Jb and derivation of B statistics

HARMONIE SYSTEM TRAINING WEEK
Norrköping, 19-23 September, 2011

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Structure

- Theoretical background
- Description of procedure for deriving background error statistics
- Diagnosing the background error statistics
- Introducing the newly derived statistics into the data assimilation
- Interpolation of background error statistics between different domains for technical data assimilation tests
- Recent and on-going developments

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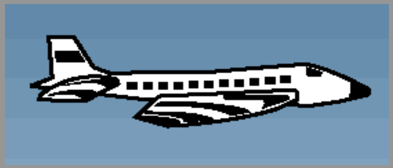
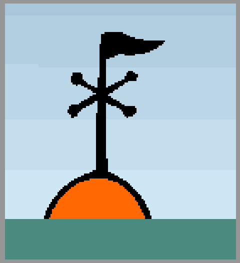
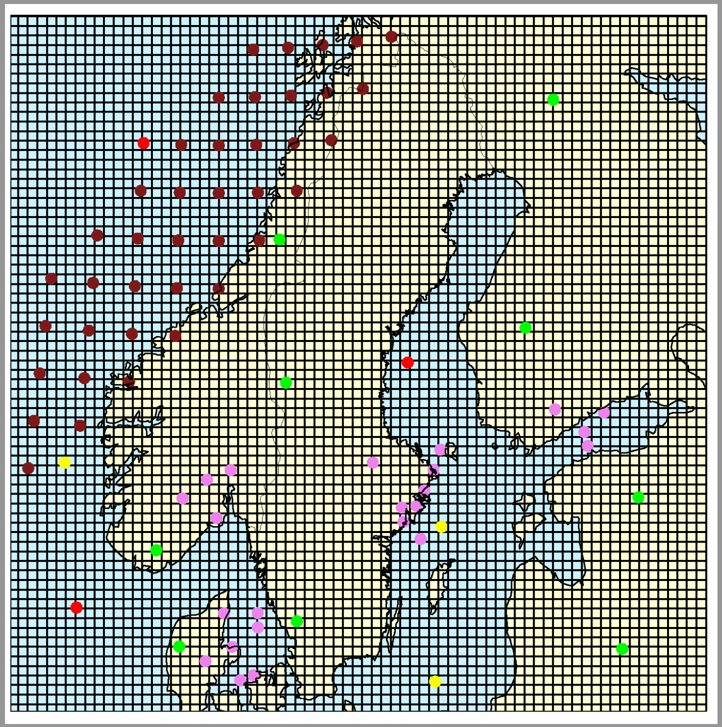
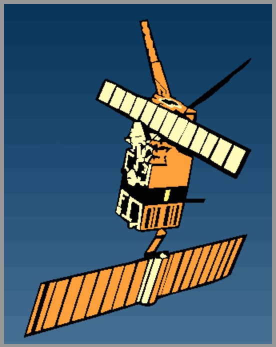
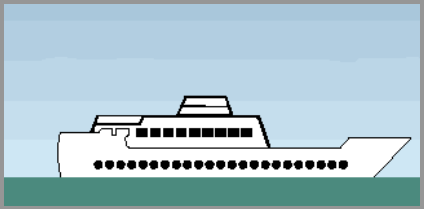
Data assimilation











(a priori information needed)

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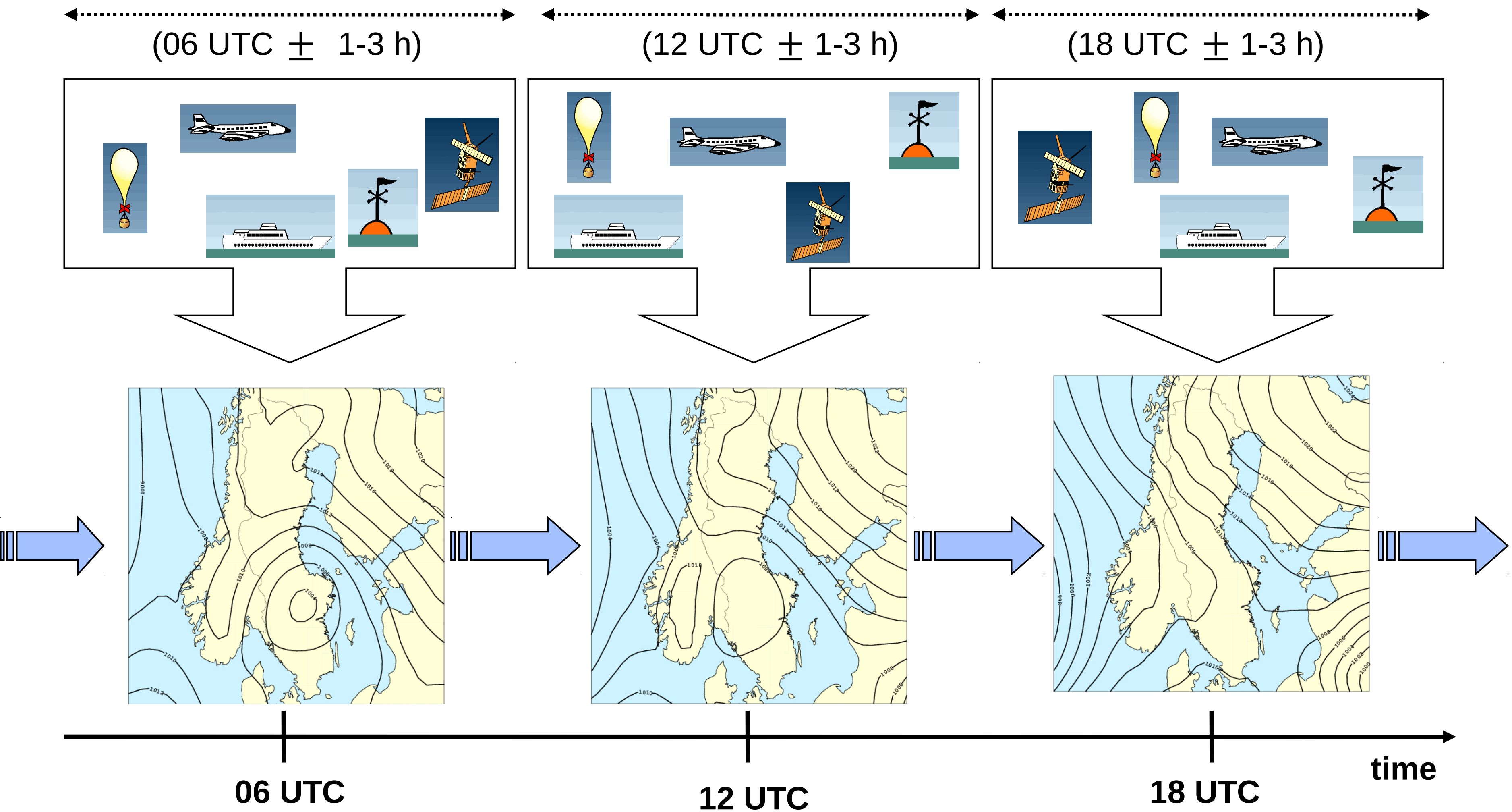
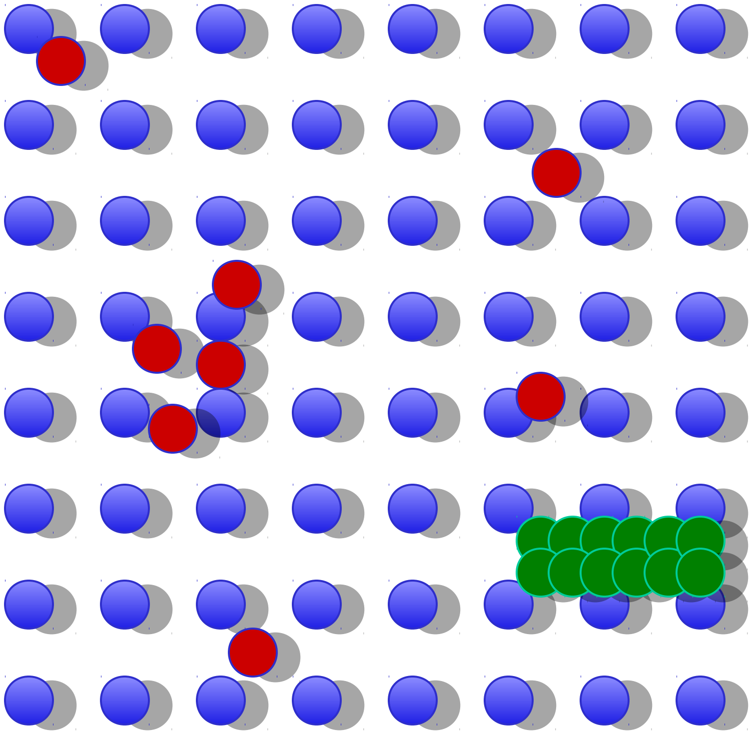
Intermittent data-assimilation



