Comparison of the forecast background errors for nested grids in COAMPS

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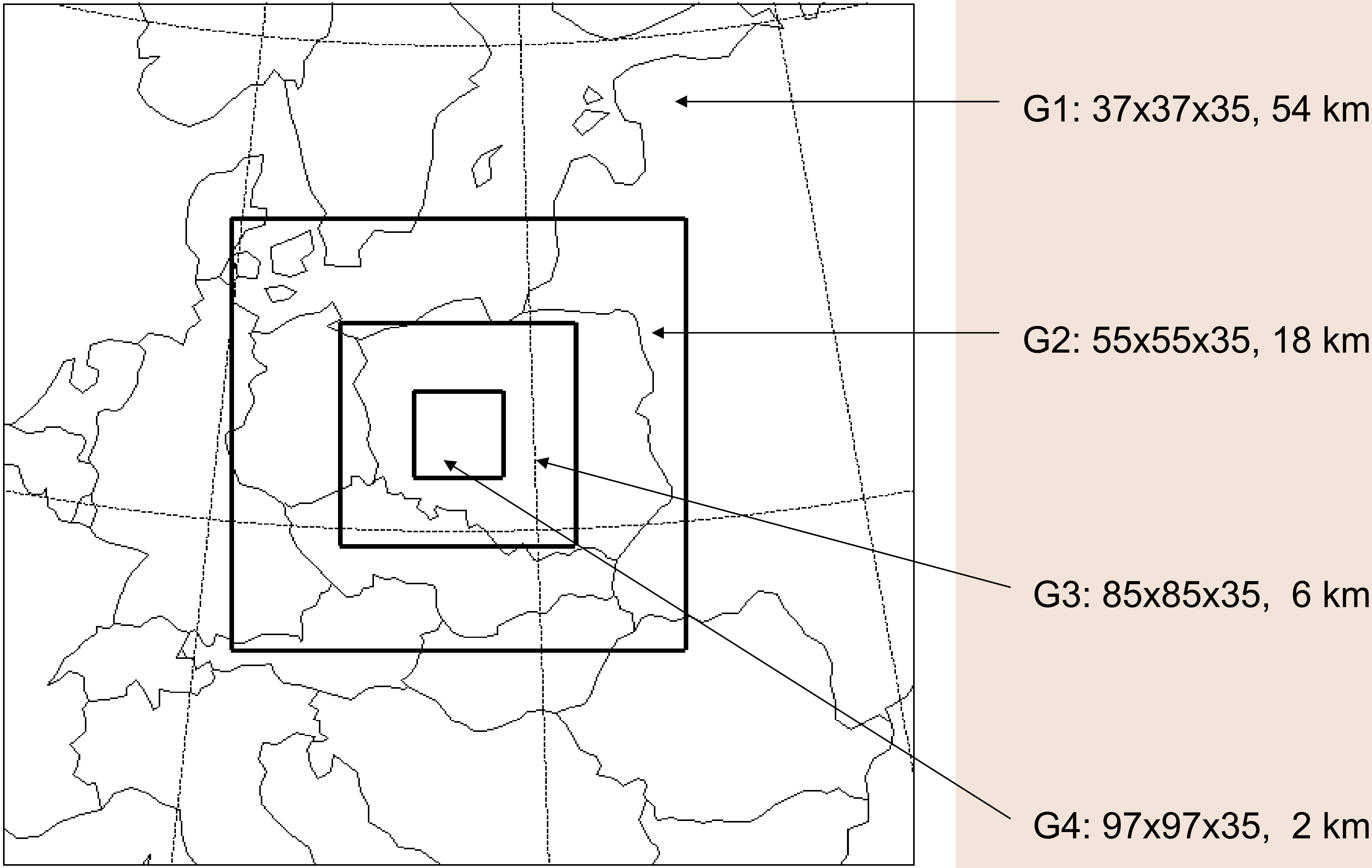
Mesoscale Modeling

COAMPS™: **Coupled Ocean/Atmosphere Mesoscale Prediction System**

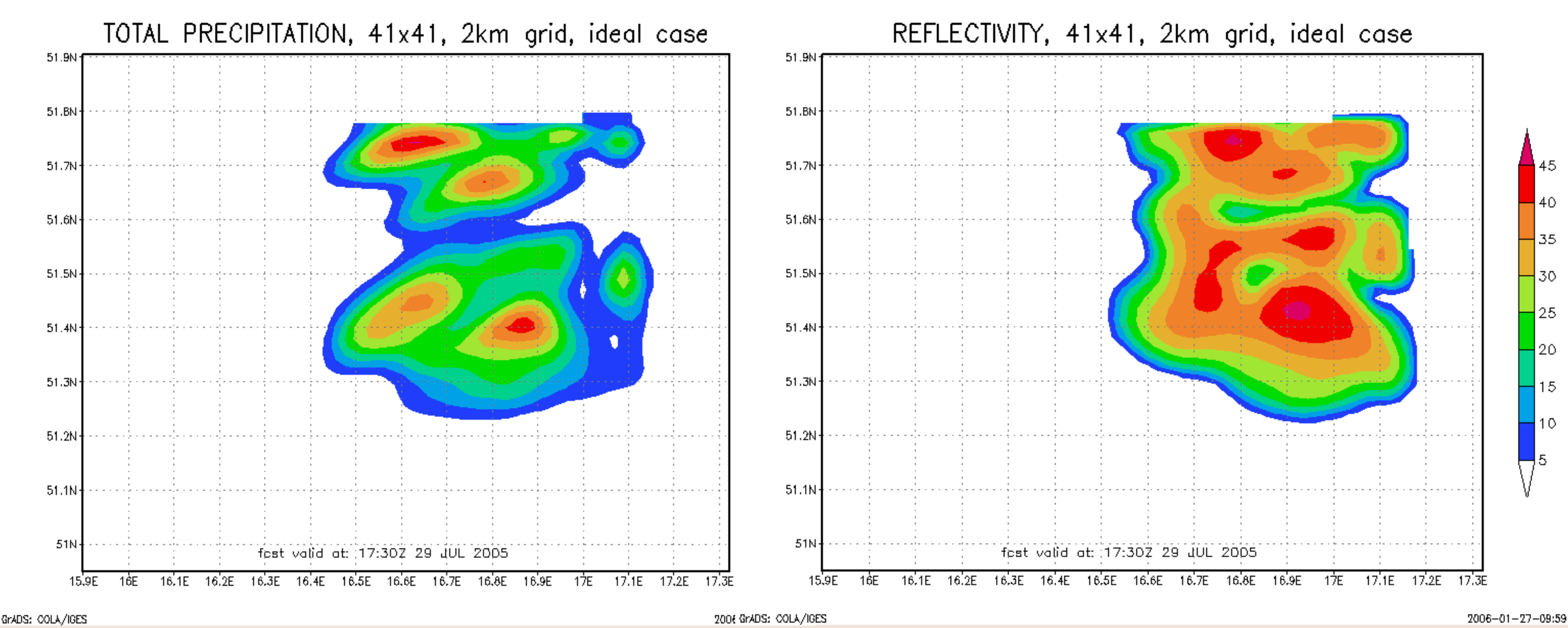
Focus: **0-3 day high-resolution forecasts**

- Complex Data Quality Control
- Analysis:
  - Atmosphere: MVOI analyses of u, v, and Heights; Univariate analyses of T, q
  - Ocean: 2D OI of SST; 3D MVOI of T, S, SSH, Sea Ice, and Currents
- Initialization:
  - Atmosphere: Hydrostatic Constraint on Analysis Increments, and/or Digital Filter
  - Ocean: Stability check
- Model:
  - Atmosphere:
    - Numerics: Nonhydrostatic, Scheme C, Nested Grids, Sigma-z, Flexible Lateral BCs
    - Parameterizations: PBL, Convection, Explicit Moist Physics, Radiation, Surface Layer
    - Aerosols: Surface databases, High-order Transport, Dry Deposition, Wet Removal
  - Ocean: Navy Coastal Ocean Model (NCOM)
    - Numerics: Hydrostatic, Scheme C, Nested Grids, Hybrid Sigma/z
    - Parameterizations: Mellor-Yamada 2.5
- Features:
  - **Globally Relocatable** (5 Map Projections)
  - **User-Defined Grid Resolutions, Dimensions, and Number of Nested/Parent Grids**
  - **Incremental Data Assimilation; Atmosphere: 6 or 12 hours; Ocean: 12 or 24 hours**
  - **Applicable for Idealized or Real-Time Applications**
  - **Single Configuration Managed System for All Applications**
- Operations (Atmospheric Components plus 2D SST Analysis):
  - **ICM:** Large European Area, grid spacing: 39 km, forecasts to 120 hours,
    3 areas with grid spacing 13 km, forecasts to 72 hours,
    4 km grid spacing over Poland, forecasts to 24 hours.

Nested grids for an investigation of the storm development, 29 July 2005

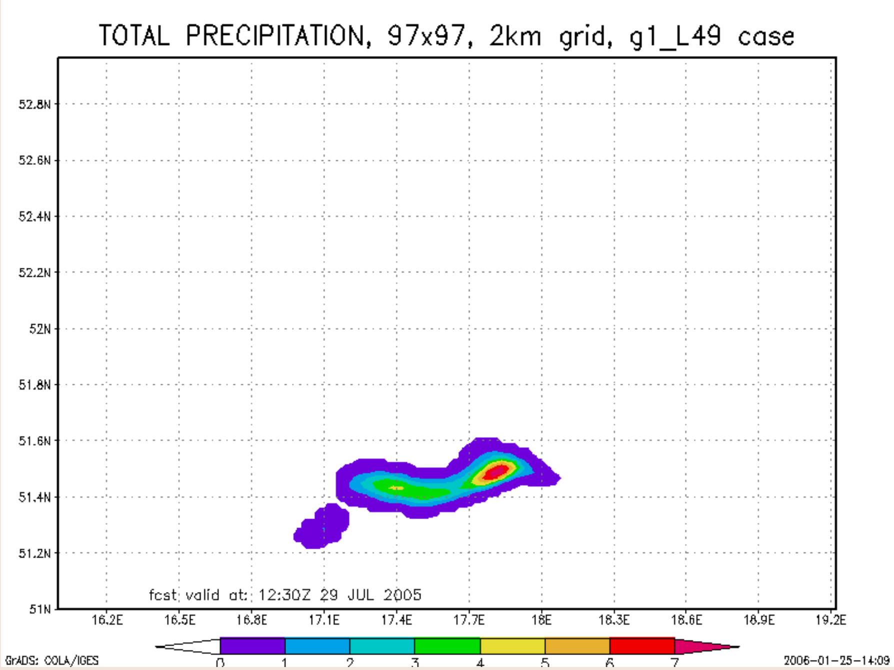


2 km grid, L35, 41x41, ideal case



precipitation

reflectivity at h=2 km



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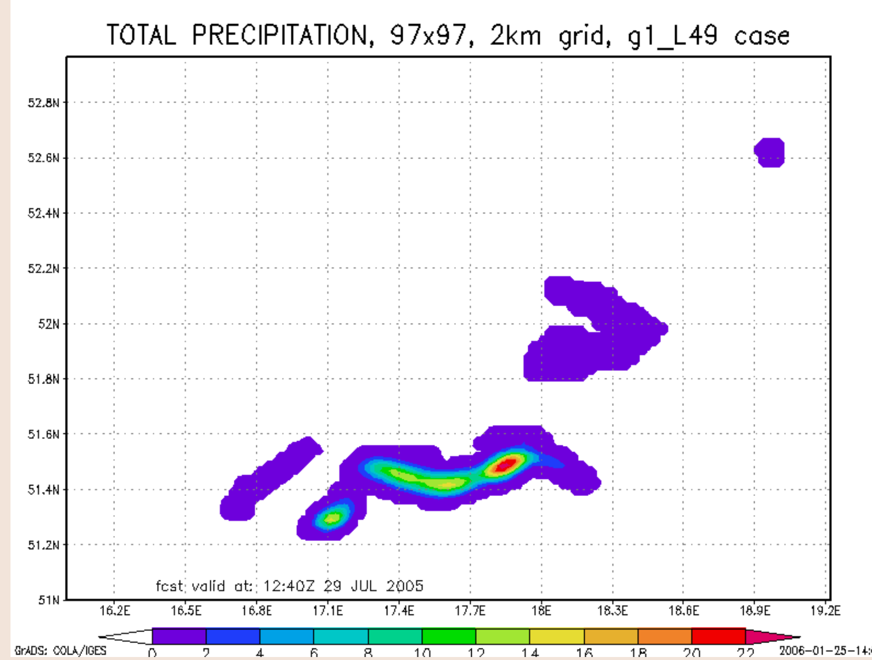

