Environment Canada Environnement Canada McGill Canada

Kilometric Scale Radar Data Assimilation with the Ensemble Kalman Filter

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Outline

I

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2. Performance of the HR-EnKF system
3. Results of HR-EnKF
   - Ensemble prediction system at convective scale
   - Flow dependent background error at convective scale

II

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   - Introduction of weather radar data
   - Preliminary results of radar data assimilation
5. Summary and future works

1. High Resolution Ensemble Kalman Filter System (HR-EnKF)

Add random perturbations

Add random perturbations (model error)

Perturbed observations

Observation

Initial guess

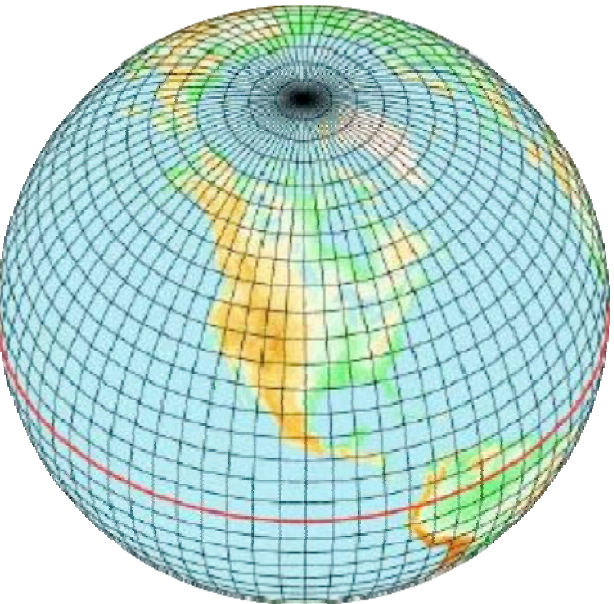
Ensemble members

Data assimilation

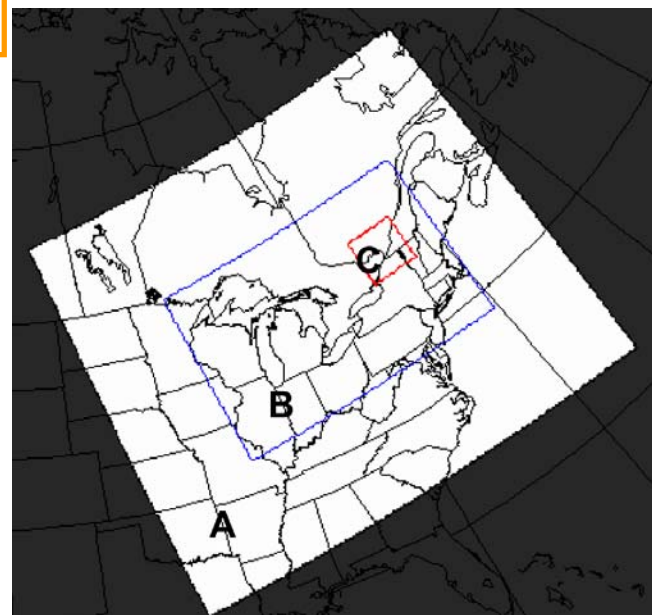
Analysis step

GEM-LAM forecast for all the members.

Forecast step



Global system (1998)
→ limited area



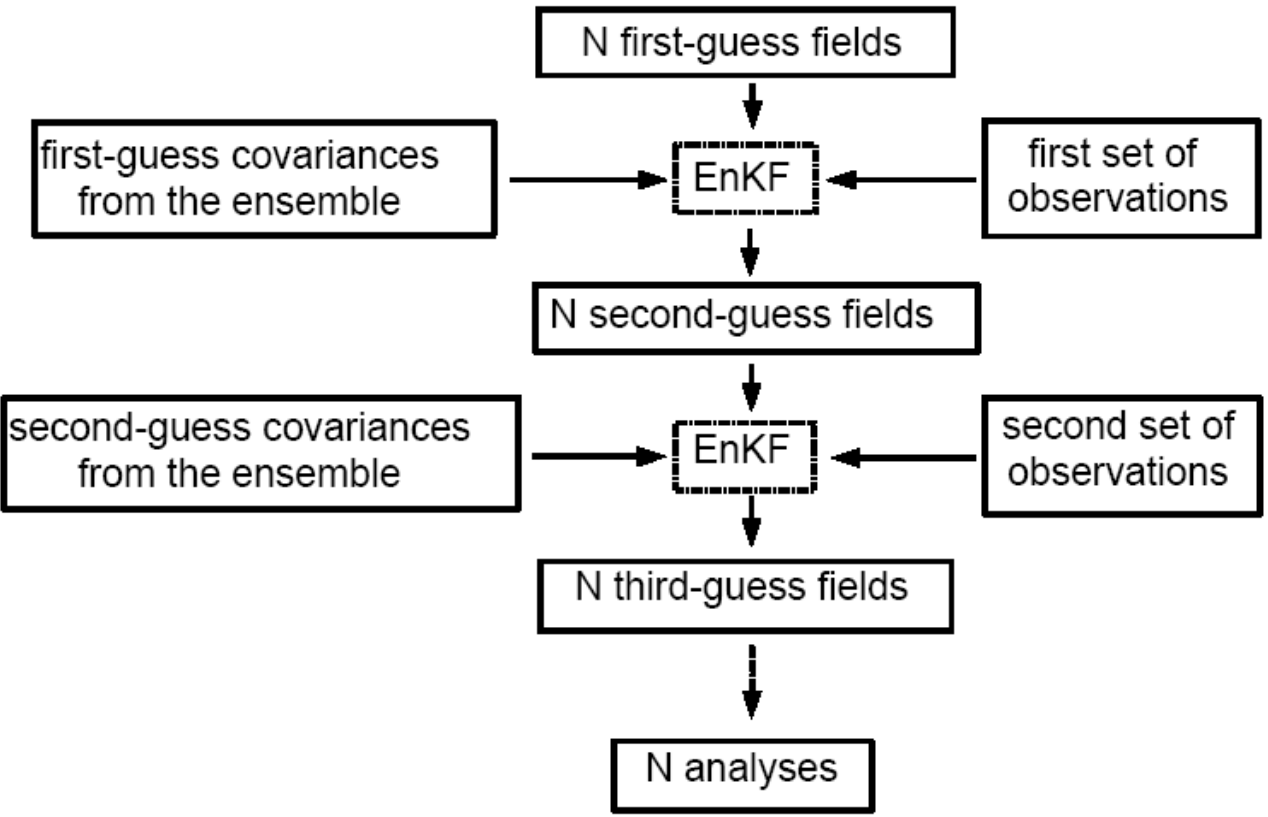
A: LAM15
B: LAM2p5
C: LAM1 300x300 (MTL region)

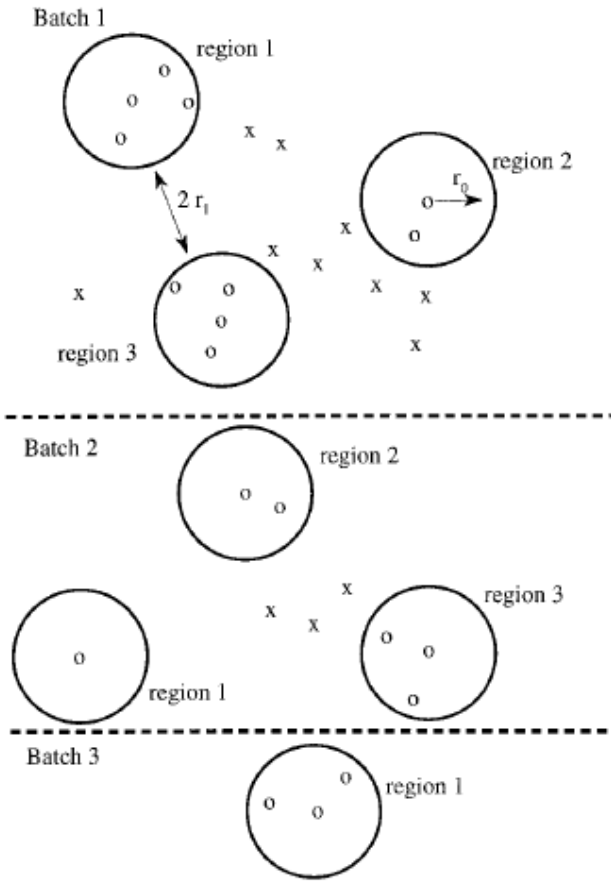
Features of the system

Sequential processing of batches of observations

$$y^0 \sim 10^6$$

Sequential ensemble Kalman filter

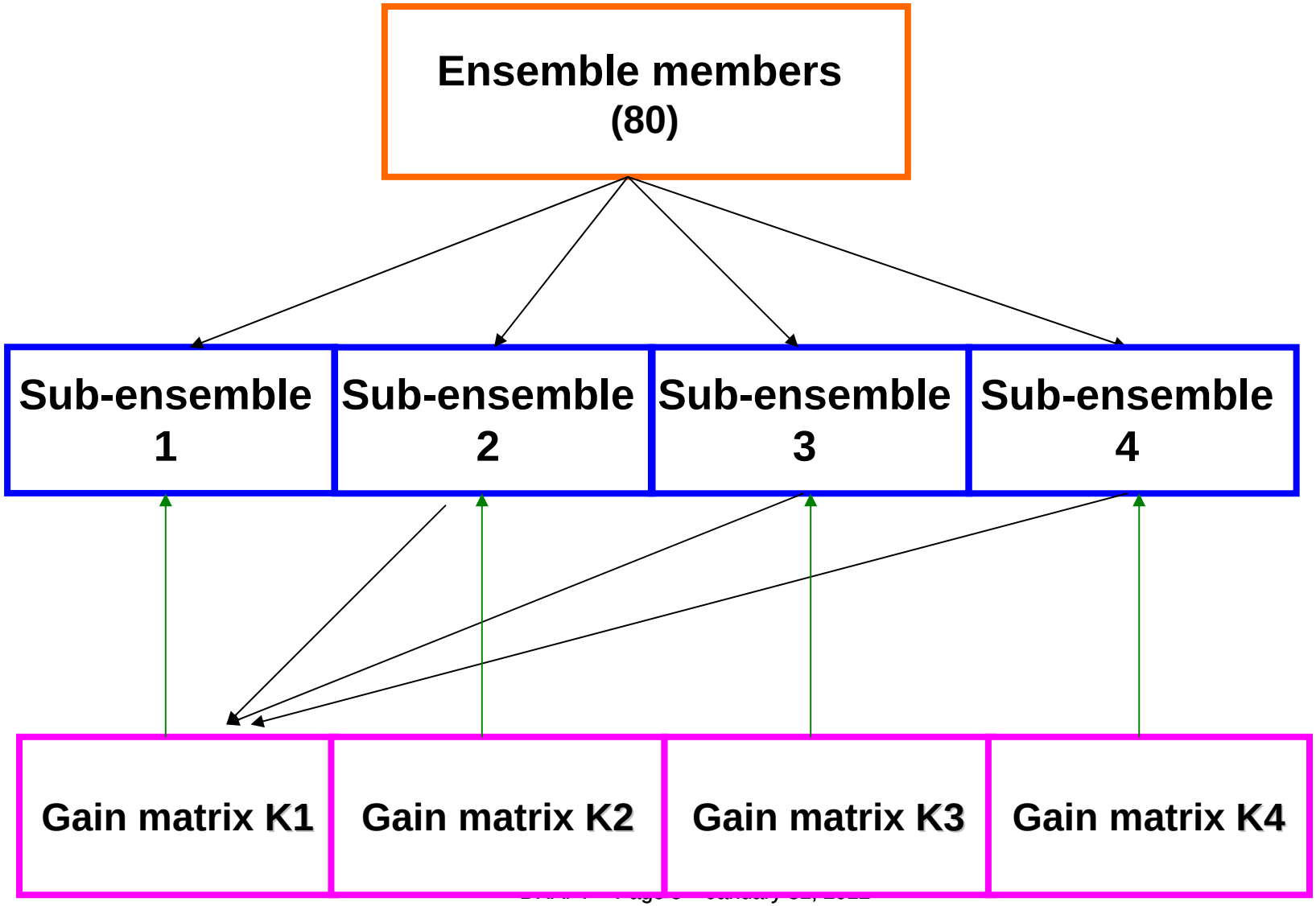




Houtekamer and Mitchell 2001

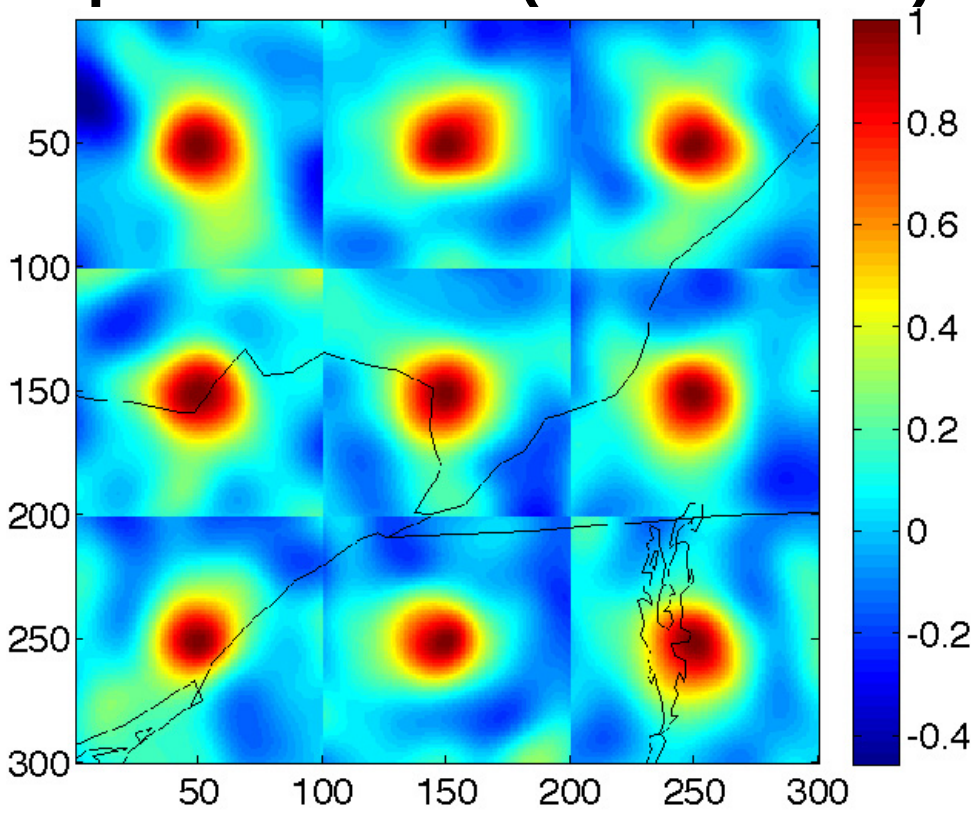
Partitioning the ensemble (to deal with the underestimation of the error structure)

$$x^a = x^f + \mathrm{K}(y - \mathrm{H}\,x^f)$$



Localization strategy

Horizontal Correlations of initial perturbations (80 members)



Temperature (degree) **850hPa**

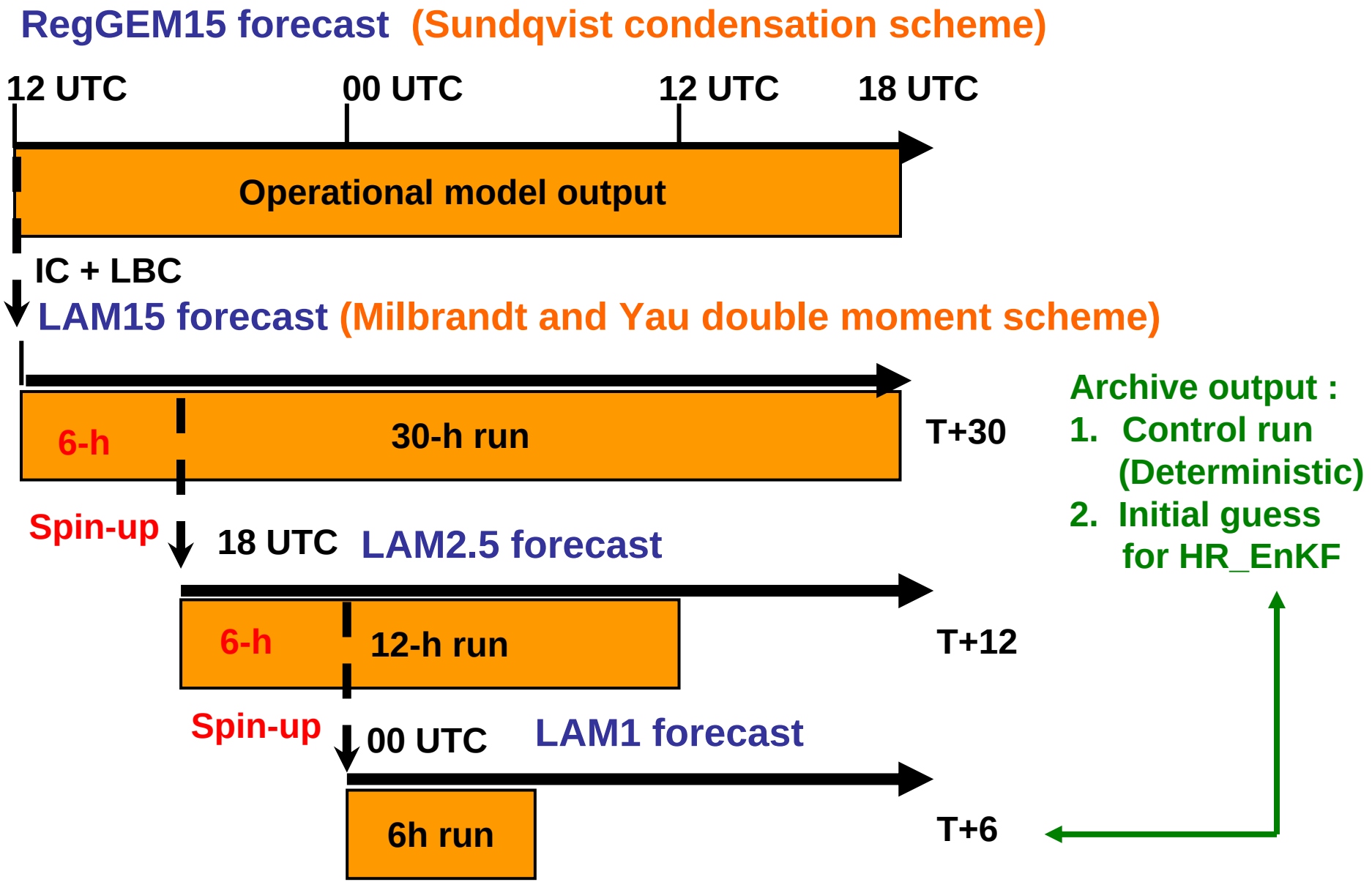
Perturbations are:
Homogeneous & Isotropic

