École Doctorale des Sciences de l'Environnement d'Île-de-France
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# Modélisation Numérique de l'Écoulement Atmosphérique et Assimilation d'Observations

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Cours 3

25 Mai 2009

### 5 - SCHEMA DES INTERACTIONS PHYSIQUES DANS LE MODELE

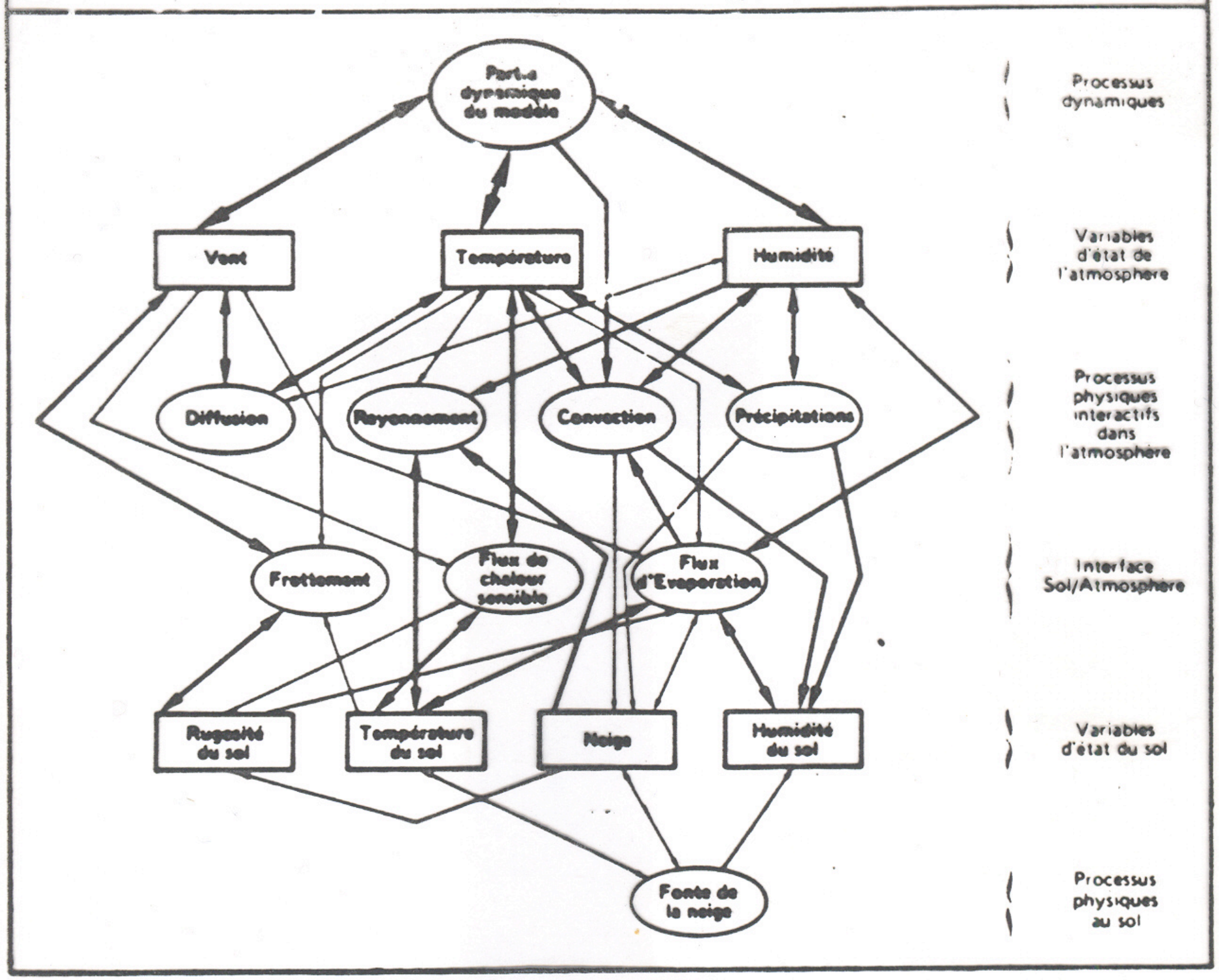



Fig. 1: Members of day 7 forecast of 500 hPa geopotential height for the ensemble originated from 25 January 1993.

*Figure 6 Hurricane Katrina mean-sea-level-pressure (MSLP) analysis for 12 UTC of 29 August 2005 and t+84h high-resolution and EPS forecasts started at 00 UTC of 26 August:*

*1st row:* *$1^{st}$ panel: MSLP analysis for 12 UTC of 29 Aug*
*$2^{nd}$ panel: MSLP t+84h $T_L$511L60 forecast started at 00 UTC of 26 Aug*
*$3^{rd}$ panel: MSLP t+84h EPS-control $T_L$255L40 forecast started at 00 UTC of 26 Aug*
*Other rows: 50 EPS-perturbed $T_L$255L40 forecast started at 00 UTC of 26 Aug.*

*The contour interval is 5 hPa, with shading patters for MSLP values lower than 990 hPa.*

*Pourquoi les météorologistes ont-ils tant de peine à prédire le temps avec quelque certitude ? Pourquoi les chutes de pluie, les tempêtes elles-mêmes nous semblent-elles arriver au hasard, de sorte que bien des gens trouvent tout naturel de prier pour avoir la pluie ou le beau temps, alors qu'ils jugeraient ridicule de demander une éclipse par une prière ?[...] un dixième de degré en plus ou en moins en un point quelconque, le cyclone éclate ici et non pas là, et il étend ses ravages sur des contrées qu'il aurait épargnées. Si on avait connu ce dixième de degré, on aurait pu le savoir d'avance, mais les observations n'étaient ni assez serrées, ni assez précises, et c'est pour cela que tout semble dû à l'intervention du hasard.*

H. Poincaré, *Science et Méthode*, Paris, 1908

**Centre Européen pour les Prévisions Météorologiques à Moyen Terme** (CEPMMT, Reading, GB)

(European Centre for Medium-range Weather Forecasts, ECMWF)

Troncature triangulaire T799 (résolution horizontale ≈ 28 kilomètres)

91 niveaux dans la direction verticale (0 - 80 km)

Dimension du vecteur d'état correspondant ≈ $2{,}3\ 10^8$

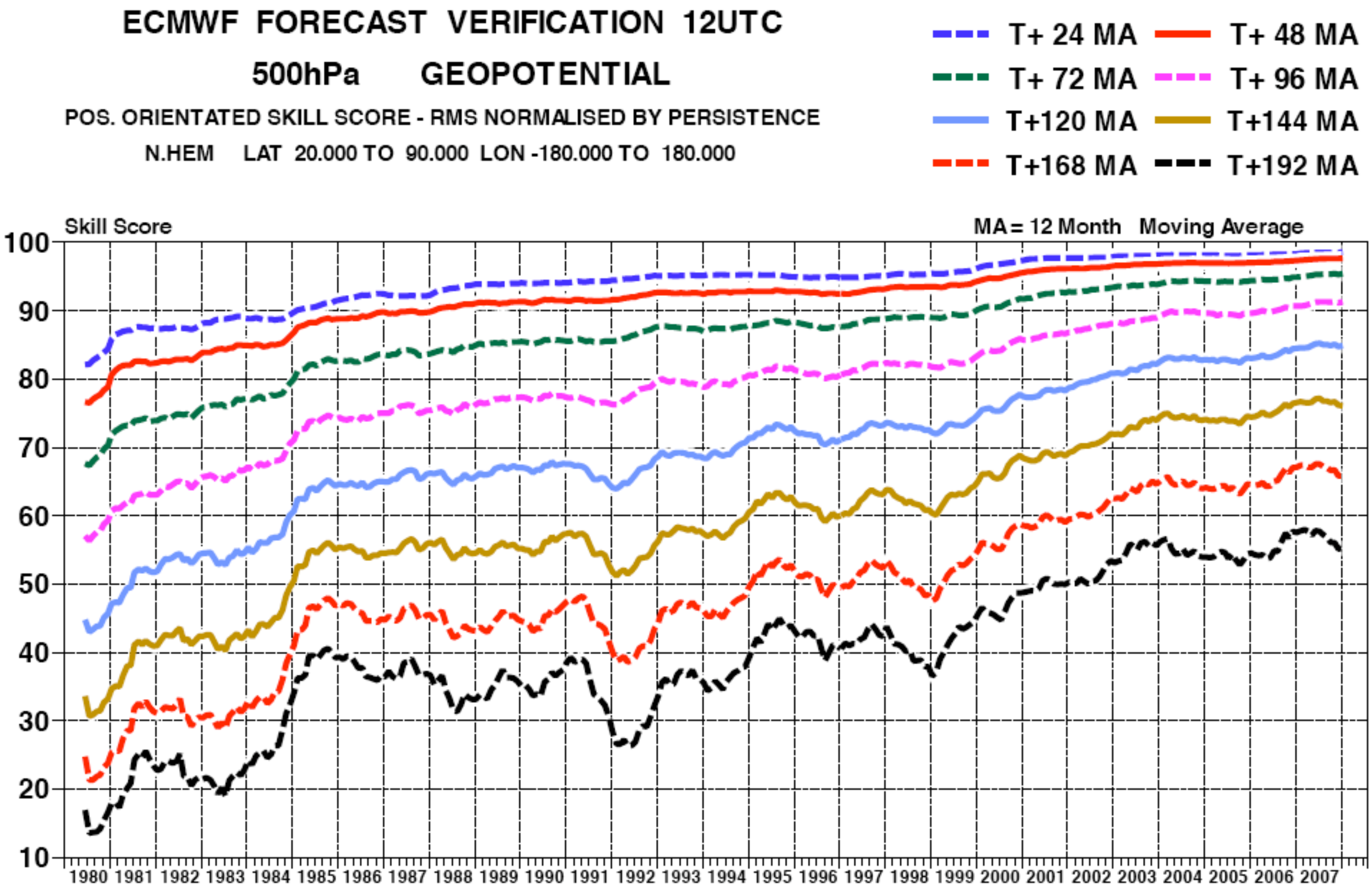
Pas de discrétisation temporelle : 12 minutes

Résultats extraits de

Richardson *et al.*, 2008, *Verification statistics and evaluations of ECMWF forecasts in 2007-2008*, Memorandum Technique *578*, CEPMMT, Reading, GB.

