Impact of Assimilating TCI and Other Field Campaign Observations On the Analysis and Prediction of Hurricane Patricia (2015)

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IFEX program

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Outline

- ❑ Motivation and background
- ❑ Experiment design
- ❑ Data impact on the analysis
- ❑ Data impact on the forecast
- ❑ Challenges on intensity forecast associated with the spin down issue
- ❑ Summary and ongoing work
- ❑ Understanding outflow impact on TC intensification rate over NW Pacific 1995-2015

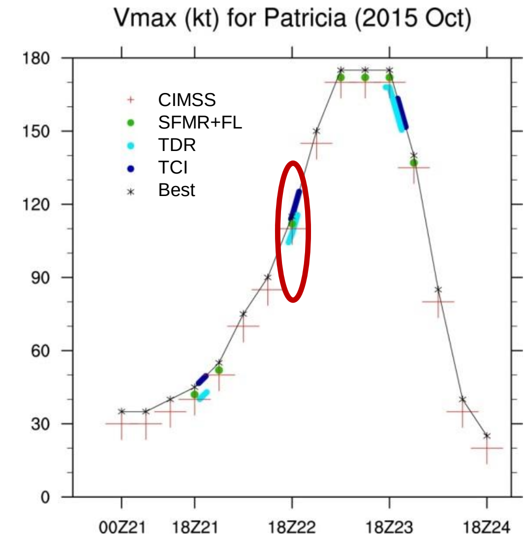
Motivation and Background

- Unprecedented observations for TCs were collected from different field campaigns. Eg:

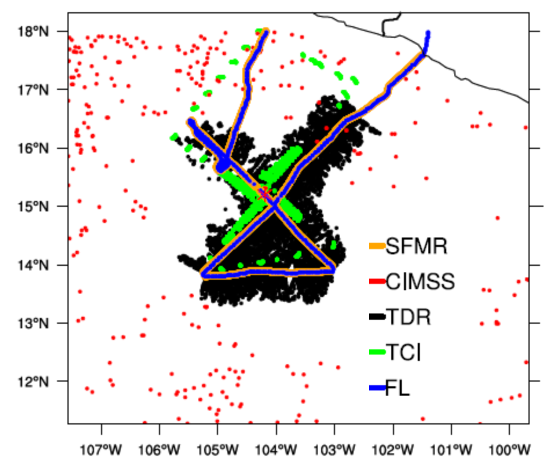
  TCI: HDSS dropsodes, HIRAD;

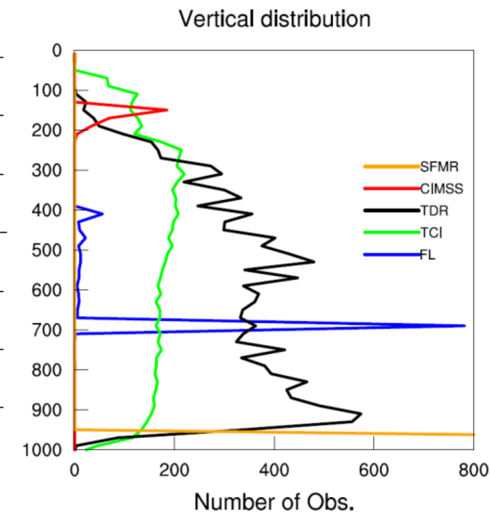
  IFEX: e.g.,Tail Doppler Radar (TDR); High Density Observations (HDOB, includes SFMR and flight level observations) onboard reconnaissance aircrafts;

  SHOUT: e.g: HIWRAP, HAMSR, HIRAD, dropsondes onboard Global Hawk.



- The field campaign observations together with other data (e.g., CIMSS AMV) provided 3-dimensional sampling of the TCs including the surface, inner cores, outflow layer and environment





Motivation and Background

- The analyses and forecasts after assimilating these observations provide unprecedented opportunities to address the following questions:

1) What are the impacts of various kinds of data on the analysis and predictions of TCs?

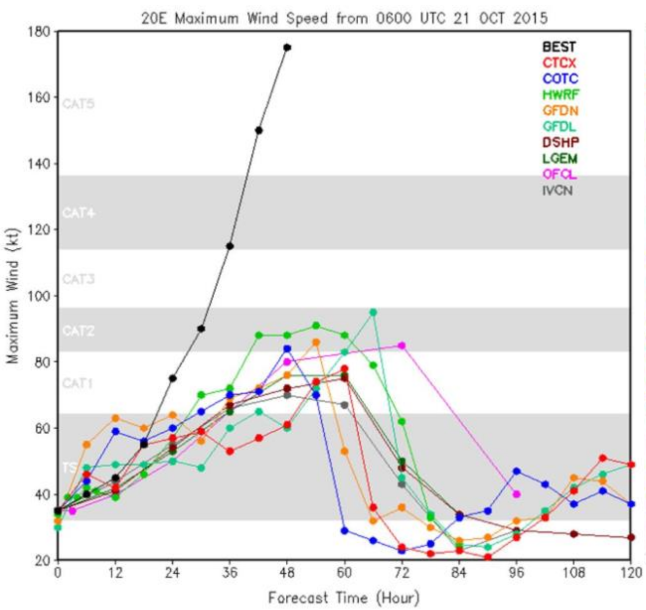
2) What is the most efficient way to extract information from all these data which sample various aspects of the TCs through data assimilation (DA)?

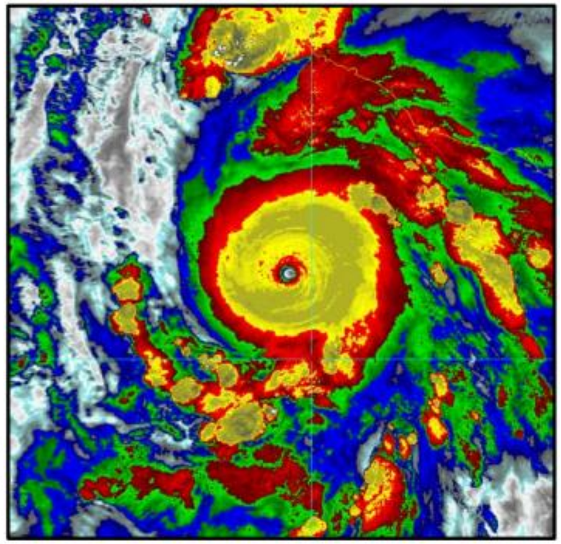
3) What is the impact of outflow on TC intensity change?

4) How is the TC outflow coupled with the inner core convection and therefore affects intensity change?

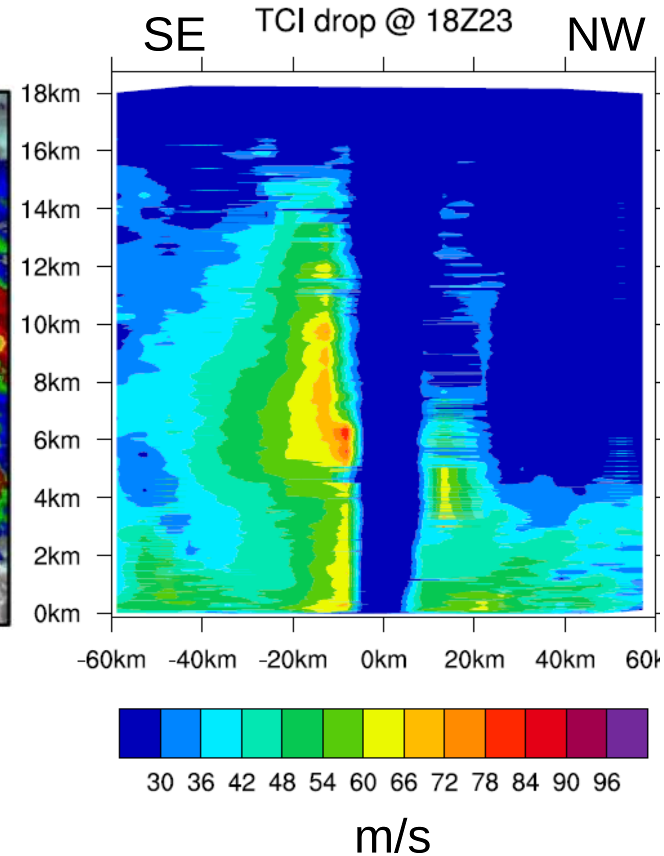
5) What is the relationship between upper level outflow and low level wind structure?

Patricia 2015: A challenging case





From NHC



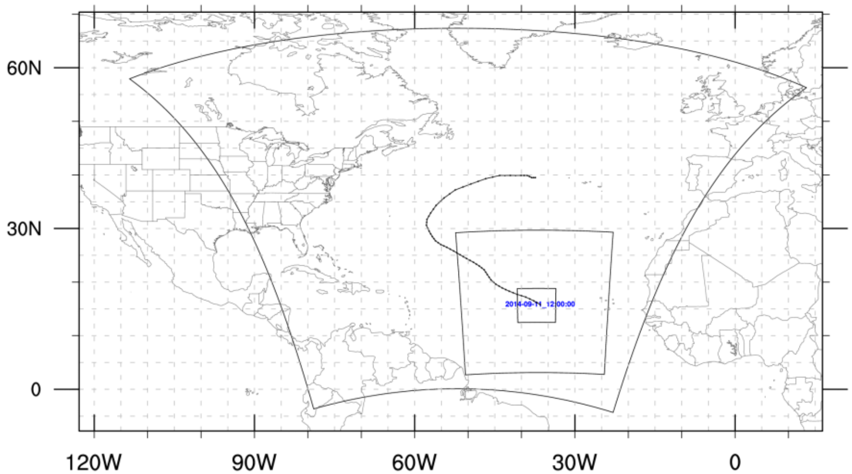
- ❑ Very fast RI
- ❑ Very small hurricane with a small eye
- ❑ A mid-level (6km) wind speed maximum