Sampling errors

↓

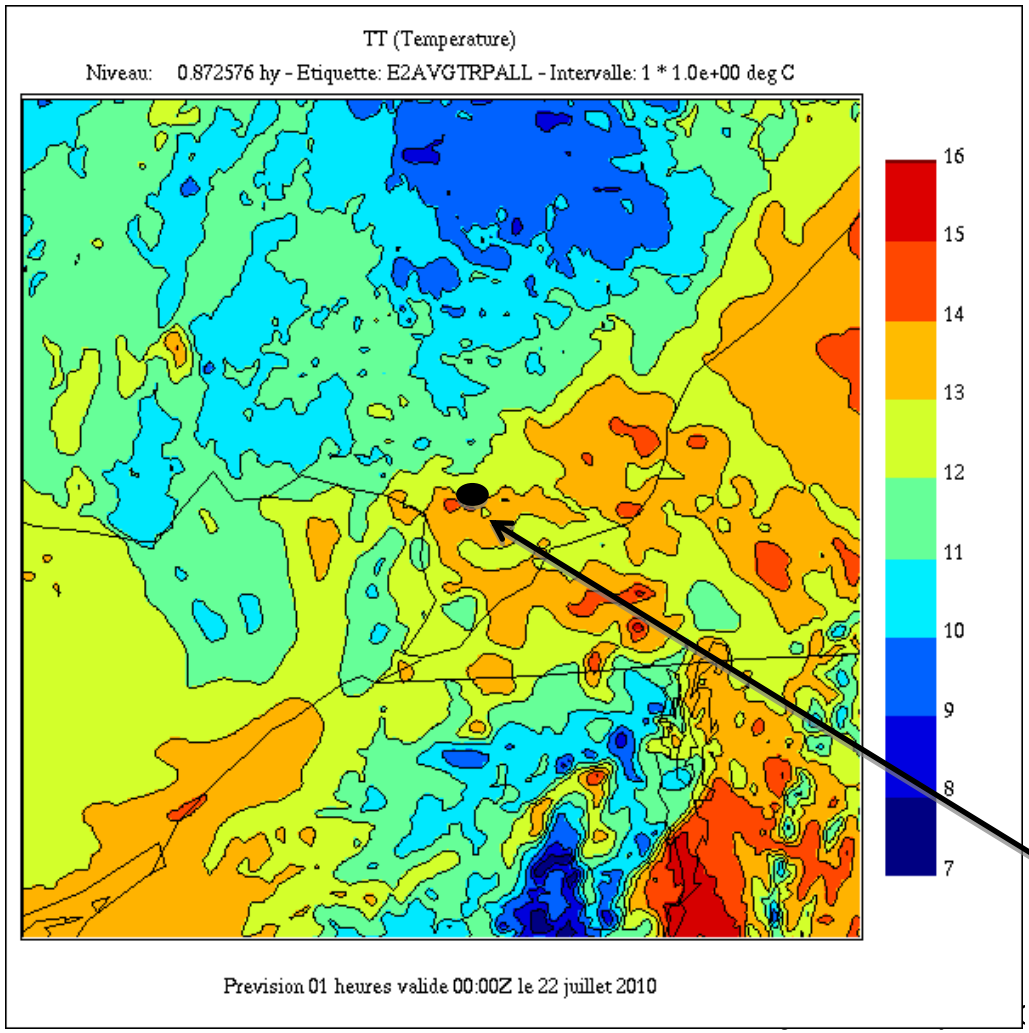
With limited members:
Localization is needed to filter out the noise

Model configuration:



2. Performance of the HR-EnKF system

Single Observation test
(Analysis step)



Initial guess at
2010 July/22/0000 UTC

Ensemble mean:
Temperature (degree)

Innovation (O-B): 1.0 deg
σ_o **: 1 deg**
σ_b **from** HP_fH^T **: 0.57 deg**

Given single observation :
temperature at
grid point (150,150)
around 850hPa

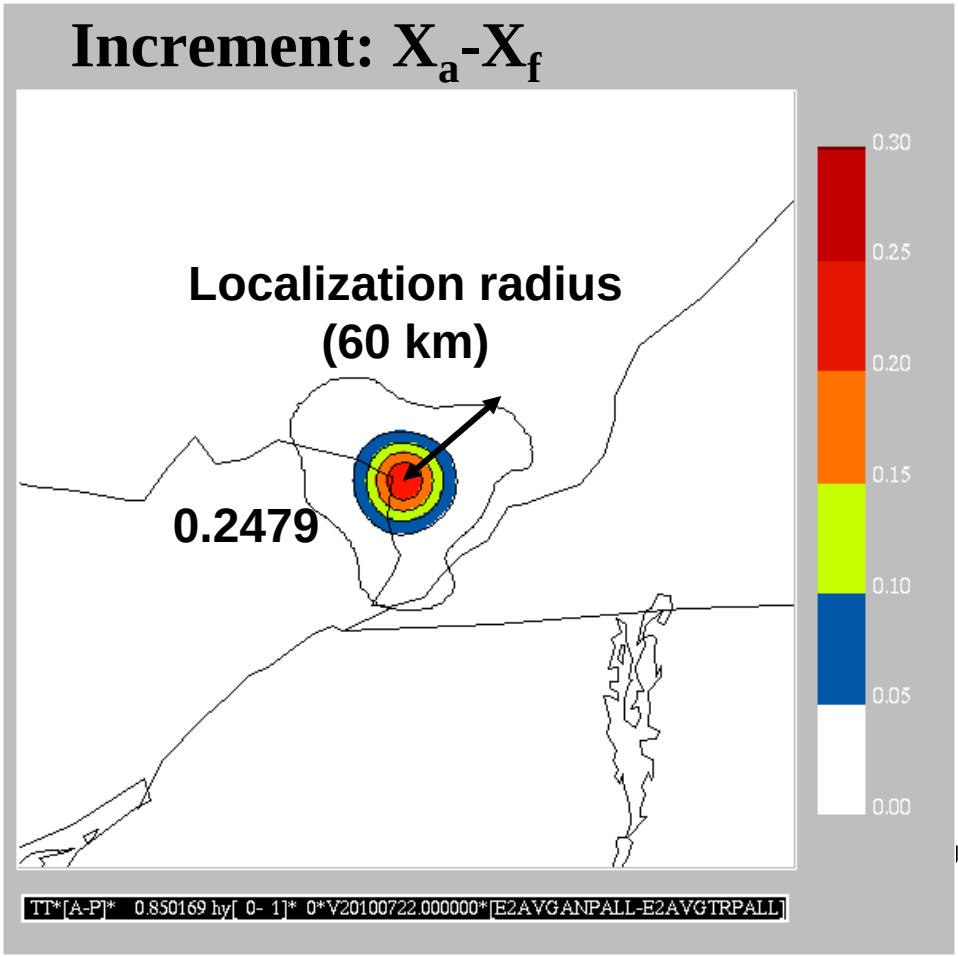
Analysis step

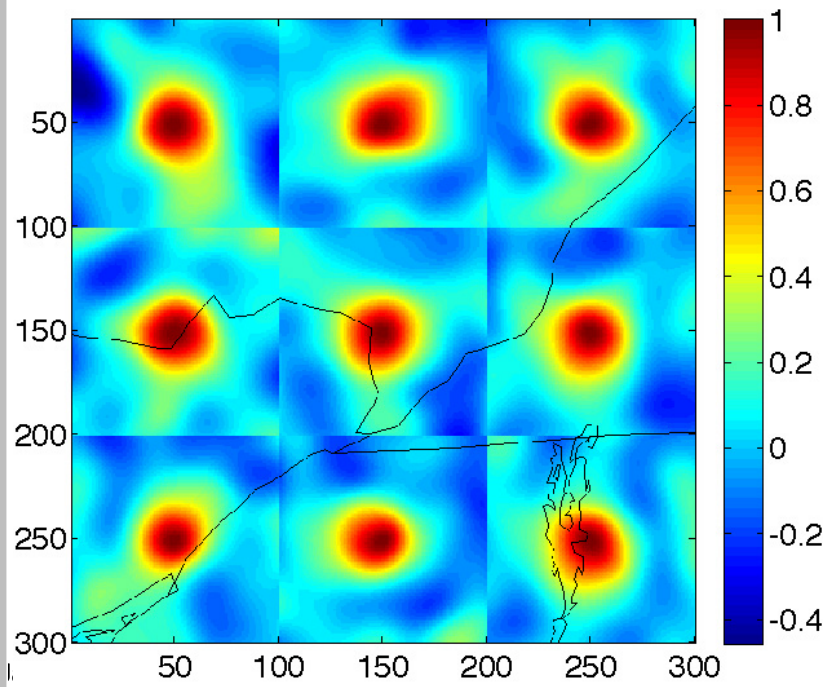
$$\mathbf{x}_a - \mathbf{x}_f = \mathbf{K}(\mathbf{z} - \mathbf{x}_f)$$

$$= \frac{\sigma_f}{\sigma_f + \sigma_o} \times (1.0) = \frac{1}{1 + \frac{\sigma_o}{\sigma_f}} \times (1.0) = \frac{1}{1 + \frac{1}{(0.57)^2}} \cong 0.25$$

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

σ_b from $\mathbf{HP_fH^T}$: 0.57 σ_o : 1



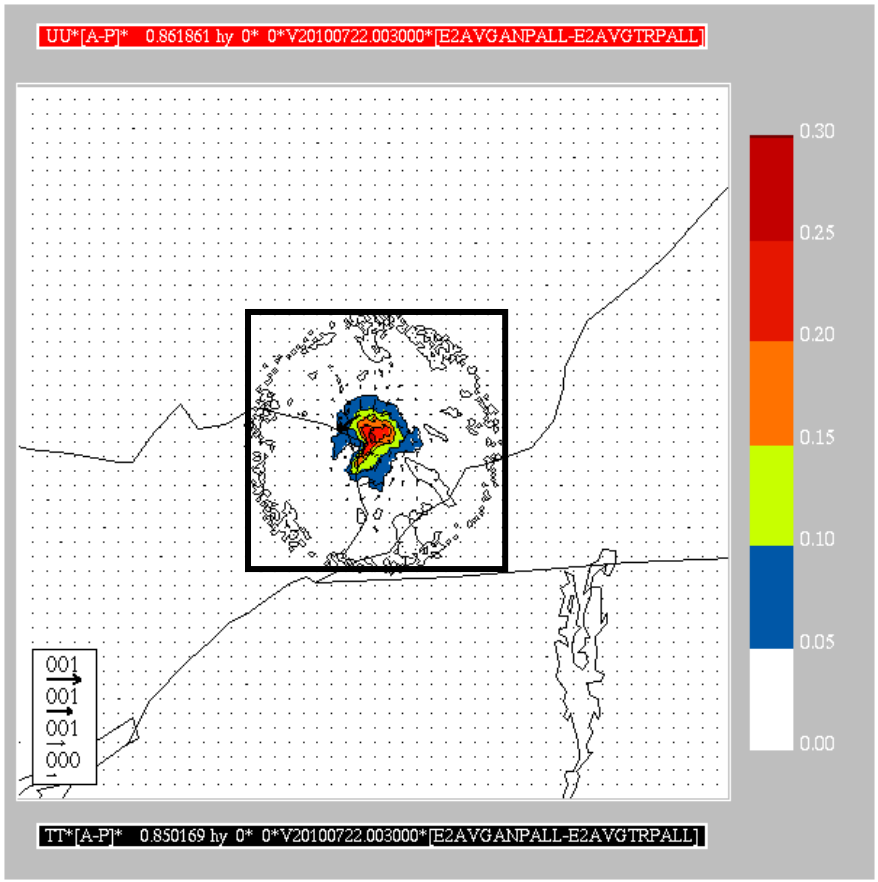


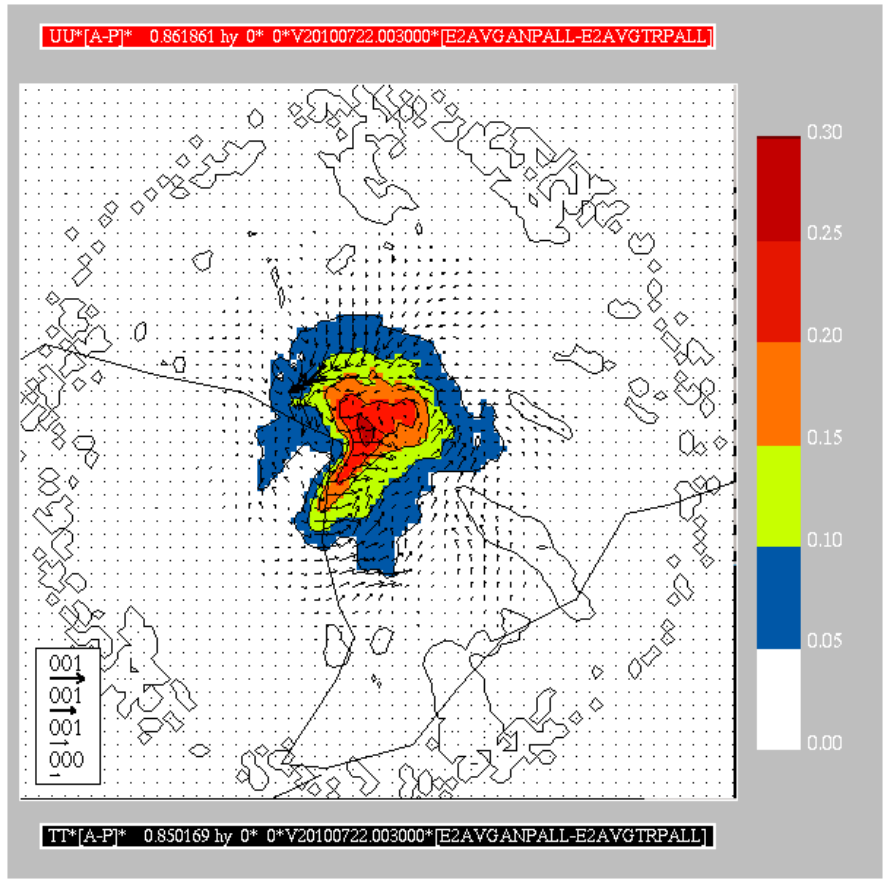
Flow dependent single observation test

Analysis step (single obs) → **Forecast step (30-min)** → **Analysis step (single obs)**

Innovation : 1.0 degree

σ_o **: 1 degree**

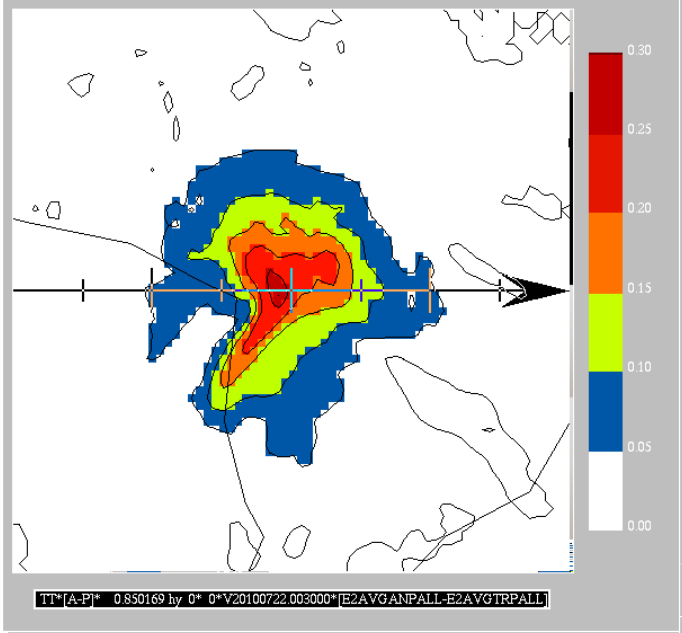


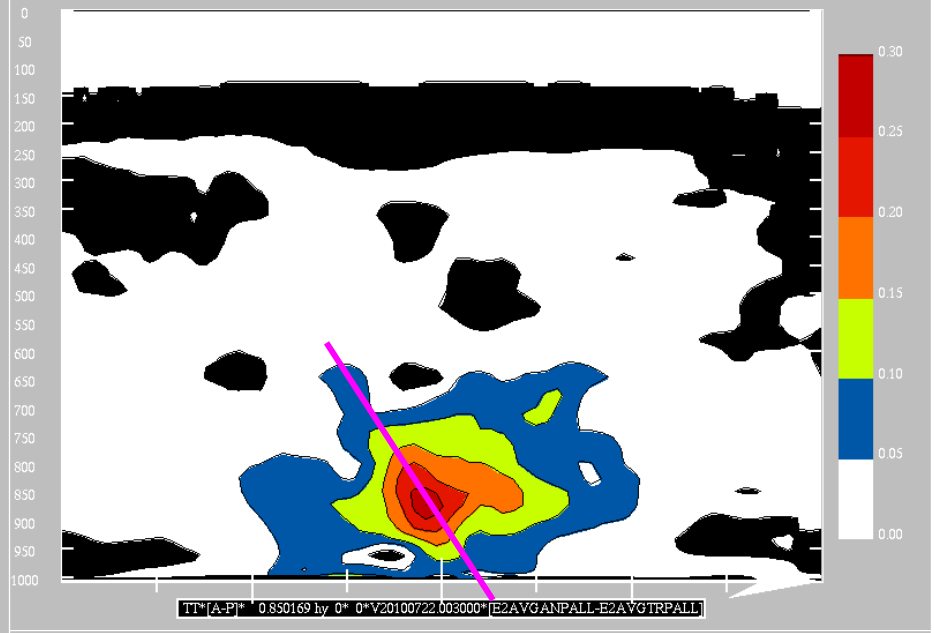


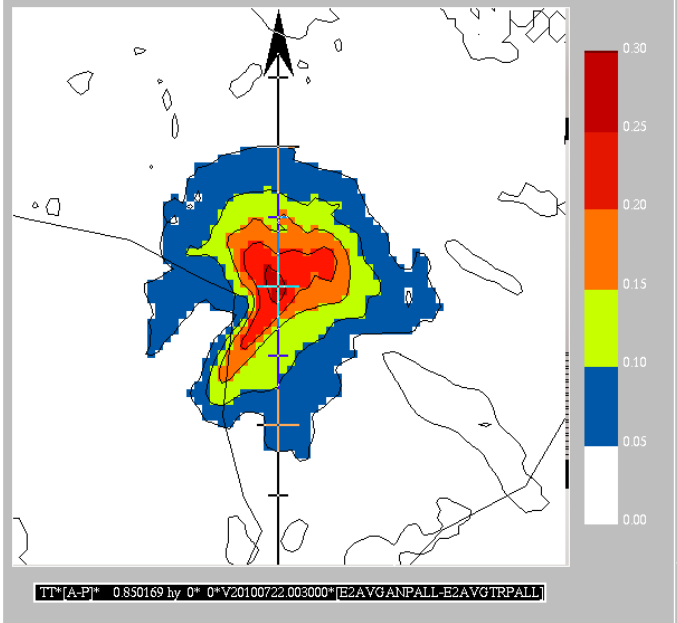
Temperature analysis increment

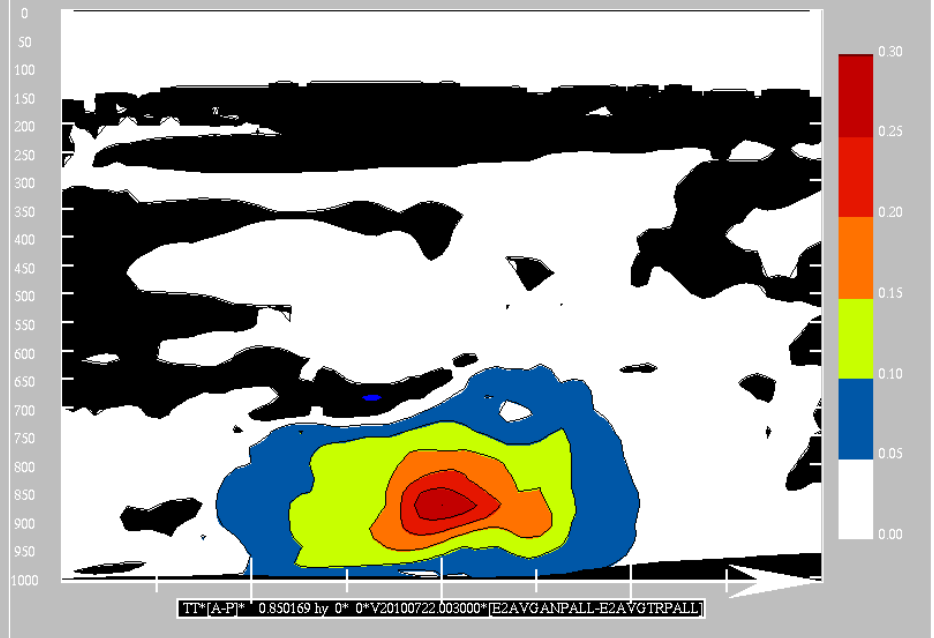
Temperature increment

vertical cross-section









3. Results of the HR_EnKF

3.1 The performance of ensemble predictions

Current set-up

- **Initial perturbations: U, V, T, HU, TG and P0**
- **Do not consider the model errors**
- **No perturbations in hydrometeor variables**
- **Cycling hydrometeor variables**
- **No radar data**

Global EnKF →use of different cloud physics parameterizations

Fix the Microphysical scheme with HR_EnKF
Milbrandt and Yau, 2005 (double moment scheme)

number concentration and mixing ratio

QB (cloud mixing ratio)

