Research on Atmospheric Data Assimilation Techniques for Antarctic Applications: Schemes and Preliminary Results

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Outline

- Motivations
- Technical schemes
- Preliminary results
- Summary

Advanced data assimilation

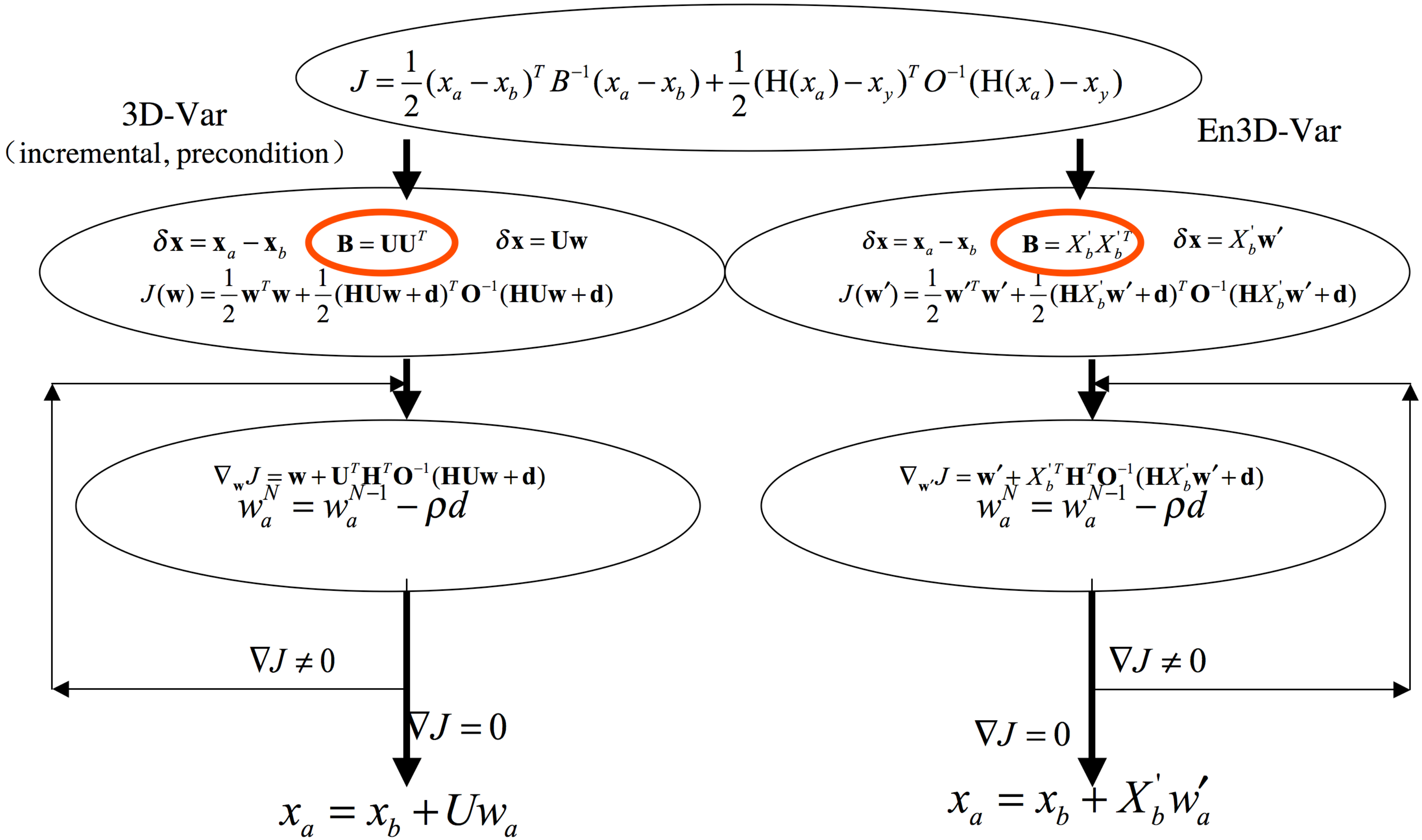
- 3D-Var
  - ✓ All data can be assimilated simultaneously, with a pre-defined background error covariance matrix.
  - ✓ Equivalent to OI, but it can ingest non-conventional data.
  - ✓ It is possible to add constraints to the cost function to control spurious noise.
- 4D-Var
  - ✓ It is a non-sequential data assimilation technique, fitting observations in the whole assimilation window (optimal trajectory).
  - ✓ It is applied in many operational centers.
  - ✓ However, there are disadvantages compared with EnKF technique (TL and AD are difficult to code; background error covariance is evolved only within assimilation window and it is usually static at analysis time).
- Ensemble Kalman filter
  - ✓ It is a hot topic in recent years, and research shows promising results.
  - ✓ It is easy to design and code, and can include any physical process as needed.
  - ✓ One of the prominent advantages is its flow-dependent background error covariance.

Advanced data assimilation

- Ensemble-based variational data assimilation, En3/4D-Var
  - ✓ It is proposed by Liu et al. (2008; 2009):

    Liu, C., Q. Xiao, and B. Wang, 2008: An ensemble-based four-dimensional variational data assimilation scheme: Part I: Technical formulation and preliminary test. *Mon. Wea. Rev.*, **136**, 3363-3373.
    Liu, C., Q. Xiao, and B. Wang, 2009: An ensemble-based four-dimensional variational data assimilation scheme: Part II: Observing system simulation experiments with Advanced Research WRF (ARW). *Mon. Wea. Rev.*, **137**, 1687-1704.
  - ✓ It is variational approach, minimizing a cost function to find the optimal analysis state.
  - ✓ It adopts the technique of EnKF to include the flow-dependent background error covariance from ensemble forecast.
  - ✓ It can be implemented in the existing variational data assimilation system without significant changes of the system setup.
  - ✓ Preliminary results from WRF En3/4D-Var are satisfactory.

En3D-Var（Lorenc 2003）



En4D-Var

$$J = \frac{1}{2}(x_a - x_b)^T B^{-1}(x_a - x_b) + \sum_{i=0}^{N} \frac{1}{2}(HM_{0\sim i}(x_a) - y_i)^T O^{-1}(HM_{0\sim i}(x_a) - y_i)$$

En4D-Var
(generalized En3D-Var)

$$\mathbf{M}X_b^{'} \approx \frac{1}{\sqrt{N-1}}(MX_{bi} - \overline{MX_b})$$

$$J(\mathbf{w}) = \frac{1}{2}\mathbf{w}^T\mathbf{w} + \frac{1}{2}\sum_{i=0}^{I}(\mathbf{HM}_{0\sim i}X_b^{'}\mathbf{w} + \mathbf{d}_i)^T\mathbf{O}^{-1}(\mathbf{HM}_{0\sim i}X_b^{'}\mathbf{w} + \mathbf{d}_i)$$

$$\nabla_{\mathbf{w}} J = \mathbf{w} + \sum_{i=0}^{I} X_b^{'T}\mathbf{M}^T{}_{i\sim 0}\mathbf{H}^T\mathbf{O}^{-1}(\mathbf{HM}_{0\sim i}X_b^{'}\mathbf{w} + \mathbf{d}_i)$$

