Ensemble Forecasting at the Meteorological Service of Canada: Status, Research, and Plans

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Talk Outline

- ***Currently operational at the global scale***
  - *Ensemble data assimilation (EnKF)*
  - *Medium range ensemble forecasting*
  - *Improvements in the EnKF and global forecast system*
- ***Collaboration with NCEP***
  - *North American super-ensemble (NAEFS)*
- ***Research and plans***
  - *Short range ensemble forecasting*

Ensemble Data Assimilation

- *The ensemble Kalman filter has been operational since January 2005*
  - *2x48 members (we use two ensembles)*
  - *Impact of (perturbed) observations is localized to 2800 km in the horizontal, and to ~15 km in the vertical*
  - *Data are supposed valid at the synoptic times*

The Ensemble Kalman Filter

$$X_a^{\alpha,i} = X_b^{\alpha,i} + K^{\beta}\left(y^{\alpha,i} - HX_b^{\alpha,i}\right)$$

$$K^{\beta} = \rho \circ \left(P^{\beta}H^{T}\right)\left(\rho \circ \left(HP^{\beta}H^{T}\right) + R\right)^{-1}$$

$$P^{\beta}H^{T} = \frac{1}{N-1}\sum_{i=1}^{N}\left(X_b^{\beta,i} - \overline{X_b^{\beta}}\right)\left(HX_b^{\beta,i} - H\overline{X_b^{\beta}}\right)^{T}$$

$$\overline{X_b^{\beta}} = \frac{1}{N}\sum_{i=1}^{N} X_b^{\beta,i}$$

ρ *is the localization covariance matrix*

$\mathbf{X}^{\alpha,i}_{\mathbf{a}}$ *is one analysis in ensemble* α

$\mathbf{X}^{\alpha,i}_{\mathbf{b}}$ *is one perturbed background field in ensemble* α

$y^{\alpha,i}$ *is one perturbed observation in ensemble* α

R *is observational error covariance matrix*

N *is the number of members per ensemble*

The numerical model used for background:

- *Global Environmental Multiscale (GEM) model (Côté et al., 1998)*
- *Grid point model*
- *Very similar to model used for deterministic medium range weather forecasts*
- *300x150 horizontal grid points*
- *28 vertical levels with top at 10 hPa*
- *The background fields are obtained from adding a 6 hour model prediction and a model error term (to be changed)*

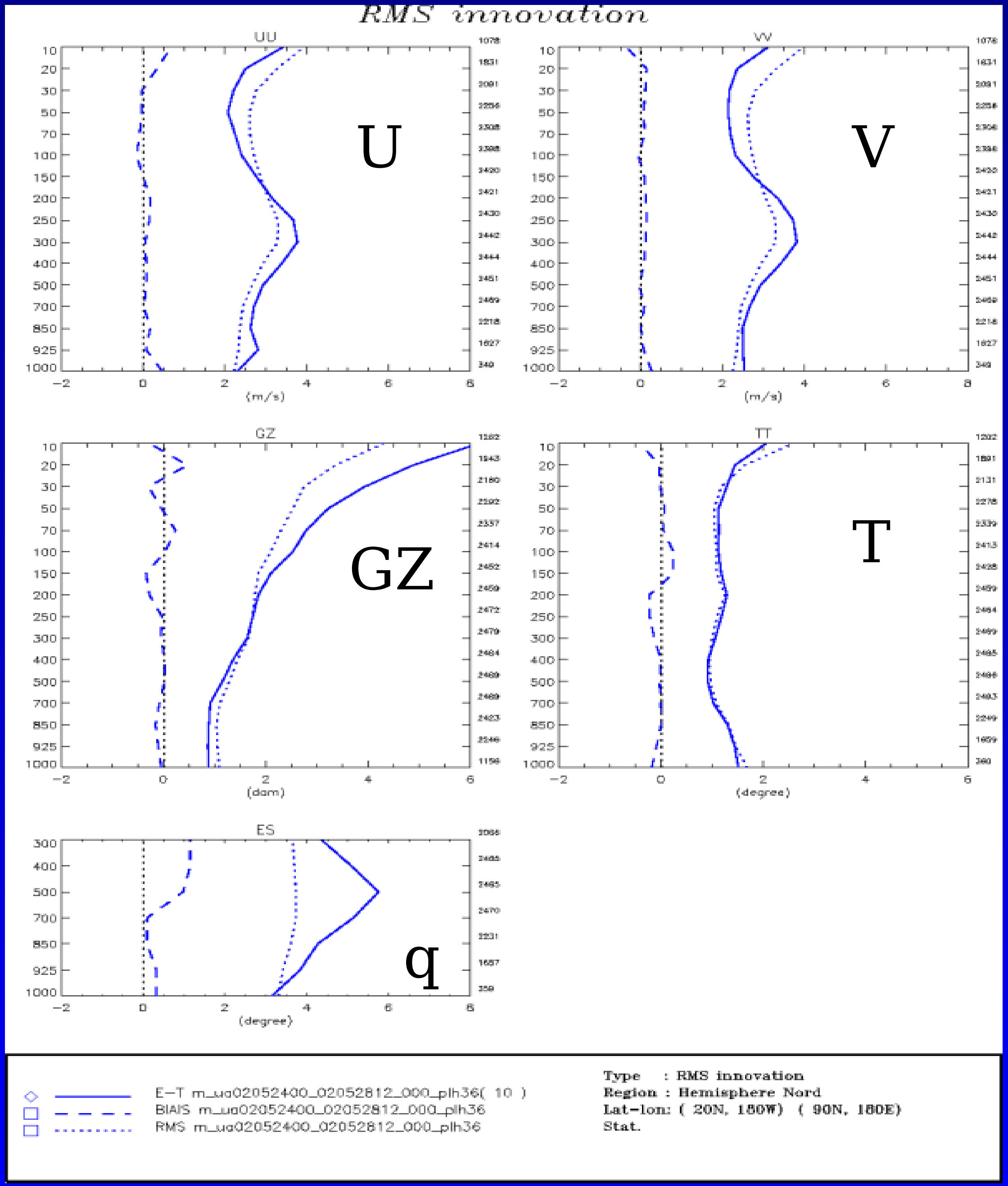
The "model error" component:

- *Hypothesis: the model error is similar in structure to the forecast error used in our centre's 4D-VAR*
- **$P(t+6h) = M\,P_a\,M^T + 0.25\,P_{4D\text{-}VAR}$**
- *Isotropic random error statistics for each member*
- *Currently the model error term includes:*
  - *A balanced component for wind, temperature and surface pressure*
  - *An unbalanced temperature component significant near the surface, in the tropics and near the top*

The observations:

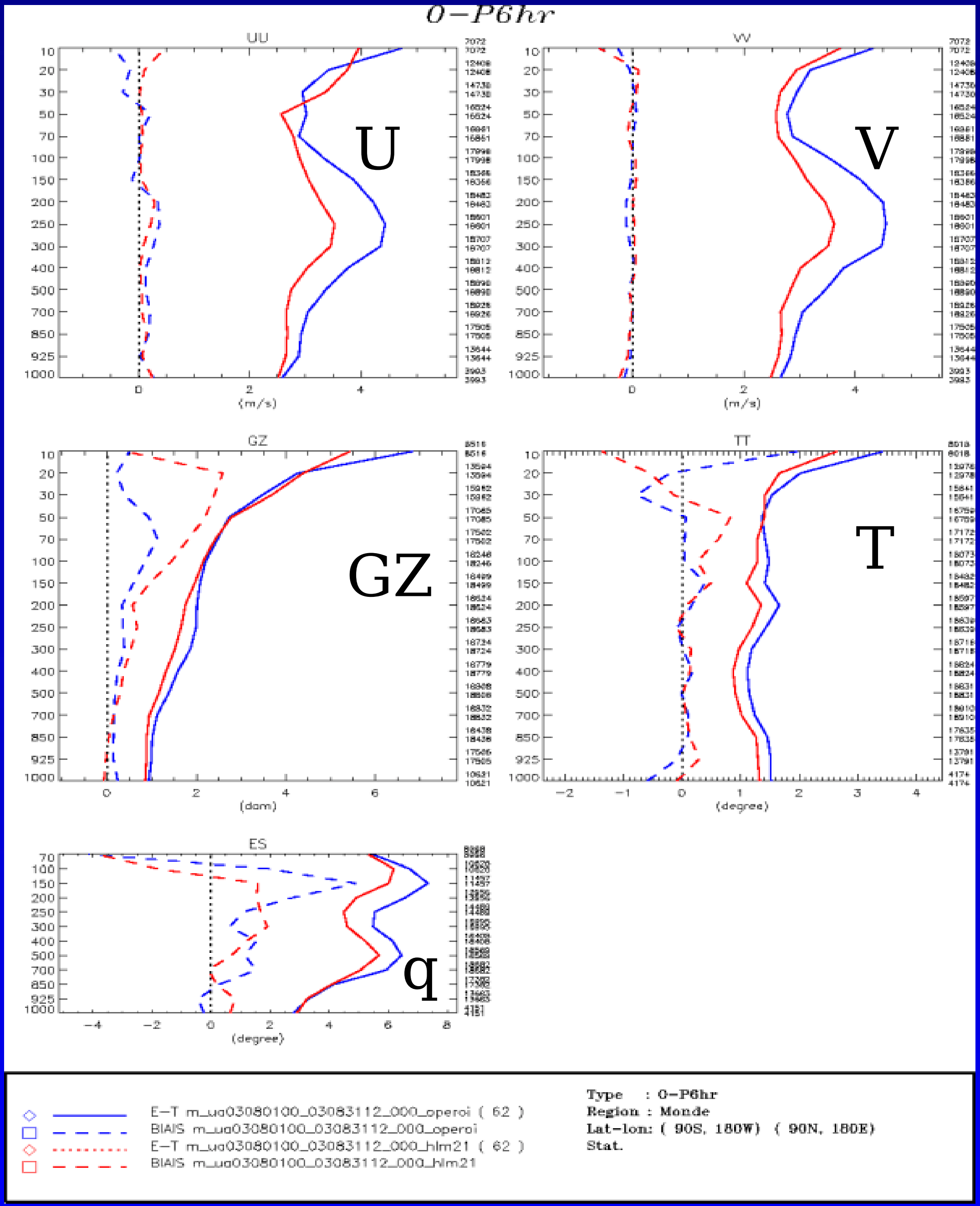
- *Try to assimilate same data as 4D-VAR*
- *Benefit from operational background check and variational quality control*
- *Same error statistic for marix* R *as in 4D-VAR*
- *Currently, we assimilate:*
  - *radiosondes: u, v, T, q, and surface pressure*
  - *aircrafts: u, v, and T*
  - *satellites: cloud track winds u, v, and AMSU-A radiances*
  - *surface observations: T, and surface pressure*
- *Surface humidity not yet assimilated*