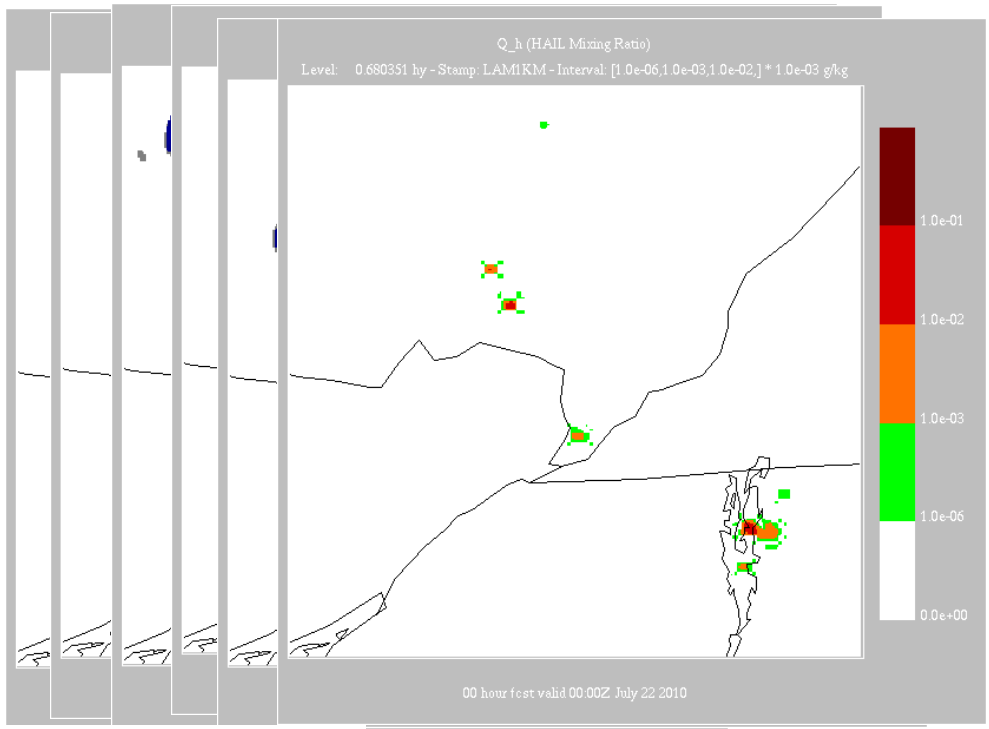
QL (rain mixing ratio)

QN (snow mixing ratio)

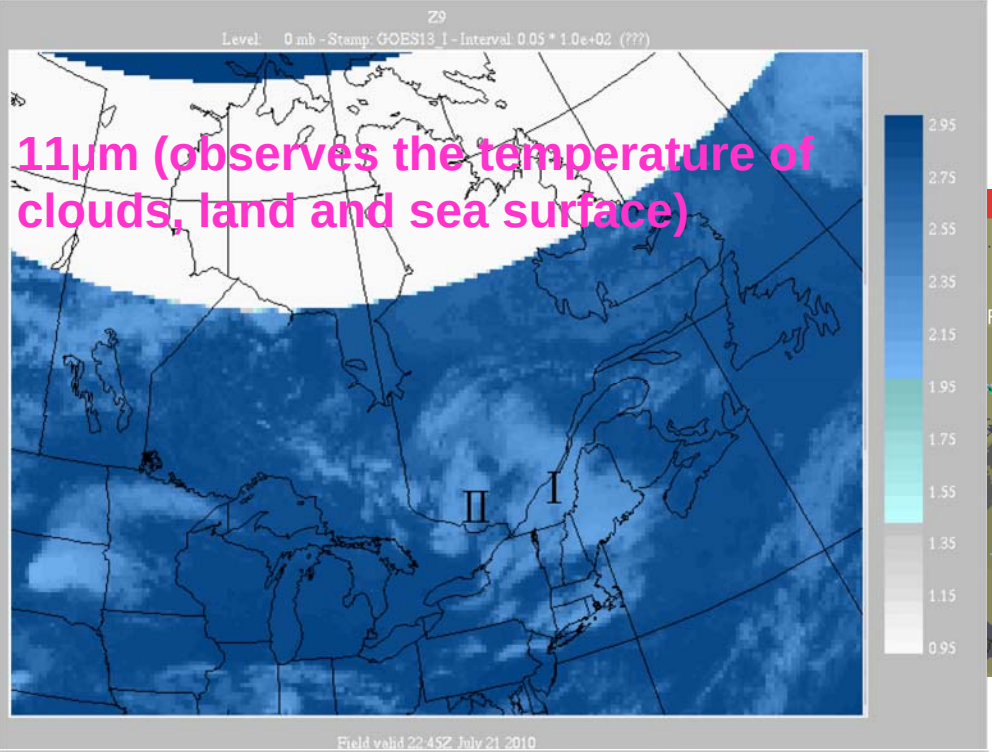
QI (ice mixing ratio)

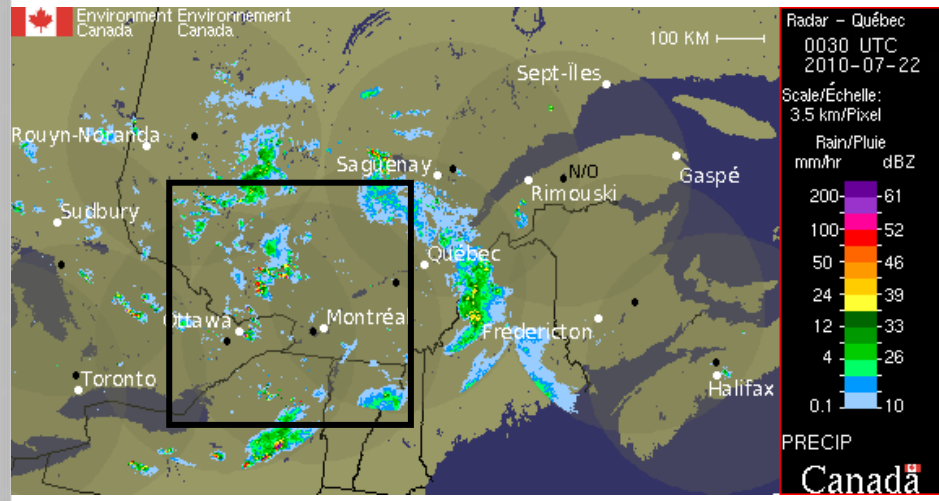
QJ (graupel mixing ratio)

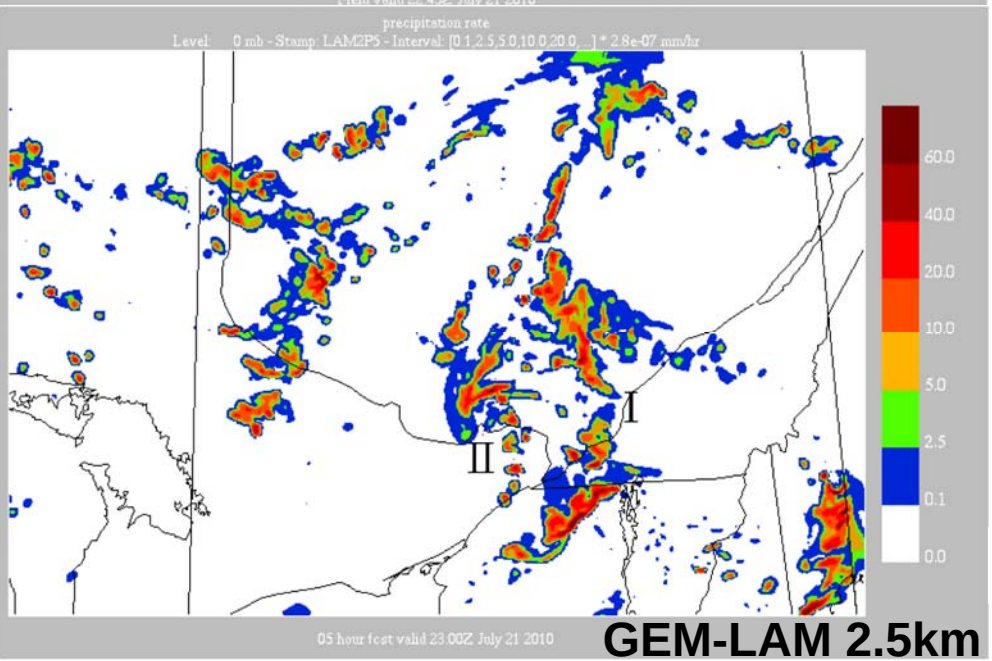
QH (hail mixing ratio)



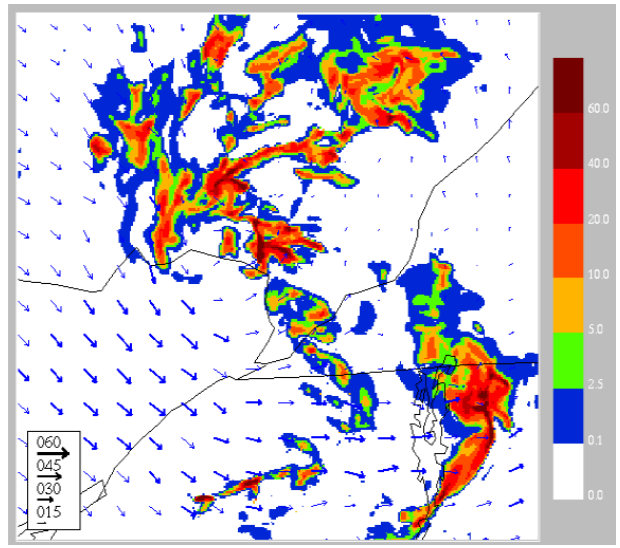
Radar observations (reflectivity)







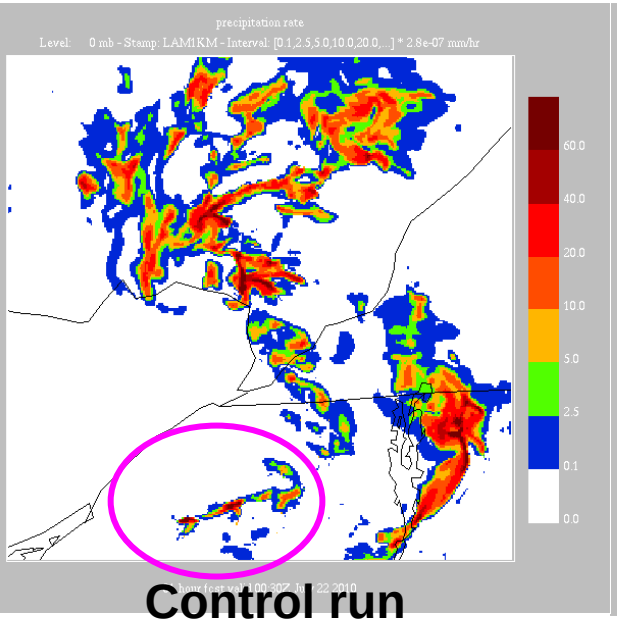
GEM-LAM 2.5km



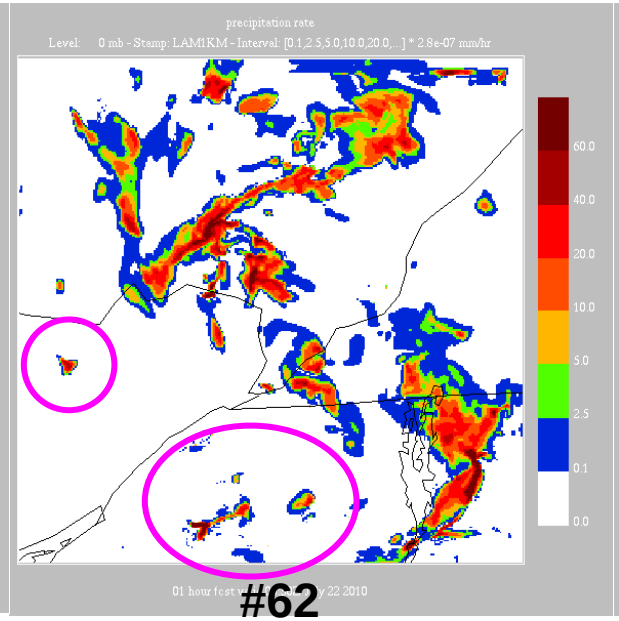
GEM-LAM 1-km 30-min

Deterministic model forecast

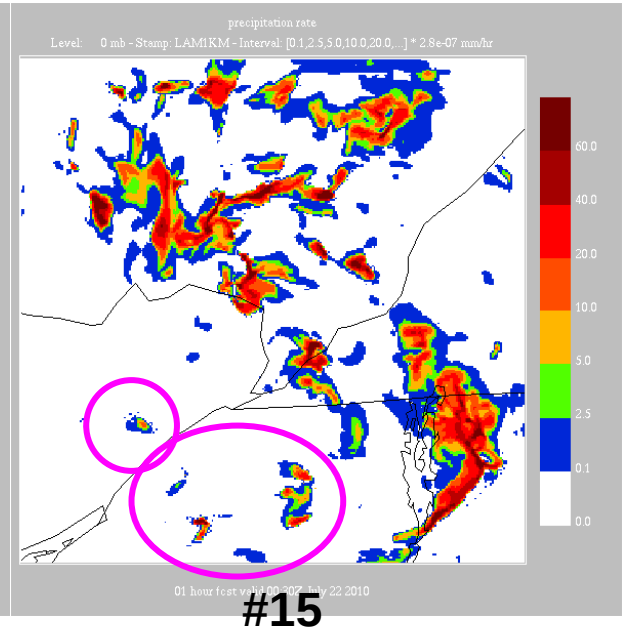
Precipitation of ensemble members



Control run (deterministic forecast)



#62



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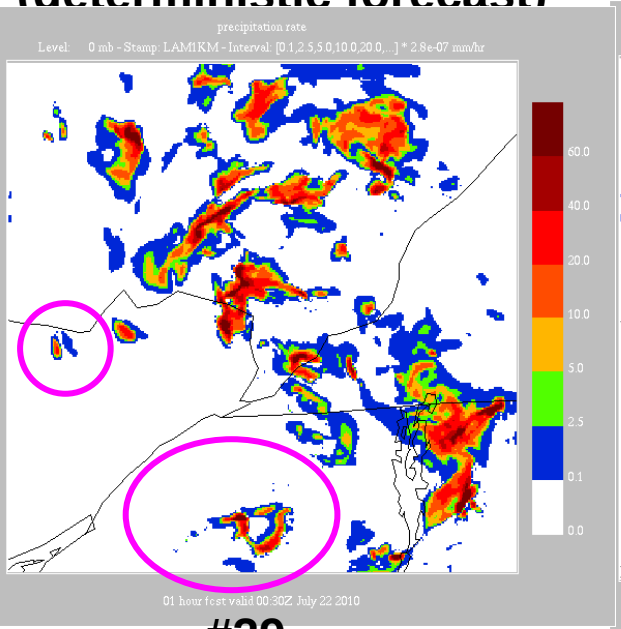

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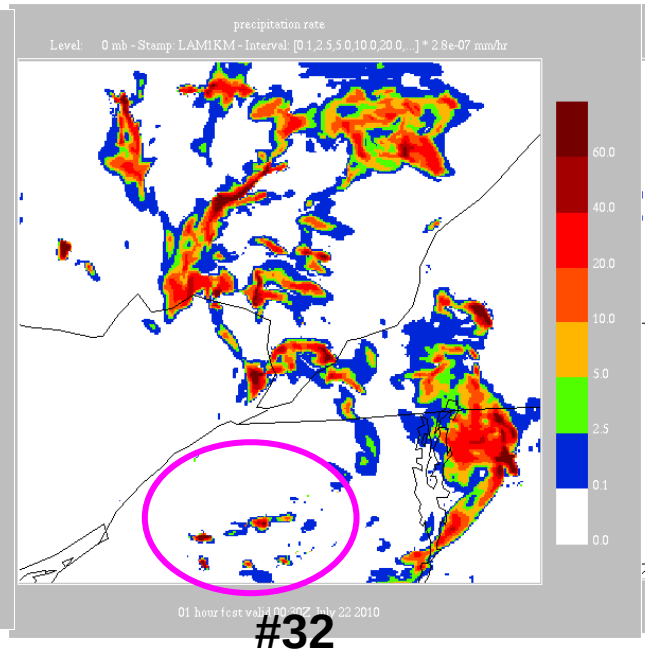

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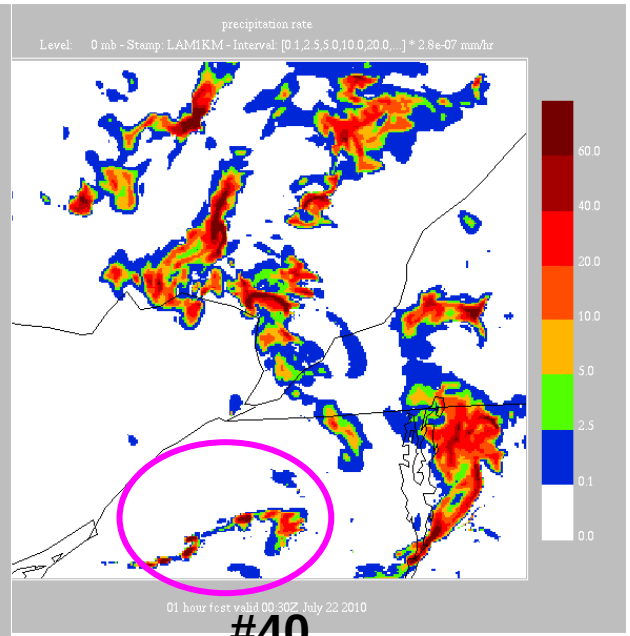
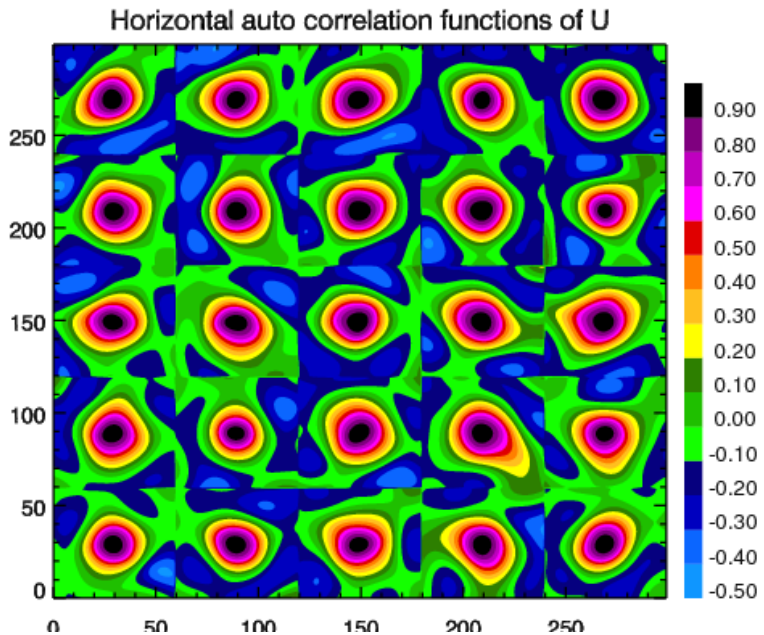


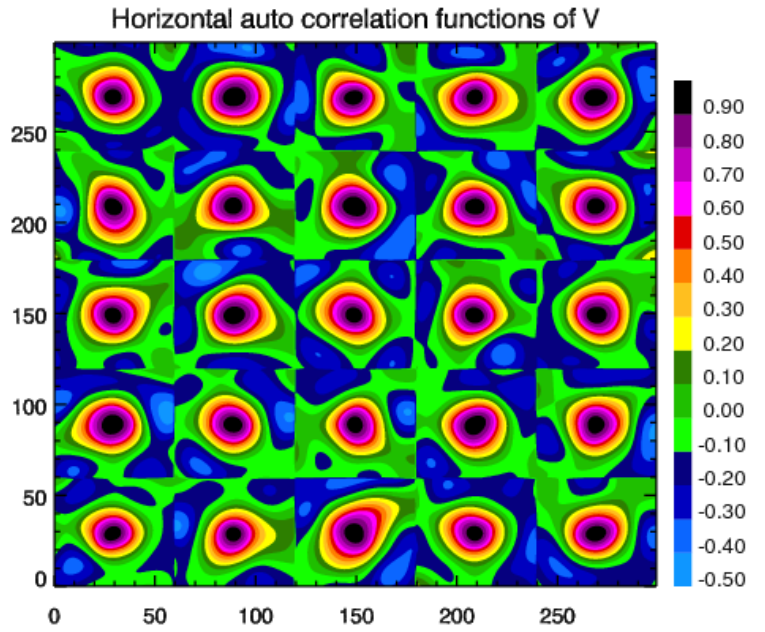
#40

3.2 Flow dependent background error at convective scale

- **The forecasting error structure are not fully known at cloud-resolving scale.**
- **By using climatology statistic from synoptic may not represent the structure at convective scale.**
- **HR-EnKF → Ensemble forecasts → investigate the forecasting errors at convective scale**