$$w_a^N = w_a^{N-1} - \rho d$$

$\nabla J \neq 0$

$\nabla J = 0$

$$x_a = x_b + X_b^{'} w_a^{\prime}$$

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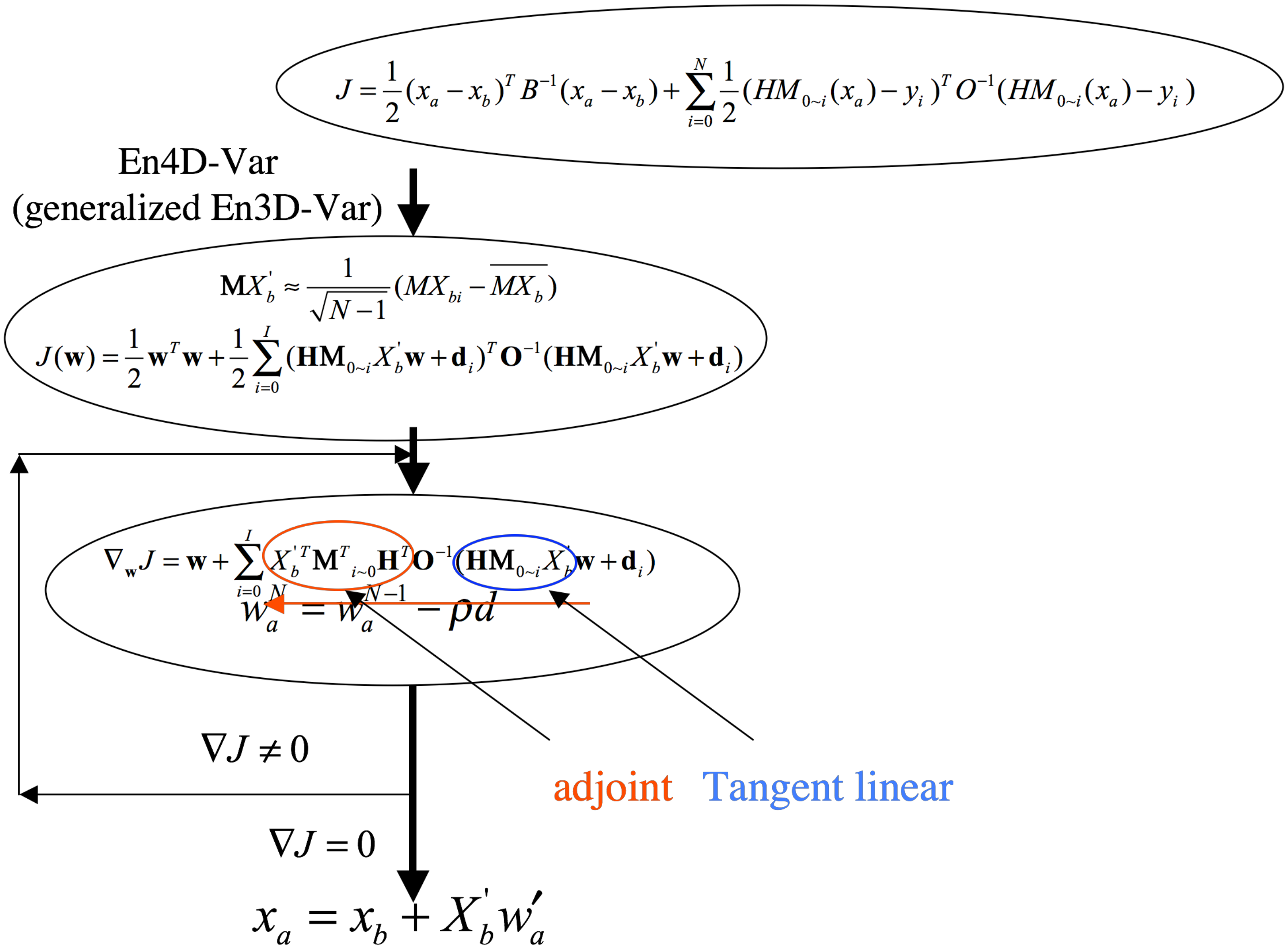
En4D-Var



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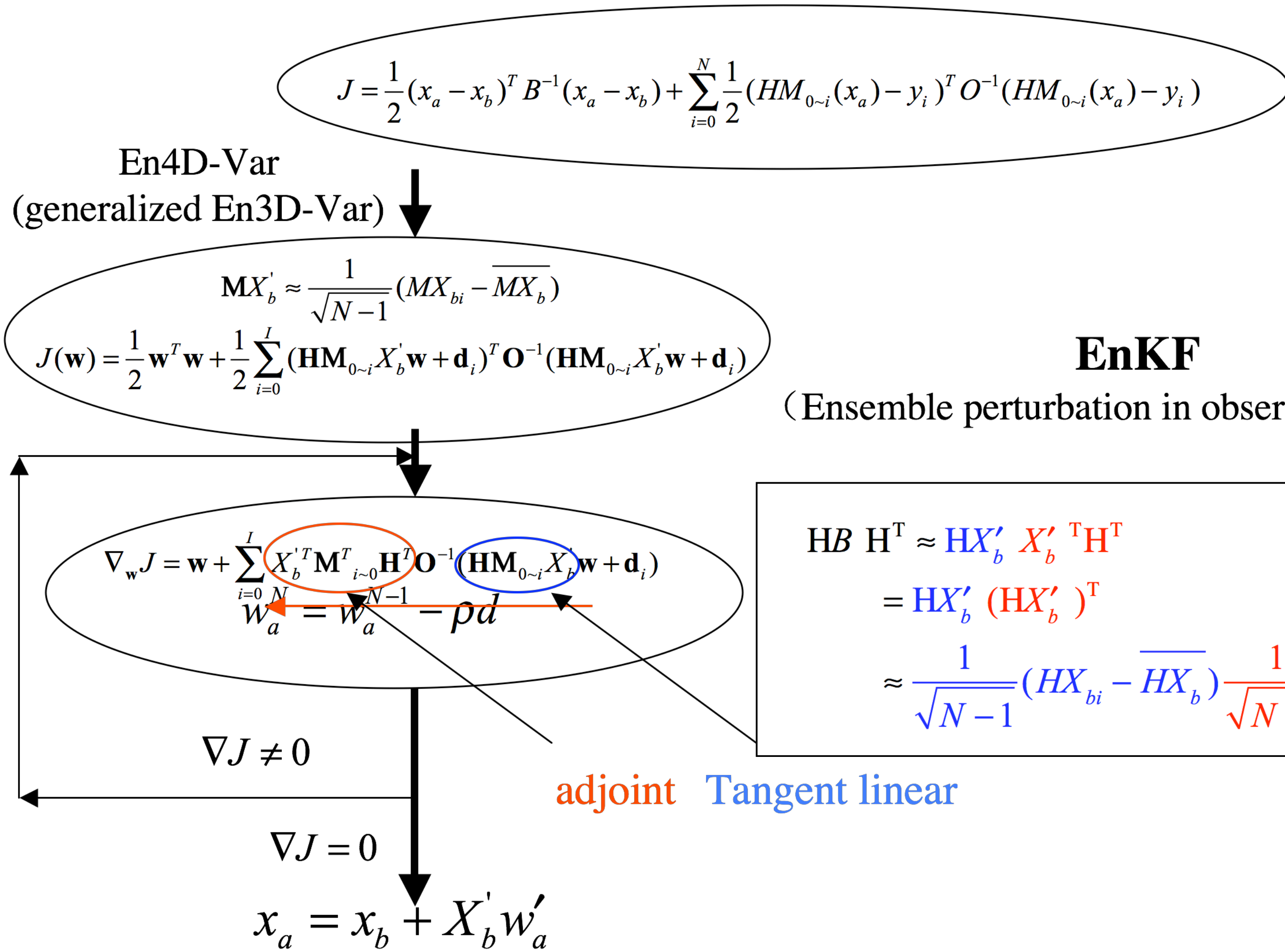
adjoint
Tangent linear

