SEMINAR AND WORKSHOP PROCEEDINGS

Seminar on data assimilation

2 - 6 September 1996

Workshop on non-linear aspects of data assimilation

9 - 11 September 1996

European Centre for Medium-Range Weather Forecasts
Europäisches Zentrum für mittelfristige Wettervorhersage
Centre européen pour les prévisions météorologiques à moyen terme

FUNDAMENTALS OF ATMOSPHERIC DATA ASSIMILATION

Roger Daley

Naval Research Laboratory,
Monterey CA, USA

Fifteen years ago, data assimilation was a minor and often neglected sub-discipline of numerical weather prediction. The situation is very different today. Data assimilation is now felt to be important for all climate/environmental monitoring and estimating the ocean state. There have been great advances in both modelling and instrumentation for a variety of atmospheric phenomena and variables, and data assimilation provides the bridge between them….

Observations, assimilation and the improvement of global weather prediction

Some results from operational forecasting and ERA-40

Adrian Simmons

(with thanks to the ERA-40 team, Tony Hollingsworth, …..)

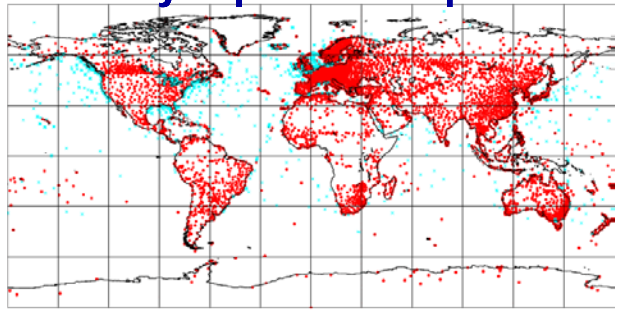
Contents

- **Introduction to data assimilation**
- **ERA-40**
  - evolution of the observing system since 1957
  - evolution of data fits and analysis increments
  - evolution of forecast accuracy
- **Recent improvements in operational forecasts**
- **Inferences from forecast differences**
  - between two operational systems
  - between successive forecasts
- **Predictability as a function of horizontal scale**

