Radiance Data Assimilation with an EnKF

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Outline

- Radiance Assimilation Methodology
- Apply to Typhoon Morakot (2009)
- Summary and future work

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)

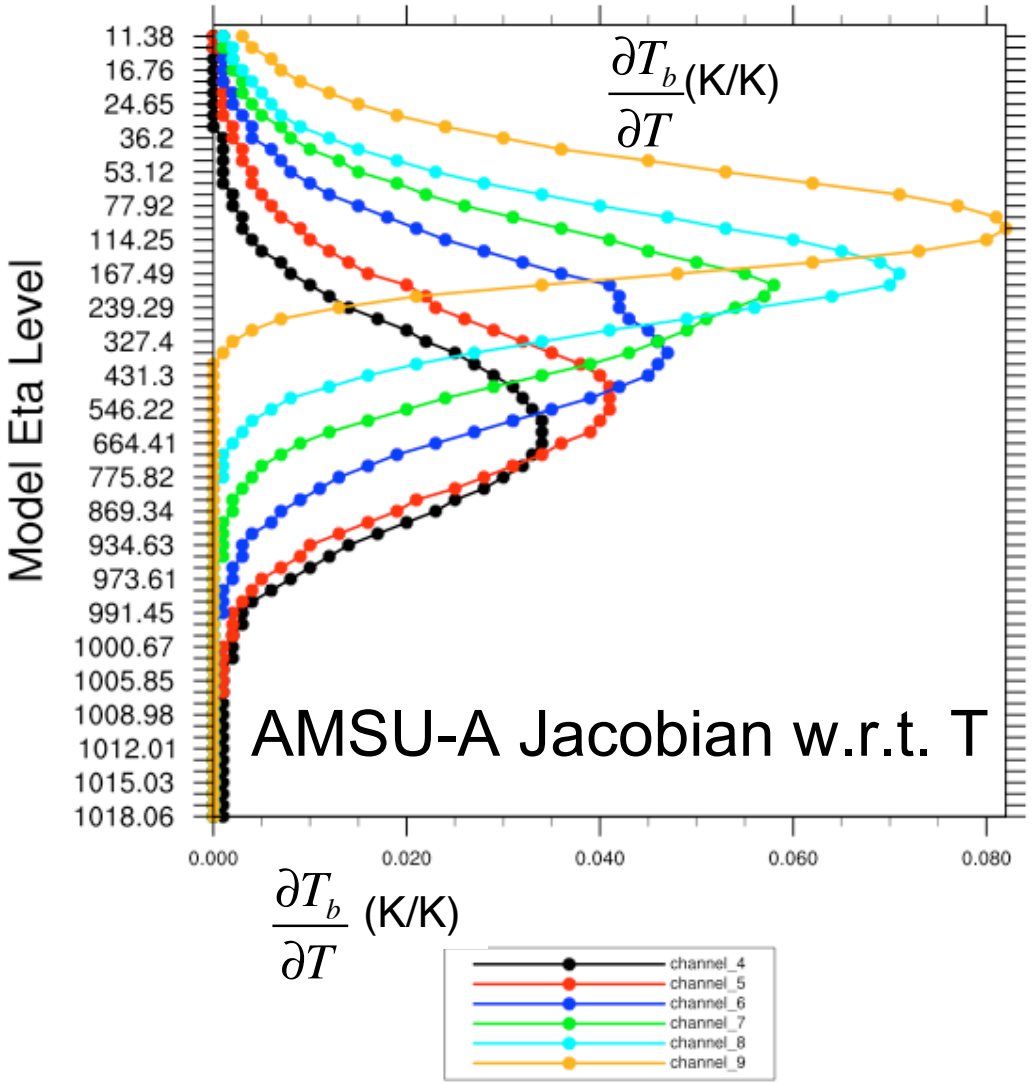
Practical Implementation

- 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 the modified DART obs_seq files.
- 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