En4D-Var

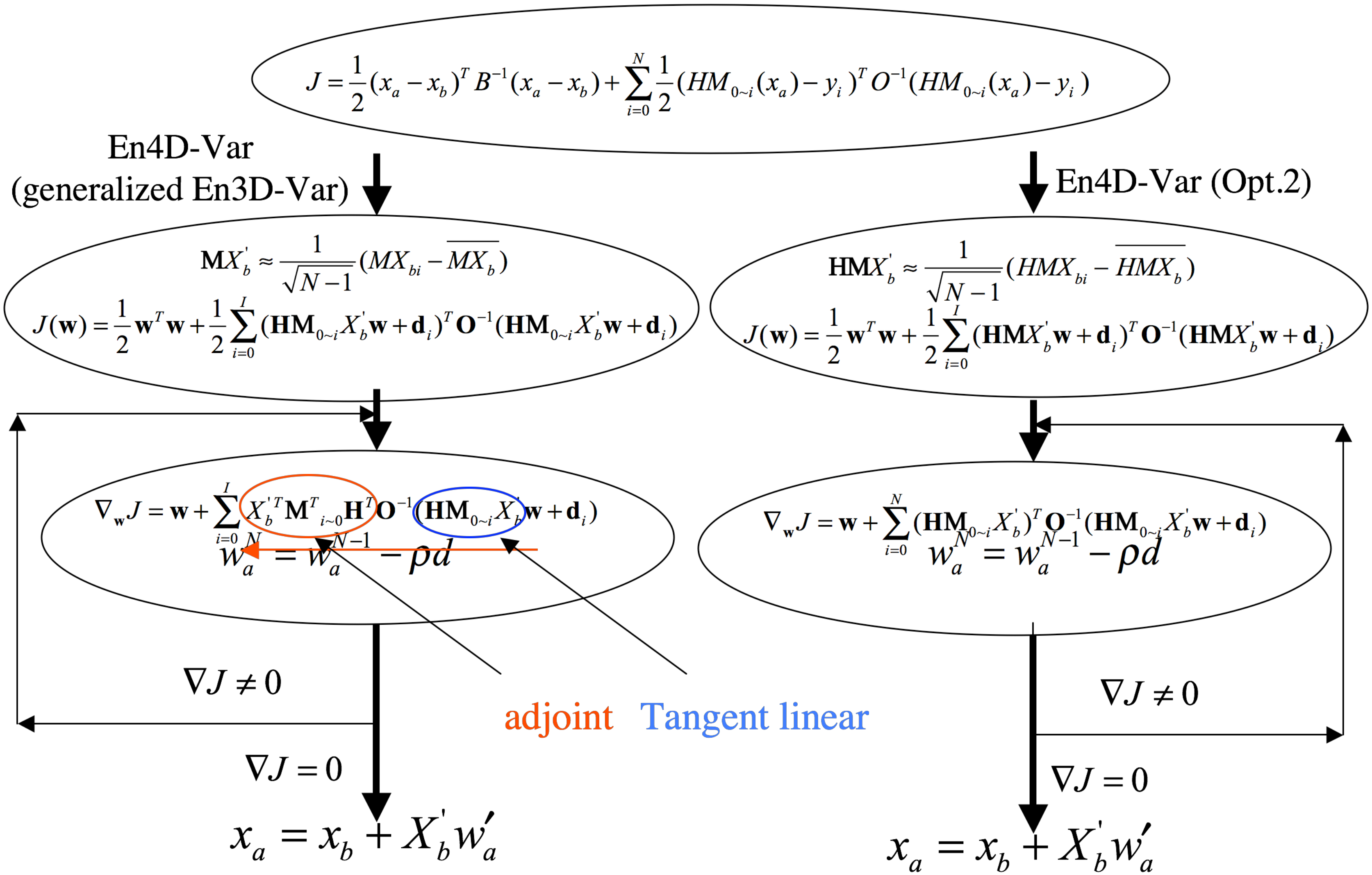


EnKF

（Ensemble perturbation in observation space）

$$\mathrm{H}B\,\mathrm{H}^{\mathrm{T}}\approx \mathrm{H}X_b^{\prime}\,X_b^{\prime\,\mathrm{T}}\mathrm{H}^{\mathrm{T}}$$
$$=\mathrm{H}X_b^{\prime}\,(\mathrm{H}X_b^{\prime})^{\mathrm{T}}$$
$$\approx\frac{1}{\sqrt{N-1}}(HX_{bi}-\overline{HX_b})\frac{1}{\sqrt{N-1}}(HX_{bi}-\overline{HX_b})^{\mathrm{T}}$$

En4D-Var



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En4D-Var
(generalized En3D-Var)
En4D-Var (Opt.2)
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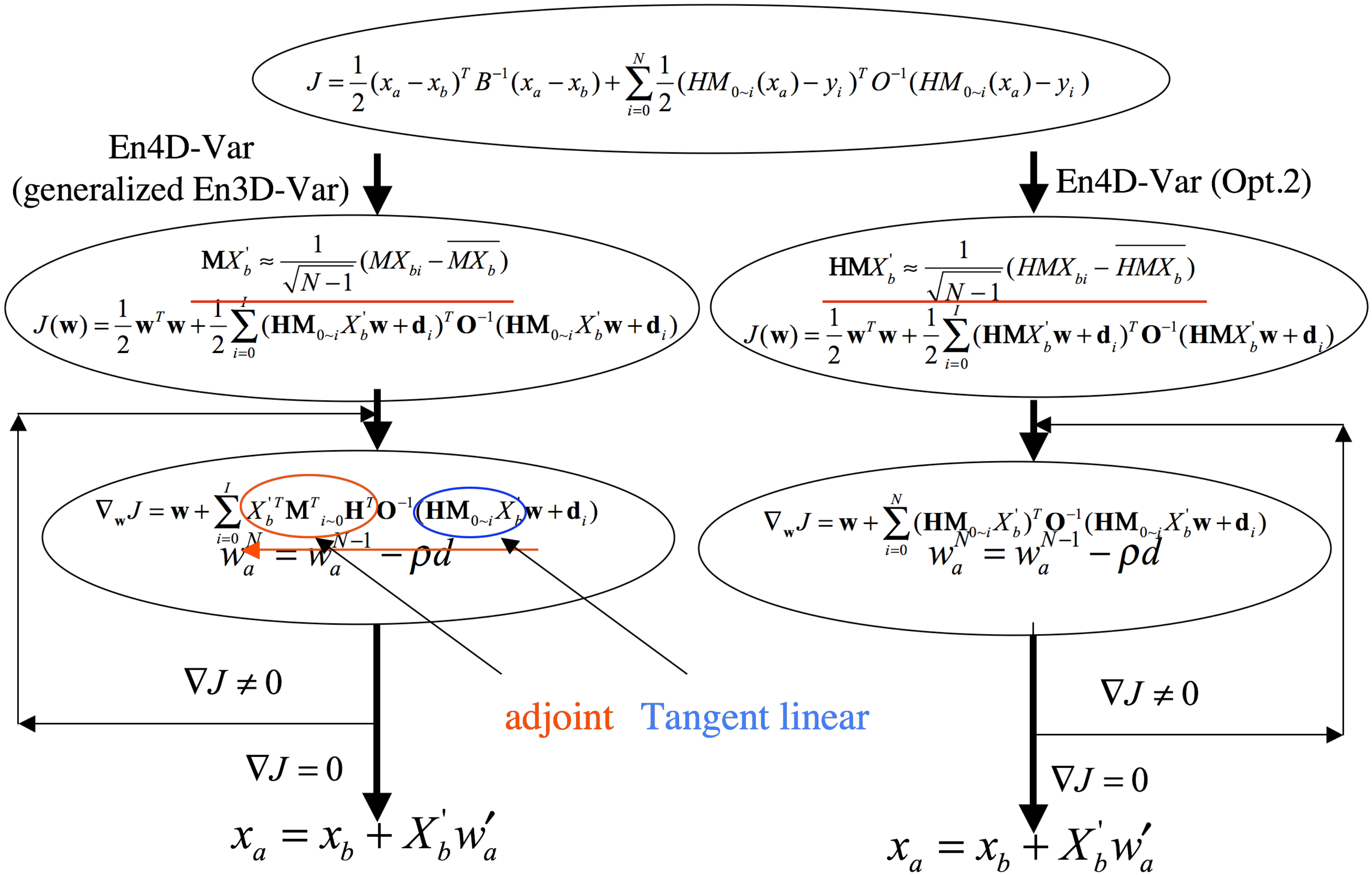
En4D-Var



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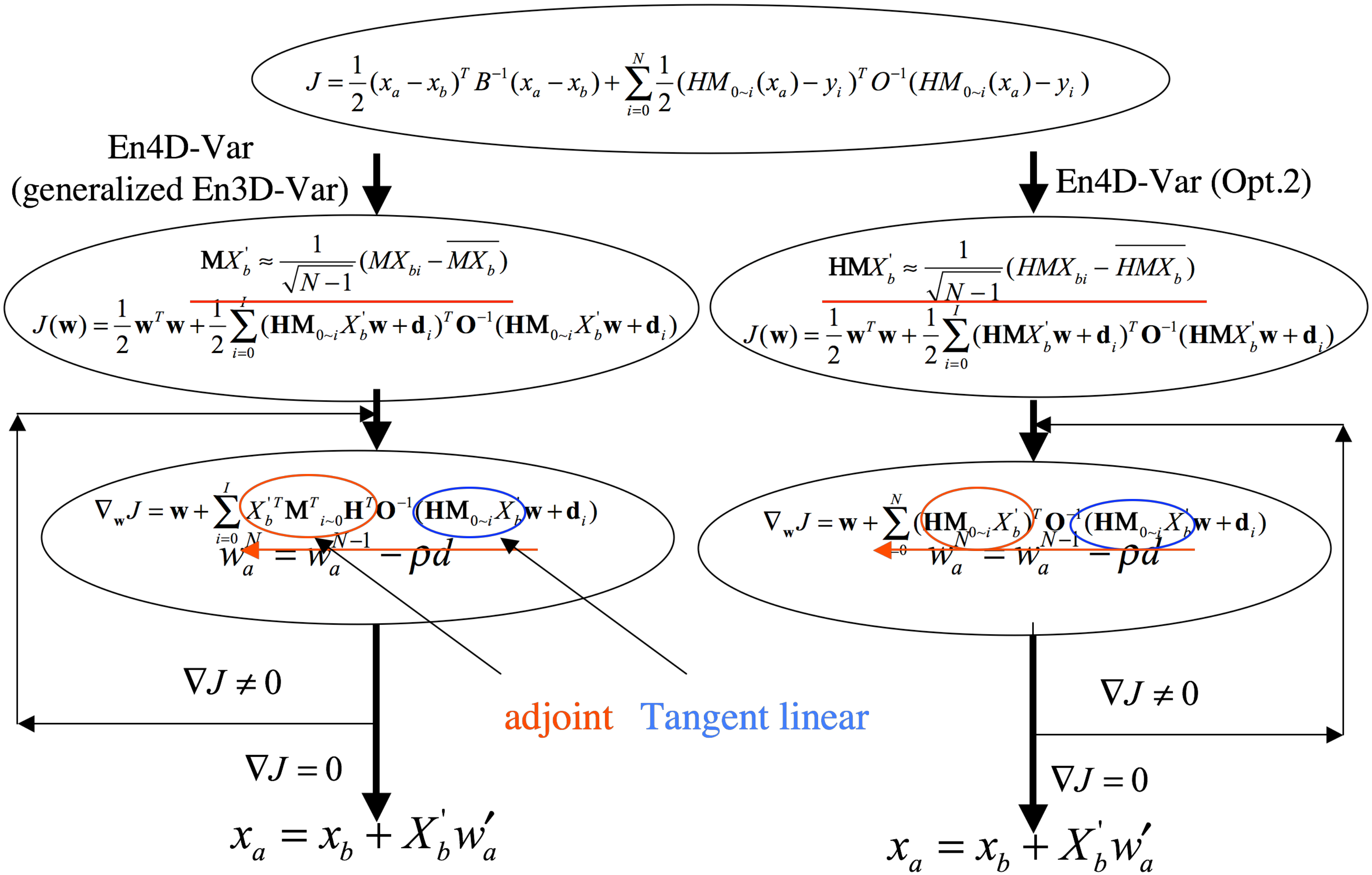
En4D-Var



