The Canadian ensemble prediction system (EPS)

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At MSC, we issue daily medium-range ensemble forecasts, based on 16 different 10-day forecasts. The differences between the 16 ensemble members are an indication of the quality of the 10-day ensemble-mean forecast.

Since 1992, many persons have contributed to the development of the EPS:

From the Canadian Meteorological Centre: Stéphane Beauregard (verification), Chantal Côté (data-assimilation), Marc Klasa (web-site and verification), Anne-Marie Leduc, Louis Lefaivre and Gérard Pellerin (system development).

From the Meteorological Research Branch: Martin Charron (modeling), Bjarne Hansen and Bin He (computing), Luc Fillion and Herschel Mitchell (data-assimilation) and Lubos Spacek (forecast model).

From McGill University: Prof. Jacques Derome

Overview

- history of EPS research at MSC (1992-2004).
- methodology.
- data-assimilation research.
- pre-operational tests with the ensemble Kalman filter.
- exchanges with other centers.
- future developments.

History

1992-1994: Development of the methodology.

1994-1998: Work towards the operational implementation of the first, 8 member, version of the EPS.

1999: Addition of 8 more members using a second dynamical model.

2001: Increase of the horizontal resolution from 1.875 to 1.2 degrees.

1994-2004: Research towards the use of an ensemble Kalman filter in the operational ensemble prediction system to replace the current Optimal Interpolation data-assimilation cycles.

2004: Operational testing of the ensemble Kalman filter.

We have 10 published papers on the design of EPS systems with 3 more papers accepted (12 in Monthly Weather Review and 1 in Nonlinear Processes in Geophysics).

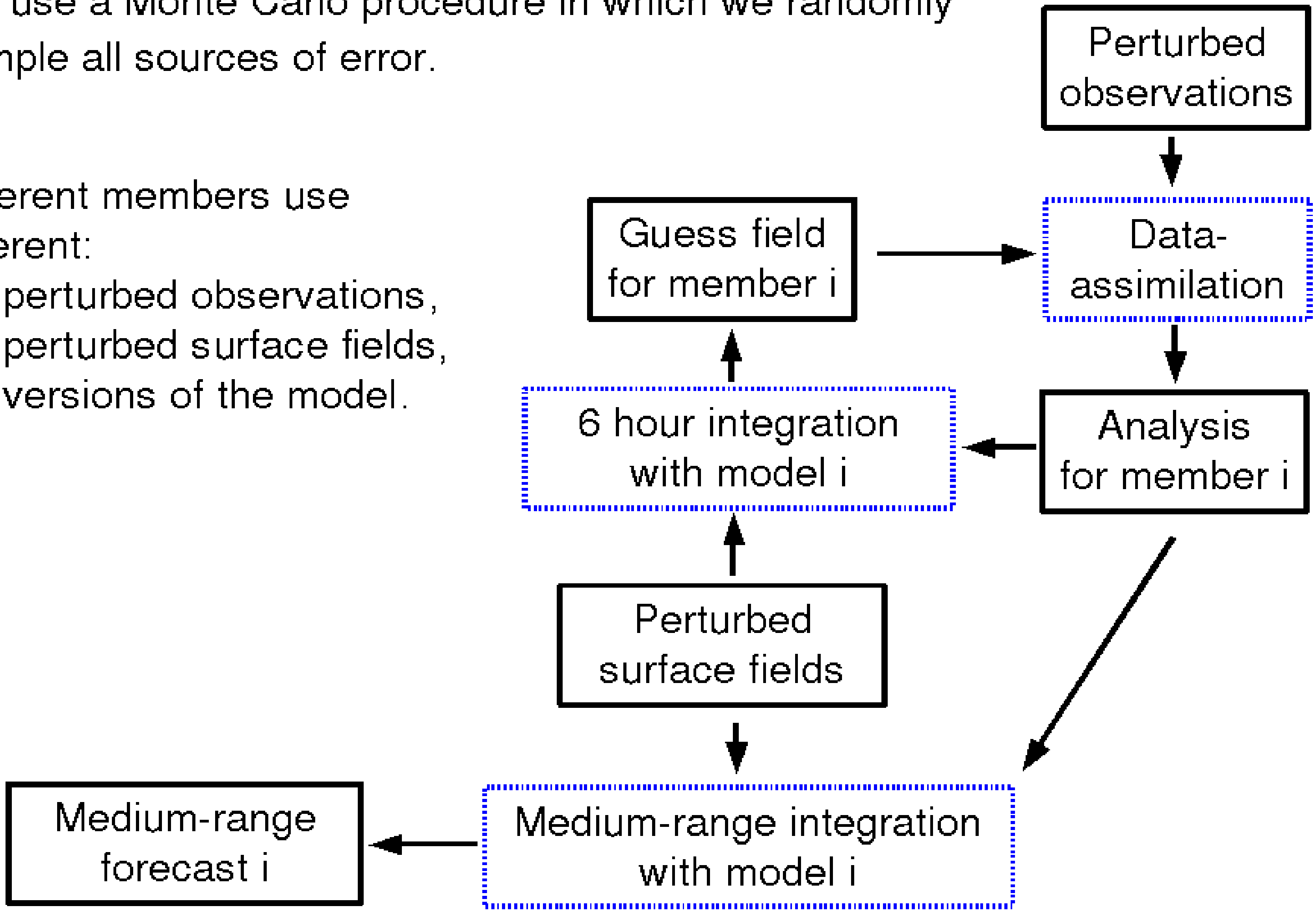
The stability of the working environment, with in particular the continuing support from MSC management, is acknowledged as an important factor in the success of the multi-year research and development projects.

