# From ERA-15 to ERA-40 and ERA-Interim

**Sakari Uppala**

**ECMWF**

**With contributions by colleagues**

# CONTENTS

- Operations ↔ Reanalysis ↔ Climate
- ERA-15 → ERA-40
- Towards the ERA-Interim
- Future reanalysis plans at ECMWF

| Operations | Reanalysis |
| --- | --- |

## Aim

- To produce high quality forecasts with early delivery to customers, once only
- To produce, with regular intervals, time series of climate quality synoptic analyses in good physical and dynamical balance over a long period

## Data assimilation system

- High resolution system, updated frequently, 3-4 times/ year
- Operational system configured in lower resolution and kept unchanged as far as possible

## Use of observations

- Proven observations used. All observations monitored, new observing systems introduced passively.
- Manual control through blacklist. Changes made based on daily monitoring
- Observations, including reprocessed and recovered, with the experience from previous reanalyses and operations
- Blacklist defined for the whole reanalysis period, based on the previous reanalyses

# Operations Reanalysis

- Operations performed one day per day using GTS observations and data from satellite producers

- Reanalysis performed ~ 10 days per day using historical pre-prepared observations and boundary fields as input

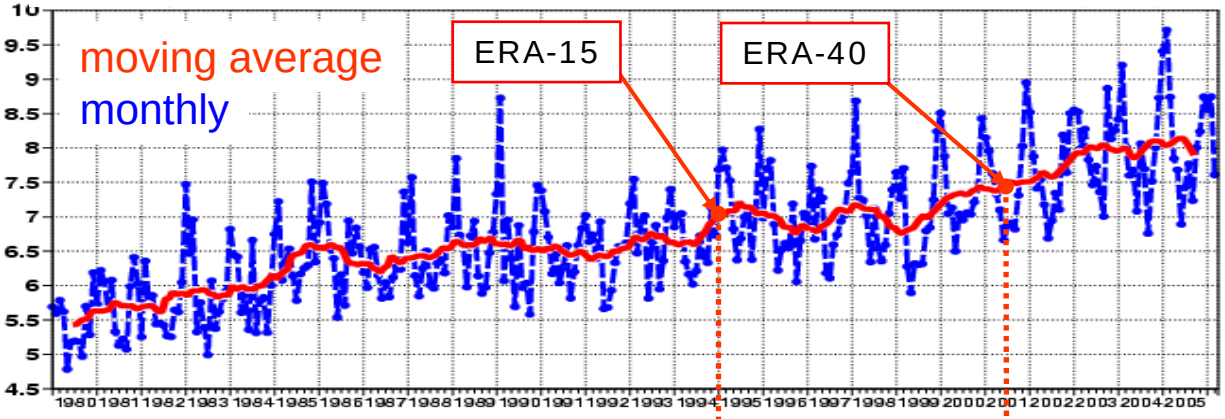
- Reanalysis team << Operations team

➔ Therefore reanalysis has a greater need to develop automated processes to identify when assimilation has a problem and adaptive algorithms to handle errors

# Operational forecast performance 1980-2006

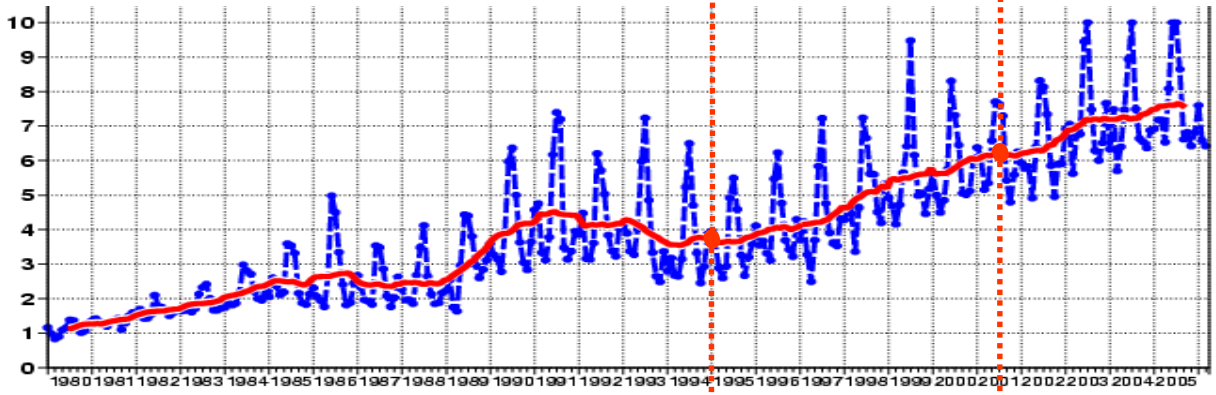
**Northern Hemisphere**

500 hPa geopotential
ANC reaching 60%



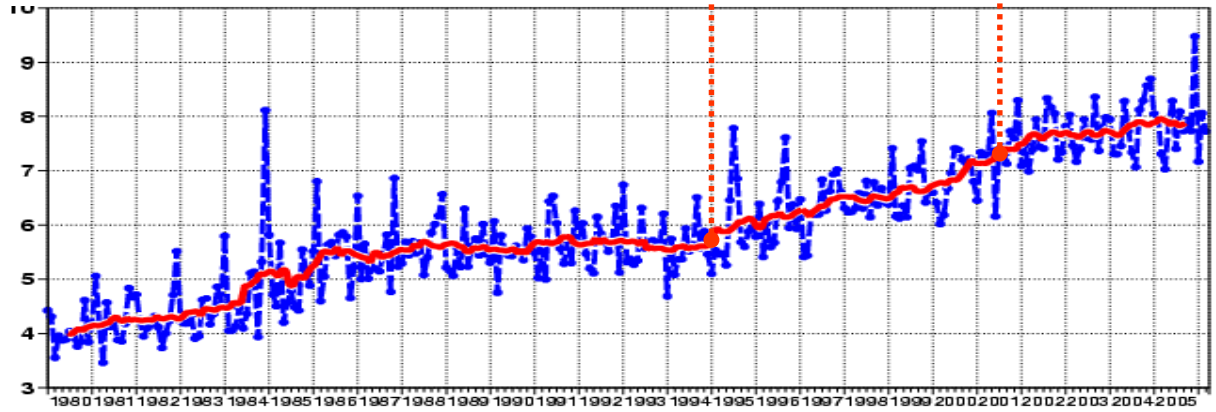

**Tropics**

850 hPa wind vector
ABC reaching 70%



**Southern Hemisphere**

500 hPa geopotential
ANC reaching 60%



# Extract from the ECMWF amended convention

*.*

*.*

*2. The objectives of the Centre shall be:*

*a) to develop, and operate on a regular basis, global models and data-assimilation systems for the dynamics, thermodynamics and composition of the Earth's fluid envelope and interacting parts of the Earth-system, with a view to:*

*i. preparing forecasts by means of numerical methods;*

*ii. providing initial conditions for the forecasts; and*

*iii. contributing to monitoring the relevant parts of the Earth-system;*

*b) to carry out scientific and technical research directed towards improving the quality of these forecasts;*

*c) to collect and store appropriate data;*

*.*

*.*

# CLIMATE

## Observational ⟷ Reanalysis

### Analysis

- Univariate
- Multivariate

### Information used in the analysis

- Single source: radiosonde temperatures, satellite radiances, $T_{2m}$ , $P_s$, precipitation, snow, …etc
- Multiple sources: Temperature, wind, humidity, pressure, radiance data. Model background used as an extra observation. Physical relationships and error statistics play important role.

### Products

- Quality controlled and bias corrected mean observations or observations interpolated into fields, often monthly, for use in climate assessments and climate model validations
- Synoptic analyses, integrals of physical processes, quality controlled observations and their departures from the background. Huge application potential including data sparse polar regions.

# CLIMATE

Observational ⟷ Reanalysis

## Analysis agreement with observations

- Excellent mean agreement by construction
- Optimize the fit to all observation types simultaneously constrained by physical knowledge

## Sea surface temperature and Sea ice dataset

- Used as a separate product
- Through physical parameterization of the assimilating model SST and ICE have a large influence on the products and also affect the bias corrections and quality control of data

# CLIMATE

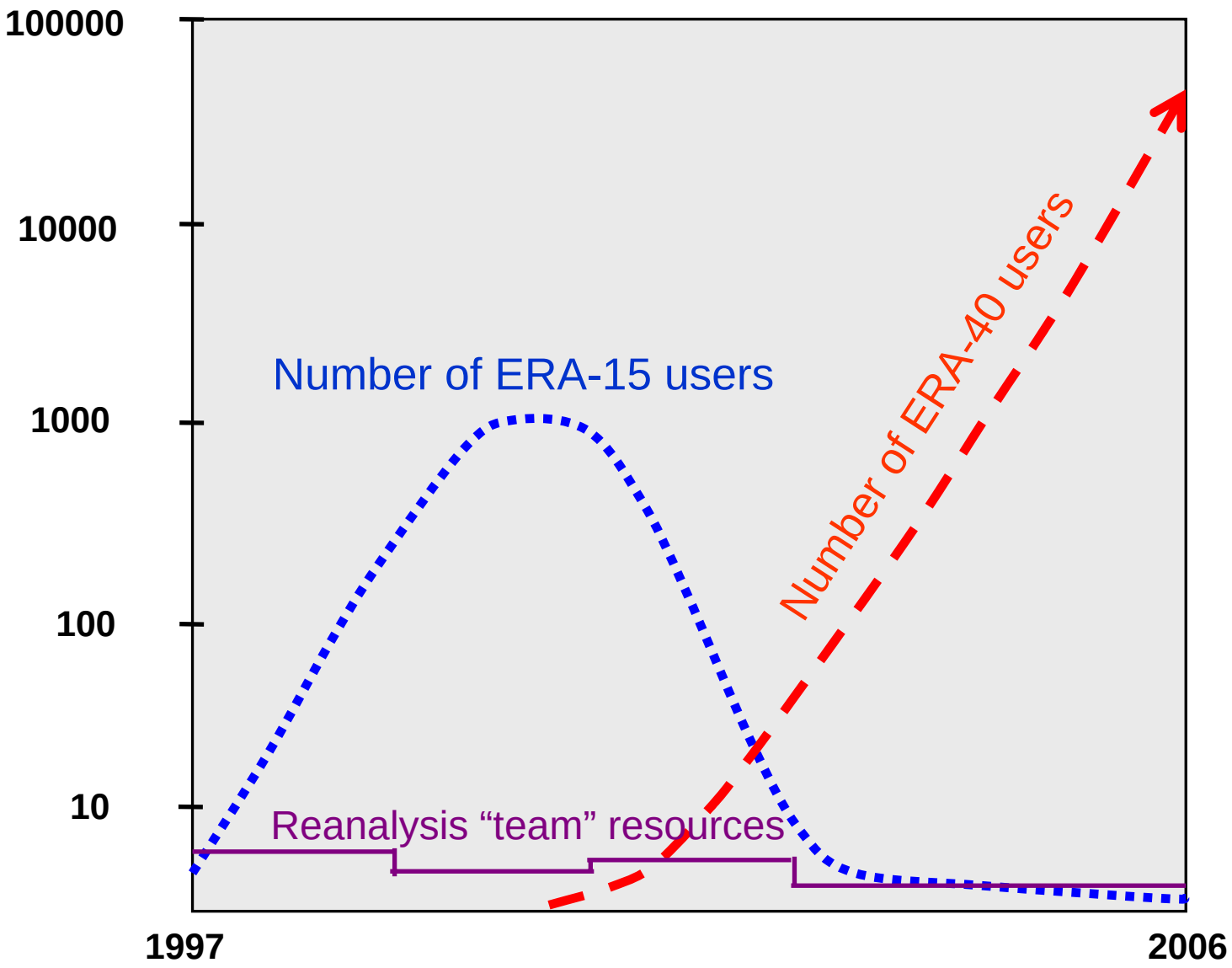
## Observational ⟷ Reanalysis

### Products & biases

- Observation biases corrected using nearby observations
- Outside observed areas biases due to interpolation method
- Model background used
  - -To correct known observational biases
  - -To tune satellite radiances
- Possible model biases affect the analyses, but are marginal over data dense areas

### Dissemination

- Results published and distributed widely
- Gridded data, indices and some observational data available on-line
- ECMWF reanalyses and products available online at lower resolution and in full resolution for the member states
- NCEP observations and reanalyses available worldwide


100000
10000
1000
100
10
1997
2006
Number of ERA-15 users
Number of ERA-40 users
Reanalysis “team” resources