Quality of error statistics



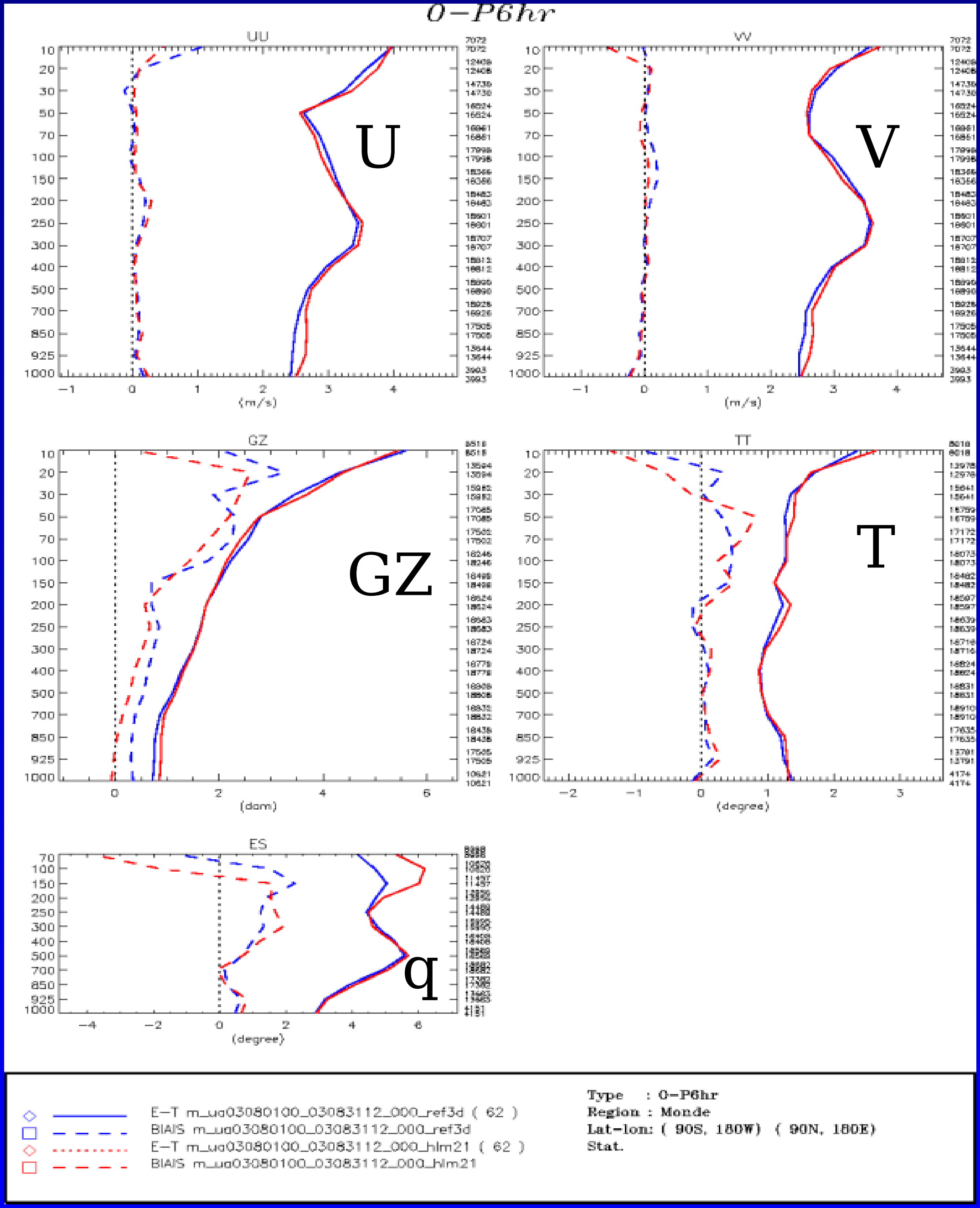
- *The solid line is the rms amplitude of the innovations corresponding with radiosondes.*
- *The dashed line is the ensemble based prediction of the innovation amplitude. It is the root of the sum of observational variance and ensemble spread.*
- *There is excellent agreement for the temperature. For winds the ensemble spread is too large near the model top. The spread is too small for humidity.*

Comparison with optimal interpolation



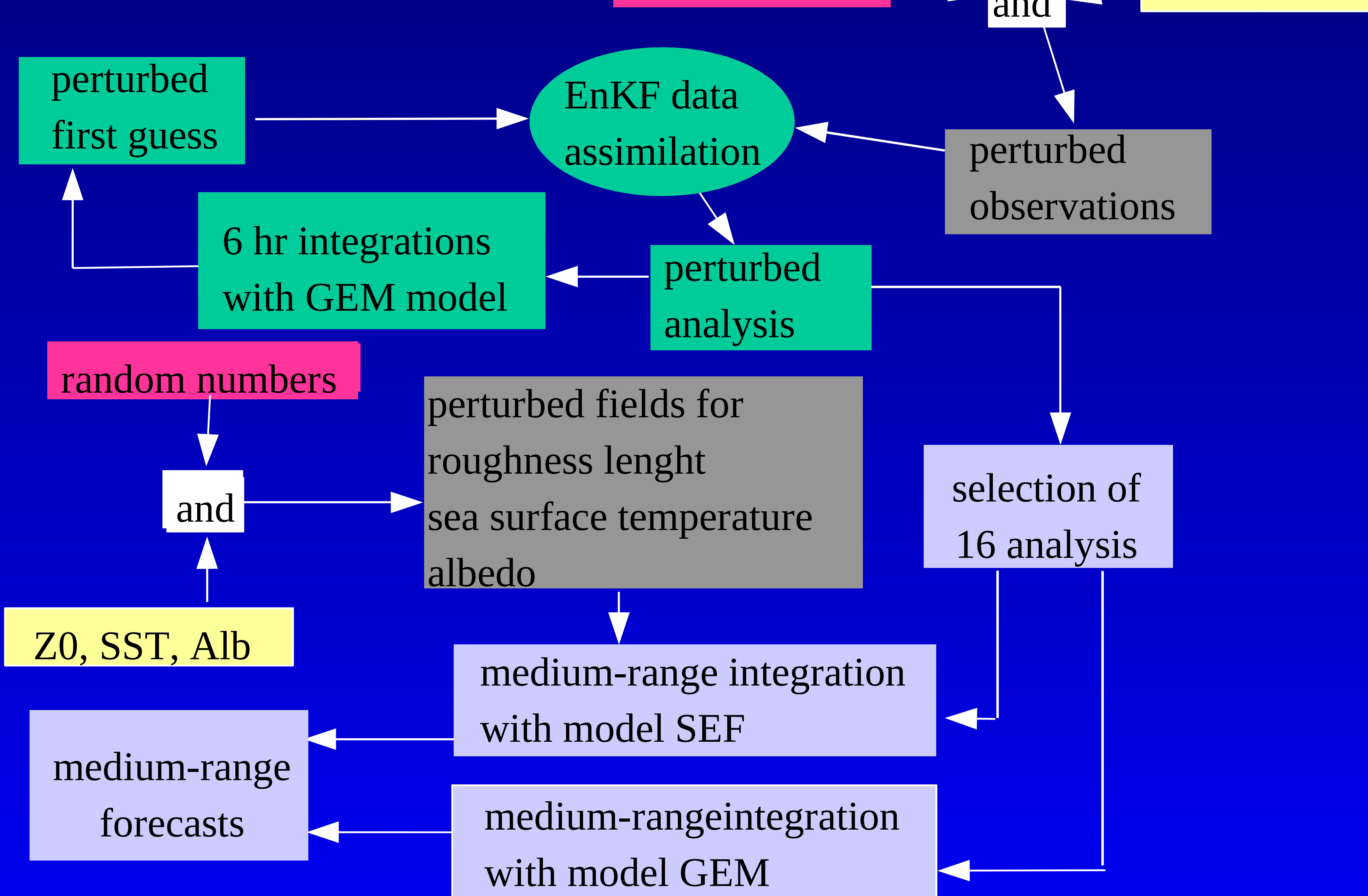
- *The solid line is the rms amplitude of the innovations corresponding with radiosondes.*
- *The dashed line is the bias*
- *Red: EnKF*
- *Blue: Optimal Interpolation*
- *Scores are for summer*

