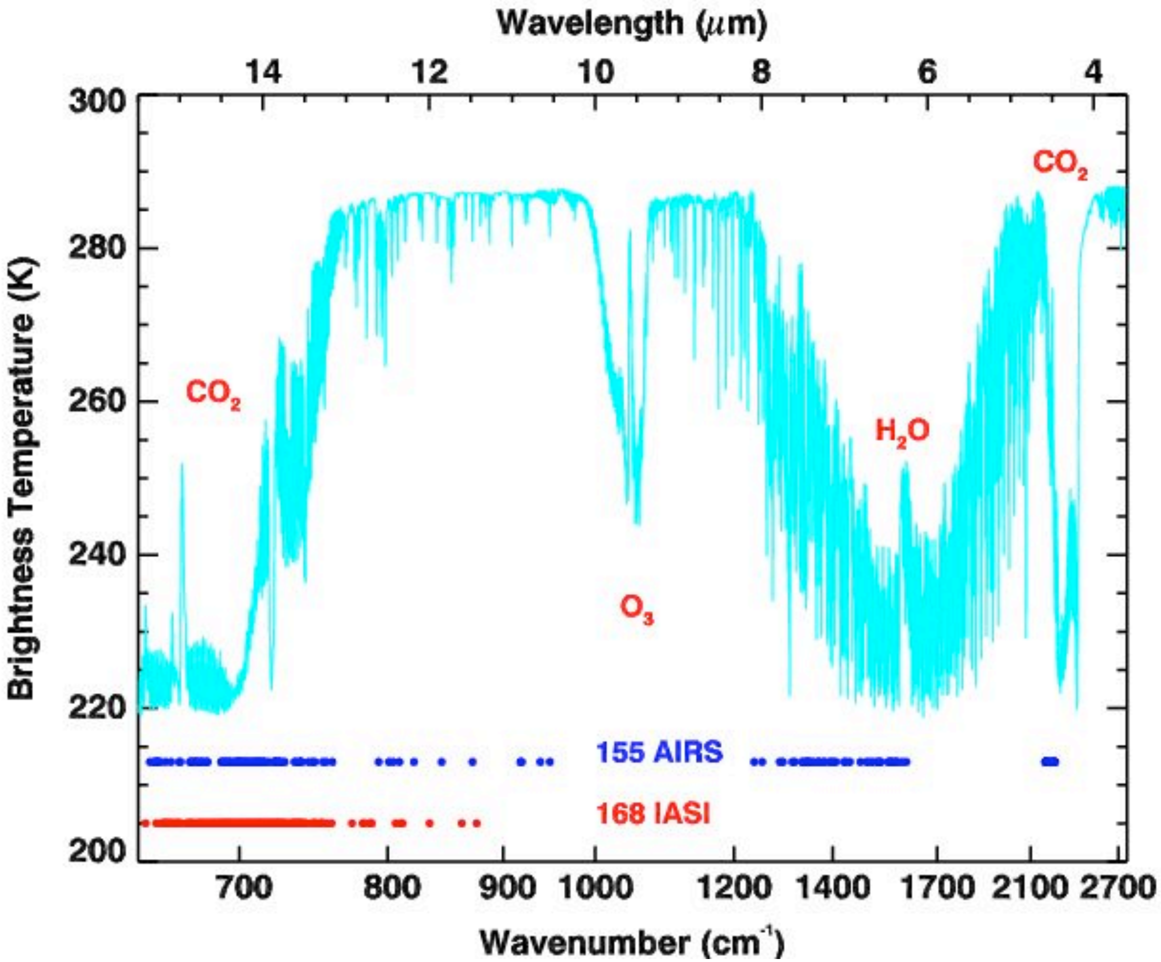
New Technologies, Applications and Reanalysis

lecture 3

Tony McNally
ECMWF

Advanced IR sounders

Advanced infrared sounders: AIRS and IASI



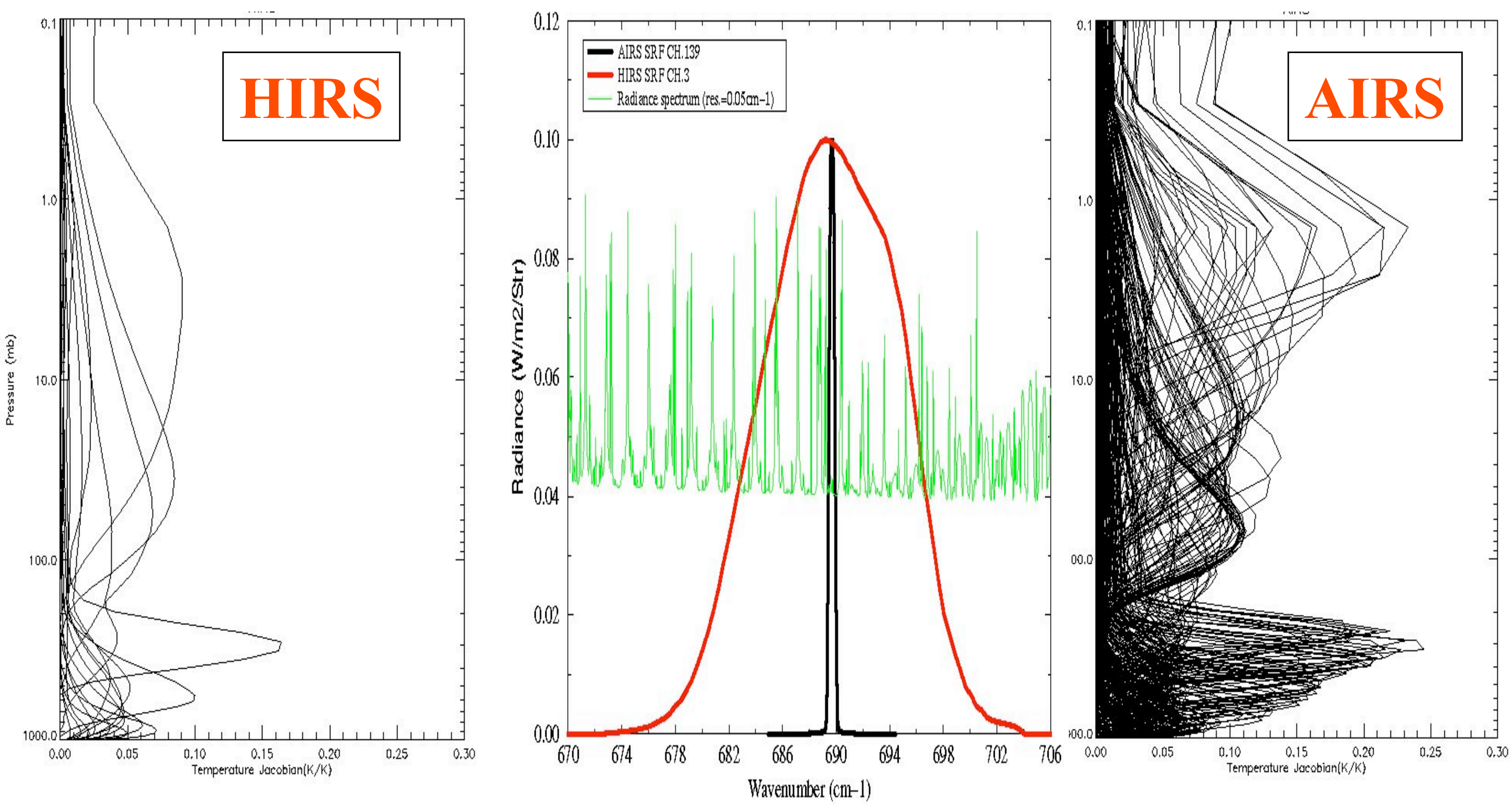
AIRS

- Operational at ECMWF since October 2003.
- 324 channels received in NRT.
- One FOV in nine used.
- Up to 155 channels may be assimilated (CO_2 and H_2O bands).

IASI

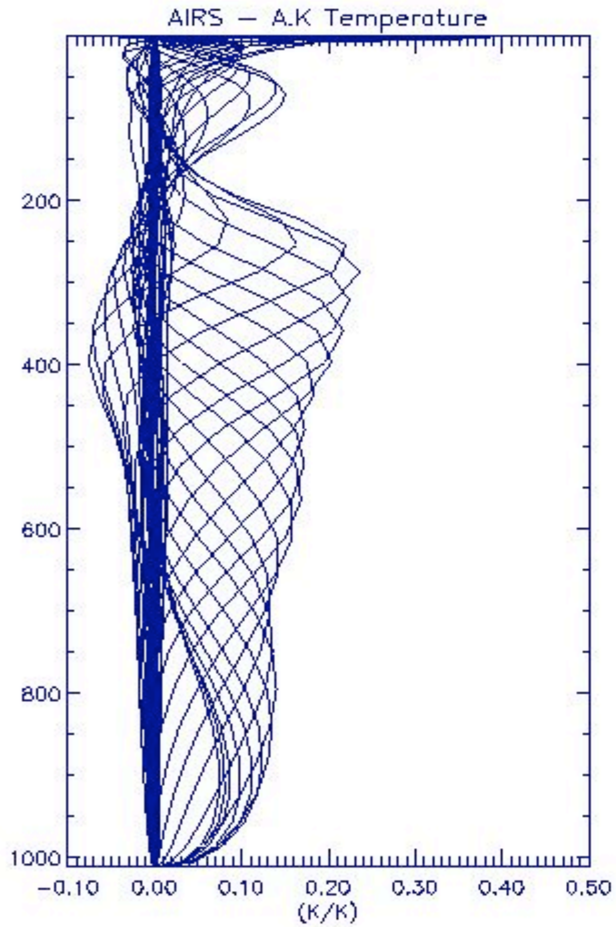
- Operational at ECMWF since June 2007.
- 8461 channels received in NRT.
- All FOVS received; only 1-in-4 used.
- 366 Channels routinely monitored.
- Up to 168 channels may be assimilated (CO_2 band only).

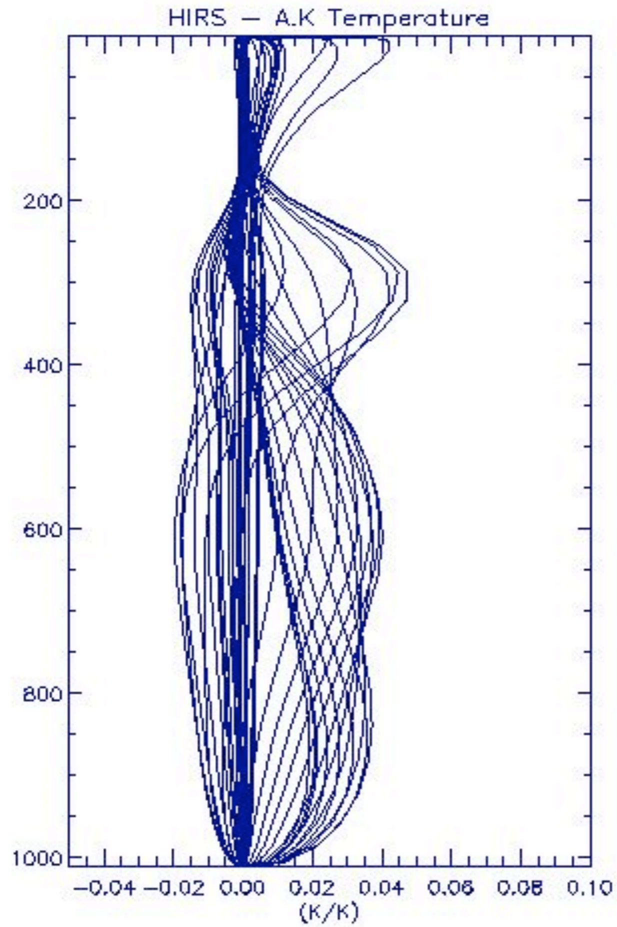
Advanced infrared sounders: AIRS and IASI