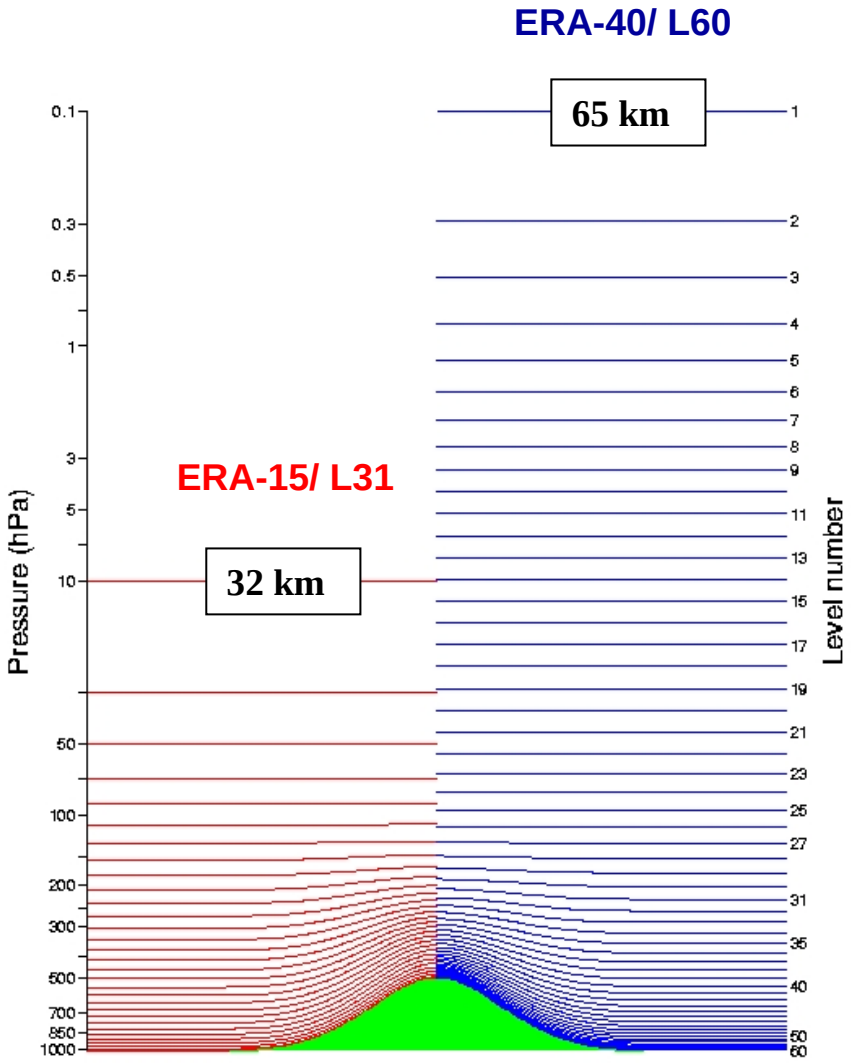
# ECMWF reanalyses

## ERA-40 1957-2002

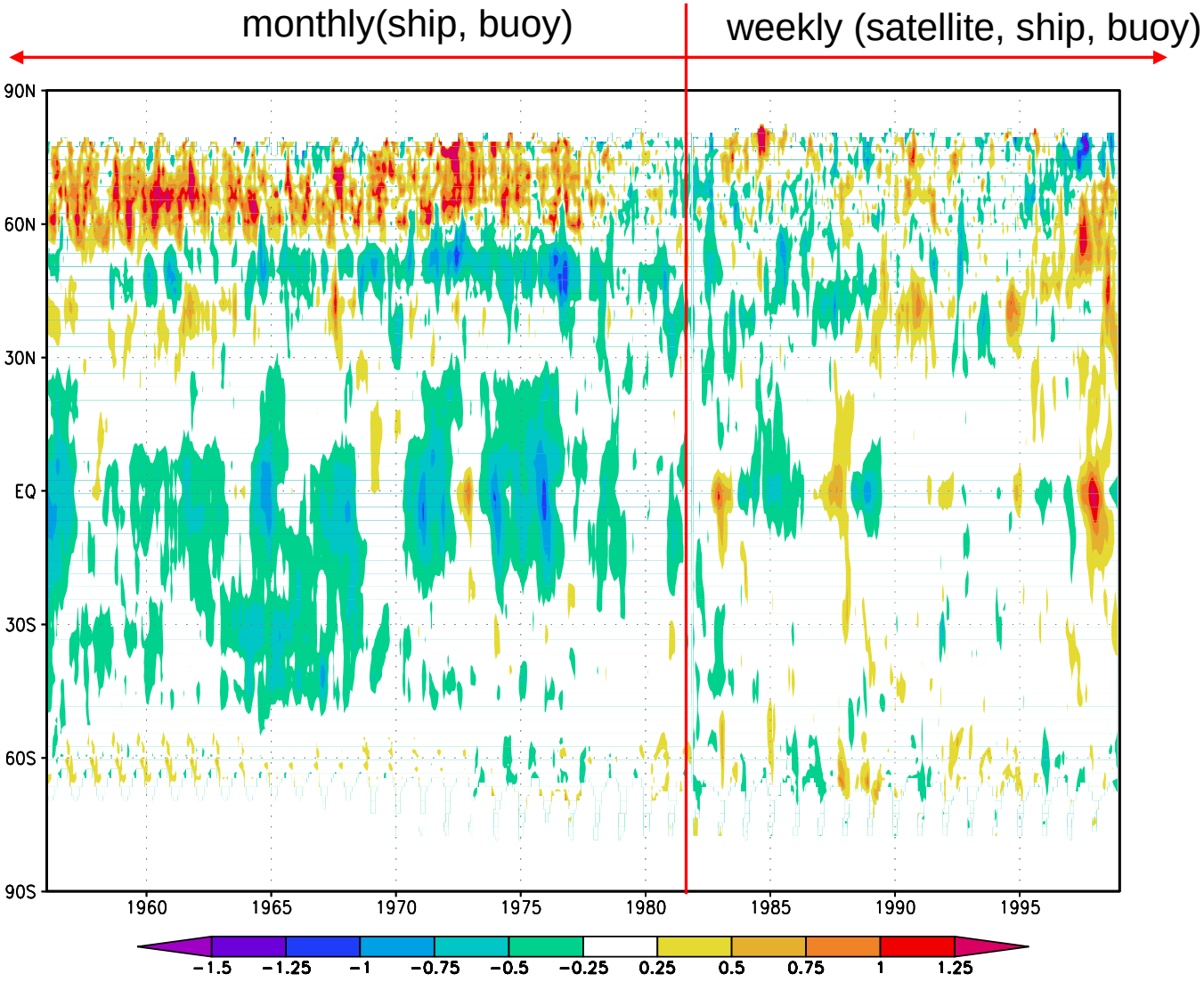
## ERA-15 1979-1993

- Improved data assimilation system
  - Assimilating model T106L31 → T159L60
  - OI → 3D-Var FGAT
  - Analysis of $O_3$
- Greatly extended use of satellite data
- ERA-15 experience ➔ ERA-40 blacklist
- More comprehensive use of conventional observations
- Use of Meteosat reprocessed winds, CSR passive
- Improved SST & ICE dataset
- Ocean wave height analysis

# Model levels



# SST anomaly, HADISST until 1981 November, NCEP 2d-Var then on

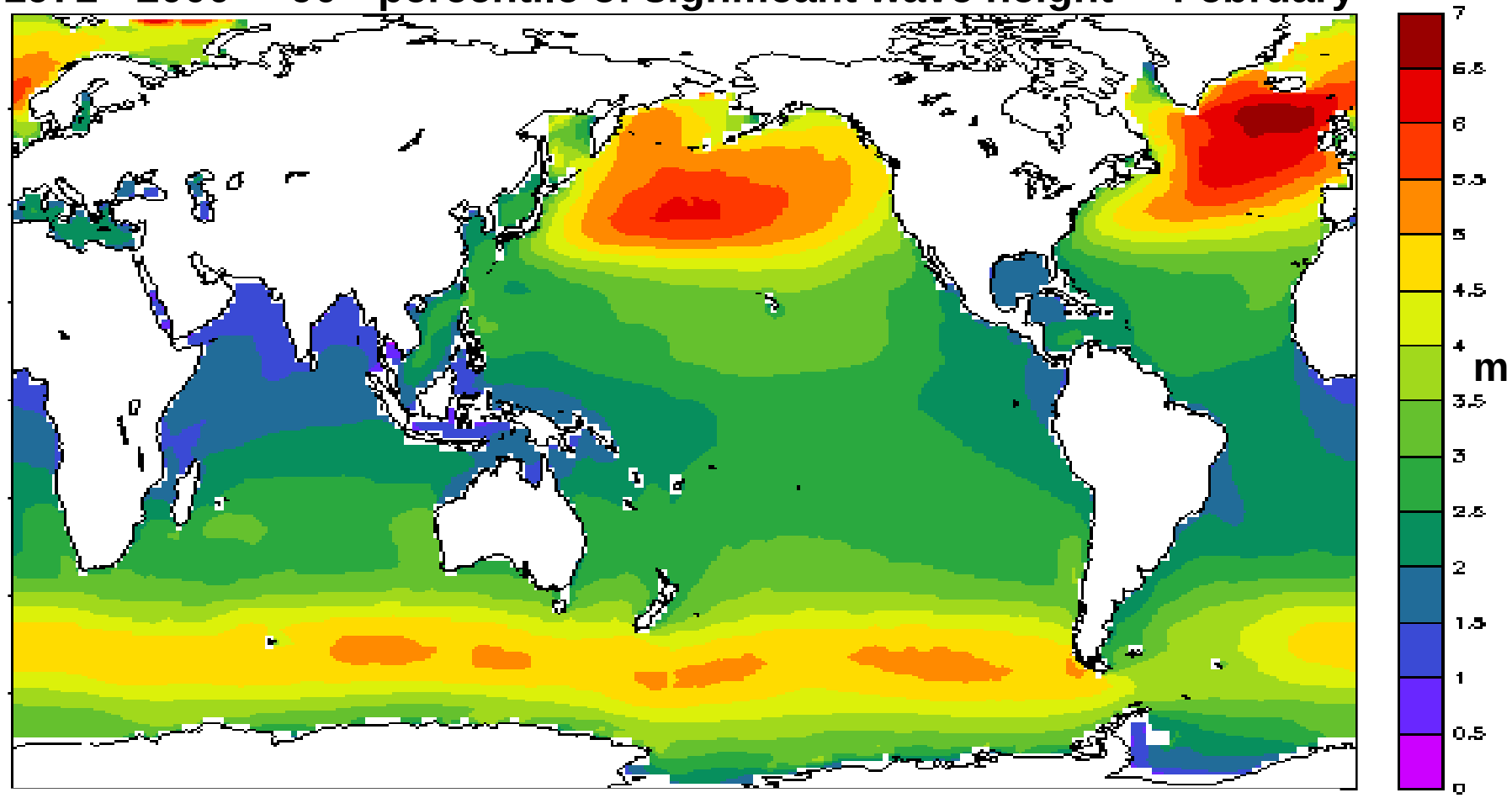


# Global wave climatology atlas

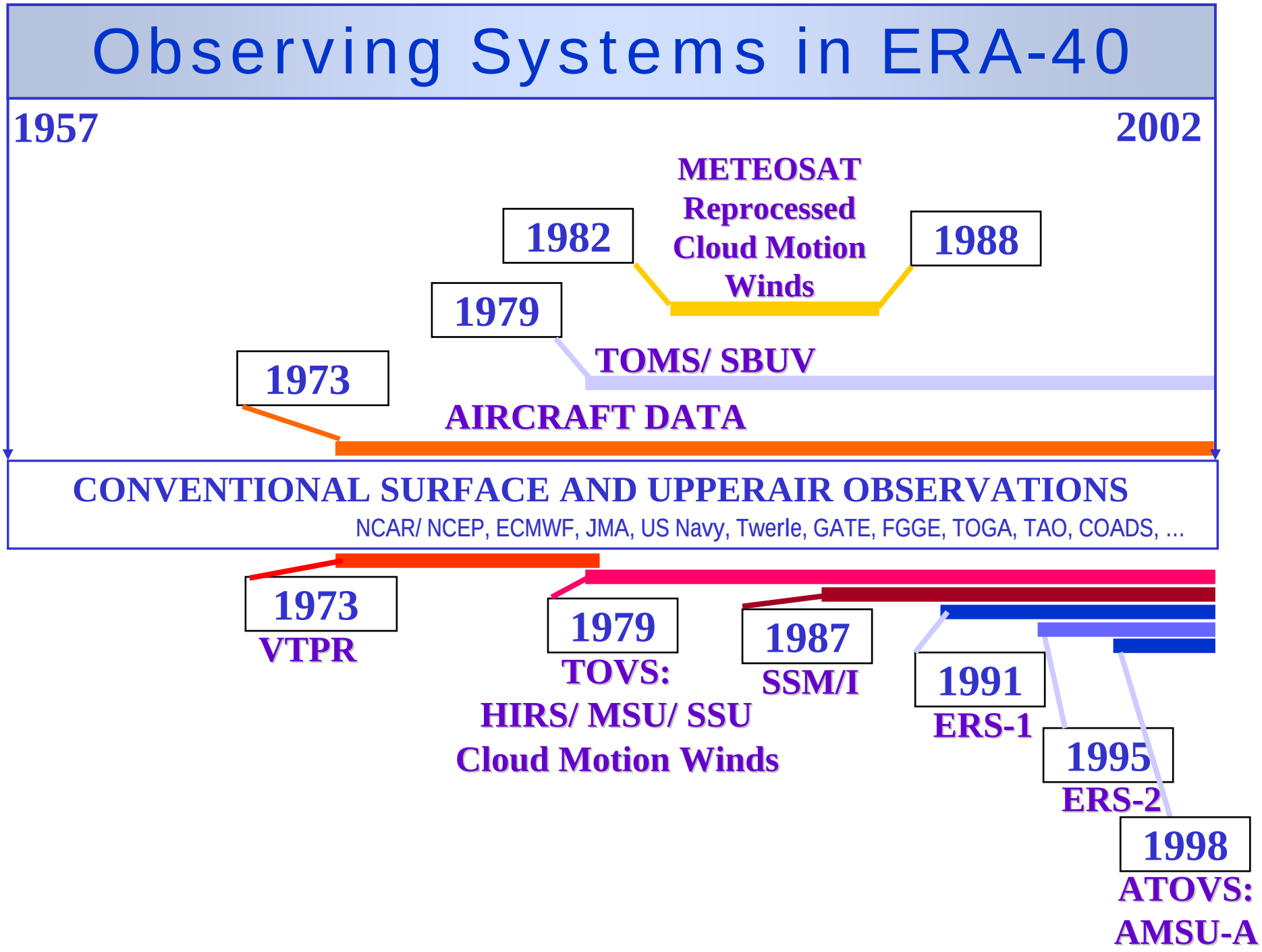
S. Caires, A. Sterl, G. Komen and V. Swail