The Monte Carlo approach to ensemble prediction

We use a Monte Carlo procedure in which we randomly sample all sources of error.

Different members use different:

- perturbed observations,
- perturbed surface fields,
- versions of the model.



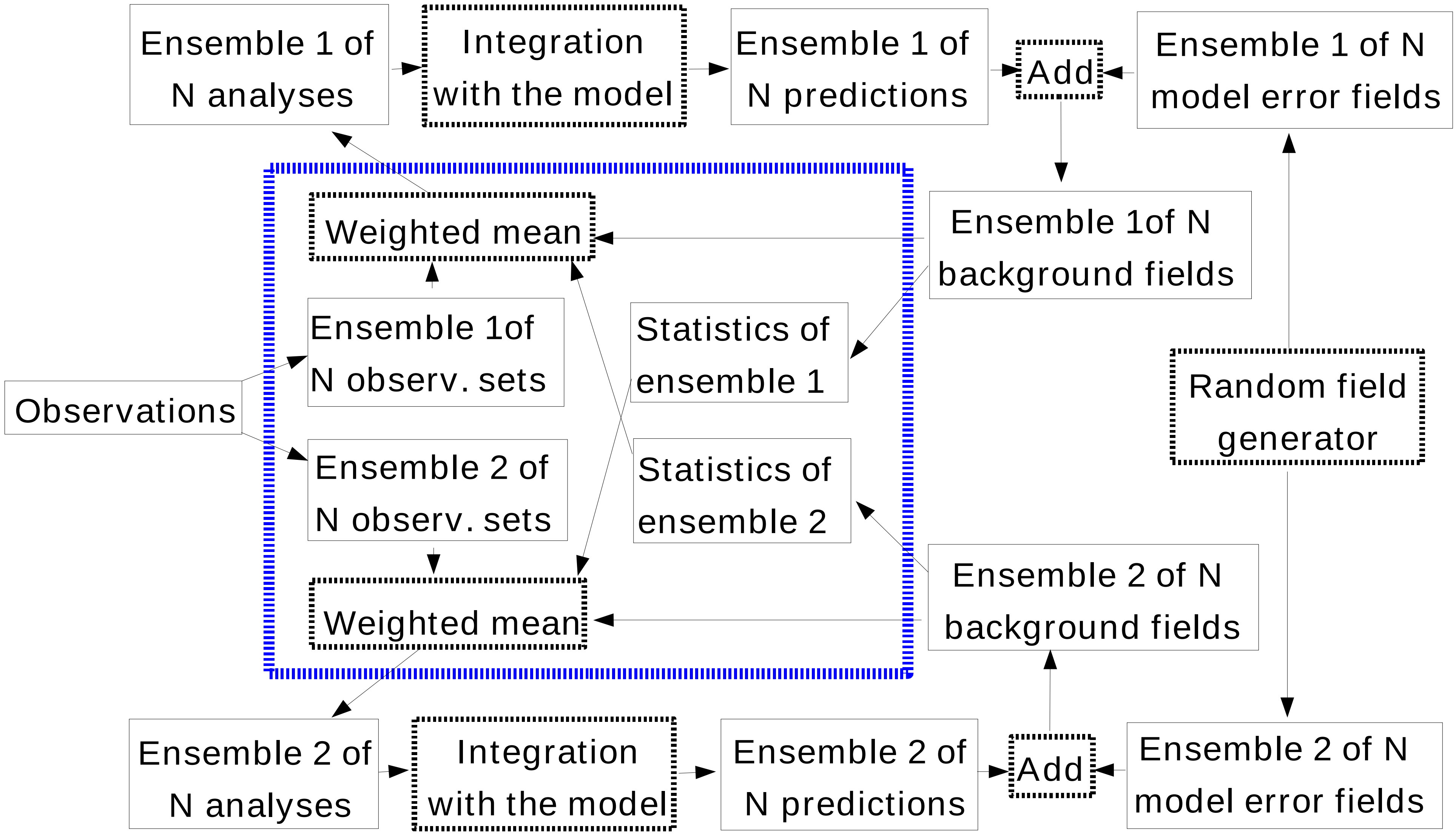
The ensemble Kalman filter

The ensemble Kalman filter (EnKF) is a 4-dimensional data-assimilation method that uses a Monte-Carlo ensemble of short-range forecasts to estimate the covariances of the forecast error.

In 1994, we started investigating the fundamentals of the method using a simple and convenient experimental environment consisting of a hemispheric barotropic model and simulated observations of streamfunction.

Encouraged by the positive results of the increasingly realistic pilot studies, we gradually transformed our research code towards a quasi-operational code that can assimilate almost all operationally available observations into the GEM primitive-equation model.

Double Ensemble Kalman Filter



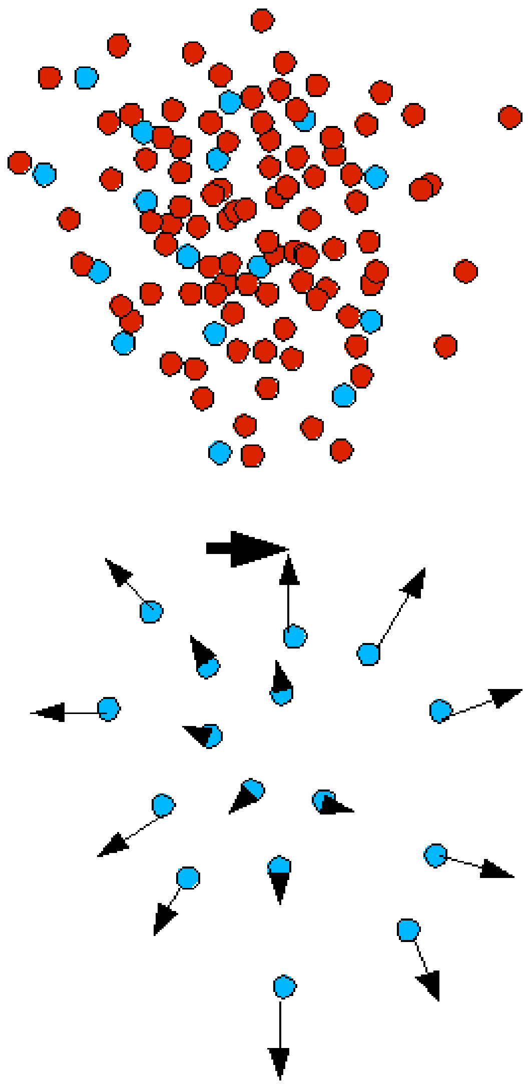
The proposed operational configuration of the EnKF.

We use a recent version (3.1.1) of the GEM-DM dynamical model. The horizontal and vertical resolution ($300 \times 150 \times 28$) match that of the GEM model in the ensemble prediction system.

We assimilate almost all the observations that are used by the operational 3D-VAR for the deterministic forecast at resolution ($400 \times 200 \times 28$), including the AMSU-A and AMSU-B radiances. We do not yet assimilate the surface observations of humidity and those observations that have recently (September 2004) been included in the deterministic system (MODIS wind observations, GOES humidity observations, AQUA AMSU-A radiances and profiler wind observations).

For both the model and the observational network, we try to stay close to the higher-resolution deterministic system.

From the ensemble of 96 analyses that are provide by the EnKF, we sample, once daily, 16 initial conditions for the 10-day integration of the EPS.



Recipe to obtain 16 initial conditions from an ensemble of 96 members:

1) Eliminate 96-16=80 ensemble members while preserving the ensemble mean.

2) Multiply the standard deviation by 1.5.