00-min Forecast Error Correlations (800mb)

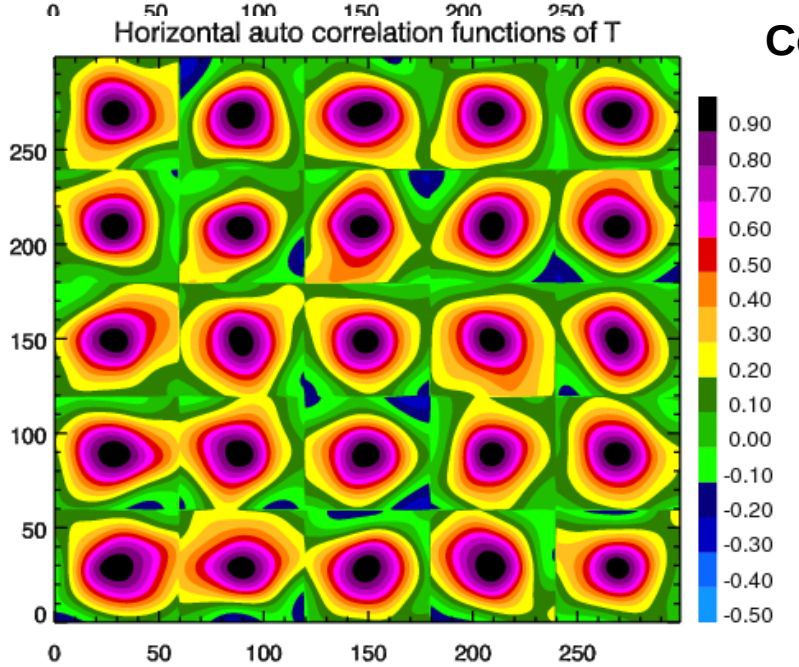




Prescribe error

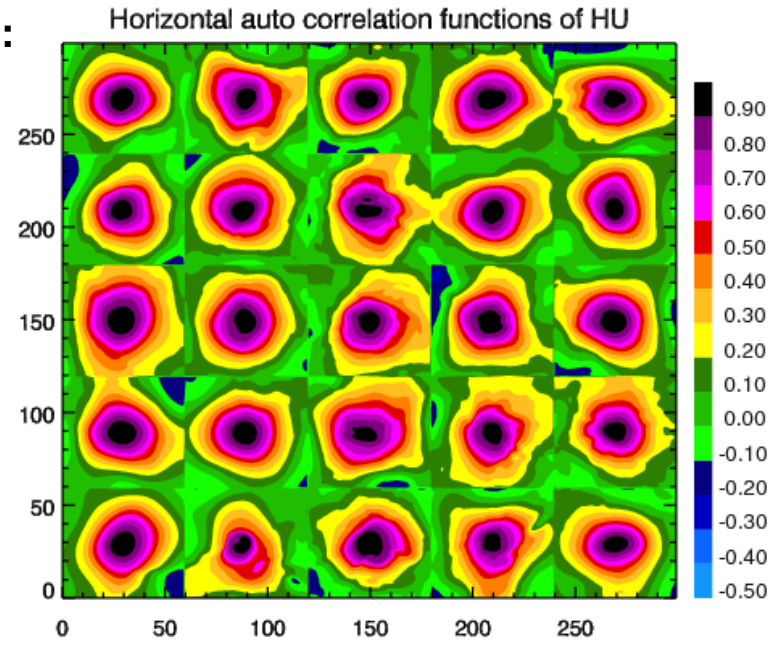
Homogeneous

Isotropic

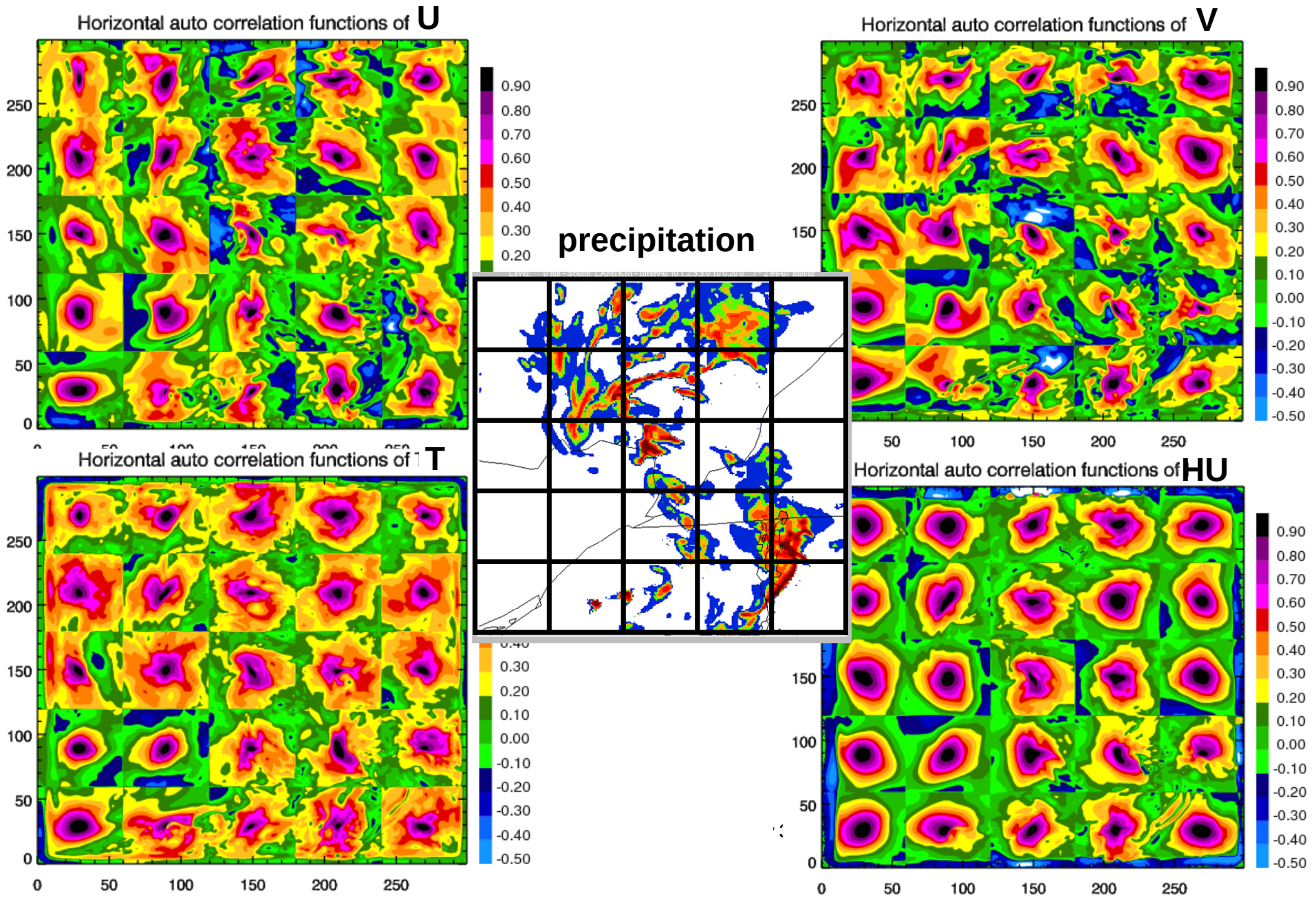


Correlation length: 10km

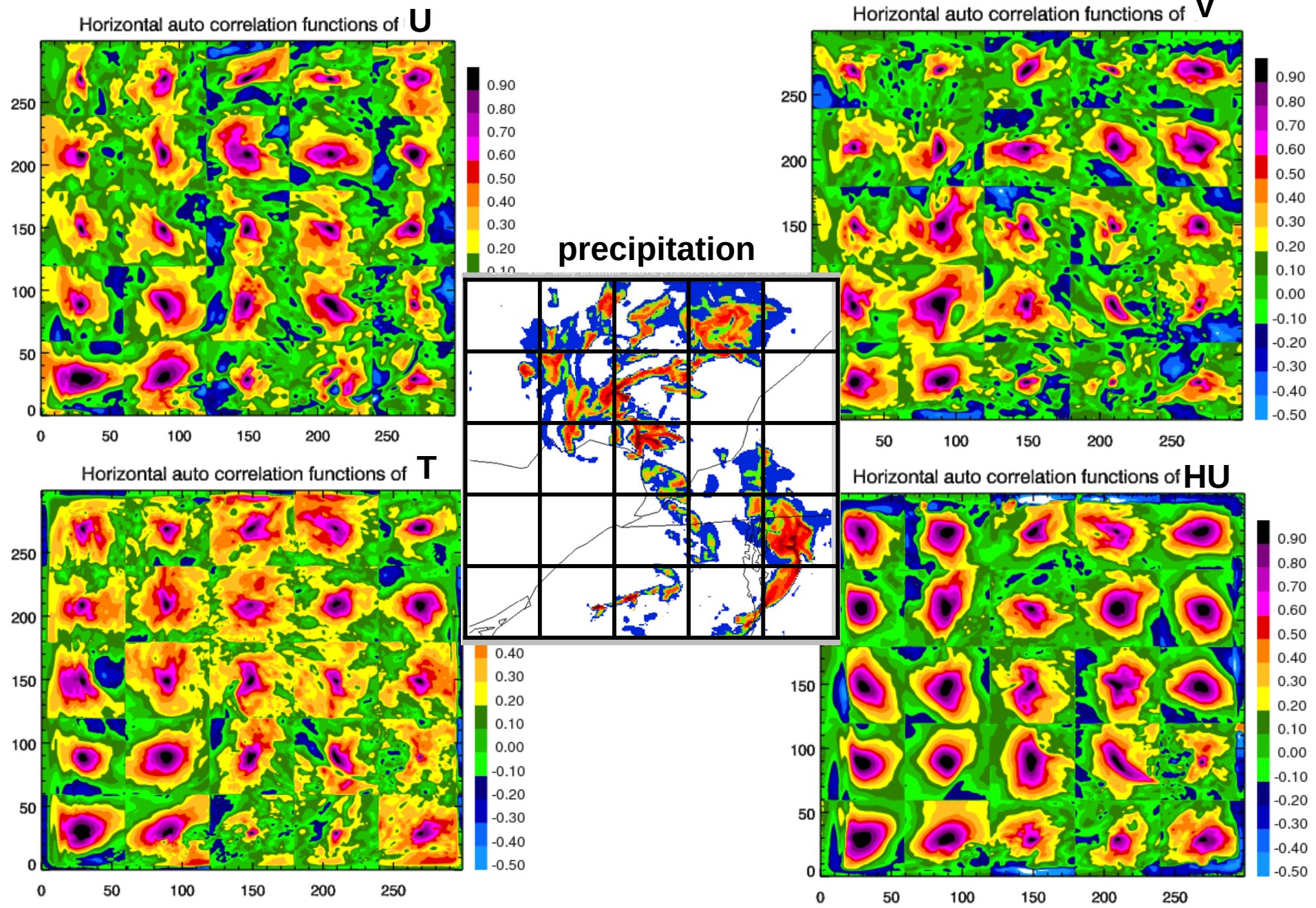
(ψ, χ, T, HU)

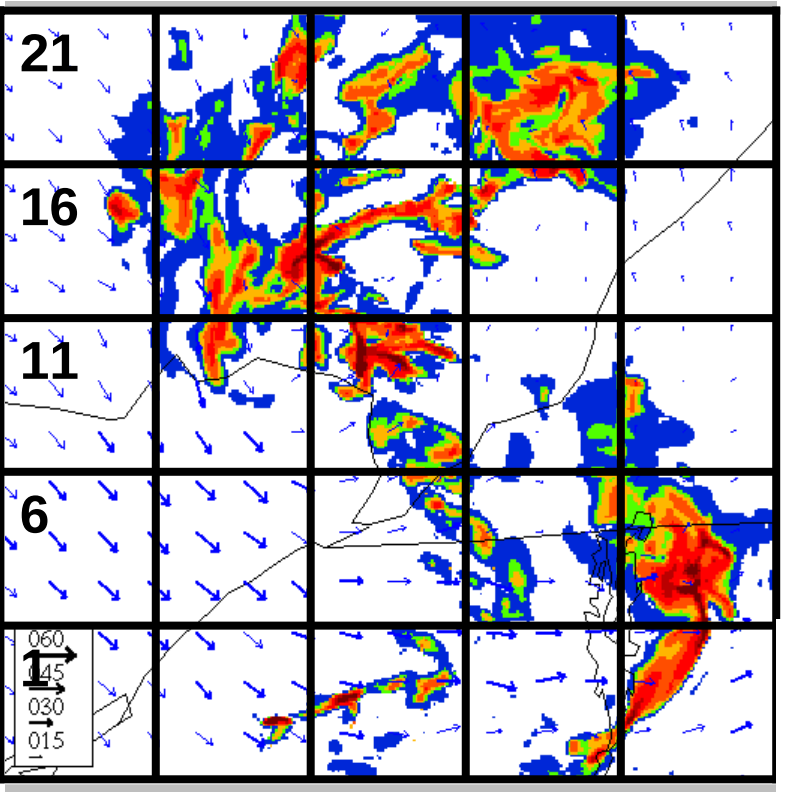


15-min Forecast Error Correlations (800mb)



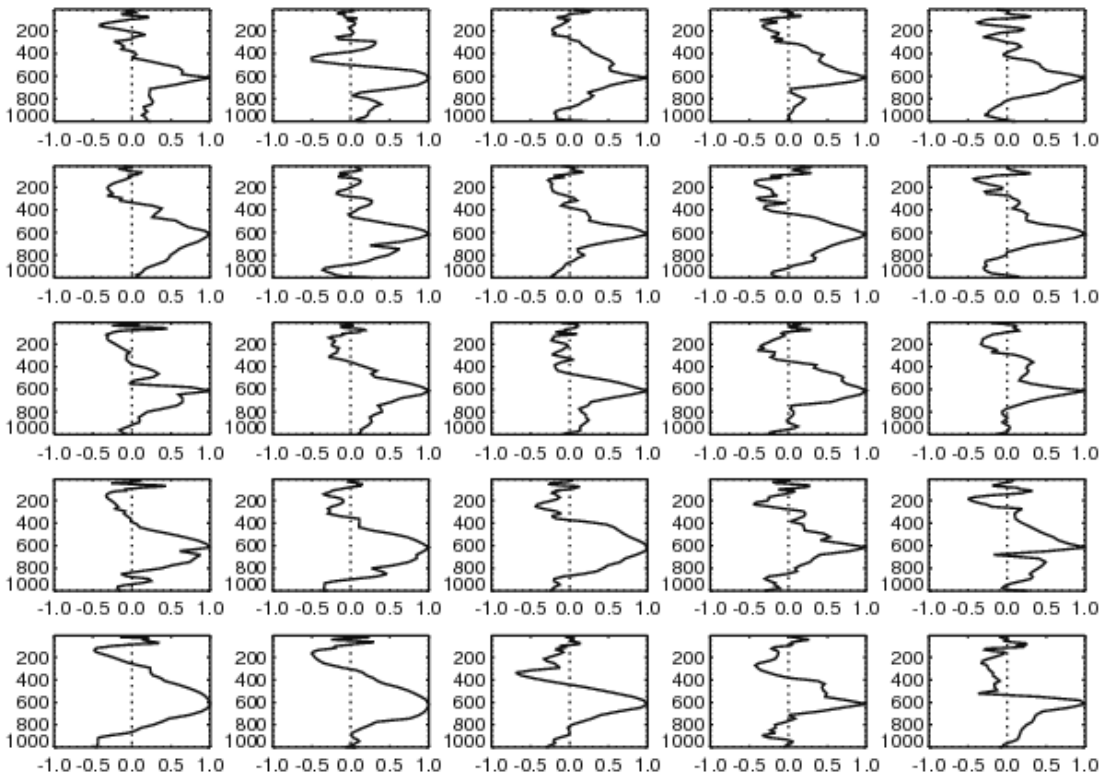
30-min Forecast Error Correlations (800mb)



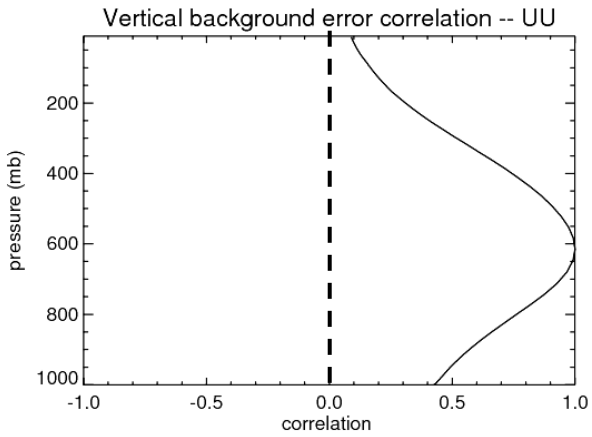


Vertical correlation of temperature

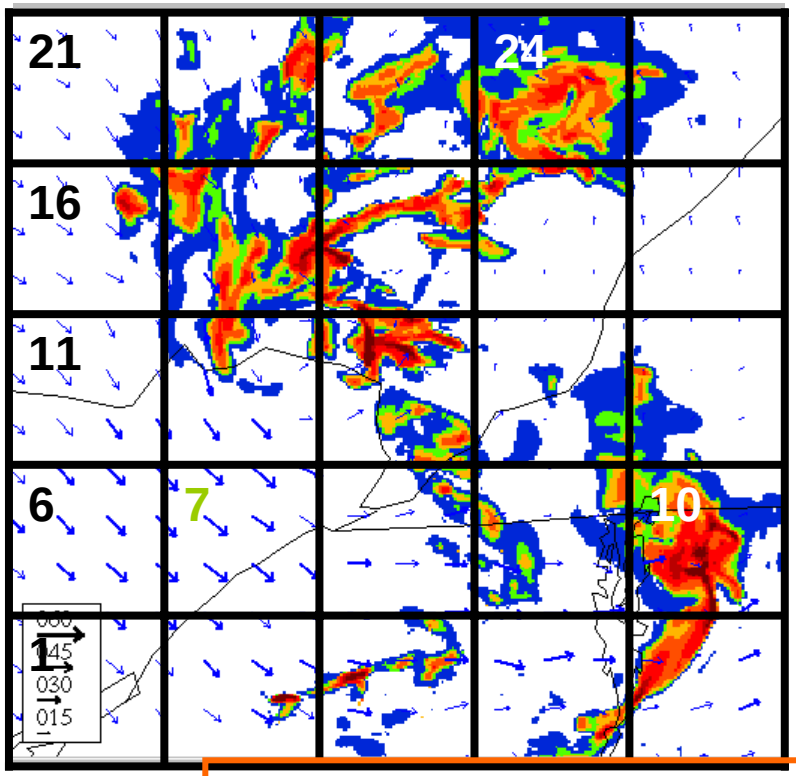
0030 UTC 30-min forecast



Initial perturbation in vertical

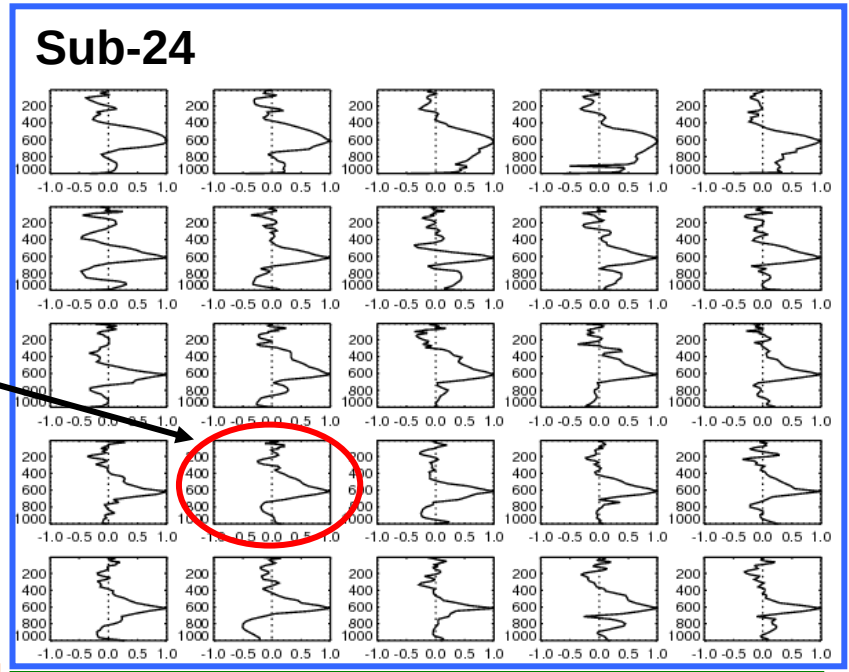


Error correlation in vertical (30-min forecast)

