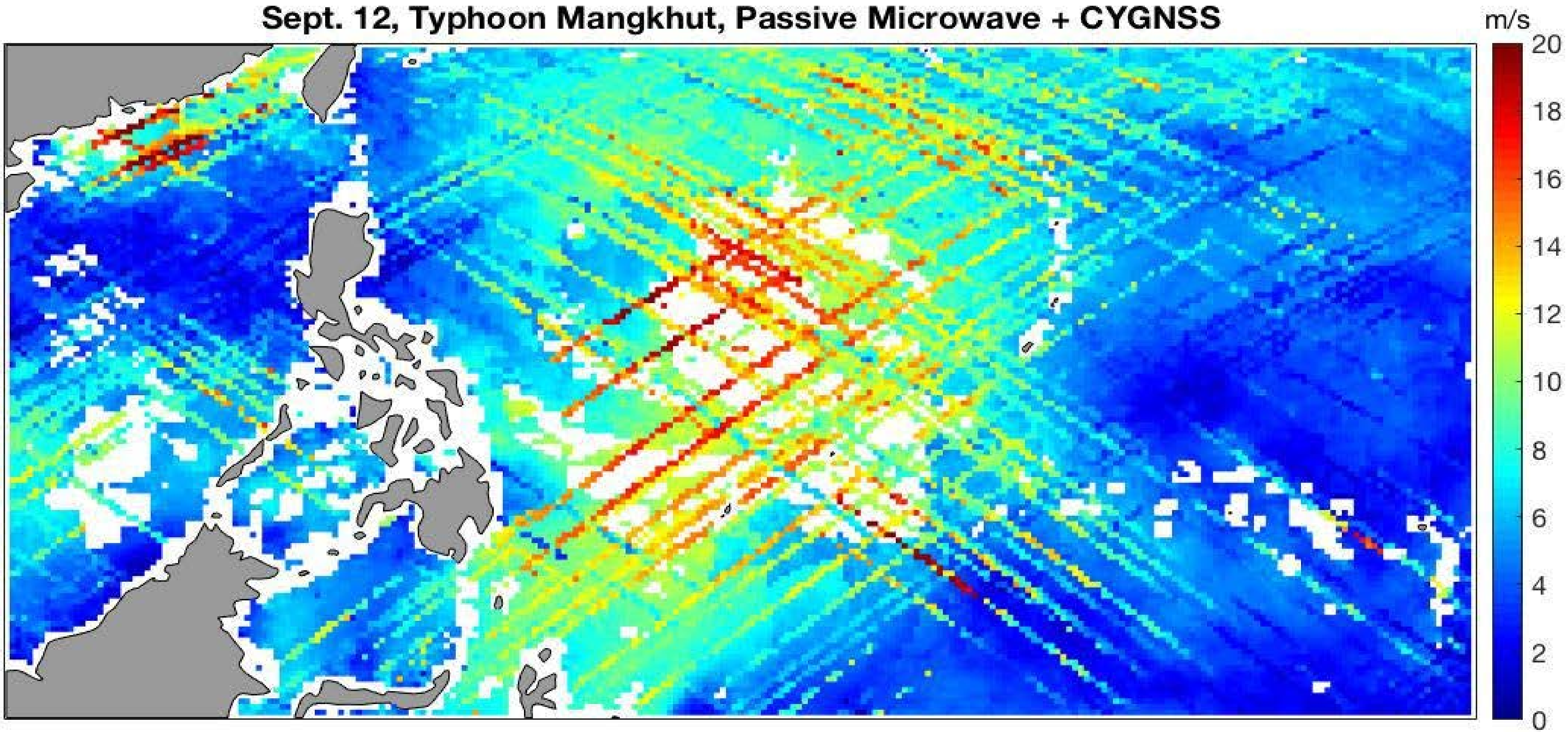
Typhoon Mangkhut

9/26/2018



Context

Typhoon Trami


Sept. 12, Typhoon Mangkhut, Passive Microwave + CYGNSS
m/s
20
18
16
14
12
10
8
6
4
2
0

Summary

- CYGNSS flux measurements commonly compare reasonably well with PISTON observations, but few data points due to low latitudes of ship and short duration of cruises;

- Flux outliers due to CYGNSS wind estimates; context is ship near outskirts of significant typhoons

Kalman Filtering

- Goal: *Generate a blended product that leverages the continuity and model-dynamics based evolution from the reanalysis with the available sampling from CYGNSS*
- Challenge: *Must take into account uncertainties of the CYGNSS observations and uncertainties in model background/evolution*
- Solution: *Make use of a local Kalman Filter*, and in particular make use of the "control-input" formulation*

$$x_k = Ax_{k-1} + Bu_{k-1} + w_{k-1}, \quad p(w) = \mathcal{N}(0, Q)$$
$$z_k = Hx_k + v_k, \quad p(v) = \mathcal{N}(0, R)$$

where:

