

The Impact of GPS Radio Occultation Data on Typhoon Prediction: An OSSE Study of Typhoon Shanshan (2006)

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Outline

- Introduction
- Model Settings and Procedures
- Experiment Design and Results
- Sensitivity Tests
- Summary

Introduction

- ❑ The typhoon prediction is affected by several factors, and it is difficult to clarify the impact of GPS RO from the simulations of real typhoon cases.
- ❑ Therefore, Observing Systems Simulation Experiments (OSSE) are designed to explore the impact of GPS RO data assimilation on typhoon prediction using high-resolution MM5 model to generate a simulated atmosphere providing **the true state**.
- ❑ Vertical **soundings** of nonlocal refractivity as modeled by a 2-D ray-tracing operator under the assumption of spherical symmetry then are assimilated into OSSE.
- ❑ OSSE for Shanshan (2006) typhoon is conducted in this study.

Model Settings and Procedures

- Model: MM5 v3.7
- Domain: 301x301x35 with H-resolution=20km (model top: 30 hPa) for MM5
- Initial time: 2006/09/12 1200 UTC with a Rankin vortex
- Integration: 24 h as the initial condition of the Natural Run (NTL) (i.e., true state)
- Observations: We can get refractivities from the Natural Run by two ways
 1. 2-D Ray tracing (MM5: 0-20 km, CIRA: 20-120 km)
 - fixed azimuth (45°)
 - bending angle(α) → retrieved refractivity (N)
 2. Be computed directly from the MM5 model

$$N = 77.6\left(\frac{P}{T}\right) + 3.73 \times 10^5 \left(\frac{P_w}{T^2}\right)$$

P : pressure

T : temperature

P_w : water vapor pressure

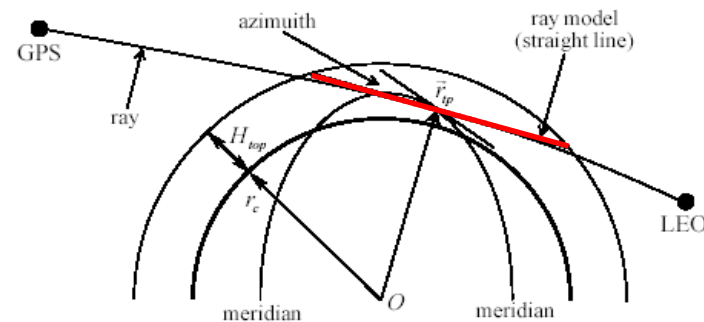
- Degradation : use 1-2-1 Shapiro filter to smooth the NTL (U, V, T, q, PP) to obtain the initial condition of the Control Run
- Assimilation system: WRF-VAR v2.1 (local operator and nonlocal operator)

The nonlocal operator

- Abel-retrieved refractivity accounts for an integrated amount of refractivity along the total path of the ray in a spherically-symmetric atmosphere.
- To take the effect of horizontal gradients into account, Sokolovskiy et al. (2005) suggest assimilation of excess phase, defined as the integrated refractivity along a straight ray.

Nonlocal (excess phase):

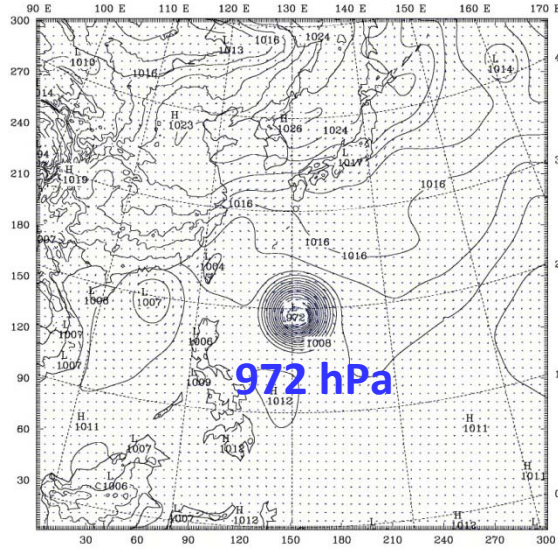
$$S = \int N \cdot dl$$



- A nonlocal operator was implemented into the WRFVAR 2.1 (Chen et al. 2008).
→ Local operator assimilating N at the perigee point.

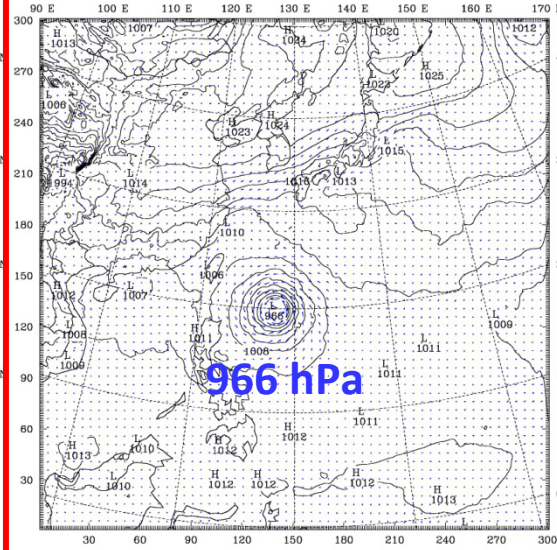
$$N = (n - 1) \times 10^6 = 77.6 \frac{P}{T} + 3.73 \times 10^5 \frac{P_w}{T^2} - 40.3 \times 10^{-12} \frac{n_e}{f^2}$$

NTL (2006/09/12 1200 UTC)



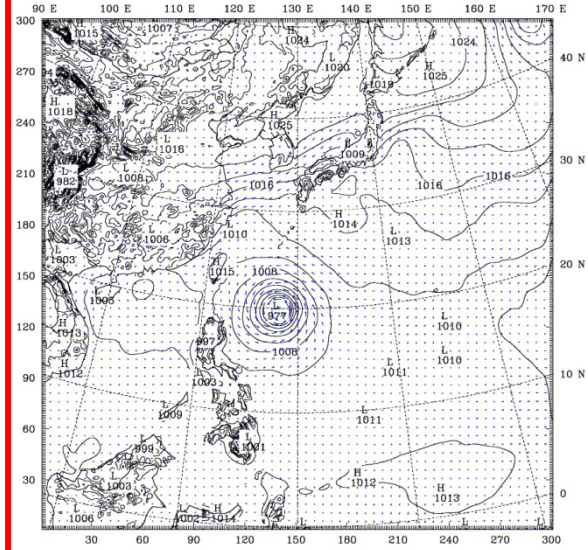
MAXIMUM VECTOR: 36.2 m s⁻¹ --
 CONTOURS: UNITS=hPa LOW= 974.00 HIGH= 1028.0 INTERVAL= 2.0000
 Model info: V3.7.0 Grell MRF PBL Simple ice 20 km, 34 levels, 40 sec

NTL (2006/09/13 1200 UTC)



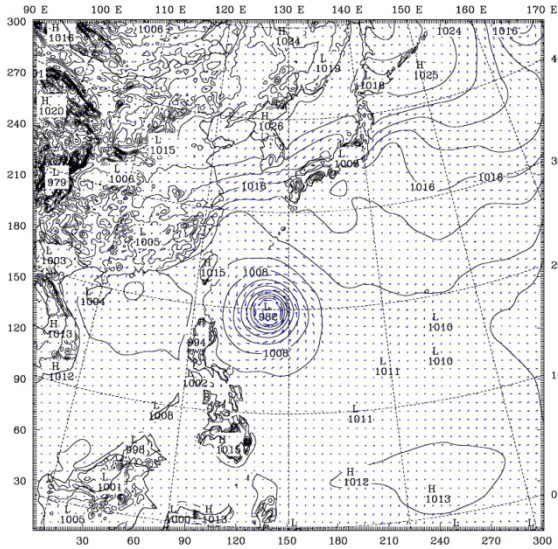
MAXIMUM VECTOR: 35.1 m s⁻¹ --
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 Model info: V3.7.0 Grell MRF PBL Simple ice 20 km, 34 levels, 40 sec

10 smoothing



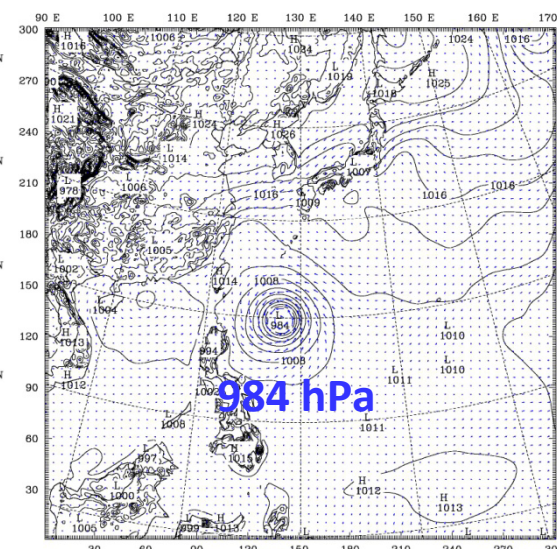
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20 smoothing



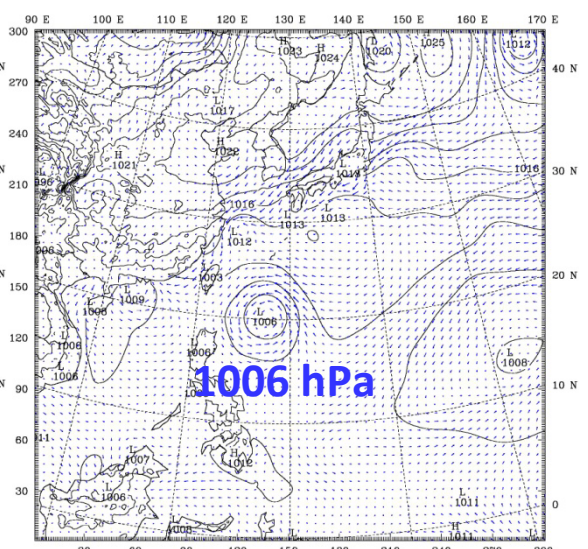
MAXIMUM VECTOR: 27.0 m s⁻¹ --
 CONTOURS: UNITS=hPa LOW= 980.00 HIGH= 1024.0 INTERVAL= 2.0000
 Model info: V3.7.0 Grell MRF PBL Simple ice 20 km, 34 levels, 40 sec

