Using satellite derived motion winds to improve monitoring and forecasting of tropical cyclones (13D.1)

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Motivations

- **Derived Motion Winds (DMVs) have improved** with the latest generation of geostationary satellites and may be under utilized
  - Greater observation density
  - Generated hourly
- Intensity forecasting aids (JTWC and NHC) are **greatly dependent on the Global Forecasting System** analyses and forecasts
  - Are about four hours latent
  - Provide input or boundary conditions for most models (statistical or numerical) used for intensity forecasting

Can DMV-based information aid in forecasting intensity change, provide more up-to-date information, and decrease some of the dependence on the GFS?

Can DMV-based information aid in radius of maximum wind estimation?

What will be discussed?

- Develop hourly upper-level **DMV (Derived Motion Wind) analyses** for tropical cyclone monitoring

- Develop four **environmental metrics** from an upper layer (100 to 350 hPa)
    1. Vertical wind shear proxy
    2. Large-scale divergence
    3. Outflow imbalances
    4. Radius of zero tangential wind

- Examine the information provided in those metrics
    1. Rapid intensification prediction
    2. Estimating the radius of maximum wind

Analyses (~2 hours latency)

Inputs (hourly):

NESDIS/STAR DMVs (GOES, Himawari)

DMWs in the 350 to 100 hPa layer

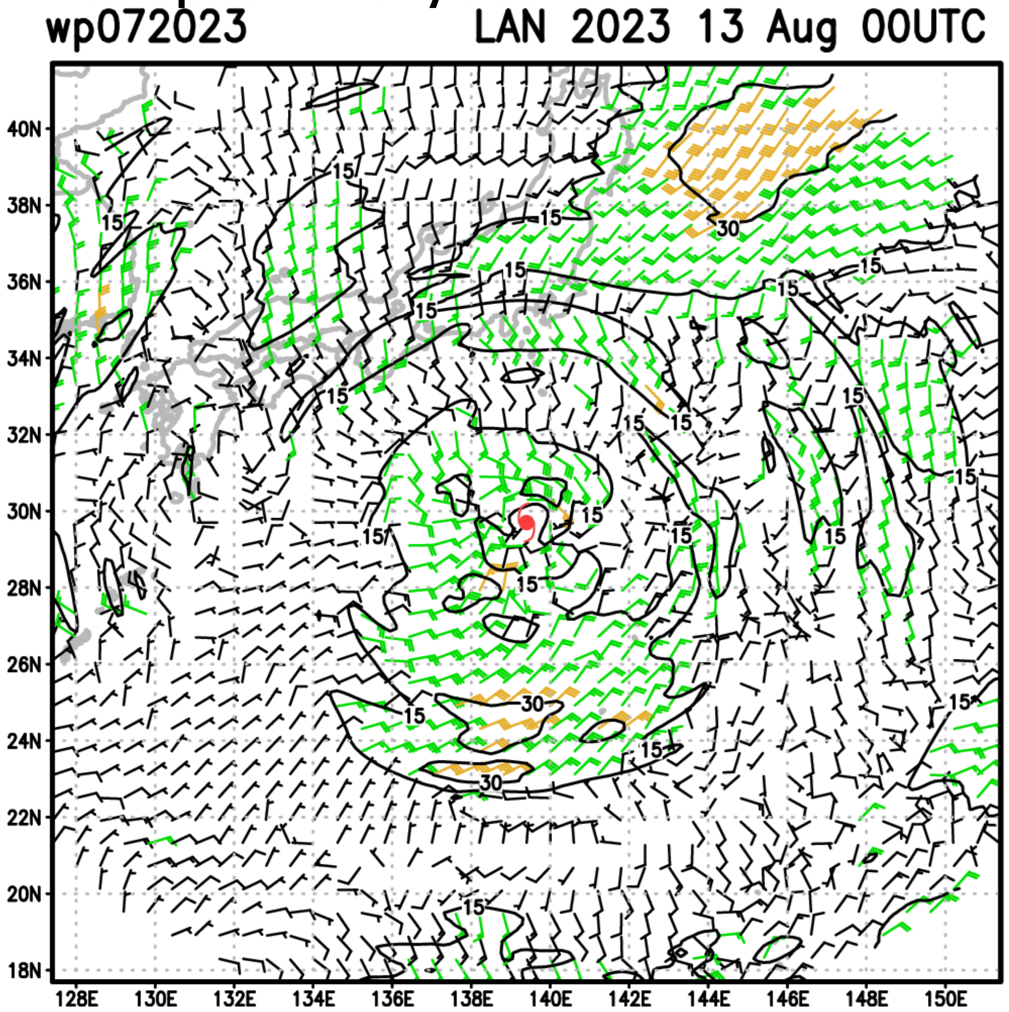
Analysis:

Iterative, objective, data-weighted analysis approach (Knaff and Slocum 2024)