Experiments for Patricia 2015

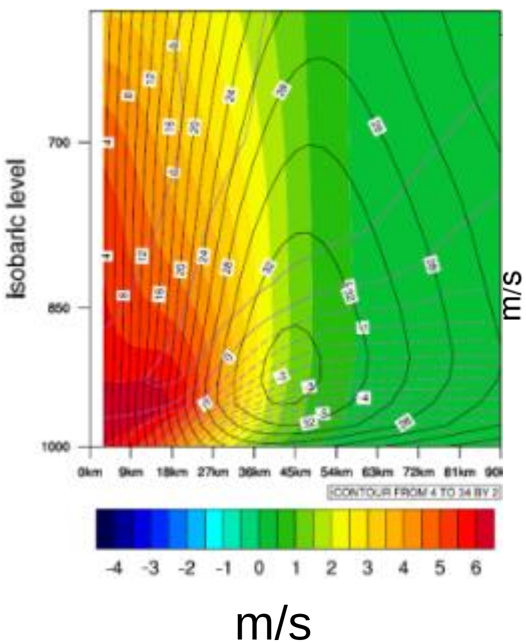
Experiment name	Description
Back	Background without any DA.
Base	Conventional in-situ data in prepbufr, tcvital, EMC AMV and radiances
TCI	Only HDSS dropsodes from TCI are assimilated
FL	Only Flight Level observations are assimilated
CIMSS	Only CIMSS AMV are assimilated
TDR	Only TDR are assimilated
SFMR	Only SMFR are assimilated
All	Conventional in-situ data in prepbufr, tcvital, TDR, SFMR, flight level observations, HDSS dropsodes from TCI, CIMSS AMV and radiances

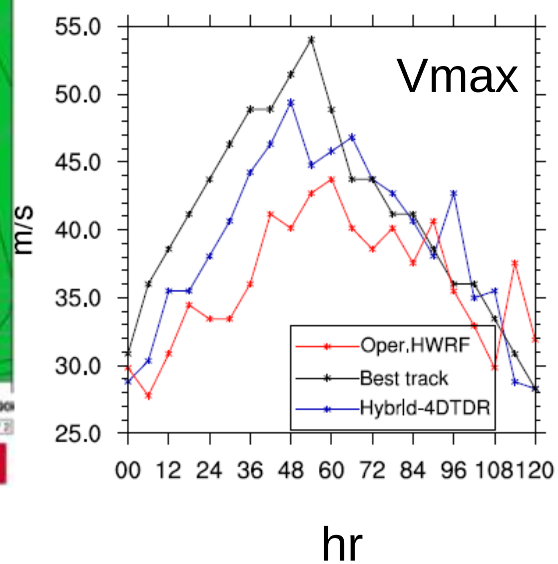
Newly developed HWRF Hybrid DA system

Lu et al. 2016 QJRMS, Lu and Wang 2016 MWR



- A GSI-based, continuously cycled, dual resolution, hybrid EnKF-Var DA system with new directed moving nest strategy, assimilating all operational observations for HWRF is developed (Lu et al. 2016; Lu and Wang 2016).

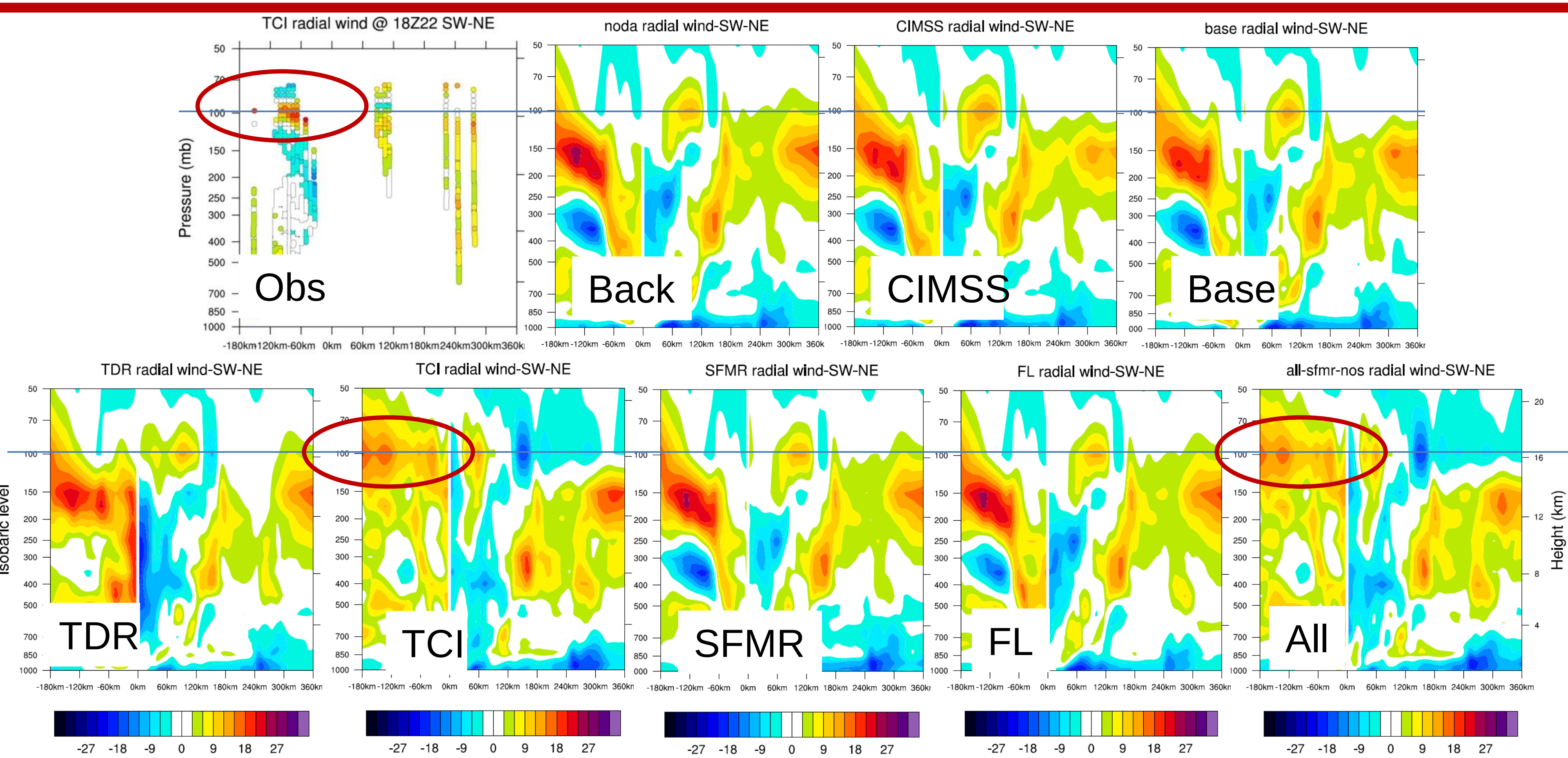




- Our experiments (e.g. Edourad 2014) suggest the new hybrid system can improve intensity forecasts compared to operational HWRF through alleviation of spin down issue due to the better analyzed storm structures.

Data Impacts on Analysis: Radial Wind

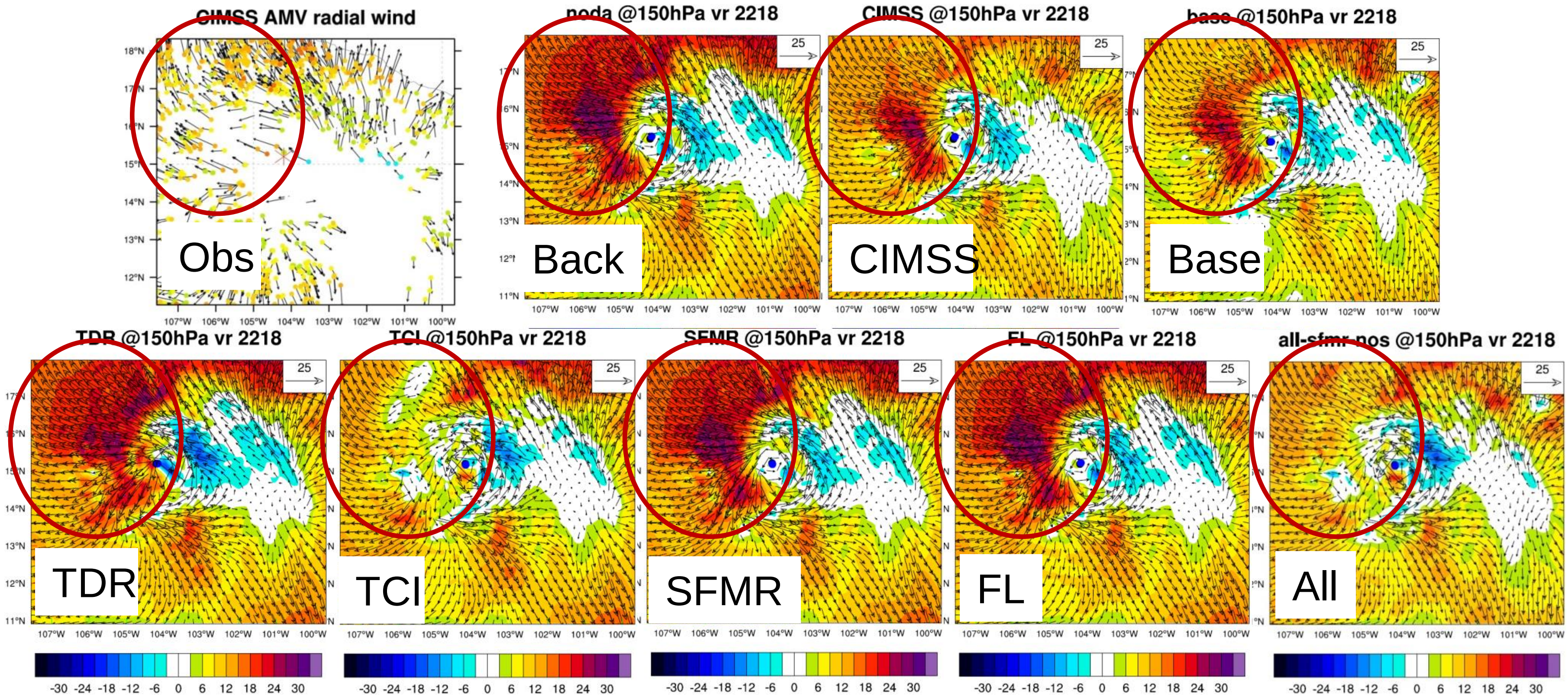
Comparing against TCI dropsondes



- Experiments assimilating TCI dropsondes elevated the outflow layer to 100 hPa.
- TDR shows some but limited correction of the outflow height.
- Other data show little impact.
- ALL performs similar to TCI.