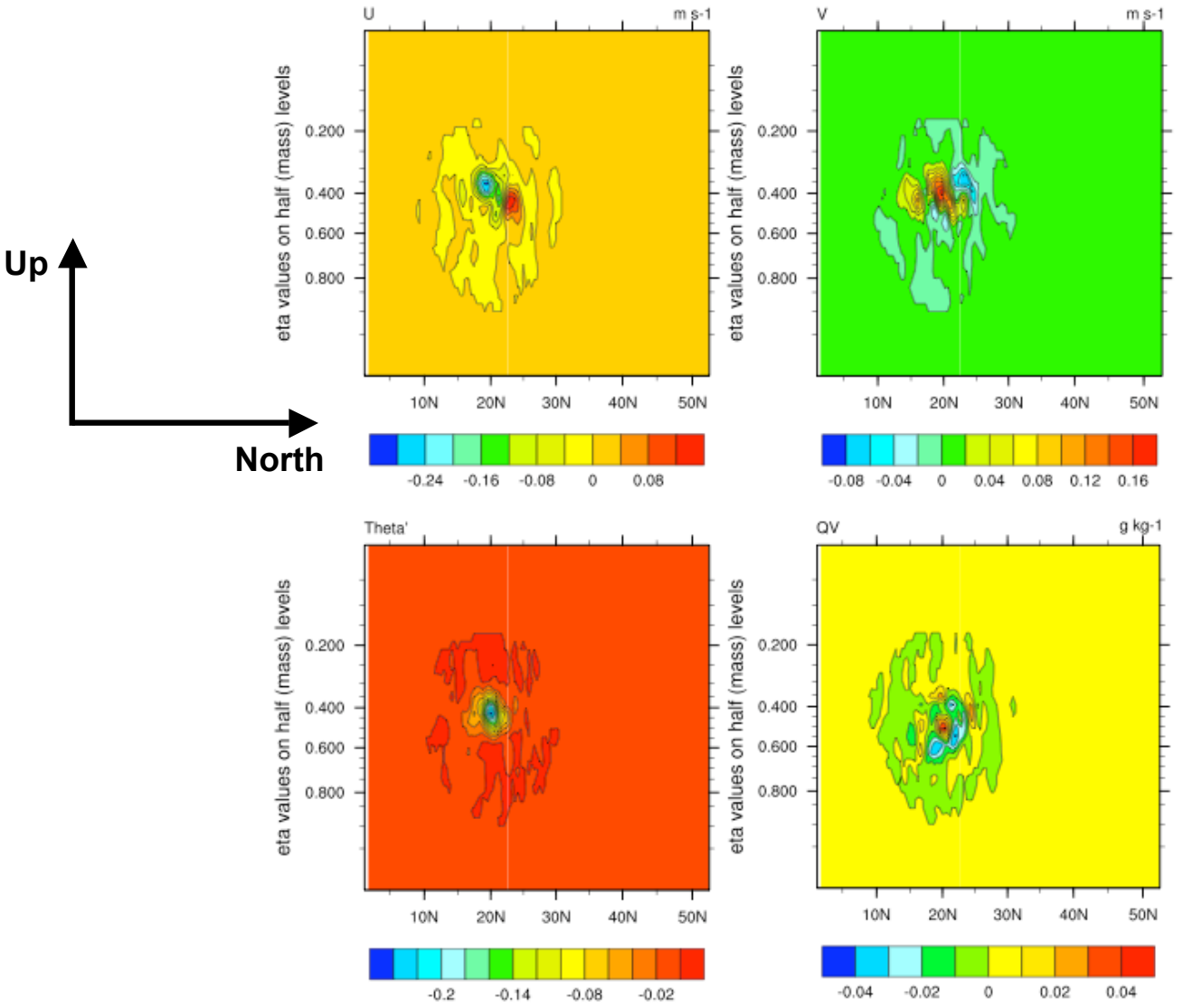
Vertical Localization

Take the height of peak levels of Jacobian as vertical coordinate

Use DART built-in vertical localization

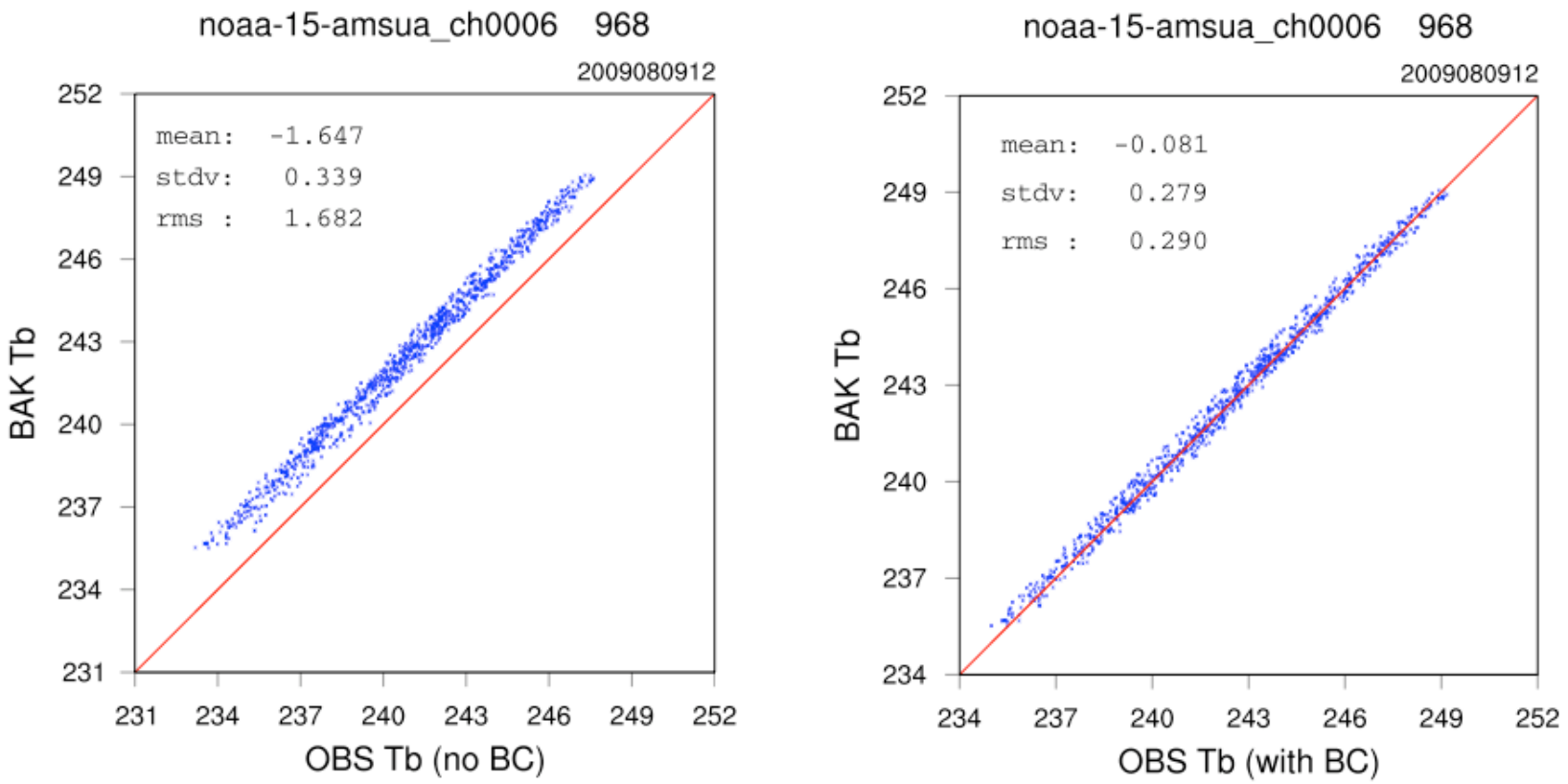


Single Observation in the Ensemble



With vertical localization

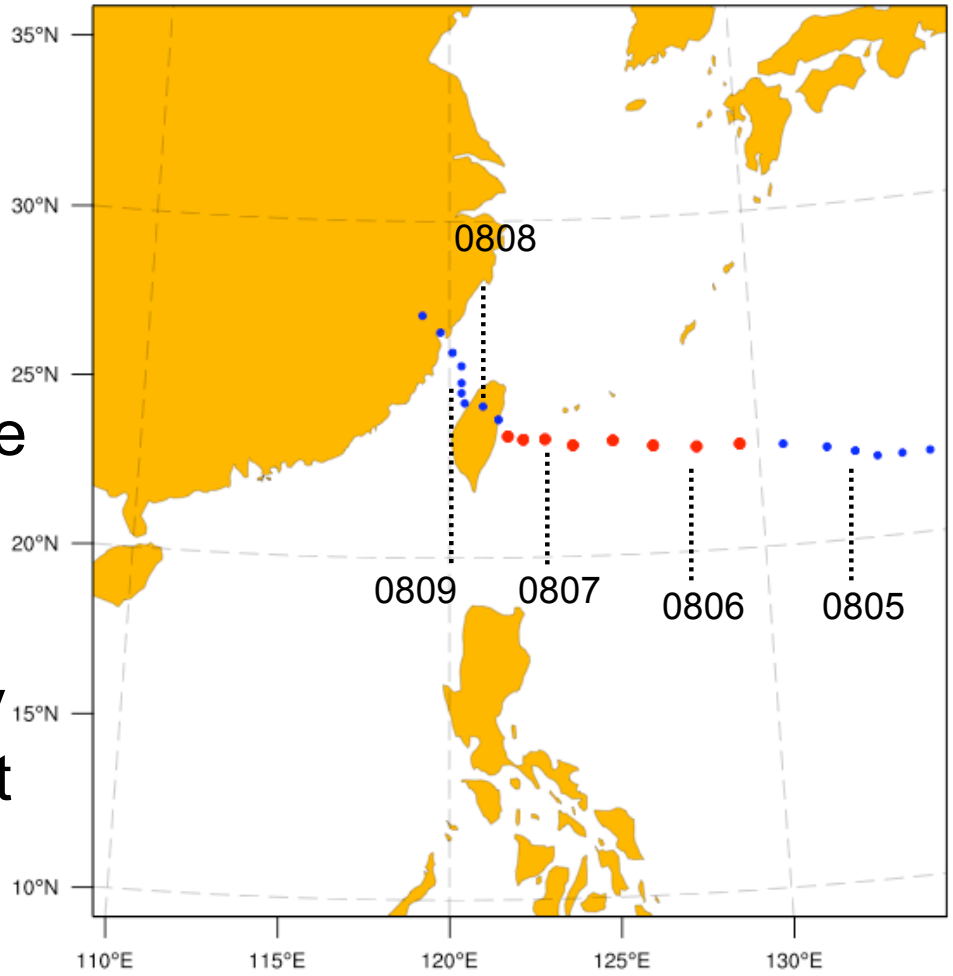
Bias Correction and QC



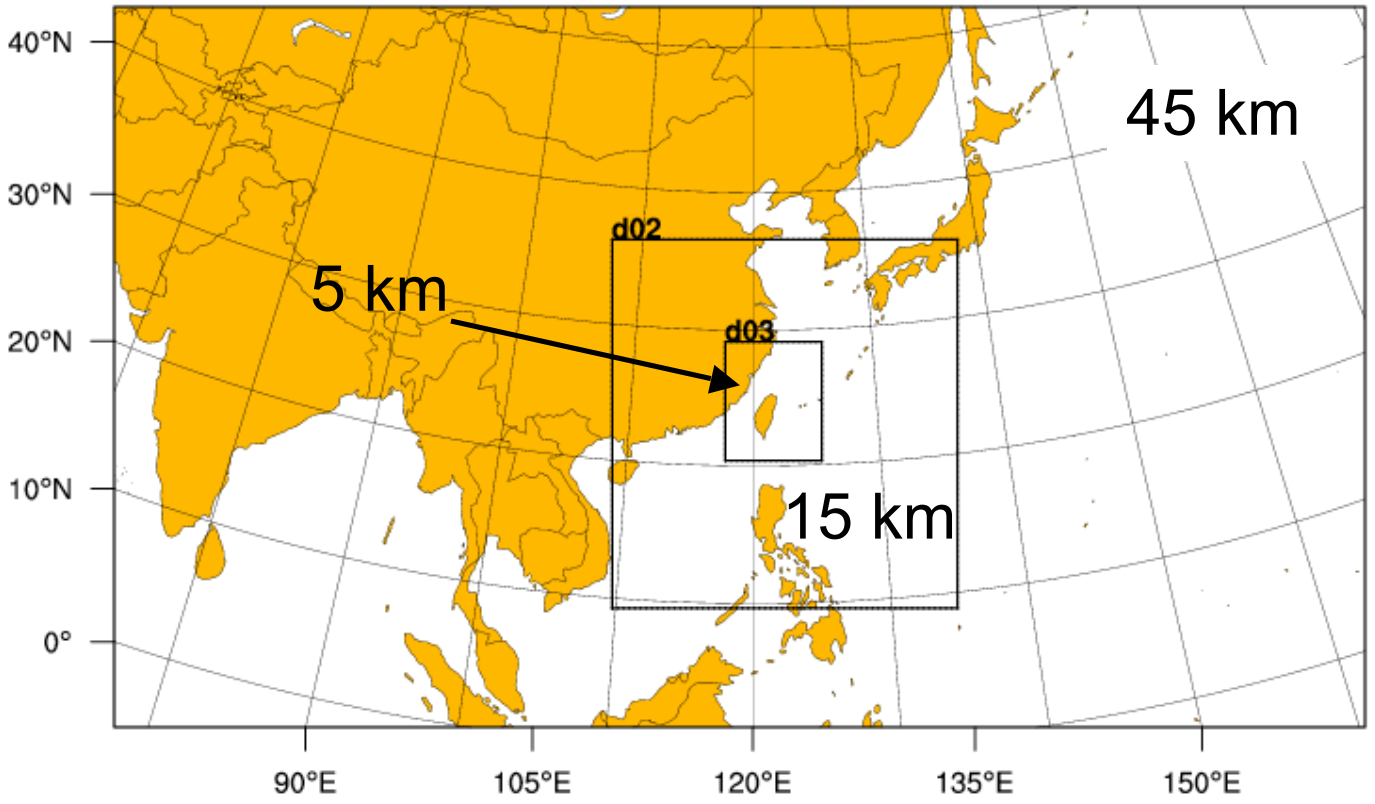
Bias correction coefficients from the end of 3DVAR experiment. Use Ensemble Mean as reference for BC and QC.

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.



CWB Computational Domains



- Version 3.1.1 of WRF-ARW
- 45 vertical levels, model top of 30 hPa
- No cumulus parameterization in d03

4 Experiments

