Assimilating only surface pressure observations in 3D and 4DVAR

(and other observing system impact studies)

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ECMWF

Acknowledgements: Graeme Kelly

Outline

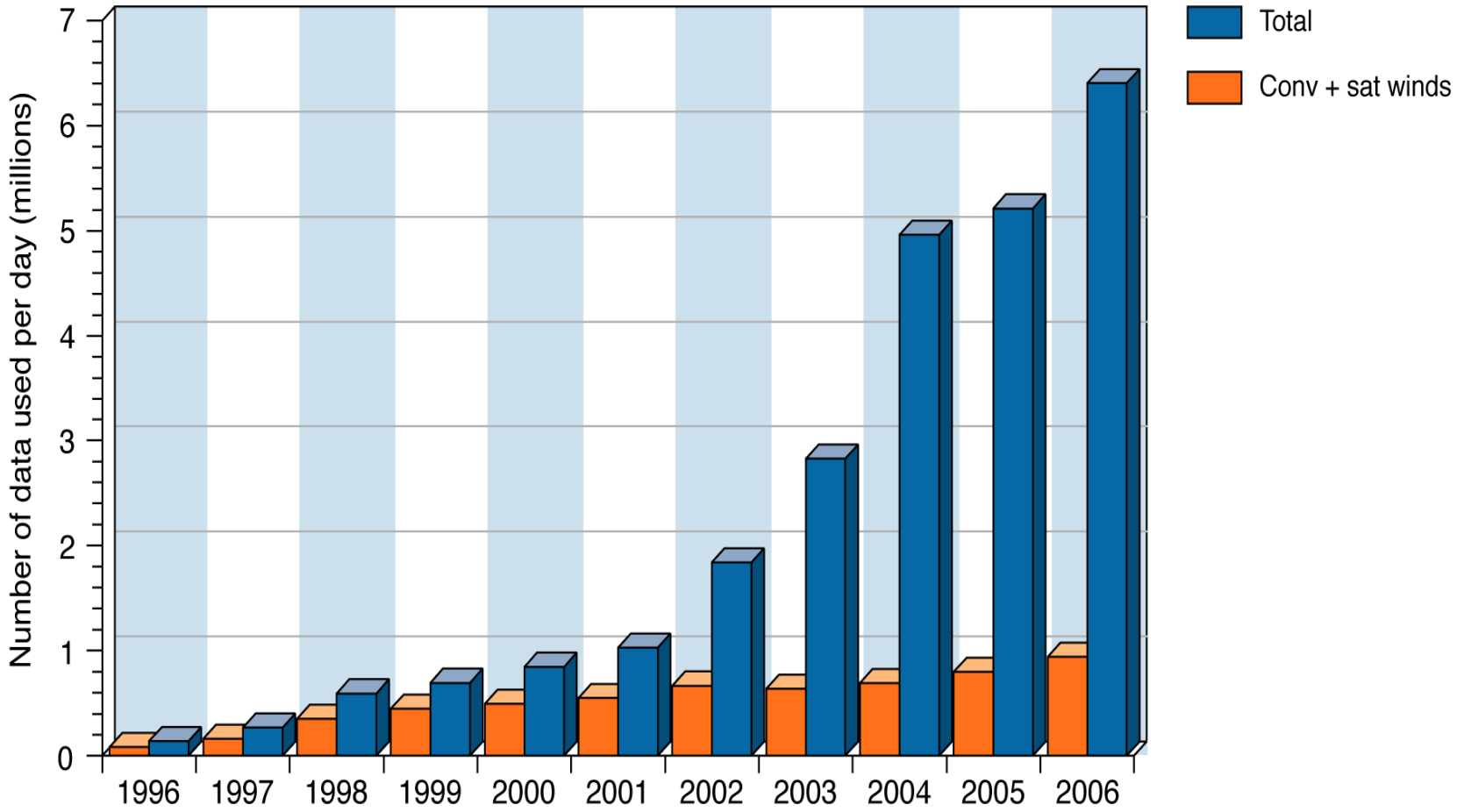
- **Context of the Study**
- **Current Contribution from Various Observing Systems to NWP**
- **“Surface Pressure only” assimilations:**
  - **Experimental Set-Up**
  - **Data coverage**
- **Results**
  - **Importance of tuning**
  - **3DVAR versus 4DVAR**
- **Conclusions**

Context of the study

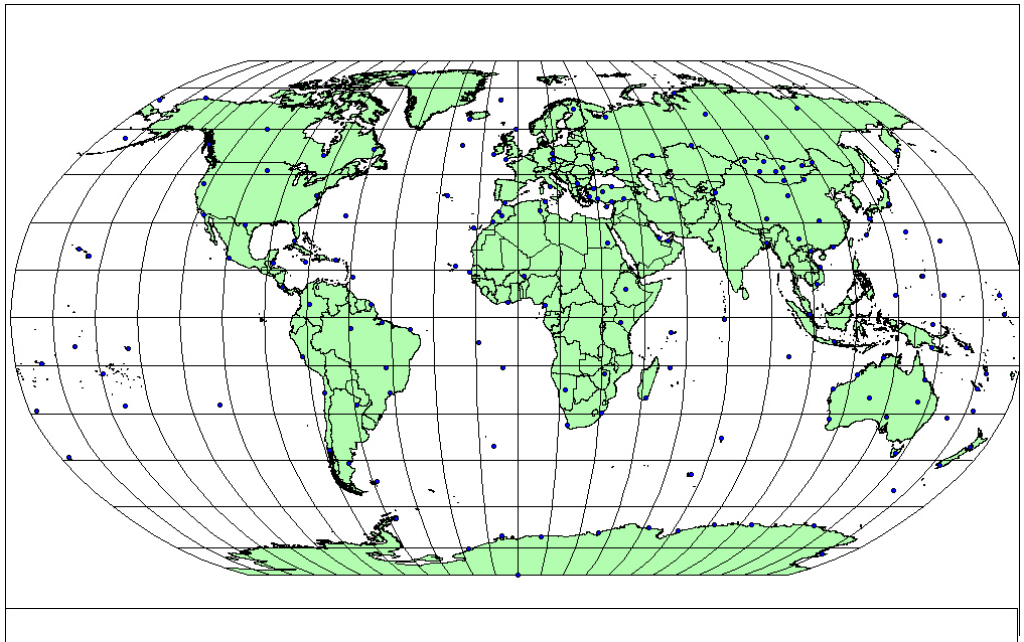
- **Impact of surface pressure observations in a system overwhelmed by satellite data**
  - **Surface pressure information is a prime User Requirement for global NWP**
  - **Recent OSEs suggest the importance of having a few but very accurate surface pressure observations**
- **Space-Terrestrial link impact studies (EUCOS/EUMETSAT)**
- **Comparison of respective performances of 4DVAR and 3DVAR in a context where the Observing System is very limited**
- **Realism of atmospheric analyses merely constrained by surface observations**
- **Support study looking at feasibility of reanalyses extended over long periods of time**

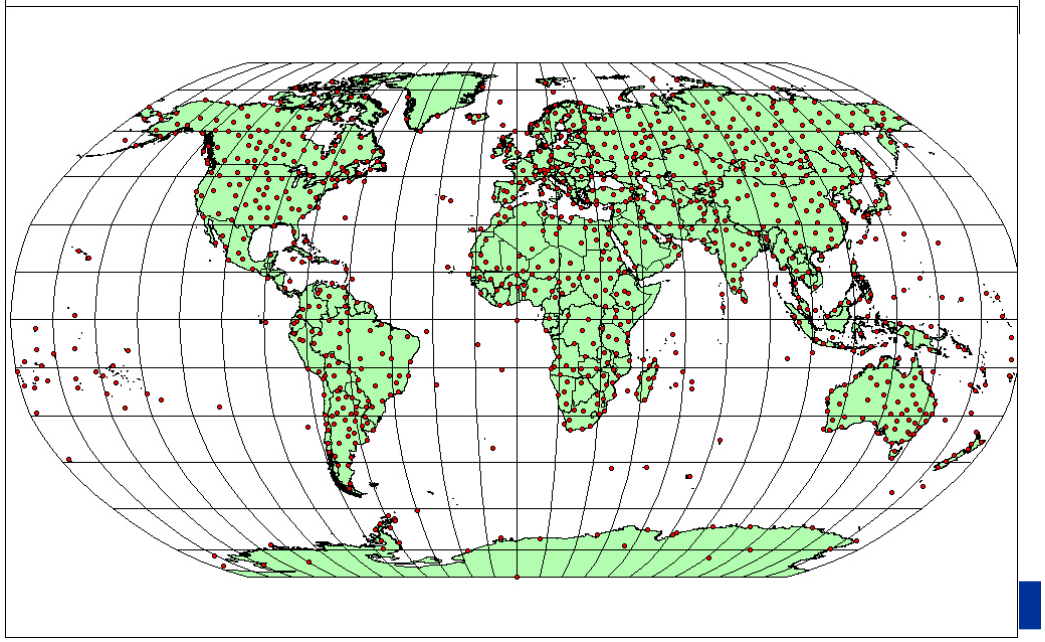
Current Contribution from Various Observing Systems to NWP

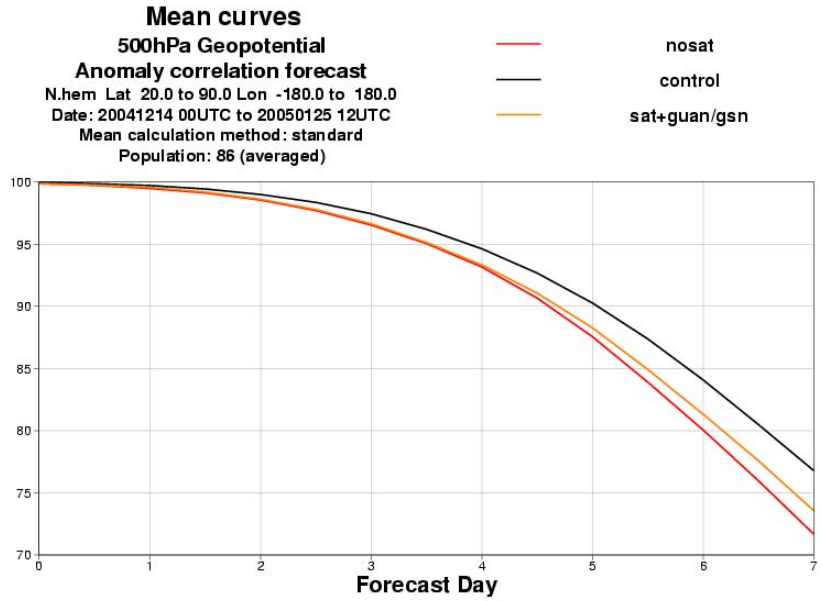
Large increase in number of data used daily over the last 10 years

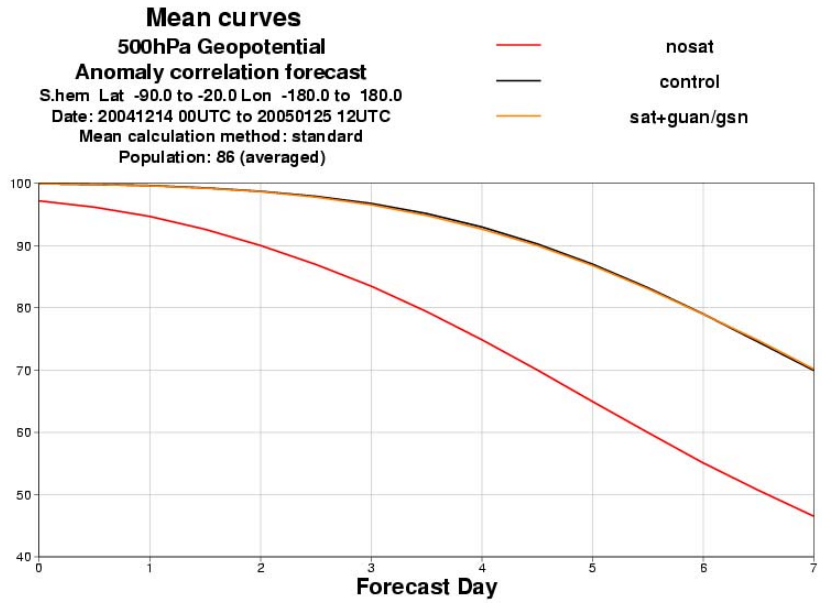


EUMETSAT-EUCOS OSEs (Space-Terrestrial impact studies)