Data Impacts on Analysis: Upper Level Radial Wind

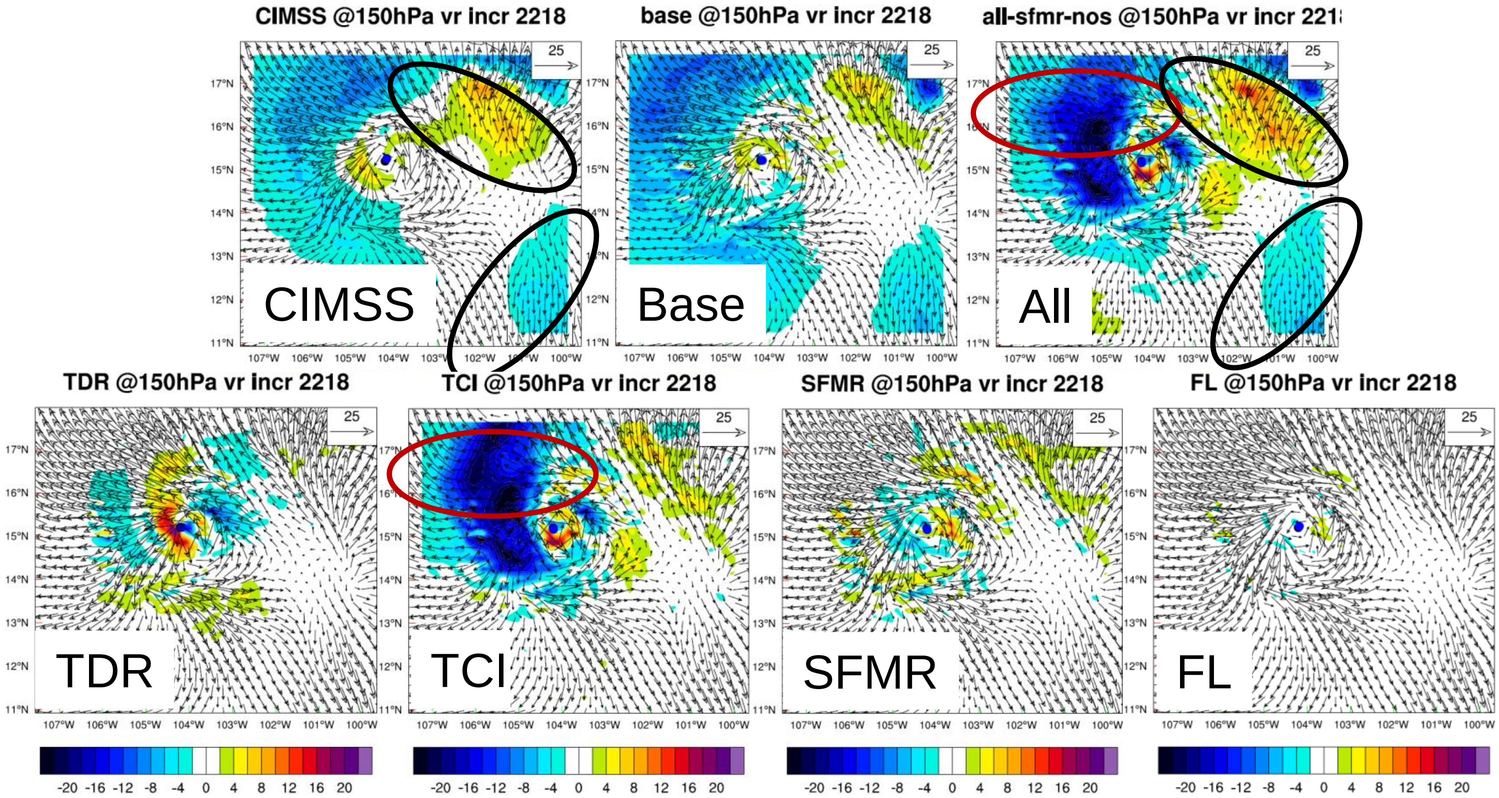
Comparing against CIMSS AMV (150hPa)



- Experiments assimilating TCI dropsondes significantly reduce the spuriously strong radial wind maximum in the western section.
- CIMSS and Base show some but limited correction on the spuriously strong radial wind.
- TDR, FL, SFMR show little or no corrections in the upper level.
- ALL shows complementary corrections between CIMSS and TCI.

Data Impacts on Analysis: Upper Level Radial Wind

Analysis increments (150hPa)



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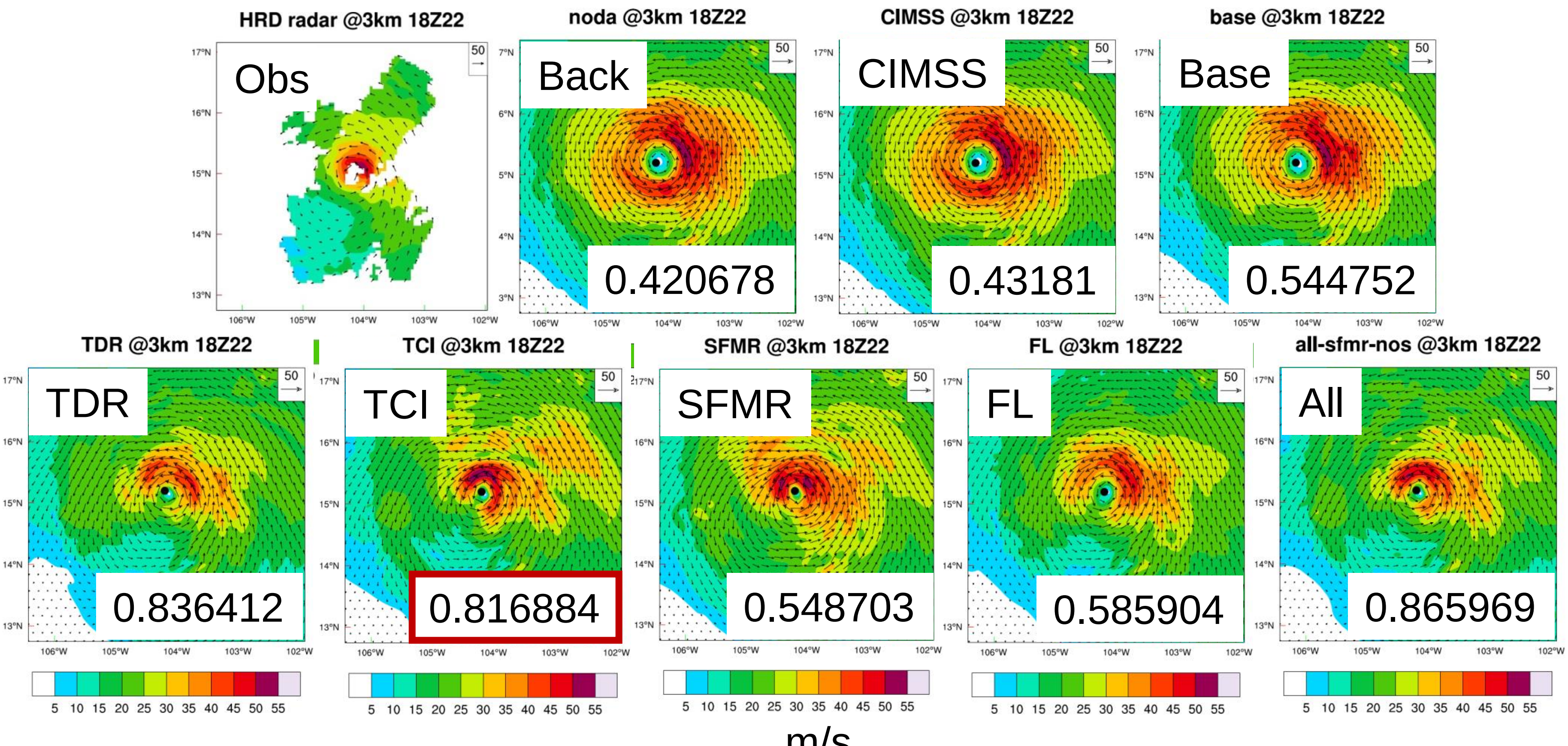
Data Impacts on Analysis: Low Level Horizontal Wind