Better measure of improved resolution is provided by the averaging kernels

AIRS



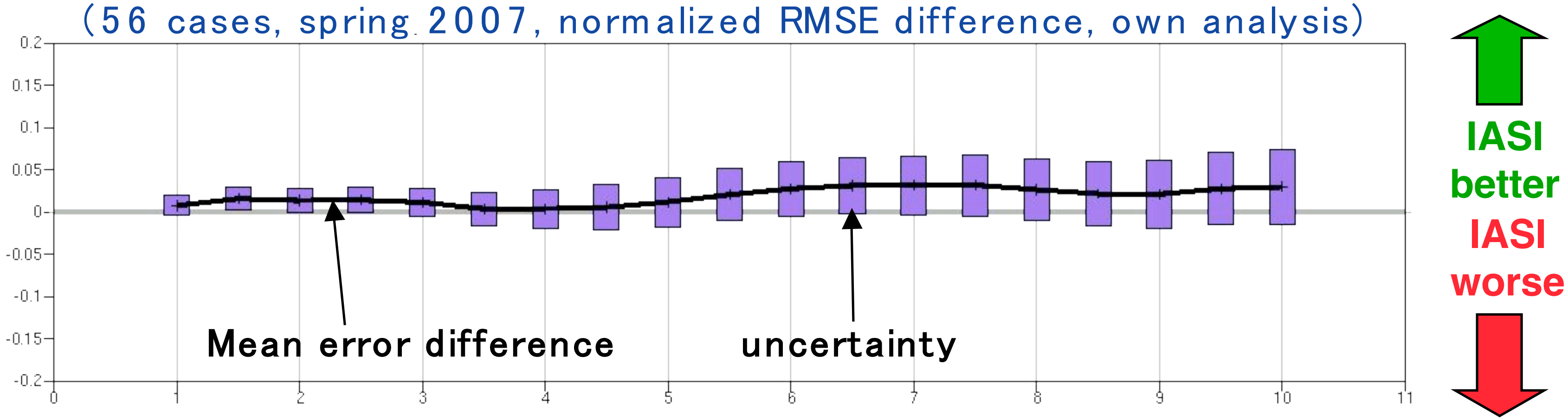


HIRS

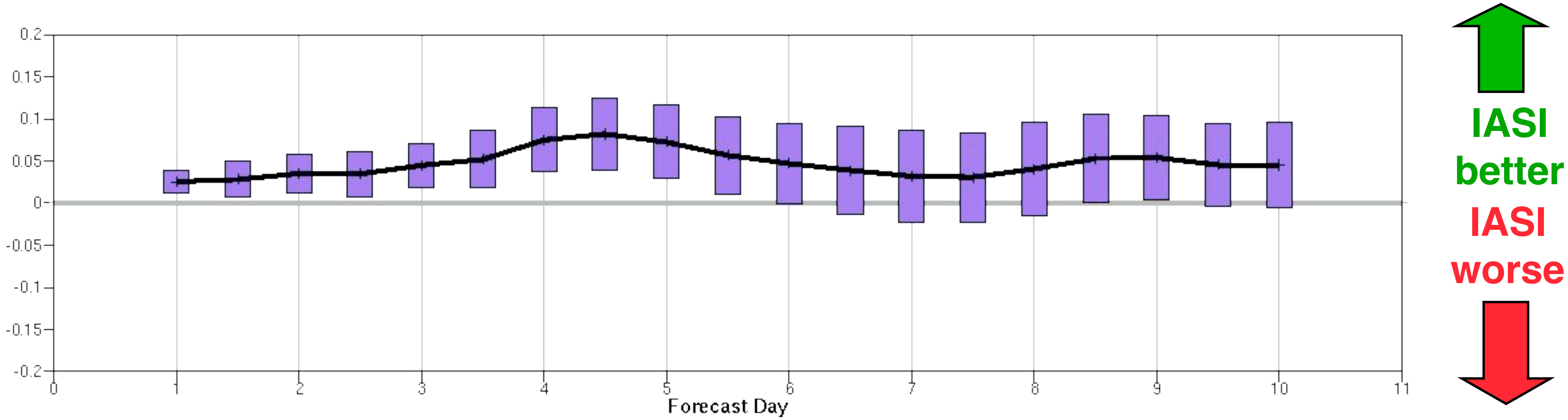
IASI forecast impact

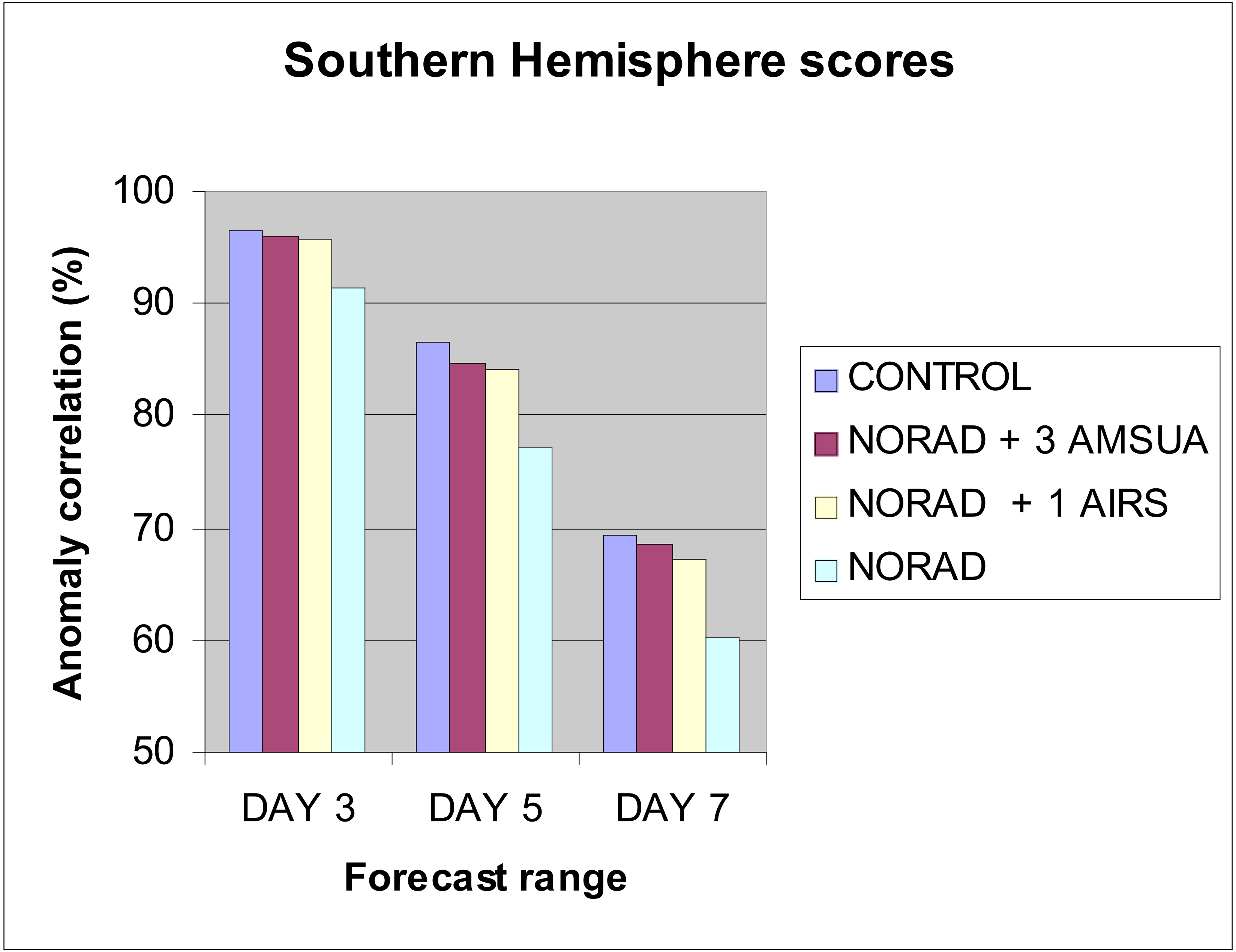
500 hPa geopotential anomaly correlation
(56 cases, spring 2007, normalized RMSE difference, own analysis)

NH



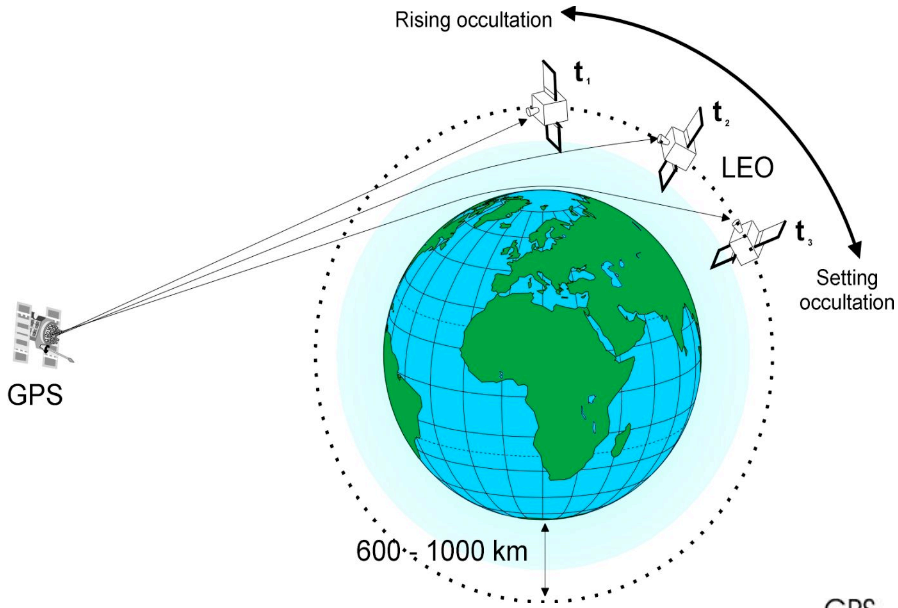
SH




Southern Hemisphere scores
Anomaly correlation (%)
100
90
80
70
60
50
DAY 3
DAY 5
DAY 7
Forecast range
CONTROL
NORAD + 3 AMSUA
NORAD + 1 AIRS
NORAD

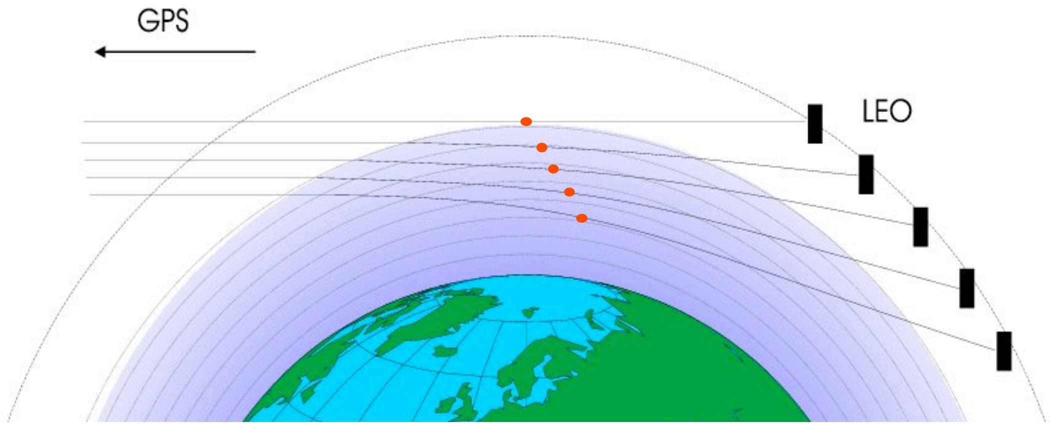
GPS Radio Occultation

Radio occultation geometry

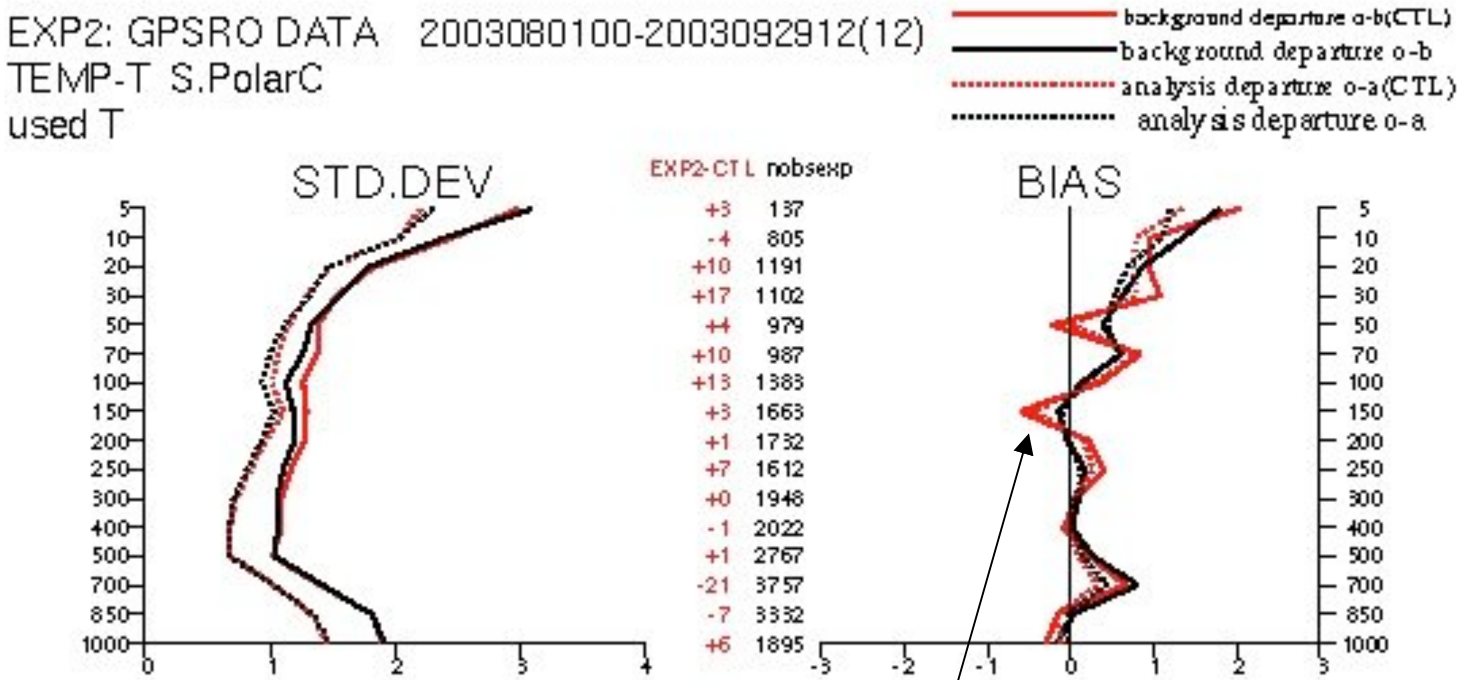


- CHAMP, COSMIC, METOP-GRAS
- The impact of the atmosphere on the signal propagation depends on the refractivity => the vertical profile of the refractivity (and further down temperature, humidity and pressure) at the location of the ray perigee can be inverted from the observation