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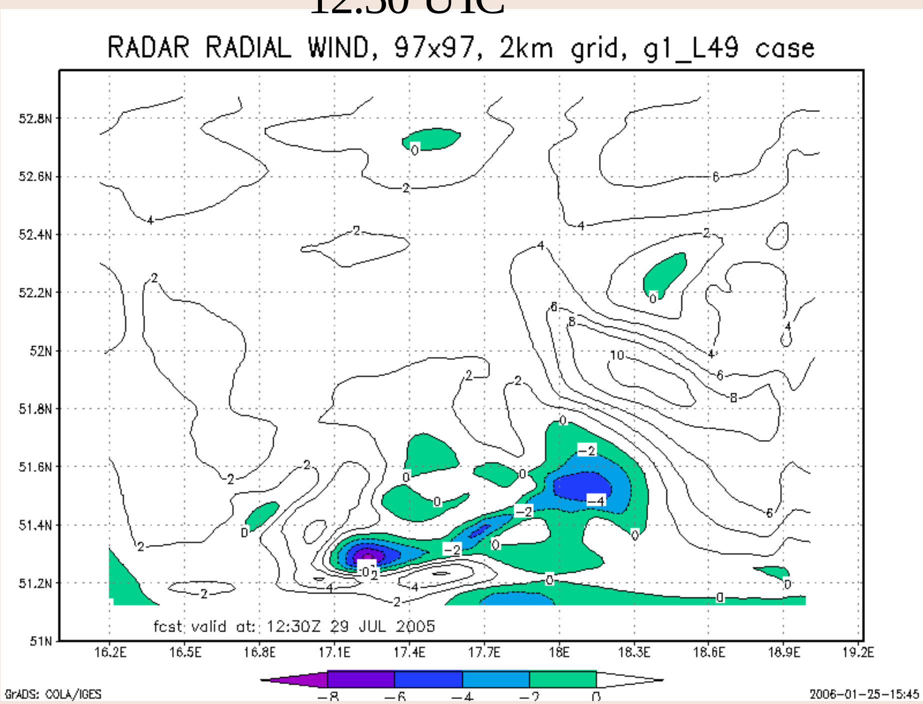

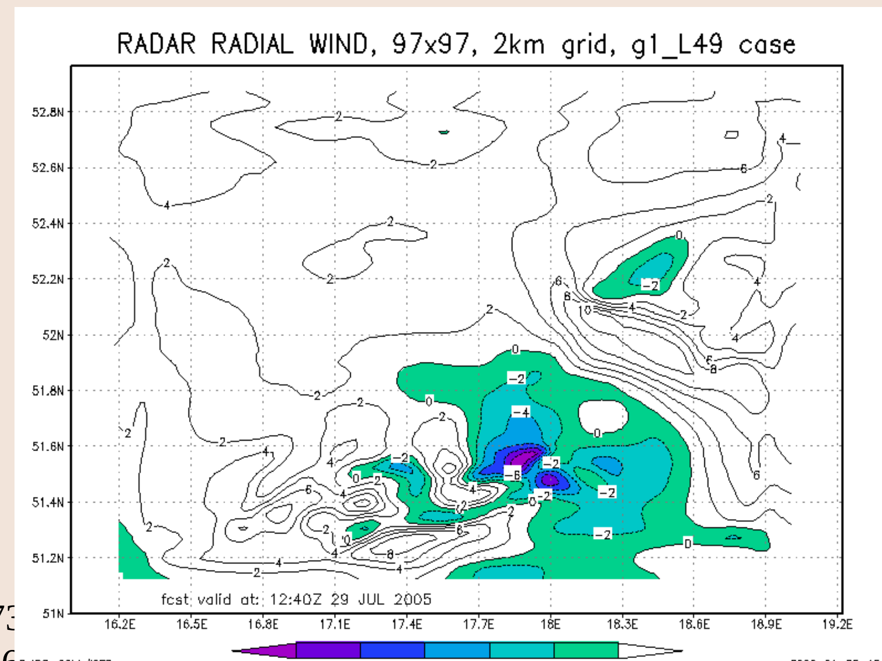

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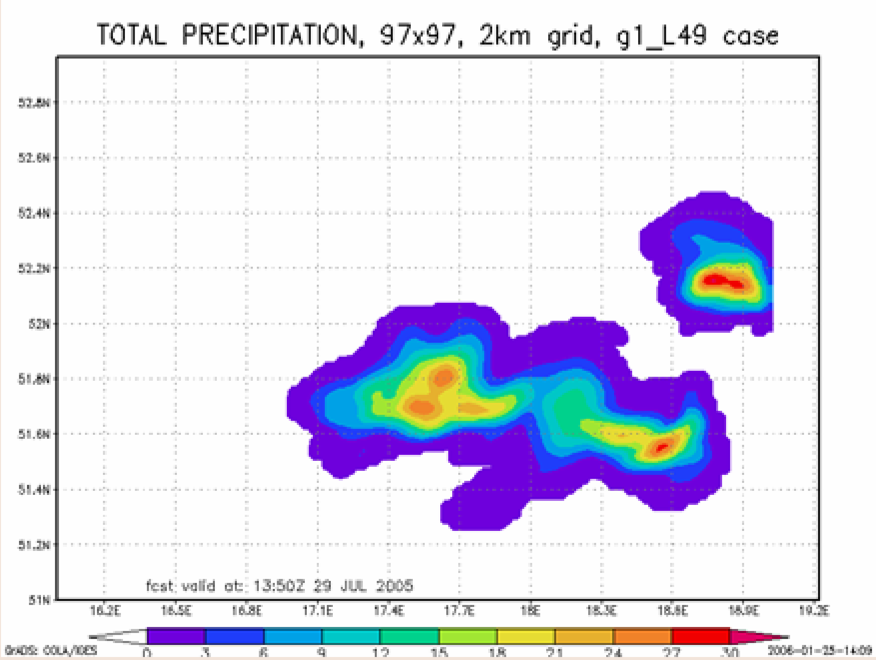

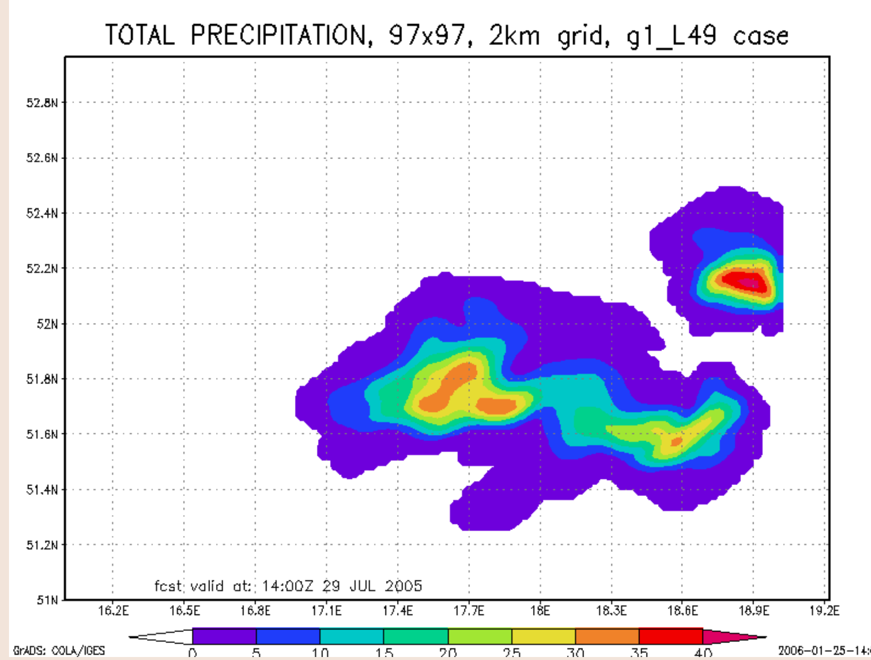

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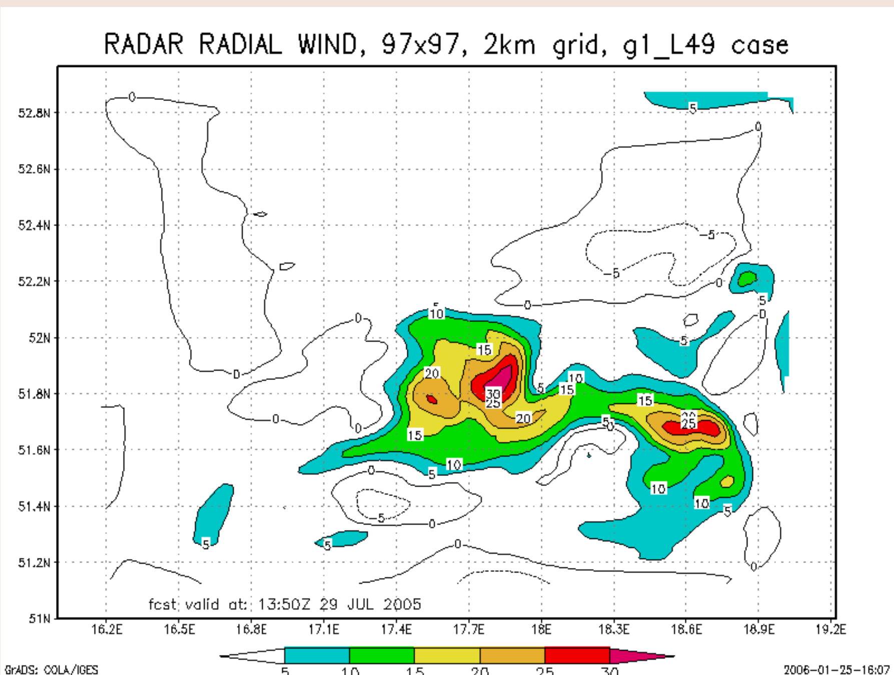

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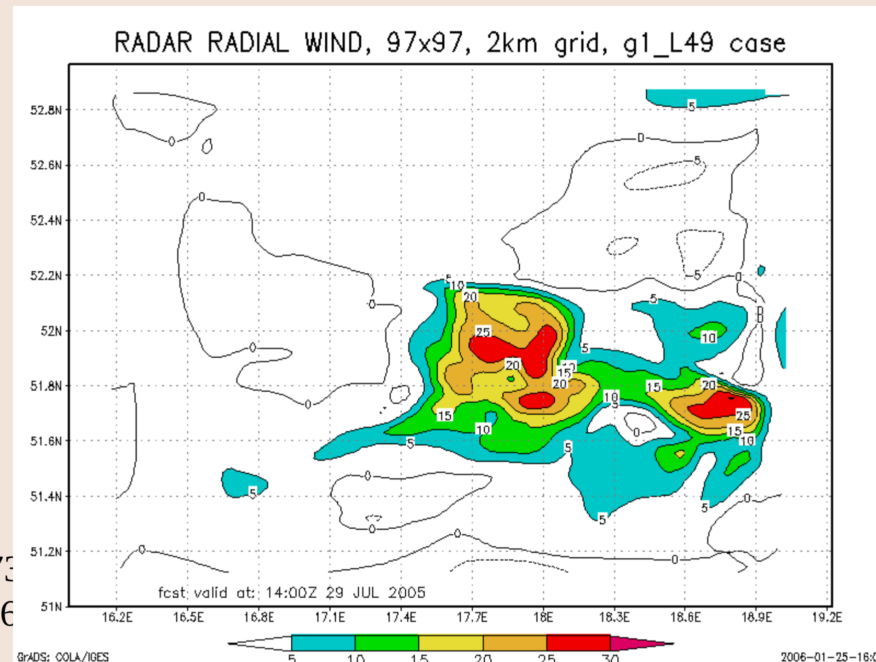
us 26



The evolution of the model state errors

- The forecast step

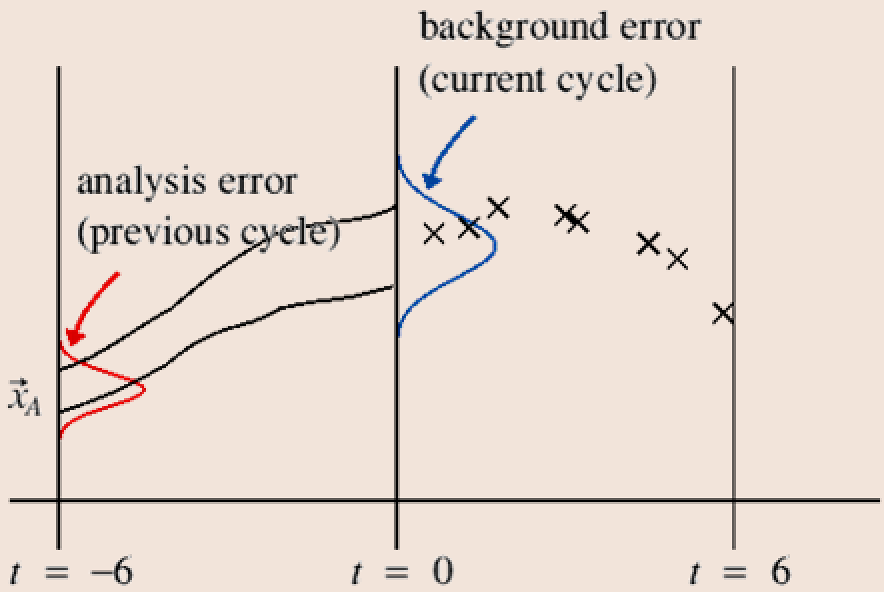
At time t_i, the analysis $\mathbf{x}^a_i$ is an estimate of the true atmospheric state $\mathbf{x}_i^*$ with uncertainties that correspond to the analysis error $\mathbf{e}^a_i = \mathbf{x}^a_i - \mathbf{x}^*_i$. The forecast field that is valid at time t_{i+1} is then obtained from this initial condition by integrating in time the forecast model according to $\mathbf{x}^b_{i+1} = \mathbf{M}\mathbf{x}_i^a$, where $\mathbf{M}$ is the operator that corresponds to the evolution of the atmosphere.