25 smoothing → CTL



MAXIMUM VECTOR: 25.3 m s⁻¹ --
 CONTOURS: UNITS=hPa LOW= 980.00 HIGH= 1024.0 INTERVAL= 2.0000
 Model info: V3.7.0 Grell MRF PBL Simple ice 20 km, 34 levels, 40 sec

AVN (2006/09/13 1200 UTC)



MAXIMUM VECTOR: 14.1 m s⁻¹ --
 CONTOURS: UNITS=hPa LOW= 998.00 HIGH= 1024.0 INTERVAL= 2.0000

Data:

N_i : model IC

N_r : retrieved

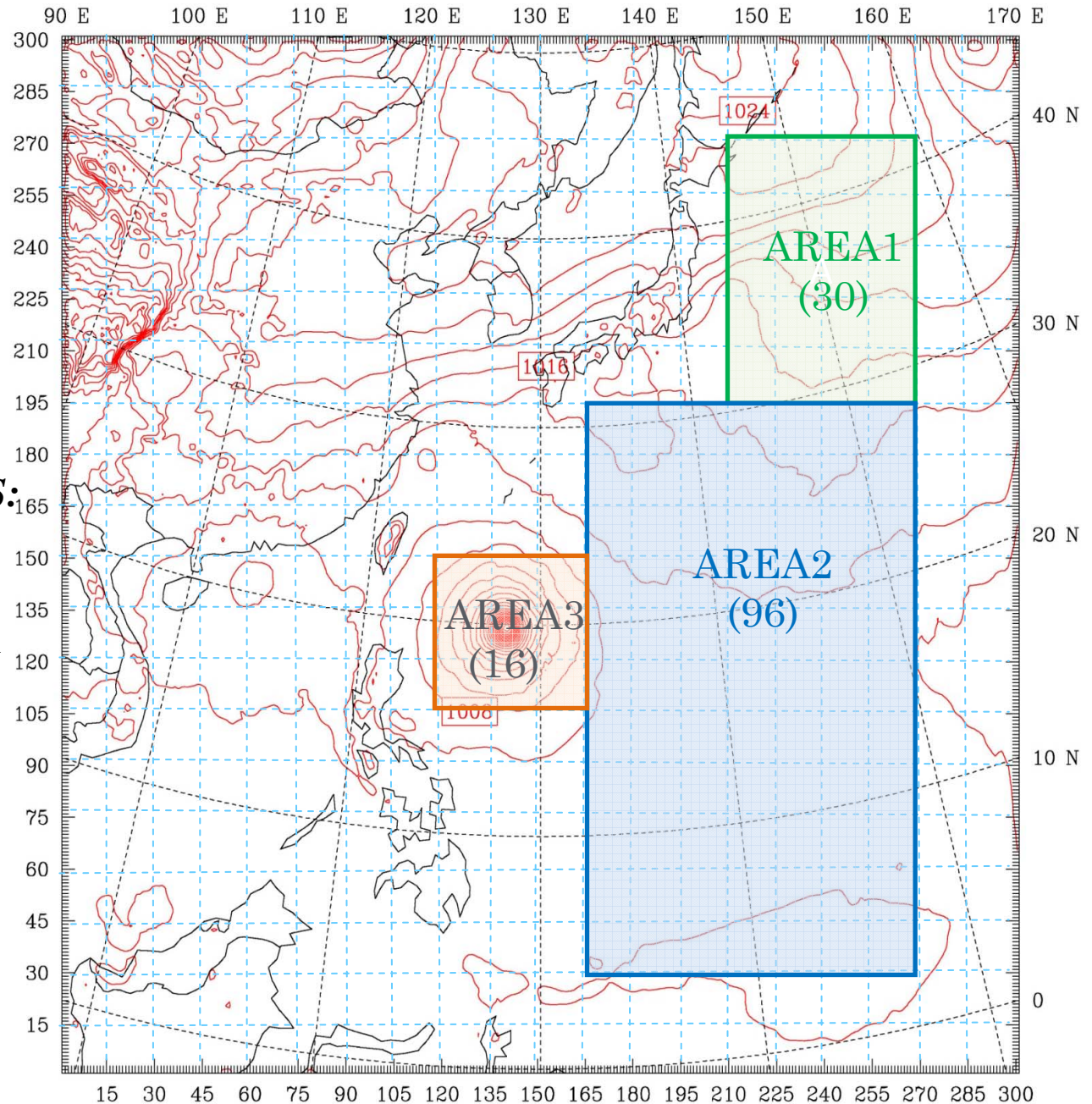
Obs. interval: ~300 km

TARGET OBSERVATIONS:

AREA1 :
over the western Pacific high

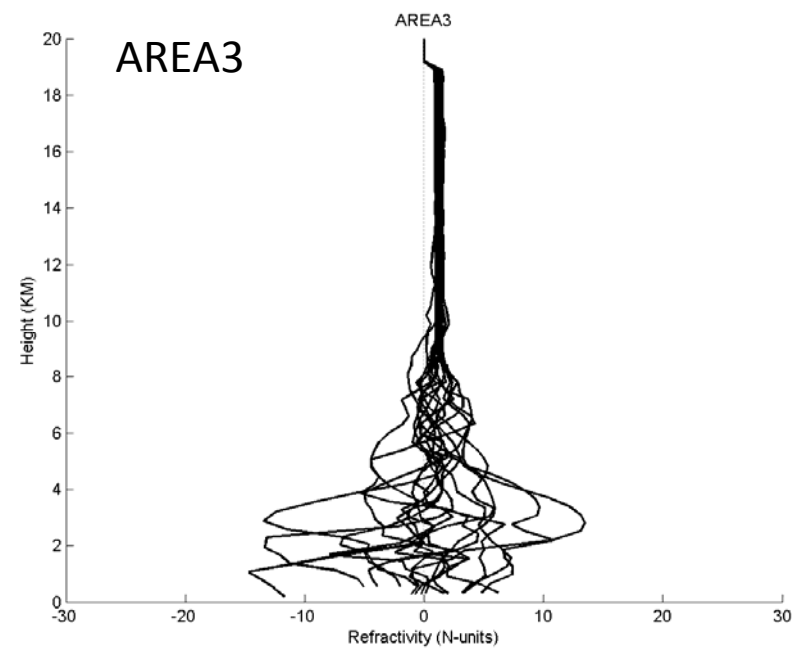
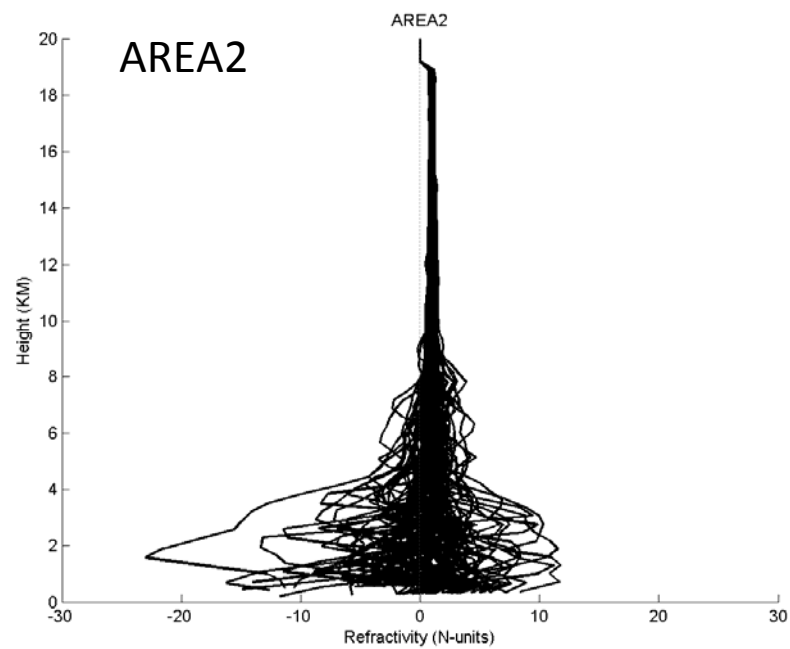
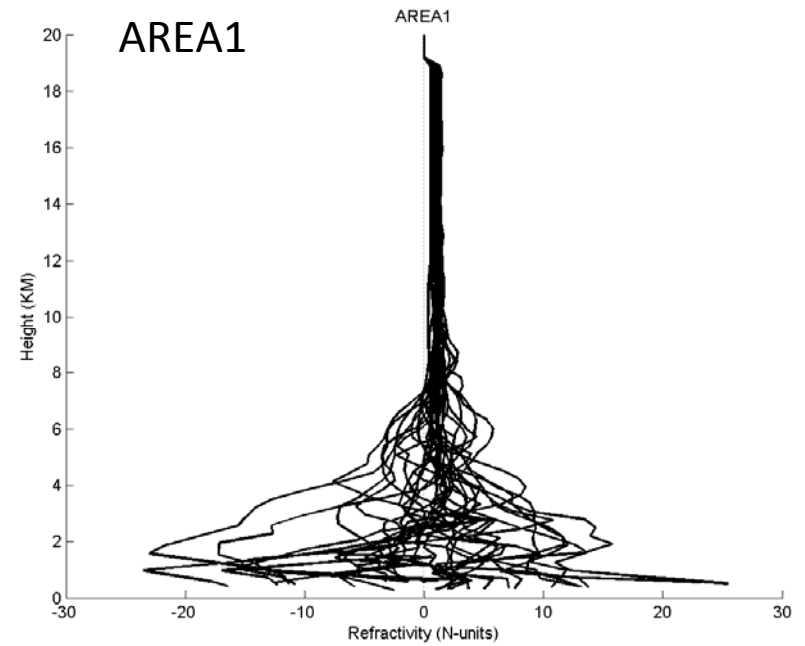
AREA2 :
over the environmental flow

