Satellite data in reanalyses

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ECMWF

Seminar on Development in the Use of Satellite Observations in NWP, 3-7 Sept 2007

Contents

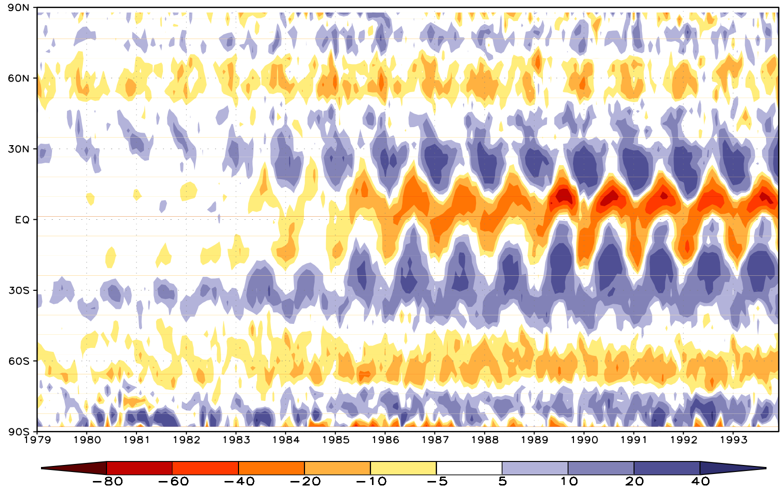
- Motivation of reanalyses
- Observing system: reanalysis perspective
- Evolving analysis schemes
- Observing system changes → analysis quality
- The impact of satellite data:

  ERA-15 ➔ ERA-40 ➔ ERA-Interim
- Future directions

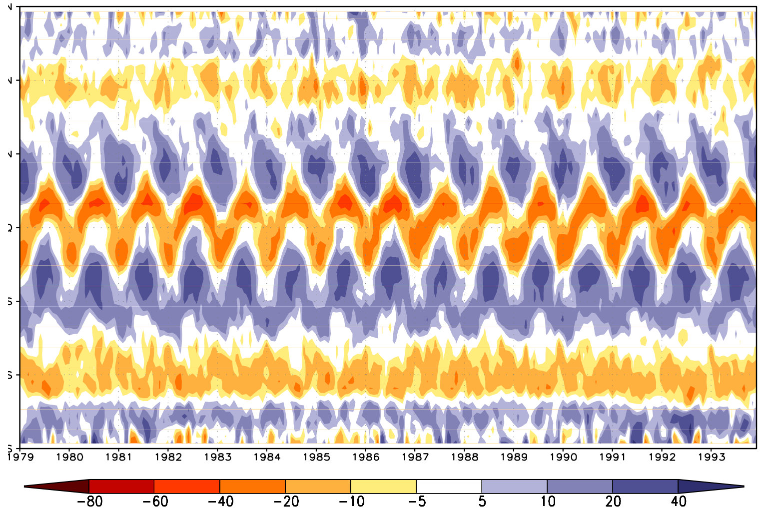
Motivation of reanalysis

Zonal mean vertical velocity mPa/s 1979-1993

OPERATIONS



ERA-15 reanalysis



(Stendel & Arpe, ERA-15 Report series No 6)

Application of reanalyses (1)

To improve understanding of

- Weather and climate
- General circulation of atmosphere
- Long term variability and trends
- Tele-connections
- Atmospheric transport
- Hydrological cycle
- Surface processes
- Predictability studies: daily → seasonal
- Extreme weather, storm tracking, tropical cyclones, …

Application of reanalyses (2)

To provide:

Initial states, external forcing or validation data for

- **Climate model integrations**
- **Ocean models**
- **Monthly and seasonal forecasting**
- **Chemical transport models**
- **DEMETER, ENSEMBLES, ENACT, CANDIDOZ, …**

A substitute for "observed statistics"

Reanalysis projects

NCEP/ NCAR	1948 → … CDAS
NASA/ DAO	1980 - 1995
ECMWF, ERA-15	1979 - 1993
ECMWF, ERA-40	1957 - 2002
ECMWF, ERA-Interim	1989 → … ECDAS
JMA, JRA-25	1979 → … CDAS
In preparation	
NASA/ MERRA	1979 →
New coupled NCEP reanalysis	1979 →
US Arctic Reanalysis System	2000 → 2010
New JRA reanalysis	1957 →

Operational forecast performance 1980-2007

Northern Hemisphere

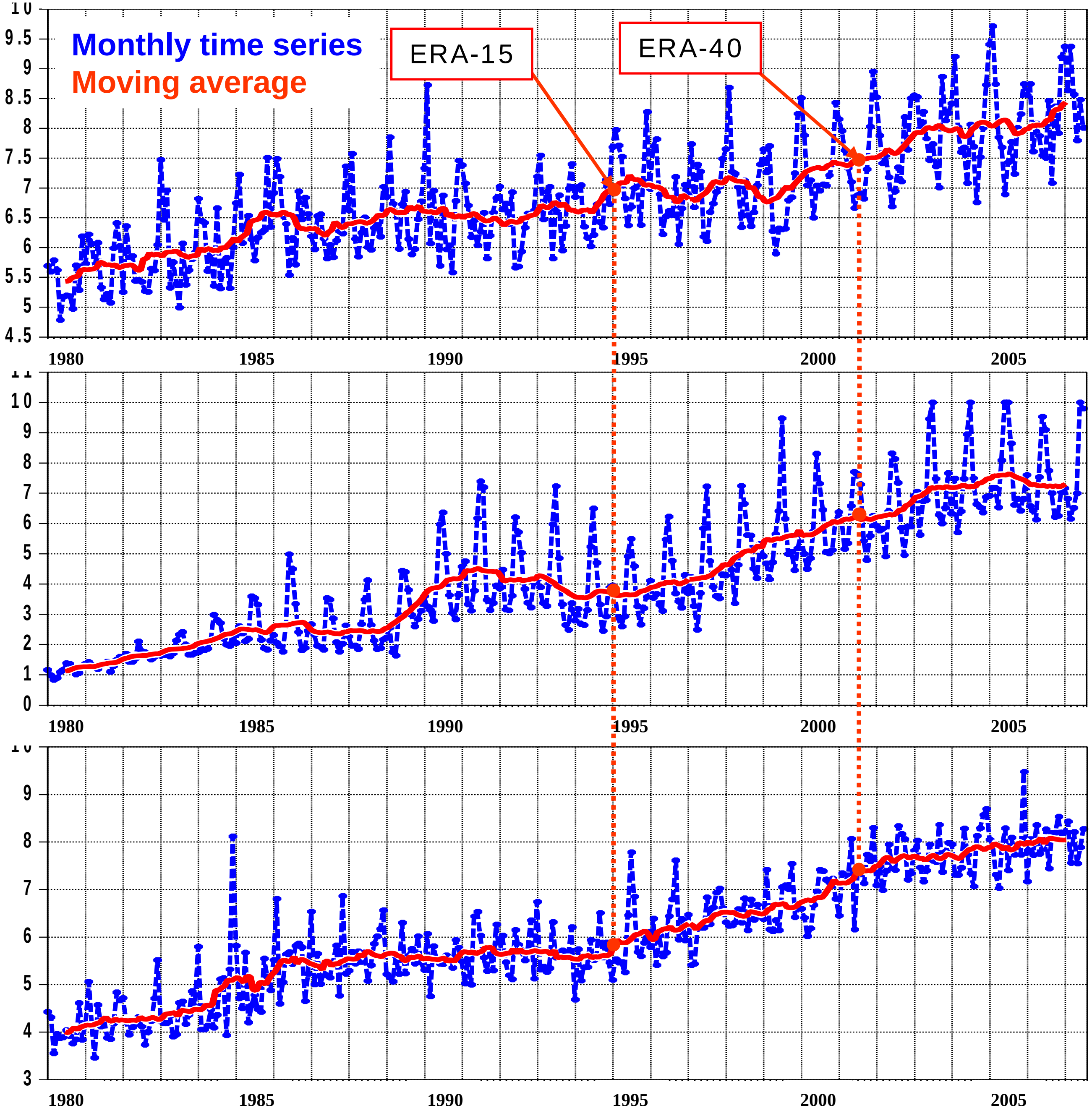
500 hPa geopotential
ANC reaching 60%

Tropics

850 hPa wind vector
ABC reaching 70%

Southern Hemisphere

500 hPa geopotential
ANC reaching 60%



Reanalysis quality depends on:

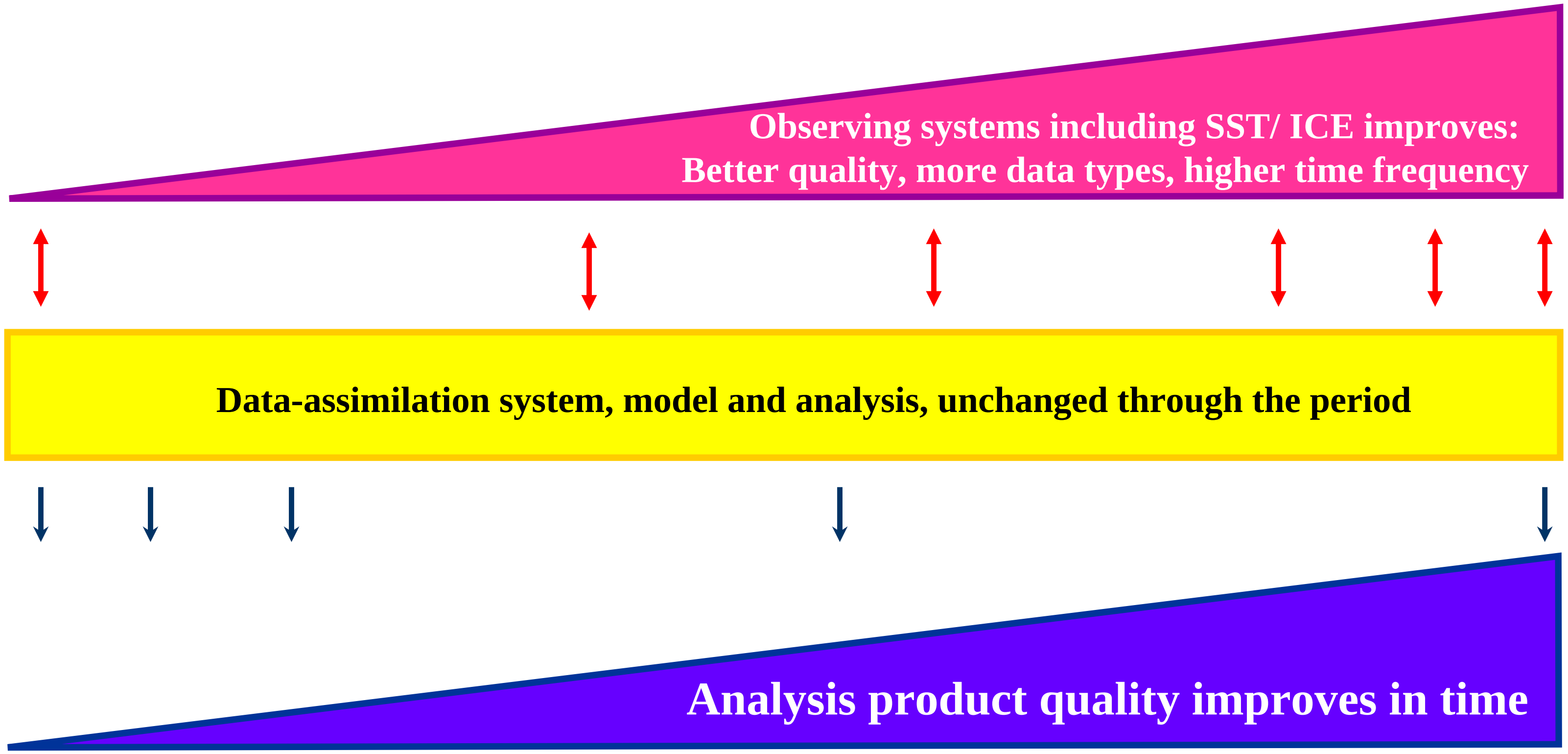
1) The available observational information:

- Conventional
- Satellite
- The spatial and vertical distribution of the previous
- Boundary forcing fields: SST and ice dataset

2) The data assimilation system:

- The analysis method and the assimilating forecast model
- The observation and background model errors