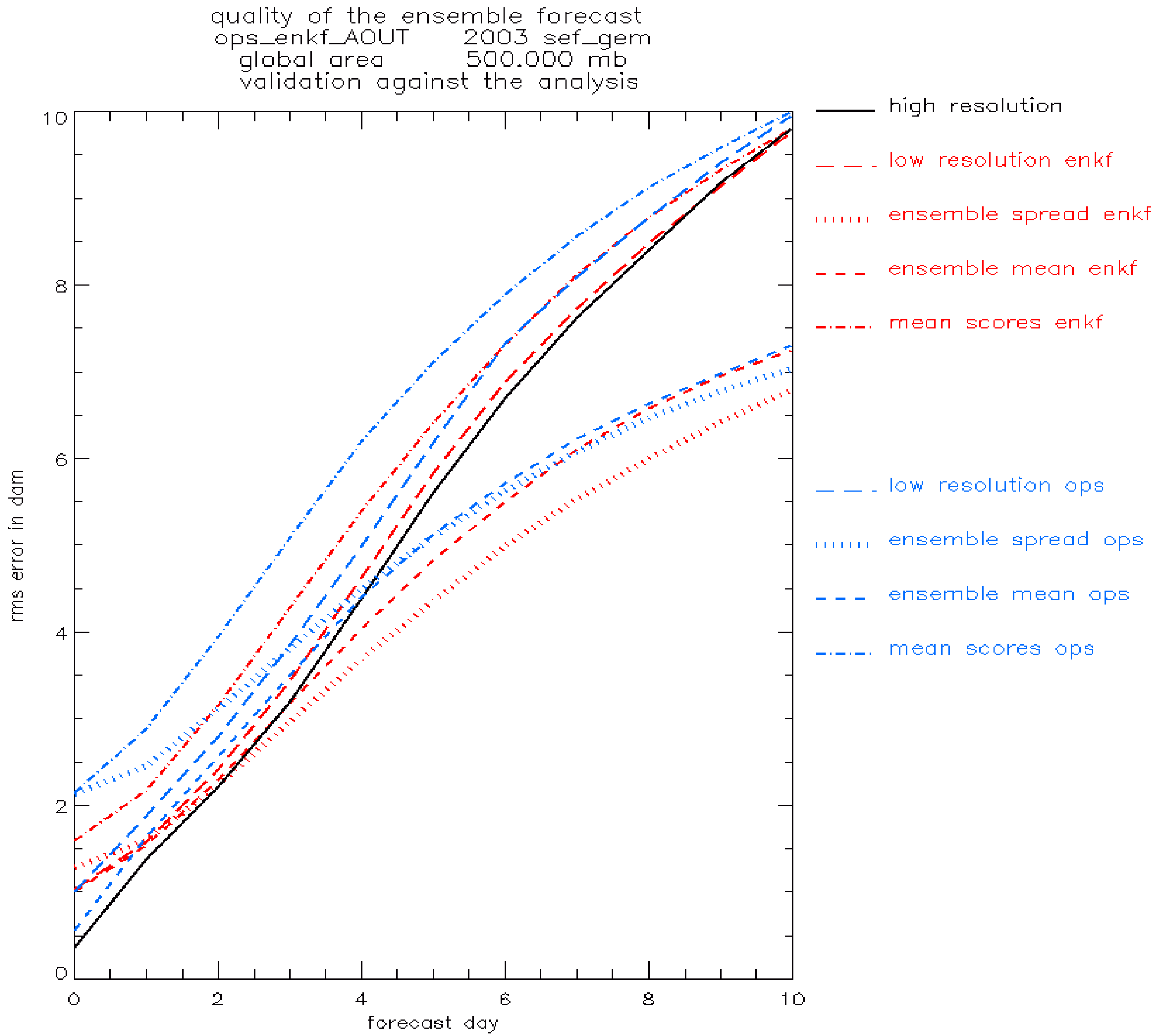
3) Correct supersaturation and negative specific humidity.

Status of pre-operational tests.

To motivate the transfer of the EnKF to operations, we performed objective verifications for the periods 27 July 2003 - 31 August 2003 and 7 January 2004 - 12 February 2004. We compared:

- The operational EPS system, which obtains its initial conditions from 8 independent data-assimilation cycles that each use differently perturbed observations, an Optimal Interpolation data-assimilation algorithm and the spectral forecast model. To make up for the fairly low quality of the ensemble of analyses, the system includes a correction towards the deterministic 3D-VAR analysis.
- An identically configured EPS, with the initial conditions now coming from the EnKF. This system uses the 3D-VAR only for the quality control of the observations.