Comparison with 3D-VAR

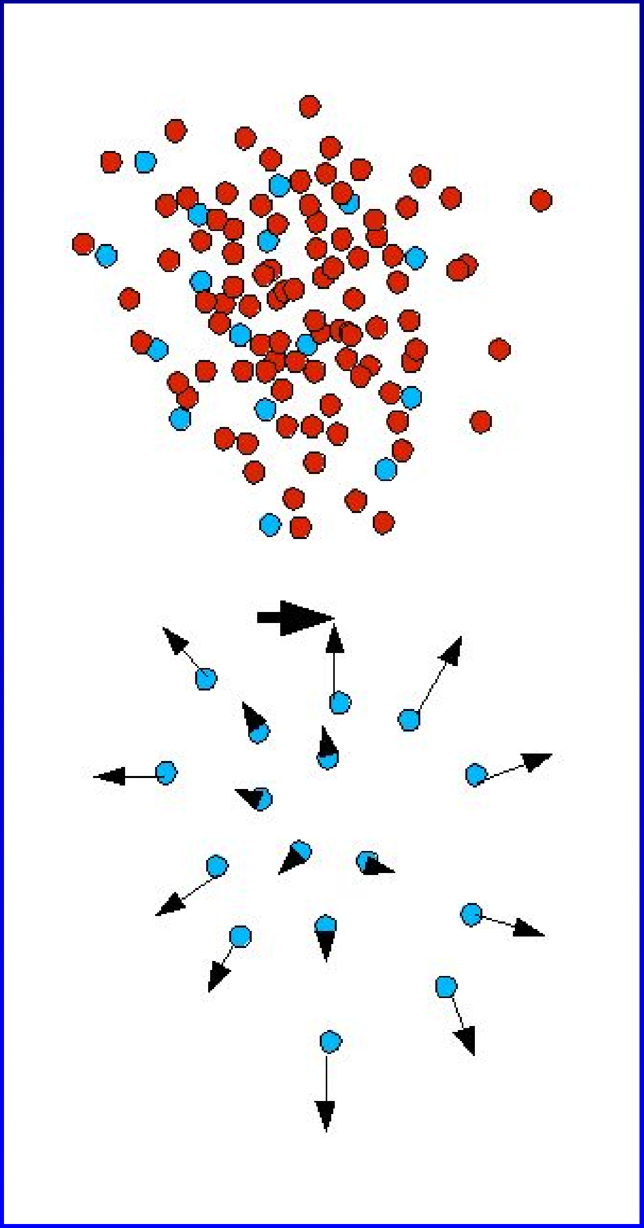


- *The solid line is the rms amplitude of the innovations corresponding with radiosondes.*
- *The dashed line is the bias*
- *Red: EnKF*
- *Blue: 3D-VAR*
- *Scores are for summer*

ENSEMBLE SET-UP



From an Ensemble of 96 Initial Conditions to an Ensemble of 16 10-Day Forecasts



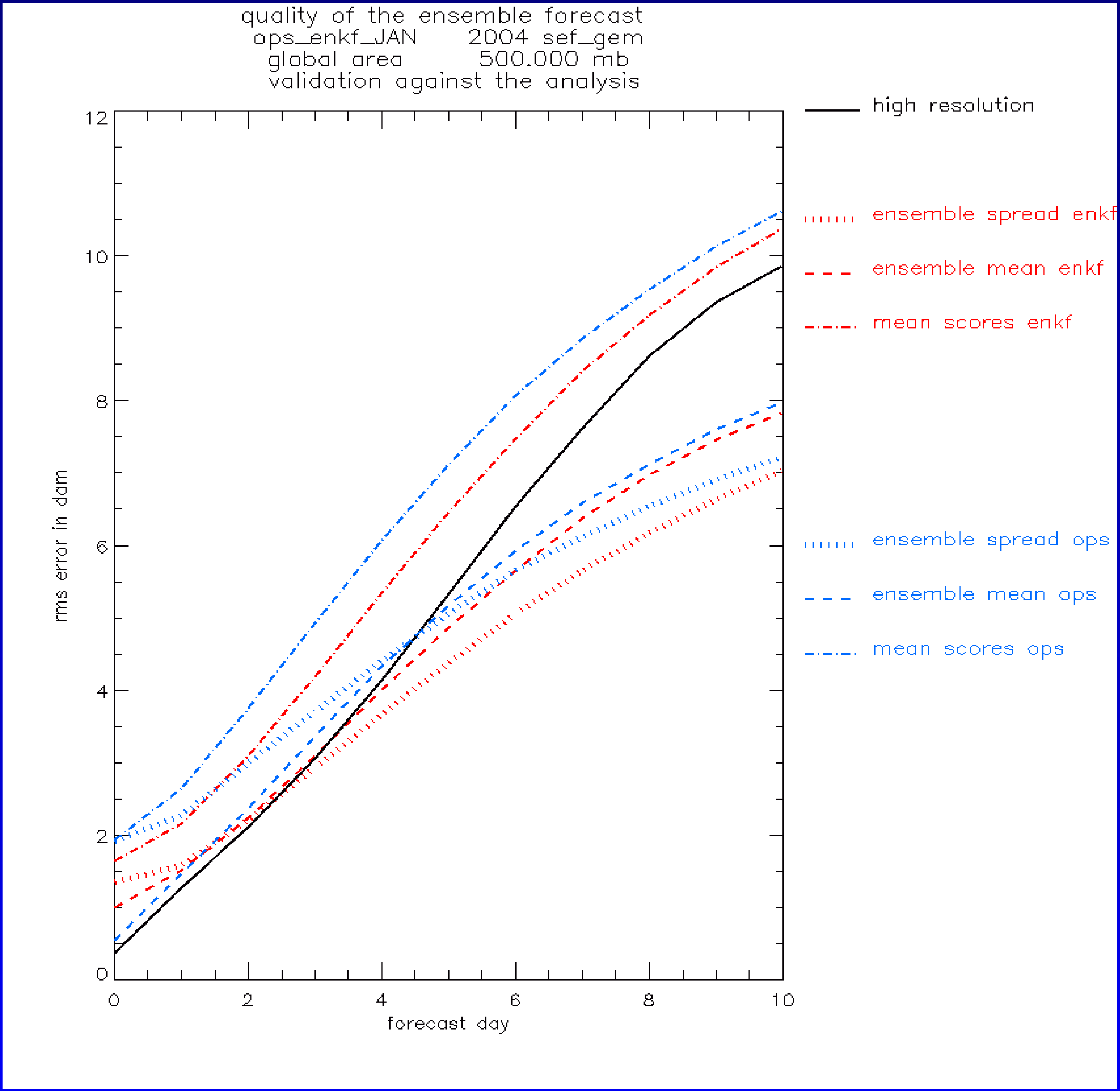
- *Choose randomly 16 members out of 96, preserving the ensemble mean.*
- *Inflate the ensemble standard deviation by a factor of 1.5 for u, v, T, q, and p_{surf}*
- *Correct q to avoid supersaturation and negative specific humidity*

Medium Range Ensemble Forecasting at CMC

- *Use of multi-model multi-parameterization approach*
  - *This is our current way of representing the “model error” component of the 10-day forecasts*
  - *The initial condition uncertainties are provided by the EnKF*
- *8 members from the GEM model (grid point) at 300x150*
- *8 members from the SEF (spectral finite element) at T149*