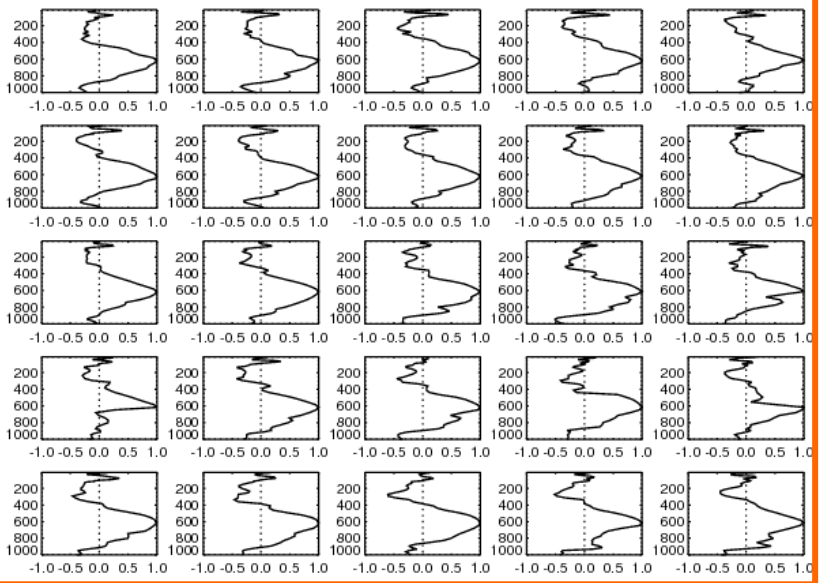


Single Obs. test

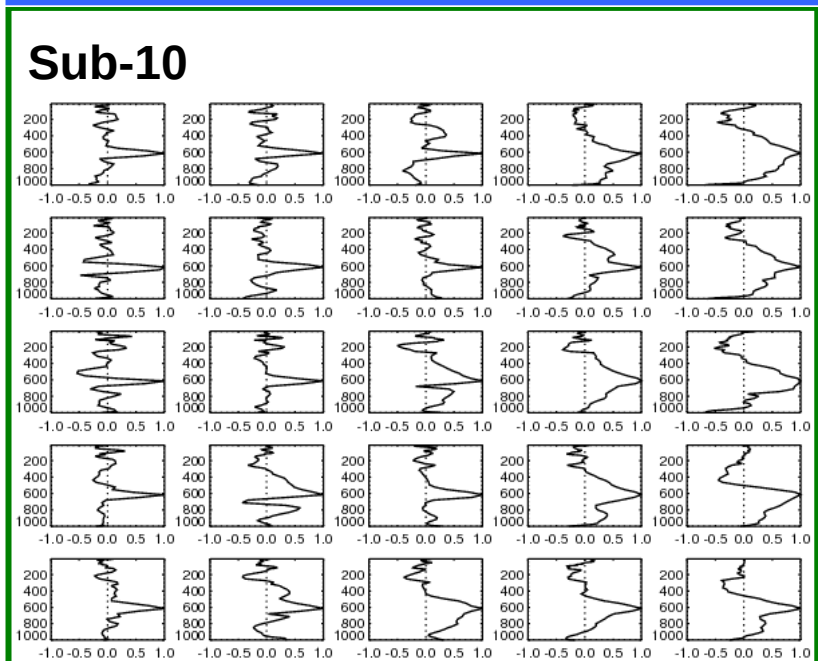
Sub-24

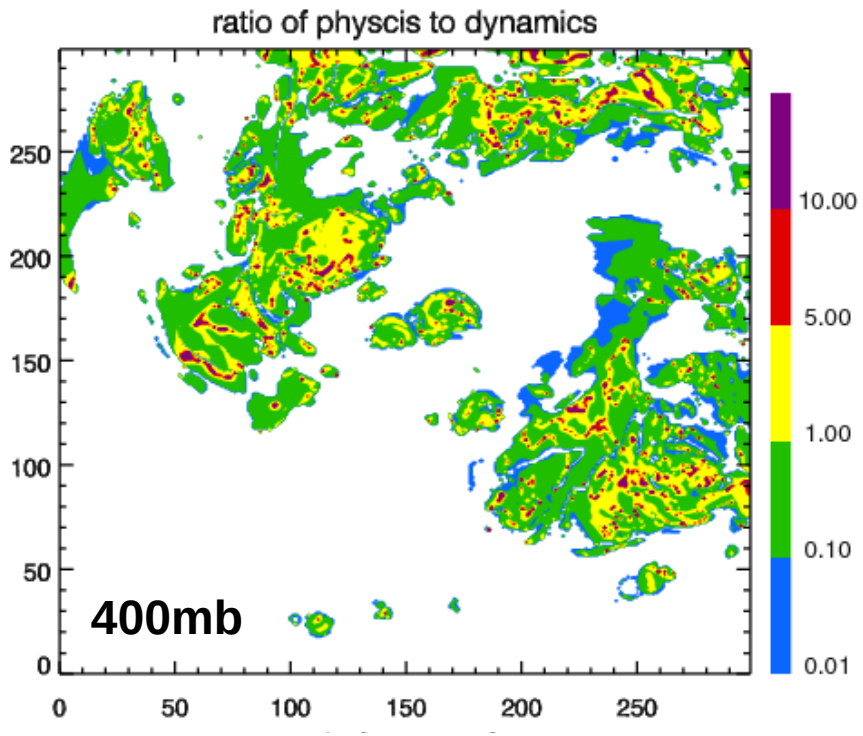


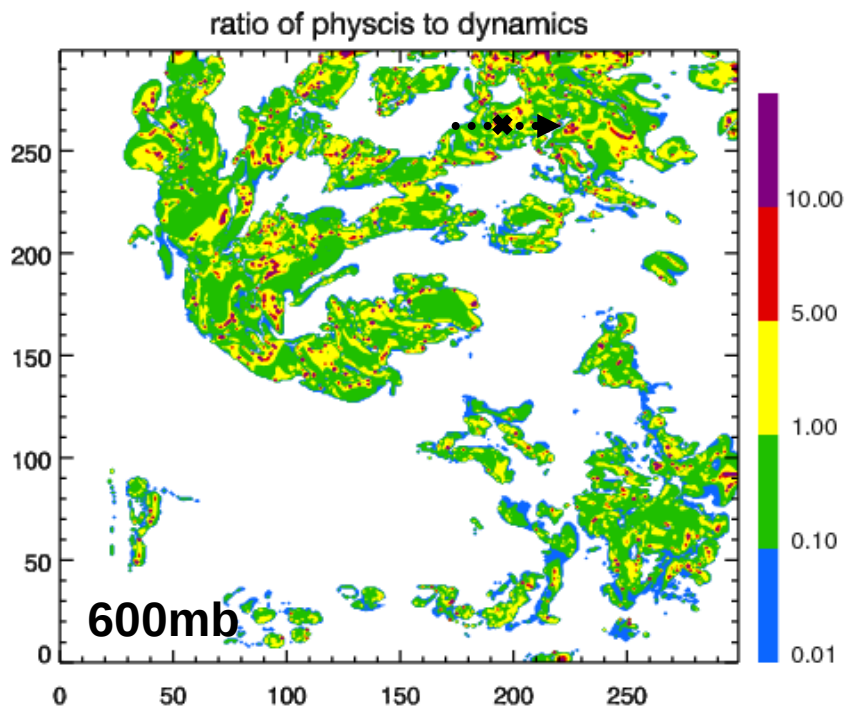
Sub-7

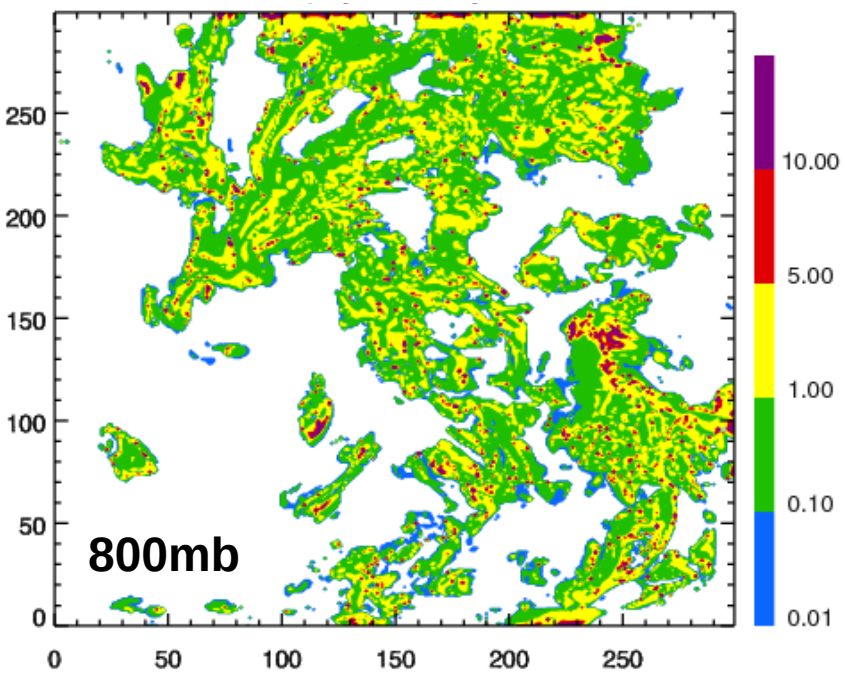


Sub-10





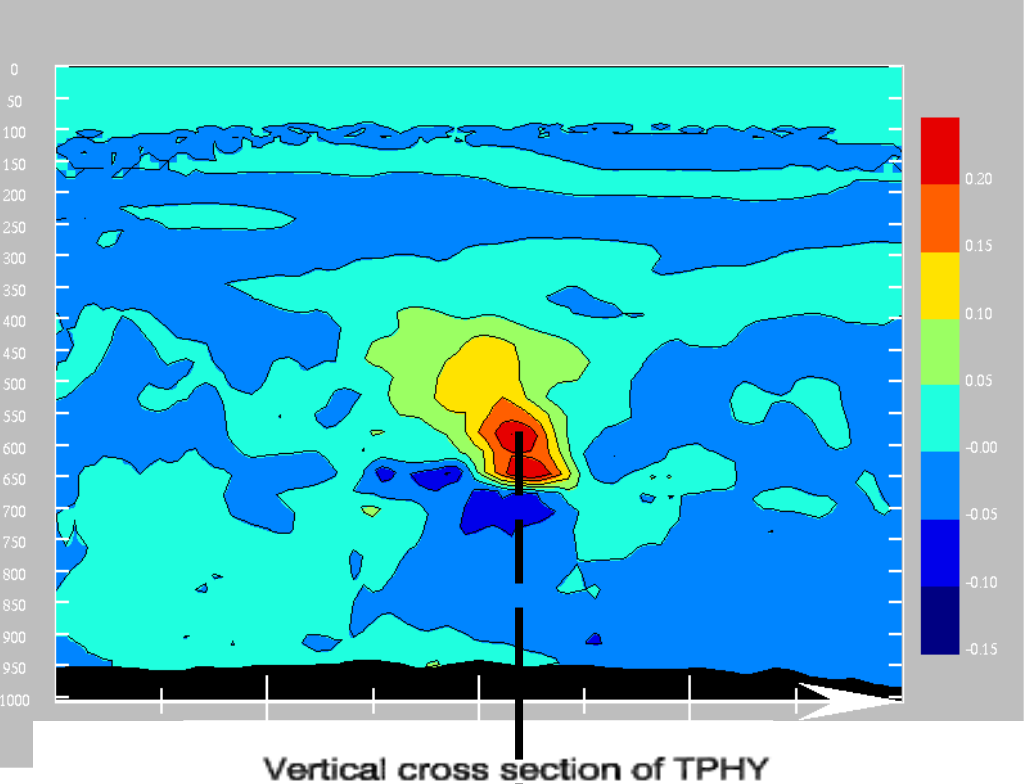




physics versus dynamics

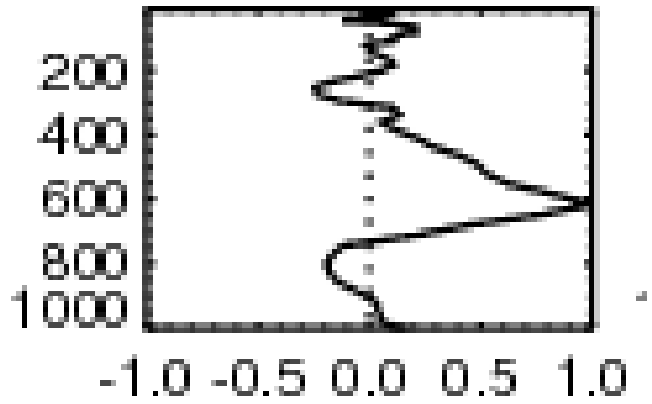
$$\text{Ratio} = \frac{|\text{T\_tendency (physics)}|}{|\text{T\_tendency (dynamics)}|}$$

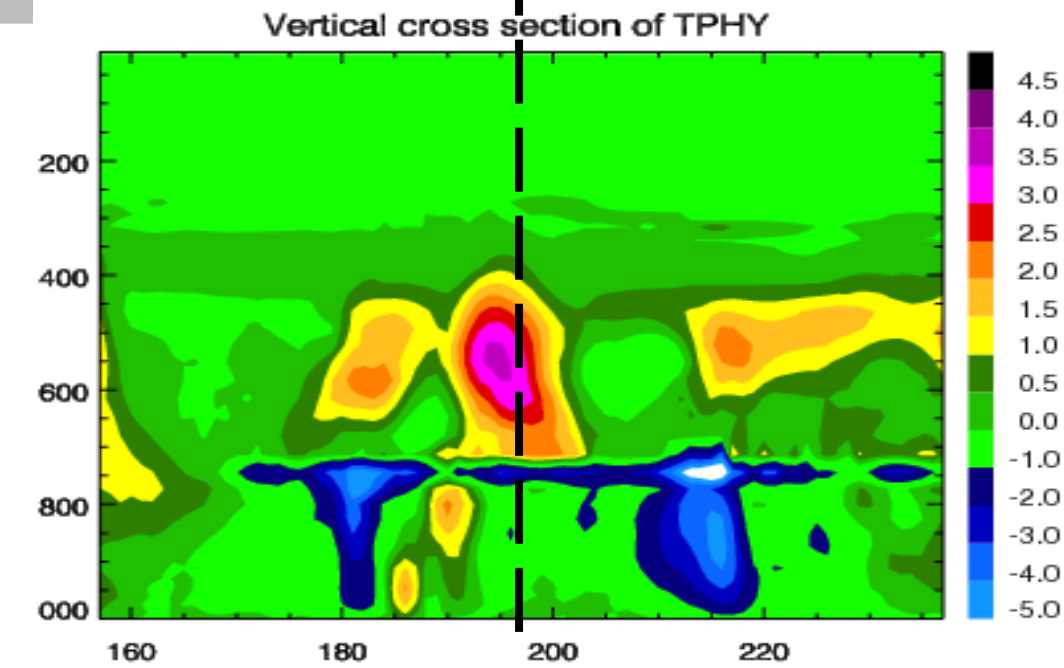
Physical processes could be as important as dynamics.



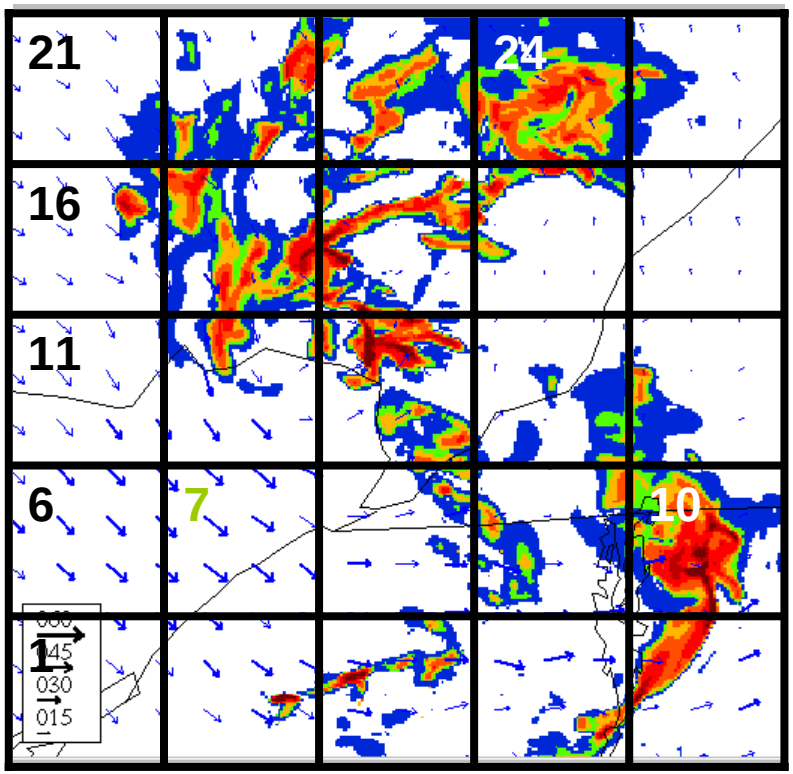
Profile of single observation test
En_KF T analysis increment

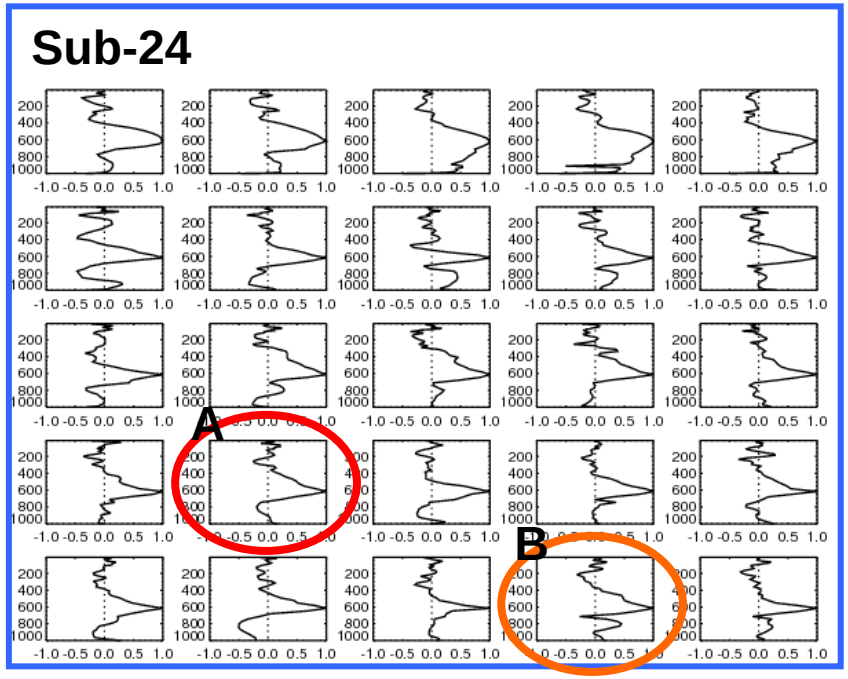
En_KF T vertical error correlation

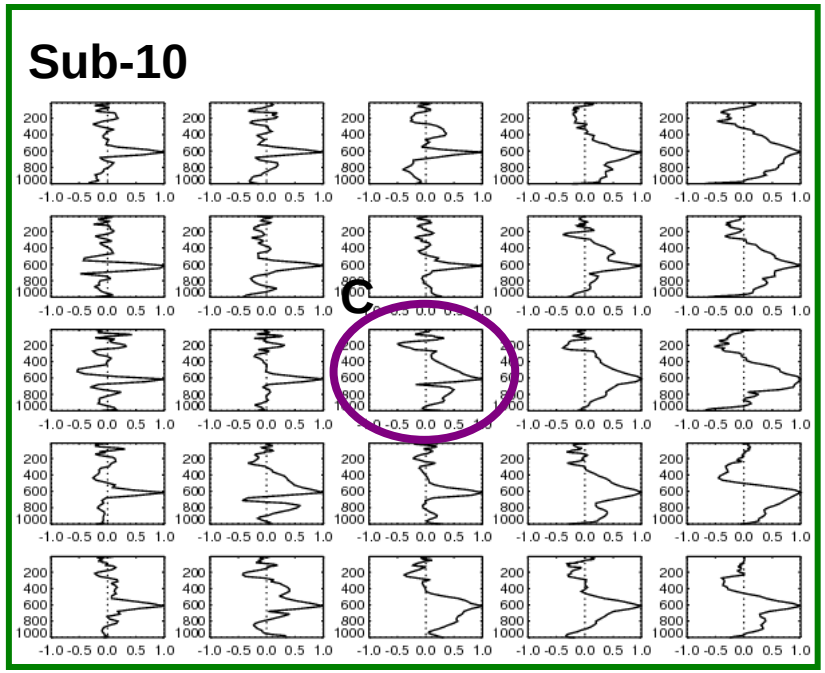




Ensemble mean of physical temperature tendency







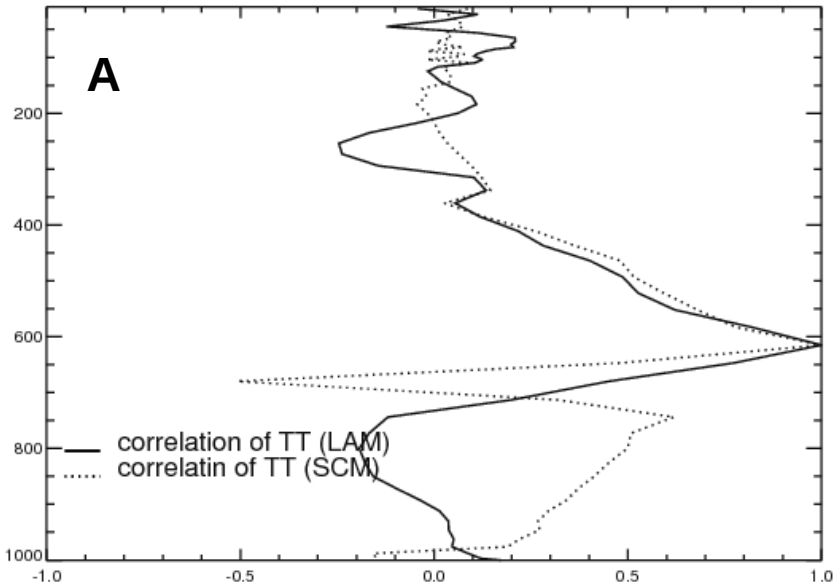
What happen by running
1-D vertical column model ?