- The analysis step

The forecast field $\mathbf{x}^b_{i+1}$ will then be used as a background for the analysis at time t_{i+1}. The analysis equation transforms the back-ground and observation vectors into the analysis vector.

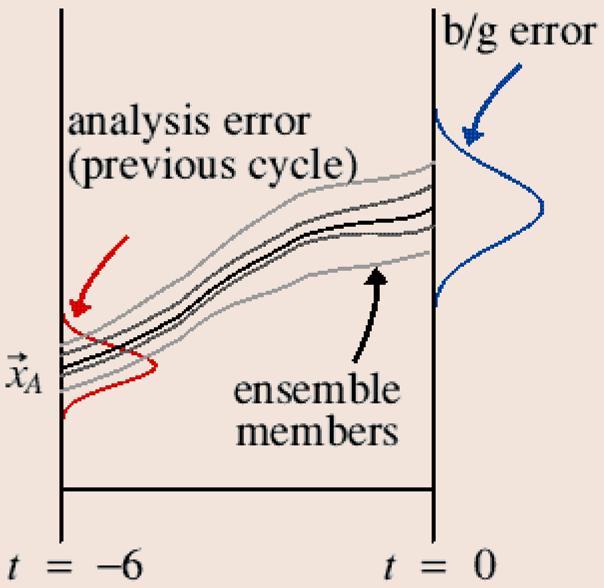
$\mathbf{x}^a_{i+1} = \mathbf{x}^b_{i+1} + \mathbf{K}(\mathbf{y}_{i+1} - \mathbf{H}\ \mathbf{x}^b_{i+1})$, where $\mathbf{y}_{i+1}$ is the observation vector at time t_{i+1} and $\mathbf{K}$ is gain matrix $\mathbf{K}=\mathbf{B}H^T(H\mathbf{B}H^T+\mathbf{R})^{-1}$. B and R are spatial covariance matrices.

Metods of an estimation of matrix B



„NMC" method

„Ensemble" method



The standard NMC method

The NMC method computes differences between forecasts that are valid at the same time, but for different ranges such as 12 and 24-h forecasts. Analysis innovations may be seen as an analysis perturbation, which is supposed to be an estimate of the analysis error e_i^a : $\varepsilon_i^a = \mathbf{K}(y_i - Hx^b_i) = \mathbf{K}(e^o_i - He^b_i)$. This allows to distinguish the respective contributions of the background and observation errors: $\varepsilon_i^a = -\mathbf{K}H\, e^b_i + \mathbf{K}e^o_i$. Comparison with an analysis dispersion equation $\varepsilon_i^a = (I-\mathbf{K}H)\, \varepsilon^b_i + \mathbf{K}\varepsilon^o_i$ shows that in the NMC method the background error weight $(I-\mathbf{K}H)$ is approximated by $-\mathbf{K}H$. In the evolution of the NMC analysis perturbations, the representation of the analysis effect consists in adding the analysis increments to some earlier increments $\varepsilon^b_{i+1} = M(x^a_i - x^b_i)$. This differs from the ensemble method, for which the representation of the analysis effect consists in applying the analysis equation to the perturbations ε^b , ε^o.

The ensemble simulation method

At time t_i, two different analyses are available. Their difference is equal to $\varepsilon_i^a = x_i^{a,k} - x_i^{a,l}$. Two forecast integrations are performed from these two initial states.The two different forecast fields may then be combined with two different sets of observations y_{i+1}^k , y_{i+1}^l, in order to provide two different analyses at time . By calculating the difference between these two analysis equations, it appears that the analysis equation is the very same equation that transforms the background and the observation differences into the analysis differences:

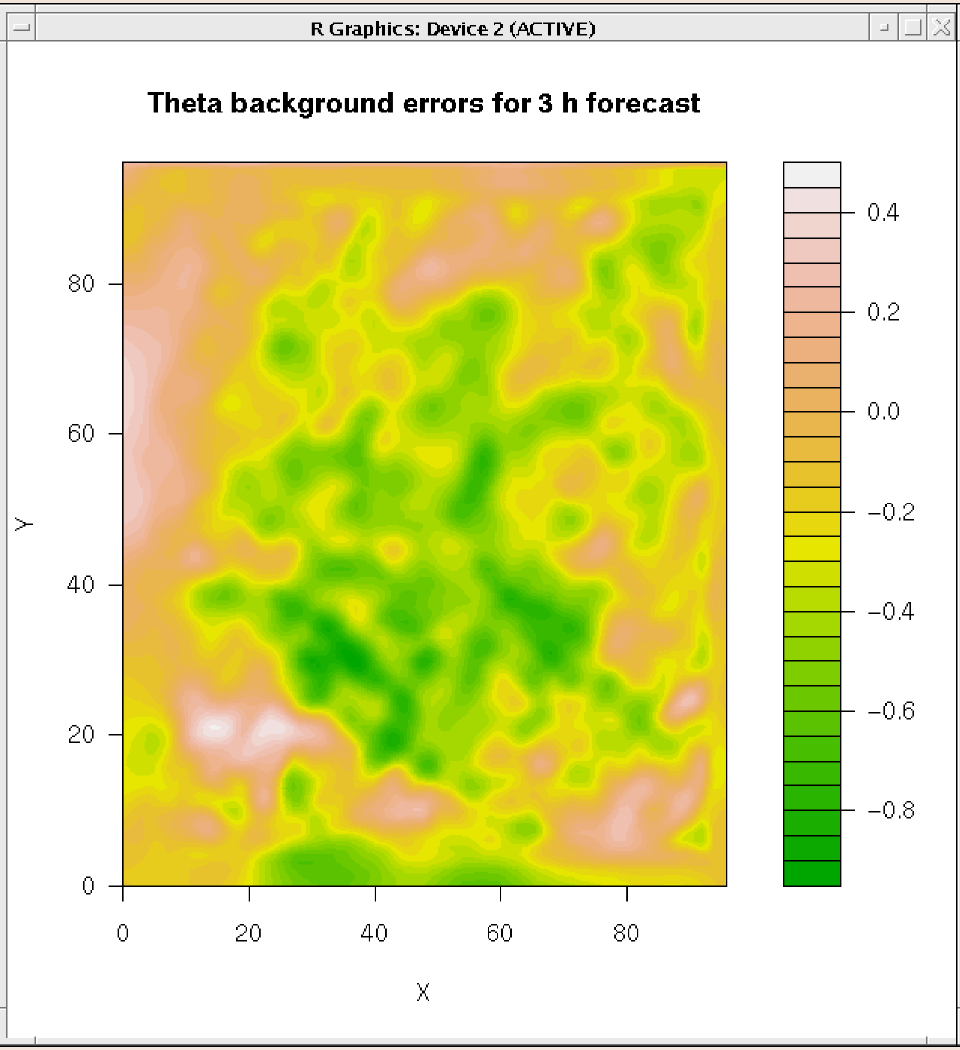
$$\varepsilon_i^a = \varepsilon_i^b + \mathbf{K}(\varepsilon^o_{i+1} - H\varepsilon^b_{i+1}).$$

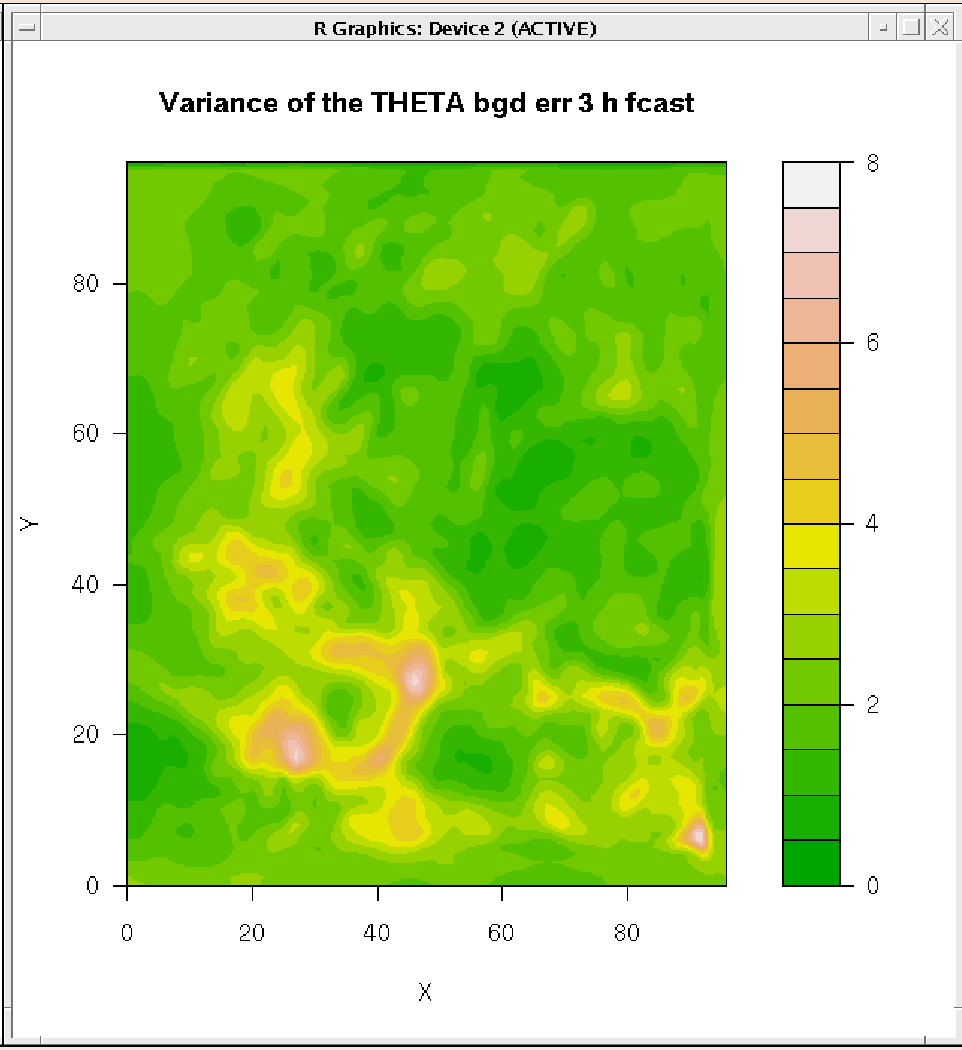
The evolution processes and equations, that affect the ensemble difference fileds, are the same as those of the true error fields.