Disponible à l'adresse

http://www.ecmwf.int/publications/library/do/references/show?id=88723



ECMWF FORECAST VERIFICATION 12UTC
500hPa GEOPOTENTIAL
POS. ORIENTATED SKILL SCORE - RMS NORMALISED BY PERSISTENCE
N.HEM LAT 20.000 TO 90.000 LON -180.000 TO 180.000
T+ 24 MA
T+ 48 MA
T+ 72 MA
T+ 96 MA
T+120 MA
T+144 MA
T+168 MA
T+192 MA
Skill Score
MA = 12 Month Moving Average
100
90
80
70
60
50
40
30
20
10
1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007

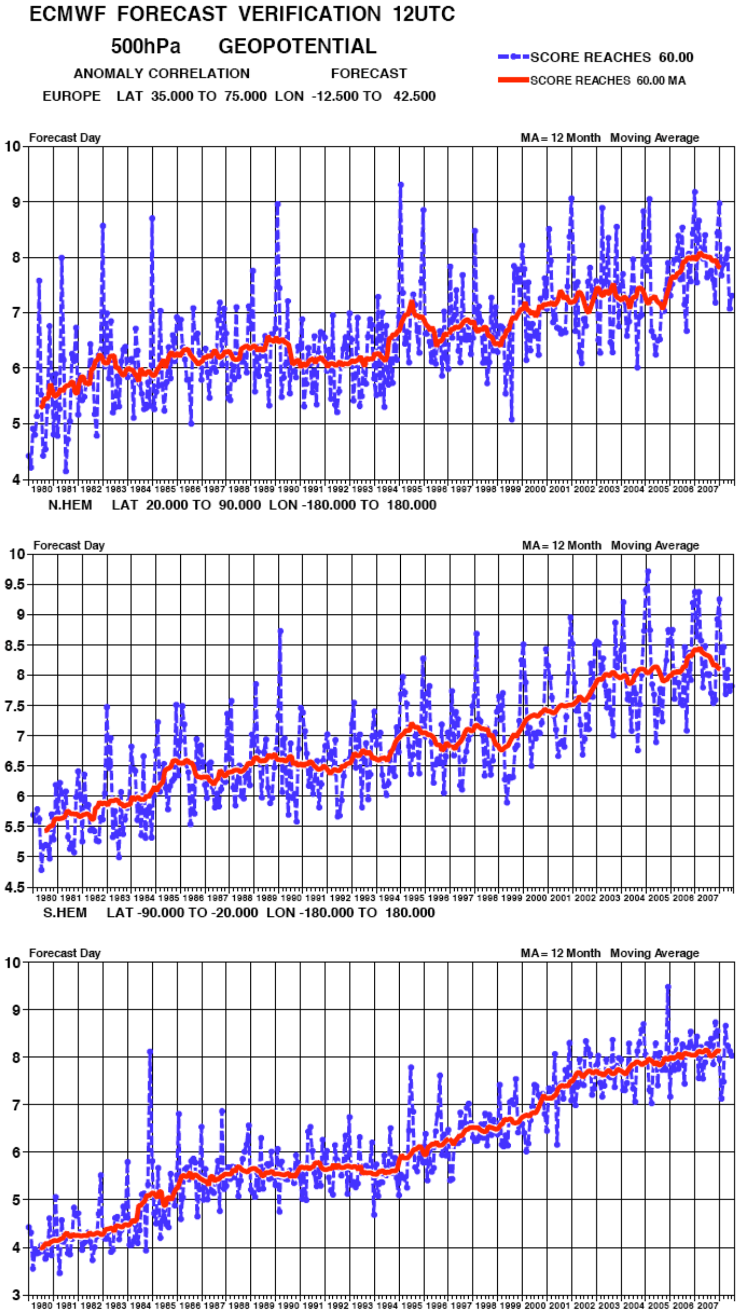
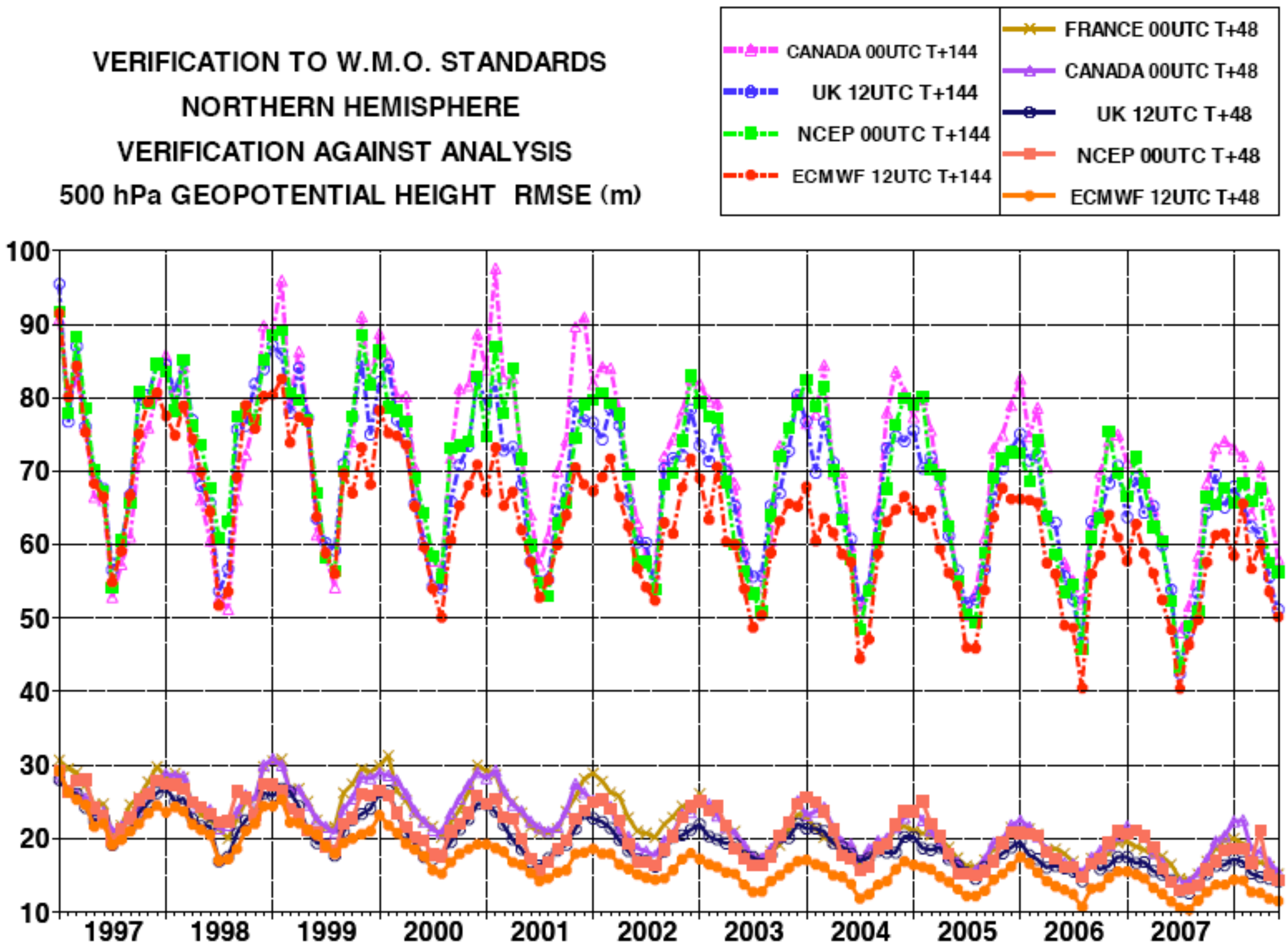
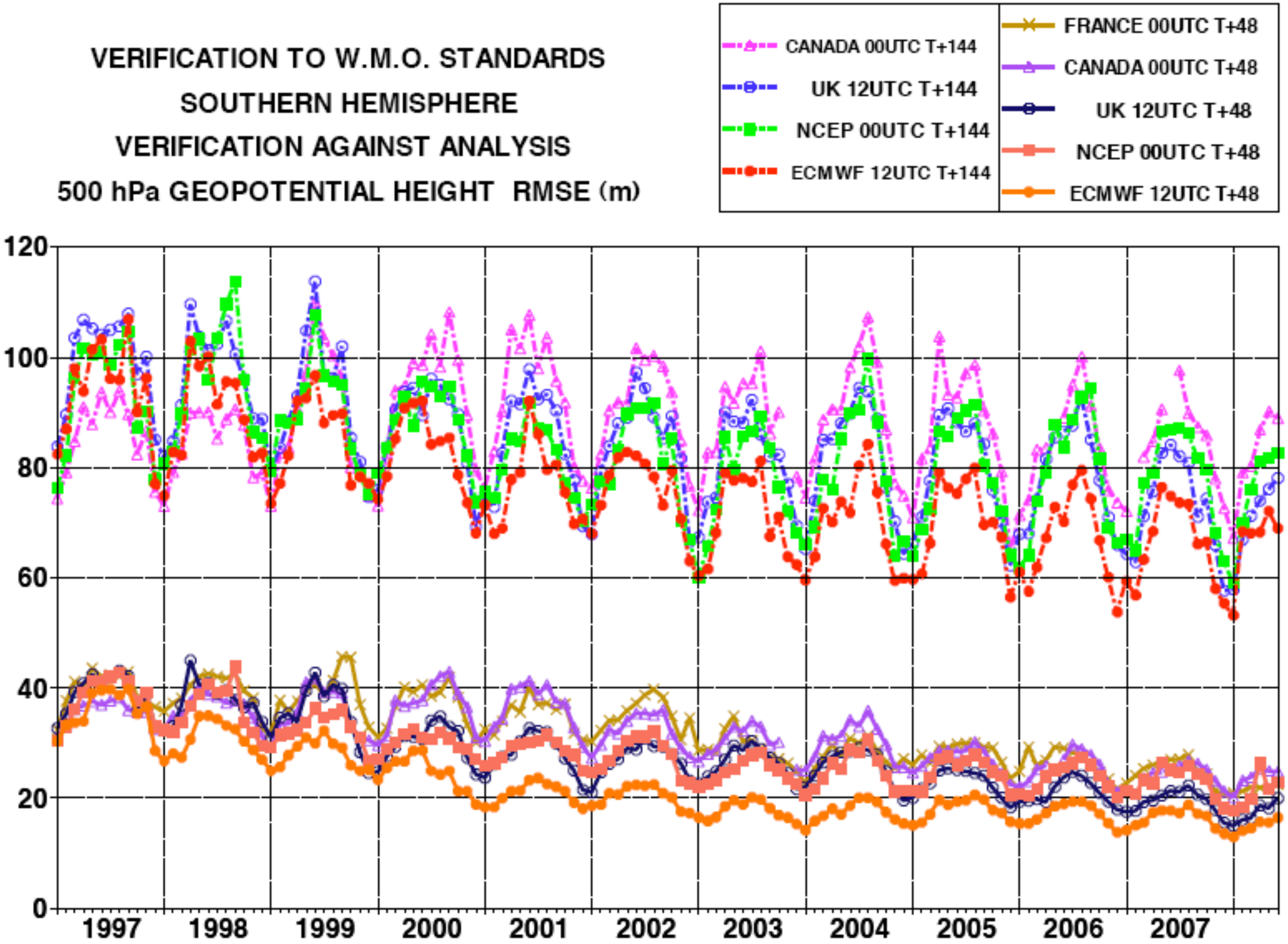
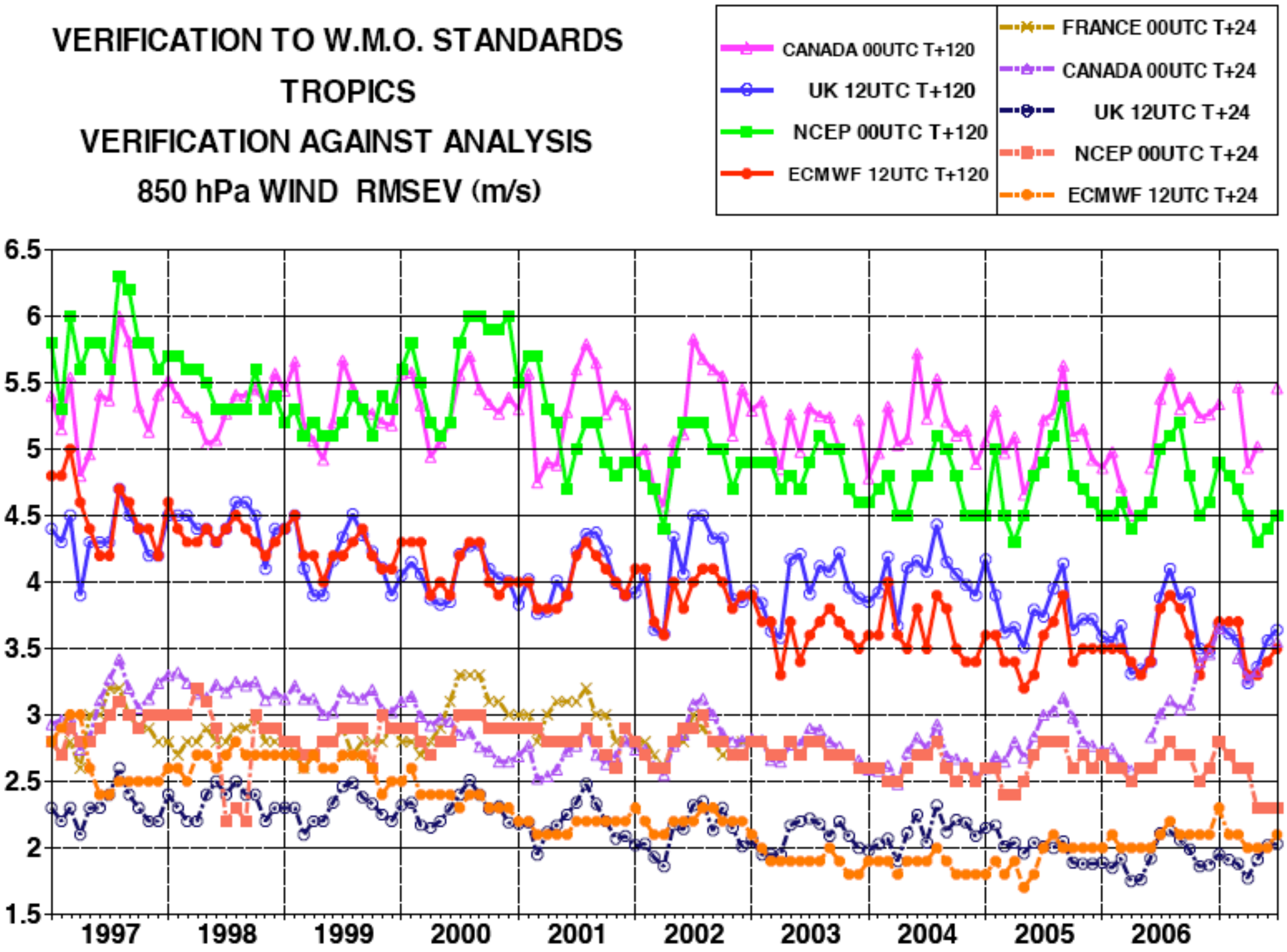