AREA3 :
over the region of typhoon
circulation



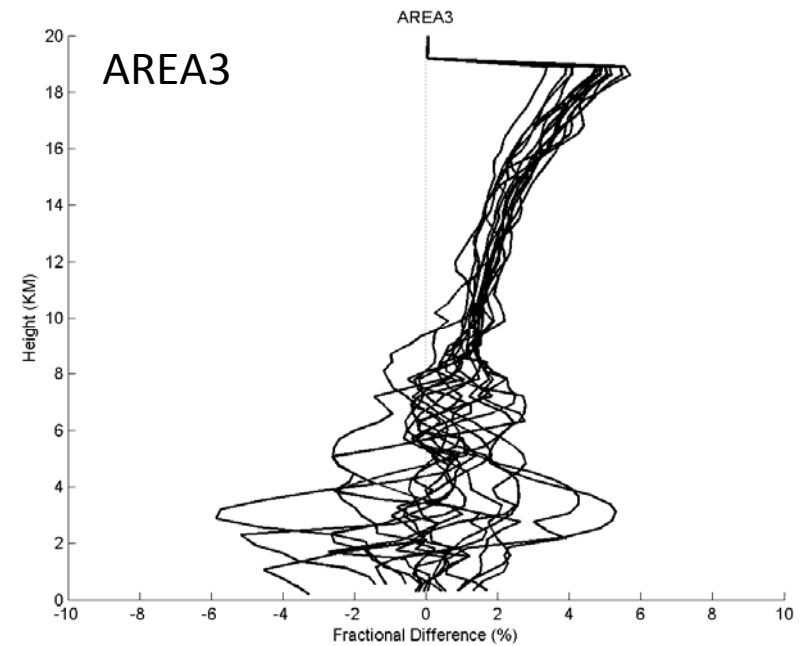
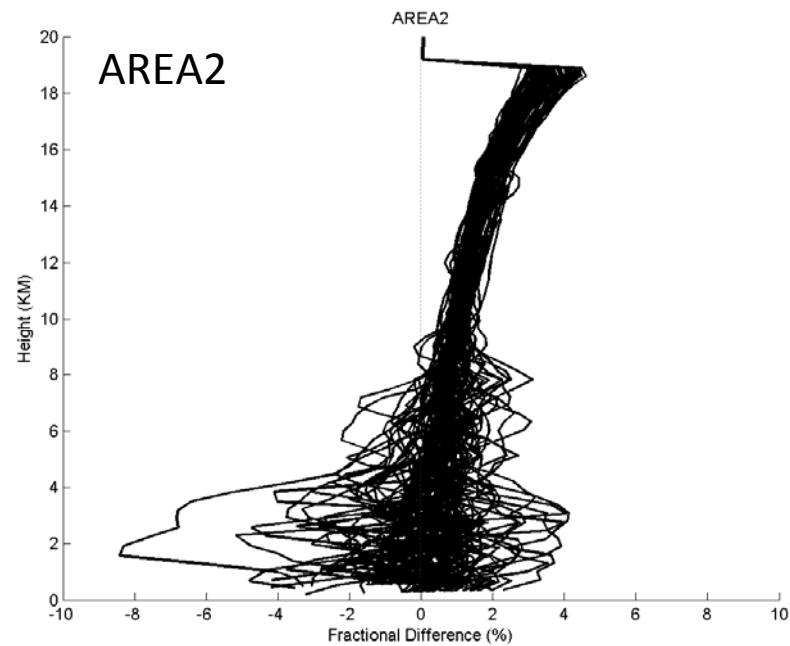
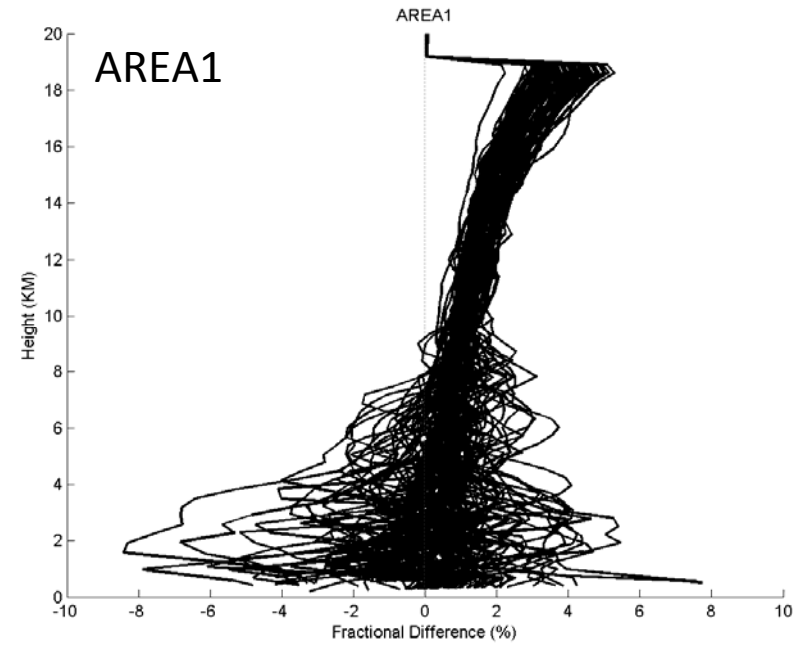
Difference

$(N_i - N_r)$



Fractional difference

$$(N_i - N_r) / \overline{N_i} \times 100\%$$



Bending Angle

$$N = 77.6\left(\frac{P}{T}\right) + 3.73 \times 10^5 \left(\frac{P_w}{T^2}\right)$$

$$n = 1 + 10^{-6} N$$

forward model

$$\alpha(a) = -2a \int_a^\infty \frac{d(\ln n) / dx}{(x^2 - a^2)^{1/2}} dx$$

assume: spherical symmetry

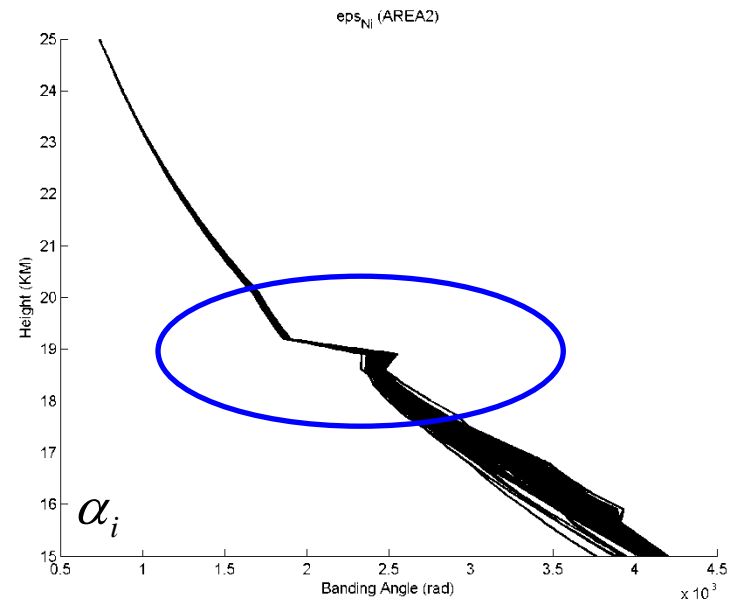
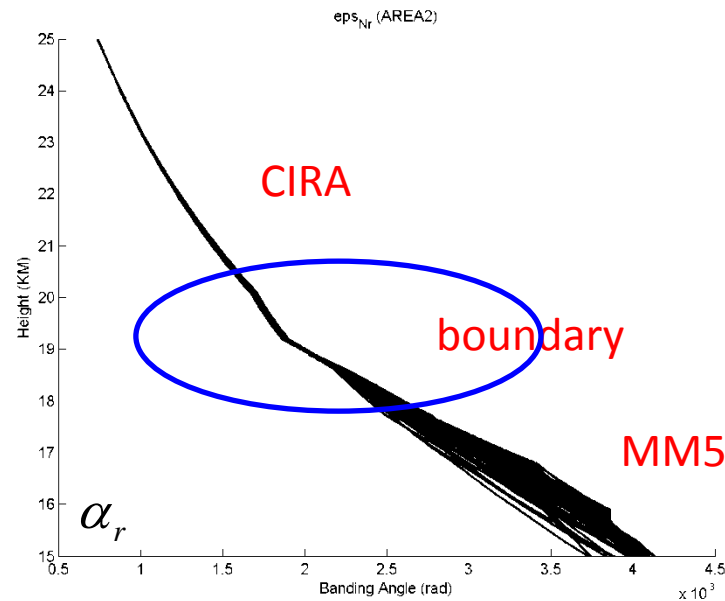
N : refractivity
 P : pressure
 T : temperature
 P_w : water vapor pressure
 n : refractive index
 α : bending angle
 a : impact parameter
 x : refractional radius

2-D ray tracing: N_i and N_r

N_i $\xrightarrow{\text{forward model}}$ α_i

N_r $\xrightarrow{\text{forward model}}$ α_r

AREA2
 96 soundings



Experiment Design

EXP	CASE NAME	DESCRIPTION
1	NTL	National run
2	CTL	Make 25-smoothing in the whole domain
3	LOC1	Take CTL as the first guess and assimilated with 30 GPS RO soundings over AREA1 (real local data – <i>i</i>) by using the local operator
4	REF1	Take CTL as the first guess and assimilated with 30 GPS RO soundings over AREA1 (retrieved local data – <i>r</i>) by using the local operator
5	LLZ1	Take CTL as the first guess and assimilated with 30 GPS RO soundings over AREA1 (retrieved local data – <i>n</i>) by using the local operator variant
6	EPH1	The same as LLZ1, but assimilated with GPS data by using the nonlocal operator
7	LOC2	The same as LOC1, but being assimilated with 96 GPS RO soundings over AREA2.
8	REF2	The same as REF1, but being assimilated with 96 GPS RO soundings over AREA2.
9	LLZ2	The same as LLZ1, but being assimilated with 96 GPS RO soundings over AREA2.
10	EPH2	The same as EPH1, but being assimilated with 96 GPS RO soundings over AREA2.
11	LOC3	The same as LOC1, but being assimilated with 16 GPS RO soundings over AREA3.
12	REF3	The same as REF1, but being assimilated with 16 GPS RO soundings over AREA3.
13	LLZ3	The same as LLZ1, but being assimilated with 16 GPS RO soundings over AREA3.
14	EPH3	The same as EPH1, but being assimilated with 16 GPS RO soundings over AREA3.