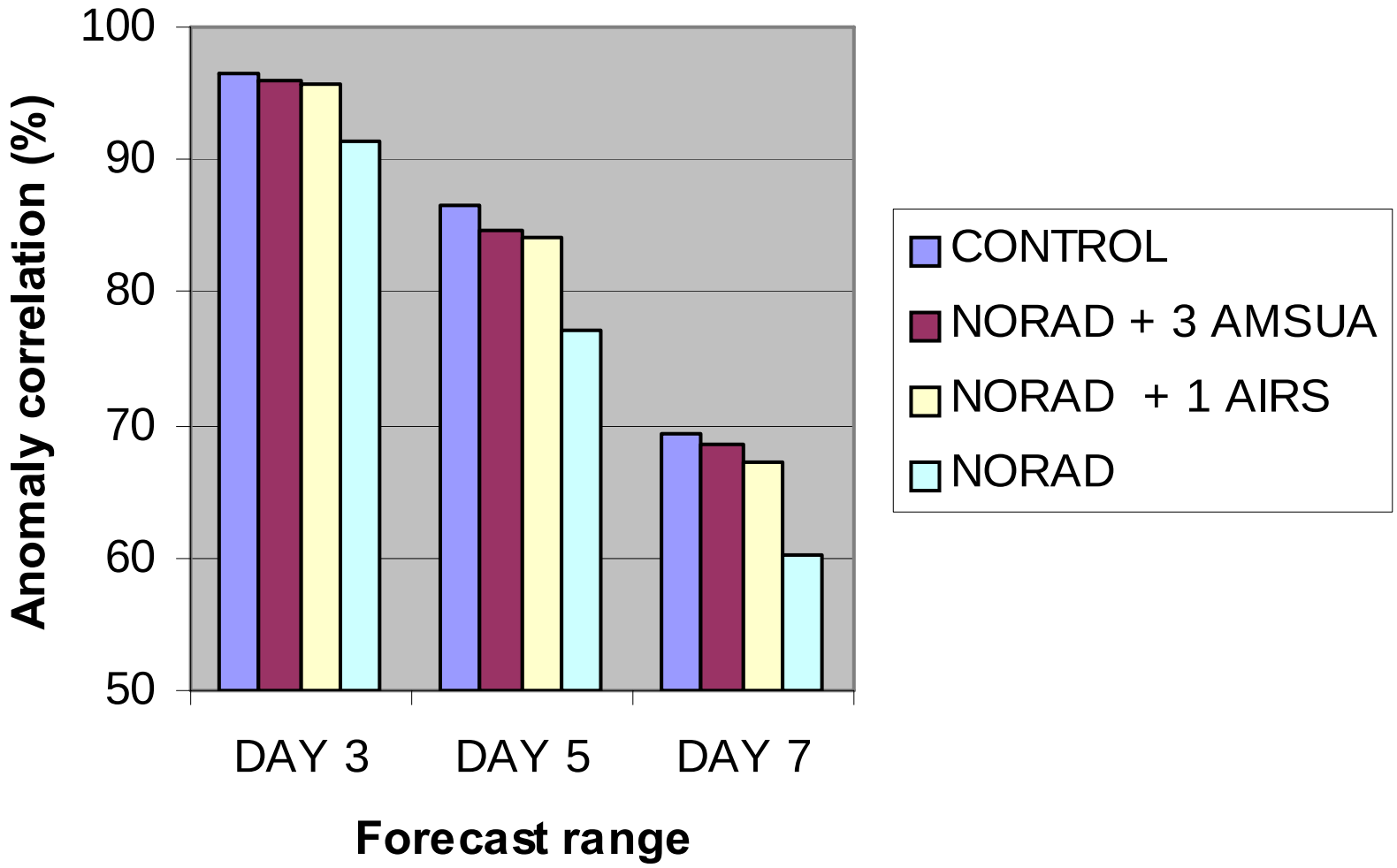




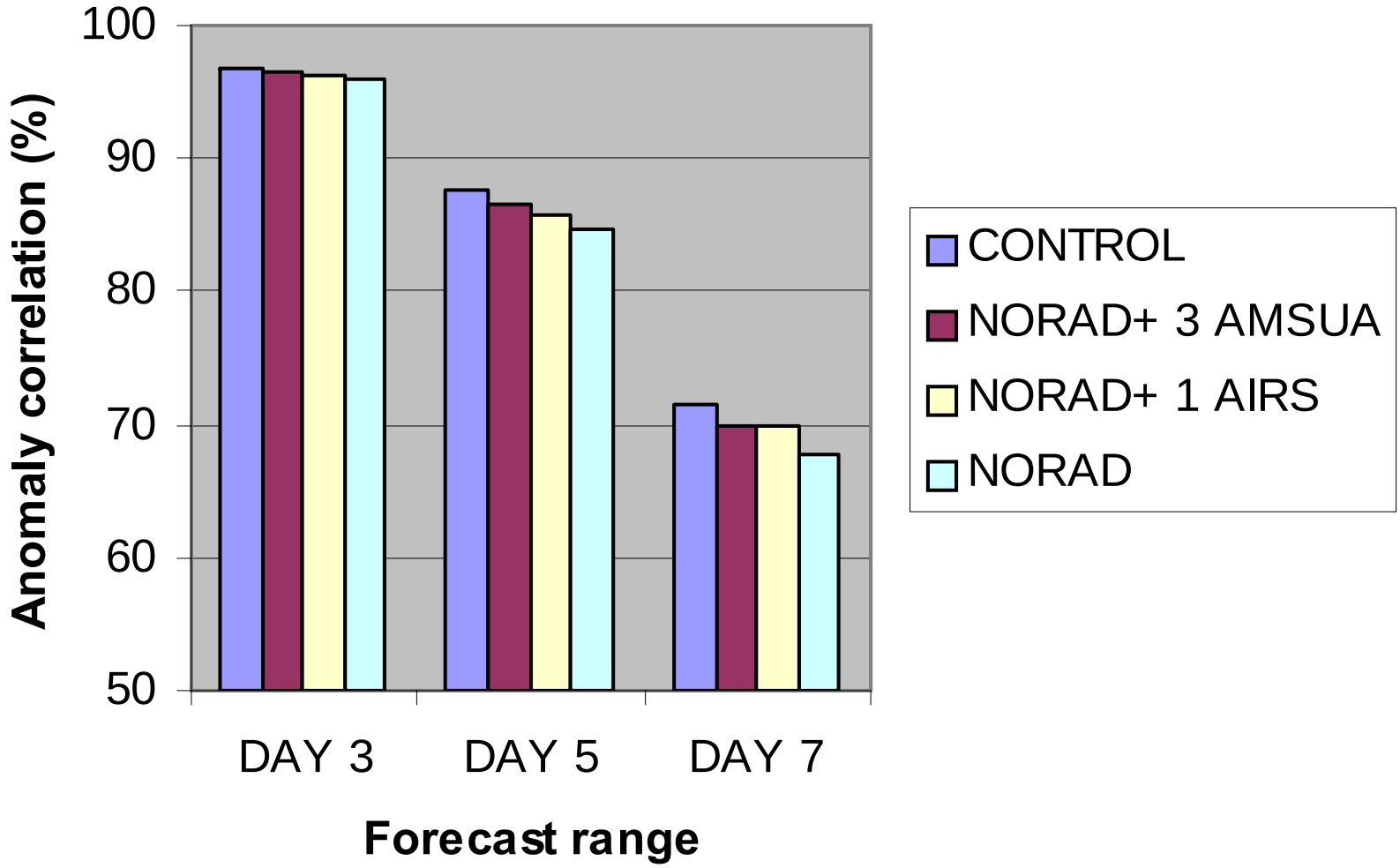




Southern Hemisphere scores

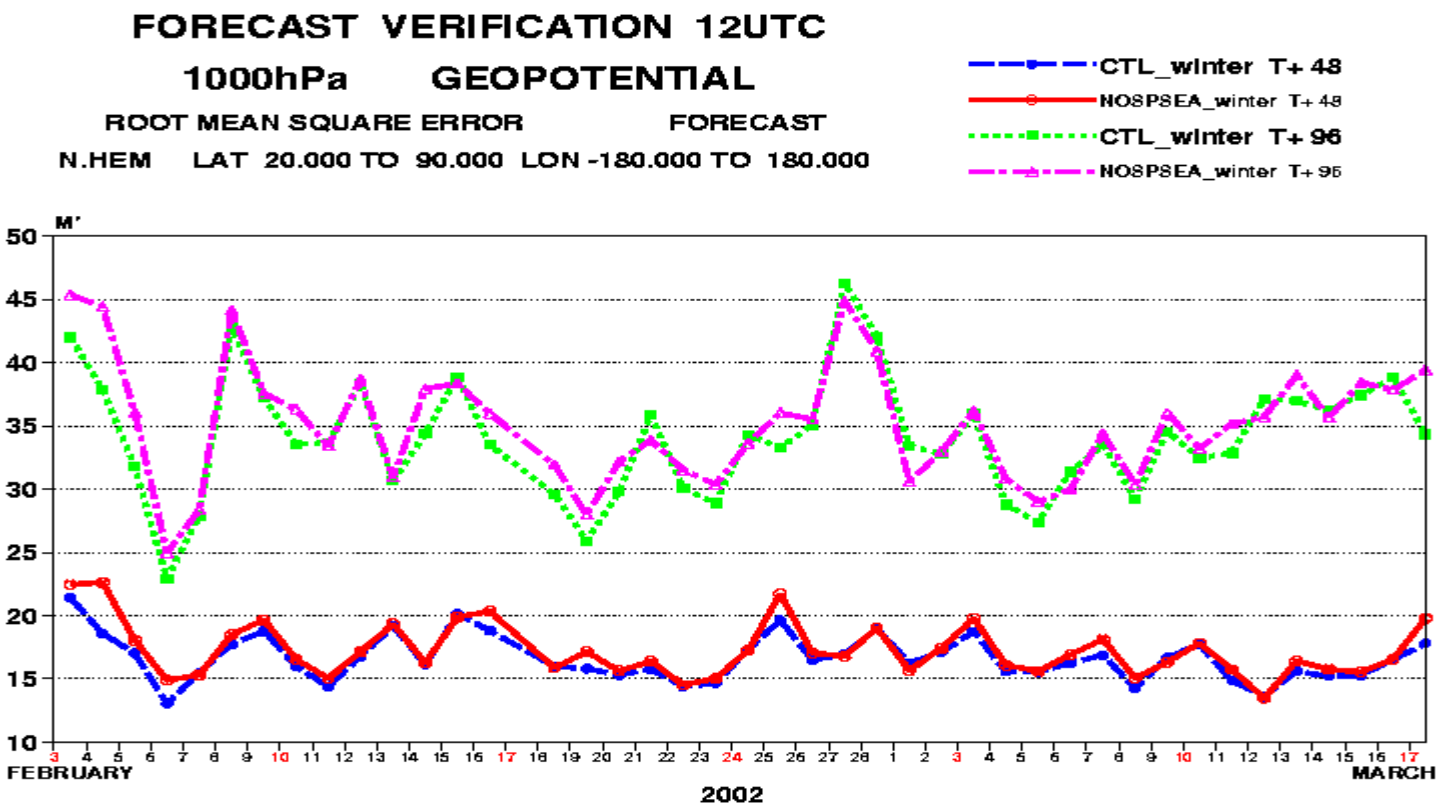


Northern Hemisphere scores



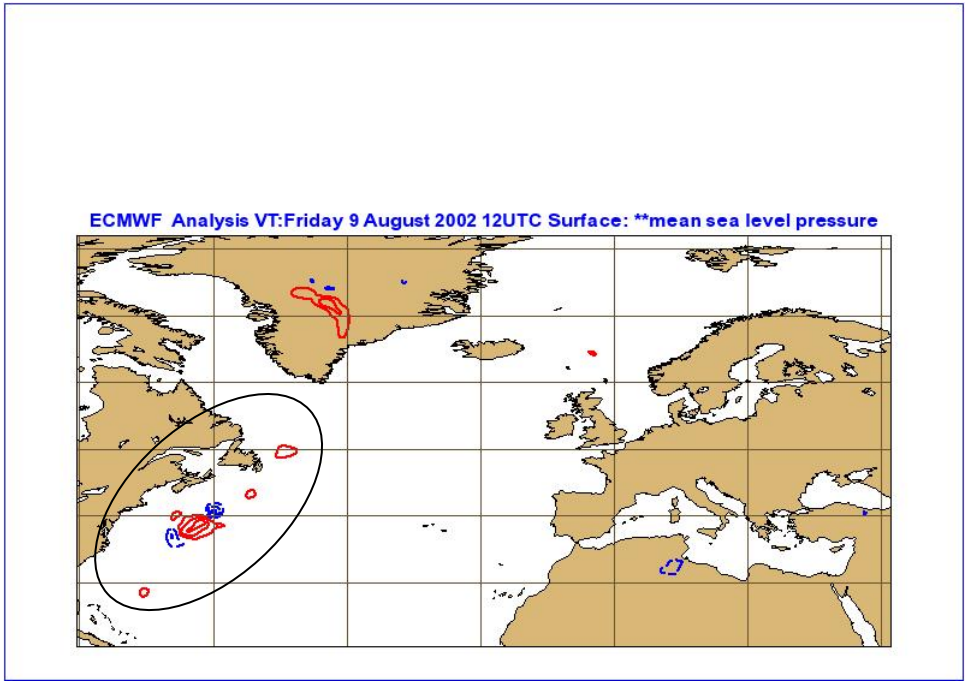
Surface data OSEs (WMO Alpbach workshop 2003)

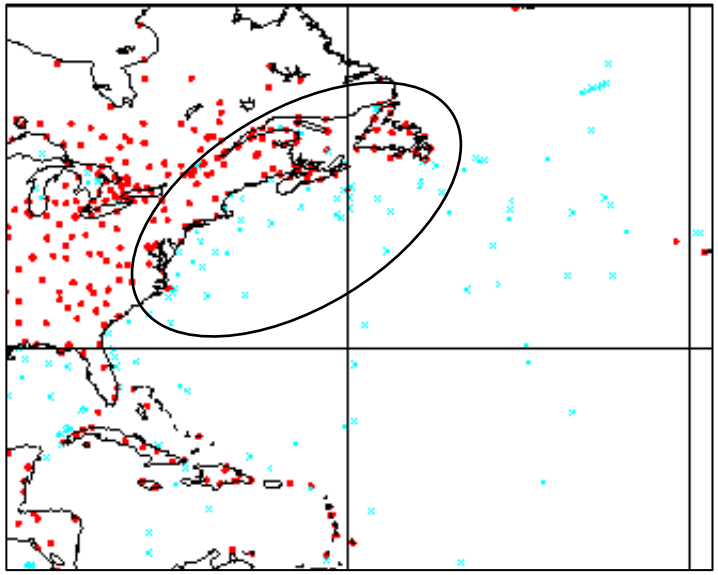
Statistically significant degradation of the scores when surface pressure observations over sea are removed



In parallel, other studies conducted by EUMETSAT concluded that it is impossible to observe surface pressure from Space with the required data coverage and accuracy.

Surface Data OSEs (Alpbach workshop 2003)





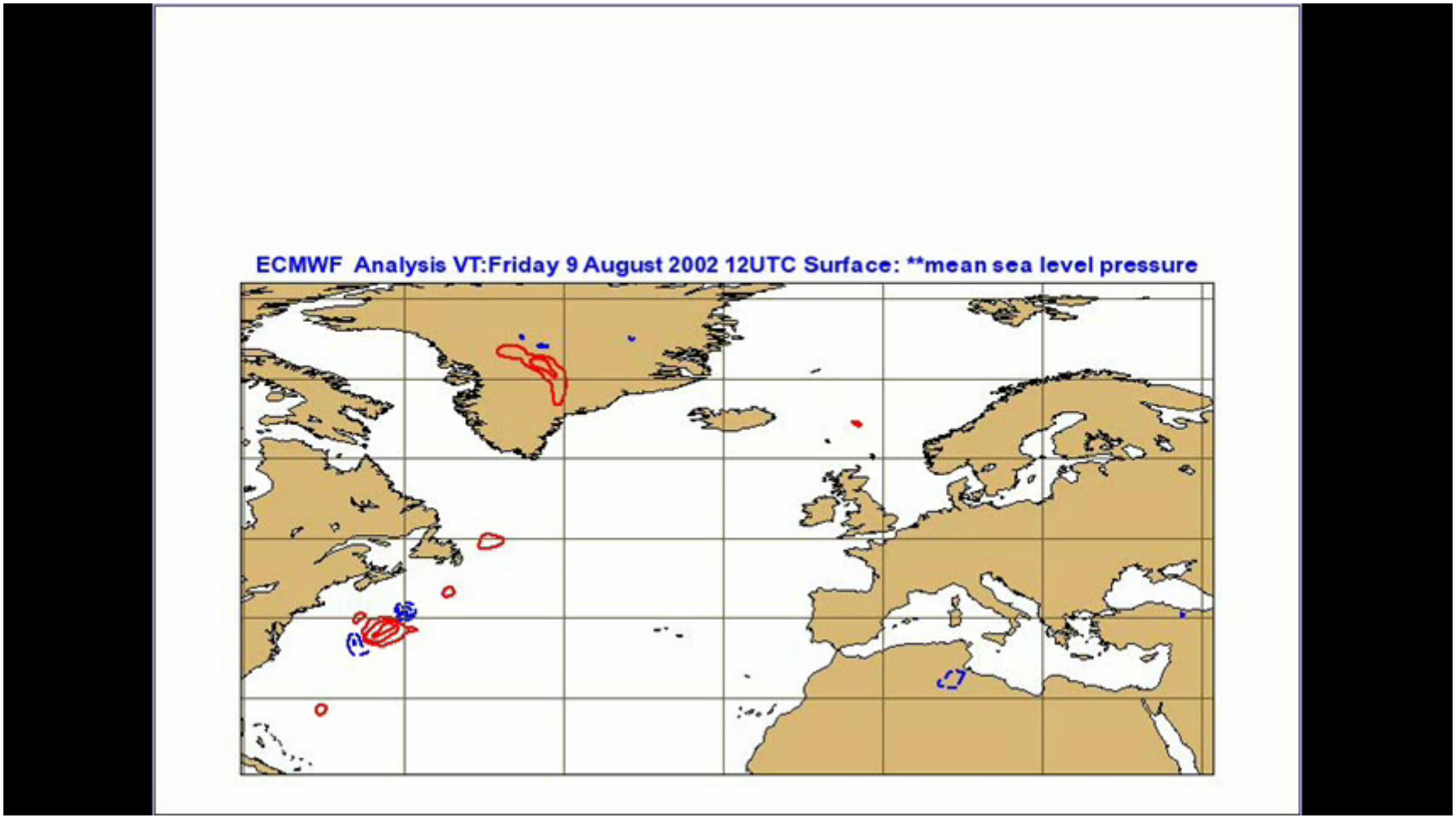
Ships

NOSHIP/BUOY – CONTRL

MSLP analysis difference

related to the presence of a few SHIPS

Time evolution of the MSL difference



How about the performance of assimilation systems if only surface pressure observations are available?

"Surface Pressure Only" assimilations

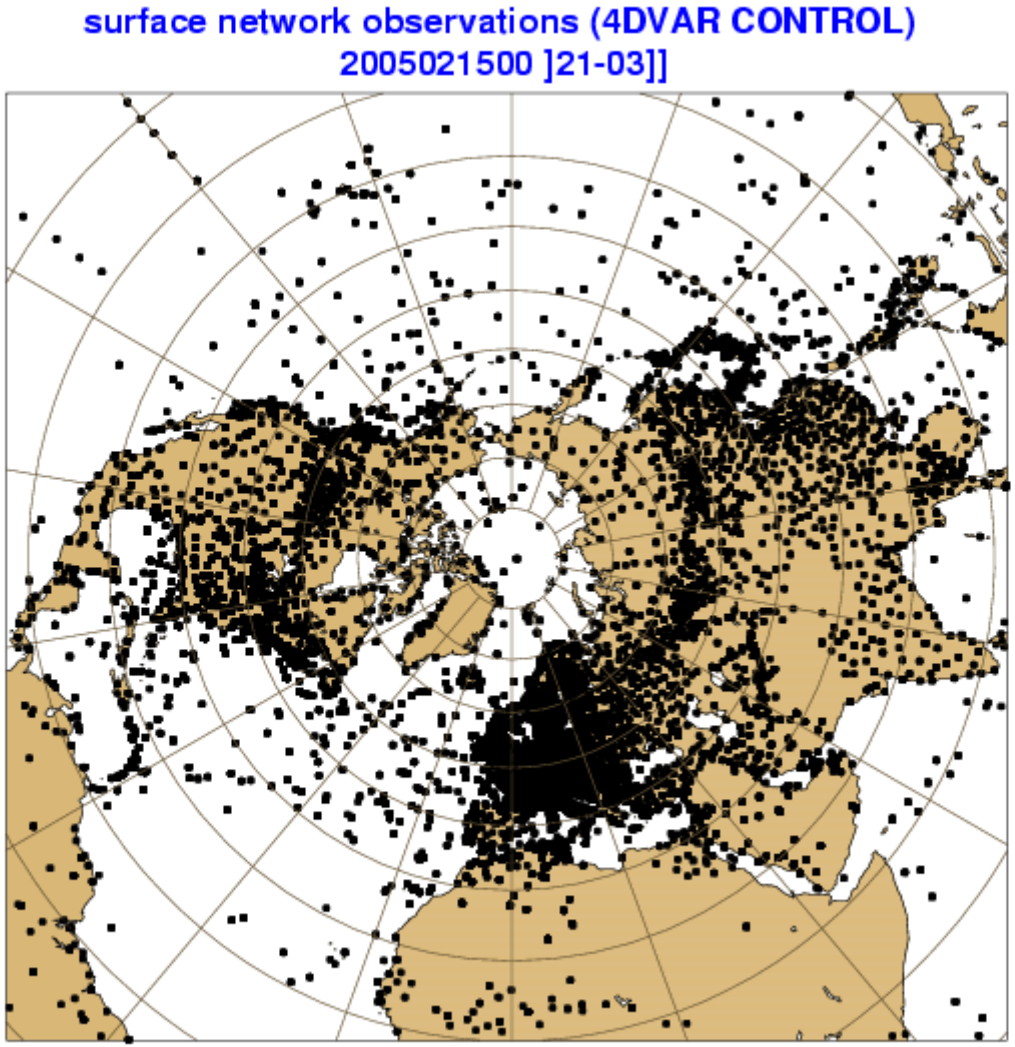
Experimental set-up

- **Assimilation and Model Configuration:**
  - **Cycle 29R1 (operational until May 2005)**
  - **Model: T159 (120km) L60**
  - **Assimilation:**
    - **3DVAR: T159L60, FGAT**
    - **4DVAR: T159L60, 12hour window (close to ERA-interim?)**
  - **Observations used in control**
    - **Radiosondes, Pilots, Synops, Buoys, Ships, Aircrafts, Profilers**
    - **AMVs, GEO CSRs, ATOVS, AIRS, SSM/I, SBUV, SCIA, SCAT**
  - **Observations used in "surface pressure only" experiments**
    - **Synops from GSN, Ships**