*Figure 2: Evolution with time of the 500hPa height forecast performance – each point on the blue curves is the forecast range at which the monthly average of the forecast anomaly correlation with the verifying analysis falls below 60% for Europe, northern and southern extratropics (the red curve is the 12-month moving average).*


VERIFICATION TO W.M.O. STANDARDS
NORTHERN HEMISPHERE
VERIFICATION AGAINST ANALYSIS
500 hPa GEOPOTENTIAL HEIGHT RMSE (m)
CANADA 00UTC T+144
UK 12UTC T+144
NCEP 00UTC T+144
ECMWF 12UTC T+144
FRANCE 00UTC T+48
CANADA 00UTC T+48
UK 12UTC T+48
NCEP 00UTC T+48
ECMWF 12UTC T+48
100
90
80
70
60
50
40
30
20
10
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007


VERIFICATION TO W.M.O. STANDARDS
SOUTHERN HEMISPHERE
VERIFICATION AGAINST ANALYSIS
500 hPa GEOPOTENTIAL HEIGHT RMSE (m)
CANADA 00UTC T+144
UK 12UTC T+144
NCEP 00UTC T+144
ECMWF 12UTC T+144
FRANCE 00UTC T+48
CANADA 00UTC T+48
UK 12UTC T+48
NCEP 00UTC T+48
ECMWF 12UTC T+48
120
100
80
60
40
20
0
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007



VERIFICATION TO W.M.O. STANDARDS
TROPICS
VERIFICATION AGAINST ANALYSIS
850 hPa WIND RMSEV (m/s)
CANADA 00UTC T+120
UK 12UTC T+120
NCEP 00UTC T+120
ECMWF 12UTC T+120
FRANCE 00UTC T+24
CANADA 00UTC T+24
UK 12UTC T+24
NCEP 00UTC T+24
ECMWF 12UTC T+24
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006

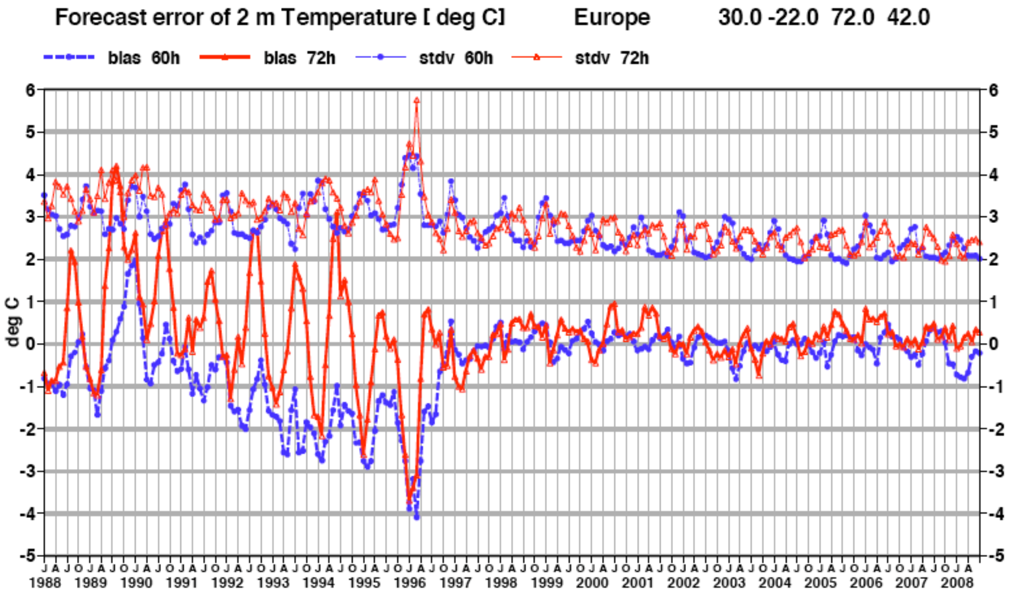



*Figure 15: Verification of 2 metre temperature forecasts against European SYNOP data on the GTS for 60-hour (night-time) and 72-hour (daytime) forecasts. Lower pair of curves are bias, upper curves are standard deviation of error.*

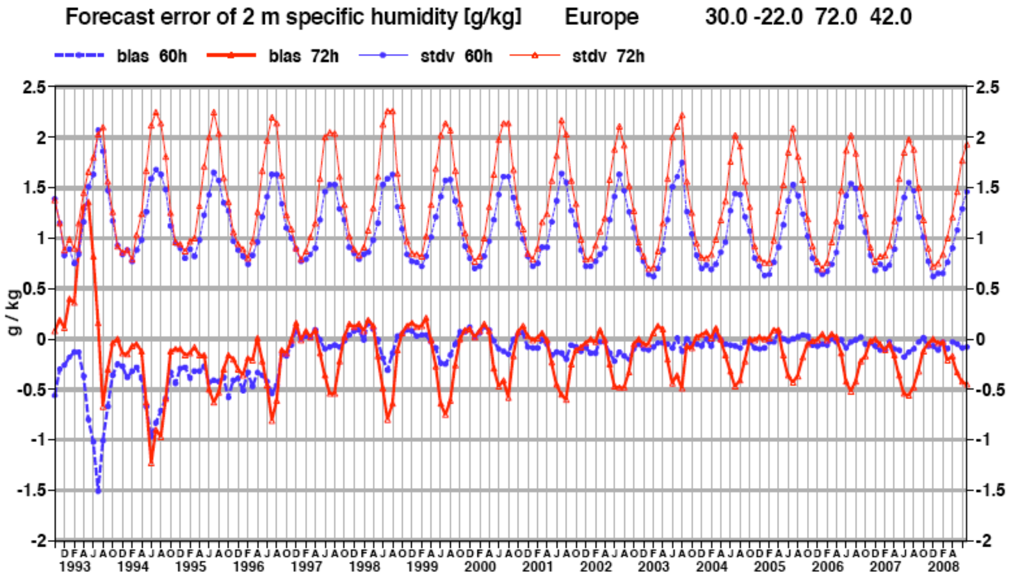



*Figure 16: Verification of 2 metre specific humidity forecasts against European SYNOP data on the GTS for 60-hour (night-time) and 72-hour (daytime) forecasts. Lower pair of curves are bias, upper curves are standard deviation of error.*