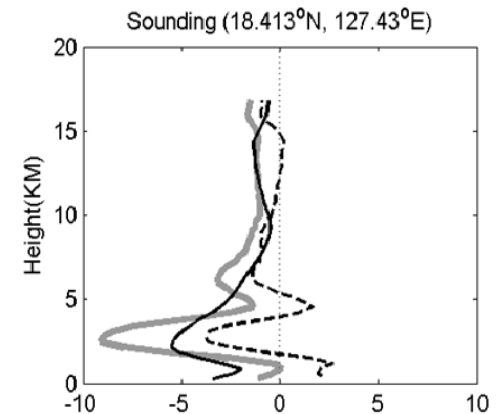
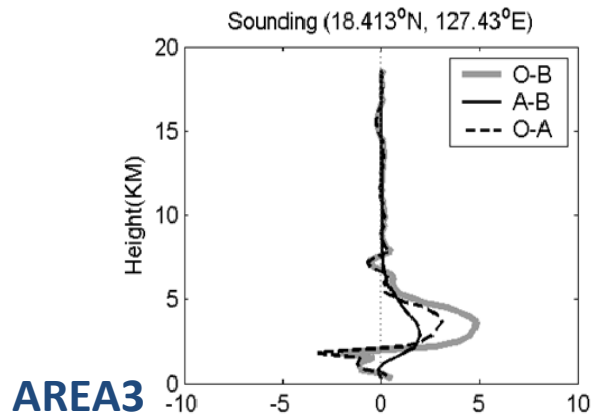
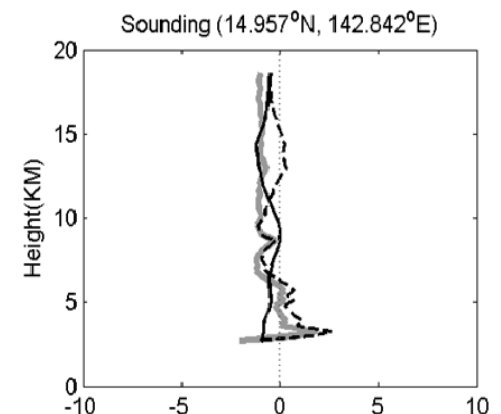
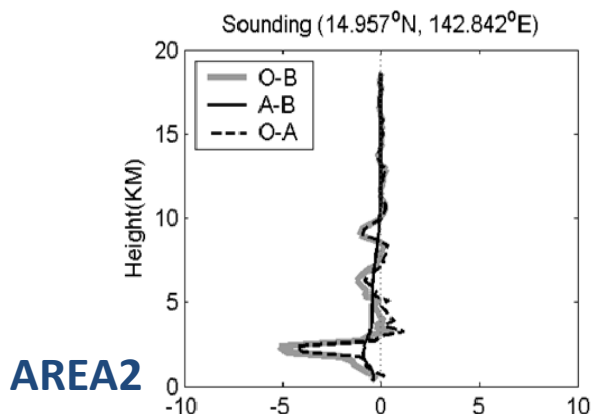
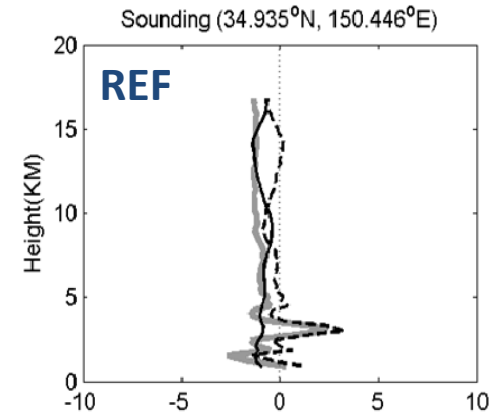
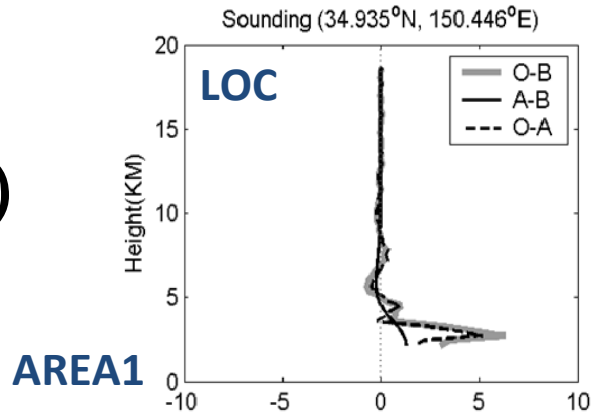
Increment (single sounding)

Using local operator

O : observation
(N_i or N_r)

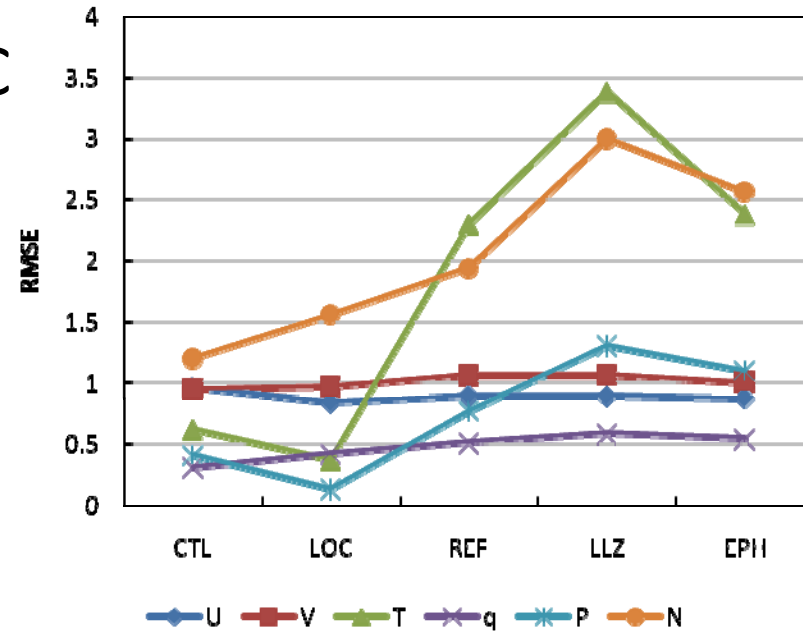
B : model first guess

A : analysis

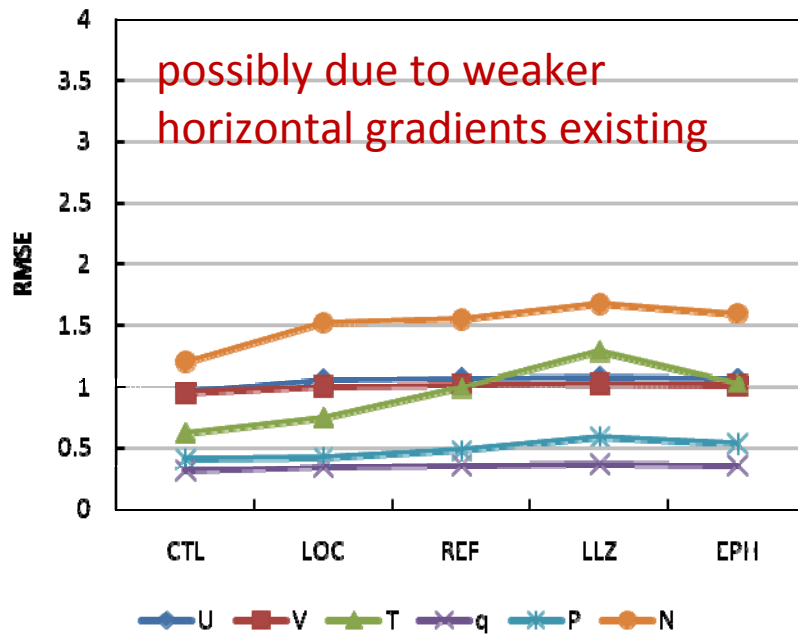


RMSE at 2006/09/13 1200 UTC (compare with NTL)