The parallel testing started on 26 August 2004. Objective verifications for the period 26 August 2004 - 23 September 2004 are highly similar to those that had been obtained in research mode. Since October 5, we also have a parallel website with products.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global area 500.000 mb
validation against the analysis
rms error in dam
forecast day
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high resolution
low resolution enkf
ensemble spread enkf
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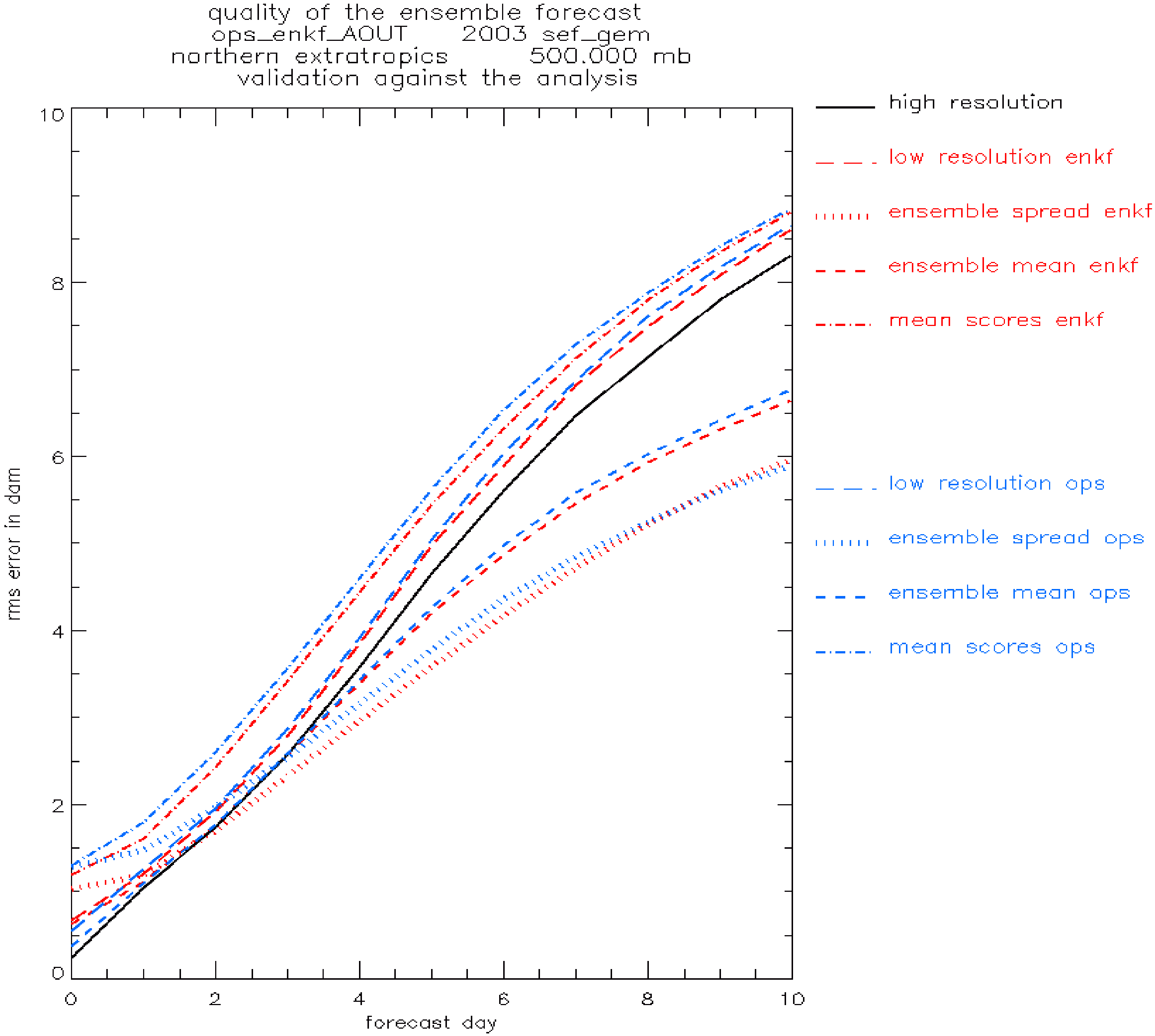
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Summary of the verifications

We have verified one month of summer forecasts, one month of winter forecasts and 8 weeks of parallel runs.