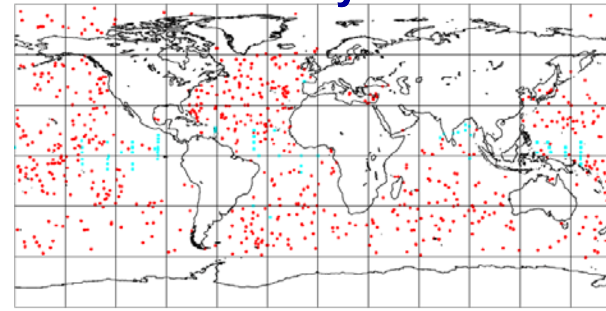
Data coverage

09 – 15 UTC
5 September 2003

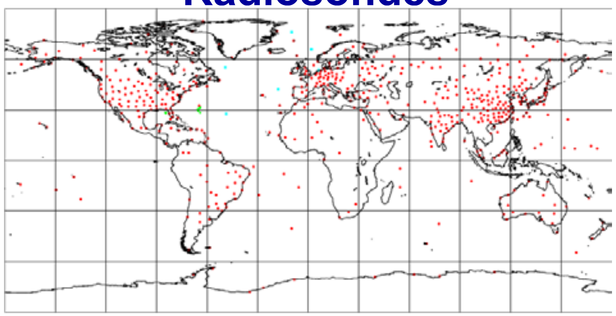
Synops and ships



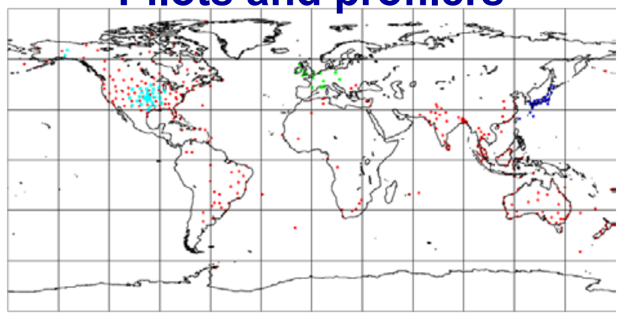
Buoys



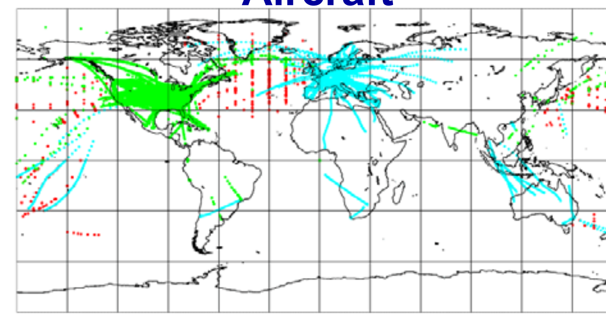
Radiosondes



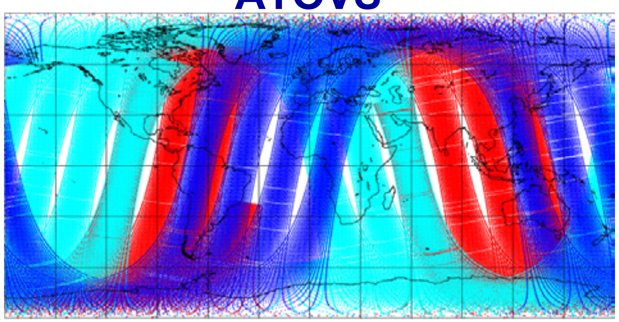
Pilots and profilers



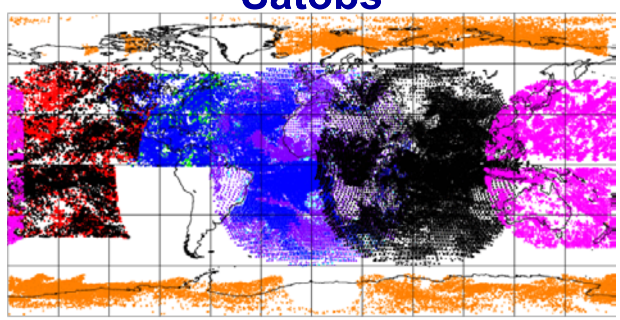
Aircraft



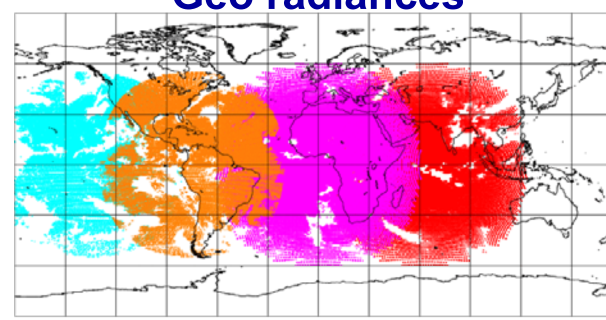
ATOVS



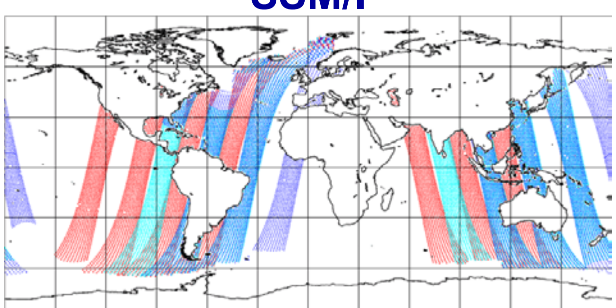
Satobs



Geo radiances

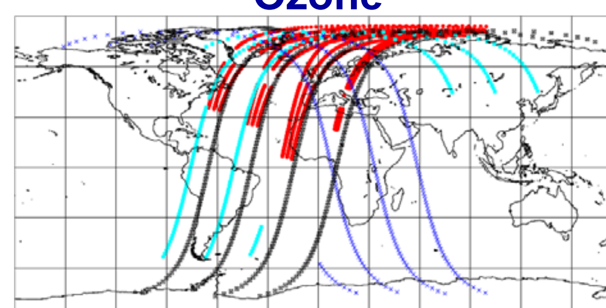


SSM/I

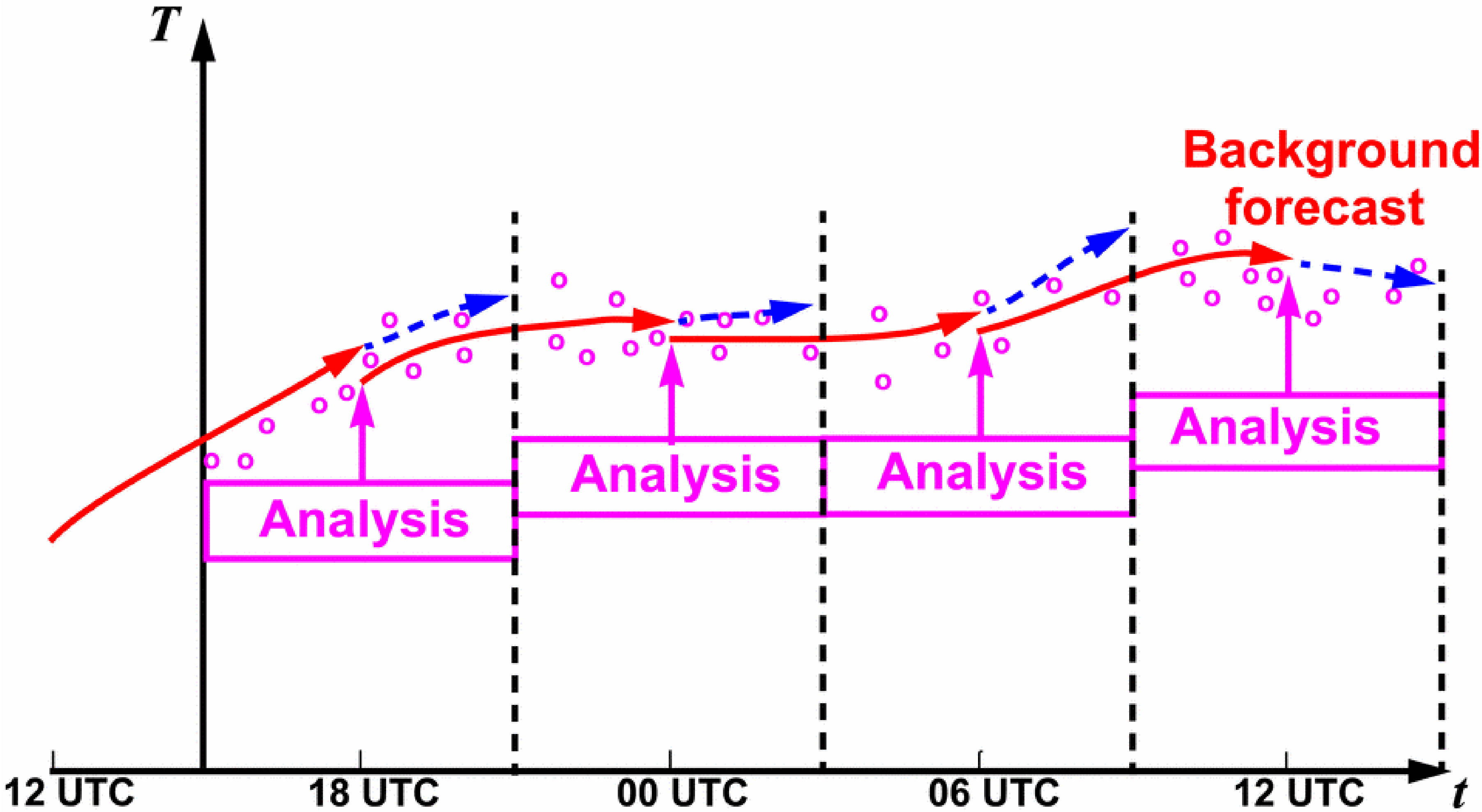


Scatterometer

Ozone



Data Assimilation



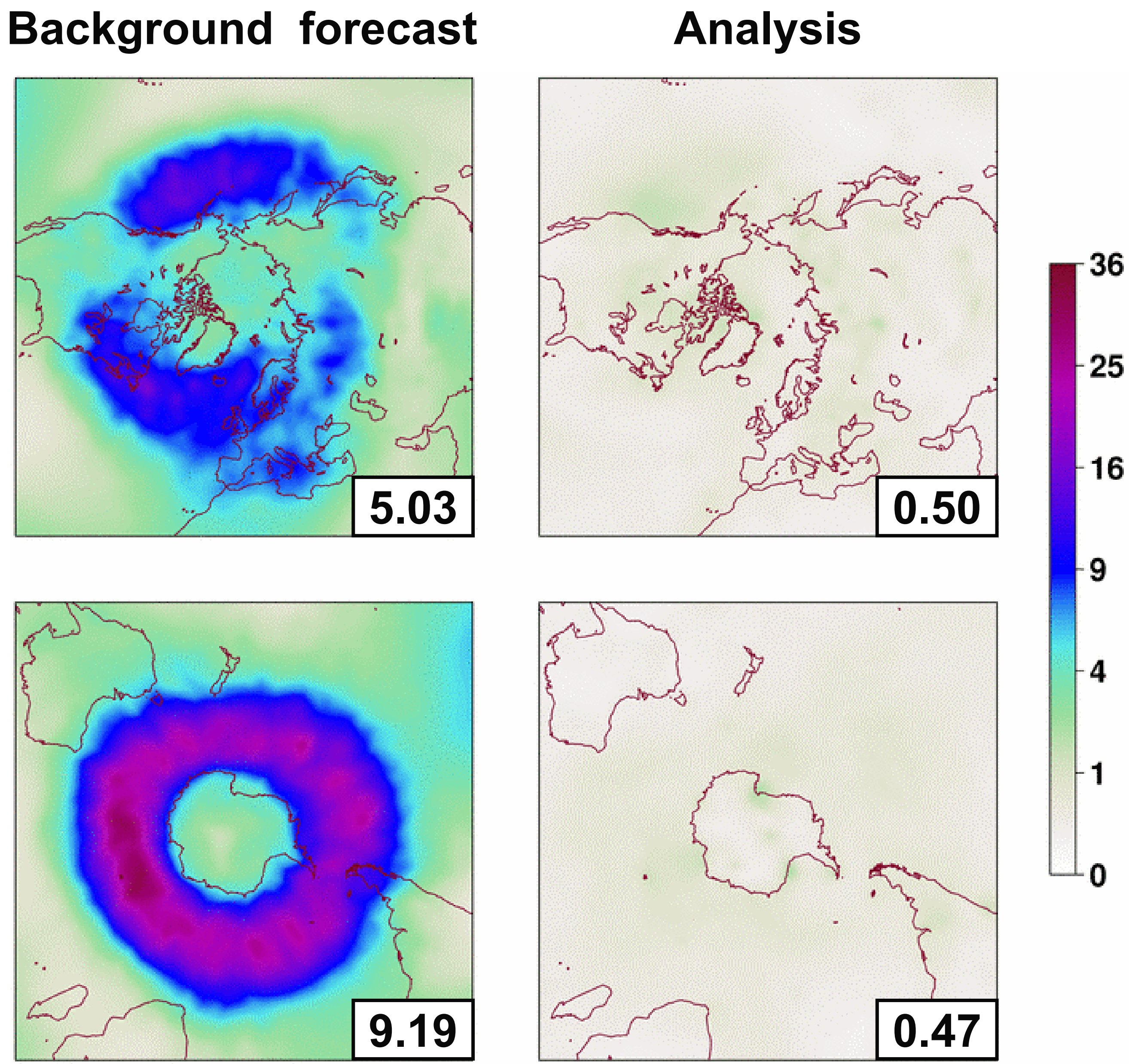
Six-hourly 3D analysis

Mean-square 500hPa height increments

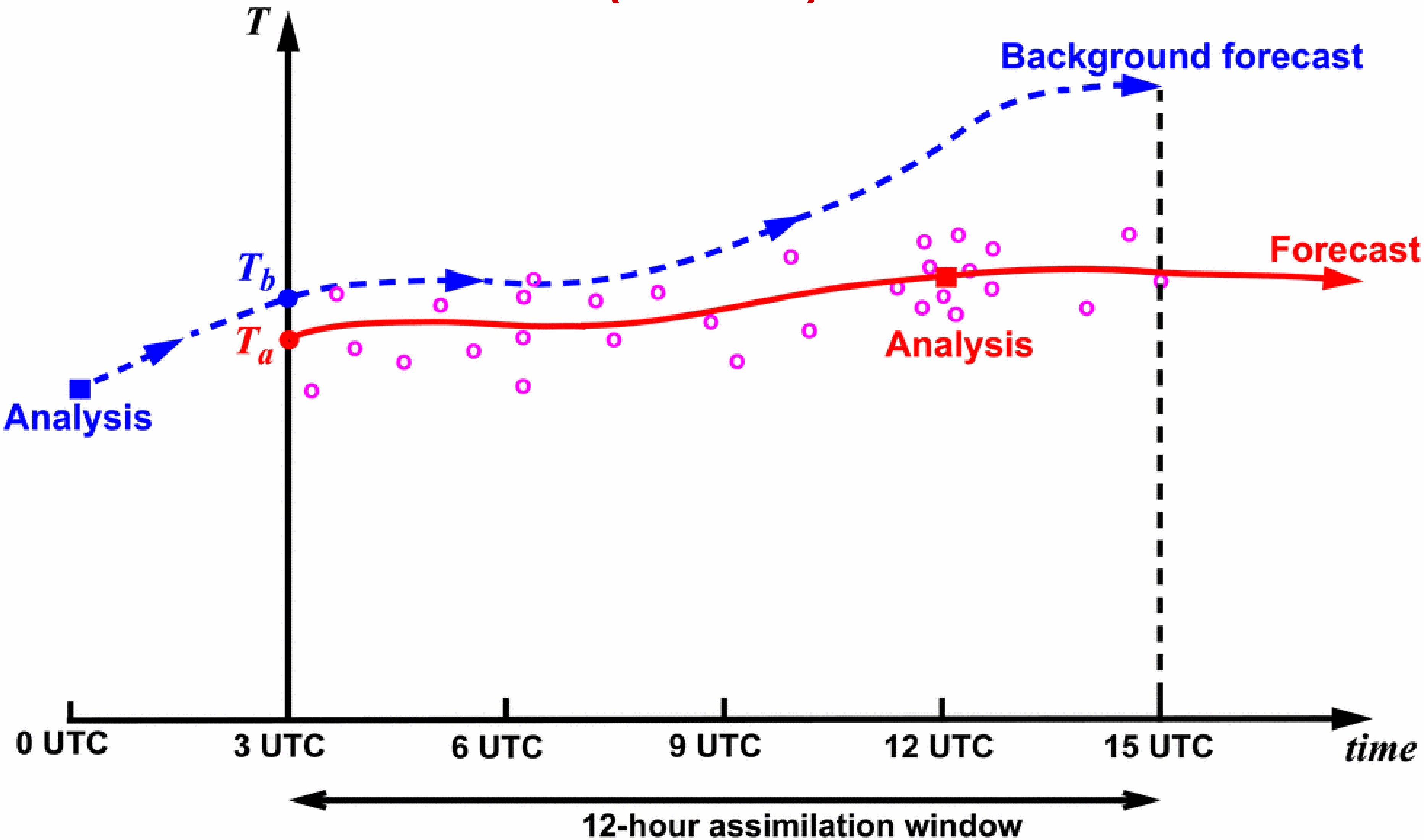
Units: $(dam)^2$

(06UTC – 12UTC)

ERA-40 3D-Var for 2001



Four Dimensional variational data assimilation (4D-Var)



ERA-40 (www.ecmwf.int/research/era)

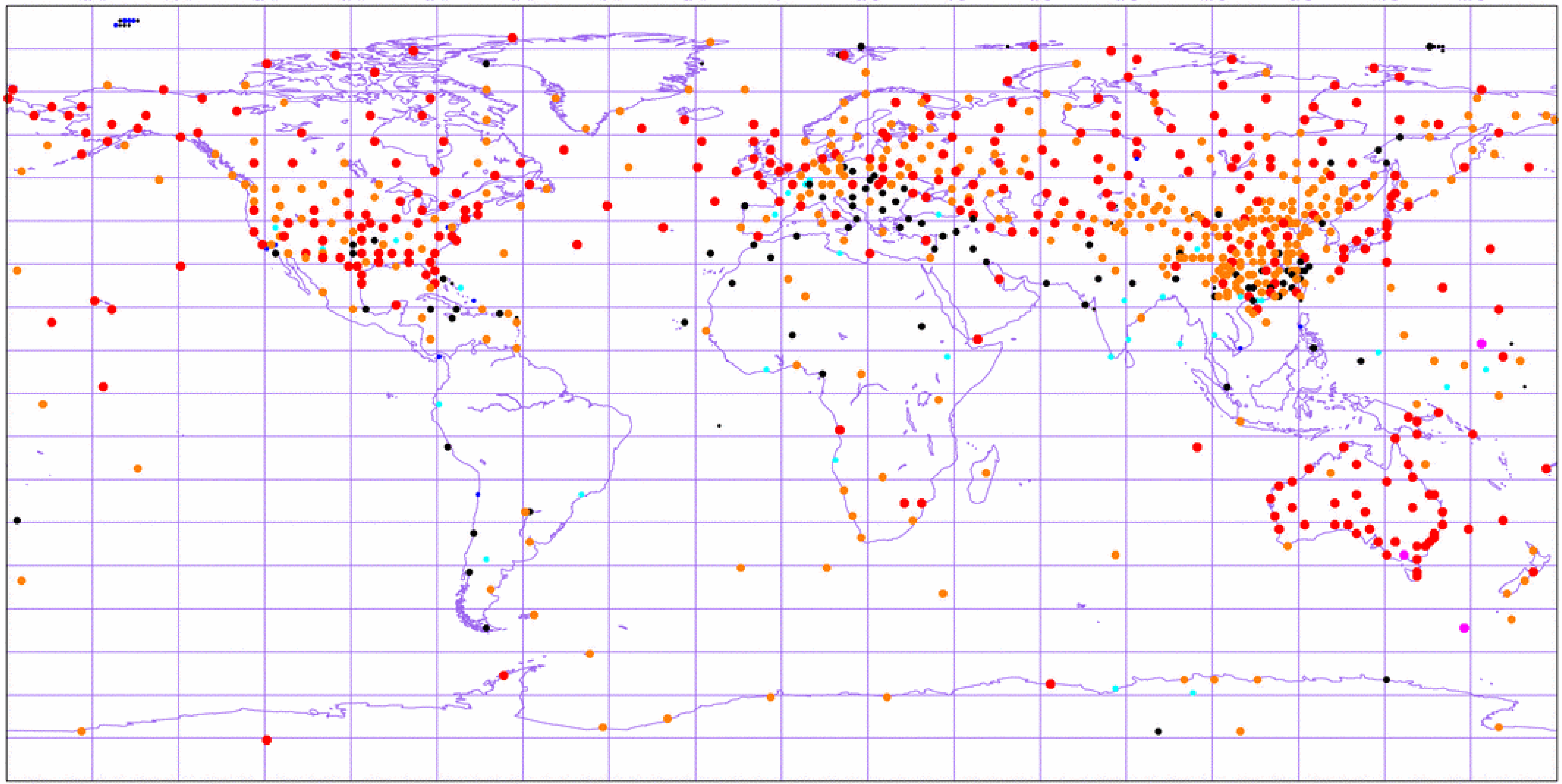
- A re-analysis from September 1957 to August 2002
- Based on cycle 23r4 of ECMWF forecasting system
  - operational from June 2001 to January 2002
- Six-hourly 3D-Var analysis
  - operations uses 12-hourly 4D-Var
- T159 horizontal resolution (~125km grid)
  - operations uses T511 (~39km grid)

ERA-40

- **Produced with considerable external support:**
  - Most of the older observations were supplied by NCAR via NCEP
  - EUMETSAT supplied reprocessed satellite winds
  - SST and sea-ice analyses were produced by the Met Office and NCEP
  - Validation partners provided valuable feedback
  - Practical support from EU, Fujitsu, IAP, JMA, PCMDI, WCRP, GCOS …
- **Production was completed in April 2003**
- **Full set of products is available from ECMWF MARS**
- **Products are (or will be) available from some national data centres**
- **2.5^{o} products are available on a public data server (http://data.ecmwf.int/data)**

Radiosonde coverage for March 1958

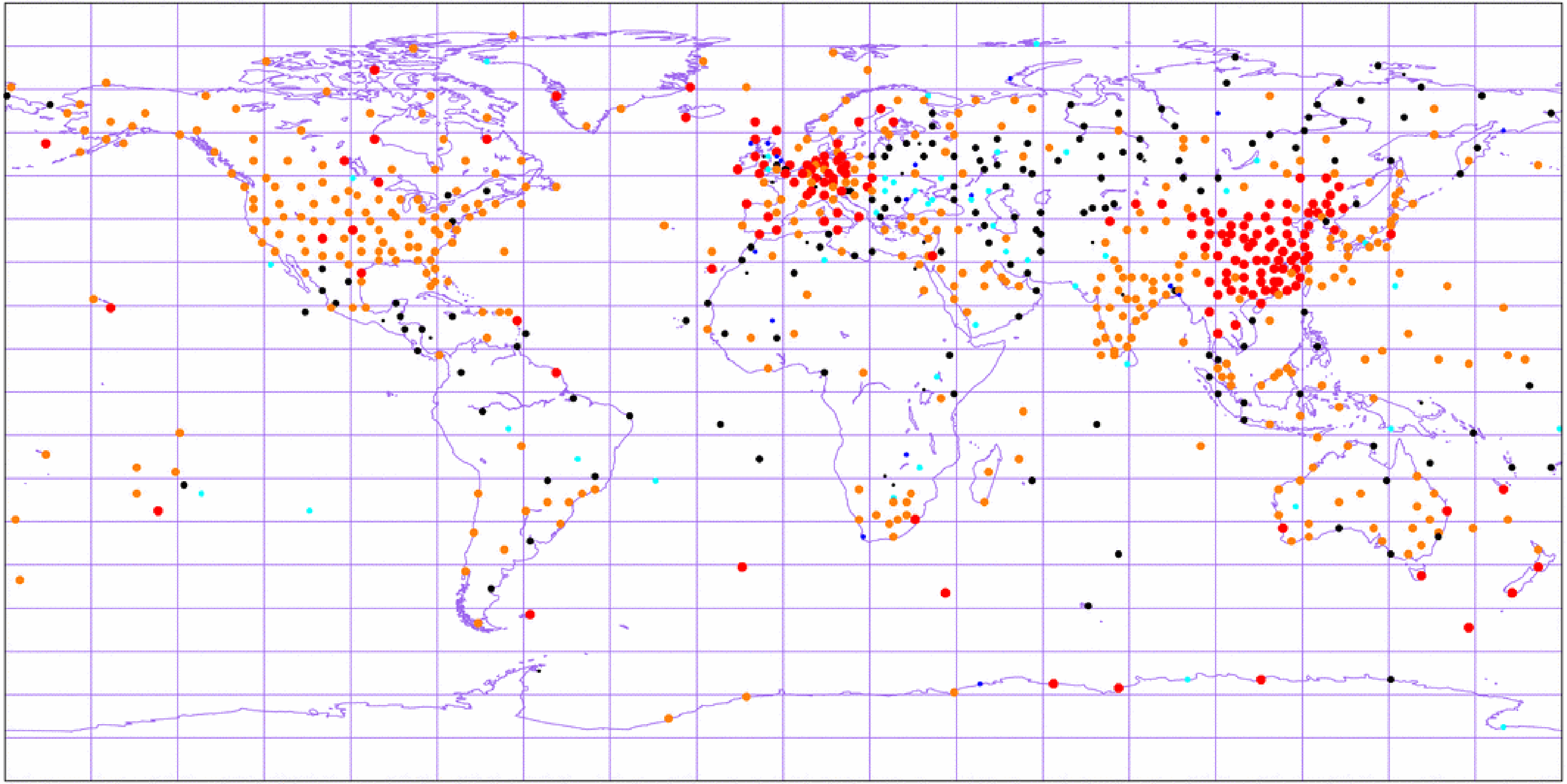
45478 reports



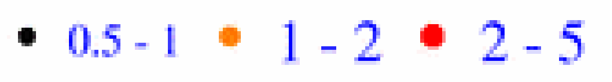
Average number of soundings per day: • 0.5 - 1 • 1 - 2 • 2 - 5