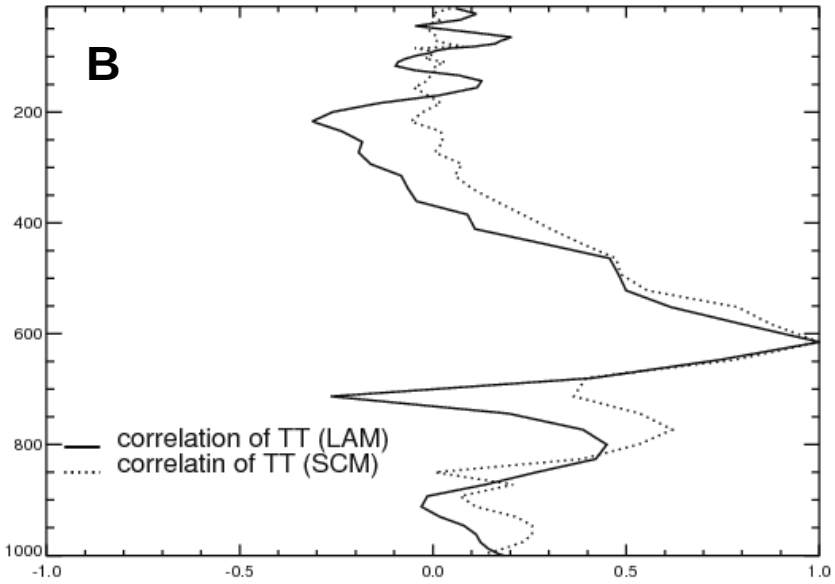
Single column model (SCM)
Ron McTaggart -Cowan

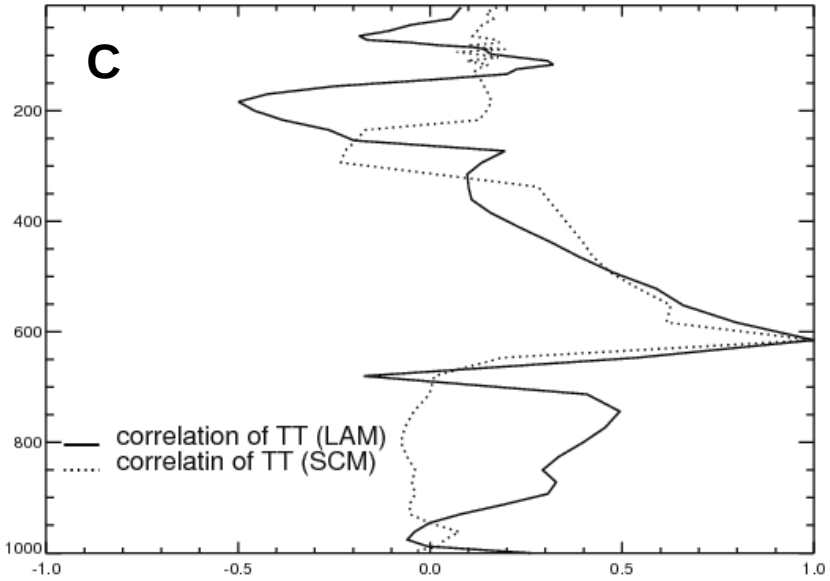
Error correlation of TT profile (Ensemble Forecasts)

V.S.

Vertical correlation of TT tendency (stochastic perturbation of SCM)

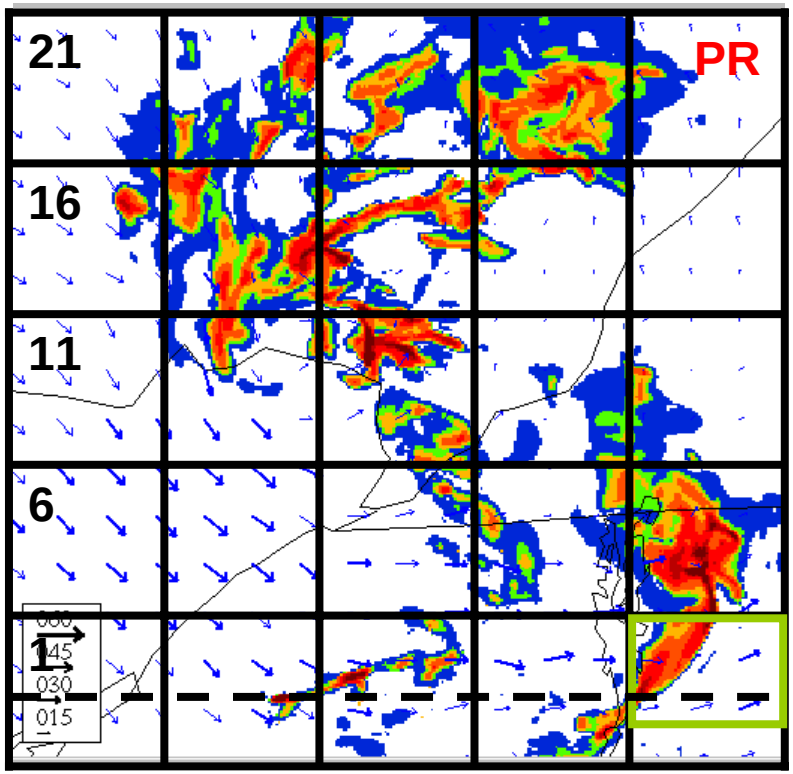


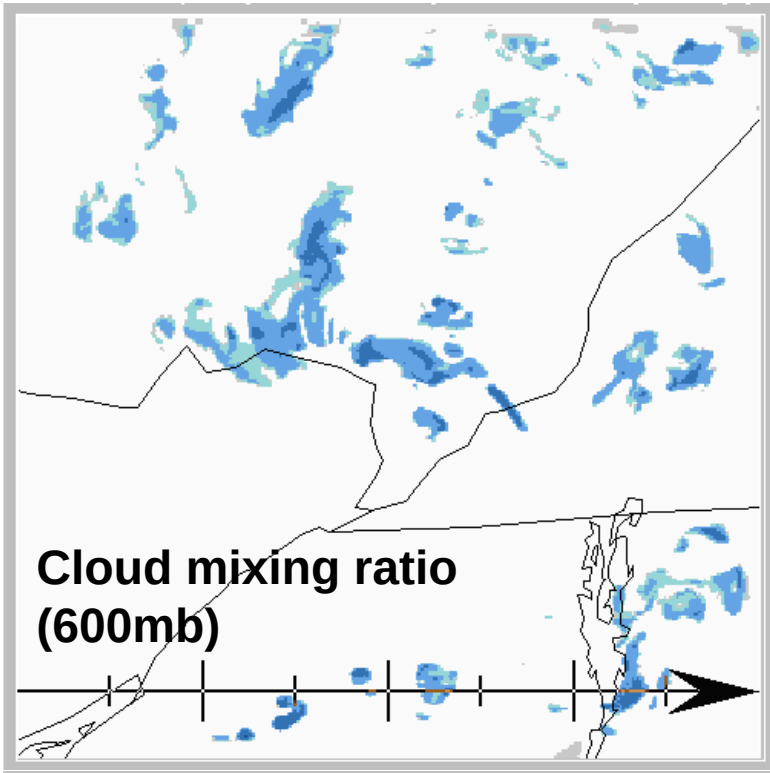


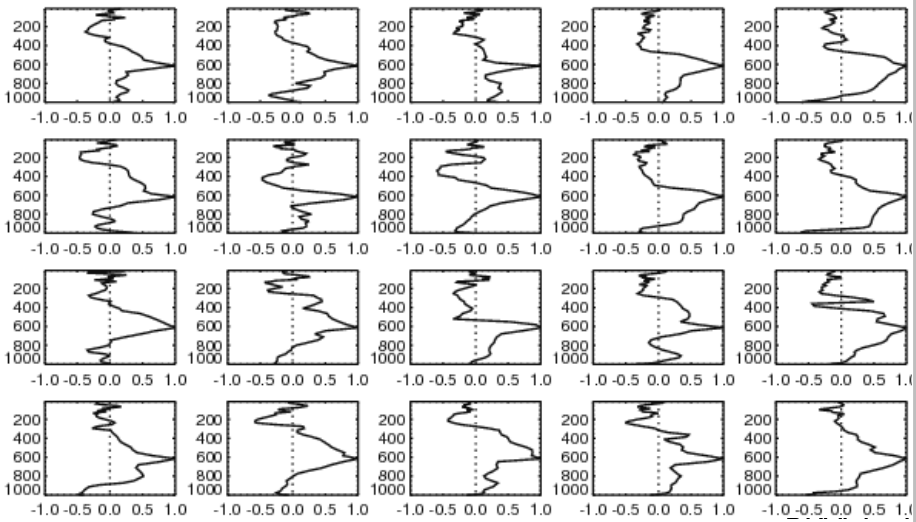


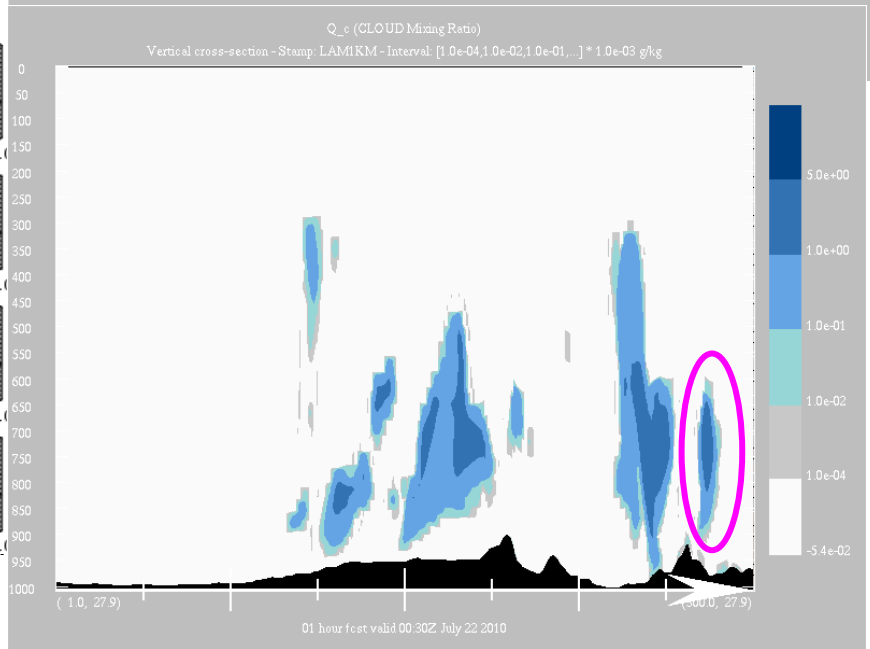
Single column model (SCM)

→ Represent the error structure


21
16
11
6
1
PR

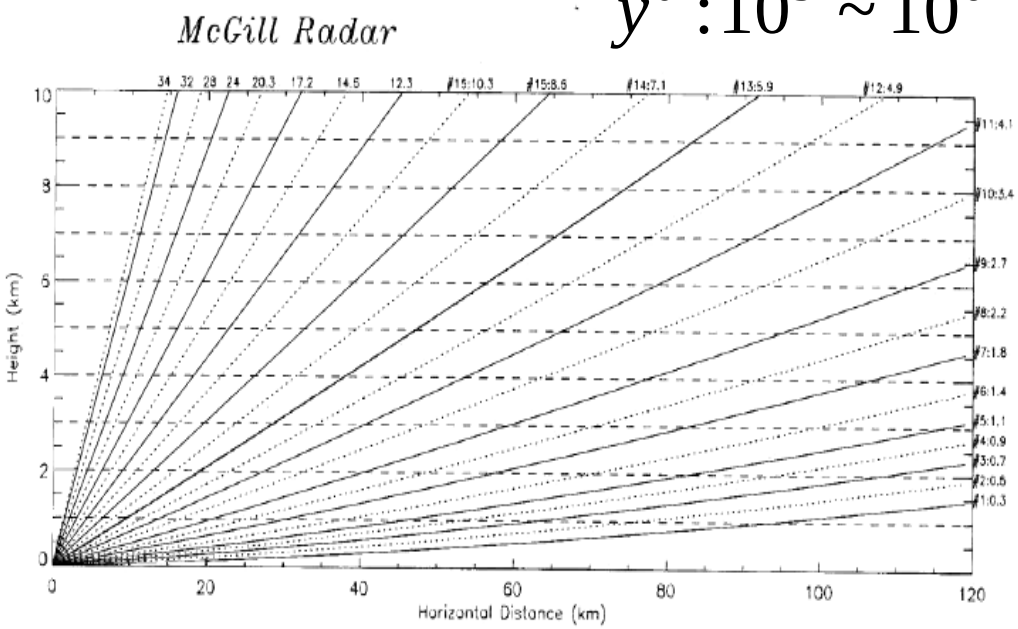

Cloud mixing ratio
(600mb)
5.0e+00
1.0e+00
1.0e-01
1.0e-02
1.0e-04
0.0e+00



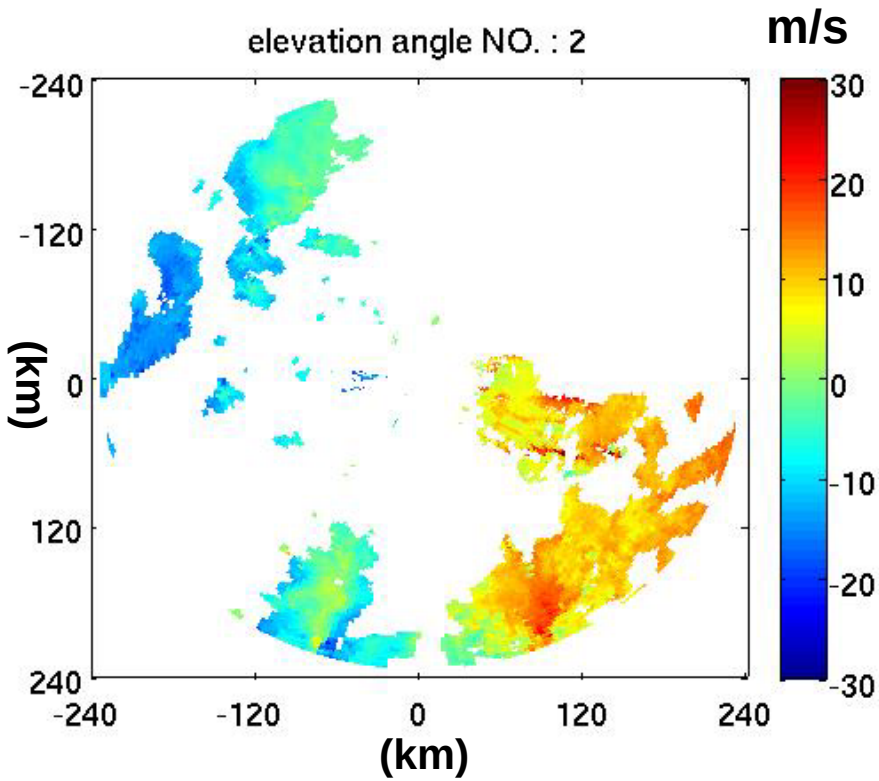

Q_c (CLOUD Mixing Ratio)
Vertical cross-section - Stamp: LAM1KM - Interval: [1.0e-04,1.0e-02,1.0e-01,...] * 1.0e-03 g/kg
5.0e+00
1.0e+00
1.0e-01
1.0e-02
1.0e-04
-5.4e-02
01 hour fcst valid 00:30Z July 22 2010