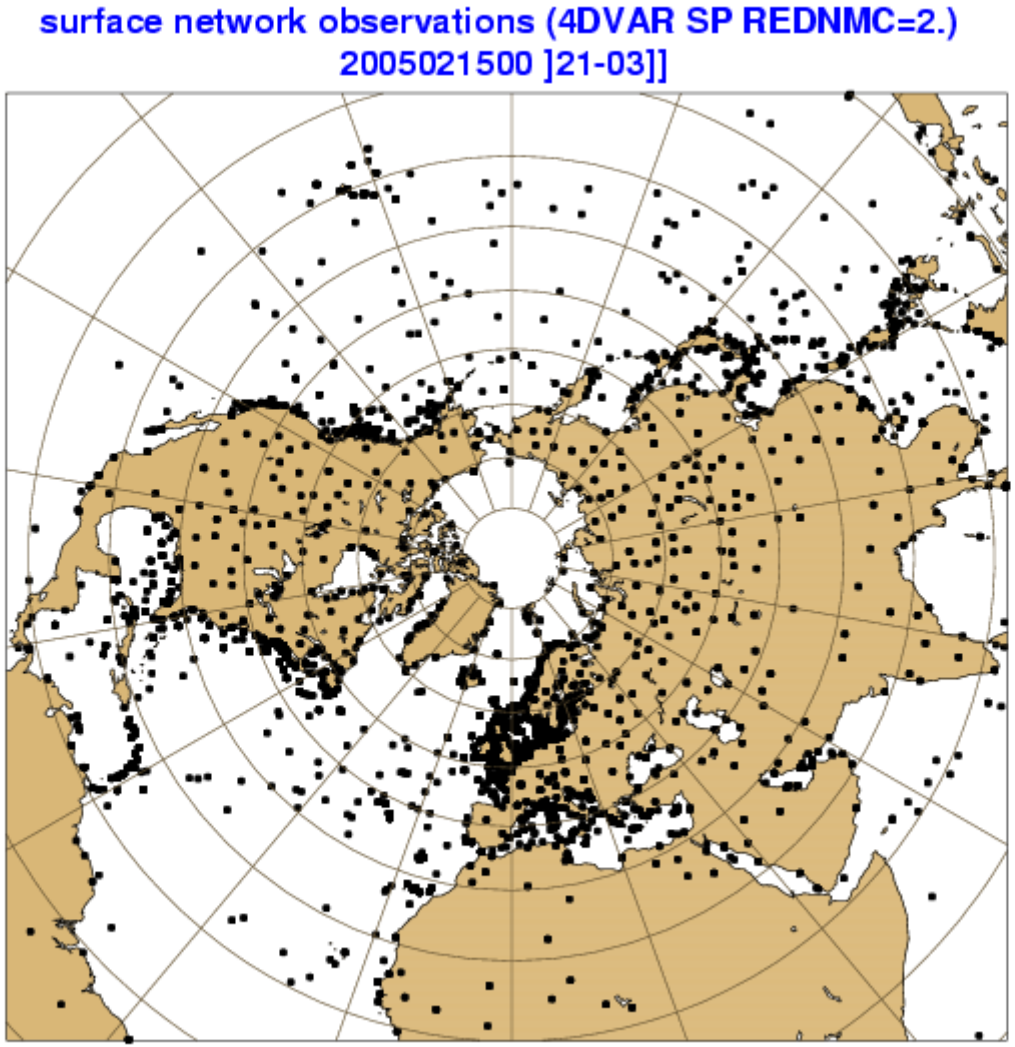
Experimental set-up

- **Period under investigation:**
  - **2004120400-2005022512**
  - **12 first days used for warm-up and excluded from statistics**
- **Six different assimilations:**
  - **3DVAR control**
  - **4DVAR control**
  - **3DVAR "surface pressure only"**
  - **4DVAR "surface pressure only"**
  - **3DVAR "surface pressure only" retuned**
  - **4DVAR "surface pressure only" retuned**
- **Simulation of a reduced surface network (GSN-SYNOPS + SHIPS)**

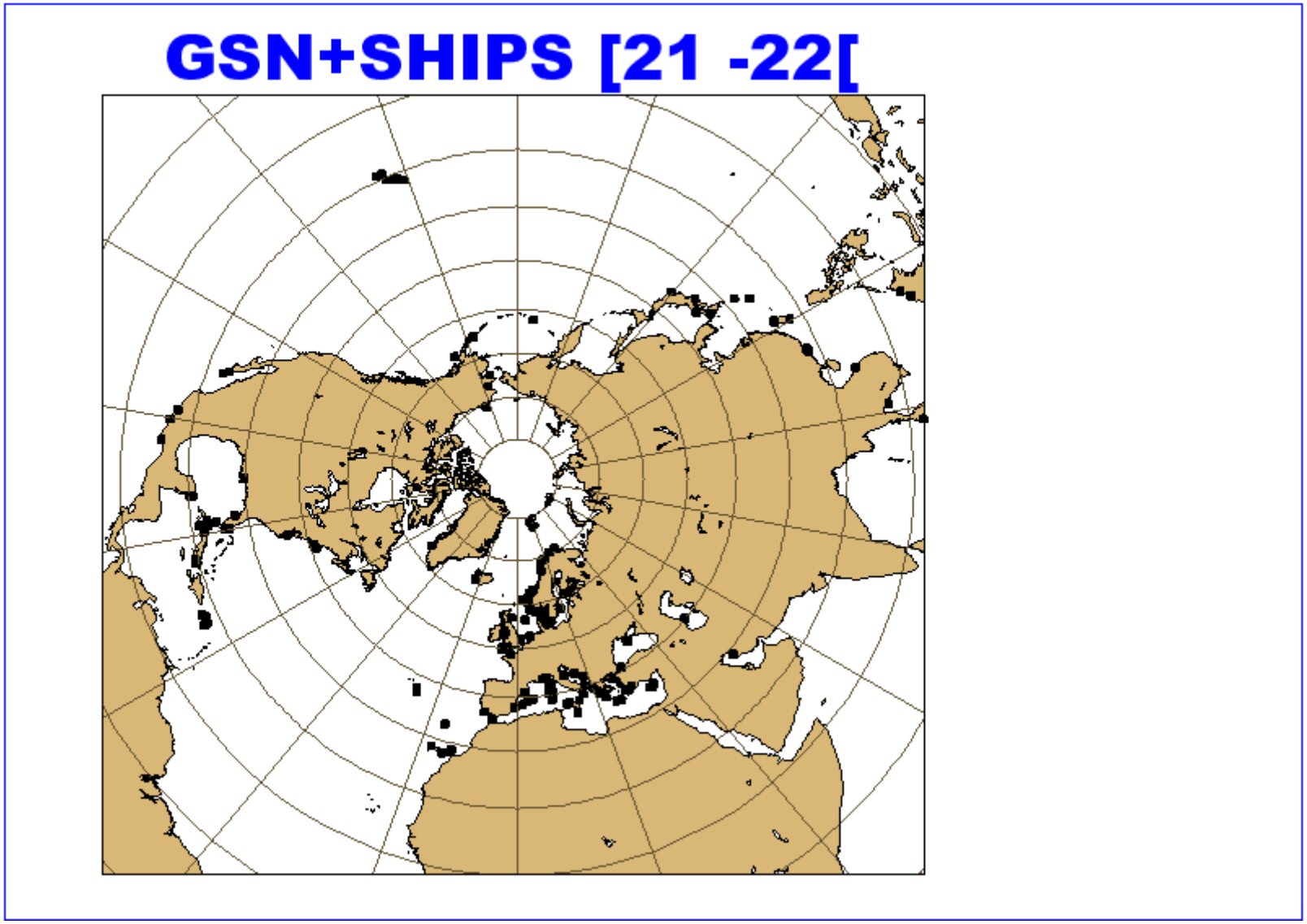
Operational surface pressure data coverage



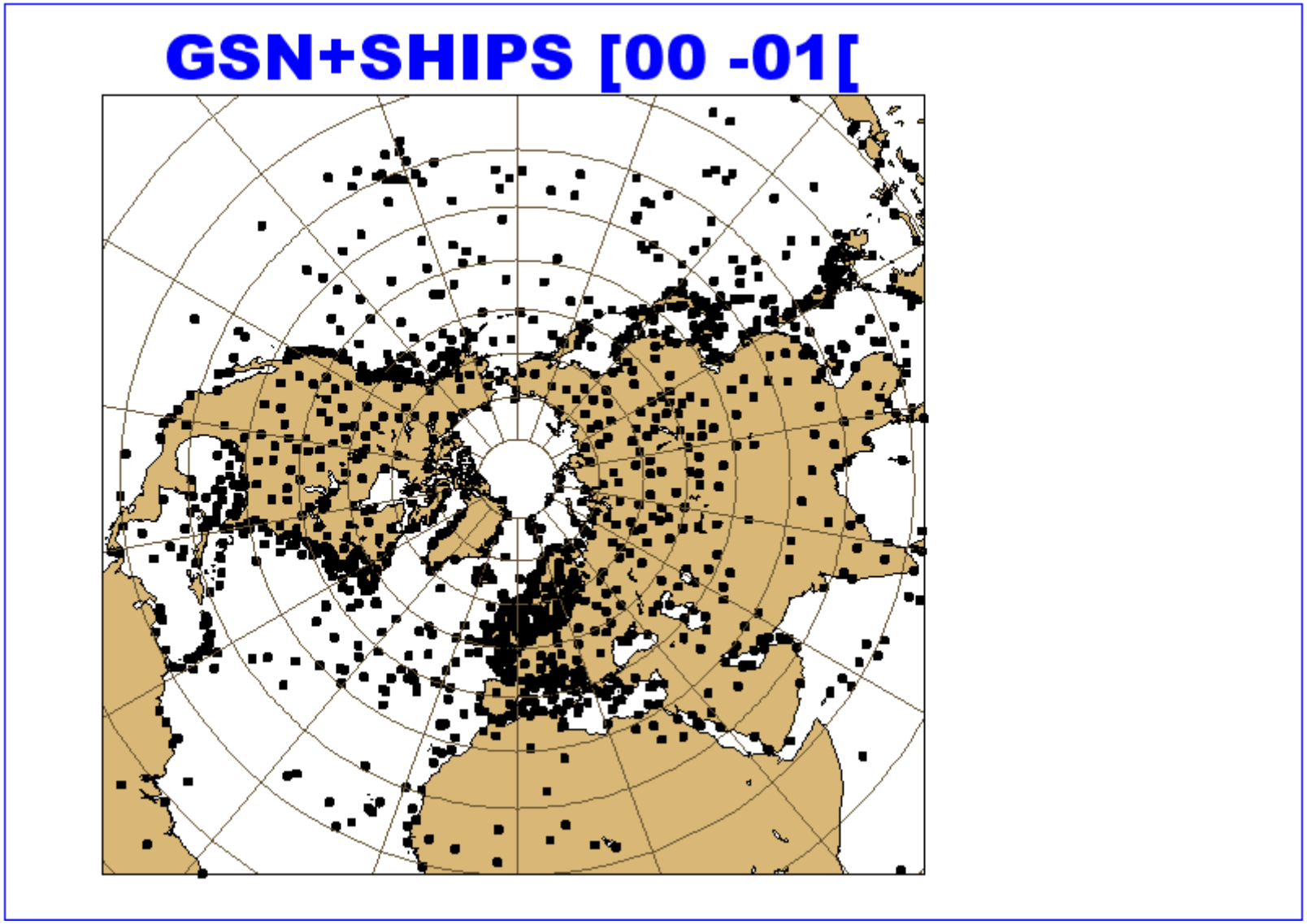
GSN+SHIP surface pressure data coverage



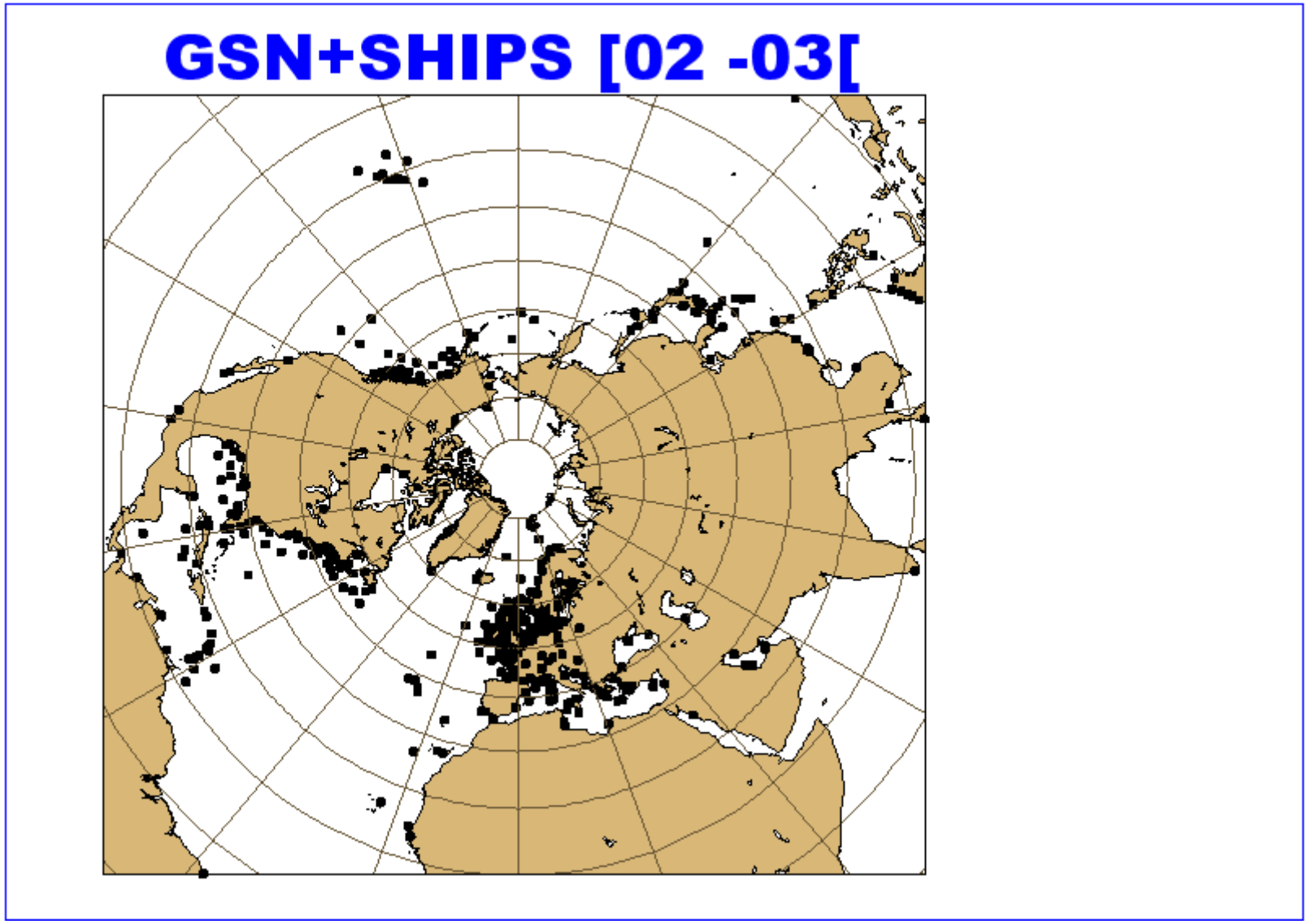
GSN+SHIP surface pressure hourly coverage



GSN+SHIP surface pressure hourly coverage



GSN+SHIP surface pressure hourly coverage



Need for tuning the 3DVAR and 4DVAR systems

- **Background error covariances have to reflect the poorer accuracy of analysis and short range forecast due to the sole use of surface pressure observations**
- **This has been done "objectively" from statistics obtained from the blunt "surface pressure only " assimilation experiments, by computing the effective σ_b**
- **3D and 4D retuned assimilations restarted on 20041215.**

$$\sum_i (obs - guess)^2 = \sigma_o^2 + \sigma_{beff}^2$$

$$\sigma_{beff} = \alpha \times \sigma_{borig}$$

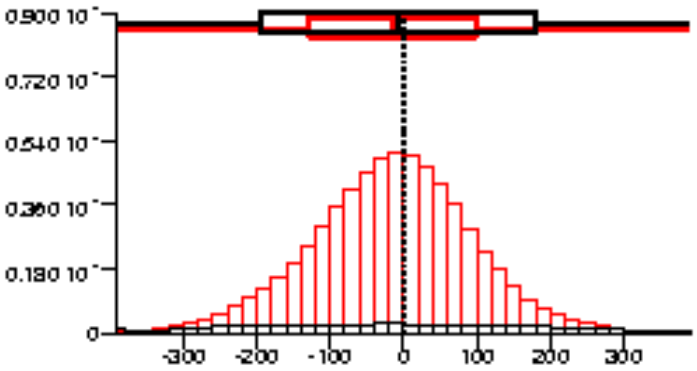
"REDNMC" factor

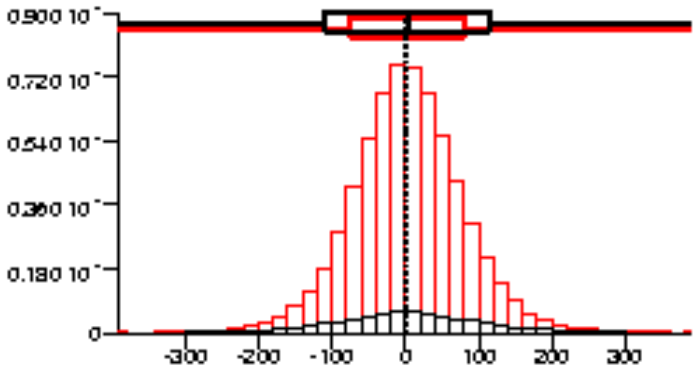
ECMWF

eq6d reduced surf.p. only 2004121512-2005011612(12)
SYNOP-Ps (Pa) N.Hemis
used p

background departure o-b
nb= 69741 (ref= 649515) rms= 189. (116.)
mean= -8.03 (-15.3) std= 189. (115.)
min= -811. (-586.) max= 688. (575.)

analysis departure o-a
nb= 69741 (ref= 649515) rms= 113. (78.9)
mean= 2.94 (3.04) std= 113. (78.8)
min= -604. (-529.) max= 683. (572.)





