Use of satellite radiances in the 4D-VAR ECMWF system
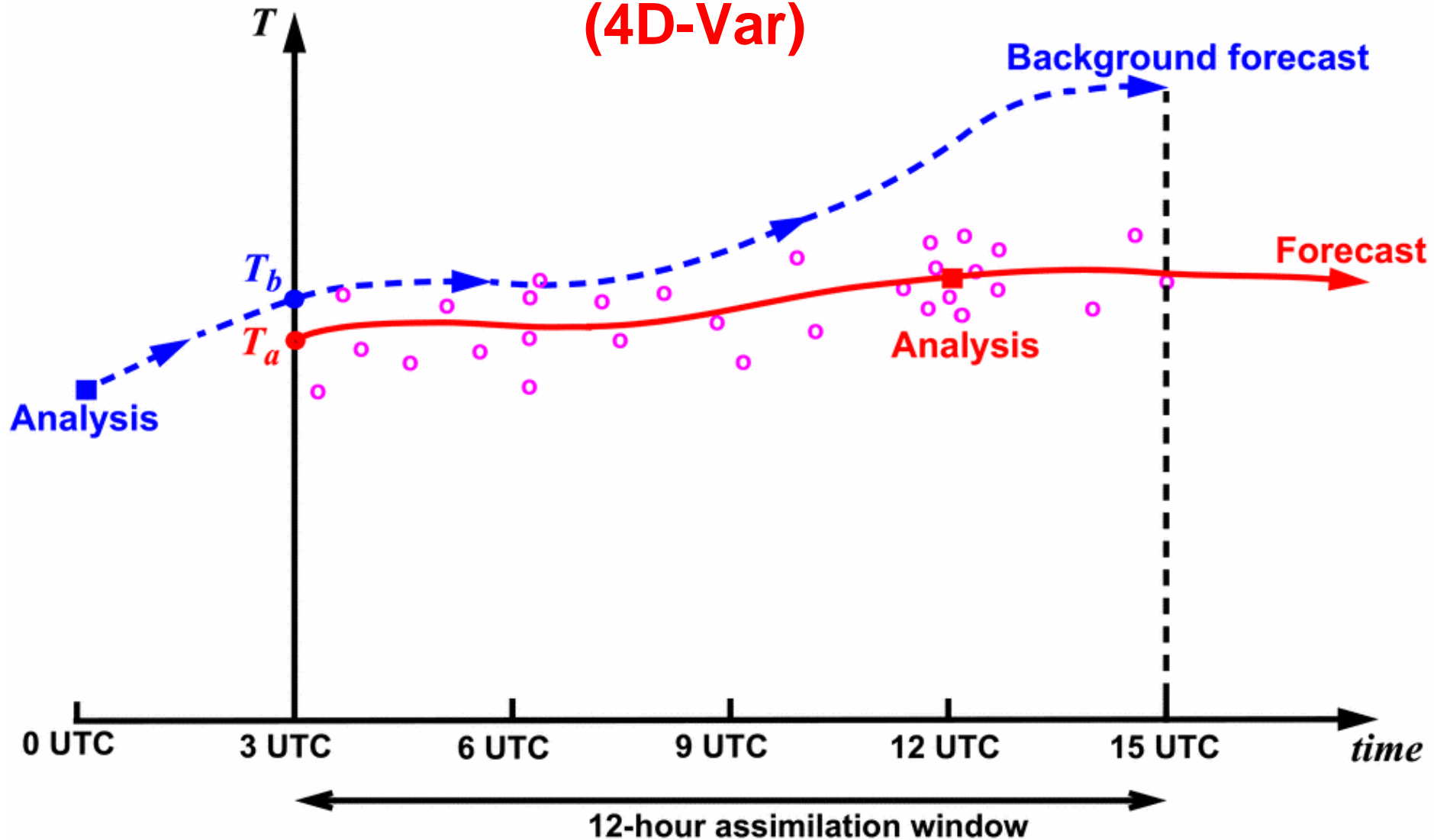
Graeme Kelly

Contrubitions from

(Jean-Noël Thépaut , Adrian Simmons, Sakari Uppala, Matthew Szyndel, Andrew Collard, Tony McNally, Sean Healy, Elias Holm, Richard Engelen and others)
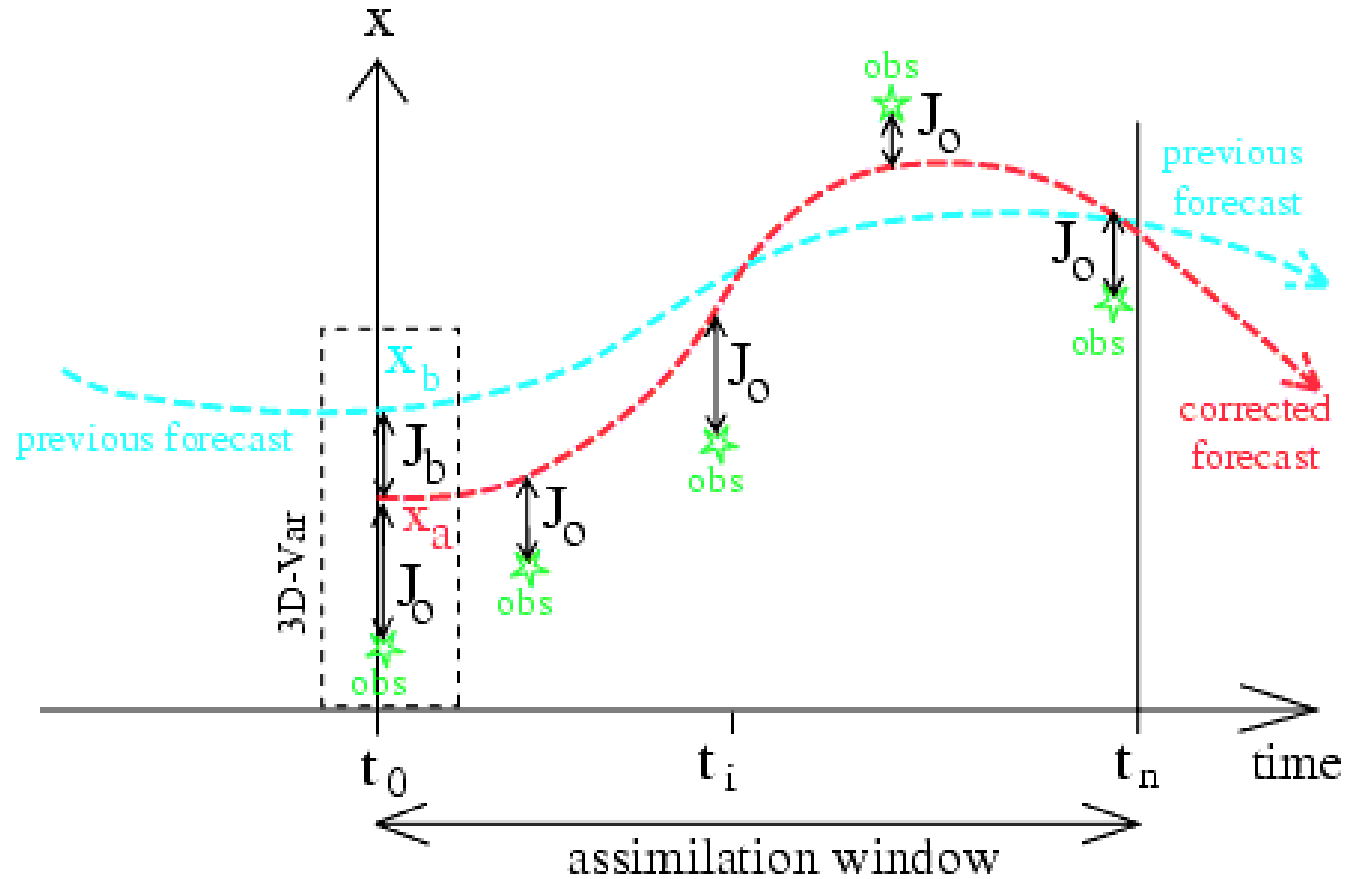
Assimilation changes

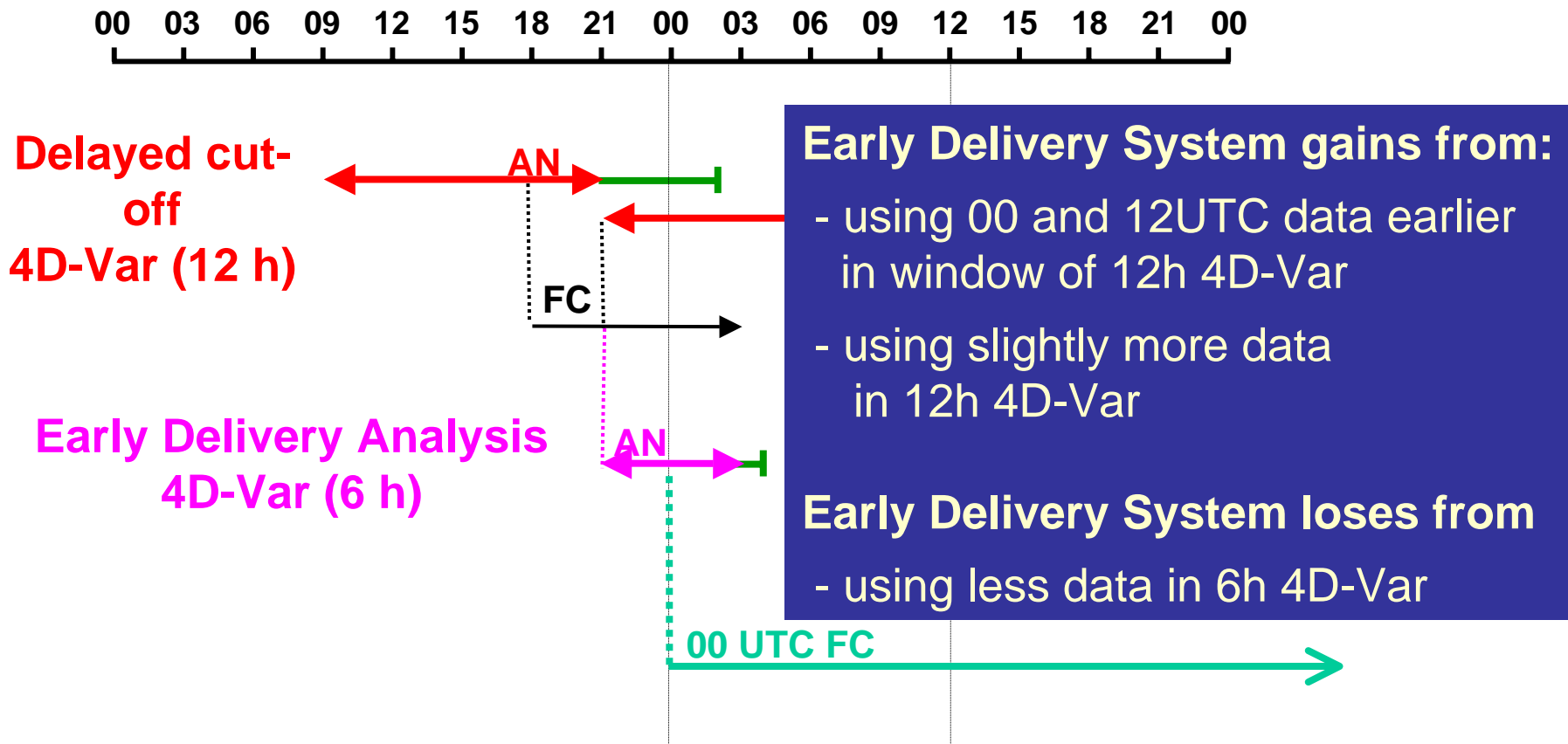## Four Dimensional variational data assimilation (4D-Var)

Conceptual difference between 3D-Var and 4D-Var

Analysis resolution at t_0 --- J_b is determined for a set of ensemble assimilations, and the statistics are not flow dependant and filter. Horizontal scales less than ~120km

The Early Delivery From 29 June 2004 System

```
00   03   06   09   12   15   18   21   00   03   06   09   12   15   18   21   00
```

Delayed cut-off
4D-Var (12 h)

AN

FC

Early Delivery Analysis
4D-Var (6 h)

AN

00 UTC FC

Early Delivery System gains from:

- using 00 and 12UTC data earlier
  in window of 12h 4D-Var

- using slightly more data
  in 12h 4D-Var

Early Delivery System loses from

- using less data in 6h 4D-Var

Anomaly correlation of 500hPa height forecasts

Northern hemisphere ———— Southern hemisphere

Day 3

Day 5

Day 7

Anomaly correlation of 500hPa height forecasts
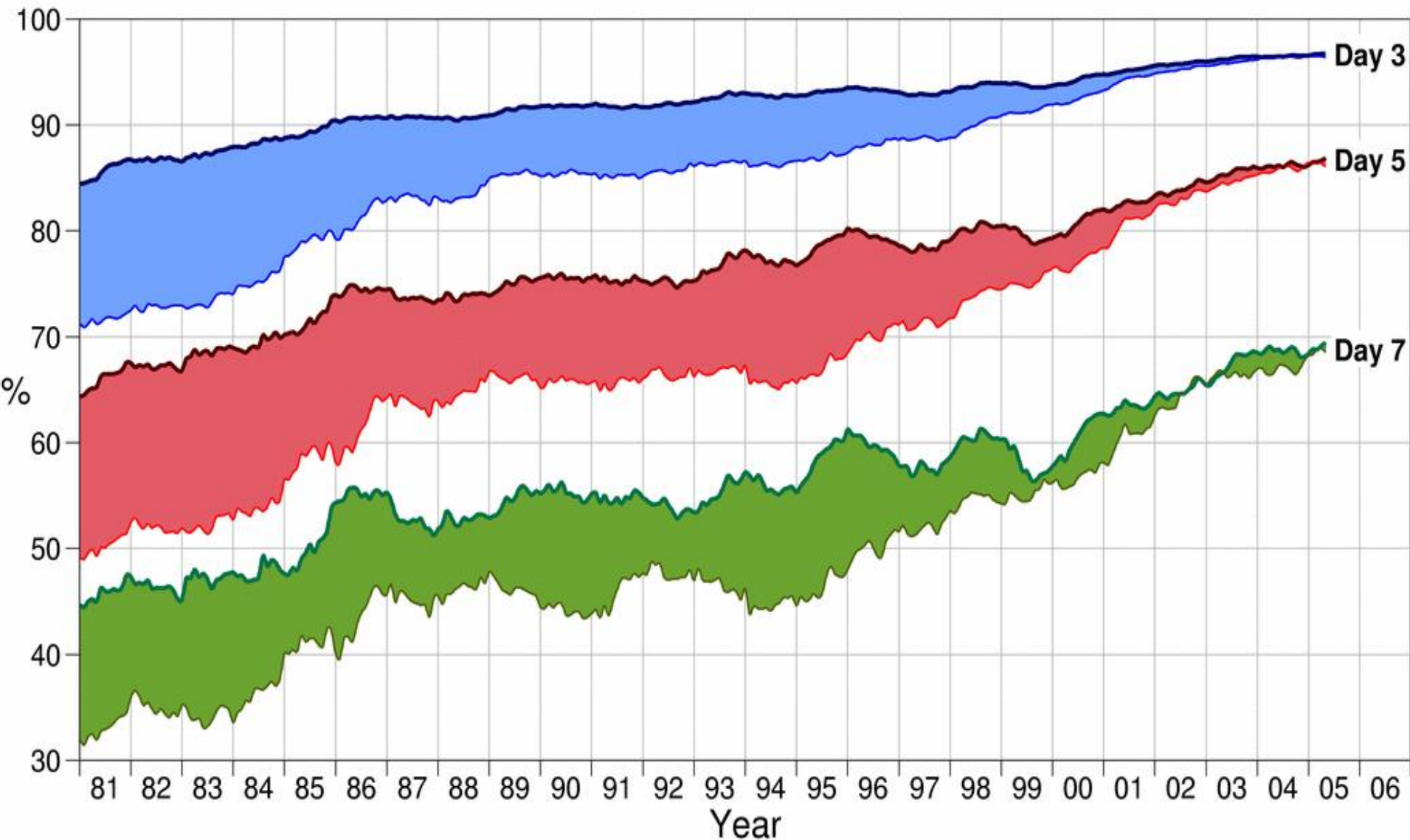
Northern hemisphere observation impact in Early Delivery System

March 2004

Early delivery system

Previous system
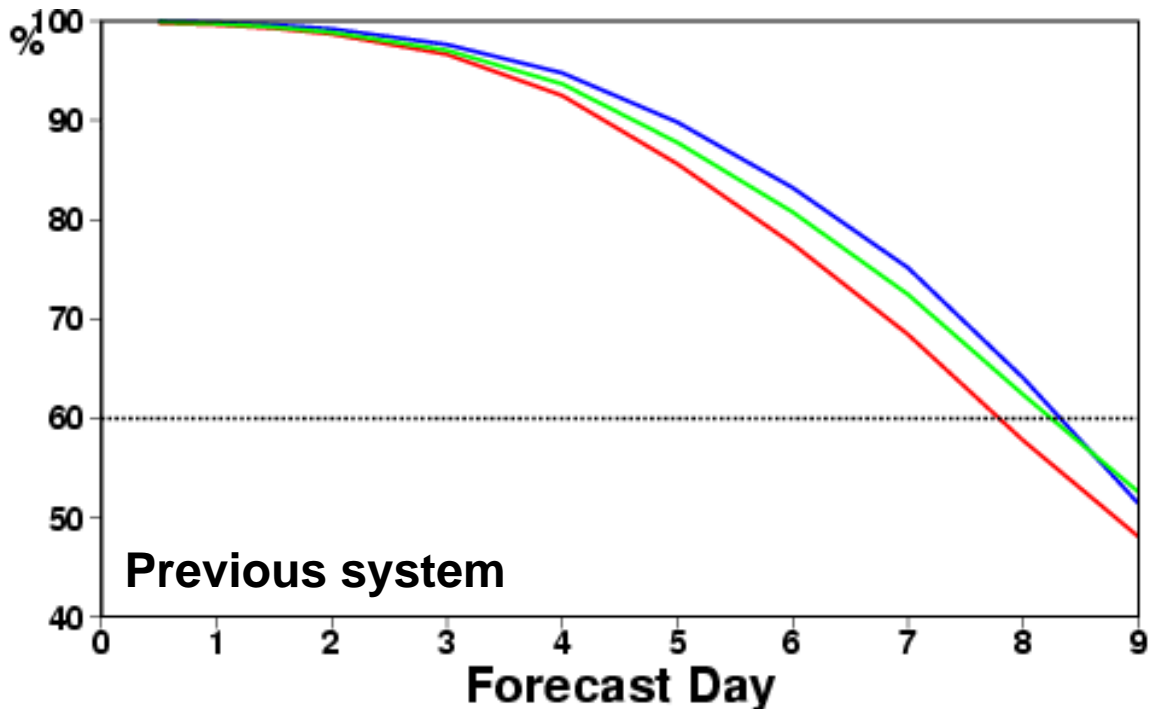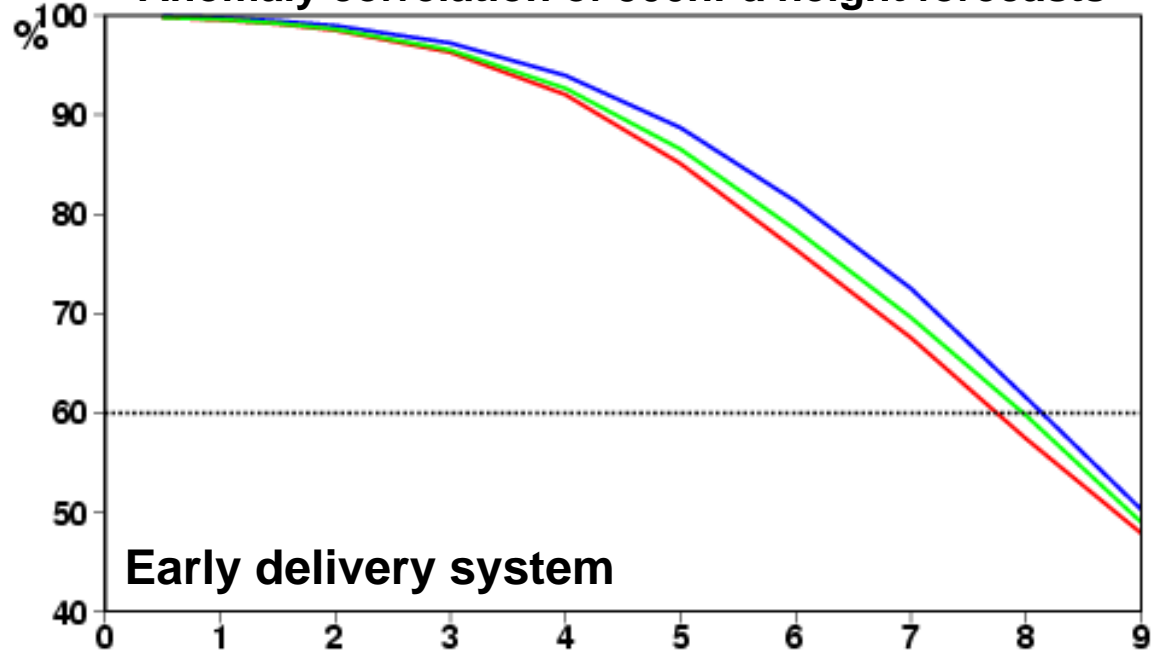
Control

No satellite data

No radiosondes/profilers

Forecast Day

Increase in model and analysis resolution

L91

L60

Pressure (hPa)

Level number

Anomaly correlation of 500hPa height forecasts, 9 August – 13 November 2004

N Hem

— T799
--- T511
···· T255

S Hem

— T799
--- T511
···· T255

Forecast Day
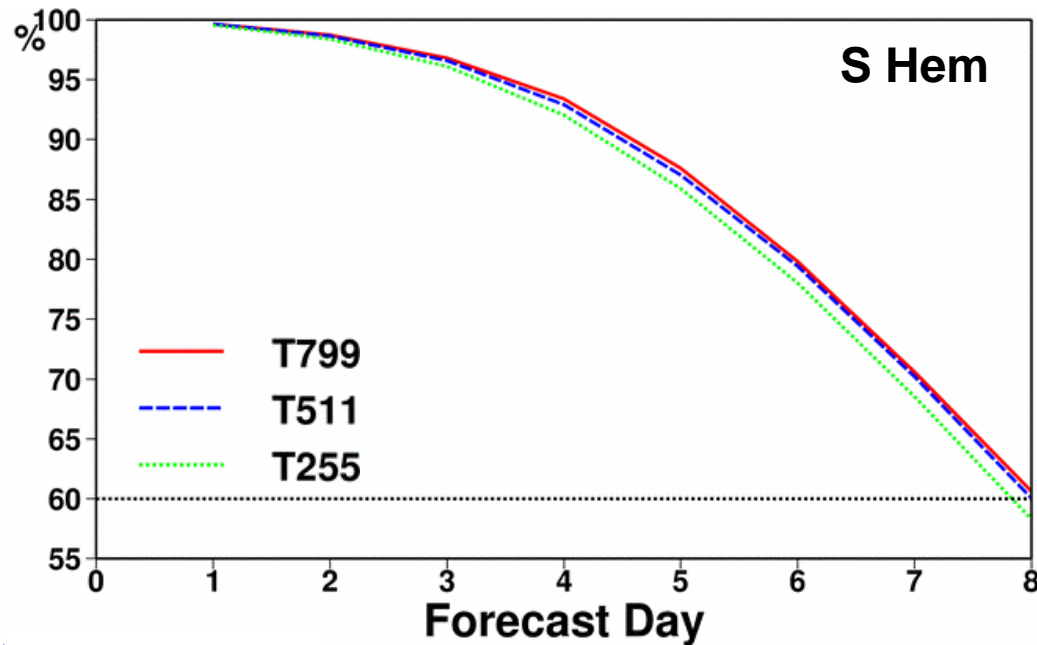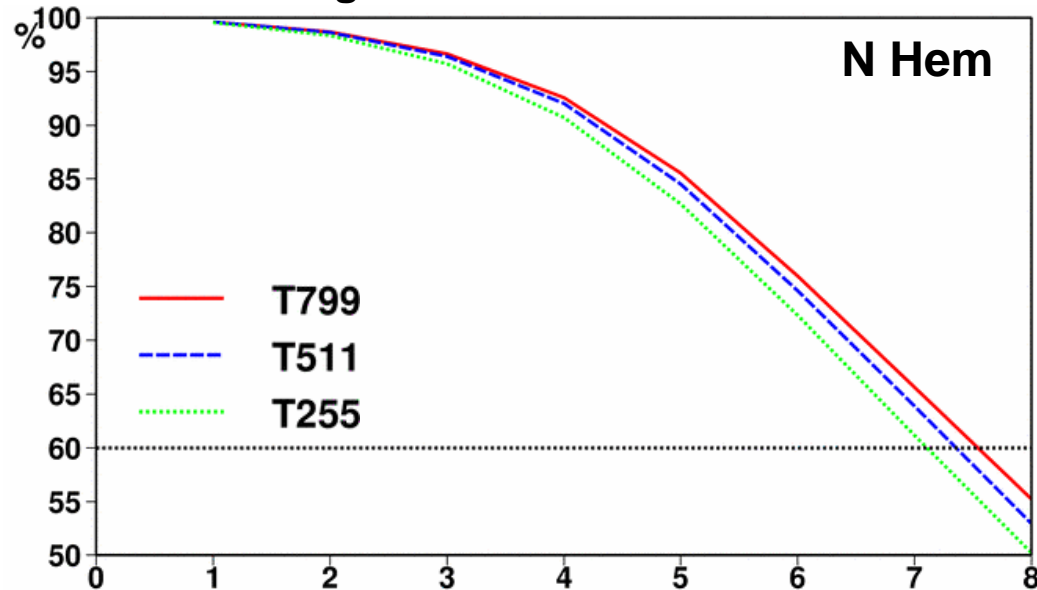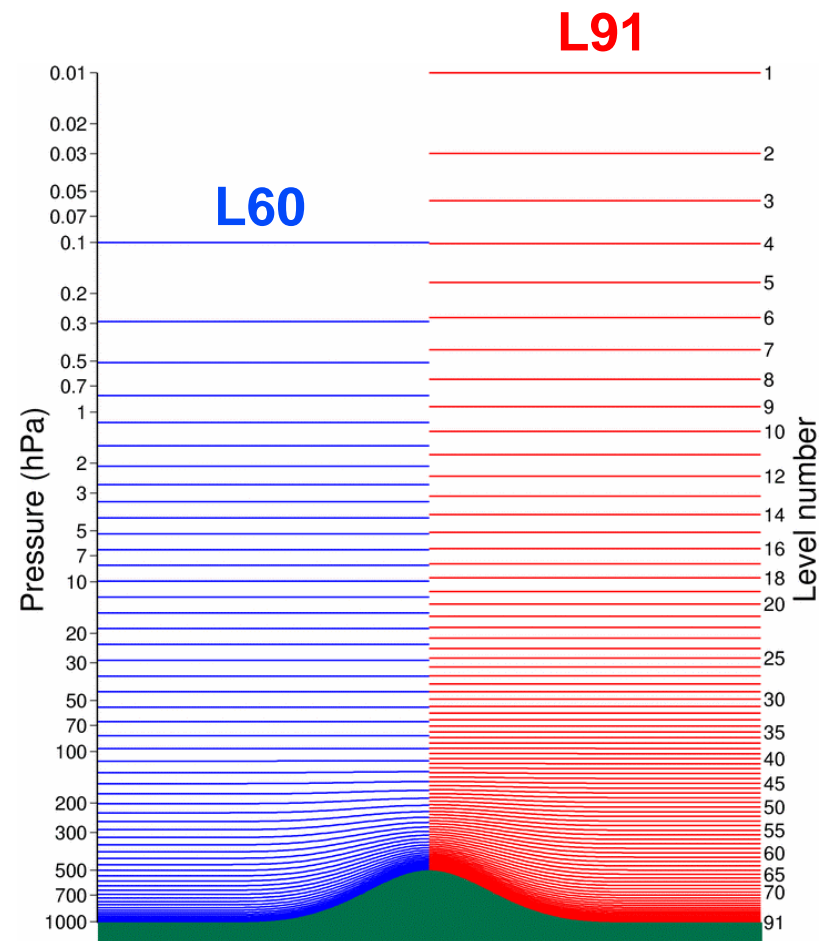
Comparison other centres
April & May 2005