Description of the different models

SEF (T149)	Radiation scheme	Convection Schemes deep	Convection Schemes shallow	Surface scheme	Number of levels	Time level
Control	Garand	Kuo	conres	Fcrest	27	3
1	Garand	Kuo	conres	ISBA	27	3
2	Garand	Ras	ktrsnt	Fcrest	27	3
3	Garand	Kuo	conres	Fcrest	27	3
4	Garand	Ras	ktrsnt	ISBA	27	3
5	Garand	Ras	ktrsnt	Fcrest	27	2
6	Garand	Kuo	conres	ISBA	27	2
7	Garand	Ras	ktrsnt	ISBA	27	2
8	Garand	Kuo	conres	Fcrest	27	2
GEM (1.2^0)	**Radiation Scheme**	**Convection Schemes deep**	**Convection Schemes shallow**	**Surface scheme**	**Number of levels**	**Time level**
9	Garand	Kuosym	ktrsnt	Fcrest	28	2
10	Garand	Ras	conres	ISBA	28	2
11	Garand	Ras	conres	Fcrest	28	2
12	Garand	Kuosym	ktrsnt	ISBA	28	2
13	Garand	Kuostd	ktrsnt	Fcrest	28	2
14	Garand	Kuostd	ktrsnt	ISBA	28	2
15	Garand	Kuosym	conres	ISBA	28	2
16	Garand	Kuo	conres	Fcrest	28	2



quality of the ensemble forecast
ops_enkf_JAN 2004 sef_gem
global area 500.000 mb
validation against the analysis
high resolution
ensemble spread enkf
ensemble mean enkf
mean scores enkf
ensemble spread ops
ensemble mean ops
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rms error in dam
forecast day
0
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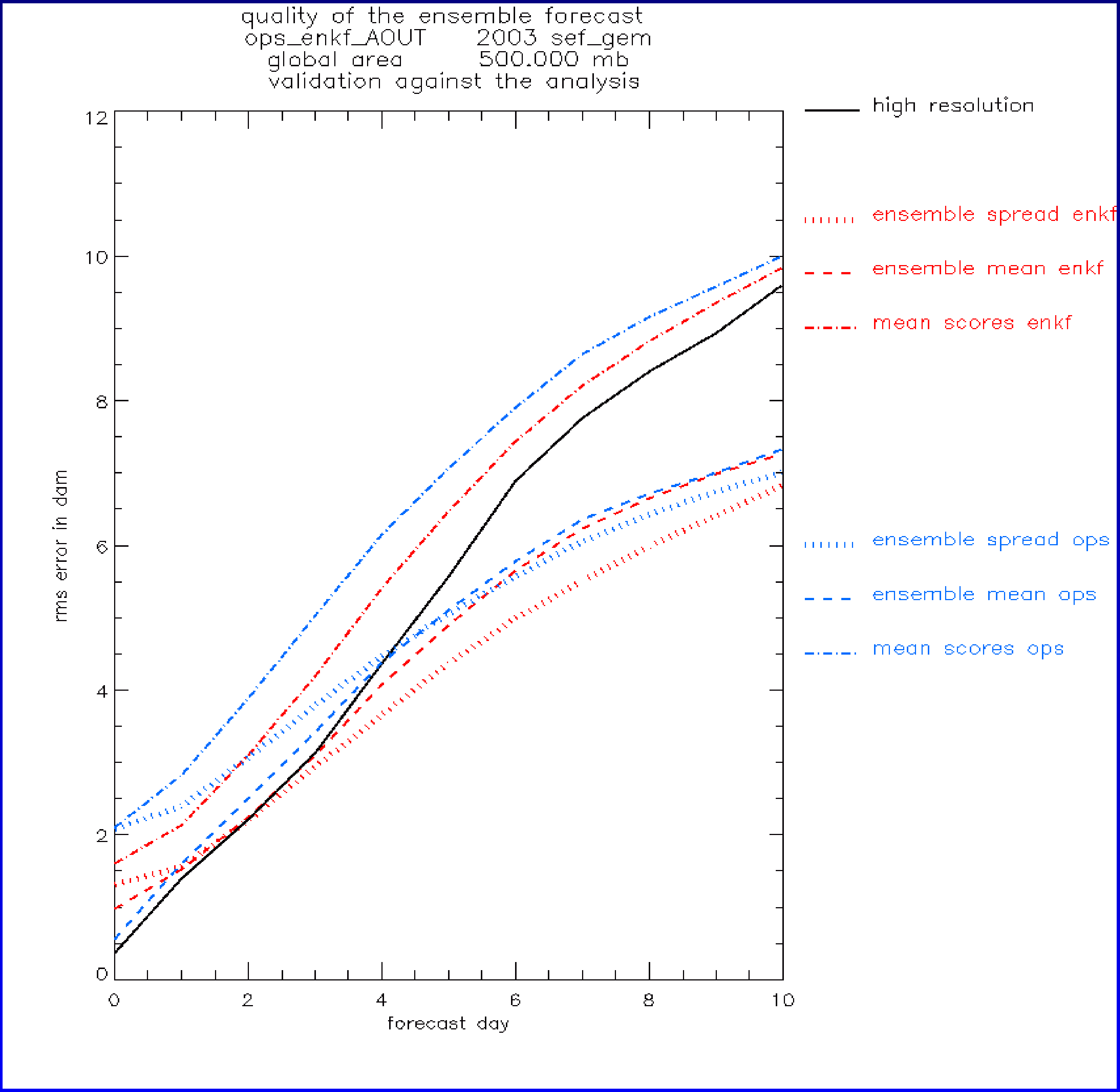
4
6
8
10
12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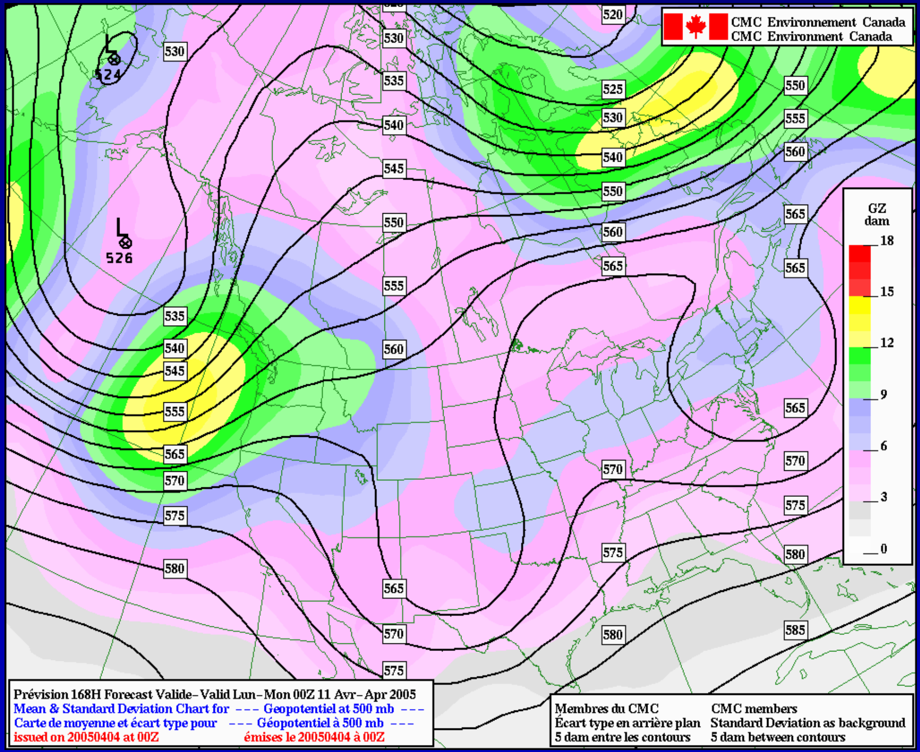
12

In Development

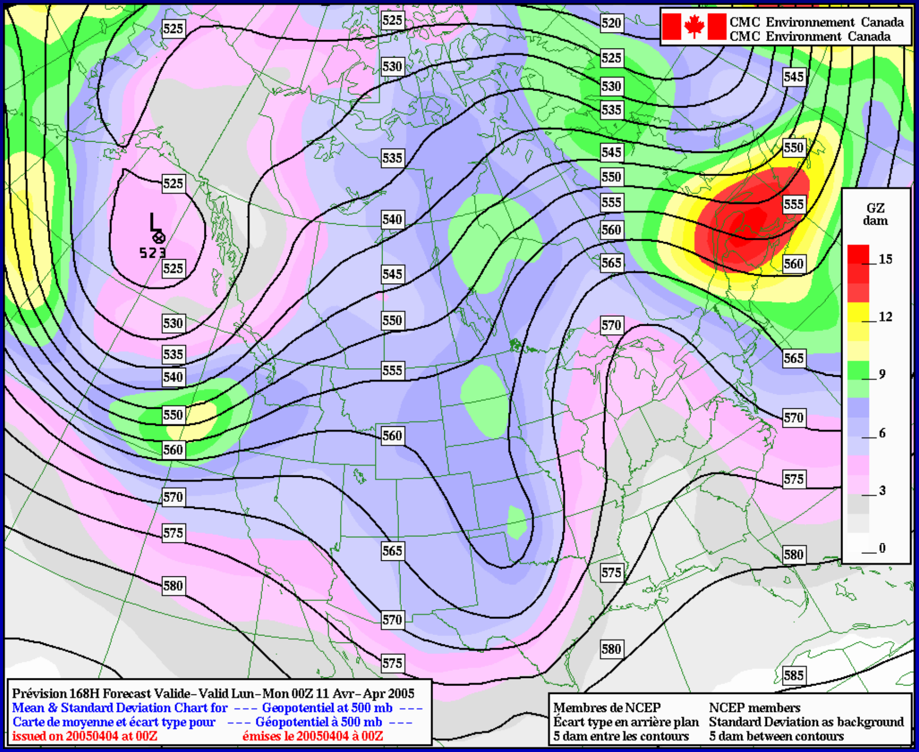
- EnKF
  - 4 ensemble configuration (allow weaker localization)
  - Later stage, assimilate data at non-synoptic times
- Forecast models
  - Test stochastic backscatter scheme based on Shutts
  - Reduce number of parameterizations
  - Extend forecasts to 15 days twice daily