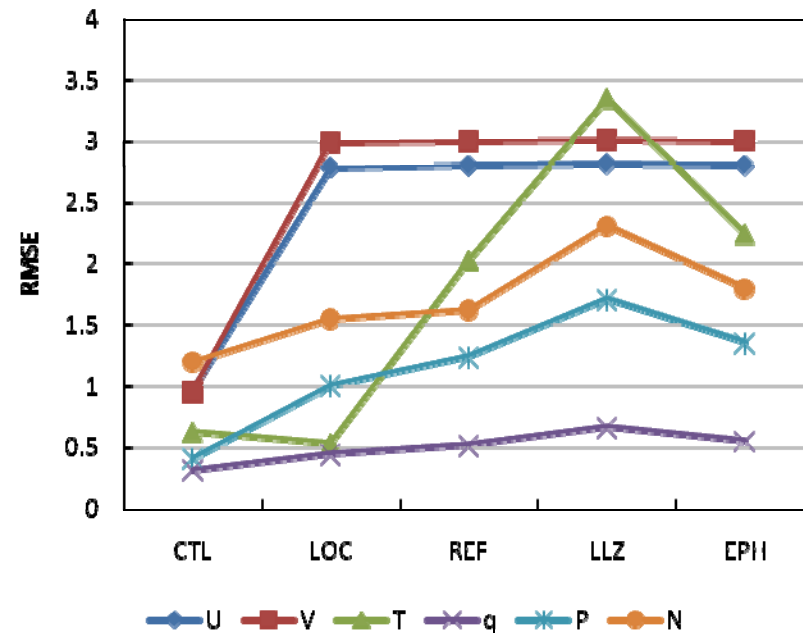
AREA1



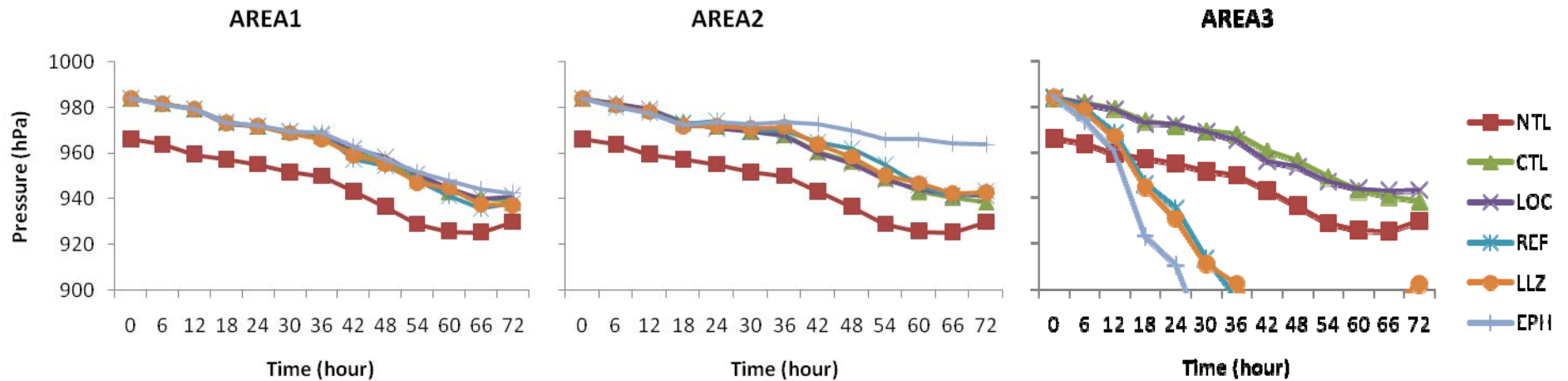
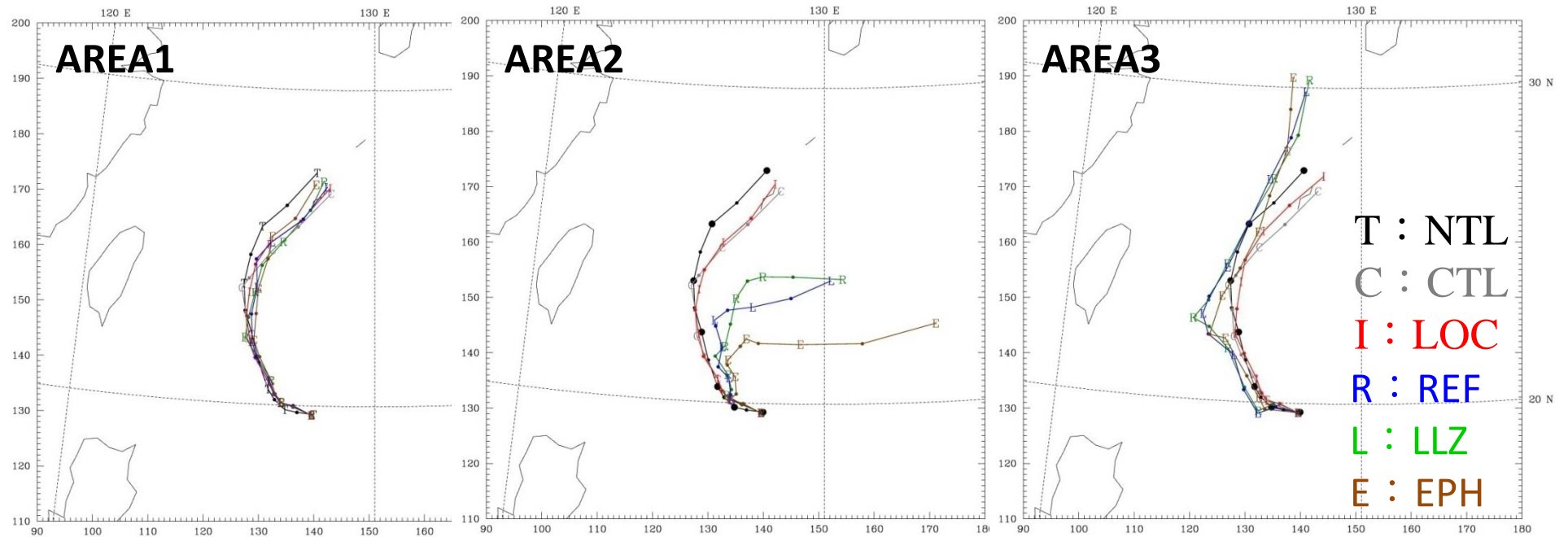
AREA2

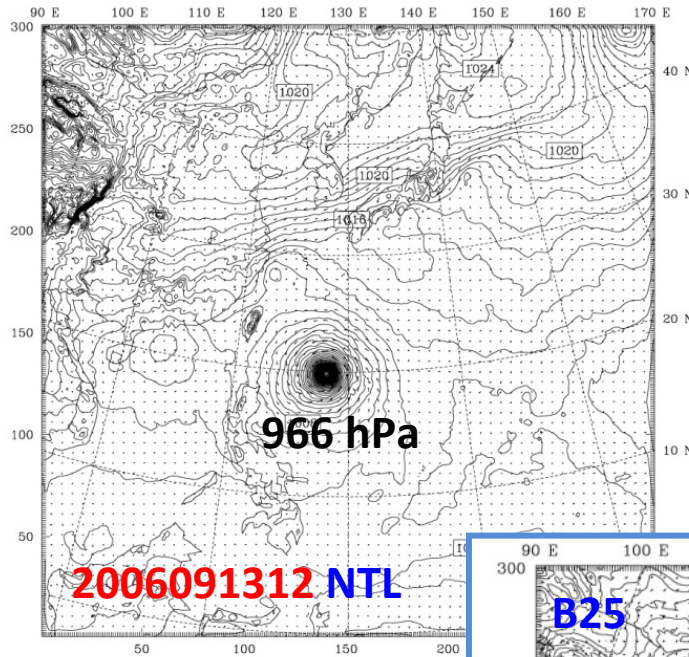


AREA3

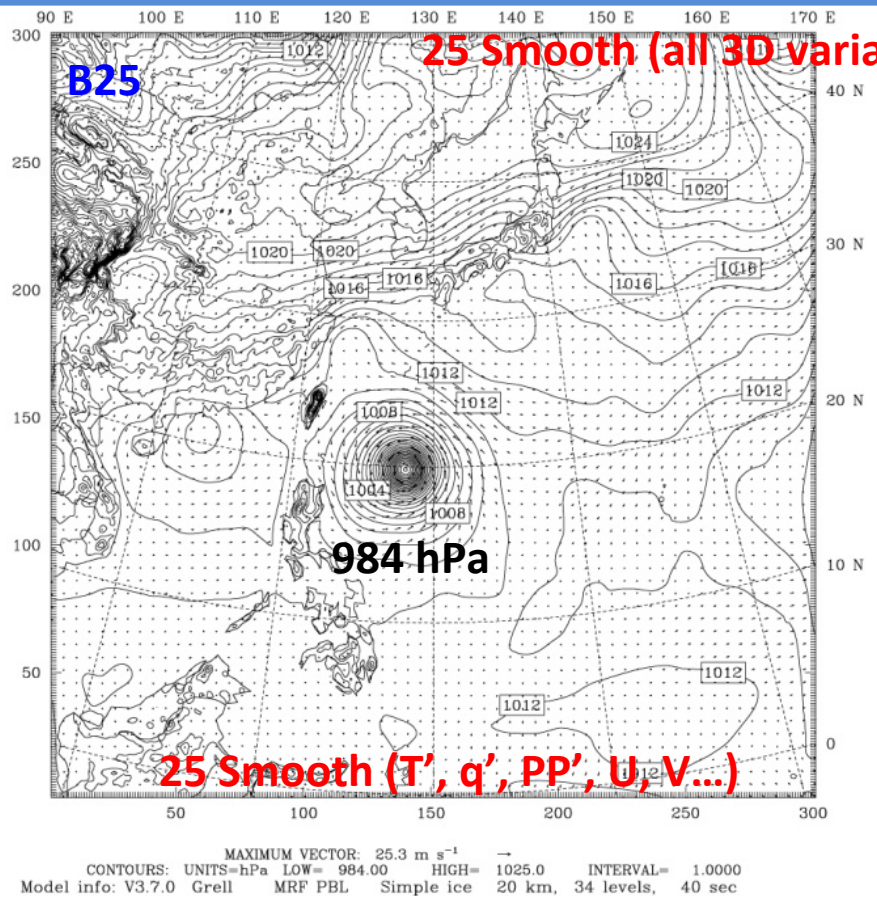
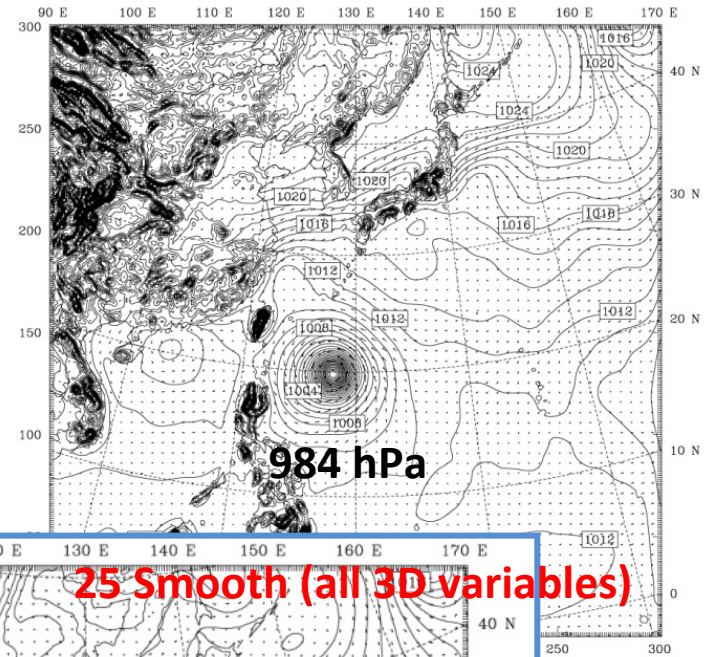


Track and Intensity



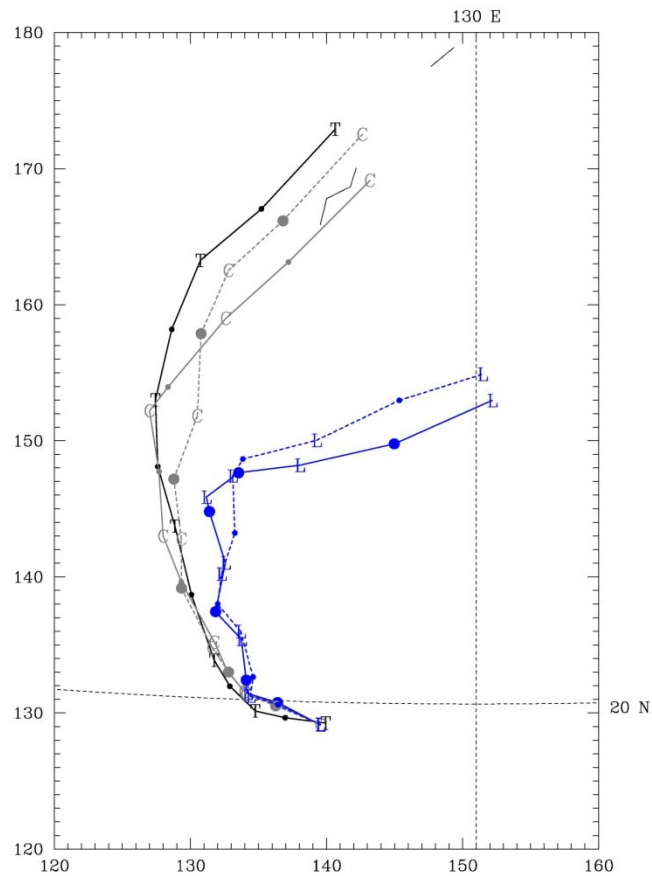


MAXIMUM VECTOR: 35.1 m s⁻¹
 CONTOURS: UNITS=hPa LOW= 967.00 HIGH= 1025.0
 Model info: V3.7.0 Grell MRF PBL Simple ice 20 km, 34 levels, 40 sec