http://www.knmi.nl/onderzk/oceano/waves/era40/atlas.html

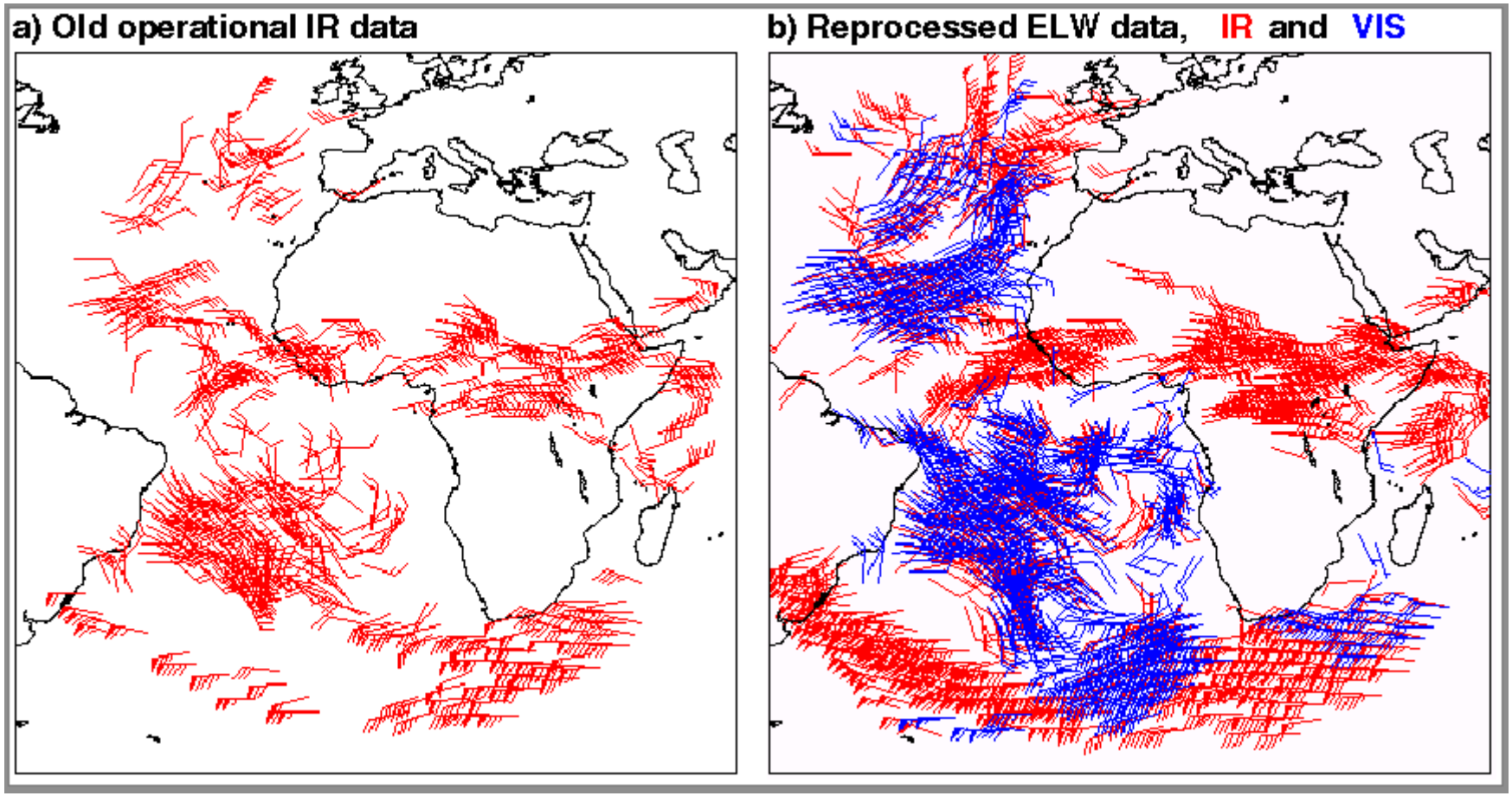
1971 - 2000 90th percentile of significant wave height February



# Observing Systems in ERA-40



# METEOSAT Reprocessed Winds



# Use of atmospheric satellite data in reanalyses

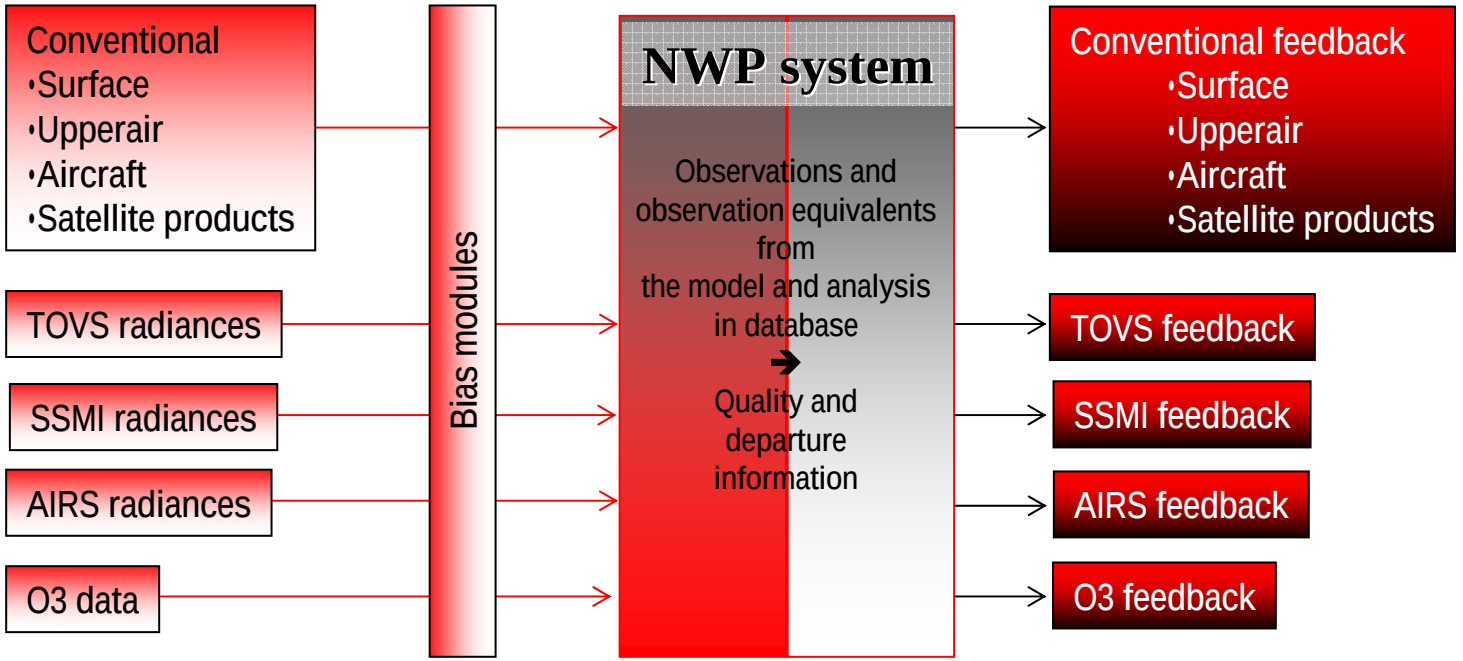
| | VTPR/ TOVS/ ATOVS | | | | | DMSP | GEO |
|---|---|---|---|---|---|---|---|
| | SSU | VTPR | HIRS | MSU | AMSU | SSM/I | |
| NCEP 1948 → | NESDIS operational T & q retrievals | | | | | - | Oper AMWs |
| ERA-15 1979-1993 | - | NA | 1D-Var retrievals of T & q using CCR. Above 100hPa NESDIS retrievals. | | NA | - | Oper AMWs |
| ERA-40 1957-2002 | 1c | 1c | 1c | 1c | 1c | 1D-Var retrievals of TCWV & wind speed | Oper+reprocessed AMWs, CSR passively |
| JRA-25 1979 → | 1c | NA | 1c | 1c | 1c | JMA retrievals of TCWV | Oper+reprocessed AMWs |
| ERA-Interim 1989 → | 1c | NA | 1c | 1c | 1c | 1c radiances and 1D-Var retrievals of rainy radiances | Oper+reprocessed AMWs, CSR passively |

# Observation biases

- Data assimilation assumes observation errors to be unbiased
- Bias correction of radiosonde temperatures
- Bias tuning of satellite radiances

Input observations

How the observations were used in the analysis (feedback)

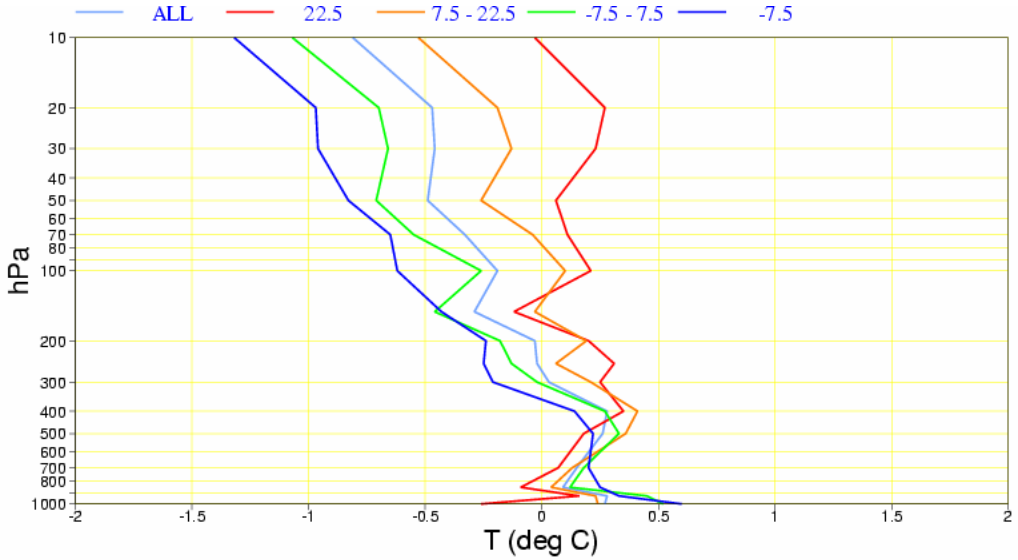



(Input and feedback observations in BUFR code)

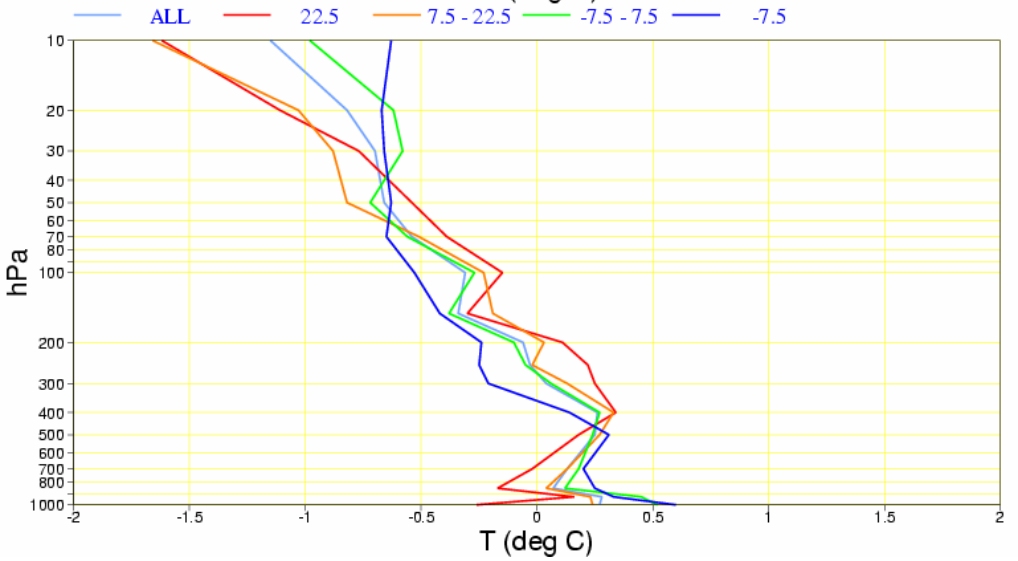
# Radiosonde temperature bias OB-FG
## (1994, South West Canada)

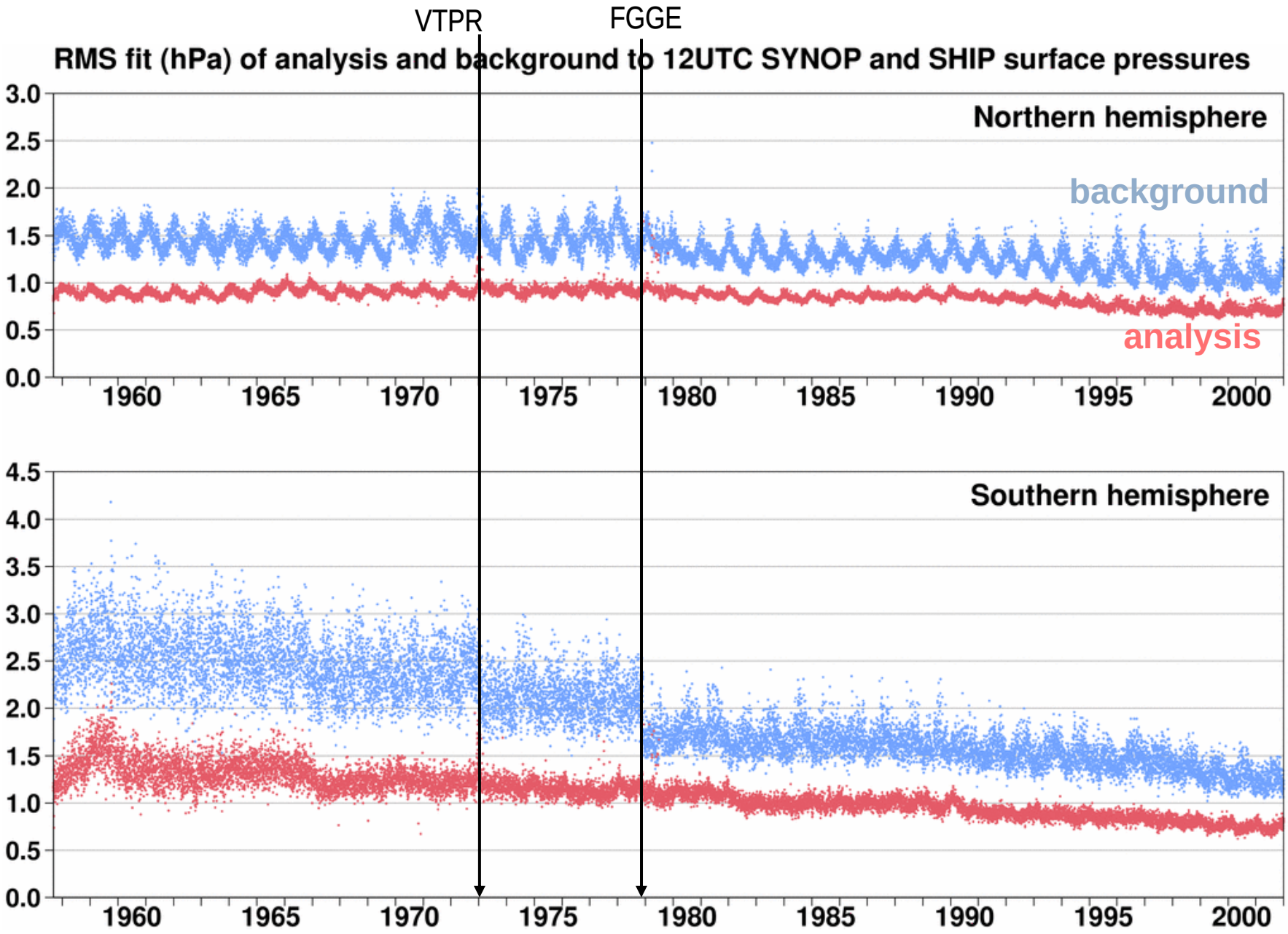
(4 solar elevation angle intervals and the mean)