● = the path of the ray perigee through the atmosphere



Radiosonde comparisons for Antarctica
12h forecasts



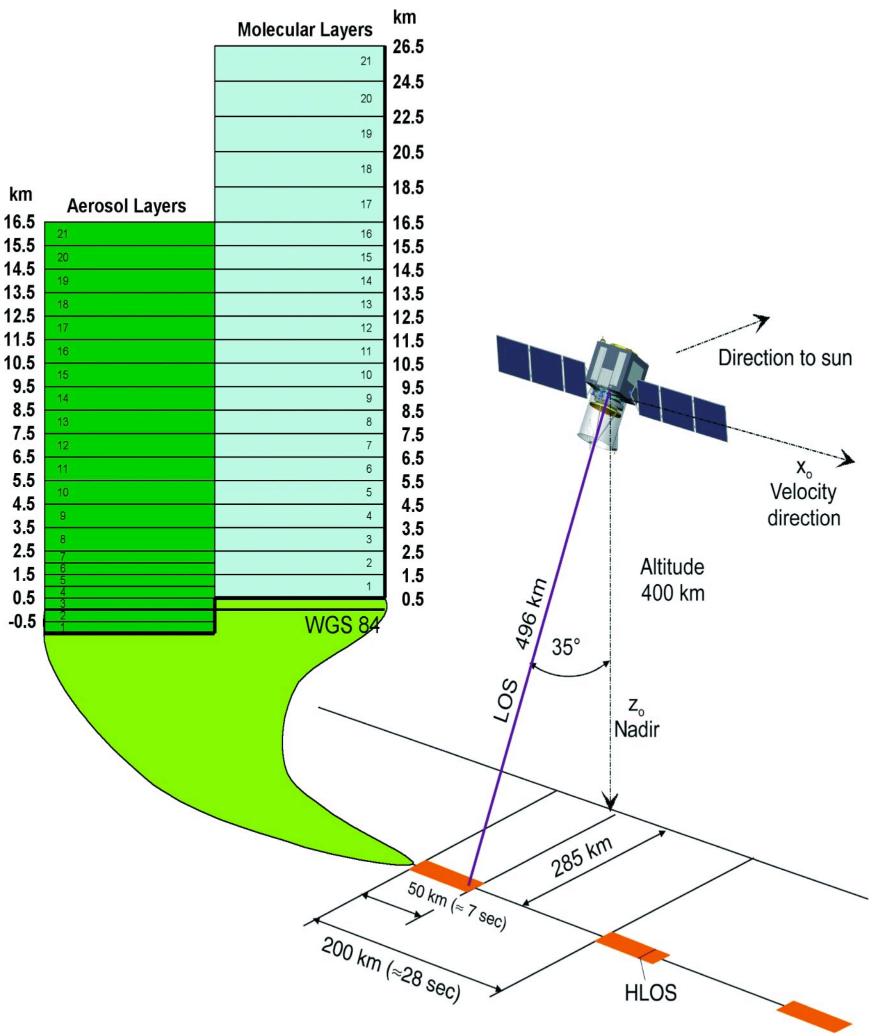
Red lines: control

Black: experiment

Structure in the mean fit thought to be caused by inconsistencies in the AIRS and AMSU bias corrections schemes (G. Kelly, ECMWF Pers. Comm)

Doppler Wind LIDAR

ADM-Aeolus

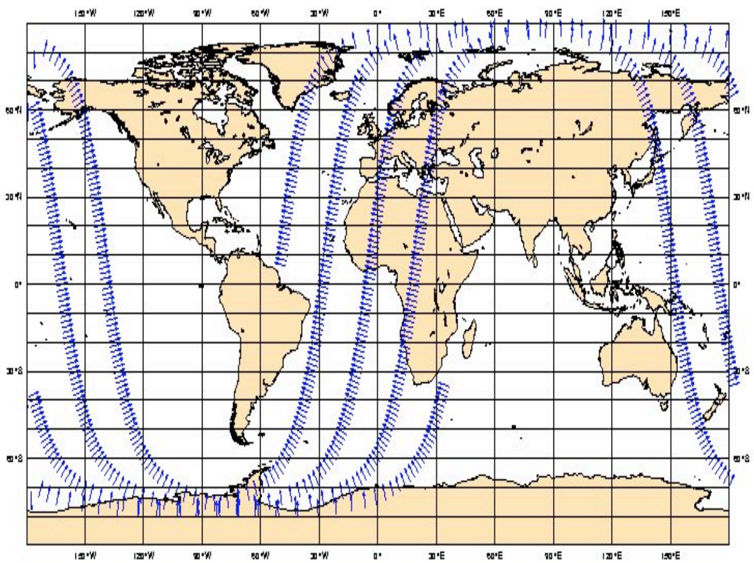


UV lidar (355 nm) with two receivers

- **Mie (aerosol), Rayleigh (molecules)**
- **both use direct detection**

Wind profiles from surface to 30 km with resolution varying from 0.5 to 2 km

- **vertical bins configurable in flight**
- **HLOS component only**
- **direction 7º from zonal at equator**
- **6 hour coverage shown**



Environmental monitoring

ECMWF role in GMES

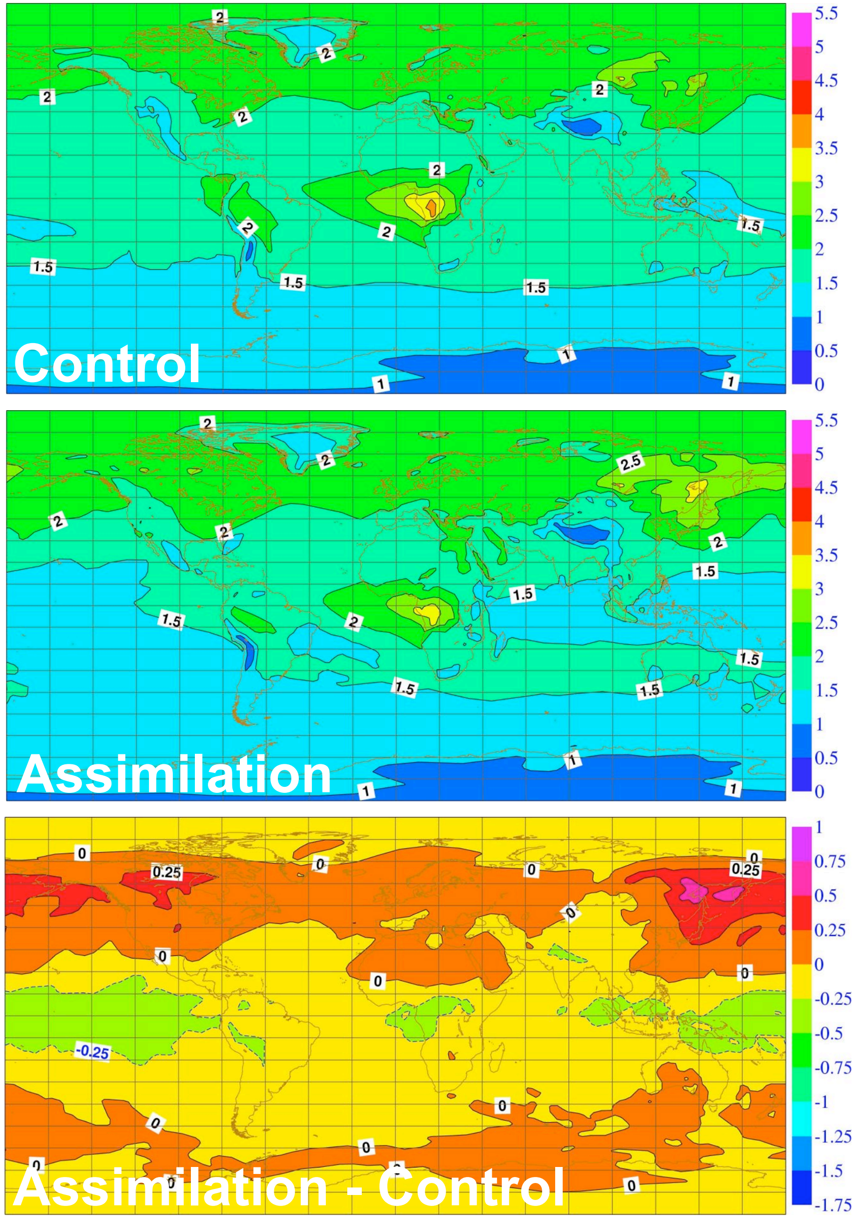
Global Monitoring for Environment and Security

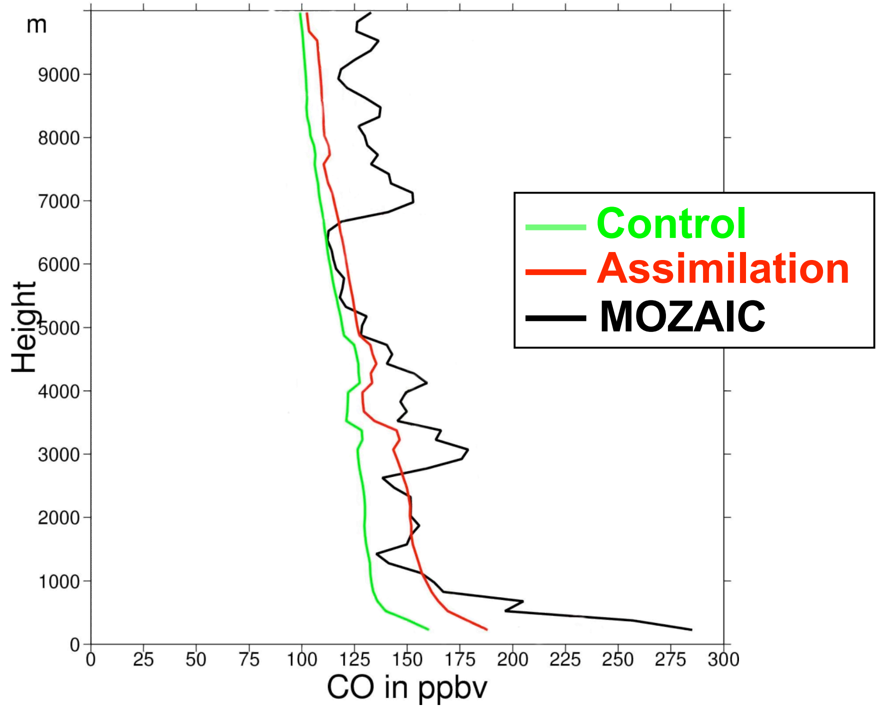
- Reactive gases
  - **Couple IFS with global CTMs, carrying O_3, CO, NO_2, SO_2 and HCHO in the IFS, and develop data assimilation**
- Aerosols
  - **Implement in IFS, based on externally-produced parameterizations, and develop data assimilation**
- Greenhouse gases
  - **Introduce CO_2 and CH_4 into global ECMWF weather forecast model (IFS) and develop data assimilation**
- Acquisition of global data, and provision of support for regional air-quality forecasting
- Near-real-time and retrospective (2003-2007) running of integrated global system

Three types of product from ECMWF real-time system

- Model simulation
  - Extended sequence of 12-hour forecasts
  - Meteorological variables are reset to analysed values from ECMWF archives
  - GEMS composition variables are carried over from preceding 12-hour forecasts
  - Used as basis for first set of near-real-time forecasts
- Control
  - Data assimilation for meteorological variables, with 6h or 12h cycling
  - No data assimilated for GEMS composition variables
  - Similar to model simulation, with differences due to different meteorological analyses and possibly cycling period
- Assimilation
  - Data assimilation for meteorological variables and (some) GEMS composition variables, with 6h or 12h cycling

Mean CO from 15 to 30 July 2003 from assimilation of MOPITT total-column data

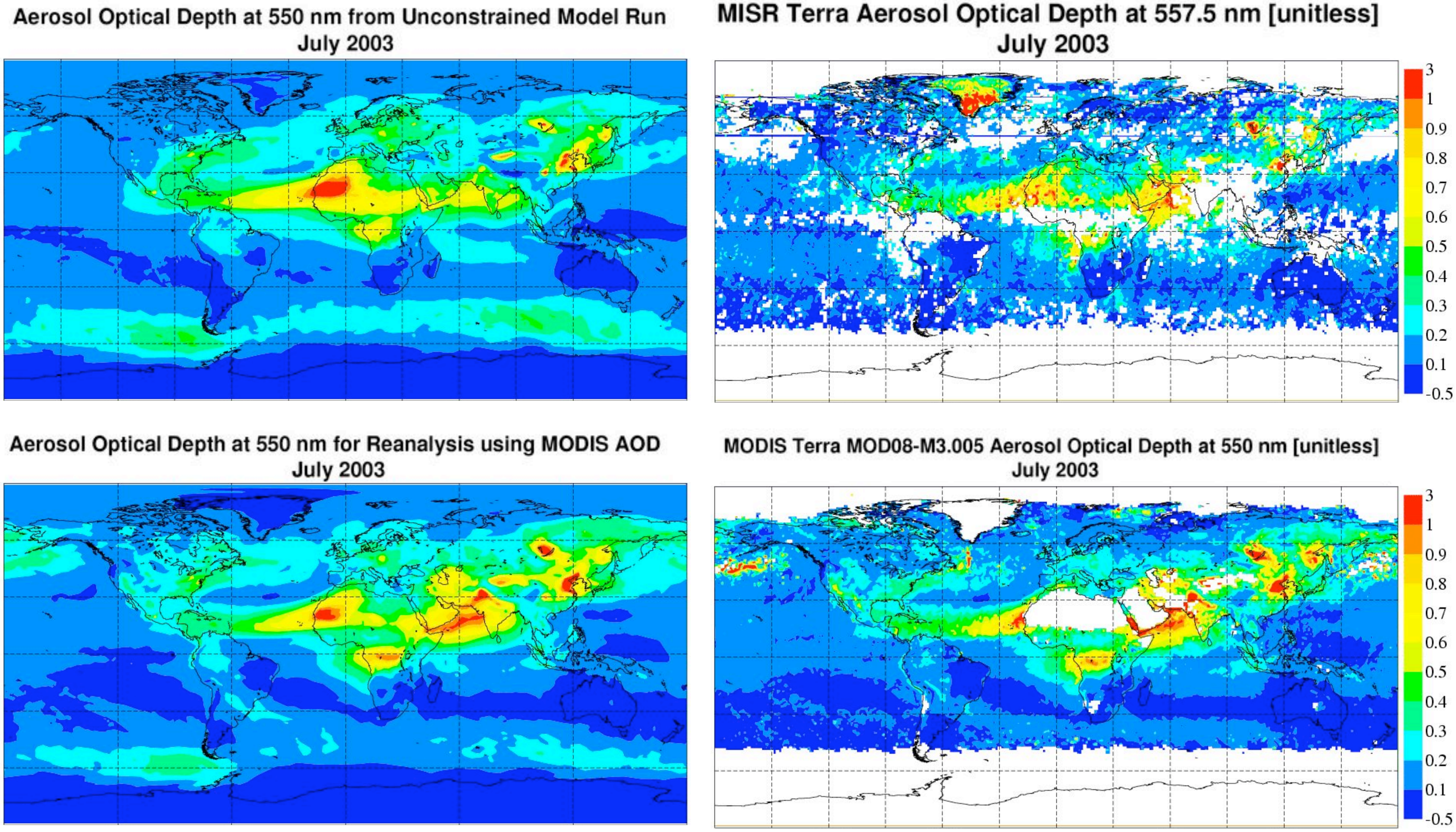




Carlos Ordóñez

Unit: 10^{18} molec/cm^2

Comparison of GEMS simulated and analysed aerosol optical depth with MODIS and MISR for July 2003