Previous analysis is the first guess

Differing smoothing constraints in the radial and azimuthal directions

Example Analyses

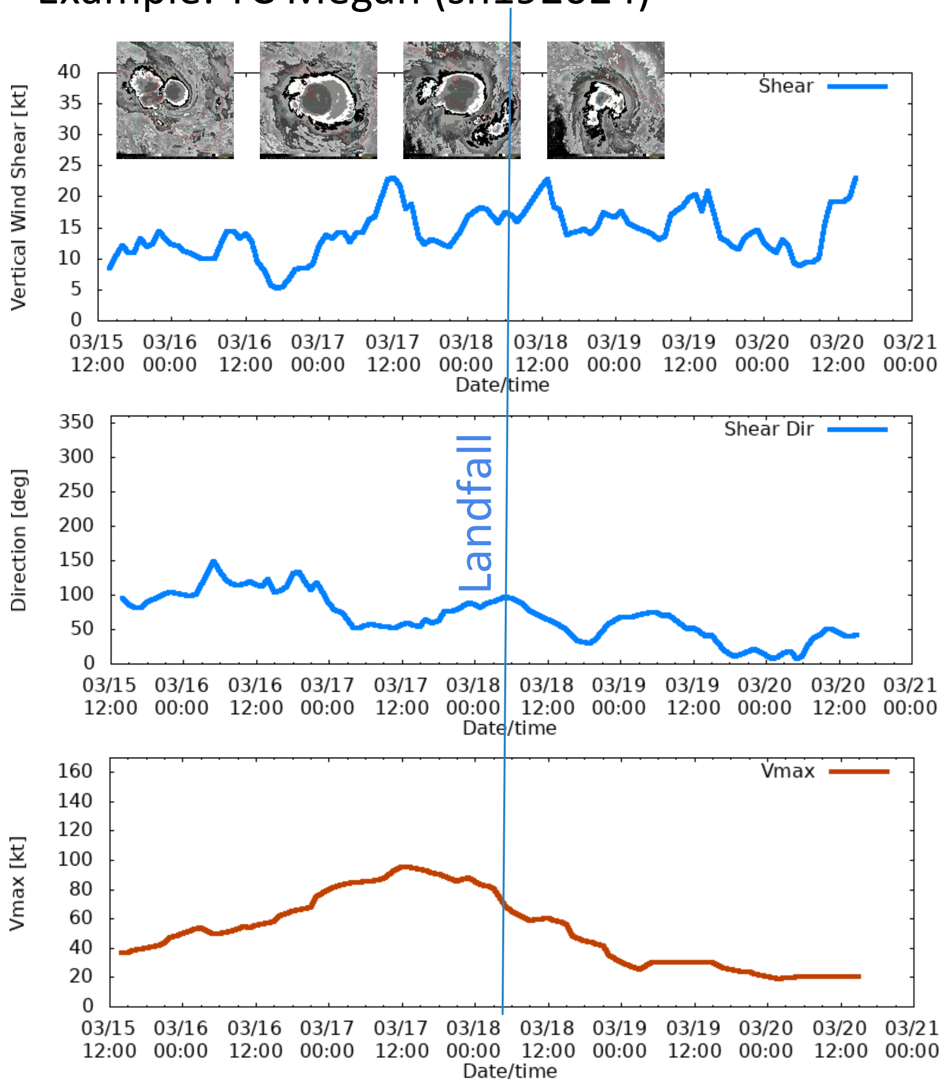


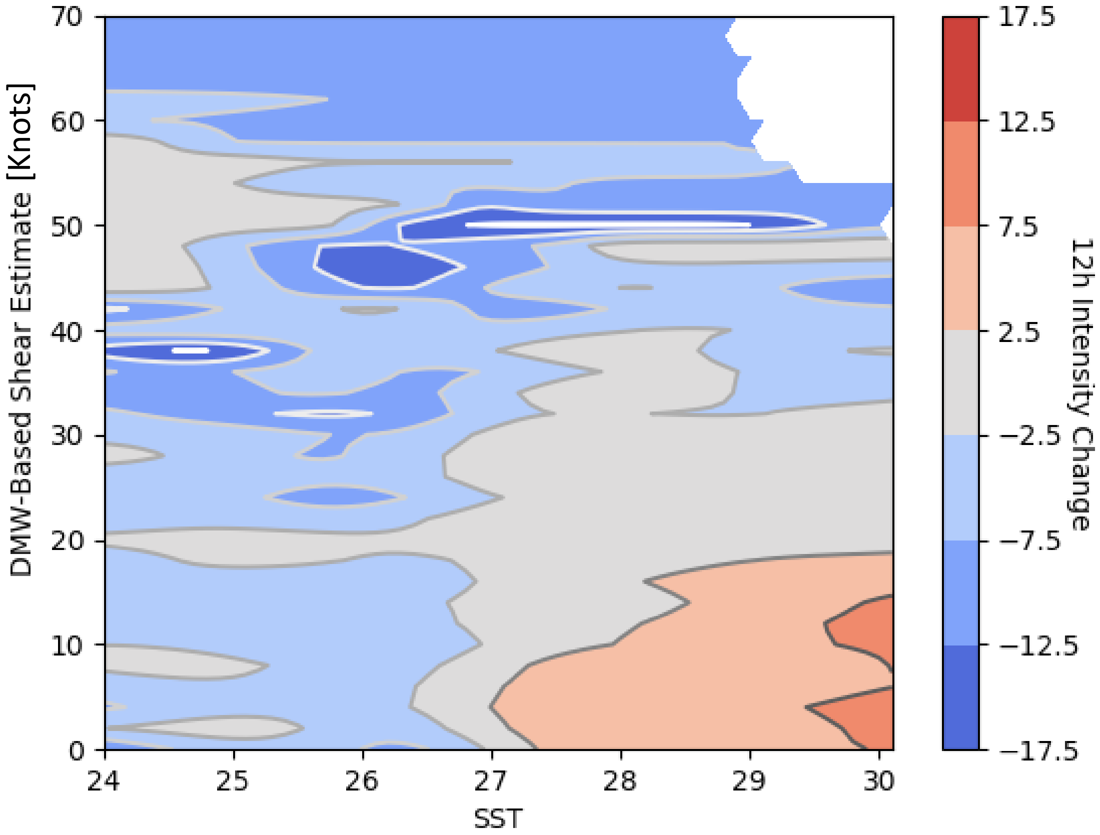
The metrics

Metric	Radial extent	Description
Vertical wind shear proxy	0 > r ≤ 500 km	Average DMV motion minus storm motion
Divergence	0 > r ≤ 1000 km	Average Divergence as in SHIPS (see Slocum et al. 2022)
Radial Outflow Imbalance	0 > r ≤ 500 km	Unbalanced radial outflow. Balance flow is based on the stream function (observed vorticity)
Radius of zero tangential wind	0 > r ≤ 1500 km	The radius of the azimuthally averaged zero tangential wind in the observed layer (350 to 100 hPa)

