Numerical Weather Prediction (NWP): Current and future challenges

Dominique Marbouty

European Centre for Medium-Range Weather Forecasts

Reading – United Kingdom

www.ecmwf.int

With input from D Richardson, A Simmons, J-N Thepaut, W Zwieflhofer

Supporting States and Co-operation

Belgium
Denmark
Germany
Spain
France
Greece
Ireland
Italy
Luxembourg
The Netherlands
Norway
Austria
Portugal
Switzerland
Finland
Sweden
Turkey
United Kingdom

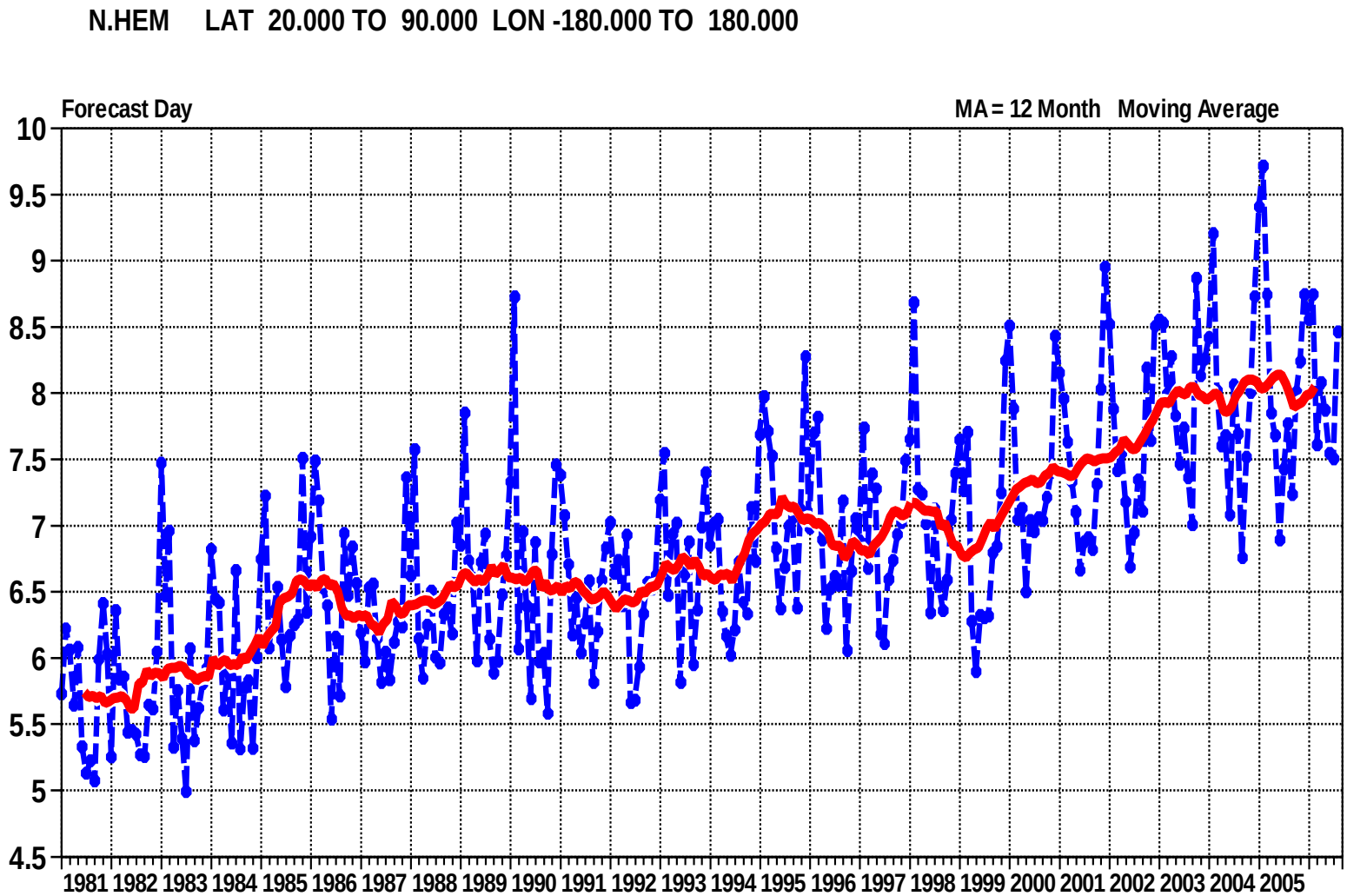
Co-operation agreements or working arrangements with:

Czech Republic
Croatia
Estonia
Hungary
Iceland
Lithuania
Morocco
Romania
Serbia
Slovenia
ACMAD
ESA
EUMETSAT
WMO
JRC
CTBTO
CLRTAP

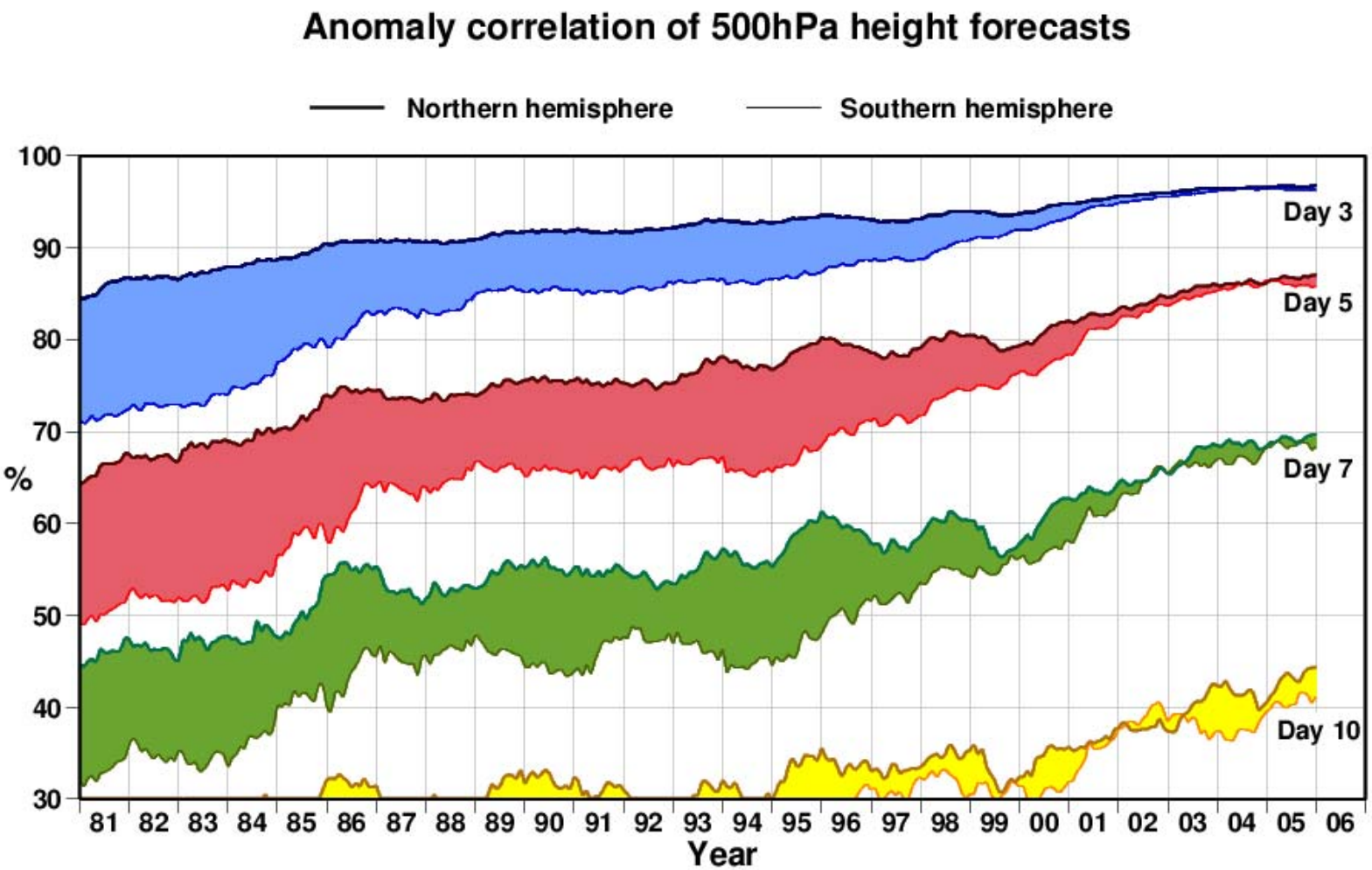
Plan

- **Recent progresses**
  - **Improved performance**
  - **Use of satellite data**
  - **Severe Weather**
  - **Ensemble forecasting**
- **Future challenges**
  - **Use of satellite data**
  - **HPC**
  - **Severe Weather: early warning**
  - **Multidisciplinarity**
  - **Unified system from weather to climate**