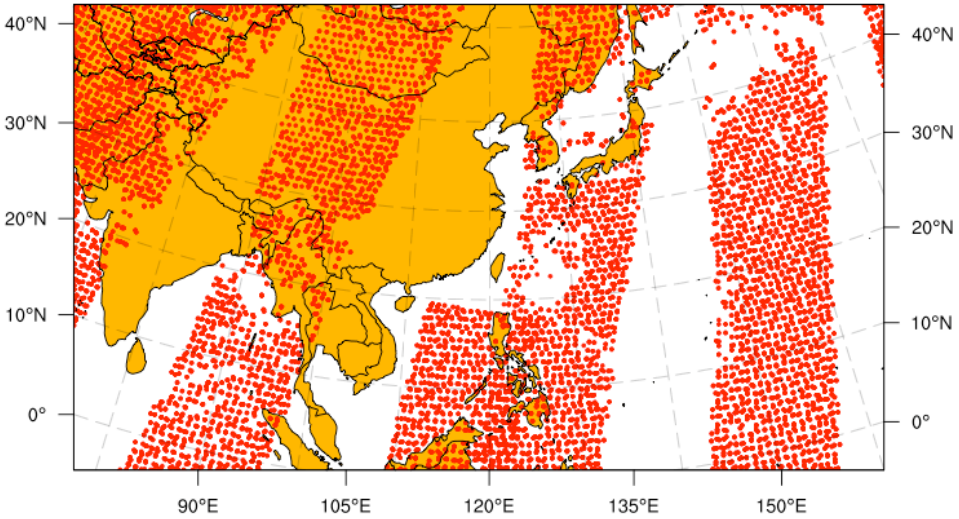
1) WRFDA-3DVAR: with conventional obs and radiances (AMSU-A/B, MHS), 6-hr full-cycling, with DA in d01 only (2009, 080318~080800)
2) Same as experiment 1, but with DA in d01 and d02
3) 64-member ensemble, 6-hr full-cycling, assimilated conventional observations in d01 *only.* Ensemble LBCs (and ICs for the 1st cycle) were generated using 3DVAR "randomcv" capability.
4) Same as experiment 3, but assimilated radiances in addition to conventional observations

*No cyclone relocation or bogus obs used during analyses

*Observation window: analysis time ±3 hrs

*A 72-hour WRF forecast was made every six hours (00/06/12/18Z) from 3DVAR analyses and ensemble mean of DART experiments.