Vertical Wind Shear Proxy

Example: TC Megan (sh192024)

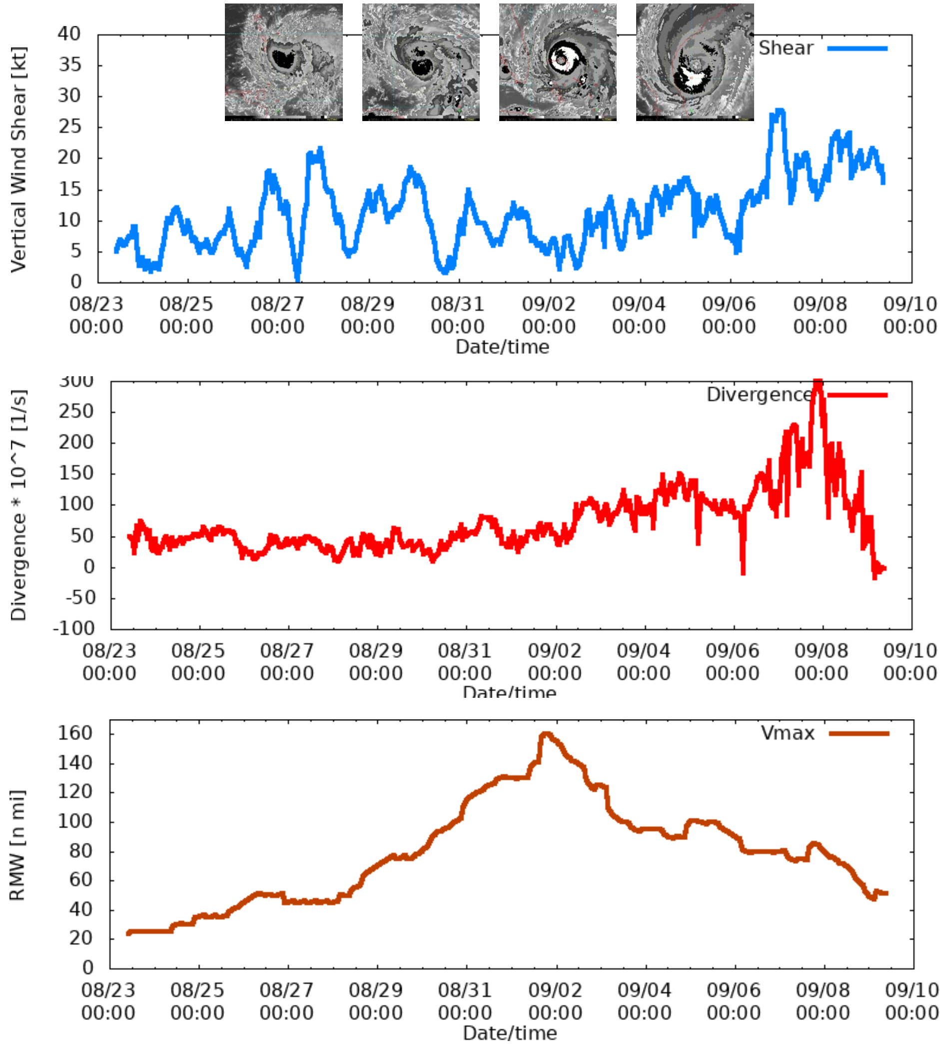


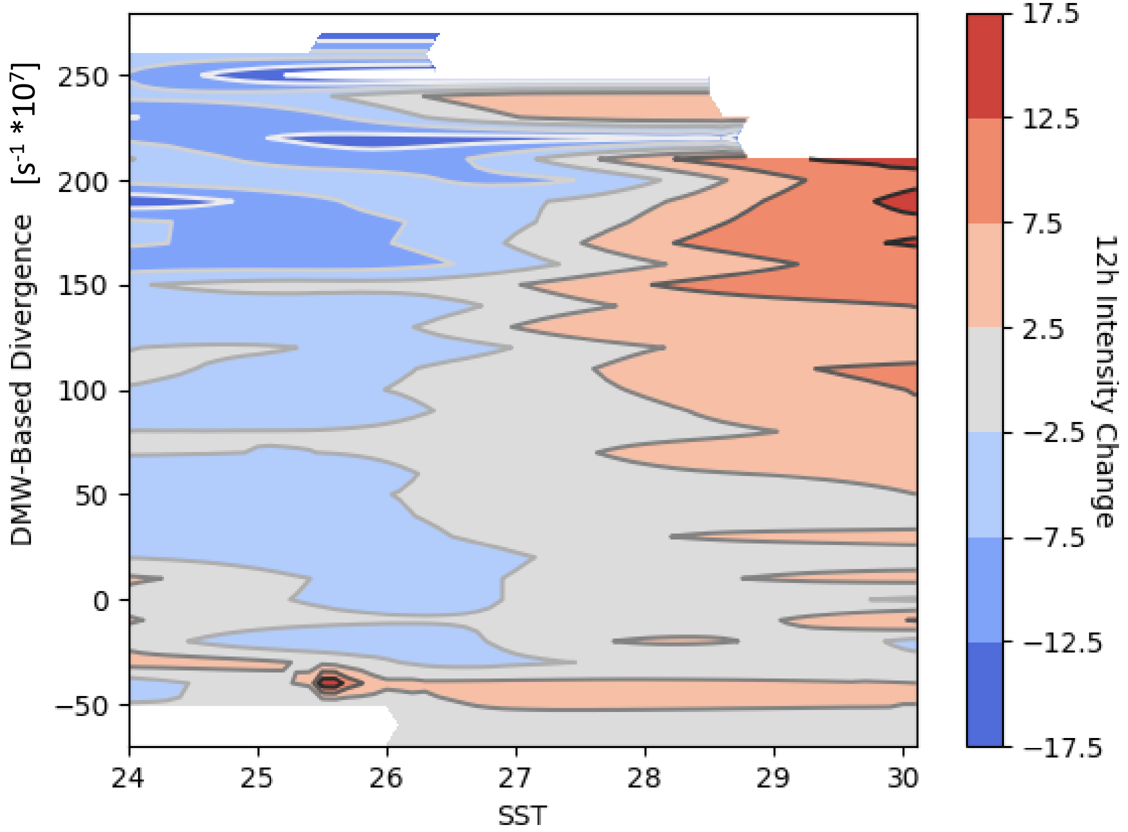


Caption: All basins (AL, EP, WP, IO, SH) 12-h intensity change as a function of climatological SST and DMV-based shear proxy for storm with initial intensities between 34 and 96 knots. A two-pass Barnes Analysis was used to create the contours.

Upper Layer Divergence

Example: Hurricane Dorian (al052019)