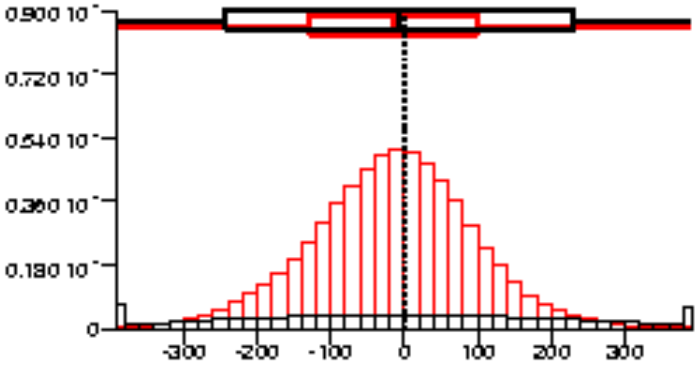
Blunt 3DVAR

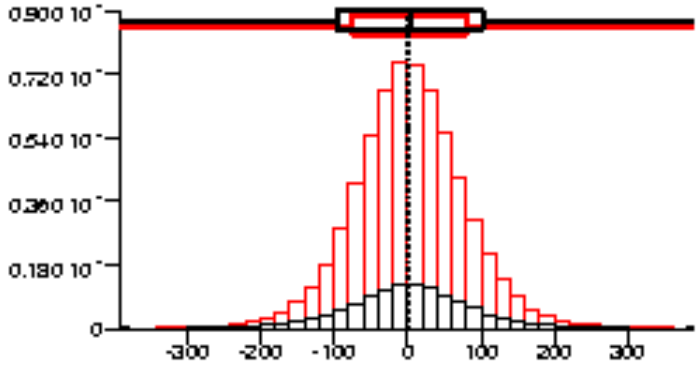
eqw3 reduced surf.p. only 2004121512-2005011612(12)
SYNOP-Ps (Pa) N.Hemis
used p

REDNMC = 2.7

background departure o-b
nb= 120898 (ref= 649515) rms= 238. (116.)
mean= -7.03 (-15.3) std= 238. (115.)
min= -0.102E+04(-586.) max= 0.100E+04(575.)

analysis departure o-a
nb= 120898 (ref= 649515) rms= 99.3 (78.9)
mean= 2.76 (3.04) std= 99.3 (78.8)
min= -754. (-529.) max= 808. (572.)





Retuned 3DVAR

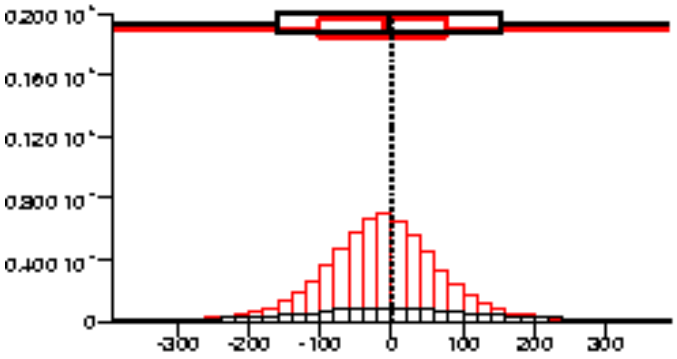
- **70% more surface pressure data added in the retuned system**
- **Better fit of the analysis to the observations**

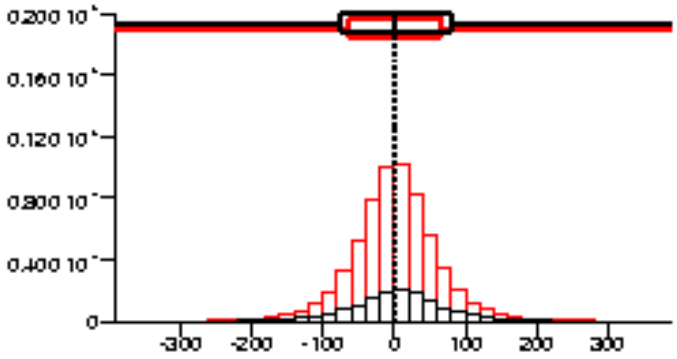
ECMWF

epig reduced surf.p. only 2004121512-2005011612(12)
SYNOP-Ps (Pa) N.Hemis
used p

background departure o-b
nb= 150809 (ref= 648277) rms= 158. (90.4)
mean= -3.32 (-12.7) std= 158. (89.5)
min= -732. (-592.) max= 756. (605.)

analysis departure o-a
nb= 150809 (ref= 648277) rms= 78.7 (64.4)
mean= 2.28 (1.01) std= 78.7 (64.4)
min= -450. (-505.) max= 403. (487.)





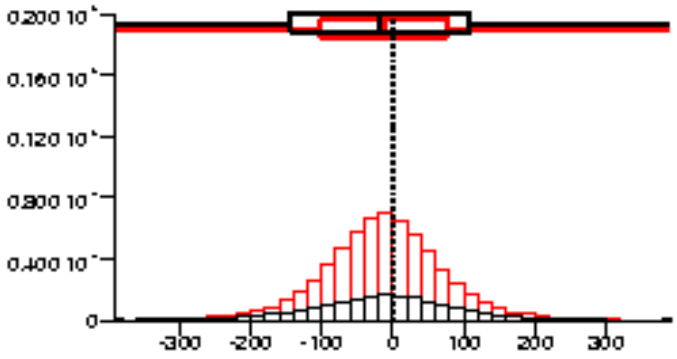
Blunt 4DVAR

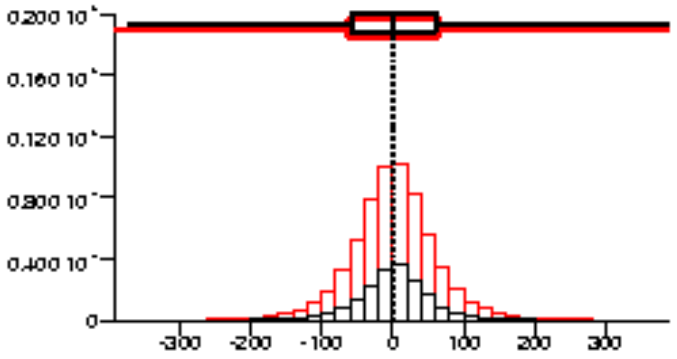
eqvw reduced surf.p. only 2004121512-2005011612(12)
SYNOP-Ps (Pa) N.Hemis
used p

REDNMC = 2.0

background departure o-b
nb= 192821 (ref= 648277) rms= 128. (90.4)
mean= -17.7 (-12.7) std= 127. (89.5)
min= -888. (-592.) max= 976. (605.)

analysis departure o-a
nb= 192821 (ref= 648277) rms= 59.8 (64.4)
mean= 1.22 (1.01) std= 59.8 (64.4)
min= -374. (-505.) max= 395. (487.)



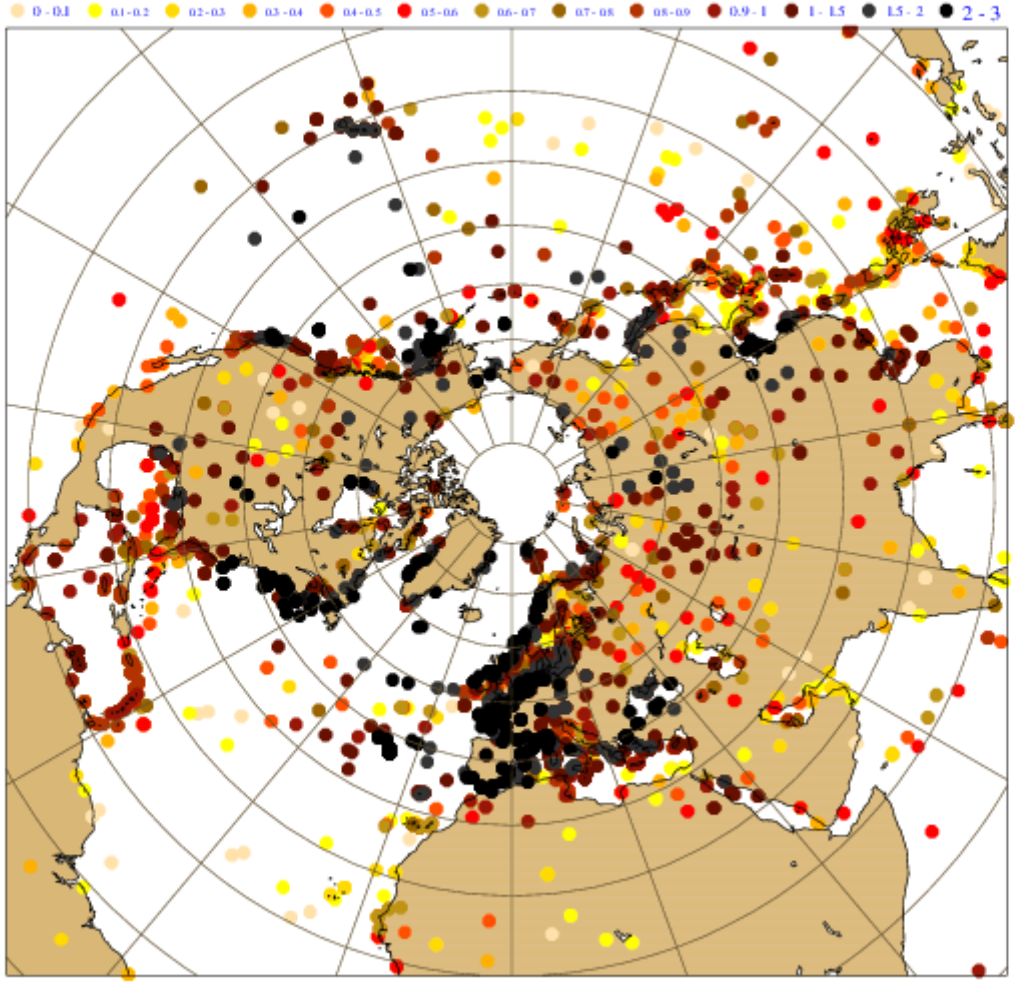


Retuned 4DVAR

- **28% more surface pressure data added in the retuned system**
- **Better fit of first-guess and analysis to observations**

ECMWF

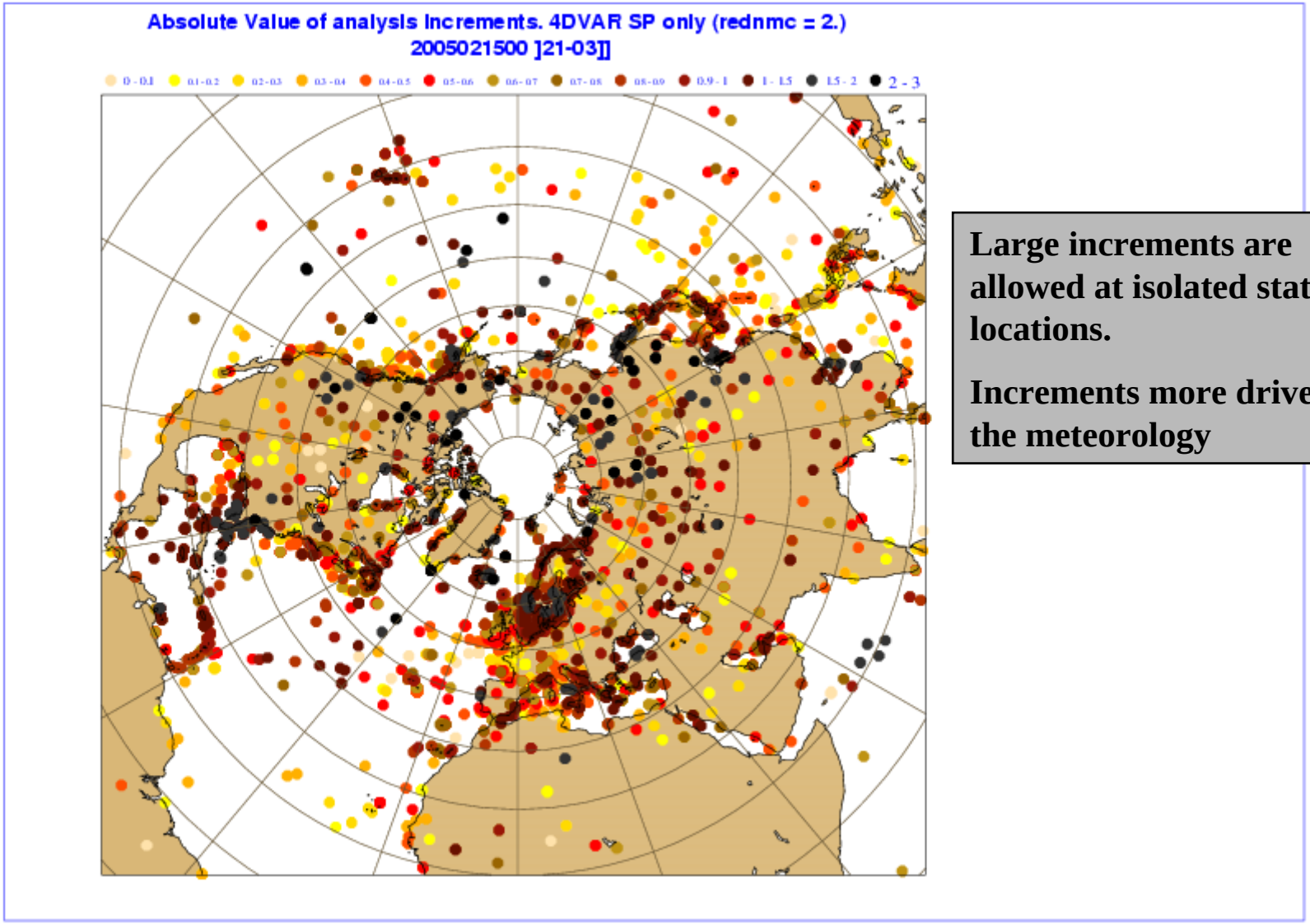
Analysis increments at station points (blunt 4DVAR)



DA does not allow large increments at isolated station locations.

Increments are largely driven by observation density

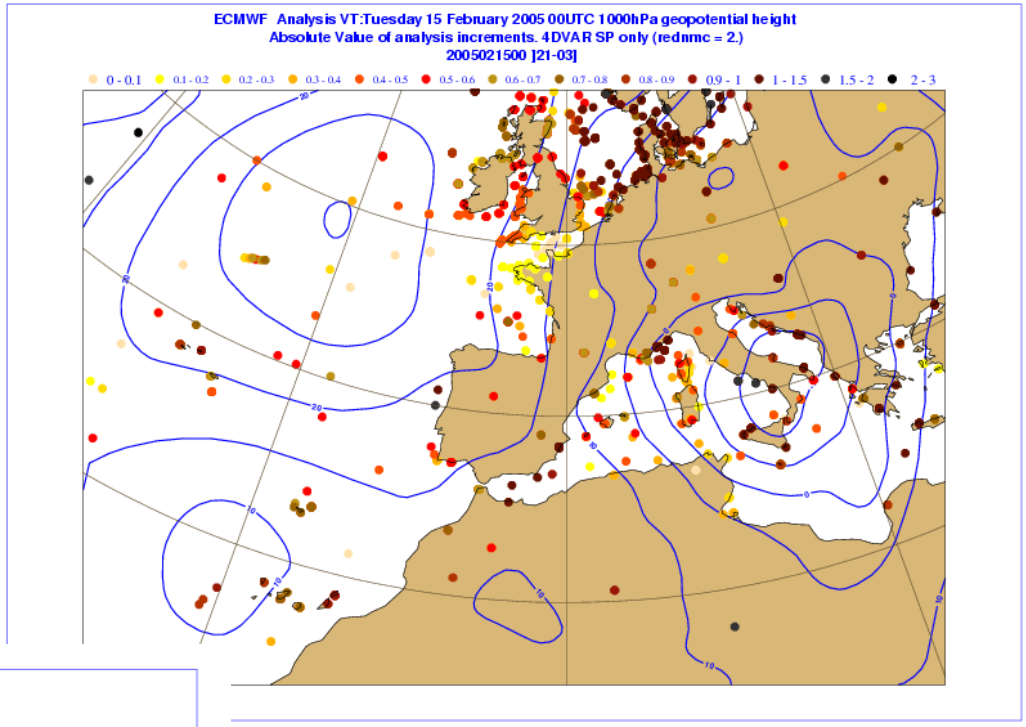
Analysis increments at station points (tuned 4DVAR)

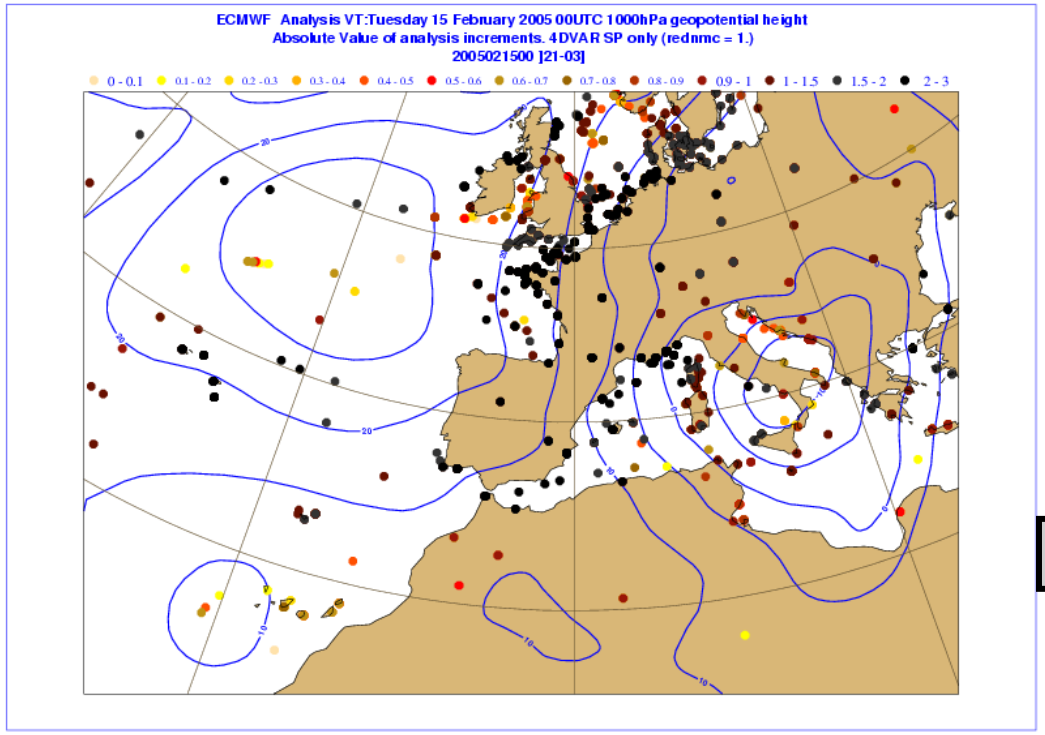


Large increments are allowed at isolated station locations.