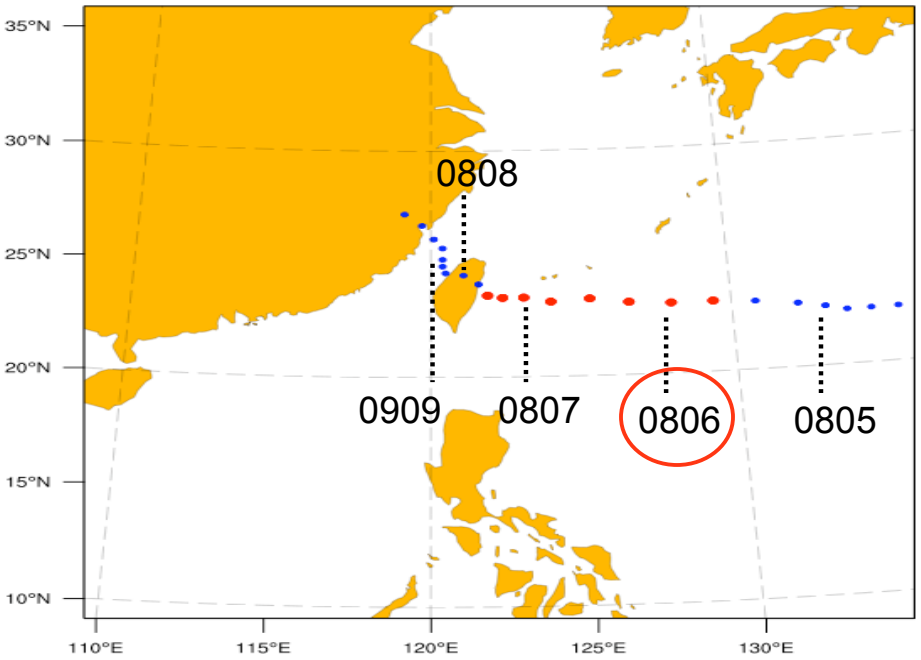
Radiance Distribution



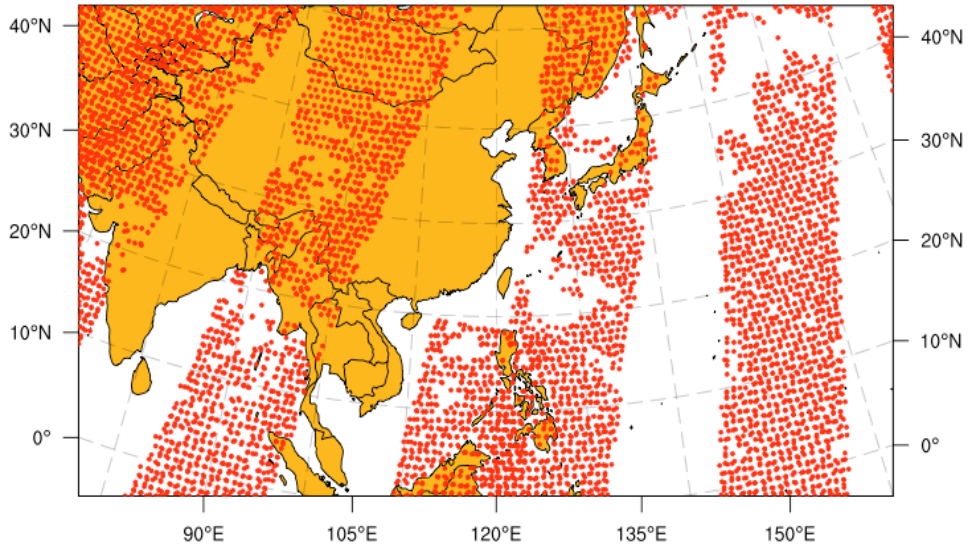
Distribution of radiances assimilated for the 06 Aug 0000 UTC analysis