The background field



Background field

Conv. observations

Sat. observations

Background error statistics

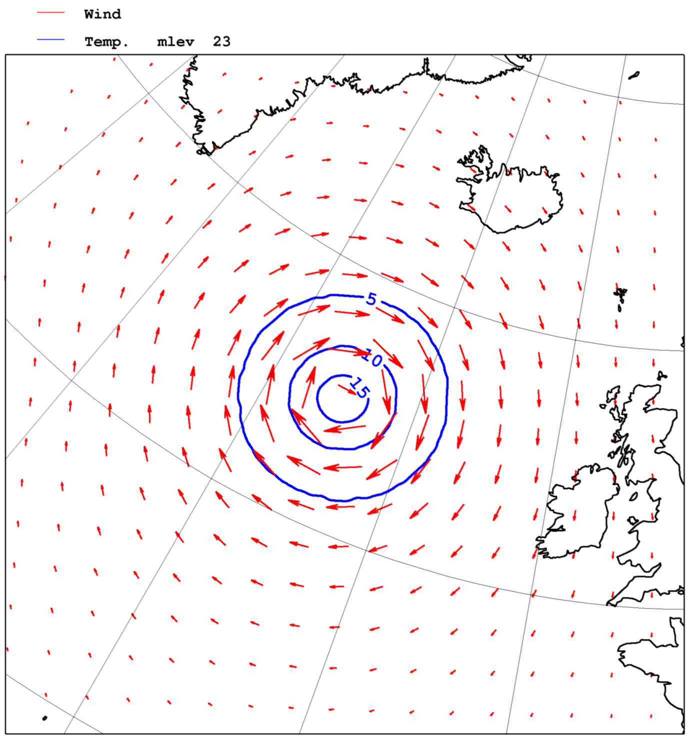
The background error covariances are characterised by the background error standard deviations (σ^b) and the background error correlations (sometimes referred to as structure functions).

standard deviations (σ^b)

correlations (structure functions)

$\sigma^b >> \sigma^0$ ➡ **Large** weight to observation

$\sigma^b << \sigma^o$ ➡ **Small** weight to observation



HARMONIE upper-air variational data assimilation

Cost function:

$$J = J_b + J_o = \frac{1}{2}\delta x^T B^{-1}\delta x + \frac{1}{2}(Hx^b + H_{tl}\delta x - y)^T R^{-1}(Hx^b + H_{tl}\delta x - y)$$

where

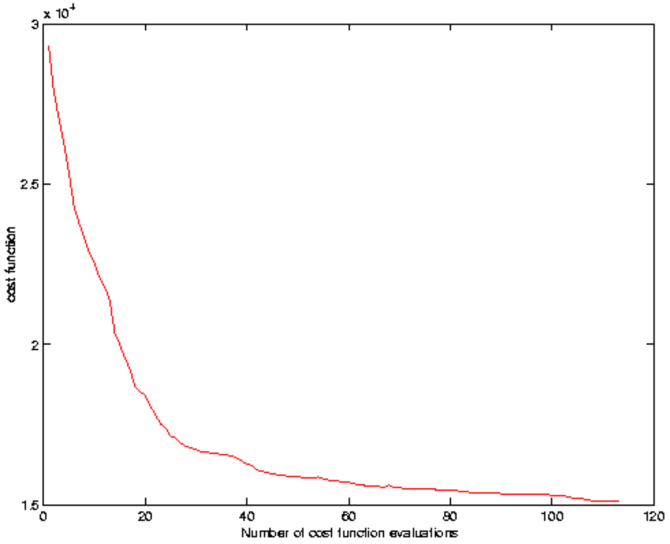
$\delta x \quad = x - x^b = \left(\delta u \quad \delta v \quad \delta T \quad \delta q \quad \delta \ln p_s\right)^T$

x^b Background state

B Background error covariances

R Observation error covariances

H, H_{tl} Observation operators



Handling of large dimension of B-matrix in HARMONIE variational data assimilation

$$J = J_b + J_o = \frac{1}{2}\delta x^T B^{-1}\delta x + \frac{1}{2}(y - Hx^b - H_{tl}\delta x)^T R^{-1}(y - Hx^b - H_{tl}\delta x)$$

where $\delta x = x - x^b = \begin{pmatrix}\delta u & \delta v & \delta T & \delta q & \delta \ln p_s\end{pmatrix}^T$