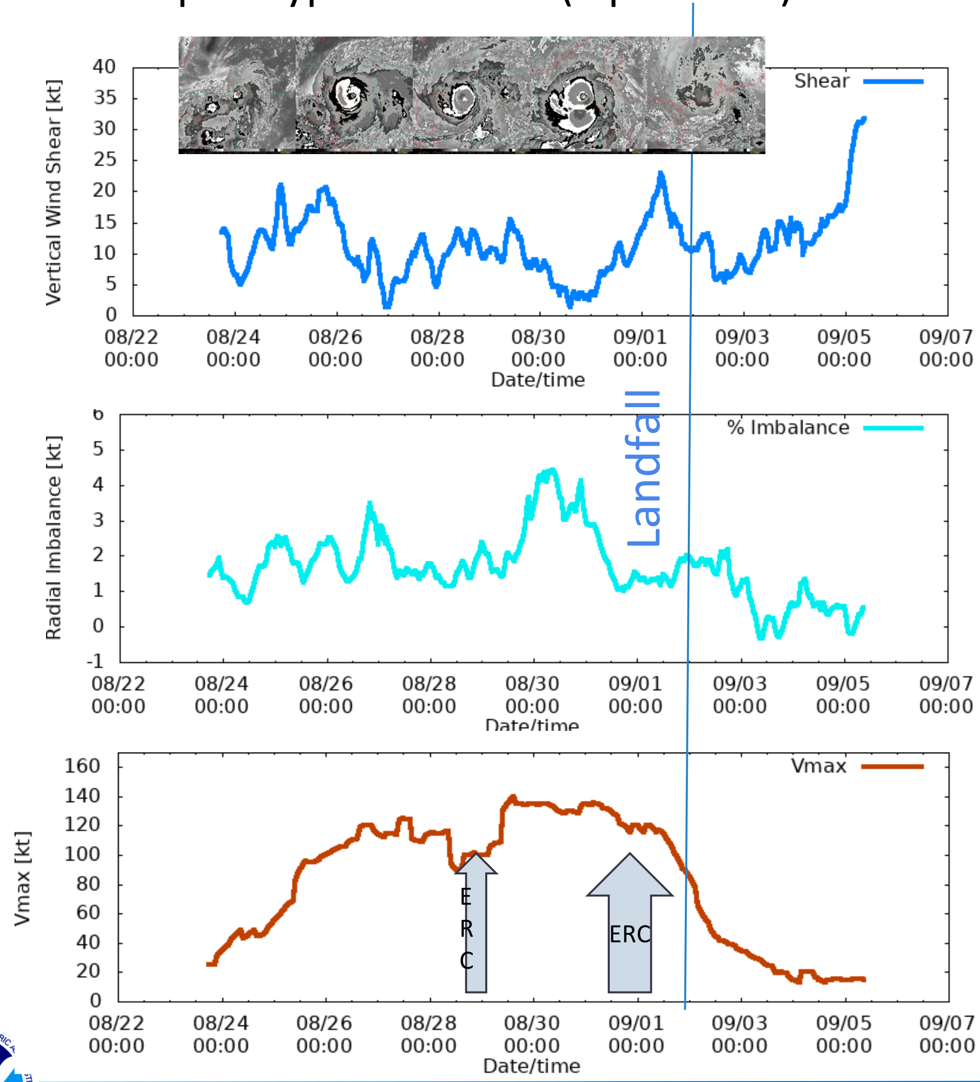


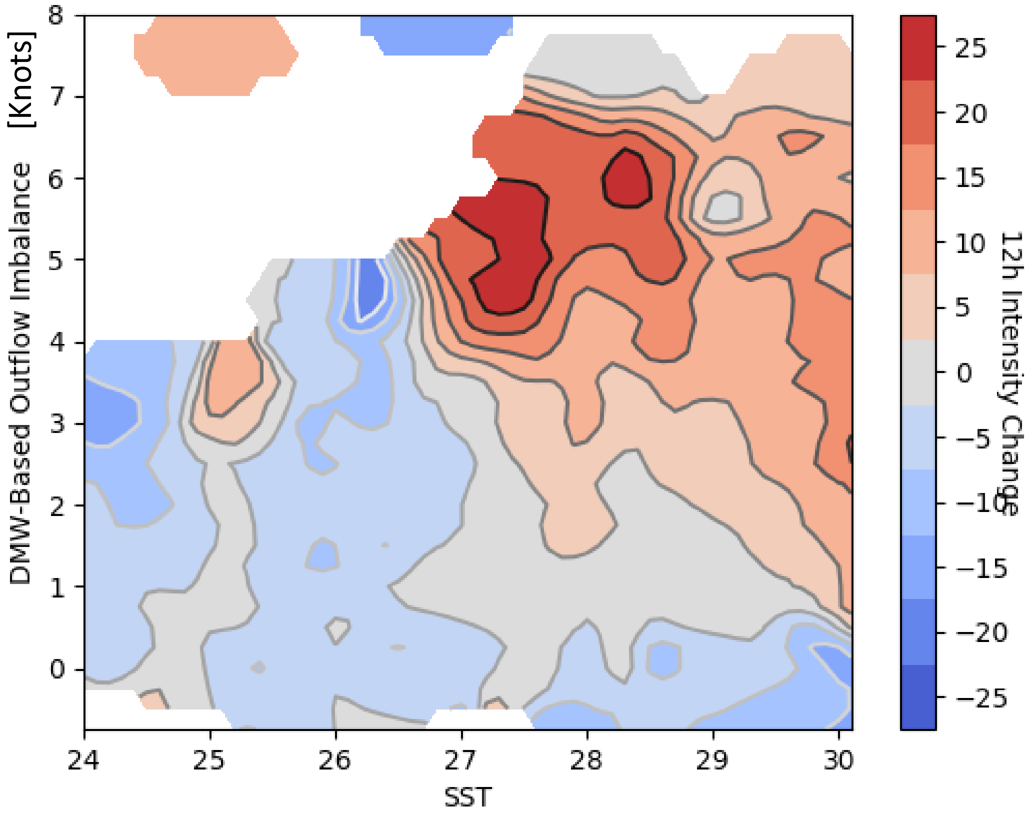


Caption: All basins (AL, EP, WP, IO, SH) 12-h intensity change as a function of climatological SST and DMV-based upper layer divergence for storm with initial intensities between 34 and 96 knots. A two-pass Barnes Analysis was used to create the contours.

Radial Outflow Imbalance

Example: Typhoon Saola (wp092023)





Caption: All basins (AL, EP, WP, IO, SH) 12-h intensity change as a function of climatological SST and