The North-American Ensemble Forecast System (NAEFS)

- *Participants: MSC (Canada), NWS (USA), and NMSM (Mexico)*
- *High level agreement: Feb. 2003 (Mexico became involved in Oct. 2004)*
- *Product generation made routinely at MSC: early 2005 (in development mode, still not operational)*
- *Major tasks:*
  - *Exchange ensemble data between two centers (MSC and NWS)*
  - *Bias correction of each set of ensemble*
  - *Develop products based on joint ensemble (high impact weather?)*
  - *Verify joint product suite, evaluate added value*



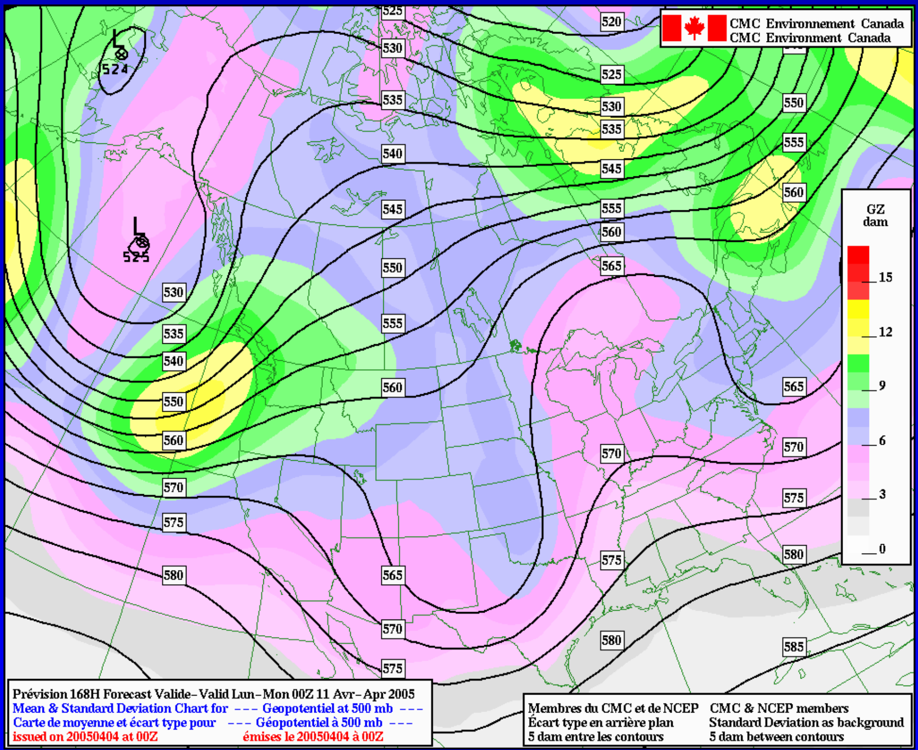
MSC



NWS

GZ at 500 hPa ensemble mean (black lines)

Ensemble standard deviation (color code)



7-day forecast over North America valid April 11 2005

Joint

Development of a Regional EPS

M. Charron (MSC), L. Spacek (MSC), Li Xiaoli (McGill)

- *Regional EPS based on targeted singular vectors*
  - *A version at 28 km resolution with 20 members over North America (LAM)*
  - *A version at 15 km resolution with 16 members over Eastern Canada (LAM)*

The 15 km REPS at MSC-McGill

- *8 singular vectors are calculated on a low resolution global grid (240x120, or about 150 km)*
- *Initial norm is global; final norm is located over a domain covering Eastern Canada (will be adapted to be over Beijing)*
- *Optimisation period is 24h and singular vector calculation includes*
  - *Vertical diffusion*
  - *Gravity wave drag*
  - *Deep Convection (Kuo)*
  - *Stratiform precipitation*
- *SVs are interpolated to the resolution of the pilot model (100 km res.)*
- *SVs are used to perturb the pilot runs producing lateral boundary and initial conditions of 16 LAM integrations*

Physics perturbations with Markov processes

- *Physical parameters/tendencies can be perturbed by a function F(λ,φ,η,t) given by:*

$$f(\lambda,\varphi,\eta,t)=\sum_{l=0}^{L}\sum_{m=-l}^{l}\sum_{k=0}^{K}a_{lmk}(t)Y_{lm}(\lambda,\varphi)e^{ik\eta}$$

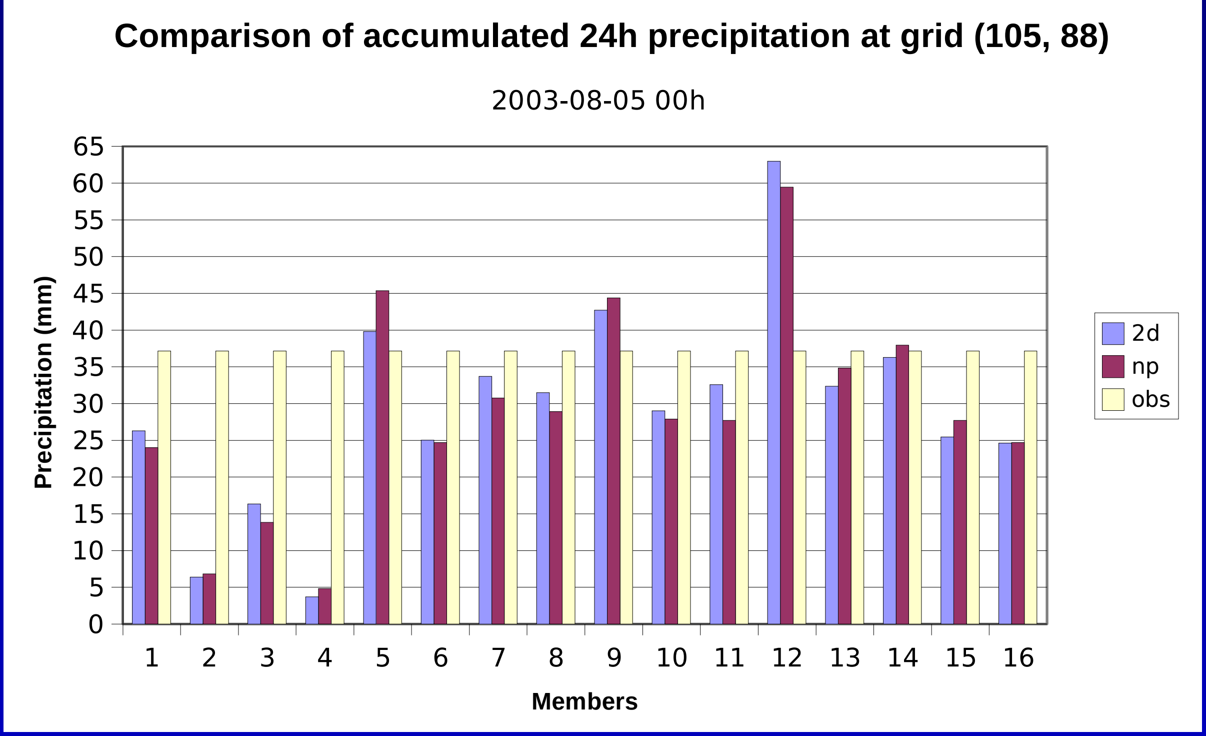
$$a_{lmk}(t)=e^{-\Delta t/\tau}a_{lmk}(t-\Delta t)+R(t)$$