Change of variable

$$\chi = U\delta x$$

$$J = \frac{1}{2}(\chi)^T(\chi) + \frac{1}{2}(y - Hx^b - H_{tl}U^{-1}\chi)^T R^{-1}(y - Hx^b - H_{tl}U^{-1}\chi)$$

where $\chi = \begin{pmatrix}\xi & \eta_u & T_u & q_u & Ps_u\end{pmatrix}^T$

Important features of δx to χ transformation (U):

- Control variables in spectral space (handling of horizontal error correlations by assuming horizontal homogeneity of error correlations)
- Separate into balanced and unbalanced (handling of cross-correlations)
- Projection on eigenvectors of vertical correlation matrices (handling of verttical error correlations)

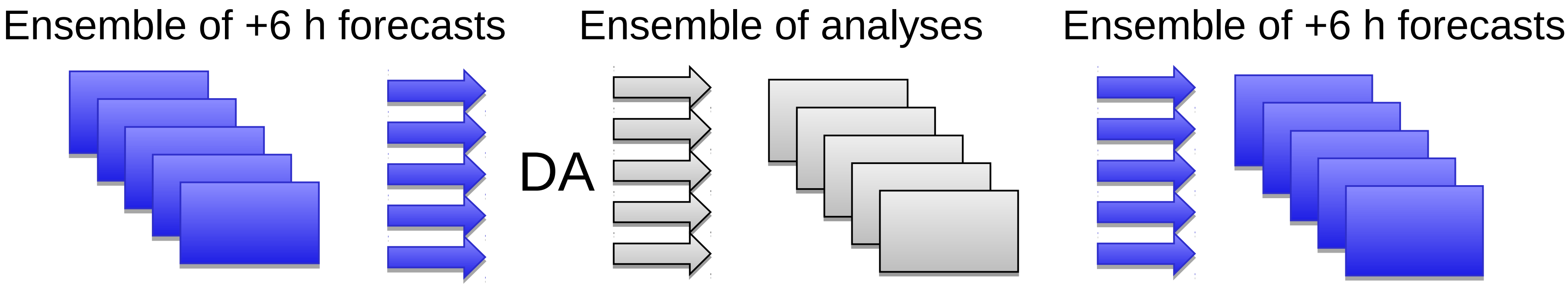
Methods for generating background error statistics

The NMC-method

Estimate error statistics from differences of forecasts valid at the same time (usually 48h-24h, but also 36h-12h).

Ensemble assimilation

Estimate error statistics from differences of a number of 6 h (or 12h) forecasts with perturbed observations, lateral boundaries, model physics.



HARMONIE current default approach

Background error statistics is calculated from differences of HARMONIE 6h forecasts, started from analyses belonging to ECMWF ensemble data assimilation experiment. Lateral boundary conditions are taken from corresponding ECMWF forecasts.

HARMONIE background error statistics

A so-called ***statistical balance*** formulation (Derber and Bouttier, 1999, Tellus, **51A**, 195-221), (Berre, 2000,**128**, MWR, 644-657) is used for deriving the background error covariances from the sample of forecast differences from the ensemble. The resulting HARMONIE statistics are contained in two files:

stabal96.cv stabal96.bal

stabal96.cv

Contains vertical background error auto-covariance matrices for each total horizontal wave number K ($K^2=k^2+l^2$) and for each control variable $(\xi \quad \eta_u \quad T_u \quad q_u \quad Ps_u)$

stabal96.bal

Describes statistically balances for $(\xi \quad \eta \quad T \quad q \quad Ps)$, for each horizontal total wave number and for each vertical level.

$$\zeta = \zeta \qquad \boldsymbol{\eta} = \mathbf{MH}\zeta + \boldsymbol{\eta}_u$$

$$(\mathbf{T}, P_s) = \mathbf{NH}\zeta + \mathbf{P}\boldsymbol{\eta}_u + (\mathbf{T}, P_s)_u$$

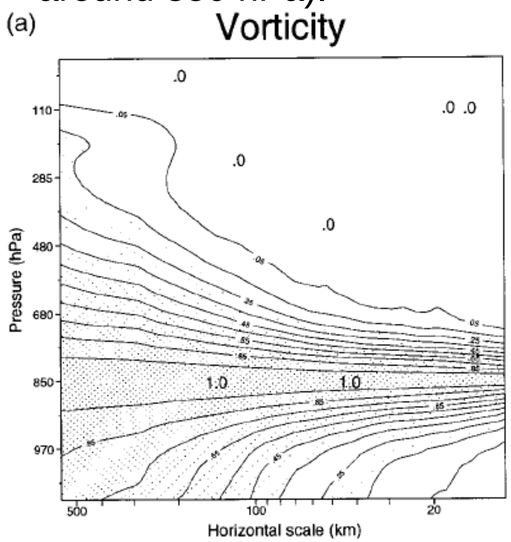
$$\mathbf{q} = \mathbf{QH}\zeta + \mathbf{R}\boldsymbol{\eta}_u + \mathbf{S}(\mathbf{T}, P_s)_u + \mathbf{q}_u,$$

where **MH**, **NH**, **P**, **QH**, **R** and **S** are matrices containing regression coefficients. These matrices are stored in stabal96.bal.

HARMONIE background error statistics

Example of information contained in auto-covariances in stabal96.cv

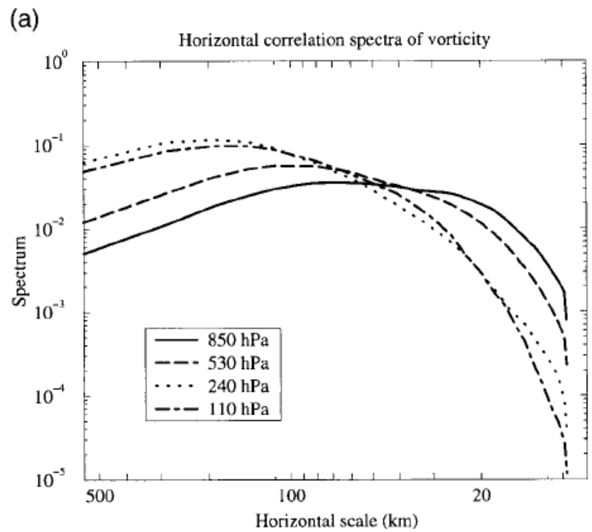
Vertical background error correlation matrix for vorticity for model level at model level 20, around 850 hPa).



total wave number →

(from Berre, 2000)