DMV-based outflow imbalance for storm with initial intensities between 34 and 96 knots. A two-pass Barnes Analysis was used to create the contours.

Radius of zero tangential wind

Why are we interested?

From Riehl (1963):

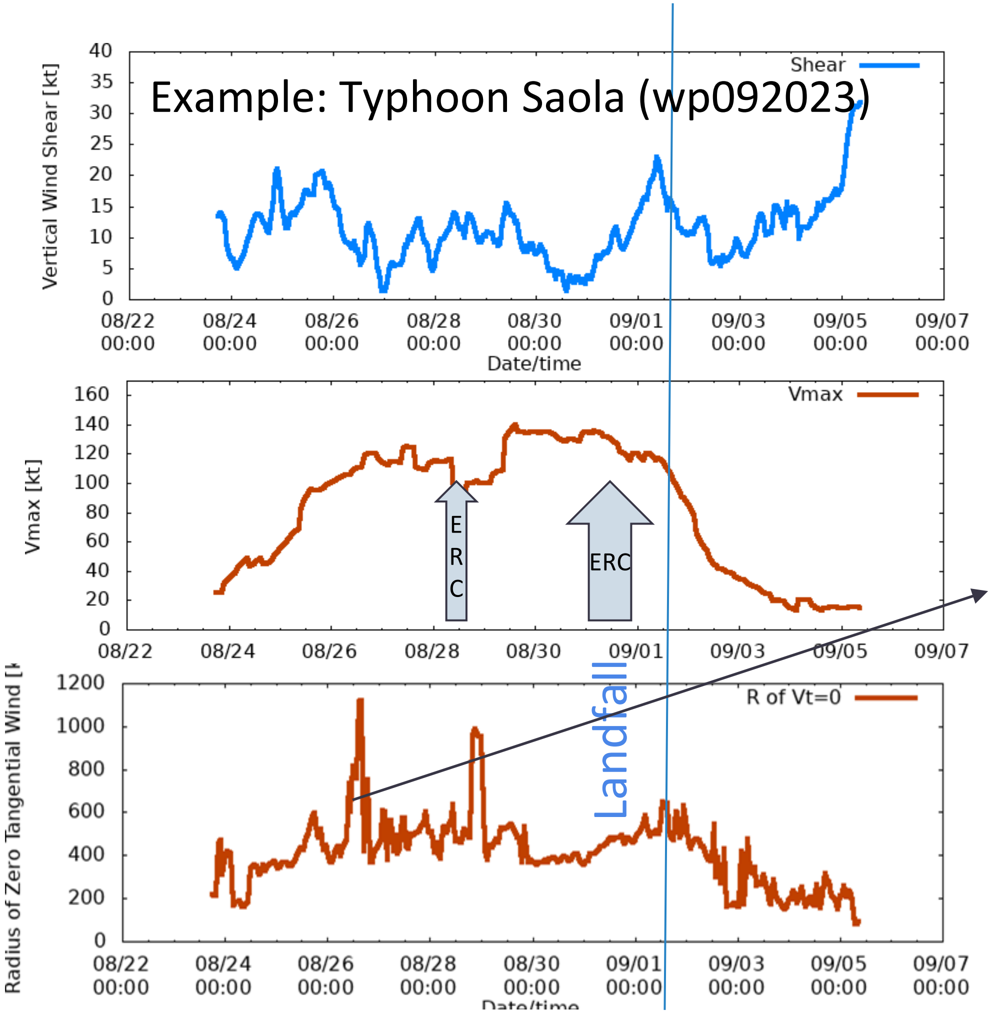
The radius of maximum wind (R_m)
$R_m = f r_o^{2/} 2V_{tm}$, where

r_o is the radius of zero tangential wind at upper levels

V_{tm} is the maximum tangential wind in the storm (i.e. V_m*cos(A)), where V_m is intensity, and A is the inflow angle.