Very similar coverage

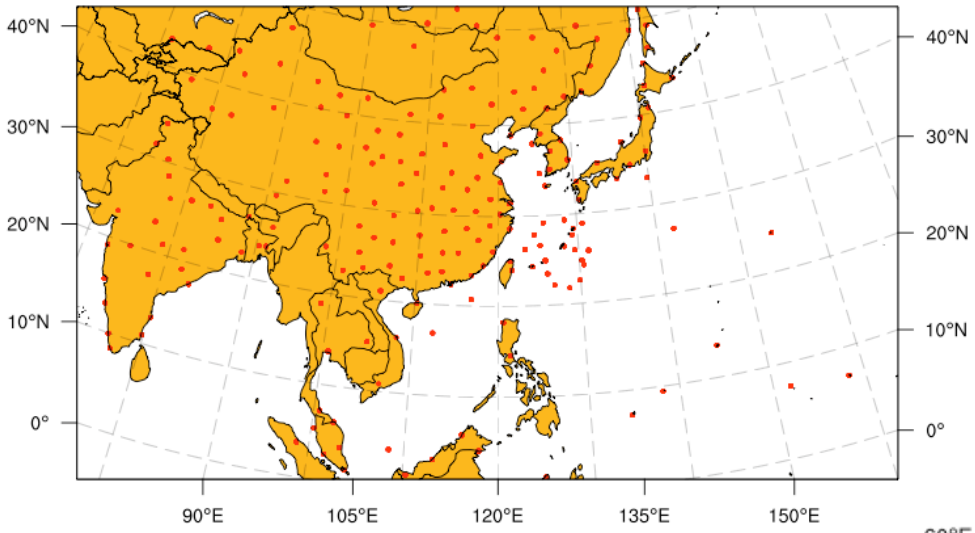
DART



WRFDA-3DVAR



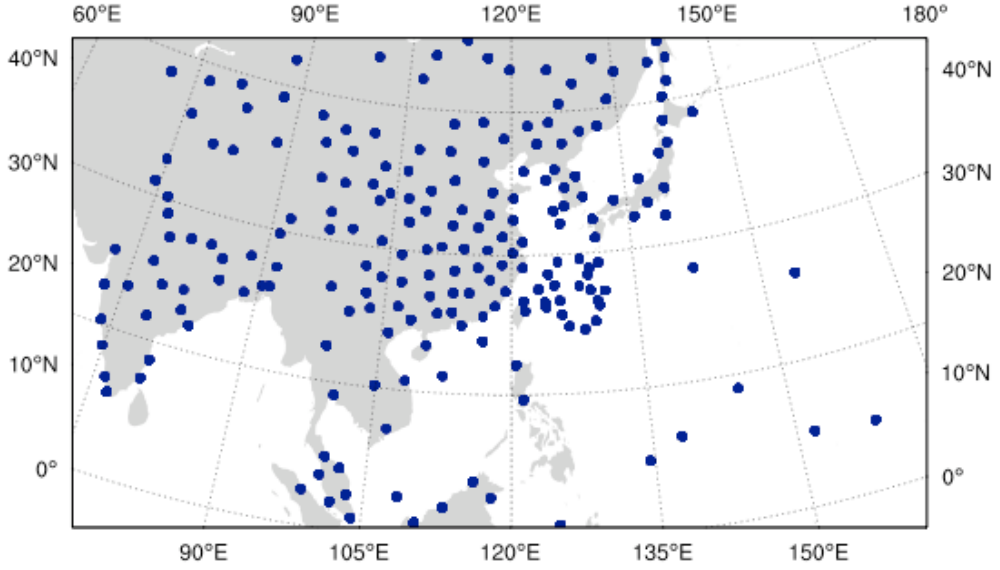
Sounding Distribution



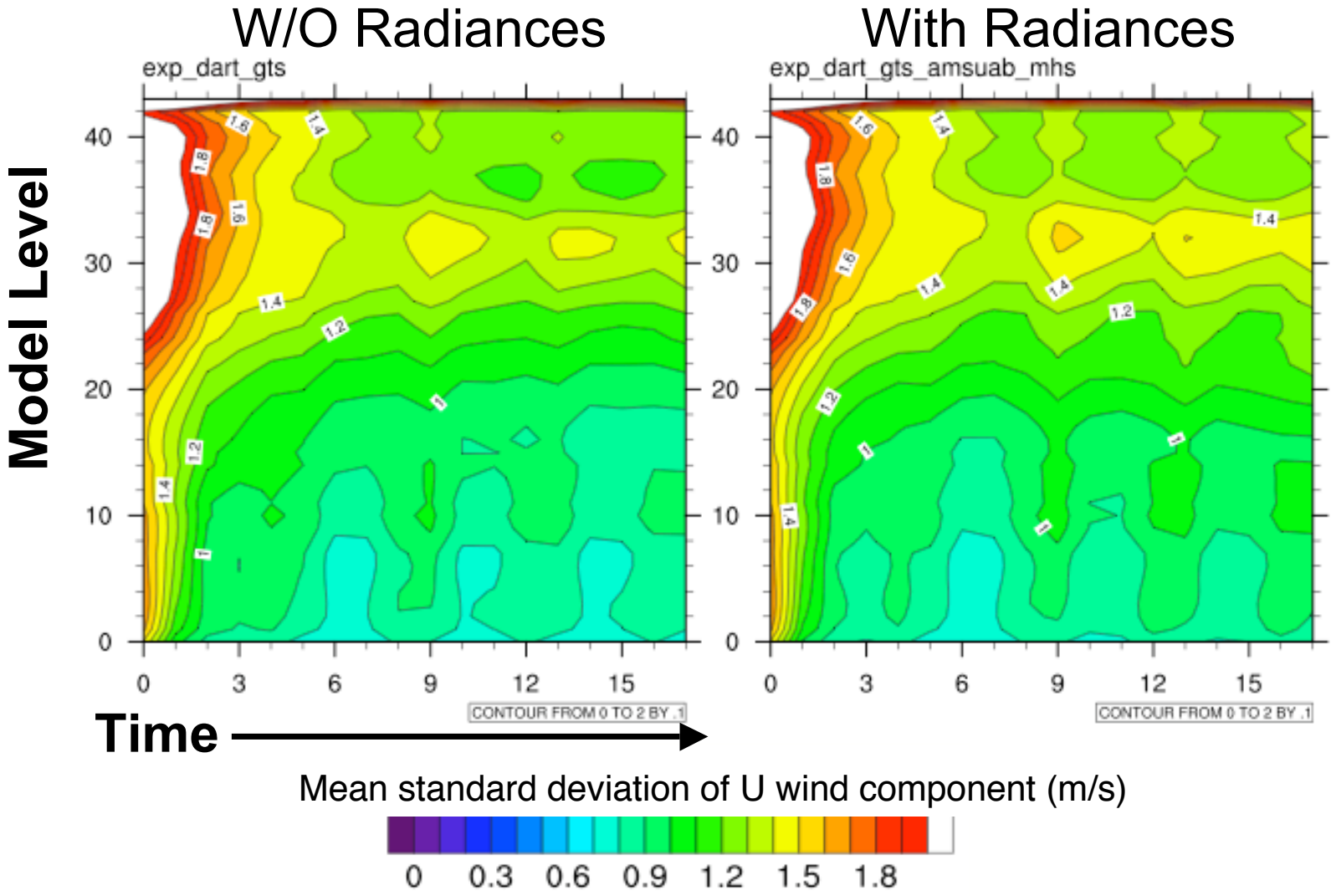
DART

Distribution of soundings assimilated for the 06 Aug 0000 UTC analysis

WRFDA-3DVAR



Prior Spread: U

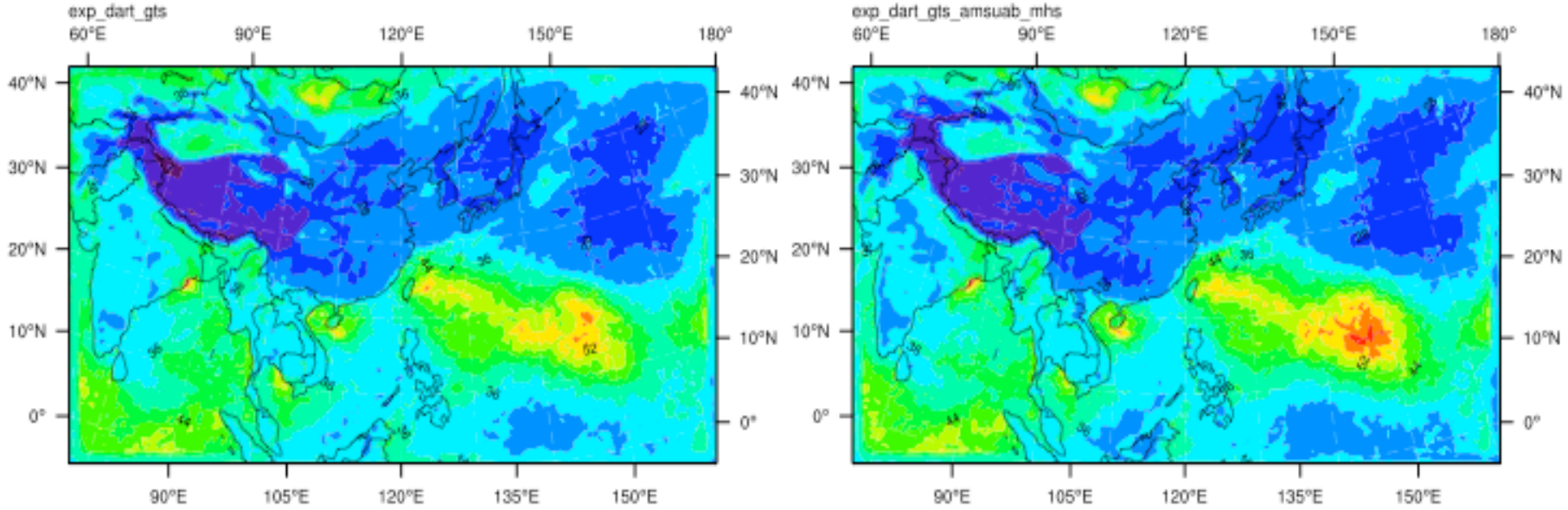


Posterior Spread: Sfc Pressure

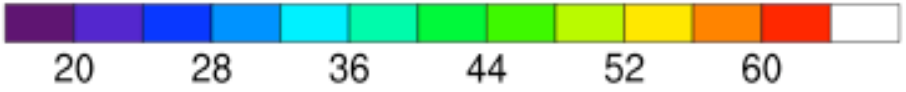
Averaged from 1800 UTC 03 Aug to 0000 UTC 08 Aug

W/O Radiances

With Radiances

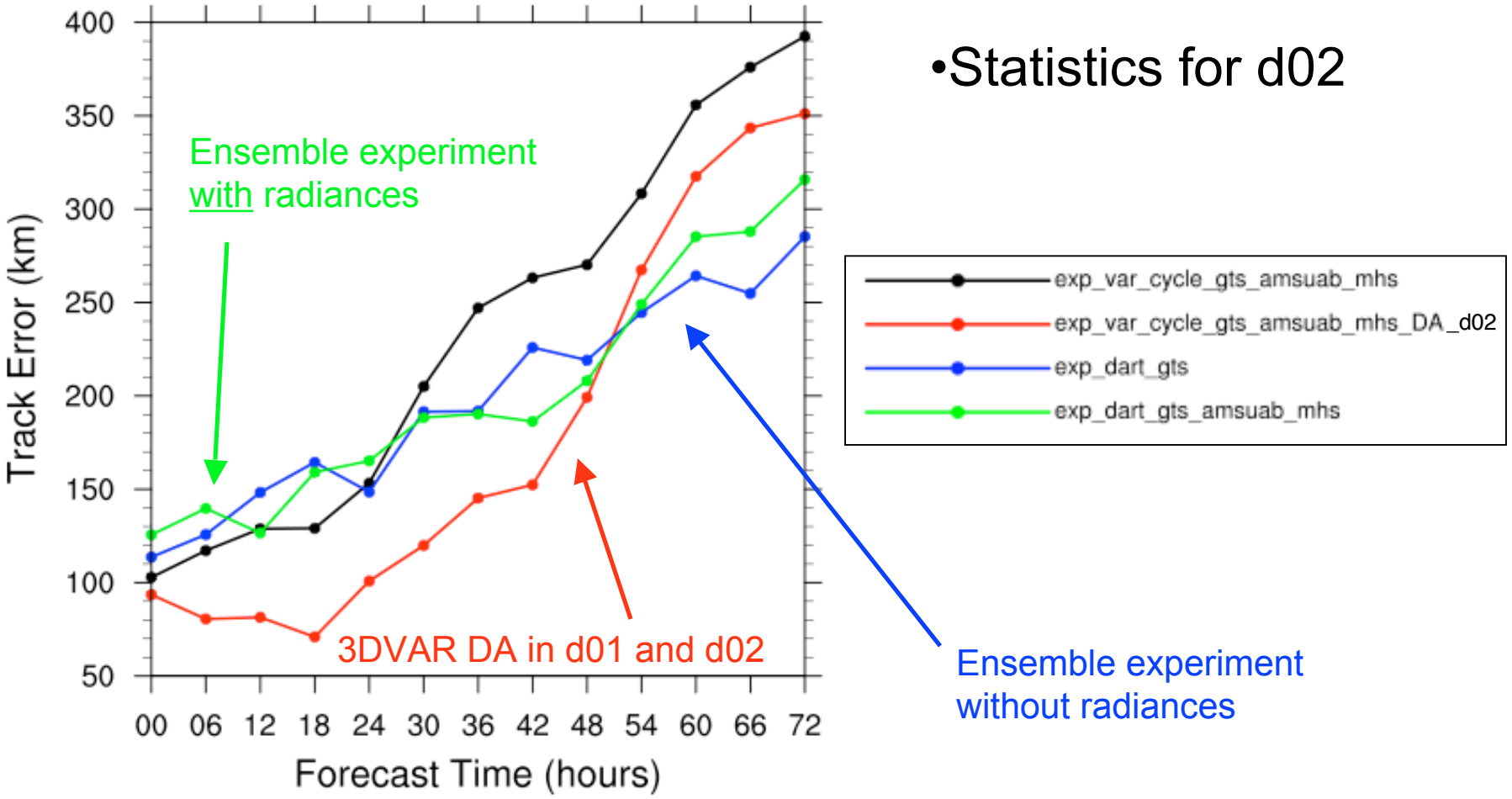


Mean standard deviation of surface pressure (Pa)