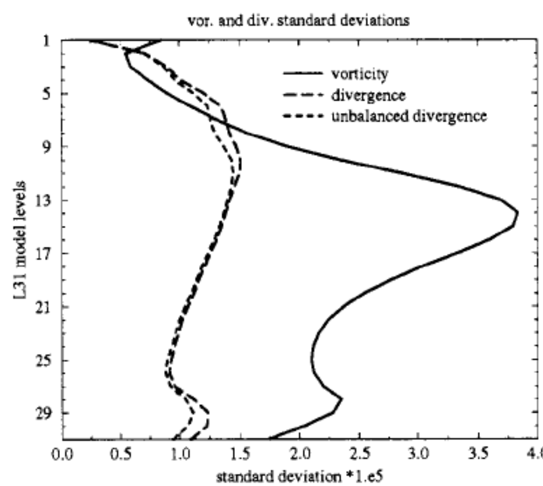
Vorticity horizontal correlation spectra for three different vertical levels.



total wave number →

(from Berre, 2000)

Vertical profile of vorticity and unbalanced divergence background error standard deviations.



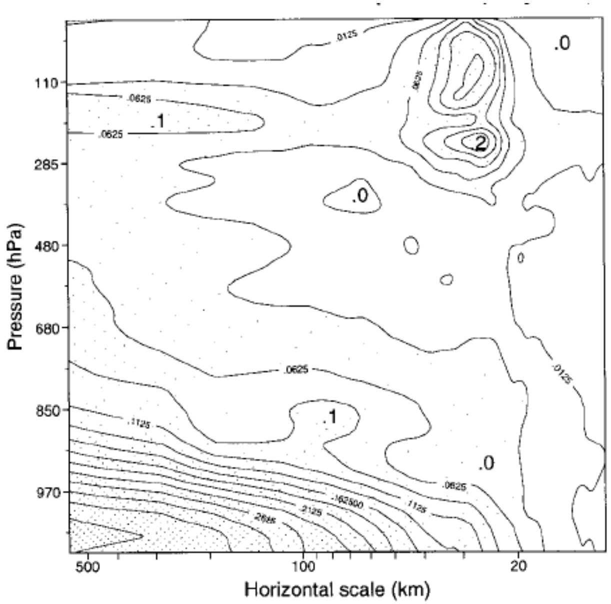
(Derber and Bouttier, 1999)

In HARMONIE the background error statistics homogenous. The vertical profiles of standard deviations are scaled with one single parameter (REDNMC).

HARMONIE background error statistics

example of information contained in regression coefficient matrices in stabal96.bal

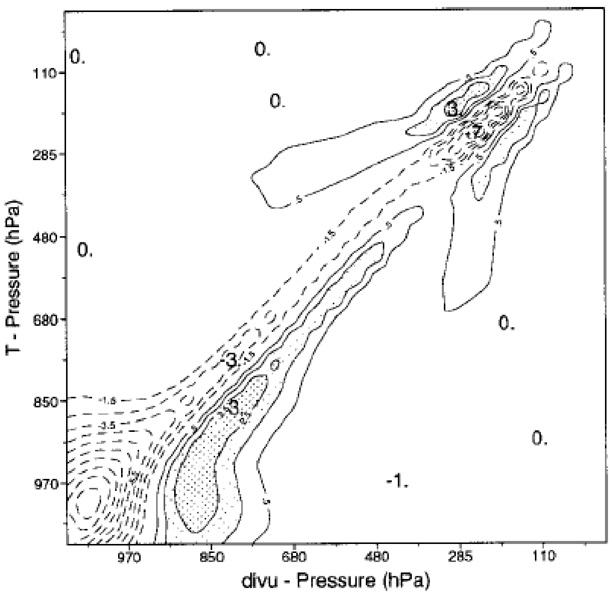
Total ratio of divergence variance explained (by vorticity)



total wave number →

(from Berre, 2000)

Average temperature-unbalanced divergence cross-covariances



(from Berre, 2000)

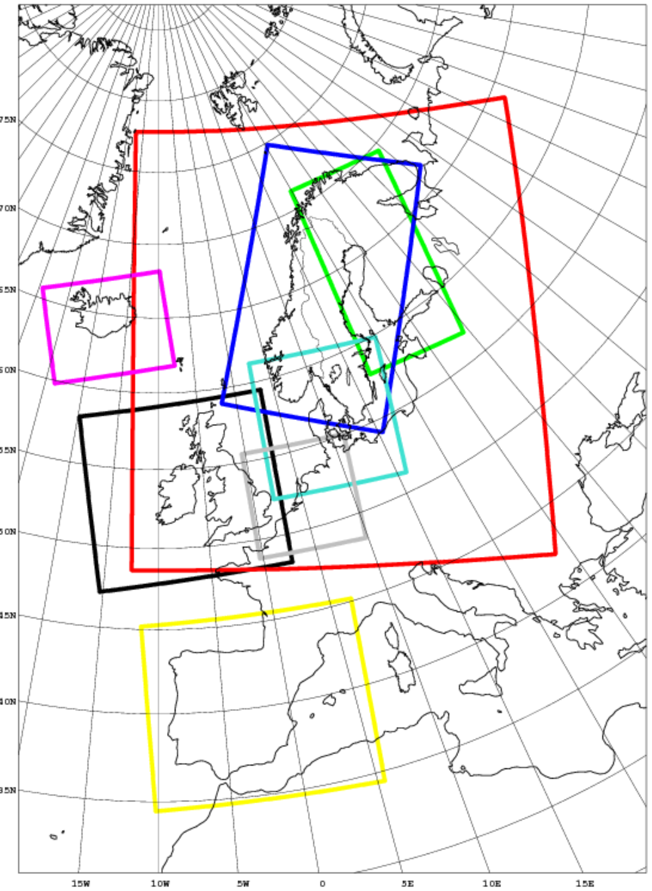
$$\zeta = \zeta \qquad \eta = \mathbf{M}\mathbf{H}\zeta + \eta_u$$

$$(\mathrm{T}, P_s) = \mathbf{N}\mathbf{H}\zeta + \mathbf{P}\eta_u + (\mathrm{T}, P_s)_u$$

$$\mathrm{q} = \mathbf{Q}\mathbf{H}\zeta + \mathbf{R}\eta_u + \mathbf{S}(\mathrm{T}, P_s)_u + \mathrm{q}_u,$$

Practicalities concerning background error statistics for HARMONIE data assimilation

- ALADIN data assimilation requires pre-calculated background error statistics for each model domain.
- The background error statistics are used in the screening ($\frac{(y-[Hx^b]_i)^2}{\sigma_b^2+\sigma_o^2} \leq L$)and minimization ($\chi = U\delta x$) steps.
- Background error statistics have already been defined for several domains (and are placed in ec:/hirlam/harmonie_jbdata/ on ecfs).
- New domains and modifications of existing domains (resolution changes, change of number of vertical levels) requires generation of background error statistics.
- The procedure for deriving background error statistics for a domain involves several steps that will be described here.
- There is also a possibility to interpolate background error statistics from one area to another. This is recommended for technical tests of the assimilation system only.