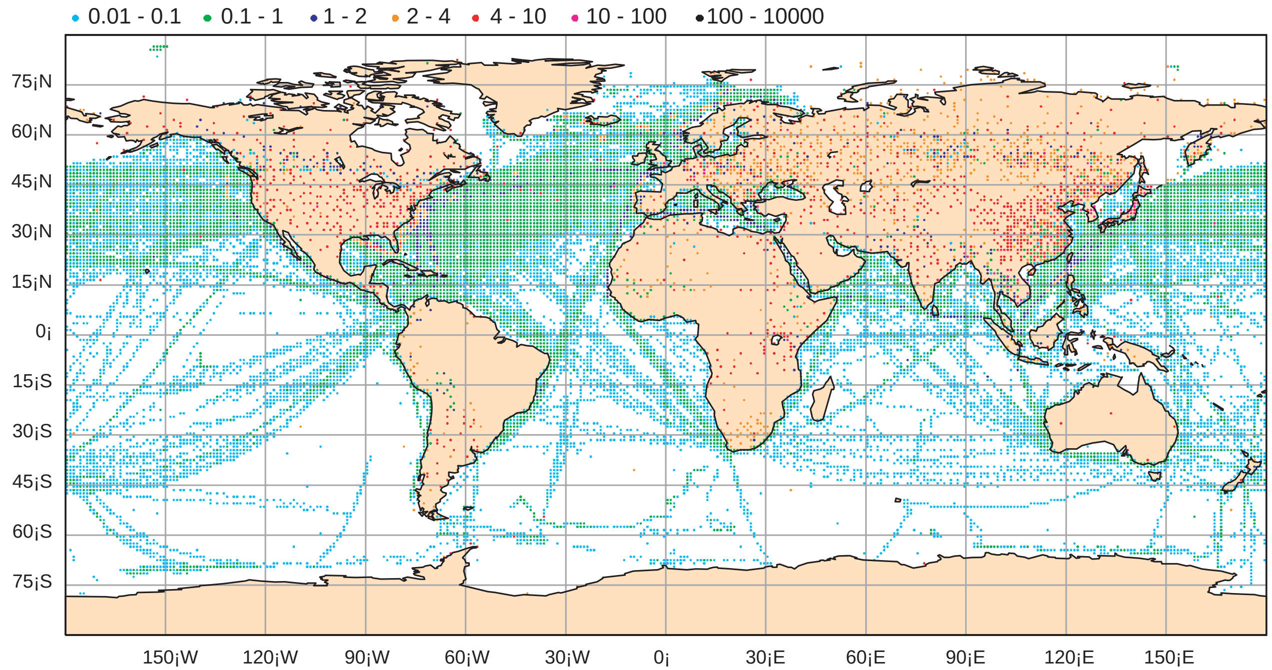
Reanalysis schematically



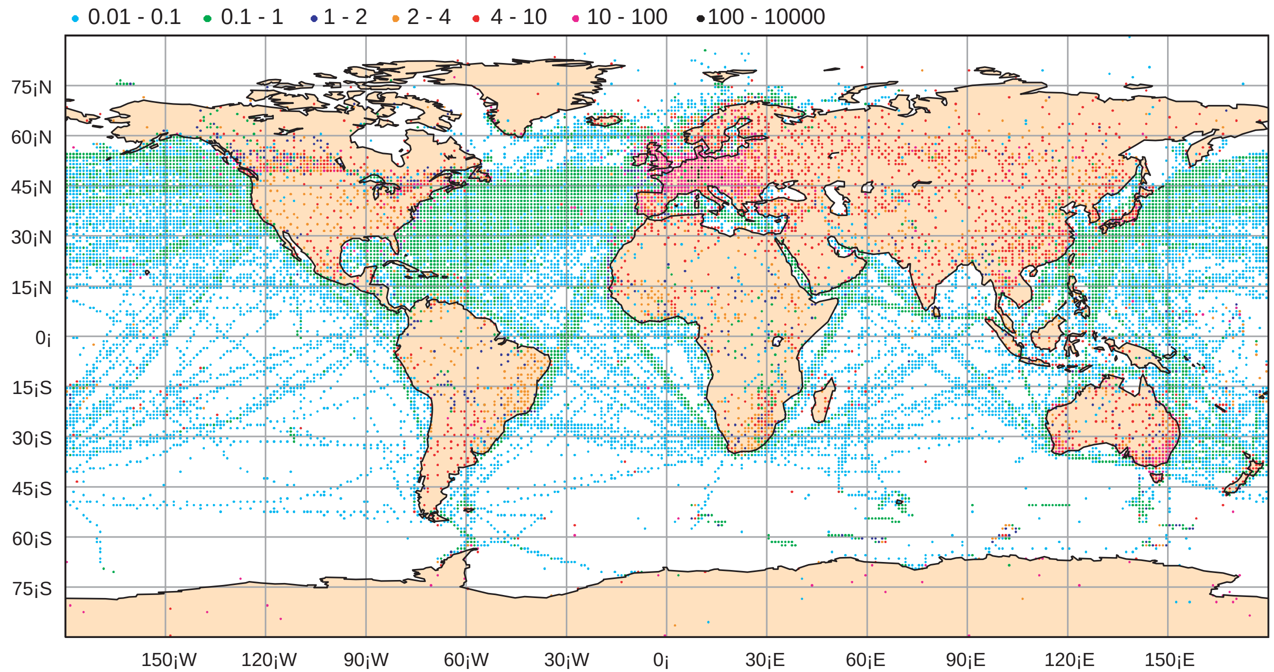
Observations for reanalysis

Surface observations

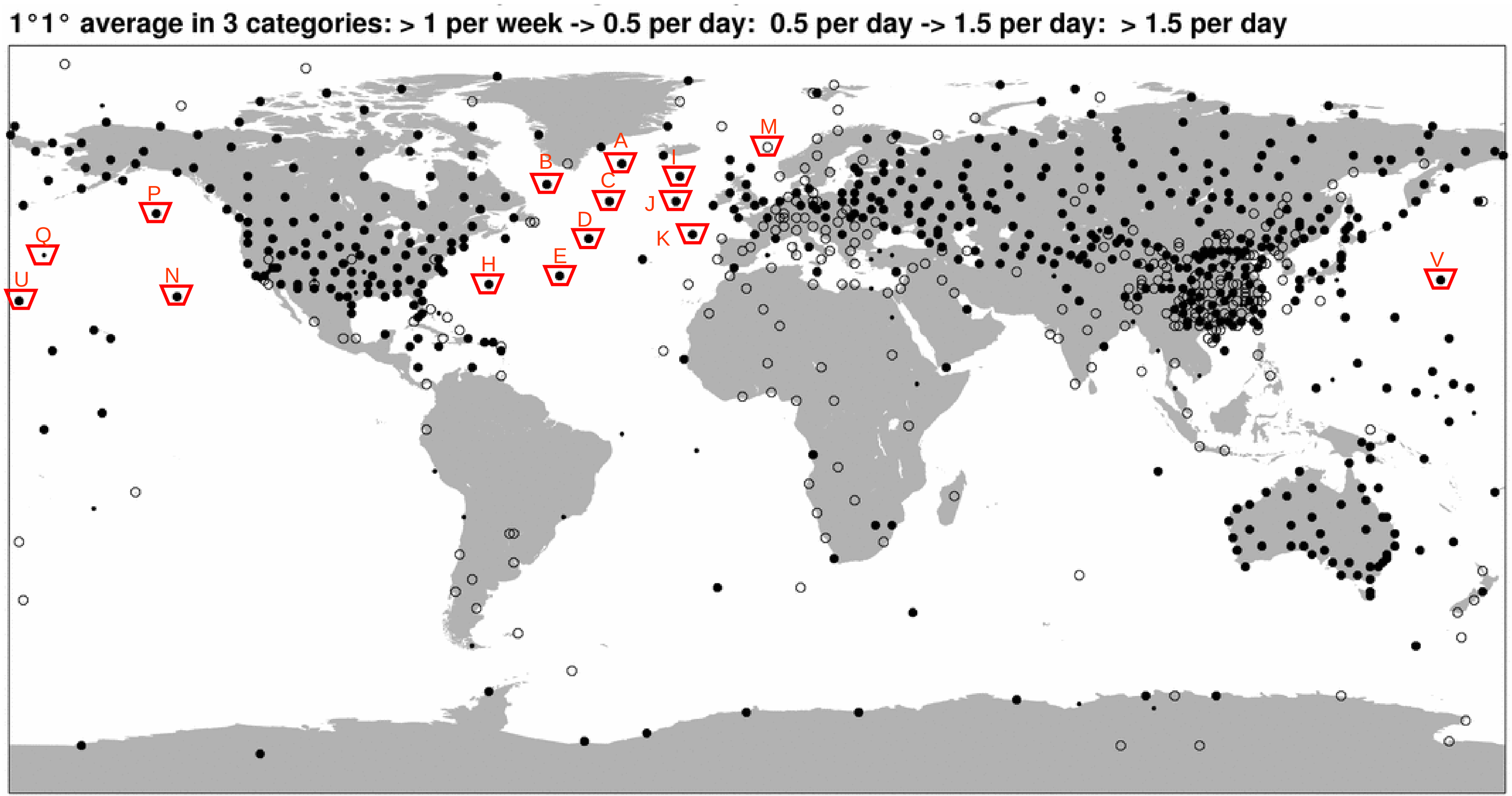
1958 March



1998 March



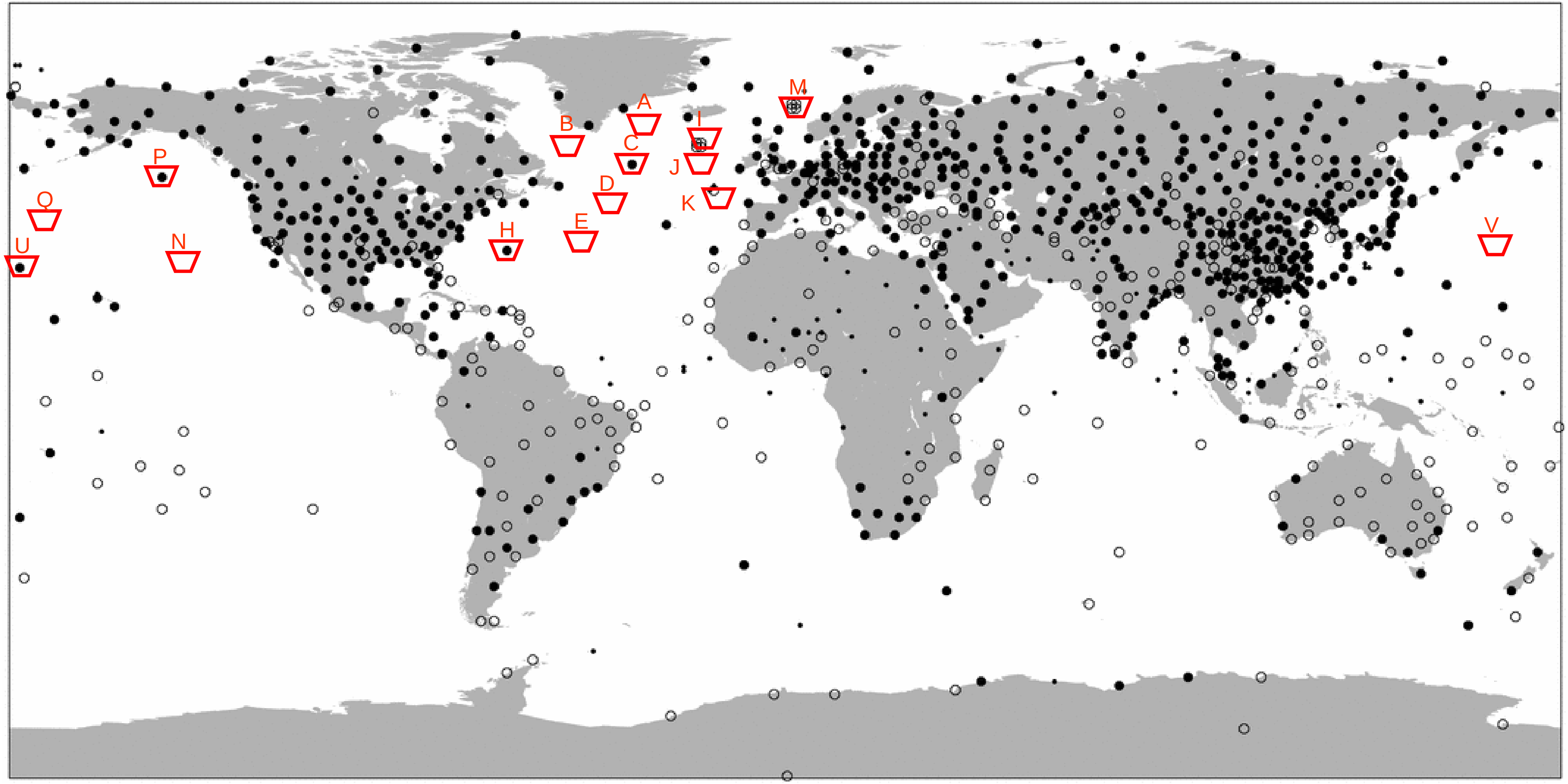
Radiosonde coverage for 1958



Average number of soundings per day: 1609

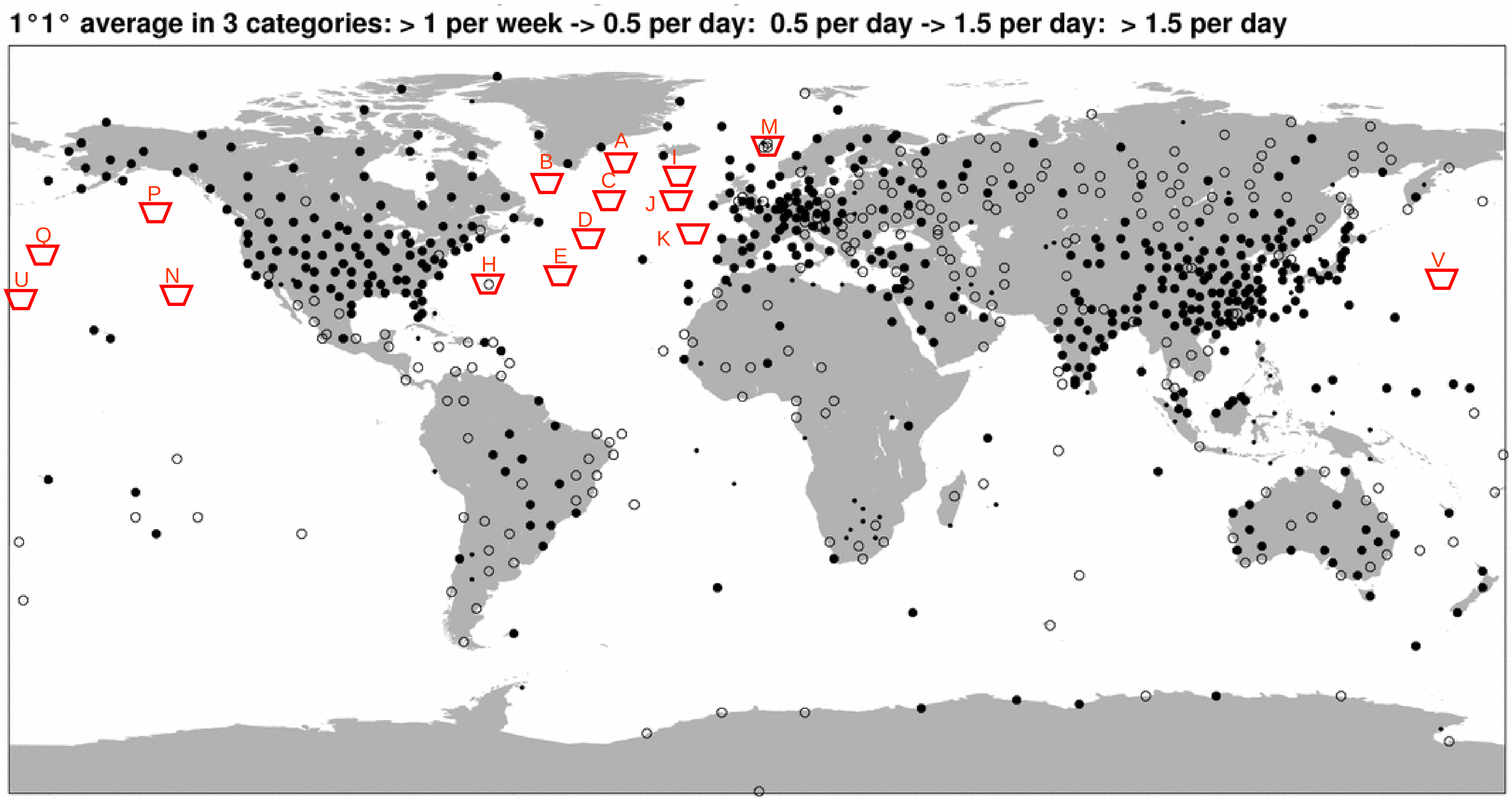
Radiosonde coverage for 1979

1°1° average in 3 categories: > 1 per week -> 0.5 per day: 0.5 per day -> 1.5 per day: > 1.5 per day



Average number of soundings per day: 1626

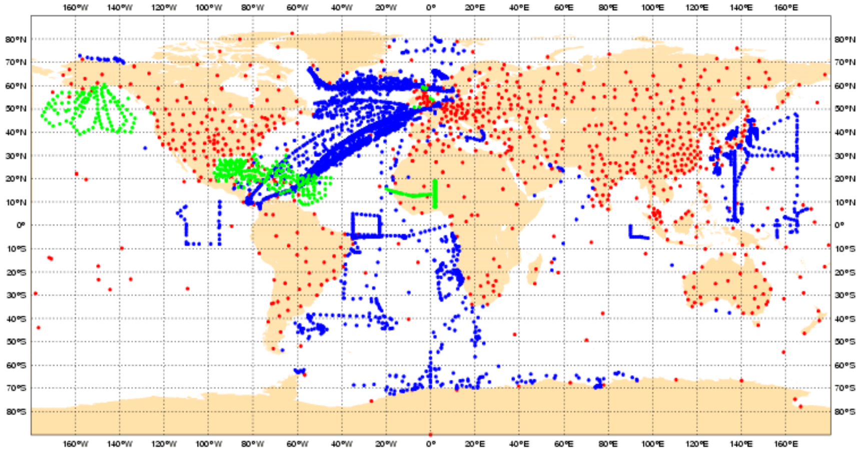
Radiosonde coverage for 2001



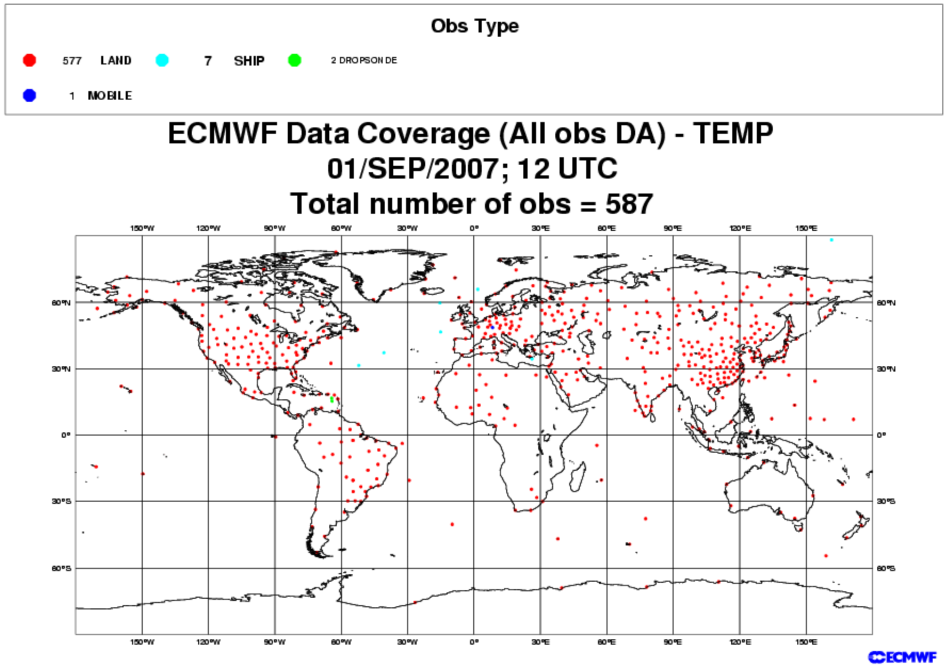
Average number of soundings per day: 1189

Year 2000

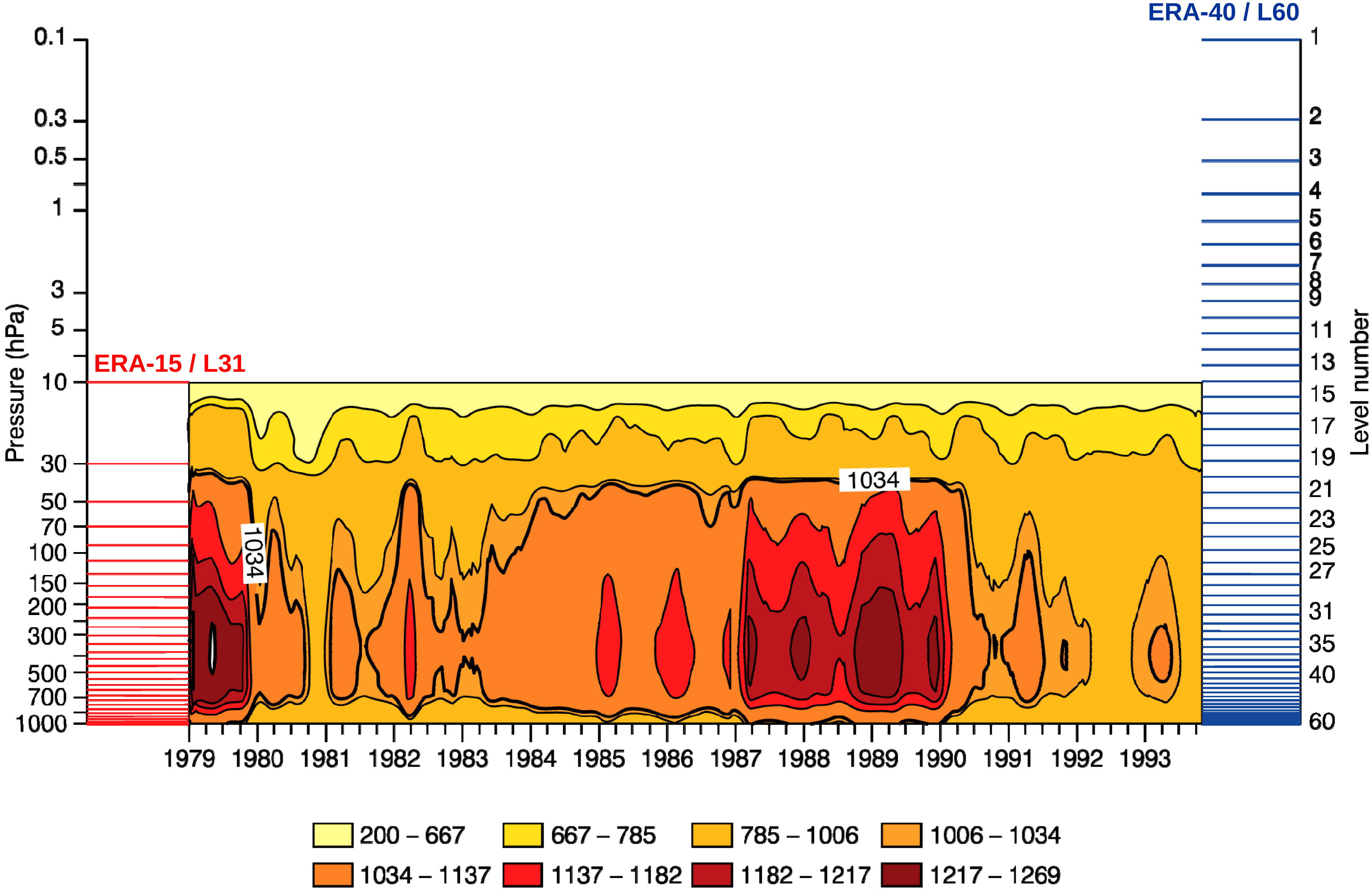
mobile ships, Dropsondes and radiosondes



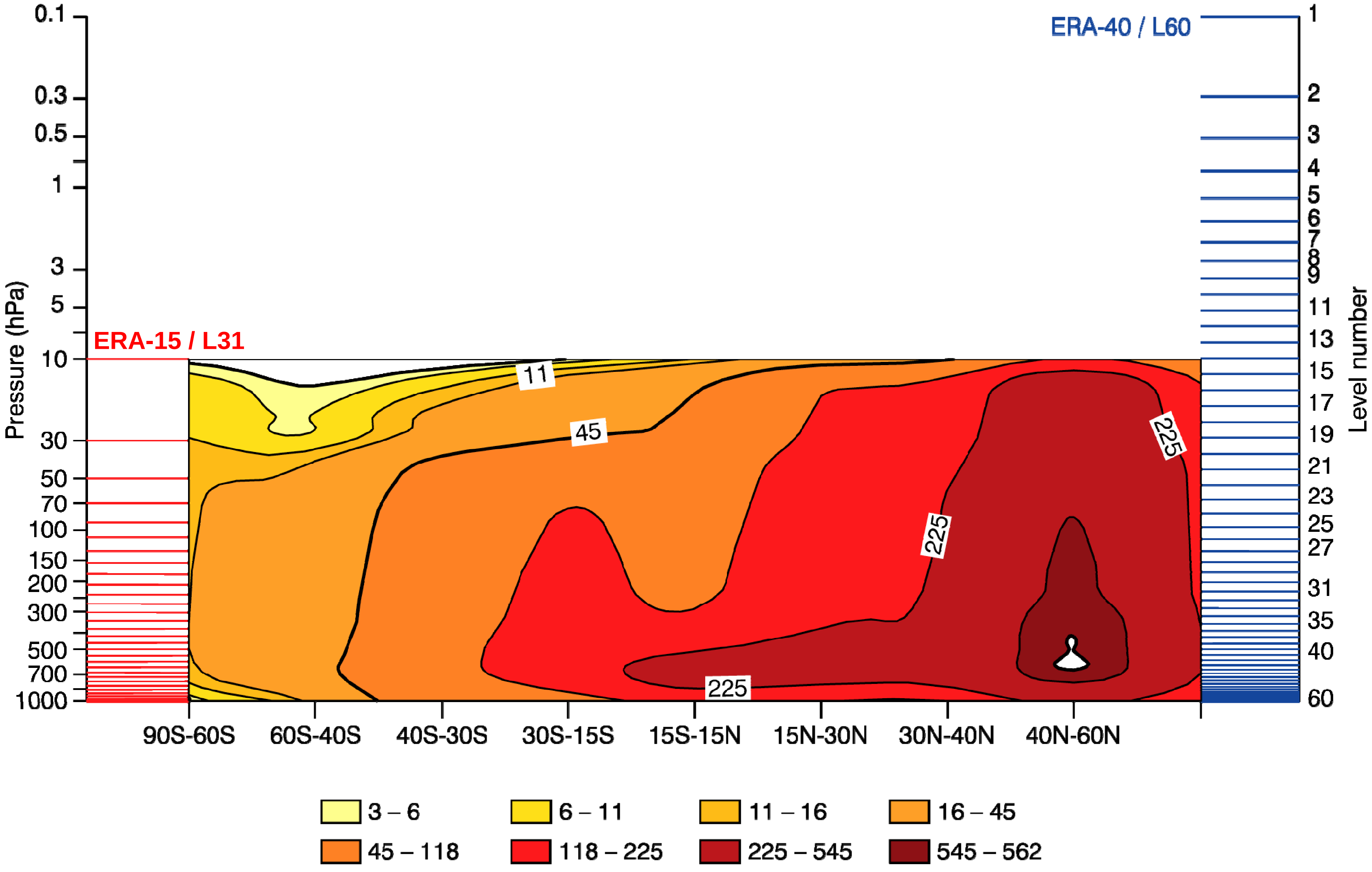
A single analysis time



Daily number of radiosondes in the Northern Hemisphere



Zonal mean number of radiosondes



GARP
THE GLOBAL ATMOSPHERIC RESEARCH PROGRAM (1969)

MAIN OBJECTIVES

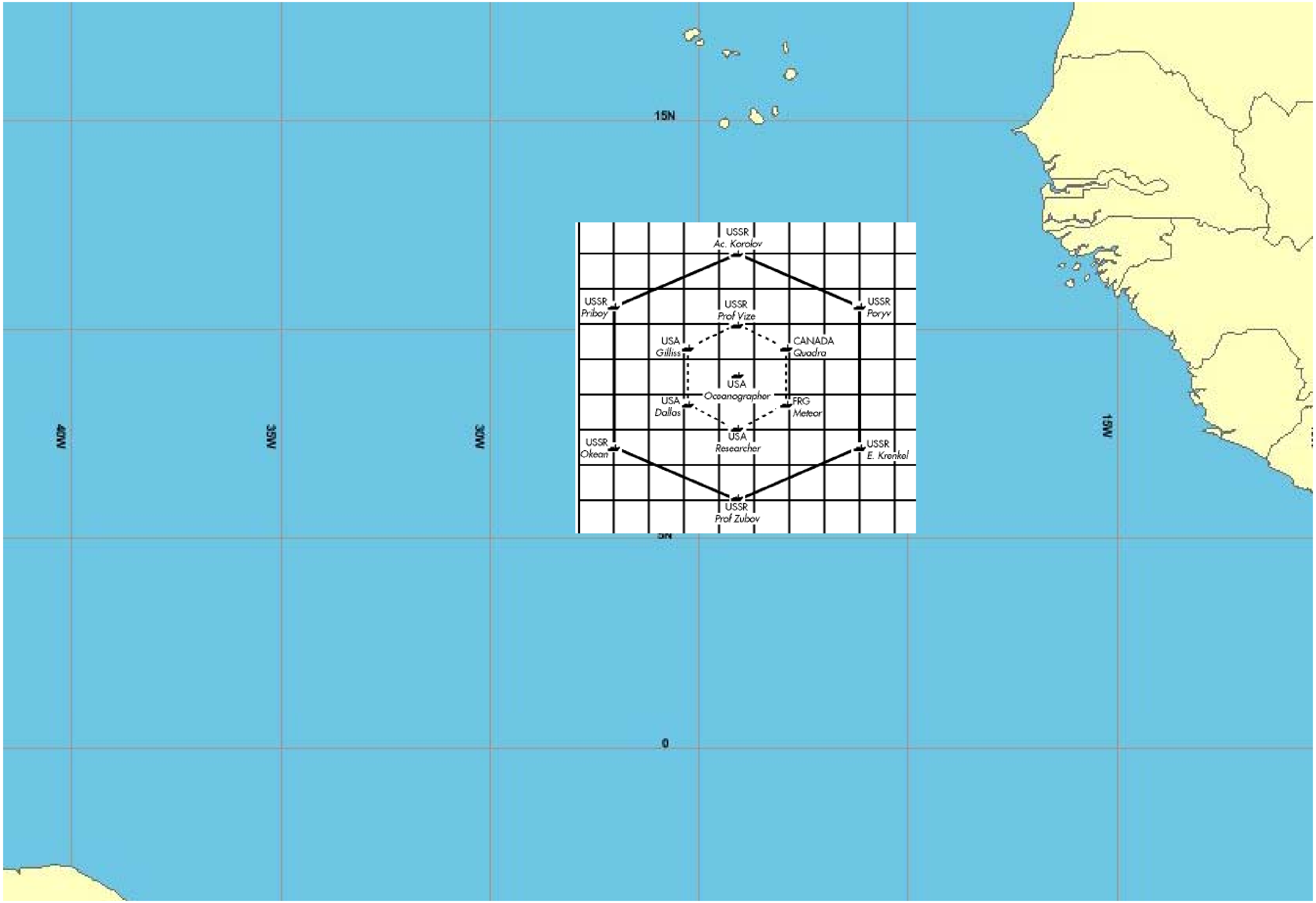
Improved understanding of the physical processes of the general atmospheric circulation	Formulation of improved physico-mathematical models of the atmosphere	Optimum design for a global observing system

Program components: Tropical (GATE), Global, other (MONEX,POLEX,…)