Average Track Error

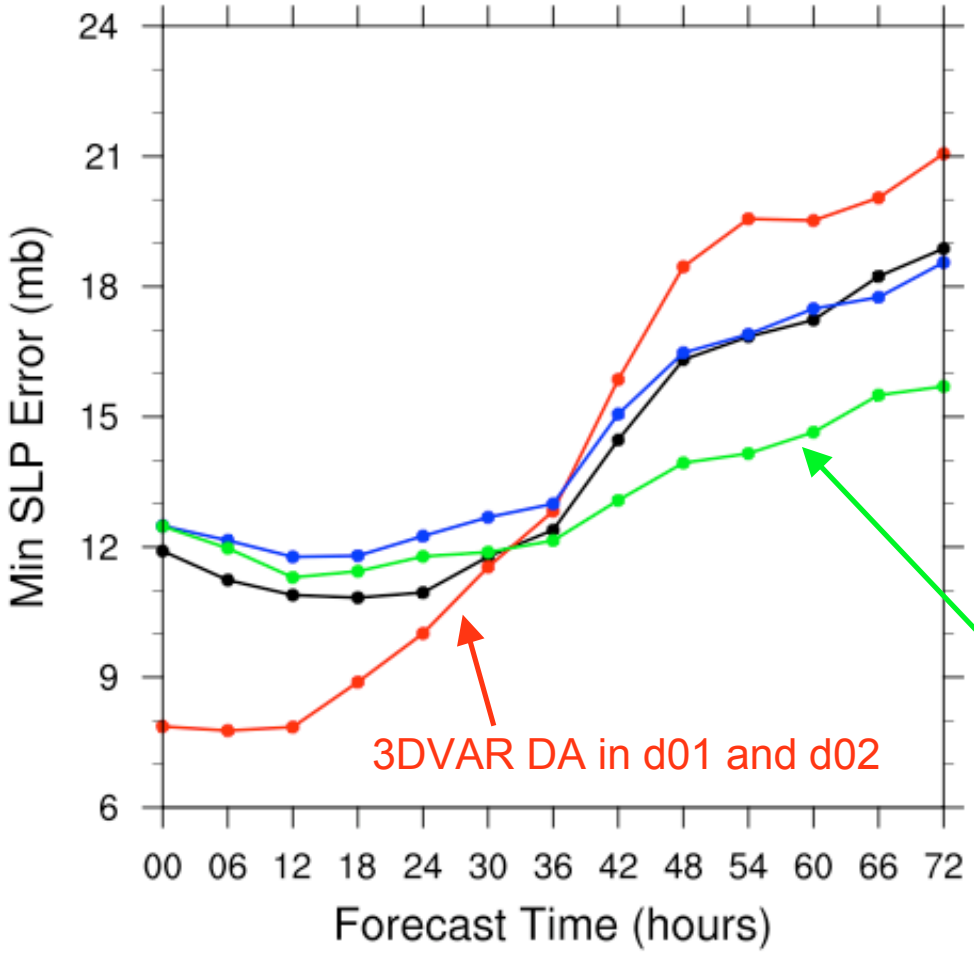
- Averaged from 1800 UTC 03 Aug to 0000 UTC 08 Aug