With the EnKF:

- We obtain a higher quality ensemble-mean for in particular the Southern Hemisphere.
- We have initially a smaller spread in the ensemble, but we have faster growth-rates of the perturbations, leading to a better overall agreement between the amplitude of the ensemble spread and the ensemble mean error.
- The verifications for the individual members are better.

We continue the parallel run, to allow the operational forecasters, who only have the full suite of products since October 5, to evaluate the EnKF-based EPS. In the case of an operational implementation, this will be a "first ever" for our centre.

International Collaboration

- With the National Centers for Environmental Prediction (NCEP), we exchange the ensemble forecast on a quasi-operational basis. The purpose is to arrive at a joint set of products based on the combined NCEP-MSC ensemble.
- We exchange ideas with the Australian Bureau of Meteorology, which has a project to develop and implement an EnKF.
- With NCEP and the European Centre for Medium-Range Weather Forecasts (ECMWF), we performed a comparative verification of our medium-range ensemble prediction systems for the period May-June-July 2002.

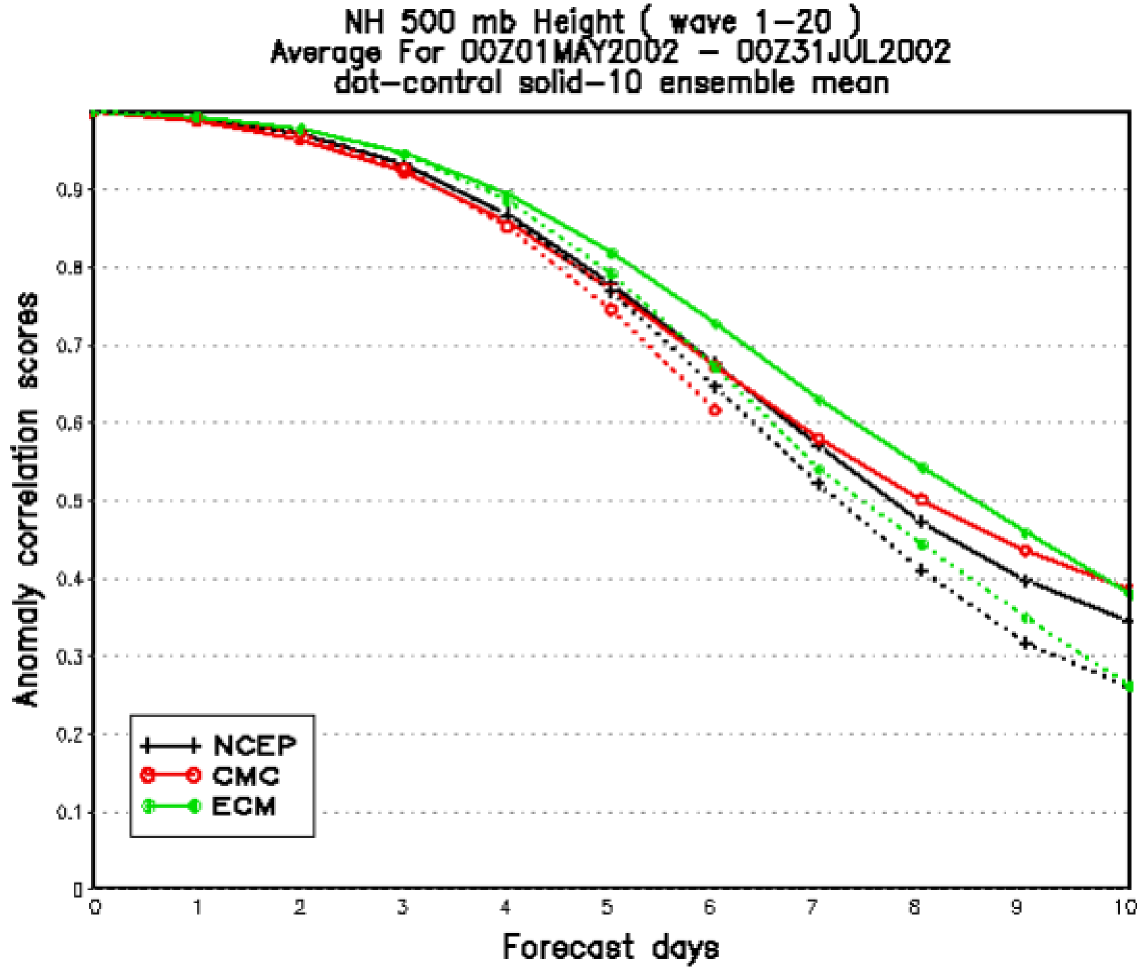

Figure 4. May-June-July 2002 average PAC for the control (dotted lines) and the ensemble-mean (solid lines) of the EC-EPS (green lines), the MSC-EPS (red lines) and the NCEP-EPS (black lines).Values refer to the 500 hPa geopotential height over the northern hemisphere latitudinal band 20º-80ºN.