4. HR_EnKF system with radar data

$y^0 : 10^5 \sim 10^6$



2010 July 22 0000 UTC



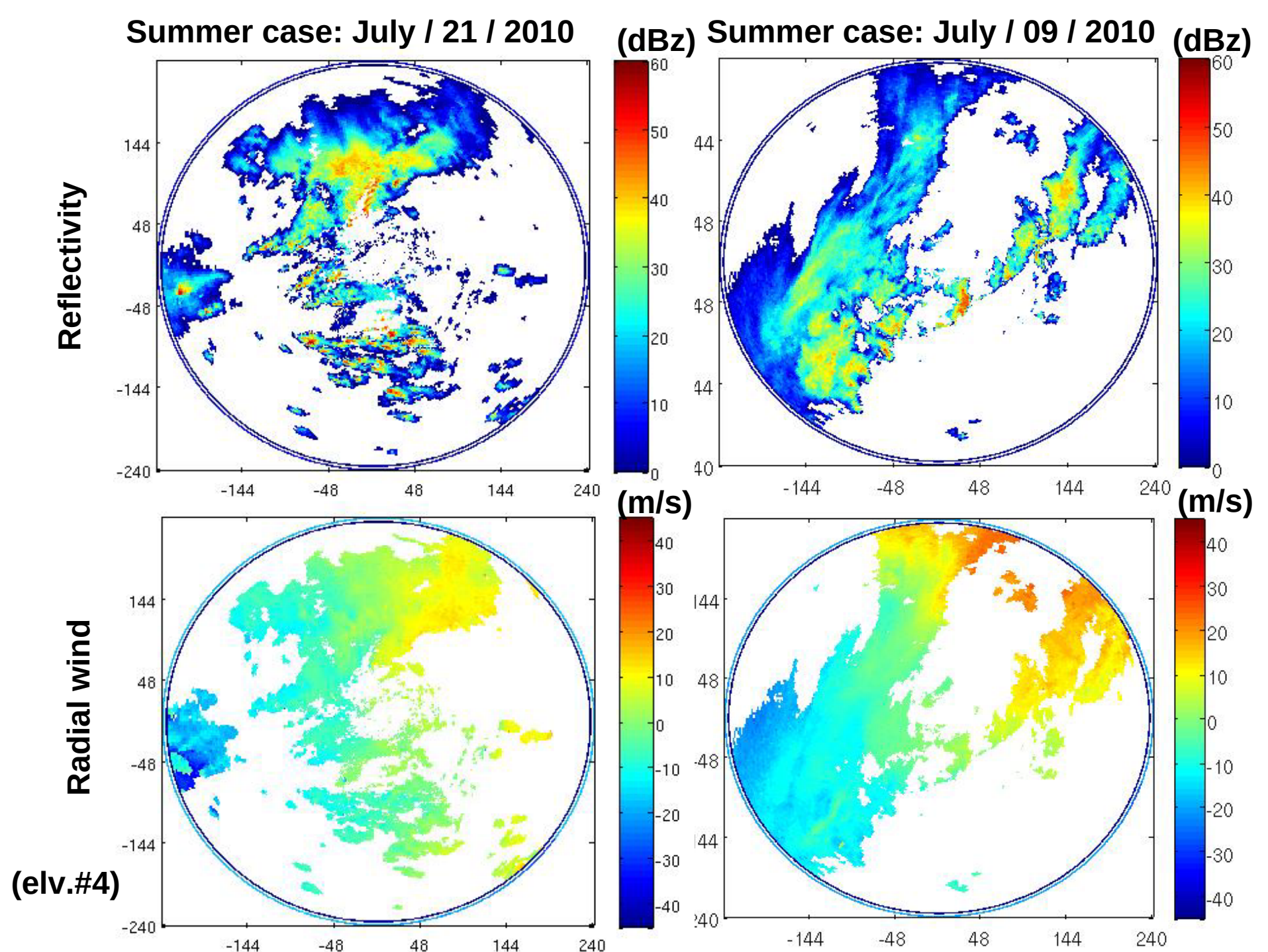
Forward model for raidal wind

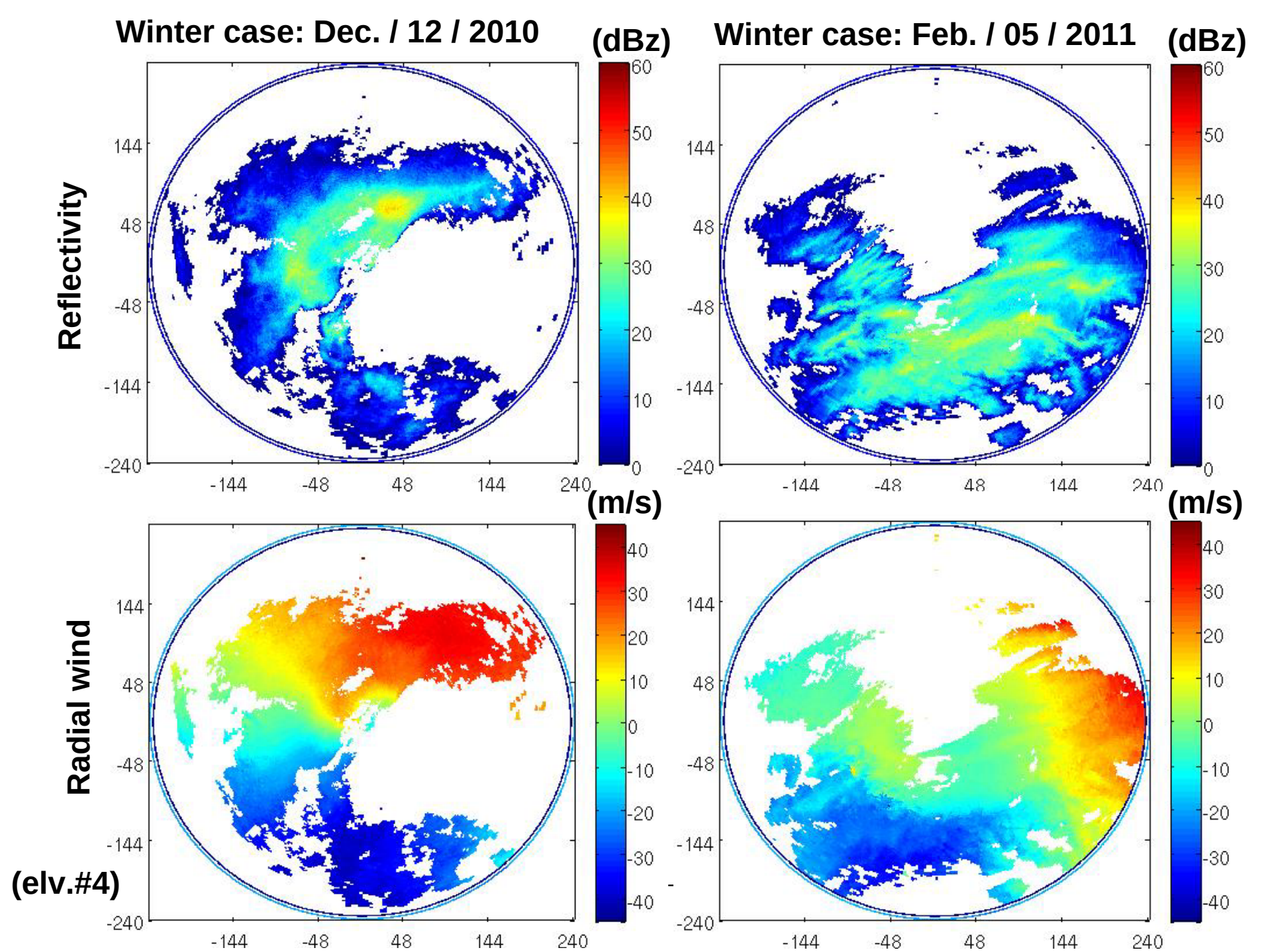
$$V_r = u\frac{x}{r} + v\frac{y}{r} + (w + V_t)\frac{z}{r}$$

Current test

Raindrop terminal velocity

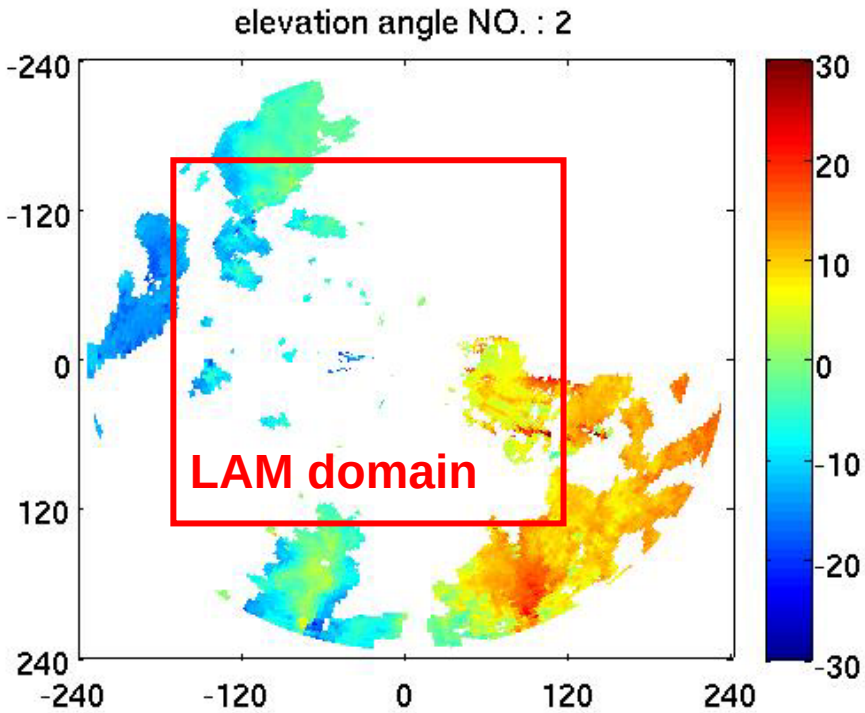
plan position indicator (PPI),

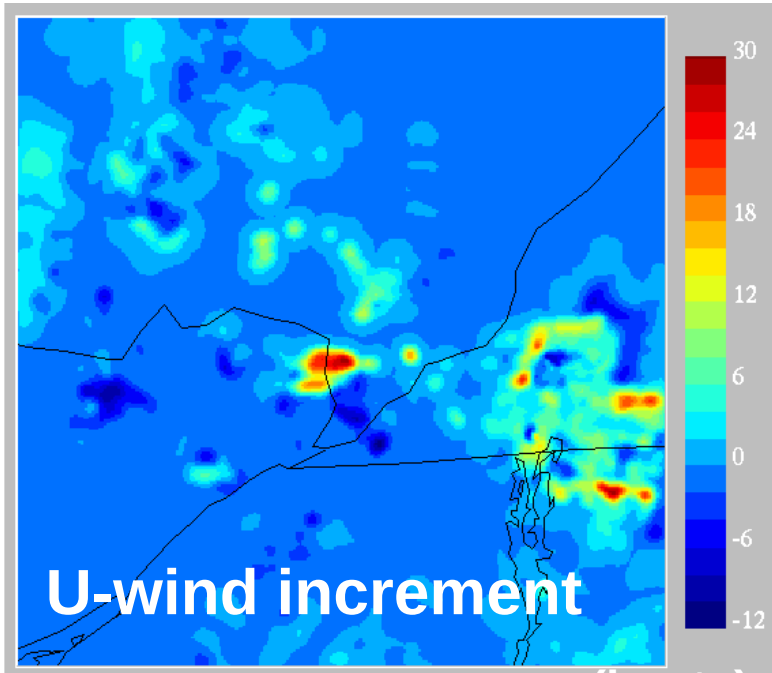

Summer case: July / 21 / 2010
(dBz)
Summer case: July / 09 / 2010
(dBz)
Reflectivity
Radial wind
(m/s)
(m/s)
(elv.#4)
144
48
-48
-144
-240
-144
-48
48
144
240
60
50
40
30
20
10
0
44
48
40
-30
-40

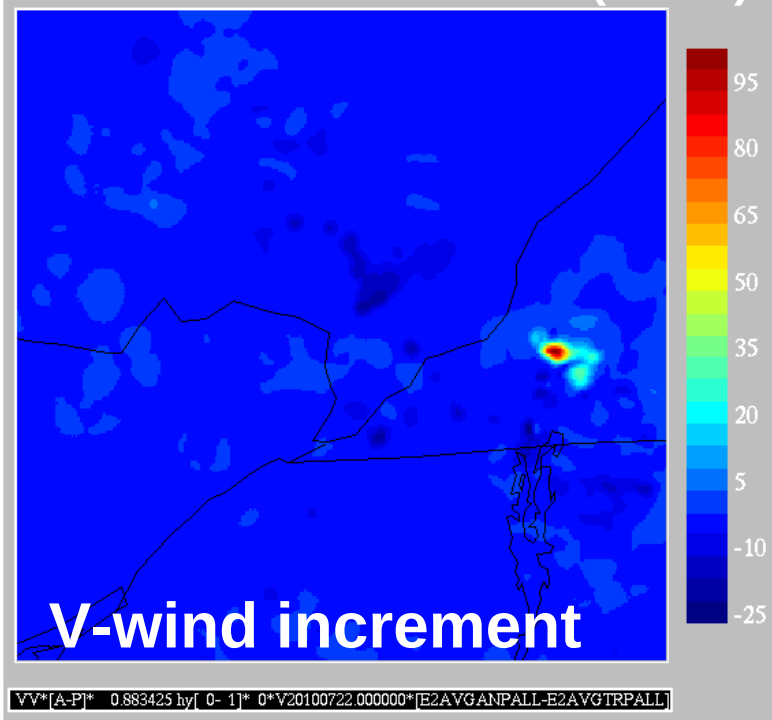

Winter case: Dec. / 12 / 2010
Winter case: Feb. / 05 / 2011
(dBz)
(dBz)
Reflectivity
Radial wind
(m/s)
(m/s)
(elv.#4)
144
48
-48
-144
-240
-144
-48
48
144
240
60
50
40
30
20
10
0
40
30
20
10
0
-10
-20
-30
-40

Issue with very dense observations

Use all observed radial wind







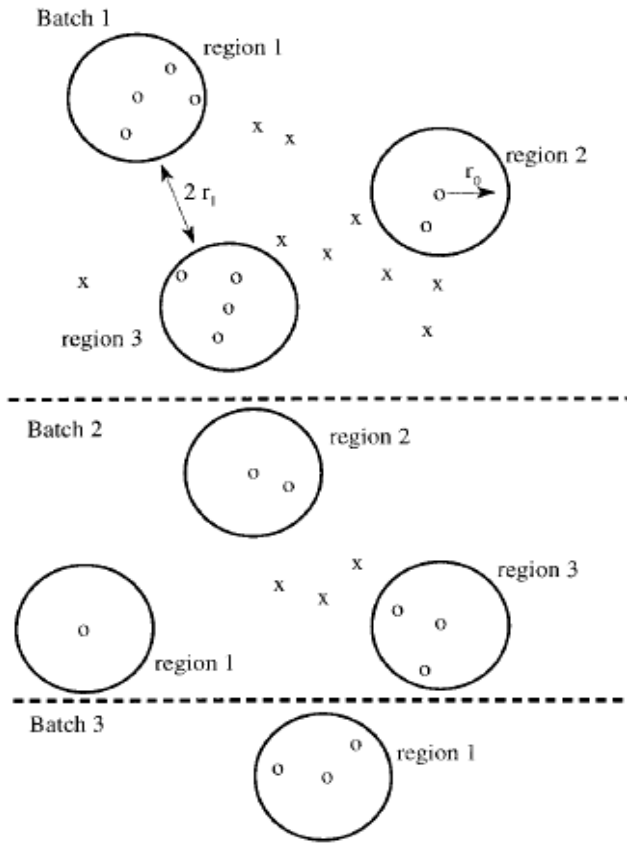
Why we need data thinning procedure

1. **Observation error structure, R, is unknown and the error of radar data is correlated (actively studied in radar groups)**

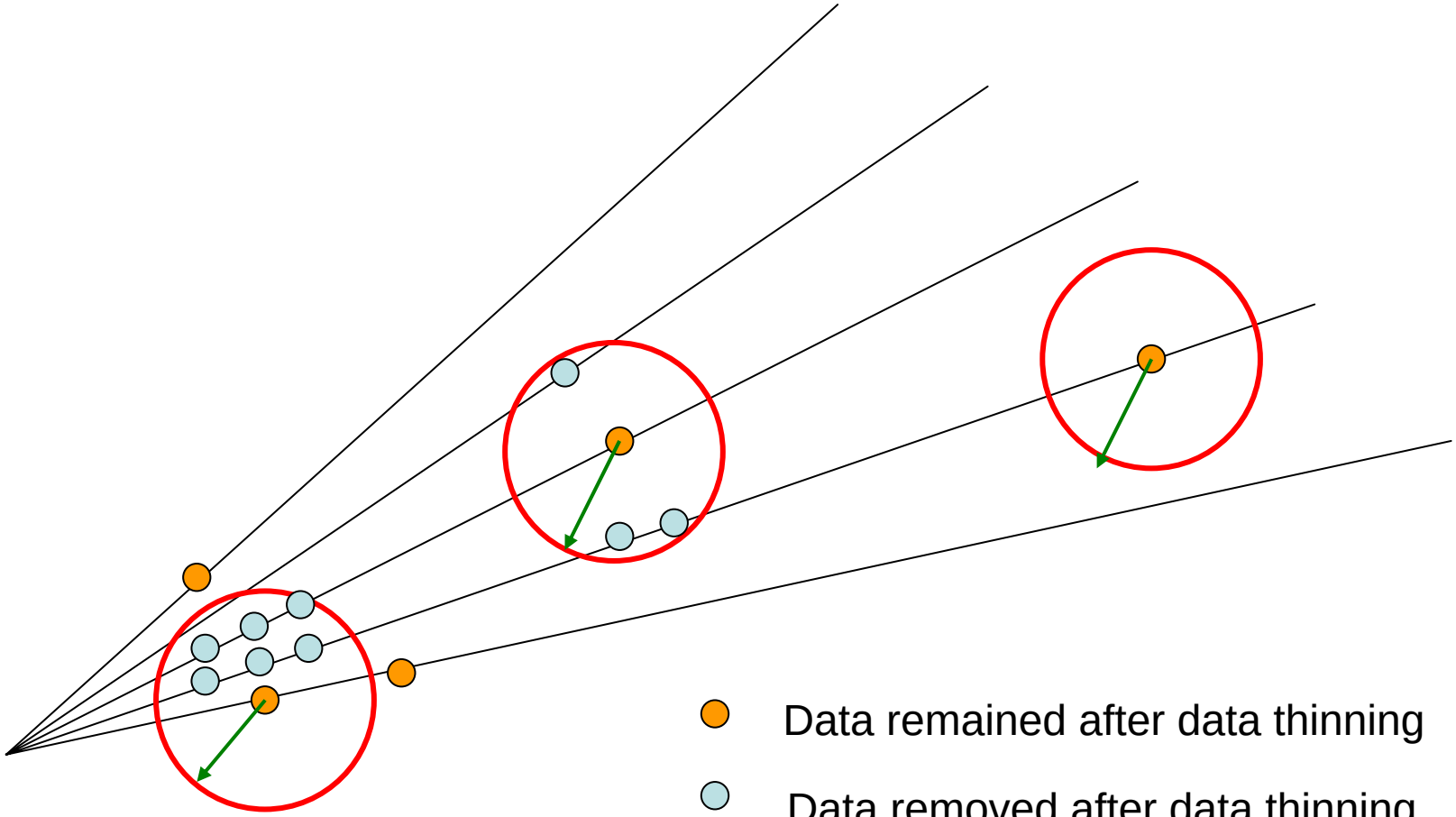
2. **Batching process will cause problems with radar data**

   *** batching process is valid when observations are uncorrelated**

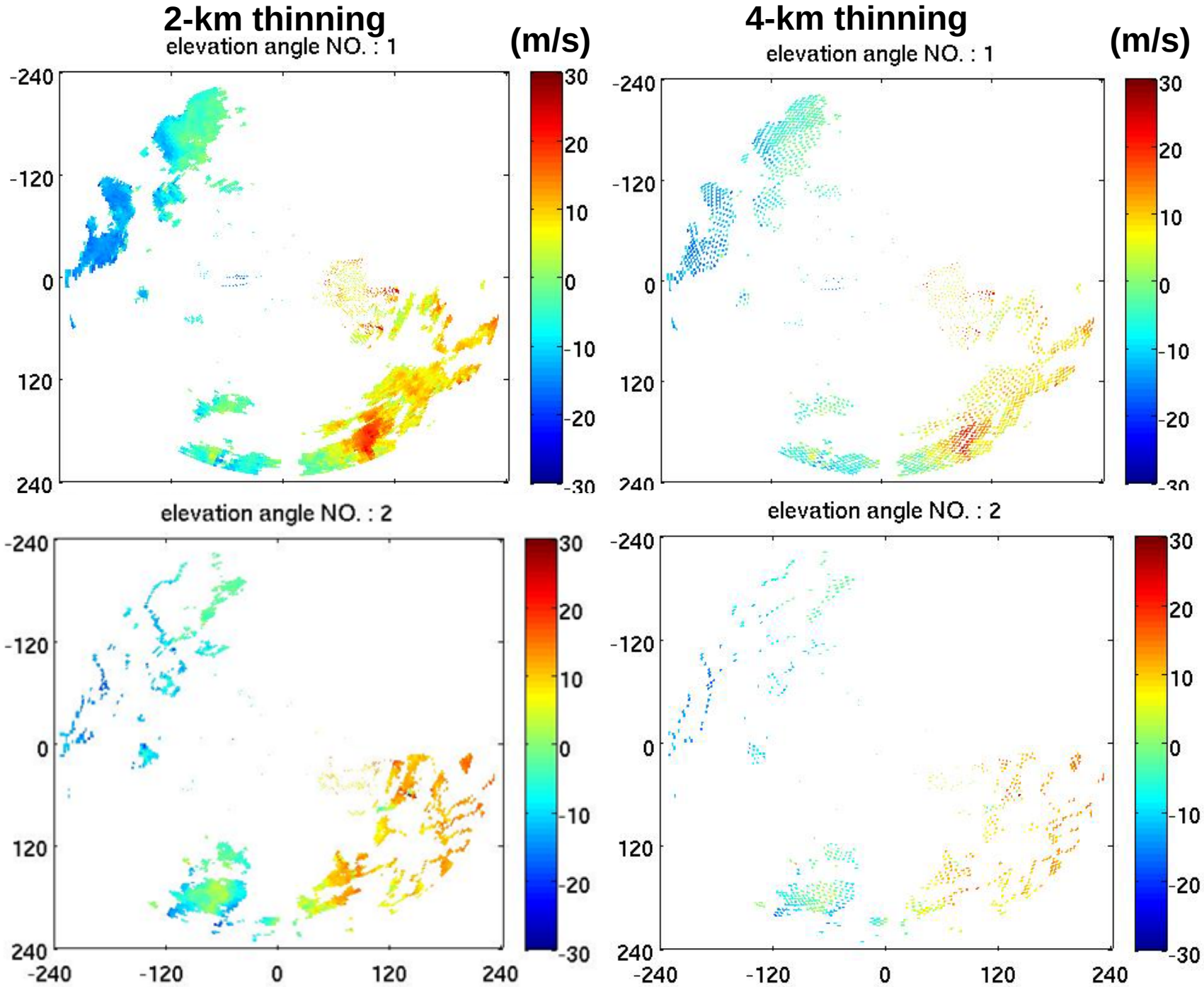
   *** number of batches will increase the errors due to the ensemble size**