Increments more driven by the meteorology

Tuned 4DVAR “SPONLY”





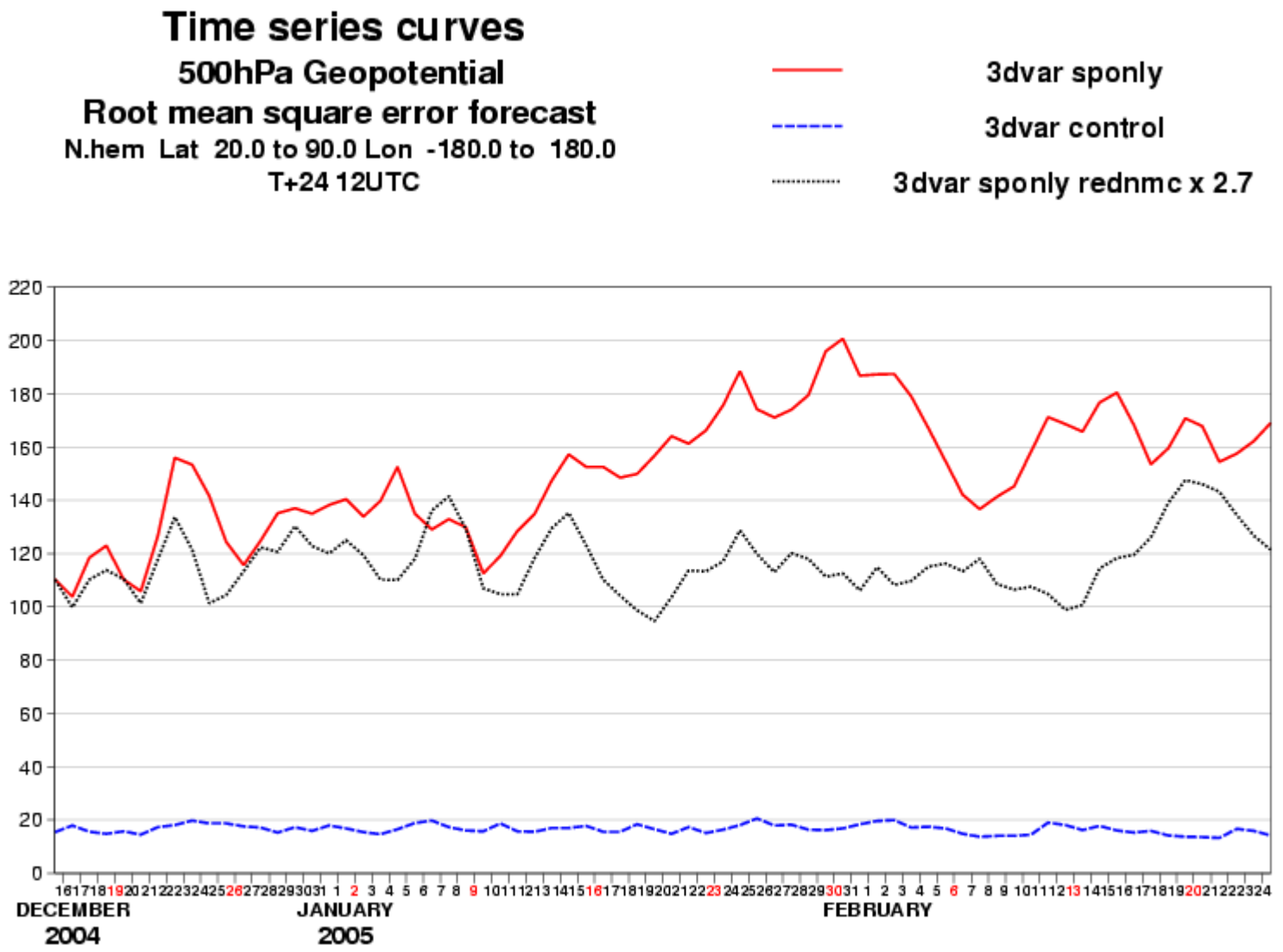
BLUNT 4DVAR “SPONLY”

ECMWF

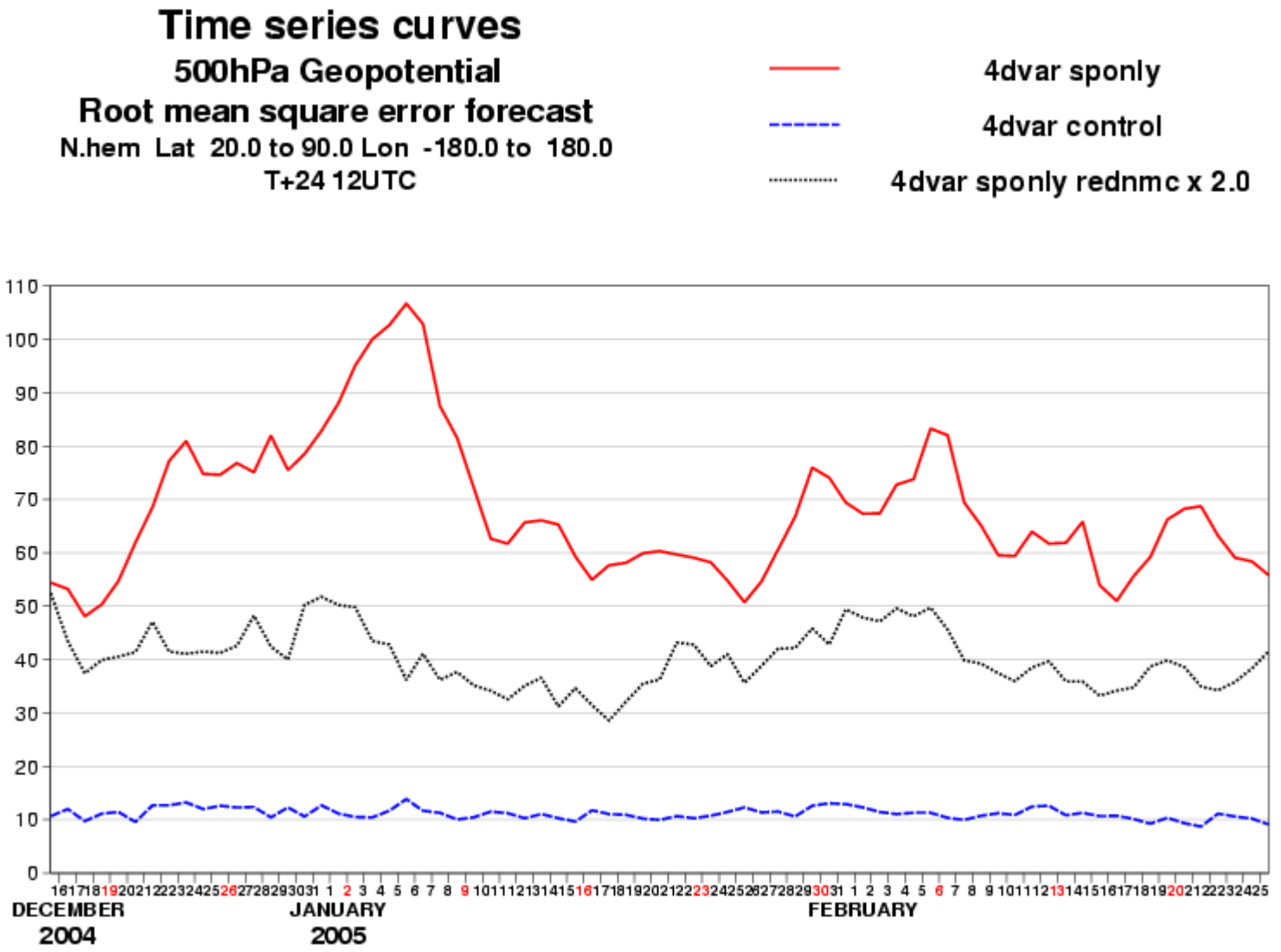
Average Use of Surface Pressure Observations (NH)

- **4DVAR control: ~ 5000 obs per 6 hour**
  - **(NB: + ~ 1.5 million of other data)**
- **3DVAR SP only (tuned): ~ 950 obs per 6 hour**
- **4DVAR SP only (tuned): ~ 1300 obs per 6 hour**

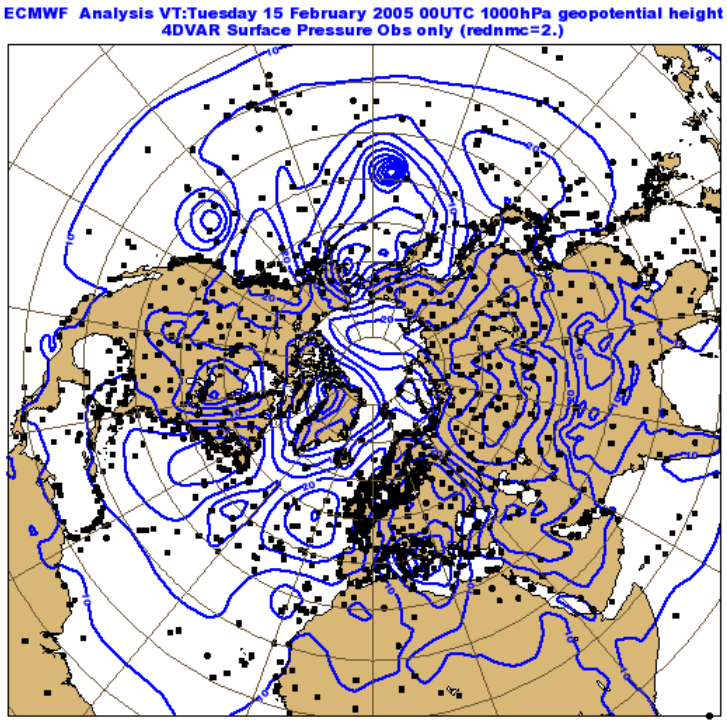
Impact of tuning (3DVAR Surf. Press. only)



Impact of tuning (4DVAR Surf. Press. only)

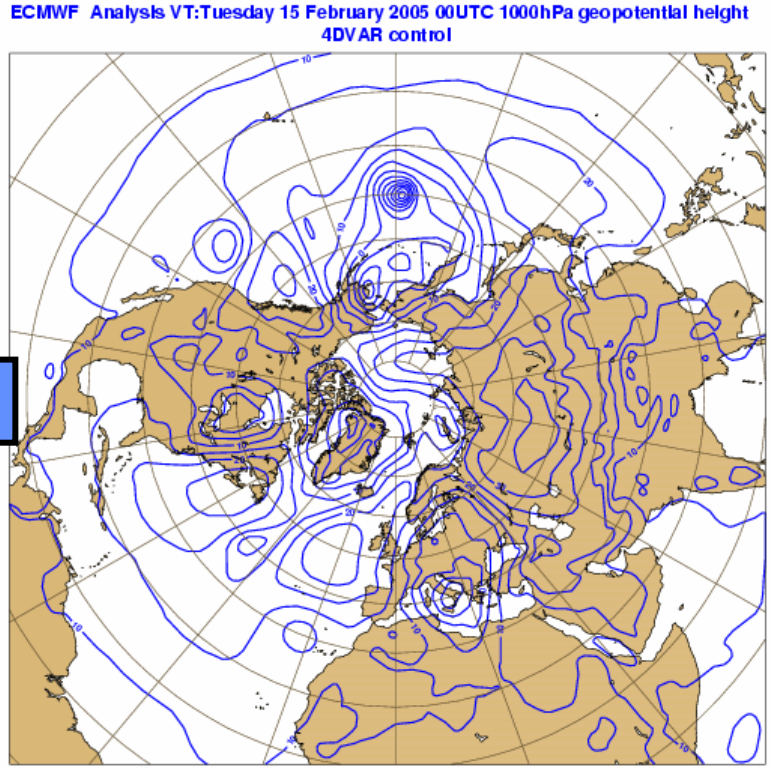


3DVAR versus 4DVAR



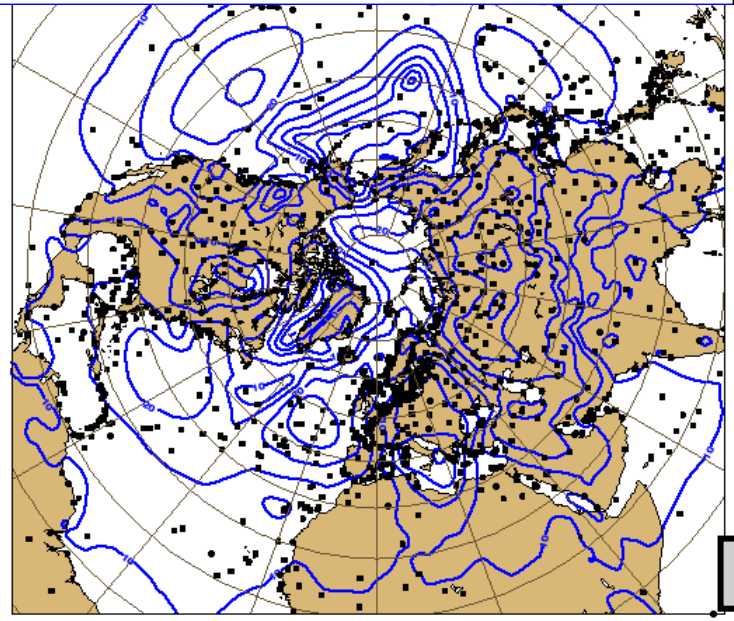
4DVAR SPONLY

2005-02-15 00UTC



Z 1000hPa

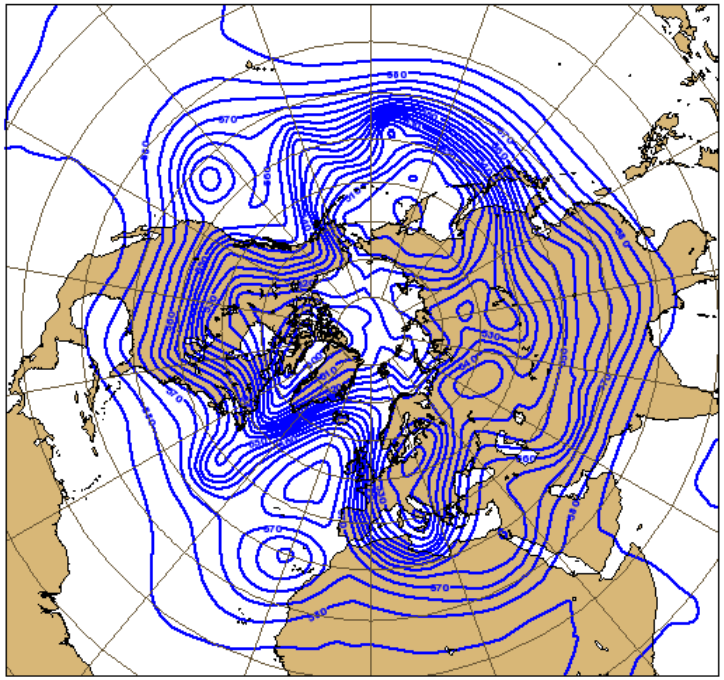
CONTROL



3DVAR SPONLY

ECMWF

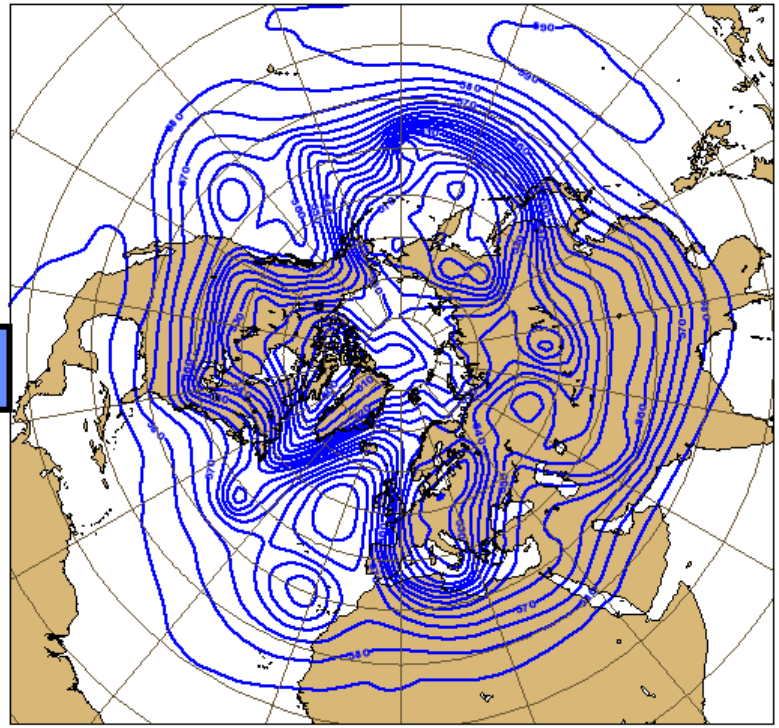
ECMWF Analysis VT:Tuesday 15 February 2005 00UTC 500hPa geopotential height
4DVAR Surface Pressure Obs only (rednmc=2.)