Practical procedure for deriving HARMONIE background error statistics

Find detailed instructions on:

https://hirlam.org/trac/wiki/HarmonieSystemDocumentation/Structurefunctions

- Produce an ensemble of HARMONIE +6h forecasts taking initial fields and later boundary conditions from an ECMWF ensemble data assimilation experiment. Apply 4 parallel downscaling runs and run once a day for 1.5 months.

- Generate forecast difference files from forecasts (in FA format) valid at the same time of the ensemble. This is achieved by compiling and running program for making forecast difference files from the forecasts. Output format of difference files are in a format suitable for coming Jb statistics calculations.

- Calculate backround error statistics by applying an existing statistics program (festat) to the forecast difference files.

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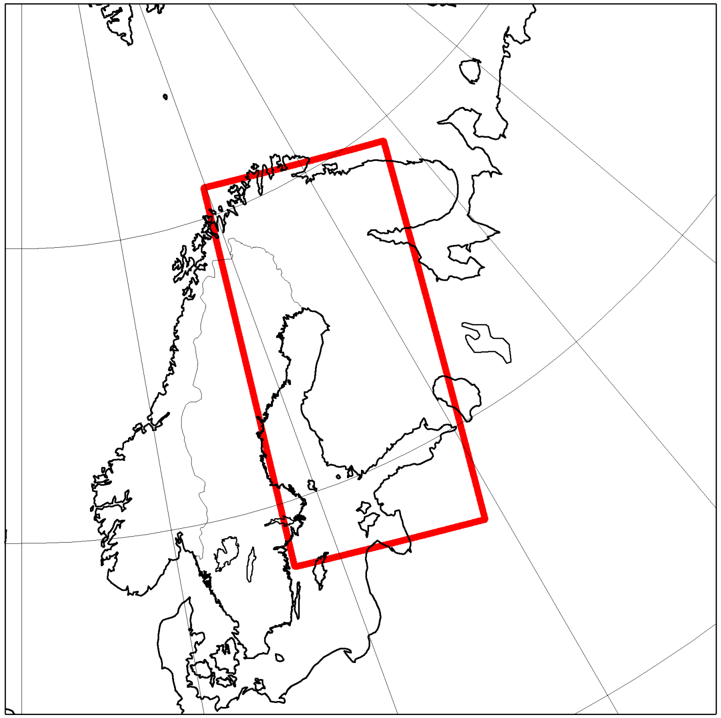
Instructions when utilizing HARMONIE cycle 36h1.4 for an example when using AROME DOMAIN=FINLAND with 65 vertical levels and 2.5 km horizontal resolution



STEP 1: Generate an ensemble of HARMONIE 6 h forecasts

a.Prepare experiments for running 4 HARMONIE runs with downscaling of ECMWF ensemble data assimilation results for the period 20060920-20061031. Create 36h14e1 to 36h14e4 directories as described below for 36h14e1. 36h14e2 to 36h14e4 procedure is exactly the same, except for that you do include 'export JB_ENS_MEMBER=2' etc, instead of 'export JB_ENS_MEMBER=1' at the bottom of config_exp.h.

- *On ecgate* $HOME directory create hm_home/36h14e1 directory and go there.
- Create the experiment by typing

  ~hlam/Harmonie setup -r /home/ms/spsehlam/hlam/harmonie_release/tags/harmonie-36h1.4

- edit sms/config_exp.h as follows:

set DOMAIN=FINLAND, FCINT=24, BDSTRATEGY=jb_ensemble, OUTINT=6, ANAATMO=none, ANASURF=none, ECFSLOC=ec and at the end add line 'export JB_ENS_MEMBER=1'

- Add updates for 'domain_prop' by placed in $HOME/hm_home/36h14e1 typing ecp ec:/smx/Jb_wiki_ml/util.tar ., followed by tar -cvf util.tar

b. Launch experiments by from $HOME/hm_home/36h14e1 to $HOME/hm_home/36h14e4 *on ecgate*, by typing

~hlam/Harmonie start DTG=2006092000 DTGEND=2006103100 LLMAIN=06

(in a couple of hours forecasts will start to appear at ec:/$uid/harmonie/$EXP/$YYYY/$MM/$DD/$HH)

STEP 2: Generate forecast difference files

a. Compile program for making forecast differences

- *On ecgate*, copy your experiment $HOME/hm_home/36h14e1 to $HOME/hm_home/36h14_df
- In $HOME/hm_home/36h14_df, remove the file 'experiment_is_locked'

- Placed in $HOME/hm_home/36h14_df type: ecp ec:/smx/Jb_wiki_ml/src_arome.tar . , followed by tar -xvf src_aldalr.tar (in case of ALADIN or ALARO utilize src_aldalr.tar instead of src_arome.tar). This will result in a directory src with updated source code needed for generation of forecast difference program.
  - Placed in $HOME/hm_home/ 36h14_df launch experiment by typing: ~hlam/Harmonie start DTG=2006092000
    - When the build (compilation) step is finished then stop mini-SMS.

(You will *on c1a* find the $TEMP/hm_home/36h14_df/bin/MASTERODB.

It is the program that will be used in the next part of STEP 2, running program for generating forecast differences)

STEP 2: Generate forecast difference files

b. Running program for making forecast differences

- Log in to c1a (placed on ecgate type: rlogin c1a).
- Go to $TEMP, followed by ecp /ec:/smx/Jb_wiki_ml/Jb_dir.tar ., followed by tar -xvf Jb_dir.tar. You will get a ‘Jb_dir’ with a number of subdirectories.