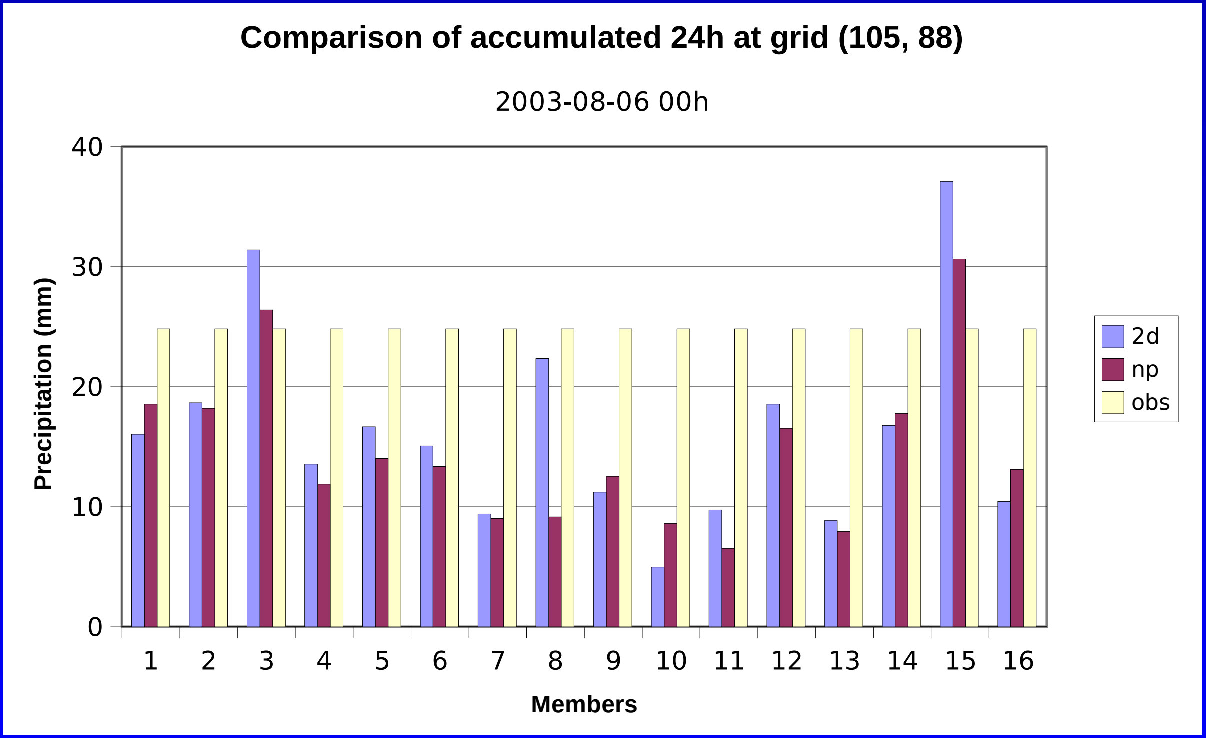
$$F(\lambda,\varphi,\eta,t)=Sf(\lambda,\varphi,\eta,t)$$

Perturbation of CAPE in the Kane-Fritsch convection scheme

- *Only the LAMs are perturbed with Markov chains*
- *CAPE perturbation similar to Lin and Neelin (GRL 2000), except*
  - *CAPE becomes CAPE**$F(\lambda,\varphi,t)$
- *Decorrelation time scale: 12 and 6 hours*
- *Truncation of the perturbed field: T7 and T14*

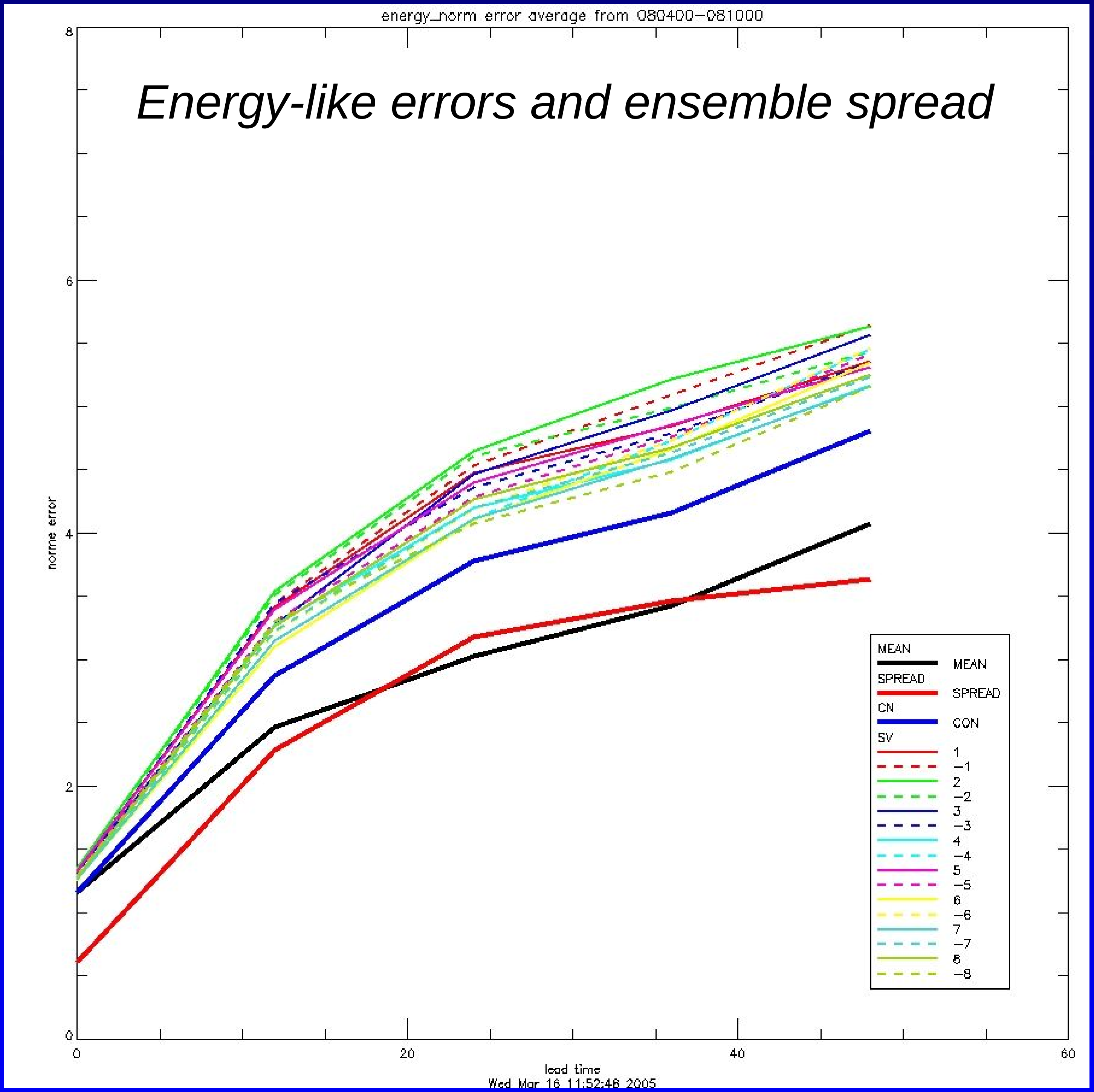
Impact of perturbing CAPE on precipitation