Geo-stationary satellites

Cloud motion vector
SATOB   619,356

Polar-orbiting satellites

ATOVS   858,805
SSMI   74,898
OZONE   9,689

Radiances   1,548,837

AIRCRAFT
AIREP   Total =
AMDAR   107,073
ACAR

TEMP
Land   1,181
Ship   19

PILOT   805
Profiler   2,818

SYNOP – Ship 6,655
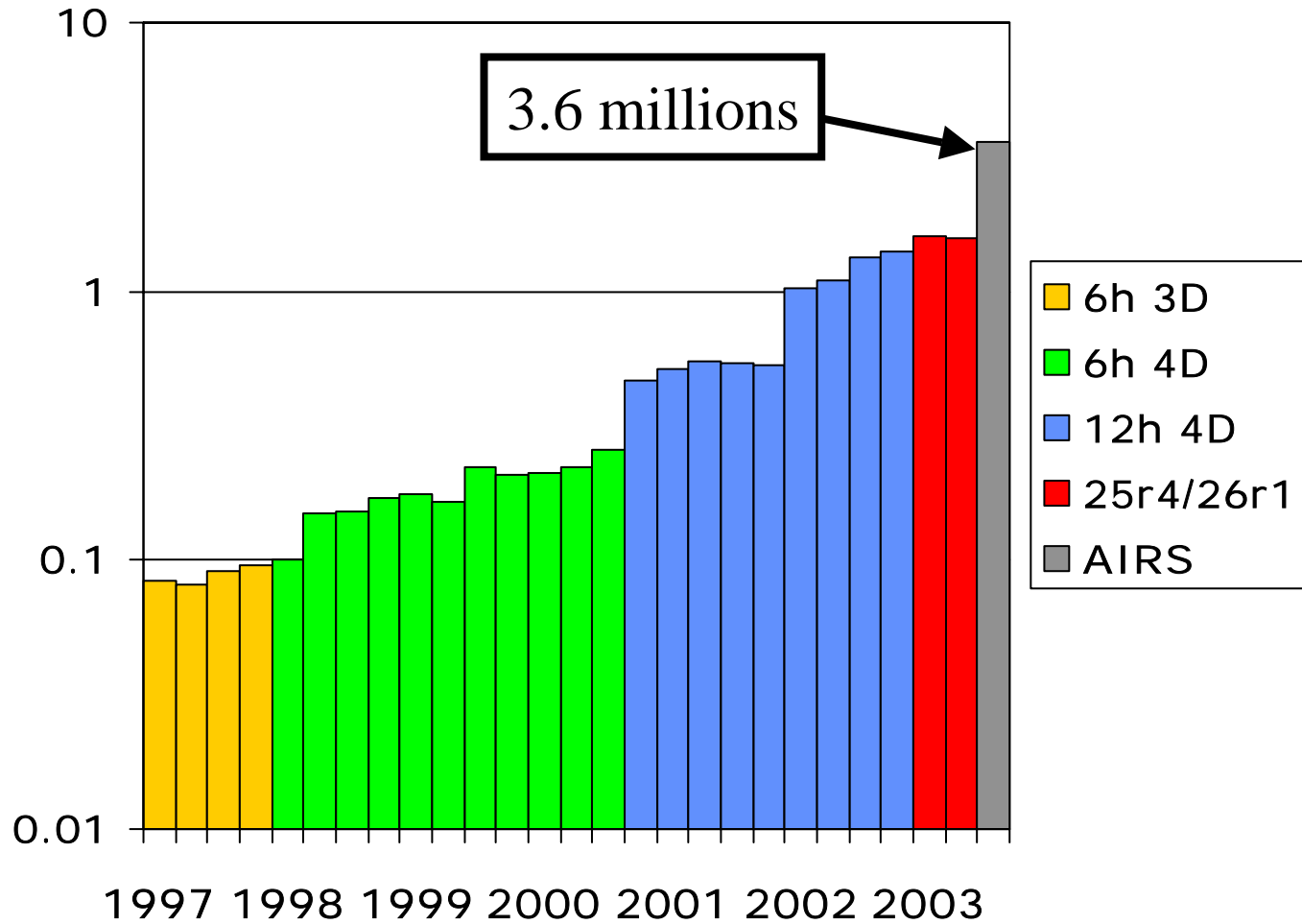
Buoys
Drifting   12,335
Moored   411

SYNOP – Land 55,498
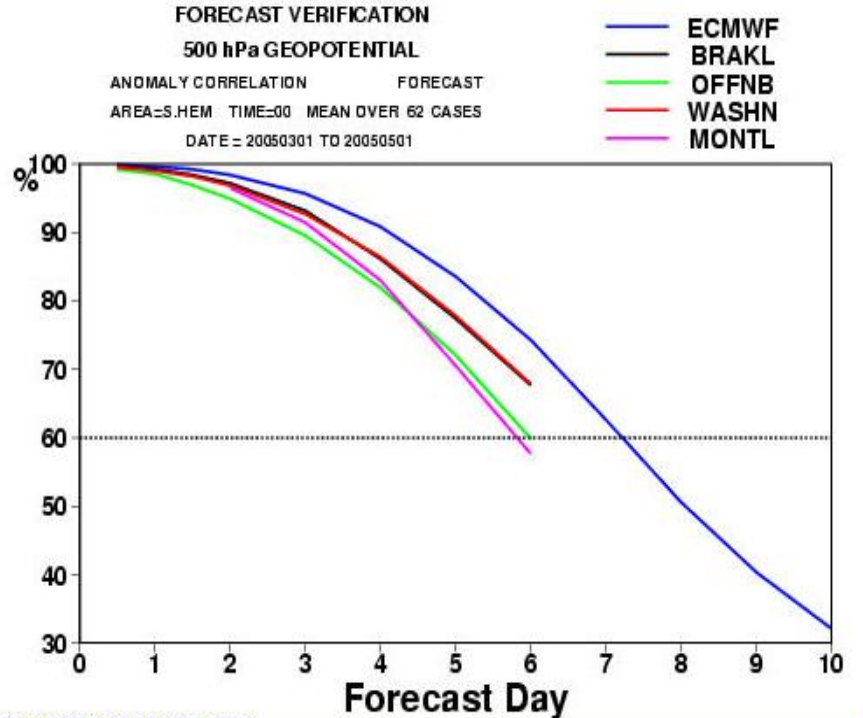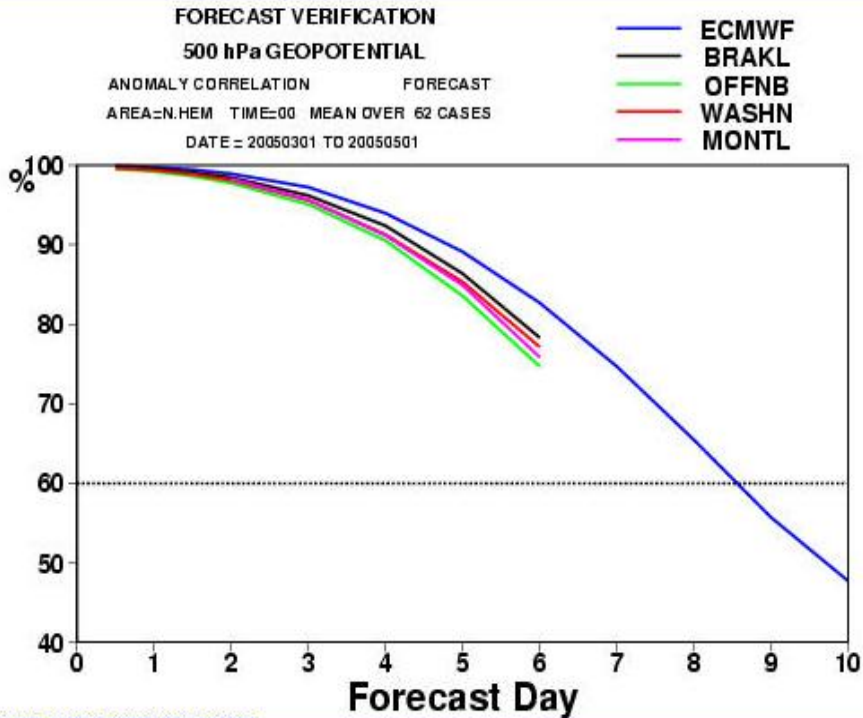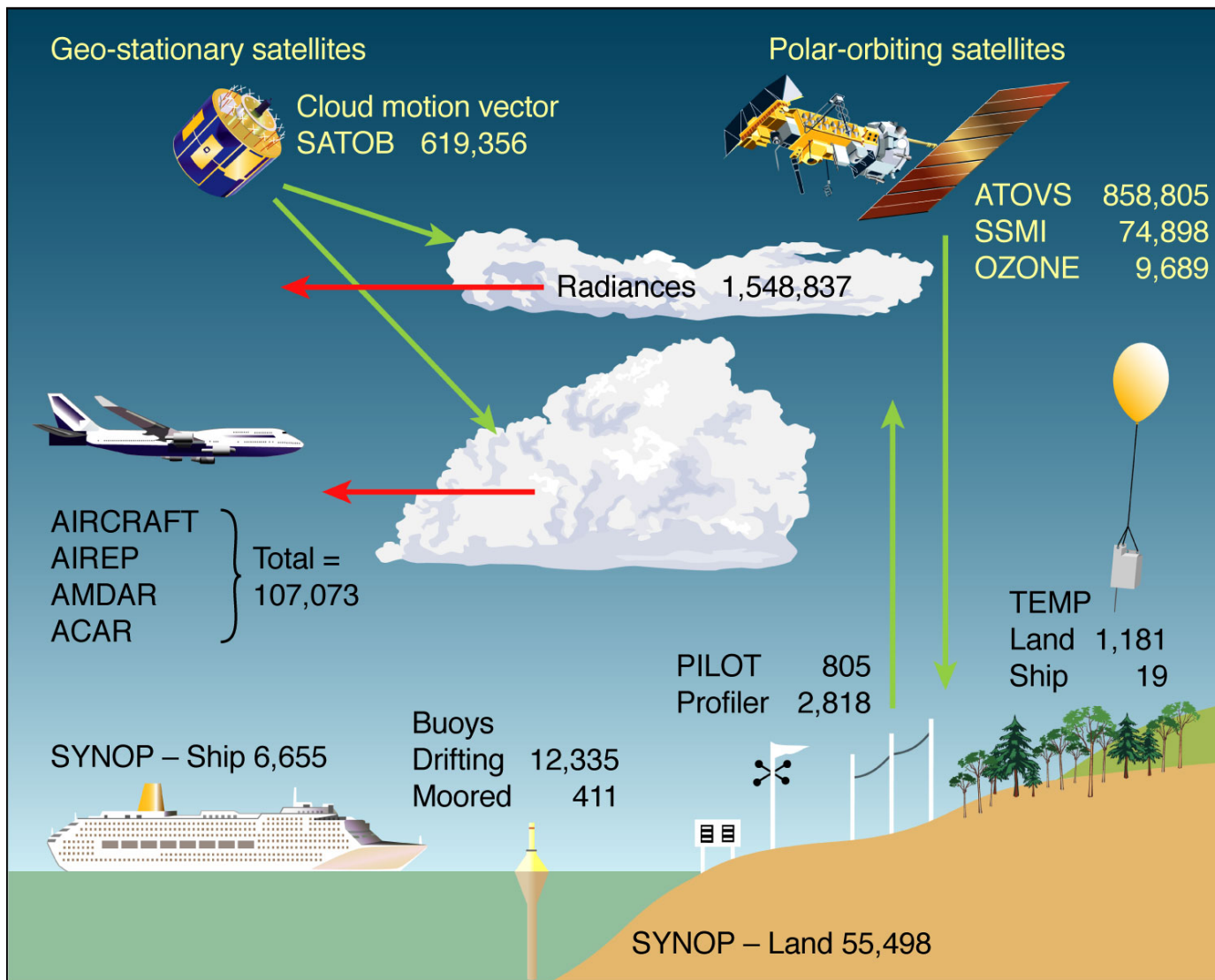
The numbers refer to all data items received over a 24 hour period on 5 July 2004 (without AIRS)