MAXIMUM VECTOR: 25.3 m s⁻¹
 CONTOURS: UNITS=hPa LOW= 984.00 HIGH= 1025.0 INTERVAL= 1.0000
 Model info: V3.7.0 Grell MRF PBL Simple ice 20 km, 34 levels, 40 sec

Sensitivity Tests



T : NTL

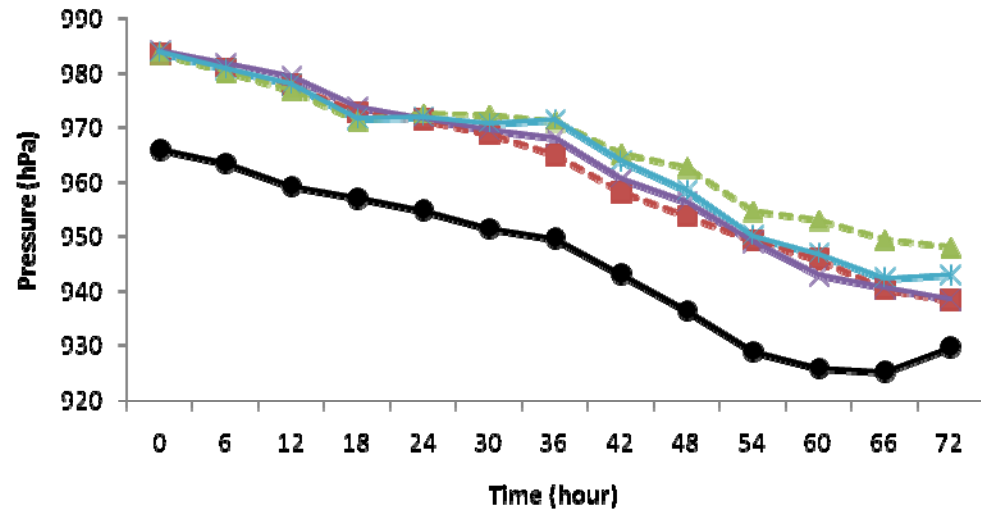
C : CTL

L : LLZ

Solid line: 25 Smooth (all 3D variables)