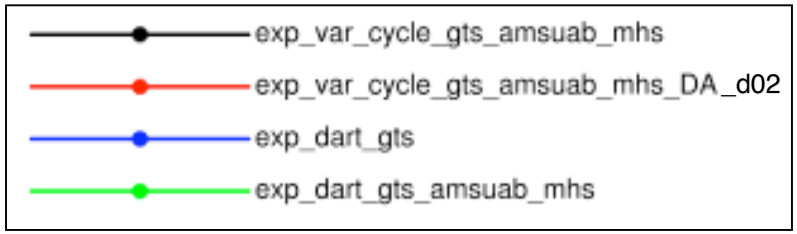
- Statistics for d02

Average Min SLP Error

- Averaged from 1800 UTC 03 Aug to 0000 UTC 08 Aug

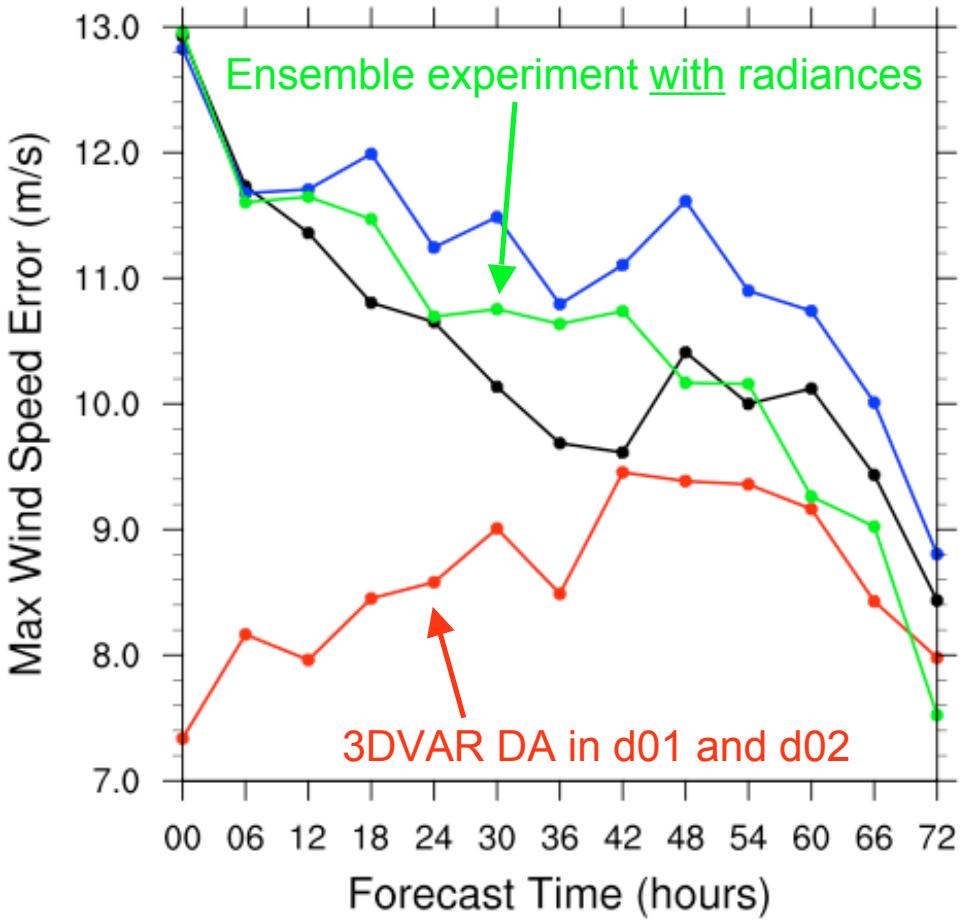


- Statistics for d02

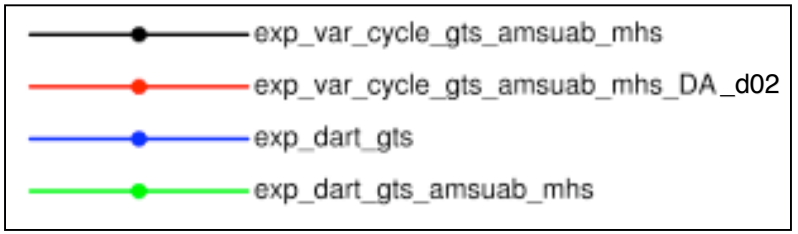


Average Max Wind Speed Error

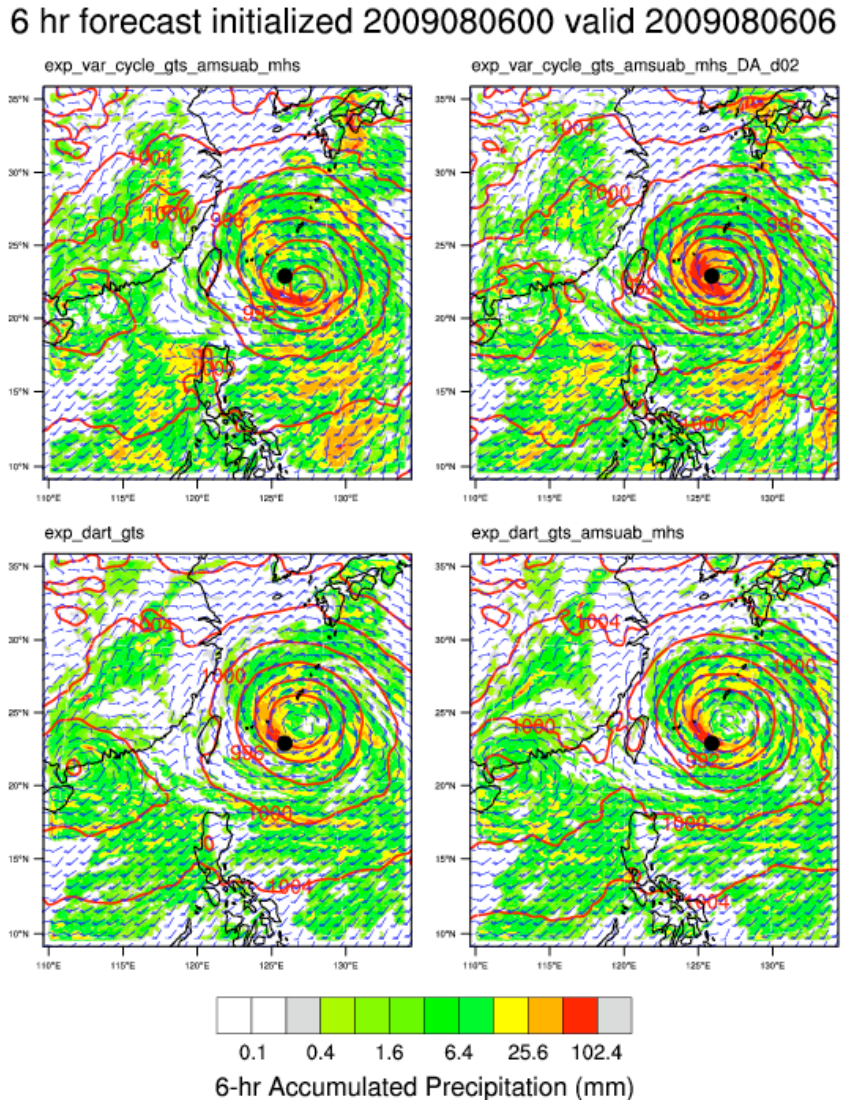
- Averaged from 1800 UTC 03 Aug to 0000 UTC 08 Aug