- In scripts (cd scripts) you find the script makediff. Take a look at it and modify $uid ‘smx' to your own uid and set paths to find your data and executables (MASTERODB should be taken from the directory $TEMP/hm_home/36h14_df/bin/MASTERODB and forecast files from your ensemble experiments, as stored on ecfs). Modify start and end dates to match the ones of your experiment. (in case of ALADIN/ALARO modify makediff to use $TEMP/Jb_dir/nam/difaldalr.36h14.nml instead of difarm.36h14.nml).
- Positioned in scripts directory, launch makediff by typing:

  llsubmit ./makediff

(Out directory will be on $TEMP/Jb_dir. Note three sub-directories 'Diff2 Stat Work'. 'Work' is where the calculations take place and 'Diff2' where the output difference files appear in a format suitable for coming structure function calculation (names like nmcstat2006092000.0i, i=1,..4))

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STEP 3: Calculation of background error statistics

a. Preparations

- *On c1a* go to $TEMP/Jb_dir/scripts where you modify paths and dates in linkdiff script.
- Placed in $TEMP/Jb_dir/scripts run linkdiff by typing ./linkdiff to generate symbolic links in '$TEMP/Jb_dir/Stat‘ pointing at difference files '$TEMP/Jb_dir/Diff’ .
- Compile program for generating forecast differences (festat.x) by placed in $TEMP/Jb_dir/festat_src typing make.
- Go to $TEMP to where you also copy the executable TEMP/hm_home/36h14_df/bin/domain_prop and the forecast FA file ec:/smx/harmonie/36h14e1/2006/09/20/00 /ICMSHHARM+0006.
- Placed at $TEMP extract geometrical information about your domain by typing:

  ./domain_prop -f ICMSHHARM+0006 -4JB
- Edit TEMP/Jb_dir/scripts/runfestat. You will find roughly 25 different namelist parameters to modify. (see $TEMP/Jb_dir/scripts/README.festat). Use the information extracted by domain_prop.

STEP 3: Calculation of background error statistics

b. Running program for generating statistics

- *On c1a* go to $TEMP/Jb_dir/scripts and launch the newly edited runfestat script by typing:

llsubmit ./festat

runfestat is using your newly compiled $TEMP/src_festat/festat.x, which is run under directory $TEMP/Jb_dir/Stat.

After 12-24 hours resulting output background error statistics files will appear in $TEMP/Jb_dir/Stat in the form of two files named

'stabfiltn*.cv' and 'stabfiltn*.bal‘

(in this example they are named

stabfiltn_FINEXP_168.cv and stabfiltn_FINEXP_168.bal)

gzip and put them on ecfs directory ec:/$uid/jbdata/

(ecp stabfiltn_FINEXP_168.bal.gz ec:/smx/jbdata/ stabfiltn_FINEXP_168.bal.gz

ecp stabfiltn_FINEXP_168.cv.gz ec:/smx/jbdata/ stabfiltn_FINEXP_168.cv.gz)

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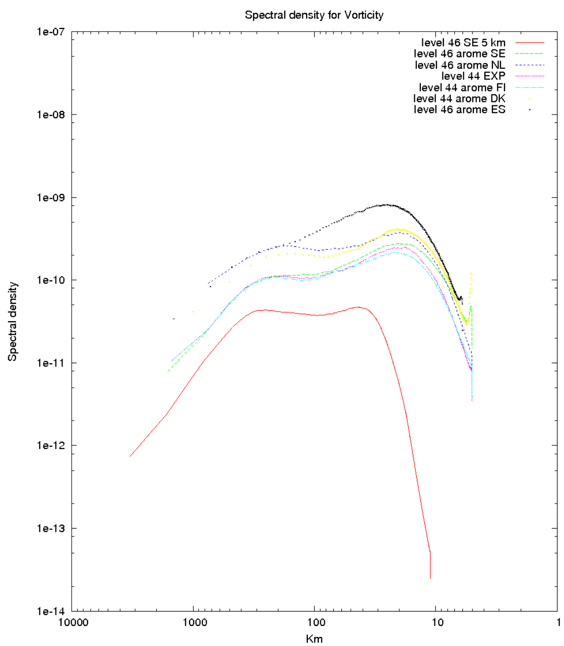
Diagnosing background error statistics

On ecgate go to $SRATCH and copy stuff for diagnosis of background error statistics ecp ec:/smx/Jb_wiki_ml/jbdiagconv.tar. Un-tar and copy newly derived background error statistics from ec:/$uid/jbdata as described on

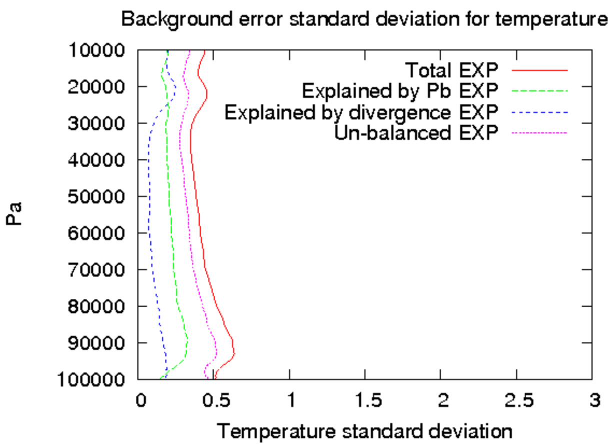
https://hirlam.org/trac/wiki/HarmonieSystemDocumentation/Structurefunctions

and then follow instructions how to apply jbdiagnose-software

Examples:



Vorticity spectral dens. at 900 hPa



EXP: newly derived statistics for FINLAND AROME domain

Recommended reading: (Berre, 2000,**128**, MWR, 644-657), (Gustafsson, pdf on wiki page above)

In addtion, single observation impact studies provide useful information!

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Run 3D-Var data assimilation with newly derived background error statistics (in this case for FINLAND AROME domain)

https://hirlam.org/trac/wiki/HarmonieSystemDocumentation/Structurefunctions

- On ecgate create $HOME/hm_home/36h14as directory, go there, and type:

~hlam/Harmonie setup –r /home/ms/spsehlam/hlam/harmonie_release/tags/harmonie-36h1.4

- set DOMAIN=FINLAND in 36h14as/sms/config_exp.h
- Check out the file include.ass by typing:

~hlam/Harmonie co include.ass

(include.ass will appear in the directory $HOME/hm_home/36h14as/scr)

- In include.ass set JBDIR=ec:/smx/jbdata ,f_JBCV=stabfiltn_FINEXP_168.cv, f_JBBAL=stabfiltn_FINEXP_168.cv name of your .bal file in ec:/$uid/jbdata Add these three lines just before the line in include.ass that is as follows:'# NAMELISTS'. Note tuning parameters REDNMC=0.6 and REDZONE=100 for FINLAND domain. (default REDNMC=0.9 and REDZONE=100).
- From $HOME/hm_home/36h14as launch experiment by typing