Forecast background error, V wind component

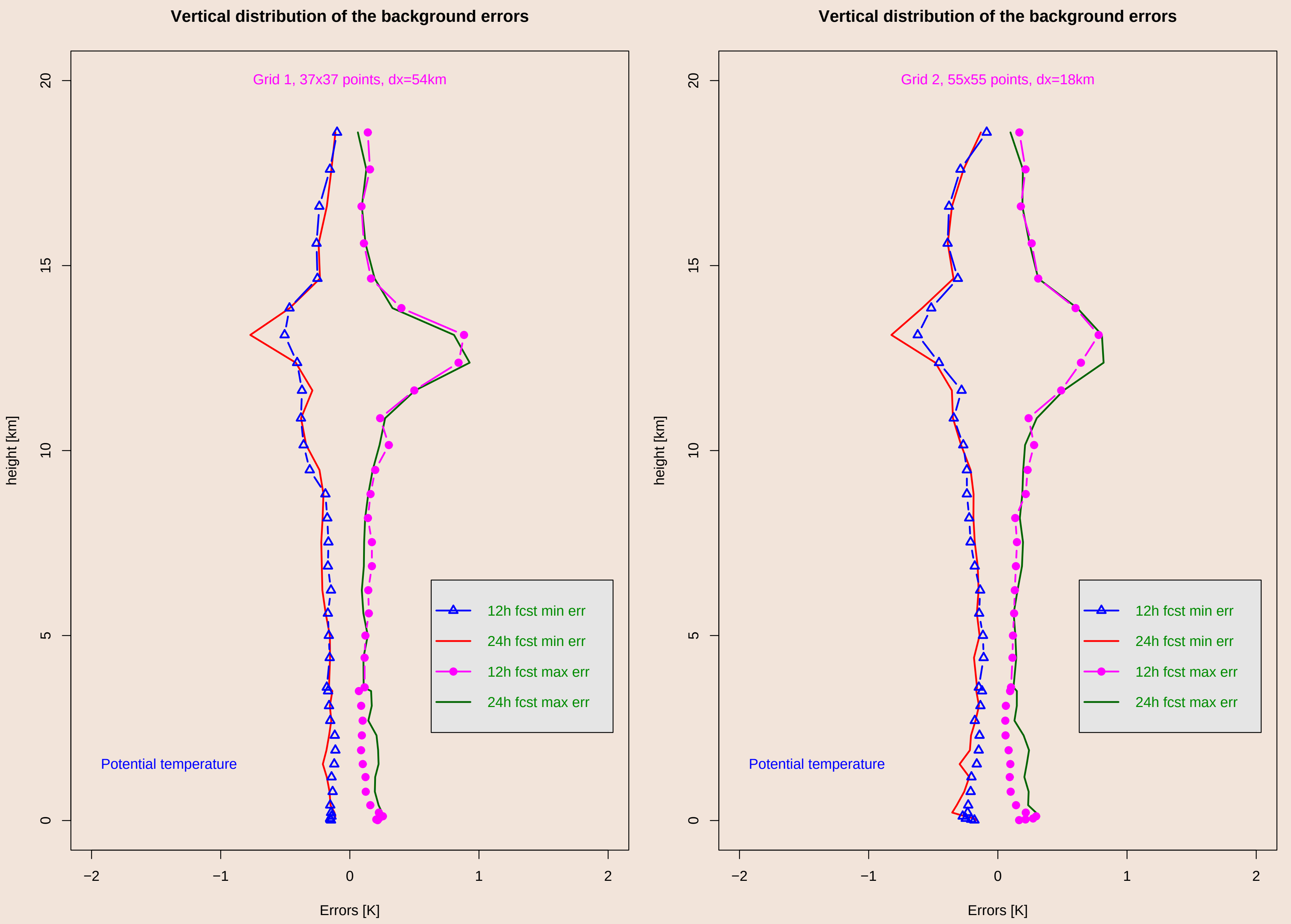
Mean error

Variance

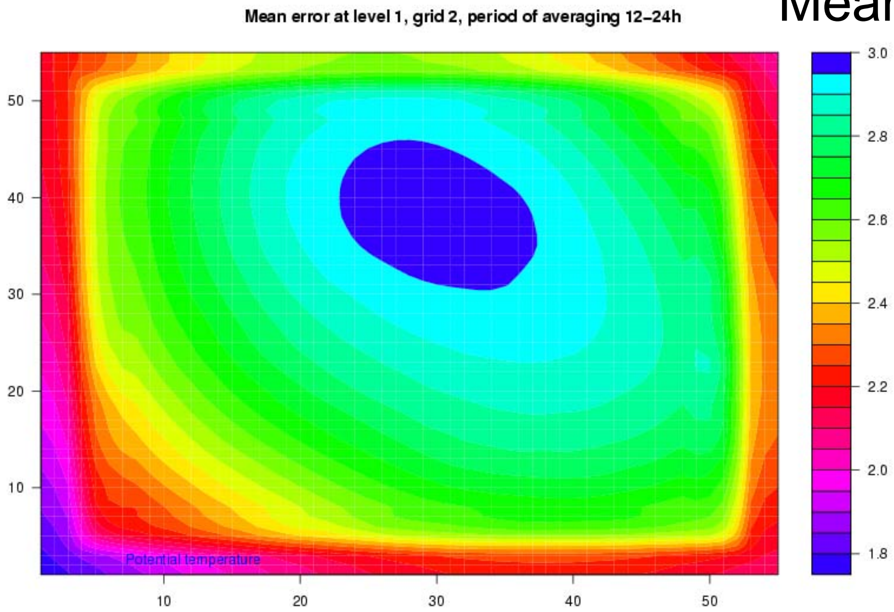


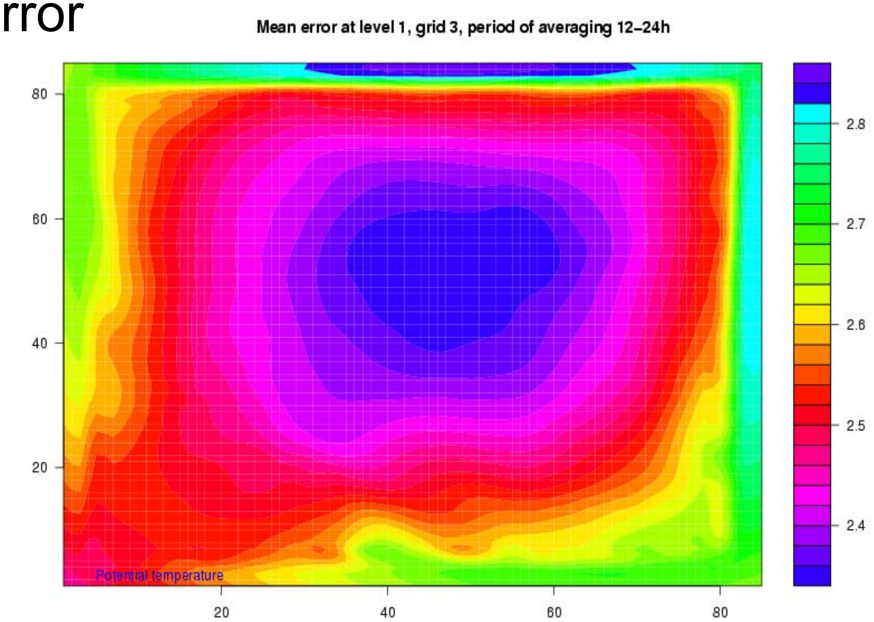


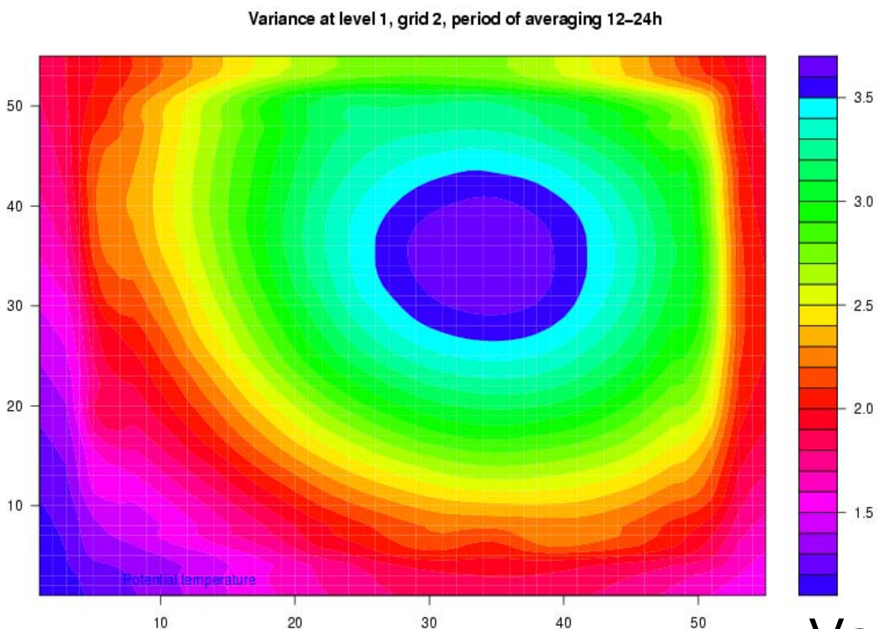
2 km grid, L35, 97x97 results for 28 model level (~1.2 km)

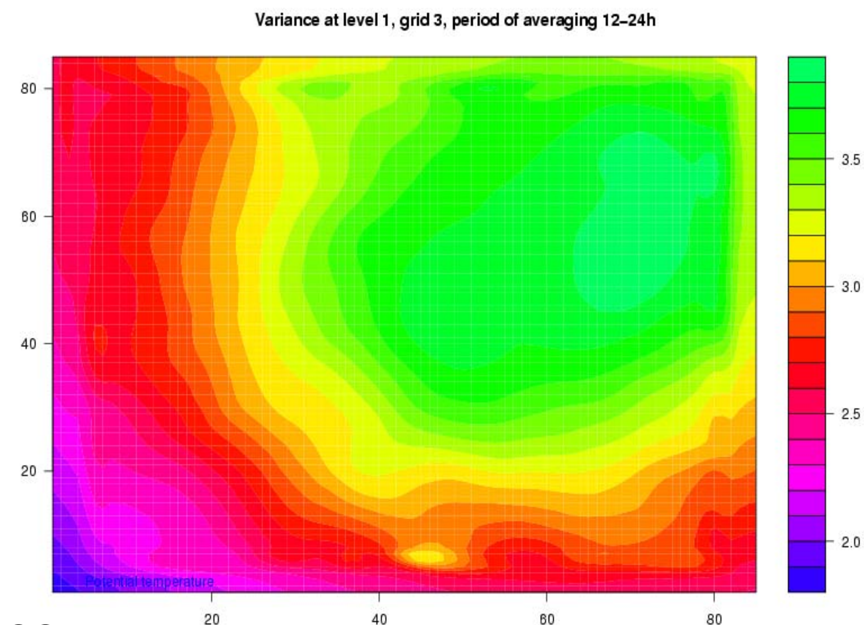

Vertical distribution of the background errors
Grid 1, 37x37 points, dx=54km
height [km]
Errors [K]
Potential temperature
12h fcst min err
24h fcst min err
12h fcst max err
24h fcst max err
Vertical distribution of the background errors
Grid 2, 55x55 points, dx=18km
height [km]
Errors [K]
Potential temperature
12h fcst min err
24h fcst min err
12h fcst max err
24h fcst max err