x_k is the desired surface wind speed state, for a single map grid box

z_k are CYGNSS observations,

$\mathrm{A} = \mathrm{H} = \mathrm{B} = \mathrm{I}$,

u_k are MERRA-2 hourly time-tendencies, and

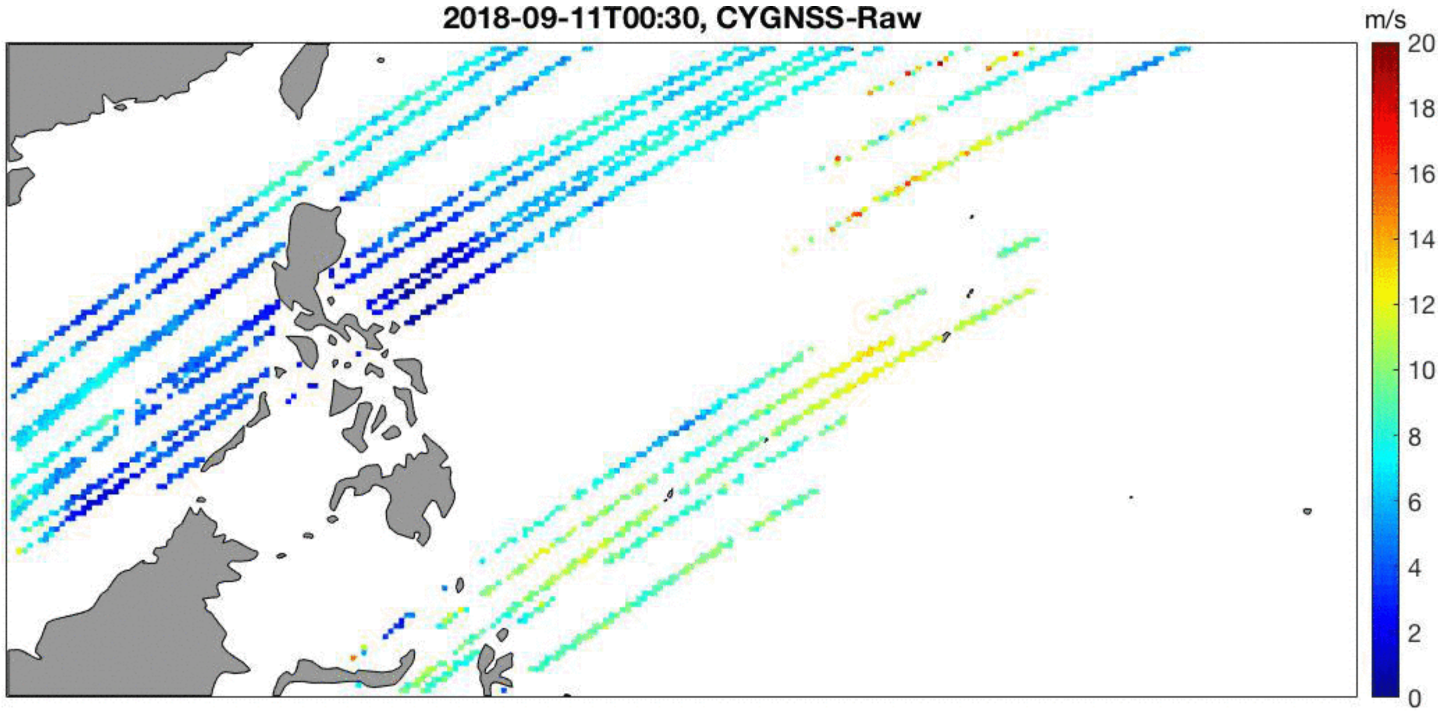
w, v are zero-mean Gaussian noise with process noise Q and observational noise R ; We use L3 wind speed errors for v

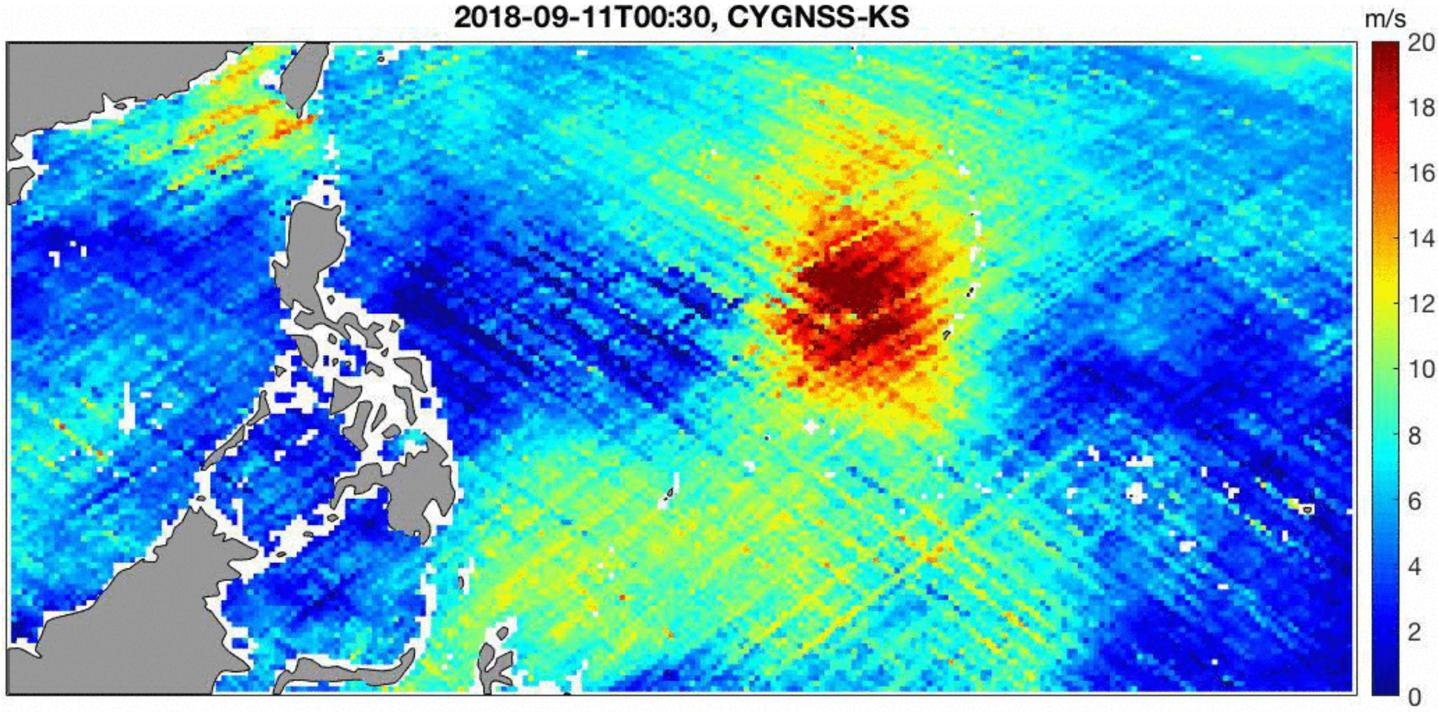
* Actually a Kalman Smoother is implemented using the RTS algorithm

Typhoon Mangkhut

Raw and Kalman Estimate

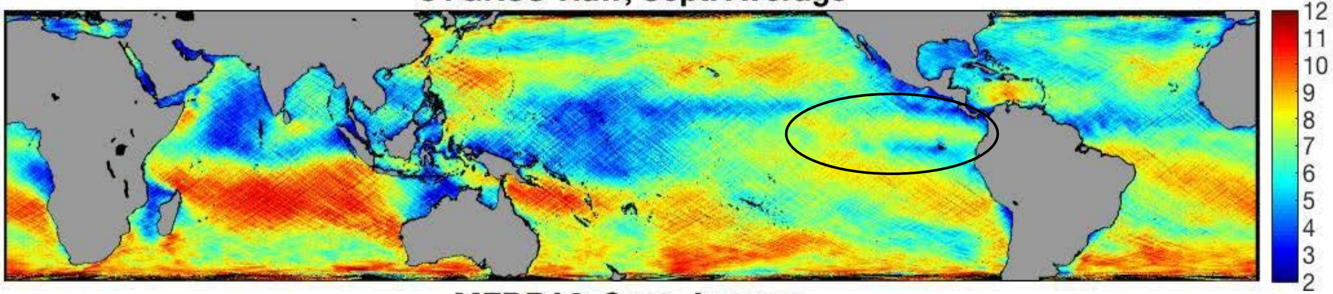
- Top panel shows the hourly evolution of sampling by CYGNSS (L3) wind speed estimates
- Bottom panel shows the gap-free hourly evolution upon using the Kalman smoother to combine the CYGNSS observed winds with MERRA2.
- With Kalman estimate, we can develop more complete estimates of area-average turbulent fluxes, including their temporal evolution