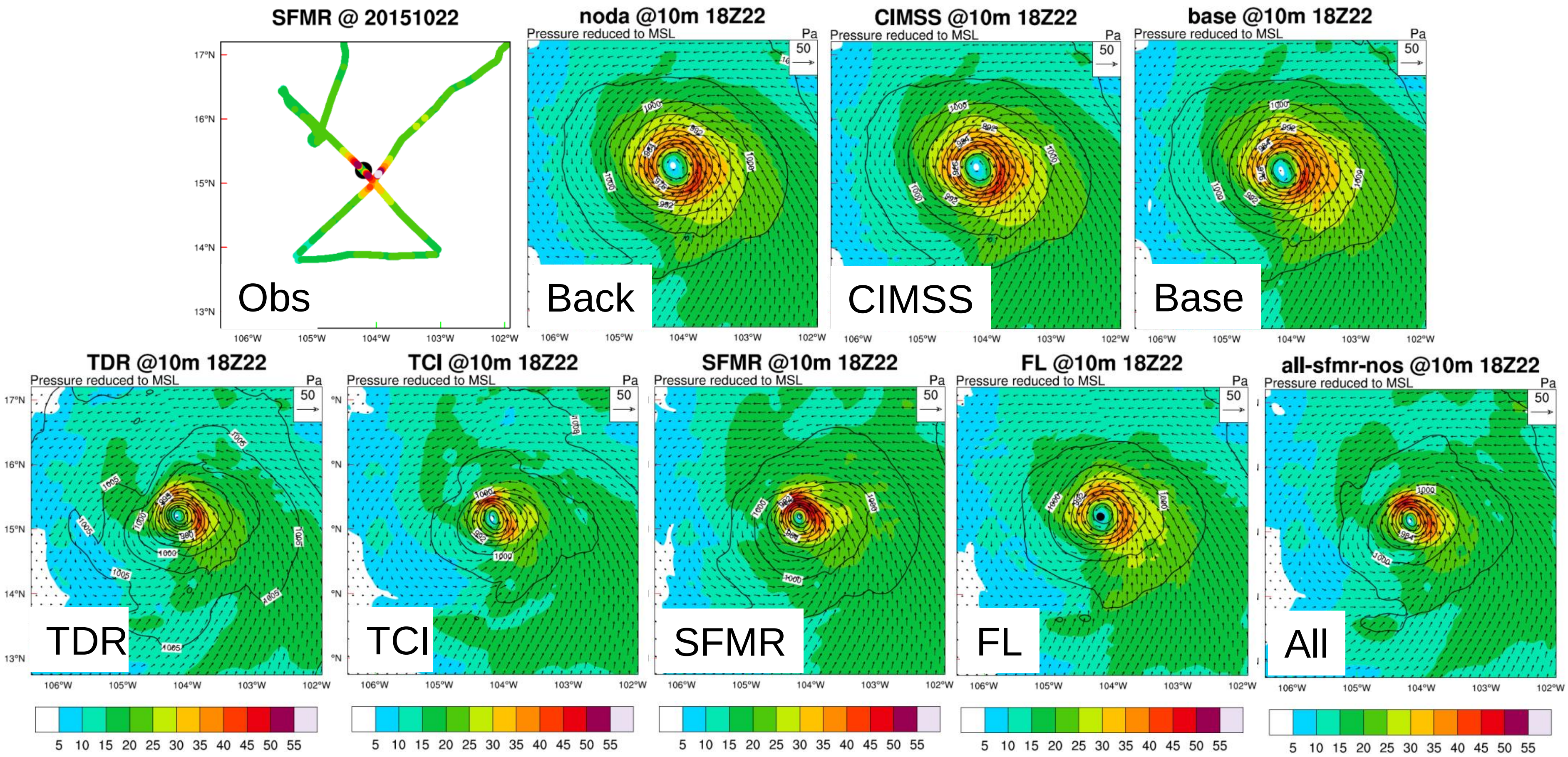
Comparing against HRD radar composite (3km)



- TDR corrects the storm size and structure significantly as expected.
- TCI produces comparable size and structure correction relative to TDR with a better peak wind.
- FL and SFMR produce limited storm size and structure correction.
- CIMSS and Base show no corrections for the inner core structures.
- ALL shows the best correlation coefficient with the HRD composite.

Data Impacts on Analysis: Surface Horizontal Wind

Comparing against SFMR observation (10m)



- Inner core observation DA (TDR, TCI, SFMR, FL) helps correct the storm size.
- Experiments assimilating SFMR increase the Vmax at the surface. Expect HIRAD to provide significantly improved Vmax in the analysis.
- ALL corrects both the storm size and Vmax.

Verification of Analysis using Independent Observation

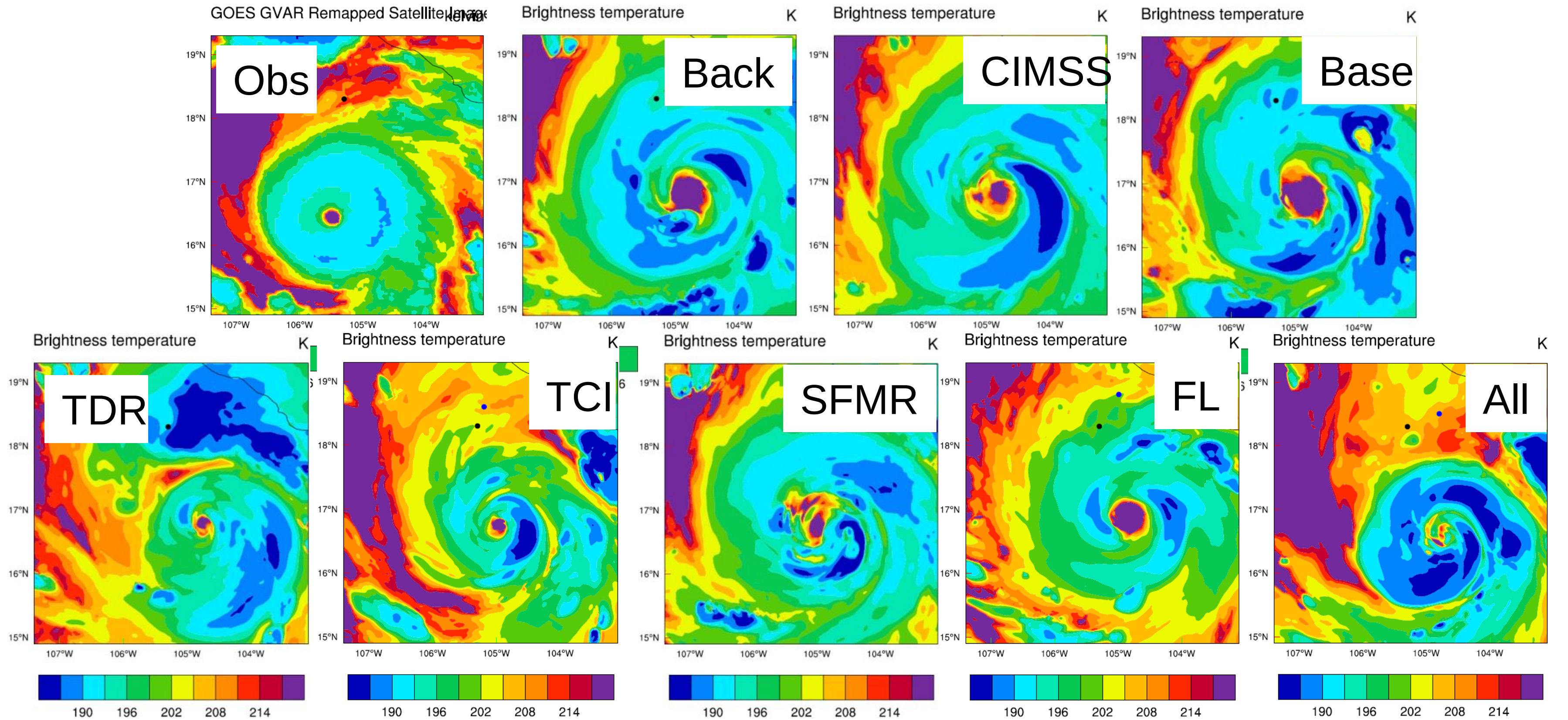
RMSE of analysis w.r.t. independent observation

Data Type \ Experiment	SFMR	FL	TCI	Base	TDR	CIMSS	Back	All
SFMR-spd (m/s)		6.31	5.68	7.35	5.83	7.41	7.41	4.51
FL-q (g/kg)	1.37		1.24	1.29	1.27	1.40	1.40	1.29
FL-t (K)	1.35		0.91	1.26	1.22	1.30	1.30	1.26
FL-uv (m/s)	5.00		3.98	4.58	3.63	5.17	5.17	4.58
TCI-q (g/kg)	1.63	1.52		1.63	1.55	1.72	1.72	1.45
TCI-t (K)	2.06	1.98		2.08	1.85	2.16	2.16	1.11
TCI-uv (m/s)	7.43	7.76		8.63	6.19	9.42	9.49	4.77
Base-q (g/kg)	2.65	2.17	2.19		2.26	2.45	2.45	1.90
Base-t (K)	4.81	4.81	4.73		4.81	4.85	4.88	2.49
Base-uv (m/s)	5.27	5.05	5.03		5.09	4.94	5.25	3.41
TDR-rw (m/s)	5.60	4.85	4.13	6.20		6.73	6.78	3.23
CIMSS-uv (m/s)	4.62	4.63	3.92	3.68	4.69		4.62	3.41

- TCI shows overall the smallest error against the independent observations, especially for q and t.
- TDR shows smallest RMSE for the wind verifications.
- Combing all observations do not always show the smallest RMSE, suggesting possible data incoherence.

Data Impacts on Forecasts: Structure

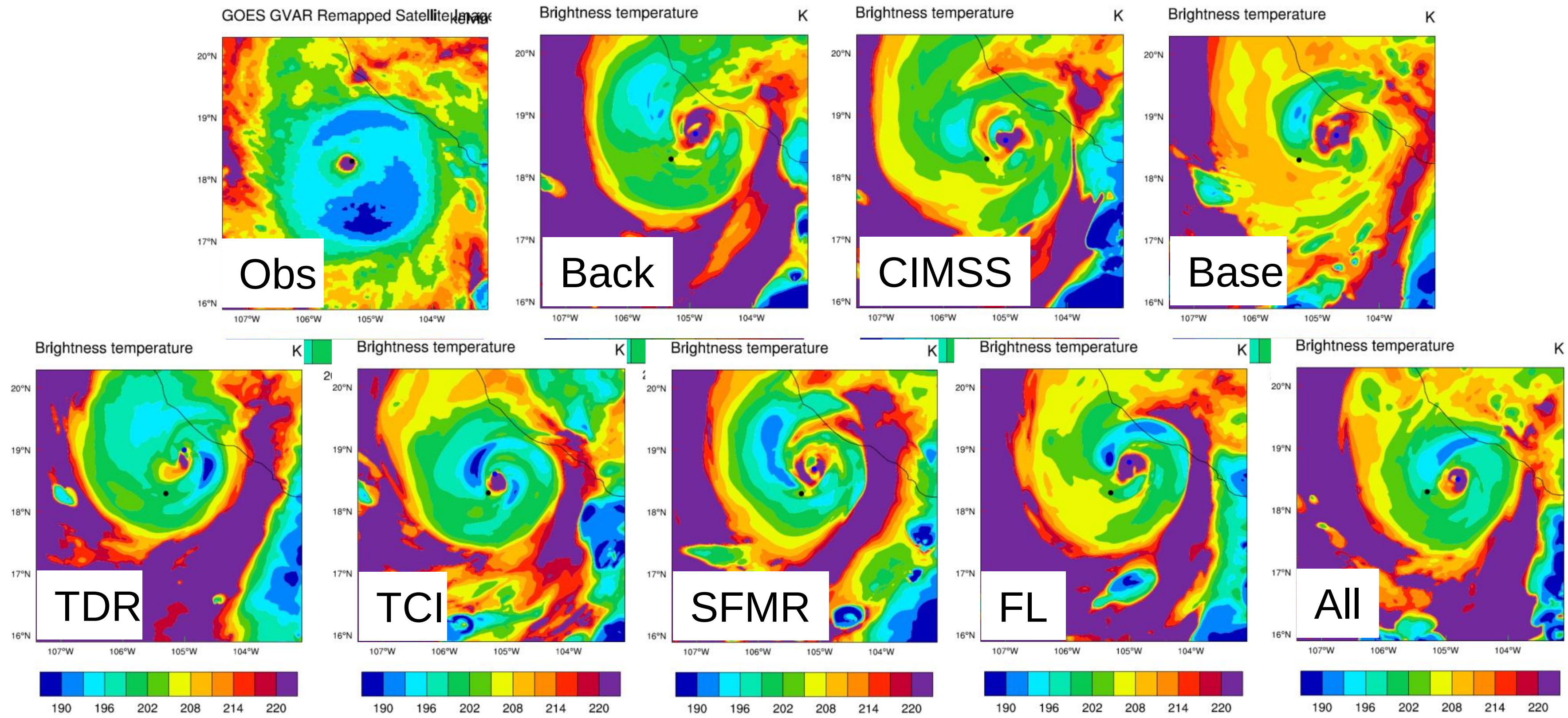
12h forecast verification against GOES-13 IR (band 4)