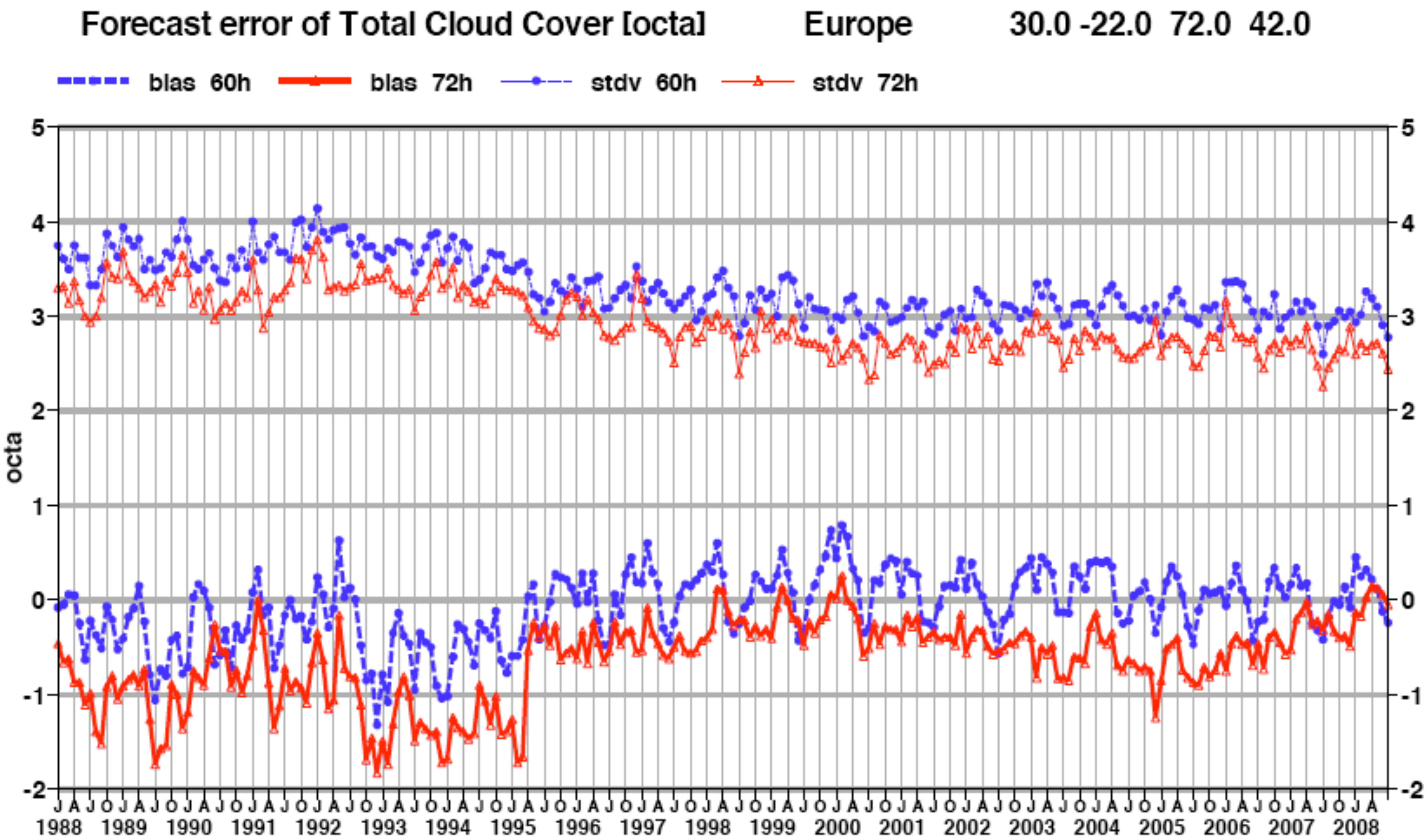



*Figure 17: Verification of total cloud cover forecasts against European SYNOP data on the GTS for 60-hour (night-time) and 72-hour (daytime) forecasts. Lower pair of curves are bias, upper curves are standard deviation of error.*

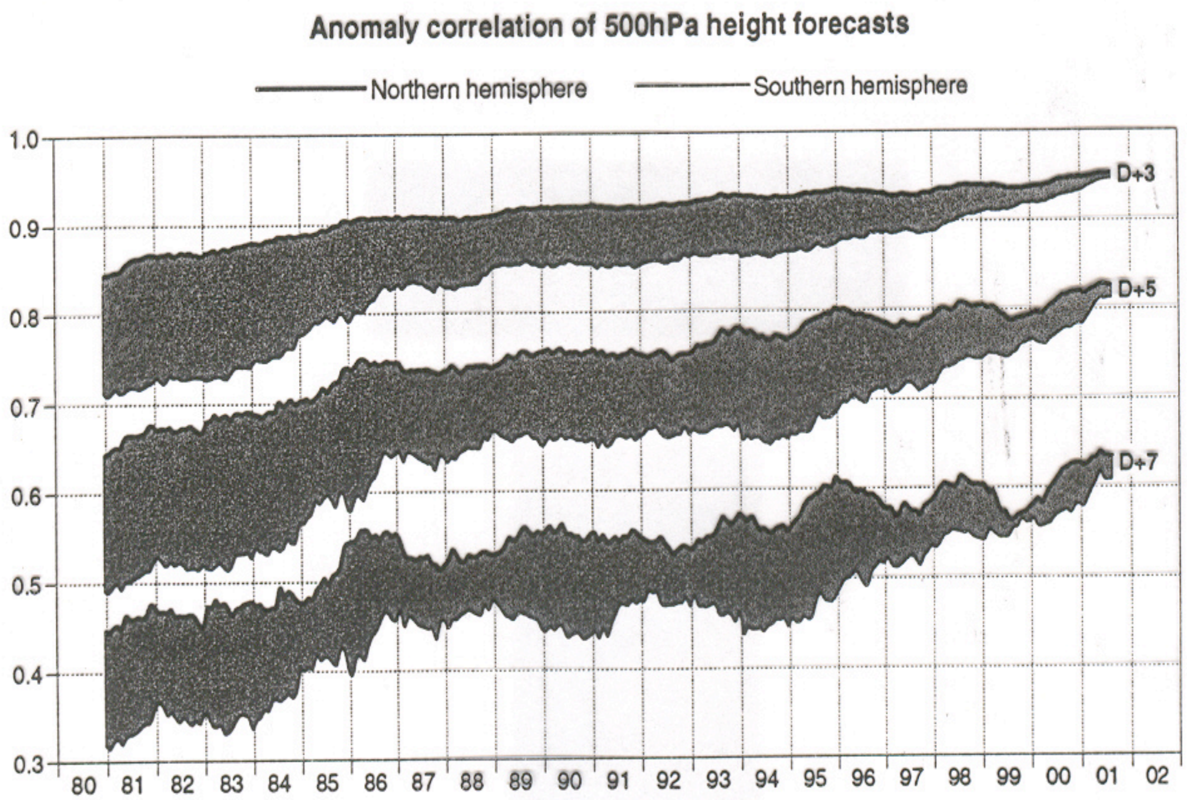



*Fig 4. Anomaly correlation coefficients of 3-, 5- and 7-day ECMWF 500hPa height forecasts for the extratropical northern and southern hemispheres, plotted in the form of annual running means of archived monthly-mean scores for the period from January 1980 to August 2001. Values plotted for a particular month are averages over that month and the 11 preceding months. The shading shows the differences in scores between the two hemispheres at the forecast ranges indicated.*

Simmons et Hollingsworth, 2002, *Q. J. R. Meteorol. Soc.,* **128**, 647-677

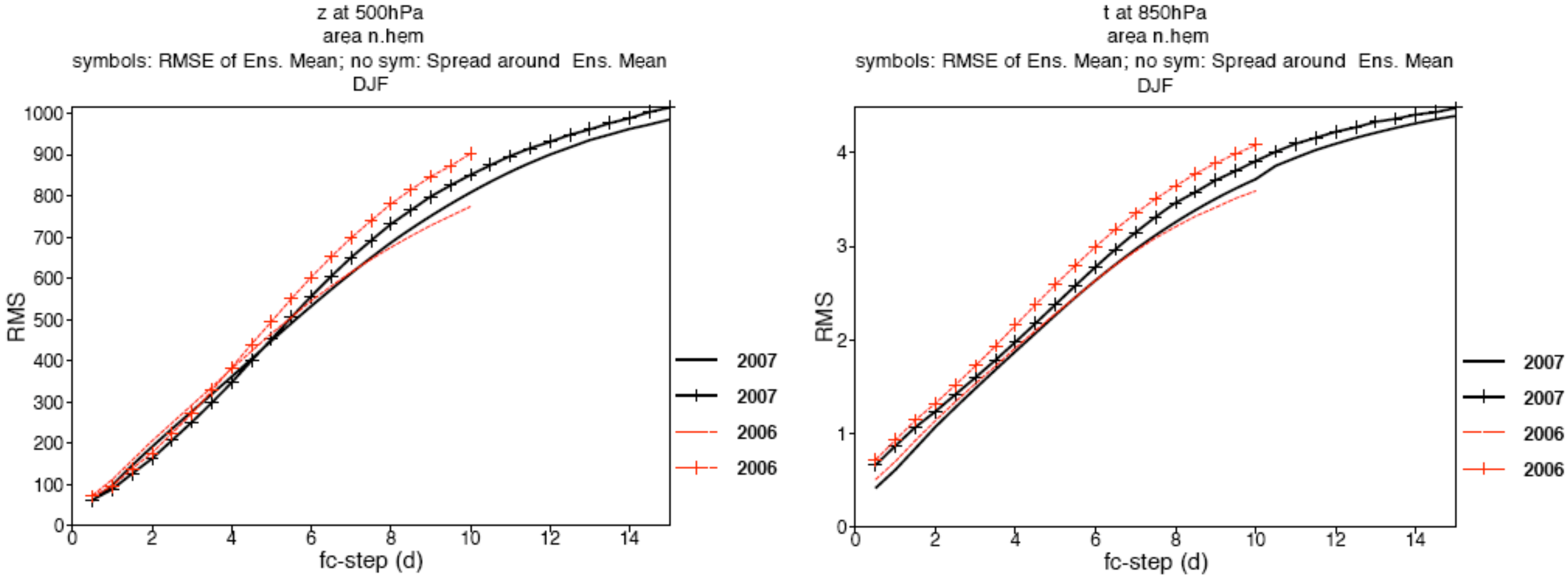



*Figure 8: Ensemble spread (standard deviation) and root mean square error of ensemble-mean (lines with crosses) for 500 hPa height (left) and 850 hPa temperature (right) for winter 2006-07 (black) and 2005-06 (red) over the extra-tropical northern hemisphere.*