Radiosonde coverage for March 1997

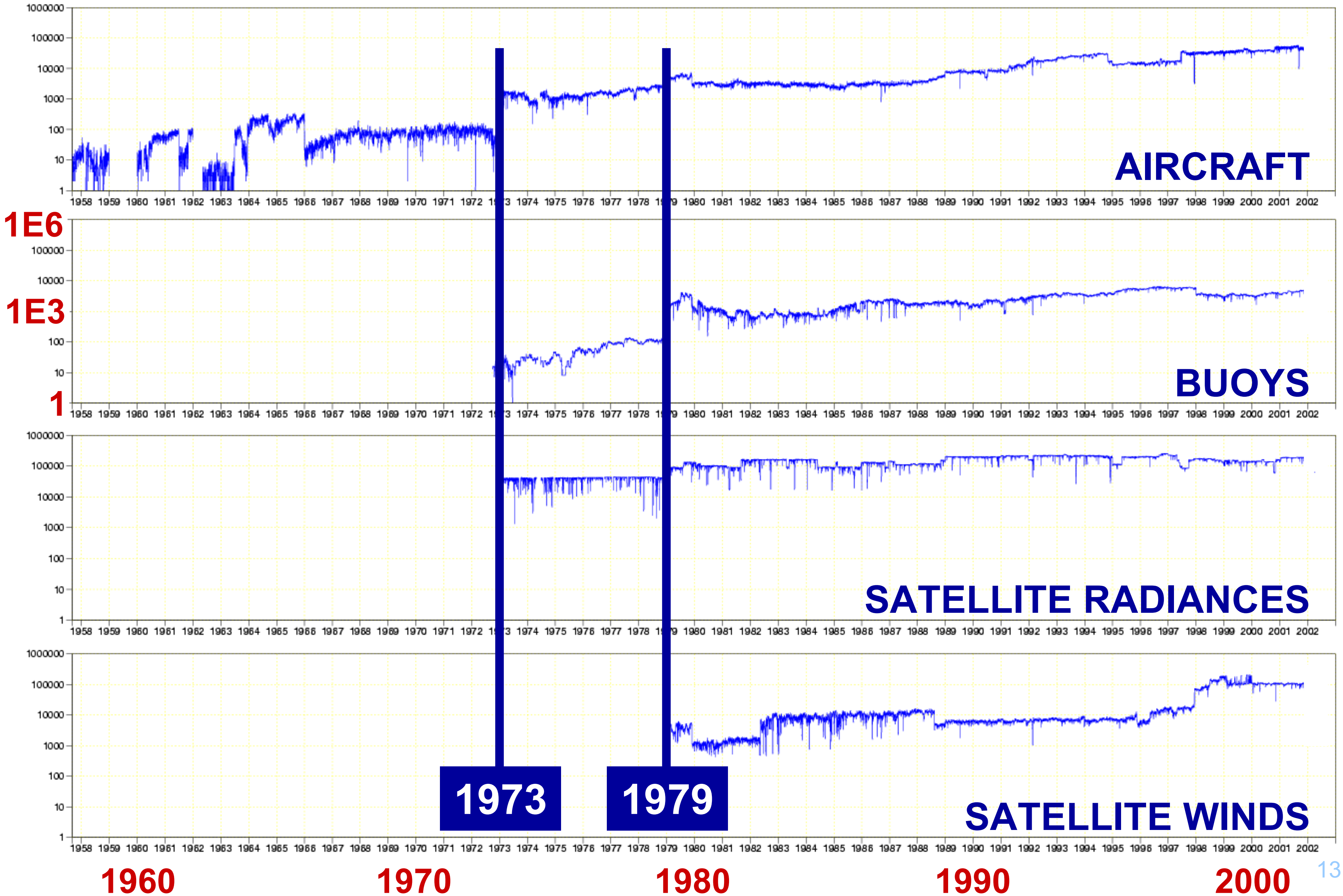
36312 reports



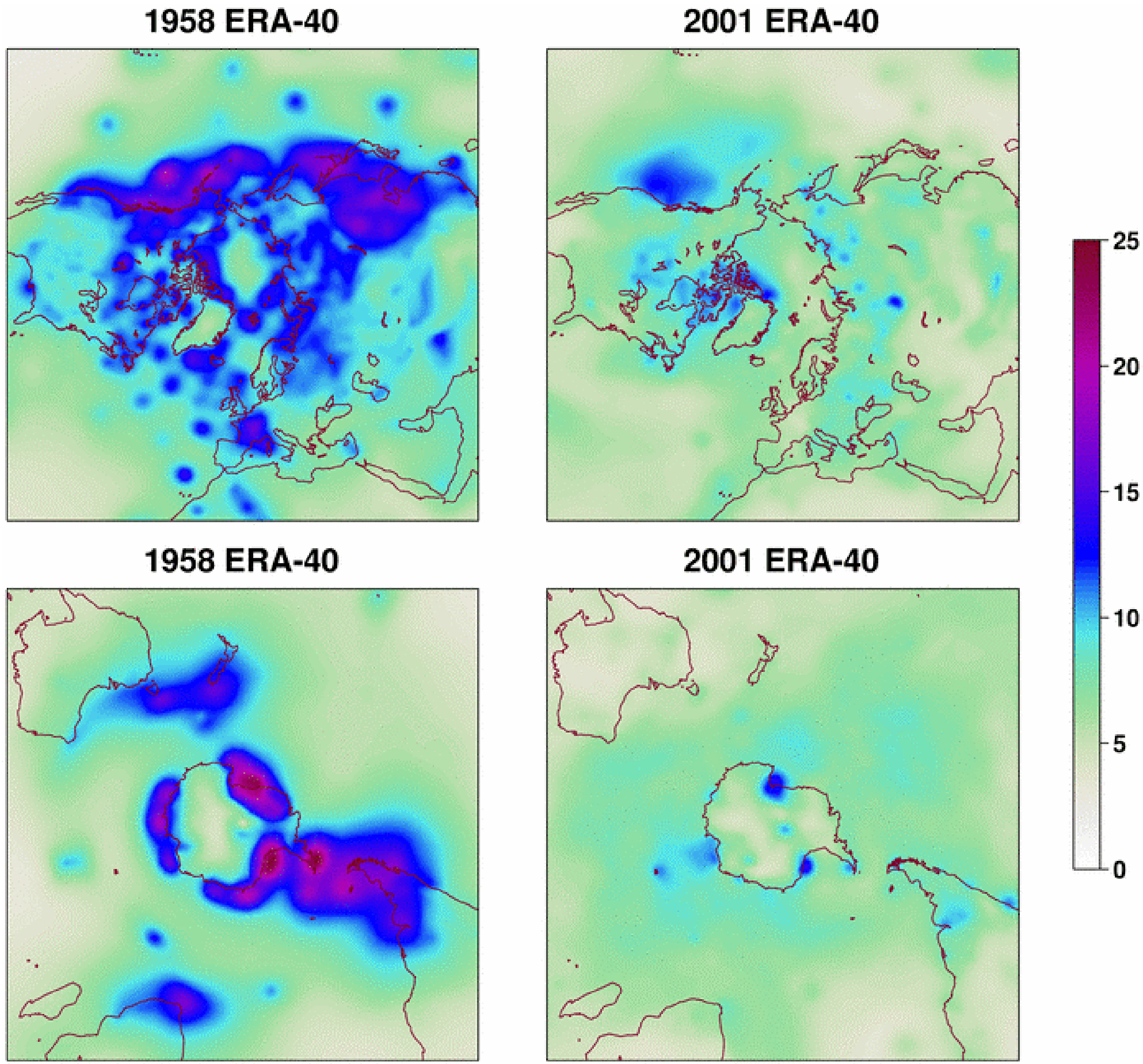
Average number of soundings per day:



Counts of observations accepted by ERA-40 system



R.m.s. 500hPa height increment (m) at 12UTC from ERA-40

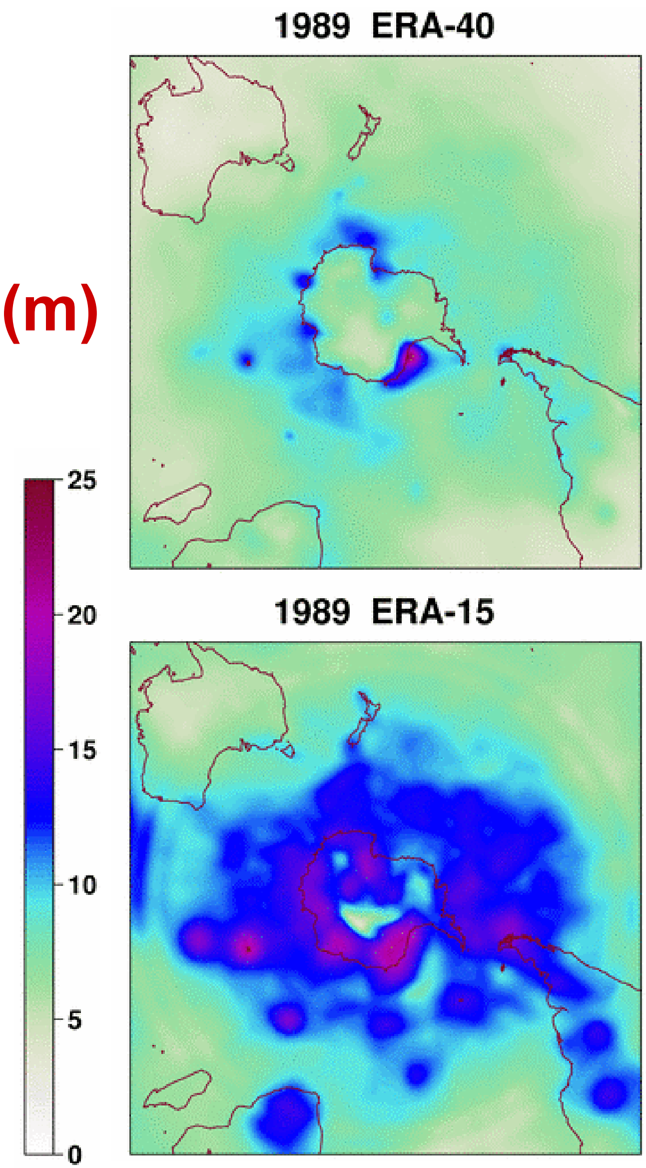


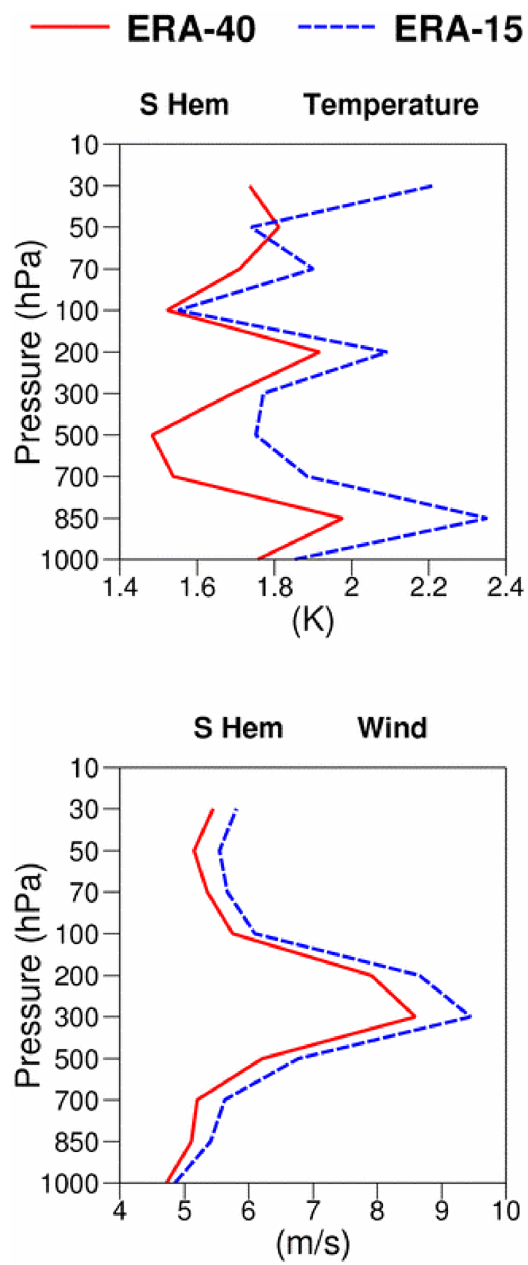
RMS(AN-BG)

AN=analysis

BG=6h background forecast

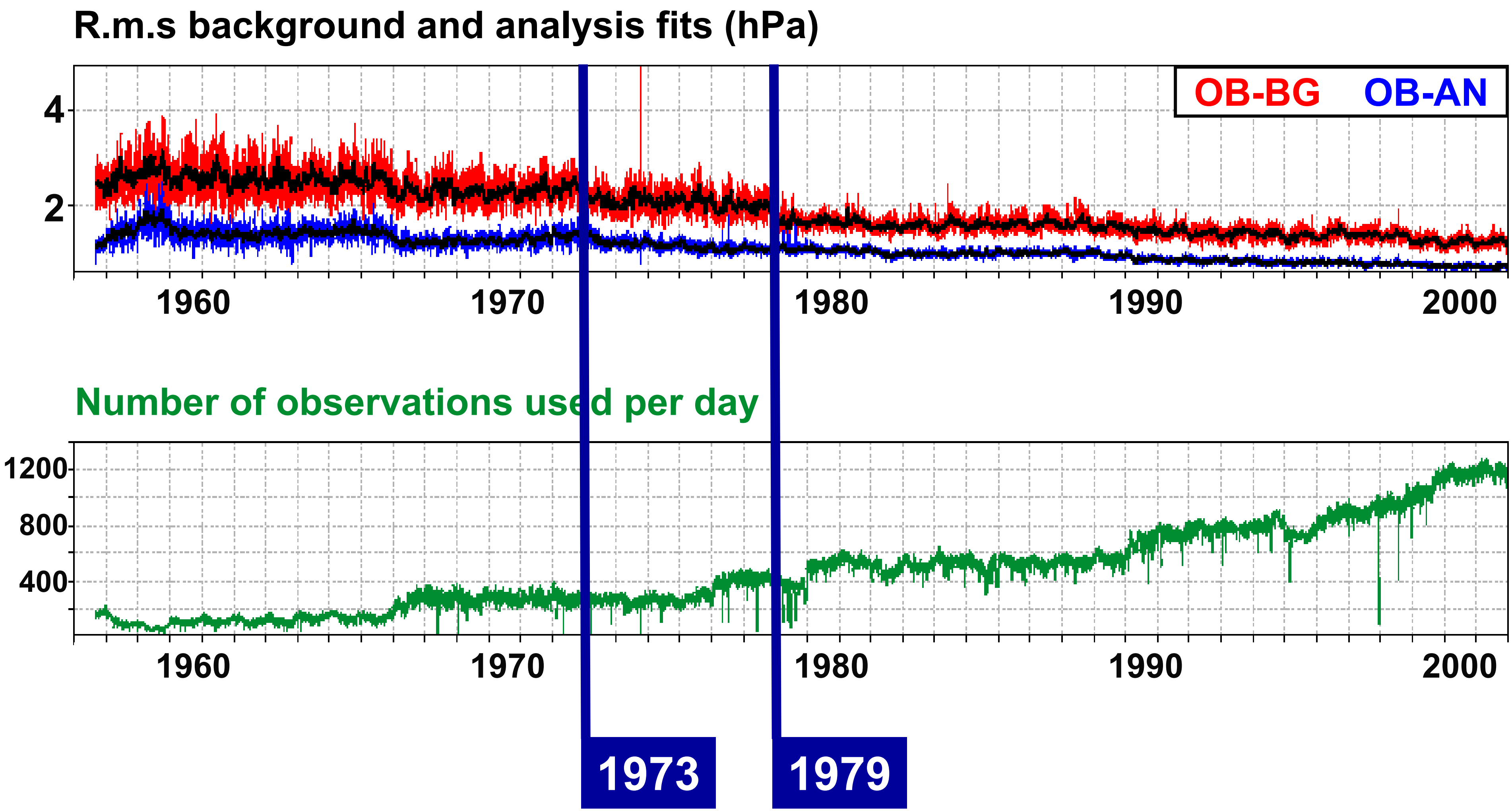
R.m.s. 500hPa height increment (m) at 12UTC