Without correction




With correction




VTPR
FGGE
RMS fit (hPa) of analysis and background to 12UTC SYNOP and SHIP surface pressures
Northern hemisphere
background
analysis
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1960
1965
1970
1975
1980
1985
1990
1995
2000
Southern hemisphere
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1960
1965
1970
1975
1980
1985
1990
1995
2000

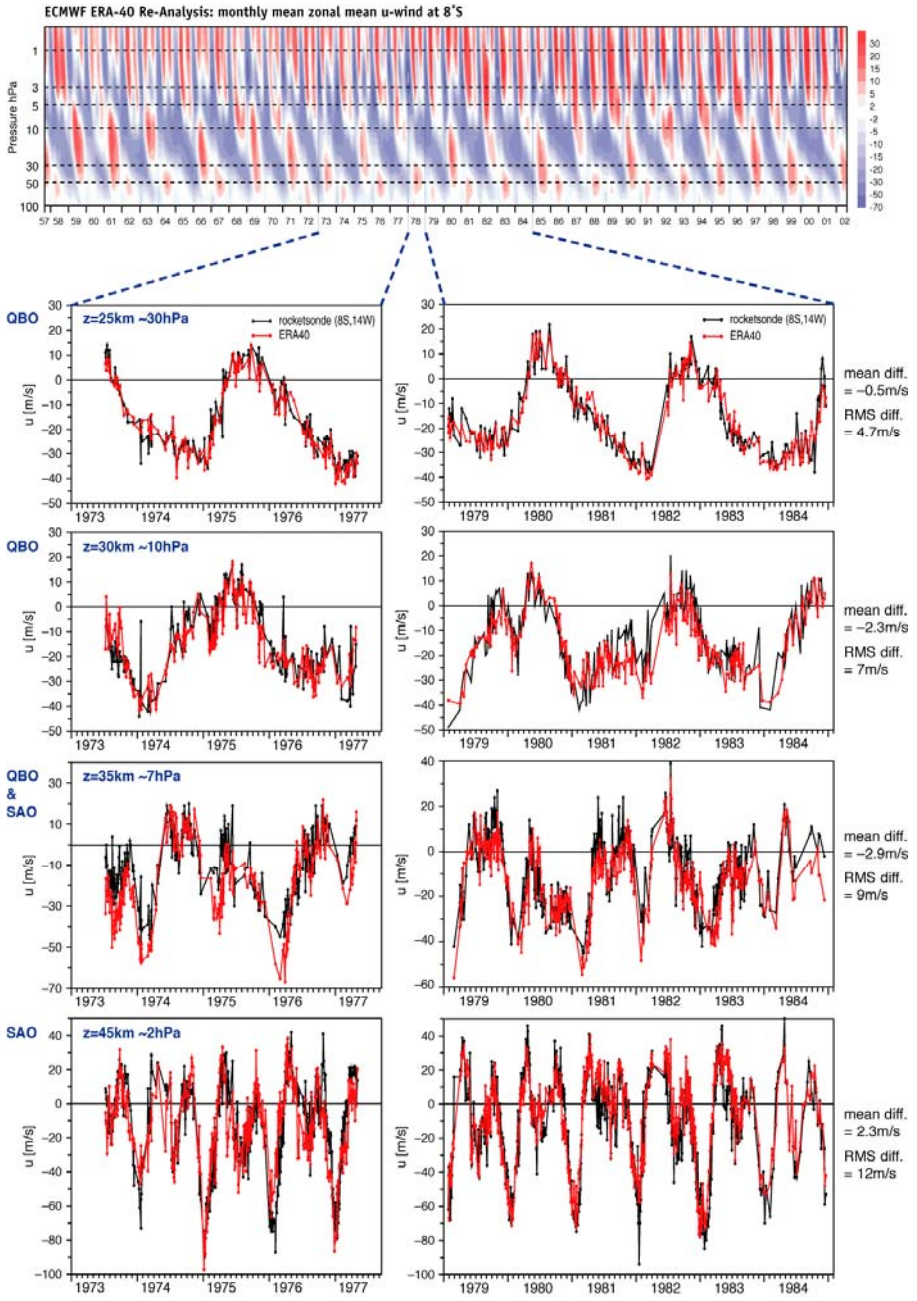
# ERA-40 winds validated against rocketsonde winds at Ascension Island

25km

30km

35km

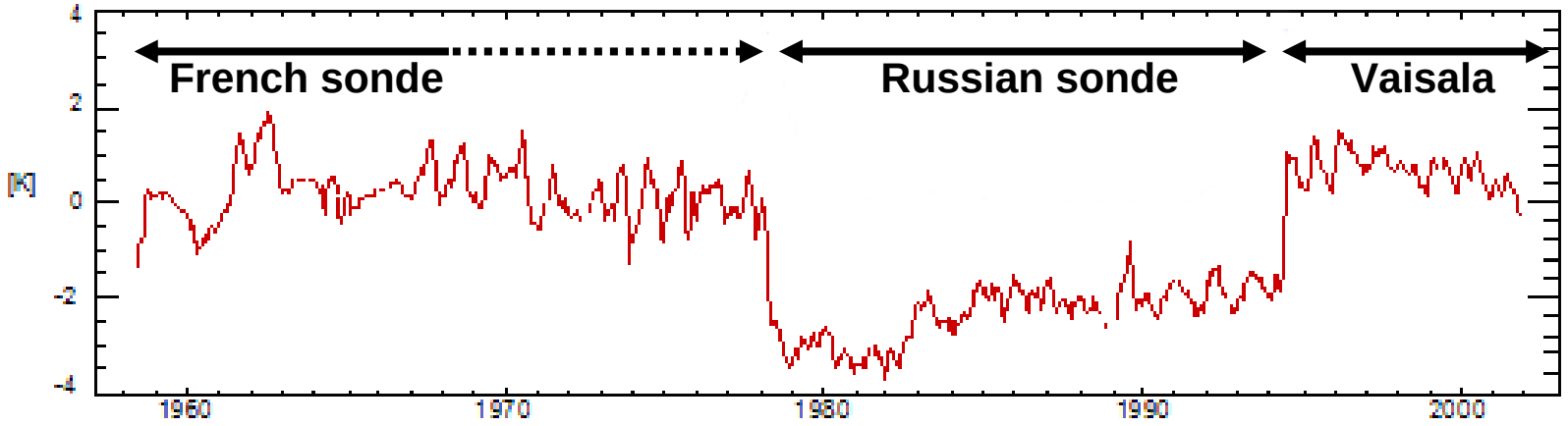
45km

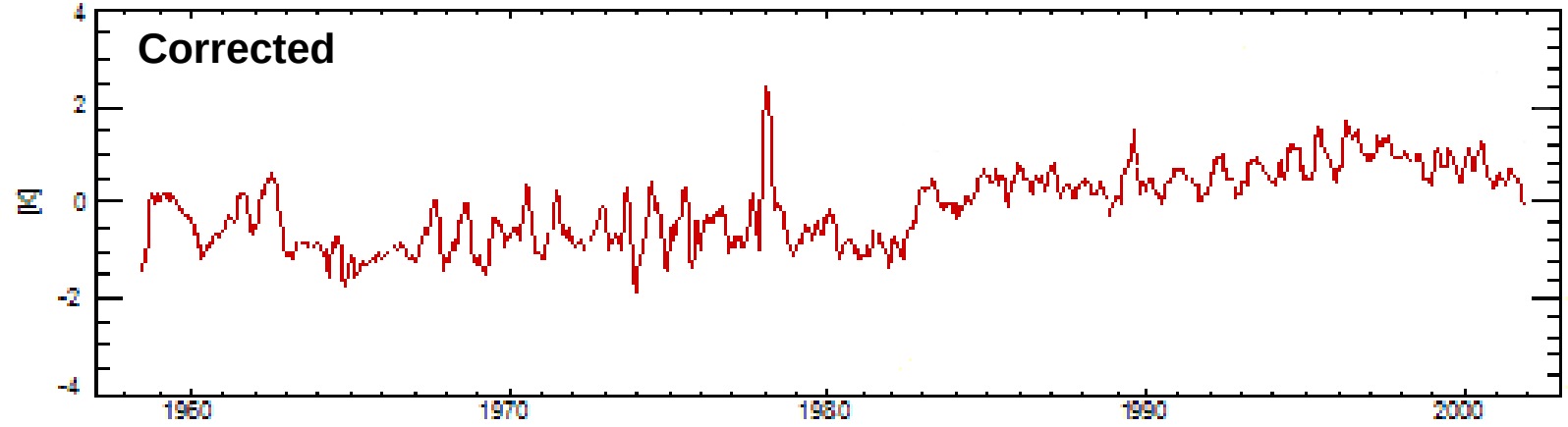


# Need to homogenize radiosonde biases in time

(example: Haimberger, 2005 using ERA-40 feedback data)

**SAIGON / TAN-SON-NHUT 00UTC 200hPa temperature (Background – Observation)**



ERA-Interim 1989 → to continue as CDAS

ERA-40 1957-2002

**Experimental program to decide the DA configuration**

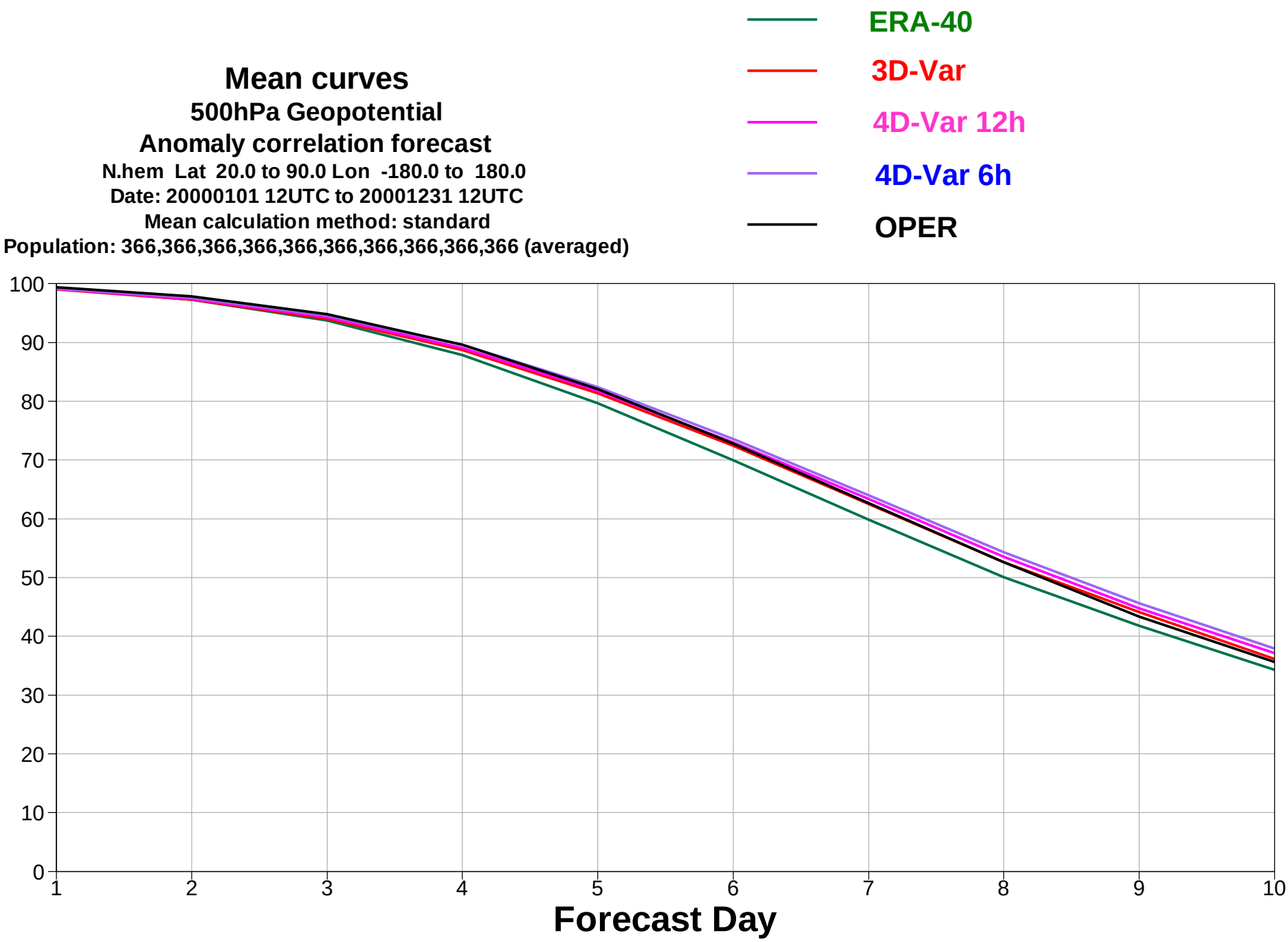
- Period August 1999 → December 2000
  - 3D-Var FGAT
  - 6 hour 4D-Var
  - 12 hour 4D-Var
  - Static <-> Adaptive radiance bias tuning (Dick Dee)
  - Model version T159L60 with significant upgrades since ERA-40
- Technical development of the monitoring environment
- Preliminary runs 1989 →
  - passive radiance assimilation,1989 → 1997 …

ERA-Interim 1989 → to continue as CDAS

ERA-40 1957-2002

**Several performance measures**

- The Hydrological cycle (Per Kållberg)
- The Age of air (Beatriz Monge-Sanz, University of Leeds)
- Forecast performance
- Time series of Observations-Background departures (Dick Dee)
- Detection of Tropical cyclones
- Analysis increments


Mean curves
500hPa Geopotential
Anomaly correlation forecast
N.hem Lat 20.0 to 90.0 Lon -180.0 to 180.0
Date: 20000101 12UTC to 20001231 12UTC
Mean calculation method: standard
Population: 366,366,366,366,366,366,366,366,366,366 (averaged)
ERA-40
3D-Var
4D-Var 12h
4D-Var 6h
OPER
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
7
8
9
10
Forecast Day