Number of observational data used in the ECMWF assimilation system (with AIRS)

September 2004

- **Use data from EUMETSAT ATOVS Retransmission System**

- **Improved AIRS bias correction and cloud detection**

- **Assimilation of Meteosat Second Generation (Meteosat-8) water vapour radiances (in place of Meteosat-7 radiances)**

- **New version of fast radiative transfer model: RTTOV8**

- **Corrected use of AMSU-B over land**

- **Use of total ozone retrievals from SCIAMACHY on ENVISAT**

- **Improved use of TEMP and SYNOP humidity observations**

- **Small revisions to surface, convection and cloud schemes**

- **Radiation frequency reduced from three hourly to hourly**

- **Better vertical diffusion in the first minimization of 4D-Var**

EUMETSAT ATOVS Retransmission Service (EARS)
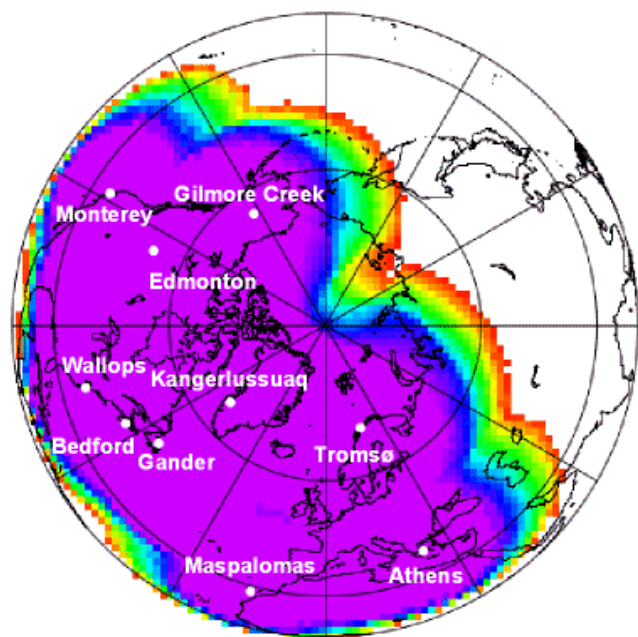
STATISTICS FOR RADIANCES (EARS) FROM NOAA-16 / AMSU-A - 07
MEAN OBSERVATION (USED)
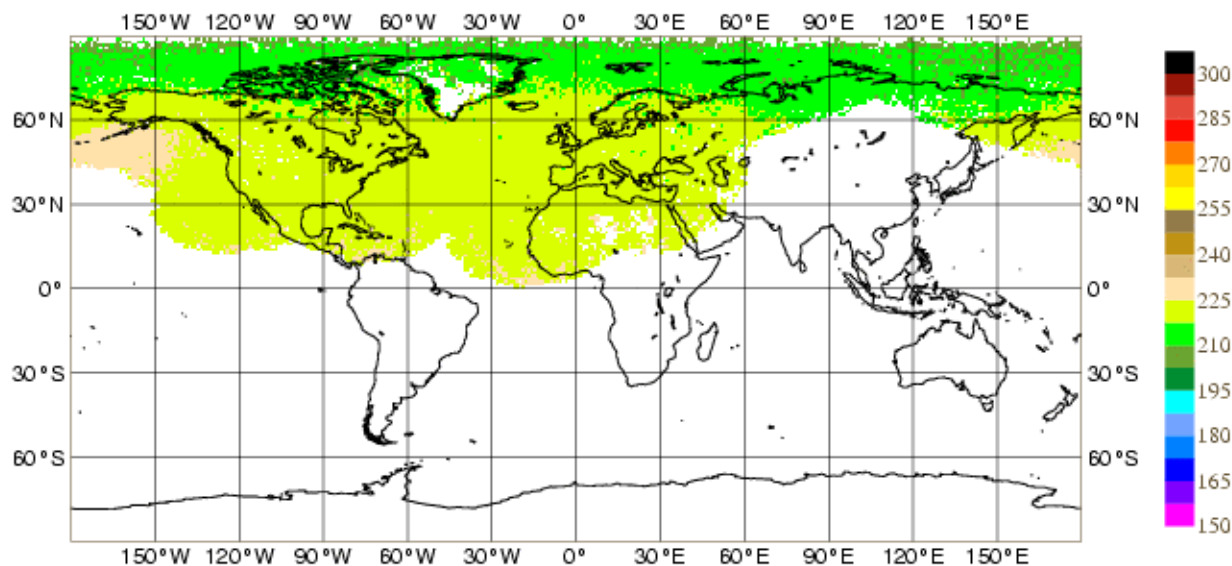DATA PERIOD = 2004120100 - 2004122506 , HOUR =   ALL
EXP = 0001
Min: 202.9   Max: 229.75   Mean: 219.74

April 2005

- Blacklist ten AIRS channels with long tails in humidity weighting functions in the stratosphere

- MODIS winds from AQUA as well as TERRA, plus reduced observation error

- Updates for simulated GEO imagery (Met-8 channels)

- 1D-Var analysis of rain-affected radiances active in the screening, including an upgraded version of RTTOV-8

- Monitoring of ground-based GPS

April 2005 (continued)

- Wavelet Jb, with statistics based on new DA-ensemble for ozone

- Surface pressure bias correction and reduced observation errors for automatic stations

- Activate METAR, stop using PAOBS

- New moist boundary layer scheme
- Bugfix to first timestep of semi-Lagrangian physics
- Modification to tile coupling of snow cover
- Bugfix to QNEGAT
- New dissipation source function for wave model

ECMWF operations since September 2004

- **AQUA AIRS**
- **3xAMSUA (NOAA-15/16/17) + AQUA AMSUA**
- **3 SSMI (F-13/14/15)**
- **2xHIRS (NOAA-14/17)**
- **2xAMSU-B (NOAA-16/17)**
- **Radiances from 5xGEOS (Met-5/7 GOES-9/10/12)**
- **Winds from 5xGEOS (Met-5/7 GOES-9/10/12)and MODIS/TERRA**
- **SeaWinds from QuiKSCAT**
- **ERS-2 Altimeter / SAR (limited coverage)**
- **SBUV (NOAA 16)**
- **ENVISAT OZONE (MIPAS+SCIAMACHY)**
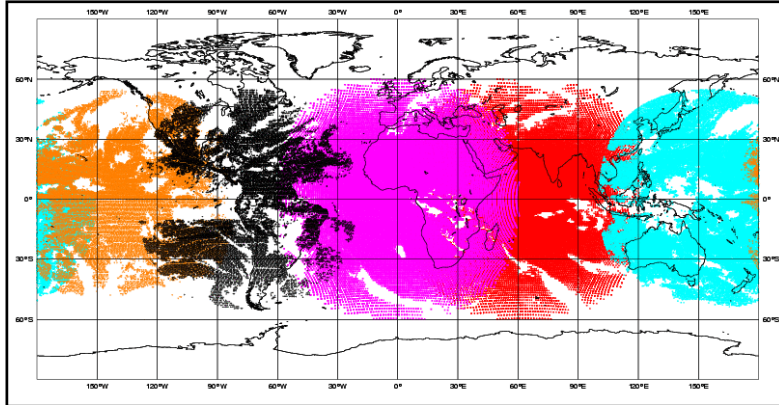
28 satellite data sources

Typical distribution of observations

In situ observations

synop-ship:

buoy:
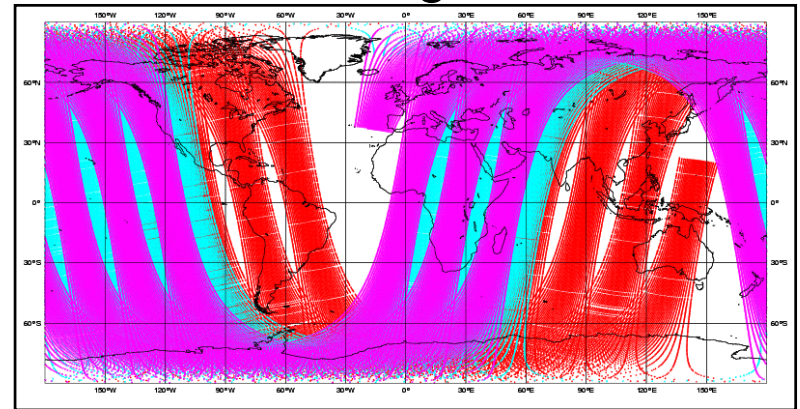
temp:

pilot:

aircraft:
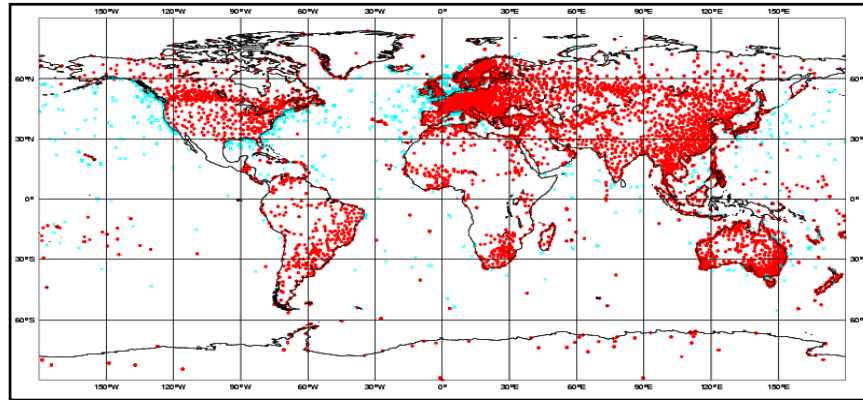
Geostationary satellites

Grad, Satob

## Polar-orbiting satellites

ATOVS, AIRS, SCAT, SSMI, Ozone

14/03/2004 00UTC

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

- **A re-analysis from September 1957 to August 2002 based on operational code (June 2001)**

- **Six-hourly 3D-Var analysisT159 horizontal resolution (~125km grid) ops T511 (~39km grid)**

- **Testing 4D-Var for INTERIM re-analysis at various resolutions**

- **T159/L60/L91 horizontal resolution (~125km grid) T511/L60/L91 horizontal resolution (~39km grid)**