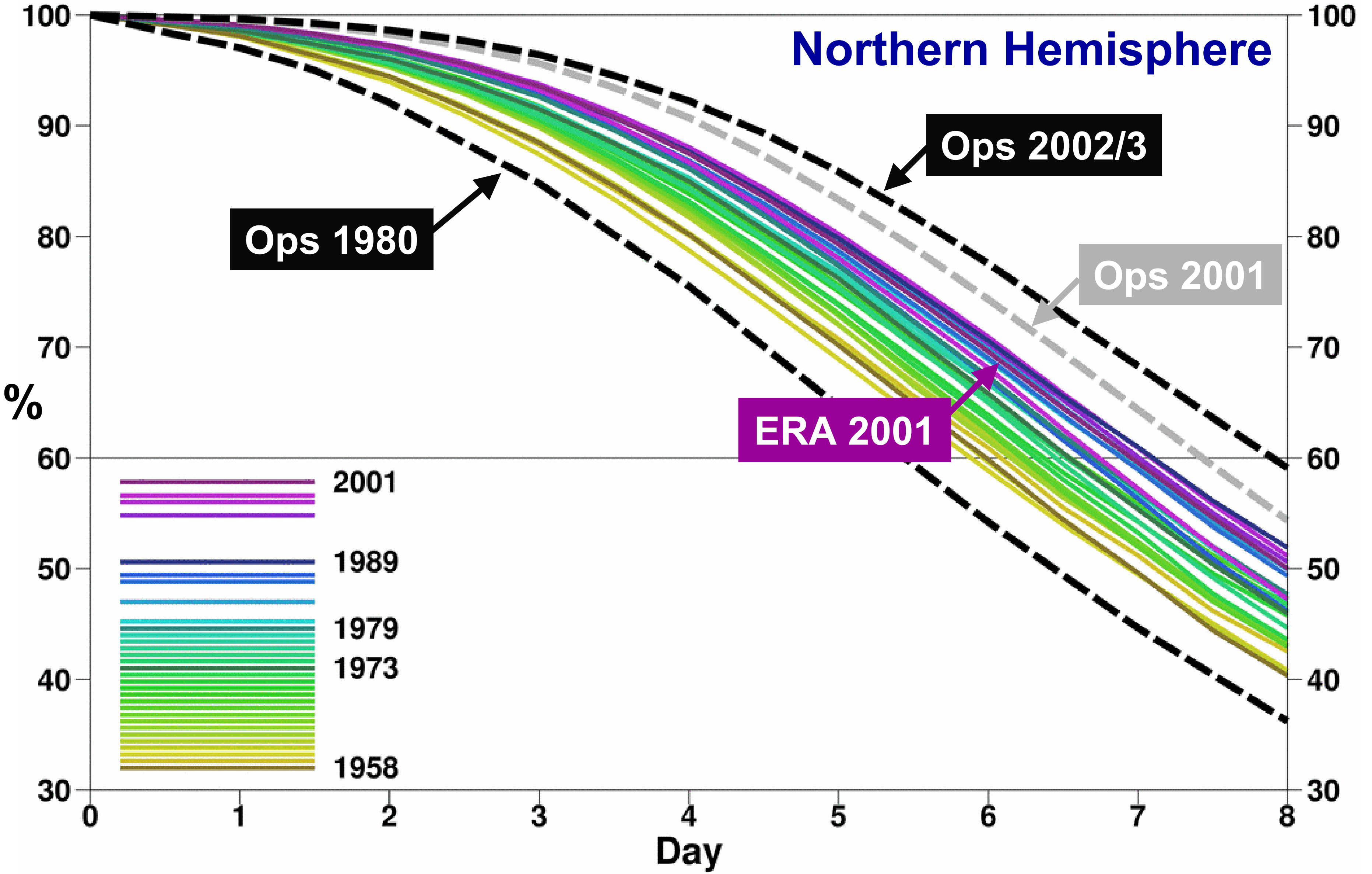


24-hour 12UTC forecast error vs sondes

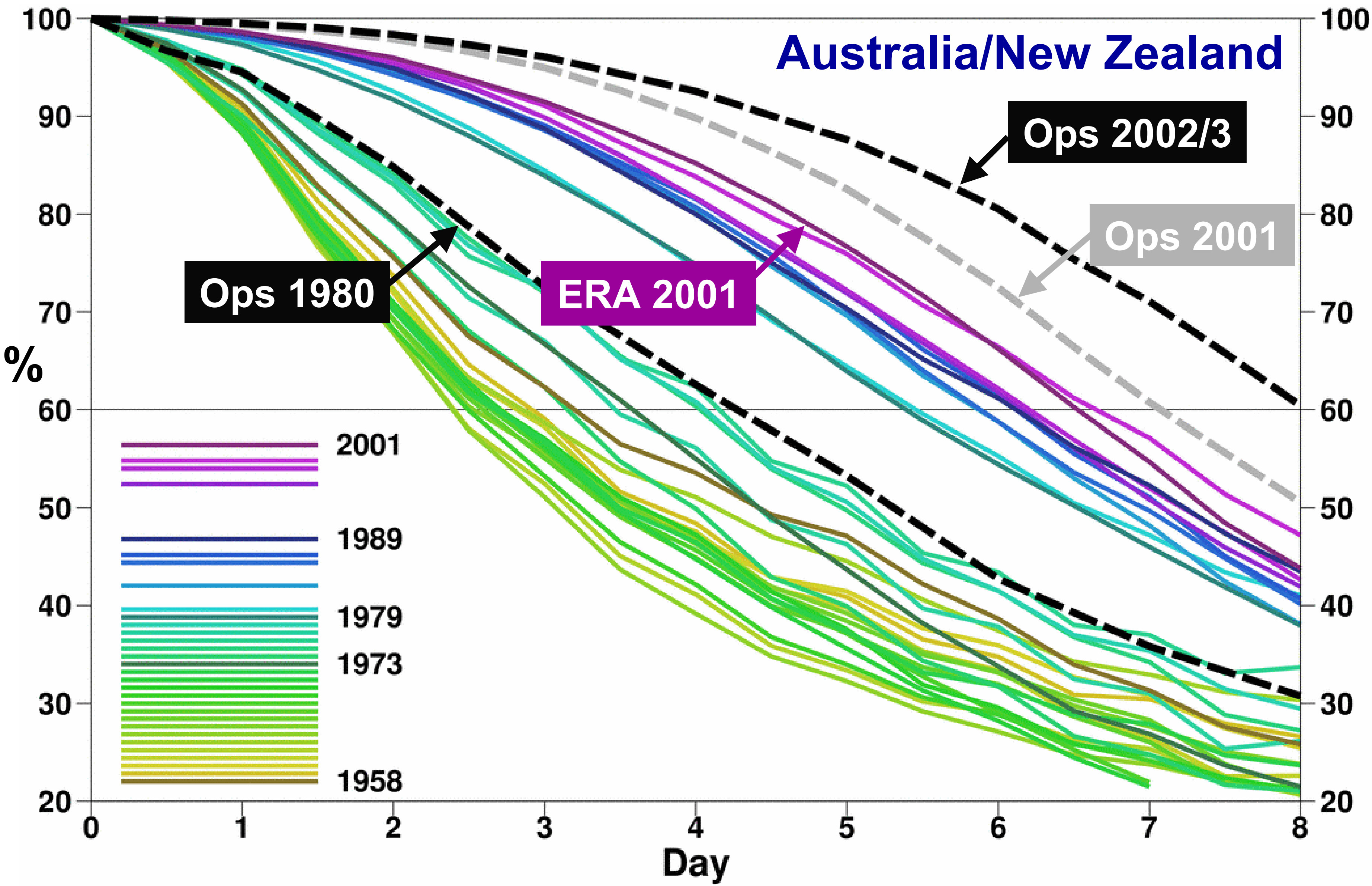
Use of SYNOP surface pressure observations over the extratropical southern hemisphere in ERA-40



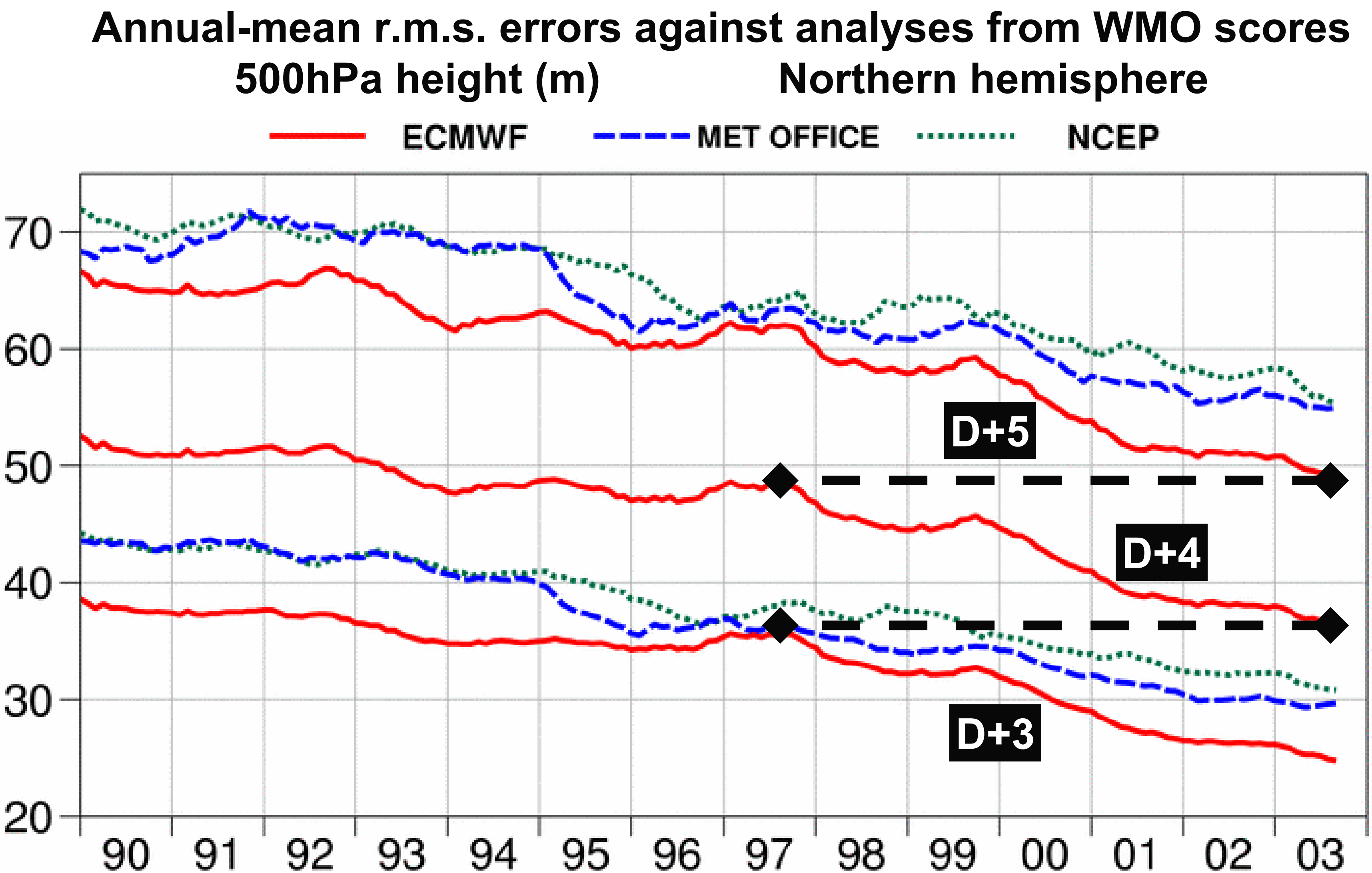
Anomaly correlations of 500hPa height forecasts



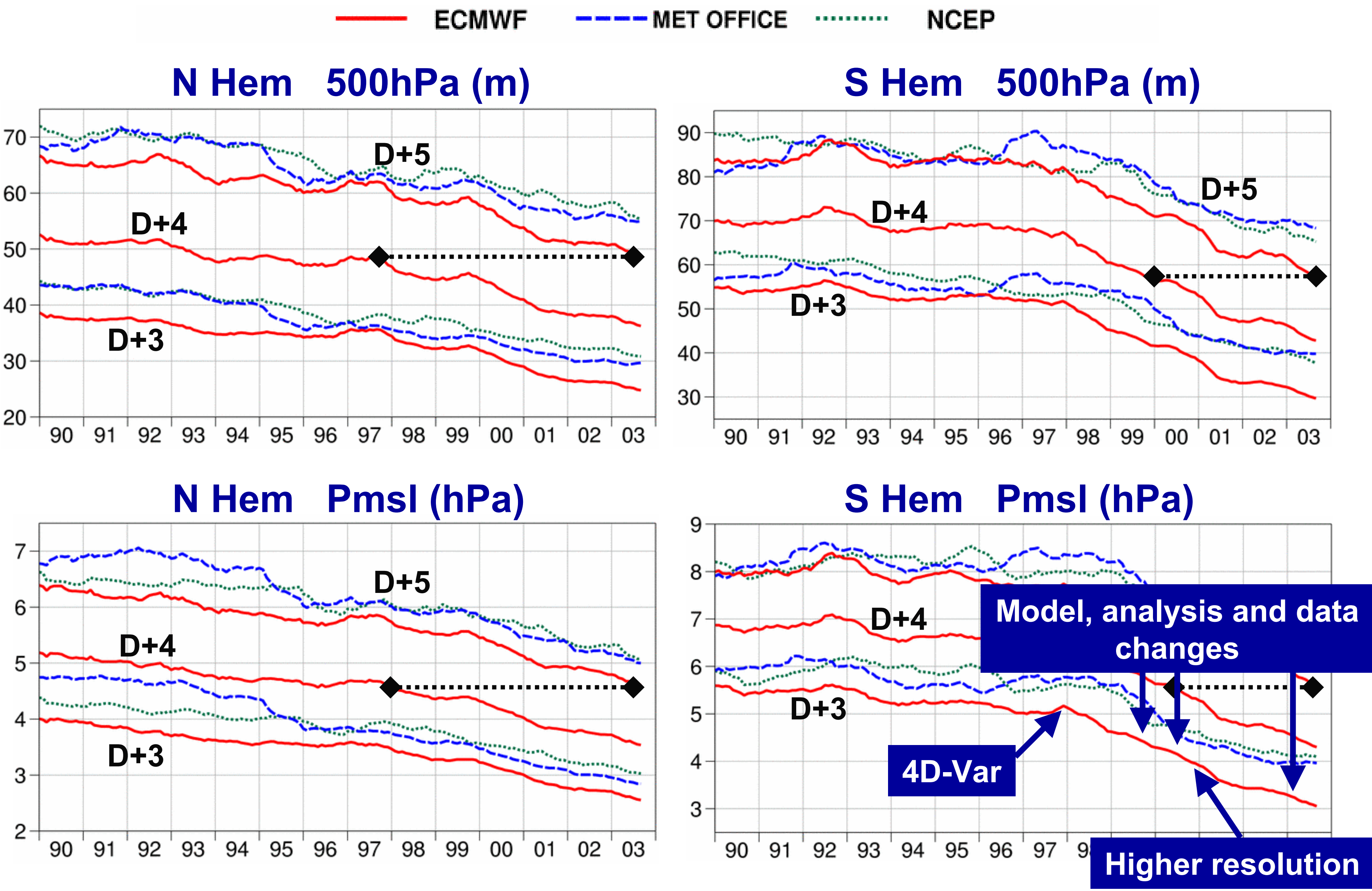
Anomaly correlations of 500hPa height forecasts



Recent improvement in the accuracy of forecasts

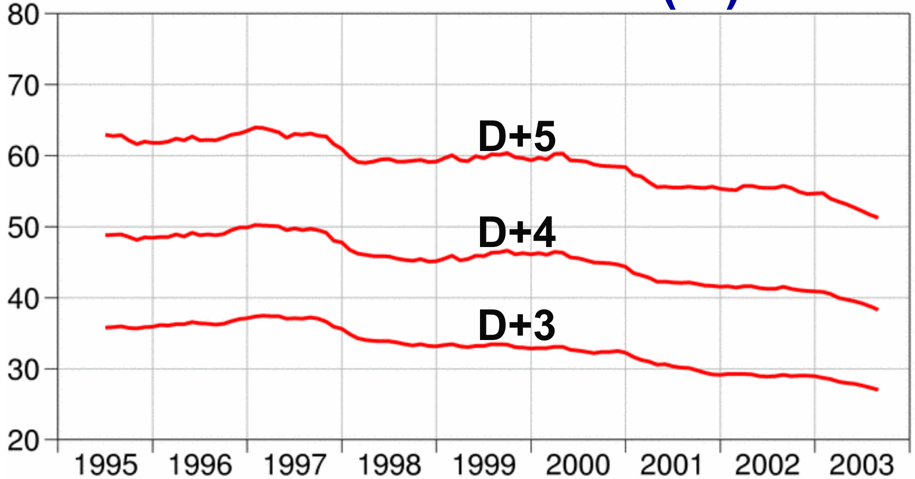


Annual-mean r.m.s. errors against analyses from WMO scores

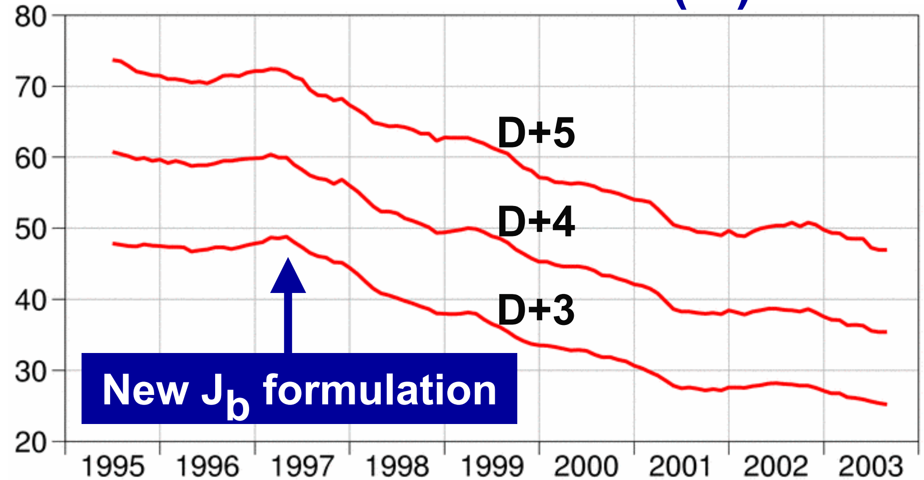


Annual-mean r.m.s. errors against radiosondes from WMO scores

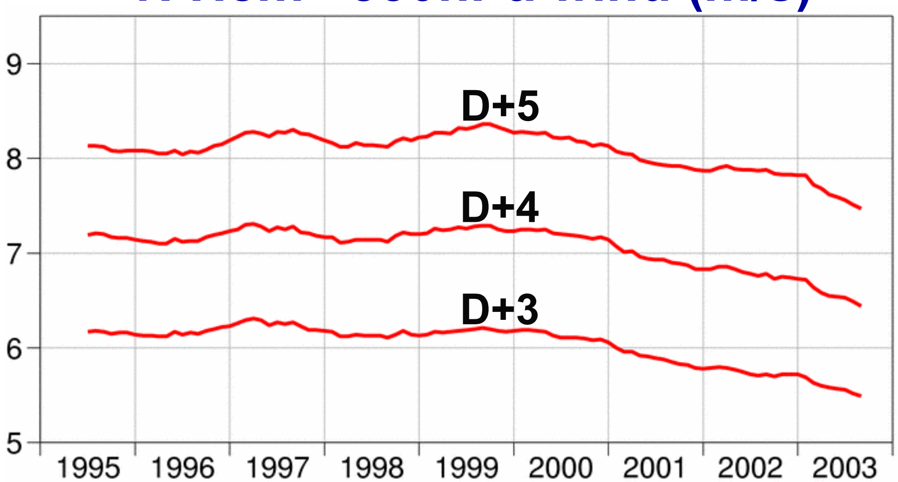
N Hem 500hPa (m)