# Mean curves

**500hPa Geopotential**

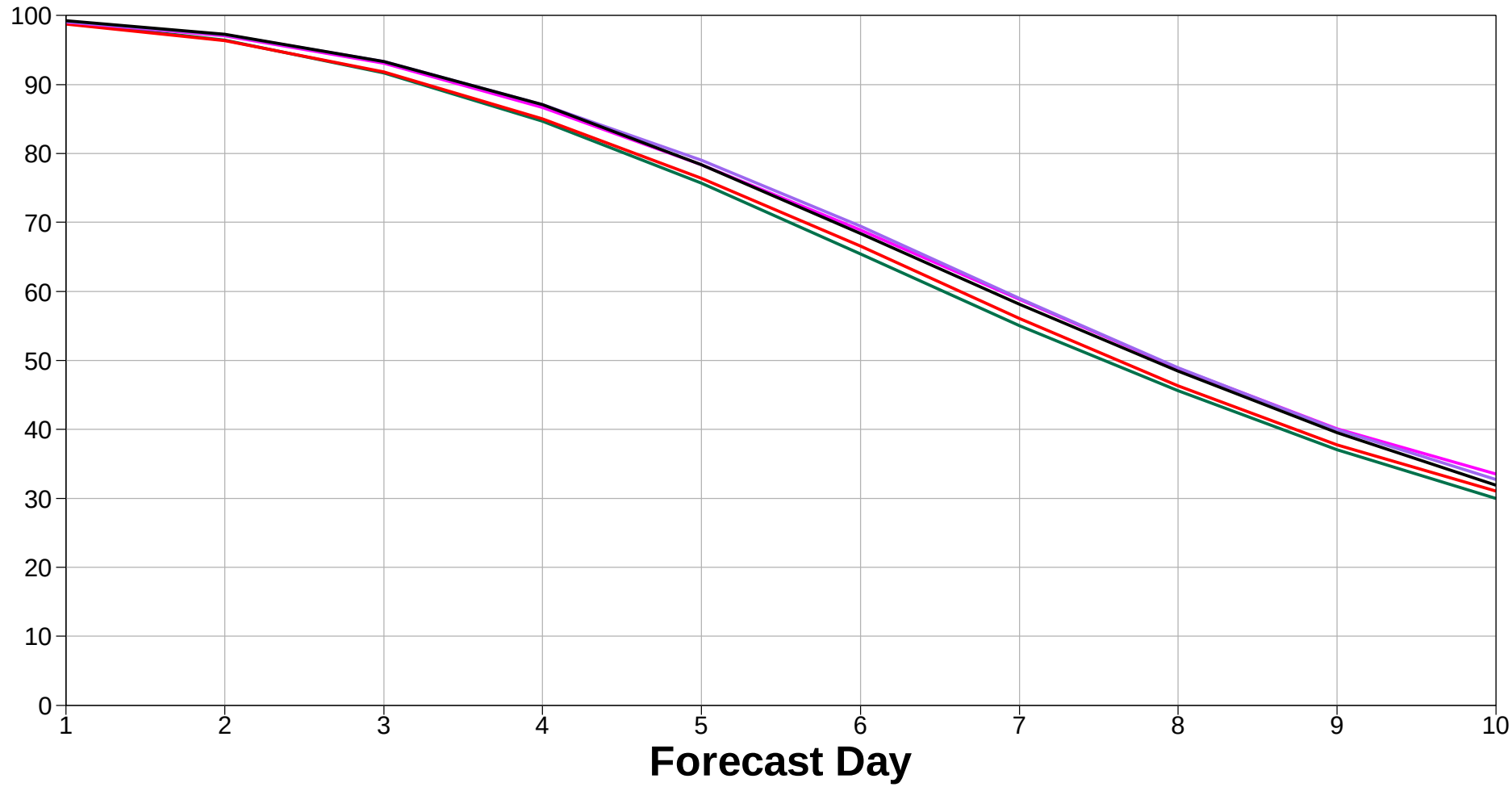
**Anomaly correlation forecast**

**S.hem Lat -90.0 to -20.0 Lon -180.0 to 180.0**

**Date: 20000101 12UTC to 20001231 12UTC**

**Mean calculation method: standard**

**Population: 366,366,366,366,366,366,366,366,366,366 (averaged)**



# Mean curves

## 500hPa Geopotential

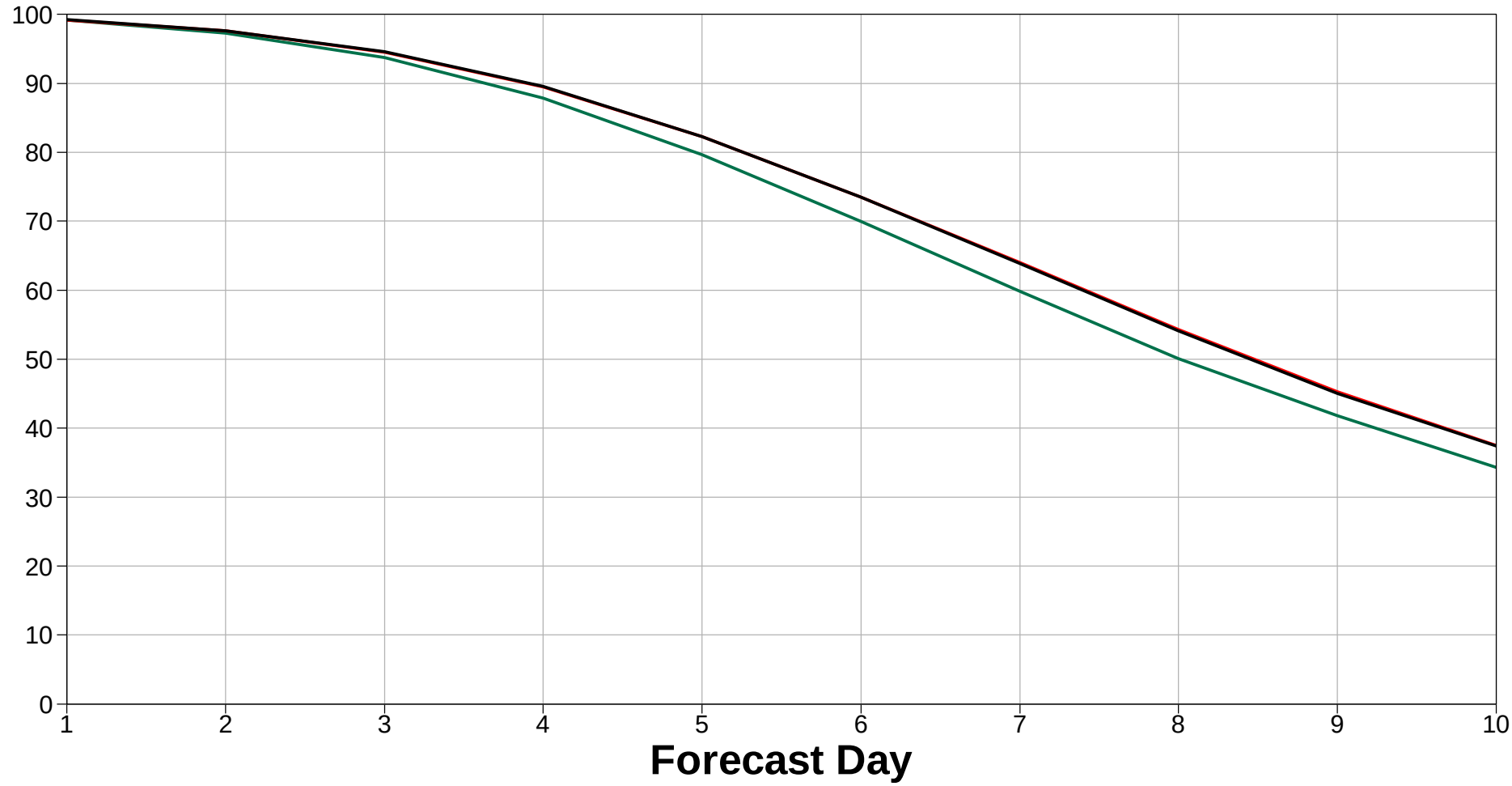
## Anomaly correlation forecast

**N.hem Lat 20.0 to 90.0 Lon -180.0 to 180.0**

**Date: 20000101 12UTC to 20001231 12UTC**

**Mean calculation method: standard**

**Population: 366,366,366,366,366,366,366,366,366,366 (averaged)**



# Mean curves

## 500hPa Geopotential

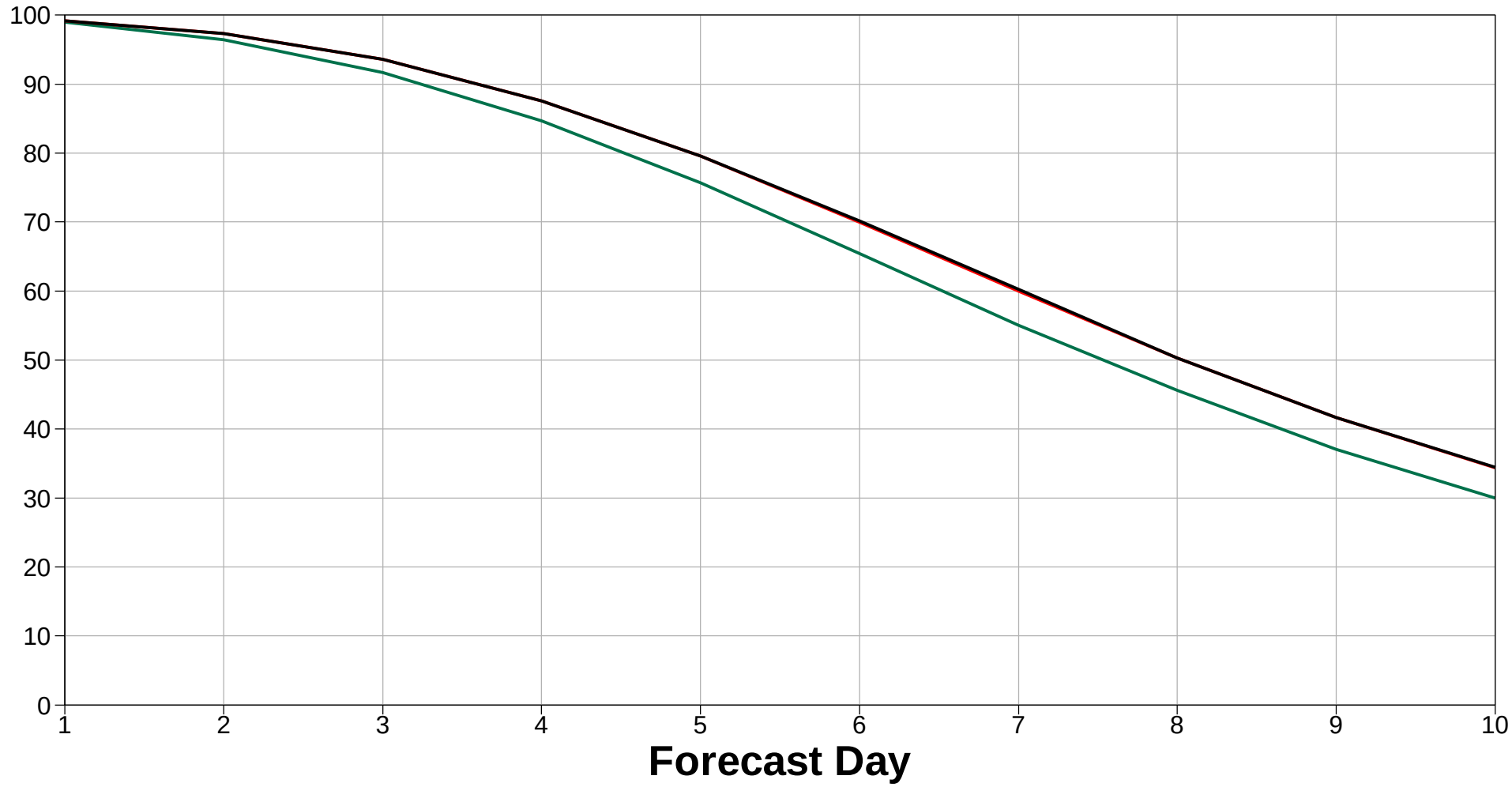
## Anomaly correlation forecast

**S.hem Lat -90.0 to -20.0 Lon -180.0 to 180.0**

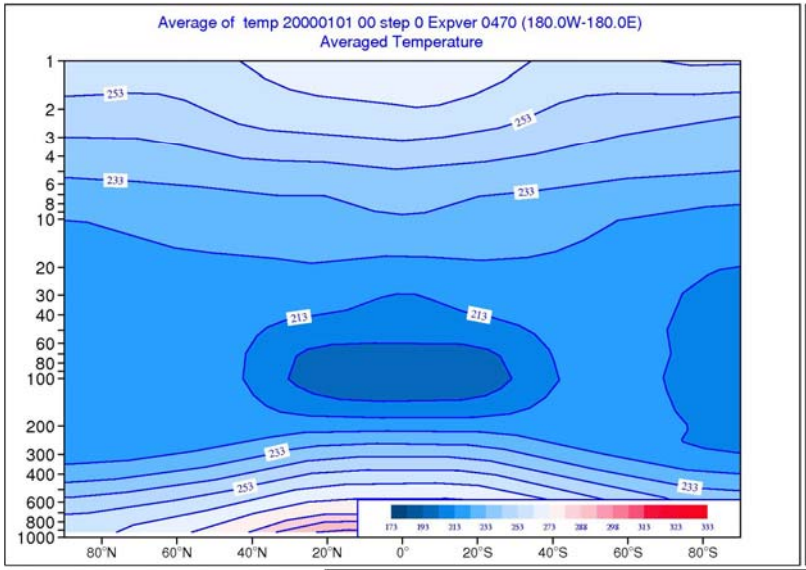
**Date: 20000101 12UTC to 20001231 12UTC**

