Radiance Data Assimilation with an EnKF

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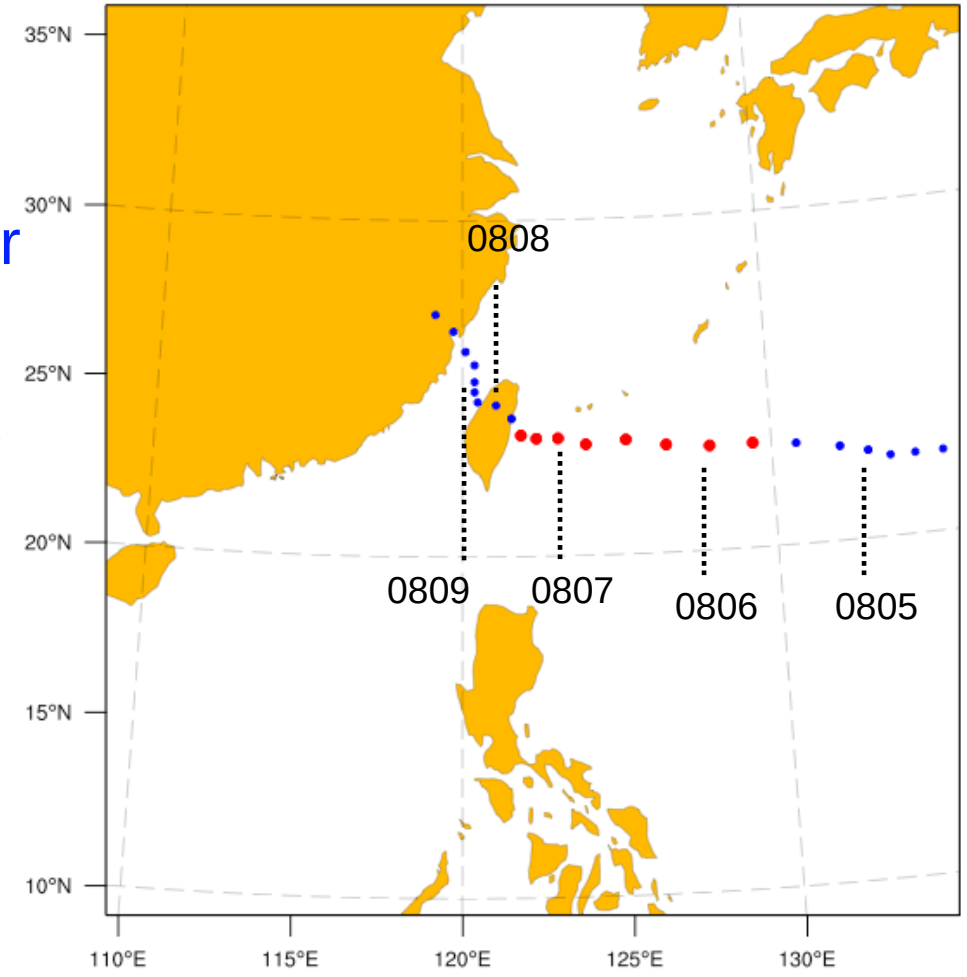
*NCAR is sponsored by the National Science Foundation

Typhoon Morakot

- Red: Typhoon
- Blue: Tropical storm or depression
- Numbers refer to date at 0000 UTC: (0806…06 Aug 2009)
- Produced very heavy precip. over Taiwan at landfall.



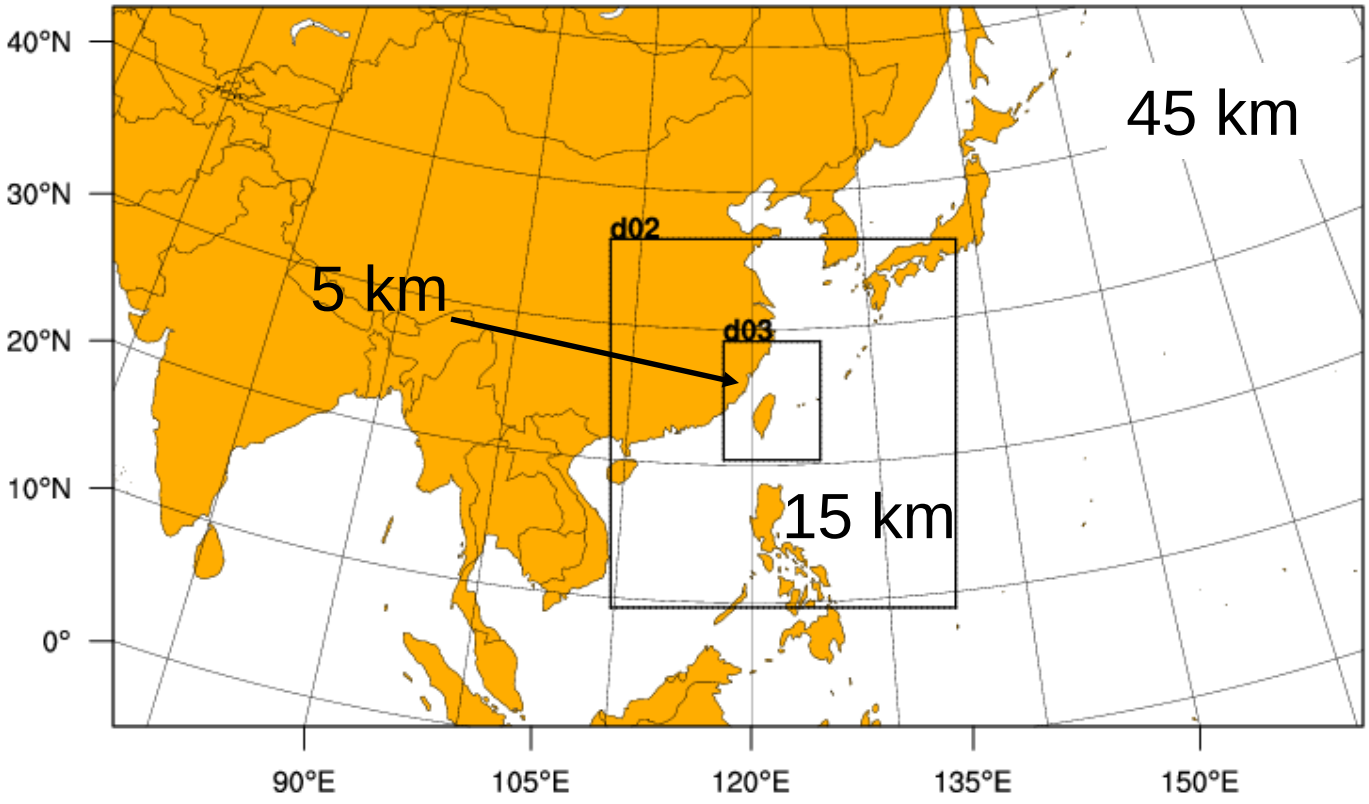
Typhoon Morakot

Photo courtesy of Owen Shieh (University of Oklahoma)

Typhoon Morakot

Typhoon Morakot

Computational Domains



Experiments

1) WRFDA-3DVAR: conventional obs only, 6-hr full-cycling, DA in d01 only
2) Same as experiment 1, but with the addition of radiances (AMSU-A/B, MHS sensors)
3) Same as experiment 2, but with DA in d01 and d02

Deterministic

4) 64-member ensemble using DART* software, 6-hr full-cycling, assimilated conventional observations in d01 *only*
5) Same as experiment 4, but assimilated radiances in addition to conventional observations