Evolution over 25 years

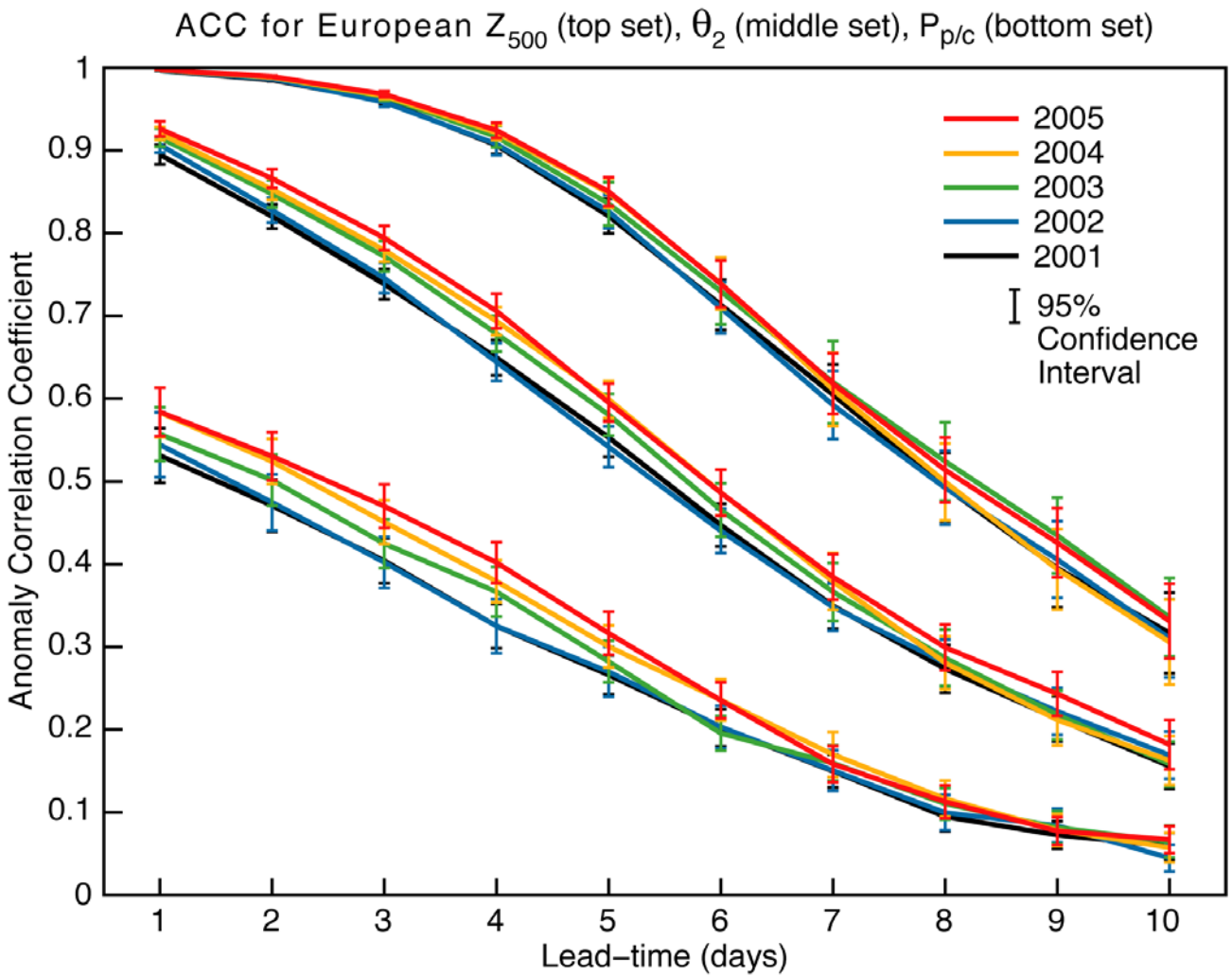


Evolution of deterministic forecasts scores



ECMWF

Weather oriented scoring methods



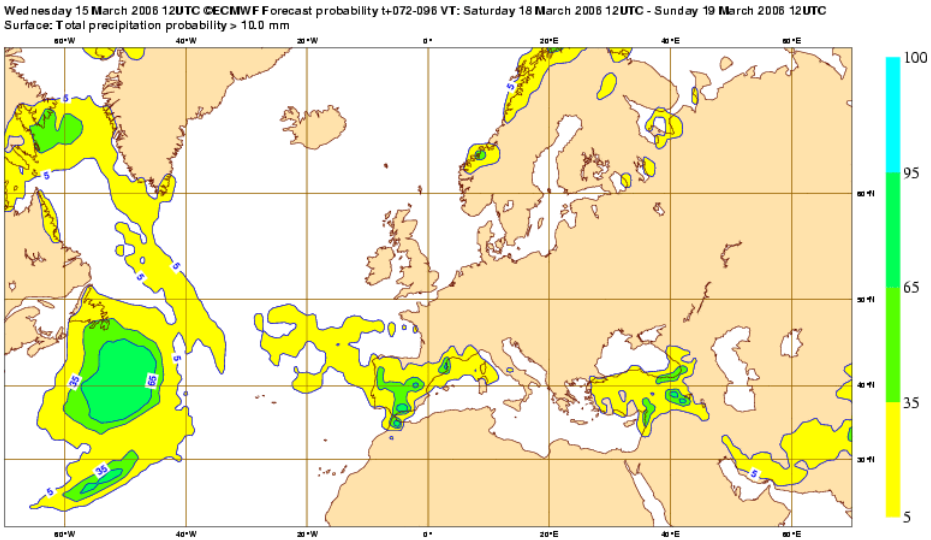
Z500

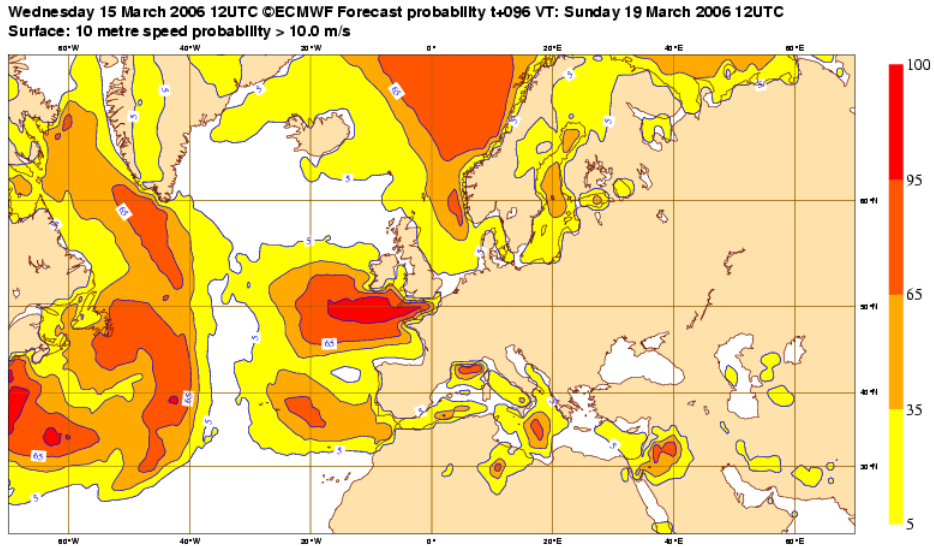
PV2

24h Precip

ECMWF

EPS forecasts (field probabilities)





Probability of precipitation more than 10mm in 24 hours

Probability of 10m wind speed more than 10 m/s

Base Wed. 15/03/06 12UTC, Valid Sun 19/03/06 12UTC

EFI Europe

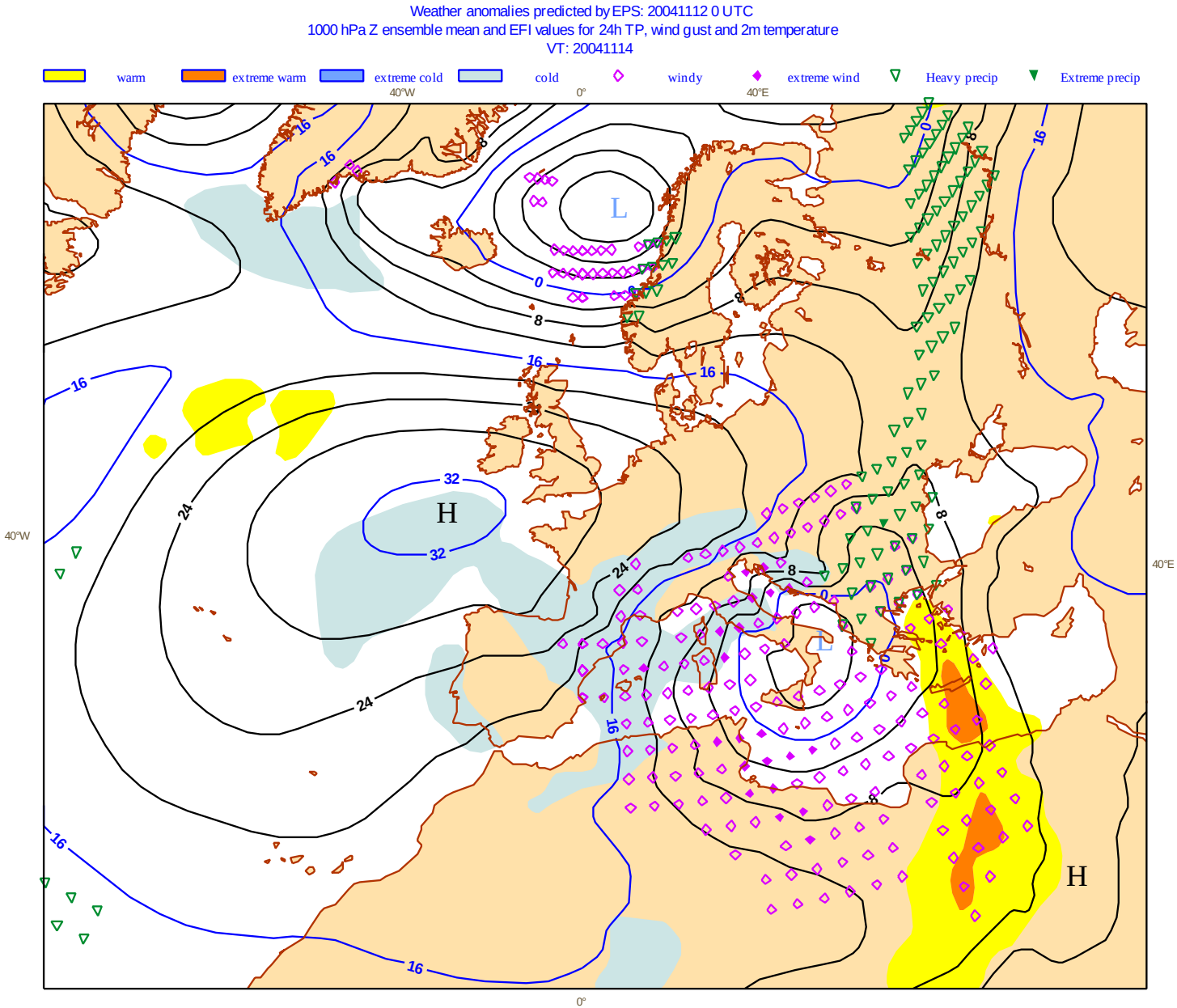
14/11/04

Weather risk map

Location-dependent

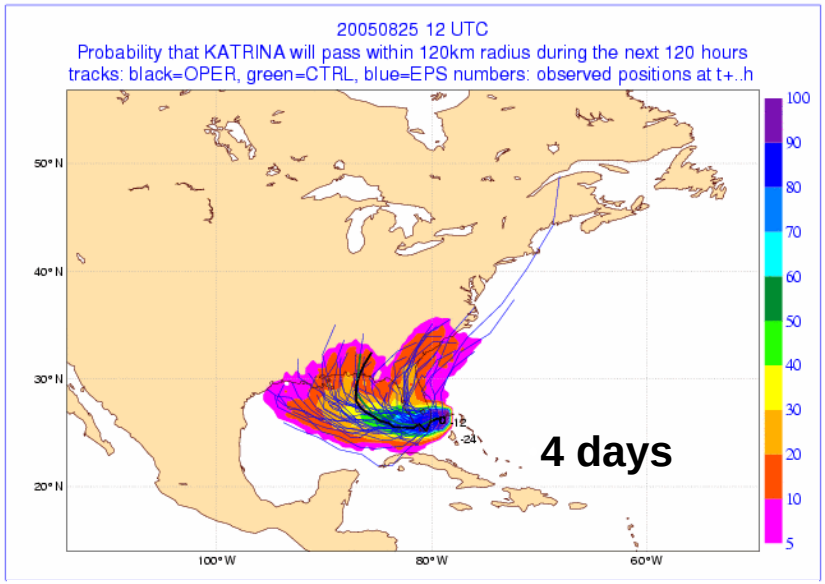
Model grid

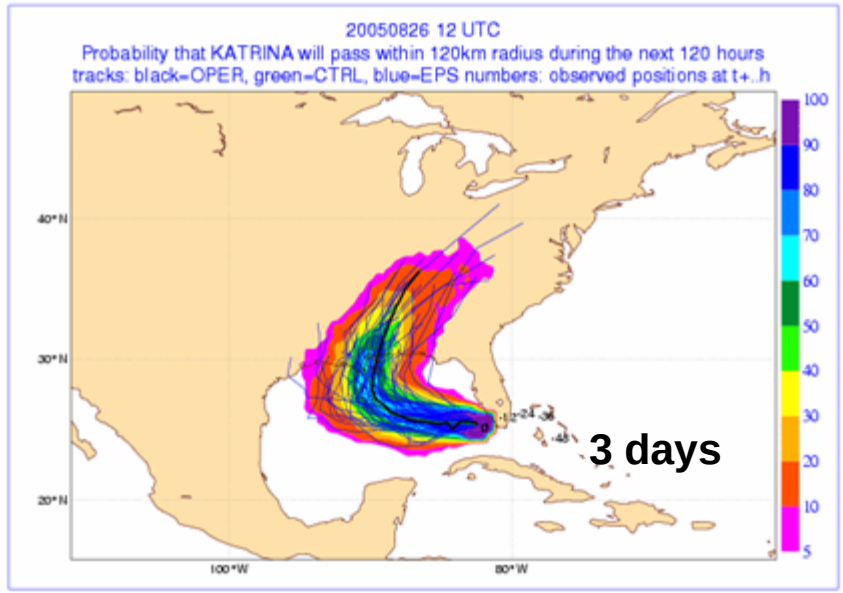
Interactive

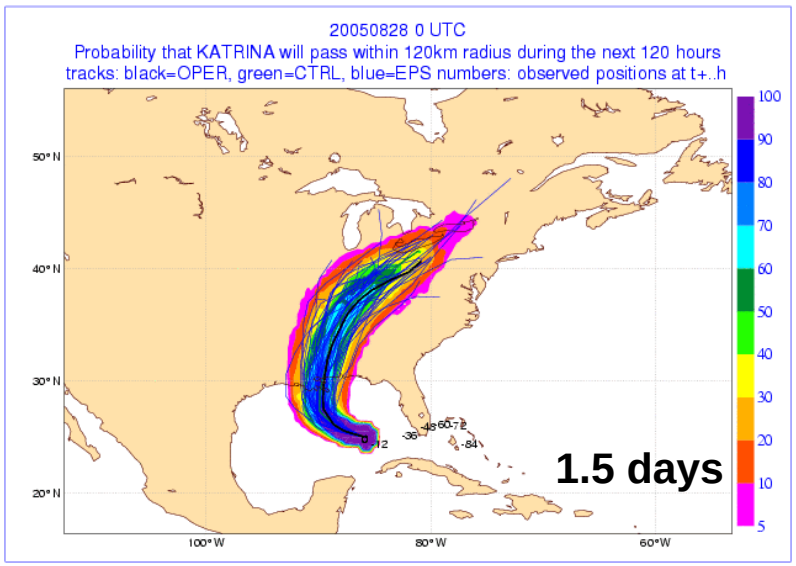


ECMWF

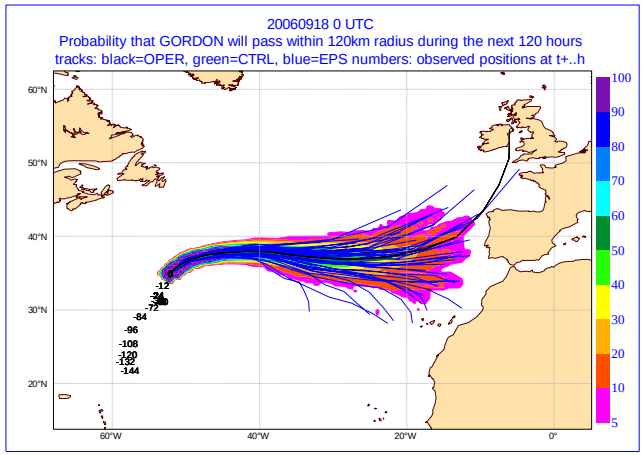
Katrina forecasts (days from landfall)