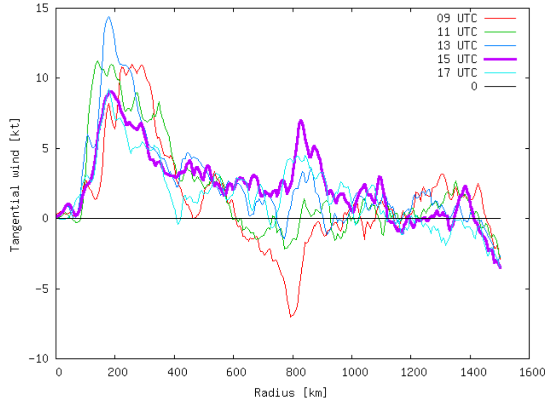
Problems with using DMVs for this application:

1. DMVs are observed at cloud/feature height/pressure
2. DMVs are **not observed at a constant level** with lowest pressures observed nearer the core
   a. So, the Vt=0 is not at the maximum outflow from the eye
3. DMVs are **not created in highly curved flow (eyewall)**



Caption: DMV-based shear (top), operational intensity (middle), radius of zero tangential wind (bottom). Timing of ERCs and landfall are provided.

With a ridge approaching from the west the radial profiles are adversely impacted



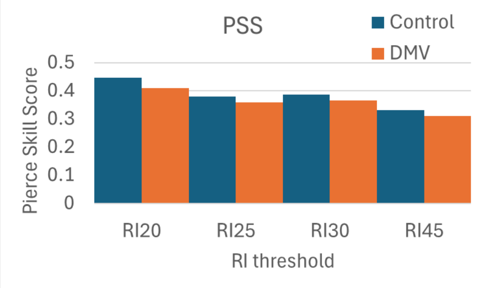
The ridge would turn the storm to the west (left turn)

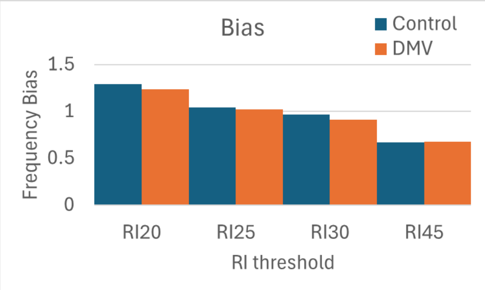
Experiments in the Rapid Intensification Prediction Aid (RIPA, Knaff et al. 2020)

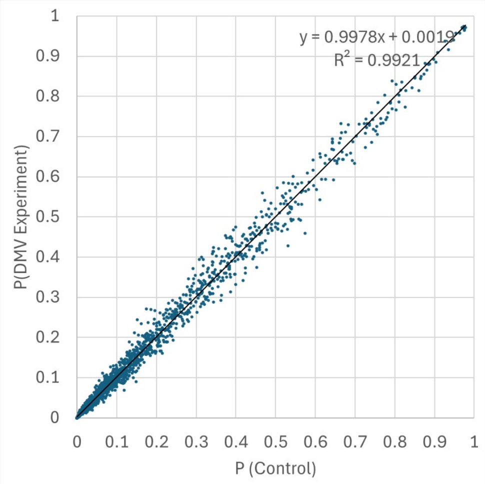
Experiment:

- Replace the t=0 generalized shear (GSHR) and divergence (DIVC) with DMV-based values in the SHIPS diagnostics files
- Assume 2-hour latency
- Use a histogram matching routine to create estimates of GSHR and DIVC
- Compare results with a control using 40% or greater as a YES (Sampson et al. 2011)

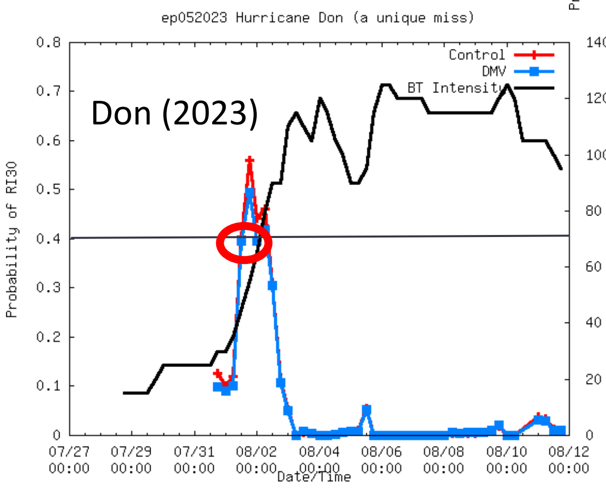
Slightly lower Pierce Skill Scores (PSS)
Reduced biases (some good/bad)