- TCI produces the most reasonable 12 hour brightness temperature forecast against the observation in terms of eye and storm size and convection pattern.
- Back and Base produce a larger storm with a larger eye than obs. CIMSS corrects size of the eye some but the overall storm is still larger than obs.
- TDR has a right size for the eye but more extensive convection. FL has a larger eye than obs. and SFMR has a less organized storm.
- ALL produces a right size but stronger convection.

Data Impacts on Forecasts: Structure

24h forecast Verification against GOES-13 IR (band 4)

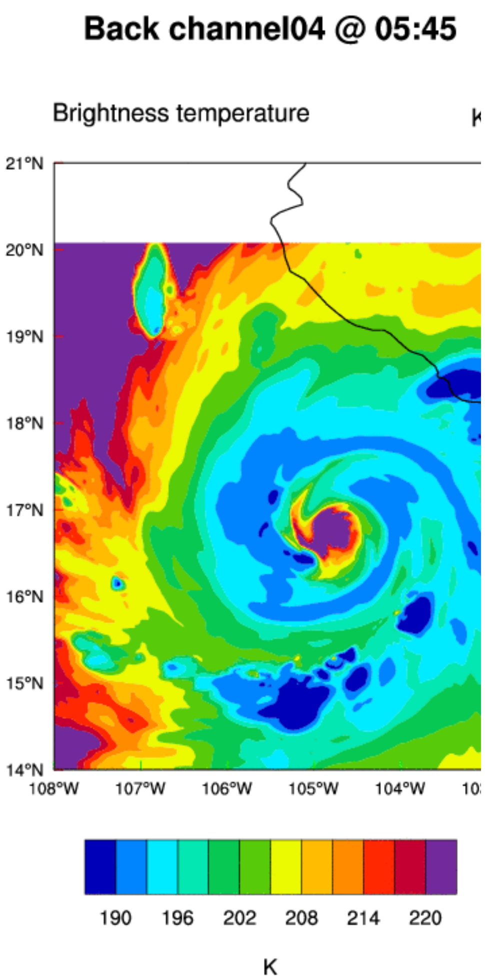


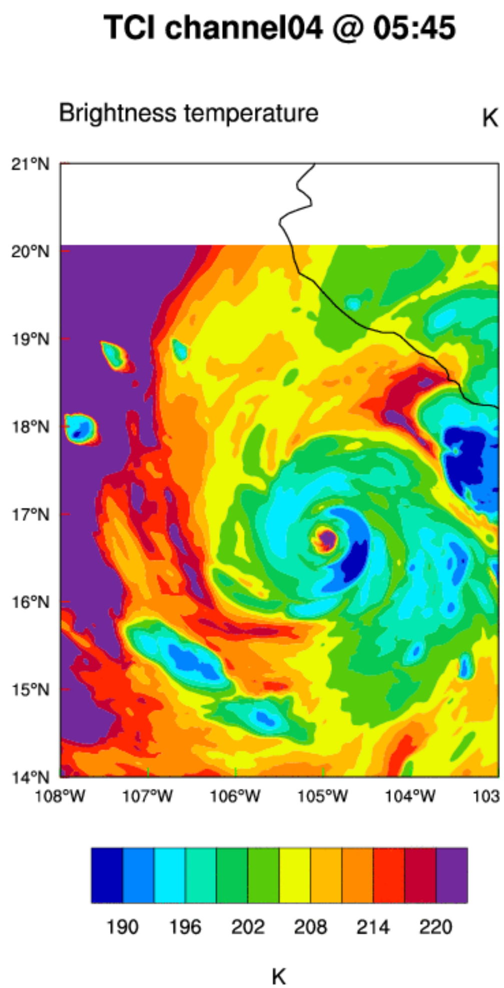
- TCI produces the most reasonable 24 hour brightness temperature forecast against the observation in terms of eye and storm size and convection pattern.

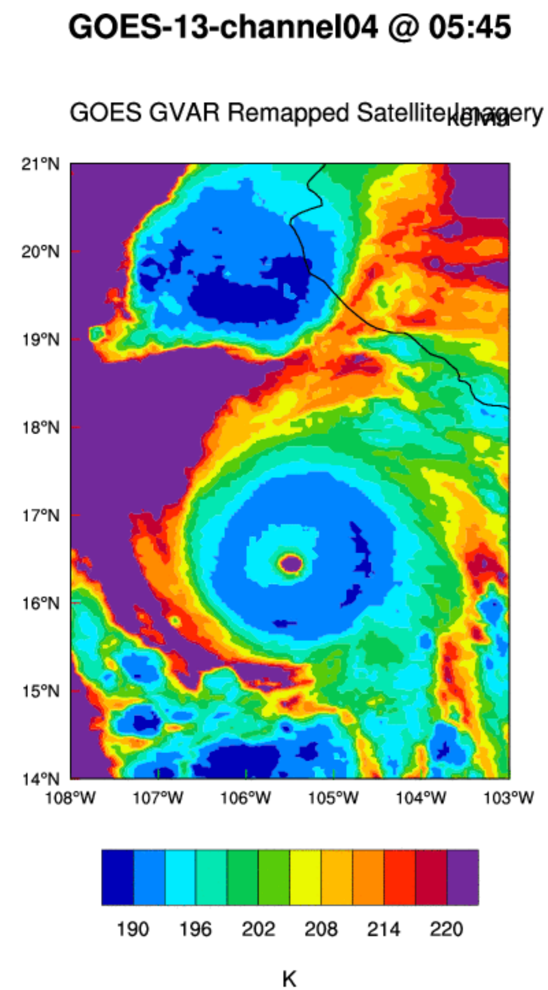
- ALL comparable to TCI.