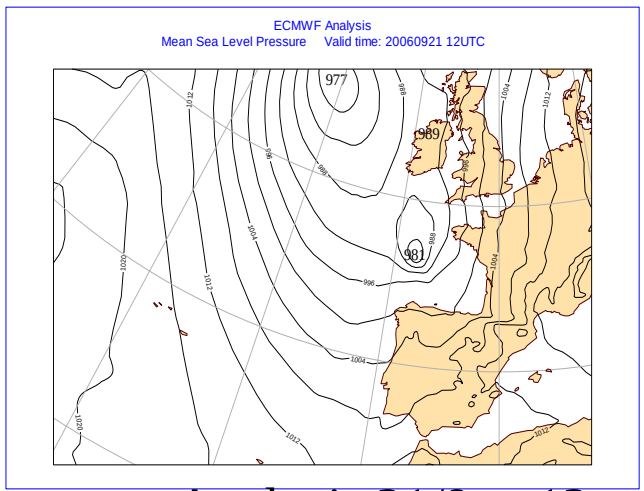






Severe Weather: Gordon forecast

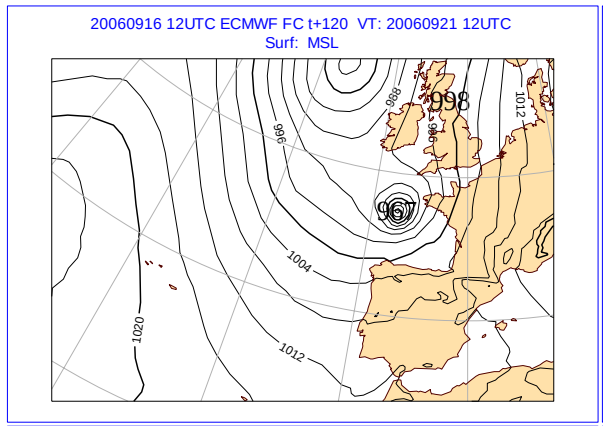




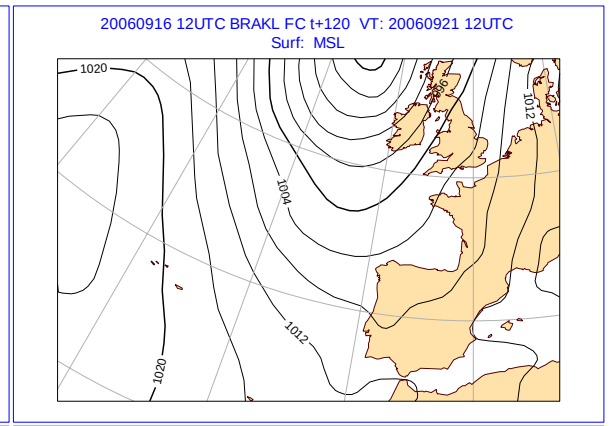
Analysis 21/9 at 12

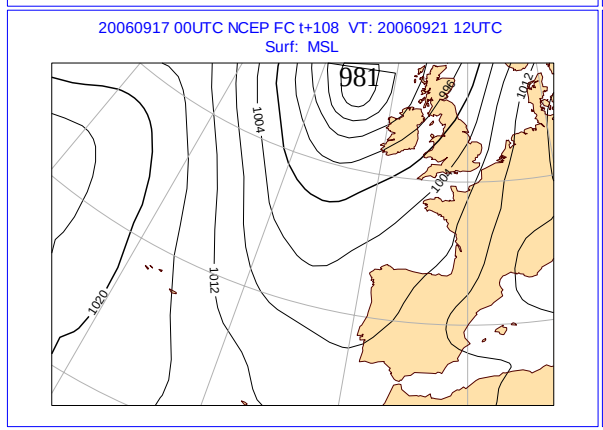
5 Days forecast for 21/9 at 12

ECMWF

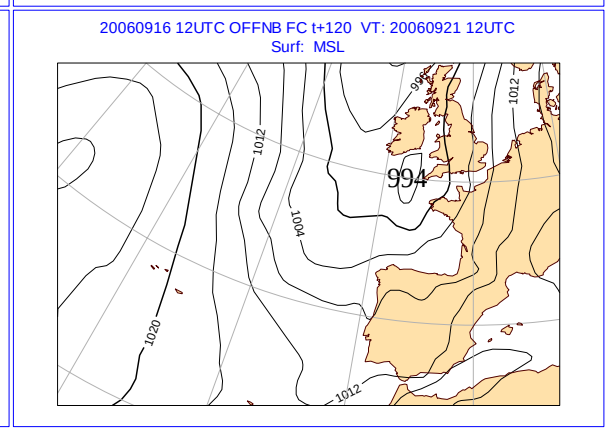


UK MO





NCEP



DWD

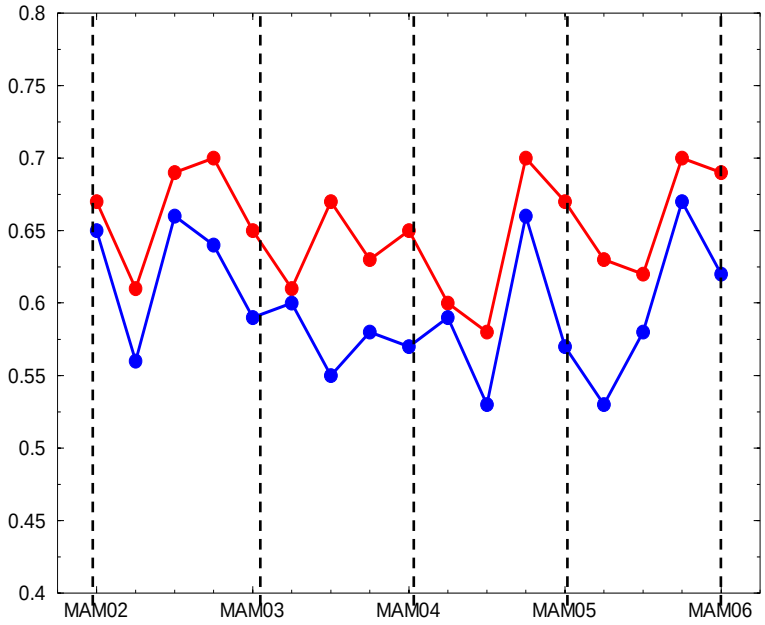
Performance over the Northern Extratropics