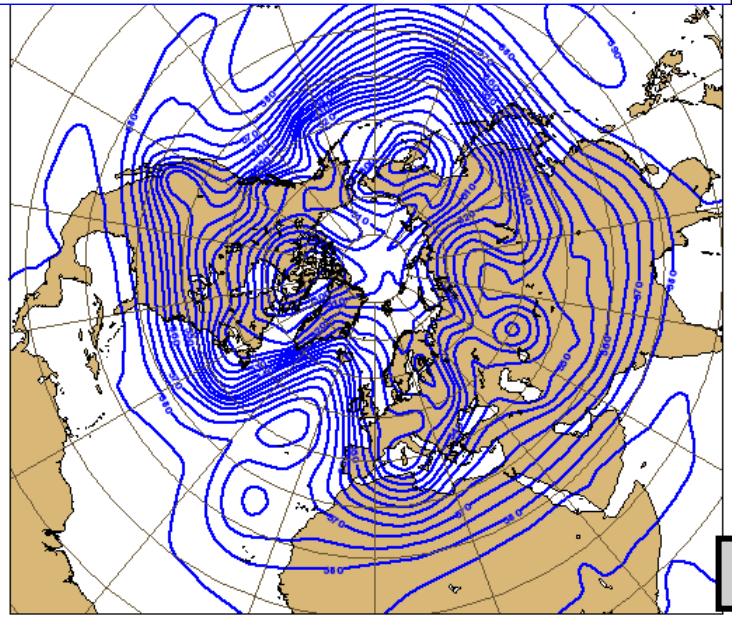
4DVAR SPONLY

2005-02-15 00UTC

ECMWF Analysis VT:Tuesday 15 February 2005 00UTC 500hPa geopotential height
4DVAR Control Analysis



Z 500hPa

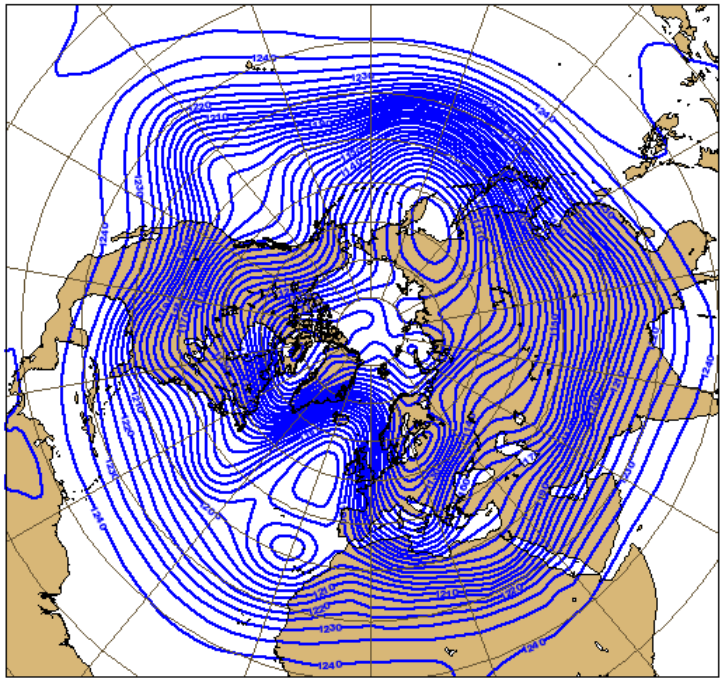


CONTROL

3DVAR SPONLY

ECMWF

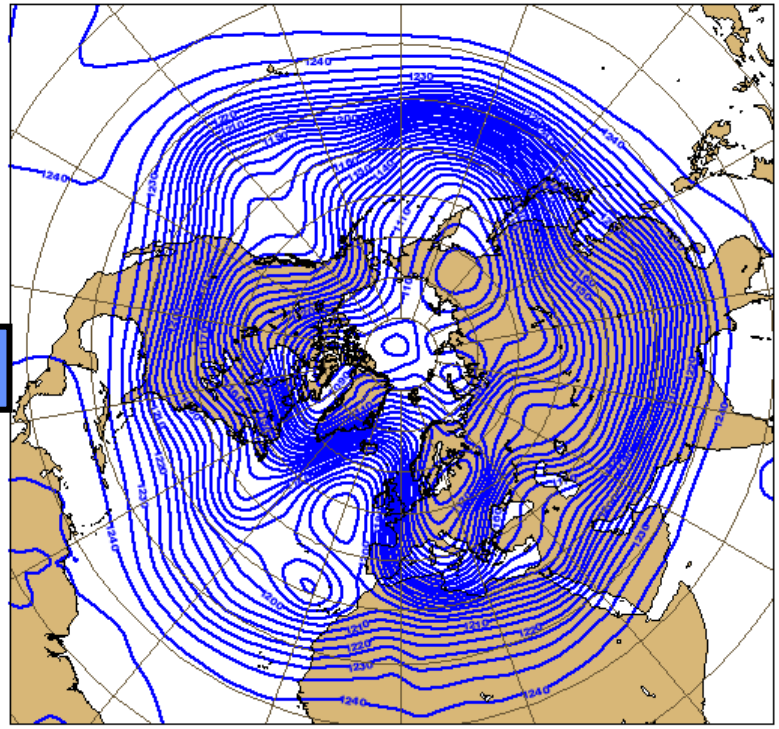
ECMWF Analysis VT:Tuesday 15 February 2005 00UTC 200hPa geopotential height
4DVAR Surface Pressure Obs only (rednmc=2.)



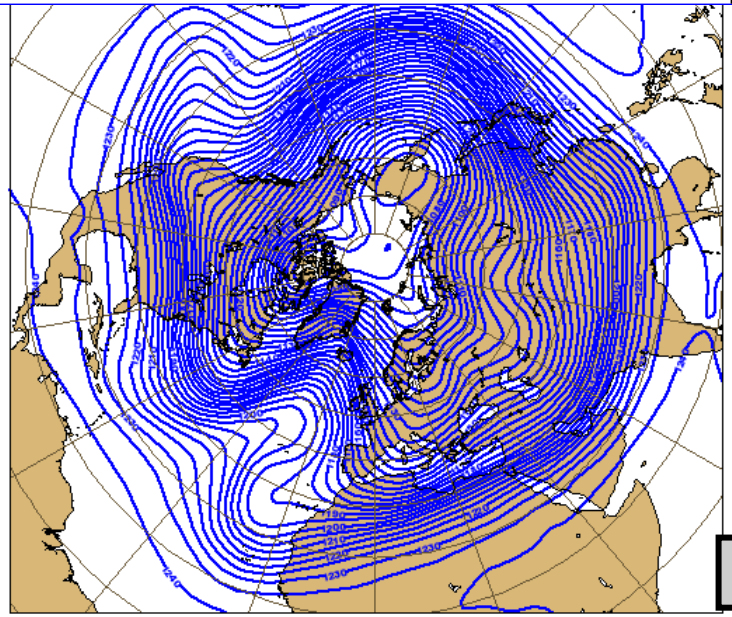
4DVAR SPONLY

2005-02-15 00UTC

ECMWF Analysis VT:Tuesday 15 February 2005 00UTC 200hPa geopotential height
4DVAR Control Analysis



Z 200hPa

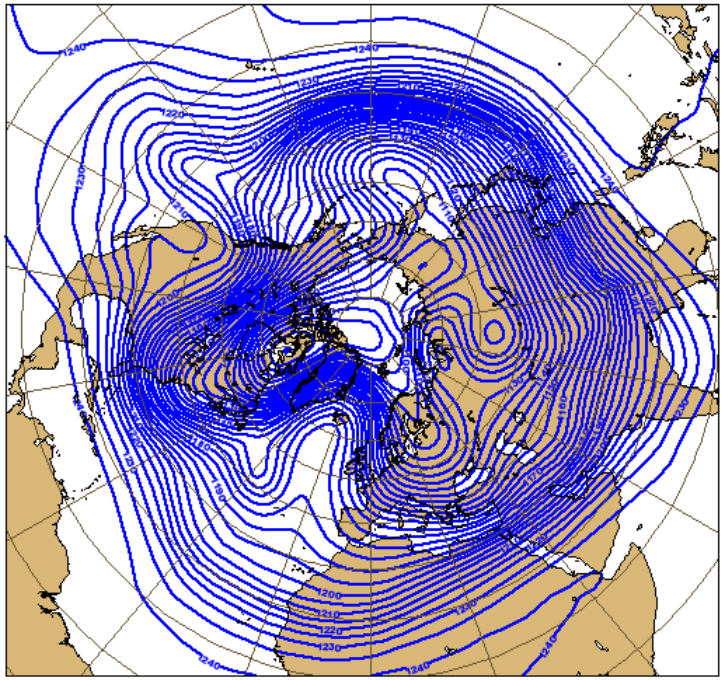


CONTROL

3DVAR SPONLY

ECMWF

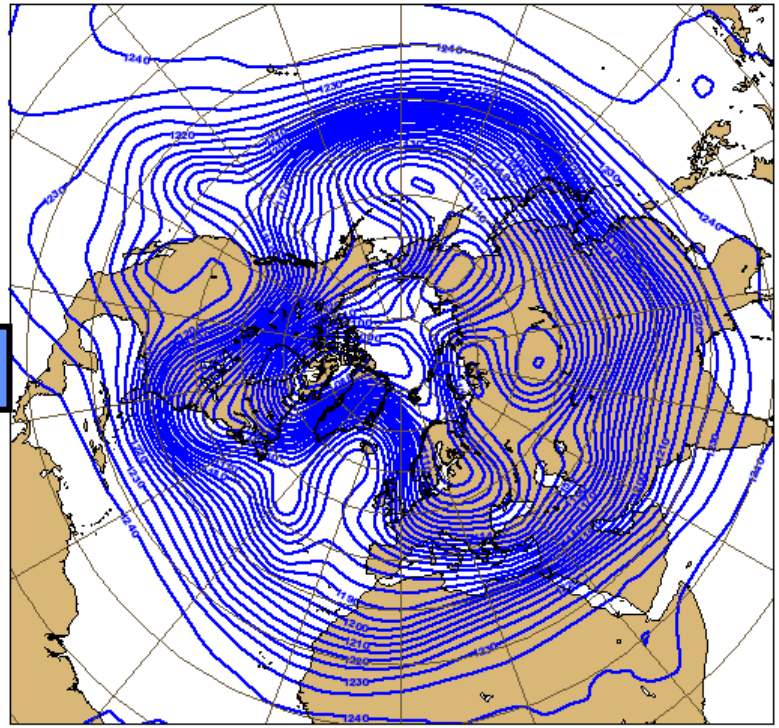
ECMWF Analysis VT:Monday 24 January 2005 00UTC 200hPa geopotential height
4DVAR SP only (rednmc=2.)



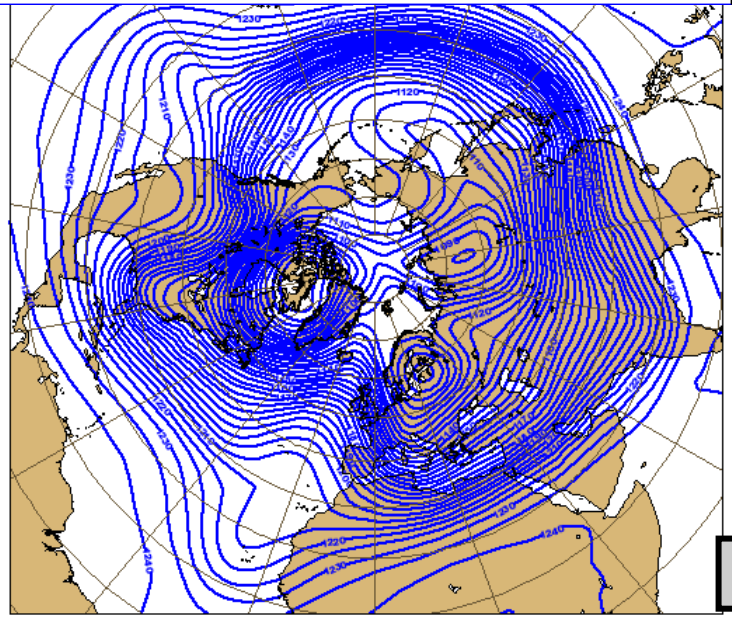
4DVAR SPONLY

2005-02-24 00UTC

ECMWF Analysis VT:Monday 24 January 2005 00UTC 200hPa geopotential height
4DVAR Control Analysis



Z 200hPa

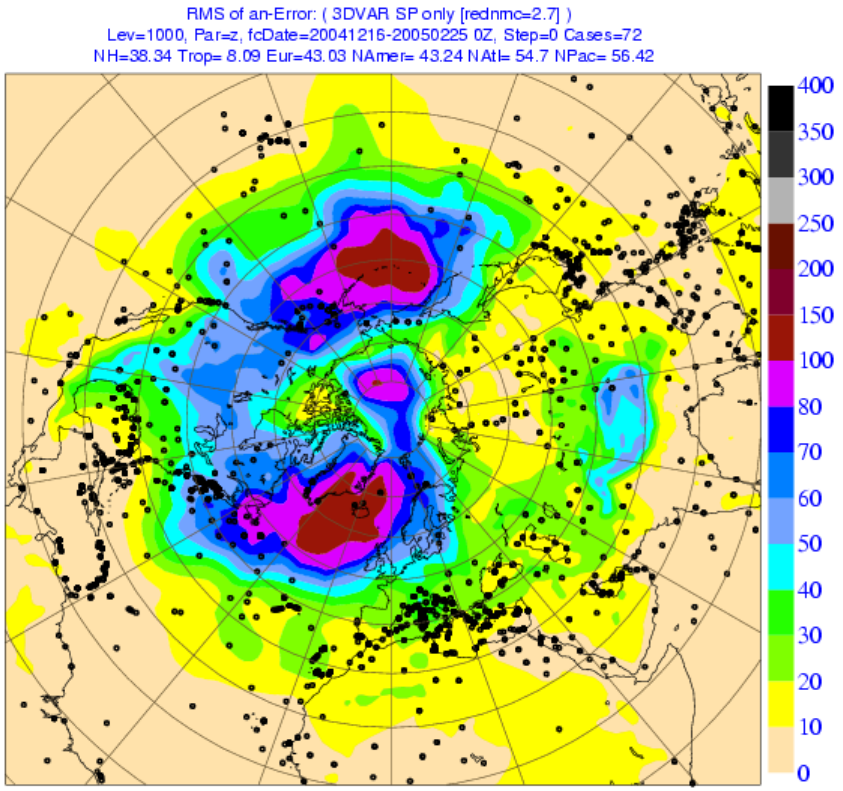


CONTROL

3DVAR SPONLY

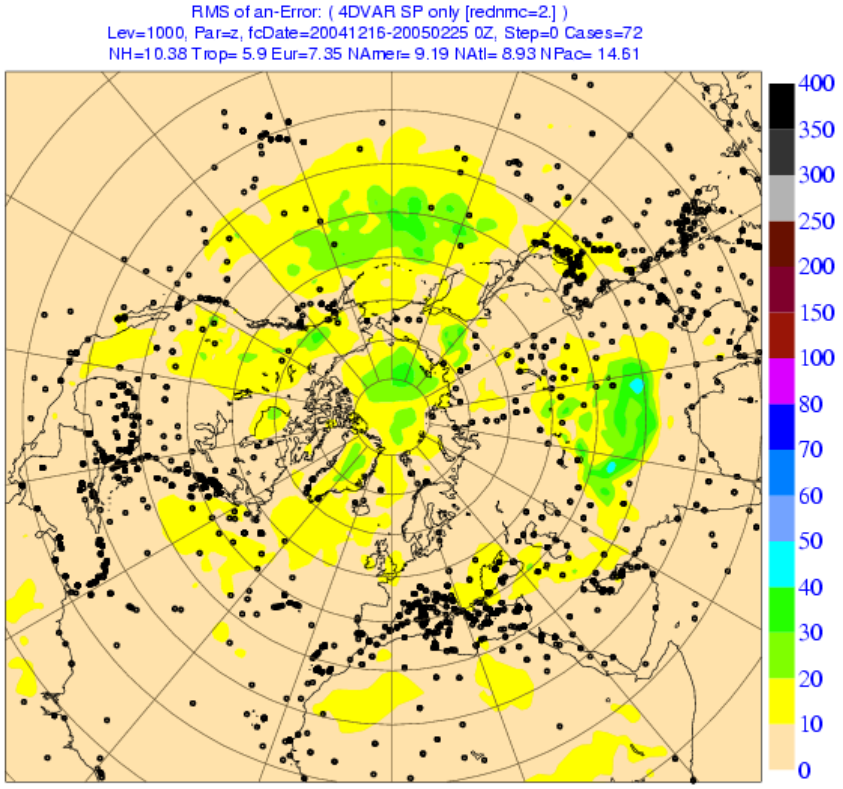
ECMWF

Averaged RMS analysis error (1000hPa)