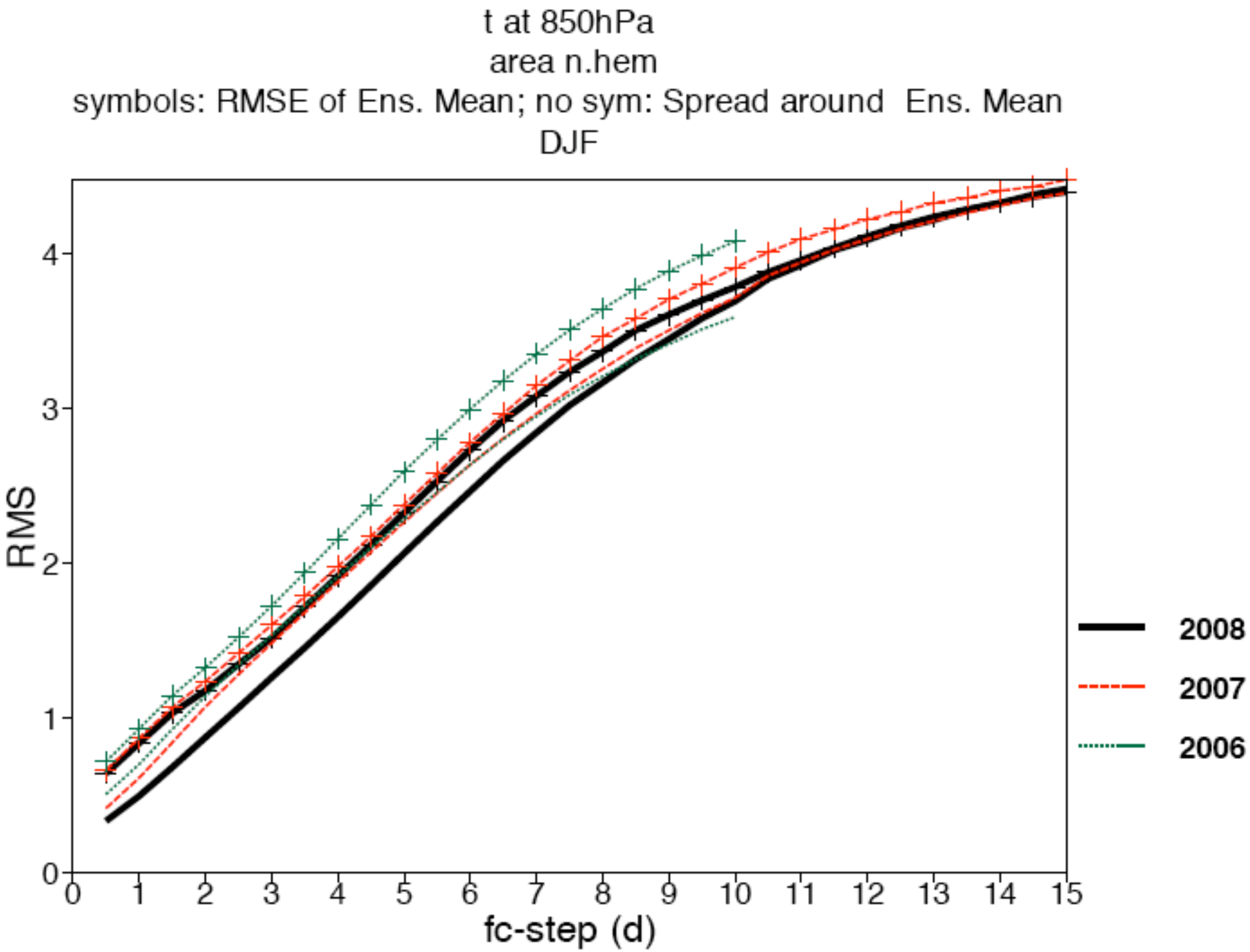



*Figure 8: Ensemble spread (standard deviation) and root mean square error of ensemble-mean (lines with crosses) for 500 hPa height (top) and 850 hPa temperature (bottom) for winter 2007-08 (black), 2006-07 (red) and 2005-06 (green) over the extra-tropical northern hemisphere.*

## Problèmes restants

- Cycle de l'eau (évaporation, condensation, influence sur le rayonnement absorbé ou émis par l'atmosphère)

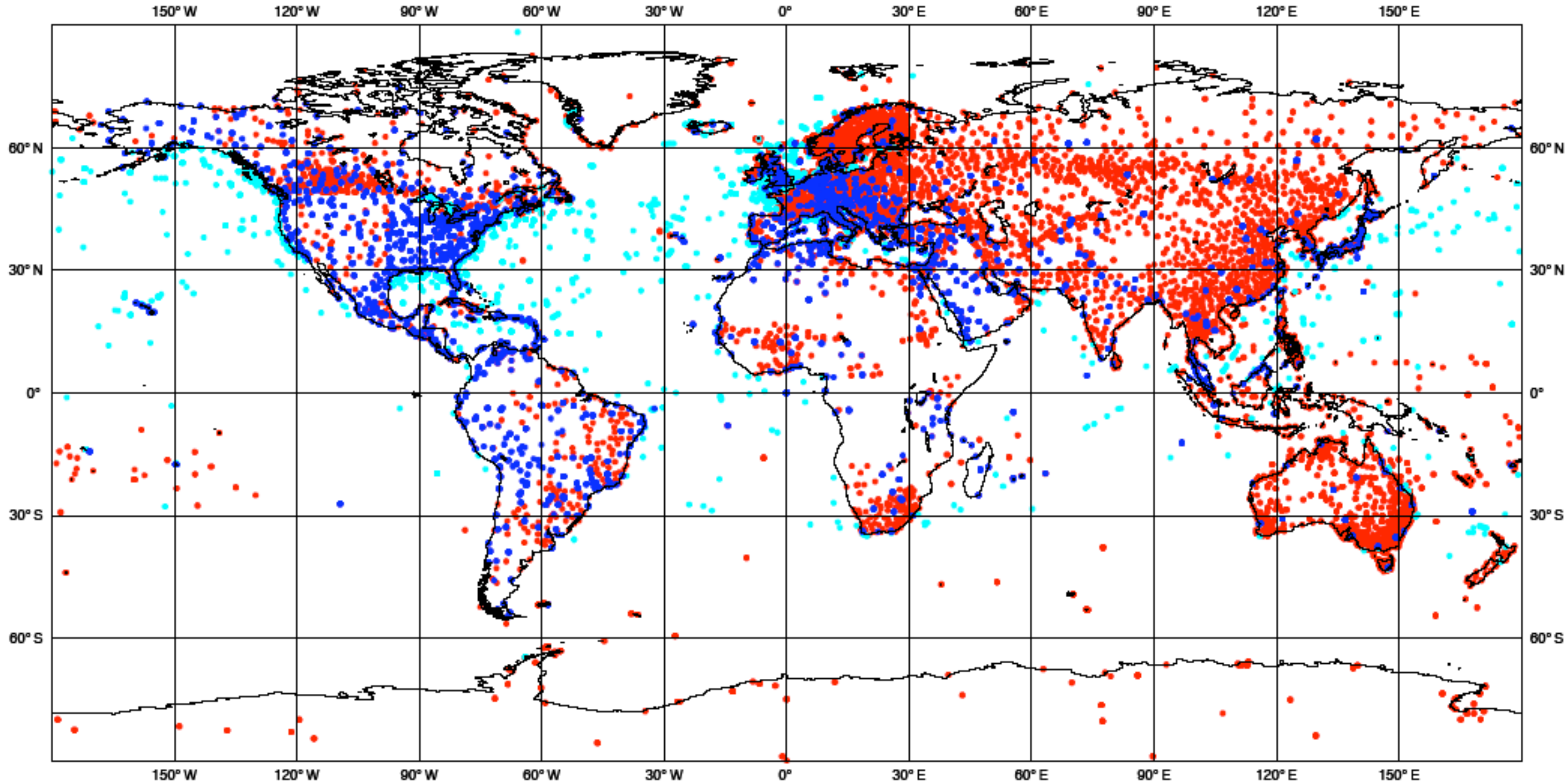
- Échanges avec l'océan ou la surface continentale (chaleur, eau, quantité de mouvement, …)