~hlam/Harmonie start DTG=2010010306 DTGEND=2010010312 LLMAIN=06

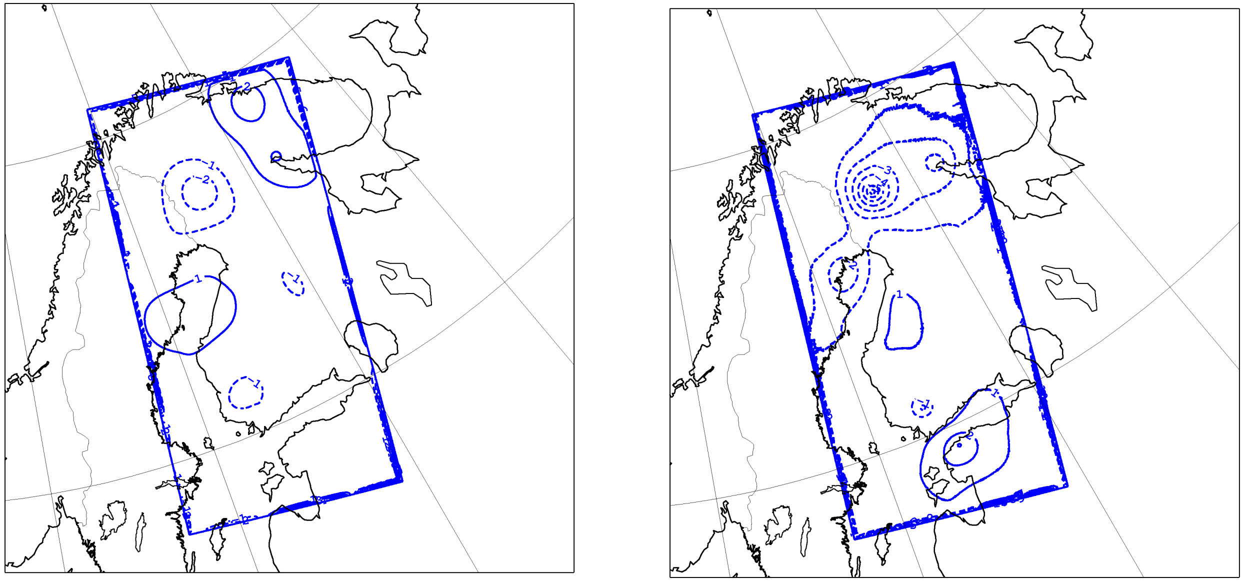
ectmp:/smx/harmonie/36h14_as/YYYY/MM/DD/HH/MXMIN1999+0000 (analysis)

ectmp:/smx/harmonie/36h14_as/YYYY/MM/DD/HH/ICMSHANAL+0000 (bg with surface analysis applied)

Plot of analysis increments

https://hirlam.org/trac/wiki/HarmonieSystemDocumentation/Structurefunctions

MXMIN1999+0000.grib minus ICMSHANAL+0000.grib



Temperature analysis increments (unit: tenths of K) for 2010010312 at model levels 23 (close to 500 hPa) and model level 65 (close to surface).

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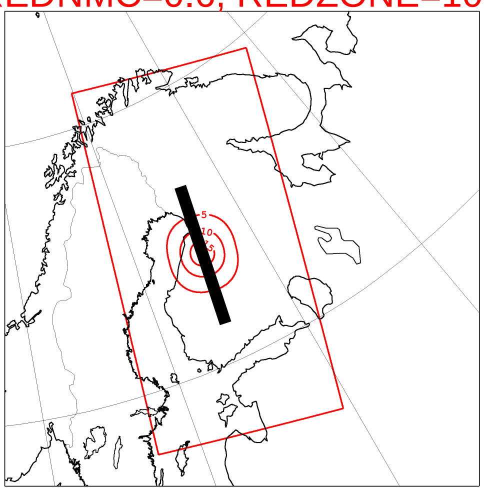
Single observation impact experiment

https://hirlam.org/trac/wiki/HarmonieSystemDocumentation/SingleObs

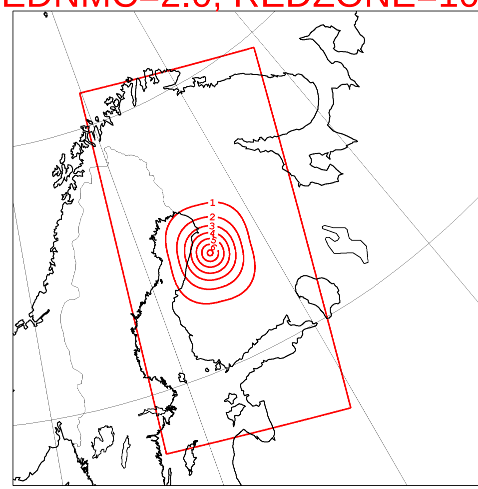
(modify scr/RunBatodb to use OBSOUL.ref contained in ec:/smx/sinob_wki_ml/sinob.tar)

Temperature analysis increments due to one single temperature observation 1 K warmer than the corresponding background value (unit: hundreds of K)

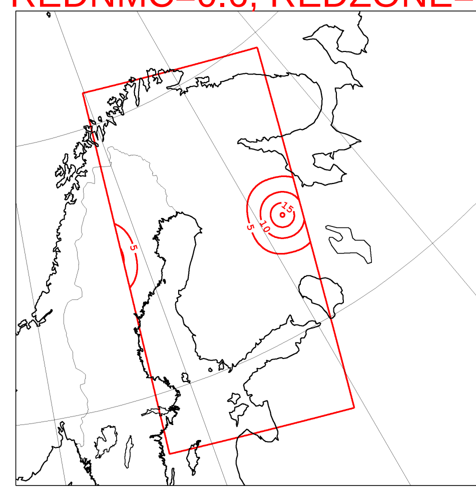
REDNMC=0.6, REDZONE=100



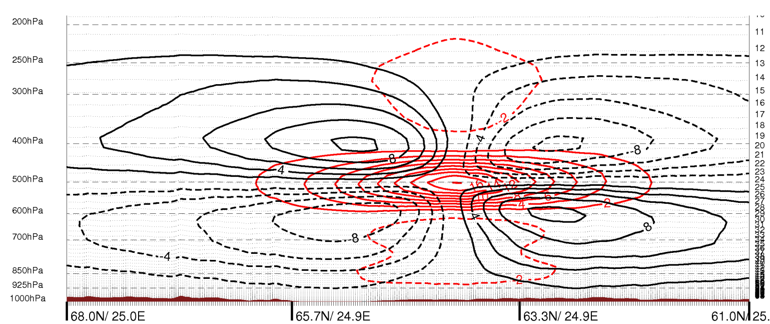
REDNMC=2.0, REDZONE=100



REDNMC=0.6, REDZONE=10



Vert. cross section of temperature and wind increments (unit: hundreds of: K, m/s)