- ➔ *Perturbing the ICs with SVs has more impact on precip than perturbing CAPE*

Energy-like errors and ensemble spread

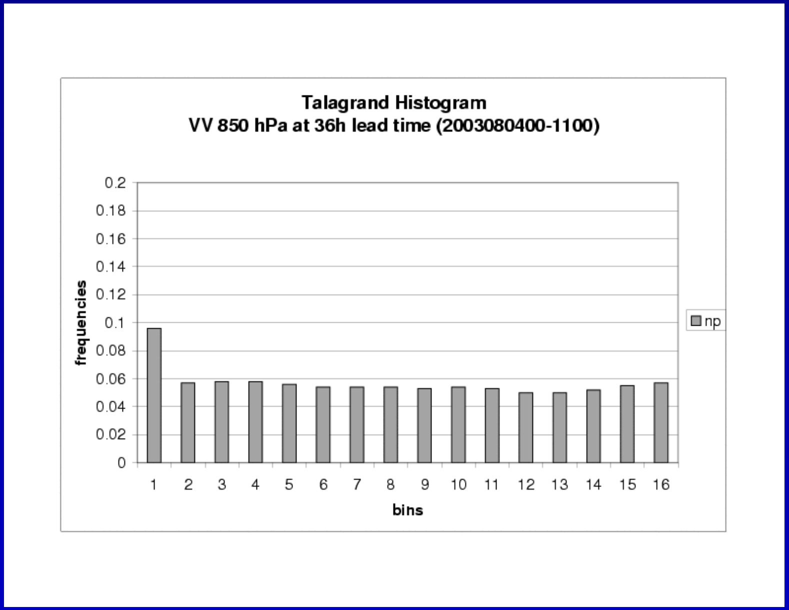


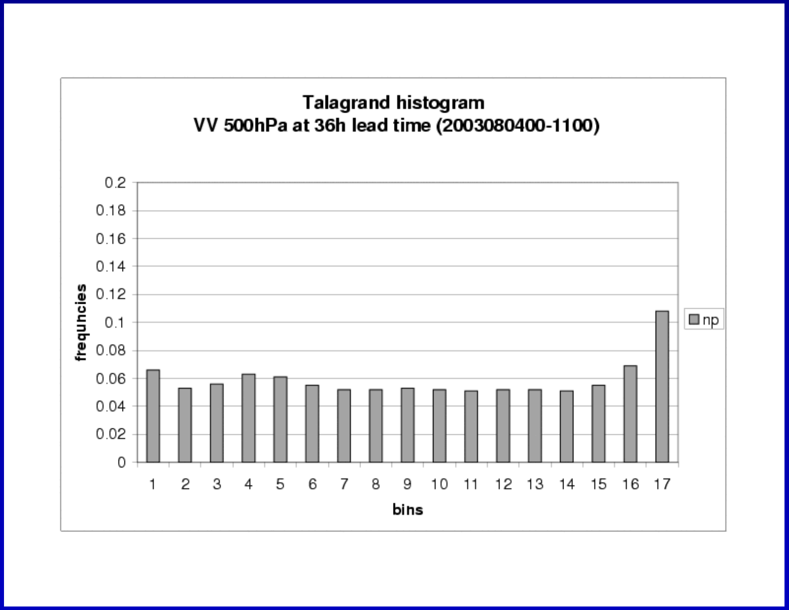
Blue: Unperturbed

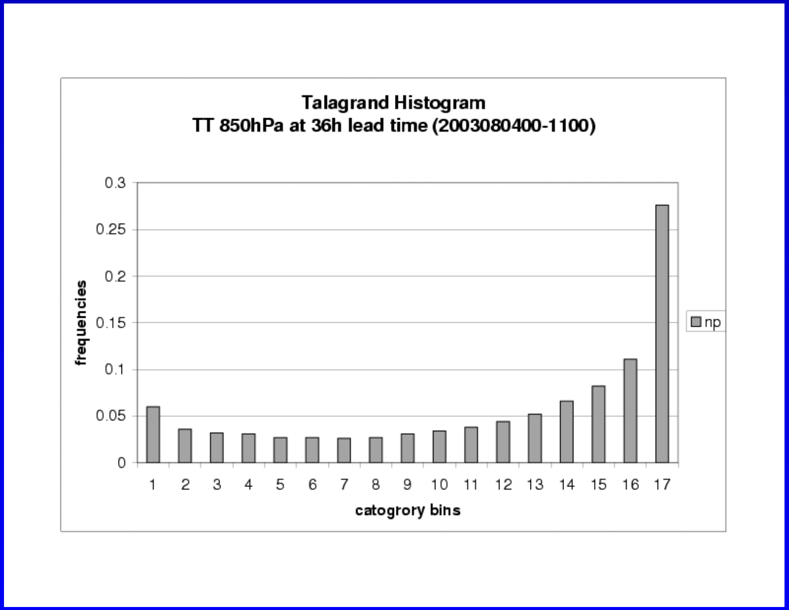
Black: Ens. Mean

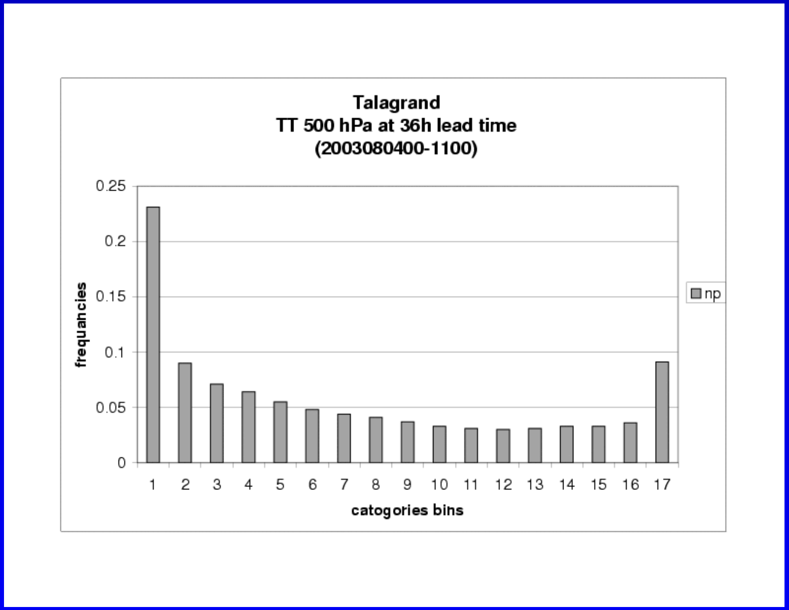
Red: Ens. Std Dev.

Talagrand Diagrams (August 4 to 11, 2003)









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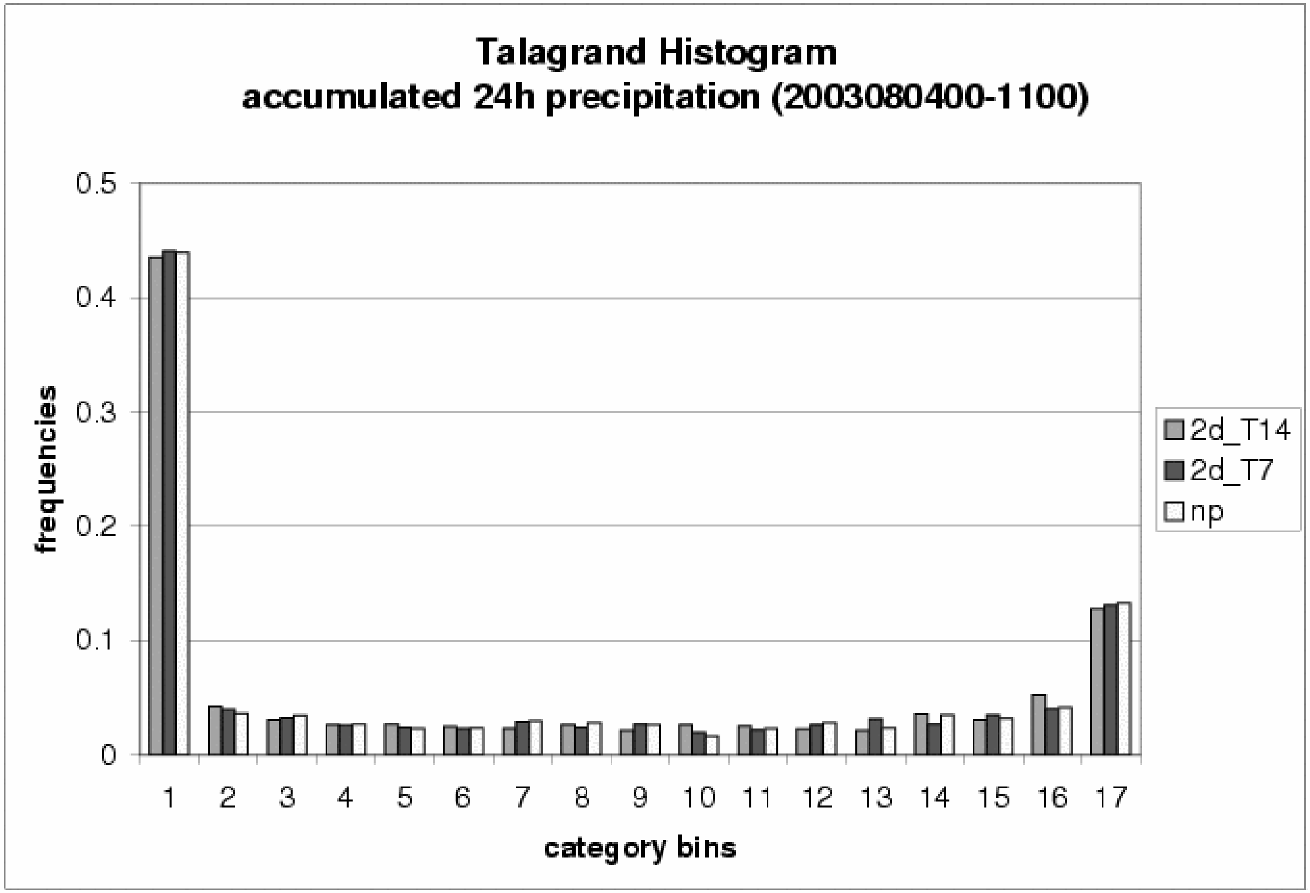
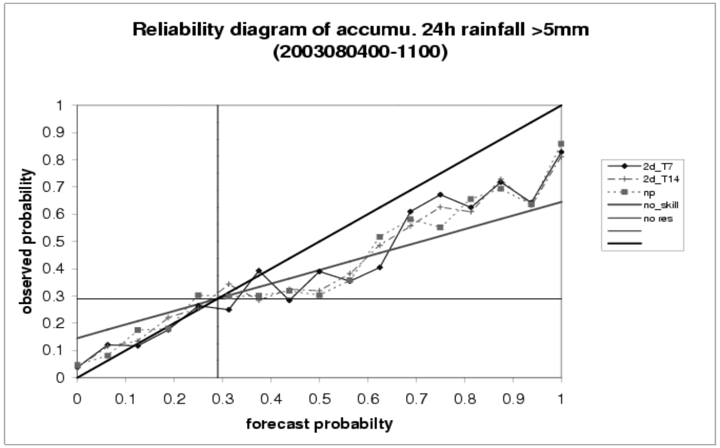
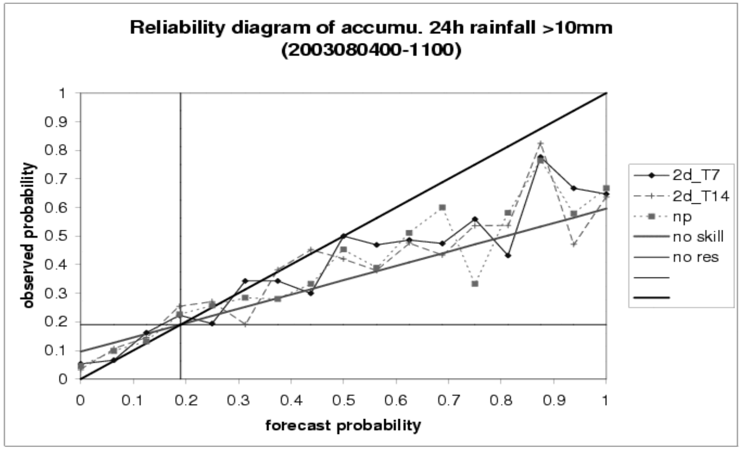
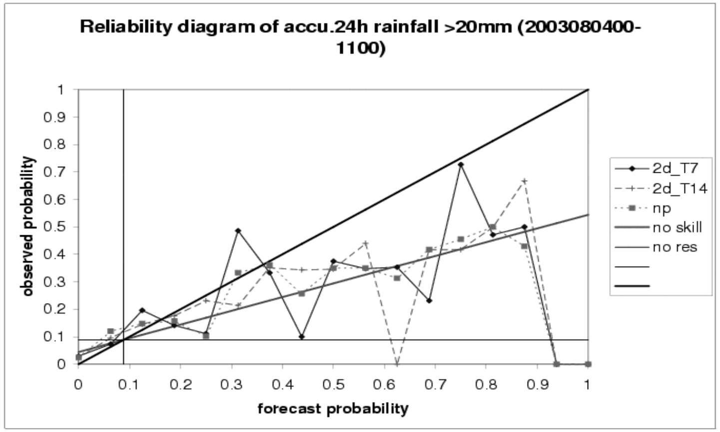
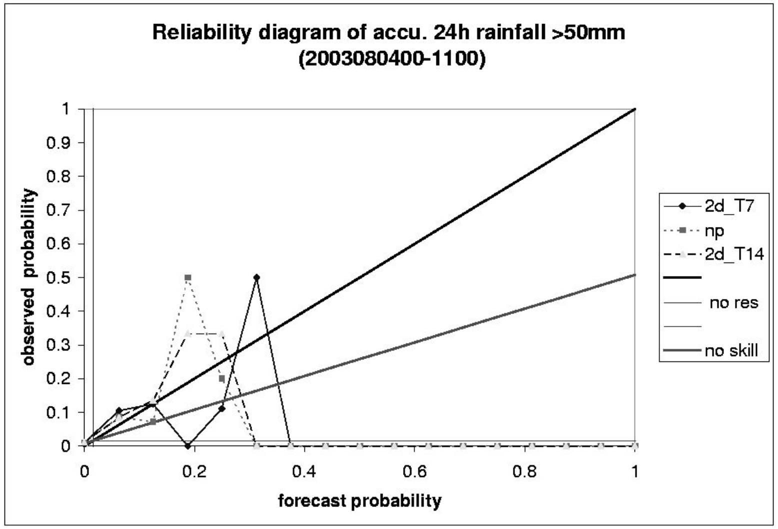