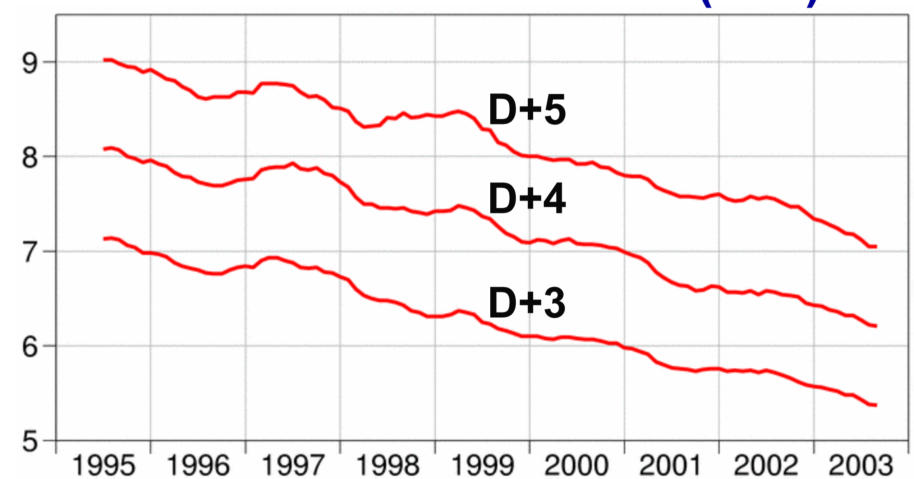
S Hem 500hPa (m)



N Hem 850hPa wind (m/s)



S Hem 850hPa wind (m/s)



Some aspects of the differences:

between ECMWF and Met Office analyses and forecasts

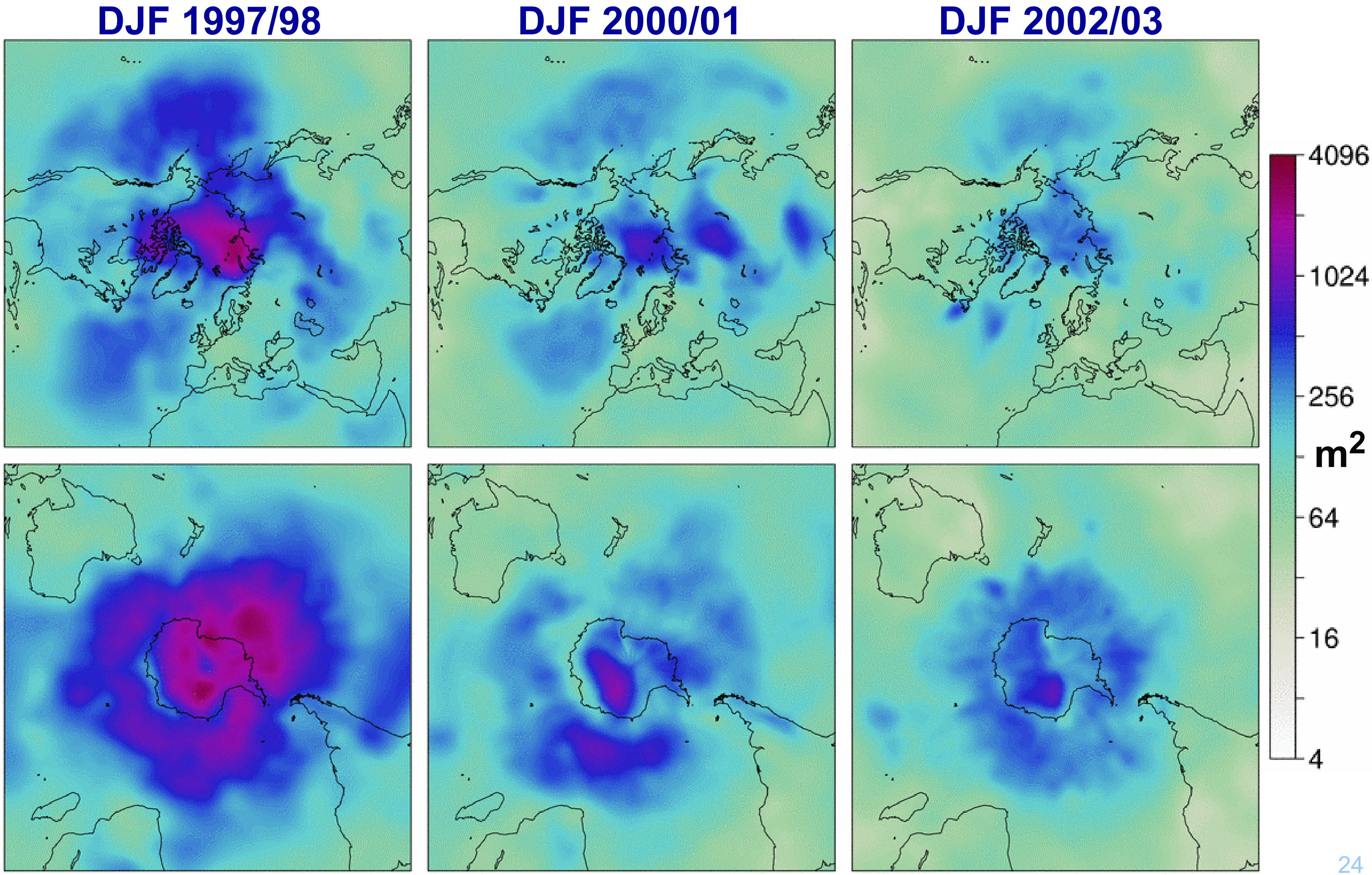
between successive ECMWF forecasts

R.m.s. differences (m) between ECMWF and Met Office 500hPa height analyses

December – February

	N Hem	S Hem
1997/98	14.1	21.2
1998/99	15.6	21.4
1999/00	12.2	16.3
2000/01	9.8	11.6
2001/02	10.1	11.5
2002/03	7.8	10.2

Mean square difference between ECMWF and Met Office 500hPa height analyses

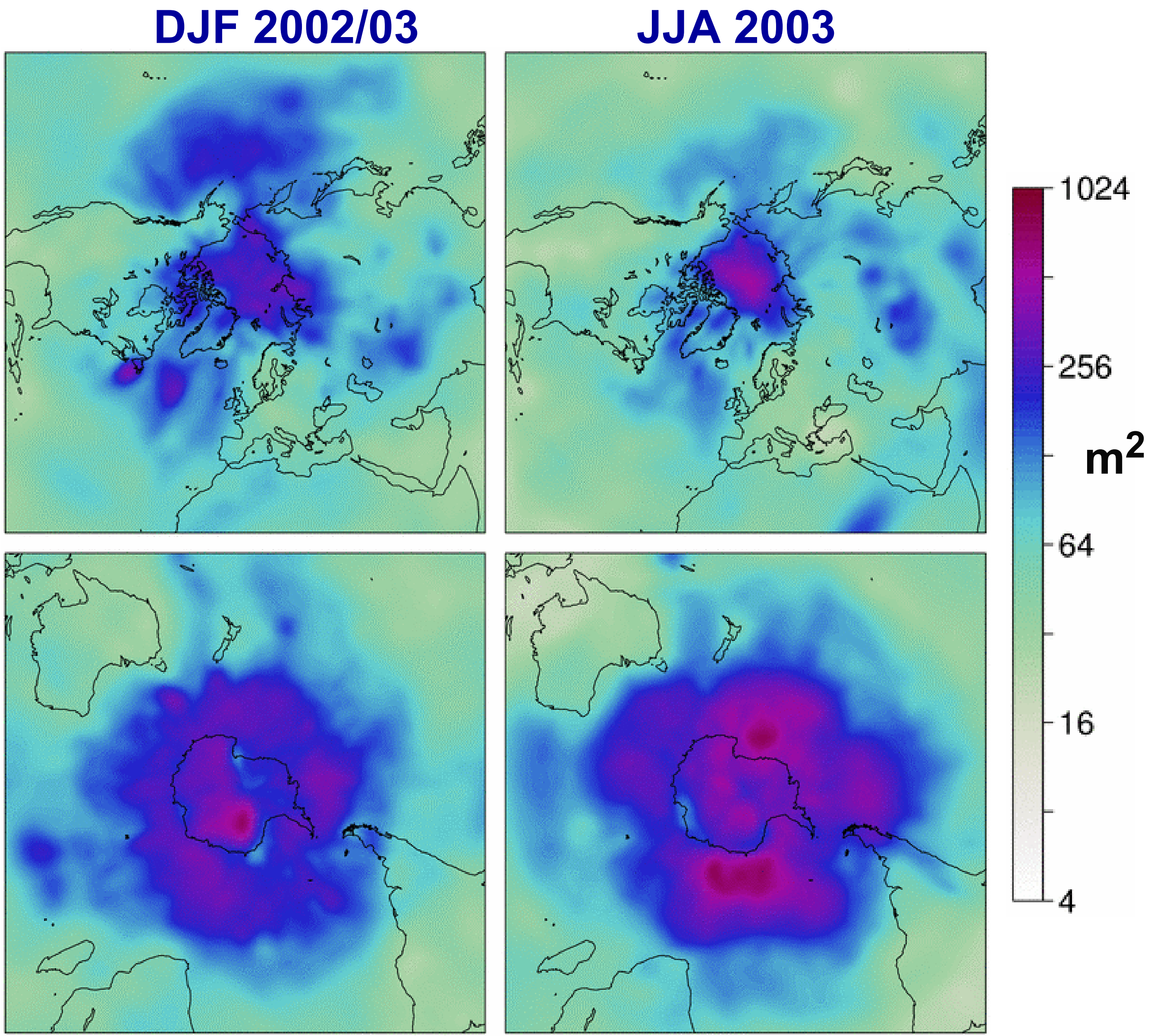


R.m.s. differences (m) between ECMWF and Met Office 500hPa height analyses

June – August

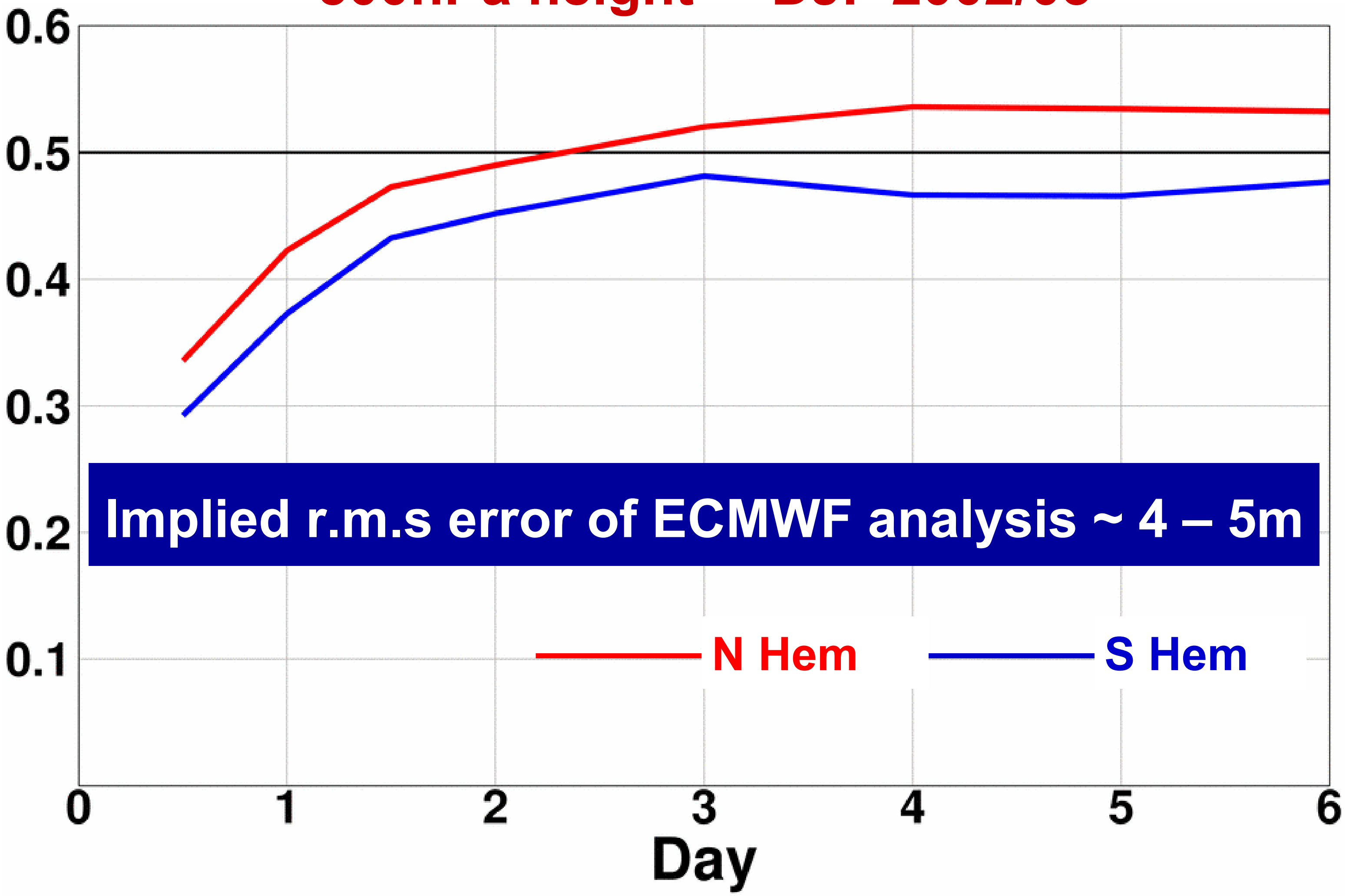
	N Hem	S Hem
1998	10.6	29.7
1999	10.3	27.4
2000	8.9	17.0
2001	8.2	14.2
2002	8.3	12.3
2003	5.5	10.7

Mean square difference between ECMWF and Met Office 500hPa height analyses



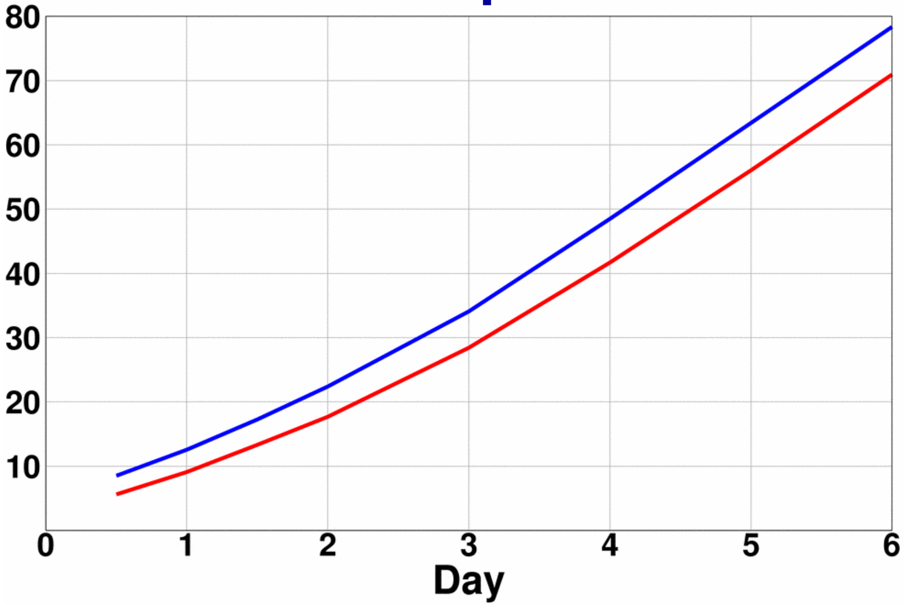
Correlation between ECMWF forecast errors and Met Office forecast errors

500hPa height DJF 2002/03

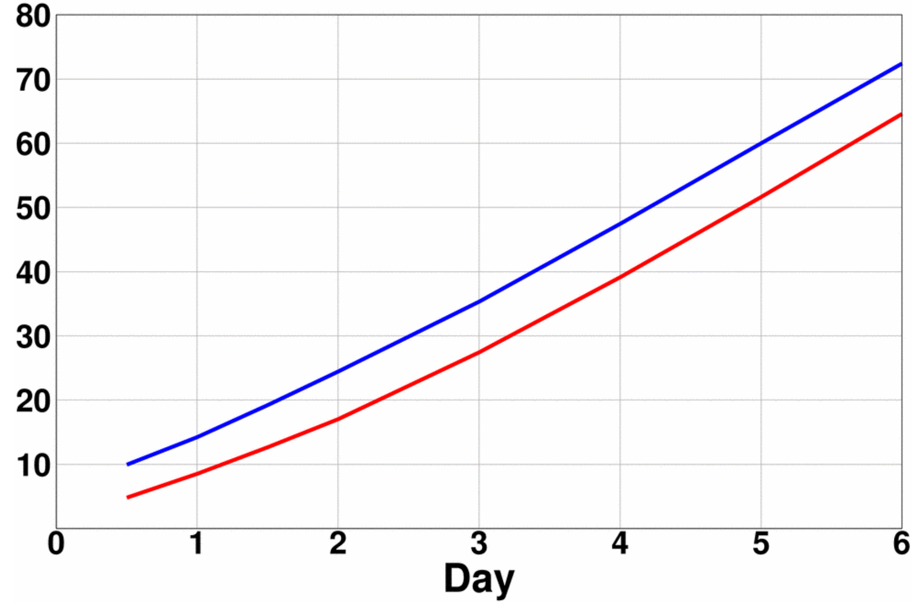


R.m.s. 500hPa height forecast errors (m)