Mean error





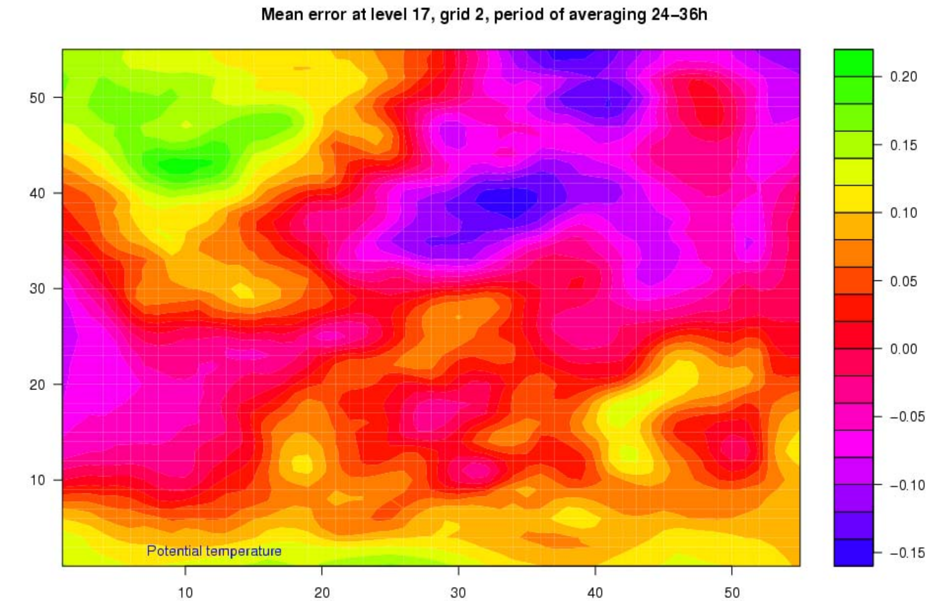


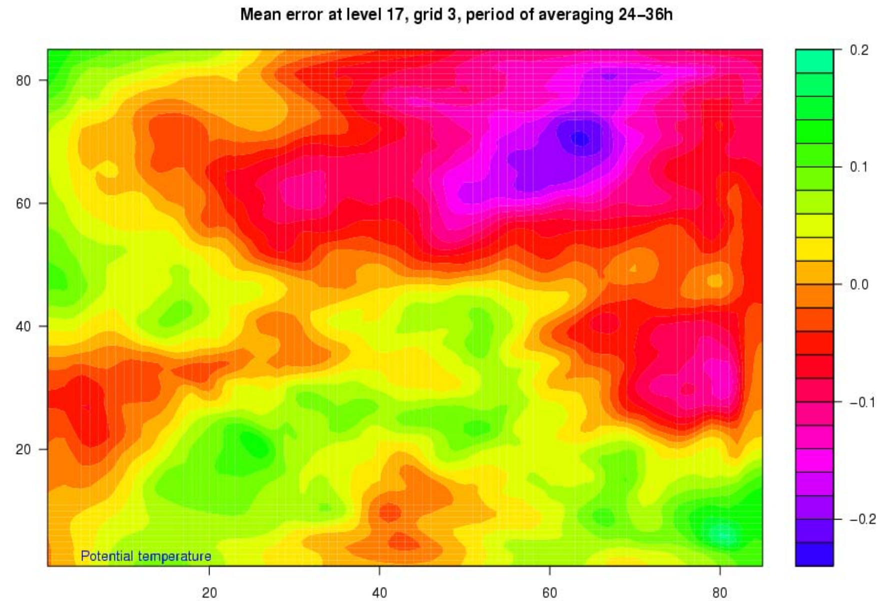


Variance

18 km grid

6 km grid

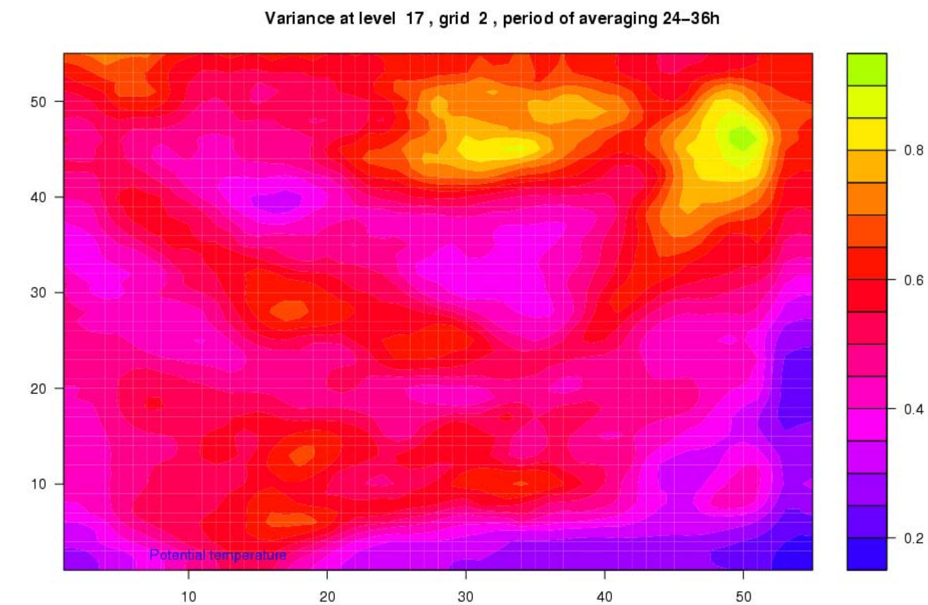


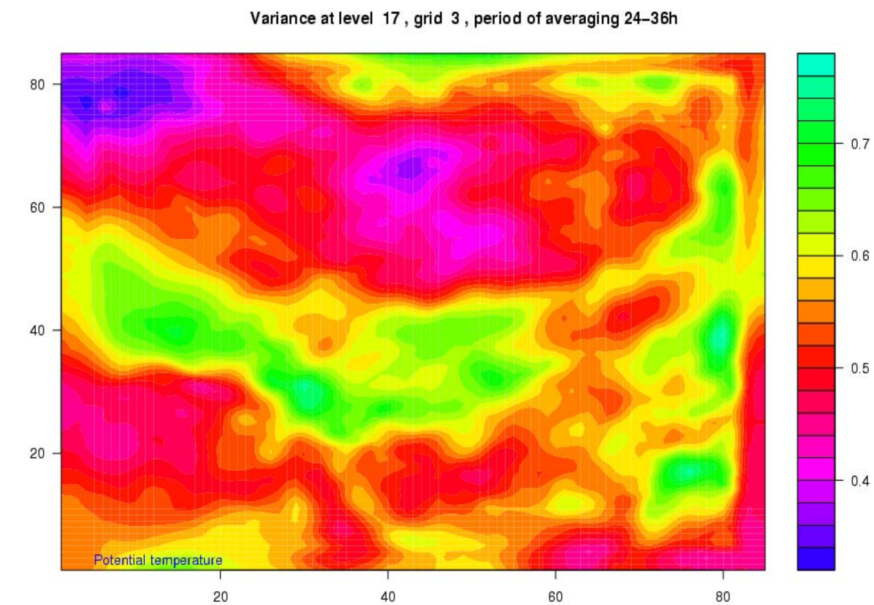


18 km grid

Level 17, 5 km

6 km grid





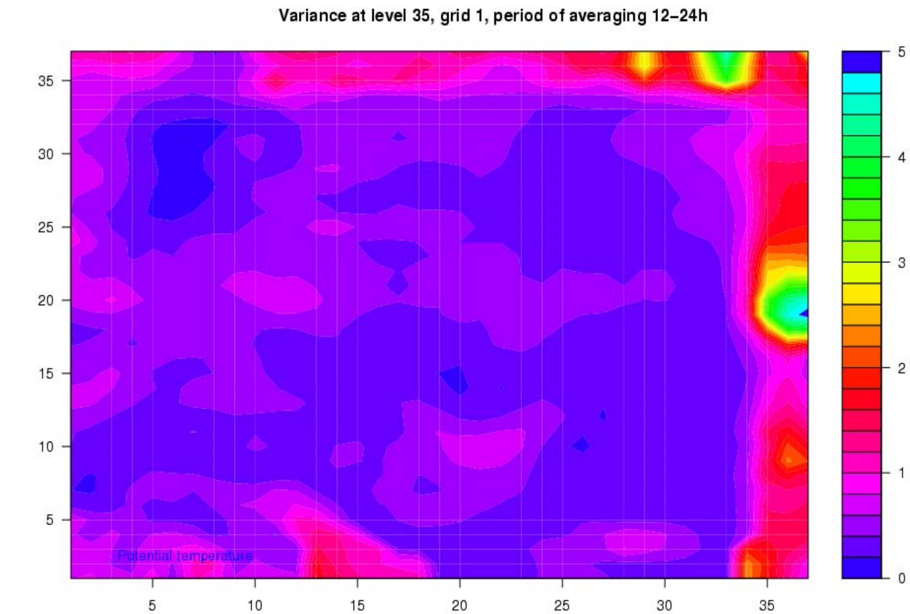
Ensemble initiation methodology

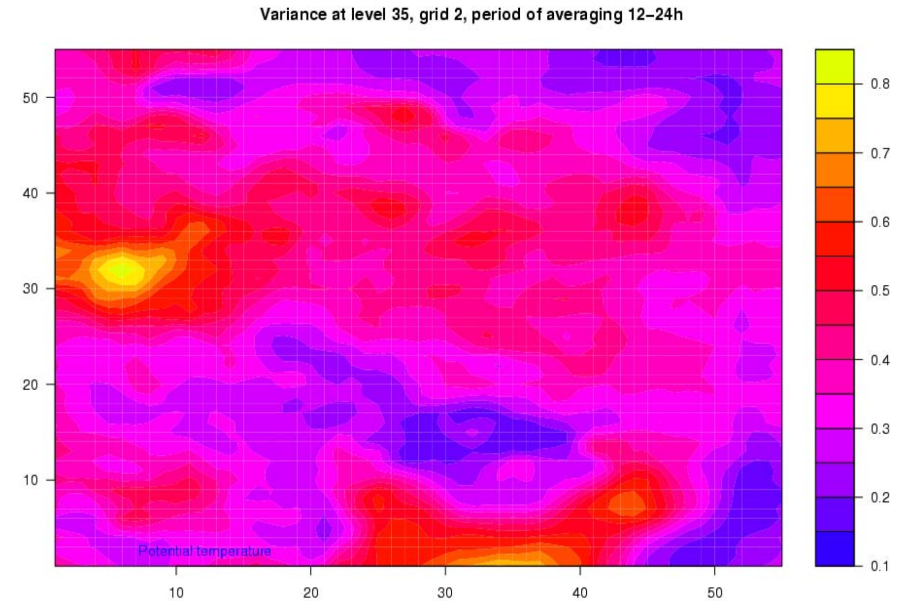
- The uncorrelated-random method

  A standard uncorrelated normal random variable with zero mean and unit variance is created first (by Box-Muller method). Using a prescribed standard deviation σ_z, on can create an uncorrelated random variable $Z \sim N(0,\sigma_z)$. Then, using the linear transformation **F**=**I**, the actual initial pertutrbation used is P=Z. This is followed by an ensemble integration from t_o-τ to t_o.

- the correlated random method

  In order to improve the forecast error covariance at time t_o, a change of variable P=**F**Z is introduced at time t_o-τ, which creates correlated random perturbations. The matrix **F** is a block-diagonal Toeplitz matrix, with the elements calculated using the space-limited compactly support function. Each block corresponds to a particular model variable.