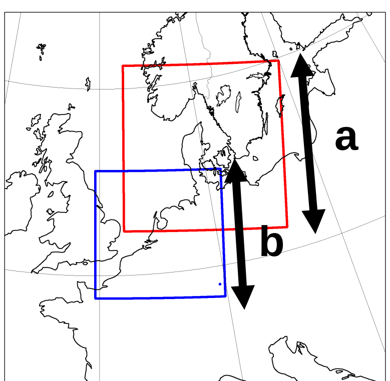
Interpolation of background error statistics between different domains for technical data assimilation tests

On ecgate go to $SRATCH and copy stuff for interpolation of background error statistics ecp ec:/smx/Jb_wiki_ml/jbdiagconv.tar. Copy input background error statistics from ec:/$uid/jbdata as described on

https://hirlam.org/trac/wiki/HarmonieSystemDocumentation/Structurefunctions

and then follow instructions how to apply jbconv-software

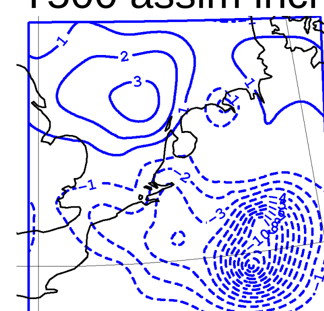
- *Input and output domain must have same number of vertical levels.*
- *Input domain must have larger wave number 1 (a>b*
- *Horisontal resolution may differ. (In case of larger output horizontal resolution than input horizontal resolution coefficient for wave numbers not represented in input domain set to 0 in output statistics. Truncation of spectra in case of higher horizontal resolution in input domain.*
- *See detailed example for conversion of Jb-statistics below:*



Input domain. DENMARK AROME domain with 65 vertical levels and 2.5 km hor. res.

Output domain. NETHERLANDS AROME domain with 65 vertical levels and 2.5 km hor. res.

T500 assim incr.



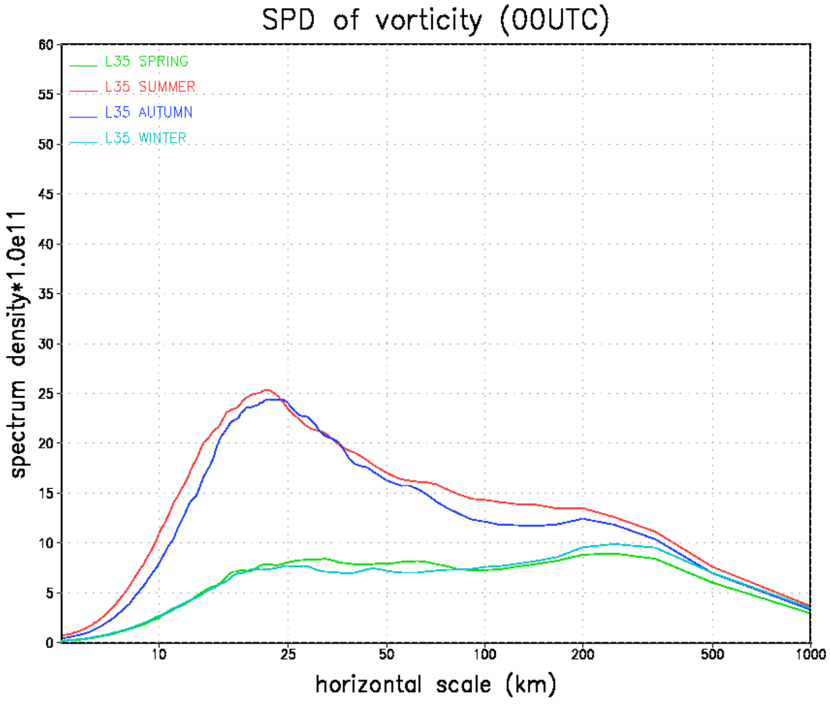
Recent and on-going Jb -related developments

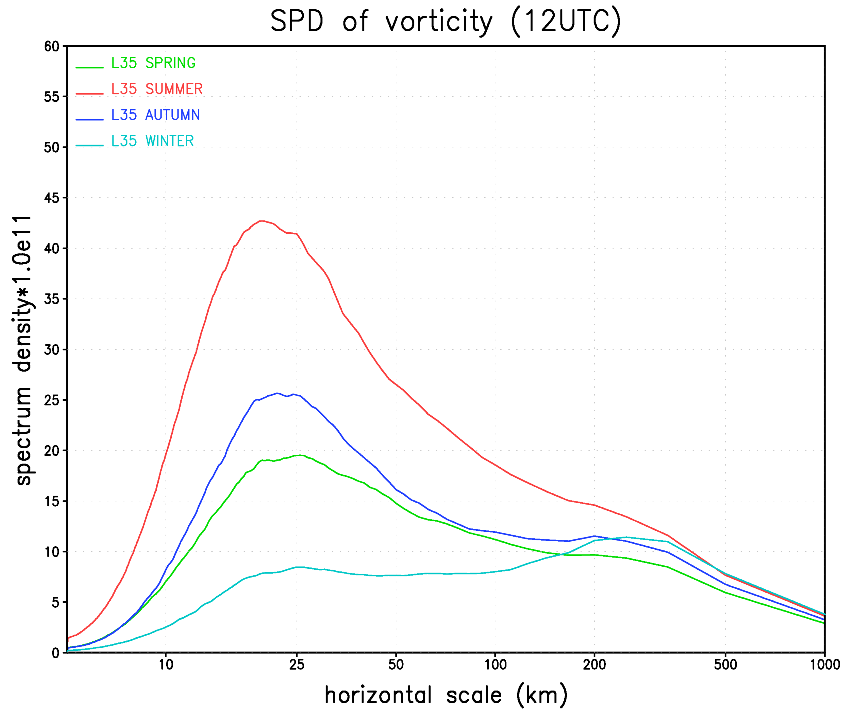
- Prepare HARMONIE for utilization of ECMWF ensemble data assimilation results from longer period. Potential representation of seasonal as well as daily variations in Jb statistics.
- Introduction of ensemble data assimilation into the HARMONIE reference system, for derivation of structure functions. Perturbed observations, model physics and lateral boundary conditions.
- Introduction of program for objective tuning for REDNMC parameter.
- Improvements to avoid problem with wrap-around of analysis increments from observations close to lateral boundaries .

Recent HARMONIE Developments

(by Shiyu Zhuang, DMI)

Background error statistics derived with downscaling from 6h forecast of ECMWF ensemble forecasts for different seasons and times of the day.





Background error statistics for vorticity at ~750 hPa for vertical level derived from data 2010030100-20110228. Left for different seasons and right for day/night.