Northern hemisphere



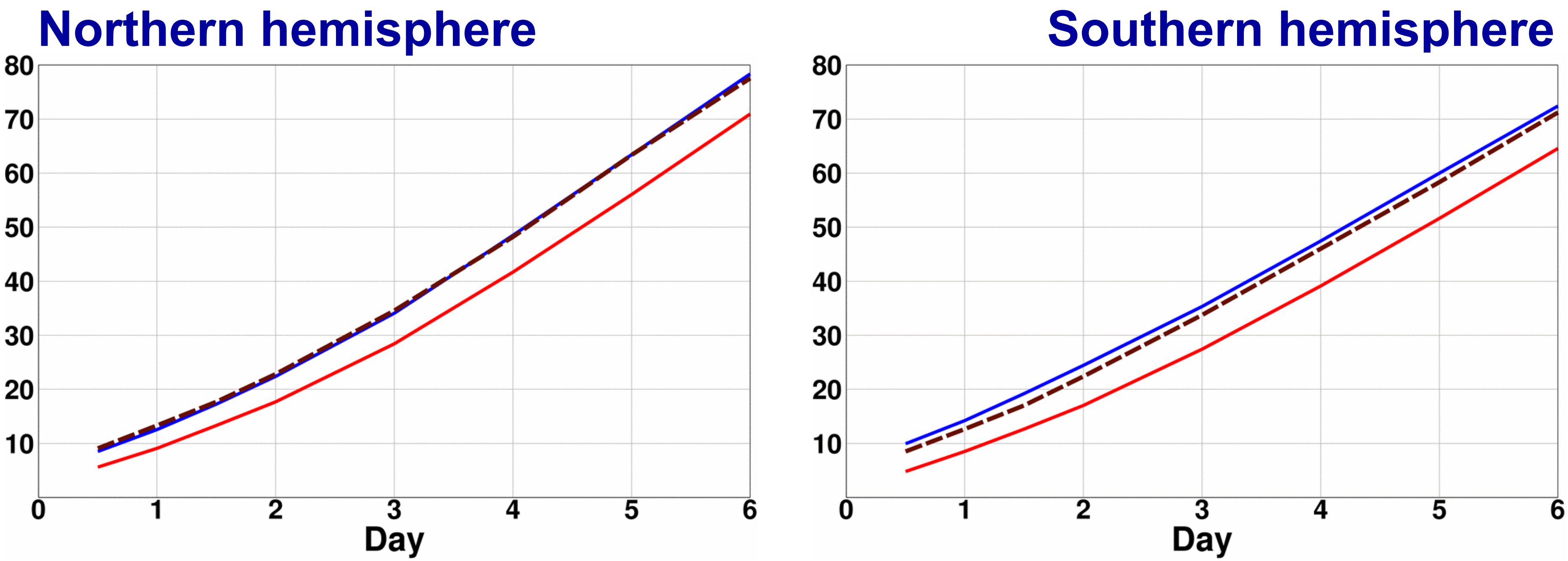
Southern hemisphere



R.m.s ECMWF errors

R.m.s. Met Office errors

R.m.s. 500hPa height forecast errors (m)

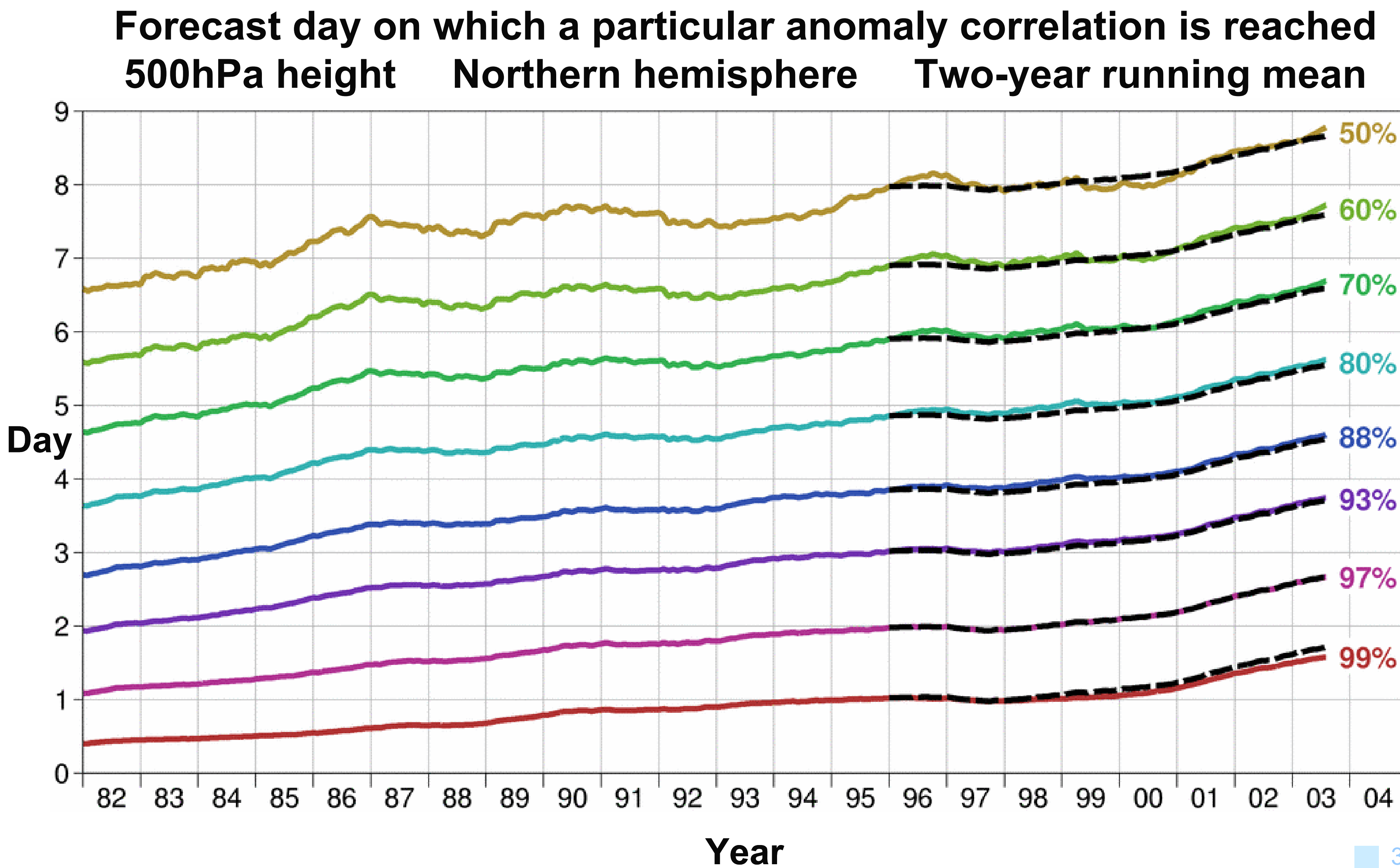


R.m.s ECMWF errors

R.m.s. Met Office errors

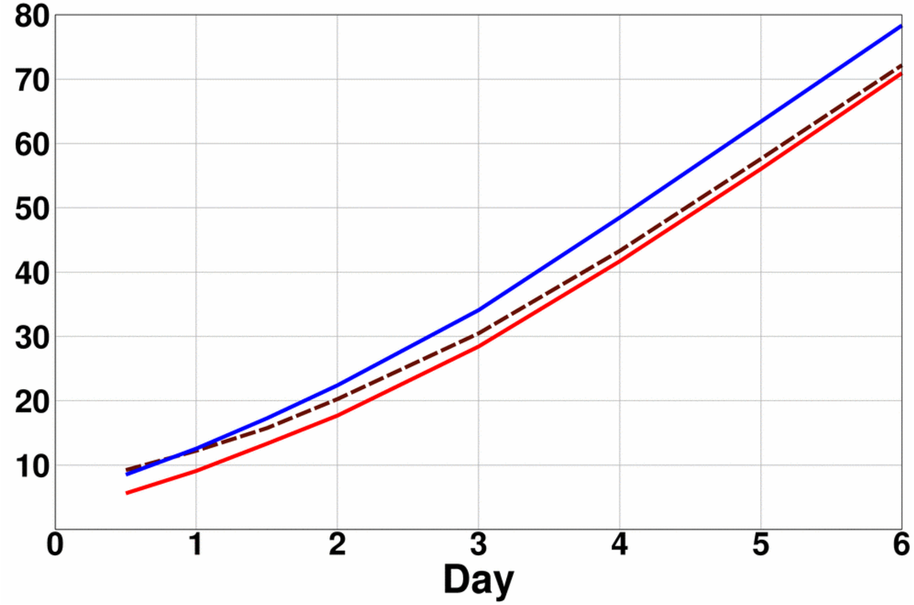
R.m.s. ECMWF errors of 12-hour-old forecasts

Tony Hollingsworth's valediction:

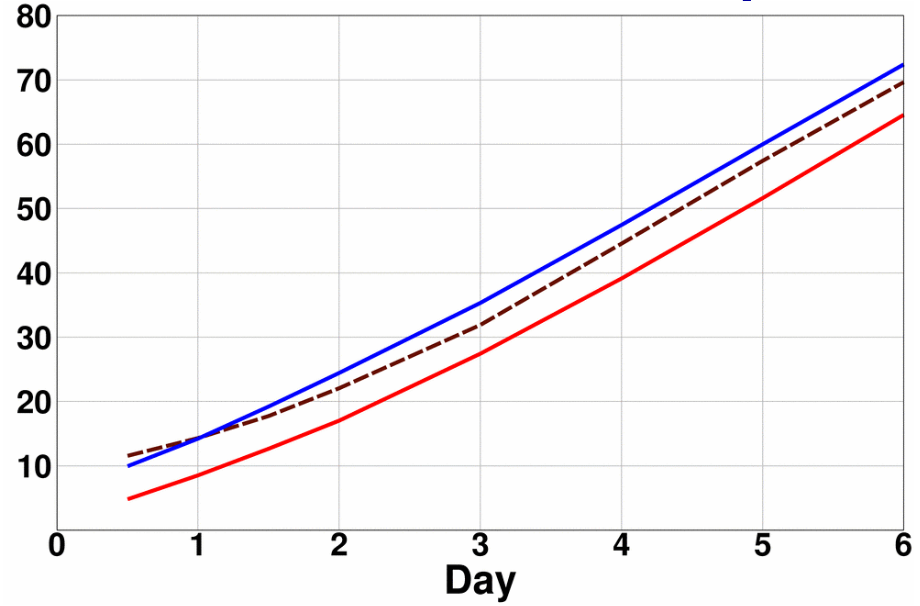


R.m.s. 500hPa height forecast errors (m)

Northern hemisphere



Southern hemisphere

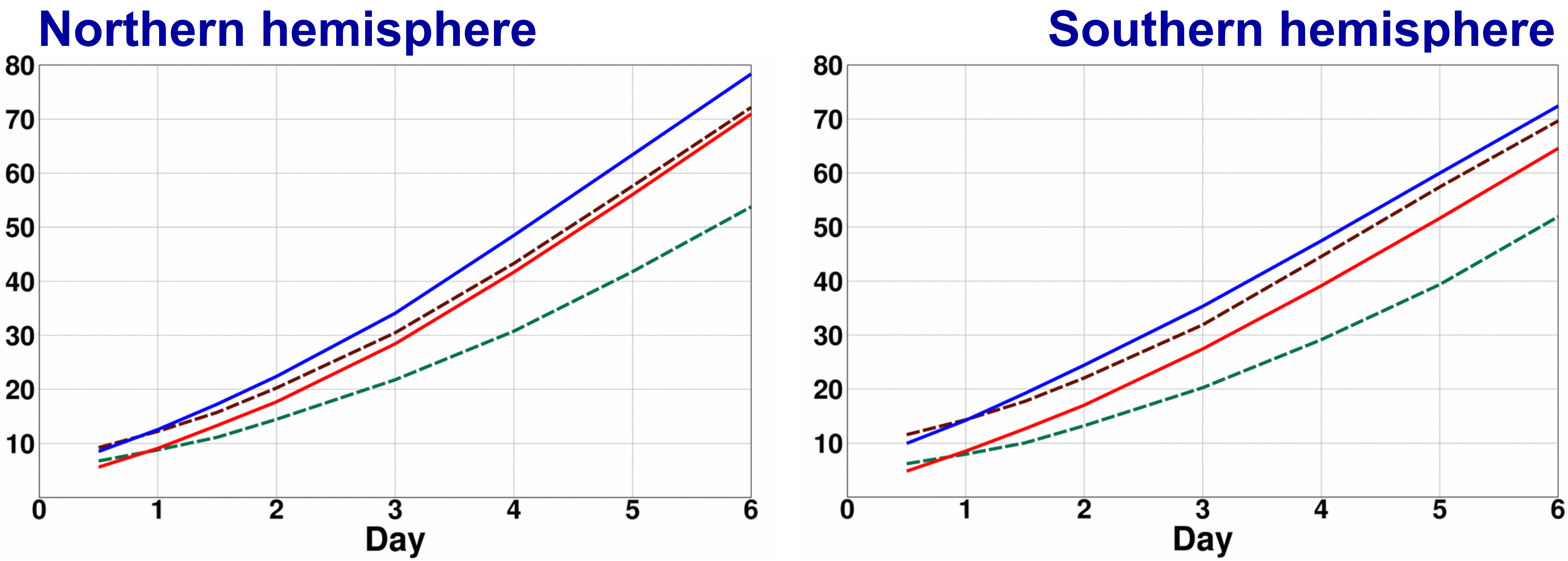


R.m.s ECMWF errors

R.m.s. Met Office errors

R.m.s. differences: ECMWF – Met Office

R.m.s. 500hPa height forecast errors (m)



R.m.s ECMWF errors

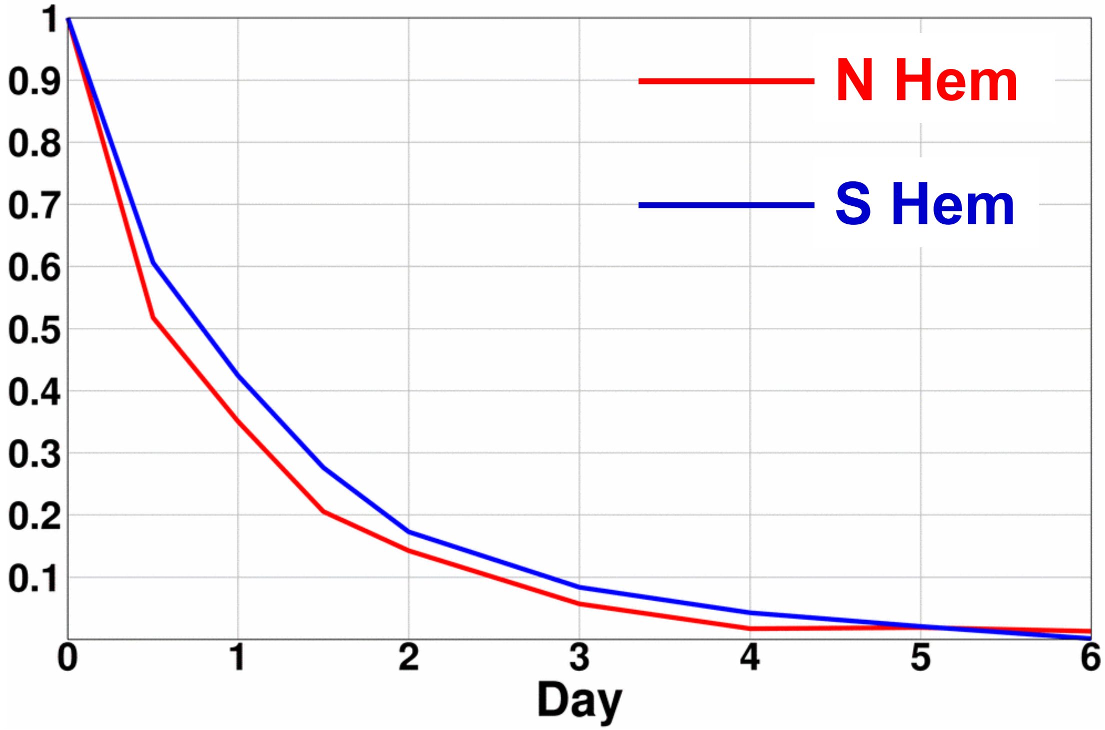
R.m.s. Met Office errors

R.m.s. differences: ECMWF – Met Office

R.m.s. differences: ECMWF - (ECMWF - 12h)