Comparison of 3/4DVAR T159 (4 months)
500 hPa rms error
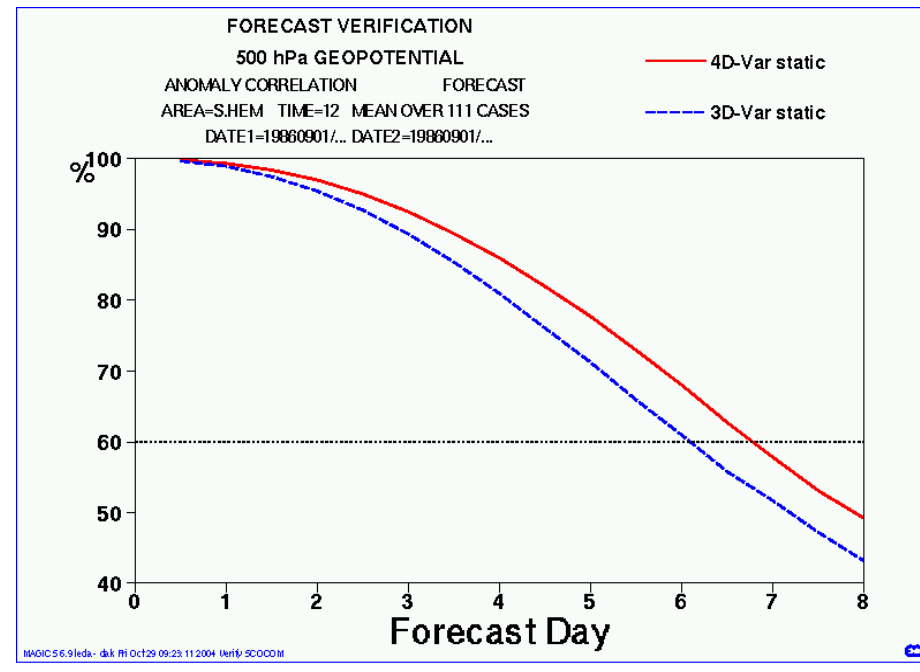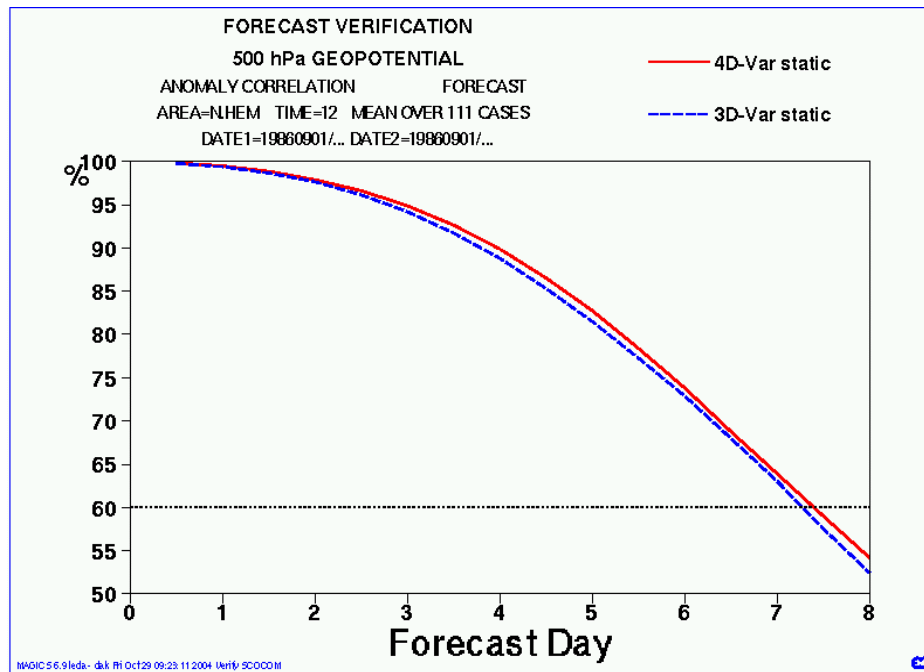
Time series

FORECAST VERIFICATION 12UTC
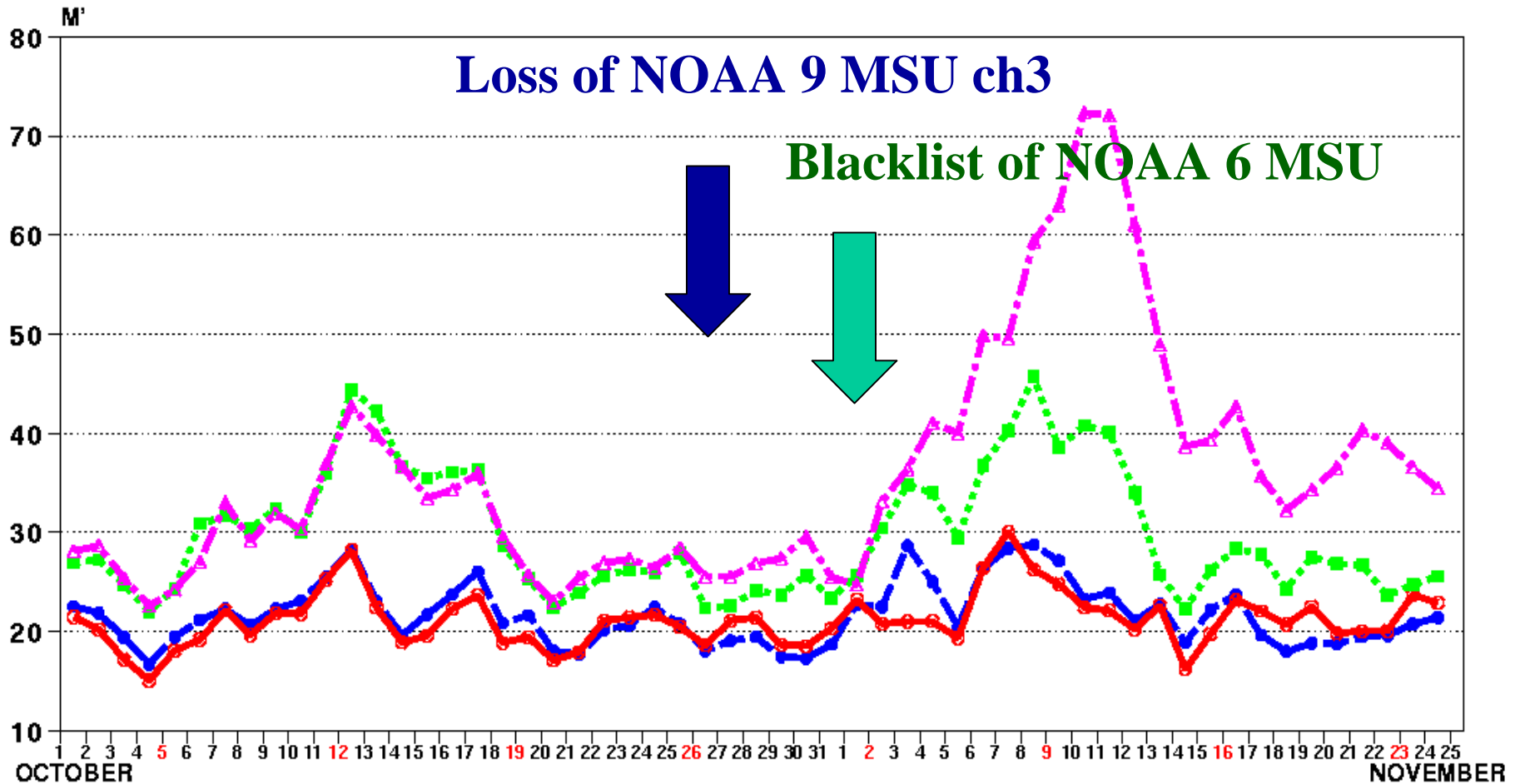
500hPa   GEOPOTENTIAL
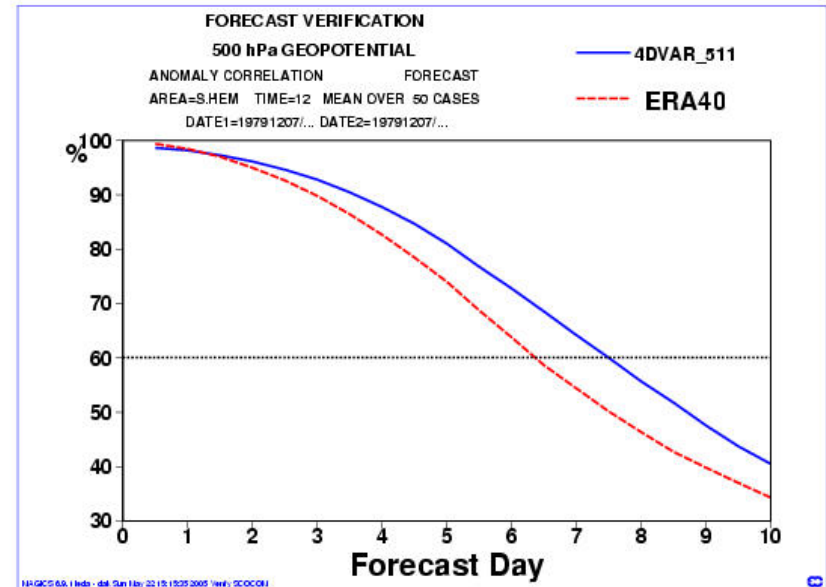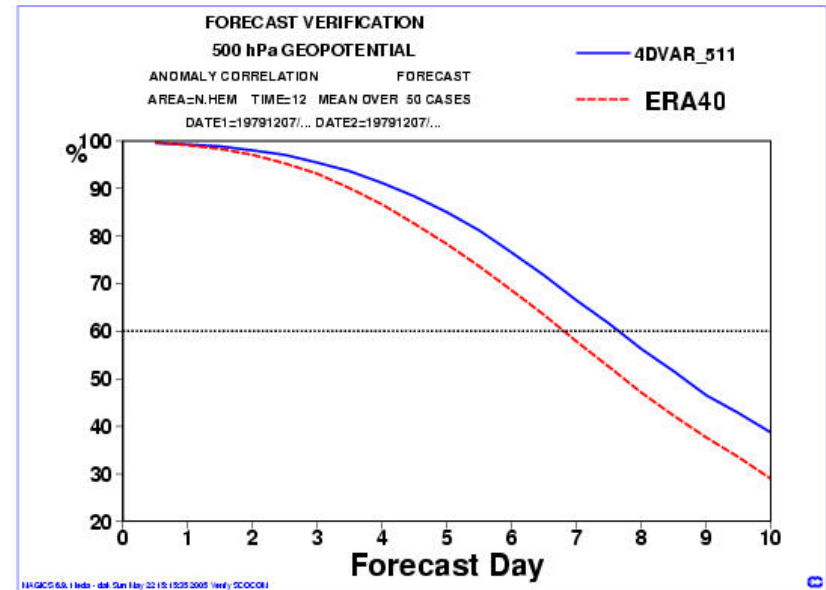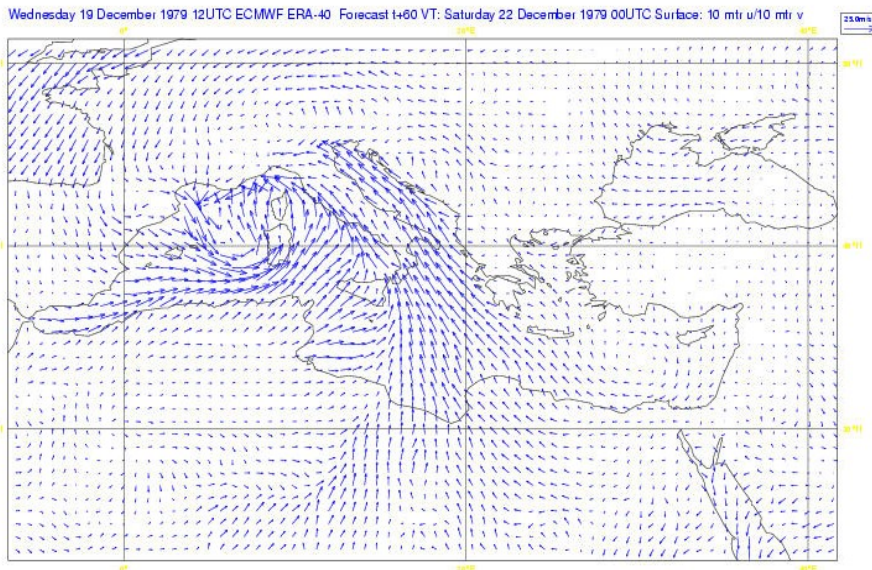
ROOT MEAN SQUARE ERROR   FORECAST

S.HEM   LAT -90.000 TO -20.000 LON -180.000 TO 180.000

- - - - 4d_adspc T+ 36
——— 4d_stat T+ 36
.... 3d_adsp T+ 36
-·-·- 3d_stat T+ 36

Loss of NOAA 9 MSU ch3

Blacklist of NOAA 6 MSU

T511/L60 Venice storm 1979 Dec the 2nd Highest tide since 1900

Five day forecast

Wednesday 19 December 1979 12UTC ECMWF ERA-40 Forecast t+60 VT: Saturday 22 December 1979 00UTC Surface: 10 mtr u/10 mtr v

FORECAST VERIFICATION
500 hPa GEOPOTENTIAL
ANOMALY CORRELATION   FORECAST
AREA=N.HEM   TIME=12   MEAN OVER 50 CASES
DATE1=19791207/... DATE2=19791207/...
— 4DVAR_511
--- ERA40

FORECAST VERIFICATION
500 hPa GEOPOTENTIAL
ANOMALY CORRELATION   FORECAST
AREA=S.HEM   TIME=12   MEAN OVER 50 CASES
DATE1=19791207/... DATE2=19791207/...
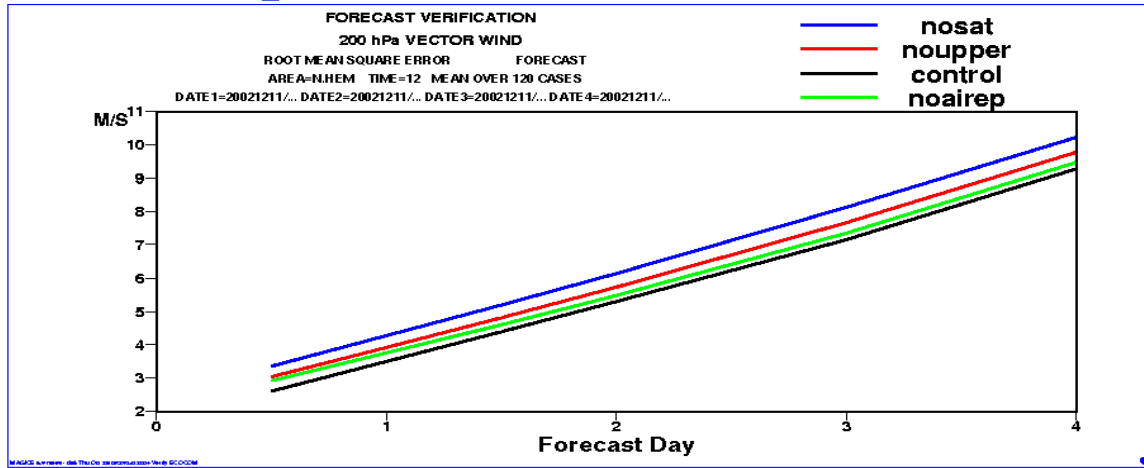— 4DVAR_511
--- ERA40

OSE's ECMWF (1997, 1999 and 2002)

A series of OSE's were run with the current operational version (at the time) of the ecmwf system

The 2002 OSE used :
(4dvar (TL511 40km) forecast model and (TL159/511 120km) 4dvar analysis).