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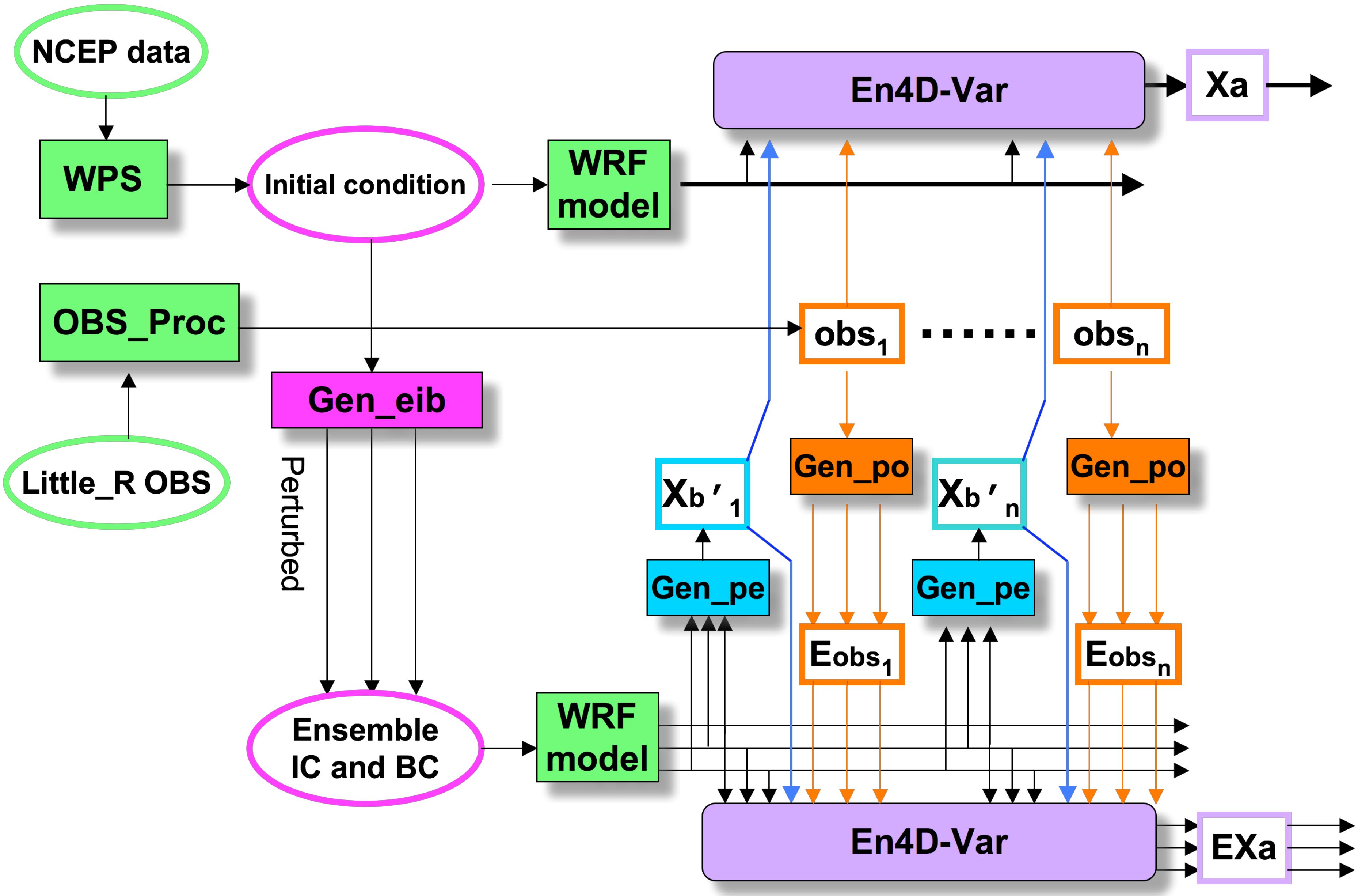
Some characteristics of En4D-Var

- En4D-Var uses the flow-dependent B matrix from ensemble forecast.
- It avoids tangent linear and adjoint models in its formulation (in Opt.2).
- It couples incremental approach with preconditioning using ensemble perturbation matrix.
- But sampling errors are introduced to En4D-Var (in Opt.2).

Flow Chart for WRF-En4DVar



Experimental designs for OPP project

- Experiments with various data assimilation techniques for the Antarctic weather predictions through case studies and a month long verification.

- The data assimilation techniques to be tested are WRF 3D-Var, 4D-Var, En3D-Var and En4D-Var.

- The case selected is a cyclone penetrating the Western Antarctic Ice Sheet (WAIS) from 1200 UTC 3 through 1200 UTC 6 October 2007.

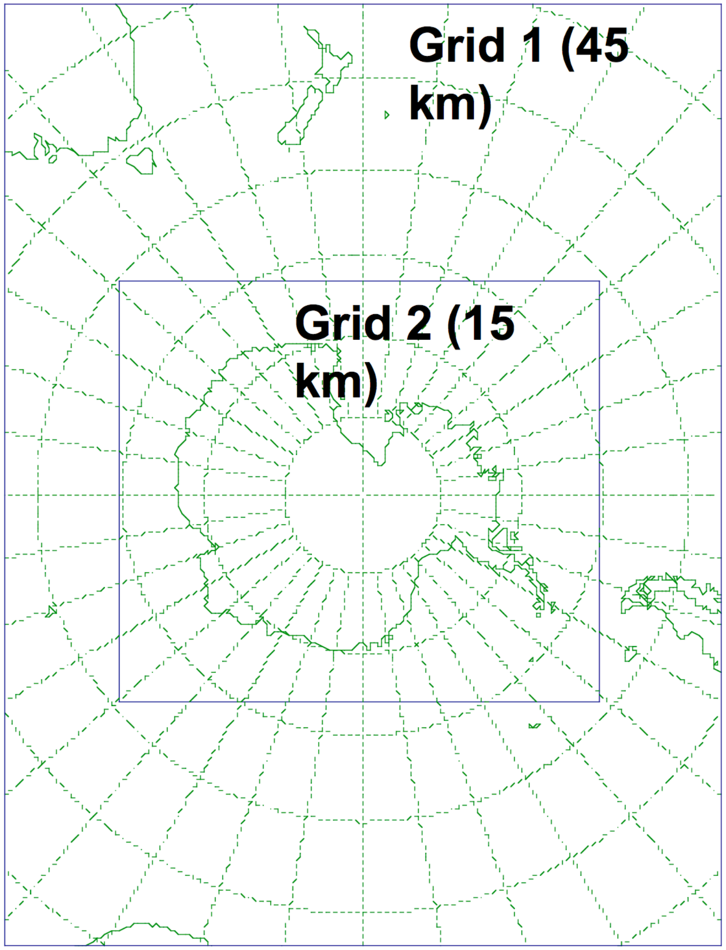
- Verification will be performed for the whole month of October 2007.