Correlation between differences in 500hPa height forecasts and differences in verifying analyses

(ECMWF – Met Office)

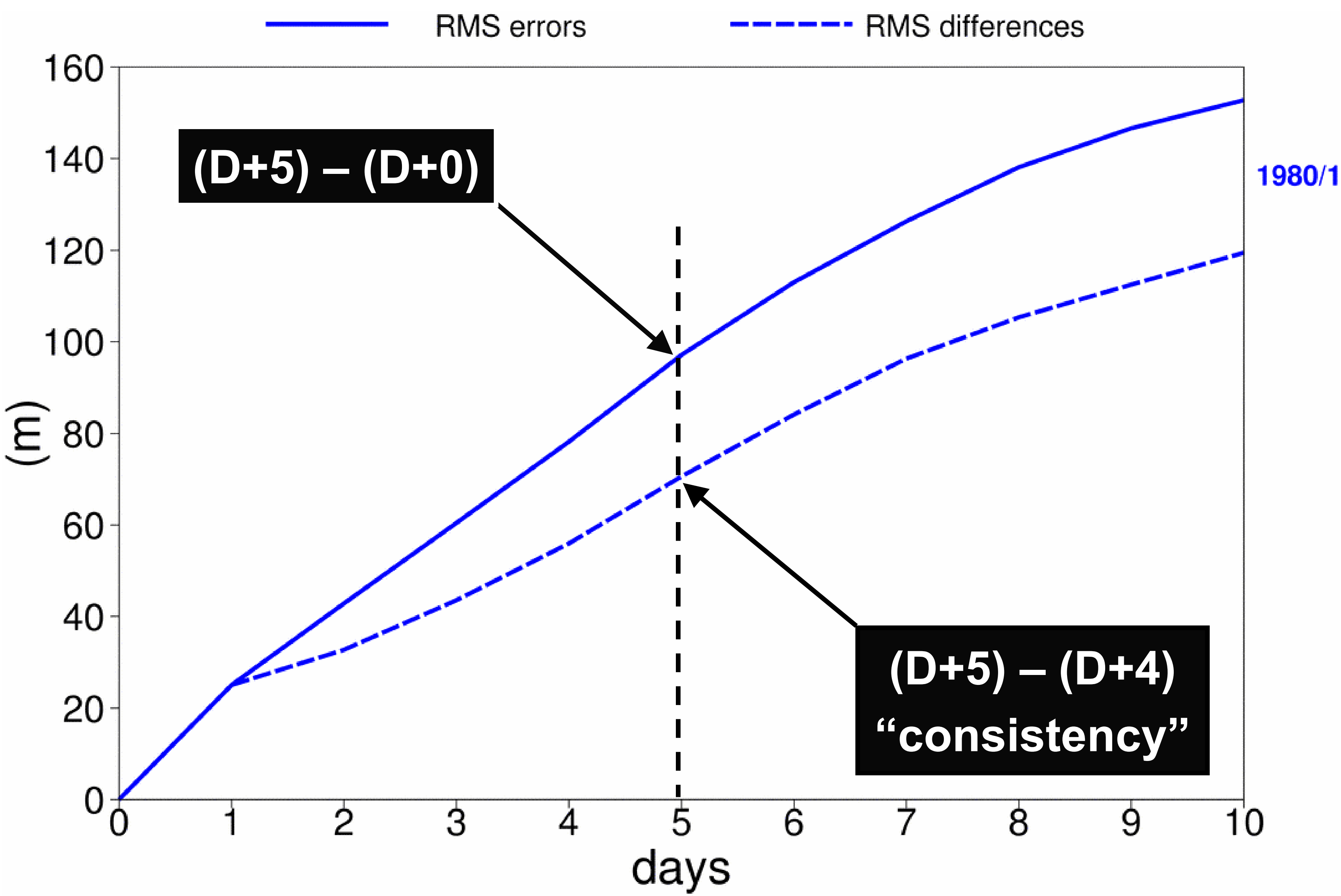


Error of the verifying analysis contributes little to measured forecast error from 12h onwards:

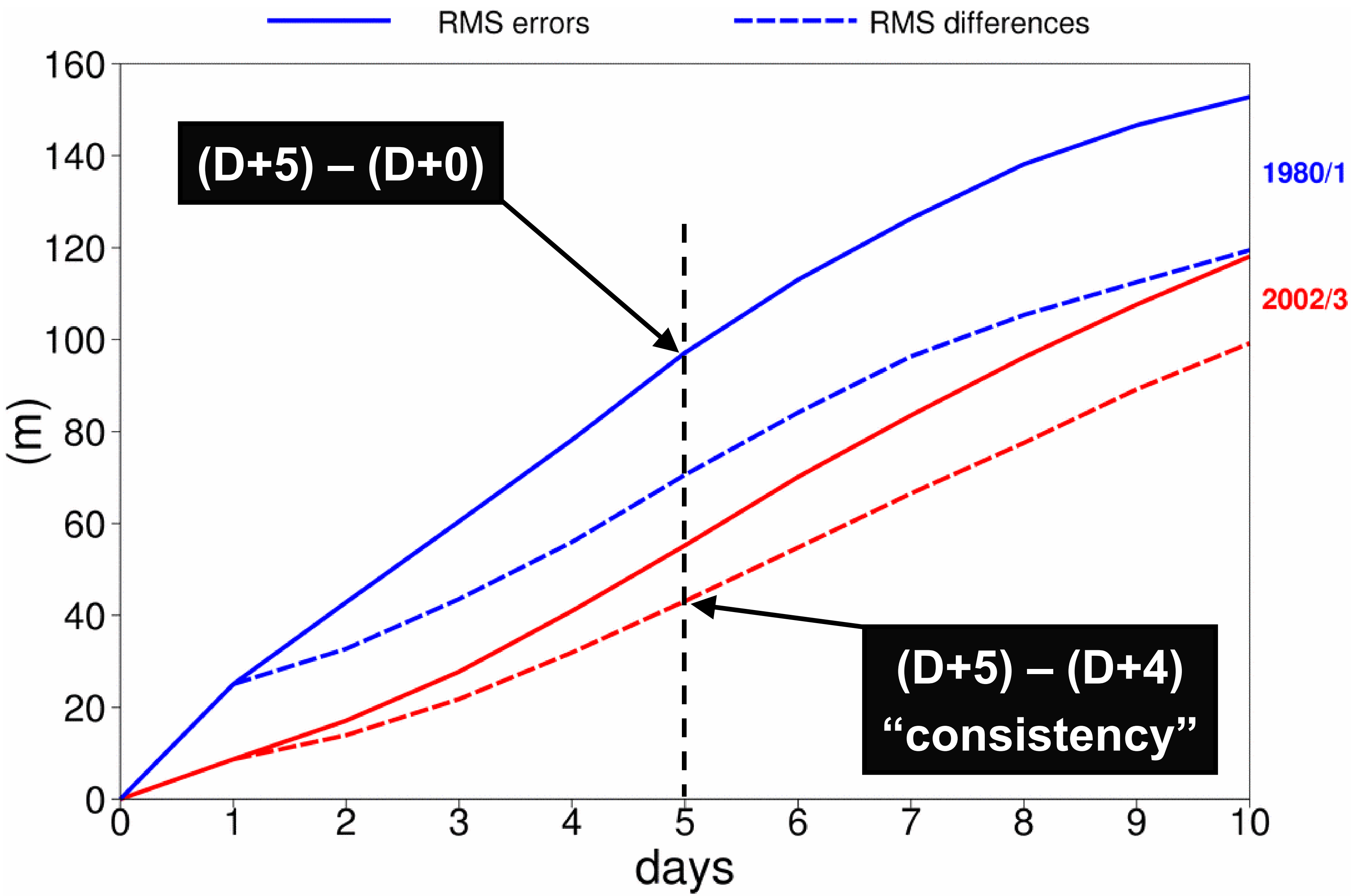
$$f_{measured}^2 = f_{true}^2 - 2 f_{true} e_{ec} C_{f_{true}, e_{ec}} + e_{ec}^2$$

For current measured forecast errors, and estimated analysis errors and correlations, the terms $-2 f_{true} e_{ec} C_{f_{true}, e_{ec}}$ and $+e_{ec}^2$ tend to cancel in short range, and are relatively small at longer ranges.

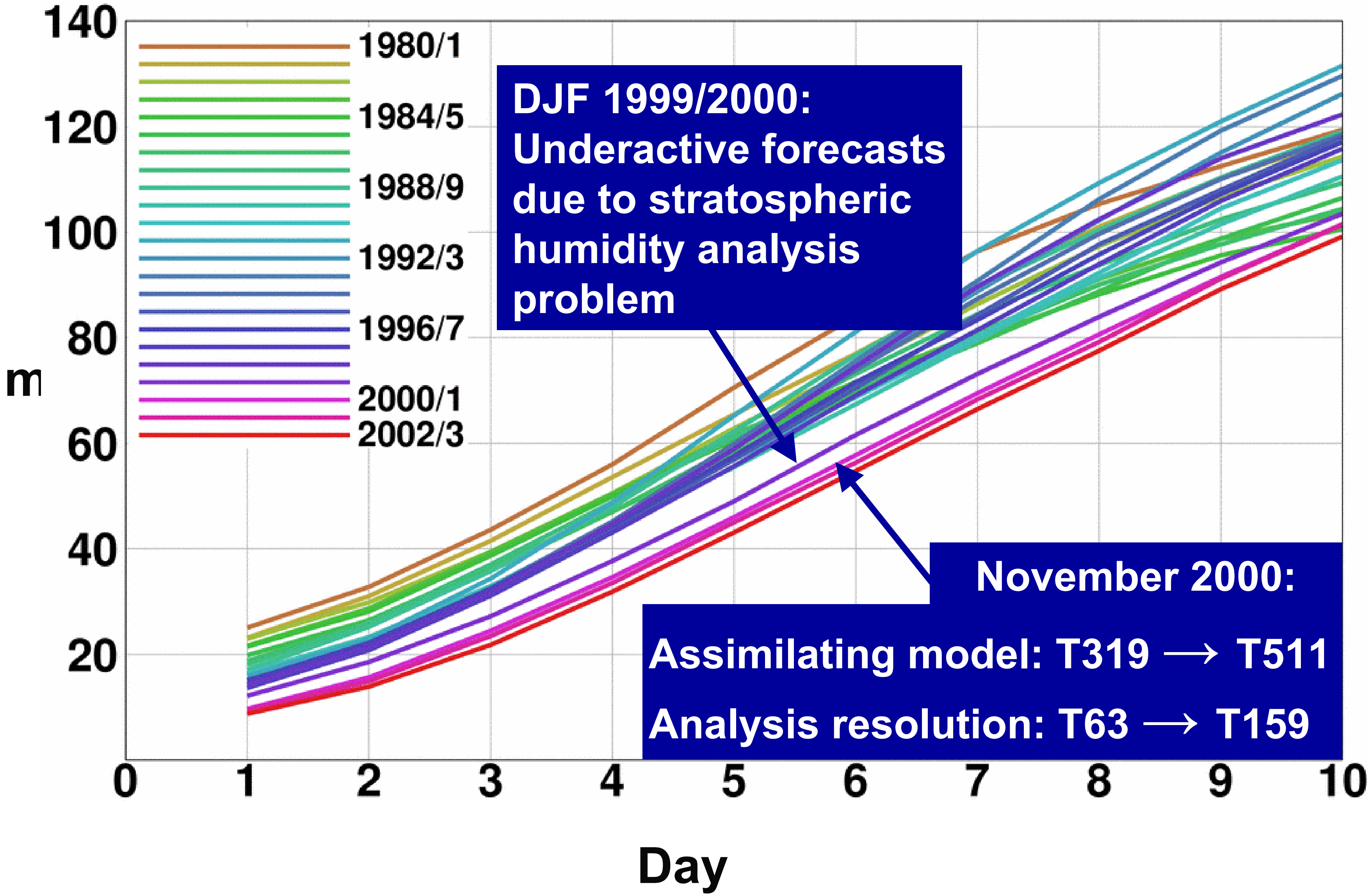
R.m.s. errors and differences between successive forecasts
Northern hemisphere 500hPa height Winter



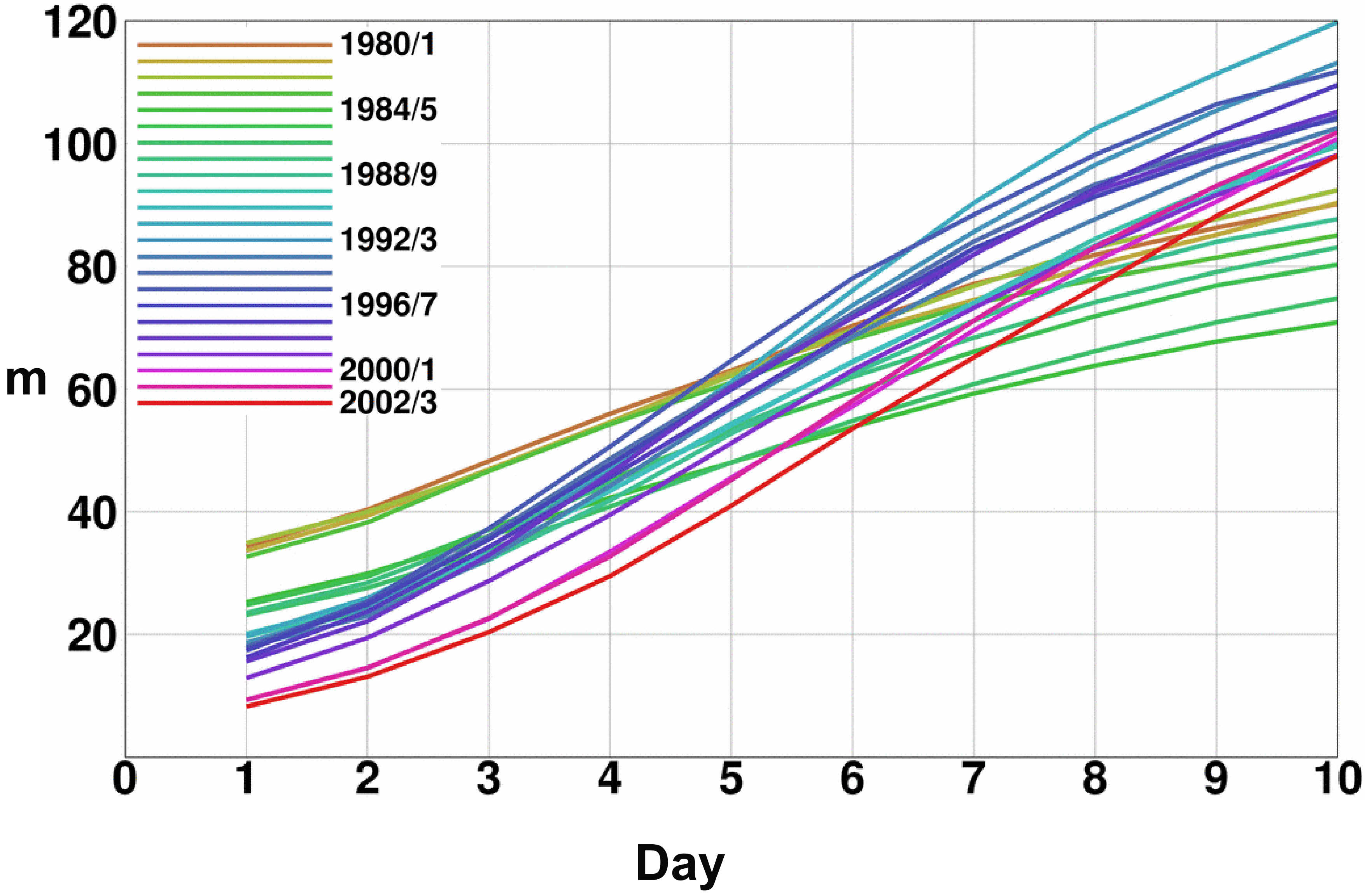
R.m.s. errors and differences between successive forecasts
Northern hemisphere 500hPa height Winter