- …

**Obs Type**

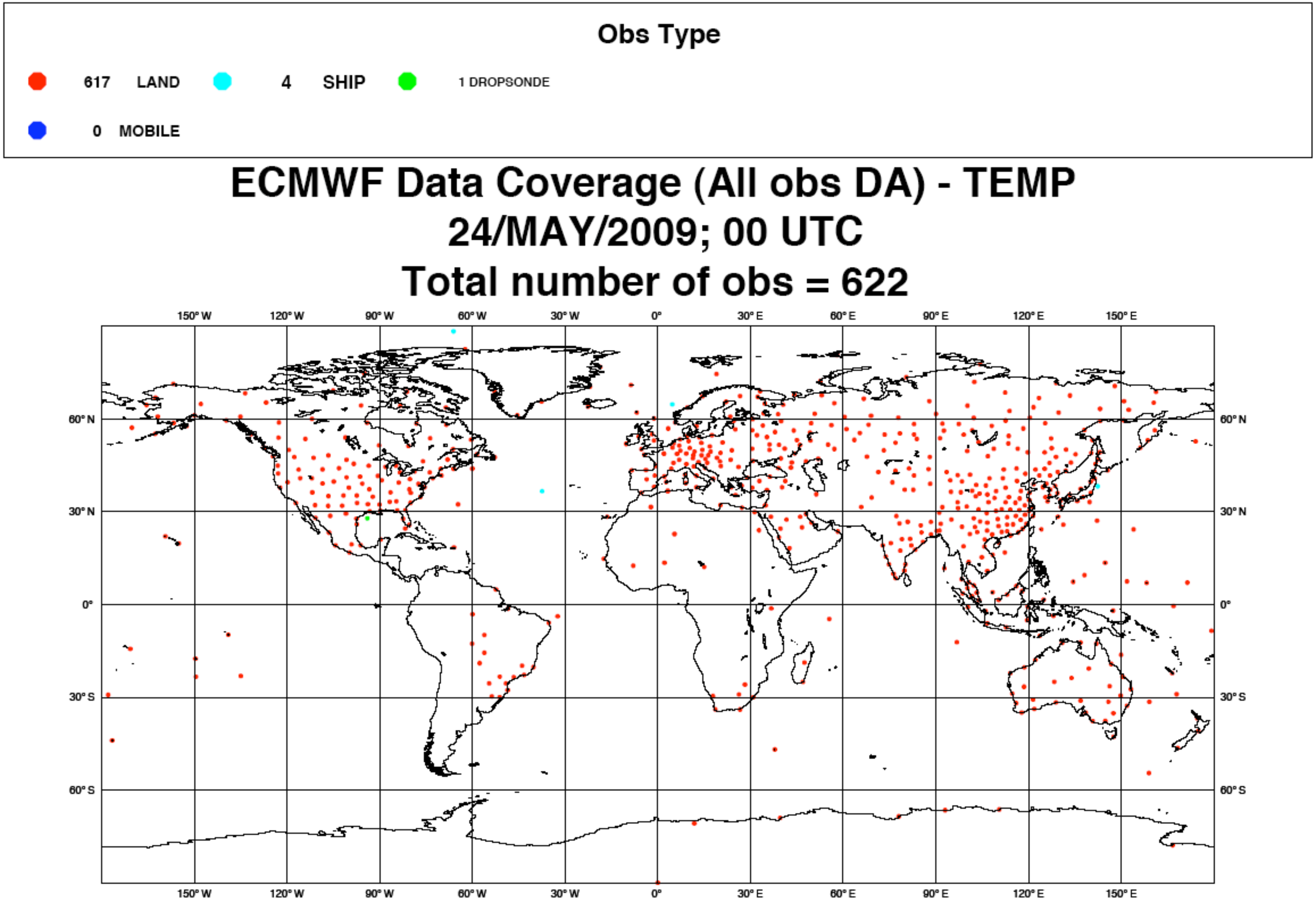
16987 SYNOP · 2514 SHIP · 9733 METAR

# ECMWF Data Coverage (All obs DA) - SYNOP/SHIP
## 24/MAY/2009; 00 UTC
## Total number of obs = 29234




ECMWF

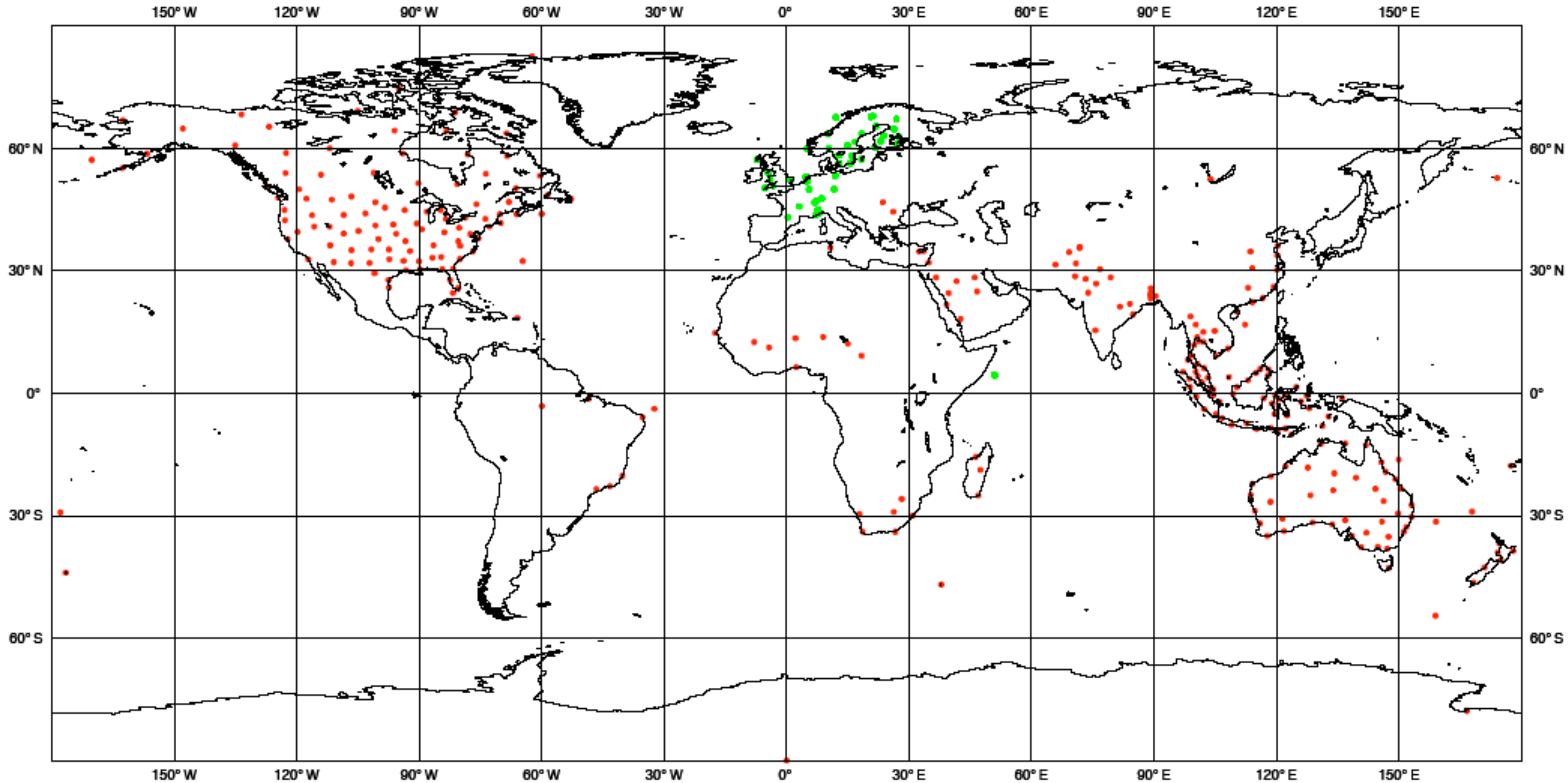
# ECMWF Data Coverage (All obs DA) - TEMP
## 24/MAY/2009; 00 UTC
## Total number of obs = 622