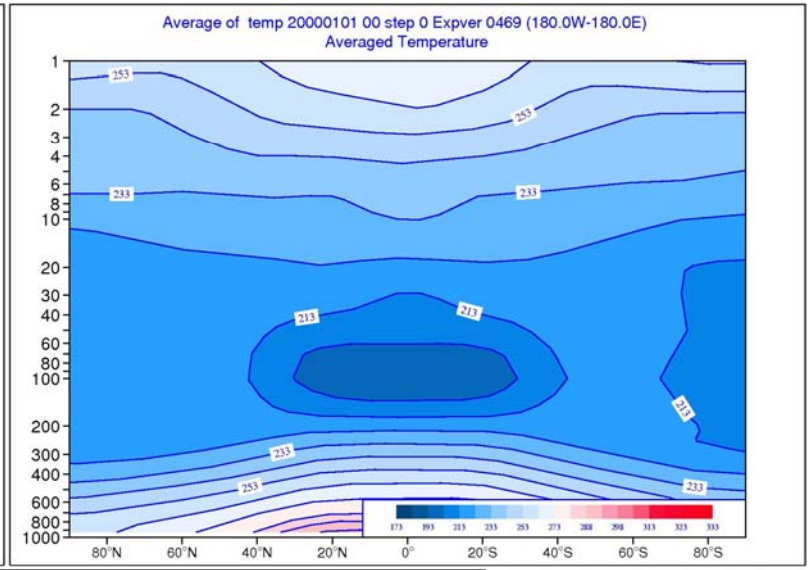
**Mean calculation method: standard**

**Population: 366,366,366,366,366,366,366,366,366,366 (averaged)**

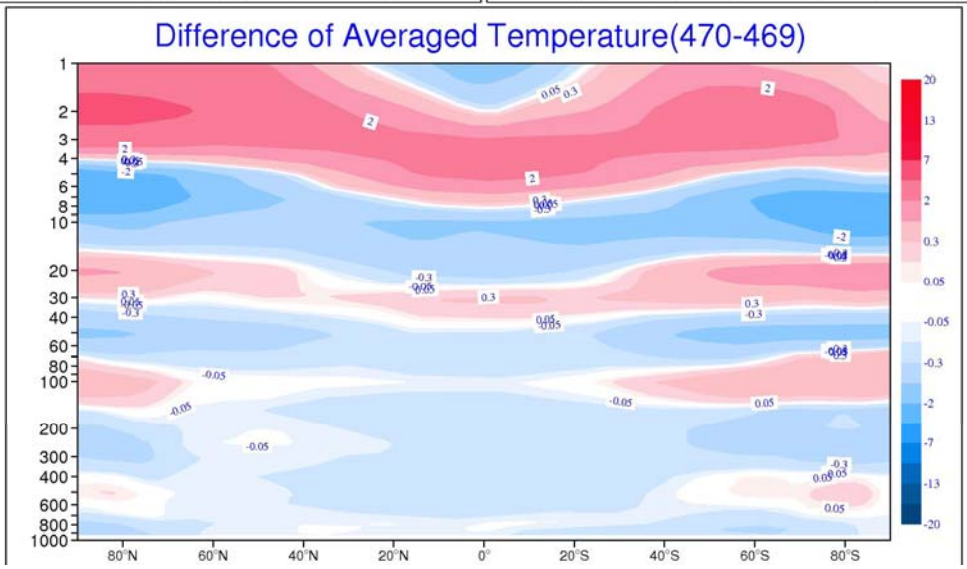


# Averaged Zonal Temperature



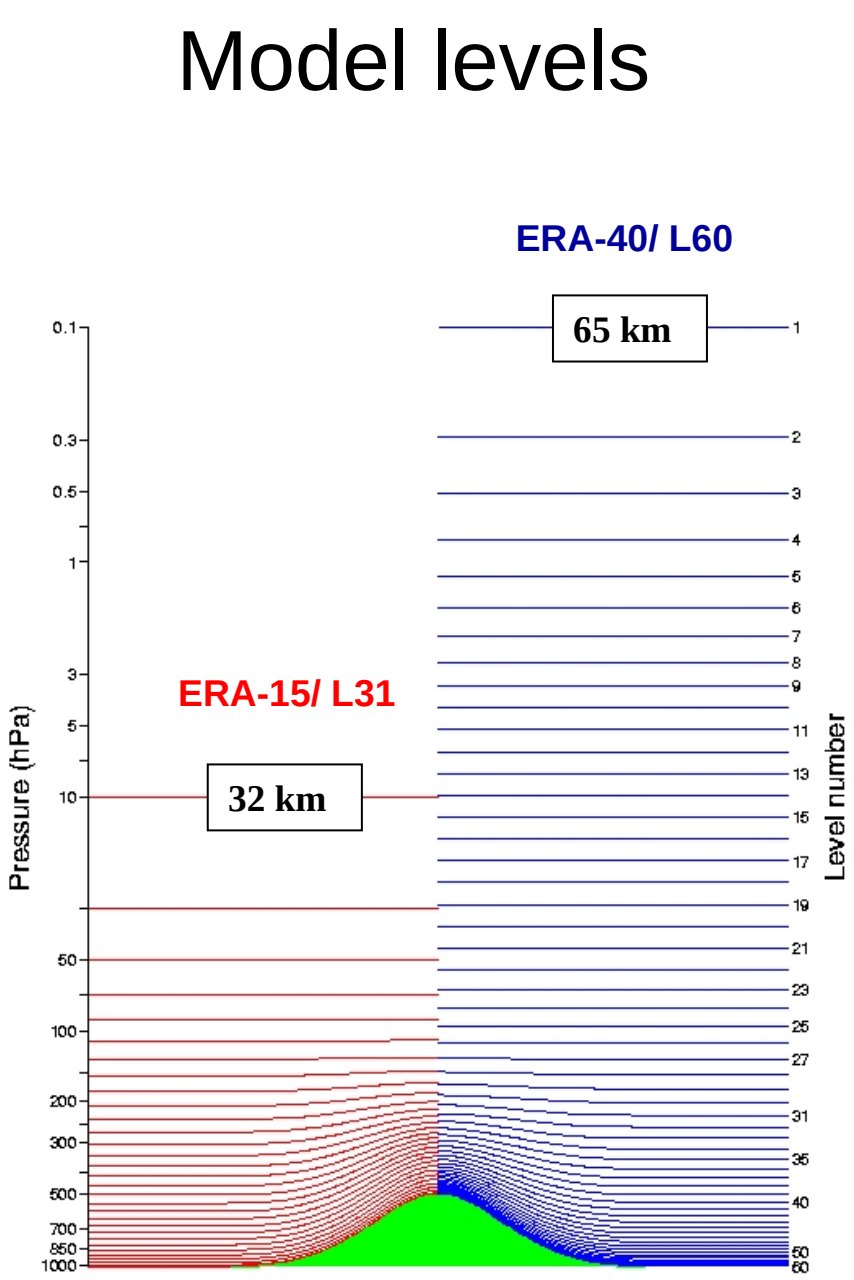



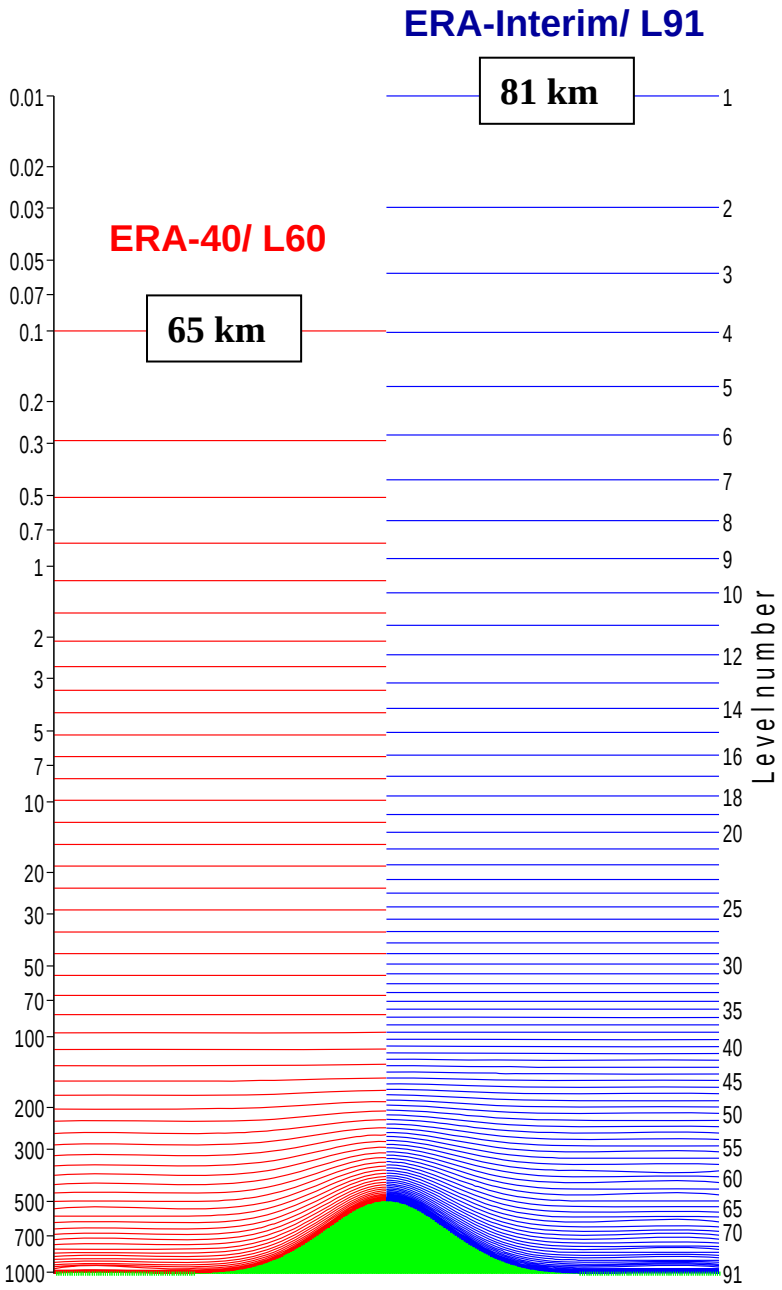

**Adaptive**




**Static**

# Model levels



ERA-Interim 1989 → to continue as CDAS

ERA-40 1957-2002

Data assimilation system CY31R1

- 12 hour 4D-Var
- T255L91
- Wavelet Jb
- New humidity analysis
- Improved model physics

ERA-Interim 1989 → to continue as CDAS

ERA-40 1957-2002

# Use of observations

- ERA-40 and ECMWF operational observations the basic input source
- Satellite level-1c radiances

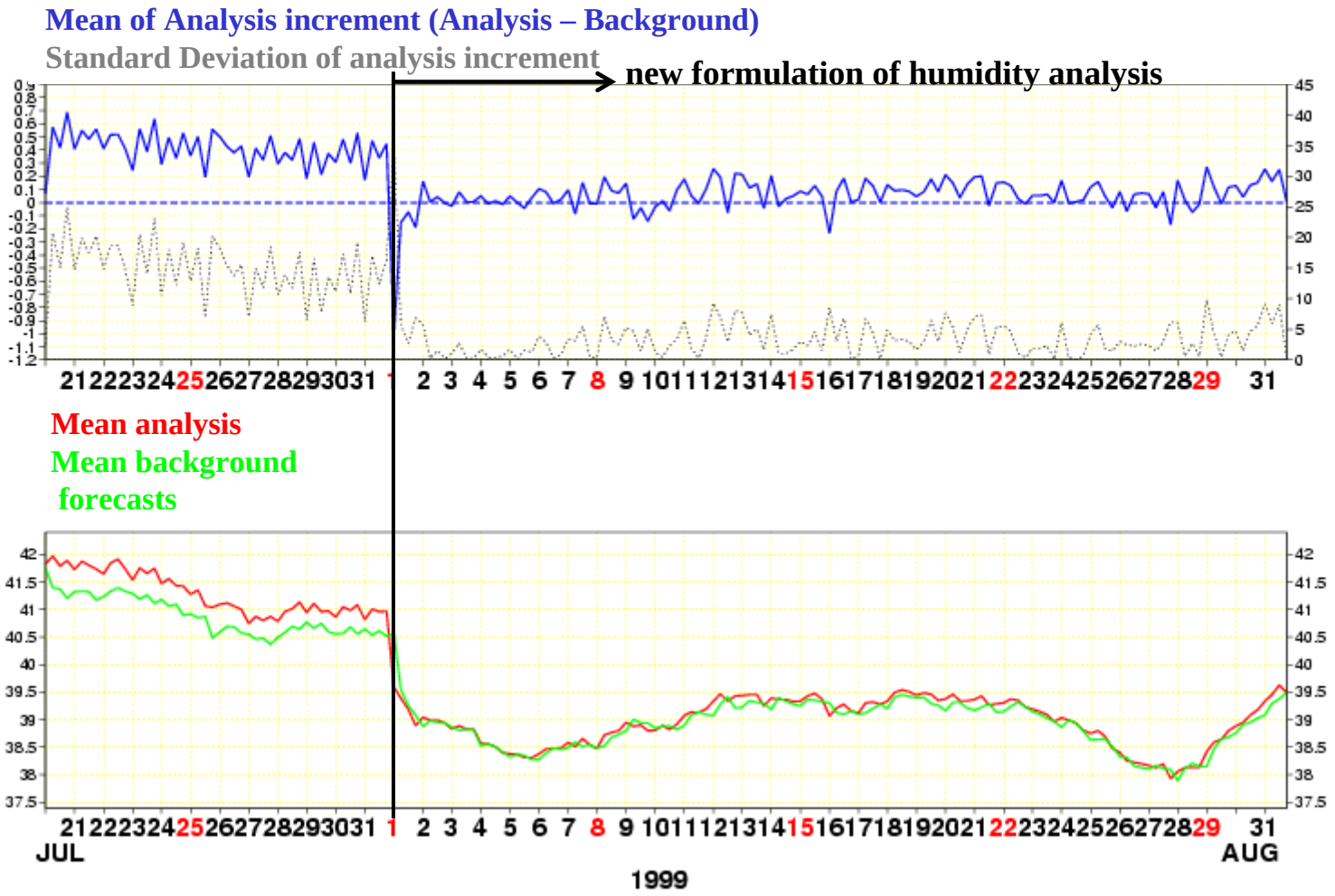
  Better RTTOV and improved use of radiances especially IR

  Assimilation of clear radiances and 1d-retrievals of rain affected radiances from SSM/I

  Adaptive bias correction
- Improved use of radiosondes

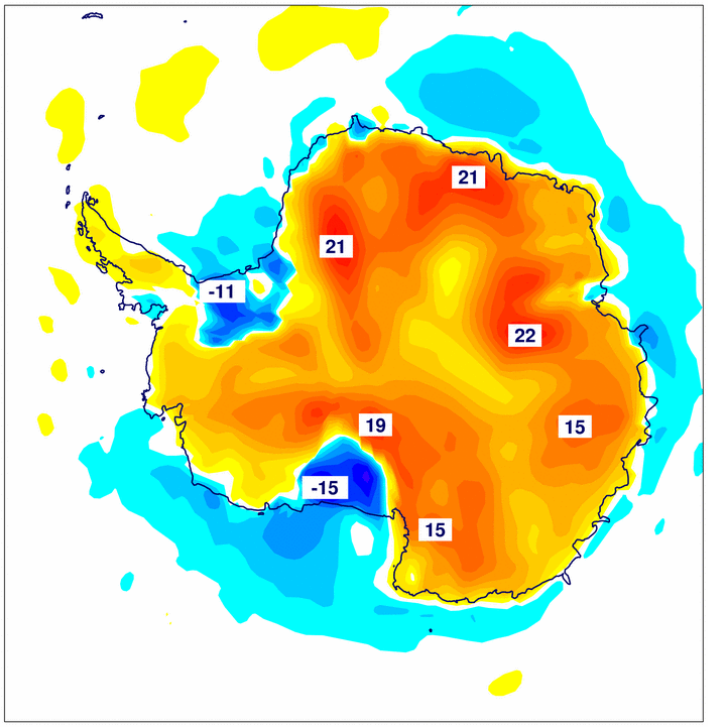
  Bias correction and homogenization based on ERA-40 and experimental runs (Leopold Haimberger)
- Correction of SHIP/ SYNOP surface pressure biases
- Use of reprocessed Meteosat winds
- Use of GOME profile data from RAL
- New set of Altimeter wave height data 1991→ (Jean Bidlot)