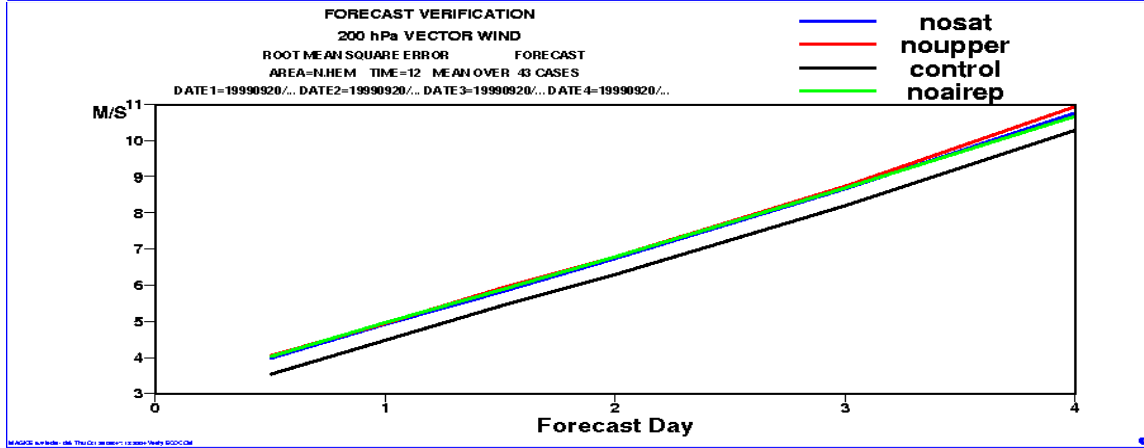The number of cases:
1997 OSE 34 days *(Kelly 1998)*
1999 OSE 43 days *(Bouttier and kelly 2001)*
2002 OSE 120 days *(Kelly 2004)*

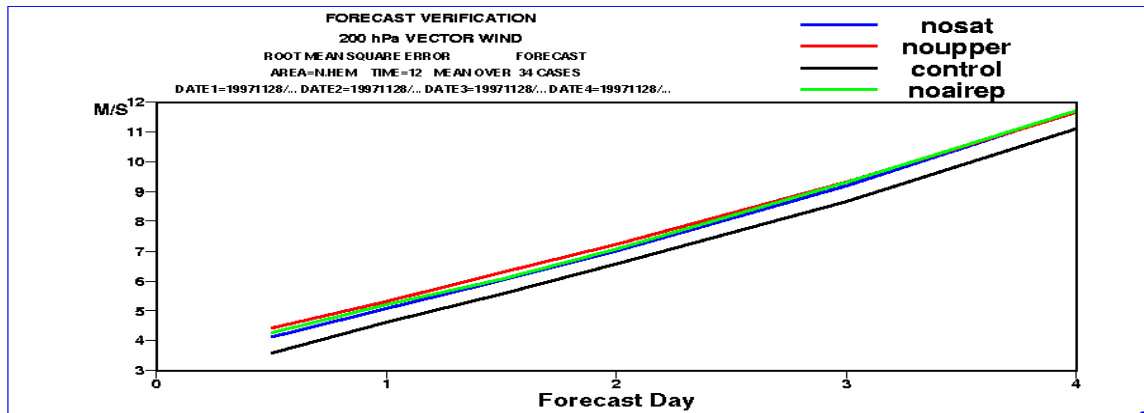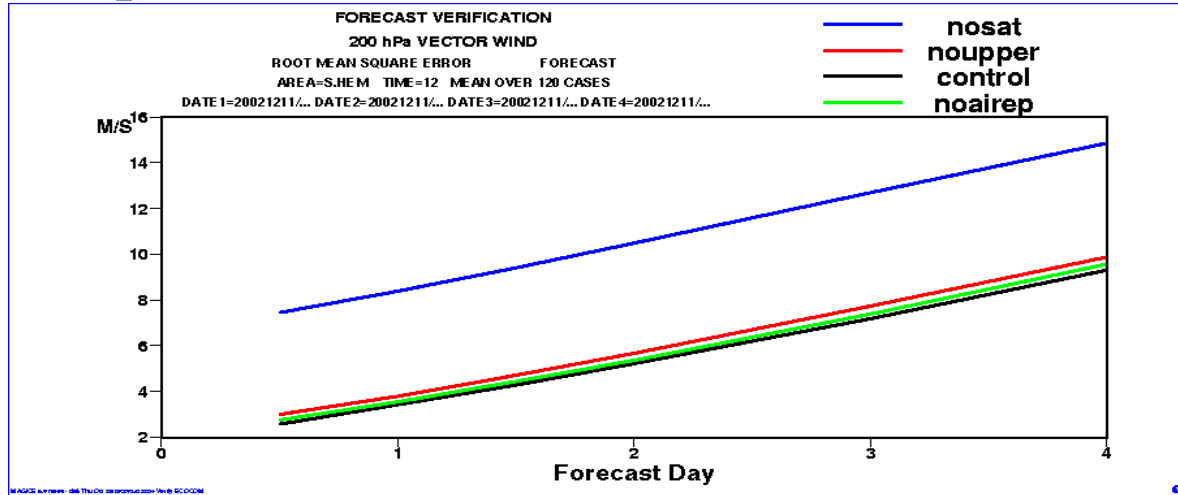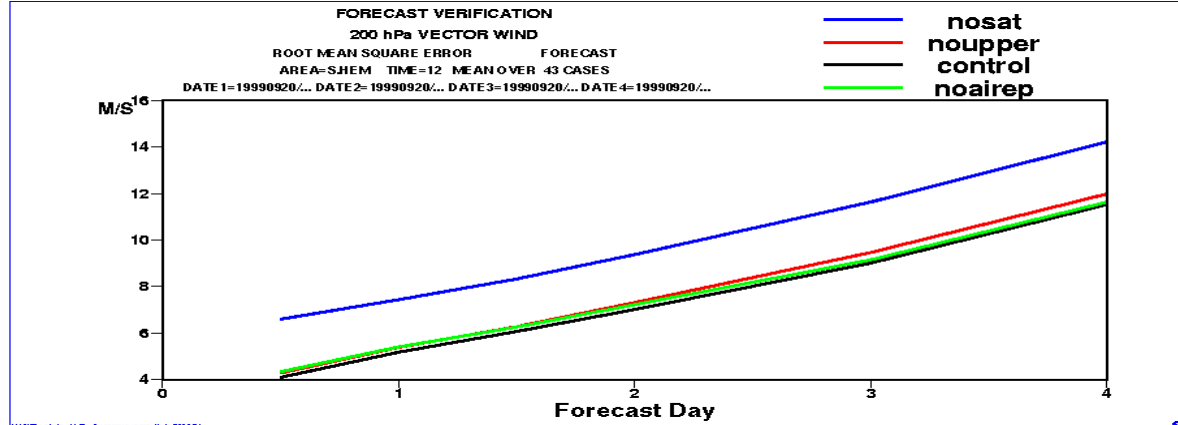# Northern Hemispheric OSE's (RMS 200hPa vector wind)

2002

1999

1997

Tropical OSE's (RMS 200hPa vector wind)

2002

FORECAST VERIFICATION
200 hPa VECTOR WIND
ROOT MEAN SQUARE ERROR   FORECAST
AREA=S.HEM   TIME=12   MEAN OVER 120 CASES
DATE1=20021211/... DATE2=20021211/... DATE3=20021211/... DATE4=20021211/...

nosat
noupper
control
noairep

1999

FORECAST VERIFICATION
200 hPa VECTOR WIND
ROOT MEAN SQUARE ERROR   FORECAST
AREA=S.HEM   TIME=12   MEAN OVER 43 CASES
DATE1=19990920/... DATE2= 19990920/... DATE3=19990920/... DATE4=19990920/...

nosat
noupper
control
noairep

1997

FORECAST VERIFICATION
200 hPa VECTOR WIND
ROOT MEAN SQUARE ERROR   FORECAST
AREA=S.HEM   TIME=12   MEAN OVER 34 CASES
DATE1=19971128/... DATE2= 19971128/... DATE3=19971128/... DATE4=19971128/...
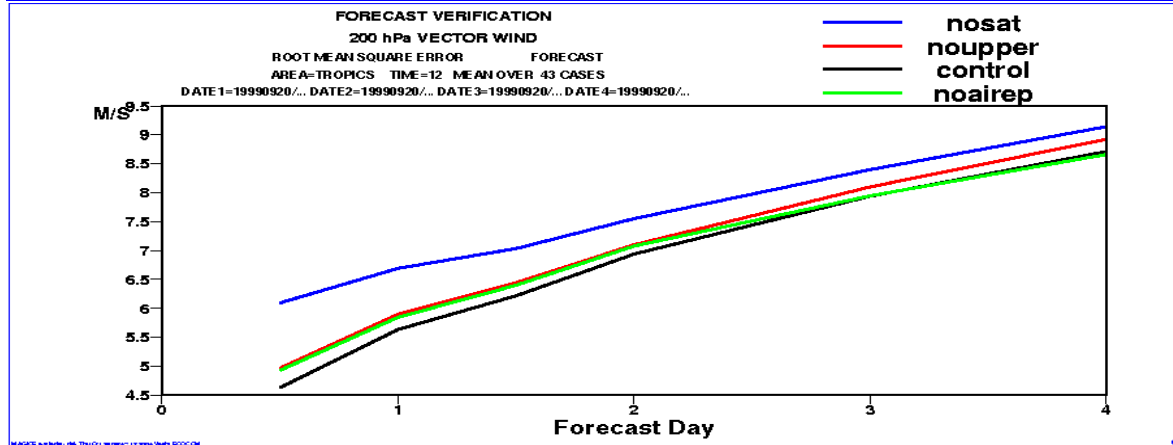
nosat
noupper
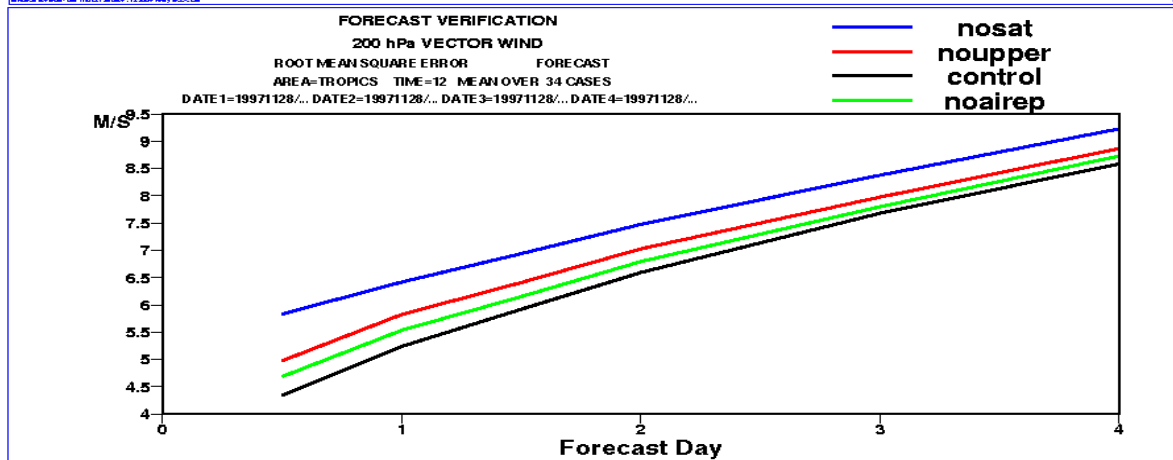control
noairep