- Some preliminary results from case study using WRF 3D-Var has been finished.

Model Domains and Physics

Model Grids:
Two-way nesting
Outer grid: 220*290 (45 km)
Inner grid: 442*418 (15 km)
43 vertical levels

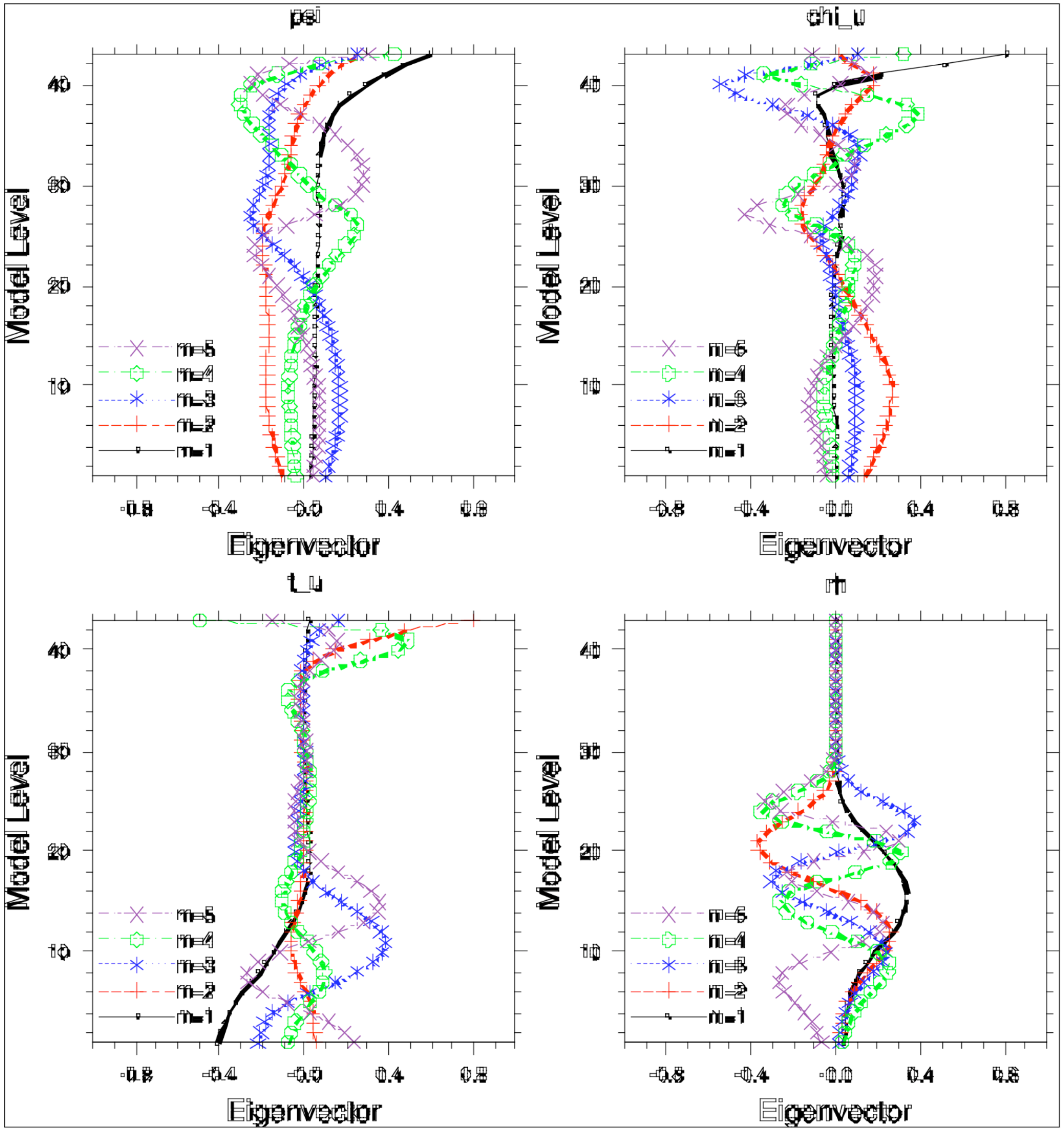
Model Physics:
WSM 5-class scheme
RRTM long wave radiation scheme
Goddard short wave radiation scheme
Mellor-Yamada-Janjic TKE PBL scheme
Kain-Fritsch (new Eta) cumulus scheme



Background Error Covariance

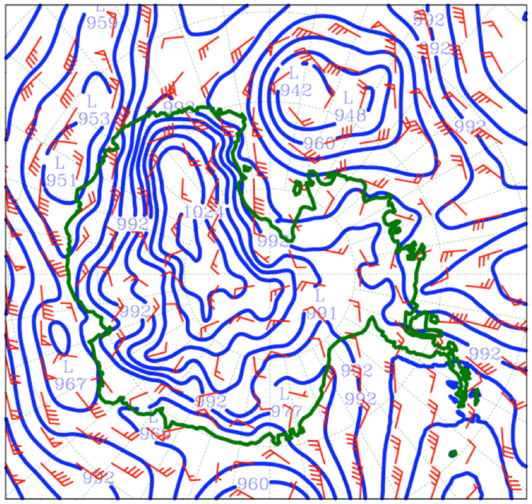
National Meteorological Center method (Parrish and Derber 1992)

The differences between 24- and 12-h forecasts in October 2007 were taken as background errors to calculate the background error covariance.

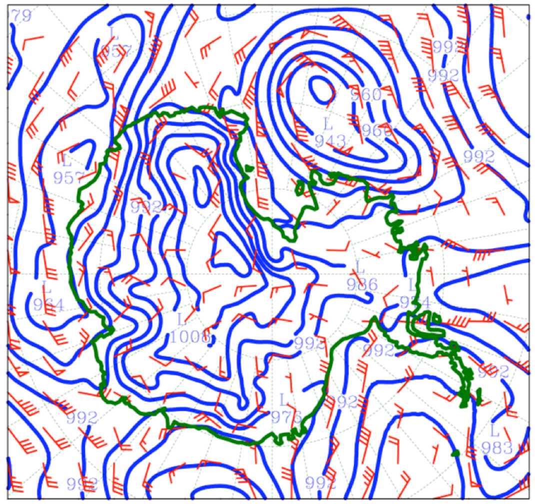


The Antarctic cyclone analysis (FNL)

0312



0400



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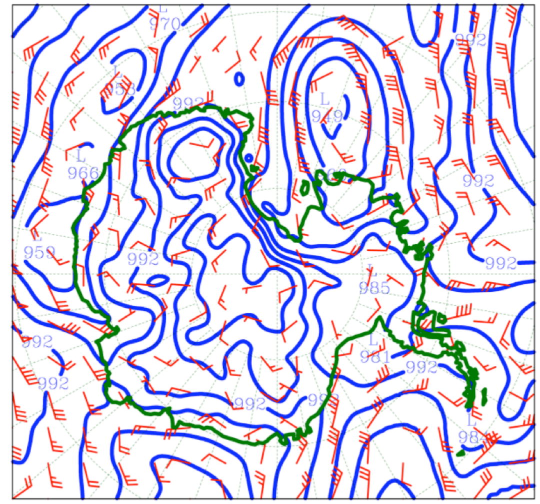

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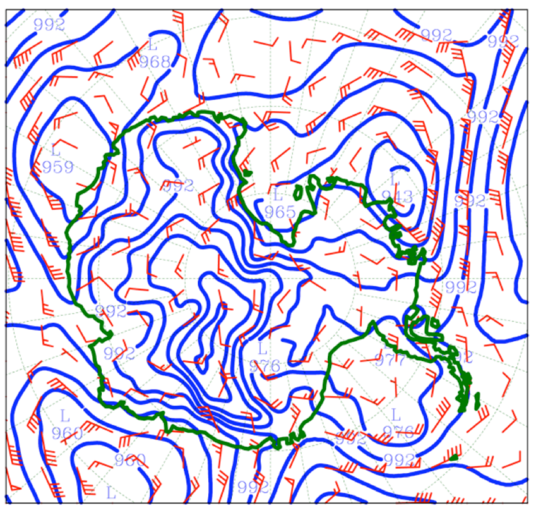