ROC area of probability of 2-meter temperature in upper tercile

Monthly Forecast

Persistence of day 5-11

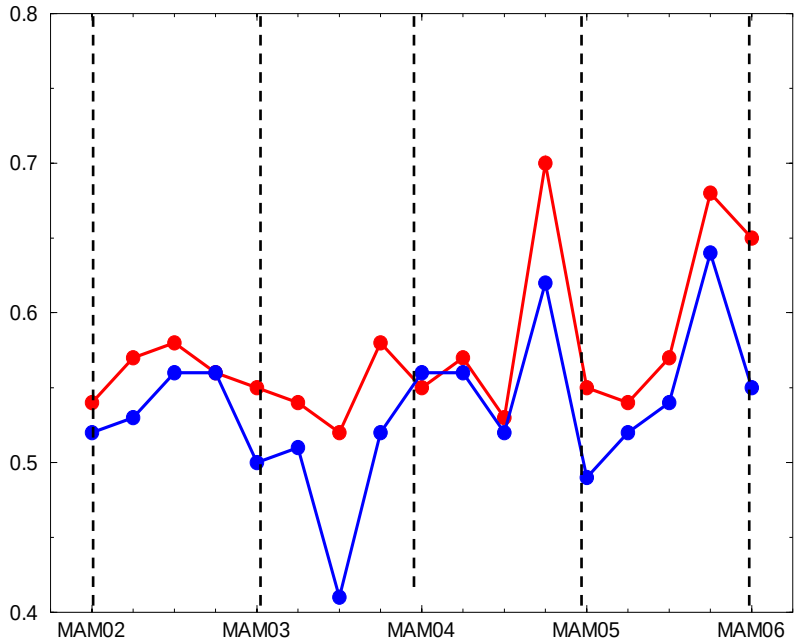
Day 12-18



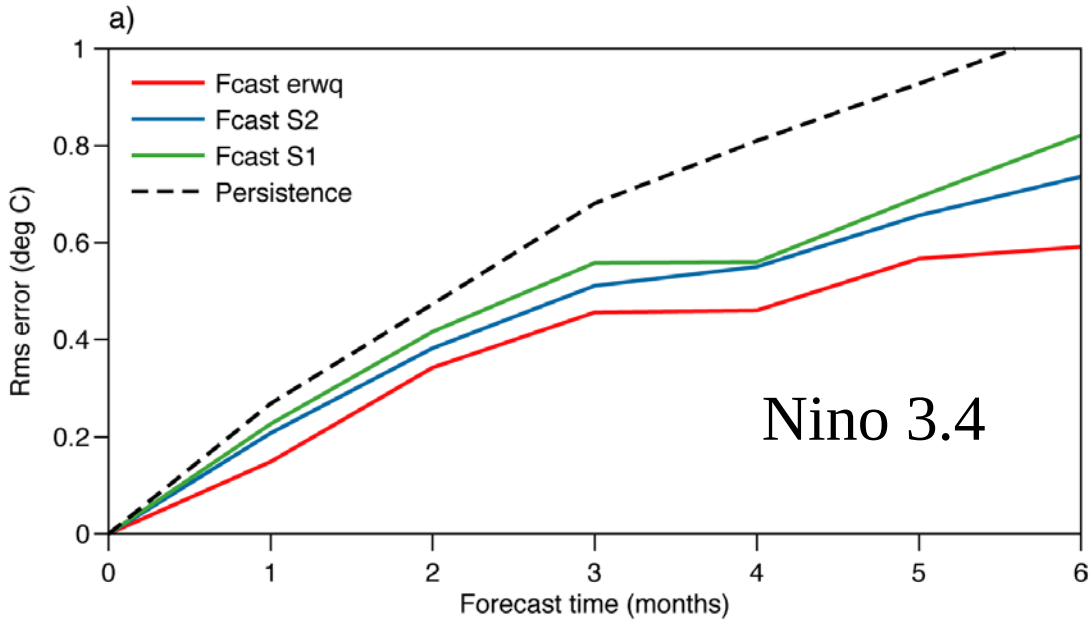
Monthly Forecast

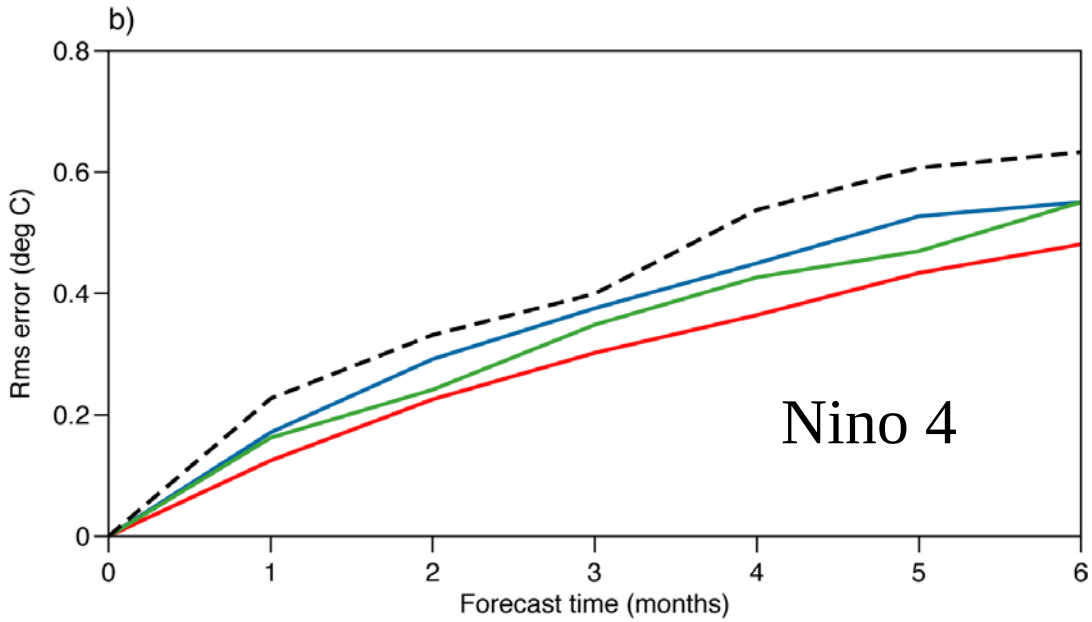
Persistence of day 12-1

Day 19-32



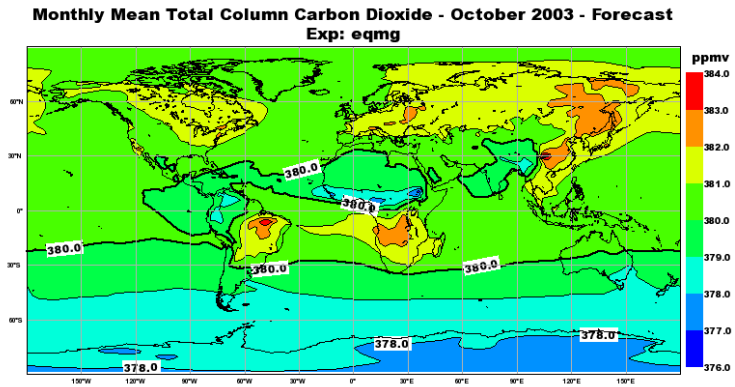
Seasonal Forecast Scores



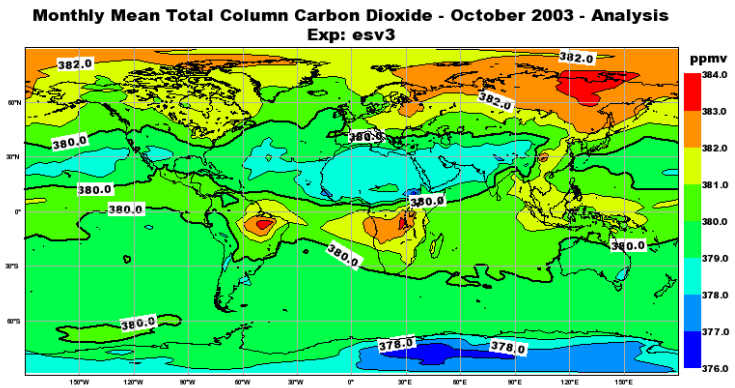


- **System 3**
- **System 2**
- **System 1**
- **Persistence**

GEMS: including chemistry in models

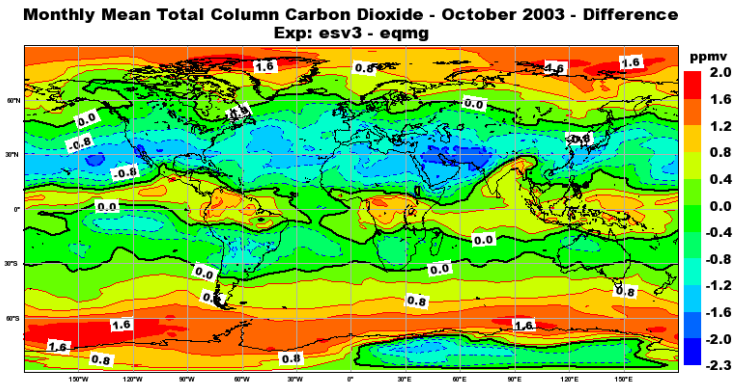


Free-running CO_2



Analysed CO_2

Monthly mean total column CO2 after 3 month assimilation (top right) shows small but significant changes (bottom right) to a simulation with free-running CO2 (top left). It is too early to draw conclusions

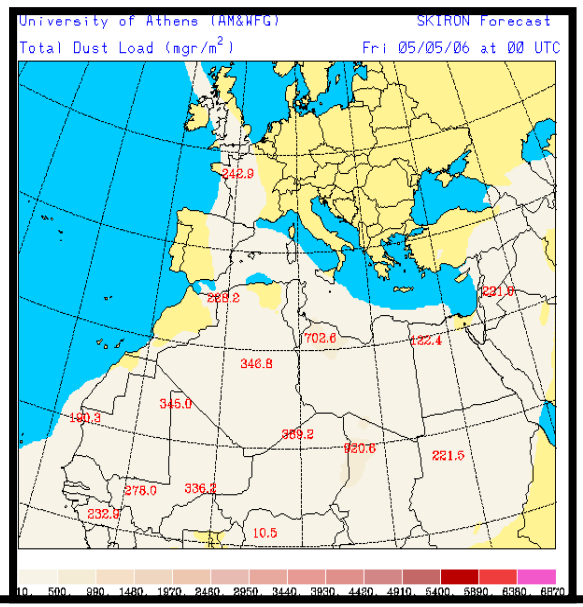


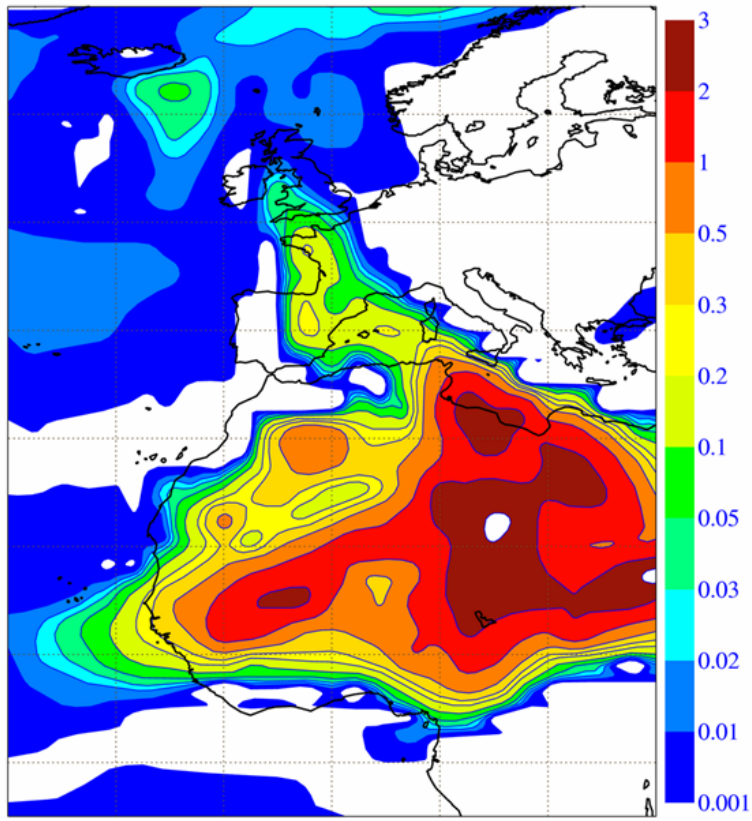
Difference

ECMWF

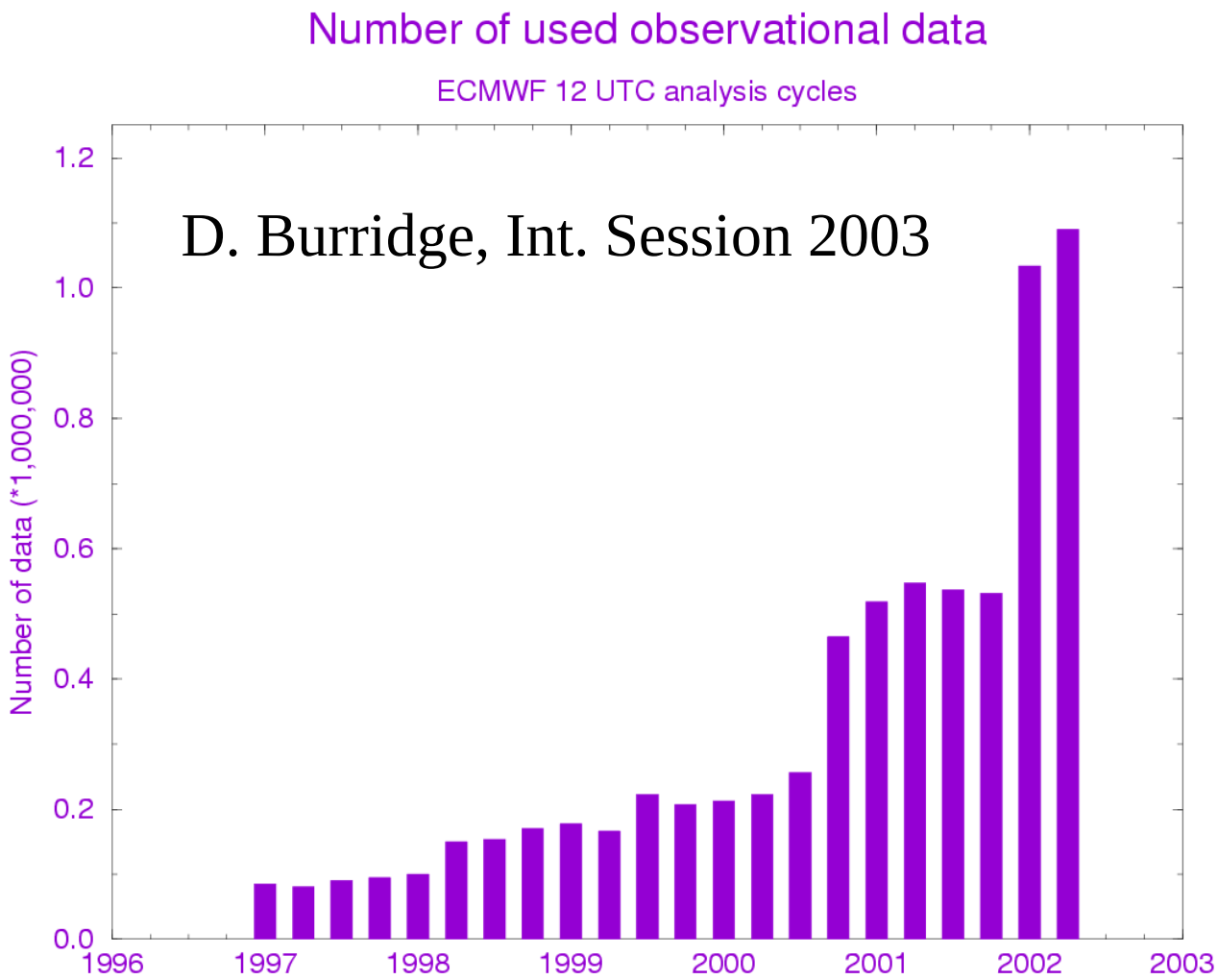
Aerosol

(right) 1 day forecast with first version of aerosol model (A1: sea salt and desert dust)
(below) verification data