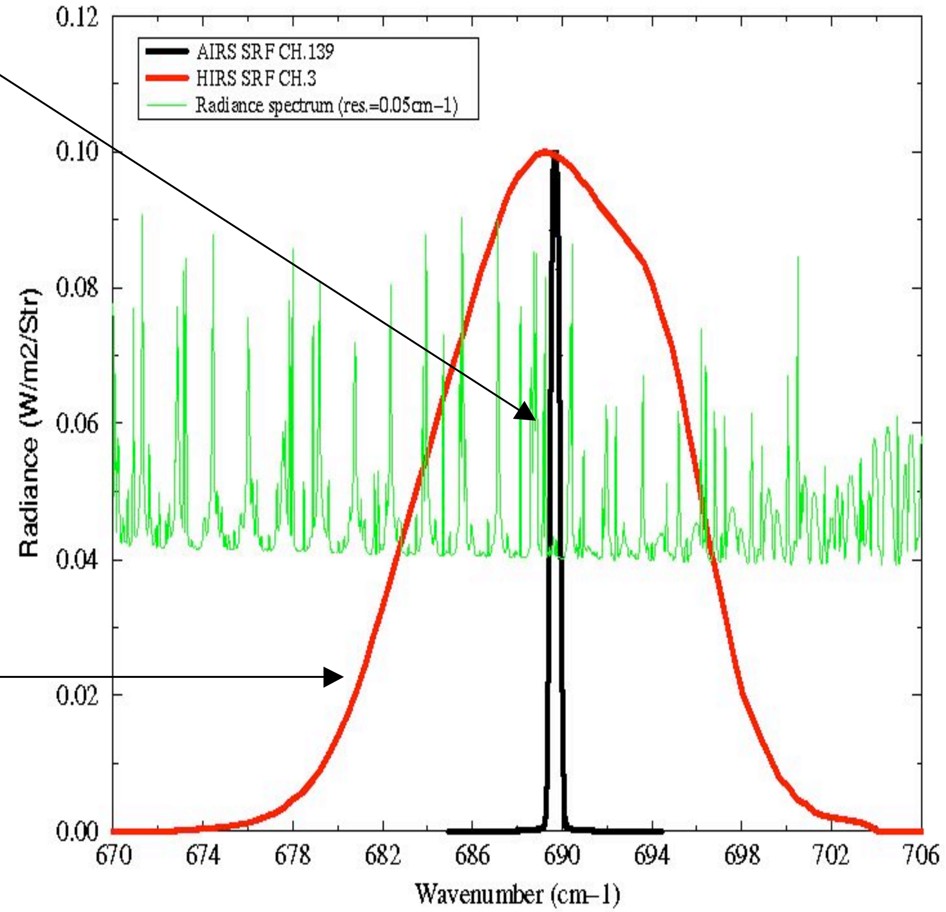


Radiance assimilation in GEMS (AIRS/IASI)

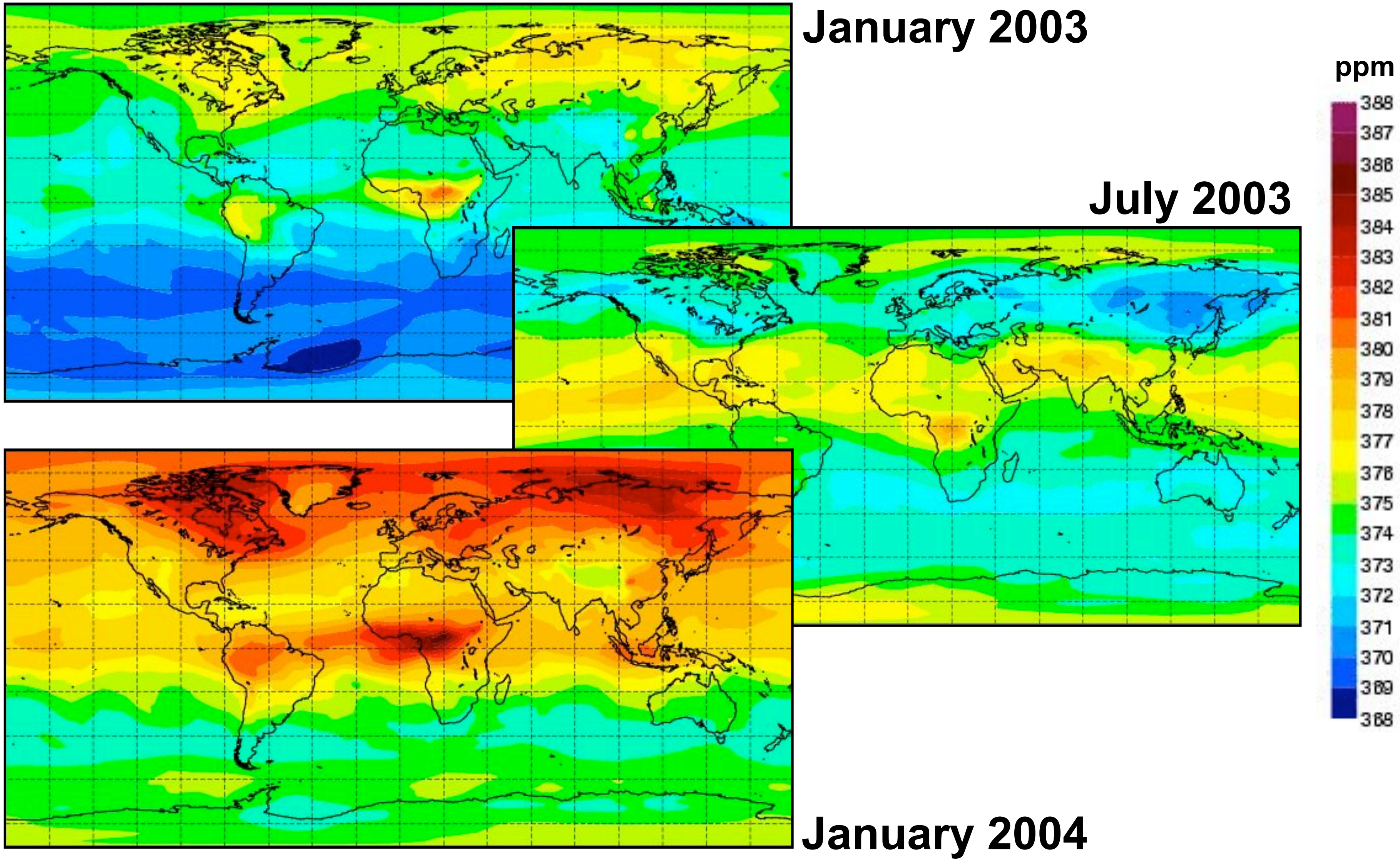
•By sampling the IR spectrum at very high resolution (R=1200) we can measure radiation that is only dependent on temperature and the atmospheric CO_2 concentration (small groups of **pure lines**)

•If we have **accurate temperature information** (from the ECMWF analysis driven by AMSUA data) we can separate out the CO_2 signal.

•Instruments with coarse spectral resolution (e.g. HIRS) sample radiation that is a mixture of absorbing species (e.g. CO_2 / N_20 / O_3 and H_2O) and cannot resolve the CO_2

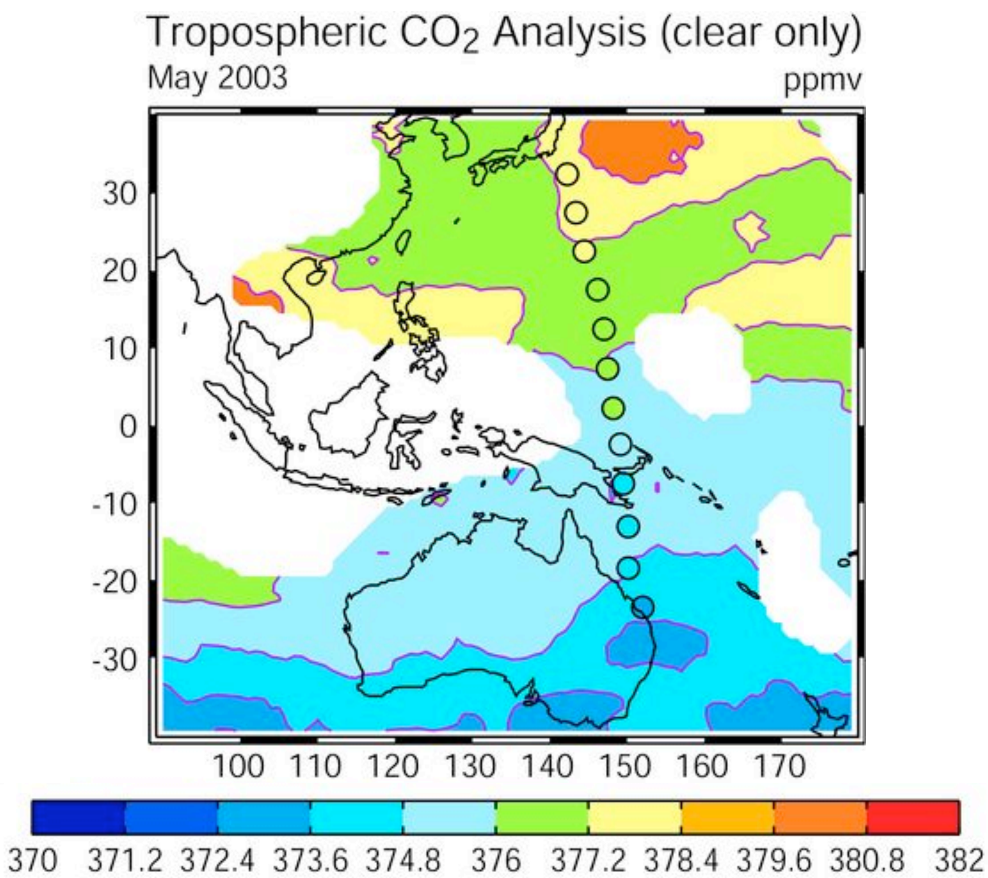


Mean column CO_2 from assimilation of AIRS radiances



http://gems.ecmwf.int

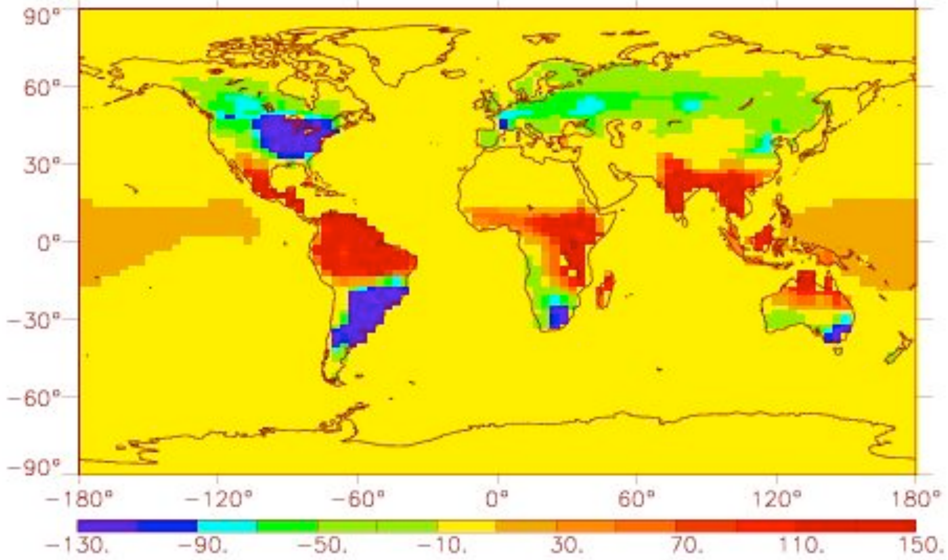
Mean column CO_2 from assimilation of AIRS radiances: Validation with aircraft



CO_2 flux inversion from AIRS data assimilation

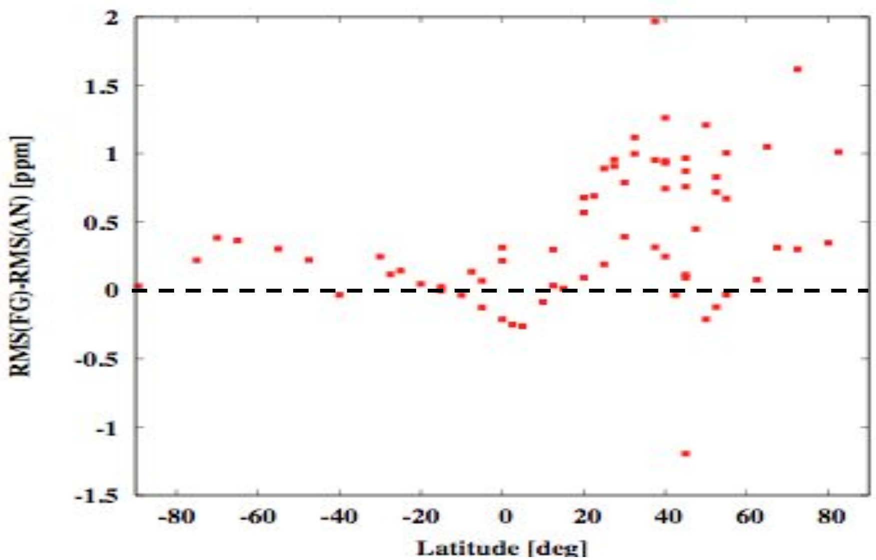
Cumulated surface flux increments derived from first CO_2 analyses for January-November 2003

Positive values imply flux into atmosphere.



(gCm[-2])

Change in RMS fit to GLOBALVIEW-CO_2 (2006) data from use of incremented fluxes from latest analysis in LMDZ transport-model simulations



(ppm)

Peter Rayner, Frédéric Chevallier

Reanalysis

What is Re-analysis ?

Analysis of past (historical) observational data using a **fixed**, tried-and-tested, operational data assimilation system.