## Obs Type

| | | | |
|---|---|---|---|
| 289 PILOT | 0 PROFILER | 813 E-PROF | 0 J-PROF |

# ECMWF Data Coverage (All obs DA) - PILOT/PROFILER
## 24/MAY/2009; 00 UTC
## Total number of obs = 1102

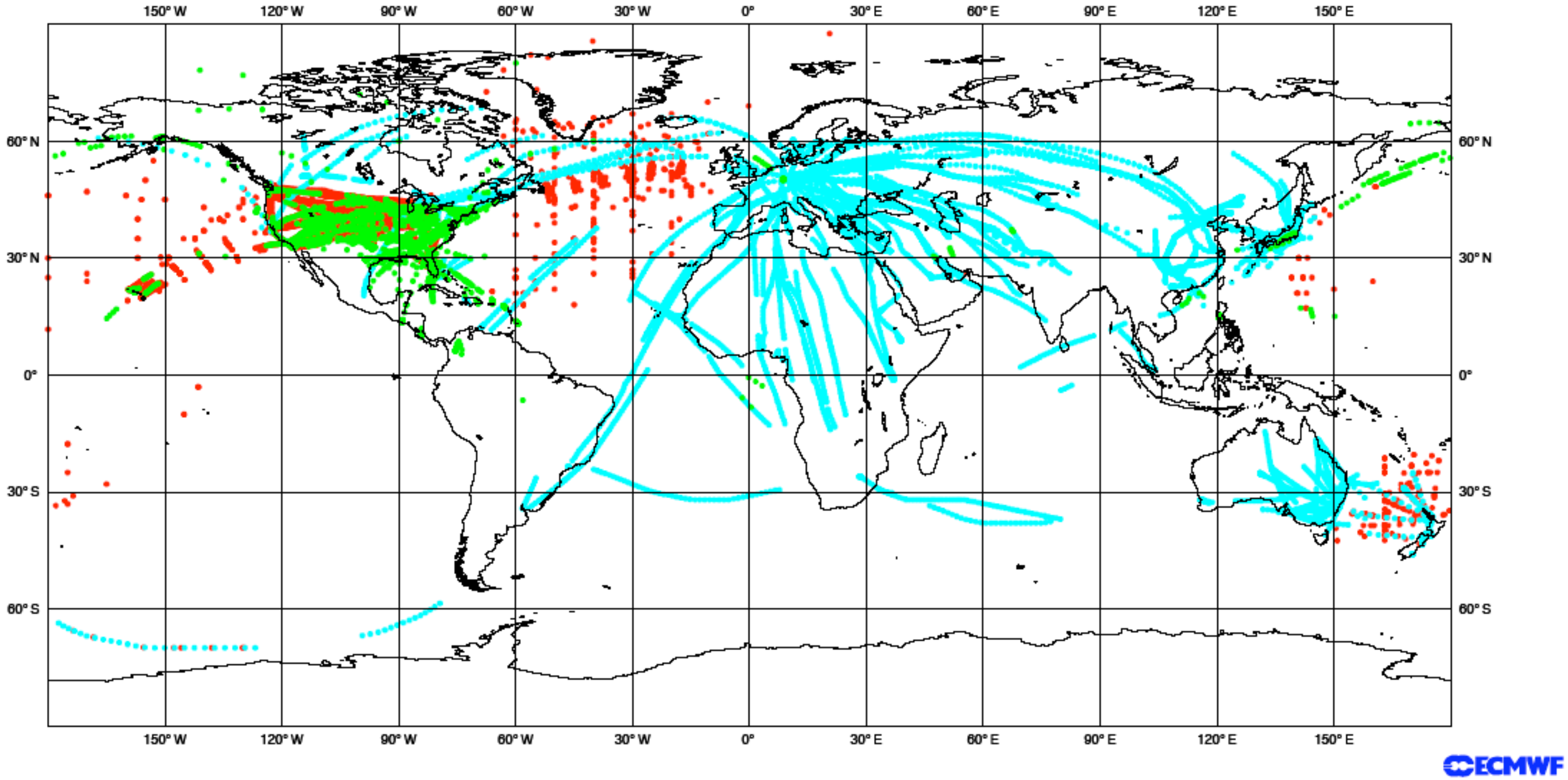


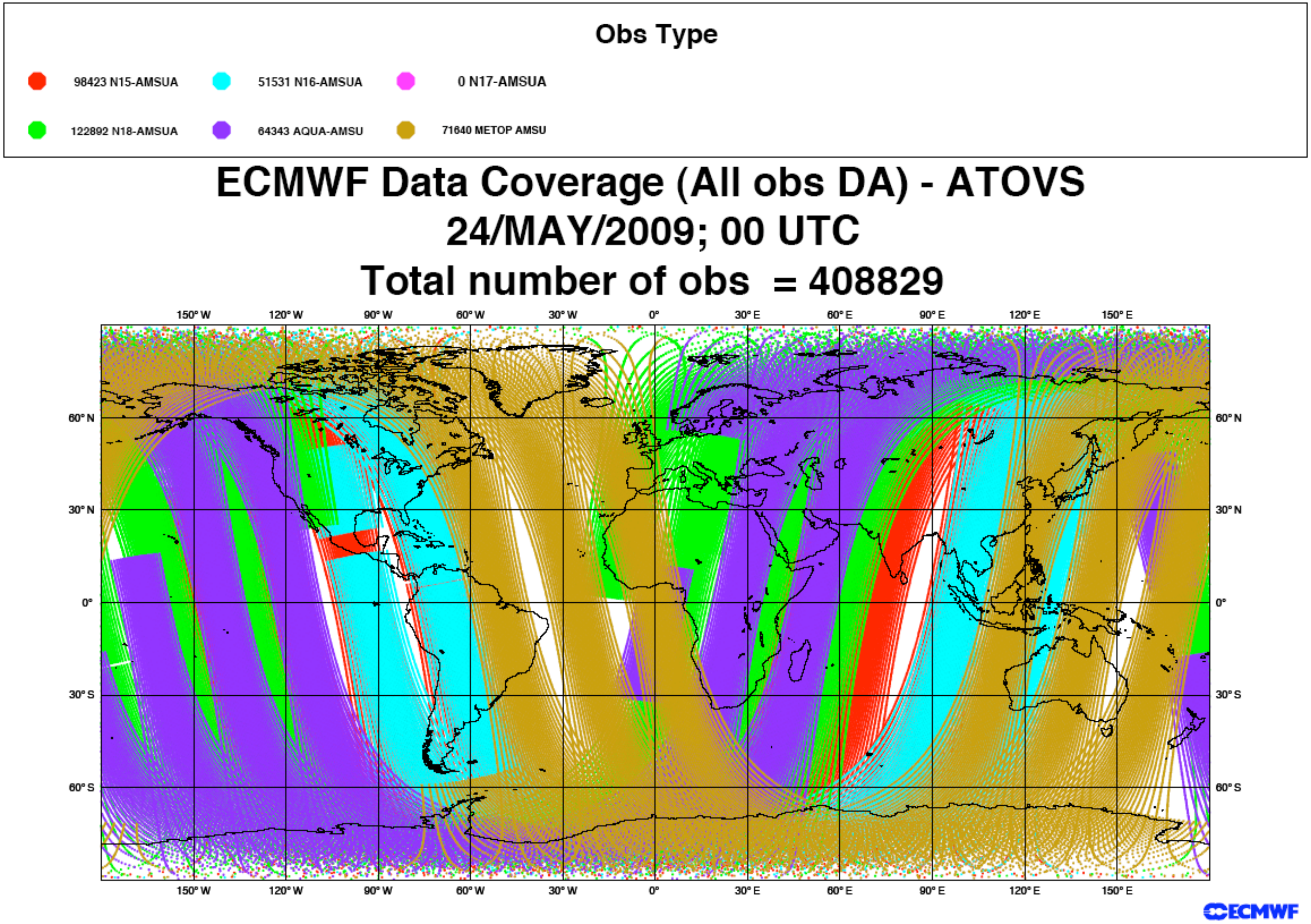

ECMWF

**Obs Type**

5711 AIREP | 13000 AMDAR | 3282 ACARS

# ECMWF Data Coverage (All obs DA) - AIRCRAFT
## 24/MAY/2009; 00 UTC
## Total number of obs = 21993

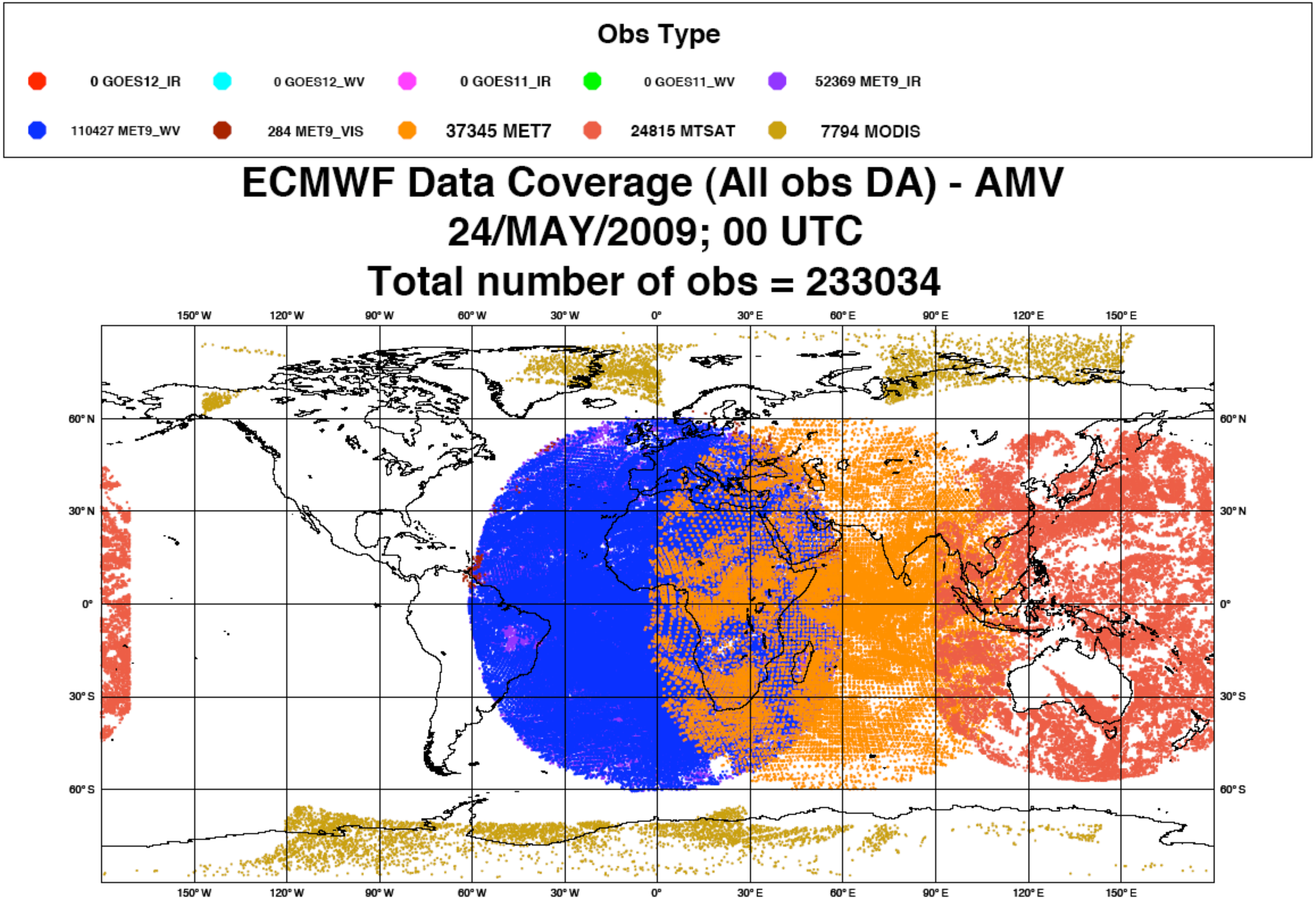



Obs Type
98423 N15-AMSUA
51531 N16-AMSUA
0 N17-AMSUA
122892 N18-AMSUA
64343 AQUA-AMSU
71640 METOP AMSU
ECMWF Data Coverage (All obs DA) - ATOVS
24/MAY/2009; 00 UTC
Total number of obs = 408829
150° W
120° W
90° W
60° W
30° W
0°
30° E
60° E
90° E
120° E
150° E
60° N
30° N
0°
30° S
60° S
ECMWF