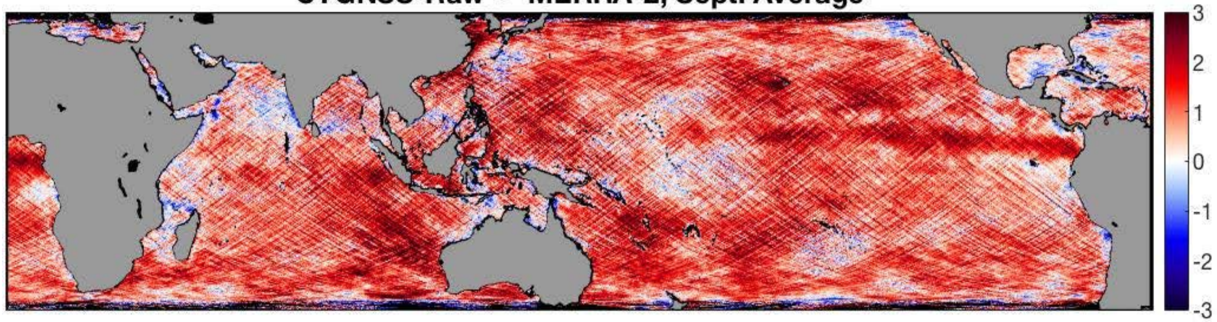


Monthly Statistics: Mean

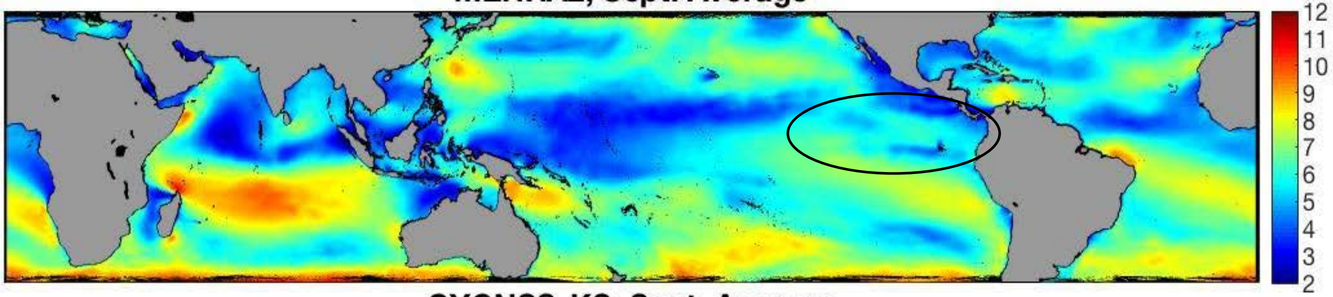
CYGNSS-Raw, Sept. Average



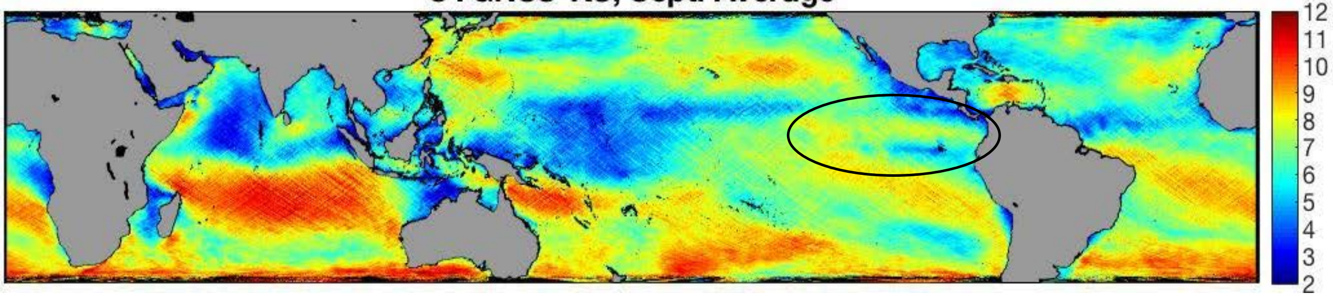
CYGNSS-Raw - MERRA-2, Sept. Average



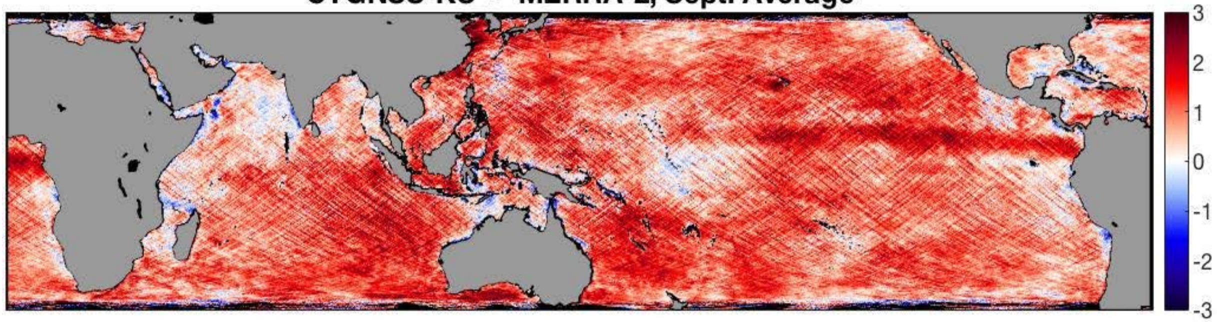
MERRA2, Sept. Average



CYGNSS-KS, Sept. Average

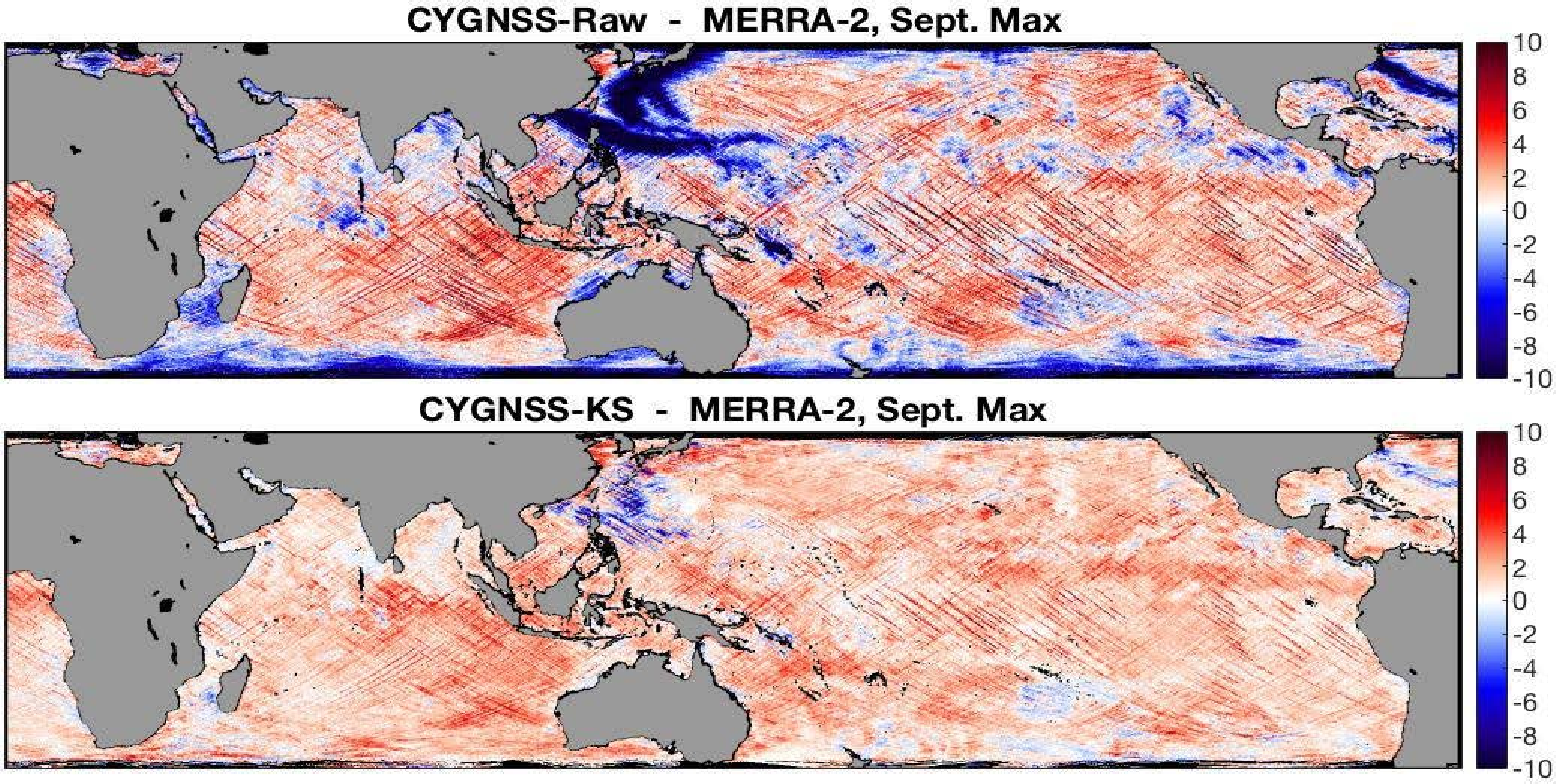


CYGNSS-KS - MERRA-2, Sept. Average



- The Kalman smoothed estimates result in a slightly smoother monthly average than the raw observations
- However, the general patterns and amplitudes of the Kalman estimates closely mirror the raw CYGNSS observations

Monthly Statistics: Max Wind



- The CYGNSS raw samples show strong underestimation (compared to MERRA-2) of maximum observed wind in Sept. 2018. This is generally associated with the tropical cyclone storm tracks; This results from both the use of the fully-developed seas retrieval *and* sampling variability around the times of peak winds at a location.
- The Kalman estimates help strongly mitigate the underestimates related to sampling; but, it can’t correct for the choice of using the fully-developed seas vs. limited-fetch retrievals

Summary & Future work – Kalman Filter

Summary

- We have developed an implementation of a Kalman Filter to leverage continuous large-scale dynamical evolution fields (i.e., the model tendencies) together with CYGNSS observations to result in a gap-free wind field estimate that can be used to mitigate the need to tradeoff temporal resolution of rapidly evolving systems.

Future work

- Need to consider performing a spatial OI to mitigate the “edge” effects related to high pixel-to-pixel sampling variability. We have already developed code to do this but more testing is needed.