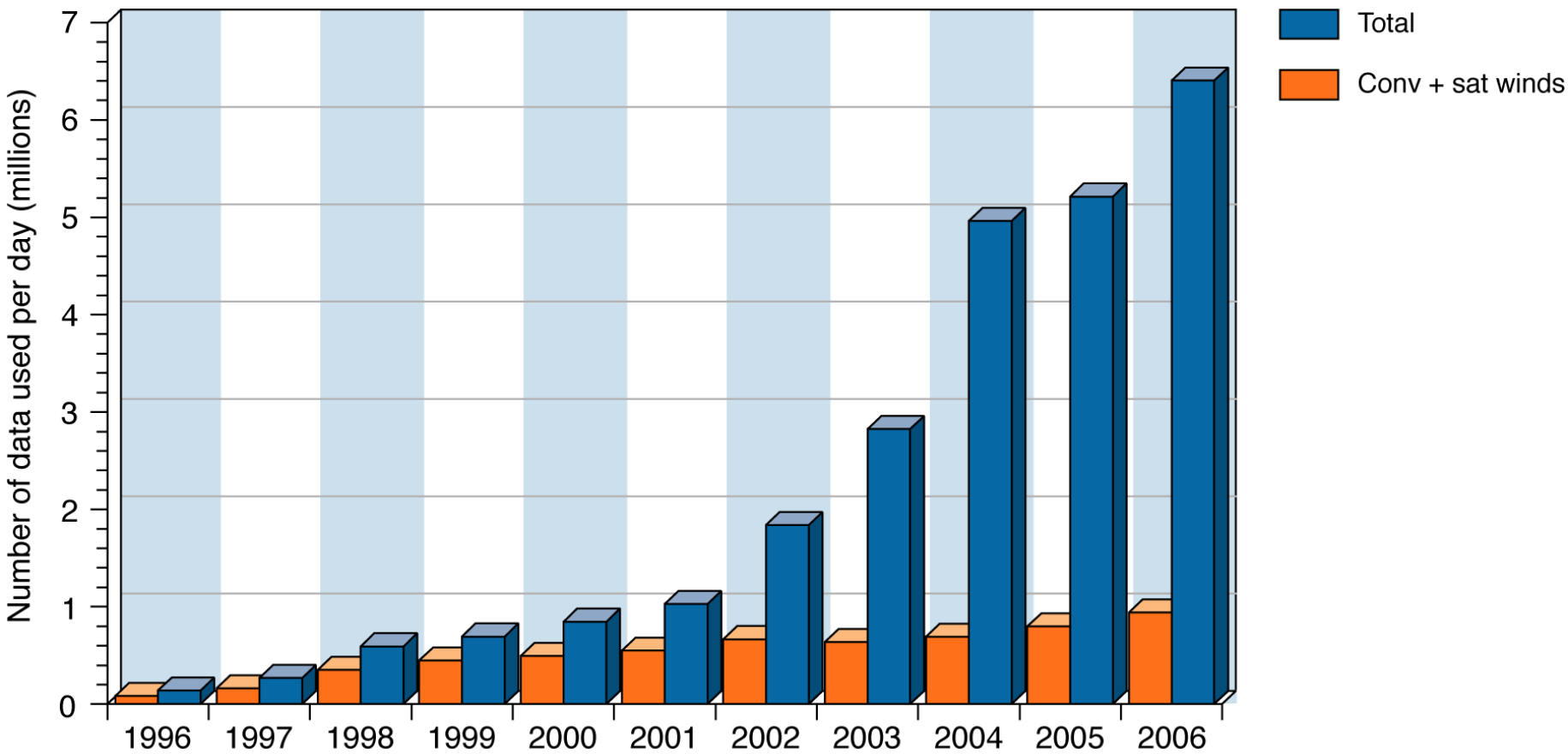


Aerosol optical depth at 0.55 micron
00UTC 5 May 2006

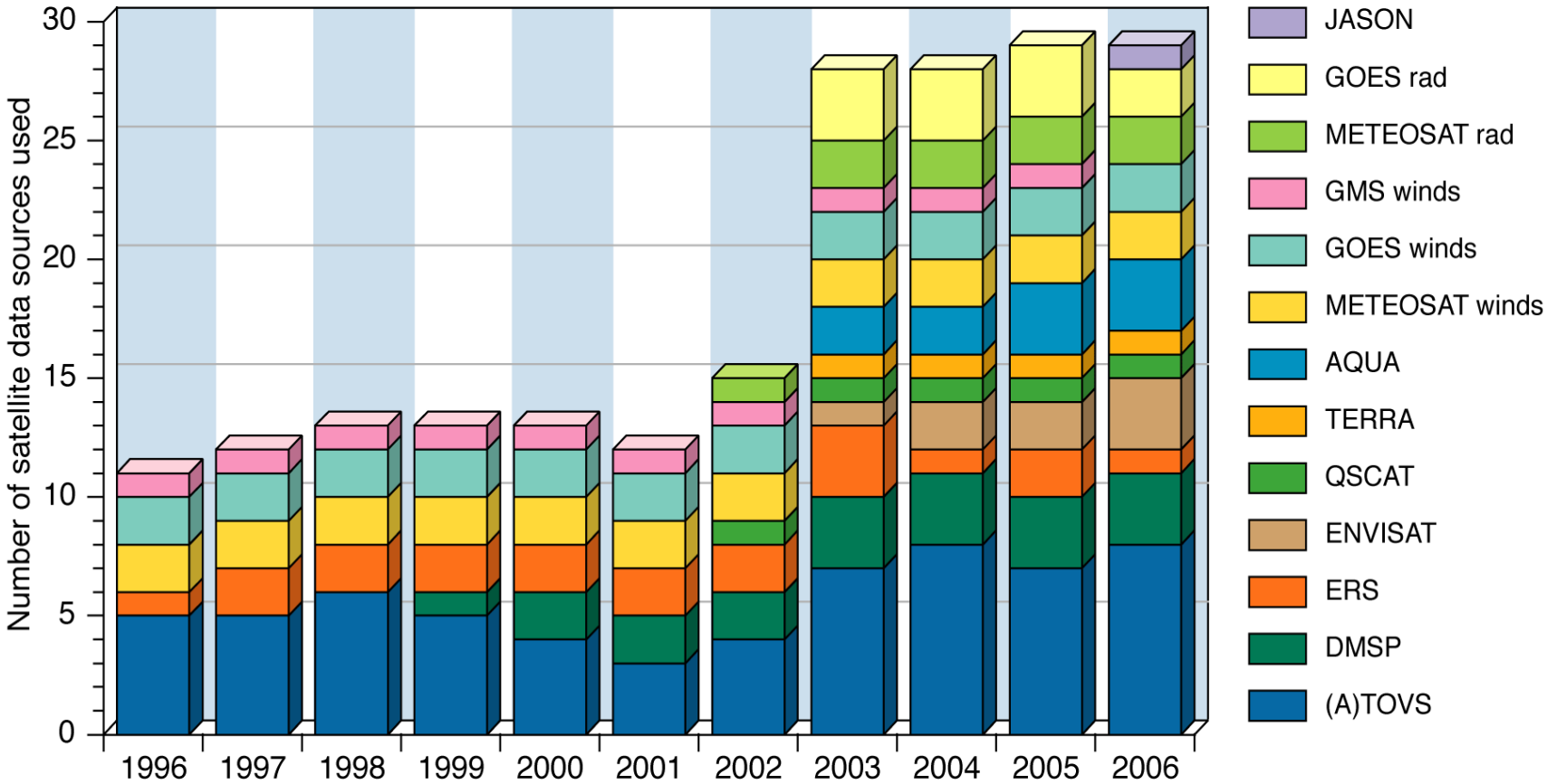


Number of used observational data per 12 UTC cycle in ECMWF's operational assimilation system, 1997-2002.