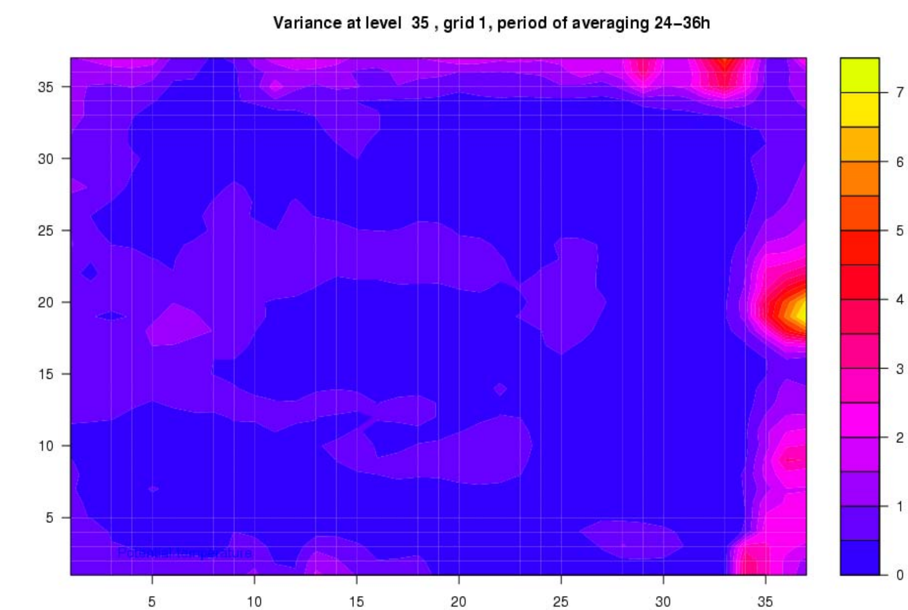


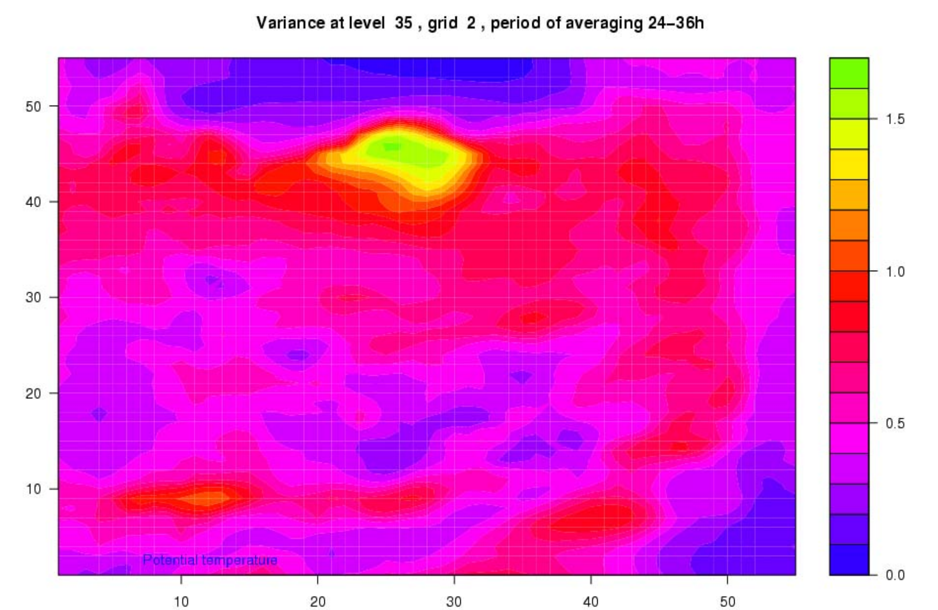


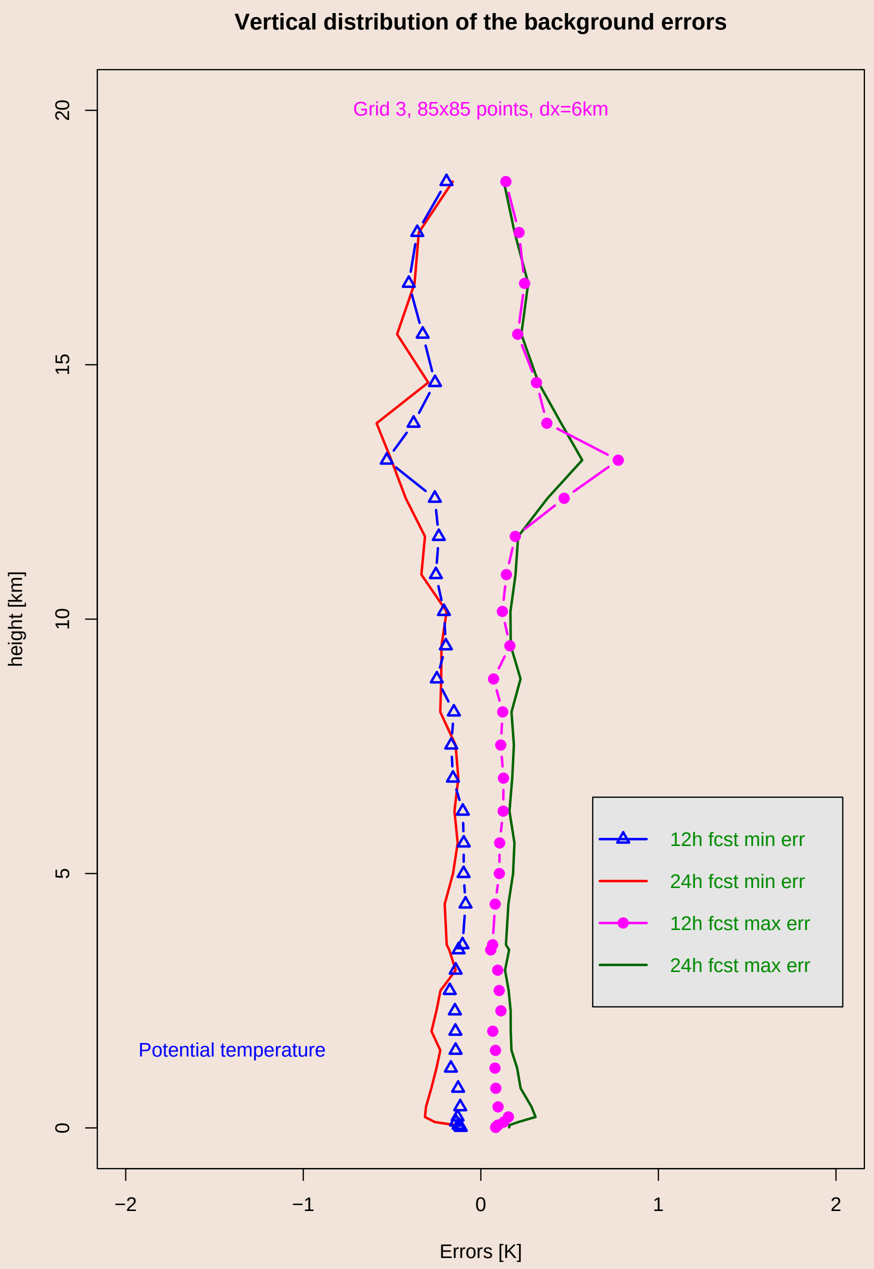
54 km grid

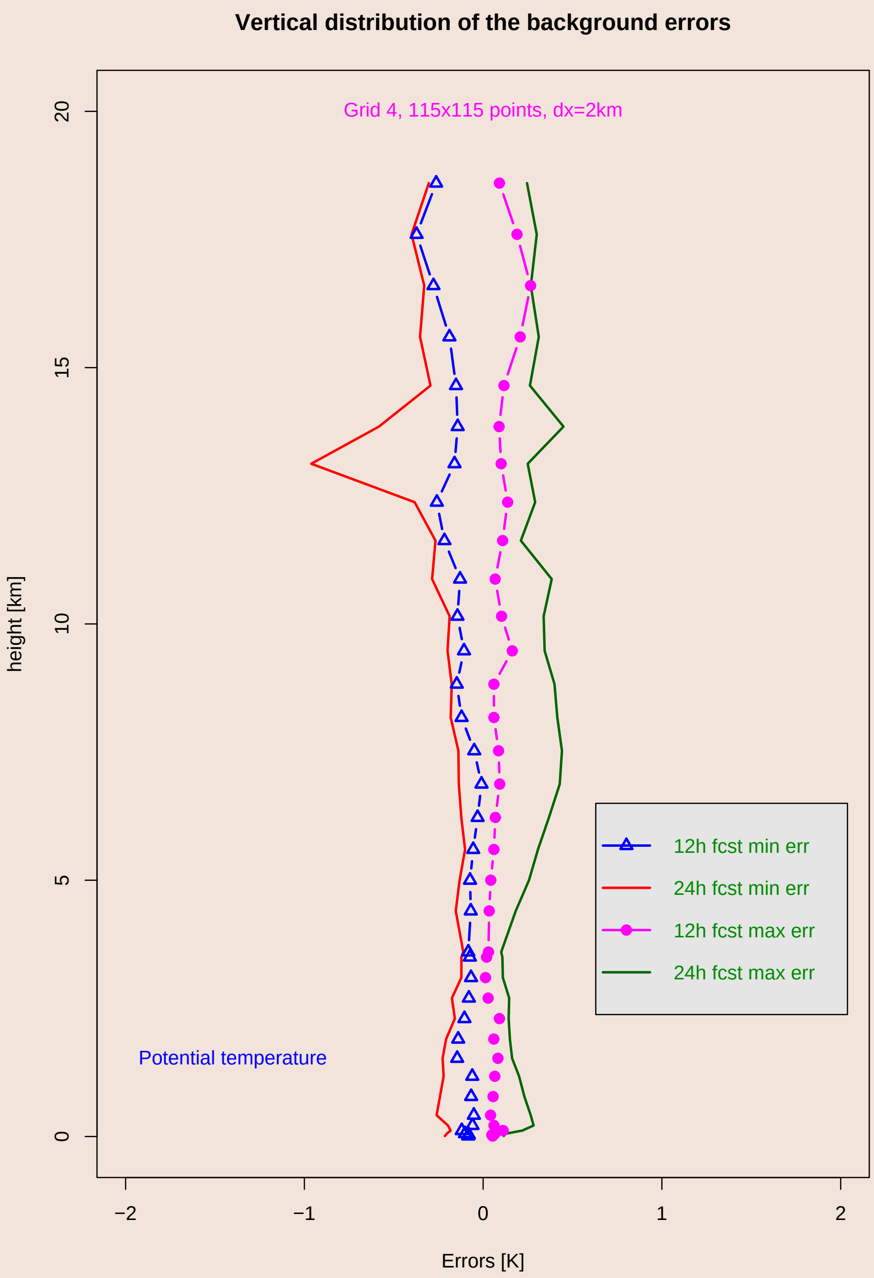
Level 35, 0.01m

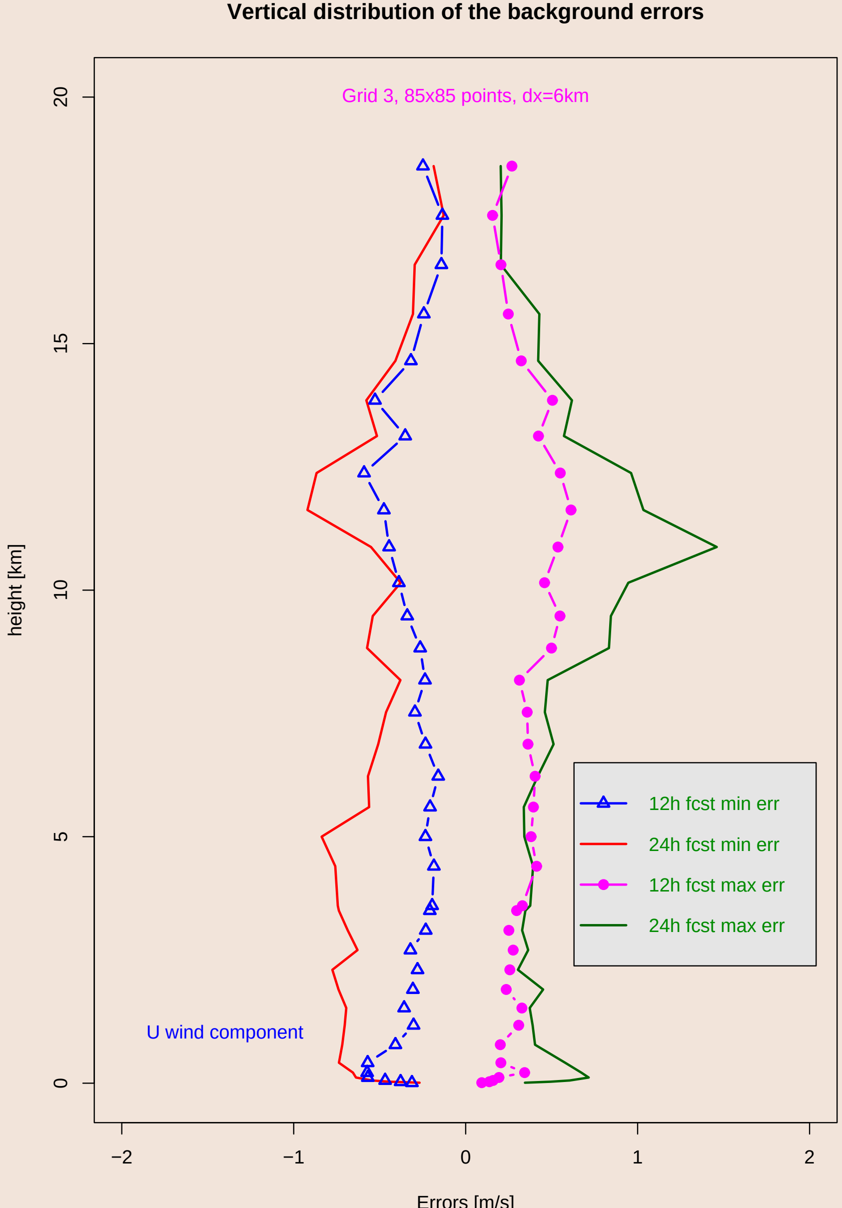
18 km grid



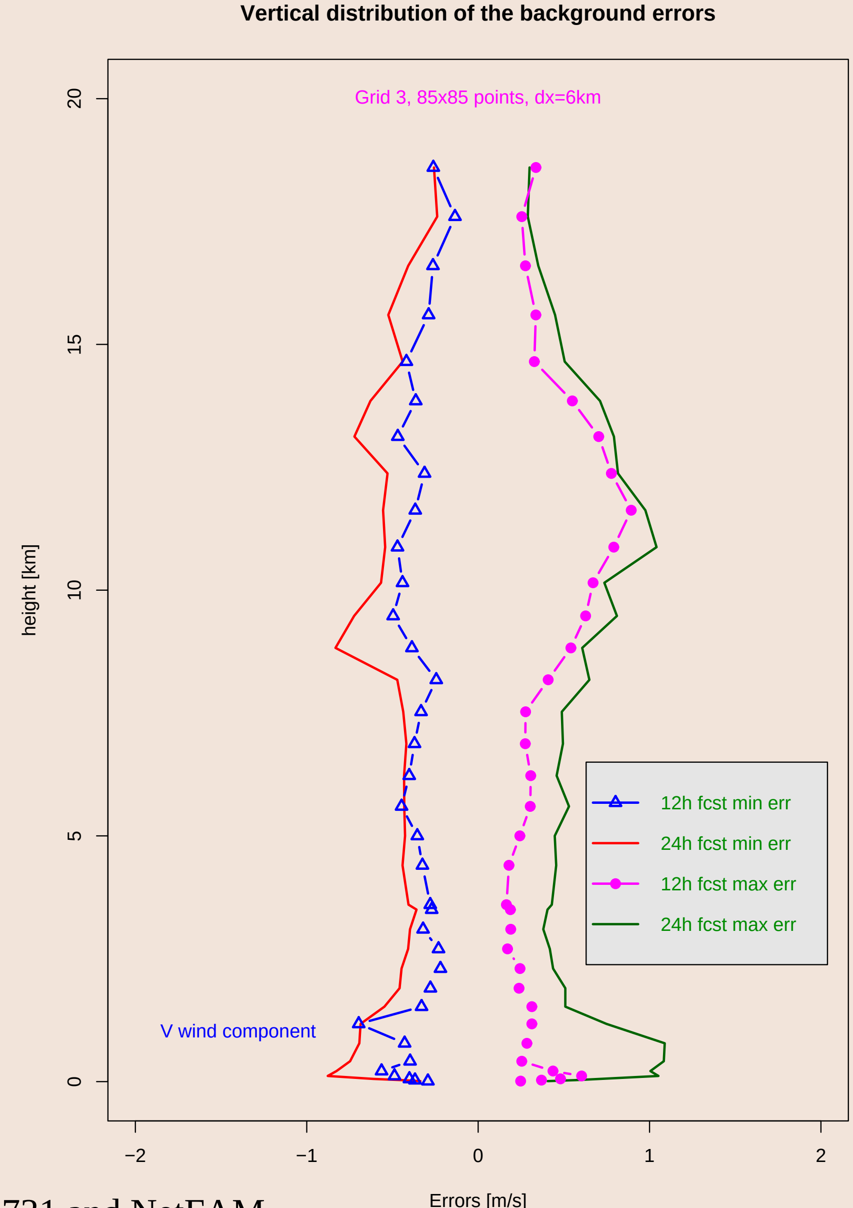



Vertical distribution of the background errors
Grid 3, 85x85 points, dx=6km
height [km]
Errors [K]
Potential temperature
12h fcst min err
24h fcst min err
12h fcst max err
24h fcst max err

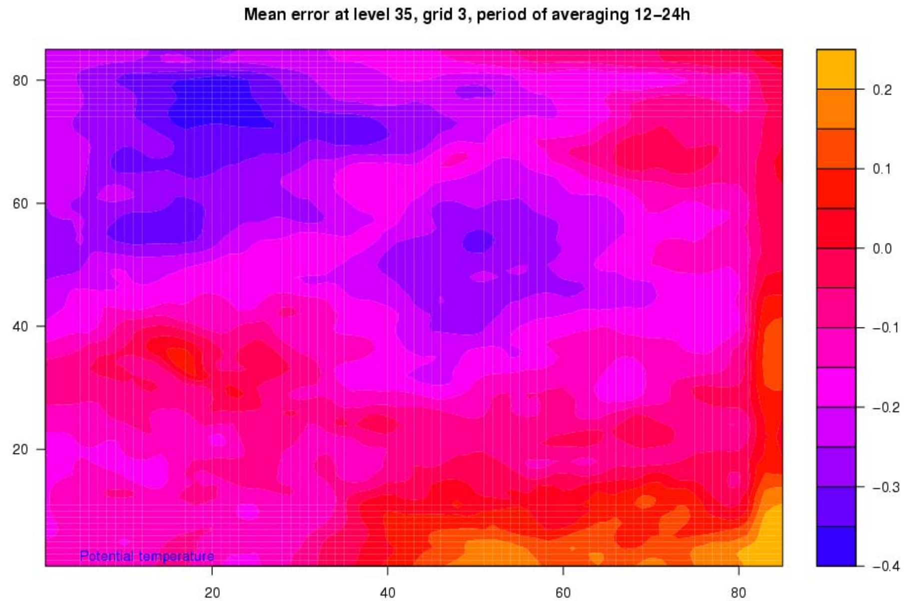

Vertical distribution of the background errors
Grid 4, 115x115 points, dx=2km