3DVAR SP ONLY

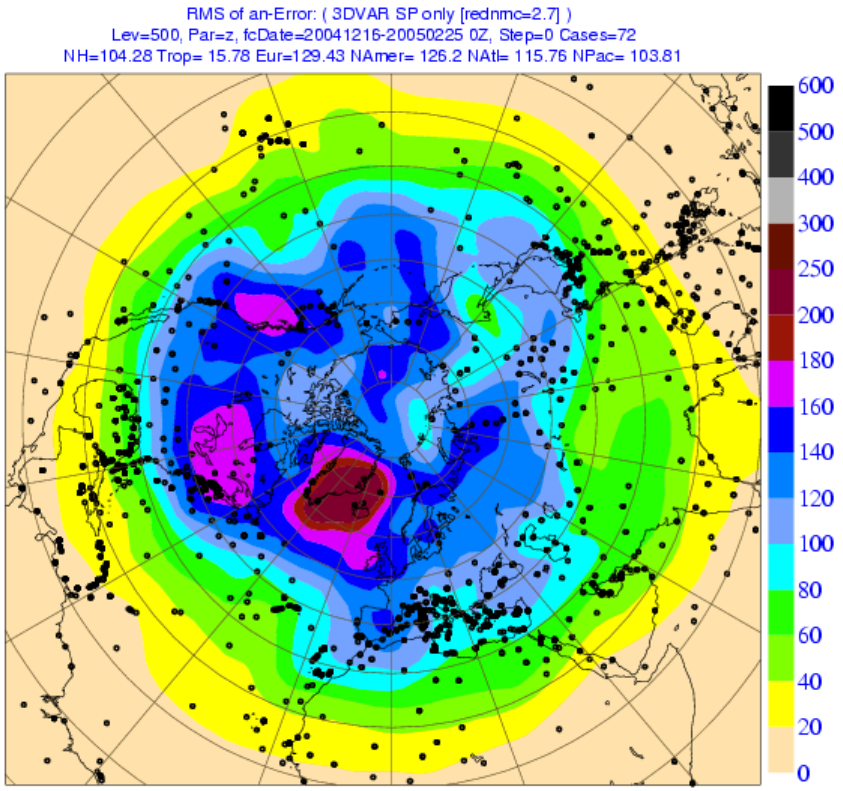
(1000hPa NH RMS AN error: 38.3 m)



4DVAR SP ONLY

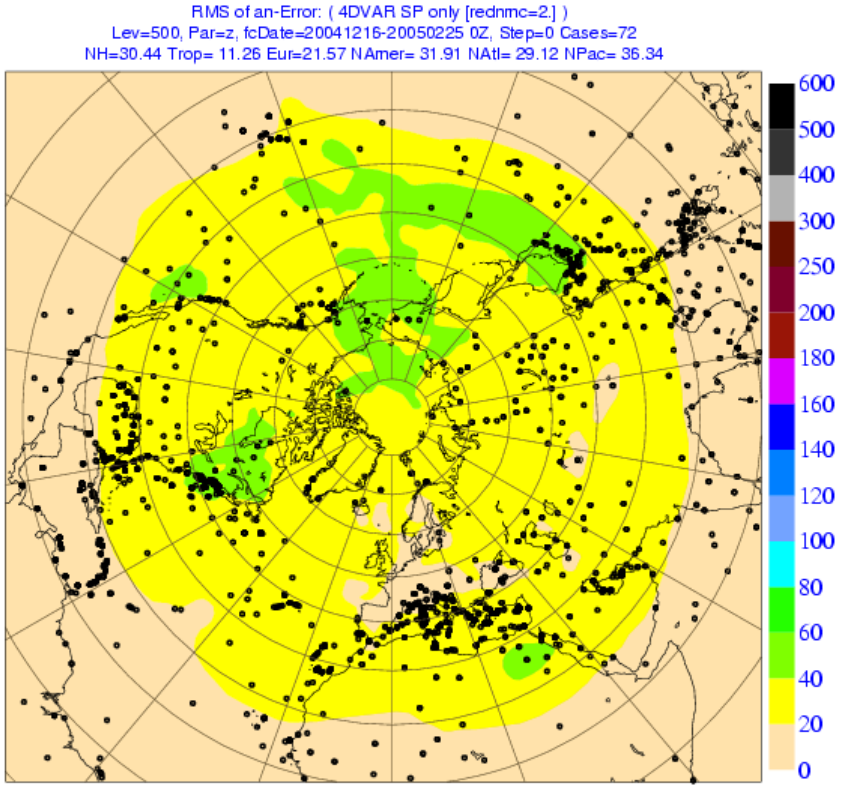
(1000hPa NH RMS AN error: 10.4 m)

Averaged RMS analysis error (500hPa)



3DVAR SP ONLY

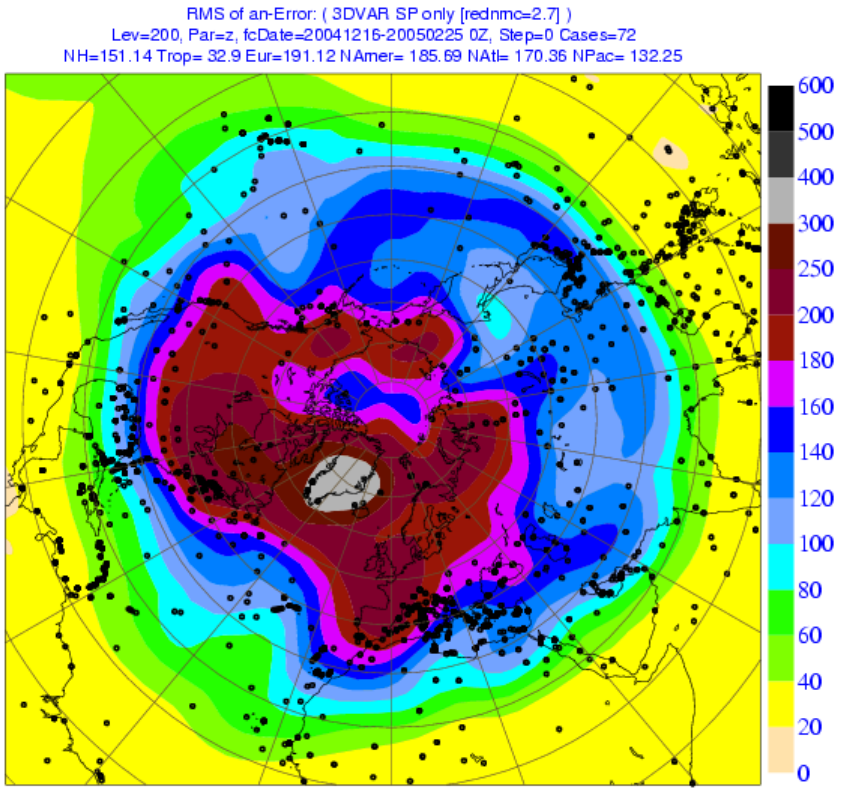
(500hPa NH RMS AN error: 104.3 m)



4DVAR SP ONLY

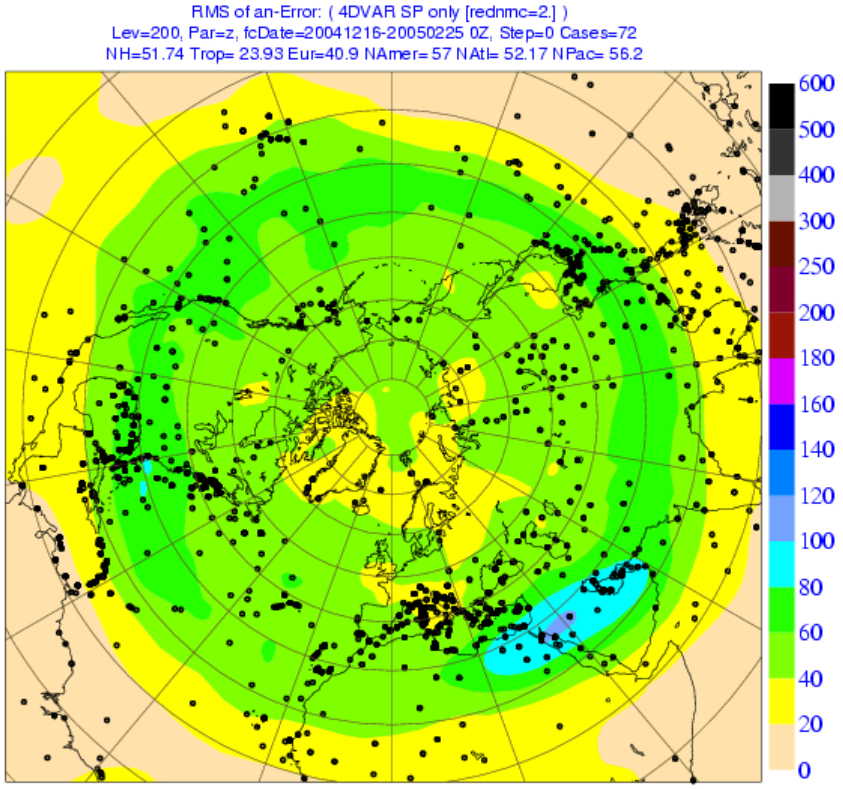
(500hPa NH RMS AN error: 30.4 m)

Averaged RMS analysis error (200hPa)



3DVAR SP ONLY

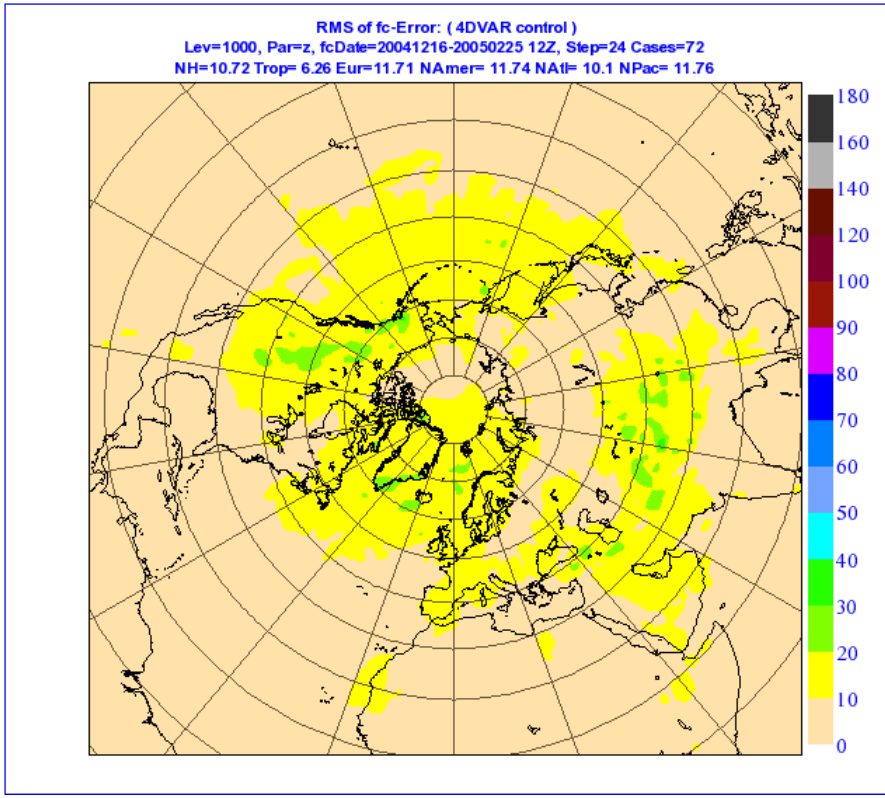
(200hPa NH RMS AN error: 151.1 m)



4DVAR SP ONLY

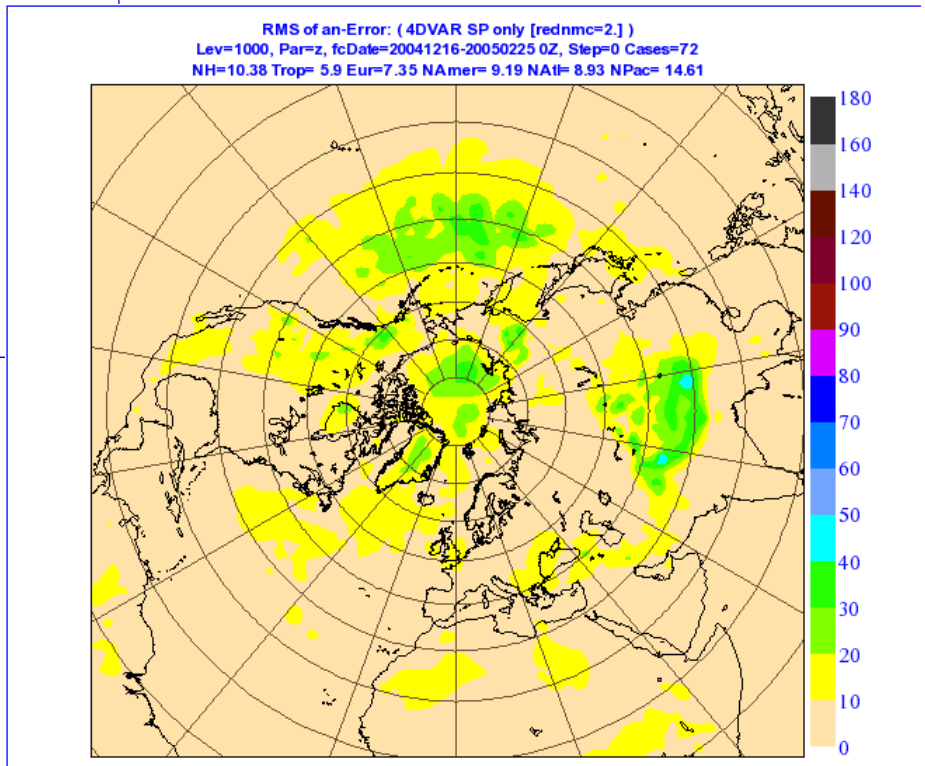
(200hPa NH RMS AN error: 51.7 m)

4DVAR "SP ONLY" VERSUS 4DVAR CONTROL (1000hPa)



4DVAR CONTROL

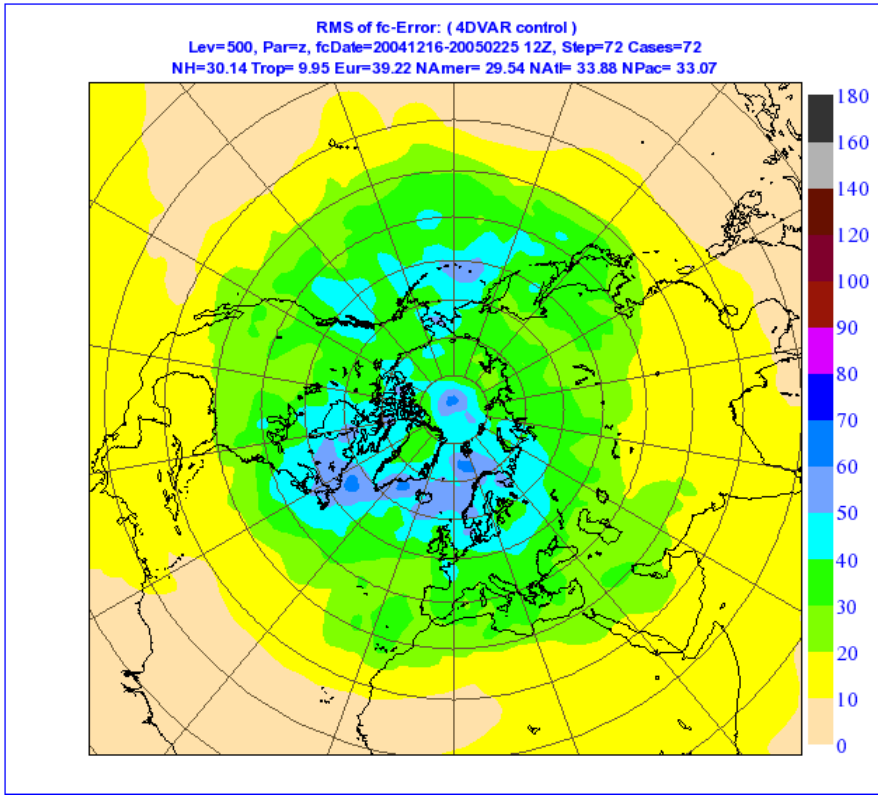
(1000hPa NH RMS 24H FC error: 10.7 m)



4DVAR SP ONLY

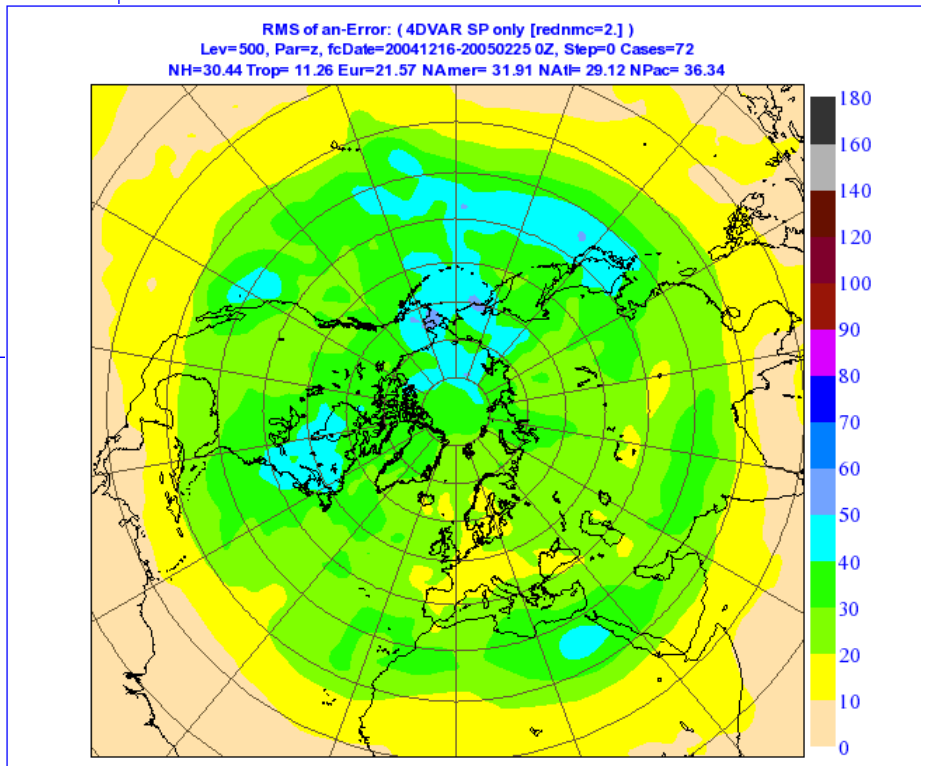
(1000hPa NH RMS AN error: 10.4 m)