Research projects	Numerical experimentation	Technological developments

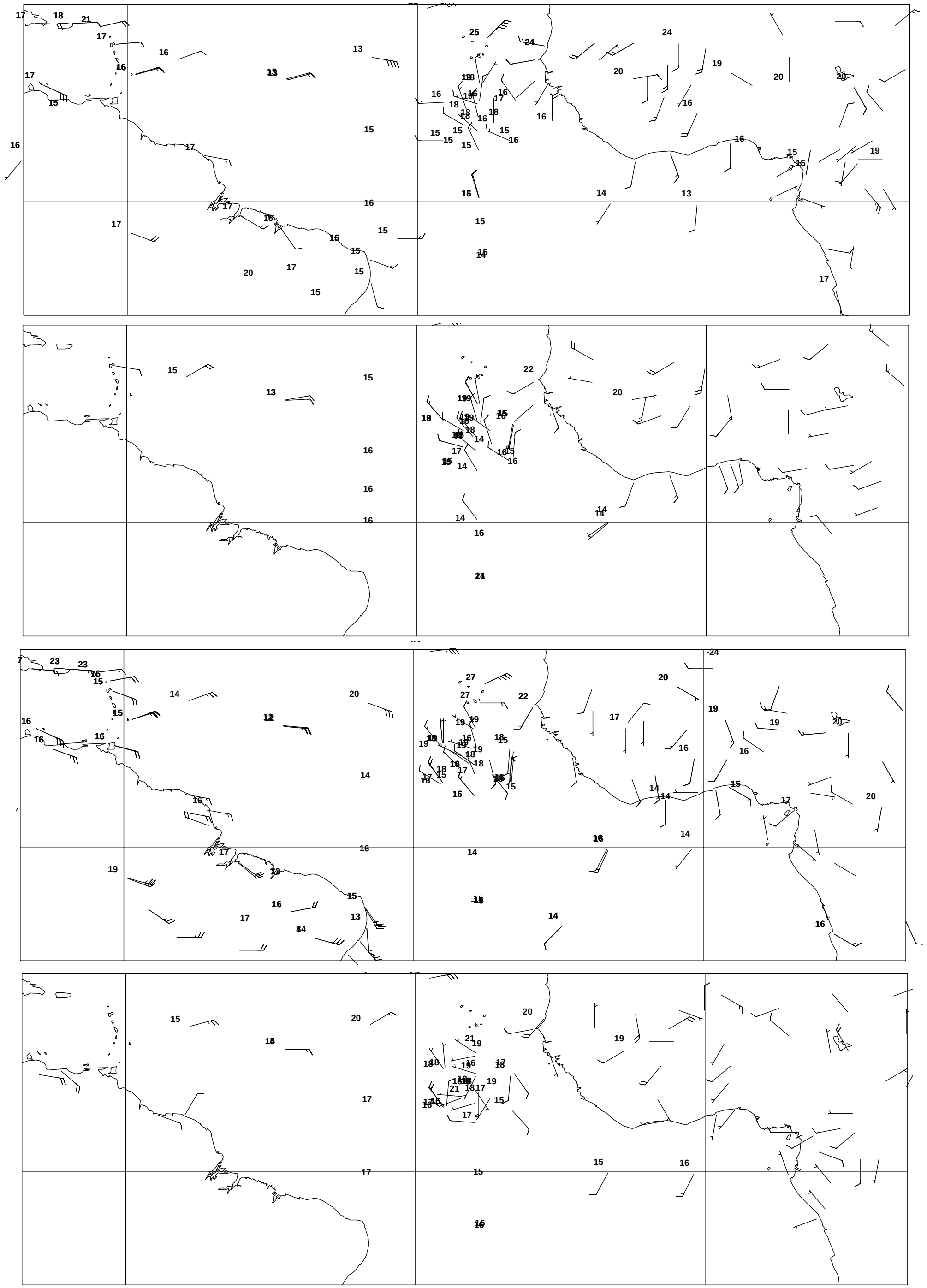
FIRST GARP GLOBAL EXPERIMENT
FGGE
December 1978 → November 1979

GATE EXPERIMENT 15 June → 19 September 1974



GATE

Example day
19740710
850 hPa
Pilot & Temp



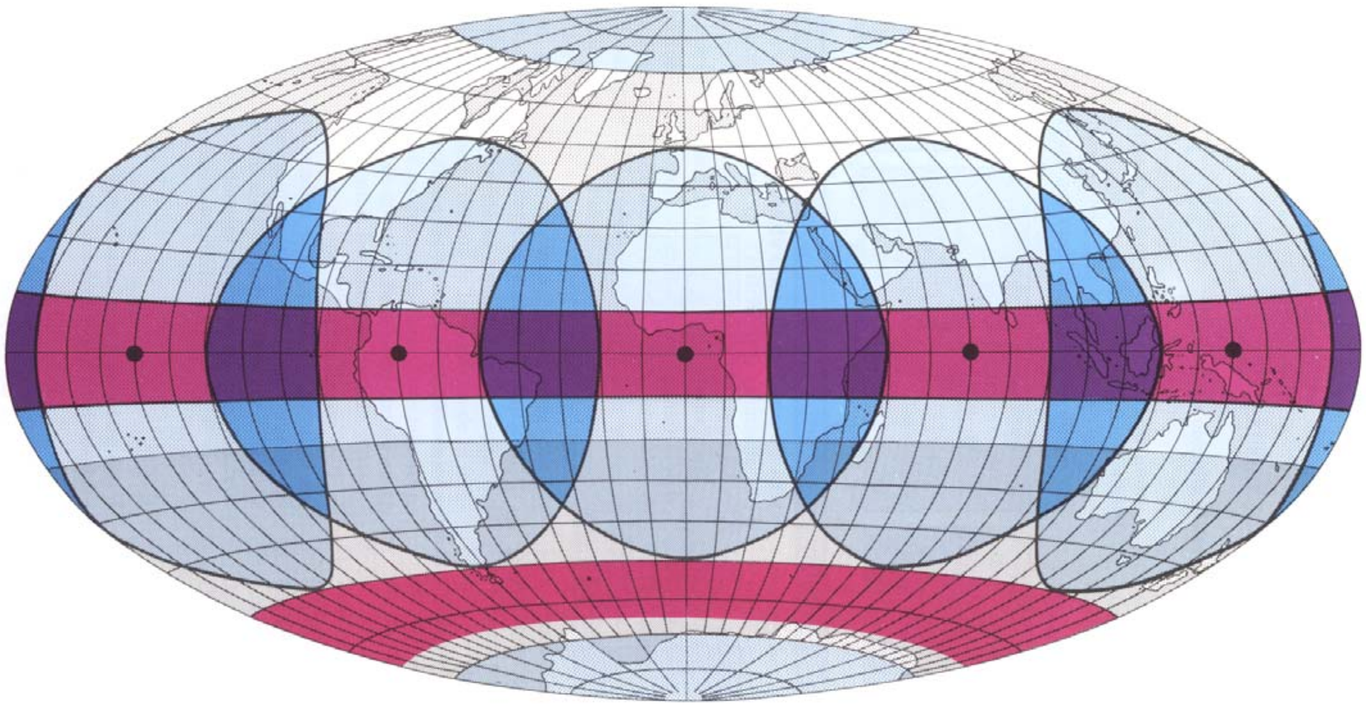
00UTC

06UTC

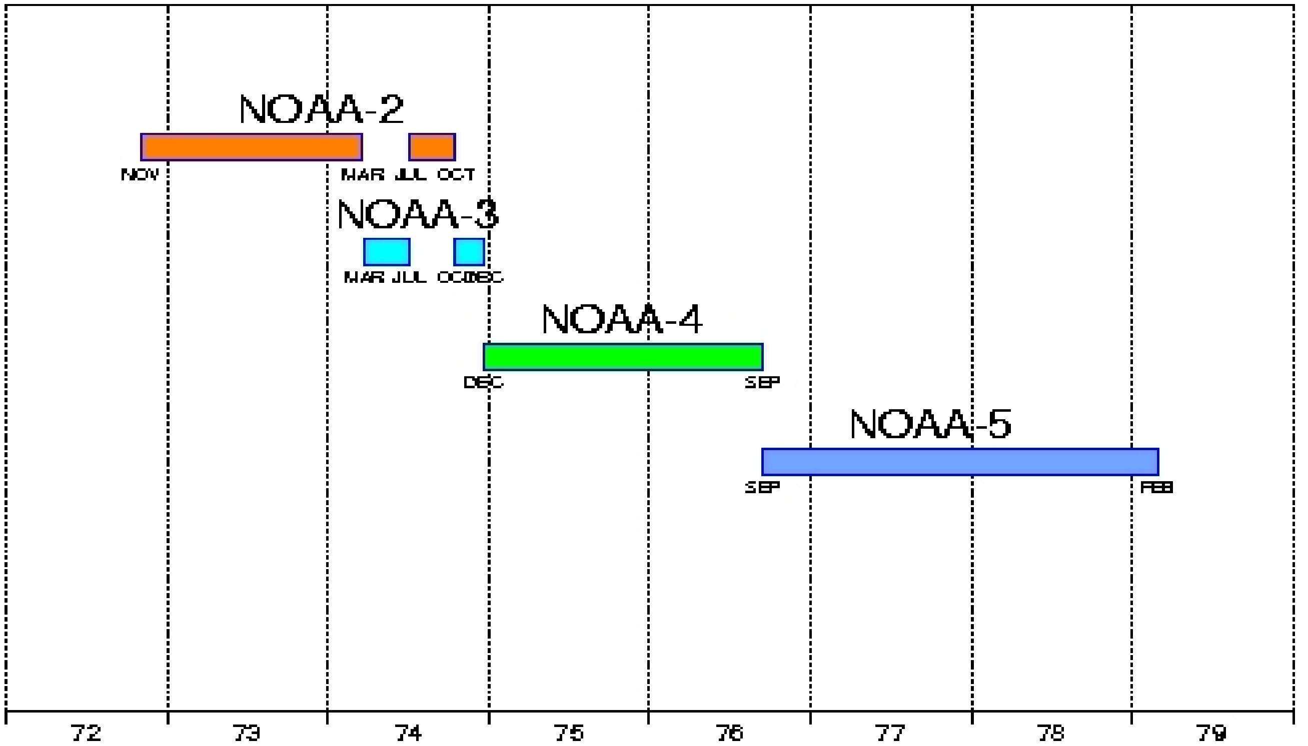
12UTC

18UTC

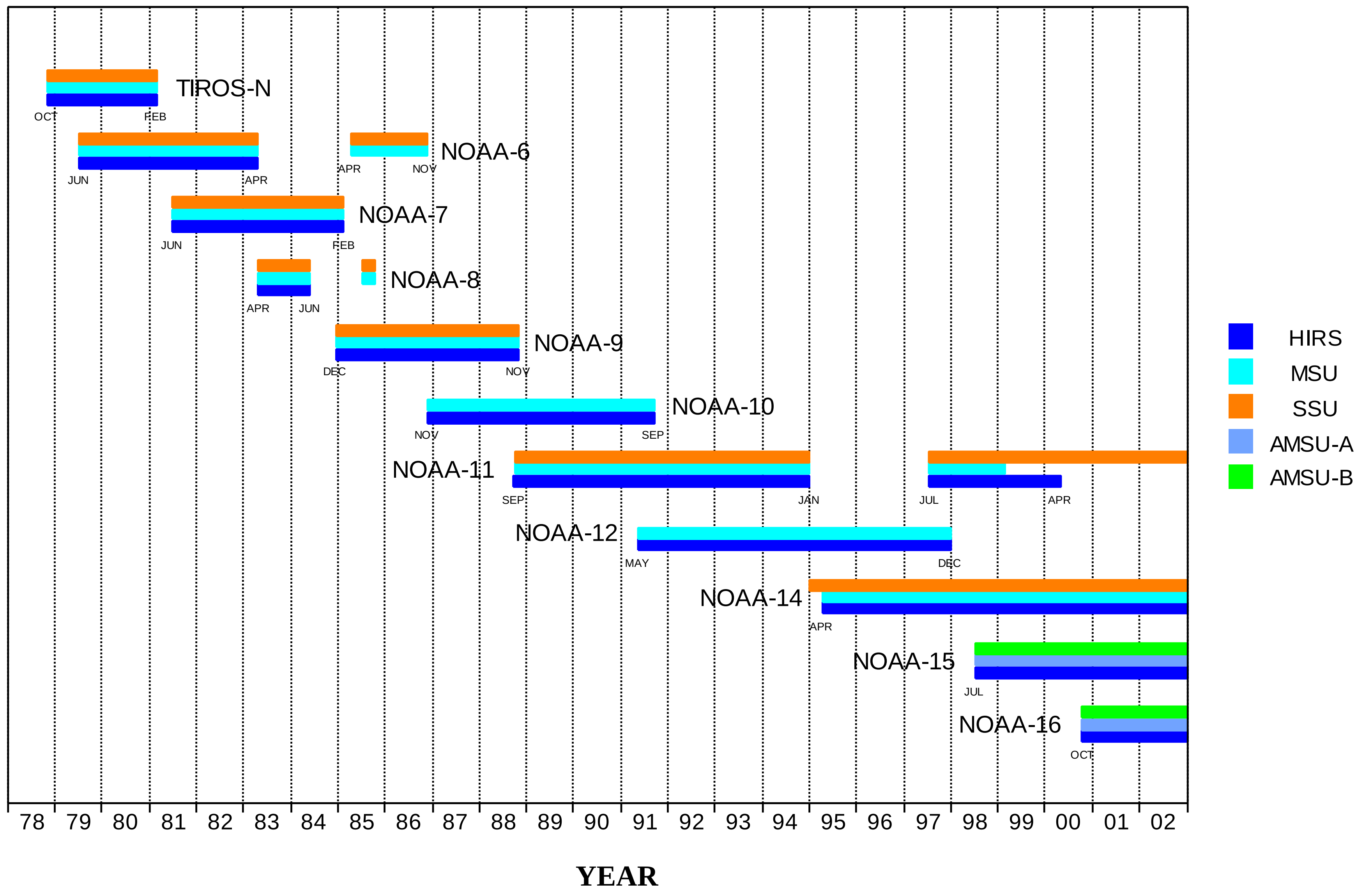
First Garp Global Experiment
FGGE 1979
Definition of the observing system

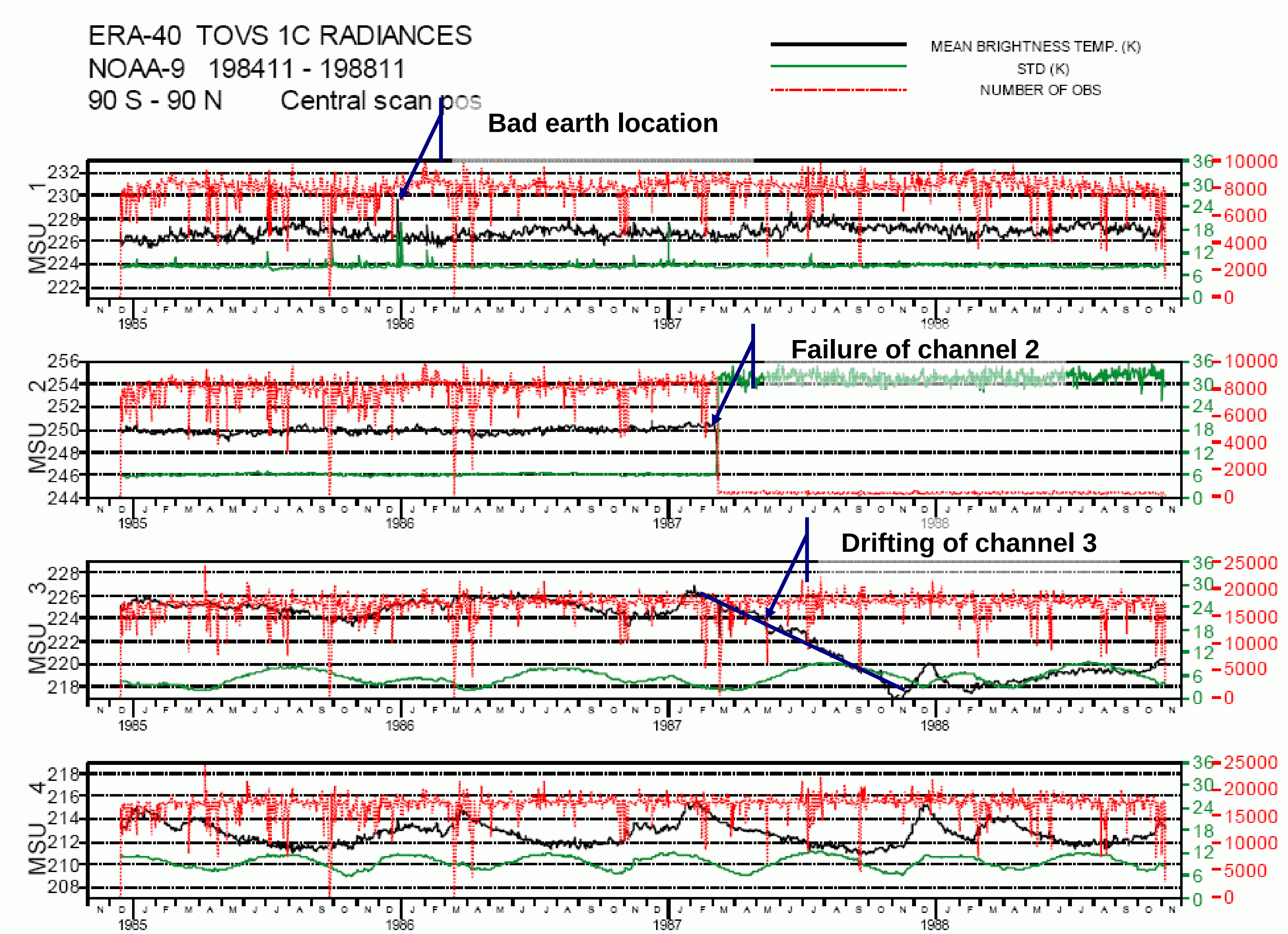


Satellites with VTPR instruments



TOVS/ATOVS satellite data 1978-2002

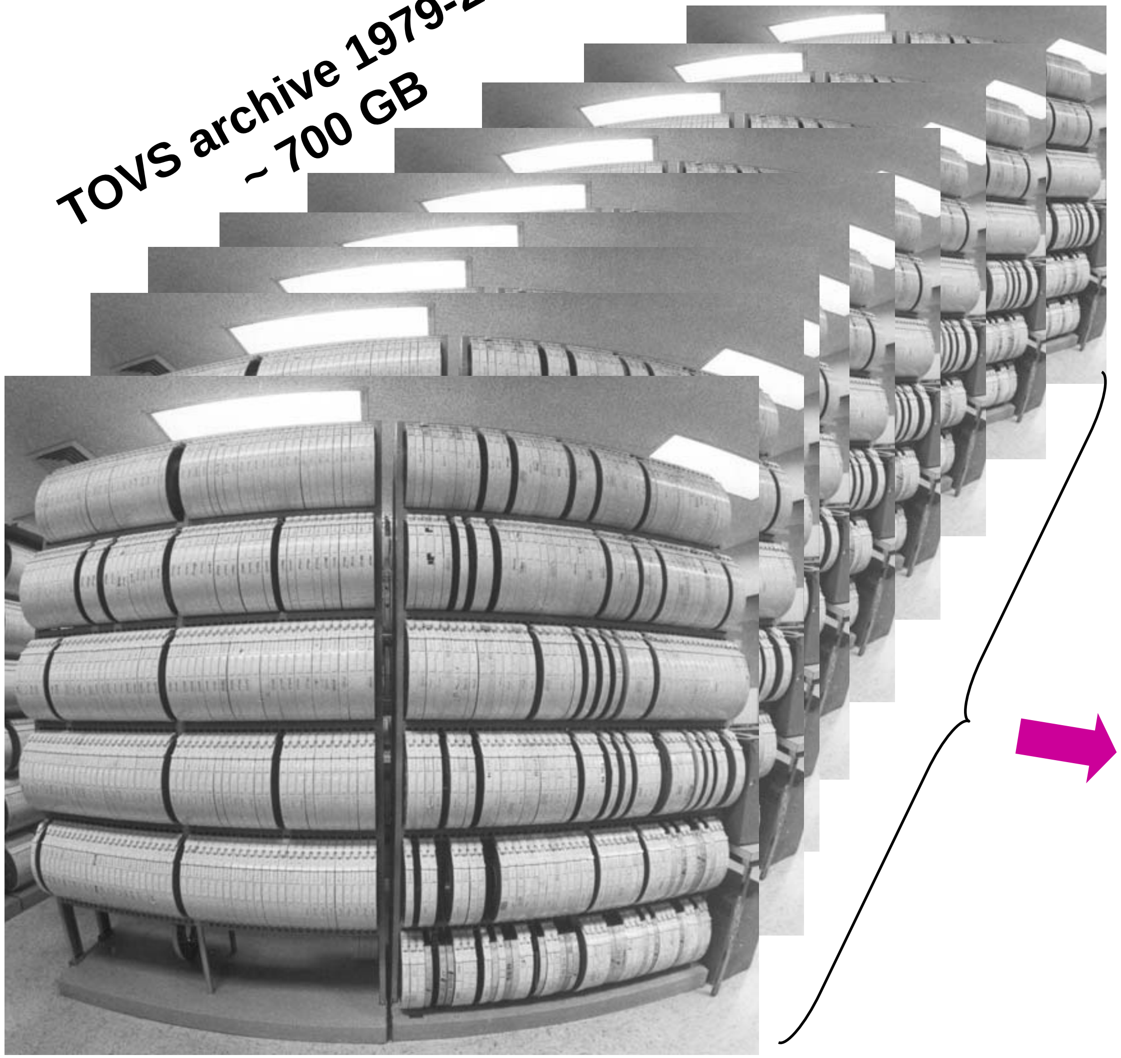




ERA-40 TOVS 1C RADIANCES
NOAA-9 198411 - 198811
90 S - 90 N Central scan pos
MEAN BRIGHTNESS TEMP. (K)
STD (K)
NUMBER OF OBS
Bad earth location
Failure of channel 2
Drifting of channel 3
MSU 1
MSU 2
MSU 3
MSU 4
1985
1986
1987
1988