# Total Column Water Vapour ($kgm^{-2}$)
# ERA-40 versus the new humidity analysis
# Tropical oceans



# Mean differences between ERA-40 and ERA-15

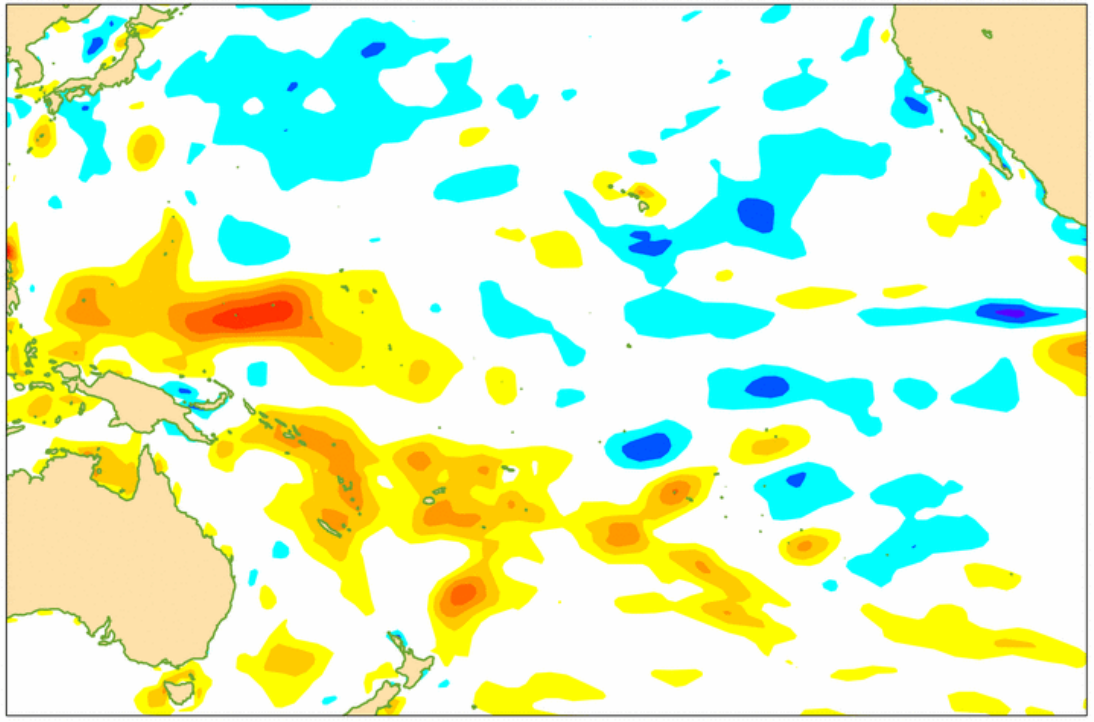
**T2m (K) July 1989**




**Contour interval 2K**

**Yellow/red indicates ERA-40 warmer than ERA-15**

**10m wind speed January 1989**

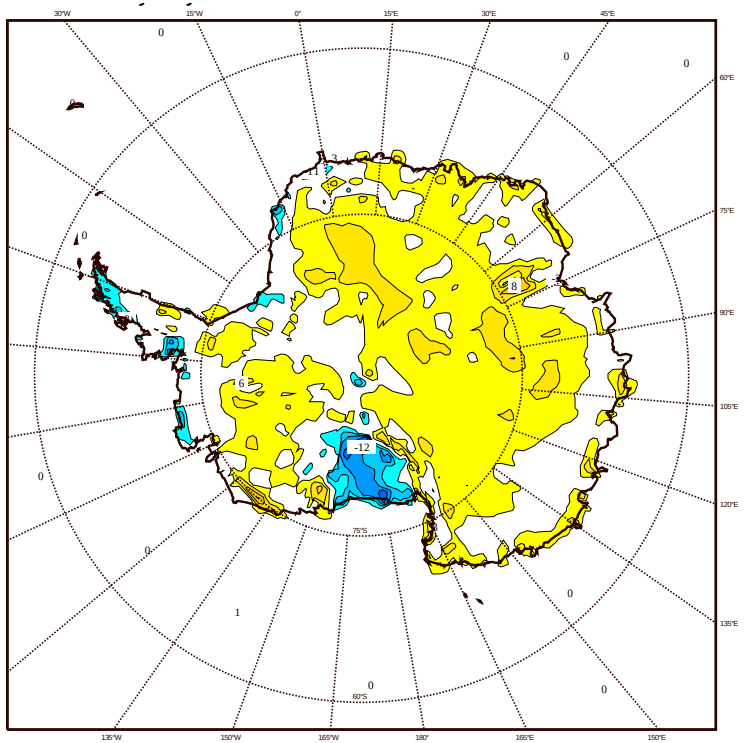


**Contour interval 0.5ms$^{-1}$**

**Yellow/red indicates ERA-40 windier than ERA-15**

# Mean differences between ERA-Interim and ERA-40

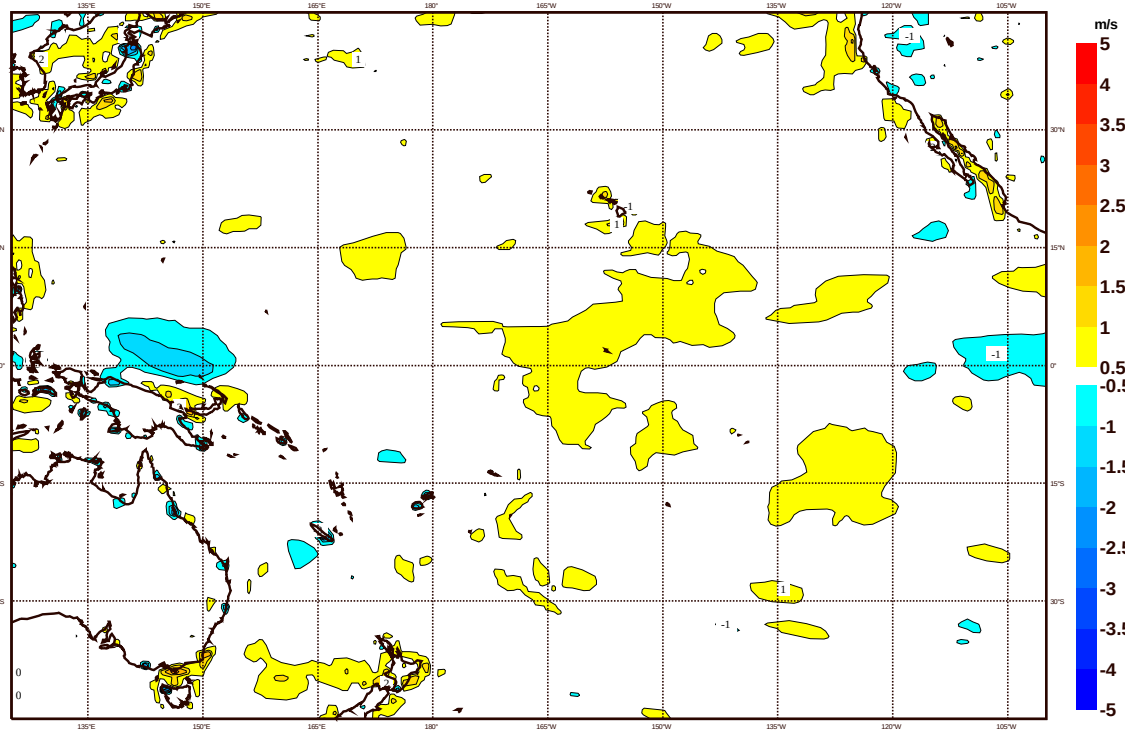
**T2m (K) June 1989**




**Contour interval 2K**

**Yellow/red indicates ERA-Interim warmer than ERA-40**

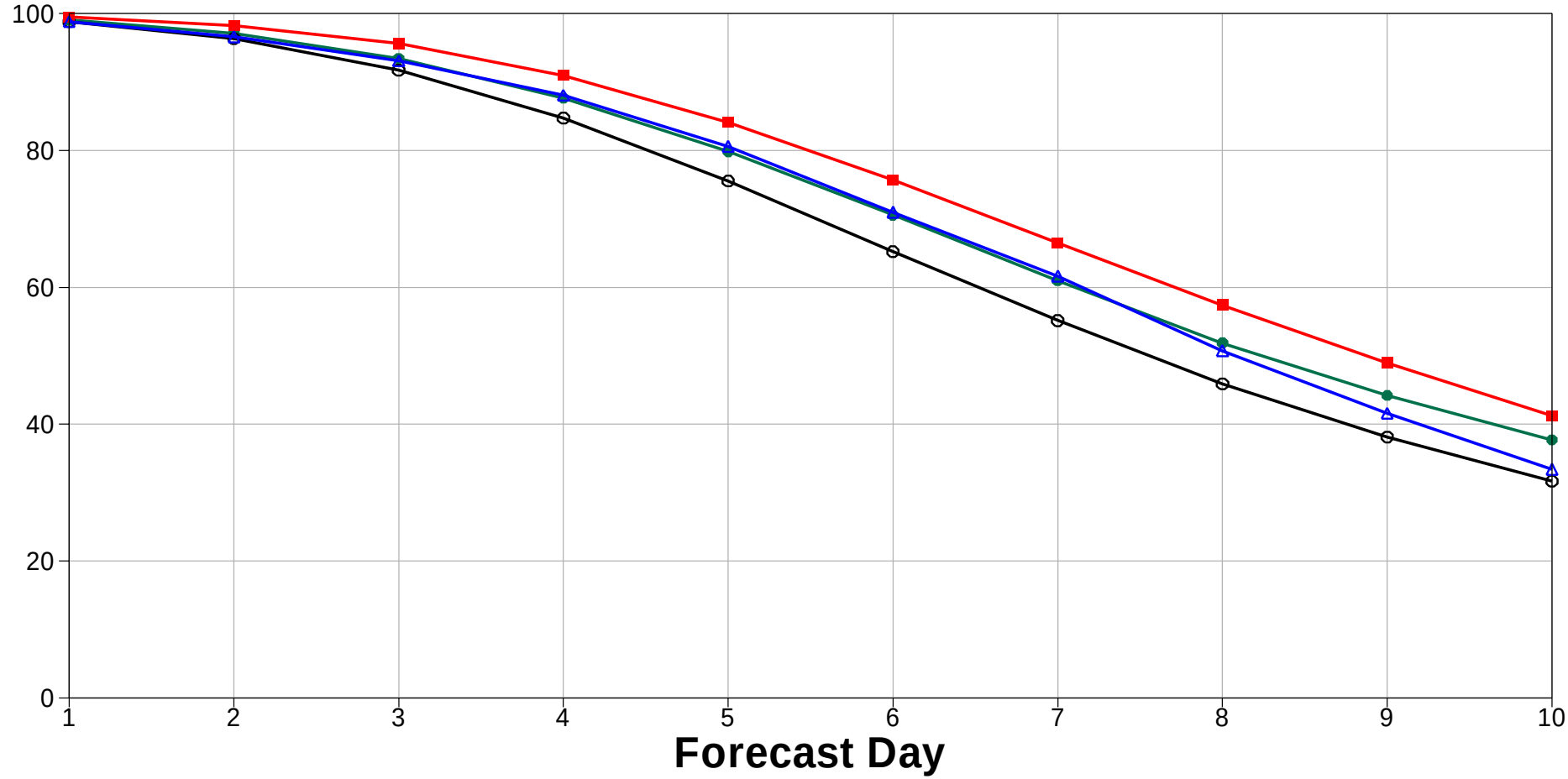
**10m wind speed January 1989**

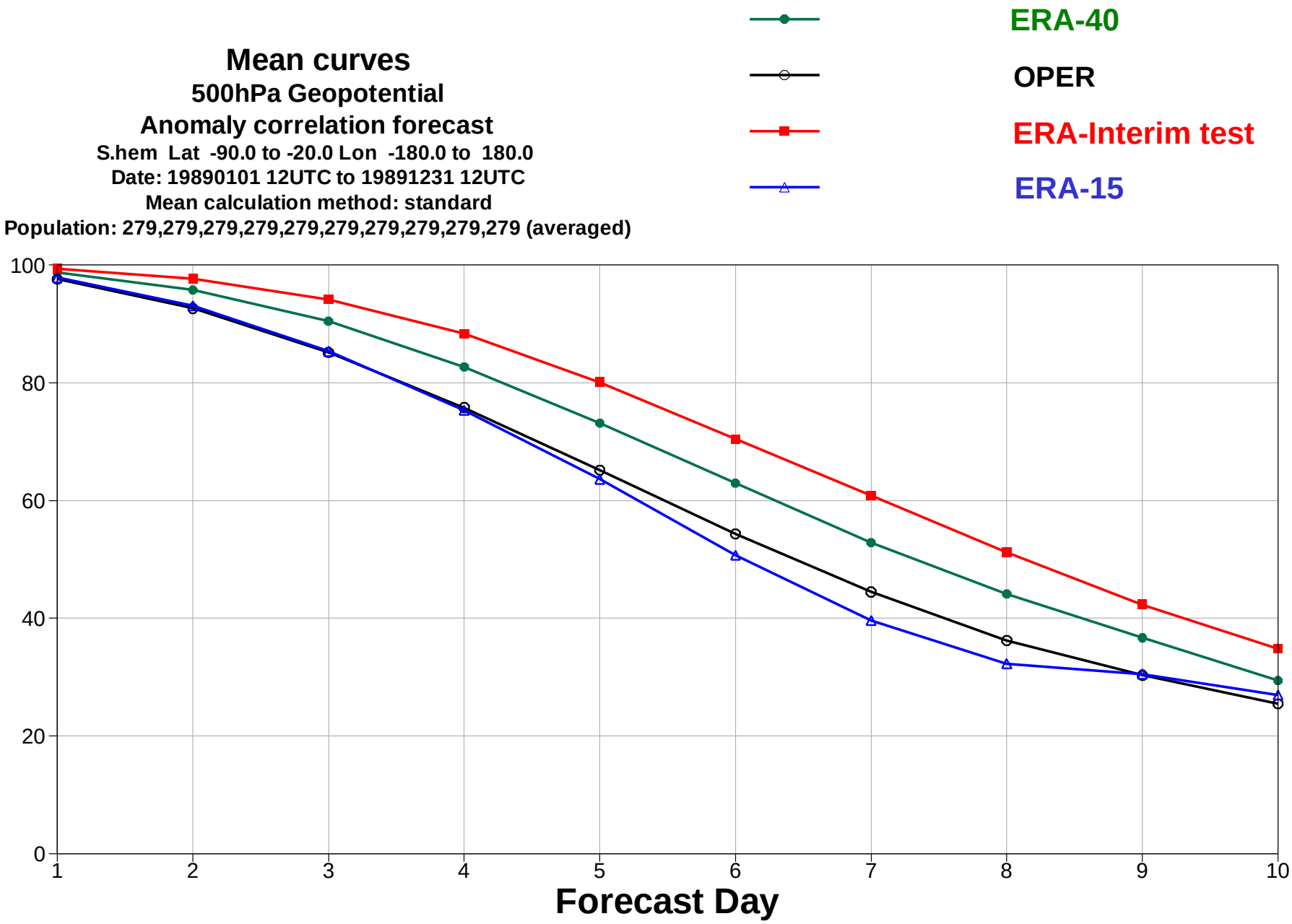


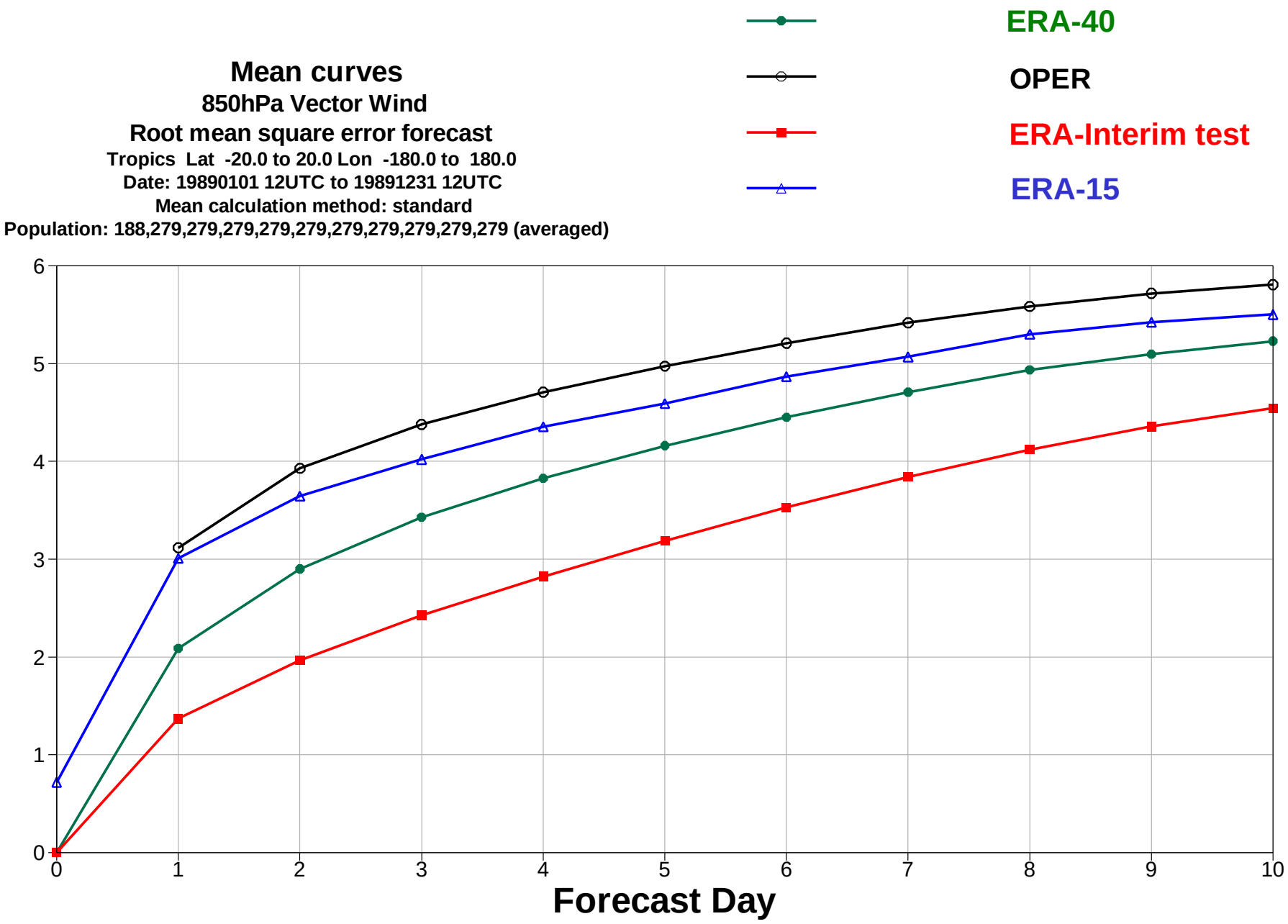

**Contour interval 0.5ms$^{-1}$**

**Yellow/red indicates ERA-Interim windier than ERA-40**

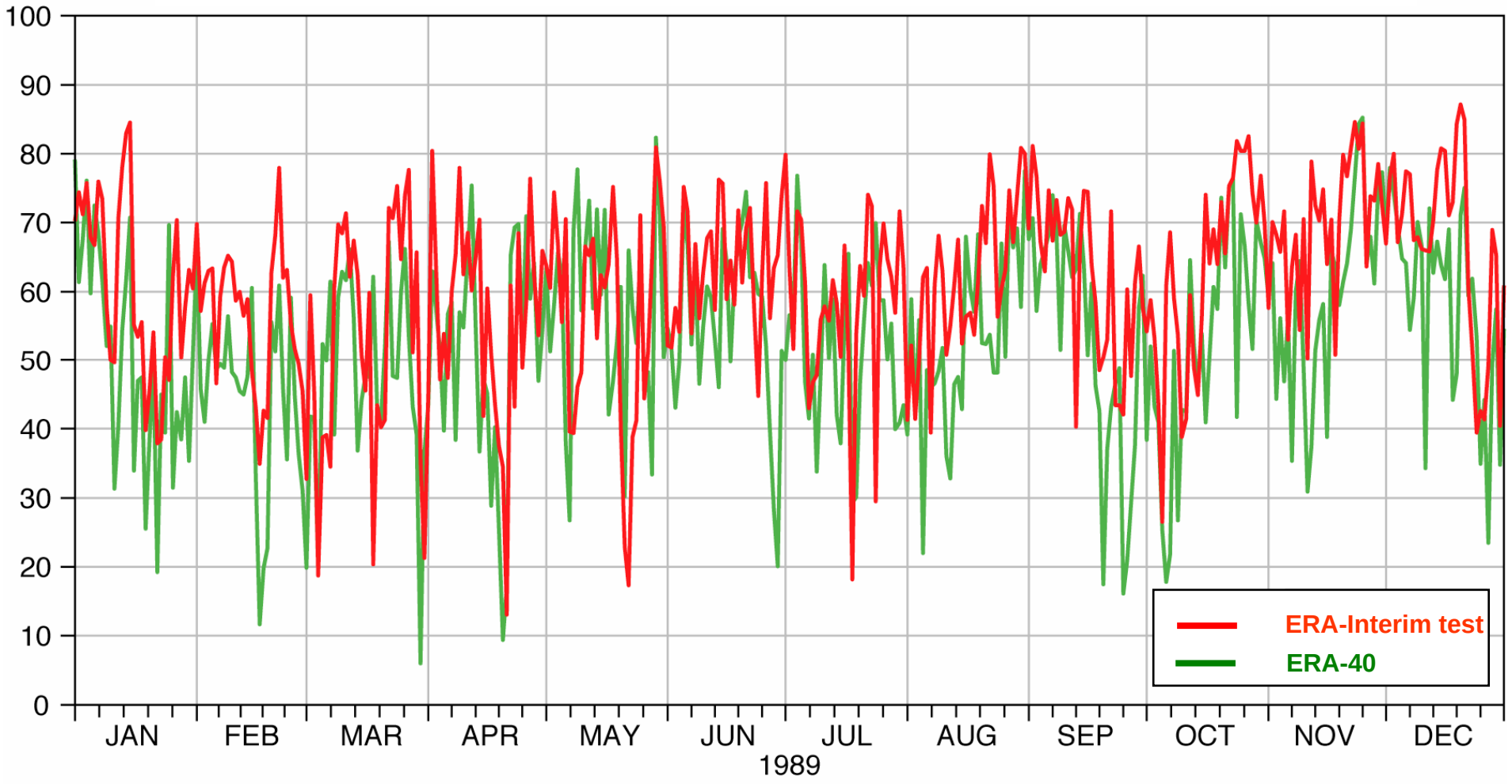
# Mean curves
## 500hPa Geopotential
## Anomaly correlation forecast
**N.hem Lat 20.0 to 90.0 Lon -180.0 to 180.0**
**Date: 19890101 12UTC to 19891231 12UTC**
**Mean calculation method: standard**
**Population: 279,279,279,279,279,279,279,279,279,279 (averaged)**




Mean curves
500hPa Geopotential
Anomaly correlation forecast