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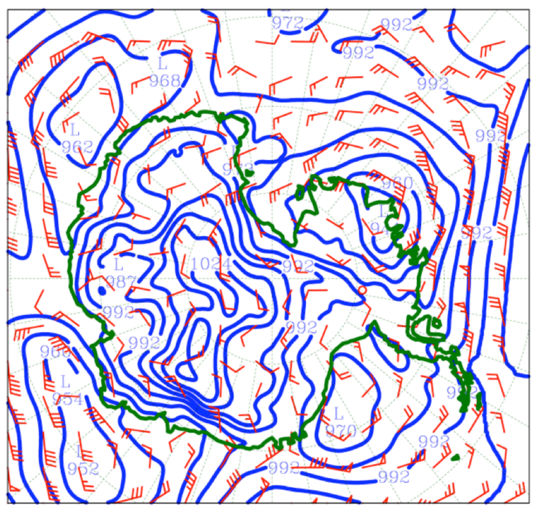

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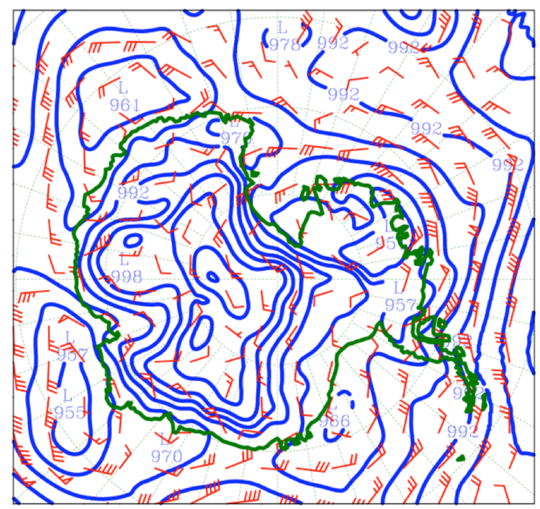
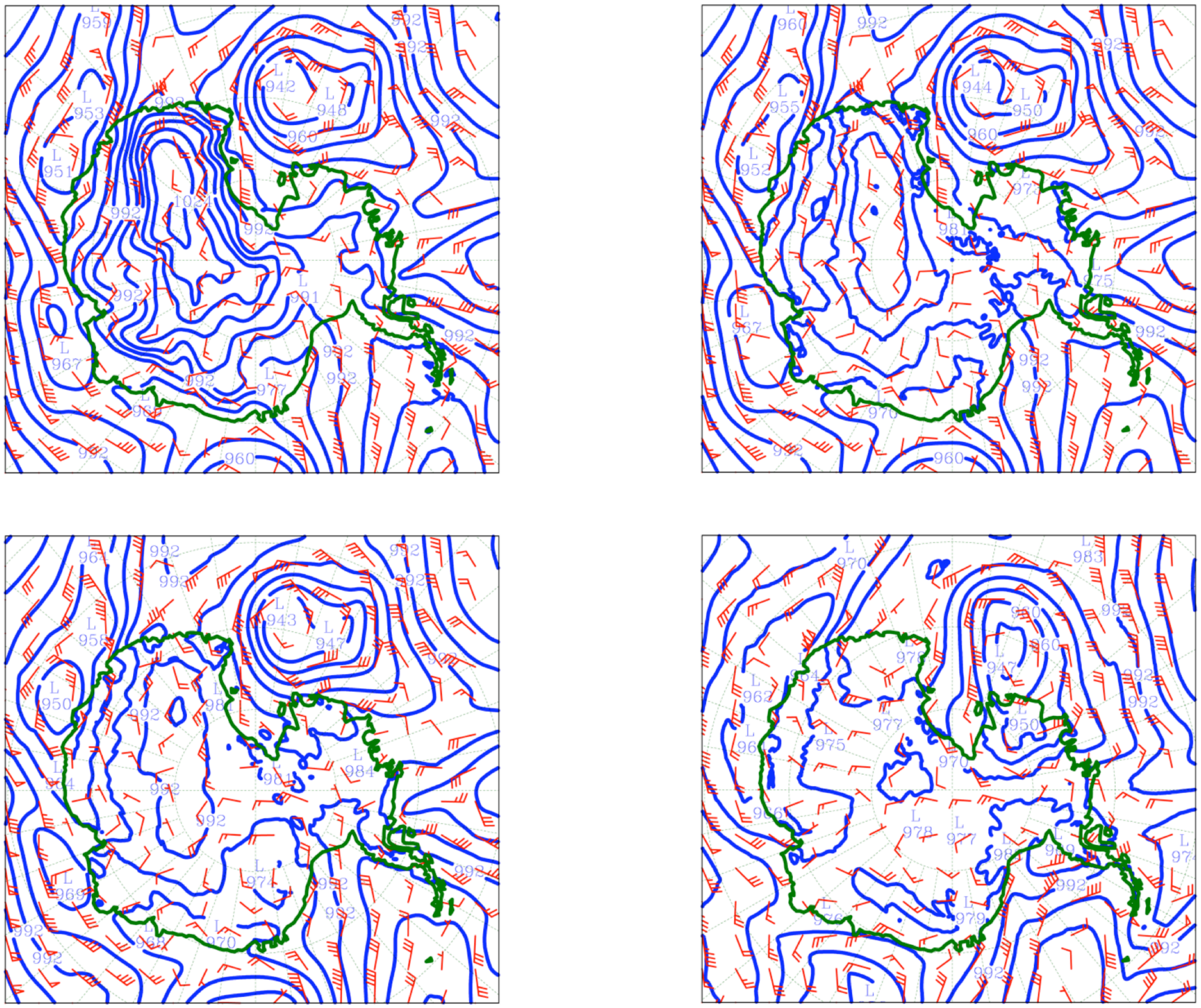


Initial state at 1200 UTC 3 Oct.

FNL

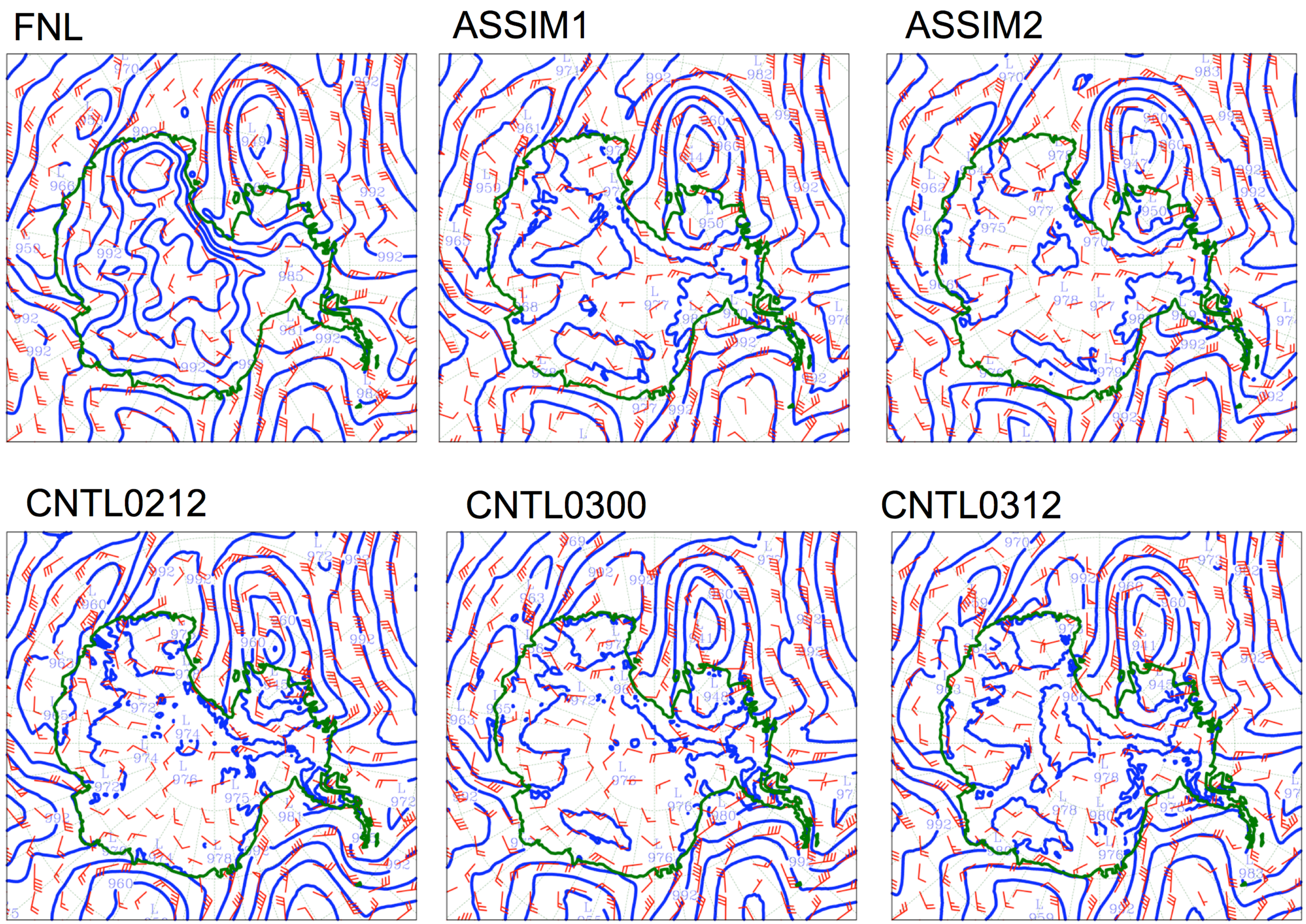
CNTL



ASSIM1 (12-h 3DVAR cycling)