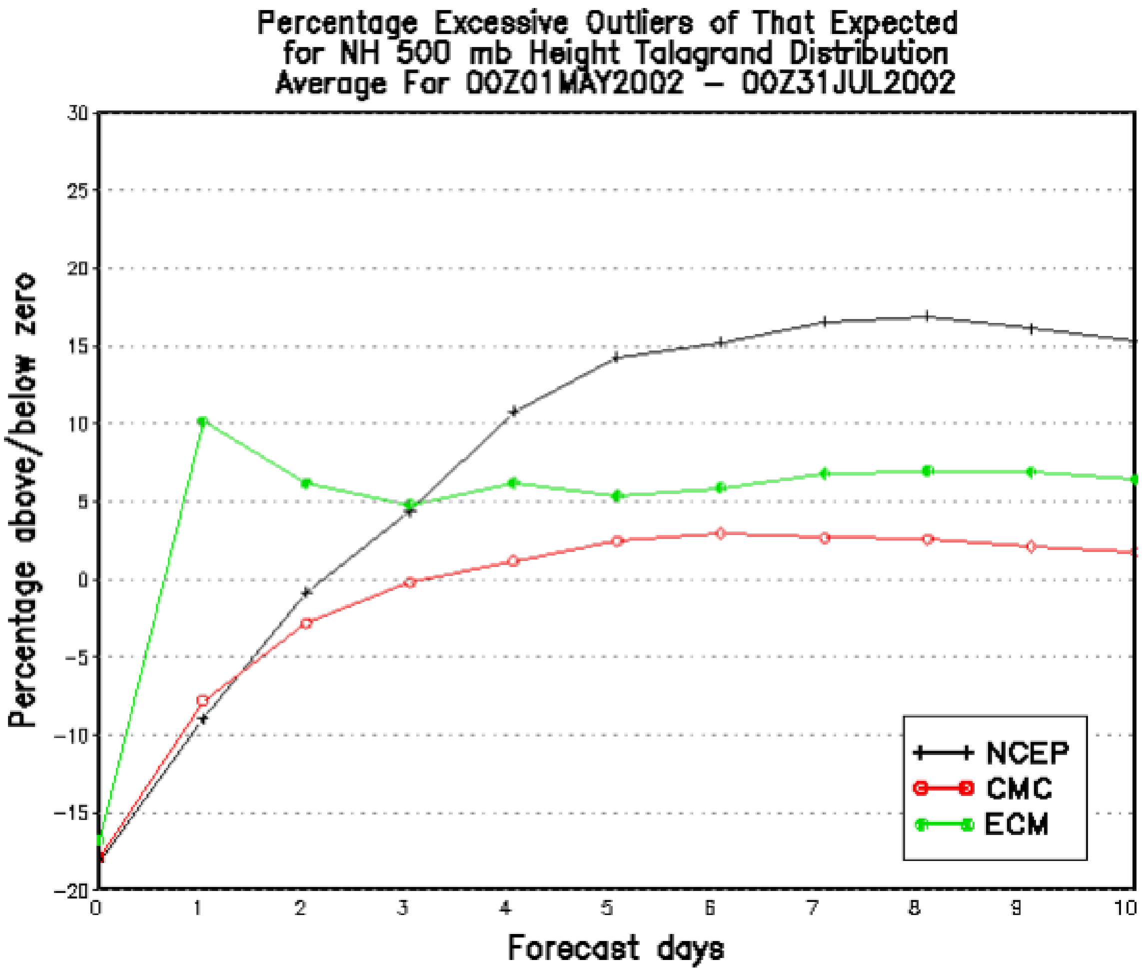

Figure 9. May-June-July 2002 average percentage of excessive outliers for the EC-EPS (green lines), the MSC-EPS (red lines) and the NCEP-EPS (black lines). Values refer to the 500 hPa geopotential height over the northern hemisphere latitudinal band 20º-80ºN.