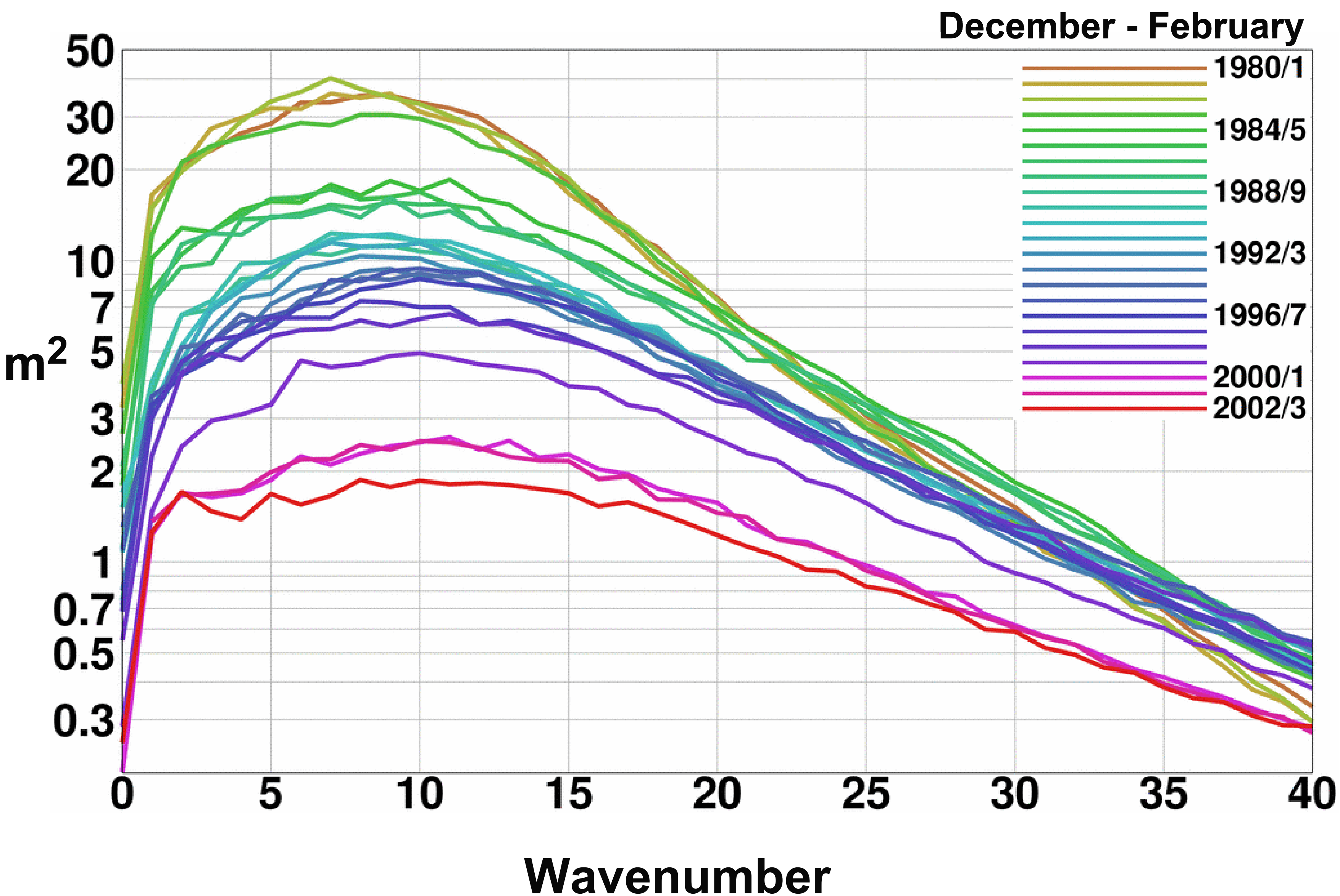
RMS differences between successive daily 500hPa height forecasts
December-February   Northern hemisphere



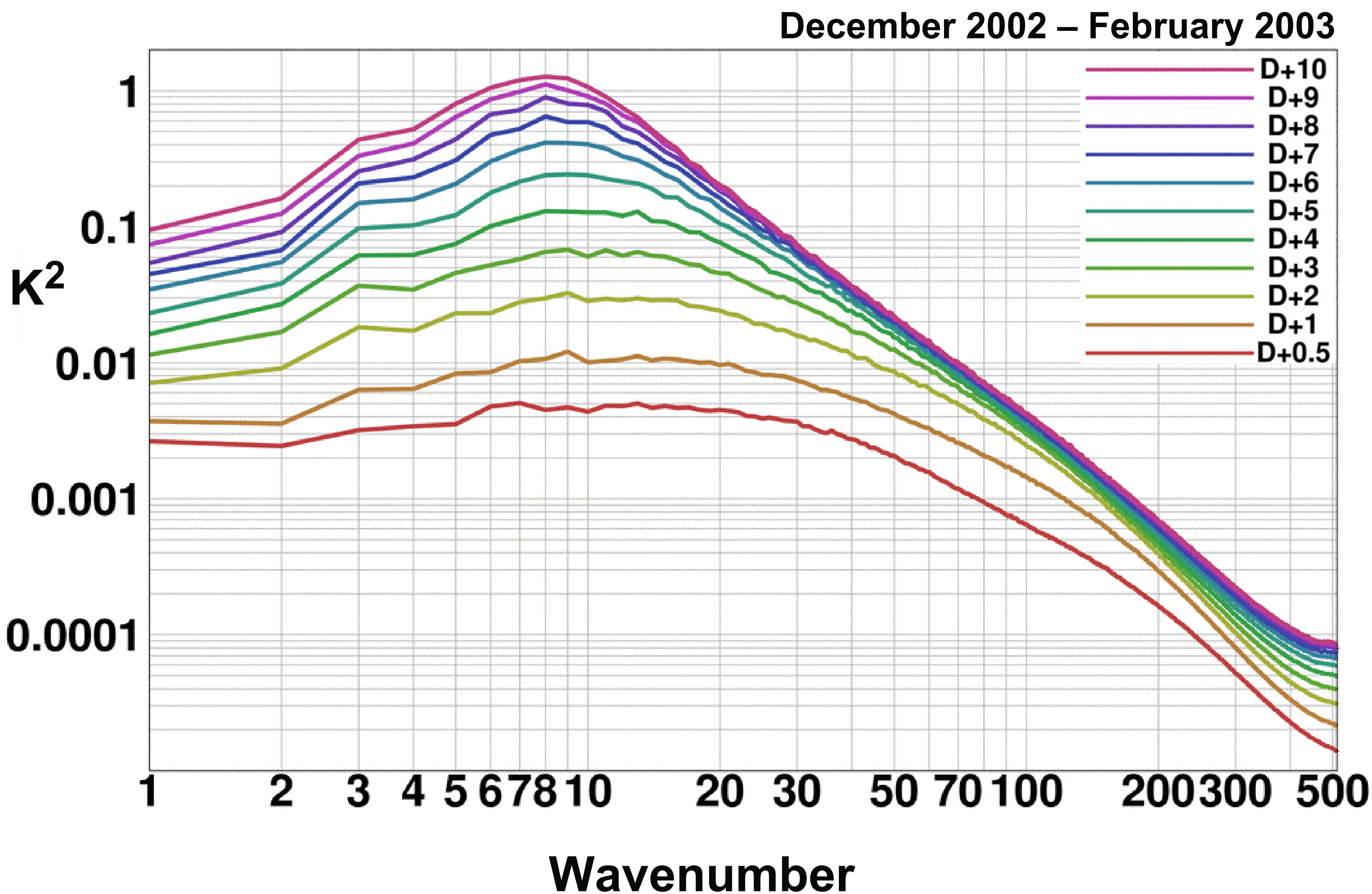
RMS differences between successive daily 500hPa height forecasts
December-February   Southern hemisphere



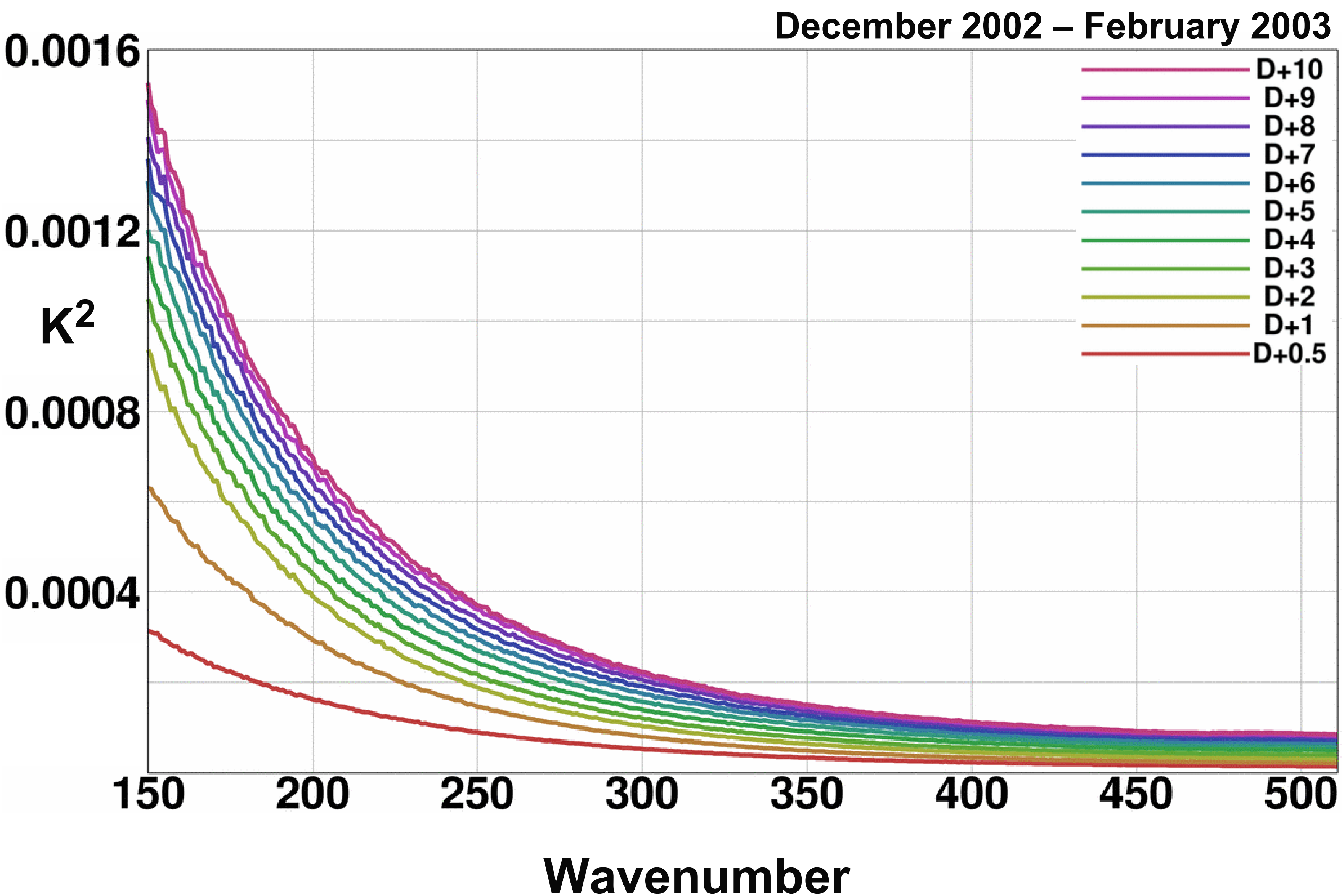
Spectra of mean-square day-1 500hPa height error variance



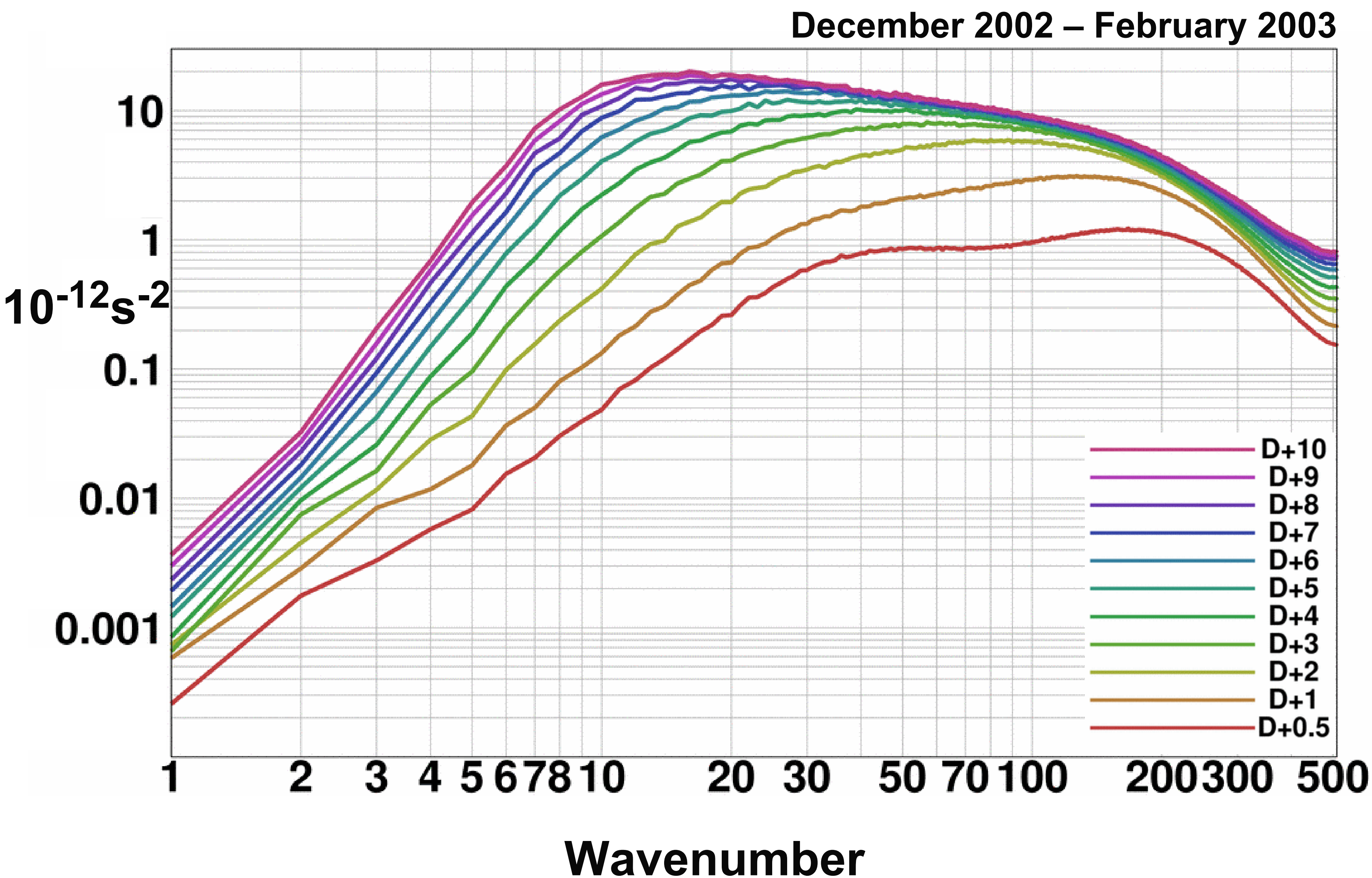
Spectra of mean-square 850hPa temperature errors



Spectra of mean-square 850hPa temperature errors



Spectra of mean-square 850hPa vorticity errors



In summary:

- There has been a clear long-term improvement in the observing system – especially for the southern hemisphere.

- There has been a substantial improvement in forecasts over the past seven years – especially arising from improved data assimilation (improved models as well as improved analysis techniques) and better observations.

- There has been some significant convergence in the performance of different centres – but significant (and informative) differences remain.

- There has been a recent improvement in the handling of smaller scales – suggesting potential for further benefit from resolution increases.