Ensemble

*DART: Data Assimilation Research Testbed

General Configurations

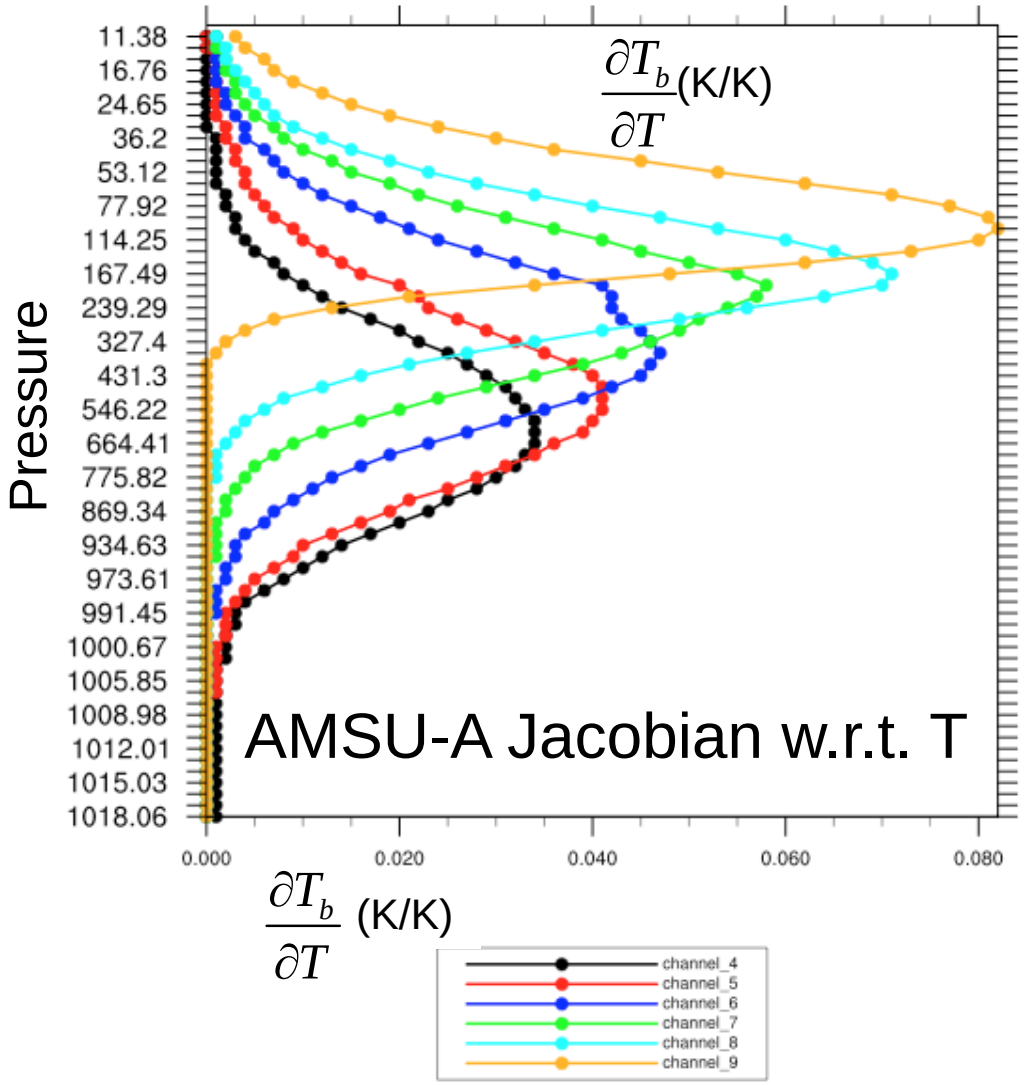
- Time period: 2009,1800 UTC 03 Aug - 1200 UTC 09 Aug
- A 72-hour WRF forecast was made every six hours (00/06/12/18Z) from 3DVAR analyses and ensemble mean of DART experiments
- Version 3.1.1 of WRF-ARW
- 45 vertical levels, model top of 30 hPa
- Observation window: analysis time ±3 hrs
- No cyclone relocation or bogus obs used during analyses

DART Obs Implementation

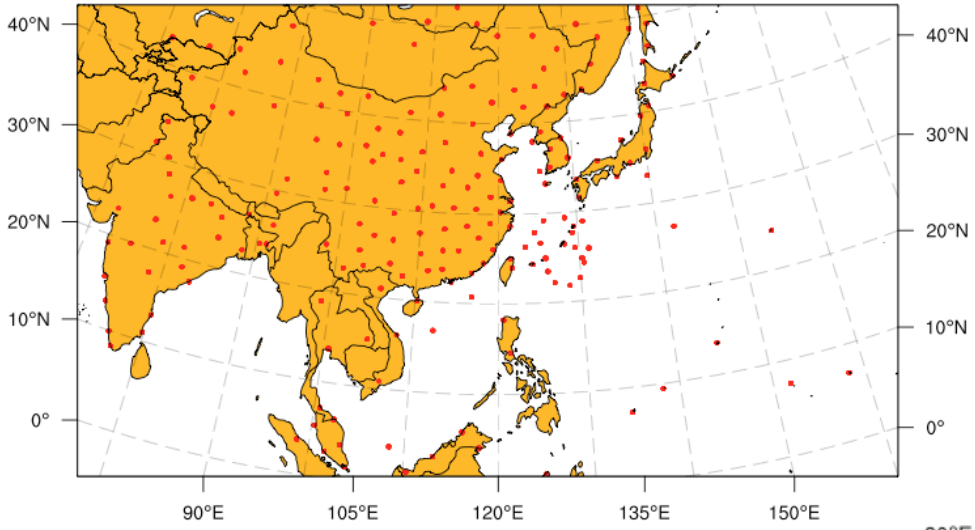
- Make use of observation operators built in the WRFDA-3DVAR
  - Obs. prior is calculated/QCed/output from WRFDA-3DVAR
  - For both conventional observations and radiances
- Convert 3DVAR output files into proper DART format
- Modify DART to directly use obs prior calculated from 3DVAR
  - DART built-in observation operators are only applied after analysis (step for diagnosing obs. posterior)
- For radiances, also output Jacobian from CRTM in addition to obs prior
  - For vertical localization