4DVAR "SP ONLY" VERSUS 4DVAR CONTROL (500hPa)



4DVAR CONTROL

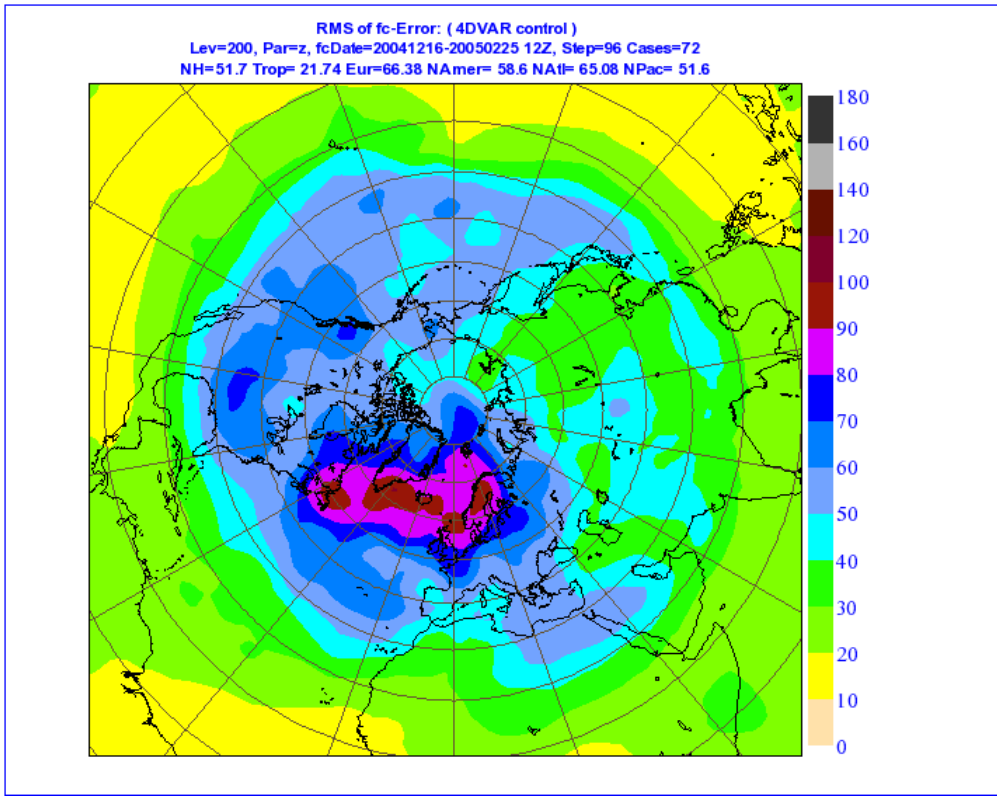
(500hPa NH RMS 72H FC error: 30.14 m)



4DVAR SP ONLY

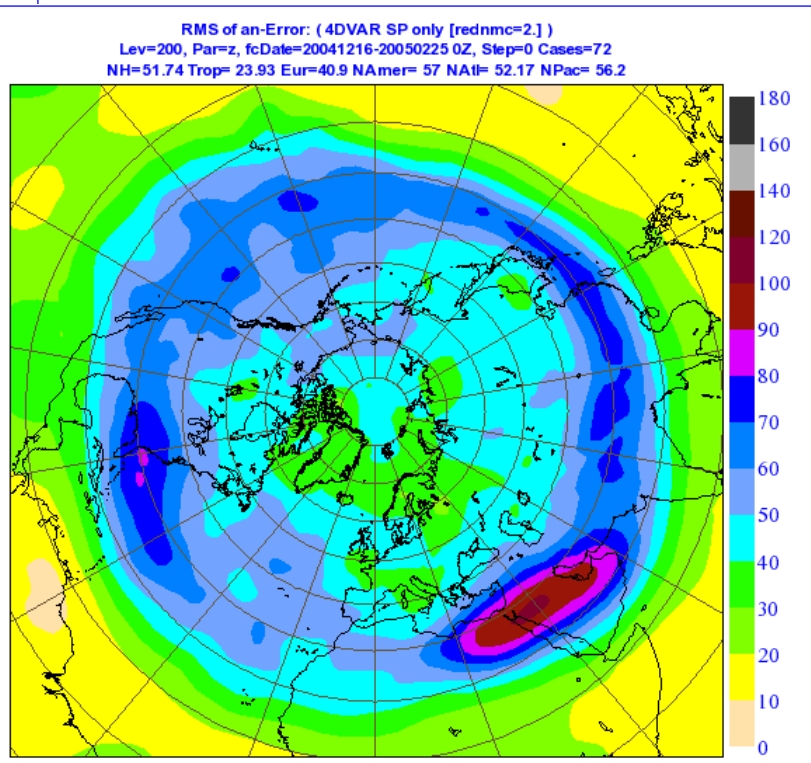
(500hPa NH RMS AN error: 30.4 m)

4DVAR "SP ONLY" VERSUS 4DVAR CONTROL (200hPa)



4DVAR CONTROL

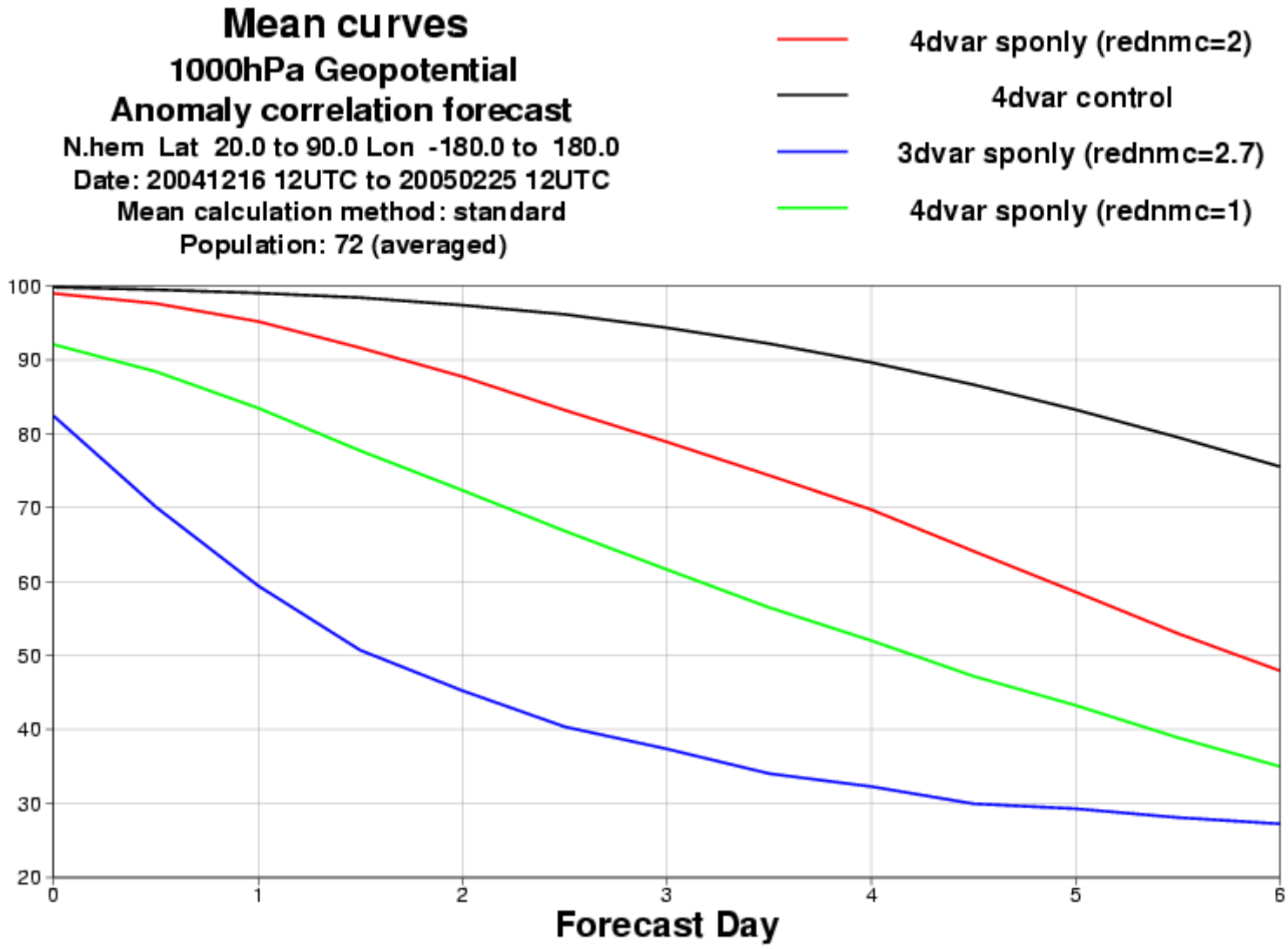
(200hPa NH RMS 96H FC error: 51.7 m)



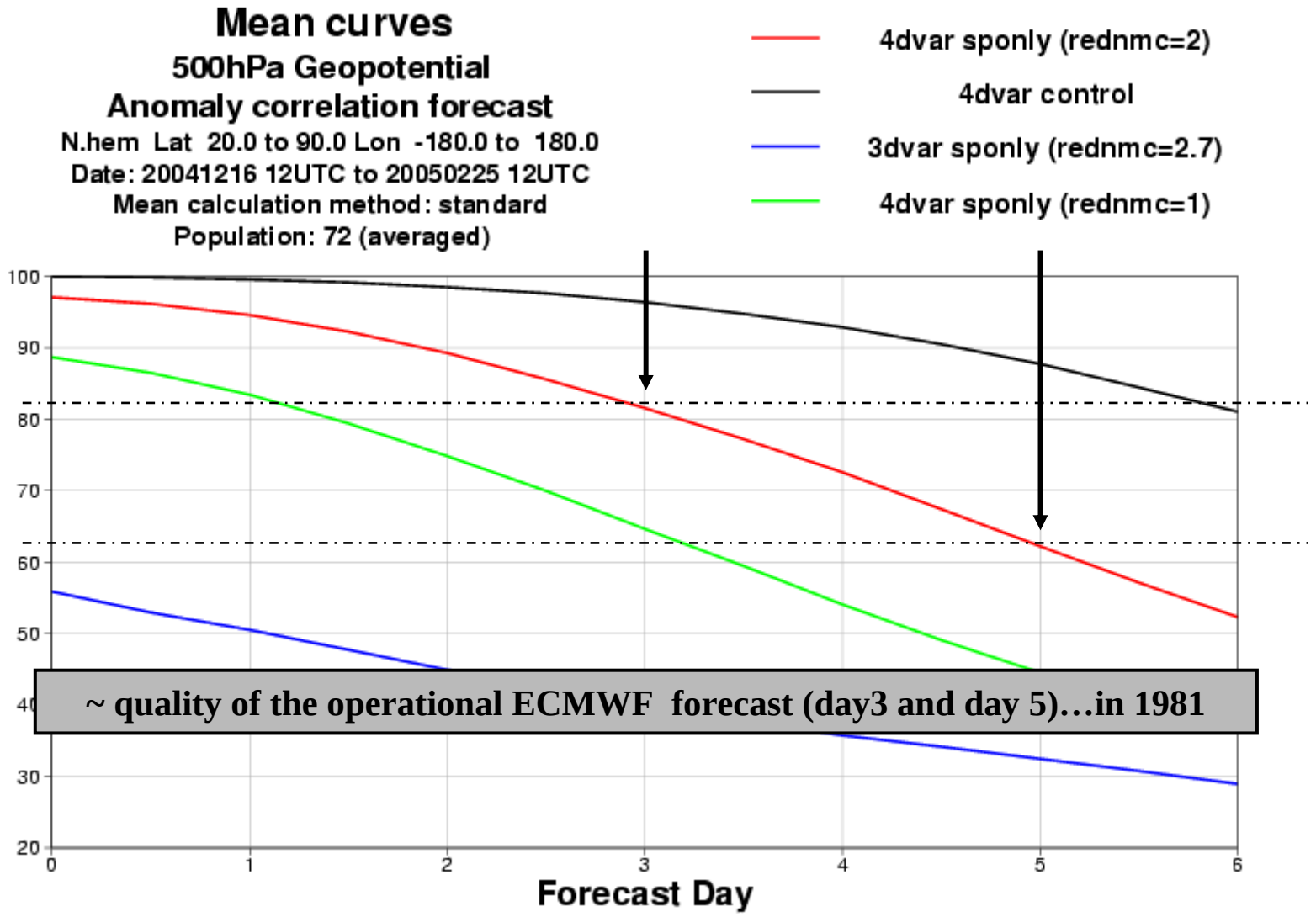
4DVAR SP ONLY

(200hPa NH RMS AN error: 51.7 m)

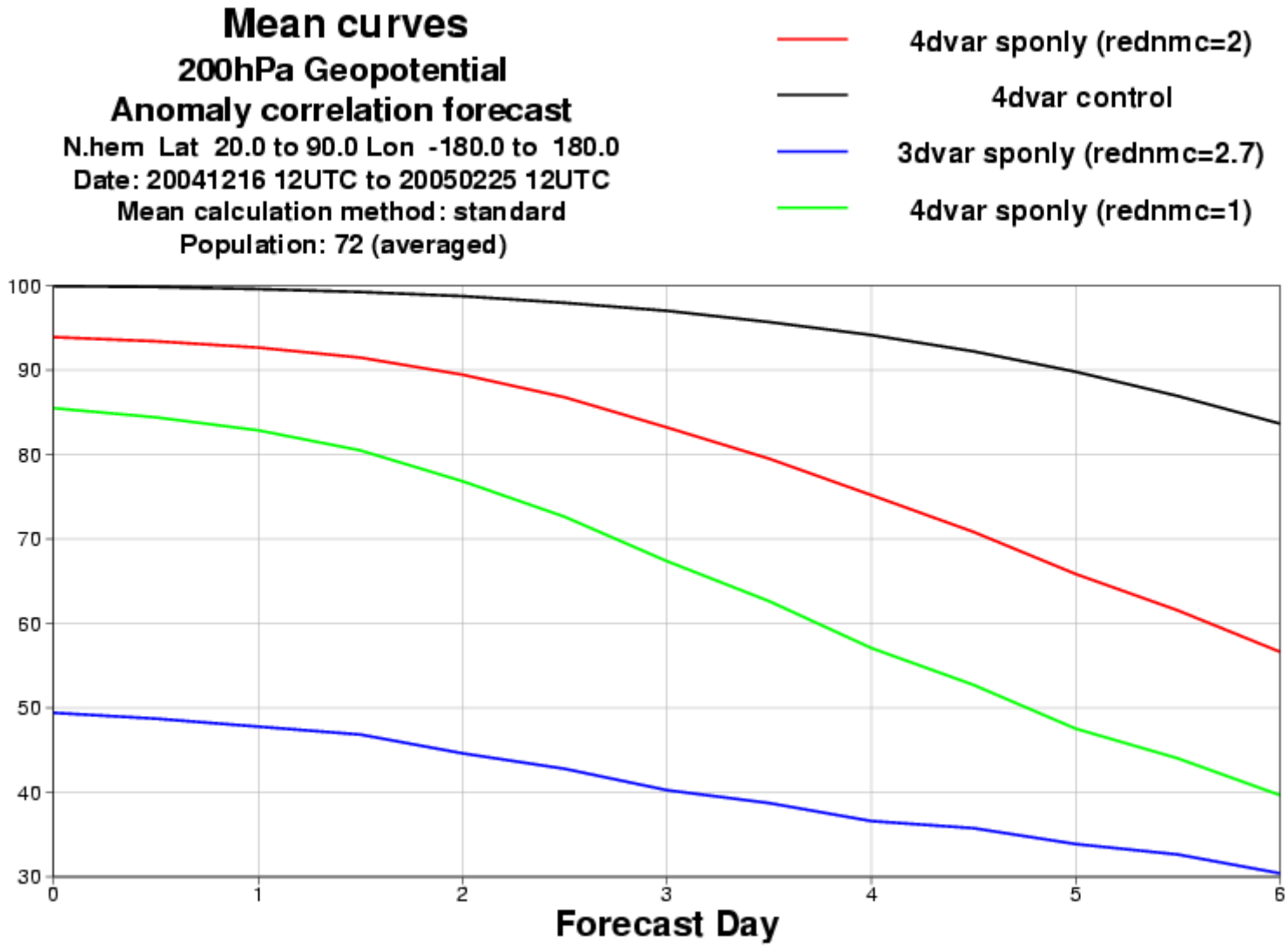
Summary: scores 1000hPa



Summary: scores 500hPa



Summary: scores 200hPa



Conclusions (1)

- **Tuning the statistics of the assimilation system when the Observing System is substantially degraded is essential**
  - **Need for an adaptive covariance model**
- **In the presence of reduced surface observing network (between 1/4th and 1/5th), and nothing else:**
  - **It is confirmed that 3DVAR (even retuned) is not able to provide sensible upper-air analyses in the Northern Hemisphere (→ Bengtsson et al. 2004)**
  - **More advanced assimilation system is necessary to extract and transfer information into data void areas in a dynamically consistent way:**
    - **4DVAR is able to propagate the information from the surface network to provide reasonable mid and upper tropospheric analyses**

Conclusions (2)

- **The quality of analyses in this "reduced surface network" context is equivalent to:**
  - 1 day (current NWP) forecast in low troposphere,
  - 3 to 4 day (current NWP) forecast in the UTLS
- **As for reanalyses before 1950's:**
  - The performance of 4DVAR in this study is certainly very encouraging
  - The system could be further tuned
    - Quality control, observational errors,…
  - To be fully convincing, the simulated observational network should be more representative of the first half of the 20th century
    - Further cut by up to 3 or 4 to reach 1900's level
    - Adapted geographical coverage (see Compo et al.)
- **Provided appropriate tuning towards past Observing Systems, 4DVAR is capable of providing realistic atmospheric analyses based on surface data**