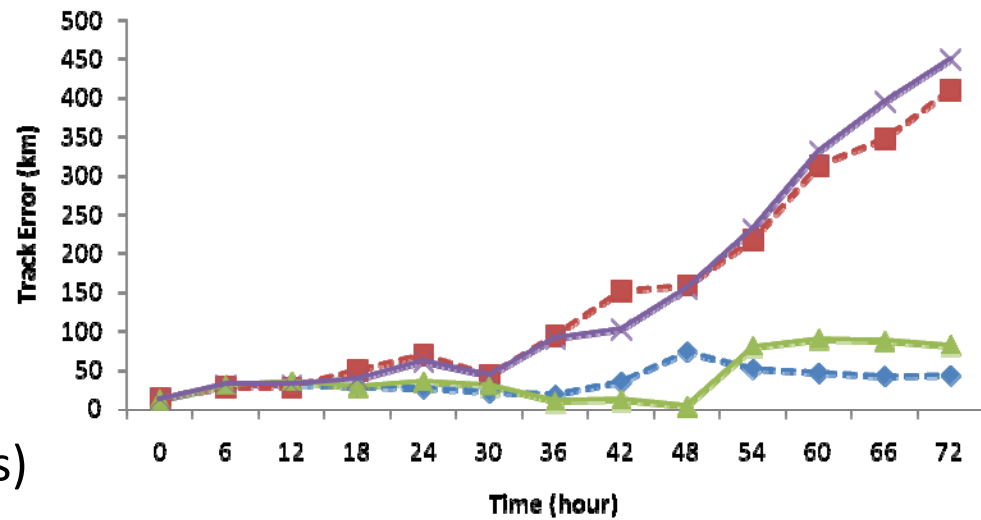
Dash line: B25

AREA2



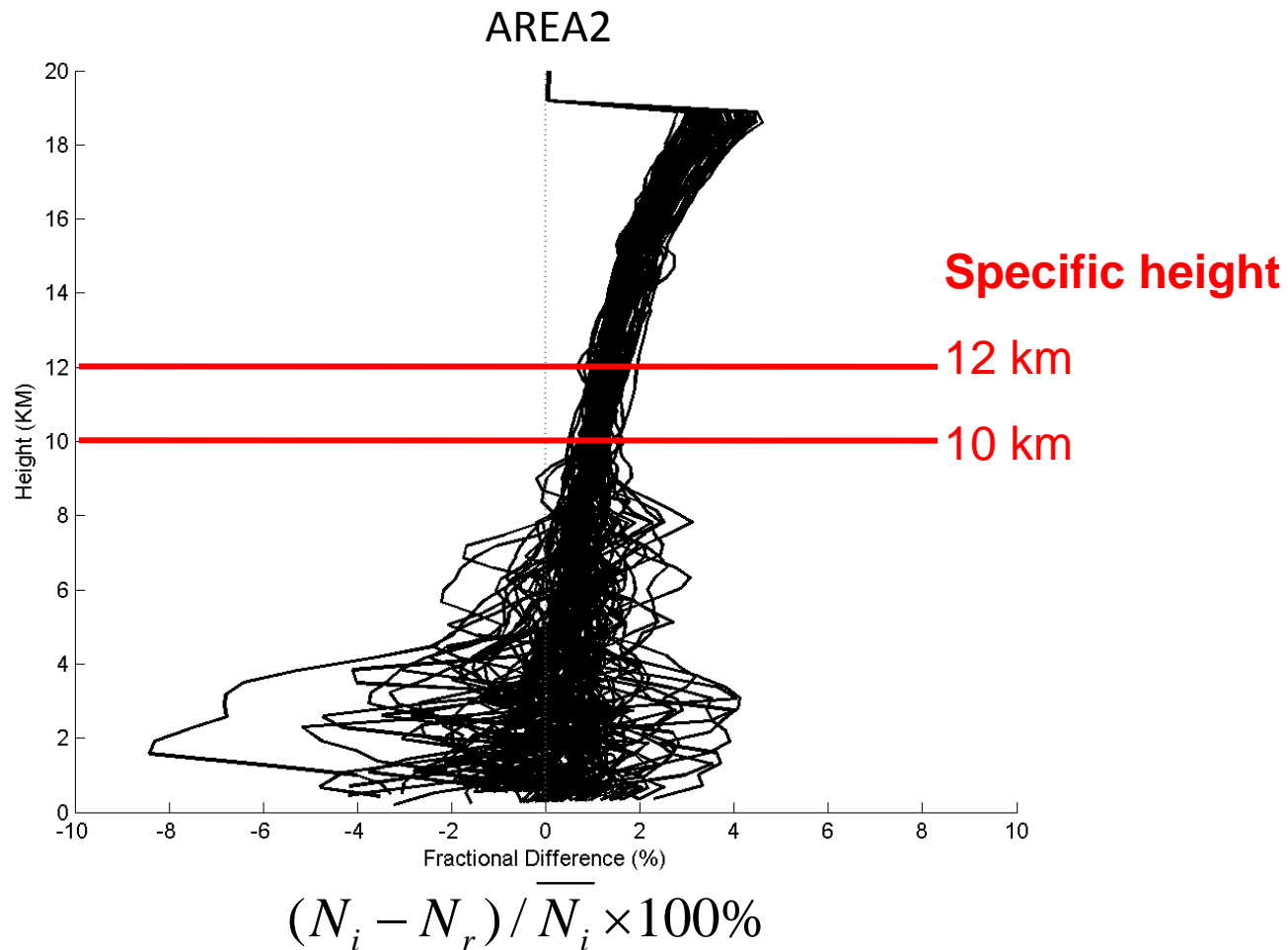
● NTL ■ B25 CTL ▲ B25 LLZ × CTL * LLZ

AREA2

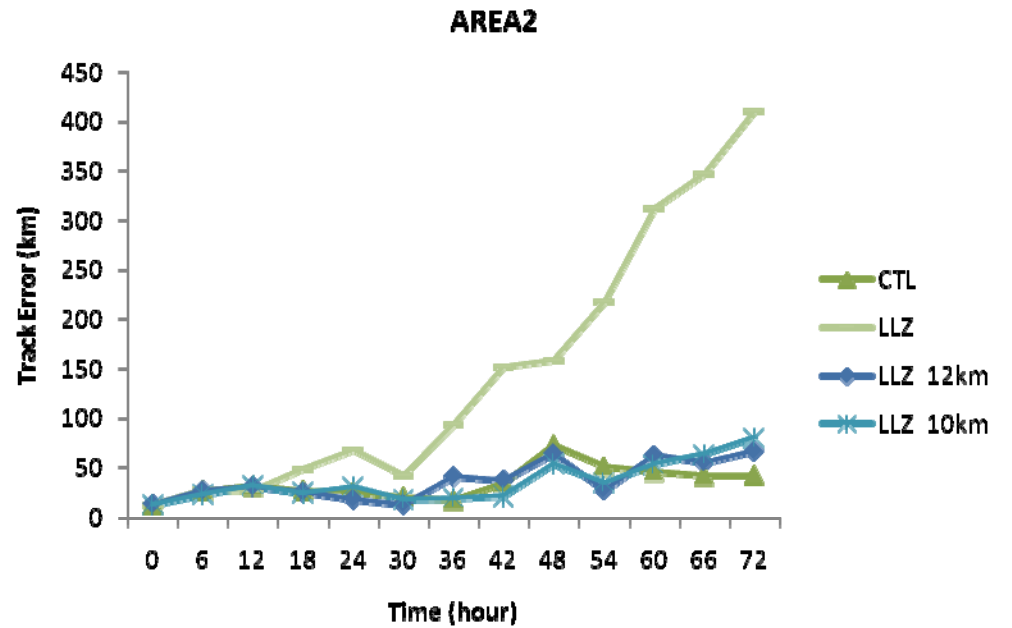
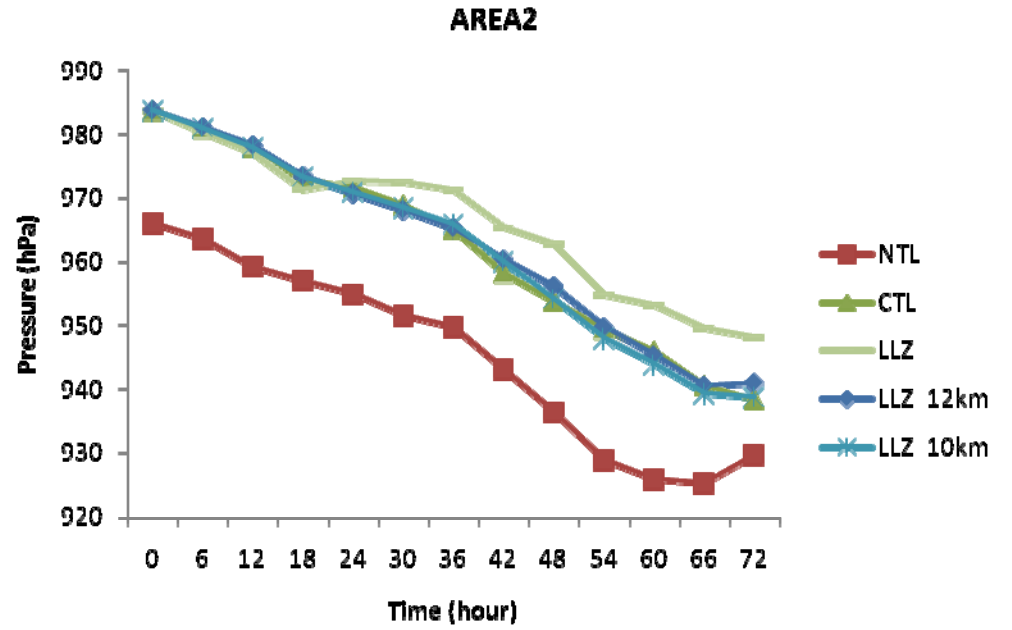
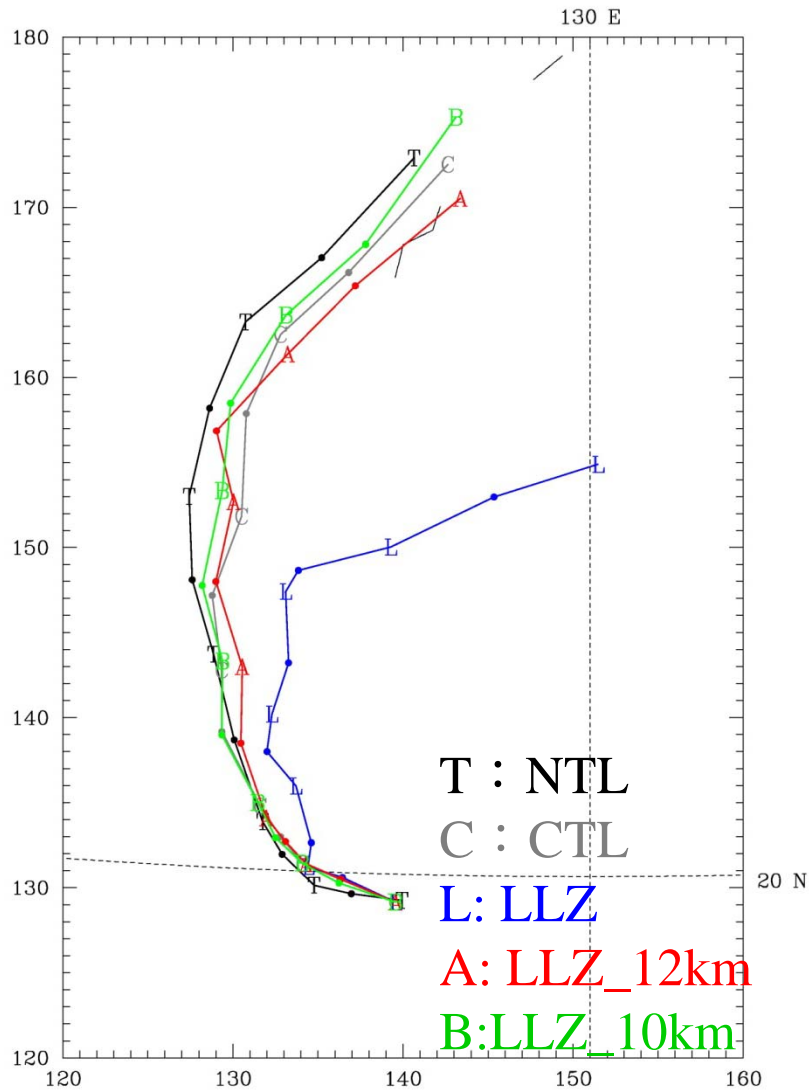


◆ B25 CTL ■ B25 LLZ ▲ CTL × LLZ

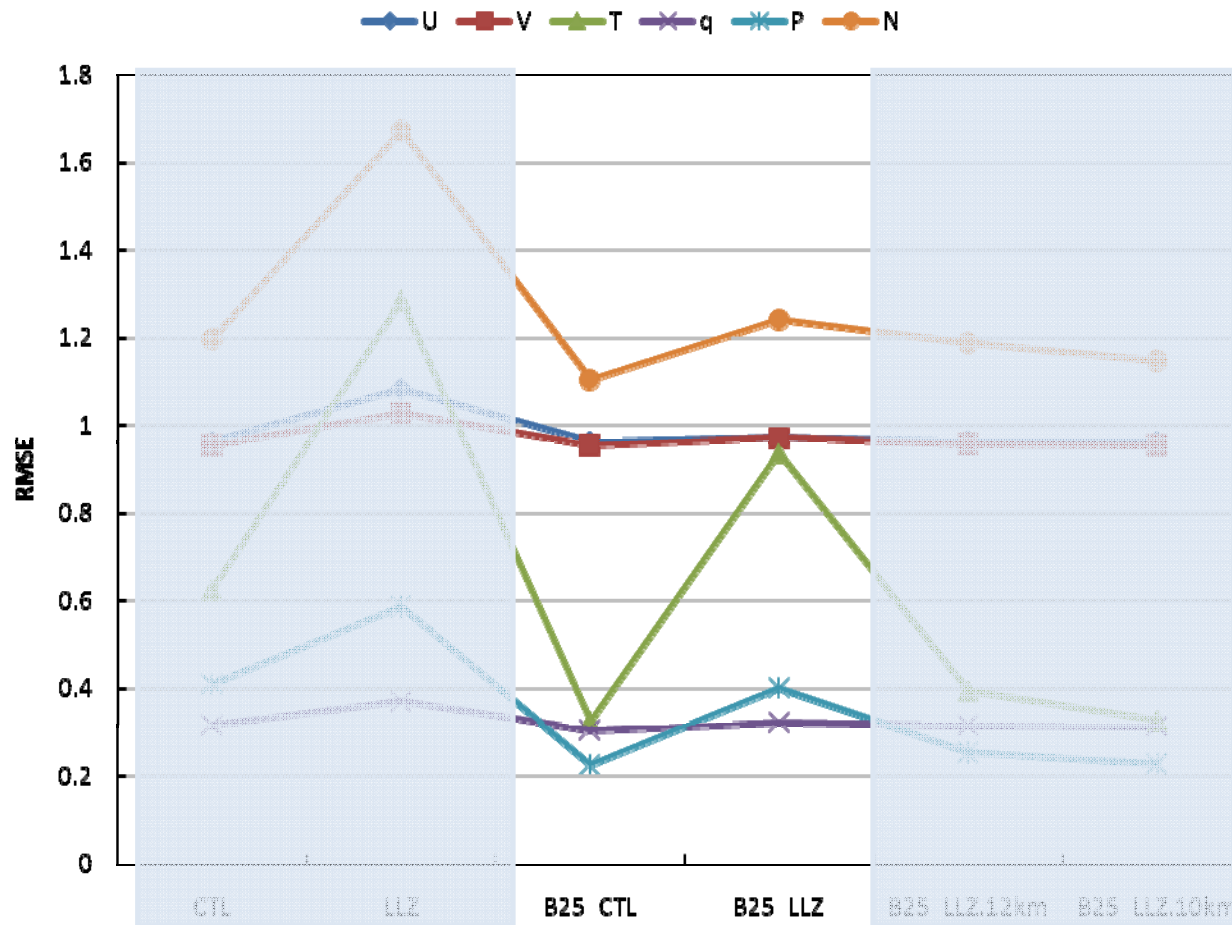
Remove observations above the specific height during data assimilation