height [km]
Errors [K]
Potential temperature
12h fcst min err
24h fcst min err
12h fcst max err
24h fcst max err

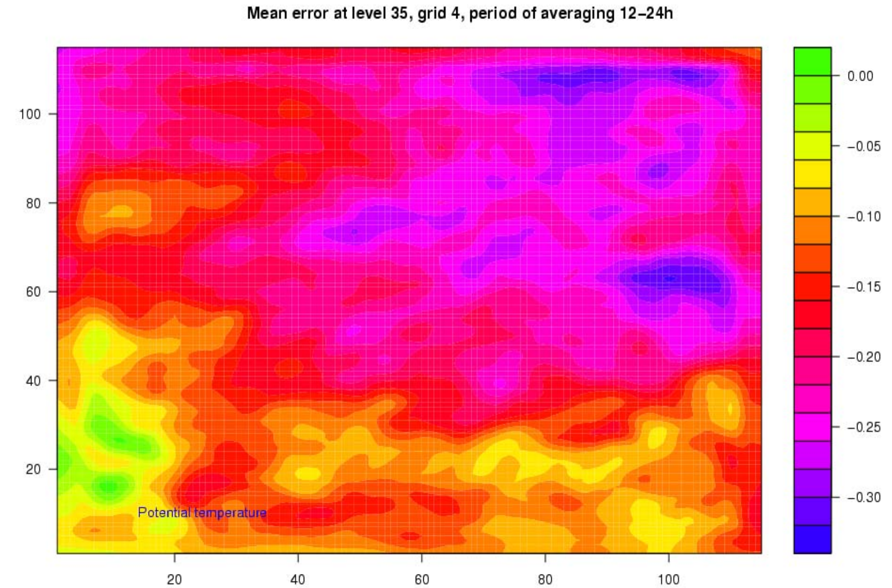


Vertical distribution of the background errors
Grid 3, 85x85 points, dx=6km
height [km]
Errors [m/s]
12h fcst min err
24h fcst min err
12h fcst max err
24h fcst max err
U wind component

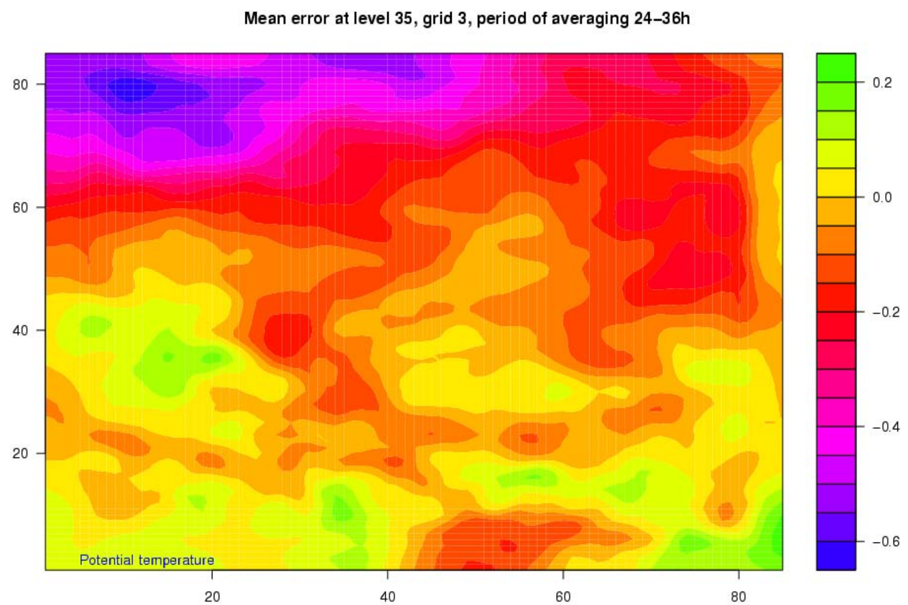


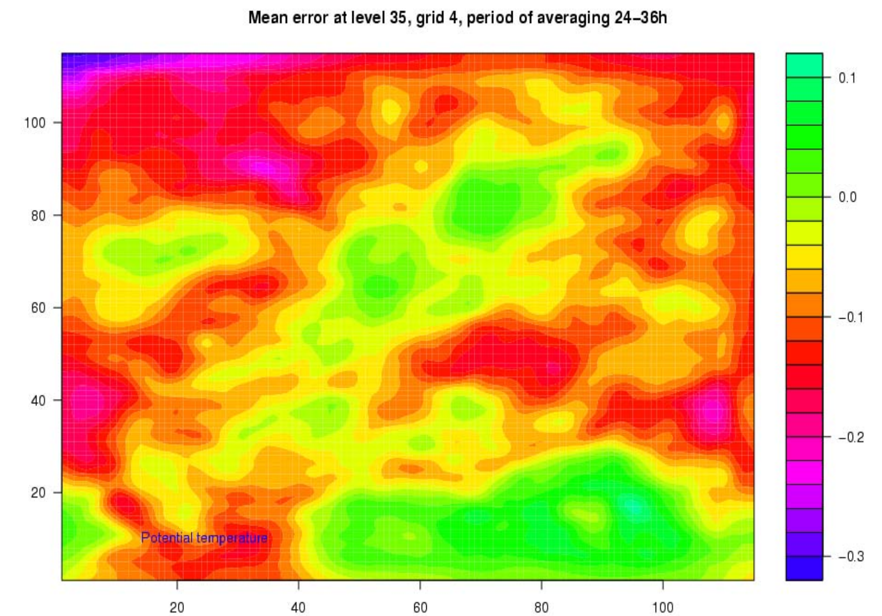
Vertical distribution of the background errors
Grid 3, 85x85 points, dx=6km
height [km]
Errors [m/s]
12h fcst min err
24h fcst min err
12h fcst max err
24h fcst max err
V wind component