Vertical Localization

Height of peak levels of Jacobian used as vertical coordinate



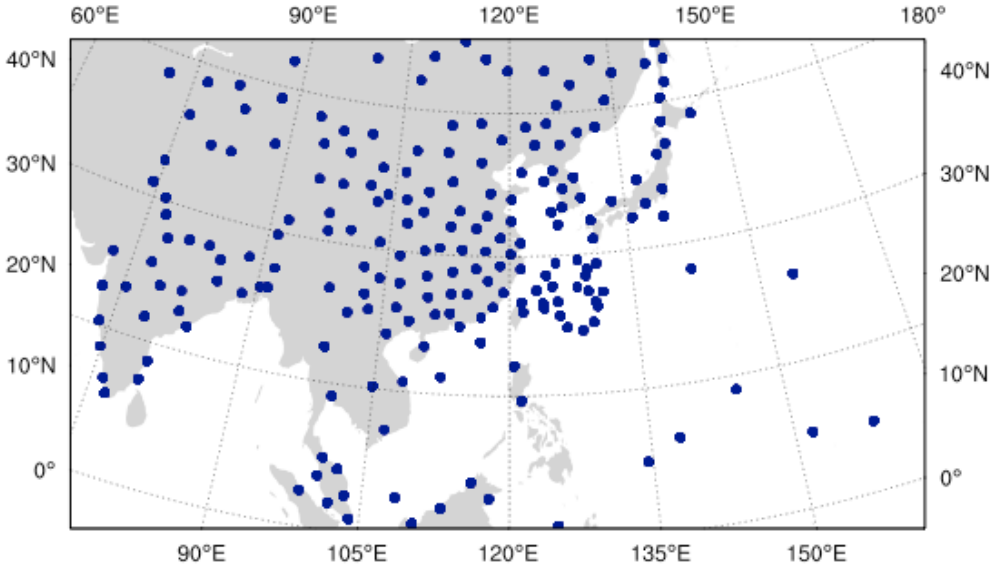
Sounding Distribution



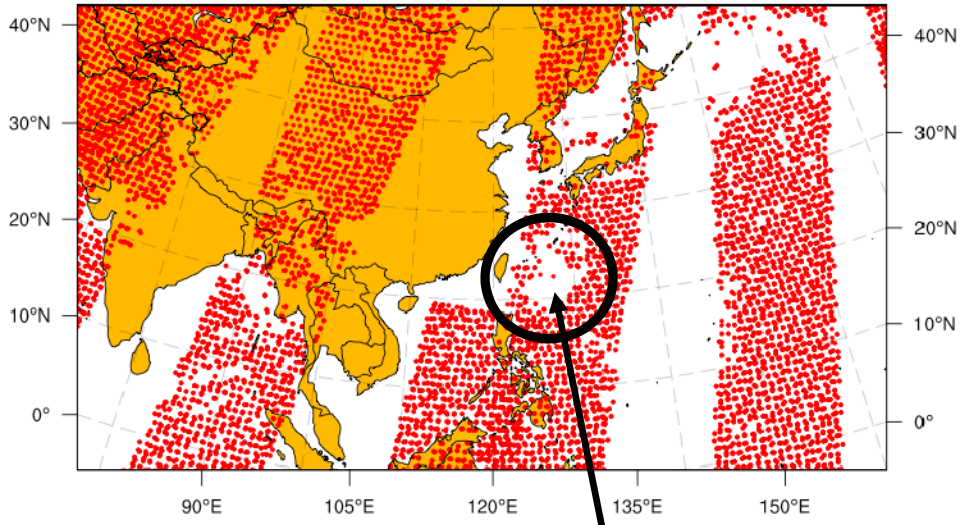
DART

Distribution of soundings assimilated for the 06 Aug 0000 UTC analysis

WRFDA-3DVAR

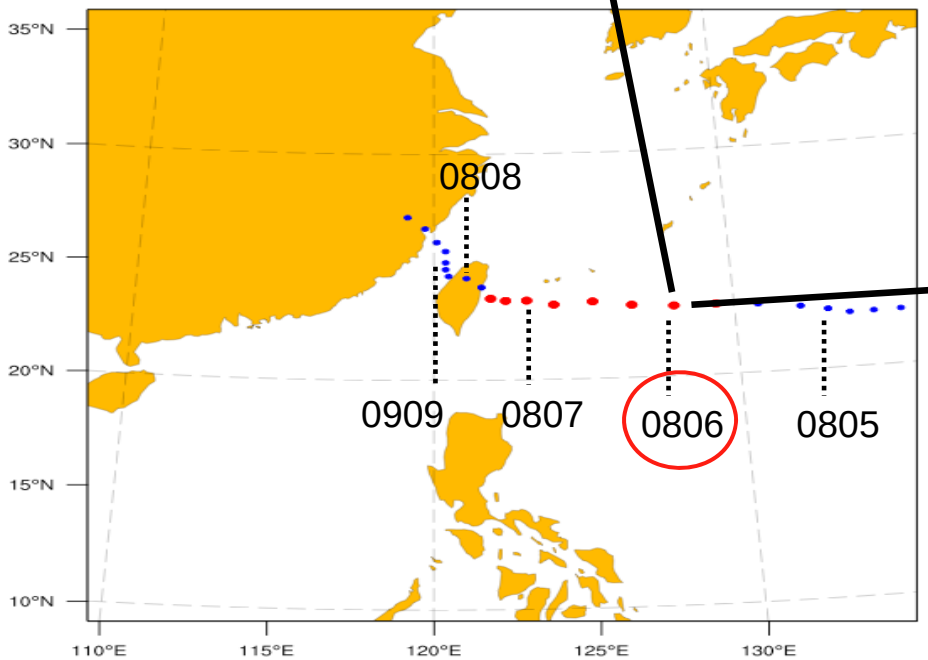


Radiance Distribution

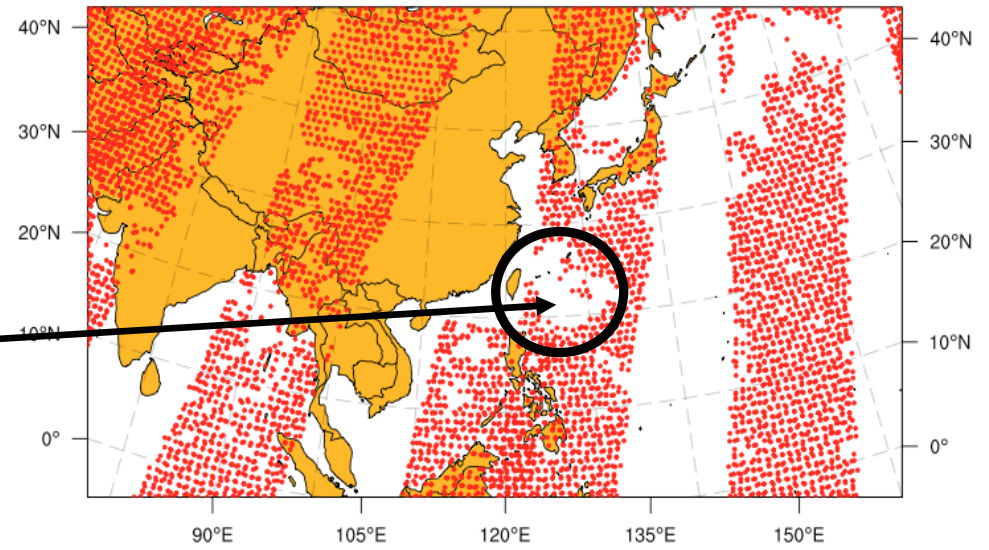


Distribution of radiances assimilated for the 06 Aug 0000 UTC analysis

DART

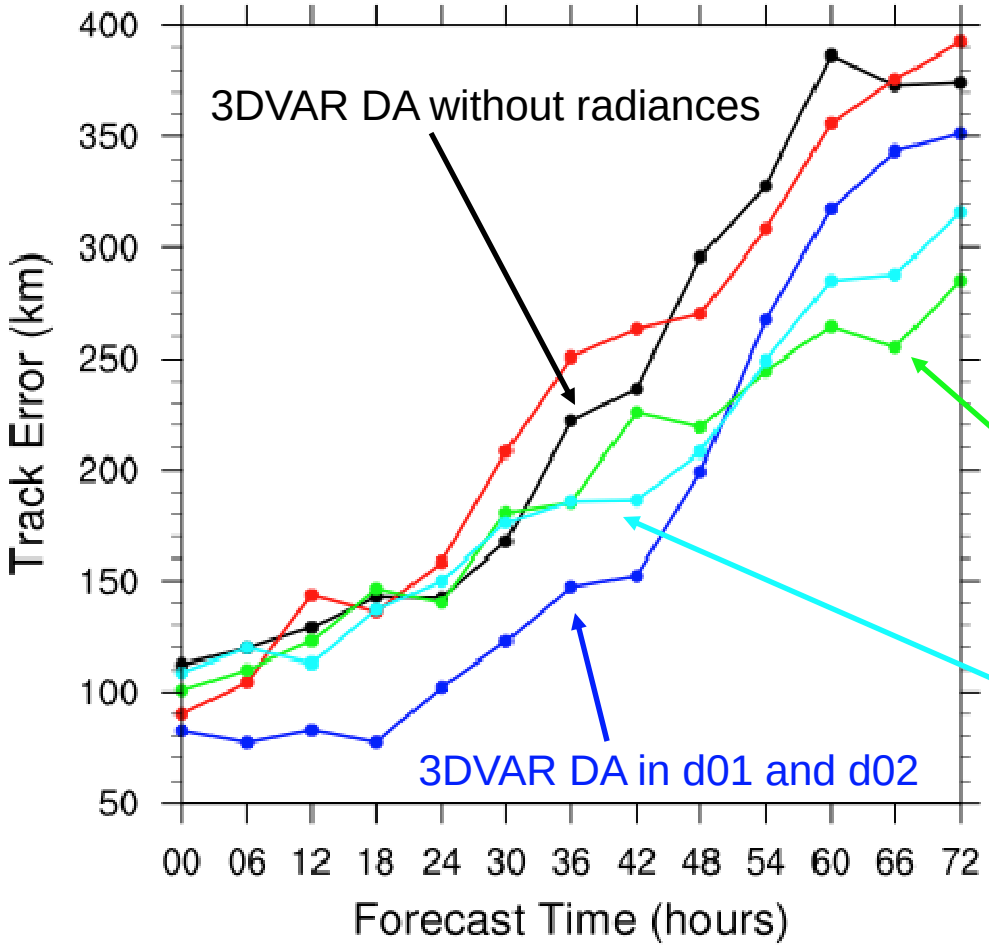


WRFDA-3DVAR

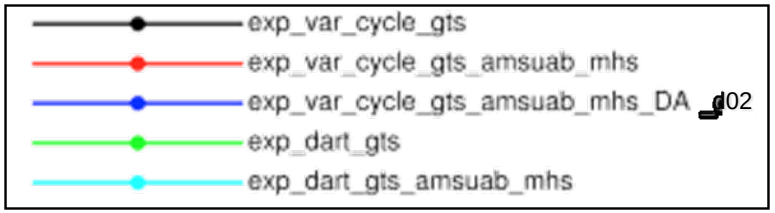


Average Track Error