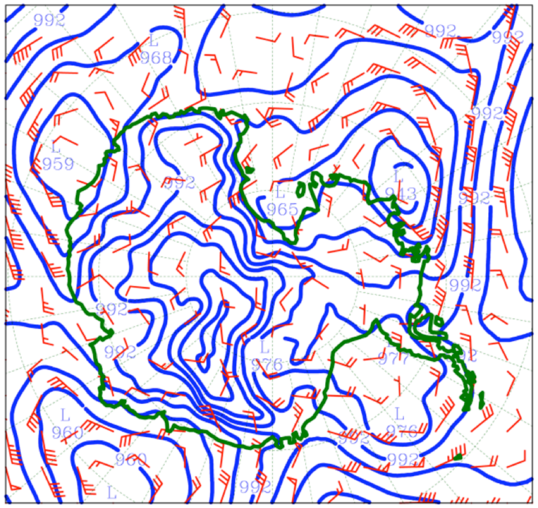
ASSIM2 (24-h 3DVAR cycling)

24-hr forecast at 1200 UTC 4 Oct.

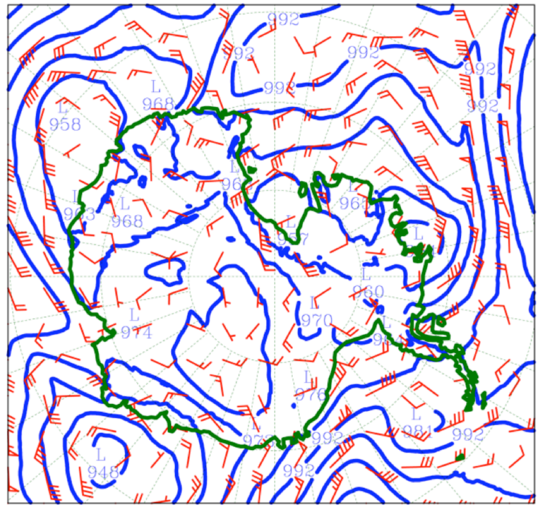


48-hr forecast at 1200 UTC 5 Oct.