Data thinning procedure in observation space



Remove more data in low level and near radar center


2-km thinning
elevation angle NO. : 1
(m/s)
4-km thinning
elevation angle NO. : 1
(m/s)
elevation angle NO. : 2
elevation angle NO. : 2
-240
-120
0
120
240
30
20
10
0
-10
-20
-30

With current case study: 2010/ July/ 22/ 0000 UTC

Radial wind (VR)	Total # of observations	percentage
All data	48533	100%
Data thinning (2-km)	10034	21%
Data thinning (4-km)	2100	~5%

The need of the computer resource between global and high resolution EnKF

Test under the super computer: zeta / saiph

	Grid pixels	Variables	Number of EnKF	Max. obs	# of CPS for analysis step
Global EnKF	400 x 200x58	U, V, T ,HU, TG and P0	192	900	160
HR EnKF	300 x 300x58	U, V, T ,HU, TG and P0	80	1000	160

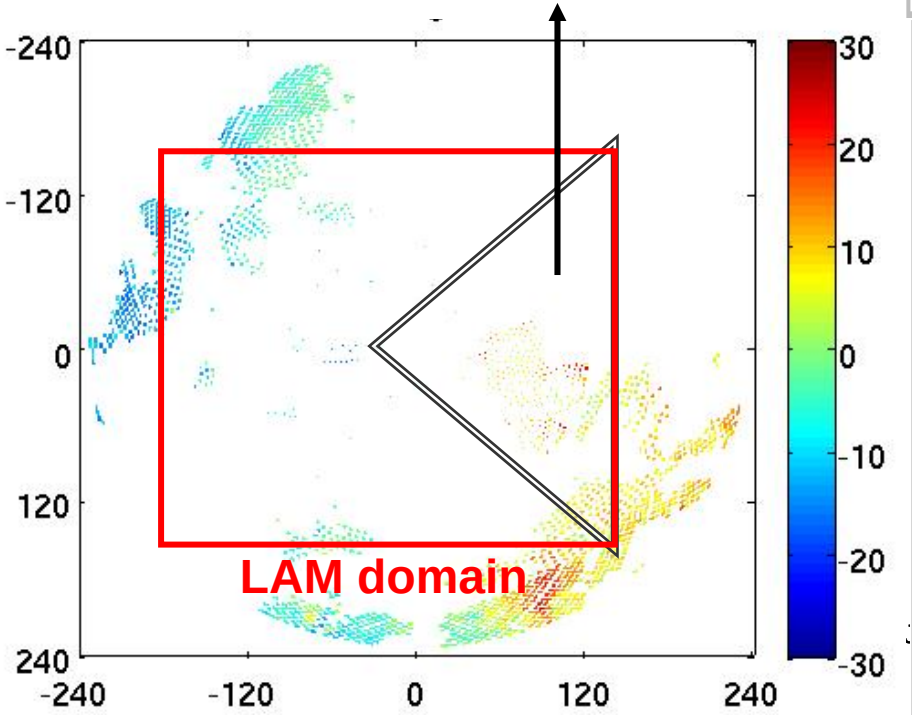
Data thinning (4-km)	2100	~5%

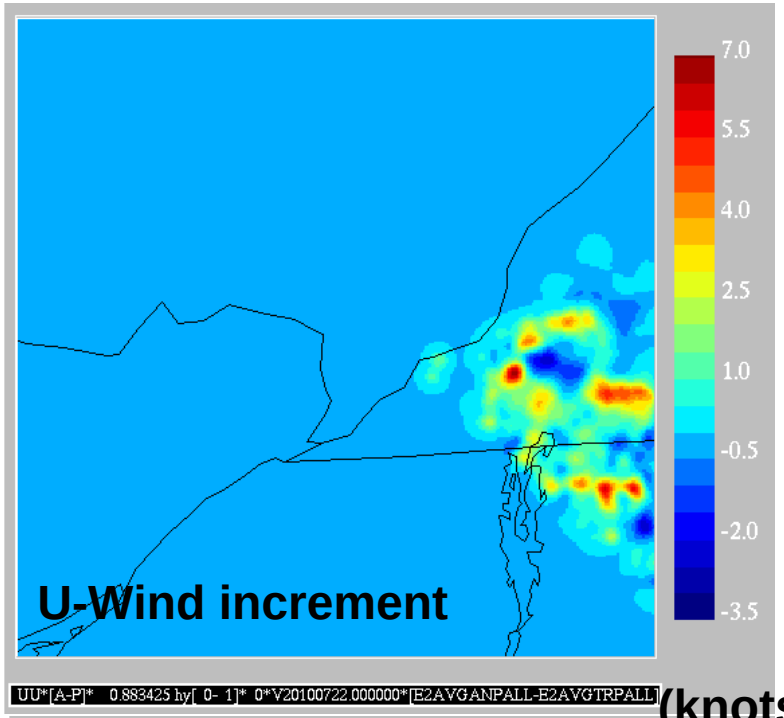
Verification of real data:

assimilating radial wind with
One batch and one region
as the reference

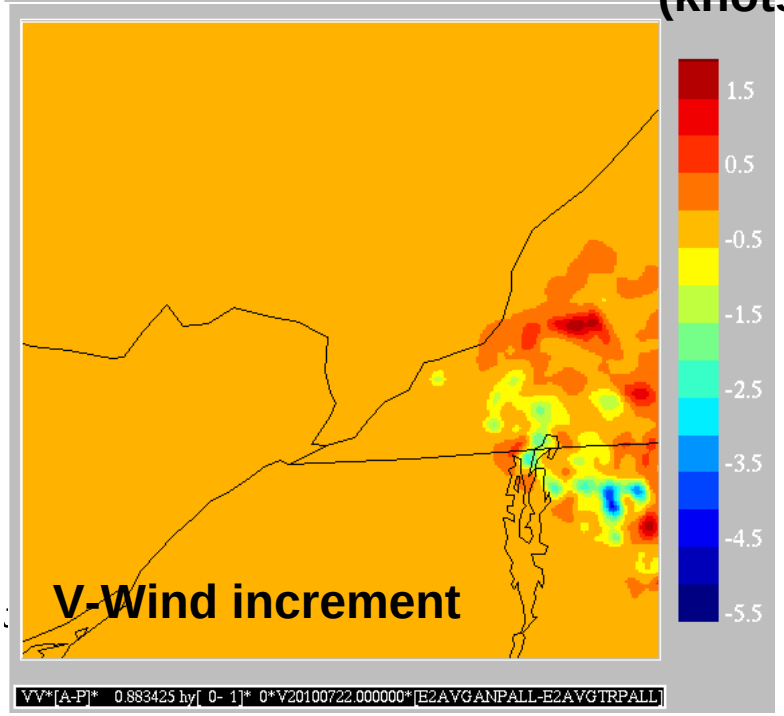
Data thinning (4km)

# of observations: 616

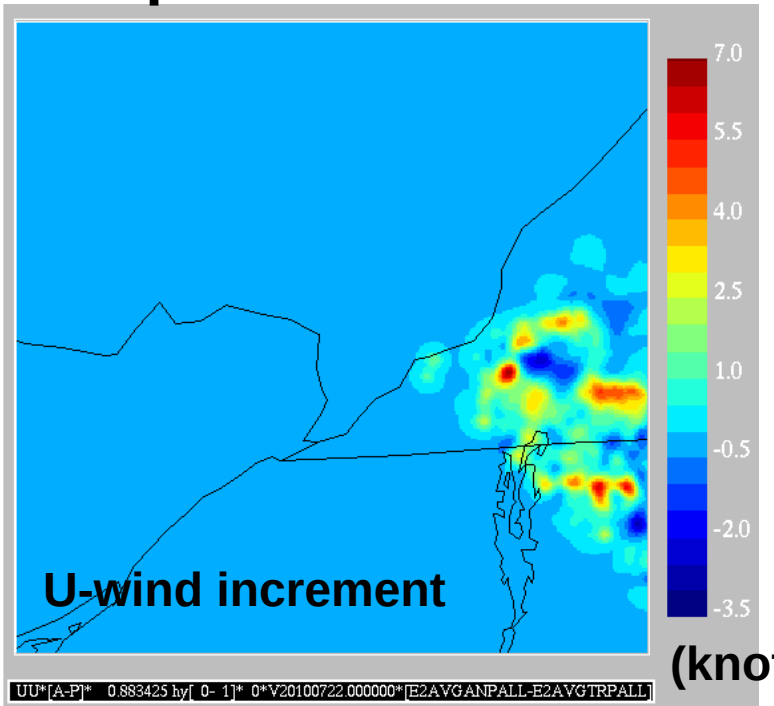




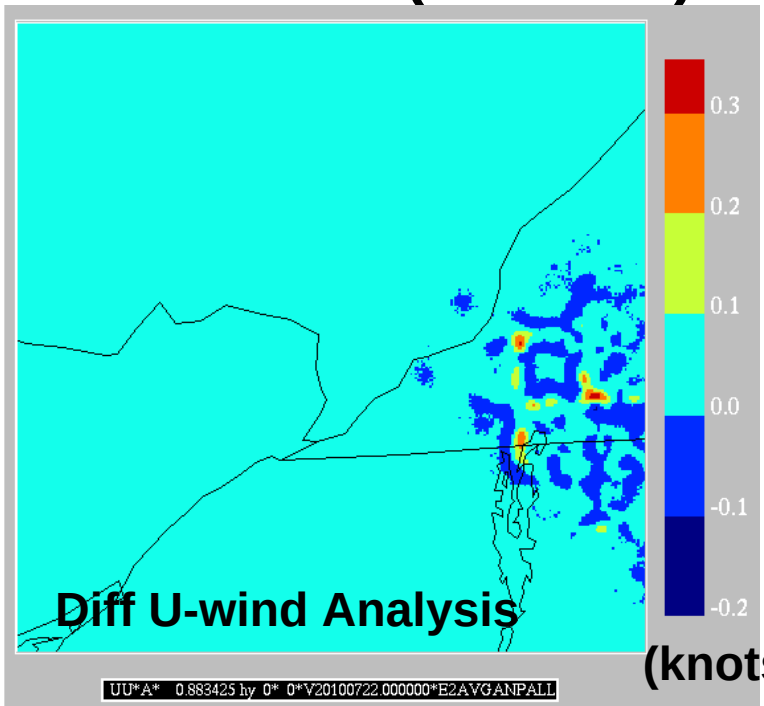
(knots)



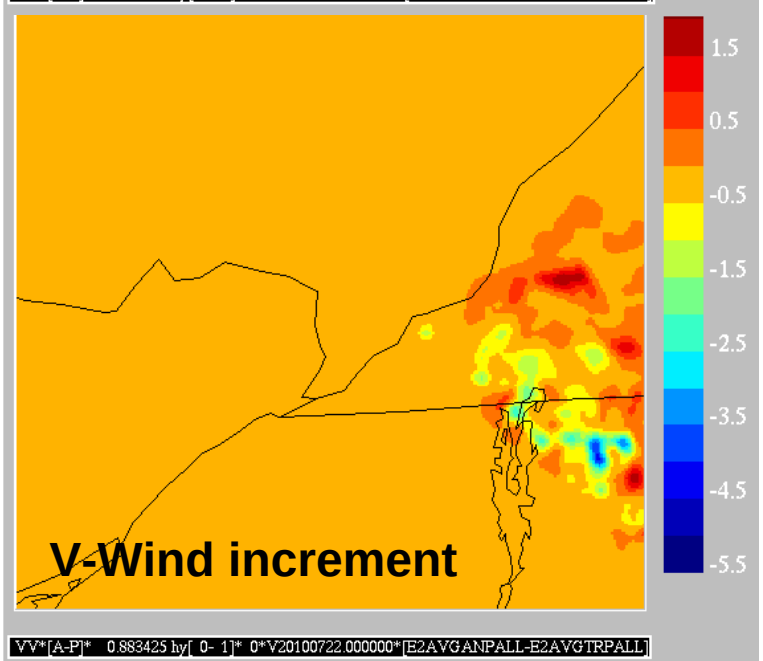
Comparison with different batches number (1 v.s. 6)

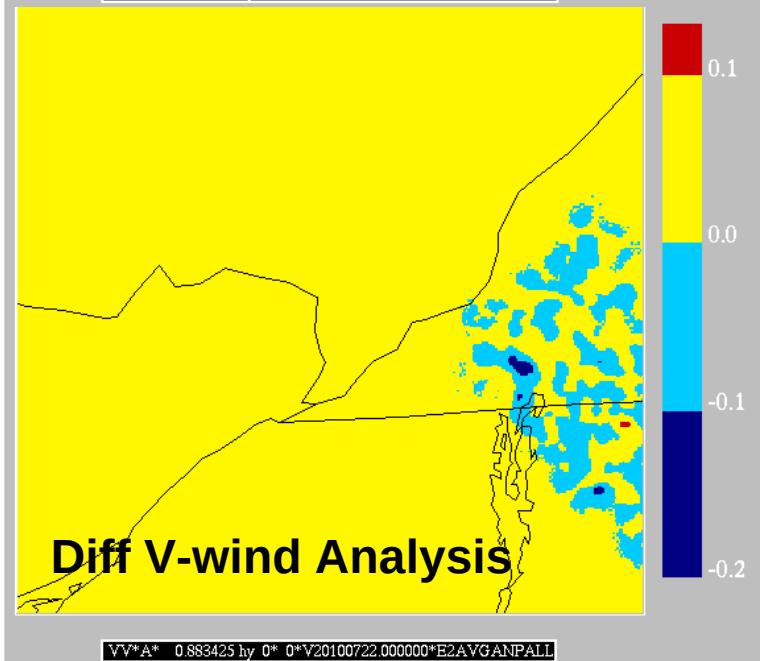


(knots)



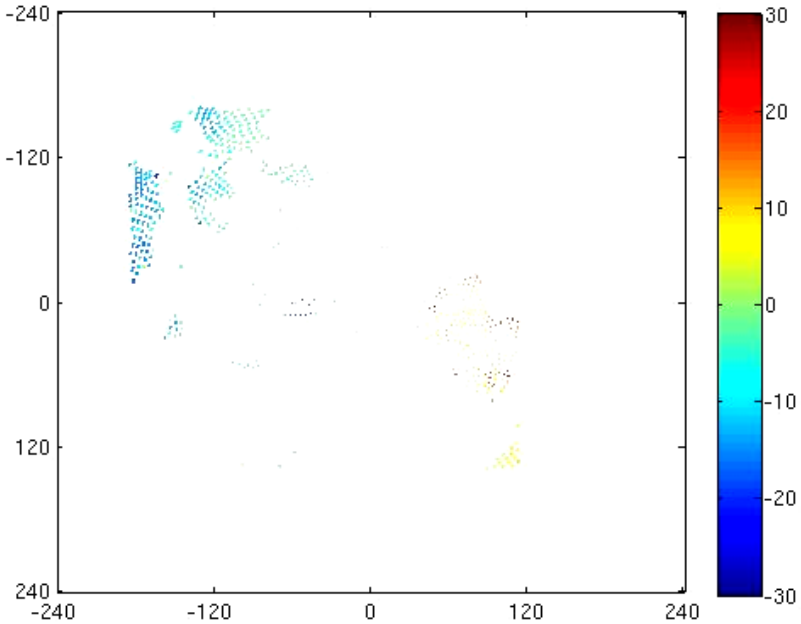
(knots)



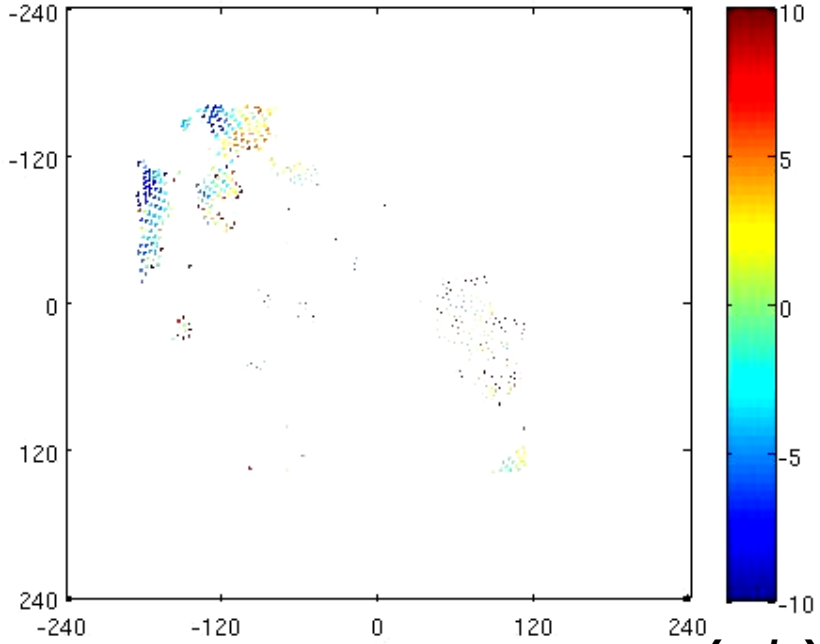


Data thinning (4km)
All radial wind in the analysis domain
# of observations: 2100

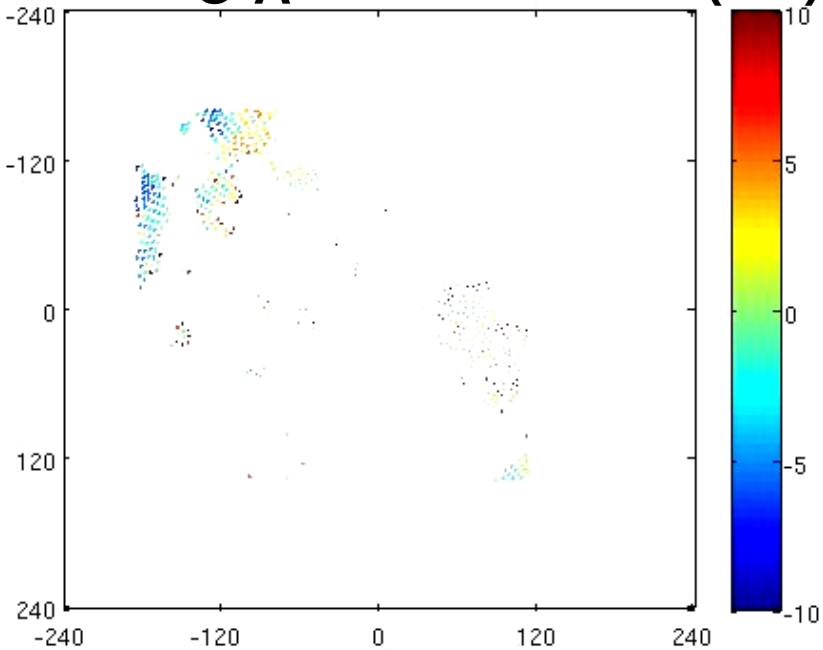
Observations



O-P (innovation) (m/s)



O-A (m/s)



5. Summary

- **The EnKF system has been modified from global to local area**
- **The ensemble forecasts present the uncertainty of the weather systems**
- **The results from ensemble forecasts (errors) showed strong flow-dependency and revealed the importance of physical processes over precipitation areas**
- **Currently, McGill radar group provides us with 15-20 cases to study**
- **To assimilate radar observations (radial wind), data thinning is necessary for the current system.**
  (global solver may be needed for very dense data in the future!)
- **Verification of assimilating radial wind is done by using one batch**

Future works

- **Quality control in HR_EnKF with radar data: background check, bias remove …etc**
- **Complete the forward model of radial wind**

$$V_r = u\frac{x}{r} + v\frac{y}{r} + (w + V_t)\frac{z}{r}$$

- **The impact of assimilating radial wind data with cycling process.**

Merci
Thank you !

Questions ?