Reliability Diagrams for Precipitation









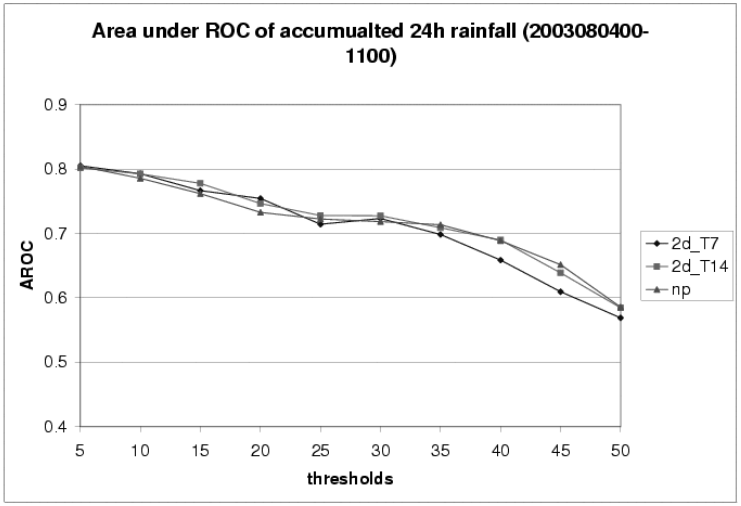
Relative Operating Characteristics (ROC) and Brier Skill Scores (BSS)

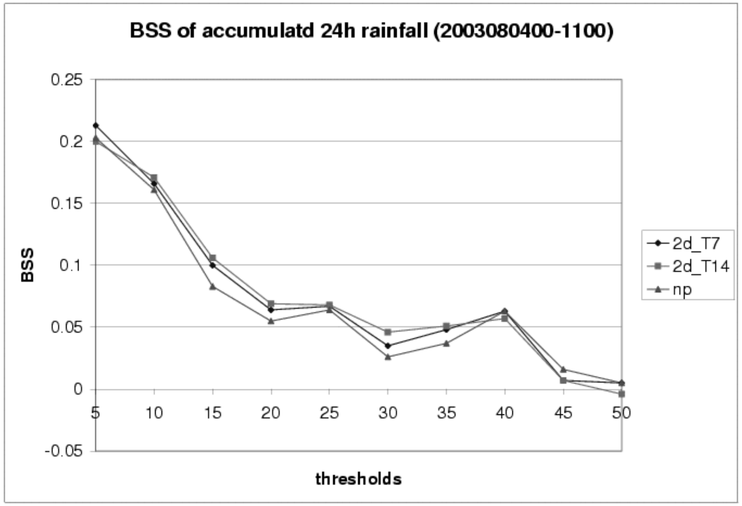
- *For precipitation:*
  - *Binary event: 24-hour accumulation (lead times from 12 to 36 hours) is greater than some specified thresholds*
  - *Dataset: 300 rain gauges over Québec*
- *For temperature:*
  - *Binary event: temperature is lower than mean temperature minus one standard deviation (different at each grid point and calculated over the studied period)*
  - *Dataset: 3D-VAR analyses at 15 km resolution*

Area under ROC

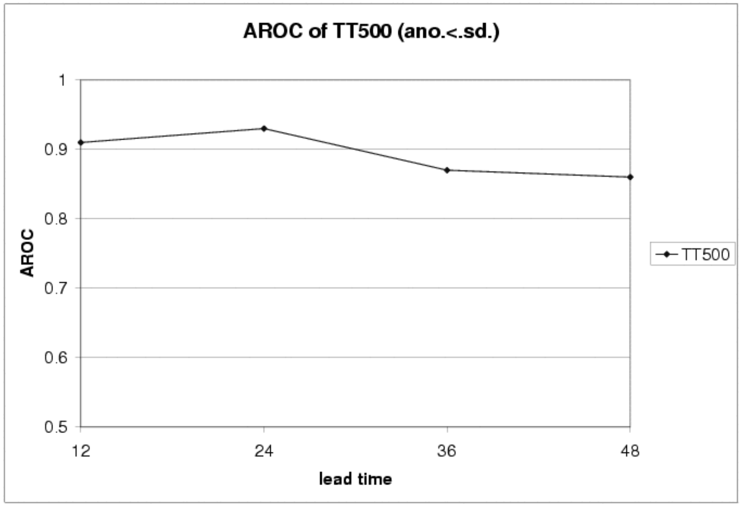
Brier Skill Score

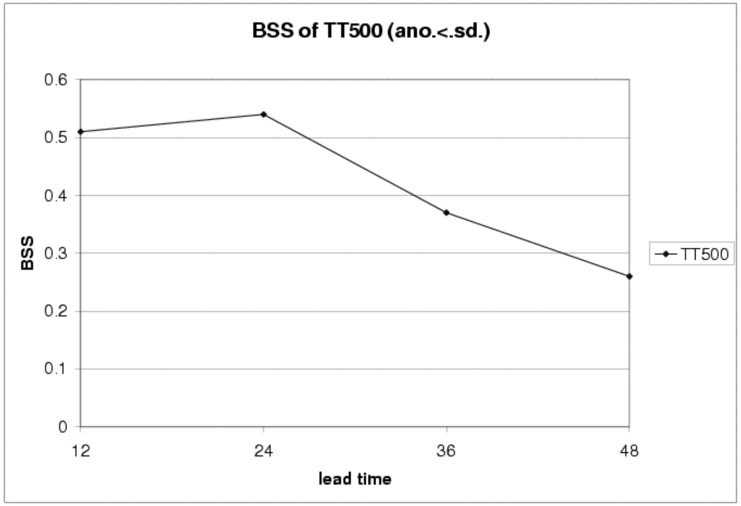
Precip. 24-h accum





Temperature





Long term objectives

- *Find a better way to account for uncertainties of the model, perhaps by introducing parameterizations that are inherently stochastic*
- *Develop a regional ensemble Kalman filter (stretched grid or limited area model)*
- *Compare the singular vector approach and a (still to be built) regional EnKF for regional ensemble predictions*