- Statistics for d02



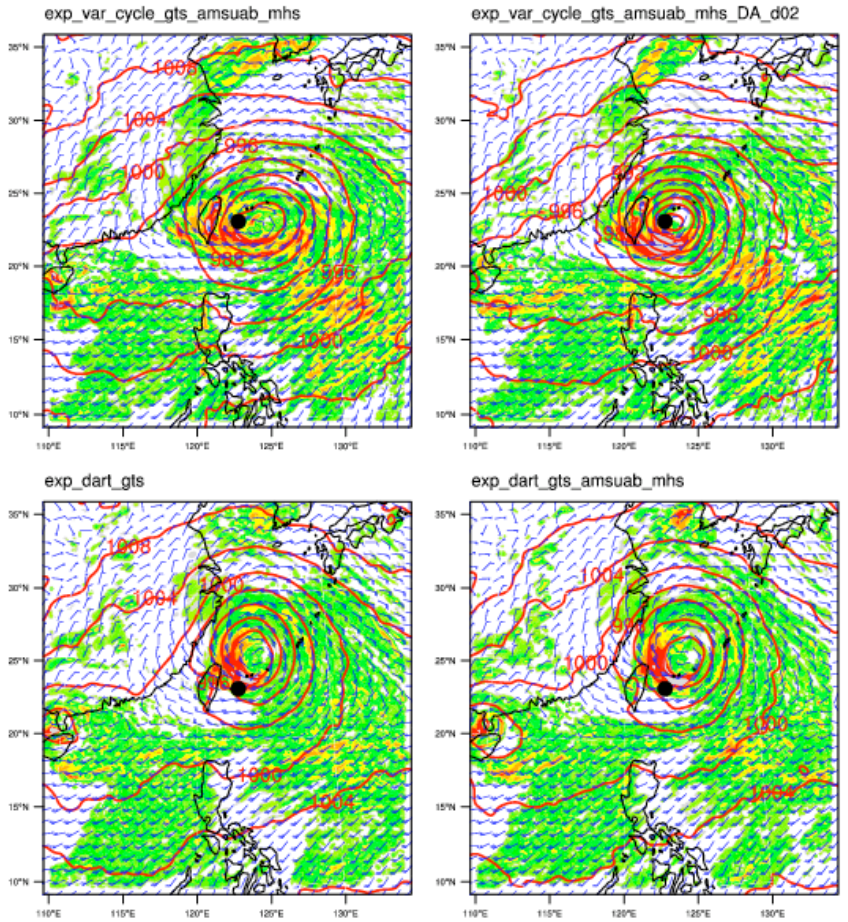
A Sample Forecast



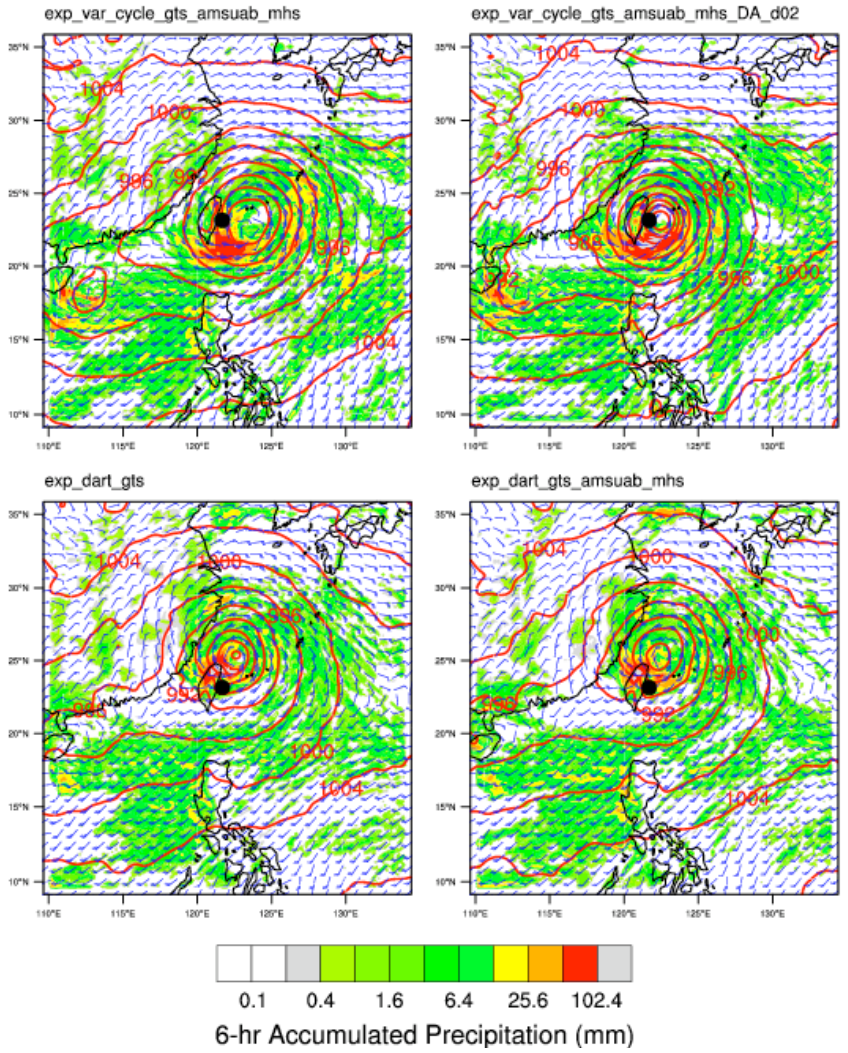
3DVAR exps. stronger

EnKF exps. Weaker

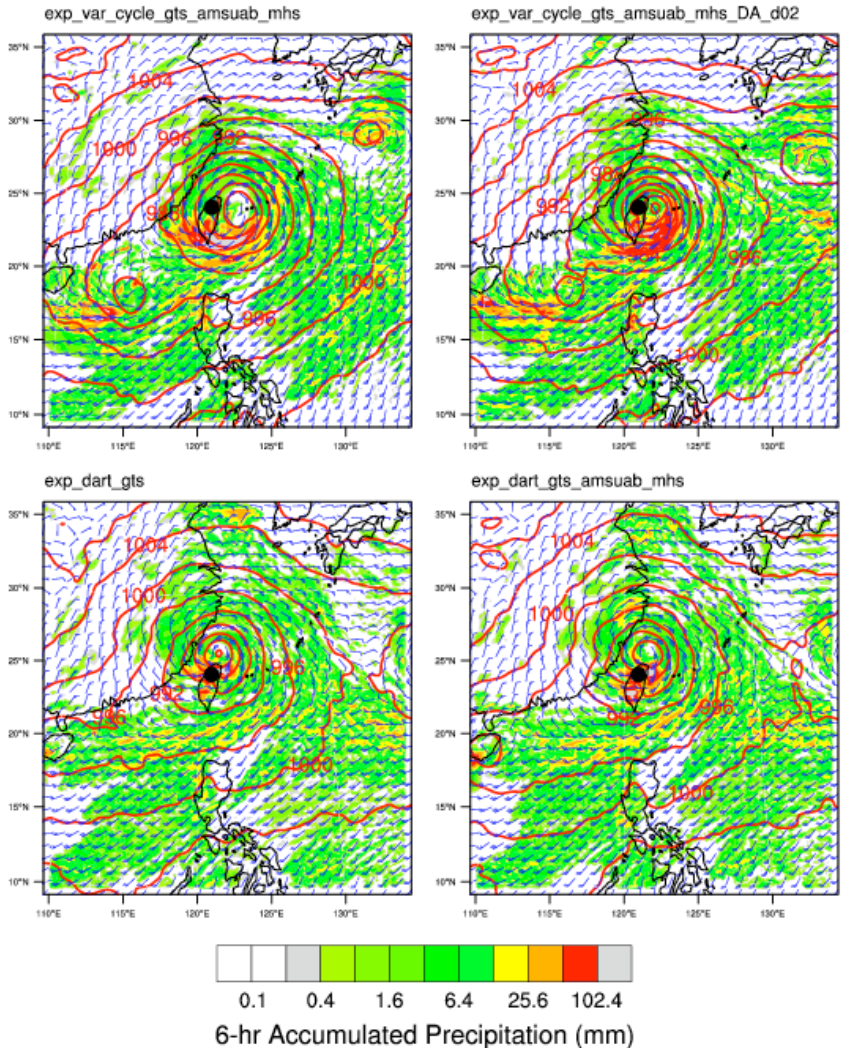
24 hr forecast initialized 2009080600 valid 2009080700

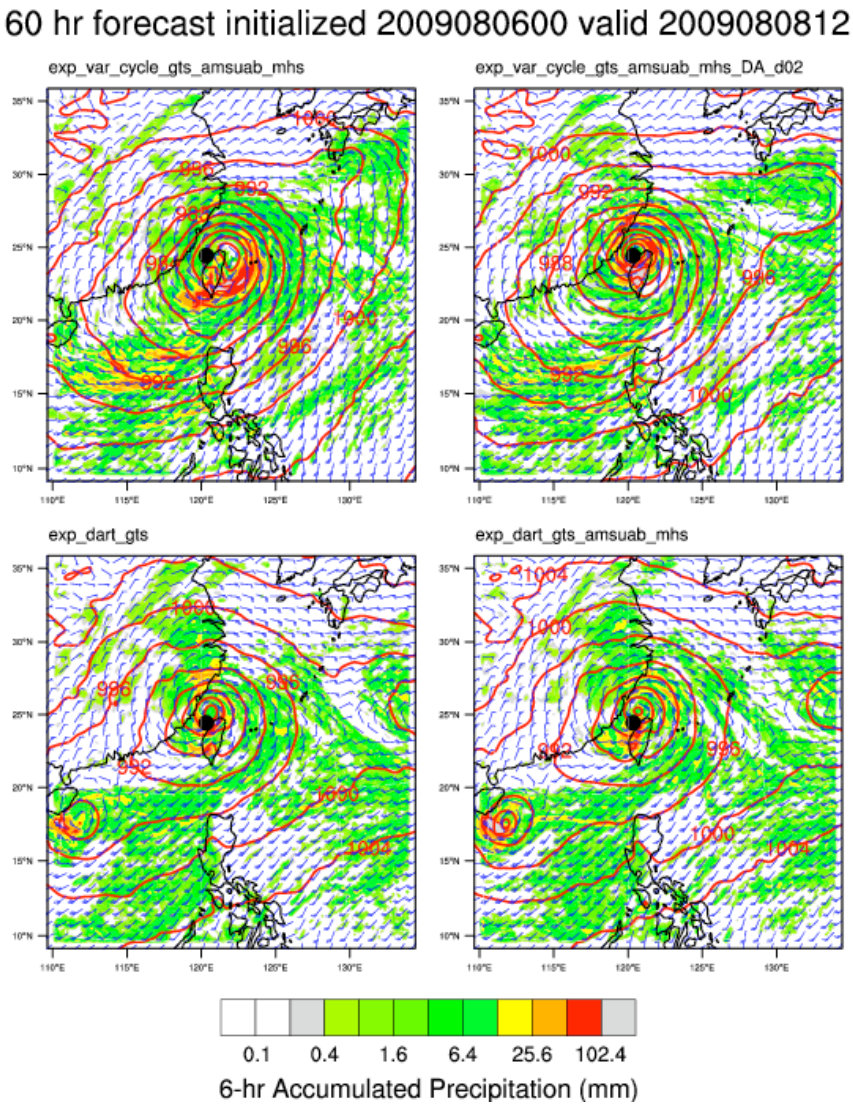


36 hr forecast initialized 2009080600 valid 2009080712



48 hr forecast initialized 2009080600 valid 2009080800





3DVAR exps.

EnKF exps.
2nd storm: Goni.
But too strong.

Summary

- EnKF-based radiance DA was implemented through the coupling with WRFDA's RTM, bias correction and QC scheme.
- For Typhoon Morakot, EnKF apparently produces better track and intensity forecasts than 3DVAR for "medium-range (I.e., beyond 36h~48h)".
- EnKF with radiances improves intensity forecast when comparing to assimilating GTS obs only.
- 3DVAR DA in both D01 and D02 adds additional value than DA in D01 only.
- Cycling DA without hurricane relocation leads to large track error.

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.