What does it produce ?

A comprehensive time series of global analyses (i.e. gridded fields of temperature, humidity, wind etc..) and a homogeneous organized / quality controlled data-set of observations.

What is it used for ?

Meteorological research – into processes, composition, low-frequency variability, predictability, model development and general climate studies.

Operational forecast performance 1980-2006

Northern Hemisphere

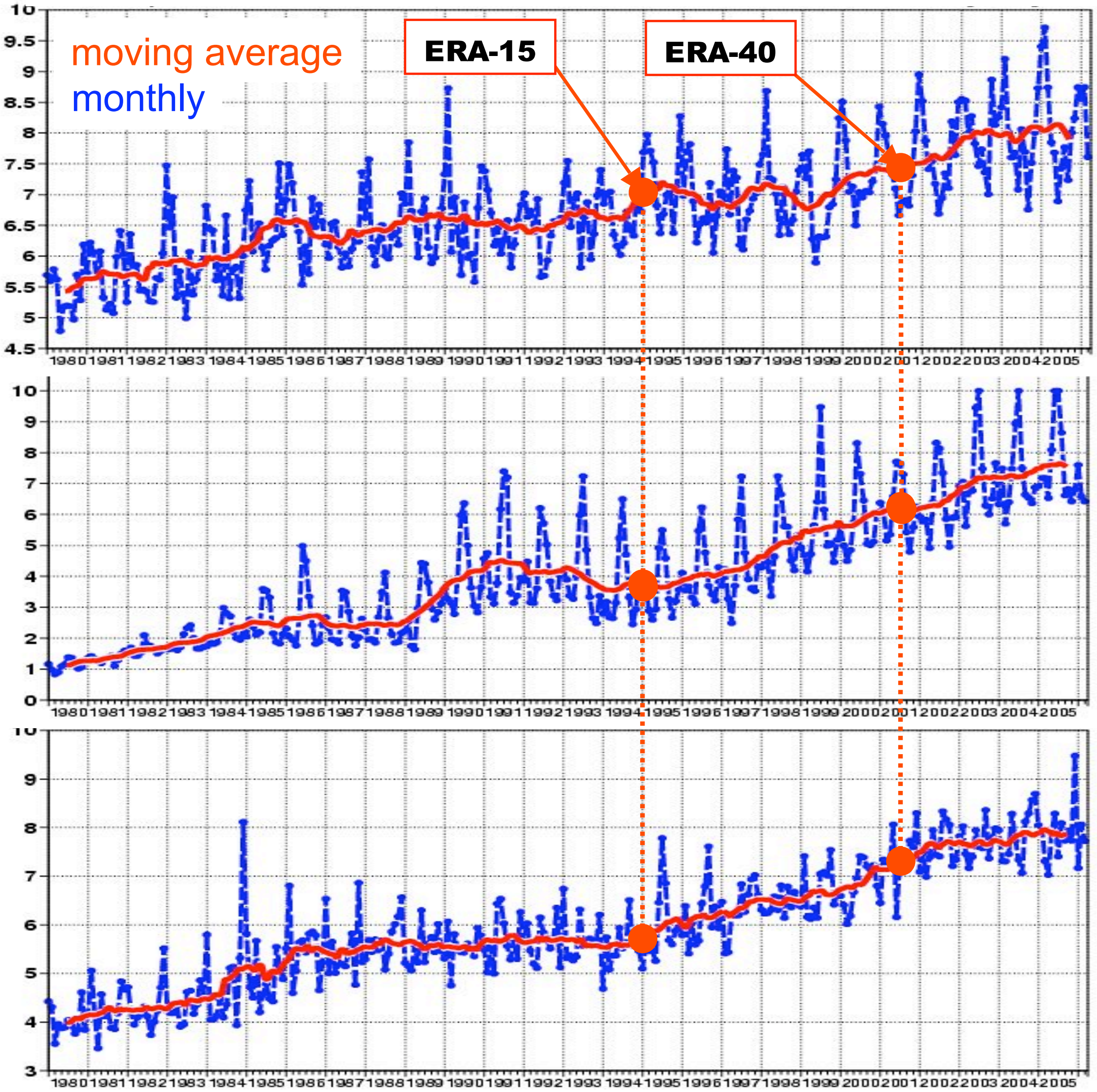
500 hPa geopotential
ANC reaching 60%

Tropics

850 hPa wind vector
ABC reaching 70%

Southern Hemisphere

500 hPa geopotential
ANC reaching 60%



Some practical considerations …

The operational assimilation method and resolution is not affordable

- We have to use a degraded, possibly less-tested configuration

The operational system has known problems

- We can implement recent fixes for some problems
- We may have to accept and try to account for other problems

The operational system is tuned / based on current observing systems

- We have to adapt the assimilation system to use older observing systems
- We have to handle changes in observation processing

If errors are found during the course of production

- We have to decide whether or not to stop / correct them / re-run

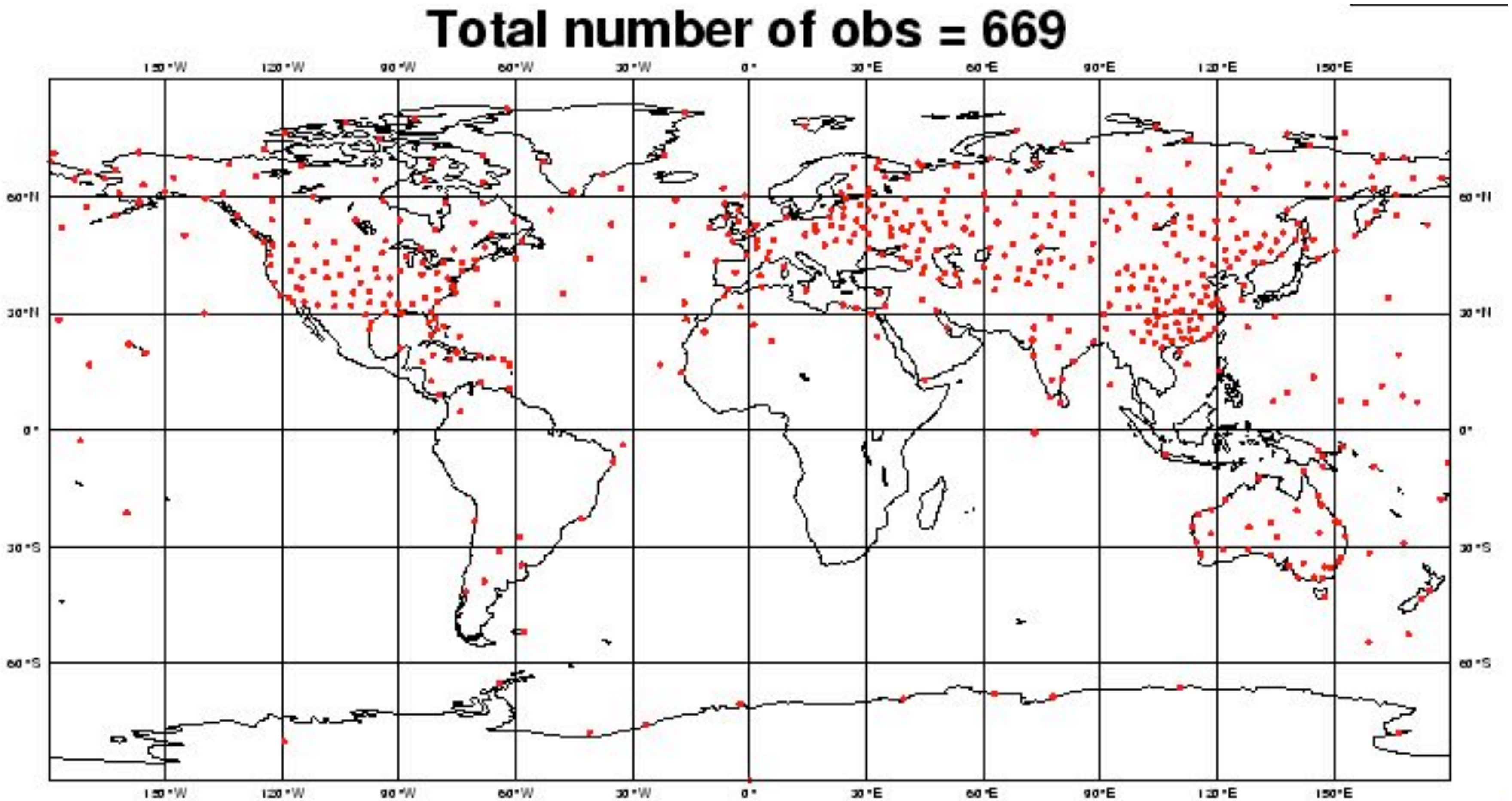
International REANALYSIS activity

NCEP/ NCAR	1948◊
NASA/ DAO	1980-1995
ECMWF, ERA-15	1979-1993
ECMWF, ERA-40	1957-2002
JMA/ JRA-25	1979-2004
ECMWF, ERA-Interim	
NASA GMAO	
Polar Reanalysis	

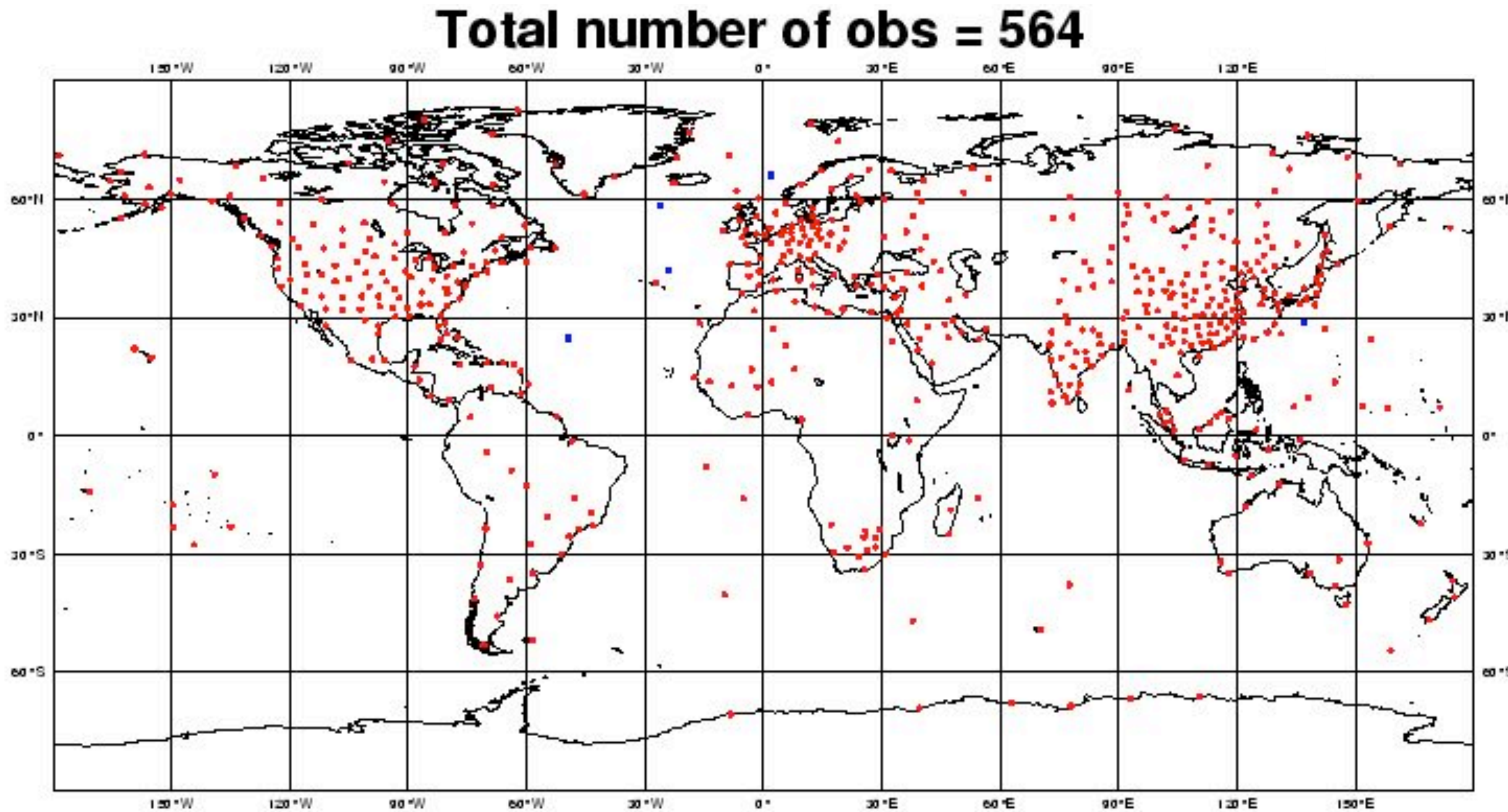
In-situ ("conventional") observations for ERA-40

• Radiosonde and pilot-balloon soundings	1957 - 2002
• Surface data from land stations and ships	1957 - 2002
• Flight-level data from commercial aircraft	1973 - 2002
• Surface data from ocean buoys	1979 - 2002