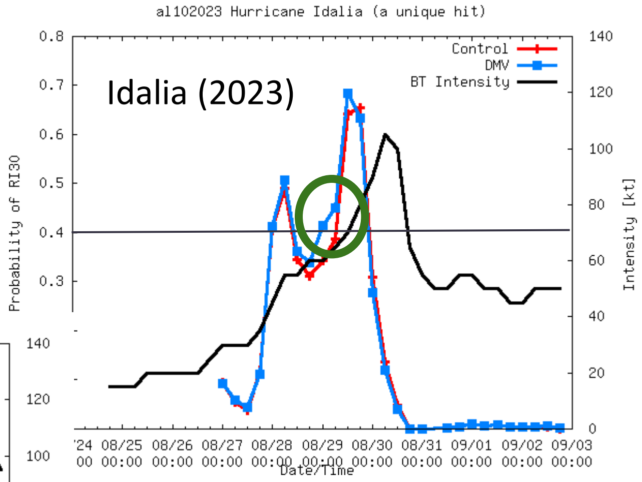




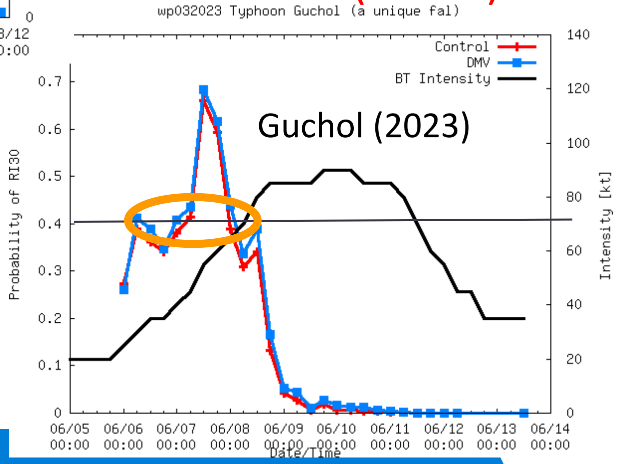


unique hits
60 >>> 90 (41.5%)
65 >>> 105 (45.1%)





unique misses
45 >>> 90 (39.5%)
65 >>> 110 (39.6%)

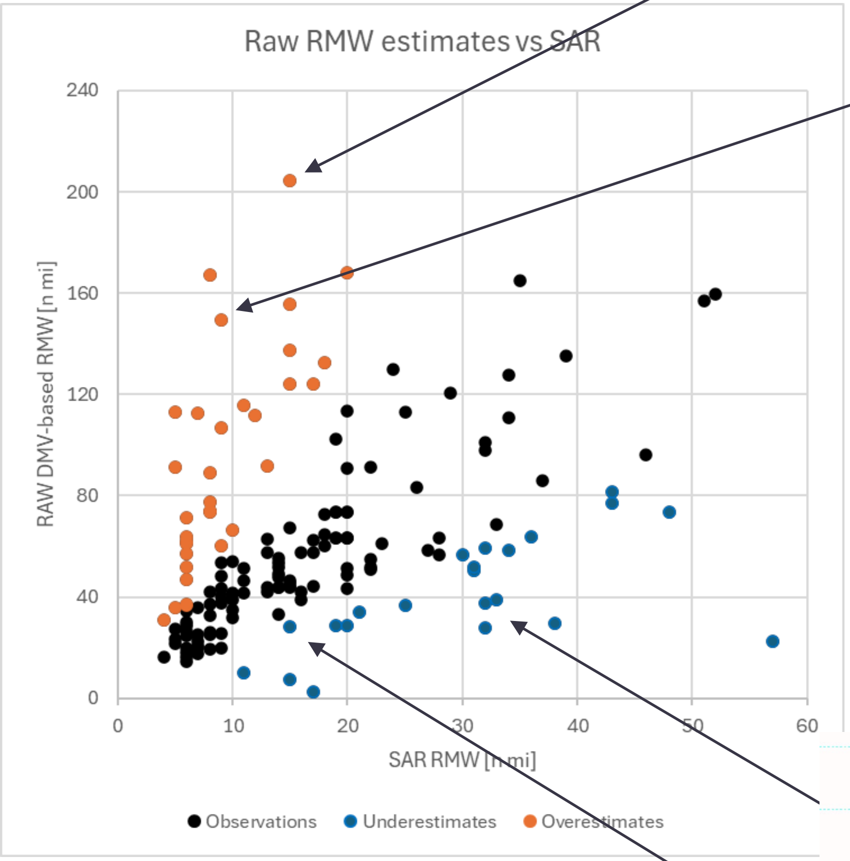


unique false alarms
30 >>> 45 (41.2%)
40 >>> 65 (40.8%)
65 >>> 85 (44.0%)

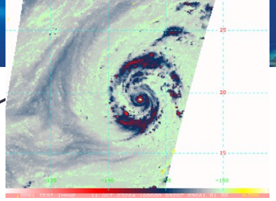
RMW Estimates

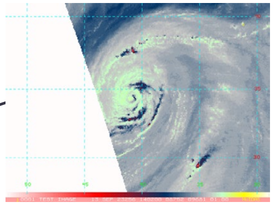
To estimate R_m

- Use the current intensity (Vm)
- Estimate a climatological rmw ($R_{mc}(\phi, Vm)$)
- Calculate local $f = 2\Omega \sin(\phi) + 2\pi Vm/R_{mc}$
- Calculate Cd (V_m) (Curcic, M., & Haus, B. K., 2020)
- Calculate inflow angle A=atan(Cd/f)

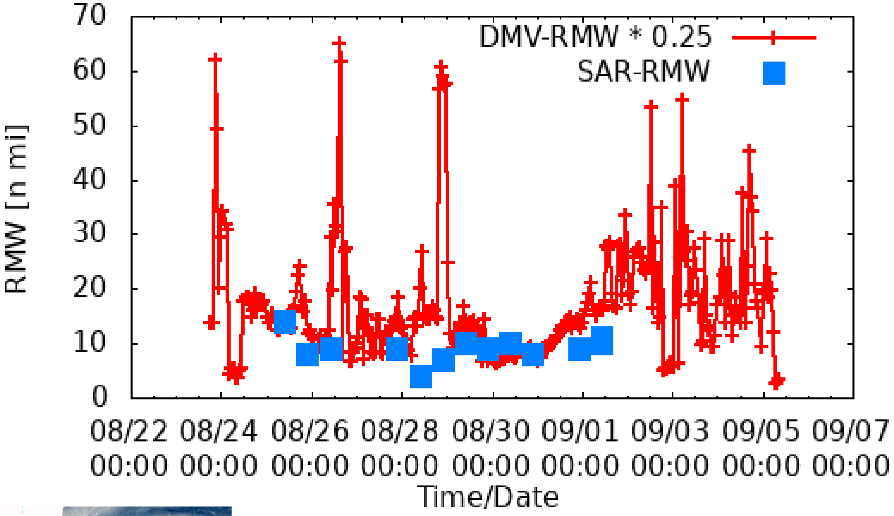


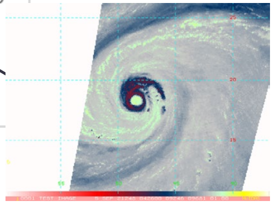
Caption: SAR RMWs vs DMV-based RMW for storms in DMV-shear < 18 knots, outflow vorticity < -5^E-7 s^{-1} and intensity >= 65 knots.