Data Impacts on Forecast: Structure

Verification against GOES-13 IR (band 4) animation

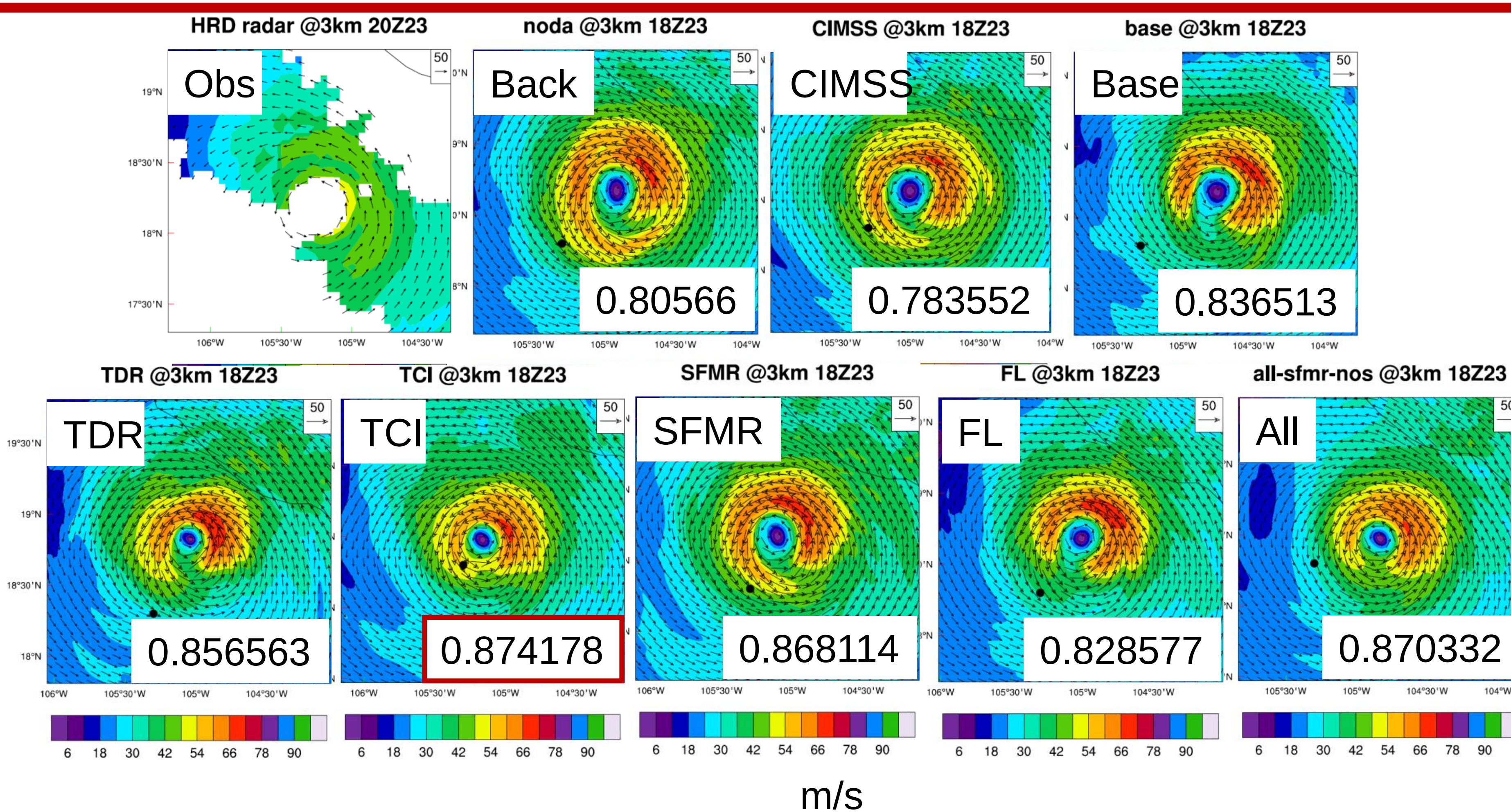






Data Impacts on Forecast: Structure

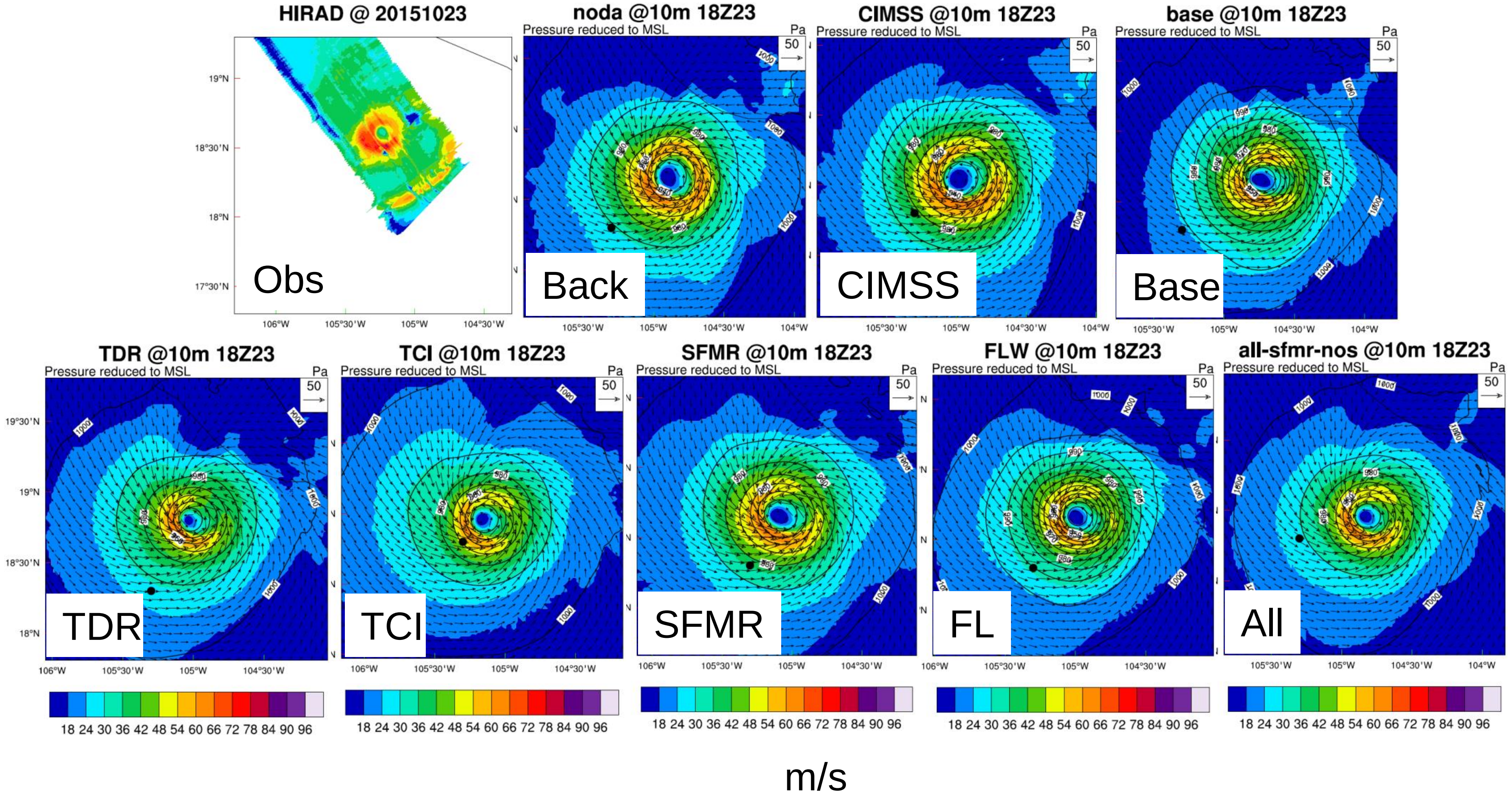
24h forecast Verification against HRD radar composite (3km)



- TDR and TCI produce the smallest storm as compared to others.

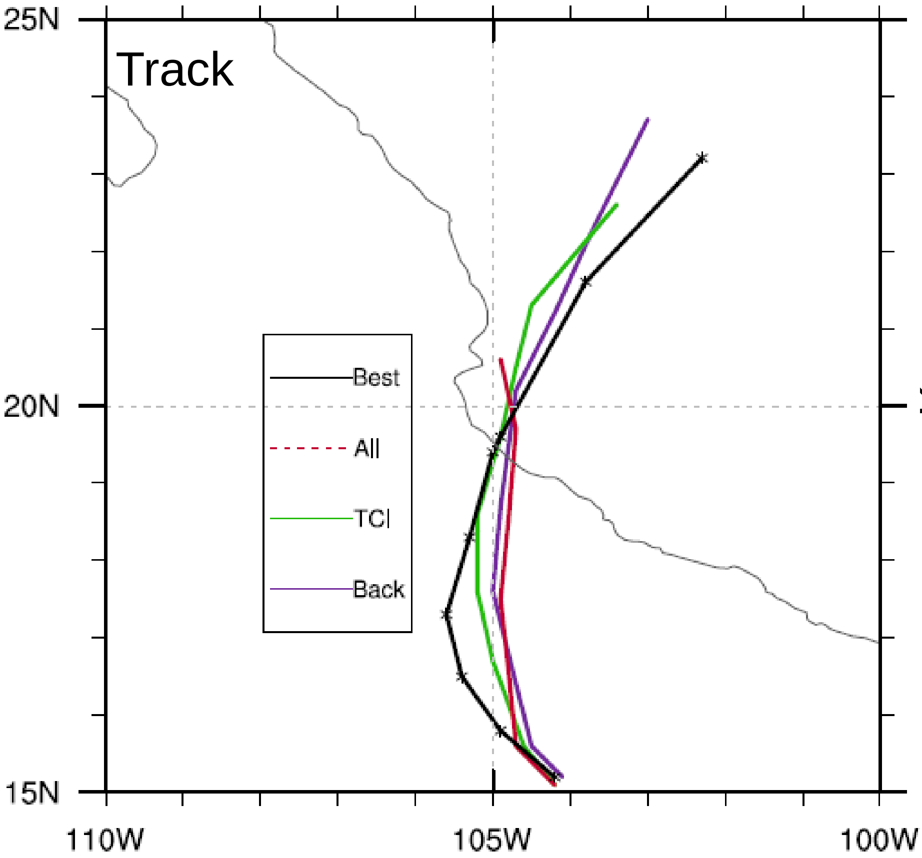
Data Impacts on Structure Forecasts

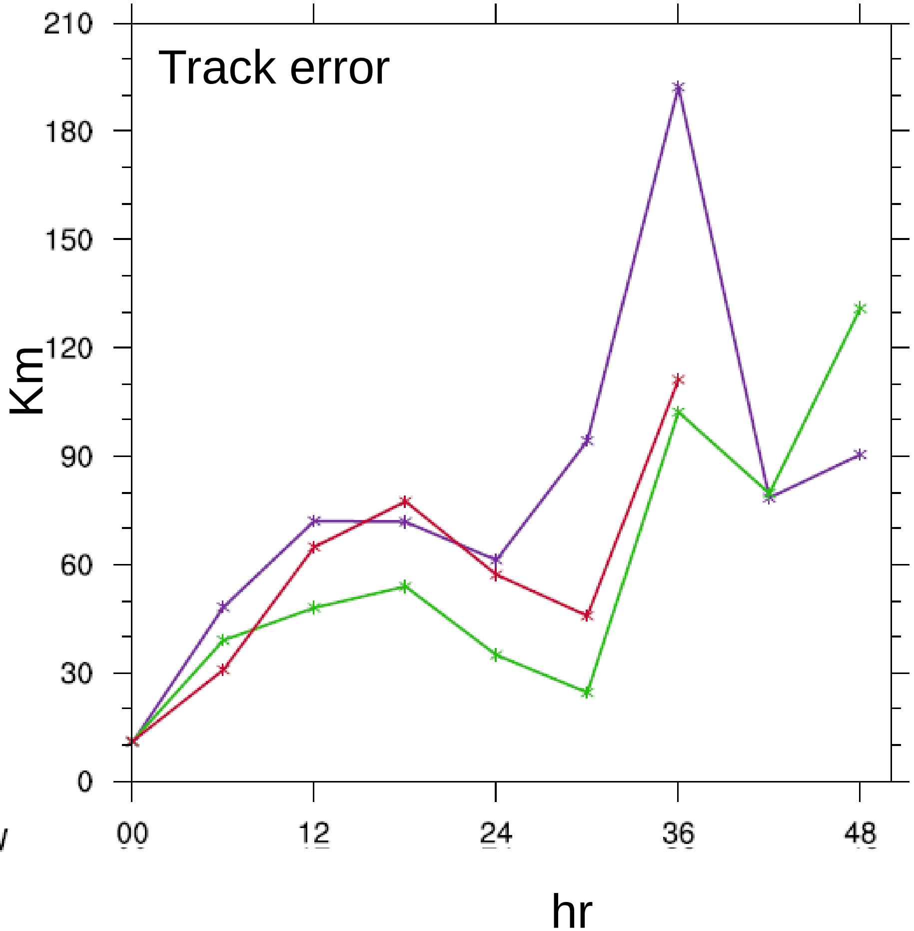
24h forecast Verification against HIRAD



- TDR and TCI produce the smallest storm size and eye size as compared to the others.