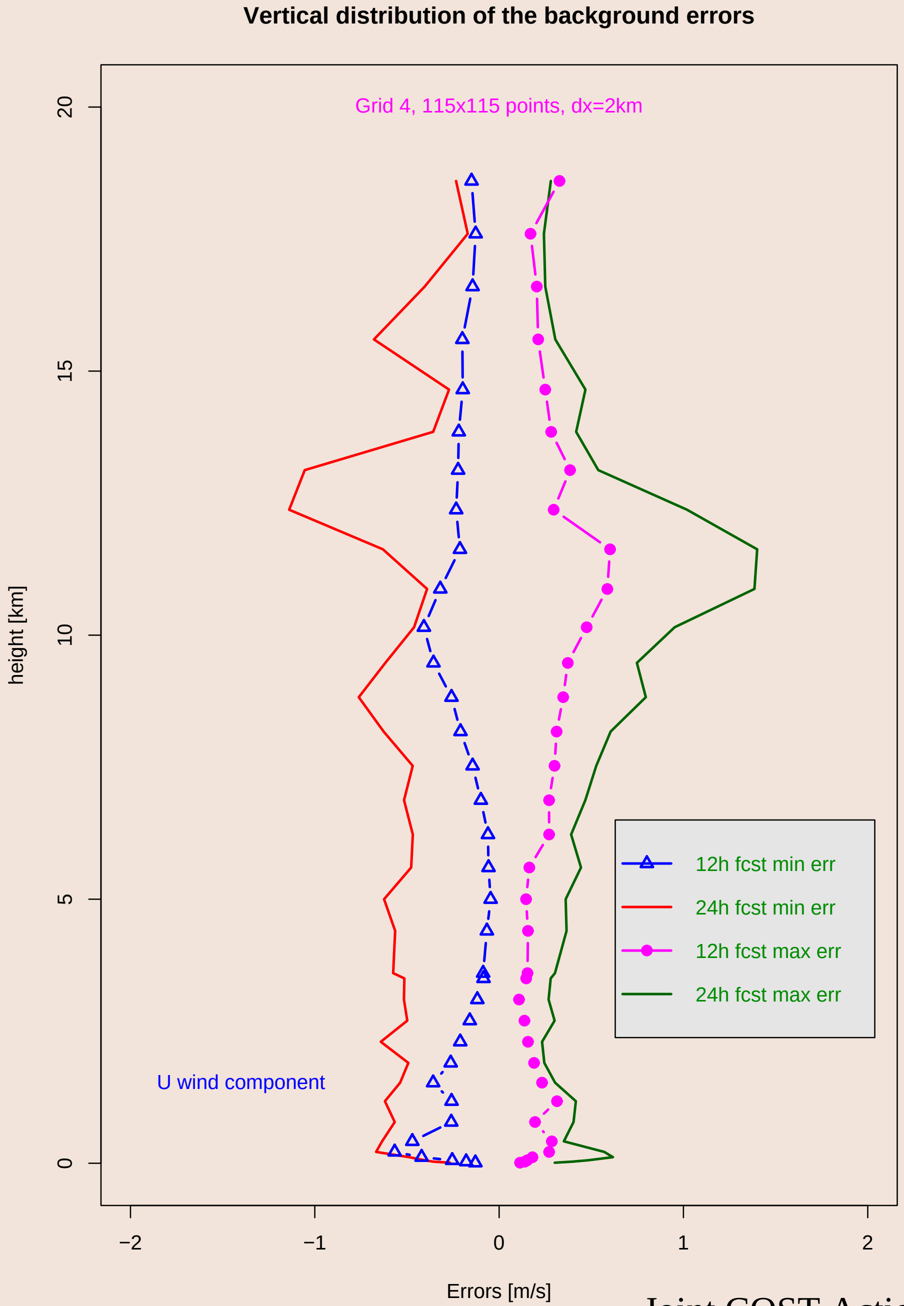




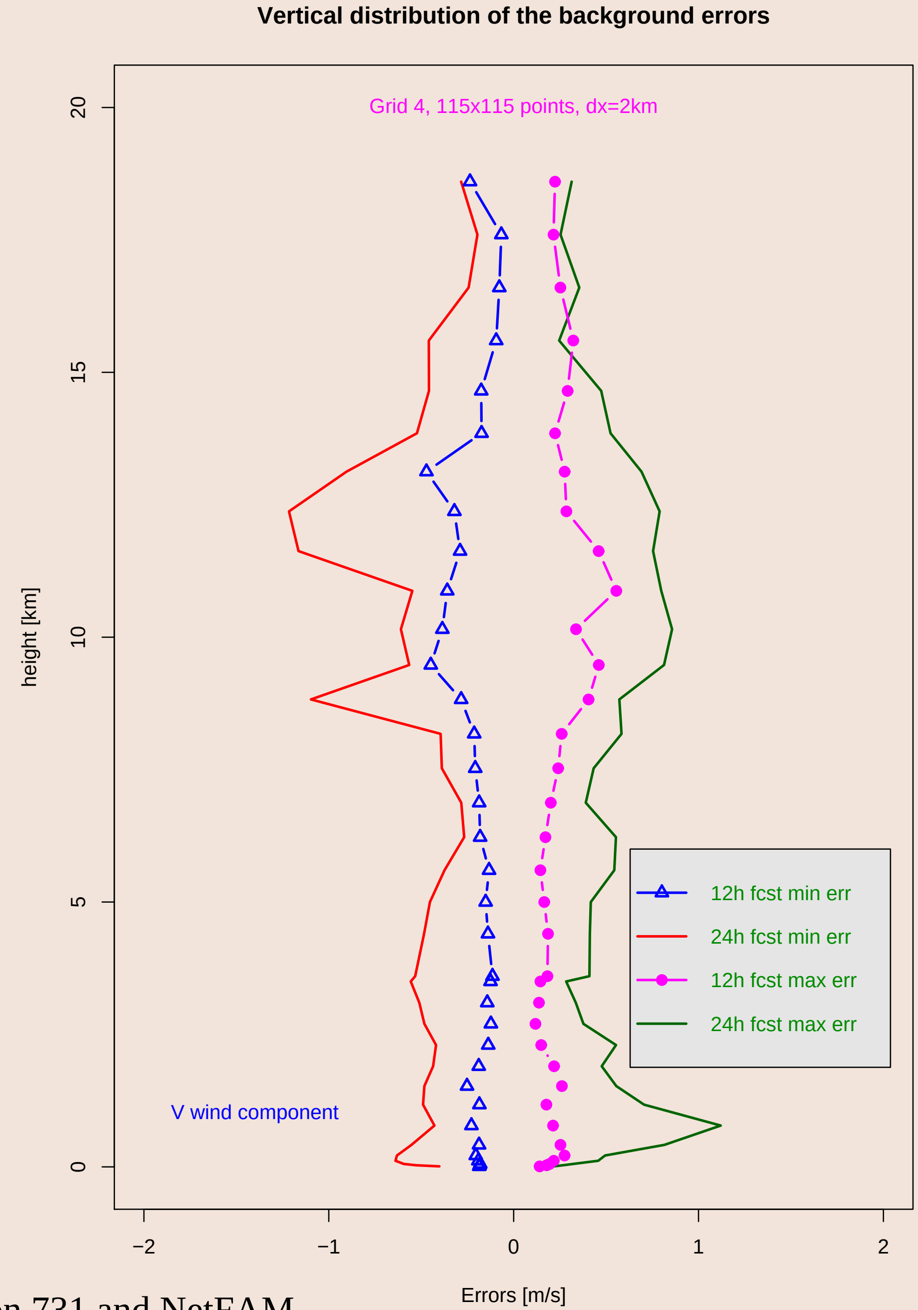
6 km grid Mean error, level 35 2 km grid







Vertical distribution of the background errors
Grid 4, 115x115 points, dx=2km
height [km]
Errors [m/s]
12h fcst min err
24h fcst min err
12h fcst max err
24h fcst max err
U wind component

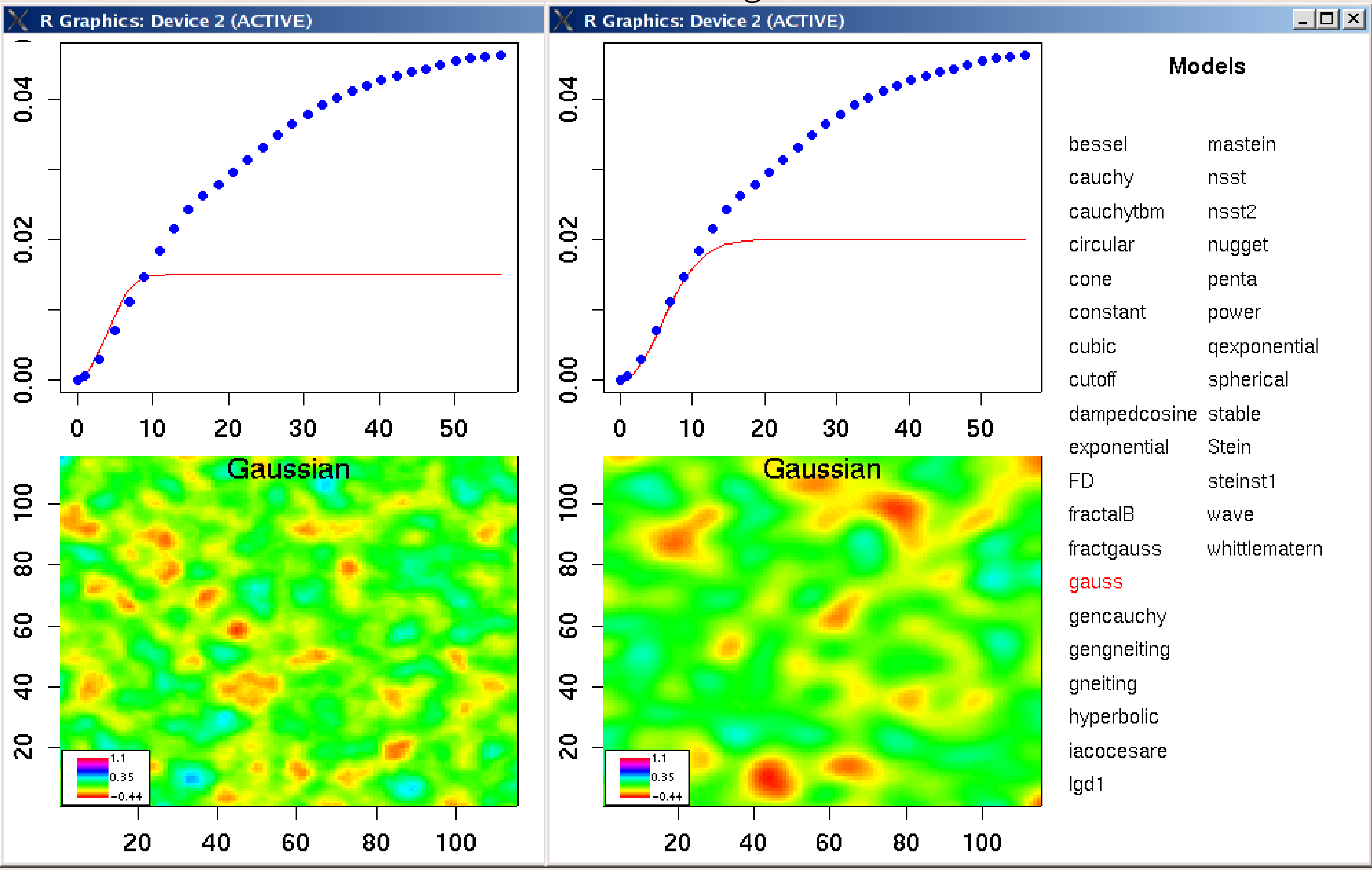


Vertical distribution of the background errors
Grid 4, 115x115 points, dx=2km
height [km]
Errors [m/s]
12h fcst min err
24h fcst min err
12h fcst max err
24h fcst max err
V wind component

Single-sample parameter estimation

Model error parameterization imply a parameterization of the innovation covariance. Considering one arbitrary time instant at which an innovation $\mathbf{v}$ is produced, we assume that we have a covariance model for $\mathbf{v}$ which involves a number of unknown parameters: $E(\mathbf{v}\mathbf{v}^T) \sim \mathbf{S}(\boldsymbol{\alpha})$, where $\mathbf{S}(\boldsymbol{\alpha})$ is a family of known covariance matrices parameterized by $\boldsymbol{\alpha}$. The conditional probability density $p(\mathbf{v}|\boldsymbol{\alpha})$ of the random vector is given by the Gaussian density function $p(\mathbf{v}|\boldsymbol{\alpha})=c[\det \mathbf{S}(\boldsymbol{\alpha})]^{-1/2} \exp\{-1/2[\mathbf{v}^T\mathbf{S}^{-1}(\boldsymbol{\alpha})\mathbf{v}]\}$ Given the innovation sample $\mathbf{v}$, the maximum likelihood parameter estimate $\boldsymbol{\alpha}^{ML}$ of $\boldsymbol{\alpha}^*$ is obtained by finding that value of $\boldsymbol{\alpha}$ for which the probability density attains a maximum. Suppose that the innovation covariance parameterization is linear in a single parameter: $\mathbf{S}(\alpha)=\alpha\ \mathbf{S}_0$ with a $\mathbf{S}_0$ fixed covariance matrix and α an unknown scalar. In this case optimization of the maximum-likehood function can be performad analytically.

cubic gauss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Conclusions

- Identifying a viable strategy for specific the back-ground error covariance remains an important problem in meteorological data assimilation
- The NMC method relies on the analysis increment equation
- In the analysis ensemble approach the analysis equation is used to transform the background and observation dispersion into the analysis dispersion
- In near future we plan to introduce on-line estimation of error covariance parameters into our OI scheme

References:

Berre L., S.E. Stefanescu and M. Belo, 2006: The representation of the analysis effect in three simulation techniques. Tellus, 58A, 196-209.

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Zupanski M., S.J. Fletcher, I.M. Navon, B. Uzunoglu, R.P. Heikes, D.A. Randall, T.D. Ringler and D. Daescu, 2006: Initiation of ensemble data assimilation, Tellus, 58A, 159-170.

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