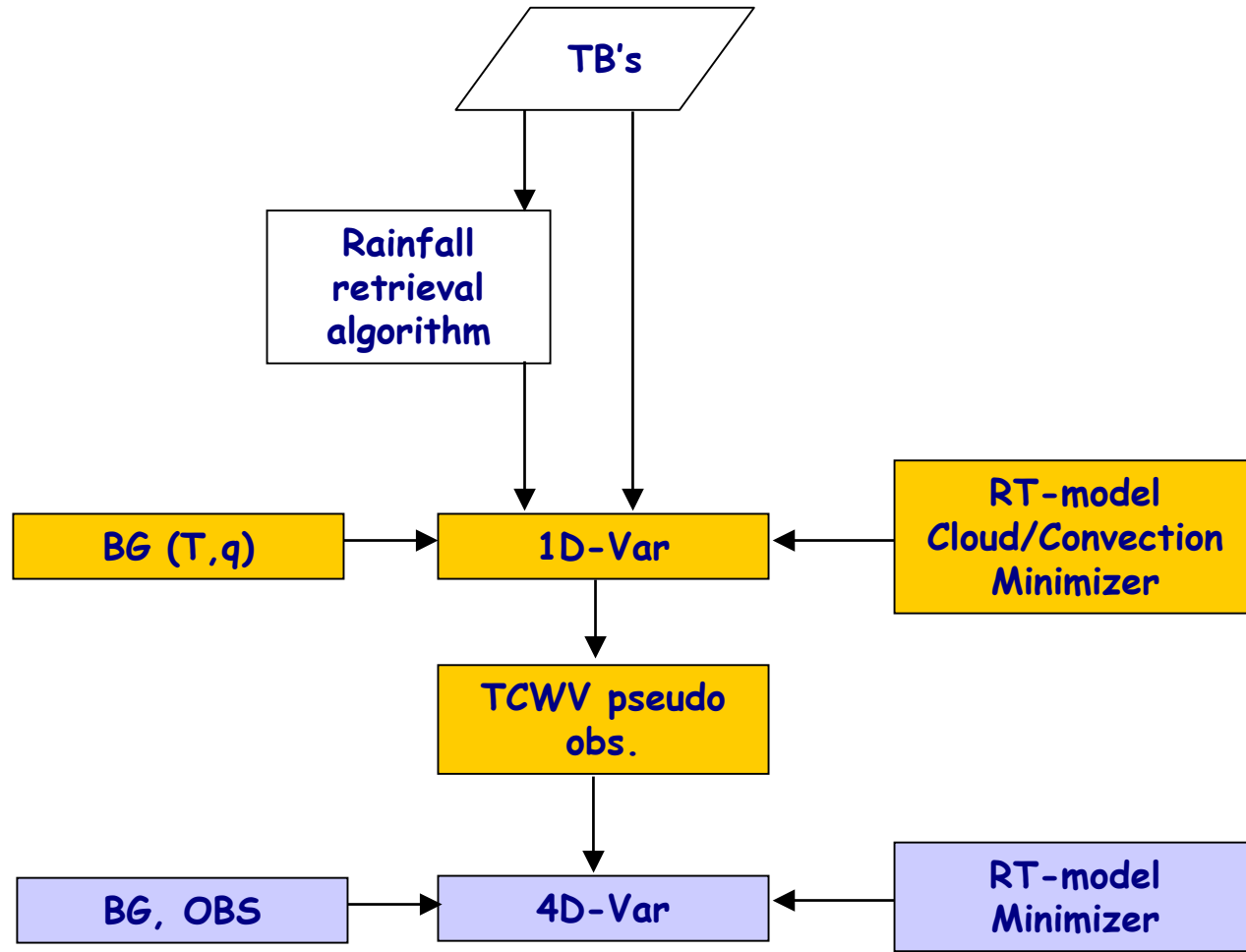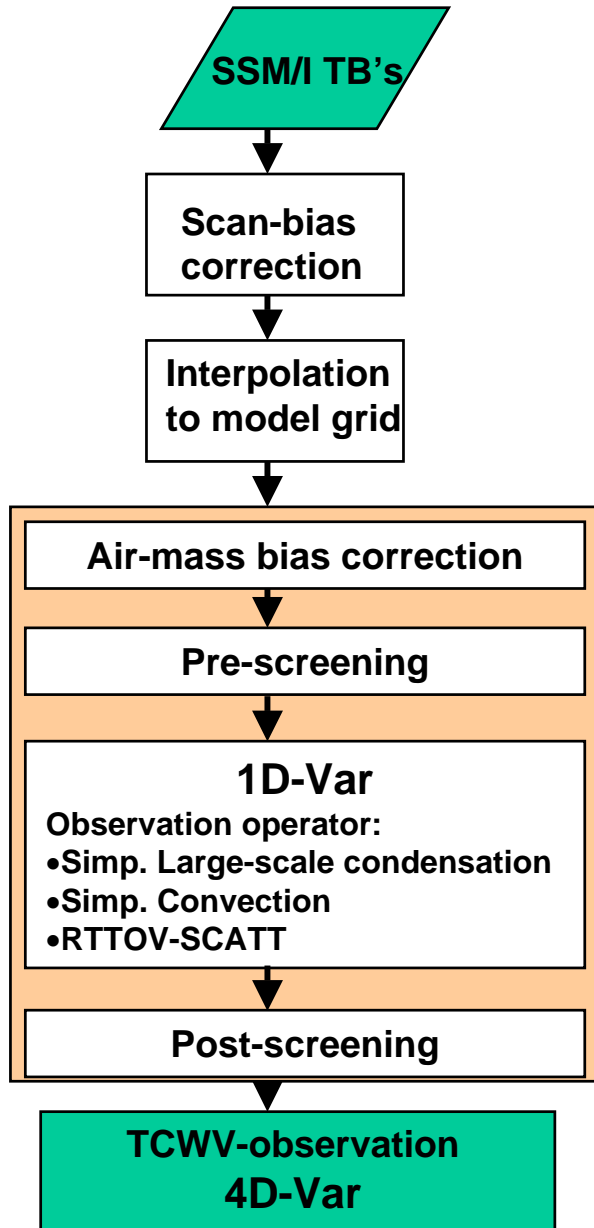# Southern Hemispheric OSE's (RMS 200hPa vector wind)

A new challenge: Assimilation of cloudy microwave radiances

## 1D+4D-Var approach to assimilate rain information from satellites (SSM/I – SSMIS)

Assimilation of Cloud/Precipitation Affected Microwave Radiances
(P. Bauer)

```
┌─────────────────┐
│   SSM/I TB's    │
└─────────────────┘
         │
         ▼
┌─────────────────┐
│   Scan-bias     │
│   correction    │
└─────────────────┘
         │
         ▼
┌─────────────────┐
│  Interpolation  │
│  to model grid  │
└─────────────────┘
         │
         ▼
┌───────────────────────────────┐
│  Air-mass bias correction     │
│         │                     │
│         ▼                     │
│     Pre-screening             │
│         │                     │
│         ▼                     │
│        1D-Var                 │
│  Observation operator:        │
│  •Simp. Large-scale condensation │
│  •Simp. Convection            │
│  •RTTOV-SCATT                 │
│         │                     │
│         ▼                     │
│     Post-screening            │
└───────────────────────────────┘
         │
         ▼
┌─────────────────┐
│ TCWV-observation│
│     4D-Var      │
└─────────────────┘
```

Important Features:

- **1D-Var executed with model physics 1st traj (15' time step, full resolution, oceans only)**

- **observations are interpolated to model grid**

- **1st time for moist physics and multiple scattering radiative transfer schemes in an observation operator**

- **only satellite observations that are intentiona assimilated in clouds and precipitation**

- **new load-balancing ensures code efficiency**

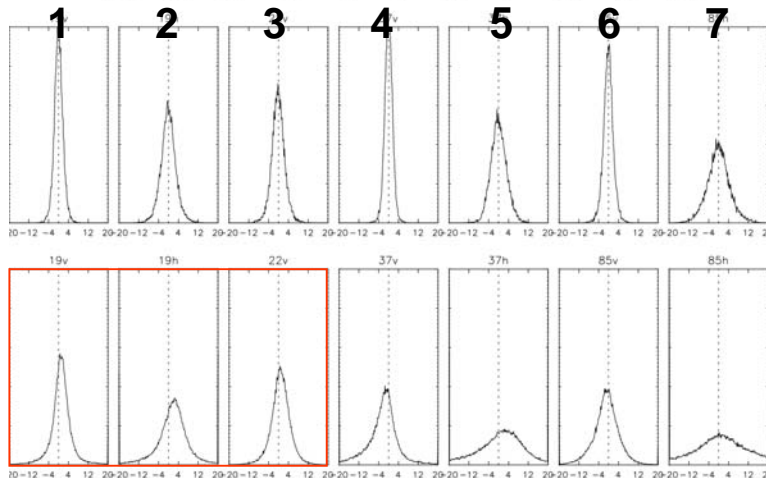# FG Radiance Departures (03/08/2004 00 UTC)
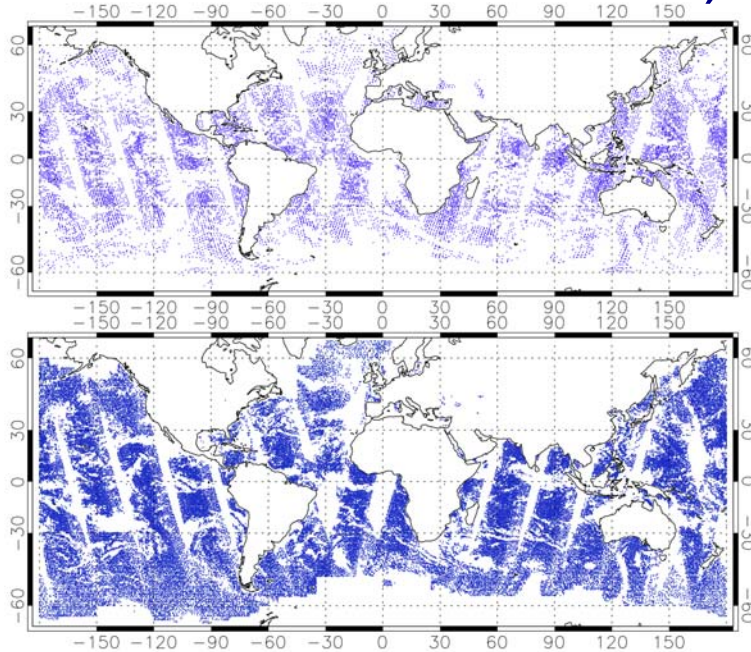
SSM/I clear-sky radiance data coverage

DCDA:	70,000 observations/cycle
DA	50,000 observations/cycle

SSM/I precipitation TCWV data coverage

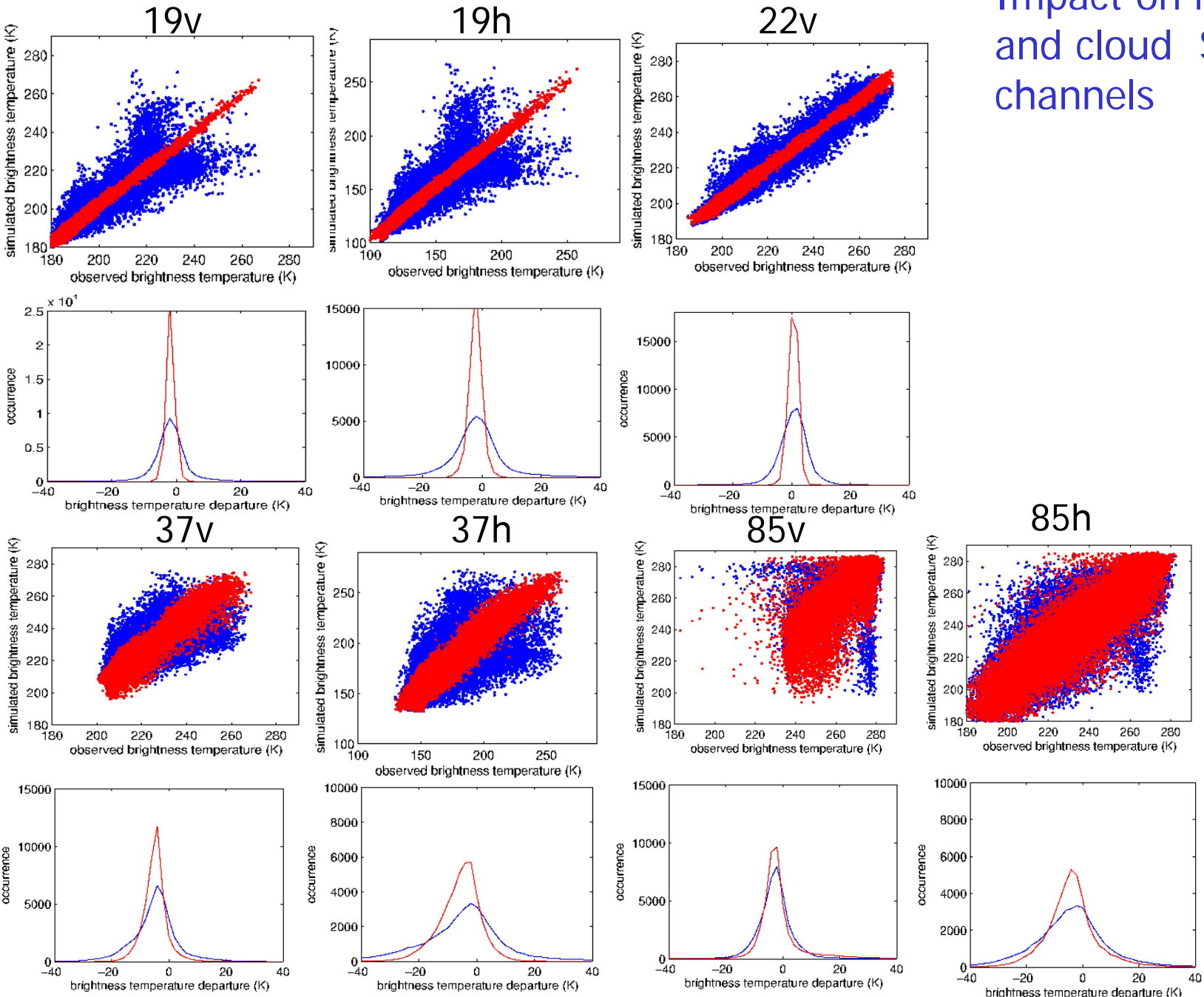| DCDA:	50,000 observations/cycle
DA	25,000 observations/cycle