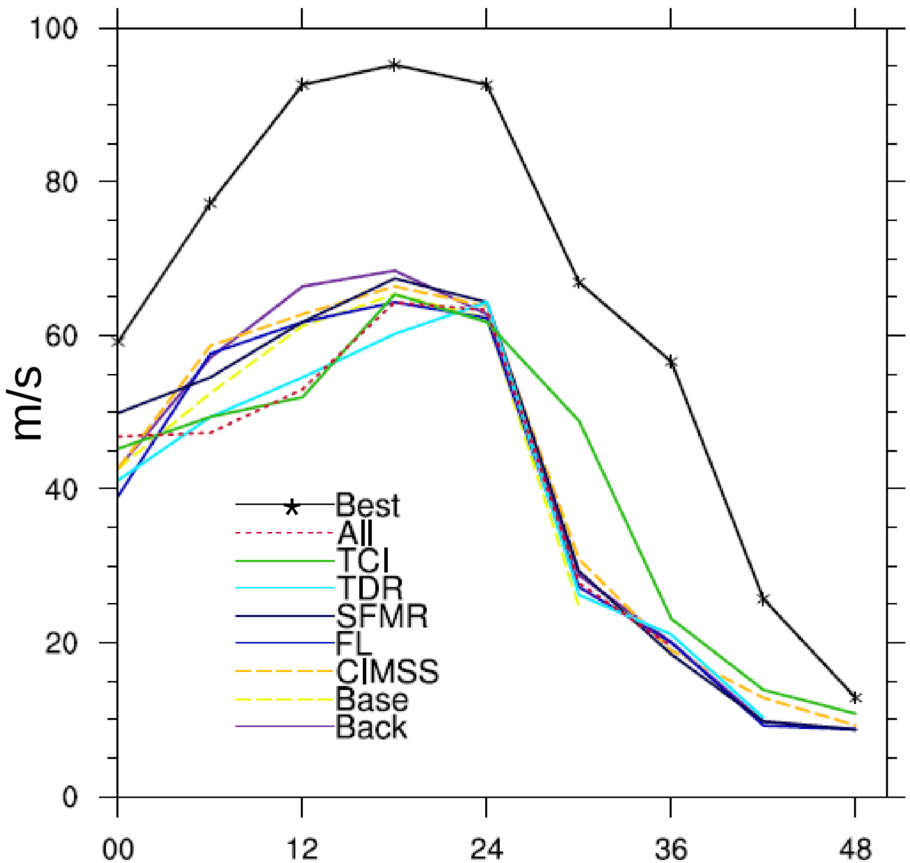
Data Impacts on Forecasts:Track

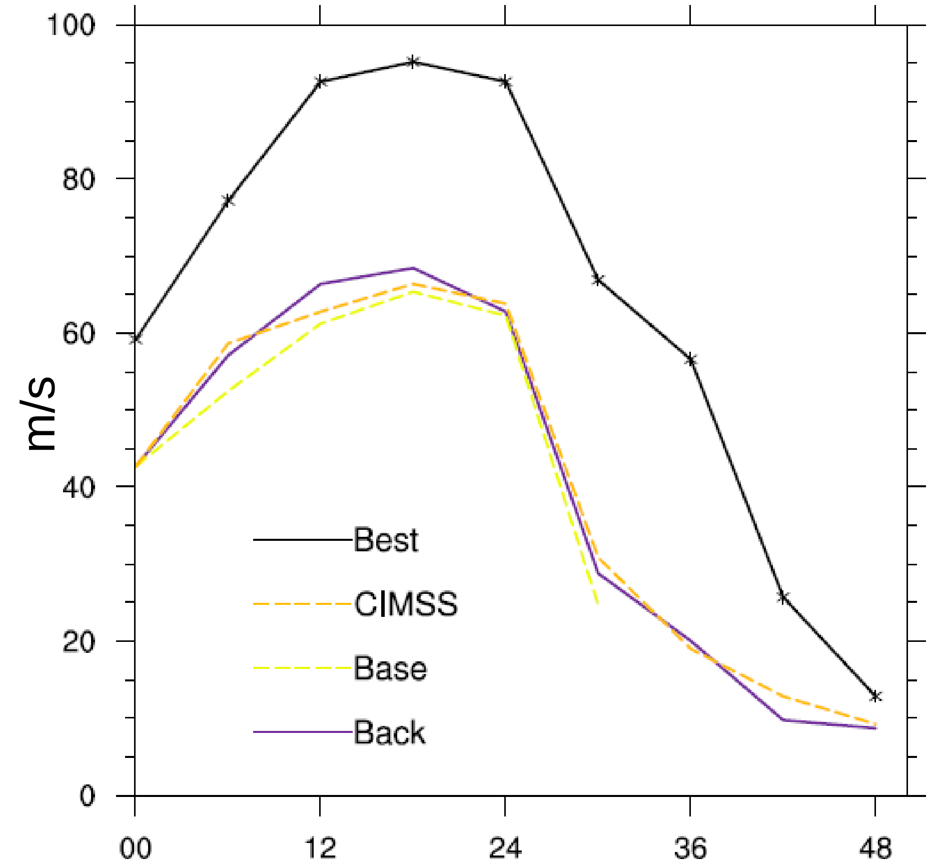




- TCI produces the most consistent track forecast improvement.

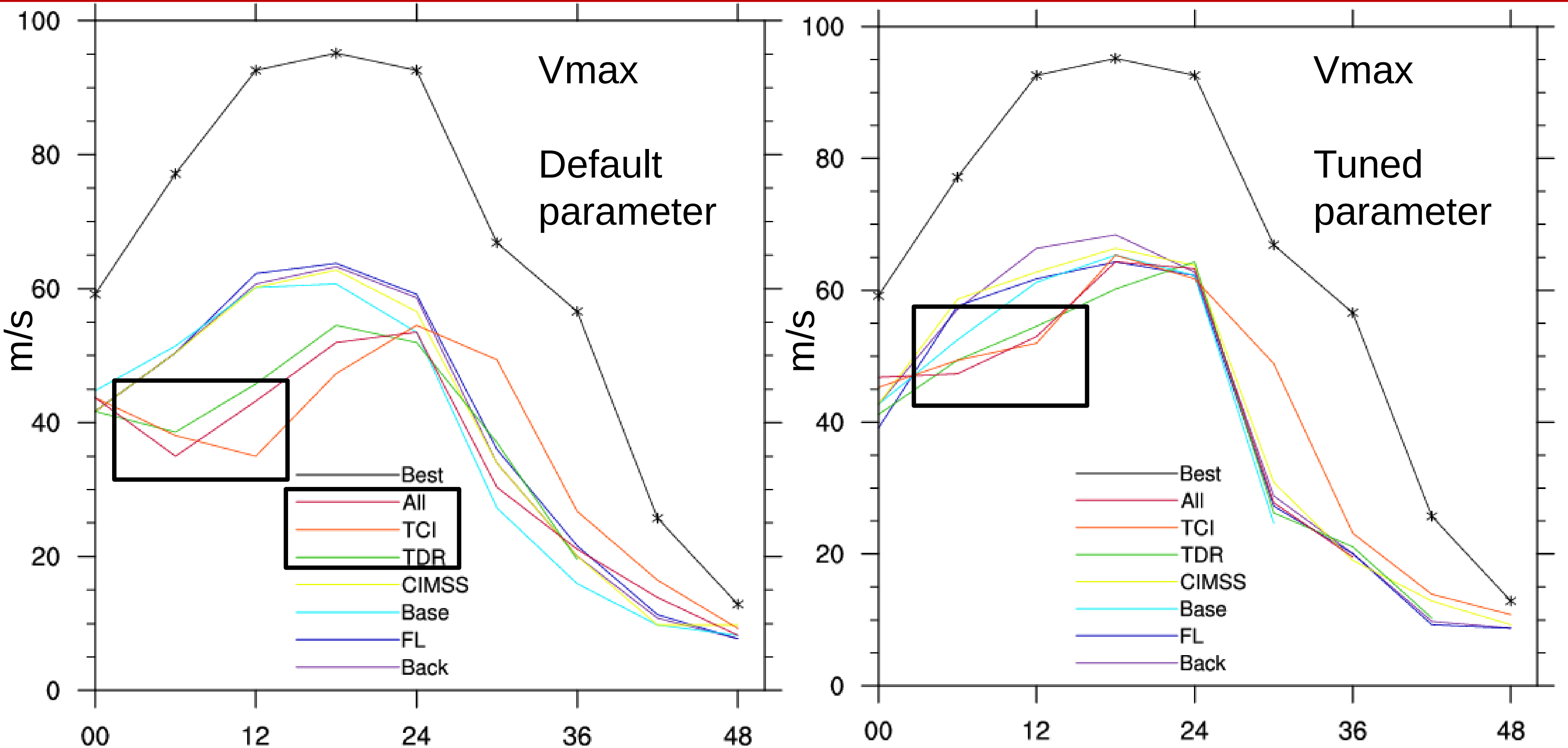
Data Impacts on Forecasts: Intensity





- SFMR can improve the Vmax analysis and forecast for the first 4 hours.
- TCI and All also show improvements of the Vmax analysis and forecast for the first 3 hours .
- TDR and FL produce even weaker Vmax forecasts at the early time.
- CIMSS and Base do not show significant different Vmax forecasts as compared to the Back.
- Although the SFMR, TDR, TCI DA provide a better analyzed inner core structure and TCI and SFMR produce improved Vmax analysis, the peak intensity isn’t improved due to slower RI. The slower RI suggests model needs to be improved further to improve RI forecast.

Alleviation of spin down through improving the model



- Spin down is significantly alleviated through testing various model parameters.
- Further investigates on the spin-down issue in relation to model parameters is still on-going.