Number of data used per day at ECMWF

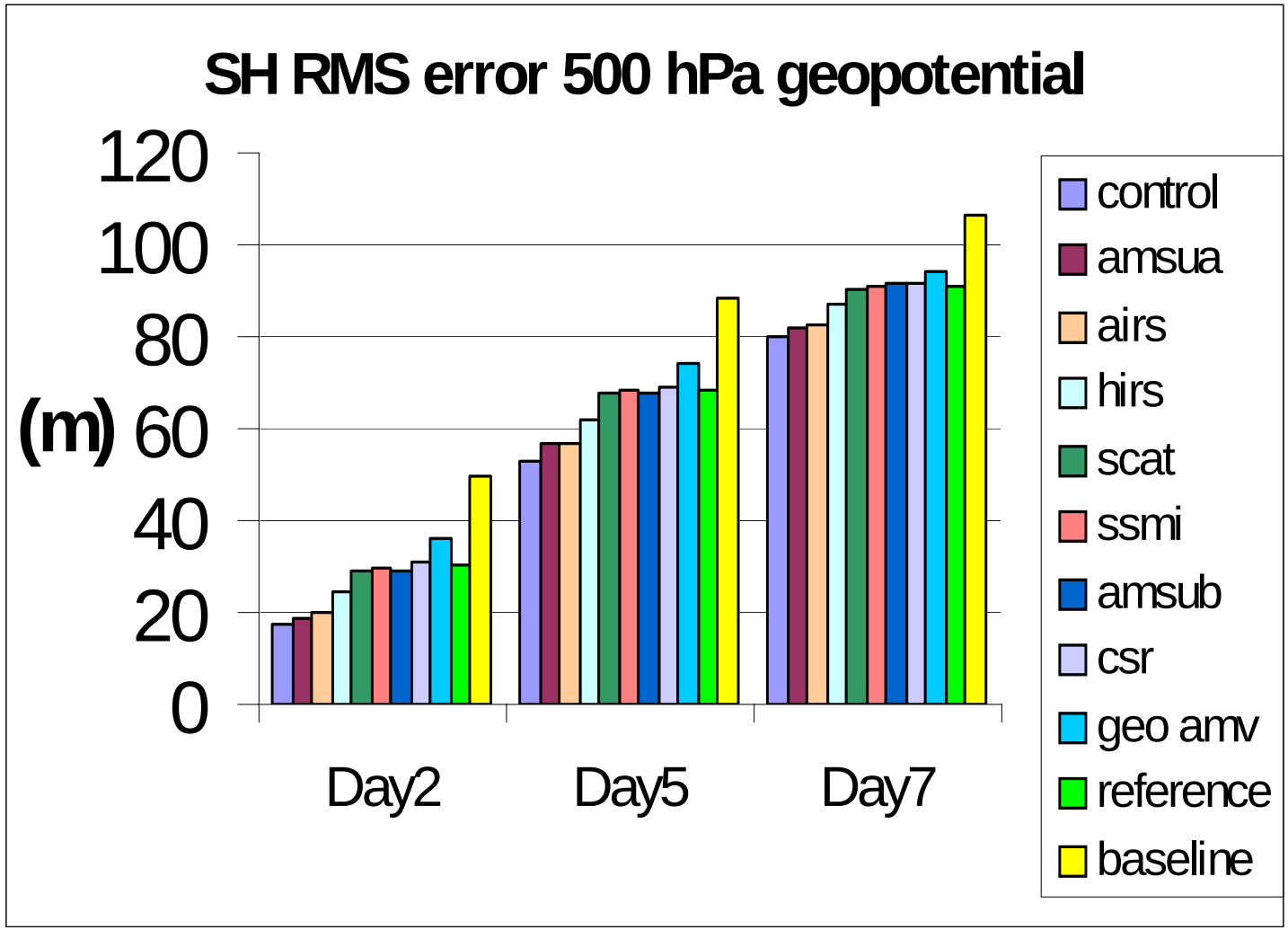


Number of satellite instruments assimilated at ECMWF

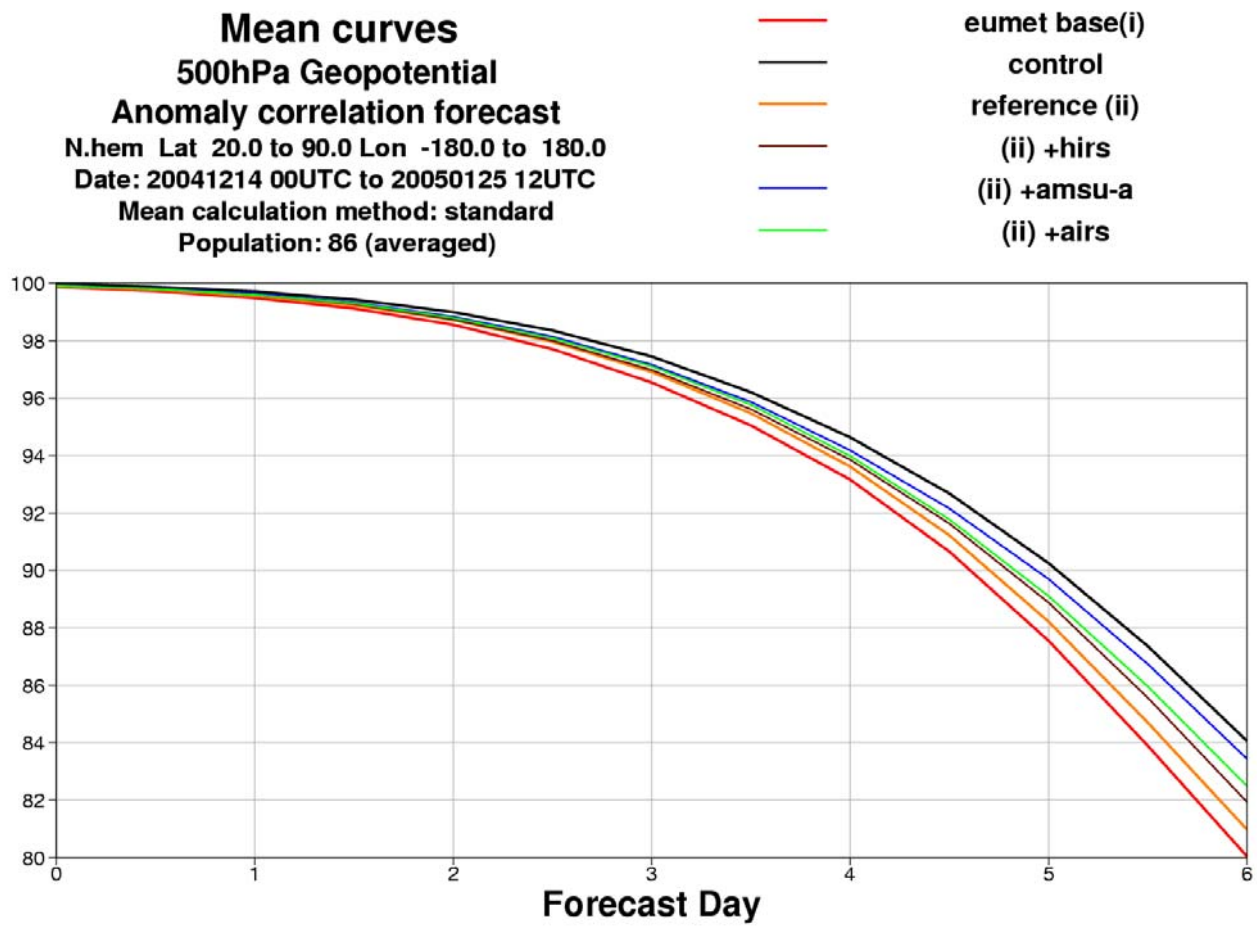


Observing System experiments

- **Control: all**
- **Baseline: conv only**
- **Reference: baseline + AMV**
- **Others: reference + instrument**