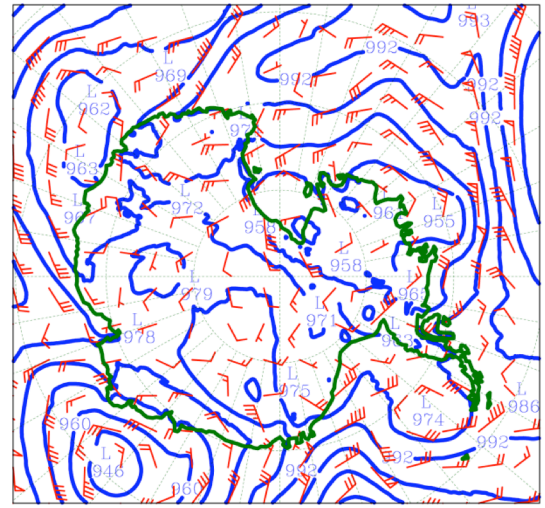
FNL



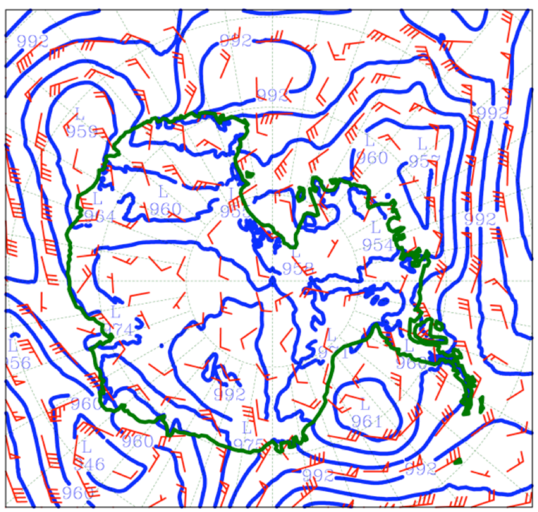
ASSIM1



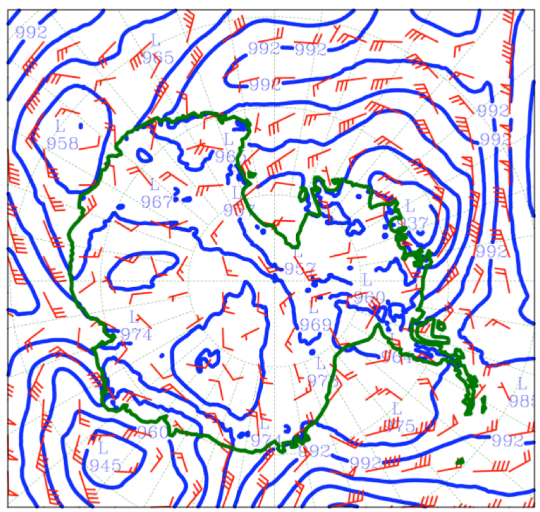
ASSIM2



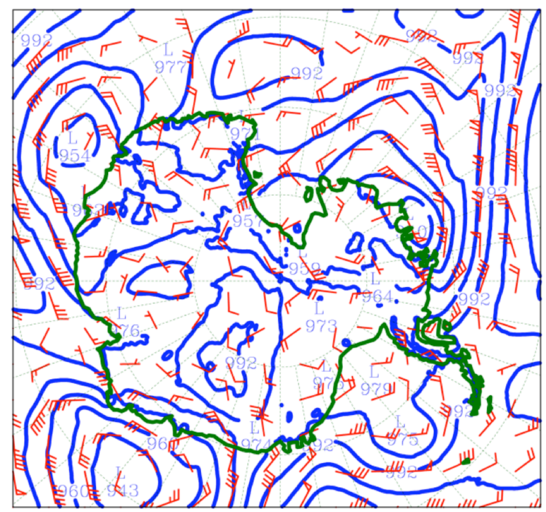
CNTL0212



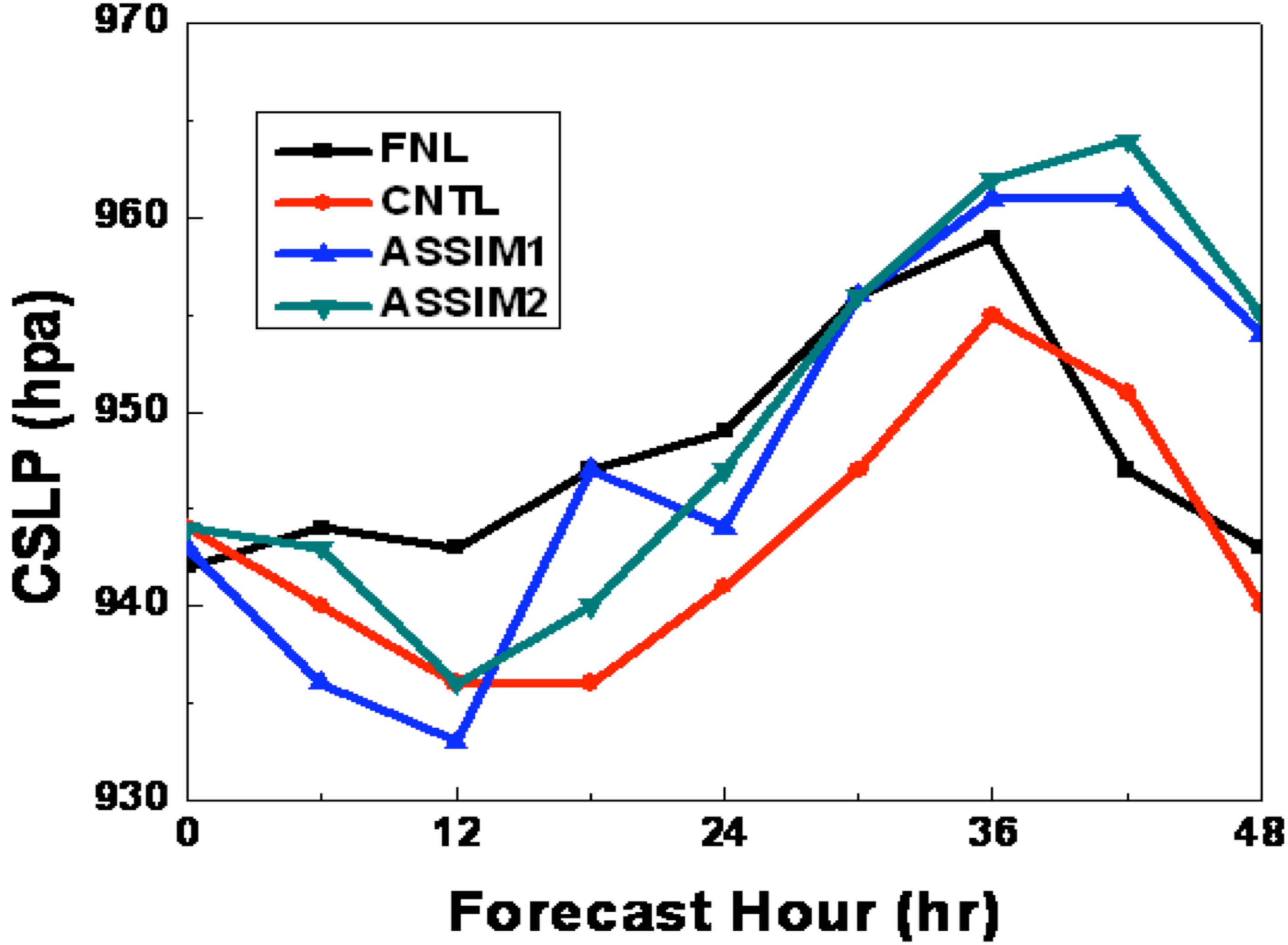
CNTL0230



CNTL0312



Intensity change



Summary and On-going Work

- Data assimilation schemes for the OPP project are designed. We will test 3DVAR, 4DVAR, En3DVAR and En4DVAR for the Antarctic applications.

- One-month runs from 0000 UTC 01 till 0000 UTC 31 October 2007, two times a day at 0000 UTC and 1200 UTC from the NCEP FNL analysis with AMPS domain configuration has been conducted. Background error covariance has been generated.

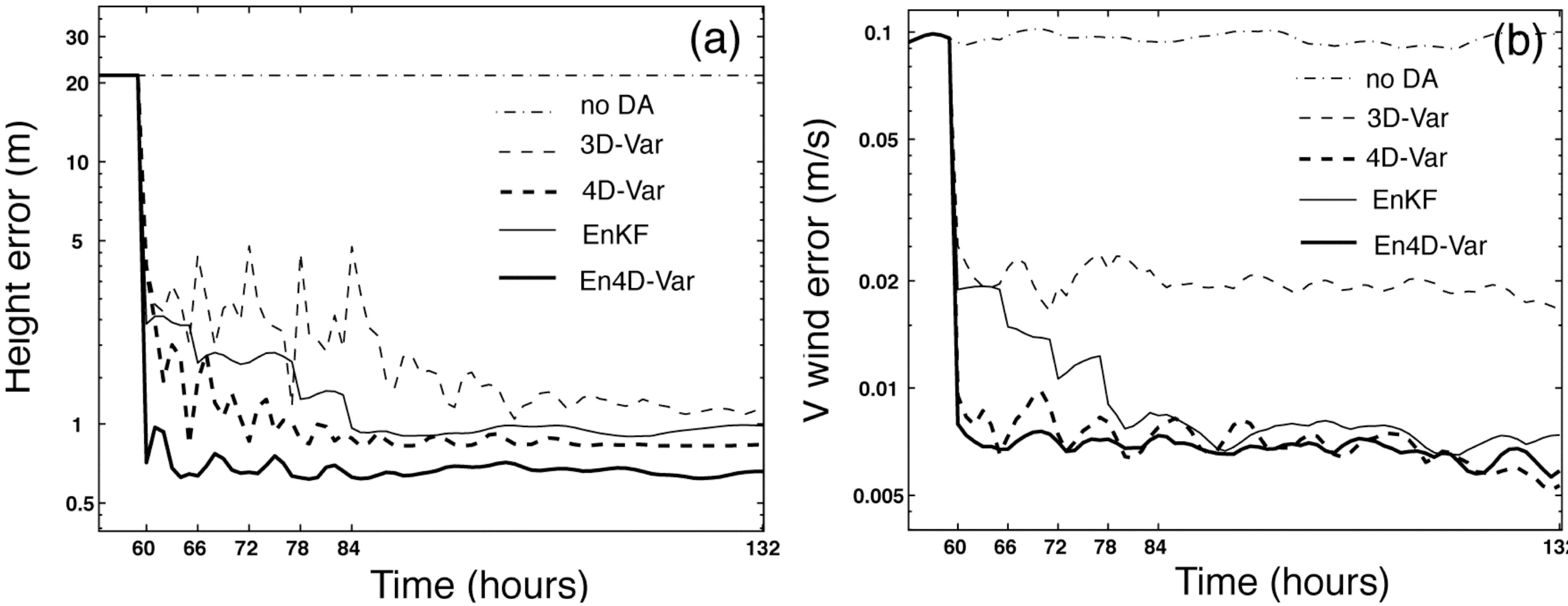
- WRF 3DVAR experiments for the Antarctic cyclone case on 3-6 October 2007 has been started. WRF 4DVAR and En3/4DVAR experiments will follow.

- We will perform one-month verifications for the designed data assimilation techniques in the future.

Thank you !

Questions and comments
are welcome.

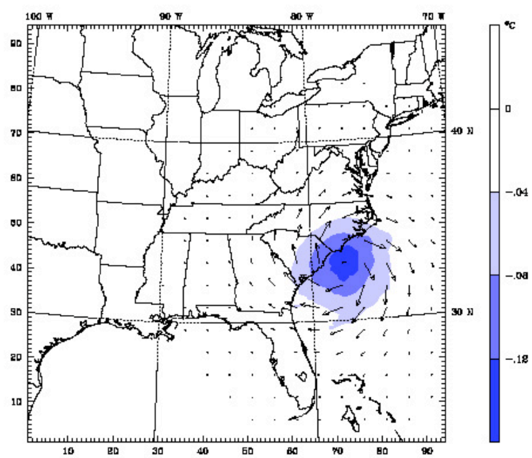
Proof-of-concept test with shallow water model



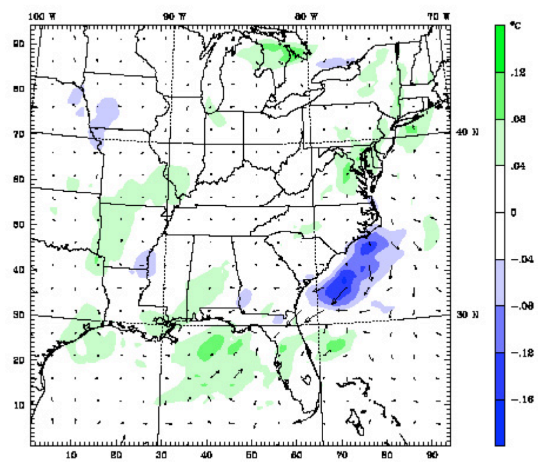
Evolution of domain-average RMSE

Single observation test

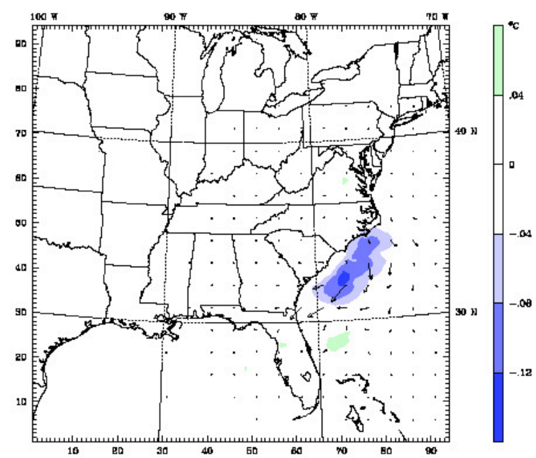
(single T observation at 850hpa at 24-12Z Jan.)



WRF-Var



En4D-Var without localization



En4D-Var with localization

Increments of wind vector and temperature at 1000hpa