Assimilation of CYGNSS data for tropical convection

Objectives

1. Assimilation of CYGNSS v2.1 L2 wind speed data (LF product)

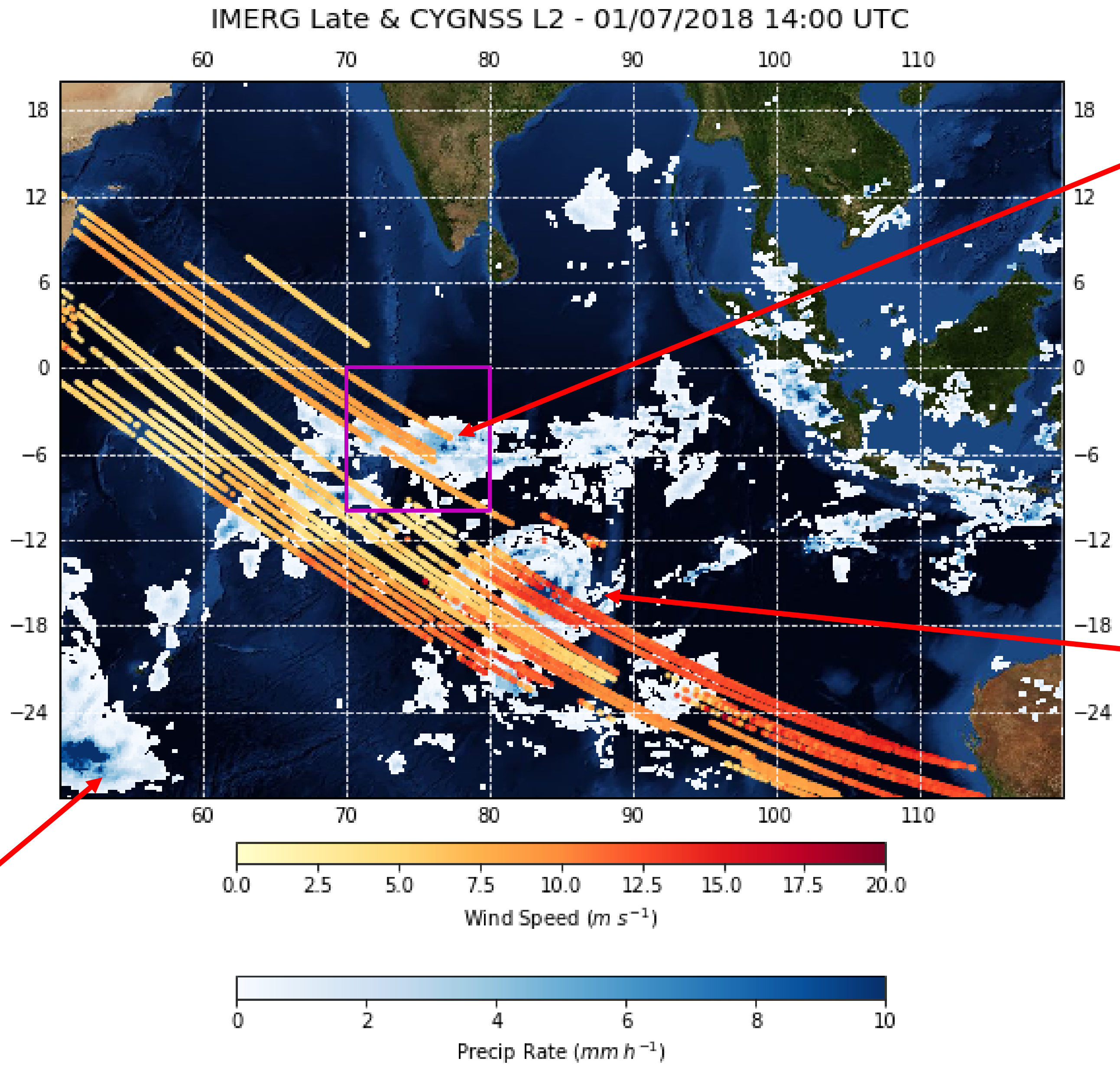
2. Assimilation of combined satellite data (IMERG precipitation, ASCAT ocean surface wind vector, and CYGNSS LF wind speed)

3. Examination of the impact of CYGNSS data on forecasts of mesoscale convection, specifically on WWBs and TCs

LF – "Limited Fetch" Geophysical Model Function (GMF) used for Young Seas
FD – "Fully Developed”

IMERG and CYGNSS

~1 hour of data



Westerly Wind Burst

(prior slide)

TC Irving

TC Ava

Assimilation of CYGNSS v2.1 L2 data for 2018 January MJO

WRFDA hybrid En3dvar (12 members)

WRF Domain: 9 km resolution (450x450x40)

WRF Model Simulation: 00 UTC 6 January – 00 UTC 09 January 2018

Data: CYGNSS v2.1 L2 wind speed

FD: Fully developed sea

LF: High winds for young sea around strong convection

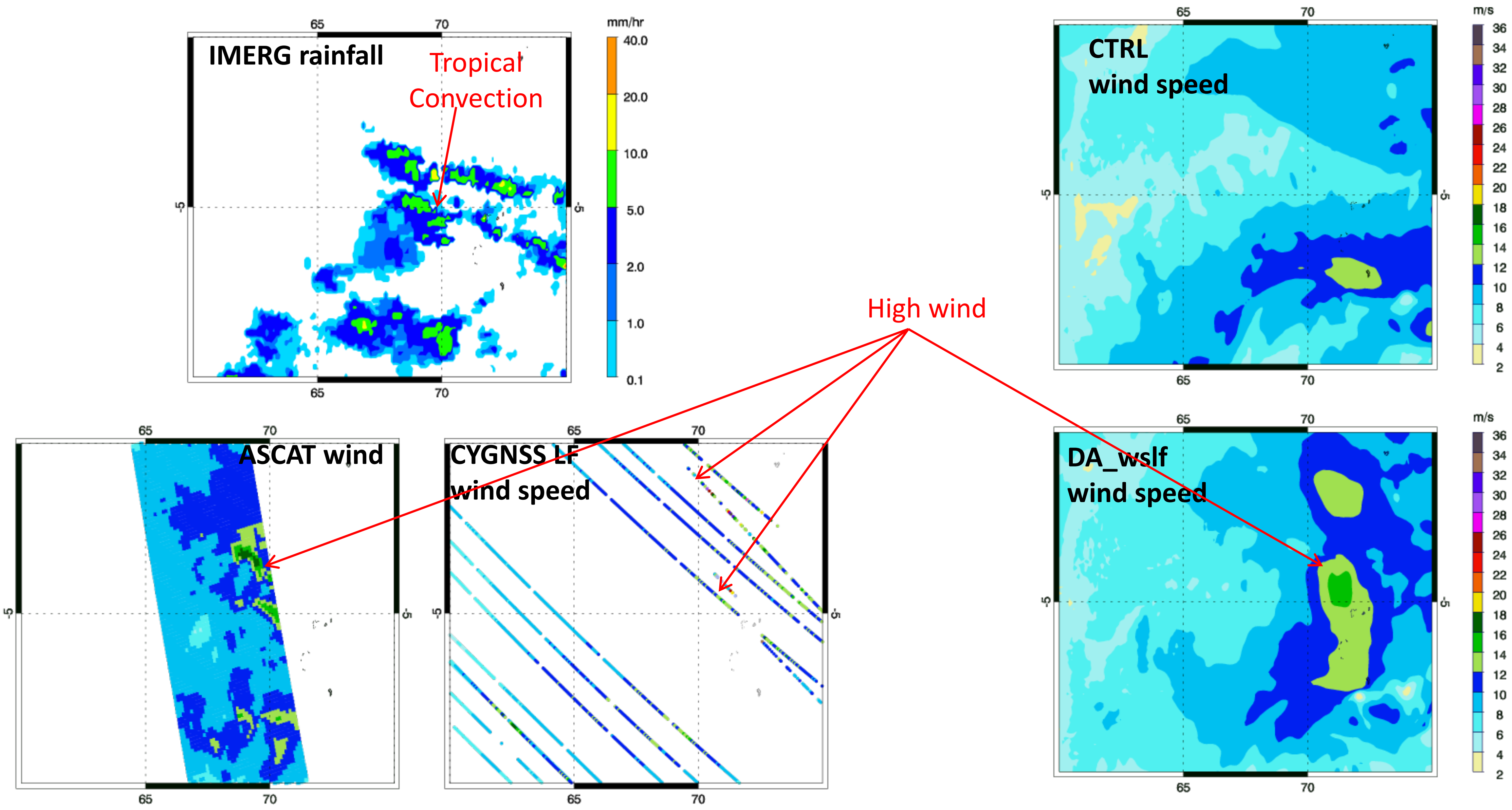
Focus: Continuous assimilation of v2.1 L2 wind speed data for the WWBs and Tropical Cyclone Irving