Radiosonde coverage in October 1961



Radiosonde coverage in May 1997

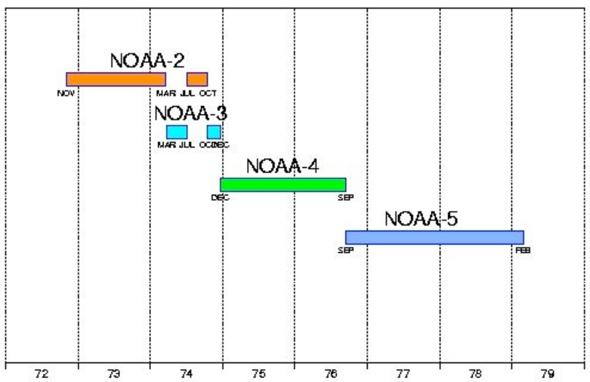


Satellite data for ERA-40

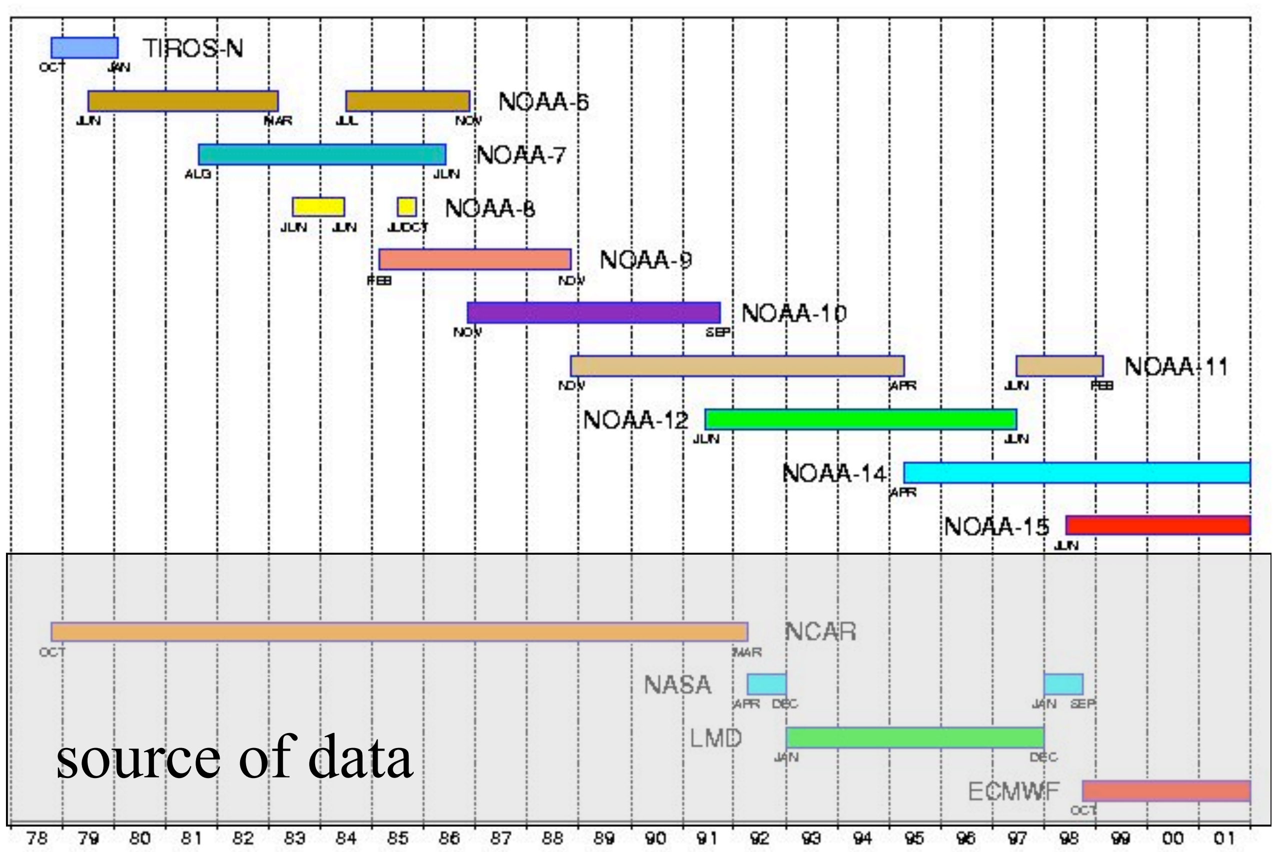
• NOAA VTPR radiances	1973 - 1978
• NOAA TOVS/ATOVS radiances	1979 - 2002
• Winds from geostationary orbit	1979 - 2002
• TOMS/SBUV ozone retrievals	1979 - 2002

The ERA-40 Re-analysis used 41 satellite instruments carried by 15 different NOAA polar satellites

VTPR instrument 72-78

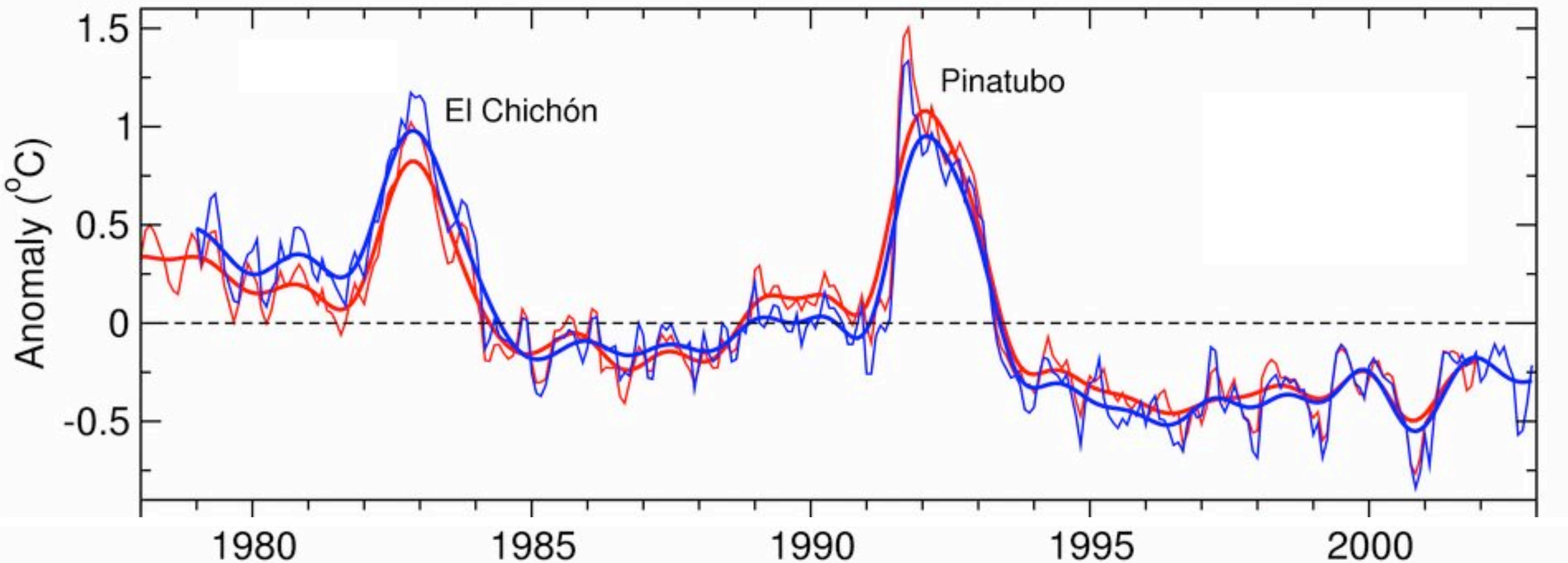


HIRS/MSU/SSU/AMSU instruments 78-02



Some considerable reanalysis successes …

Trend and variability in lower stratospheric temperature

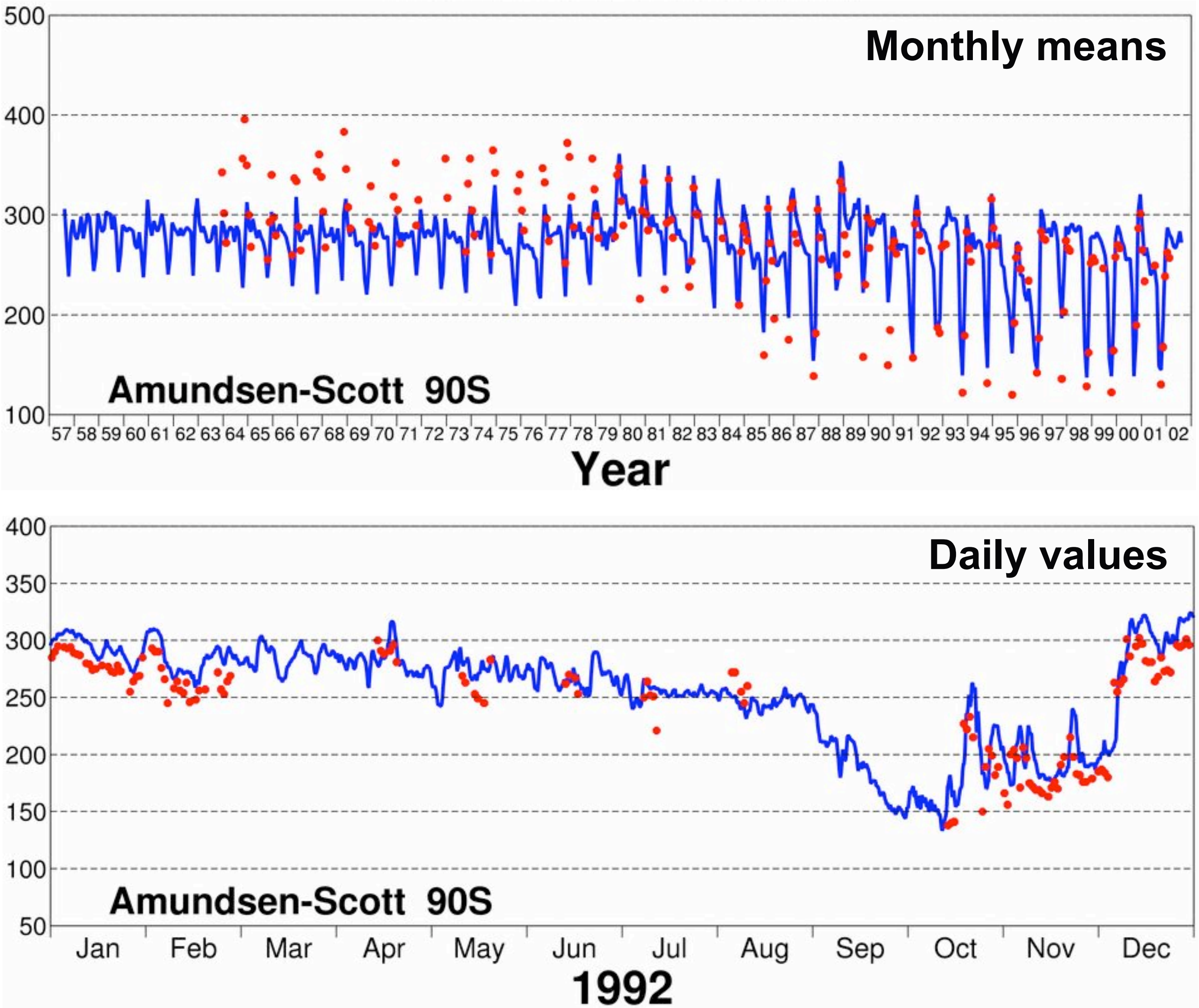


MSU-4 data analyzed by Mears et al. (2003)

ERA-40 equivalent from Ben Santer

Linear trend:		
	MSU-4	- 0.39^{O}C/decade
	ERA-40	- 0.30^{O}C/decade
	NCEP	- 0.82^{O}C/decade

Total ozone (Dobson units)



Blue: ERA-40 (TOMS and SBUV data assimilated 1979-1988 and 1991-2002)

Red: Ground-based measurements (NOAA/CMDL)