Technological advances

TOVS archive 1979-2002
~ 700 GB



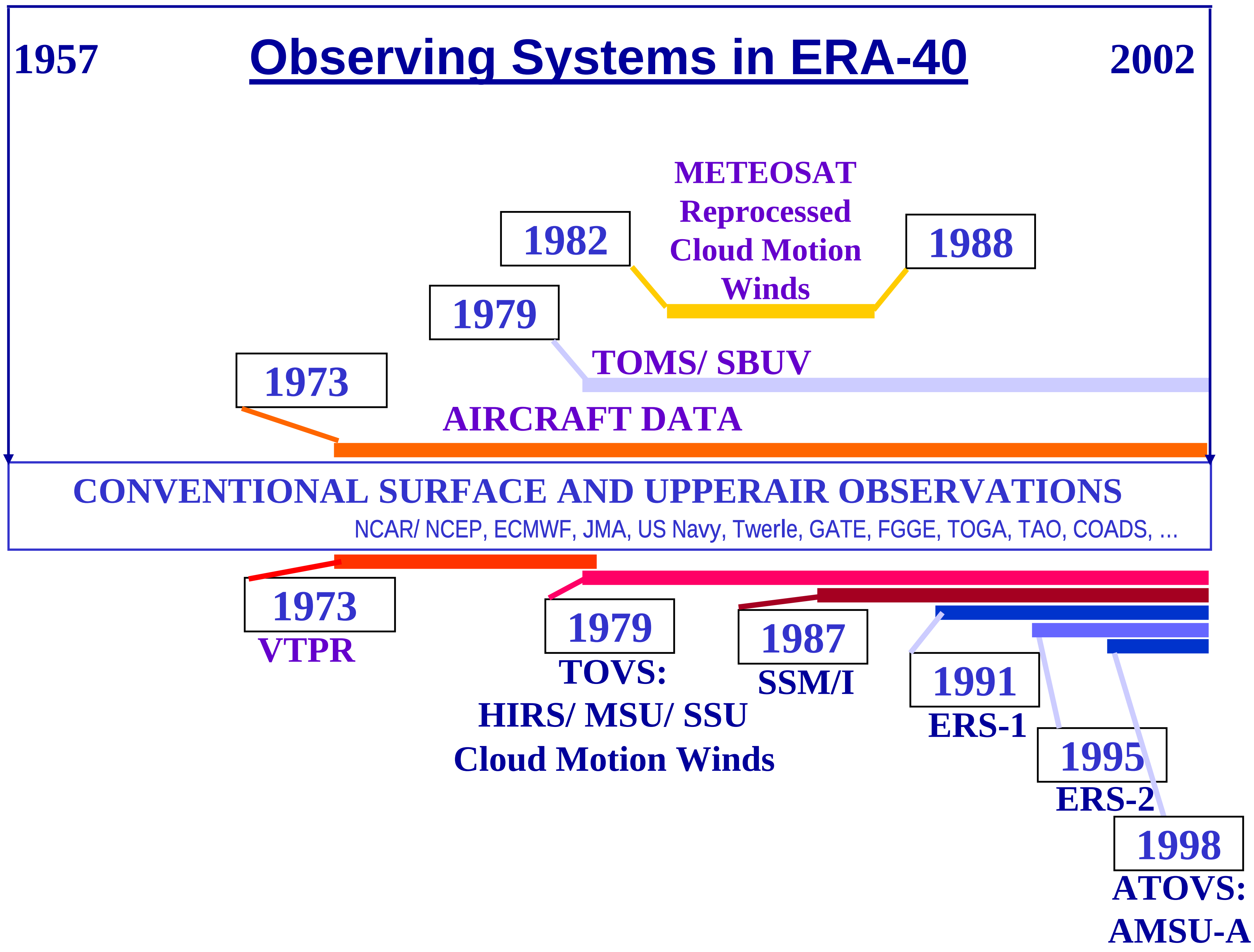
In the past

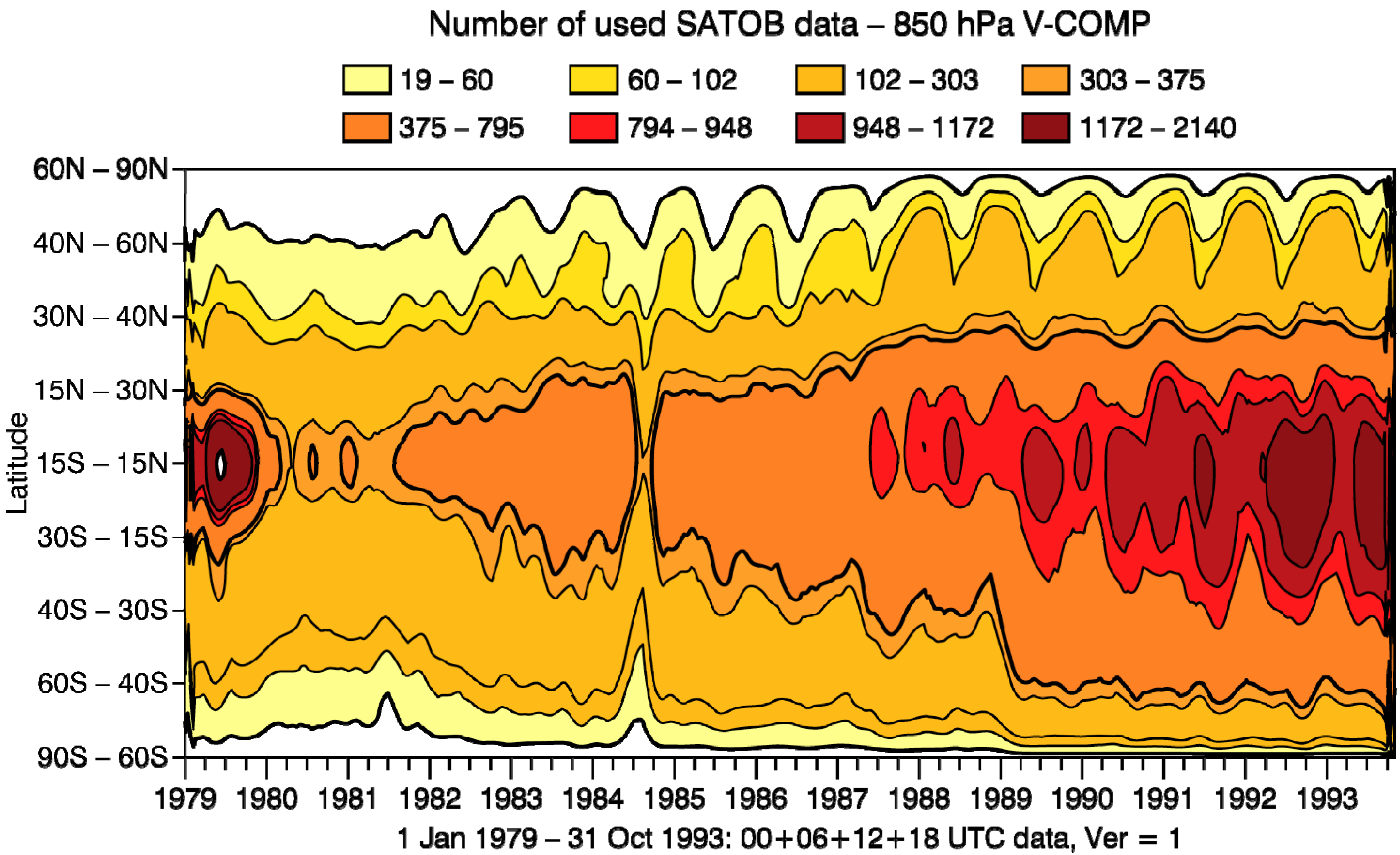
Thousands of tapes/ cartridges

Today

1 Super DLT capacity ~800GB

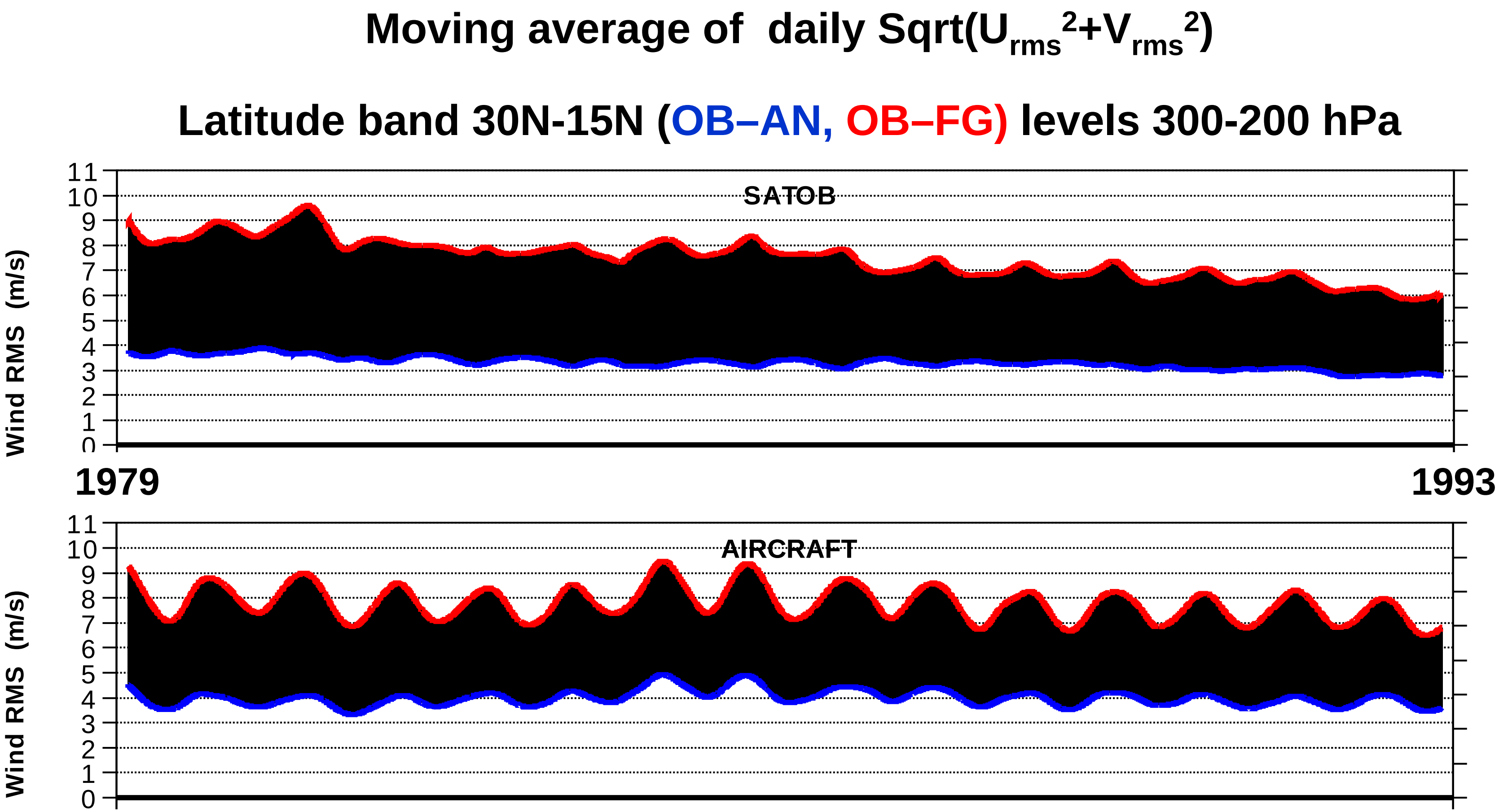
Observing Systems in ERA-40



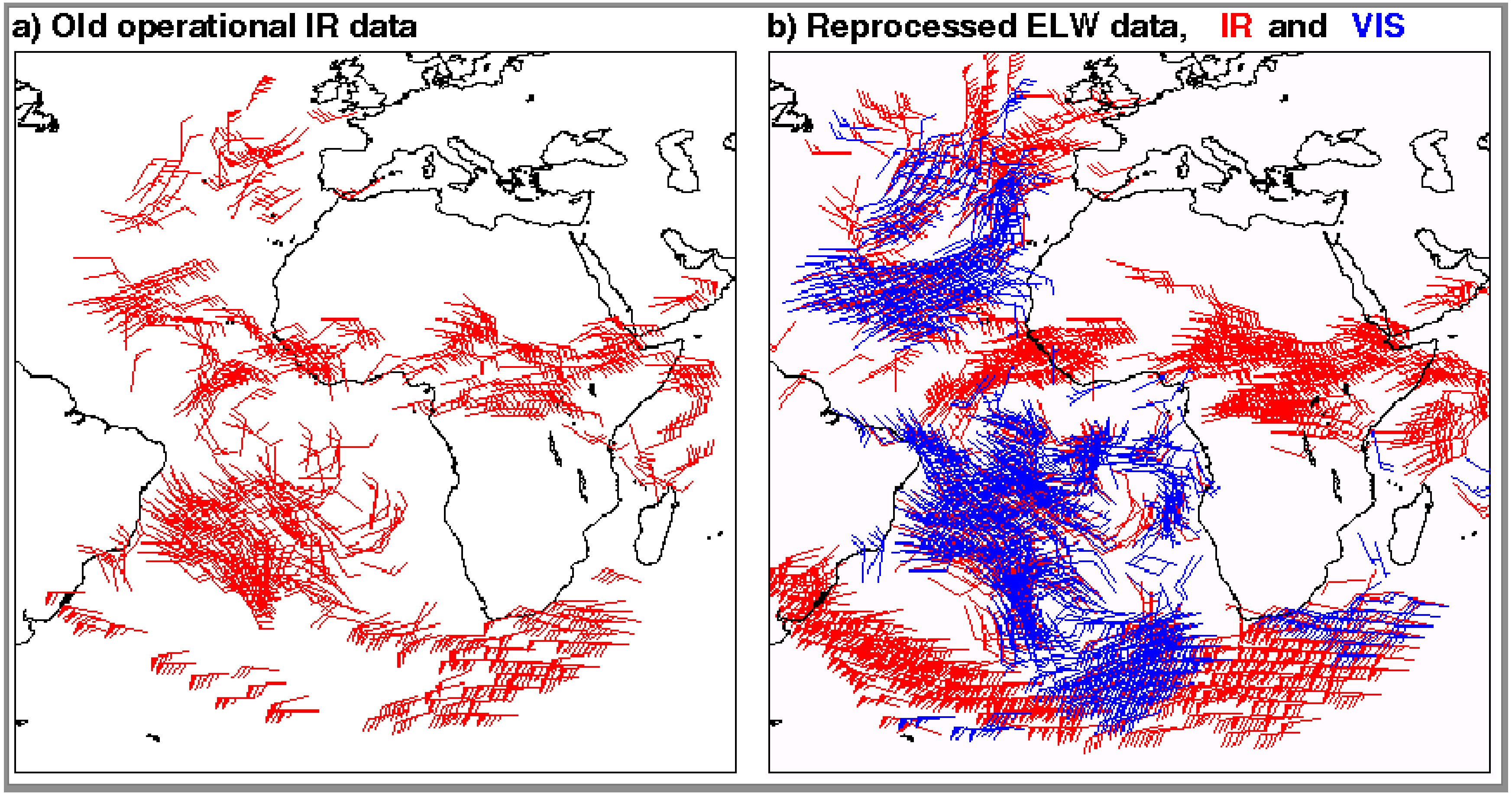


Number of used SATOB data – 850 hPa V-COMP
19 – 60
60 – 102
102 – 303
303 – 375
375 – 795
794 – 948
948 – 1172
1172 – 2140
Latitude
60N – 90N
40N – 60N
30N – 40N
15N – 30N
15S – 15N
30S – 15S
40S – 30S
60S – 40S
90S – 60S
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1 Jan 1979 – 31 Oct 1993: 00+06+12+18 UTC data, Ver = 1

Quality of Cloud Motion Winds improves



METEOSAT Reprocessed Winds



Sea Surface Temperature and Ice data

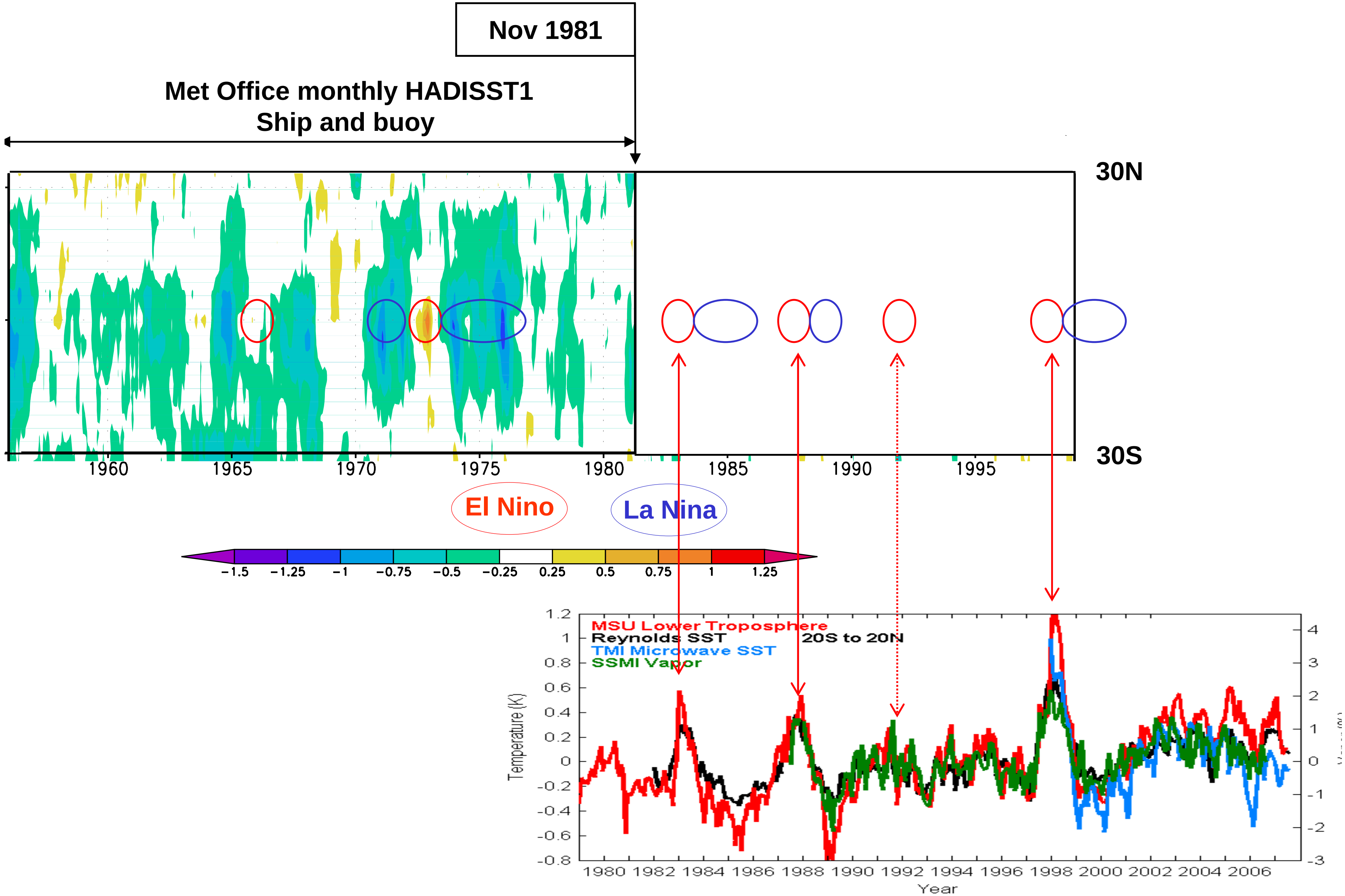
Before November 1981 (HADISST1, Met Office)

- Monthly SST analysis based on ship and buoy measurements
- Sea ice extent has large uncertainty

From November 1981

- Retrievals of SST from Advanced Very High Resolution Radiometer after cloud clearing
- Buoy and ship data
- OI or 2D-Var weekly SST analysis (R. Reynolds, NCEP)
- Background is the previous SST analysis
- Bias correction applied to satellite SSTs
- Sea ice extent determined from ice concentrations retrieved from SSMR and SSMI instruments

Interpolation to daily values



(F. Wentz, Remote Sensing Systems)

ECMWF reanalyses

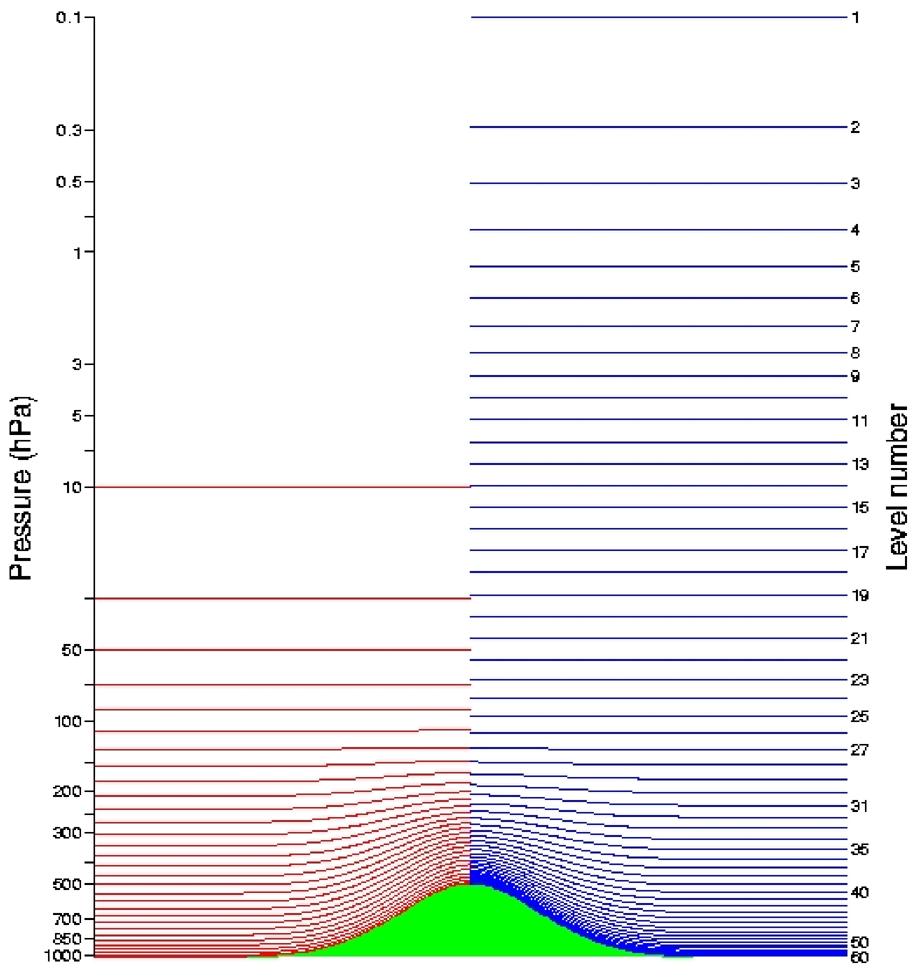
ERA-40 1957-2002

ERA-15 1979-1993

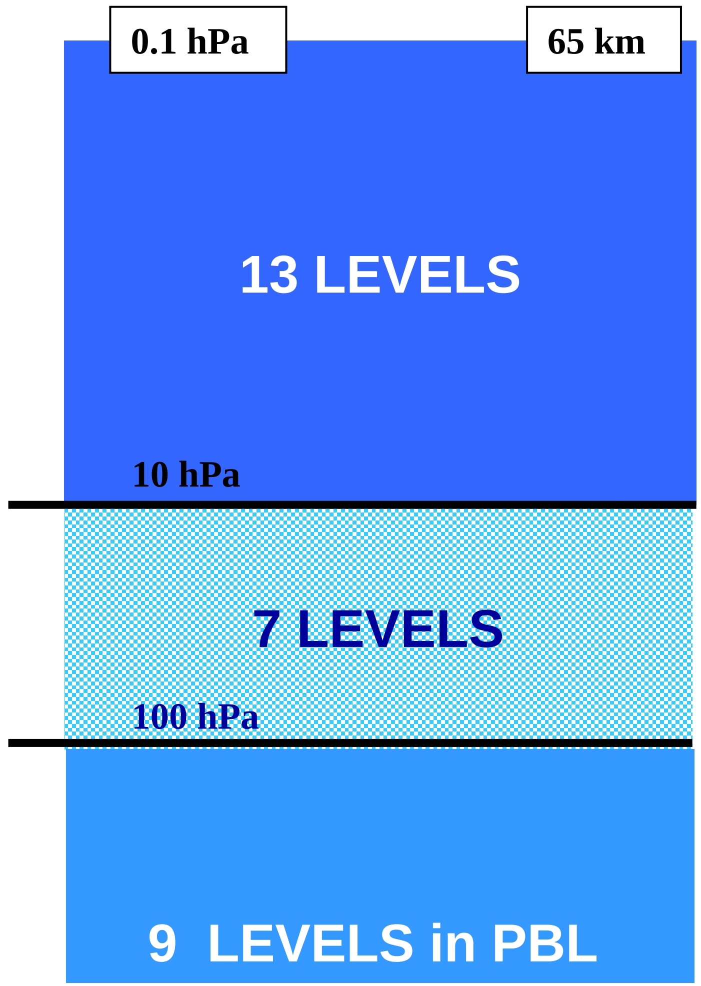
- Improved data assimilation system
  - Assimilating model T159L60
  - Optimum Interpolation → 3D-Var FGAT
  - Analysis of O_3
- More extensive use satellite radiances (from CCR → Level 1c radiances)
- ERA-15 experience ➔ ERA-40 blacklist
- More comprehensive use of conventional observations
- Use of Meteosat reprocessed winds, CSR data passive
- Improved SST & ICE dataset
- Ocean wave height analysis