- Averaged from 1800 UTC 03 Aug to 1200 UTC 09 Aug



- Statistics for d02

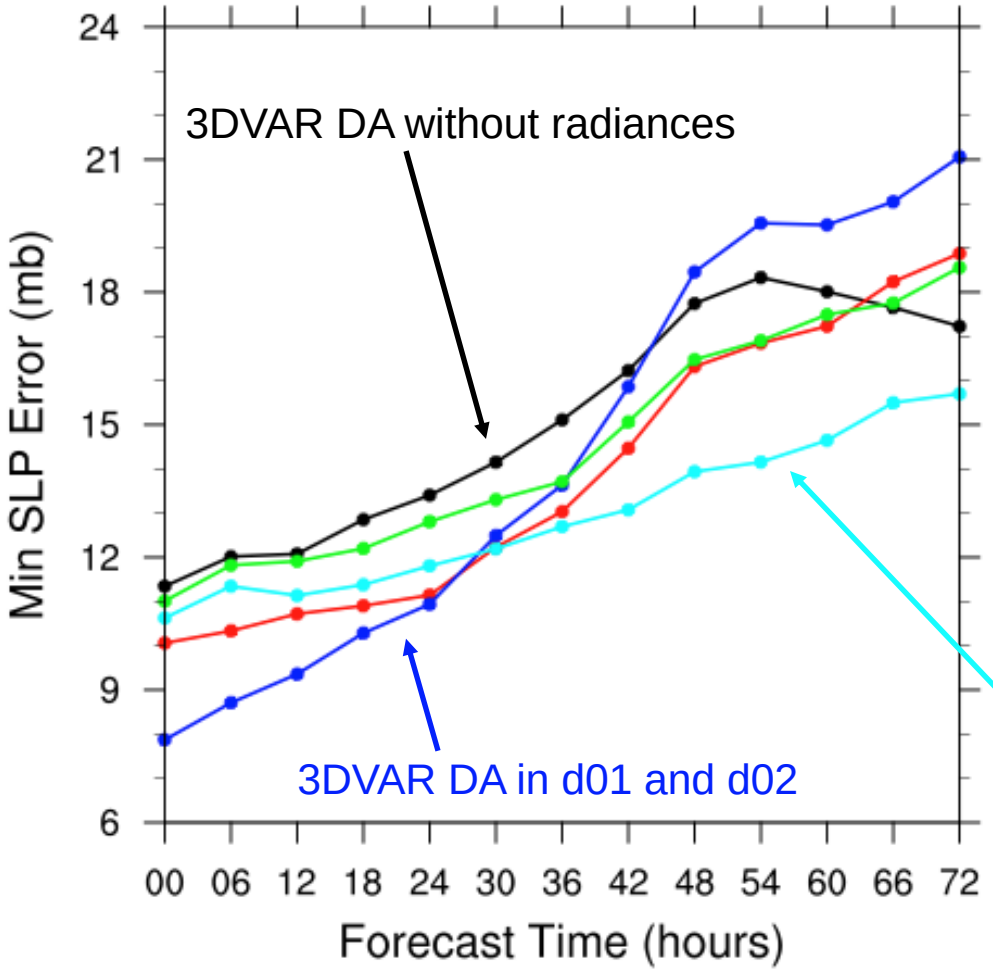


Ensemble experiment without radiances

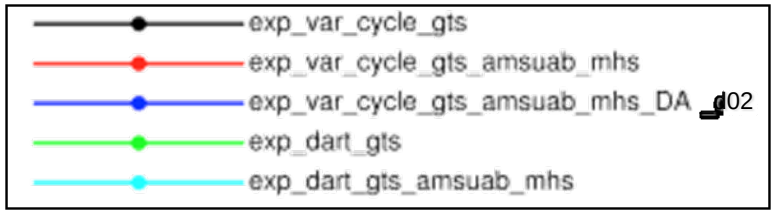
Ensemble experiment with radiances

Average Min SLP Error

- Averaged from 1800 UTC 03 Aug to 1200 UTC 09 Aug



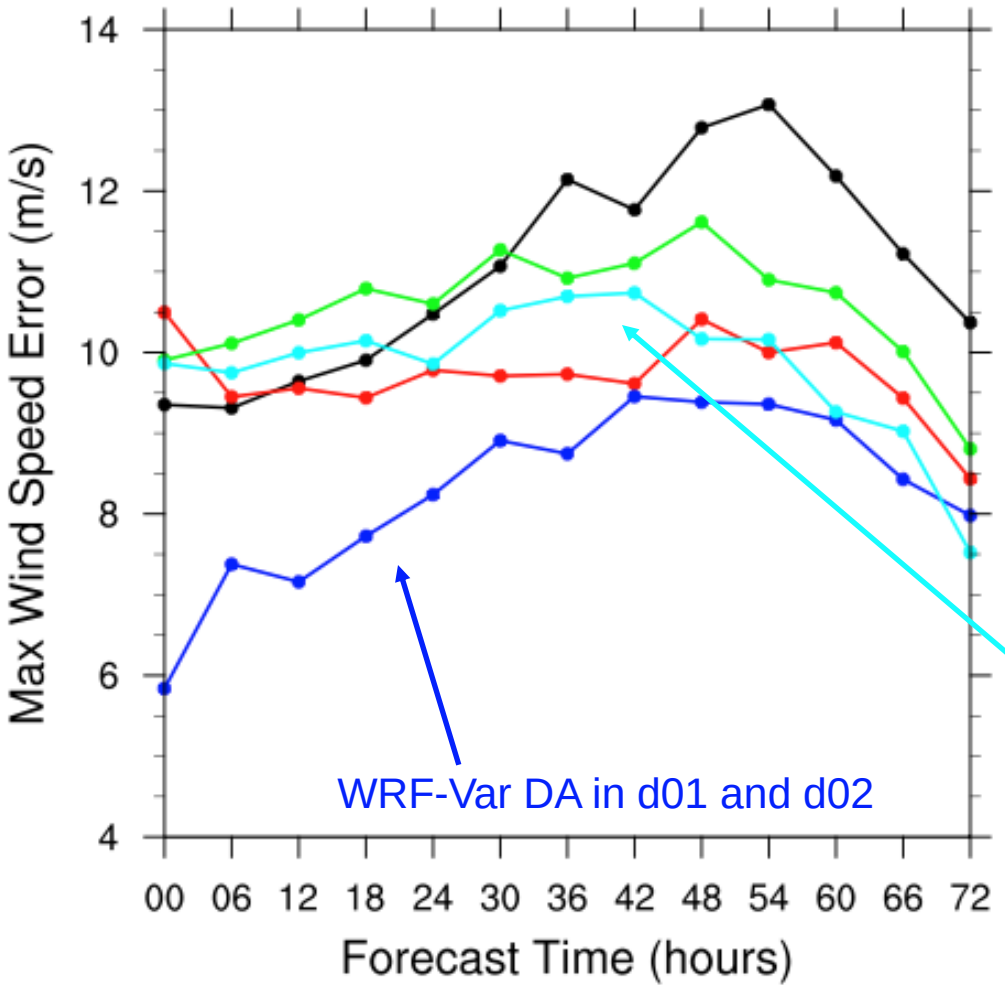
- Statistics for d02



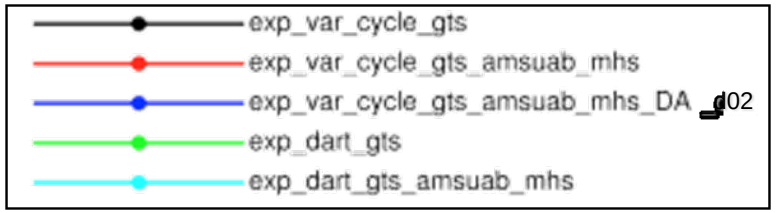
Ensemble experiment with radiances

Average Max Wind Speed Error

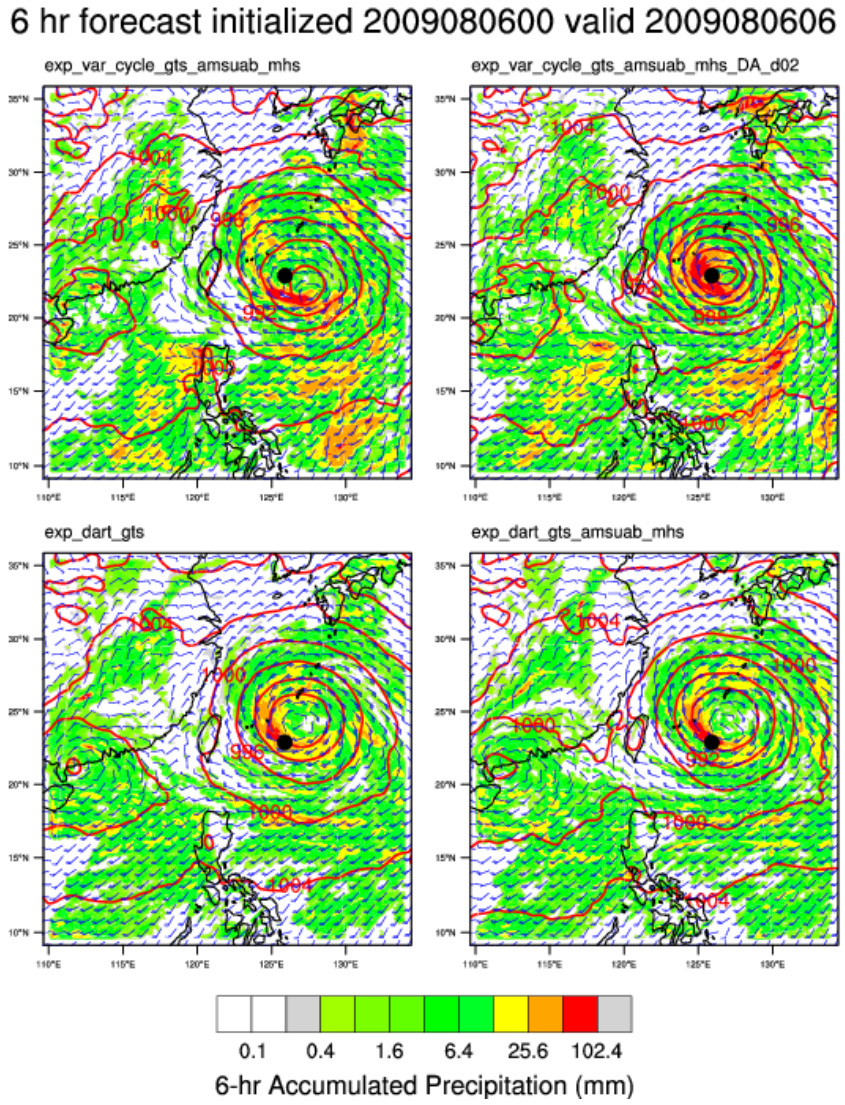
- Averaged from 1800 UTC 03 Aug to 1200 UTC 09 Aug