Observational error: 2 m/s for windspeed < 20 m/s

10% for windspeed > 20 m/s

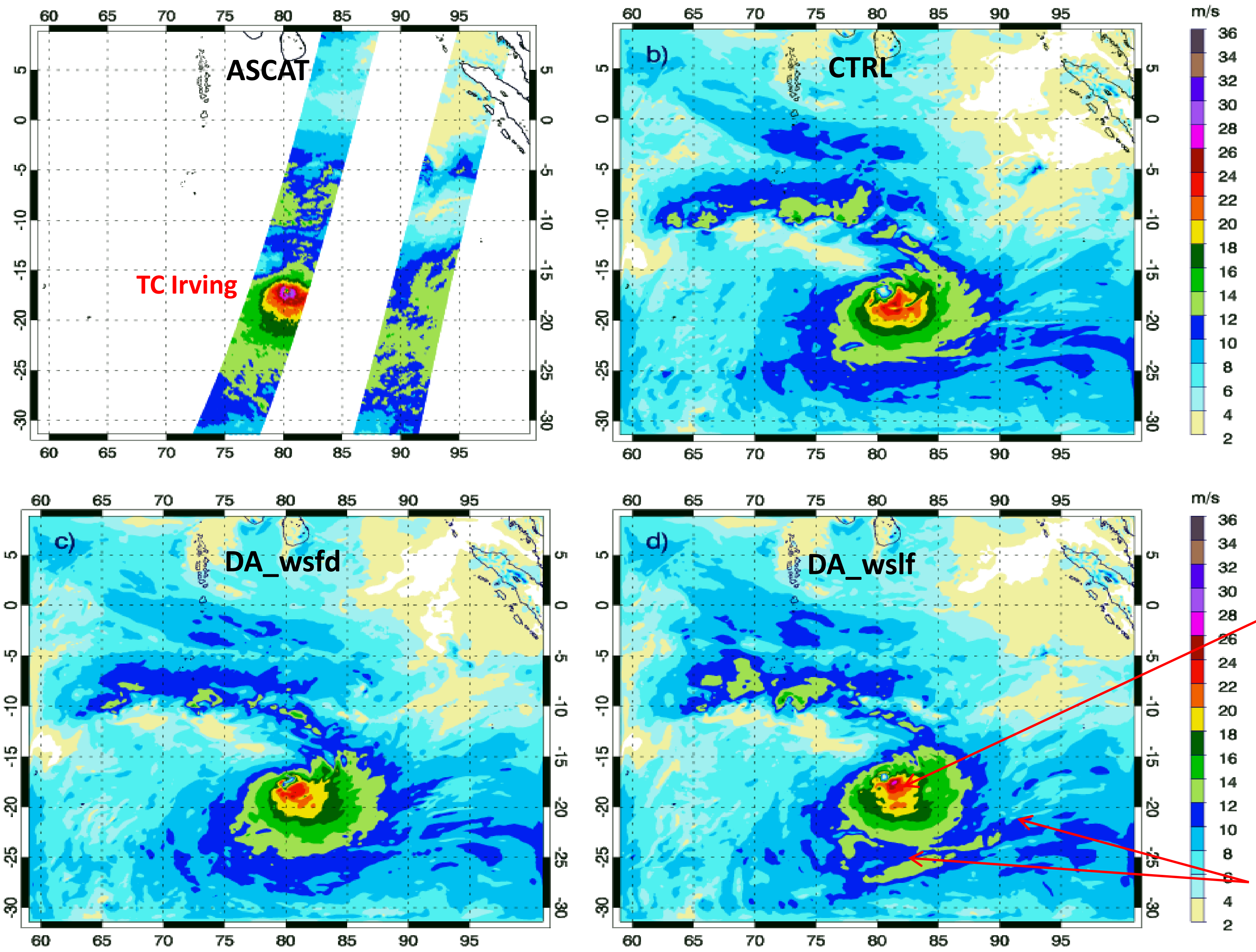
Experiment	Data Assimilation
CTRL	No
DA_wsfd	CYGNSS Level 2 FD wind speed at 00, 12, 15, 21 UTC 06 – 08 January 2018 using data ±1.5 h around the analysis times
DA_wslf	CYGNSS Level 2 LF wind speed at 00, 12, 15, 21 UTC 06 – 08 January 2018 using data ±1.5 h around the analysis times