S.hem Lat -90.0 to -20.0 Lon -180.0 to 180.0
Date: 19890101 12UTC to 19891231 12UTC
Mean calculation method: standard
Population: 279,279,279,279,279,279,279,279,279,279 (averaged)
ERA-40
OPER
ERA-Interim test
ERA-15
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
Forecast Day


Mean curves
850hPa Vector Wind
Root mean square error forecast
Tropics Lat -20.0 to 20.0 Lon -180.0 to 180.0
Date: 19890101 12UTC to 19891231 12UTC
Mean calculation method: standard
Population: 188,279,279,279,279,279,279,279,279,279,279 (averaged)
ERA-40
OPER
ERA-Interim test
ERA-15
0
1
2
3
4
5
6
0
1
2
3
4
5
6
7
8
9
10
Forecast Day

# Time series of daily D+7 forecast anomaly correlations
## Southern Hemisphere



# ERA-Interim

# ERA-70?

- **Could start in 2010 depending on resources**
- **~ 1940 →**
- **Important components**

  **<u>Recovery, organization and homogenization of observations</u>**

  **<u>Improved SST & ICE dataset</u>**

  } !!

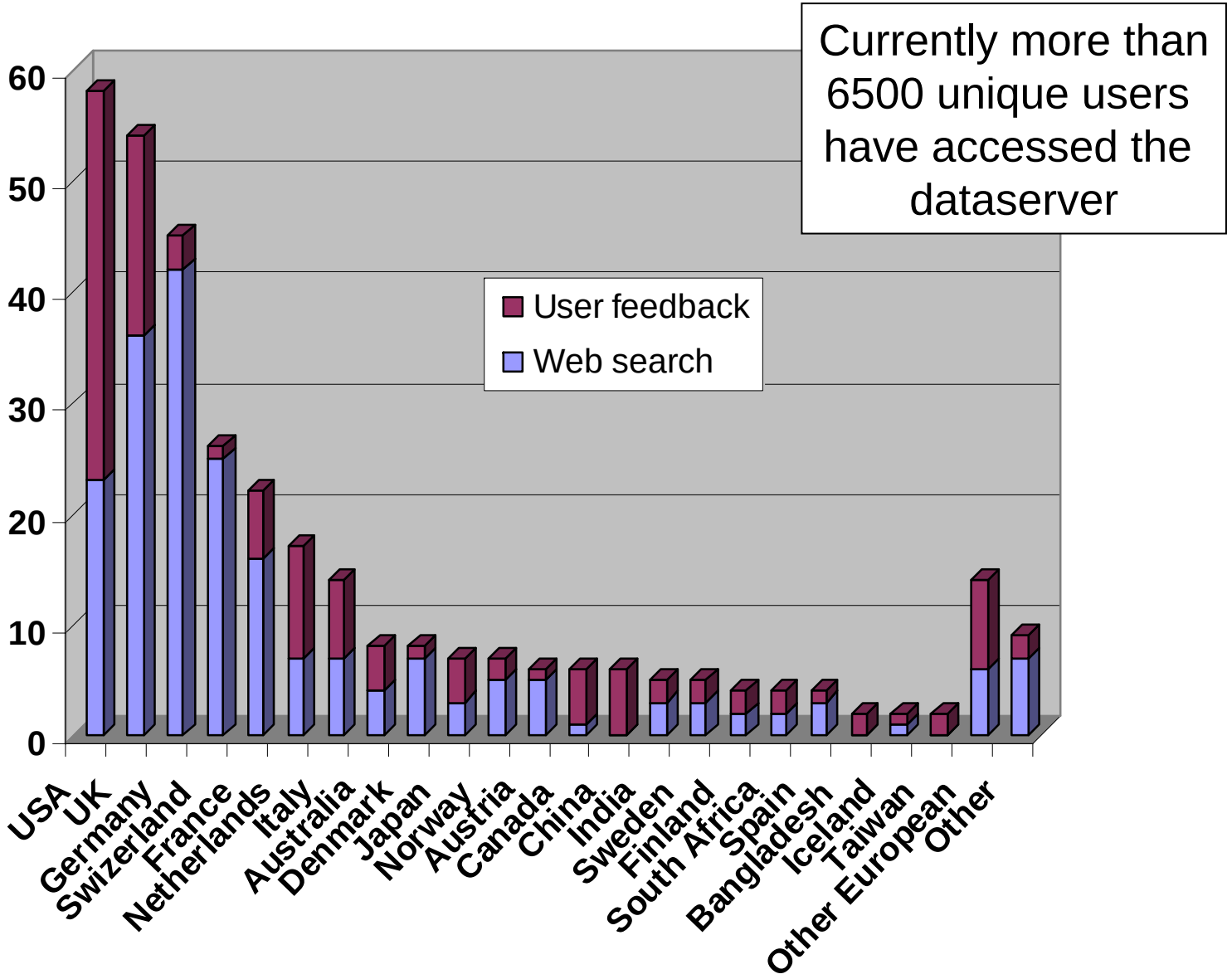
  **Variational analysis technique aimed for reanalysis**

  **Comprehensive adaptive bias handling**

  **Handling of model biases**

# Survey on the use of ERA-40 from web

http://www.ecmwf.int/research/era/era40survey/



# ERA-40 Atlas
## Top 20: Feb-June 2006

Number of unique users requesting images : 1406