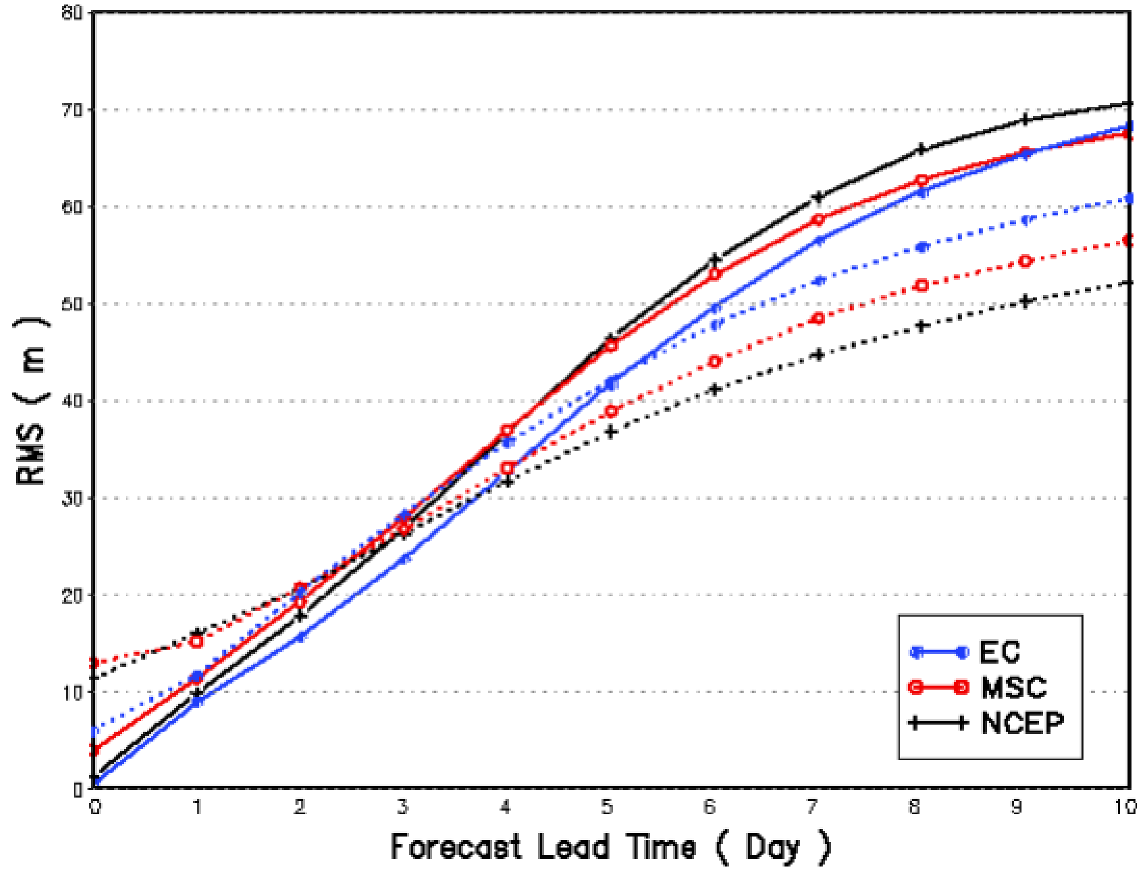

Figure 5. May-June-July 2002 average RMS error of the ensemble-mean (solid lines) and ensemble standard deviation (dotted lines) of the EC-EPS (blue lines), the MSC-EPS (red lines) and the NCEP-EPS (black lines). Values refer to the 500 hPa geopotential height over the northern hemisphere latitudinal band 20º-80ºN.

Summary of the ECMWF, NCEP, MSC EPS comparison

Conclusions:

1. The performance of an EPS depends strongly on the quality of the data assimilation and forecasting system that is used to create the initial conditions and to compute the numerical integrations.
2. A successful EPS should simulate the effect of both initial condition and model related uncertainties on forecast errors.
3. All three global systems still present a mismatch between the time-evolution of the ensemble standard deviation and the ensemble-mean error curves, suggesting that none is able to simulate in an efficient way all sources of forecast uncertainty.

The results were presented at an ECMWF seminar and will be published in Monthly Weather Review.

Upcoming implementations

1. Ensemble Kalman Filter (January 2005),
   Depends on the evaluation by the operational meteorologists.
2. Twice daily integrations (February 2005),
   The mechanics need to be worked out.
3. Integrations out to day 15 (May 2005),
   At the same time we will add more observations to the EnKF.

In his presentation, Gilbert Brunet will give an extensive overview of the research plans for the EPS