Summary

❑ Data Impact on TC structure analysis:

1. Assimilation of the TCI HDSS dropsonde data can modify the 3-dimensional structure of both inner core and outflow regions and provides the best overall TC structure analysis compared to other individual observation.

2. Assimilation of TDR or FL or SFMR data can correct 3-dimensional inner core structures but has little impact on upper level outflow regions. TDR provides 2nd best overall TC structure. SFMR confines surface the best.

3. Assimilation of the CIMSS AMV data can help modify the upper level environmental flow 100 km away from the storm center.

4. These observations are in general complementary to each other and combining all the data through DA provides overall best TC structure analysis.

Summary (Continued)

- Data Impact on forecast:

1. Assimilation of TCI data produces the best TC structure forecast and the best track forecasts. Vmax forecast is improved for the first 3 hours and after 24 hours. The better analyzed storm structures is maintained during the forecast.
2. Assimilation of TDR or flight level observations does not show significant track forecast improvement or Vmax forecast improvement. TDR produces the second best structure forecast. FL can also produce a better structure forecast than no DA.
3. Assimilation of SFMR data does not show significant improvement on track forecast. Vmax forecast for the first 4~5 hours are improved. The structure forecast is improved as compared to no DA.
4. Assimilation of CIMSS shows slightly track forecast improvement. Limited Vmax forecasts improvements are found at the early lead times. The structure forecast is not significantly improved as compared to no DA.
5. Combing all observations improve track forecast. Vmax forecasts are improved for the first 3 hours. The structure forecast are reasonably good and is comparable to TCI.
6. Although the structure is improved during both the analysis and forecast, the peak intensity is not improved due to slower RI. Efforts need to be made to improve the model to improve RI forecast.

Ongoing & future Work

- Continue exploring impact of data from TCI and other field campaign: e.g. Include TCI HIRAD; impact of upper level vs lower level TCI dropsondes; impact of TCI T vs Q vs wind; optimal data resolution; SHOUT data; other cases (e.g., Jaoquin, 2016 cases)

- Continue using DA to diagnose model errors to alleviate the spin-down issue and to improve RI forecast

- Continue understanding the scientific questions regarding RI mechanism proposed in the introduction with the utilization of the analyses and forecasts produced after assimilating these observations.

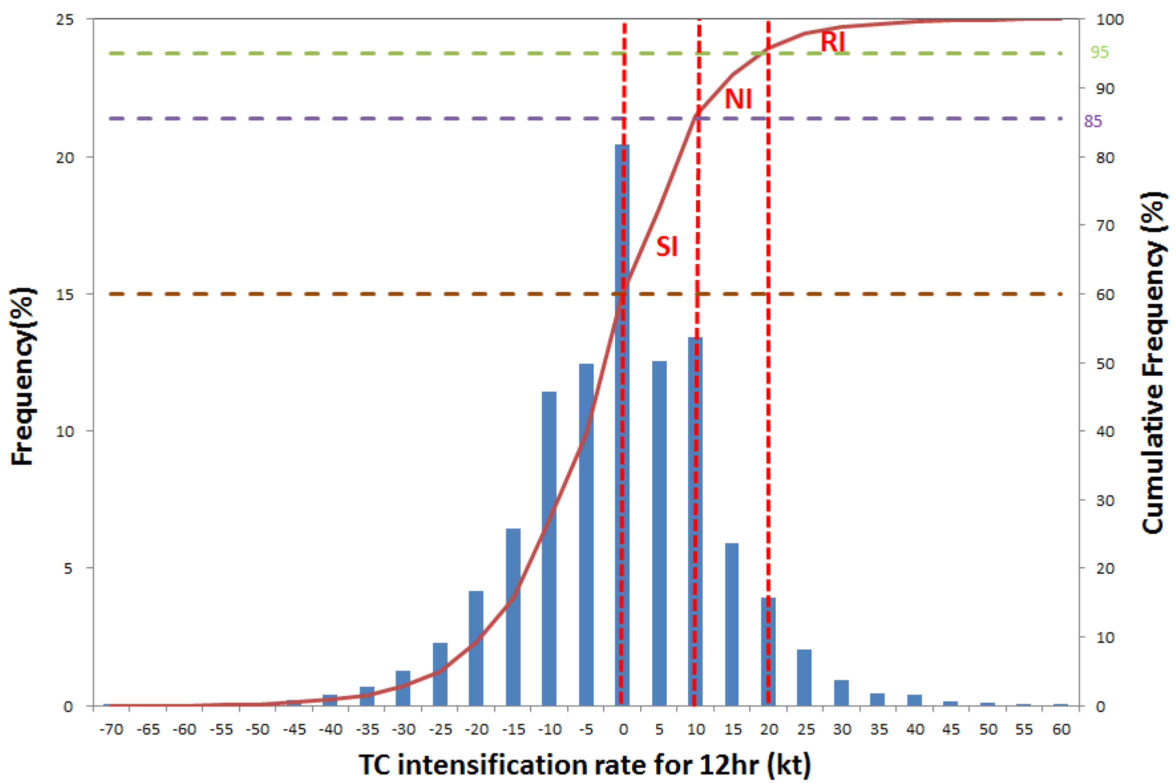
Understanding impact of outflow on TC intensification rate over NW Pacific 1995-2015

RI: $\Delta^{12h}_{umax} \geq 20kt$ & $\Delta^{6h}_{umax} \geq 5kt$

NI: $20kt > \Delta^{12h}_{umax} \geq 10kt$ & $5kt \geq \Delta^{6h}_{umax} > 0kt$

SI: $10kt > \Delta^{12h}_{umax} > 0kt$ & $\Delta^{6h}_{umax} \geq 0kt$

Δ^{6h}_{umax} *and* Δ^{12h}_{umax} *are* **TC intensity change for 6hr and 12hr, respectively.**



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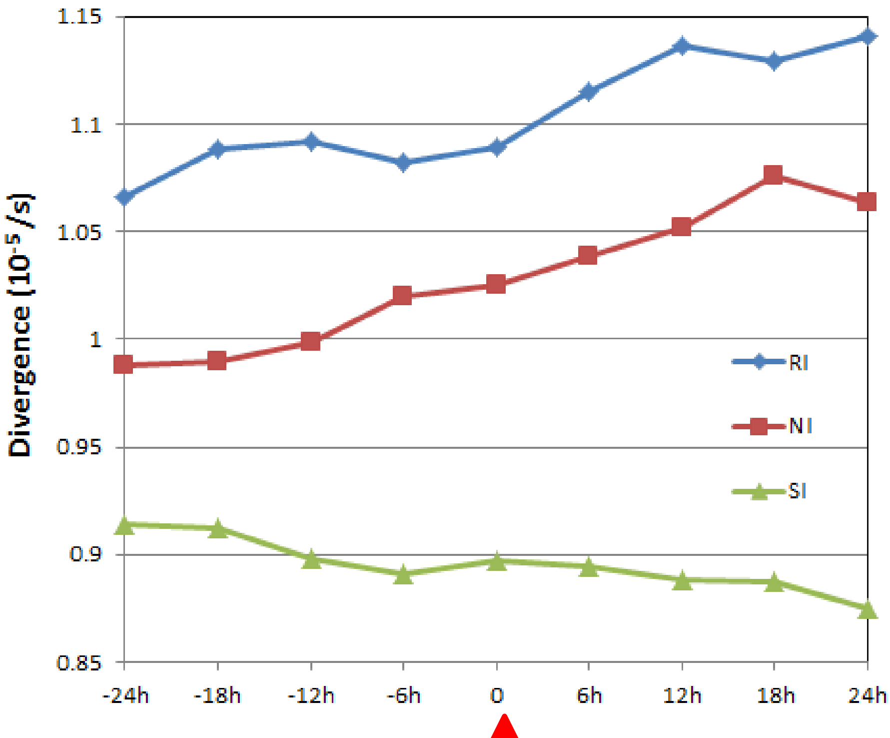
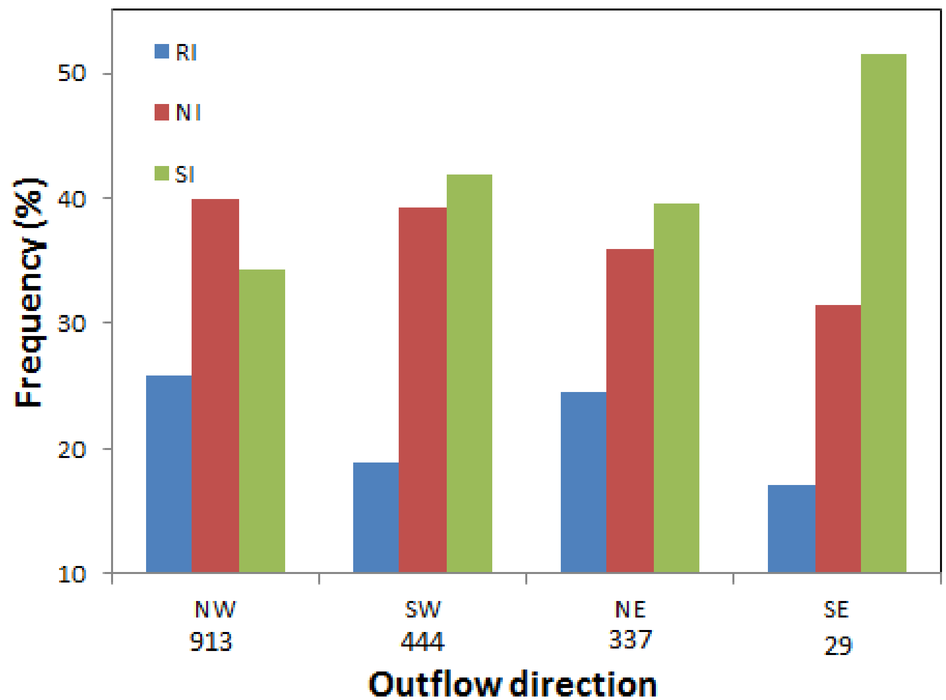


Onset of RI



- The strength of the upper_level outflow significantly affects the rate of TC intensification.
- Increase of outflow strength appears to precede the onset of RI.
- NW and NE outflow favor RI more than SW and SE outflow