Model levels

ERA-15/ L31 ERA-40/ L60



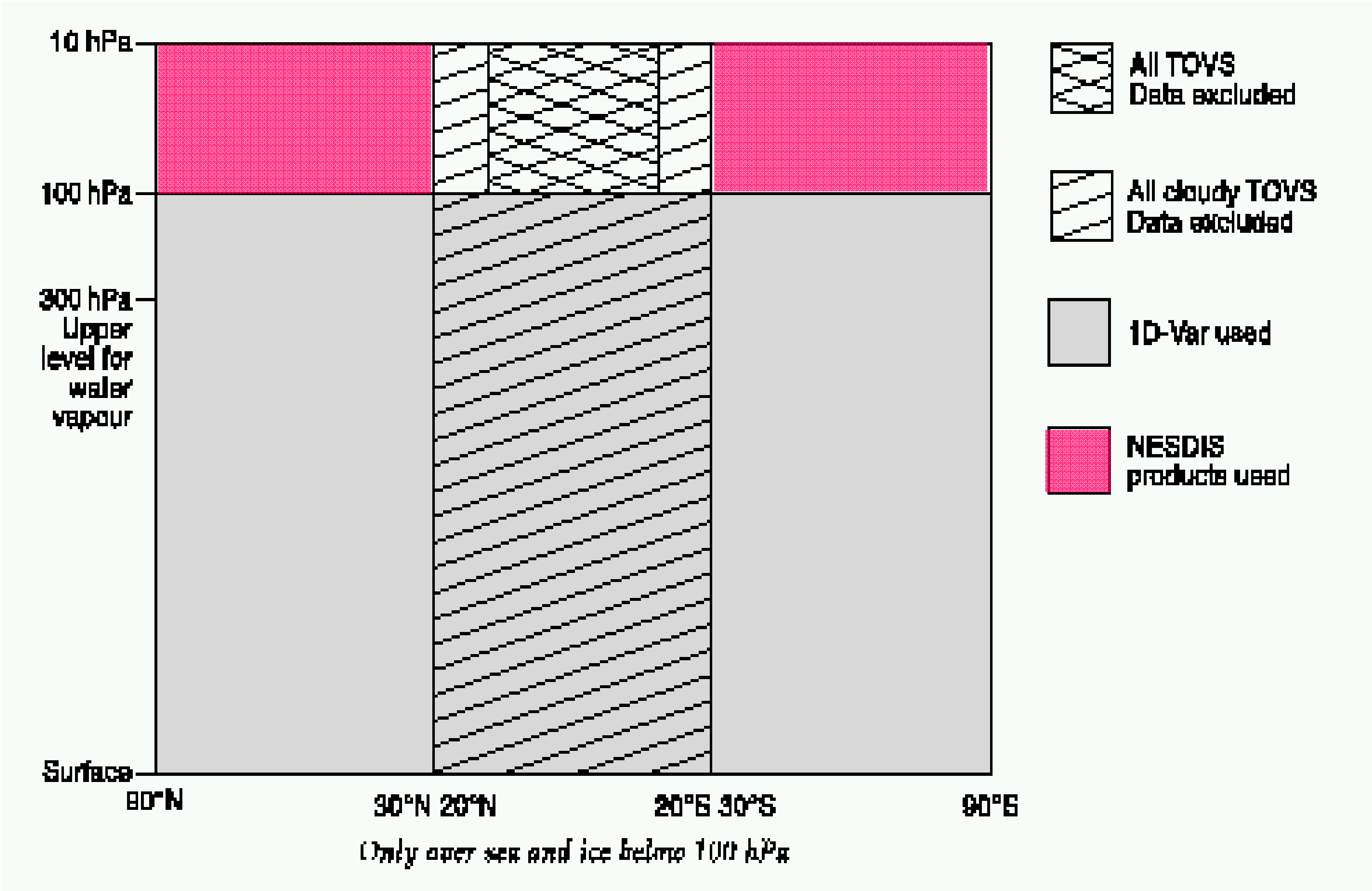
Levels added



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	-	-	1D-Var retrievals of T & q using CCR. Above 100hPa NESDIS retrievals.		-	-	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	-	1c	1c	1c	JMA retrievals of TCWV	Oper+reprocessed AMWs
ERA-Interim 1989 →	1c	-	1c	1c	1c	1c radiances and 1D-Var retrievals of rainy radiances	Oper+reprocessed AMWs, CSR passively

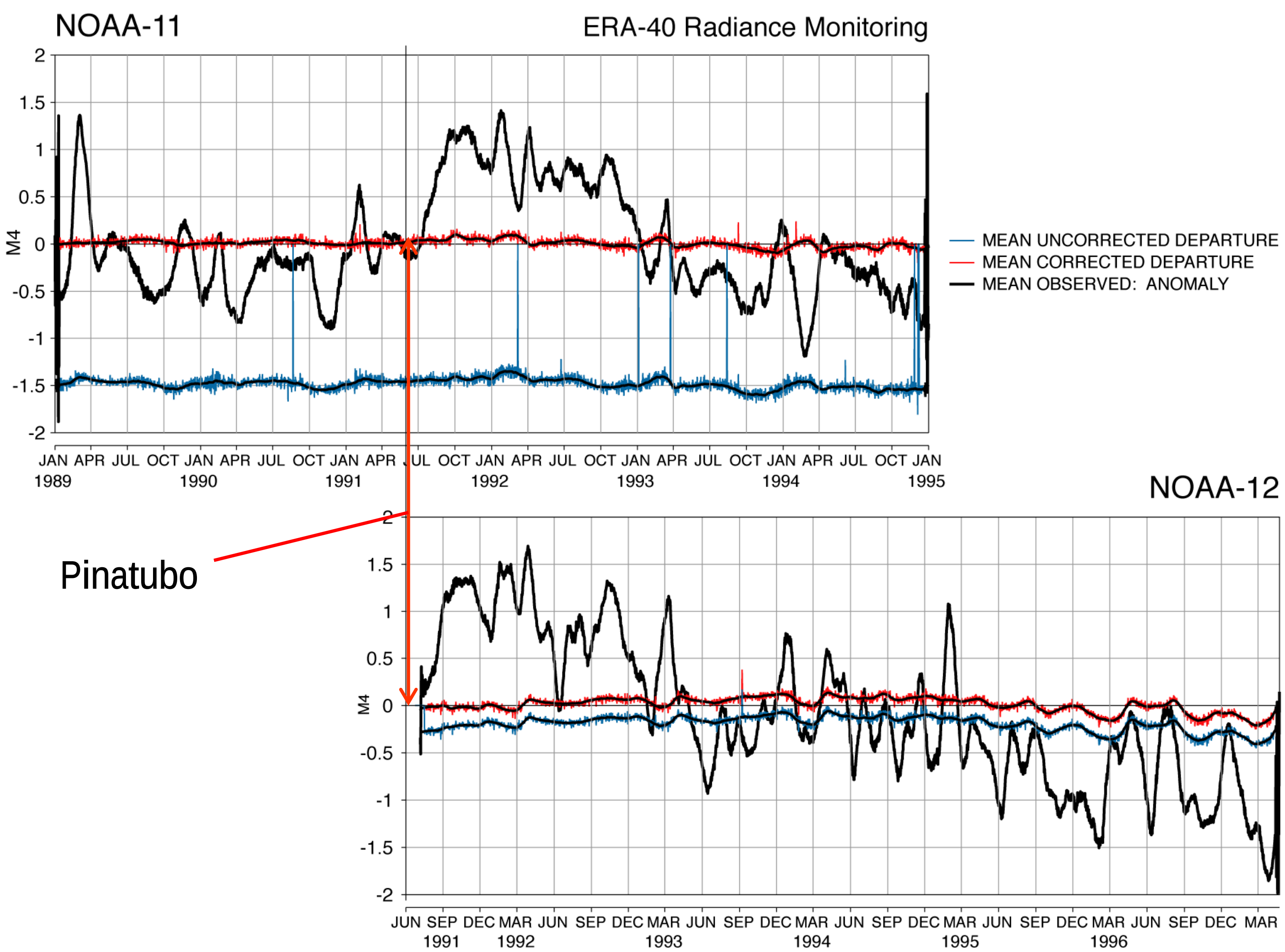
Use of TOVS data in ERA-15



Handling of biases in ERA-40

- Radiosonde temperature biases 1980 onwards
- VTPR, TOVS, SSMI and ATOVS radiances
- ERS scatterometer wind bias correction

	ERA-15	ERA-40	
	TOVS	VTPR/ TOVS/ ATOVS	SSMI
Input radiance	Cloud Cleared and nadir corrected Radiances	Level-1c calibrated at ECMWF from Level-1b	Level-1c data from RSS & ECMWF. Satellite to satellite calibration with reference to the 1st satellite, F. Wentz
Method	Static J. Eyre based on W. Smith & H. Woolf	Static B. Harris & G. Kelly	Static B. Harris & G. Kelly
Scan bias	Global offset with 0 at center	18 latitude bands	18 latitude bands
Air-mass dependent bias	Predictors: MSU-2,3 and 4, which are unaffected by clouds	Predictors: Model values , DZ(1000-300), DZ(200-50), Tskin and TCWV	Predictors: Model values ,10 m wind speed, Tskin and TCWV
Update frequency	monthly	Once per satellite life time or after a jump in instrument based on about two week statistics	Once per satellite life time or after a jump in instrument


NOAA-11
ERA-40 Radiance Monitoring
M4
MEAN UNCORRECTED DEPARTURE
MEAN CORRECTED DEPARTURE
MEAN OBSERVED: ANOMALY
JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT JAN APR JUL OCT JAN
1989 1990 1991 1992 1993 1994 1995
NOAA-12
Pinatubo
JUN SEP DEC MAR JUN SEP DEC MAR JUN SEP DEC MAR JUN SEP DEC MAR JUN SEP DEC MAR
1991 1992 1993 1994 1995 1996

ERA-15 Tropical temperature

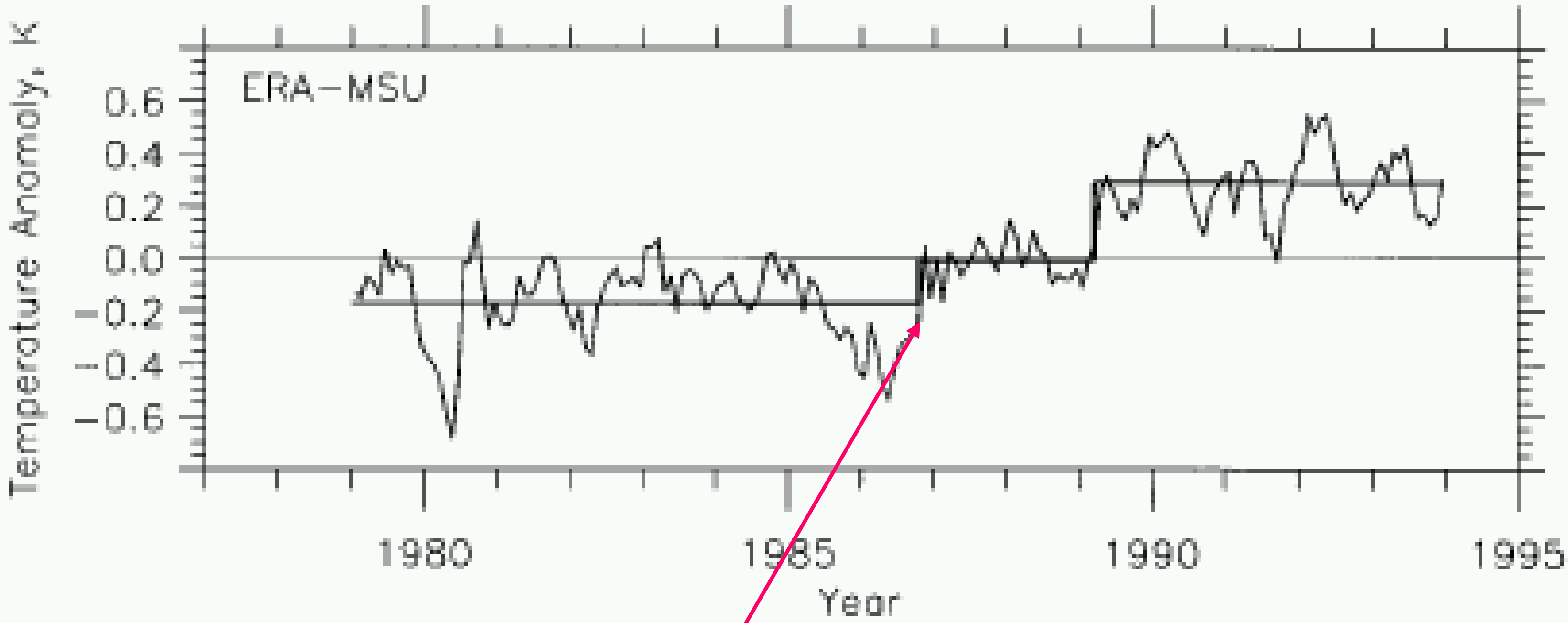


FIG. 3. Difference in time series of the monthly mean tropical (20°N to 20°S) 2LT temperatures from MSU and ERA-15, as ERA–MSU. A straight line fit has been added to the series to show the two discontinuities.

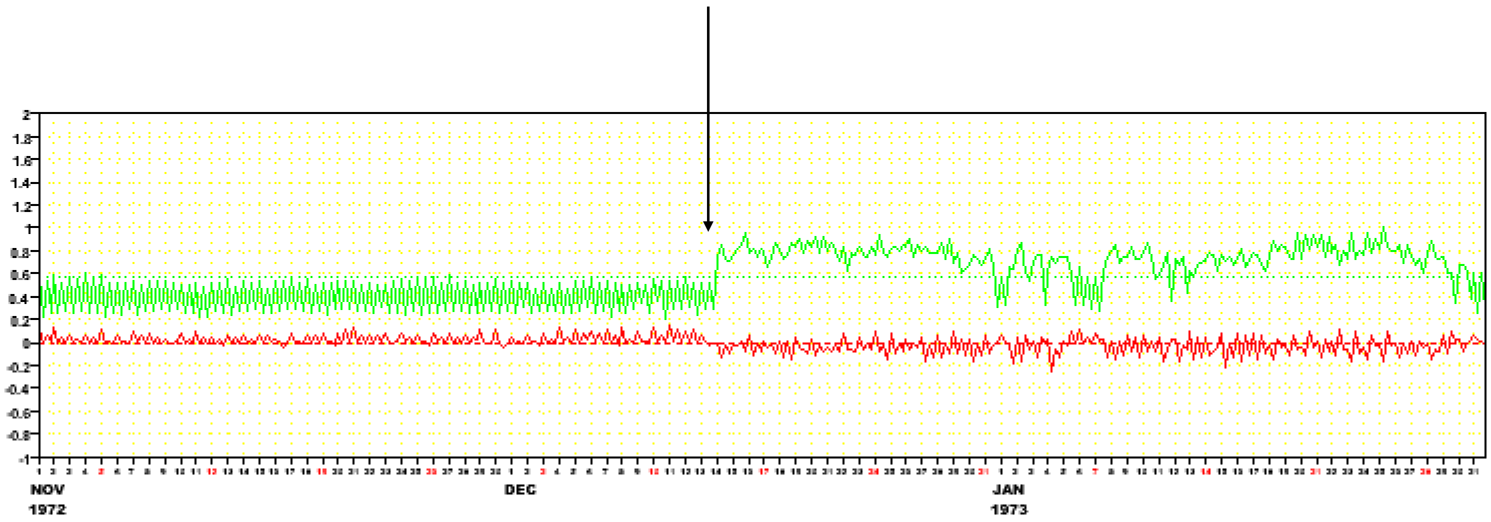
Trenberth et al. (2000)

NOAA-9 MSU-3 problem
November 1986

Quality of Analysis & Background

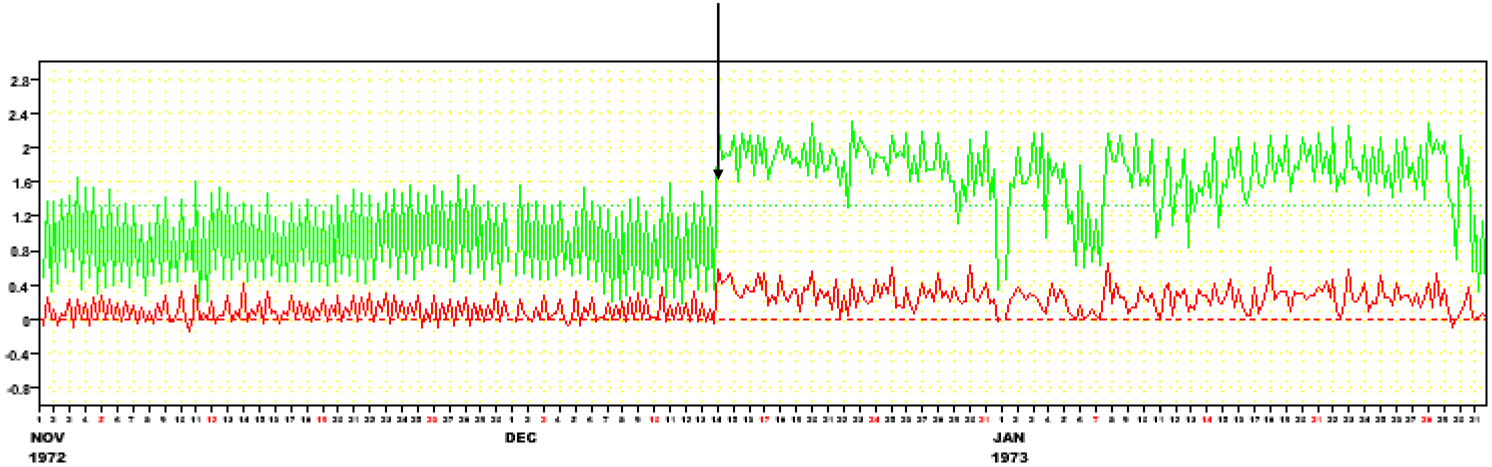
Global 500 hPa Temperature analysis mean increment and STD