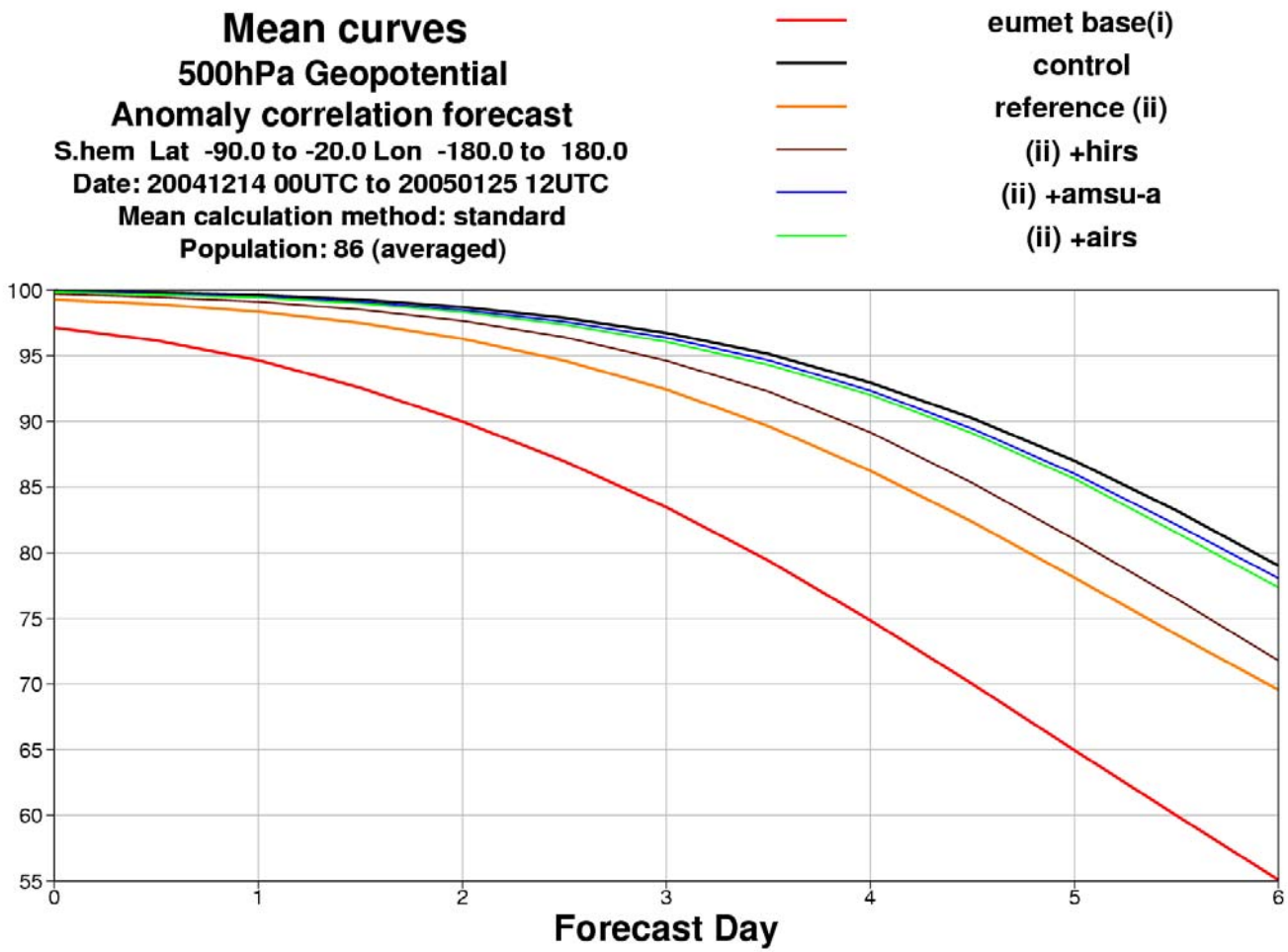


Impact of various satellite data in the Northern Hemisphere

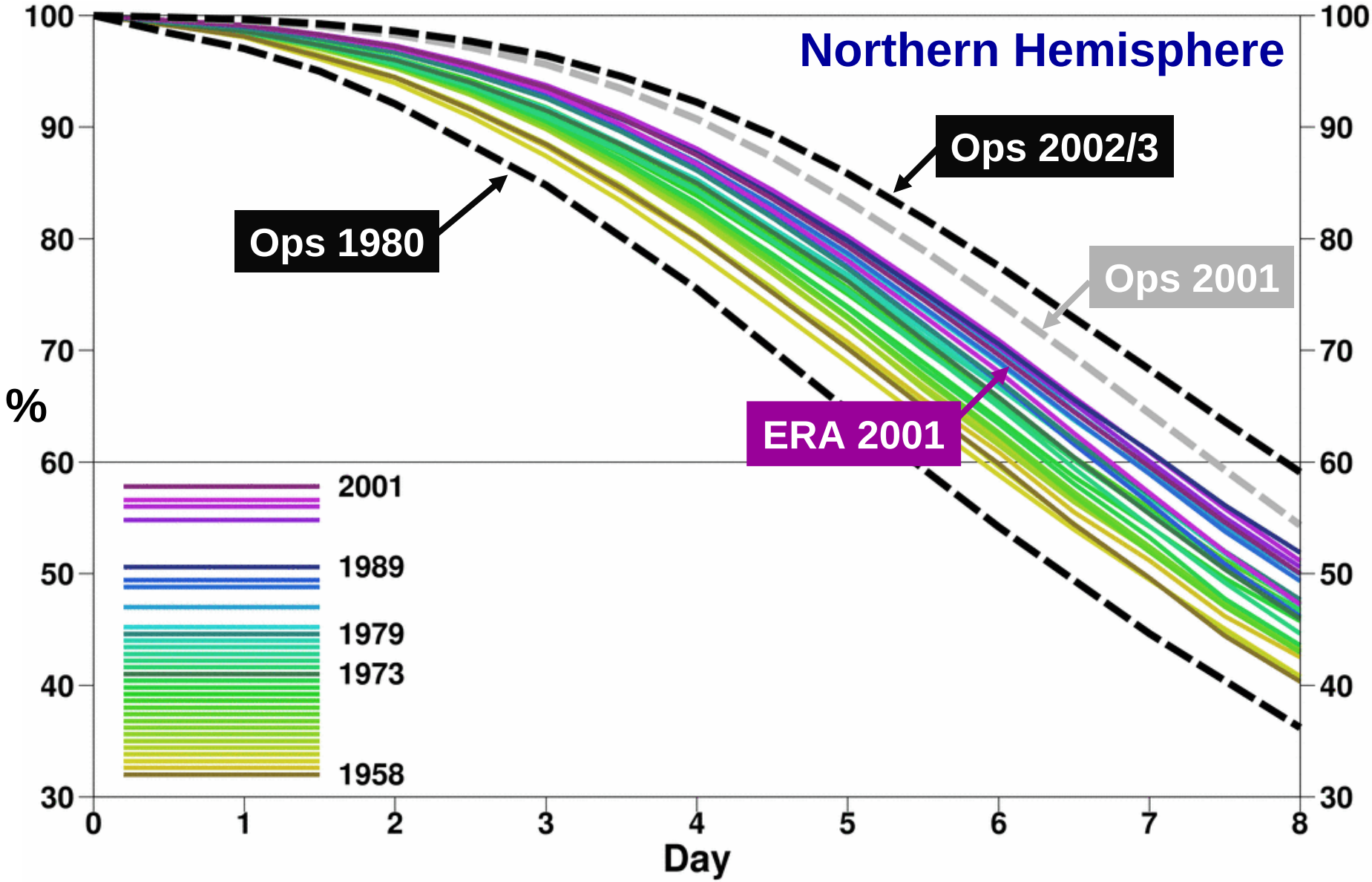


ECMWF

Idem for the Southern Hemisphere

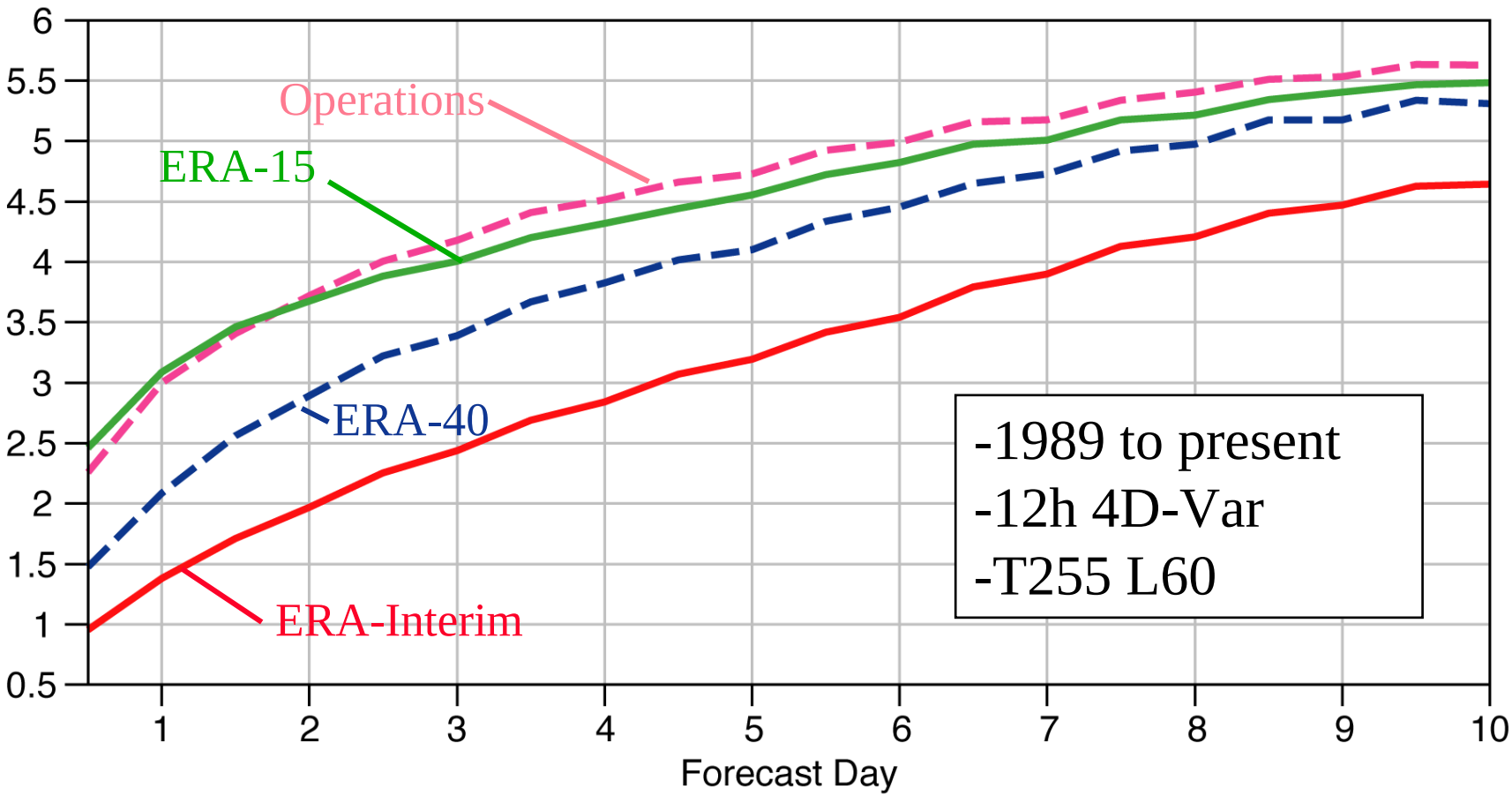


Reanalyses (ERA-40)



Reanalyses

Winds 850hPa Tropics 1989-1990



Recent progress: summary

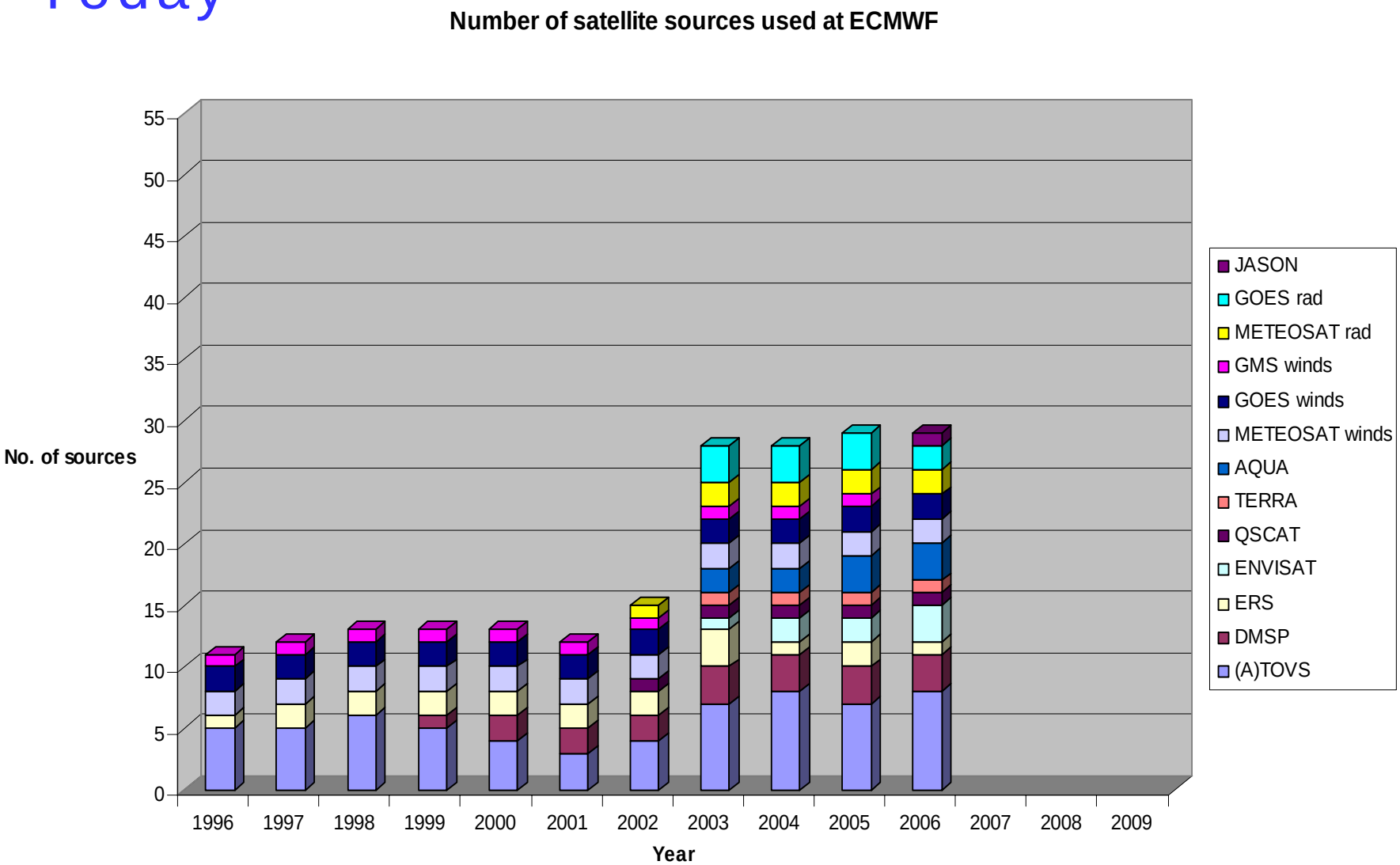
- ✓ **Important increase in NWP performance**
- ✓ **Massive investment in satellite data use**
- ✓ **Increased ability to represent severe weather events**
- ✓ **Development of probabilistic products: ensemble forecasts**
- ✓ **Developing skills in longer range: monthly and seasonal**
- ✓ **Recent inclusion of chemistry: air quality forecast**

- ✓ **By-product: reanalyses**

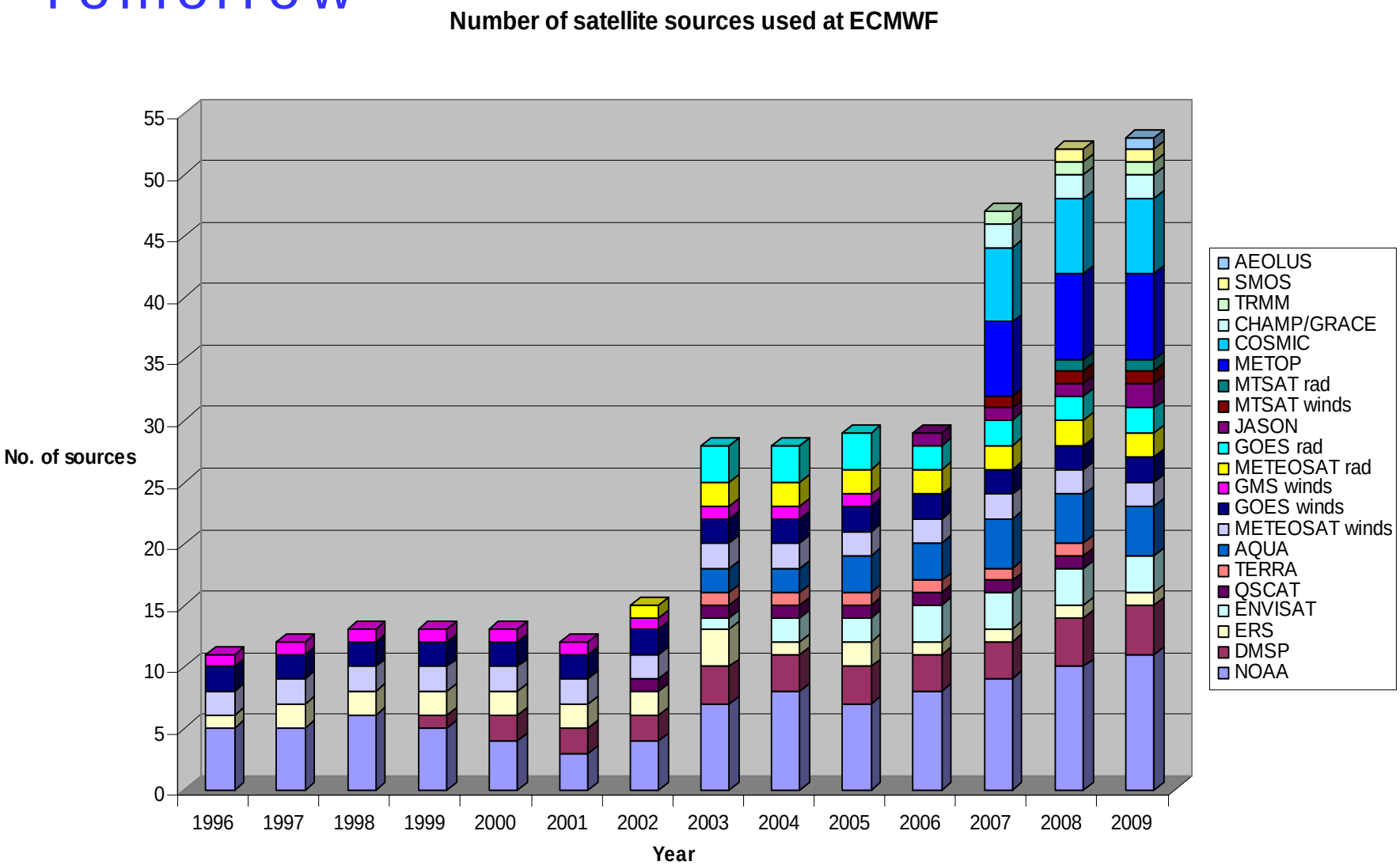
Plan

- **Recent progresses**
  - Improved performance
  - Use of satellite data
  - Severe Weather
  - Ensemble forecasting
- **Future challenges**
  - Use of satellite data
  - HPC
  - Severe Weather: early warning
  - Multidisciplinarity
  - Unified system from weather to climate

Today


Number of satellite sources used at ECMWF
No. of sources
0
5
10
15
20
25
30
35
40
45
50
55
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Year
JASON
GOES rad
METEOSAT rad
GMS winds
GOES winds
METEOSAT winds
AQUA
TERRA
QSCAT
ENVISAT
ERS
DMSP
(A)TOVS