# ECMWF Data Coverage (All obs DA) - AMV

## 24/MAY/2009; 00 UTC

## Total number of obs = 233034

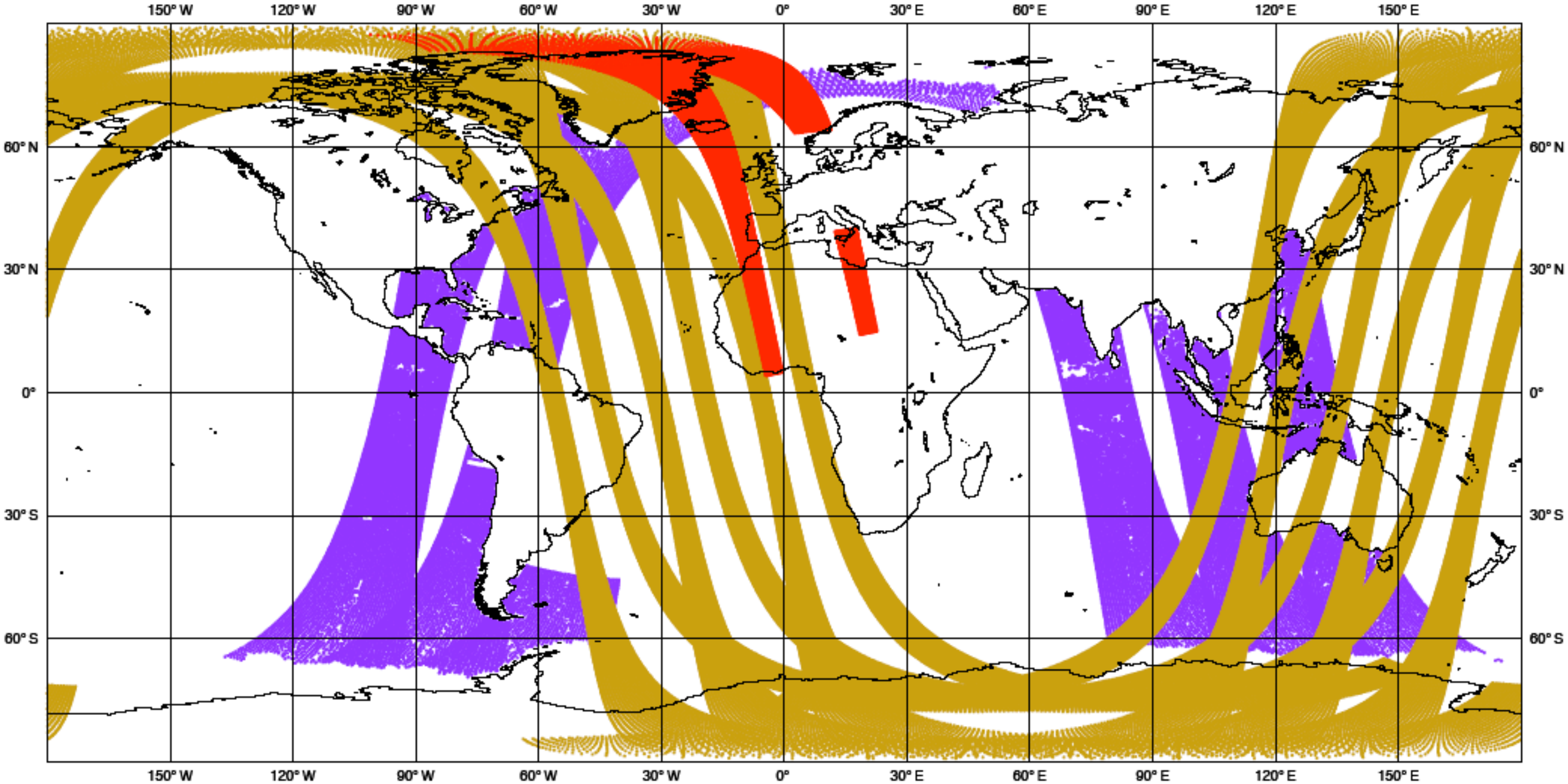



ECMWF

**Obs Type**

35722 SCAT · 208656 ASCAT · 19494 ERS-2

# ECMWF Data Coverage (All obs DA) - SCAT
# 24/MAY/2009; 00 UTC
# Total number of obs = 263872

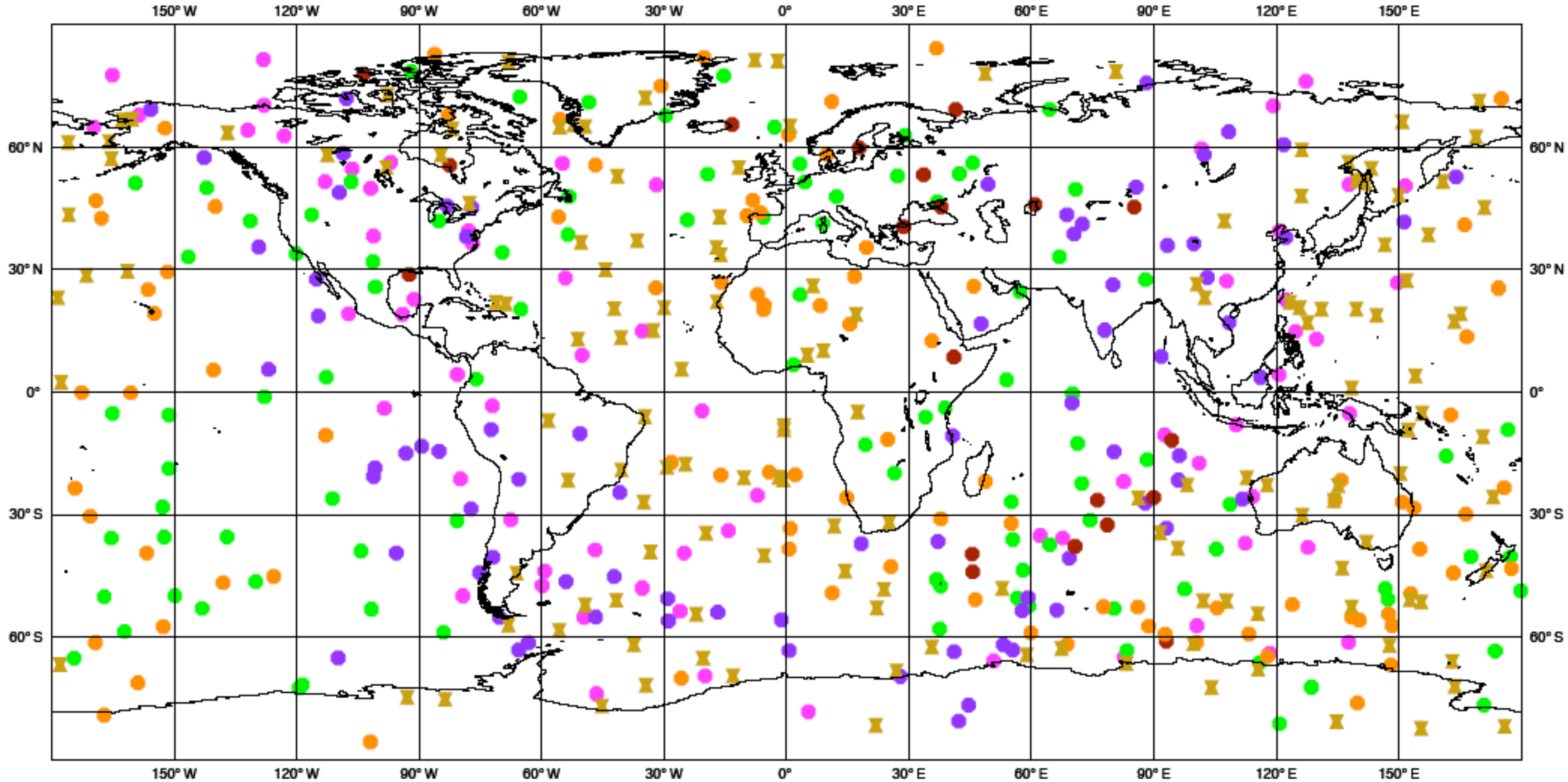



ECMWF

**Obs Type**

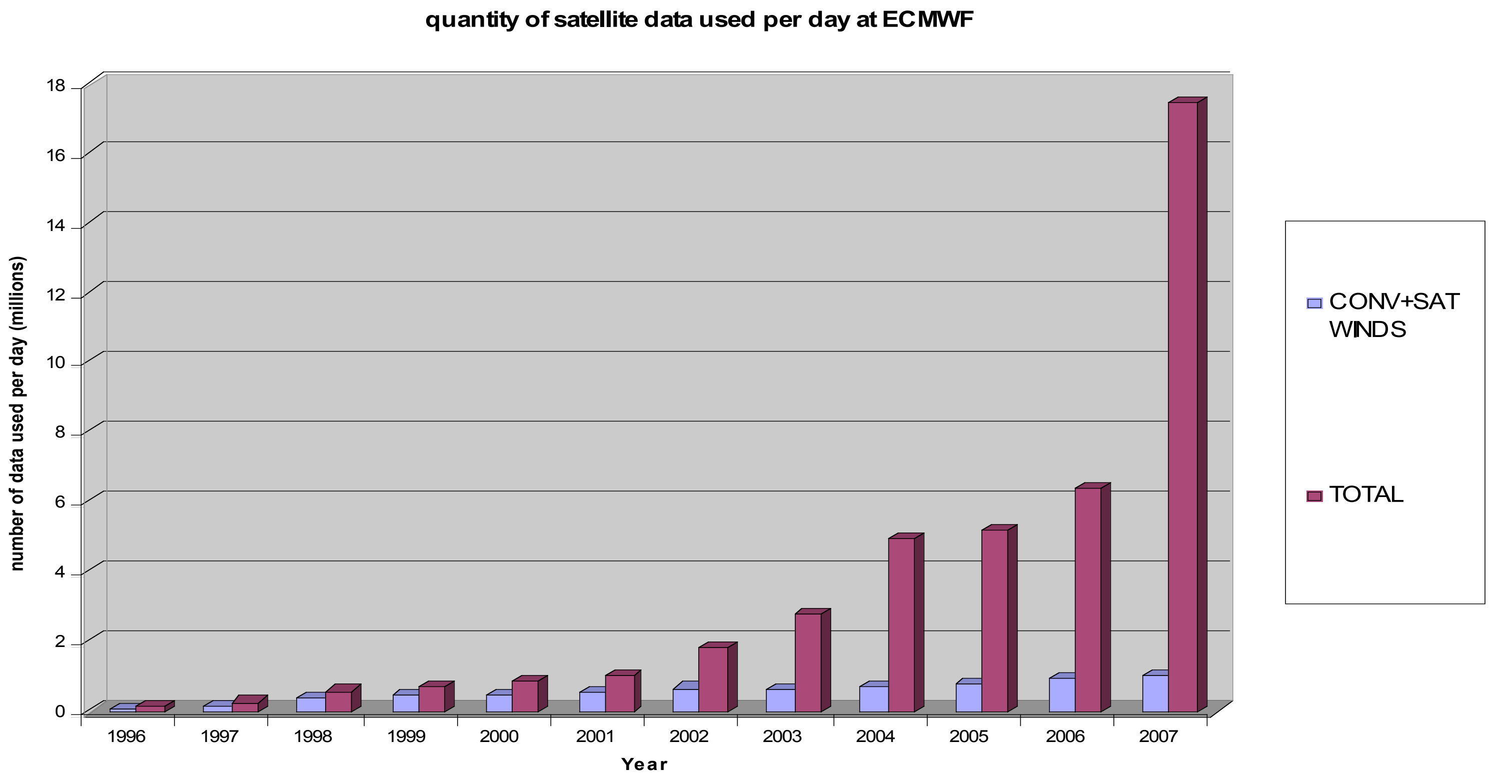
| | | | |
|---|---|---|---|
| 0 CHAMP | 0 GRACE-A | 68 COSMIC-1 | 98 COSMIC-2 |
| 78 COSMIC-3 | 0 COSMIC-4 | 20 COSMIC-5 | 93 COSMIC-6 |
| 150 GRAS | | | |

# ECMWF Data Coverage (All obs DA) - GPSRO
# 24/MAY/2009; 00 UTC
# Total number of obs = 507




ECMWF

# December 2007: Satellite data volumes used: around 18 millions per day



- Observations *synoptiques* (observations au sol, radiosondages), effectuées simultanément, par convention internationale, dans toutes les stations météorologiques du globe (00:00, 06:00, 12:00, 18:00 TU)

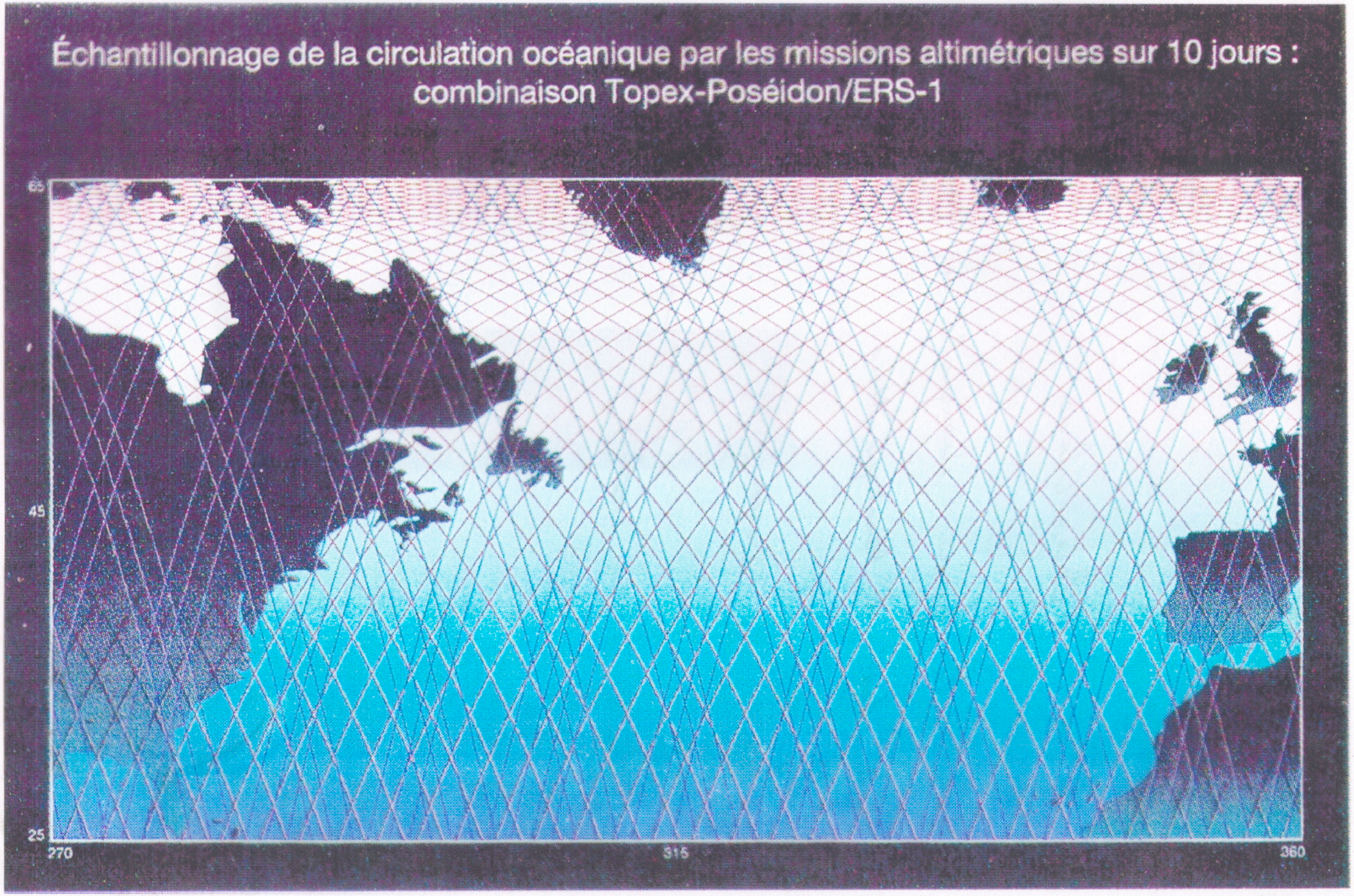
- Observations *asynoptiques* (satellites, avions), effectuées plus ou moins continûment dans le temps.

- Observations *directes* (température, pression, composantes du vent, humidité), portant sur les variables utilisées pour décrire l'état de l'écoulement dans les modèles numériques

- Observations *indirectes* (observations radiométriques, …), portant sur une combinaison plus ou moins complexe (le plus souvent, une intégrale d'espace unidimensionnelle) des variables utilisées pour décrire l'état de l'écoulement

$$y = H(\boldsymbol{x})$$

$H$ : *opérateur d'observation* (par exemple, équation de transfert radiatif)




S. Louvel, Doctoral Dissertation, 1999

Purpose of assimilation : reconstruct as accurately as possible the state of the atmospheric or oceanic flow, using all available appropriate information. The latter essentially consists of

- The observations proper, which vary in nature, resolution and accuracy, and are distributed more or less regularly in space and time.

- The physical laws governing the evolution of the flow, available in practice in the form of a discretized, and necessarily approximate, numerical model.

- 'Asymptotic' properties of the flow, such as, *e. g.*, geostrophic balance of middle latitudes. Although they basically are necessary consequences of the physical laws which govern the flow, these properties can usefully be explicitly introduced in the assimilation process.

Assimilation is one of many '*inverse problems*' encountered in many fields of science and technology

- solid Earth geophysics
- plasma physics
- 'nondestructive' probing
- navigation (spacecraft, aircraft, ….)
- …

Solution most often (if not always) based on Bayesian, or probabilistic, estimation. 'Equations' are fundamentally the same.

Difficulties specific to assimilation of meteorological and oceanographical observations :

- Very large numerical dimensions ($n \approx 10^6$-$10^8$ parameters to be estimated, $p \approx 1$-$2.10^7$ observations per 24-hour period). Difficulty aggravated in Numerical Weather Prediction by the need for the forecast to be ready in time.

- Non-trivial underlying dynamics