VTPR introduced

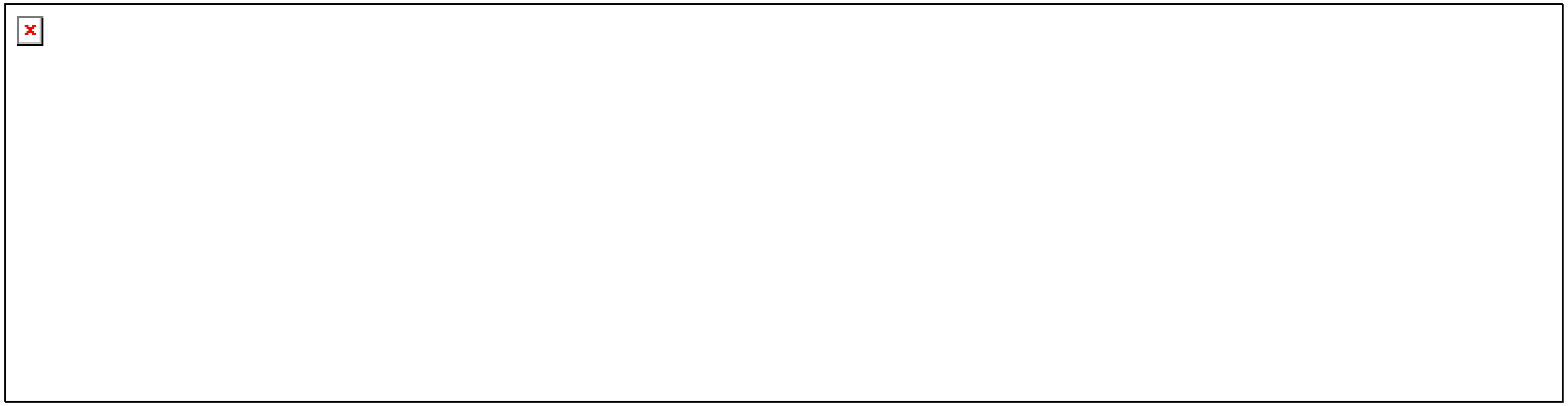


Tropical TCWV analysis mean increment and STD

VTPR

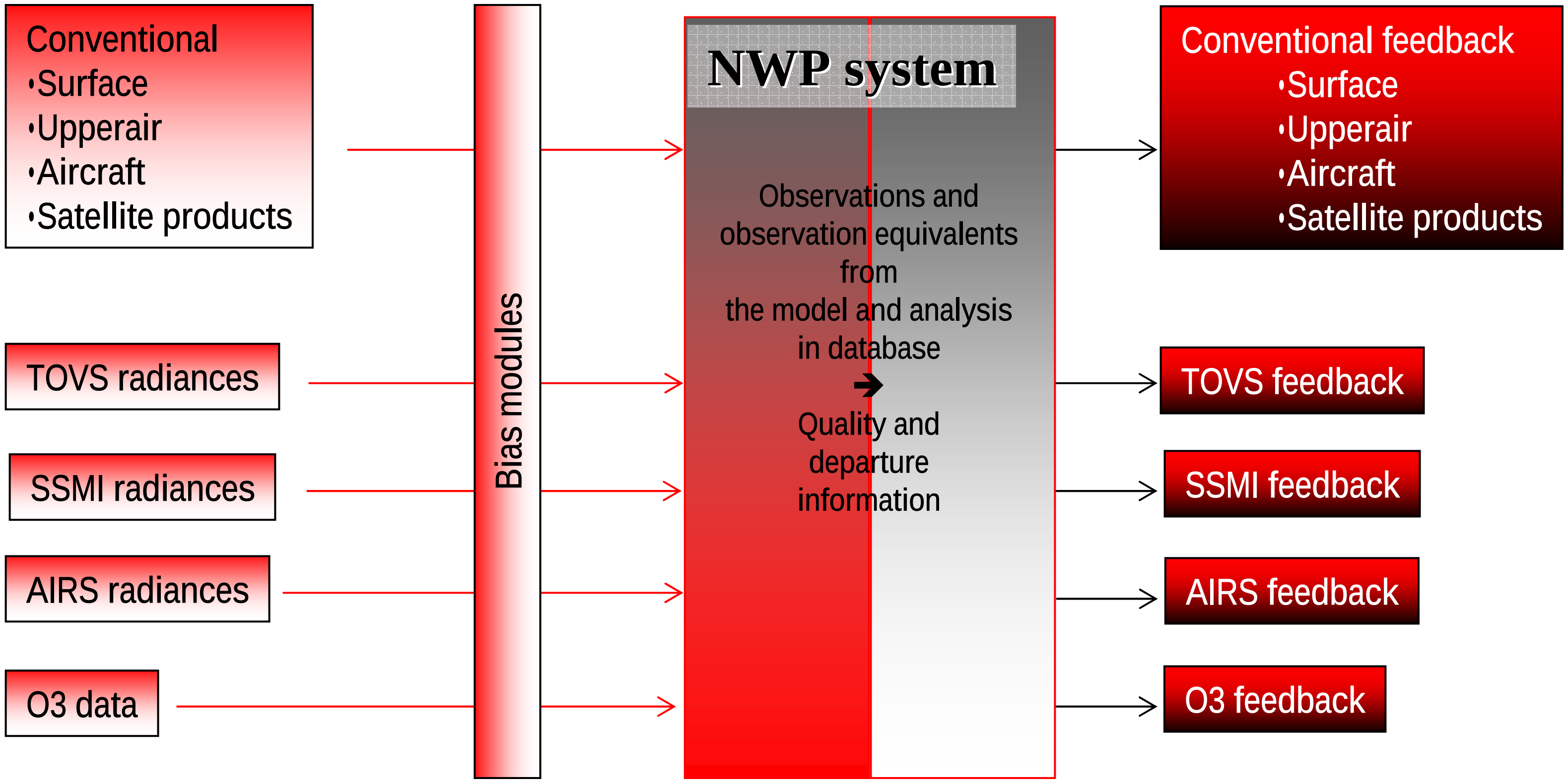


Tropical mean TCWV (kgm^{-2}) background and analysis

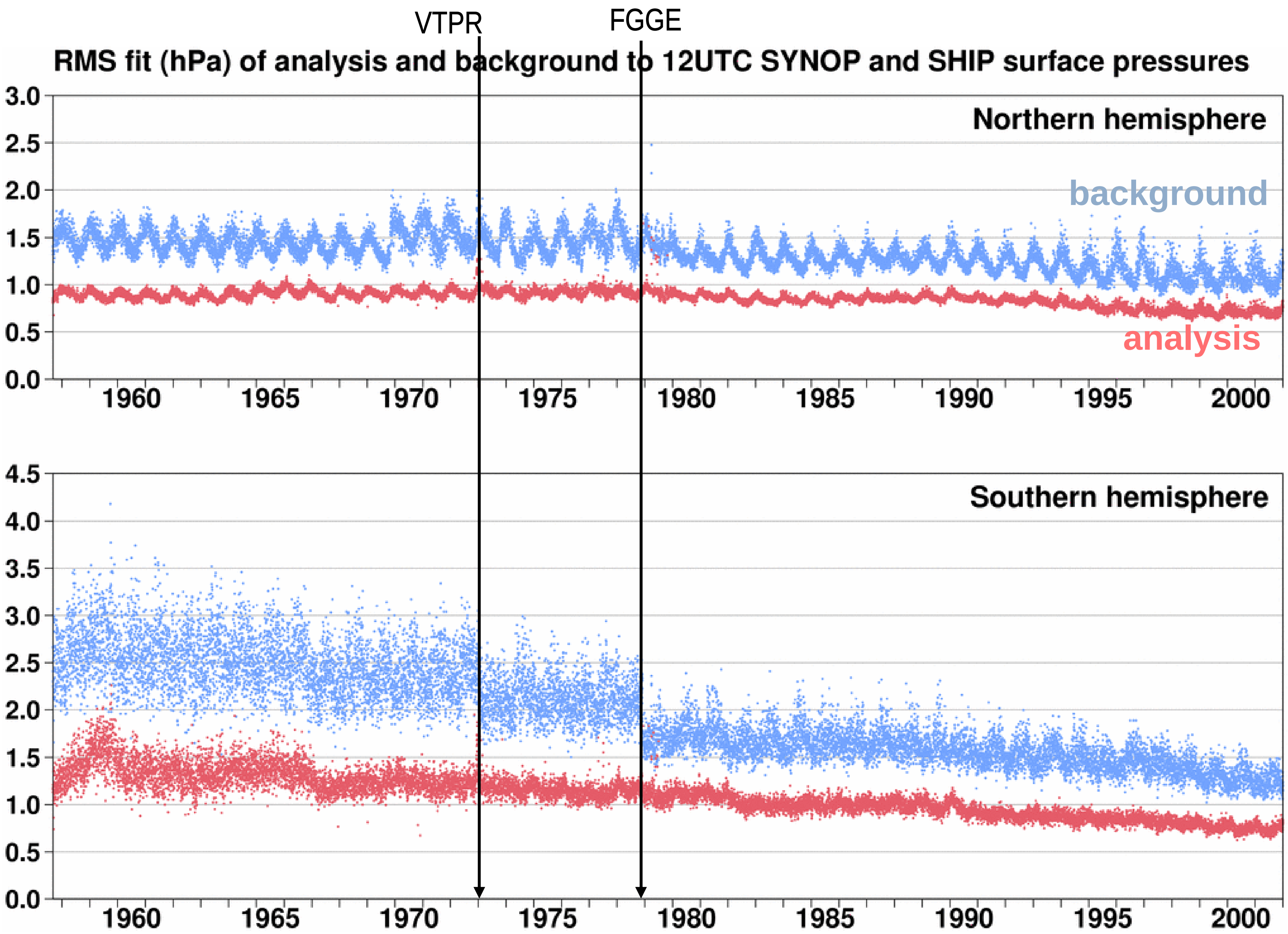


Input observations

How the observations were used in the analysis (feedback)

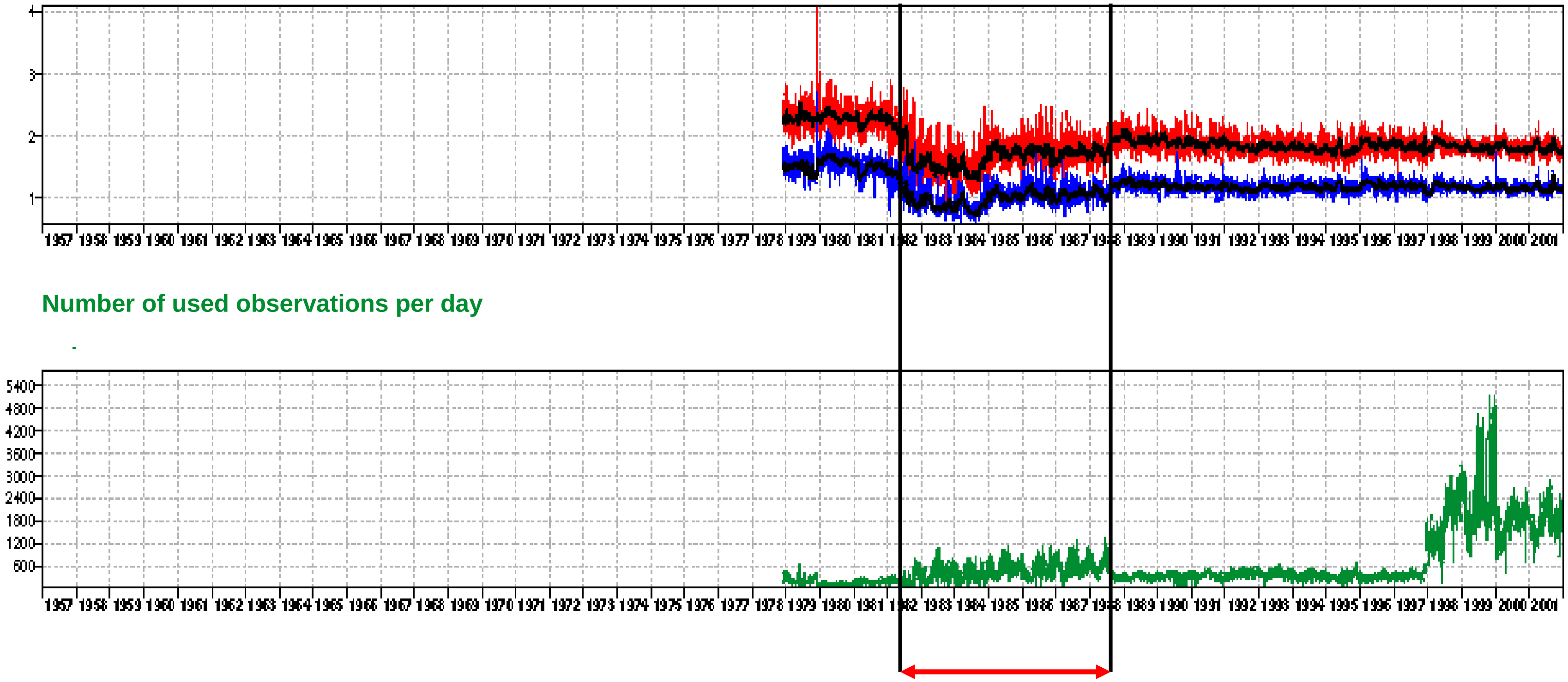


- Input and feedback observations in BUFR code as well as as the runtime database, ODB, through the period)

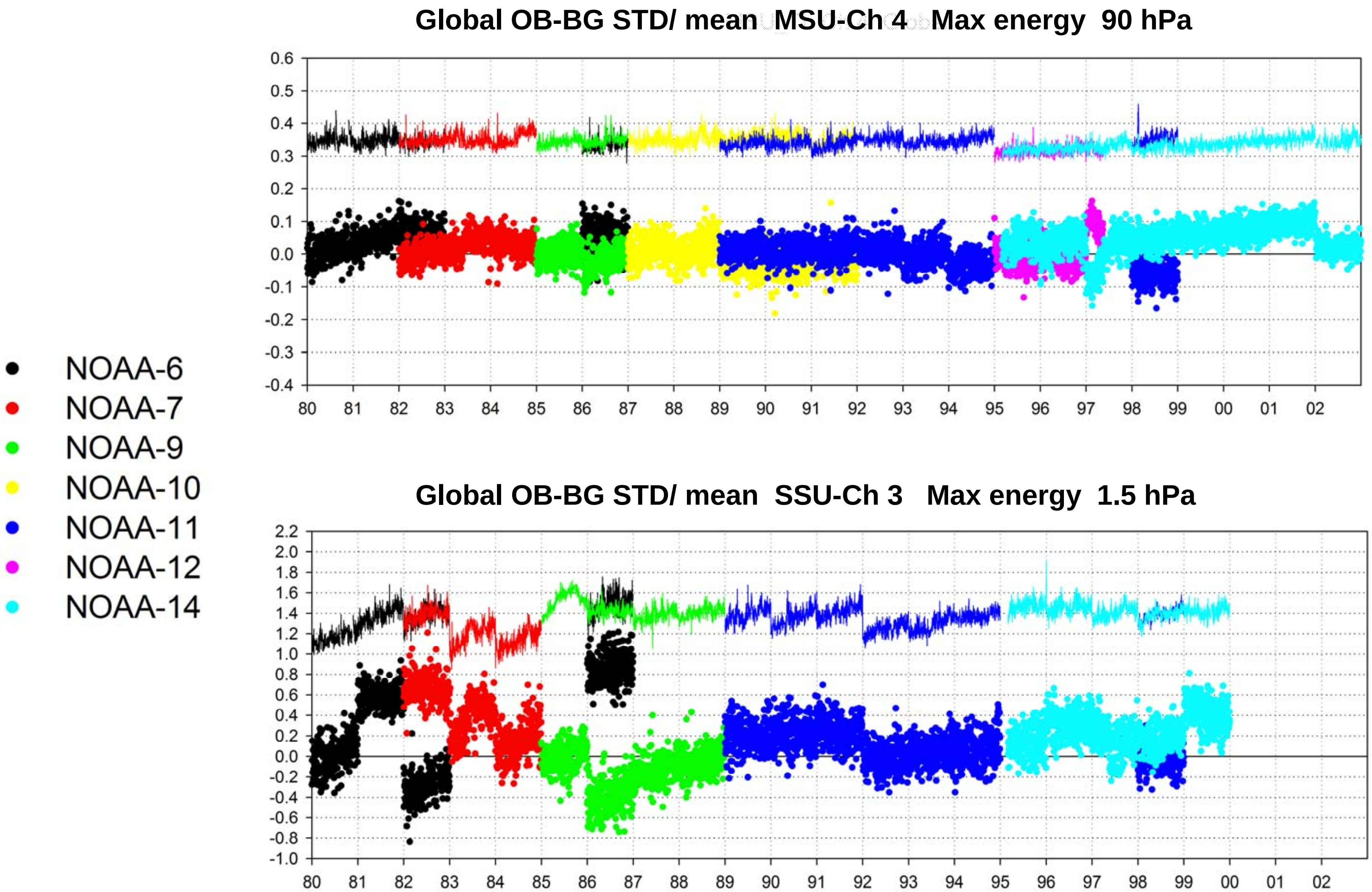


VTPR
FGGE
RMS fit (hPa) of analysis and background to 12UTC SYNOP and SHIP surface pressures
Northern hemisphere
background
analysis
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1960
1965
1970
1975
1980
1985
1990
1995
2000
Southern hemisphere
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1960
1965
1970
1975
1980
1985
1990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

ERA-40: SATOB U- Wind 850 00 UTC Tropics RMS (m/s) OB-FG OB-AN 15 days MA



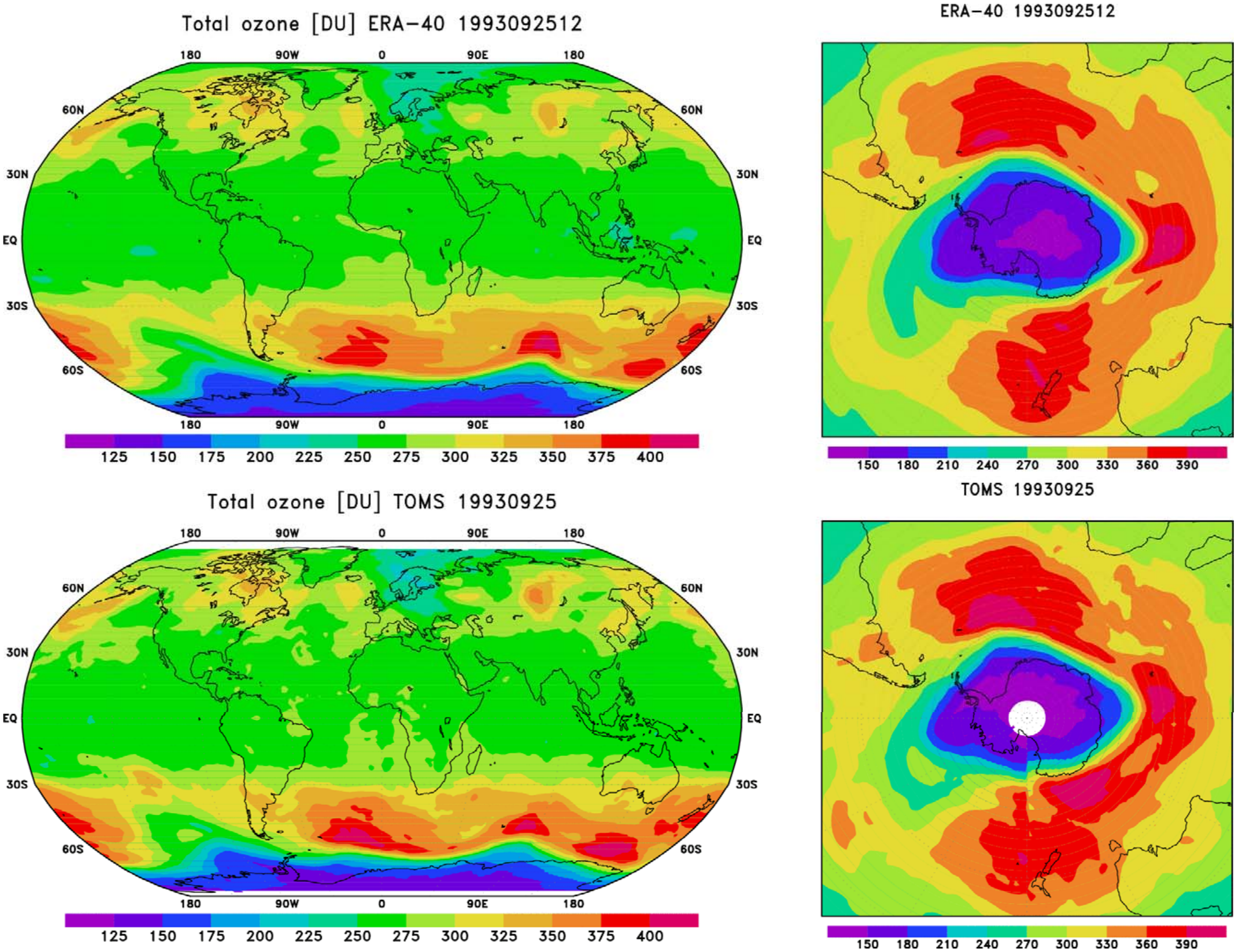
Meteosat
Reprocessed winds



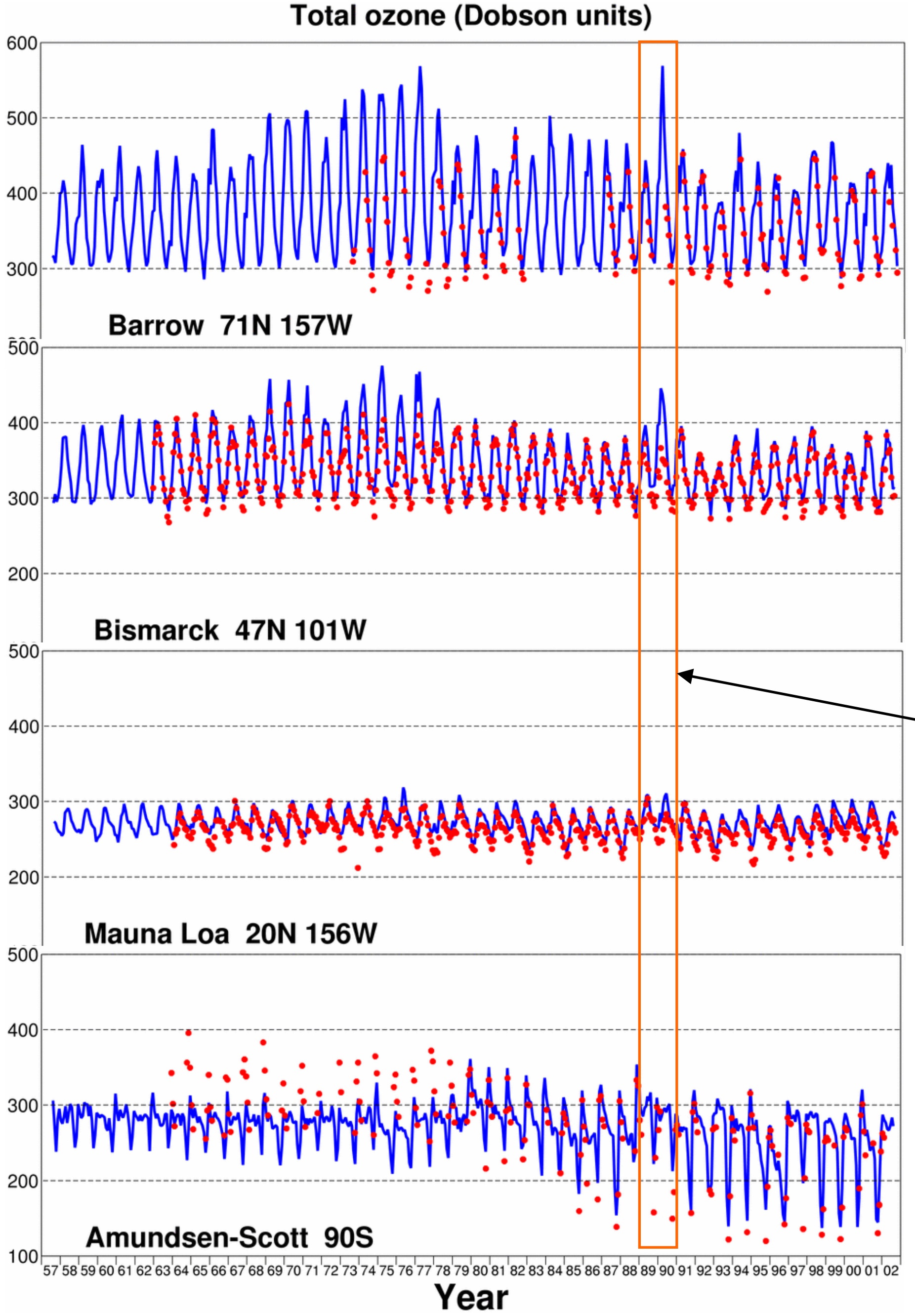
Global OB-BG STD/ mean MSU-Ch 4 Max energy 90 hPa
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02
Global OB-BG STD/ mean SSU-Ch 3 Max energy 1.5 hPa
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
-0.8
-1.0
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 00 01 02
NOAA-6
NOAA-7
NOAA-9
NOAA-10
NOAA-11
NOAA-12
NOAA-14

Analysis of ozone

The three-dimensional ozone field is consistent both with available ozone observations and the dynamical state of the atmosphere


Total ozone [DU] ERA-40 1993092512
180 90W 0 90E 180
60N 30N EQ 30S 60S
125 150 175 200 225 250 275 300 325 350 375 400
ERA-40 1993092512
150 180 210 240 270 300 330 360 390
Total ozone [DU] TOMS 19930925
180 90W 0 90E 180
60N 30N EQ 30S 60S
125 150 175 200 225 250 275 300 325 350 375 400
TOMS 19930925
150 180 210 240 270 300 330 360 390

Monthly mean values



ERA-40 analysis

TOMS and SBUV data assimilated 1979-1988 and 1991-2002.

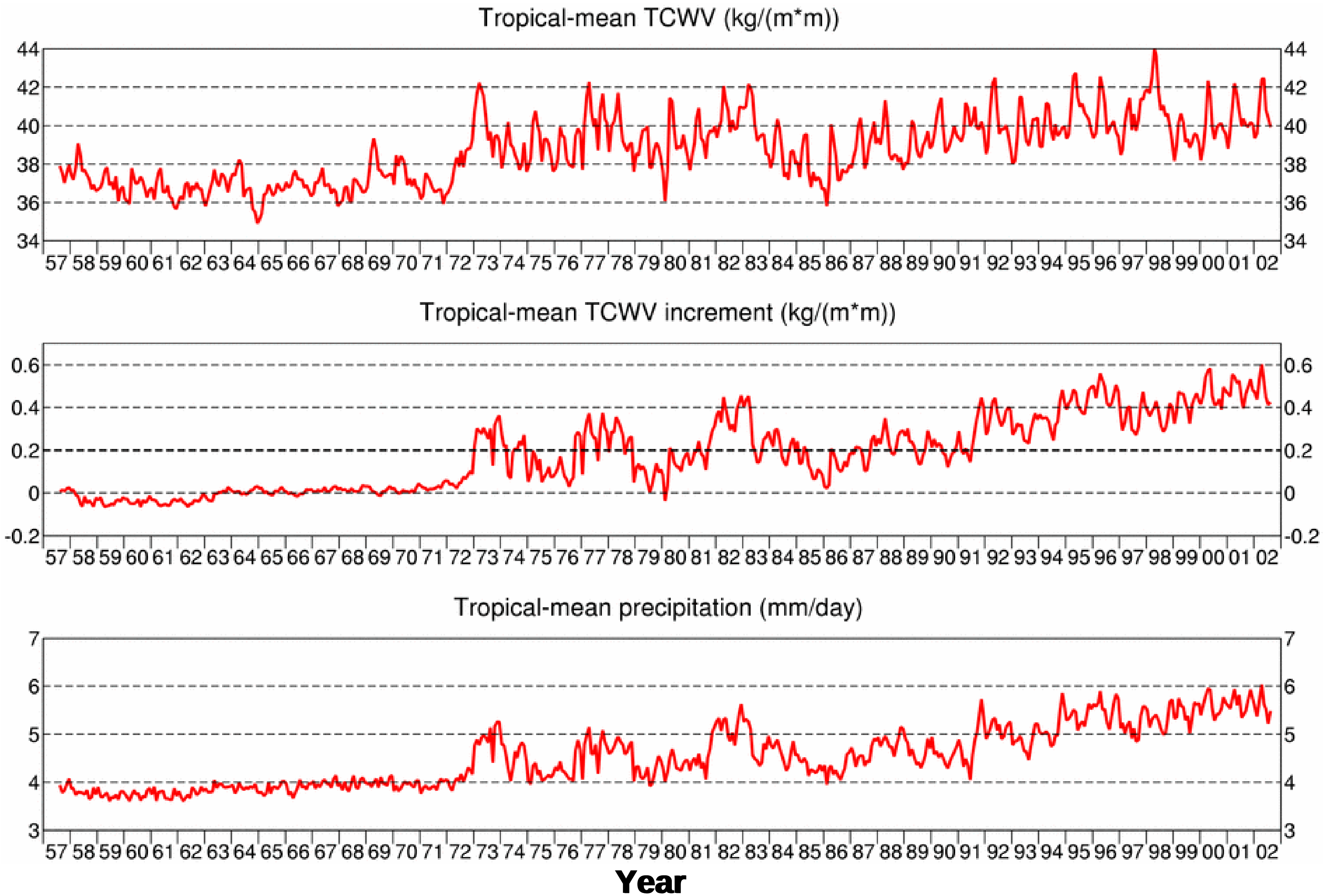
Ground-based measurements

From NOAA/ CMDL and not used in analysis.