Impact of CYGNSS v2.1 L2 LF wind speed data



15 UTC 2018-01-07

CYGNSS data impact – Surface wind of TC Irving

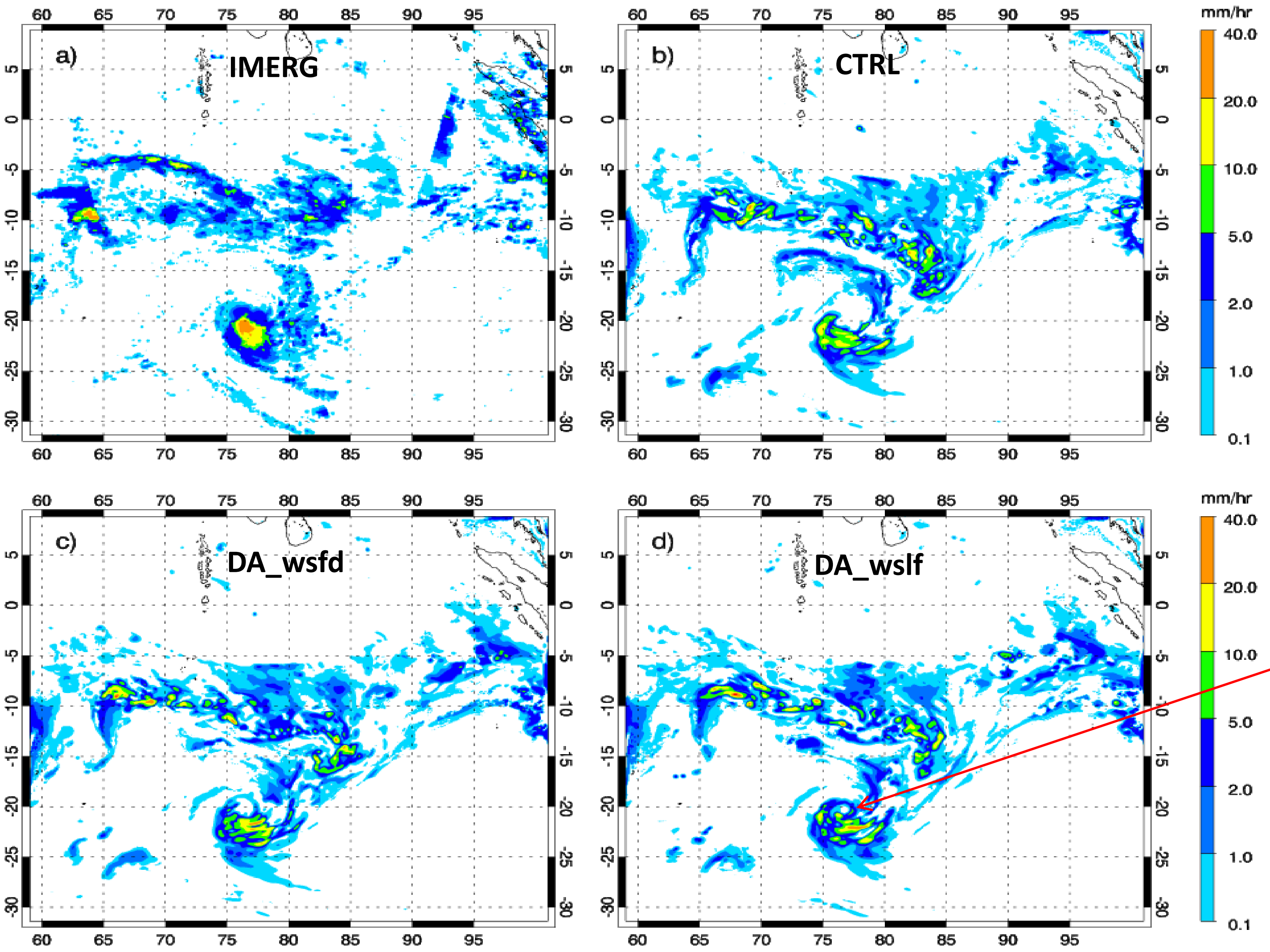


03 UTC 2018-01-08

For TC Irving, smaller eye with higher maximum surface wind, stronger precipitation around TC eyewall were found with assimilation of CYGNSS data.

Higher wind

CYGNSS data impact – 1-h Precipitation Forecast



After 11 DA cycles, 18 - 19 UTC 2018-01-08

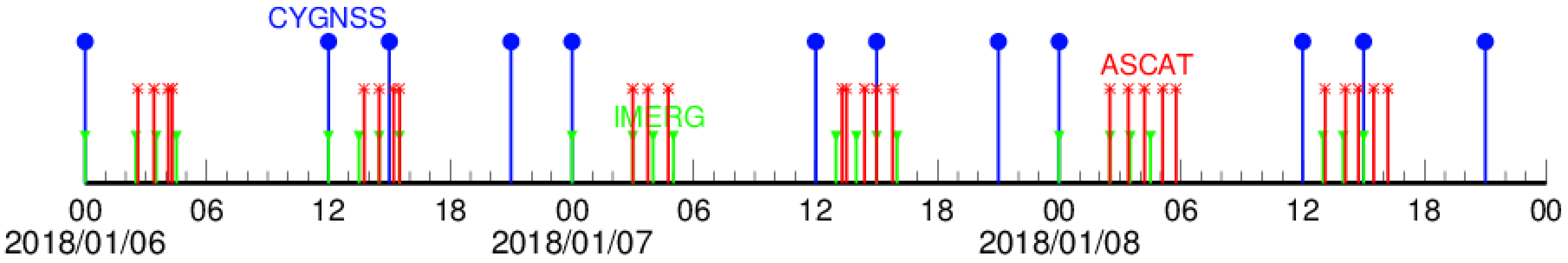
Impact found in precipitation of TC Irving when CYGNSS data is assimilated, but not significantly better than CTRL

Assimilation of combined satellite data

Data: IMERG hourly rainfall, ASCAT ocean surface wind vector, CYGNSS v2.1 L2 LF wind speed

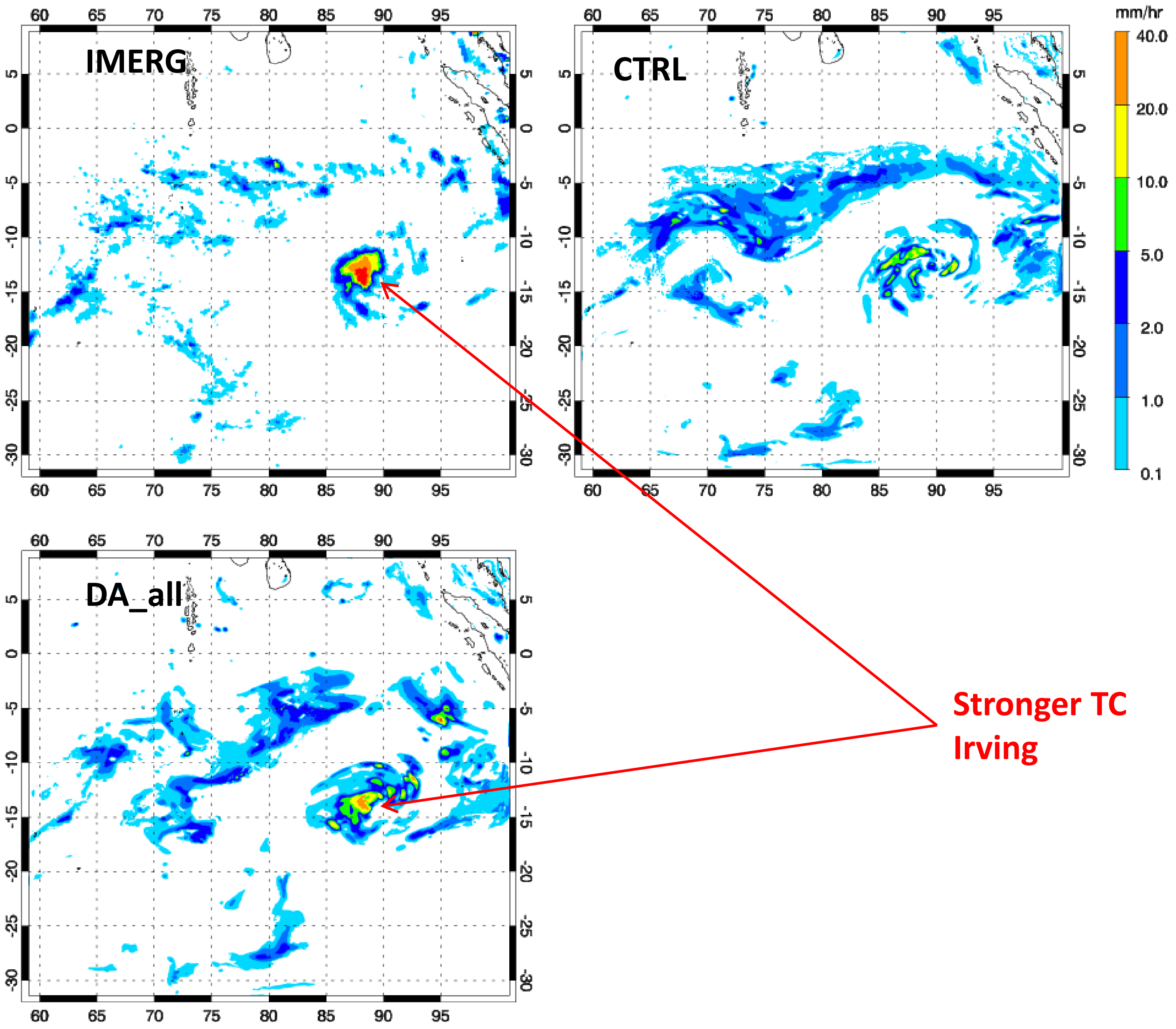
WRFDA hybrid En4dvar (12 members)