- Statistics for d02

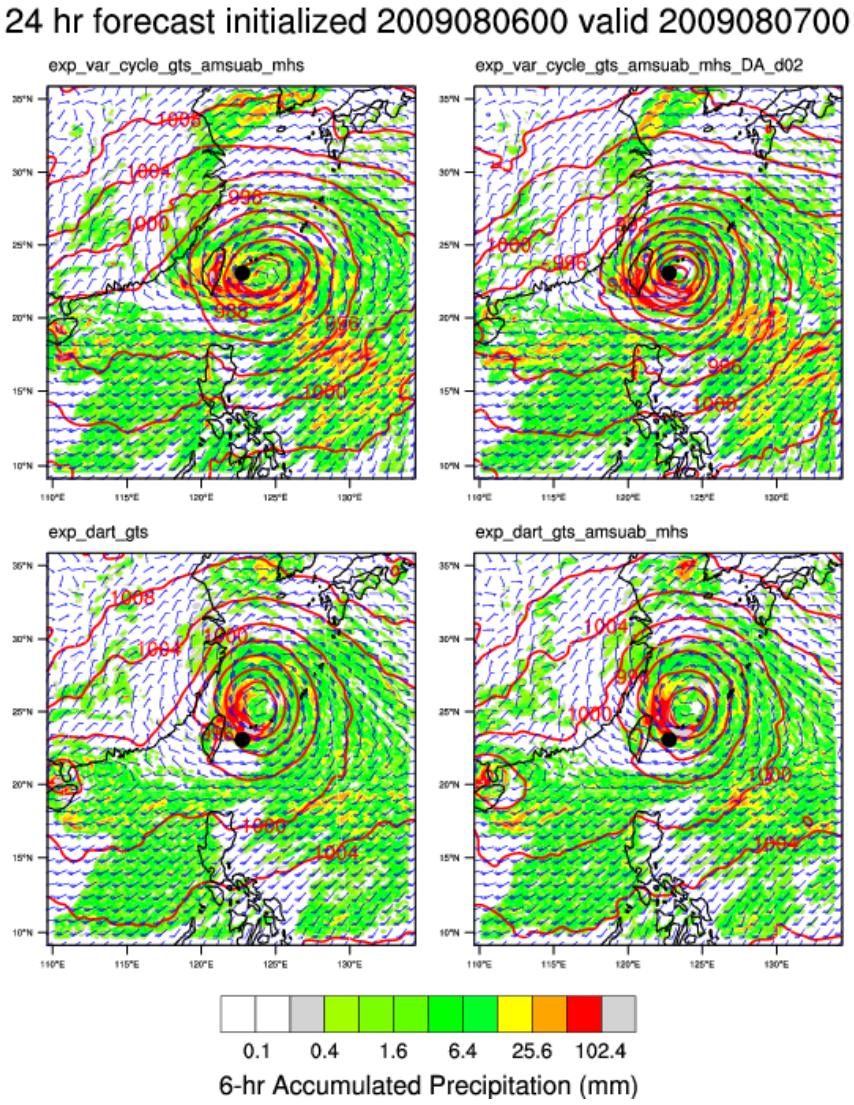


A Sample Forecast



3DVAR exps.

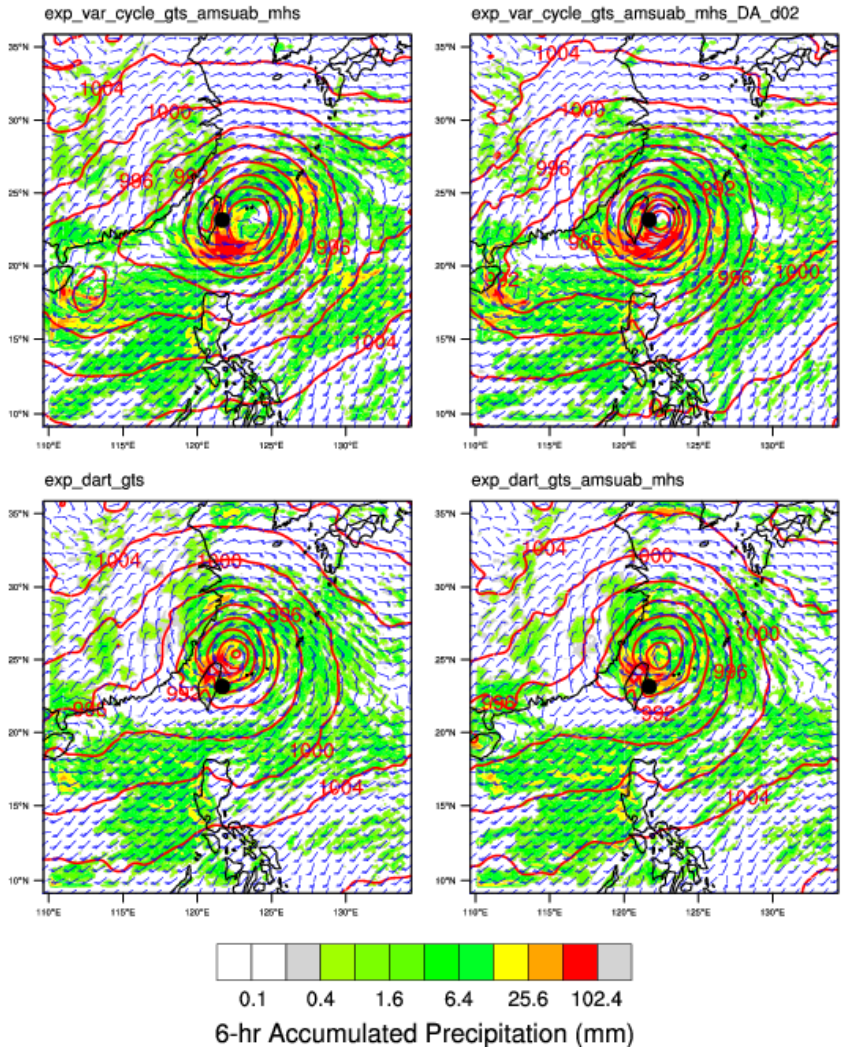
DART exps.



3DVAR exps.

DART exps.

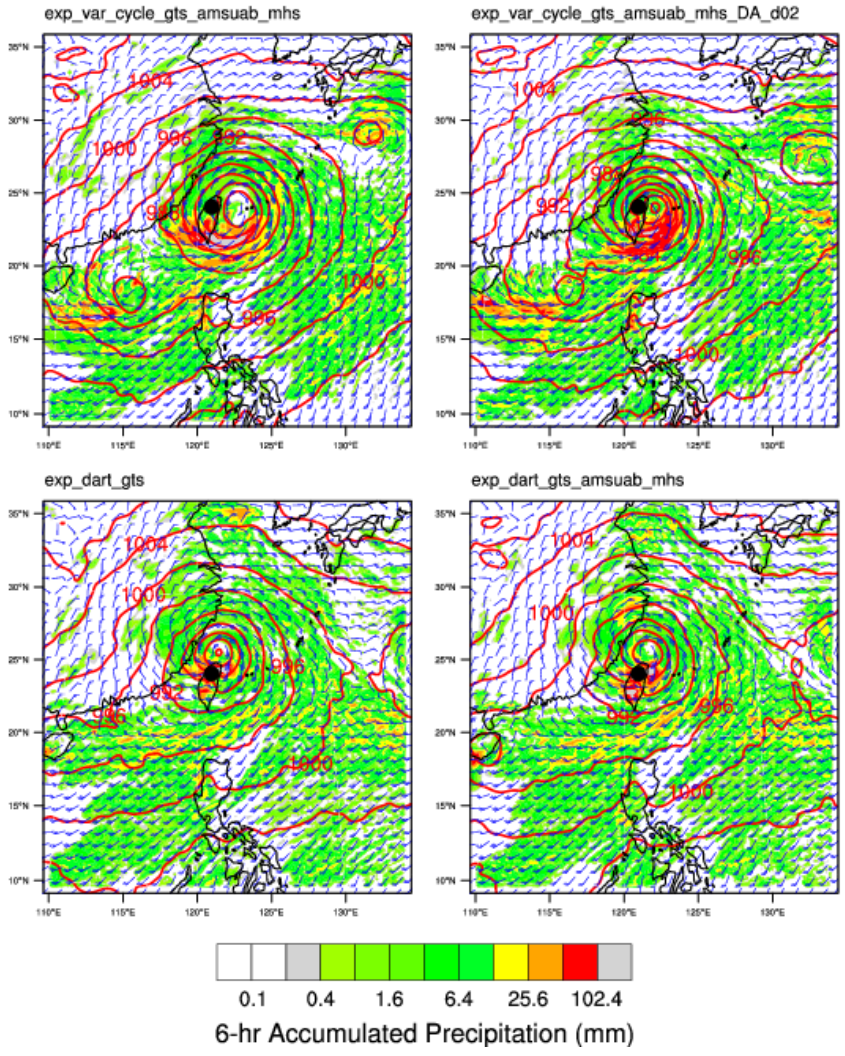
36 hr forecast initialized 2009080600 valid 2009080712



3DVAR exps.