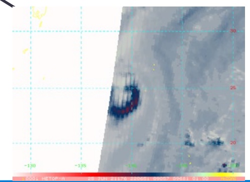




Typhoon Saola (wp092023)







- **RMW estimates ~ 4 times to large**
  - Not sensing the eyewall outflow in most cases
- The estimates however may prove useful (far right)
- It appears that
  - **Overestimates** are often display **double eyewalls** in 89GHz imagery
  - **Underestimates** either have no obvious reason, exhibit more shear/ET, or have **annular or semi-annular structures**

Summary

- DMV-based metrics appear useful for forecasting intensity changes and monitoring evolution of the radius of maximum wind
- Experiments with RIPA result in slightly degraded performance with a few more false alarms and misses, but also some additional hits
- DMWs closer to the core would be helpful for RMW and radial outflow monitoring
- It may be possible to develop short-term intensity forecasts using satellite only inputs.

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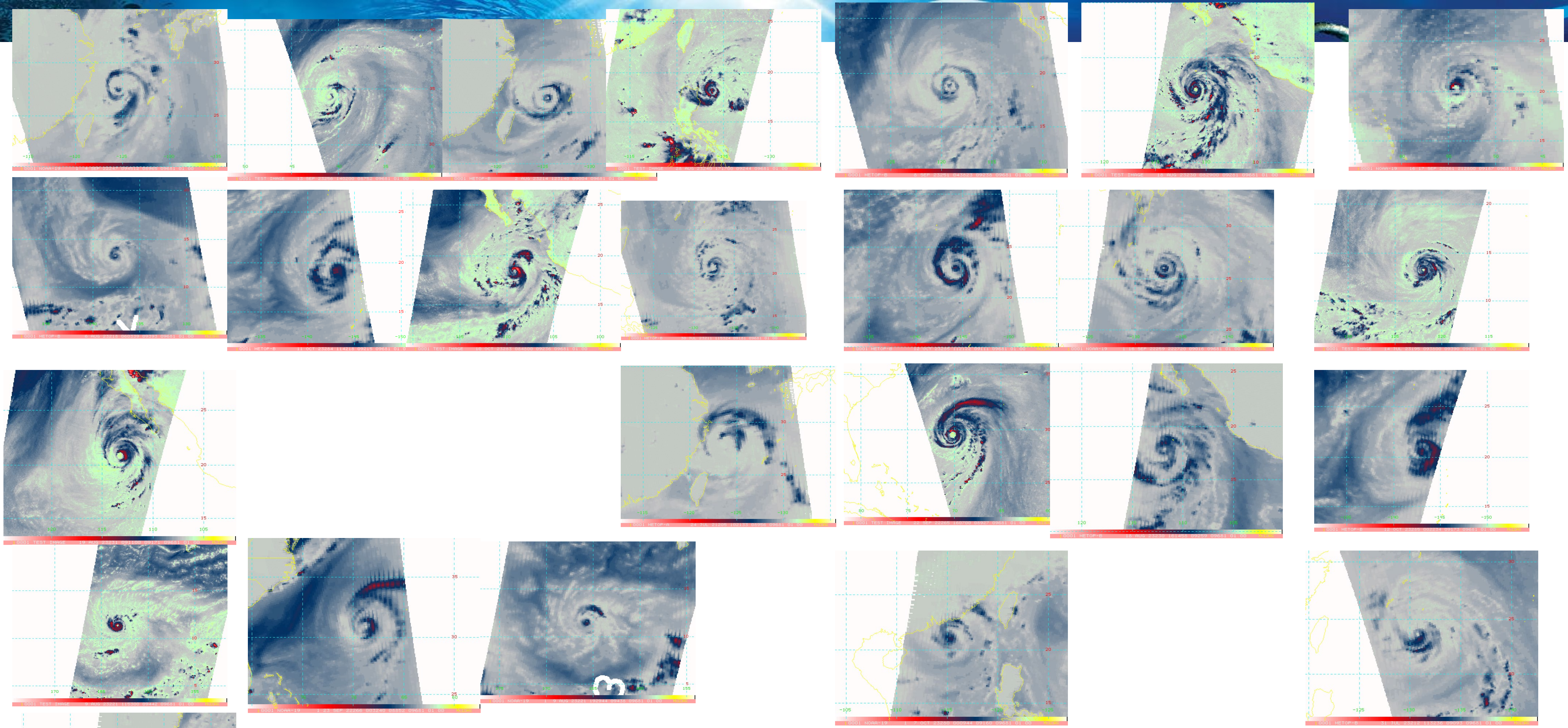
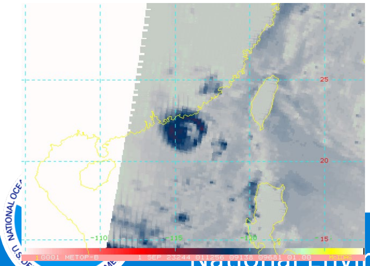

Overestimates

Underestimates