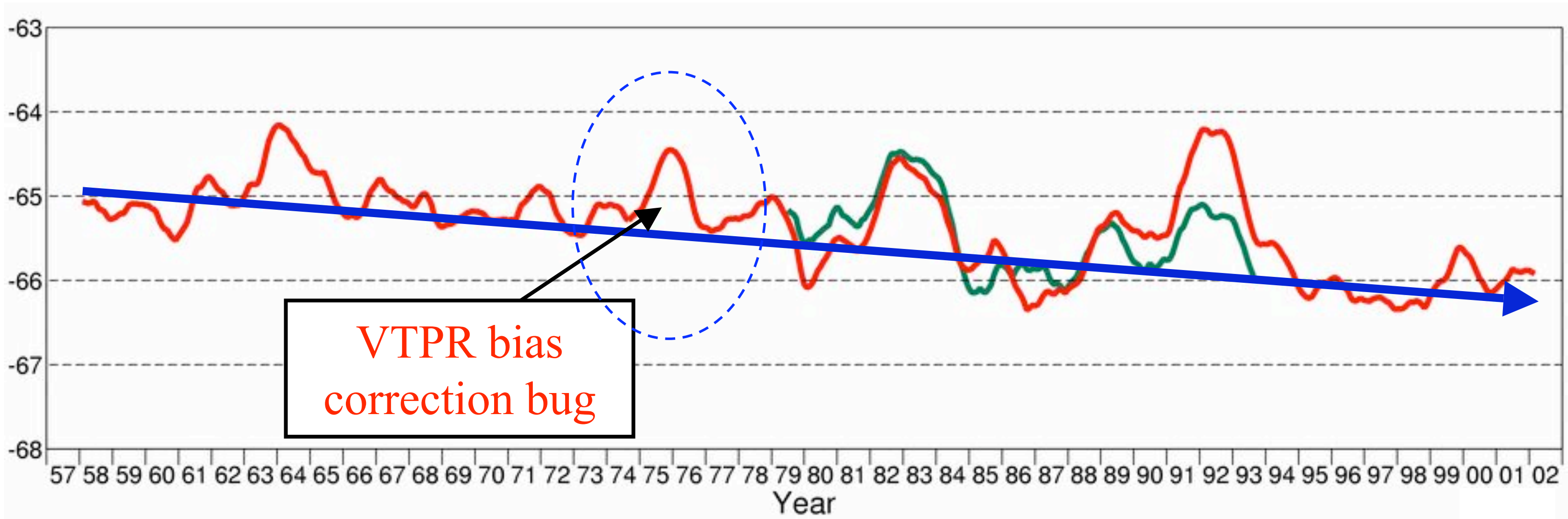
But…

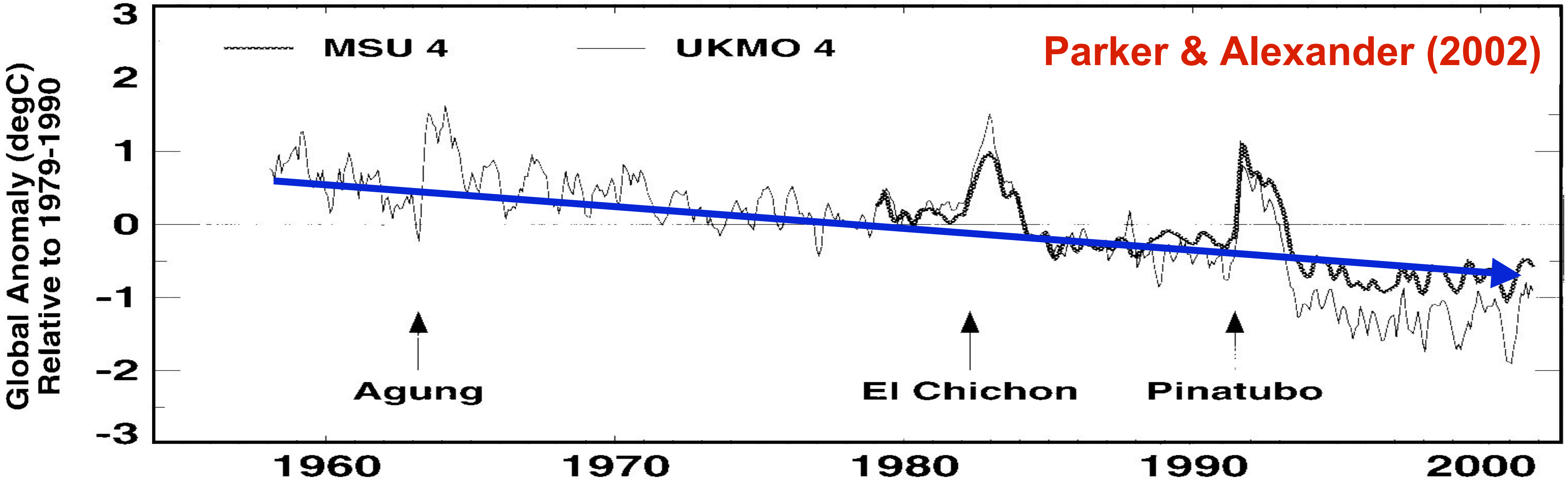
some considerable reanalysis issues …

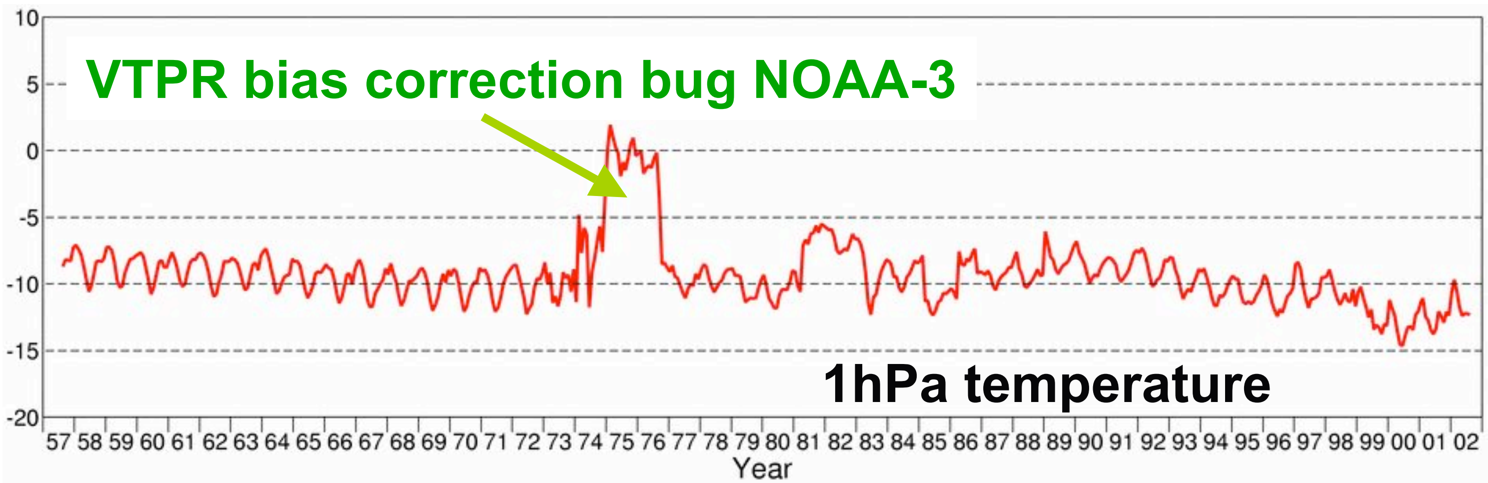
Particular Issues related to the use of satellite data in re-analysis

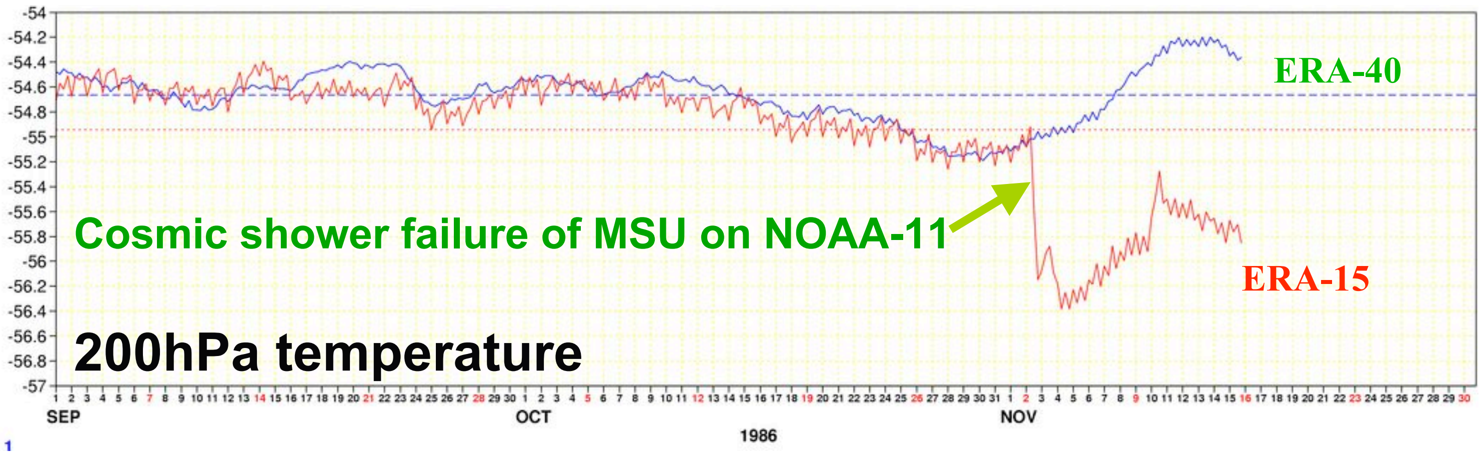
- Instrument **drift/shift** over the lifetime of a satellite
- Absolute and **inter-satellite calibration** between different satellites
- Intermittent (sudden) **disruptions / contamination** of data (by nature)
- Changes to **channel / instrument** payload
- **Events are often difficult to detect / fix in time during production…**

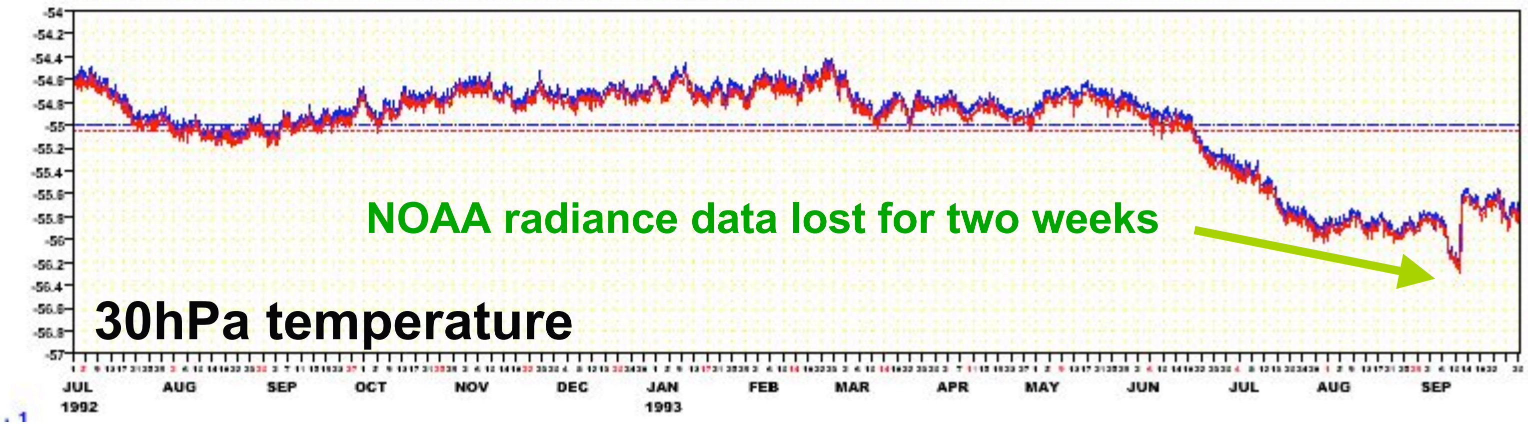
Trends in Global 70hPa temperature (real and artificial)



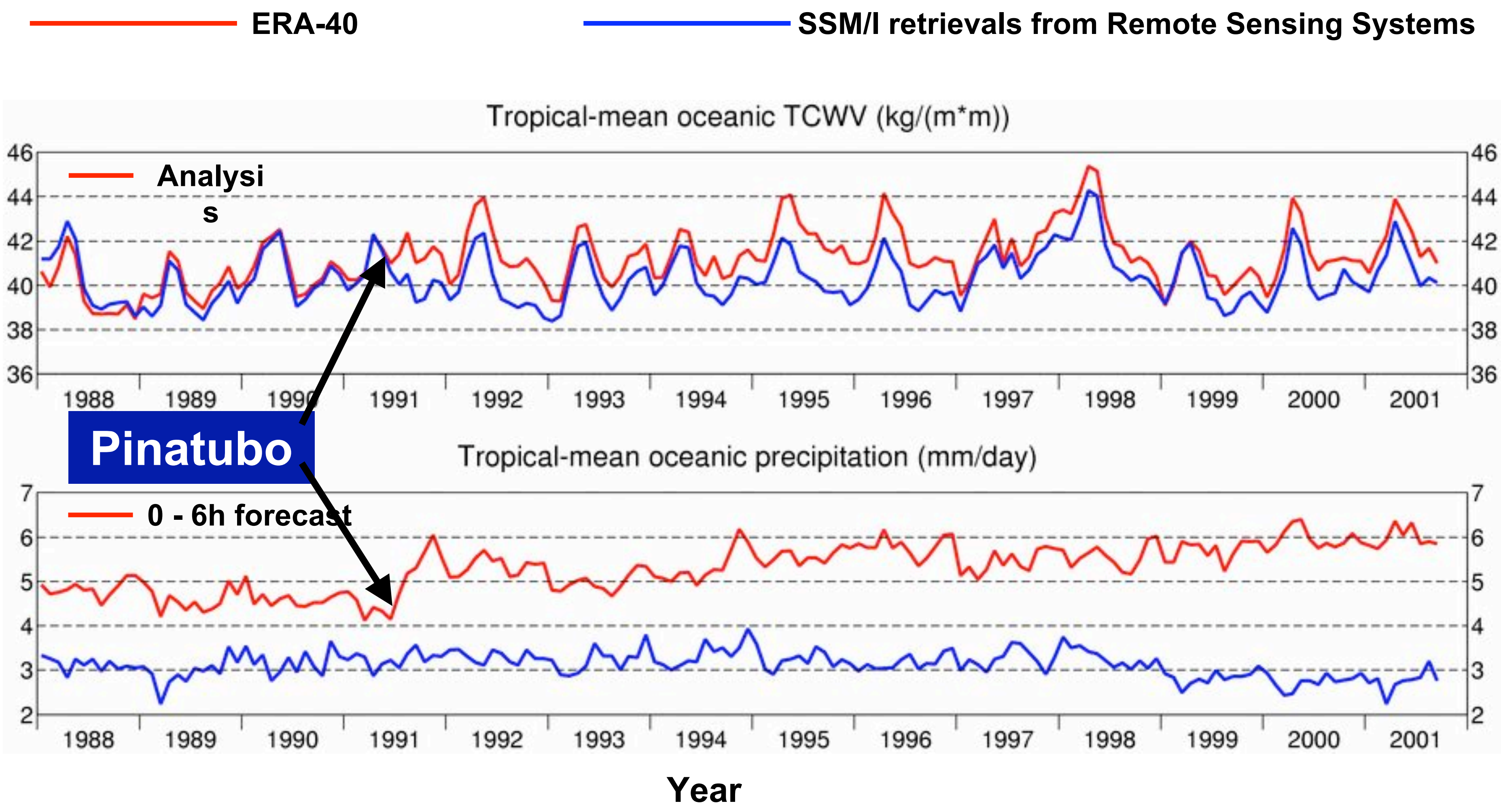



VTPR bias correction bug NOAA-3
1hPa temperature
Year


ERA-40
Cosmic shower failure of MSU on NOAA-11
ERA-15
200hPa temperature
SEP
OCT
NOV
1986


NOAA radiance data lost for two weeks
30hPa temperature
JUL
1992
AUG
SEP
OCT
NOV
DEC
JAN
1993
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP

Aspects of tropical humidity analysis



The next step...

ERA-interim

ERA-Interim 1989 ◊ to continue...