Tomorrow


Number of satellite sources used at ECMWF
No. of sources
0
5
10
15
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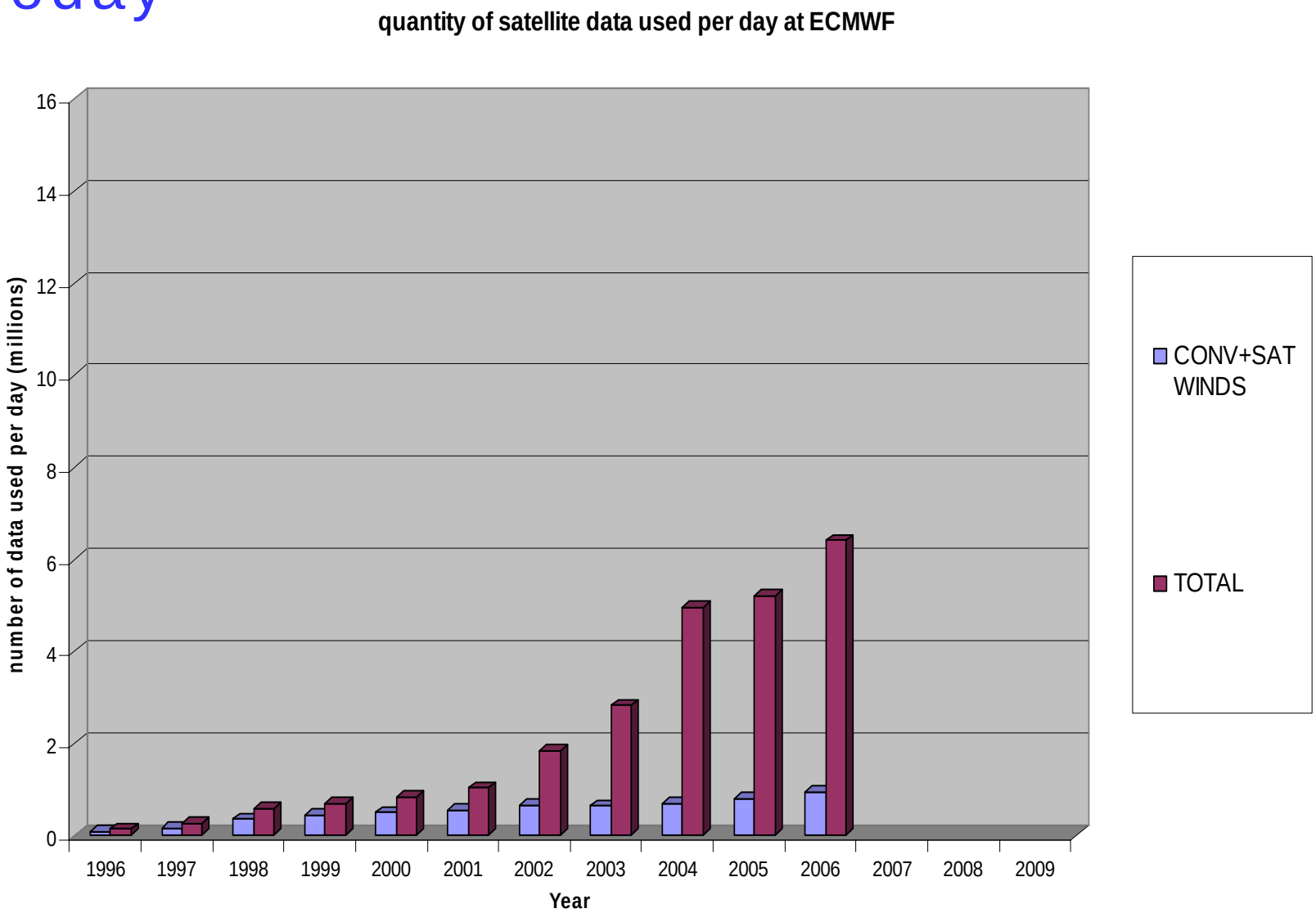
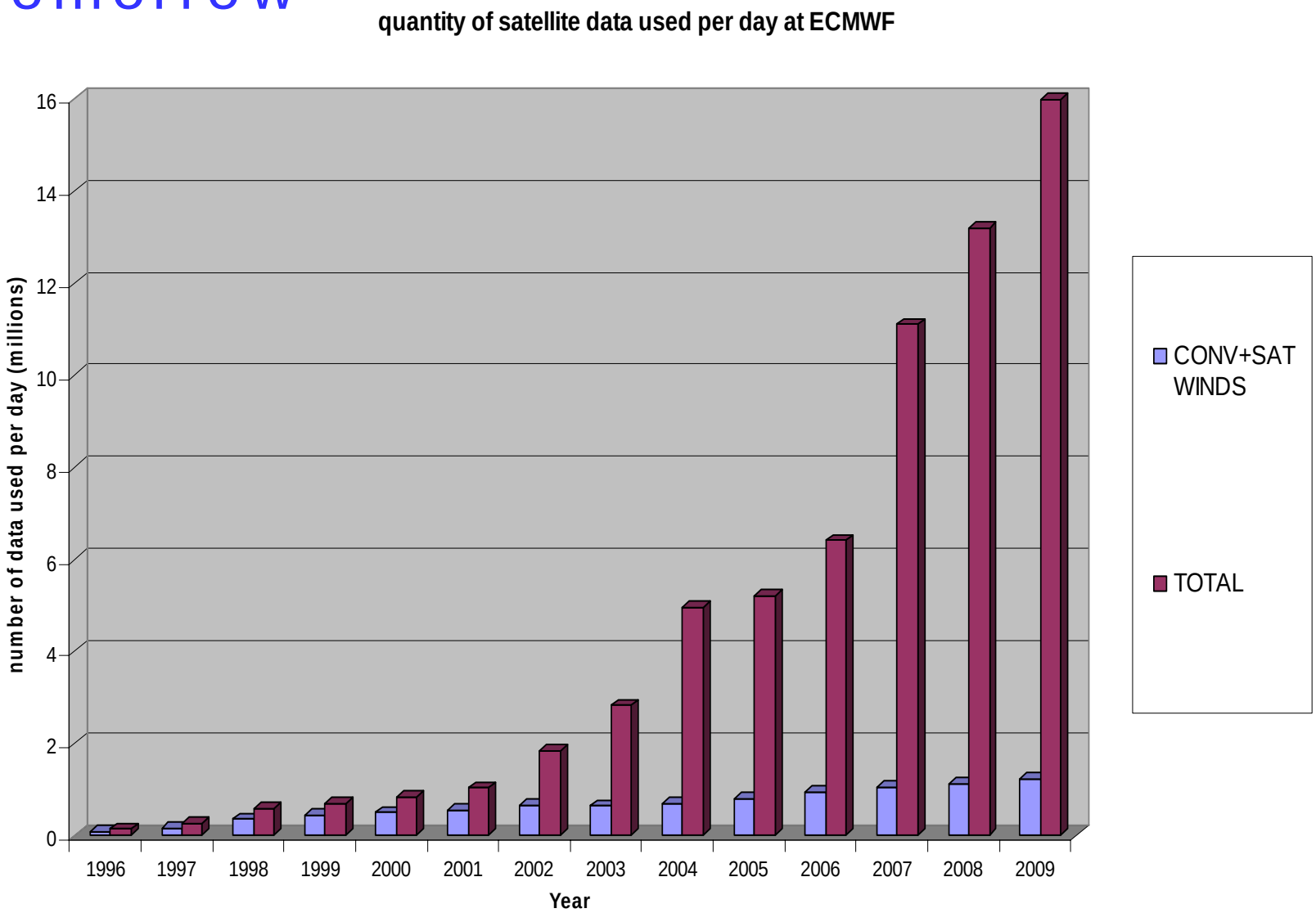
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Year
AEOLUS
SMOS
TRMM
CHAMP/GRACE
COSMIC
METOP
MTSAT rad
MTSAT winds
JASON
GOES rad
METEOSAT rad
GMS winds
GOES winds
METEOSAT winds
AQUA
TERRA
QSCAT
ENVISAT
ERS
DMSP
NOAA

Today


quantity of satellite data used per day at ECMWF
number of data used per day (millions)
16
14
12
10
8
6
4
2
0
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Year
CONV+SAT WINDS
TOTAL

Tomorrow


quantity of satellite data used per day at ECMWF
number of data used per day (millions)
0
2
4
6
8
10
12
14
16
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Year
CONV+SAT WINDS
TOTAL

Observation data count for one 12h 4D-Var cycle 0900-2100UTC 26 March 2006

Screened			Assimilated		
Synop:	389.000	(0.49%)	Synop:	60.000	(1.84%)
Aircraft:	362.000	(0.46%)	Aircraft:	179.000	(5.50%)
Dribu:	20.000	(0.03%)	Dribu:	5.600	(0.17%)
Temp:	135.000	(0.17%)	Temp:	67.000	(2.06%)
Pilot:	108.000	(0.14%)	Pilot:	48.000	(1.48%)
AMV's:	2.811.000	(3.56%)	AMV's:	127.000	(3.90%)
Radiance data:	74.825.000	(94.81%)	Radiance data:	2.646.000	(81.34%)
Scat:	269.000	(0.34%)	Scat:	122.000	(3.75%)

→ ... only 4% of the screened data are actively assimilated

(i.e. used to modify the initial conditions of the forecast model)

The challenges in satellite data use

- ✓ **Cope with the data volume**
- ✓ **Cope with the diversity of instruments**
- ✓ **Learn to use new observing techniques e.g. limb sounding**
- ✓ **Use data over land**
- ✓ **Use rain-affected data**
- ✓ **Get early access to data after launch**
- ✓ **Receive data within 30 minutes**

High Performance Computing

- **HPC is a fundamental tool for NWP**
- **Over the past 30 years there have been tremendous advances in the:**
  - **Science behind the models**
  - **Algorithms used**
  - **Raw performance of HPC systems**
- **Systems got faster thanks to:**
  - **Decrease in the processor cycle-time (Cray C90 @ 244 MHz ➔ Pentium @ ~4 GHz)**
  - **Increased parallelism (ECMWF: 32 vector pipes in 95, 4000+ processors in 2006)**
- **Will the performance/price offered by HPC systems continue to grow at the same pace?**

Challenges with HPC

- **Frequency enhancements close to its limits**
- **Growth in hardware parallelism will accelerate**
- **Getting high percentages of peak will become even harder than now**
- **Model codes are getting larger (shared components, coupled models, more processes are represented)**
- **Code destined to be shared in the community must be reasonably efficient on all prevailing architectures**
- **Any use of special hardware (eg FPGAs) is likely to be detrimental to code portability**
- **Power consumption becoming critical**

Build a comprehensive warning system for severe weather

- **Such a system needs two complementary components**
  - **Short-range warnings (0-2 days): NMSs responsibility**
  - **Early warnings (3-5 days): based on ECMWF's information**
- **Early warnings for severe weather require ensembles of global high resolution (goal 10-20 km in 2015) models**
- **This investment complements the investments required in NMSs where short-range severe weather warnings require limited area very high resolution (already 2 to 4 km) models**
- ***Reliable early warnings for severe weather will become crucial and could make the difference between a severe event and a disaster (mitigation, evacuation)***

Build a comprehensive earth system model

- **Ocean**
- **Soil**
- **Air chemistry**
- **Include applications**
  - **Floods**
  - **Health**
  - **Energy**

Necessary for ensemble forecasts

Requires to develop exchanges with other scientific communities

Build a continuous forecasting system from weather to climate

- **Difficult**
  - **For weather: initial state is crucial**
    running time and resolution
  - **For climate: model stability is crucial**
    calibration and experimentation
- **Beneficial**
  - **Weather: better model, earth system**
  - **Climate: best possible test bed, code efficiency**
- **Way forward**
  - **Develop climate versions of weather forecasting systems**
  - **More frequent common cycle**

Challenges for NWP

- ✓ **Use satellite data**
- ✓ **Use supercomputer resources**

- ✓ **Develop reliable early severe weather warning**
- ✓ **Develop a multidisciplinary approach**

Thank you for your attention

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