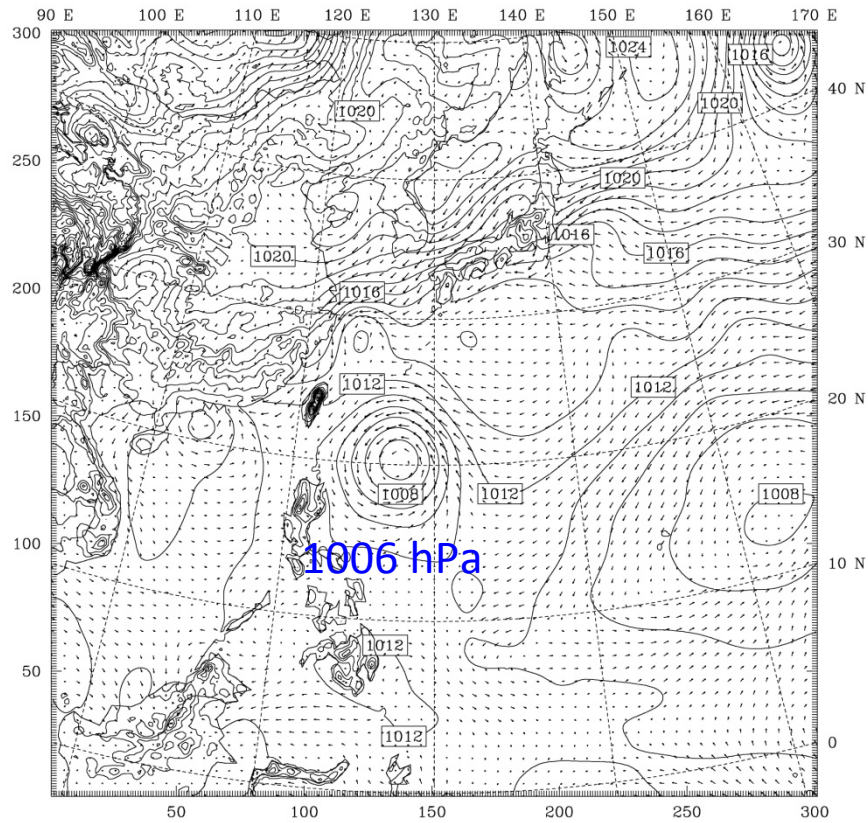
LLZ in AREA2



RMSE with NTL at the initial time

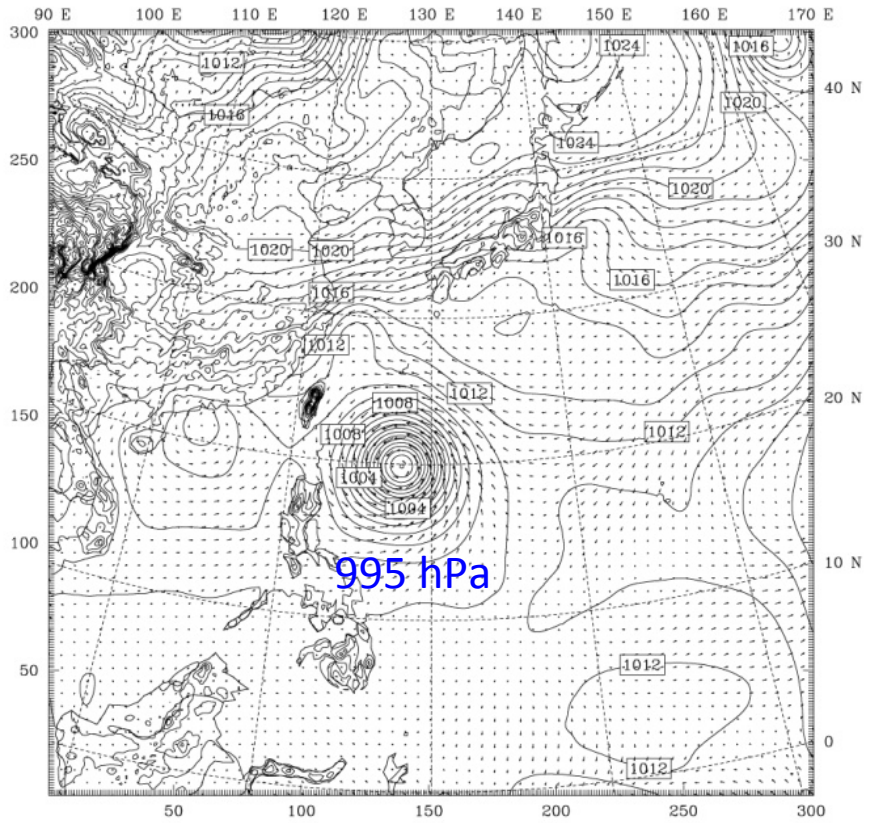


NCEP AVN



MAXIMUM VECTOR: 14.1 m s⁻¹ →
 CONTOURS: UNITS=hPa LOW= 997.00 HIGH= 1024.0 INTERVAL= 1.0000

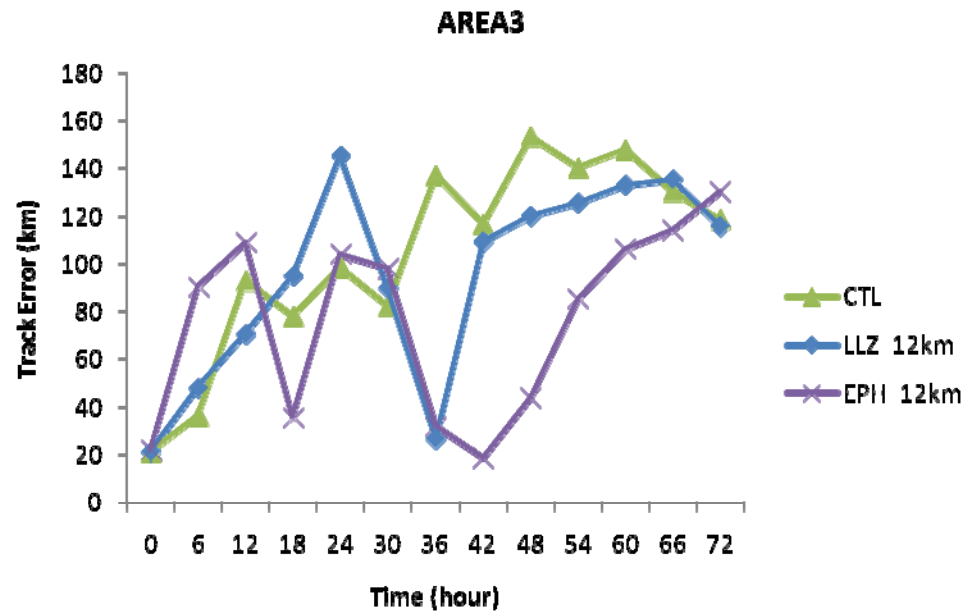
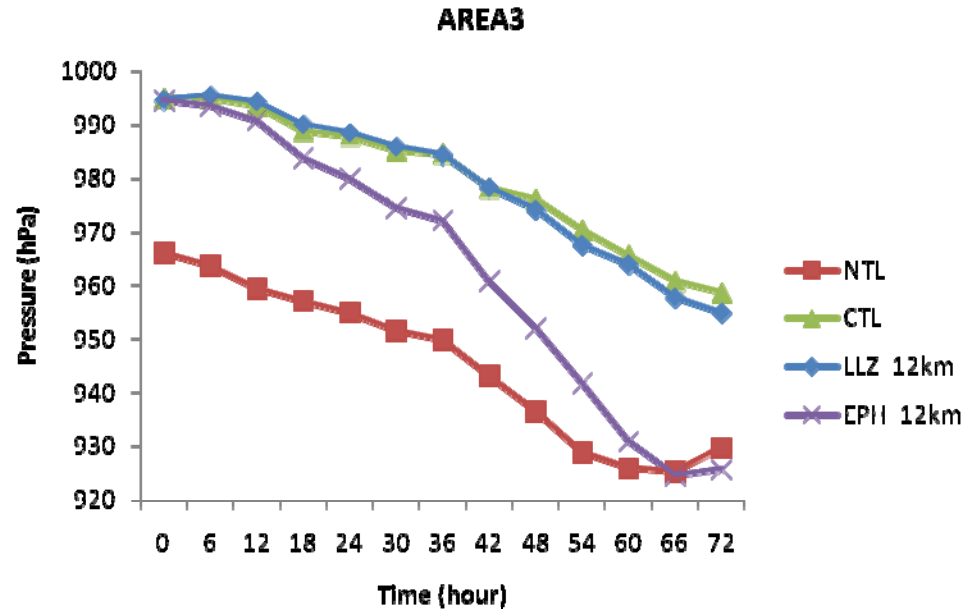
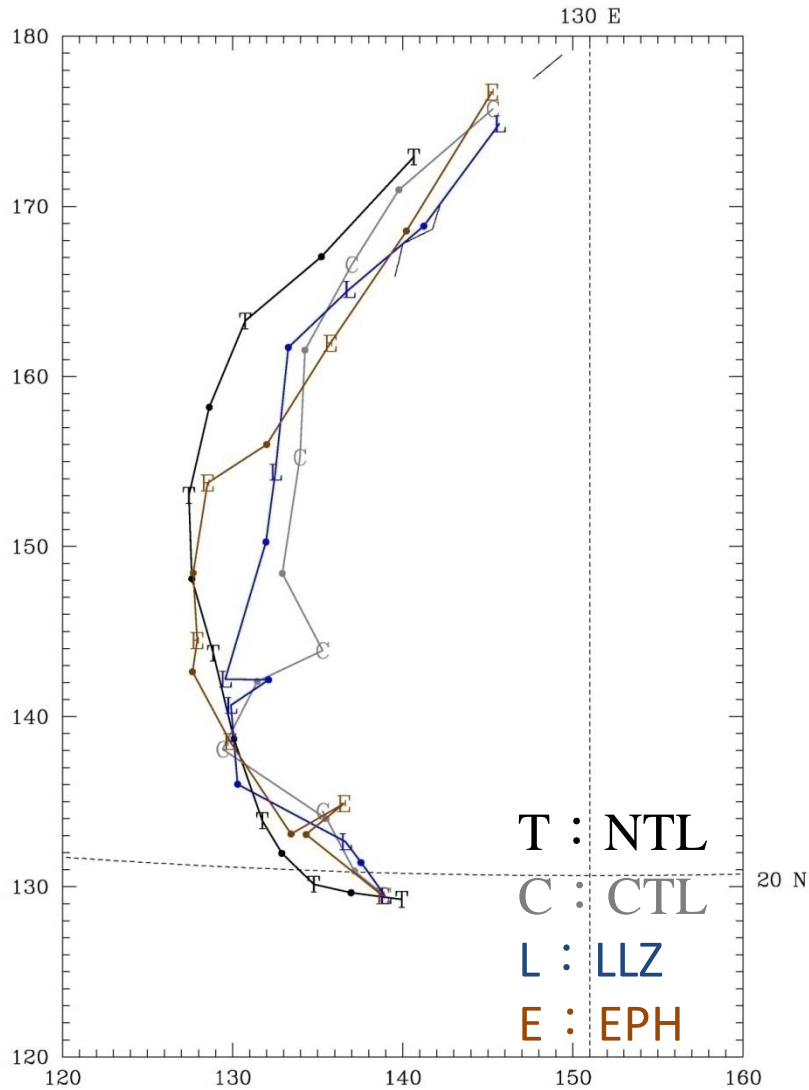
125 Smooth (T', q', PP', U, V...)



MAXIMUM VECTOR: 15.9 m s⁻¹ →
 CONTOURS: UNITS=hPa LOW= 995.00 HIGH= 1024.0 INTERVAL= 1.0000
 Model info: V3.7.0 Grell MRF PBL Simple ice 20 km, 34 levels, 40 sec

AREA3

Remove data above 12 km



Summary

- Verified against the true state, the OSSEs show that errors of the initial analysis after assimilating GPS RO soundings are quite different in AREA1 and AREA3 but are similar in AREA2 for different operators, possibly due to weaker horizontal gradients existing in the latter (upstream of typhoon).
- Spherical symmetry assumption for the nonlocal refractivity retrieved from the bending angles of 2-D ray tracing produces deviations from the local refractivity.
- The sharp gradients produced near the boundary between CIRA and MM5 states exhibit large fractional differences for both bending angle and retrieved refractivity, and thus significantly affect the typhoon prediction.
- Ignore the observations near MM5 model top in data assimilation can improve the forecast of typhoon track and intensity.
- The sensitivity tests in this study indicate further improvement on typhoon prediction by using the nonlocal operator than the local operator when the assimilated GPS RO soundings are located over typhoon circulation.

The end ~

Thank you!!