SSM/I Channels: 1 2 3 4 5 6 7

**SSM/I clear-sky
FG radiance departure pdf**

**SSM/I precipitation
FG radiance departure pdf**

Impact on rain and cloud SSMI channels

# GEMS tasks at ECMWF

- **Greenhouse gases**
  - **Start on CO_2, then CH_4, N_2O and CO**
  - **Develop modelling and data assimilation, and use analyses to infer sources and sinks for CO_2 and CH_4**

- **Reactive gases**
  - **Couple main forecast model with global CTMs**
  - **Carry O_3, NO_2, CO, SO_2 and CH_2O in main model and develop data assimilation**

- **Aerosols**
  - **Add to model, based on existing parameterizations**
  - **Develop assimilation of retrievals, then radiances**

- Integrate above components, and run past periods

- Provide boundary conditions and technical support for regional air-quality prediction
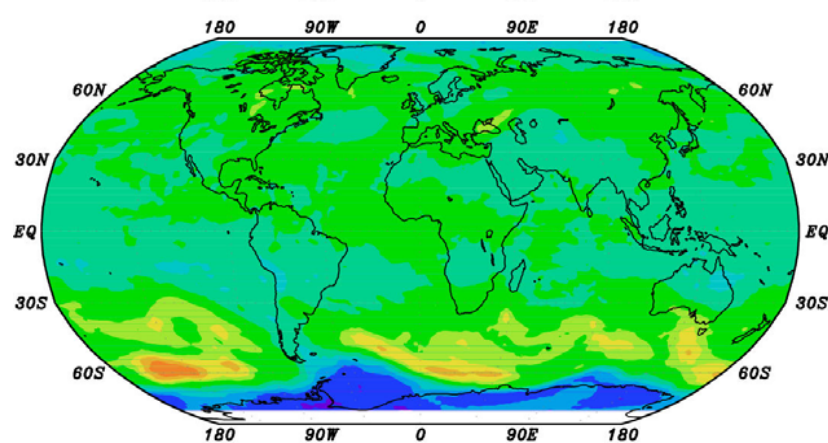
Total ozone
9 Sept 2004
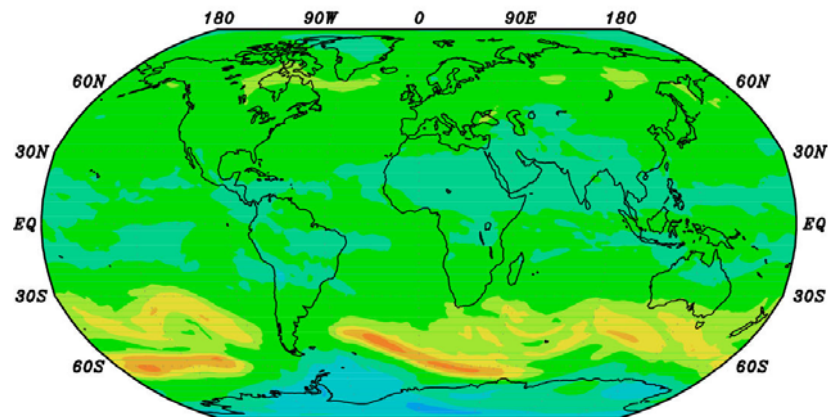
Operations, no SCIAMACHY
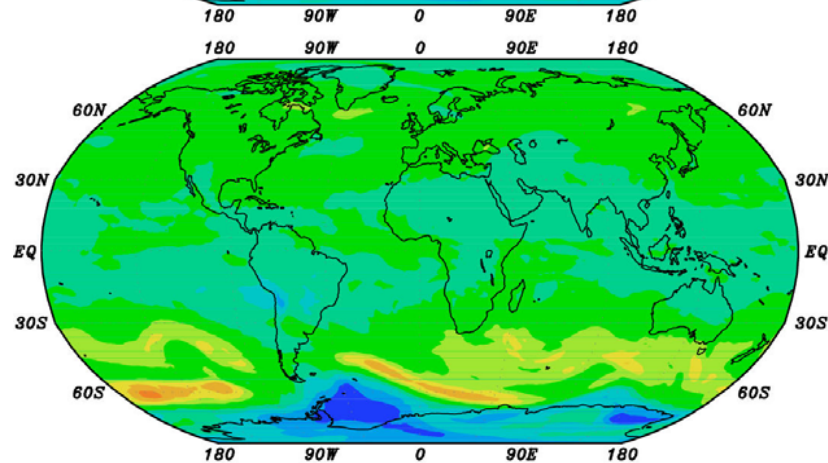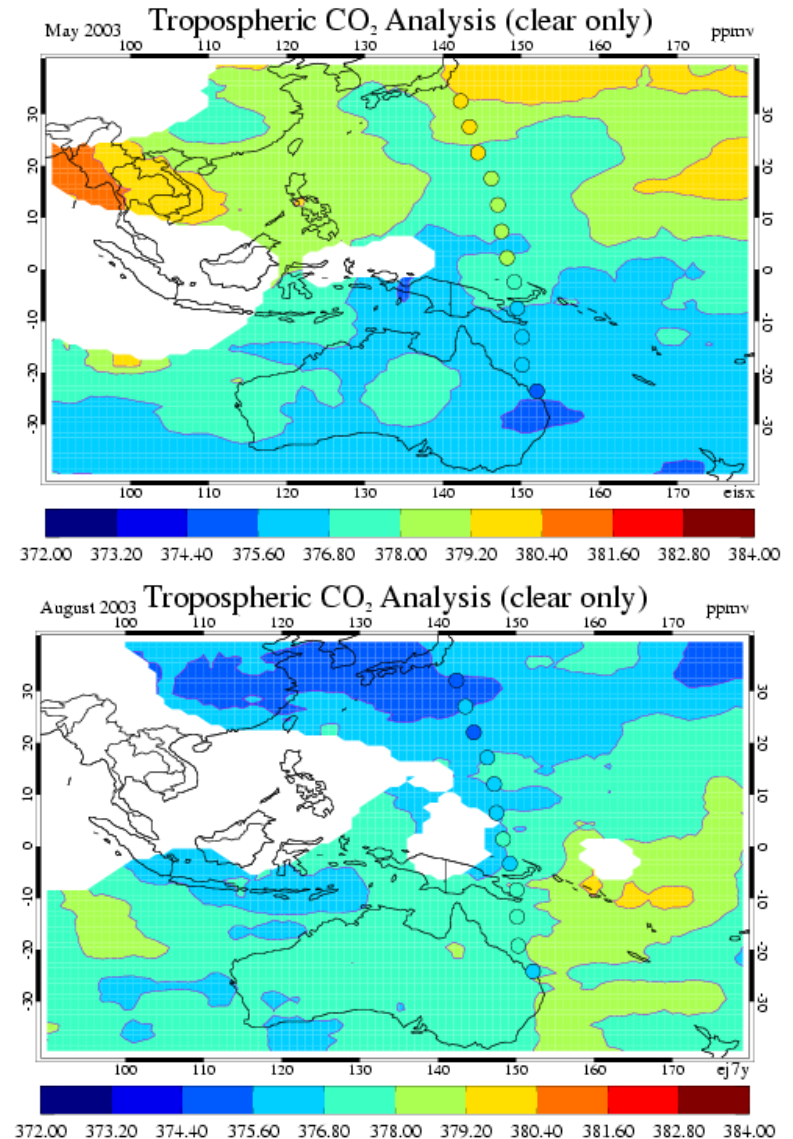
Pre-operational test, including SCIAMACHY

TOMS

125 150 200 225 250 275 325 350 375 400 450 475
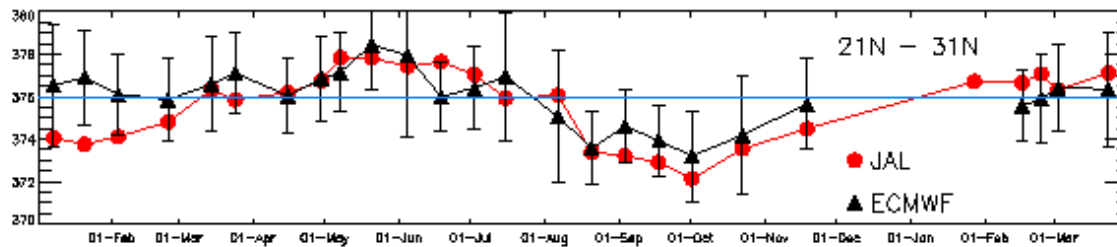
Monitoring of the CO_2

- Trace gases: CO_2, CH4, CO, N2O,..

- Reactive gases: O3, NOx,…

- Aerosols

- Exchanges between land/ocean/atmosphere

- Monitoring of the carbon cycle
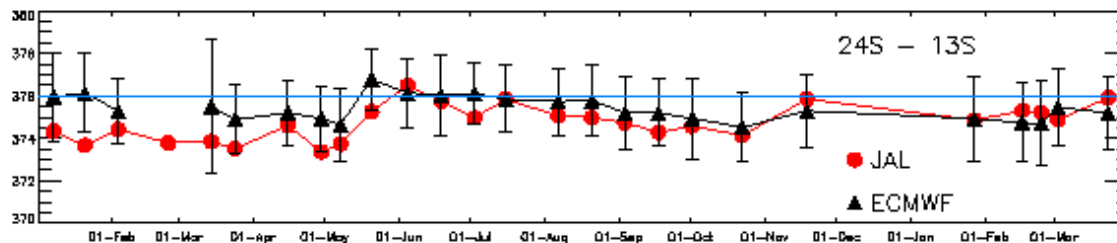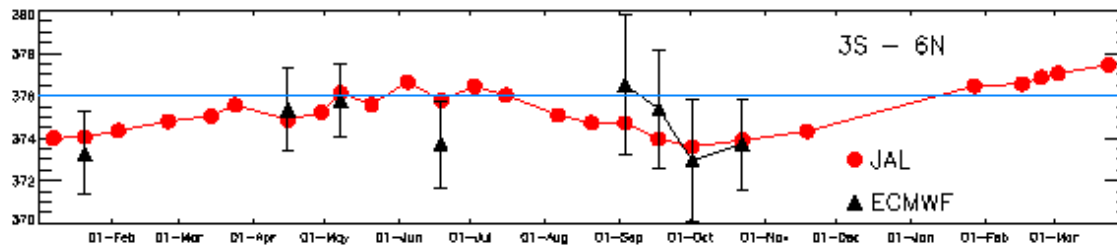

Tropospheric CO_2 from AIRS

CO$_2$ estimation

One year of AIRS radiances (Feb 03 to Mar 04) have now been analyzed inside the ECMWF 4DVAR and CO$_2$ estimates produced.

Zonal column estimates (ppmv)

In general the agreement with the sparse validation data (JAL flight data) Is quite good, although some periods need more study

Plans for 2005

- Higher vertical resolution

  ……L91 for 4D-Var and deterministic forecast

  ……L62 for EPS, seasonal and monthly forecasts

- T799 horizontal resolution in deterministic forecast and outer loops of 4D-Var with T255 inner loops (T319 for SVs?)

- Use of SSMIS amd AMSR data

- Assimilation of cloudy/precipitation data (radiances through a 1D+4D approach)

- Preparation for METOP (IASI in particular) and better exploitation of AIRS

  – Channel selection, cloud detection, monitoring,…

  – Environment monitoring