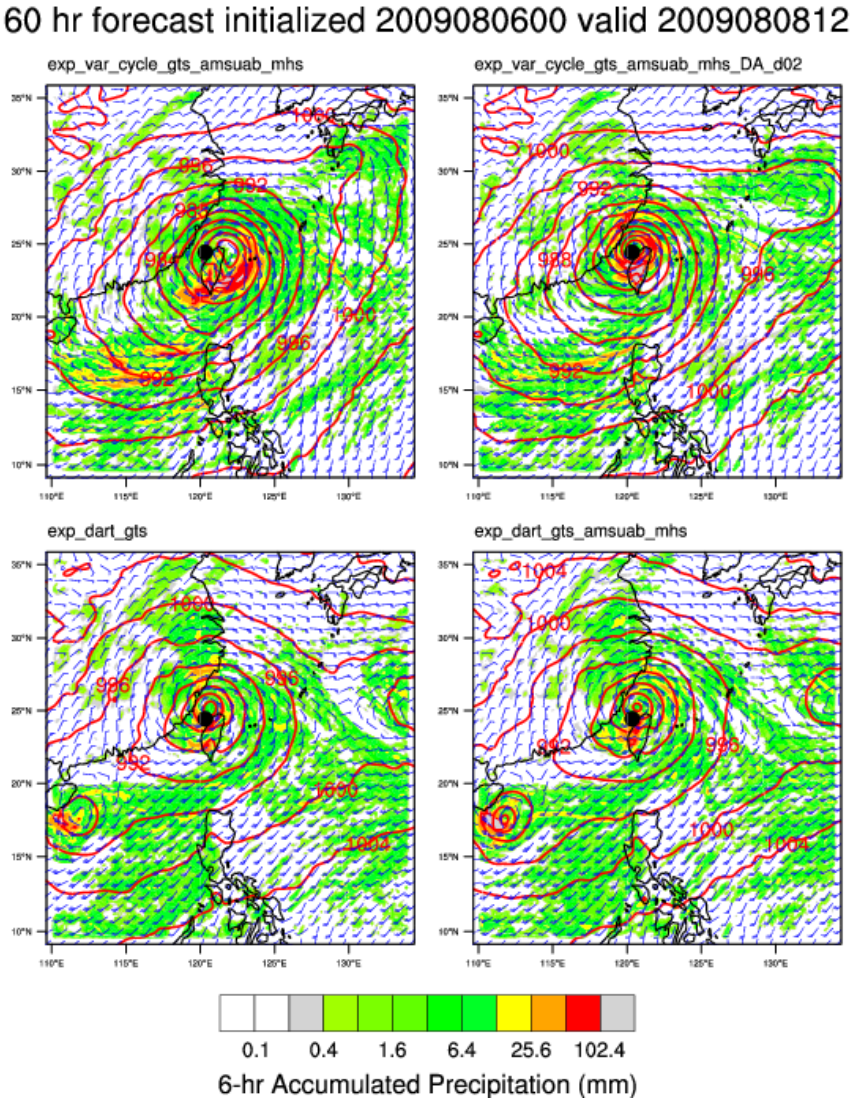
DART exps.

48 hr forecast initialized 2009080600 valid 2009080800



3DVAR exps.

DART exps.



3DVAR exps.

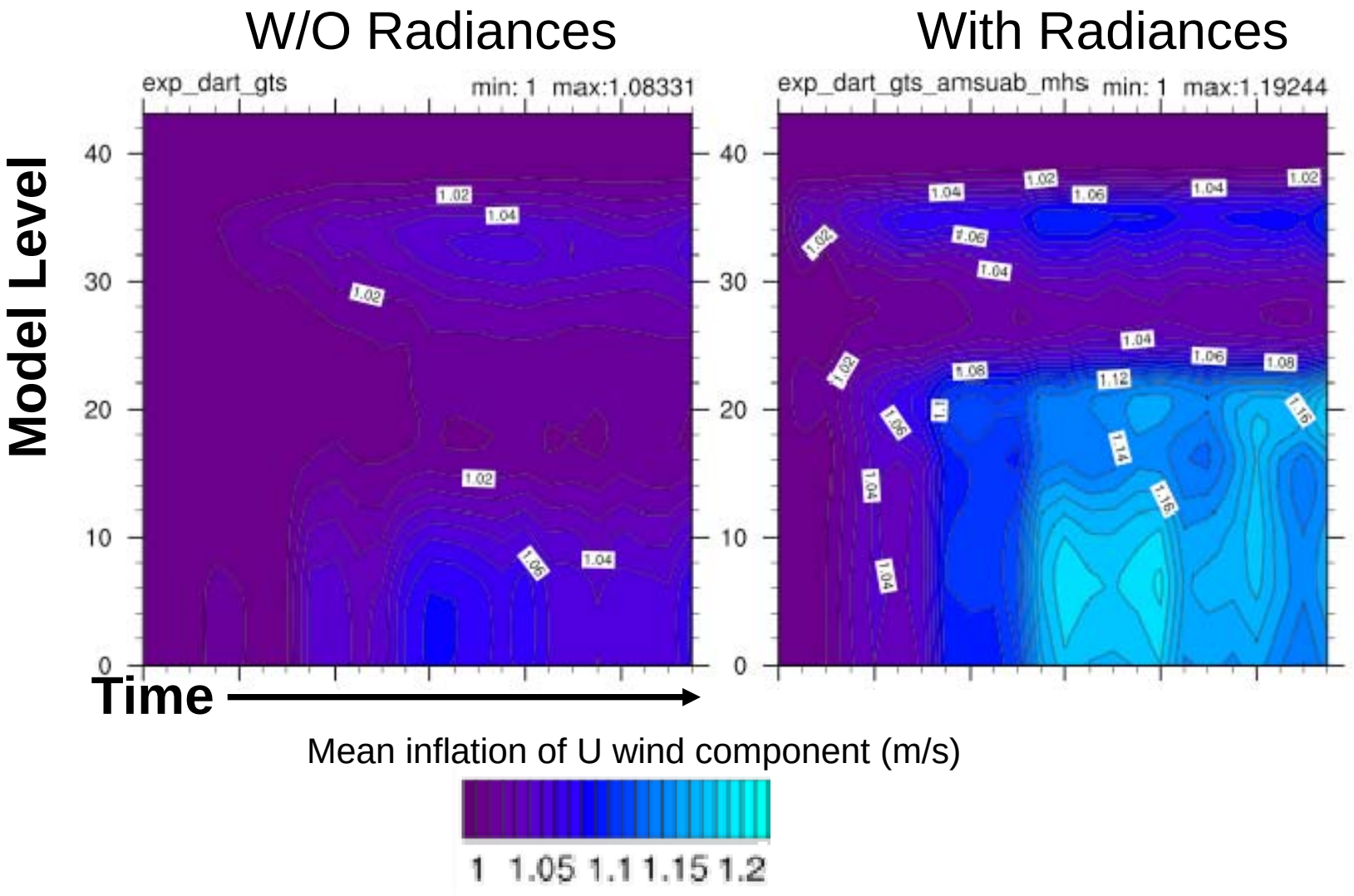
DART exps.