ERA-40 1957-2002

- Data-assimilation system

  12 hour 4D-Var

- Satellite radiances

  Adaptive bias correction

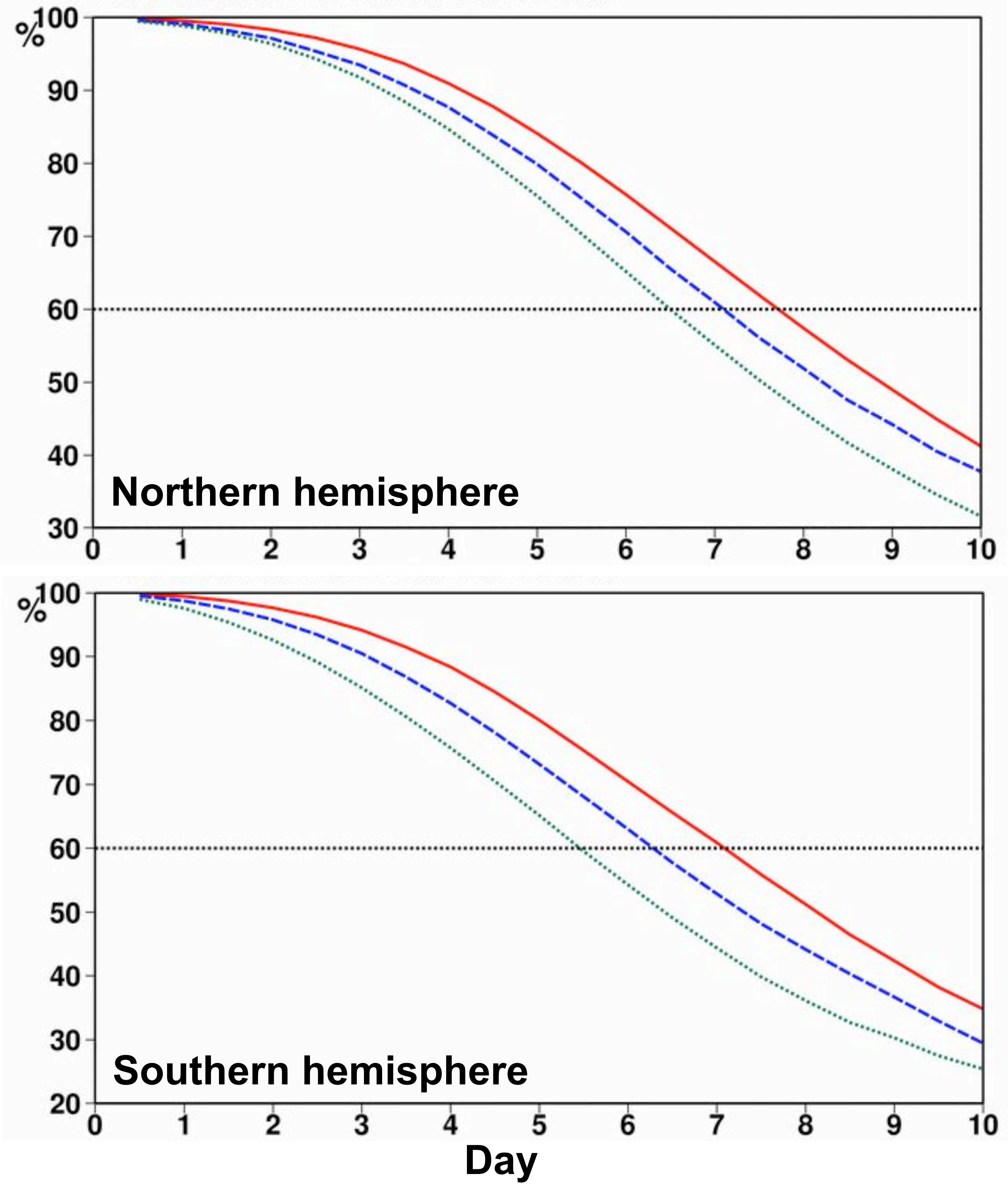
- Improved use of radiosondes

  Bias correction and homogenization based on ERA-40

Much improved 500hPa height forecasts with 4DVAR

Anomaly correlation of 500hPa height, averaged for 12UTC forecasts from 1 January to 31 December 1989

ERA-interim
ERA-40
Operations 1989



Variational bias correction of radiance data

- Radiance bias correction expressed in terms of a small number of unknown parameters:
  - A constant offset
  - Predictors depending on instrument scan position (scan bias)
  - Predictors depending on model state x (air-mass dependent bias)

- Add the bias correction parameters to the control vector in the variational analysis

J_b: background constraint for x

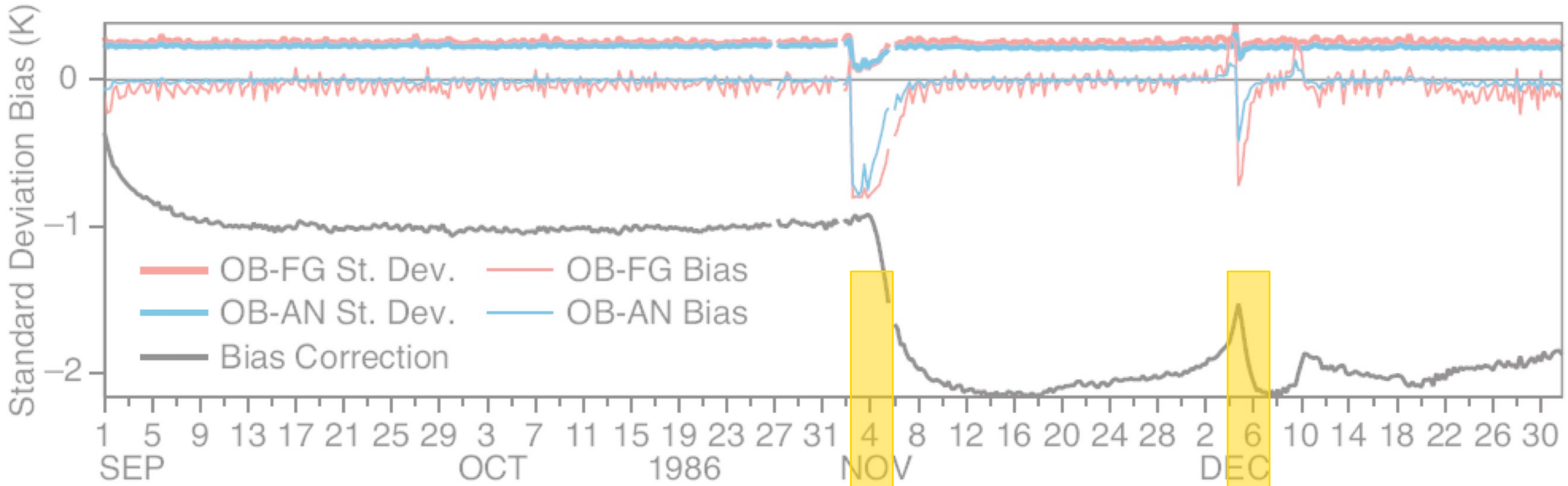
J_β: background constraint for β

$$J(x, \hat{a}) = \underbrace{(x_b - x)^T B_x^{-1} (x_b - x)}_{J_b} + \underbrace{(\hat{a}_b - \hat{a})^T B_{\hat{a}}^{-1} (\hat{a}_b - \hat{a})}_{J_\beta}$$
$$+ \underbrace{\left[y - b_o(x, \hat{a}) - h(x)\right]^T R^{-1} \left[y - b_o(x, \hat{a}) - h(x)\right]}_{J_o}$$

J_o: bias-corrected observation constraint

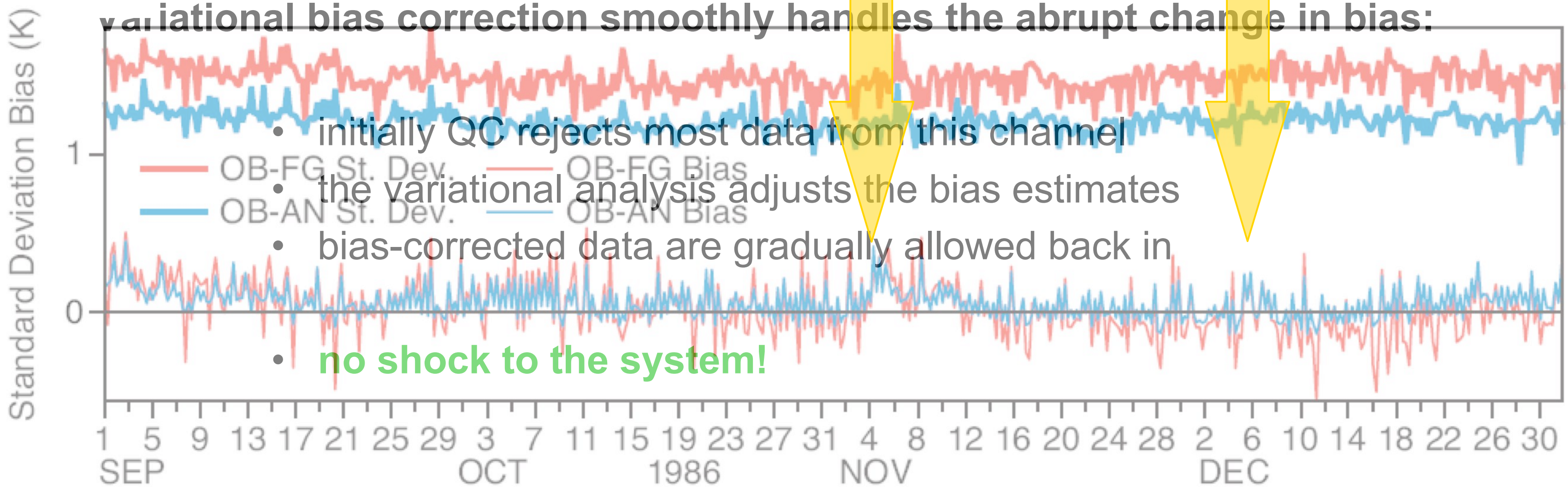
- The analysis then estimates bias parameters jointly with model state variables (Derber and Wu 1998)

NOAA-9 MSU channel 3 bias corrections (cosmic storm)



200 hPa temperature departures from radiosonde observations

variational bias correction smoothly handles the abrupt change in bias:

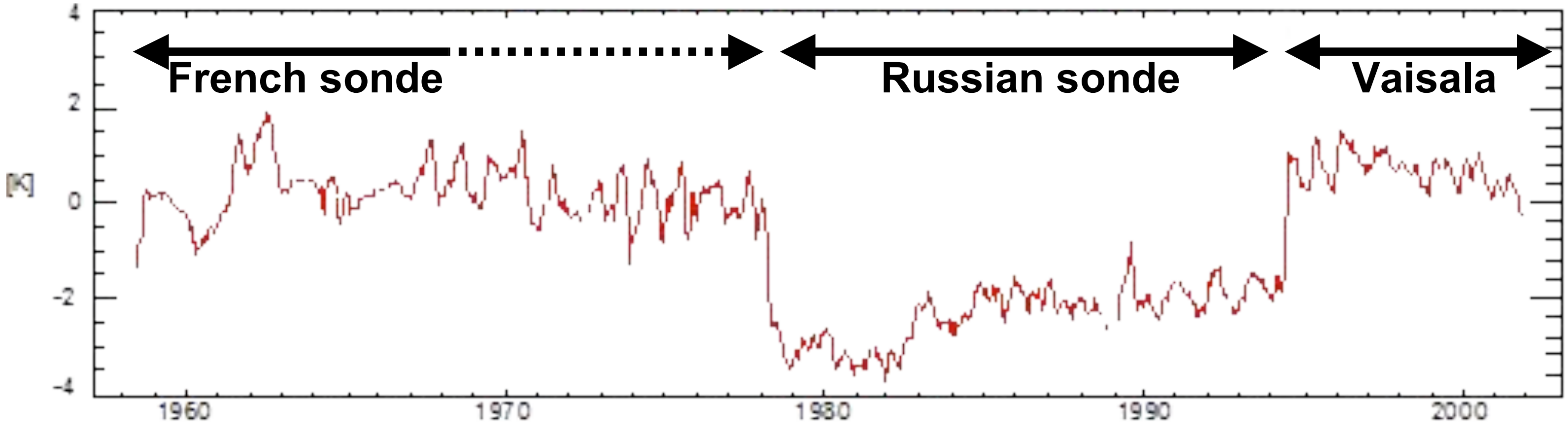


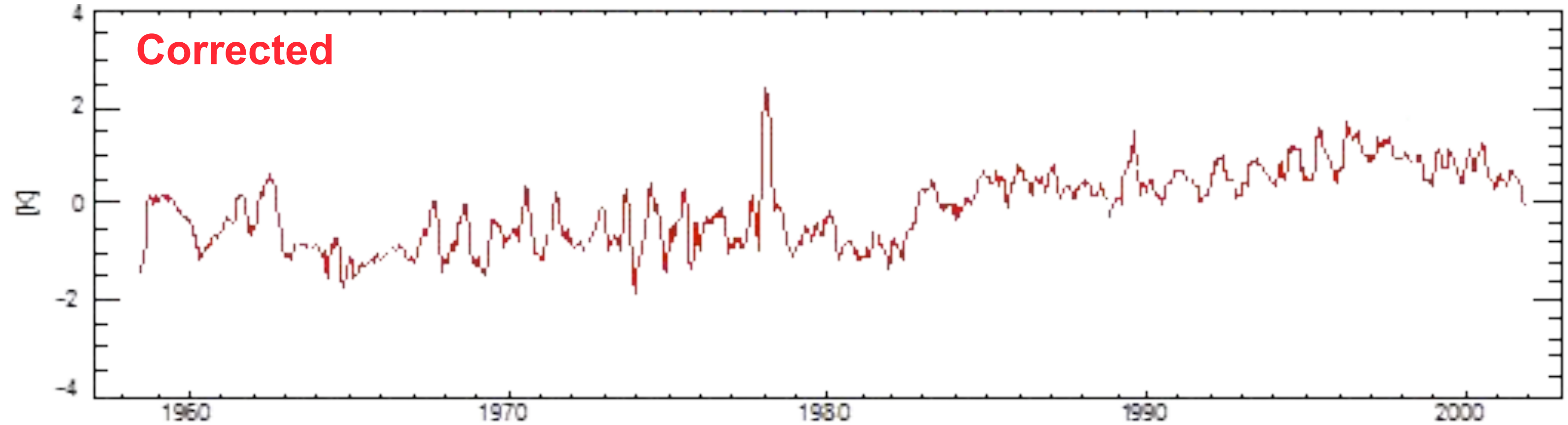
- initially QC rejects most data from this channel
- the variational analysis adjusts the bias estimates
- bias-corrected data are gradually allowed back in
- no shock to the system!

Need to homogenize radiosonde biases in time

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

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





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