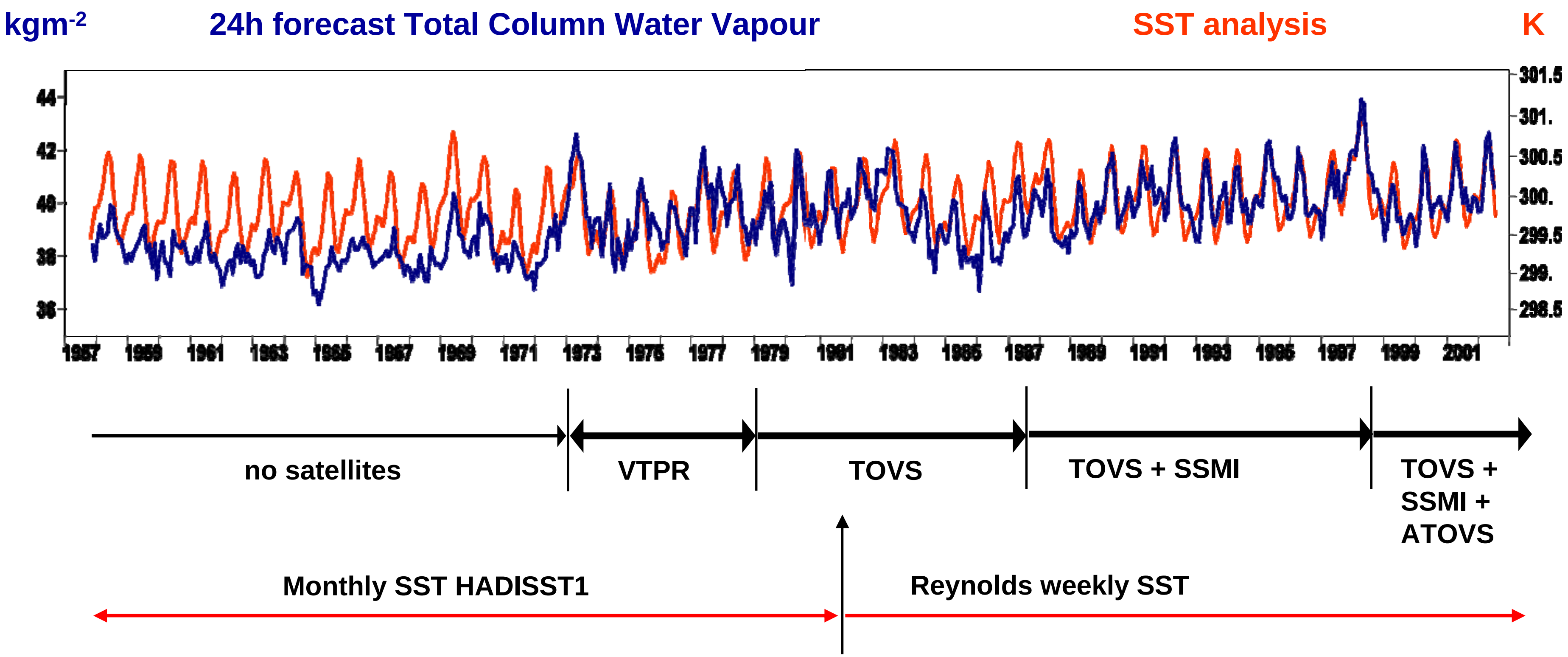
No data assimilated in 1989 and 1990.

Moisture analysis

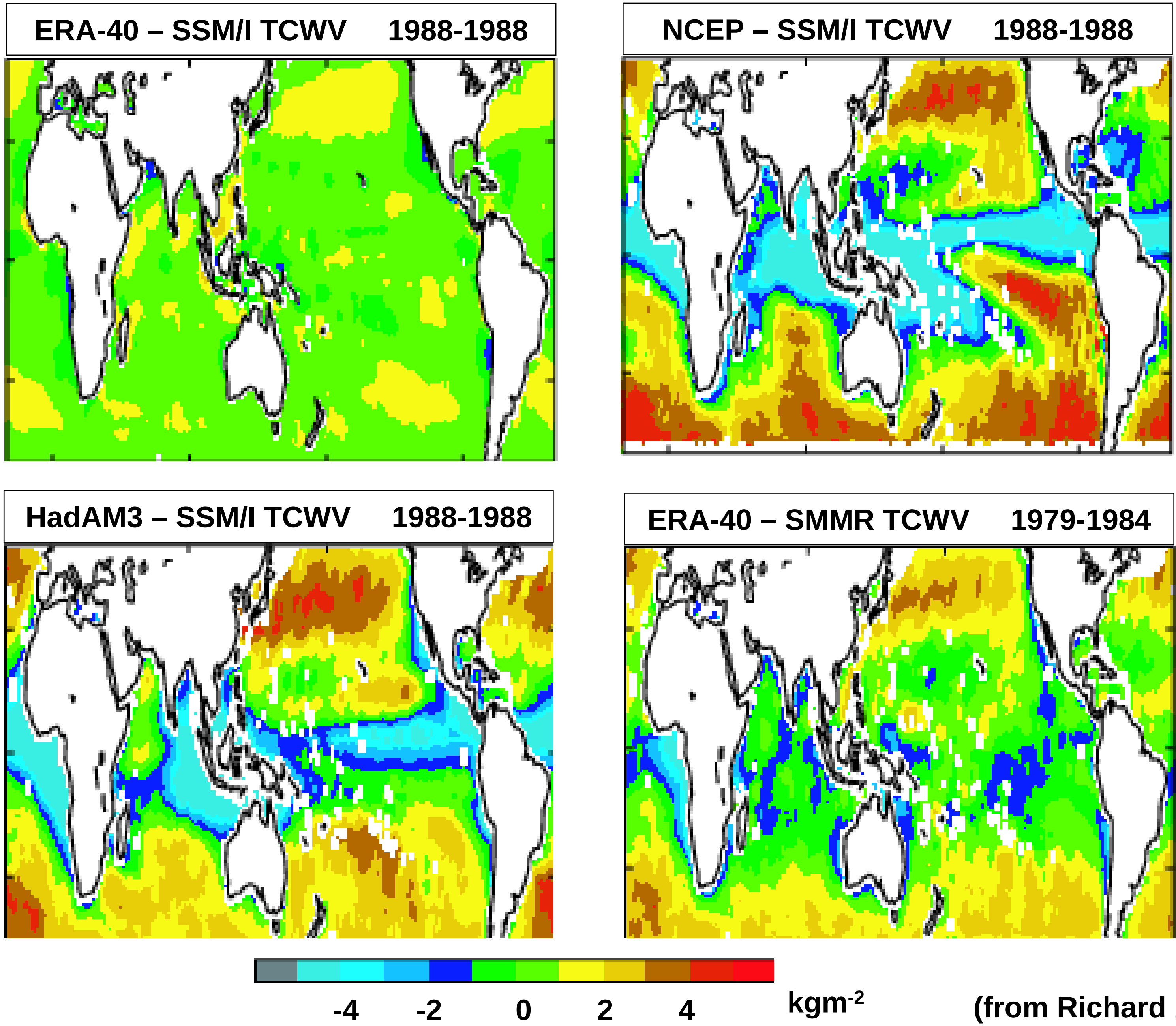
Aspects of tropical humidity analysis in ERA-40



Tropical oceans: SST ←→ TCWV



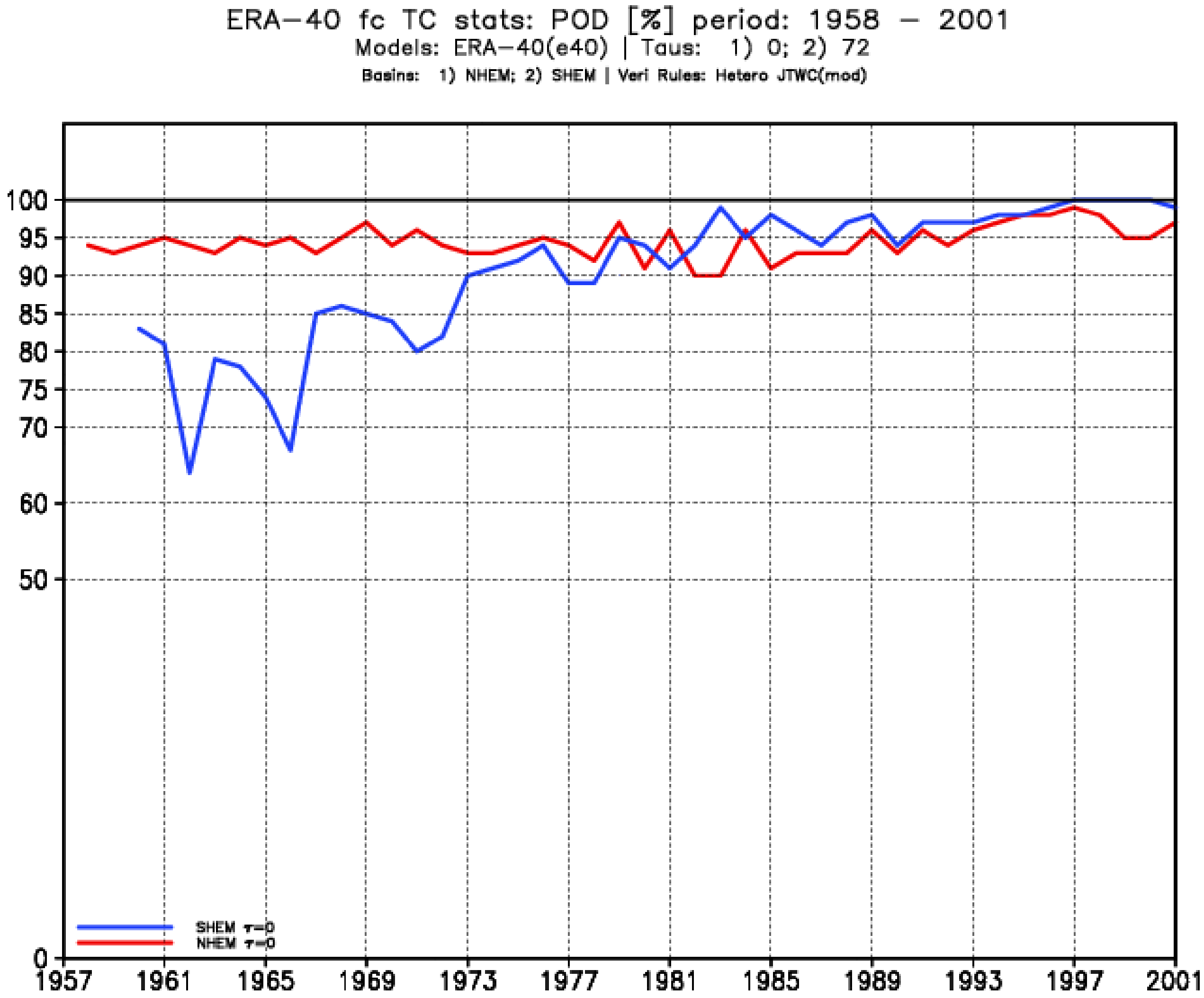
Detection of tropical cyclones



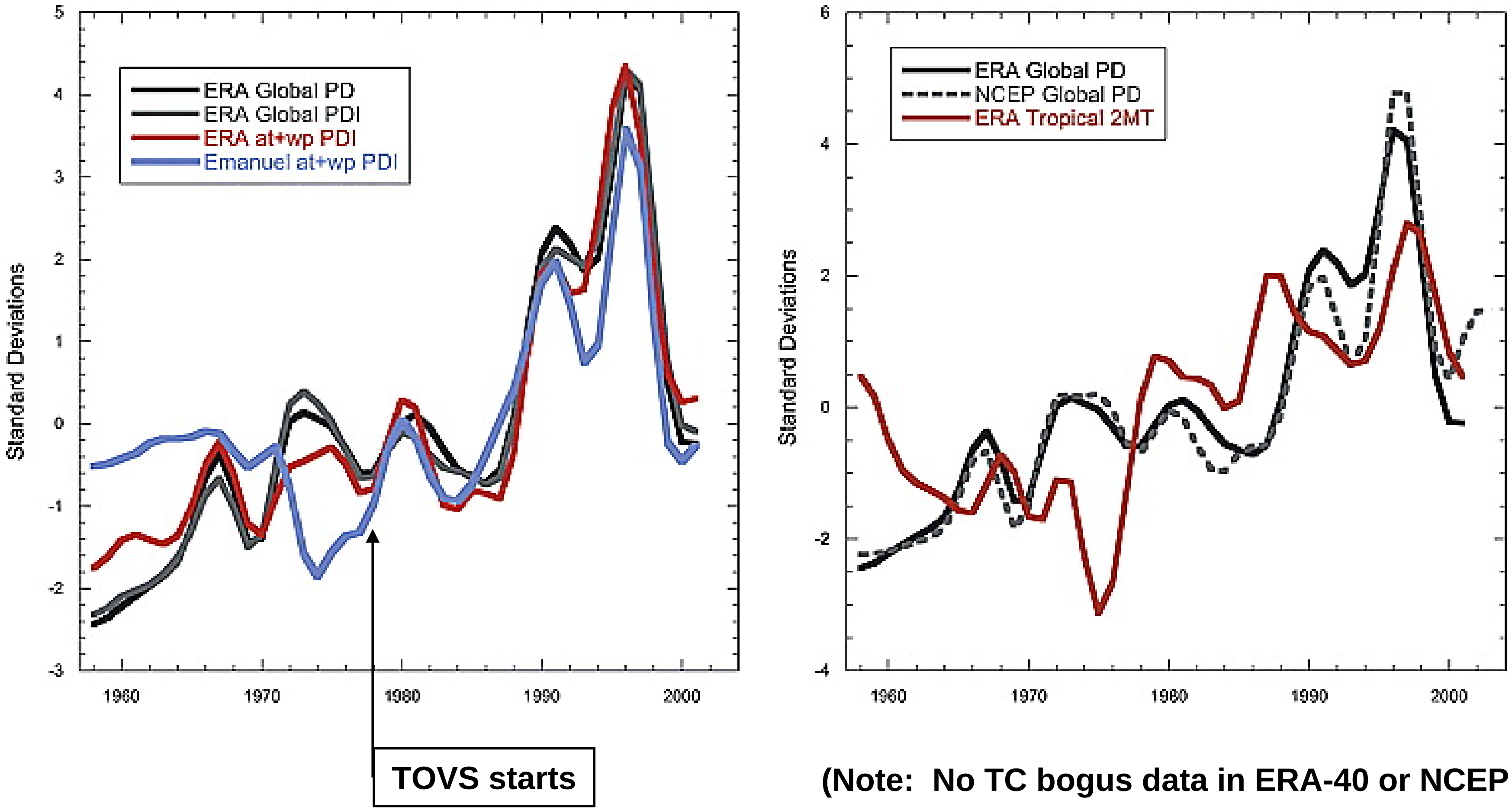
(from Richard Allan)

Climate variability and trends

Detection of tropical cyclones



Debate on the trends in tropical cyclone intensity



(Note: No TC bogus data in ERA-40 or NCEP !)

Ryan L. Sriver and Matthew Huber, 2006, Geophysical Research Letters

"Low frequency variability in globally integrated tropical cyclone power dissipation"

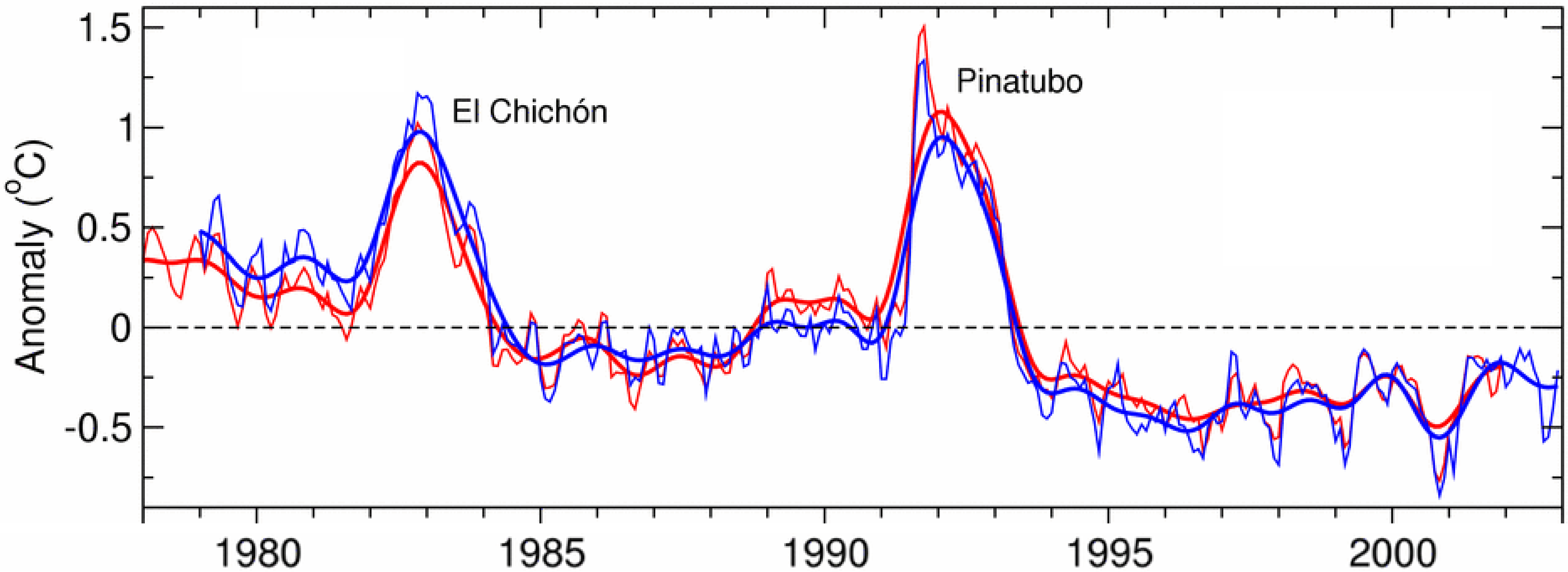
- **R. N. Maue and R. E. Hart, 2007, comment to the previous**
- **Ryan L. Sriver and Matthew Huber, 2007, Reply to comment**

Observations only ←→ Reanalysis

….
One of the most important and difficult to characterize sources of long-term drift in the data is due to the evolution of the local observing time due to slow changes in the orbital parameters of each NOAA platform, which can alias diurnal temperature changes into the long-term time series. To account for this effect, we have constructed monthly diurnal climatologies of MSU Channel 2 brightness temperature using the hourly output of a general circulation model as input for a microwave radiative transfer model.
….

(Carl A. Mears et al: Correcting the MSU Middle TroposphericTemperature for Diurnal Drifts, Remote sensing Systems)

Trend and variability in lower stratospheric temperature



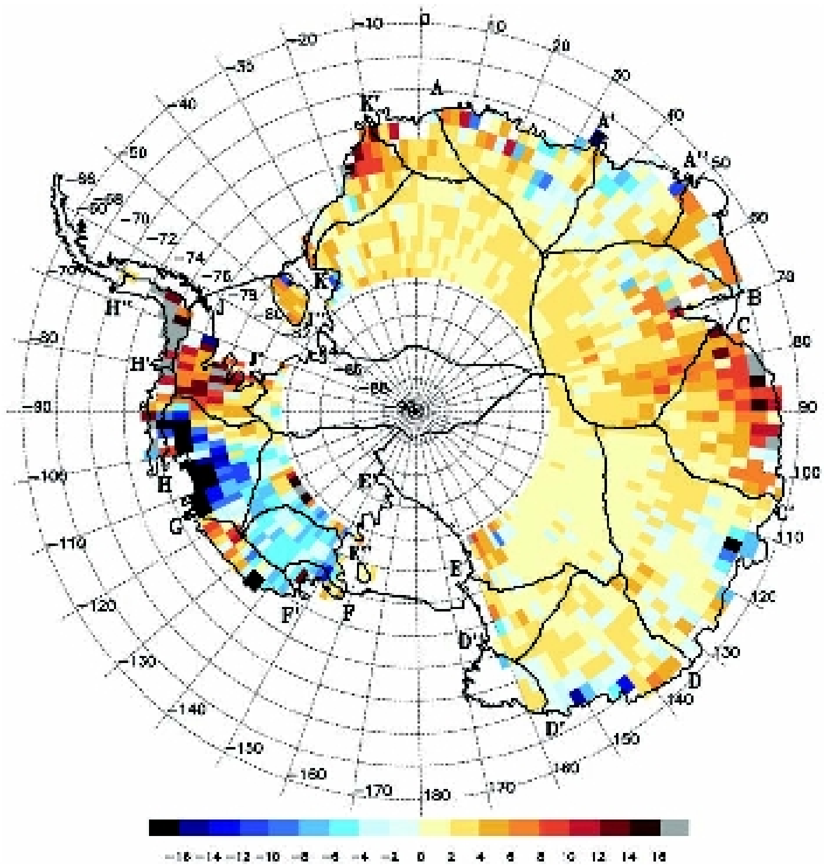
MSU-4 data analyzed by Mears et al. (2003)