Summary

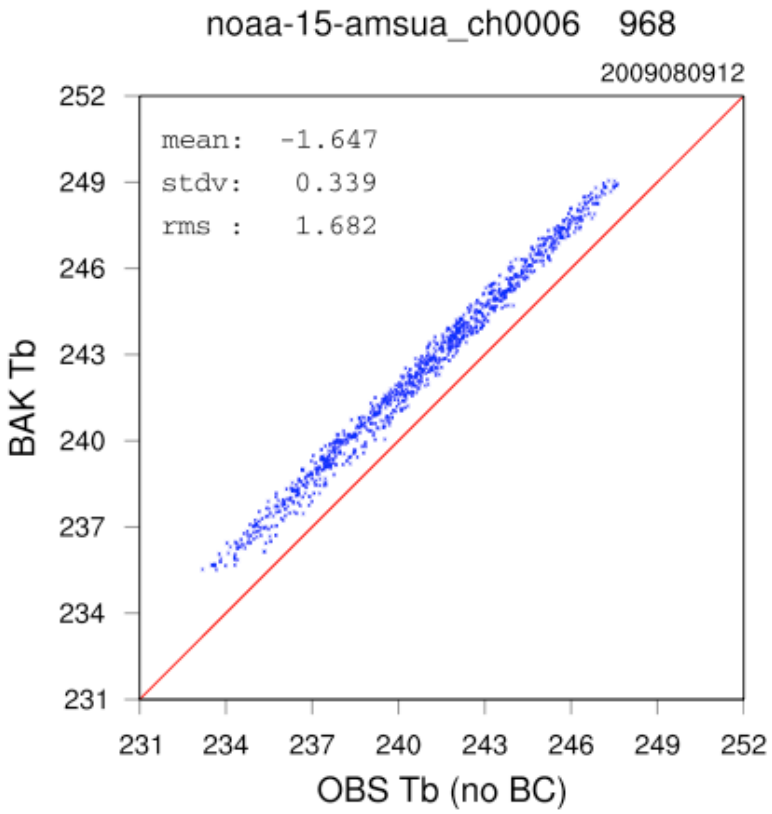
- EnKF-based radiance DA was implemented through coupling DART with WRFDA's RTM, bias correction, and QC scheme
- For Typhoon Morakot, EnKF apparently produces better track and intensity forecasts than 3DVAR for mid-range forecasts
- EnKF with radiances improves intensity forecasts when compared to assimilating conventional obs only
- 3DVAR DA in both D01 and D02 adds additional value than DA in D01 only

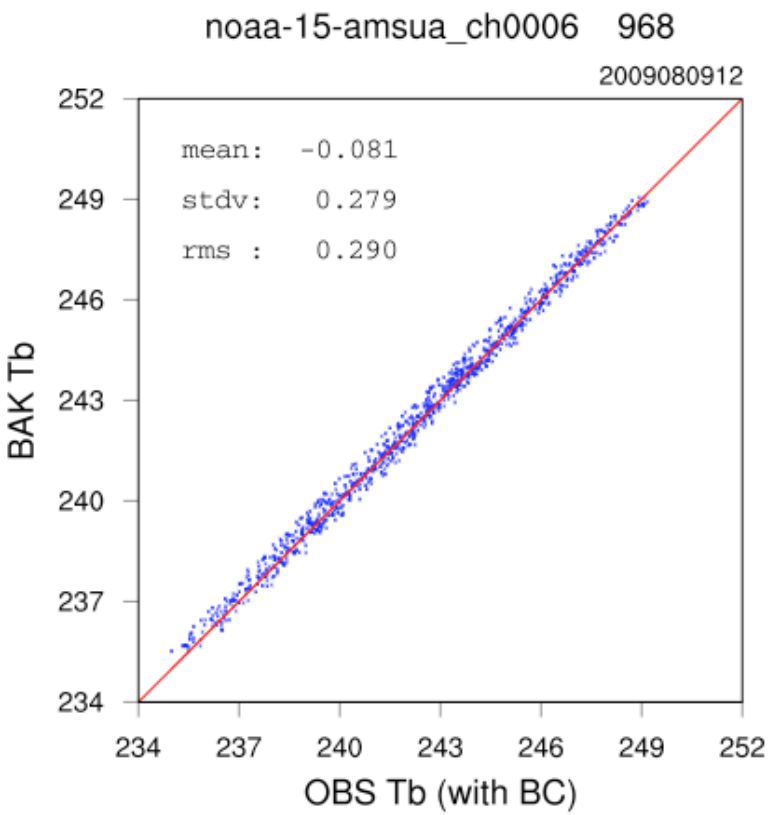

NESL

Prior Inflation: U



Bias Correction and QC





Bias correction coefficients from the end of 3DVAR experiment.
Use Ensemble Mean as reference for BC and QC.

EnKF Analysis Equation

- Kalman filter equations

$$\overline{\mathbf{x}^a} = \overline{\mathbf{x}^f} + \mathbf{K}[y^o - \overline{H(\mathbf{x}^f)}]$$

$$\mathbf{K} = \mathbf{P}^f\mathbf{H}^T(\mathbf{H}\mathbf{P}^f\mathbf{H}^T + \mathbf{R})^{-1}$$

- Use ensemble of model forecasts to compute sample covariances

$$\mathbf{P}^f\mathbf{H}^T = \mathrm{cov}(\mathbf{x}^f, \mathbf{H}\mathbf{x}^f) = \frac{1}{N-1}\sum_{k=1}^{N}(\mathbf{x}_k^f - \overline{\mathbf{x}^f})[H(\mathbf{x}_k^f) - \overline{H(\mathbf{x}_k^f)}]$$

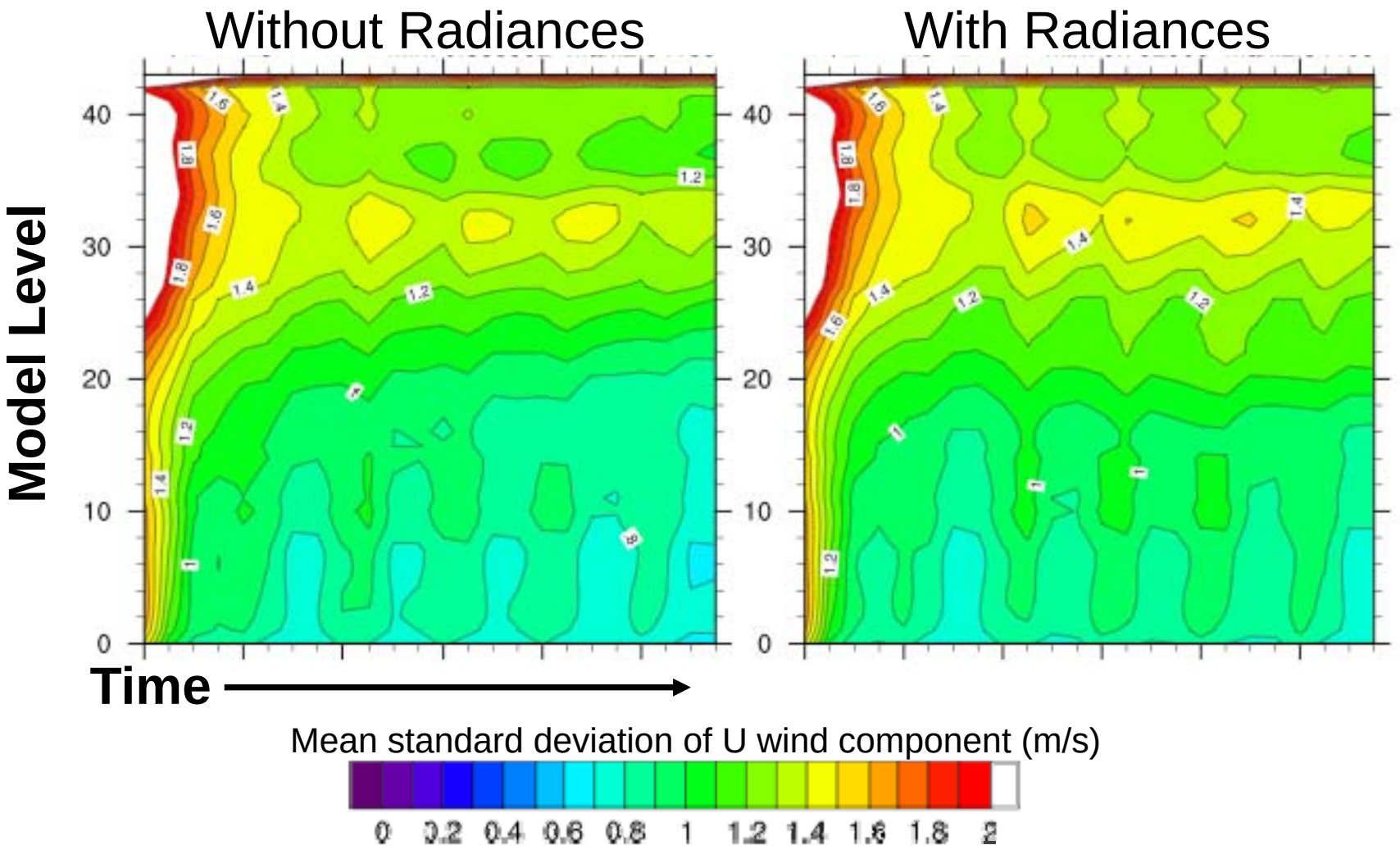
$$\mathbf{H}\mathbf{P}^f\mathbf{H}^T = \mathrm{cov}(\mathbf{H}\mathbf{x}^f, \mathbf{H}\mathbf{x}^f) = \frac{1}{N-1}\sum_{k=1}^{N}[H(\mathbf{x}_k^f) - \overline{H(\mathbf{x}_k^f)}][H(\mathbf{x}_k^f) - \overline{H(\mathbf{x}_k^f)}]$$

Only need obs. Prior!