Experiment: DA_all (Continuous assimilation of combined data with the following DA window)



Impact of assimilation combined data on precipitation forecast

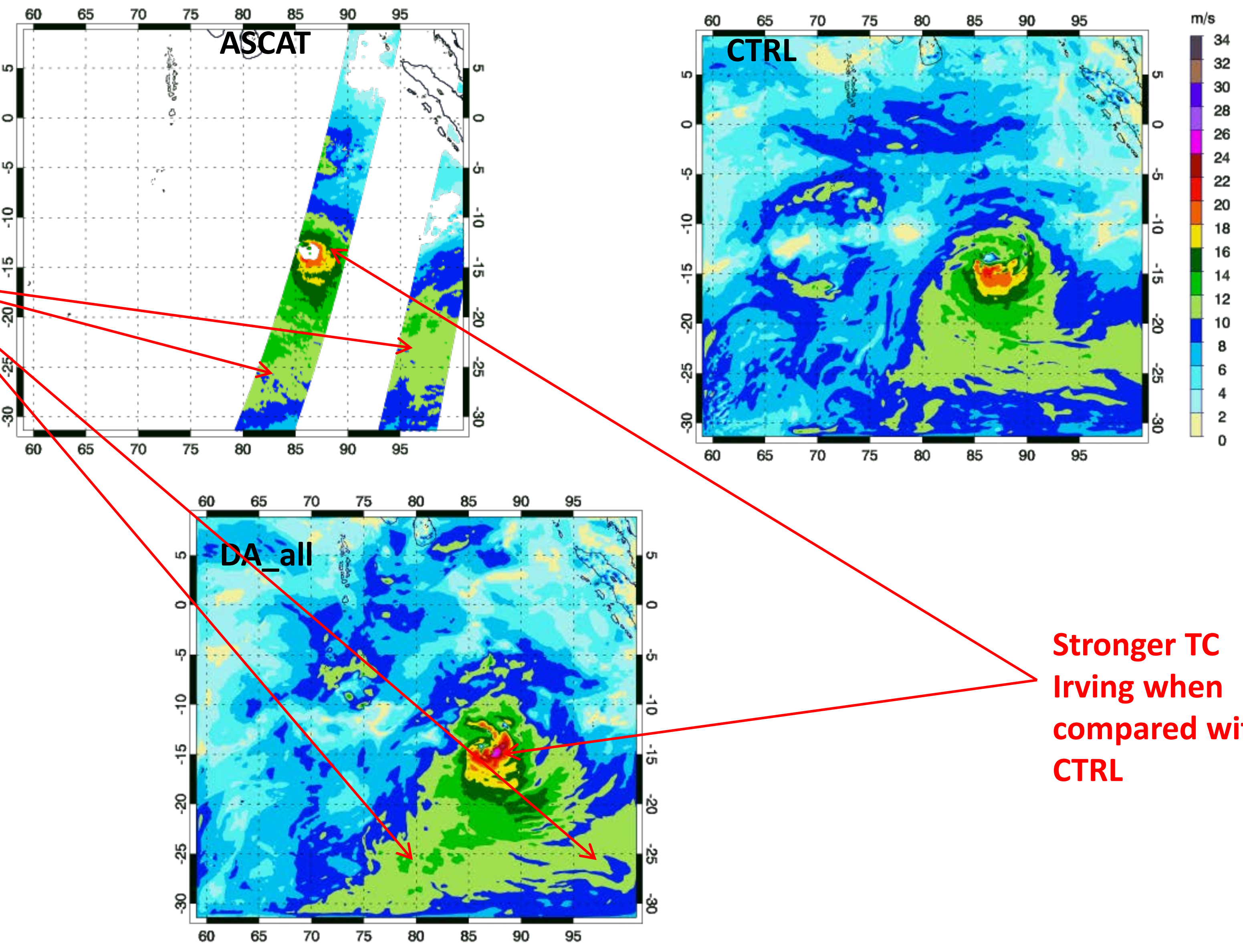
After the 3rd DA cycle
12 UTC 2018-01-06



Stronger TC
Irving

Impact of assimilation combined data on wind forecast

After the 6th DA cycle
03 UTC 2018-01-07



Higher wind over rainband area

Stronger TC Irving when compared with CTRL

Summary

- CYGNSS v2.1 data observes January 2018 MJO onset and associated WWB
- Positive impact of assimilation of v2.1 LF wind speed data found in wind field of both WWB and TC Irving (LF > FD)
- Impact of CYGNSS v2.1 wind speed data on precipitation is not significant
- Assimilation of combined data (IMERG, ASCAT, and CYGNSS) showed positive impact on precipitation and storm location -- this work is still ongoing.
- Future work: continue assimilation of combined datasets, high resolution simulation (~1km) to take advantage of the high frequency CYGNSS data