TL of Obs. Operator
(or Jacobian Matrix)

Obs. Operator
(could be non-linear)

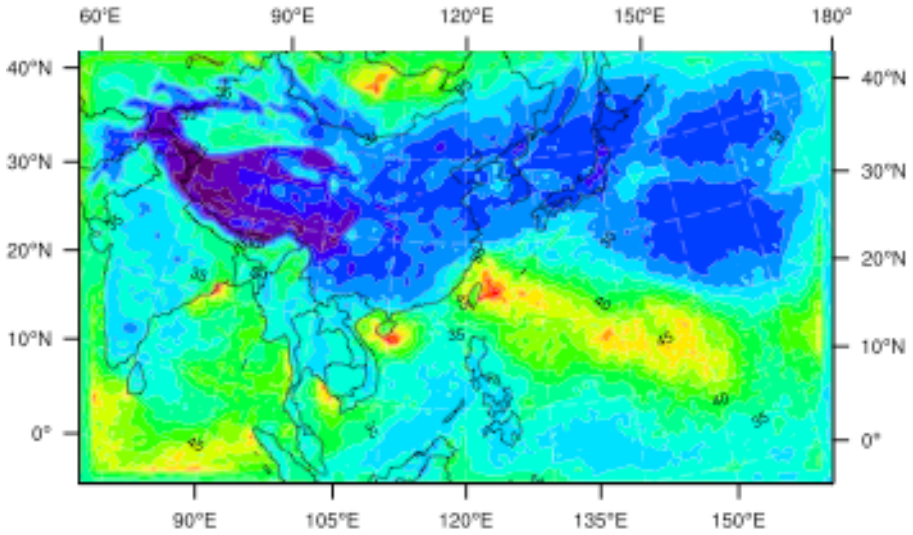
Prior Spread: U



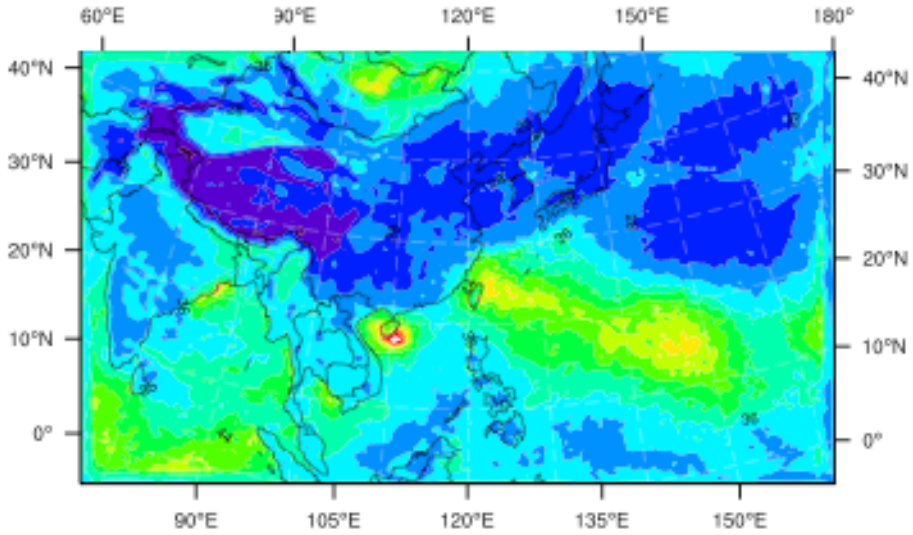
Posterior Spread: Sfc Pressure

•Averaged from 1800 UTC 03 Aug to 1200 UTC 09 Aug

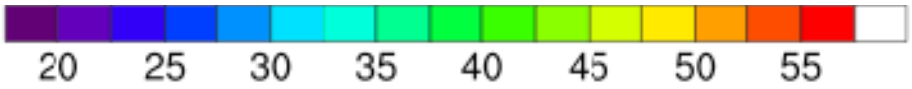
Without Radiances



With Radiances



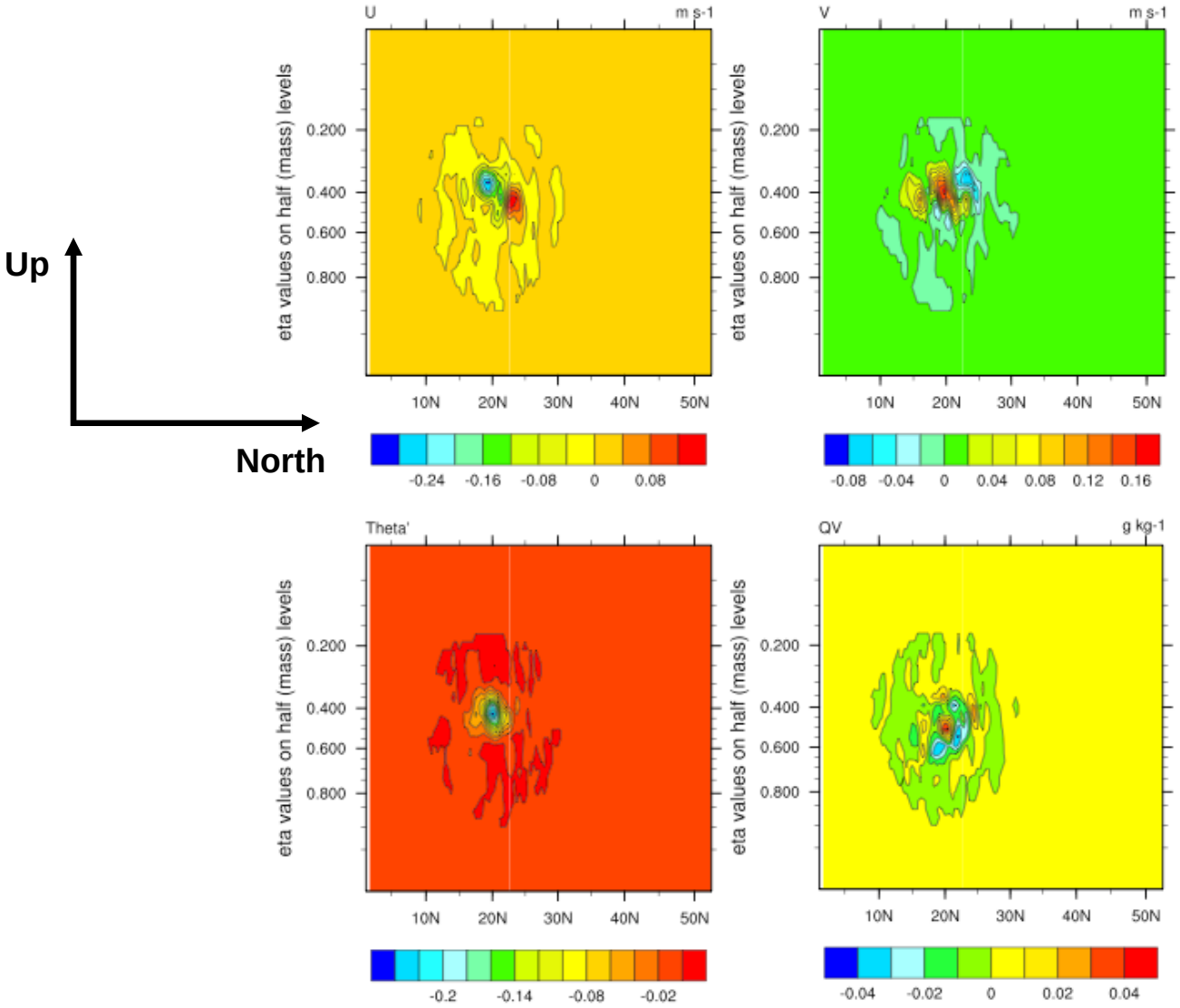
Mean standard deviation of surface pressure (Pa)



Future work

- Precip. Verification
- Ensemble DA in both D01 and D02
- Revise radiance vertical localization
  - Make use of full Jacobian profile
- Better constrain analysis track
  - Relocation, bogus DA or track DA.

Single Observation in the Ensemble



With vertical localization