ERA-40 equivalent from Ben Santer

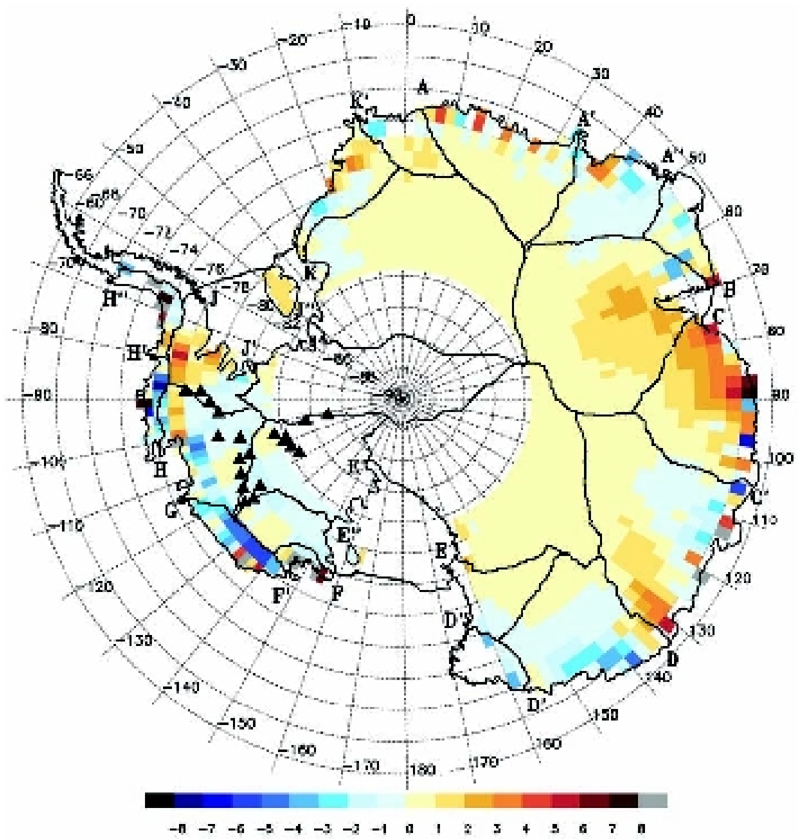
Linear trend:	**MSU-4**	**- 0.39°C/decade**
	ERA-40	**- 0.30°C/decade**
	NCEP	**- 0.82°C/decade**

Satellite radar altimeter 1992-2003

(Davis et al. Science 2005 Vol 308 No. 5730)

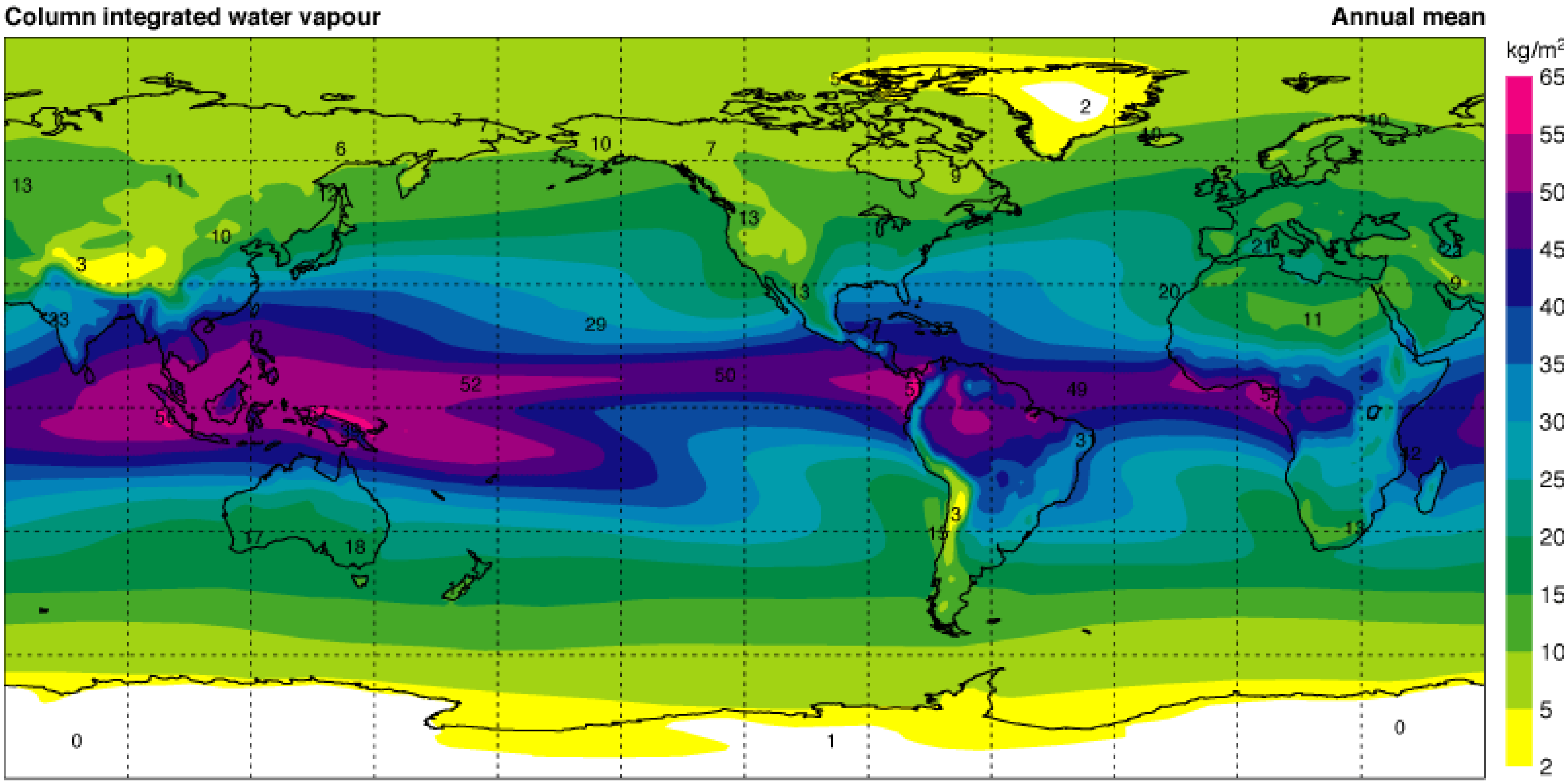


Surface elevation change rate (cm per year):
1992 → 2003



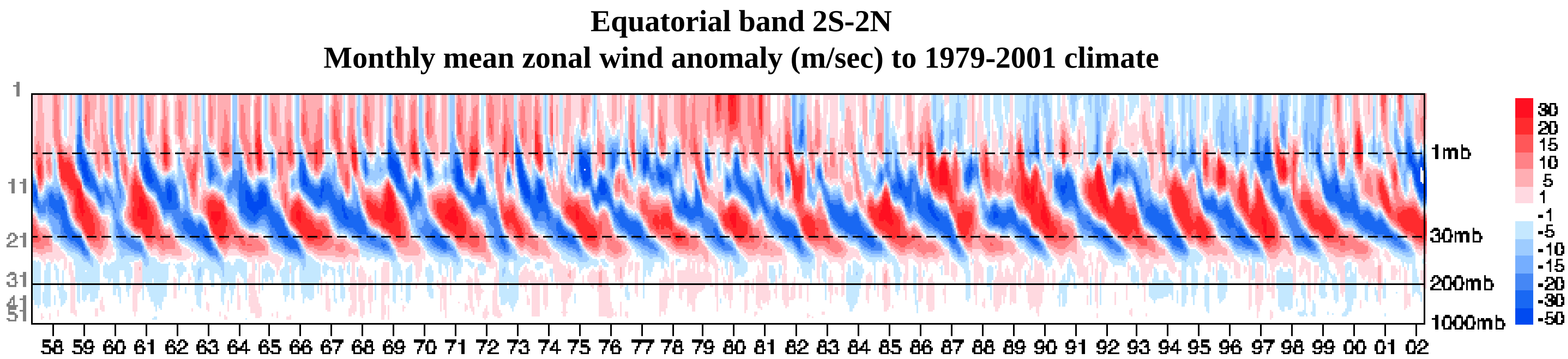
Precipitation change (cm of snow per year):
ERA-40 (1992-2001)+ ECMWF OP (2002-03)

ERA-40 Atlas 1979-2001



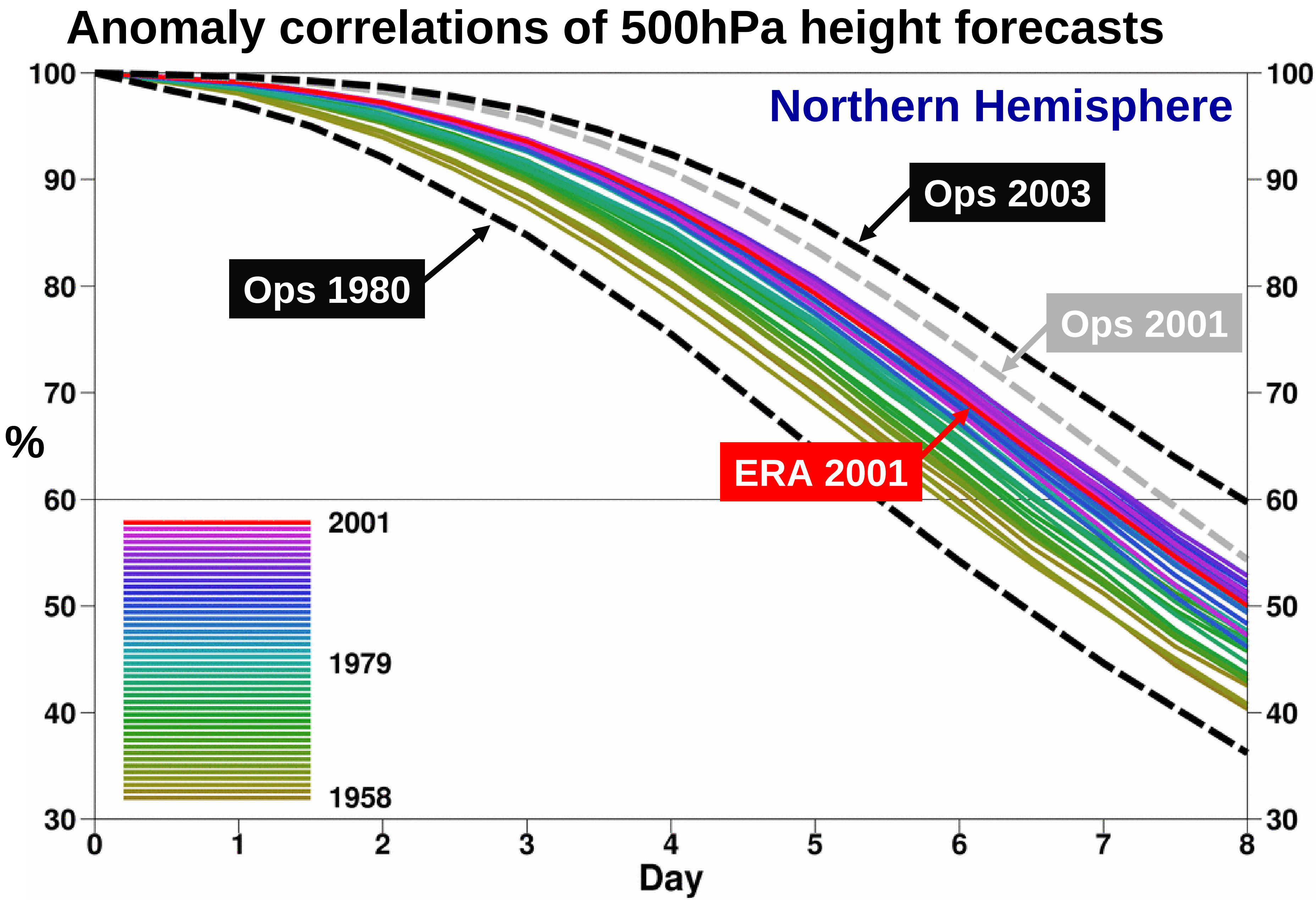
http://www.ecmwf.int/research/era/ERA-40_Atlas/docs/index.html

Quasi-Biennial Oscillation



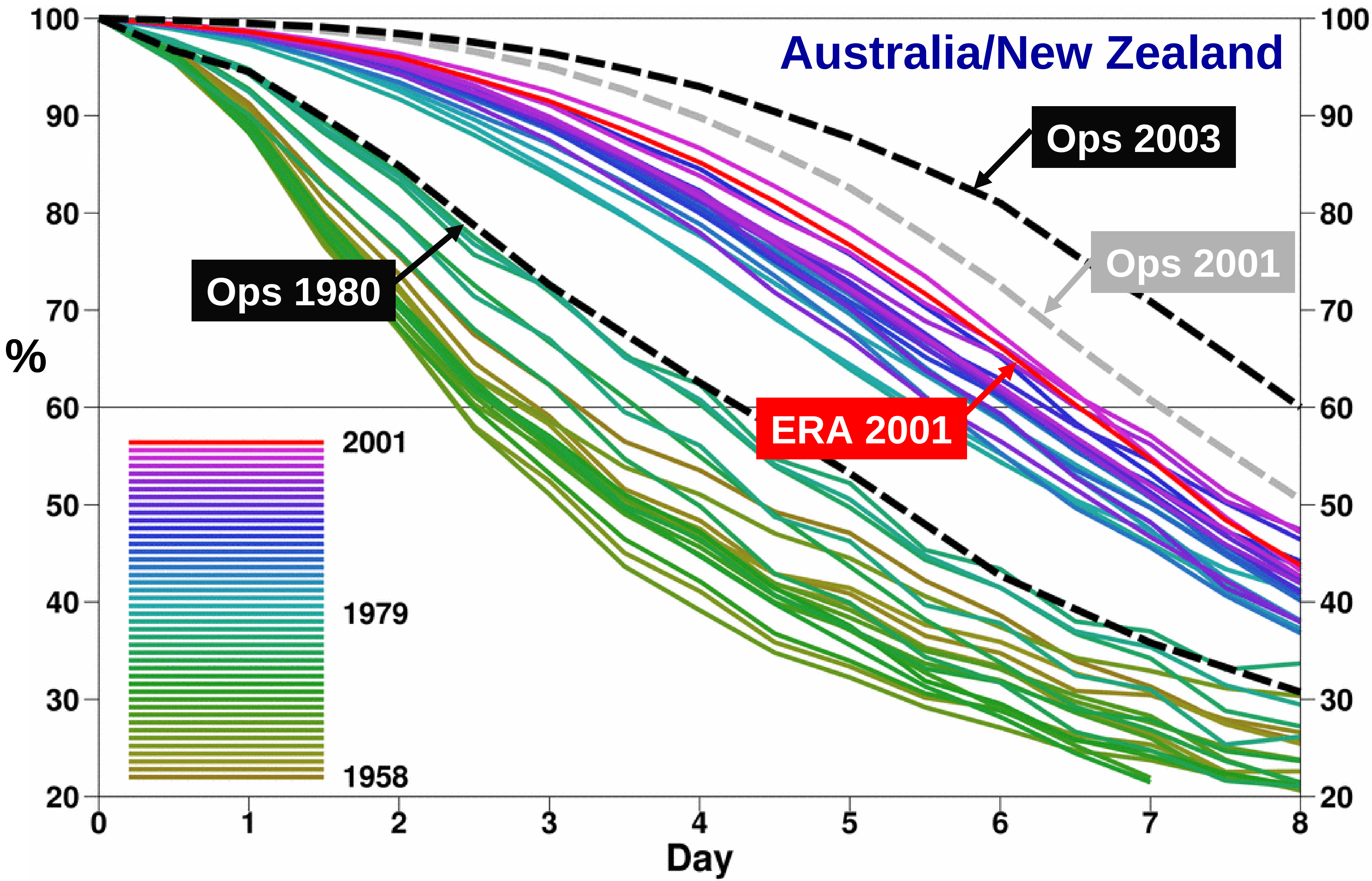
FORECAST PERFORMANCE

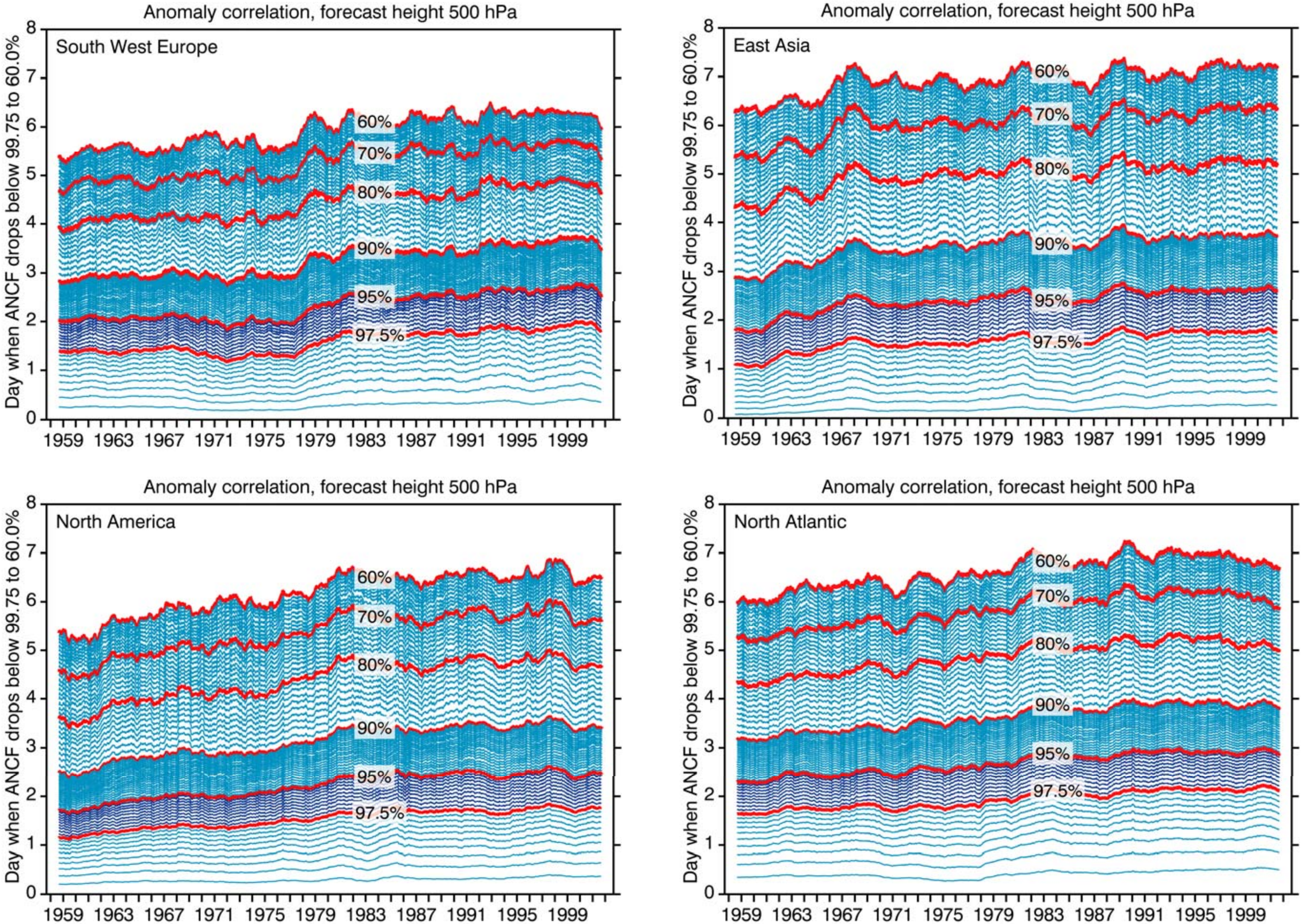
1957-2002



Anomaly correlations of 500hPa height forecasts
Northern Hemisphere
Ops 2003
Ops 1980
Ops 2001
ERA 2001
2001
1979
1958
%
Day
100
90
80
70
60
50
40
30
0
1
2
3
4
5
6
7
8

Anomaly correlations of 500hPa height forecasts




Anomaly correlation, forecast height 500 hPa
South West Europe
East Asia
North America
North Atlantic
Day when ANCF drops below 99.75 to 60.0%
60%
70%
80%
90%
95%
97.5%
0
1
2
3
4
5
6
7
8
1959
1963
1967
1971
1975
1979
1983
1987
1991
1995
1999

ERA-Interim 1989 → to continue as CDAS →

ERA-40 1957-2002

- Data-assimilation system

  T159L60 → T255L60 / 12 hour 4D-Var

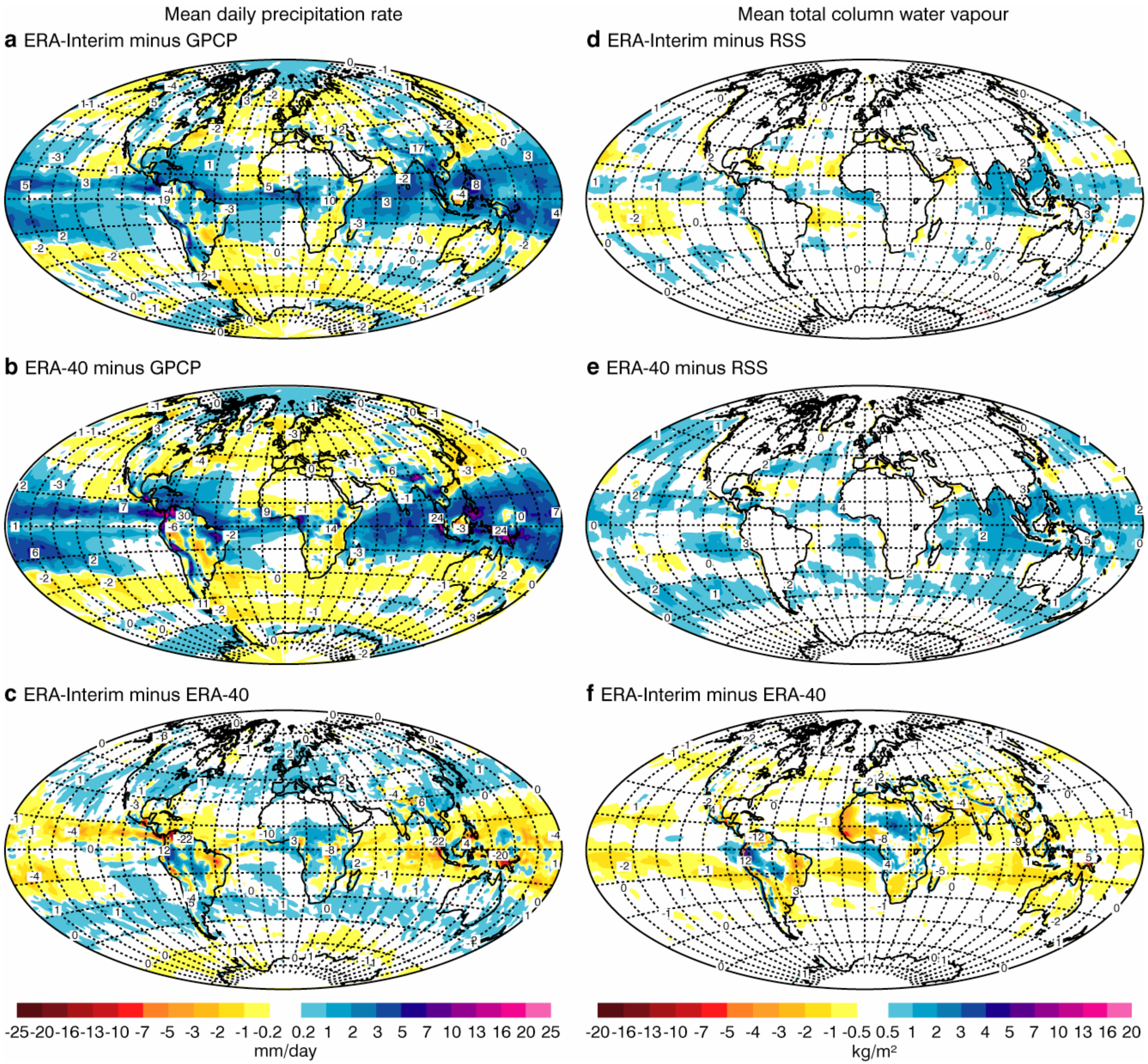
  New humidity analysis and improved model physics
- Satellite level-1c radiances

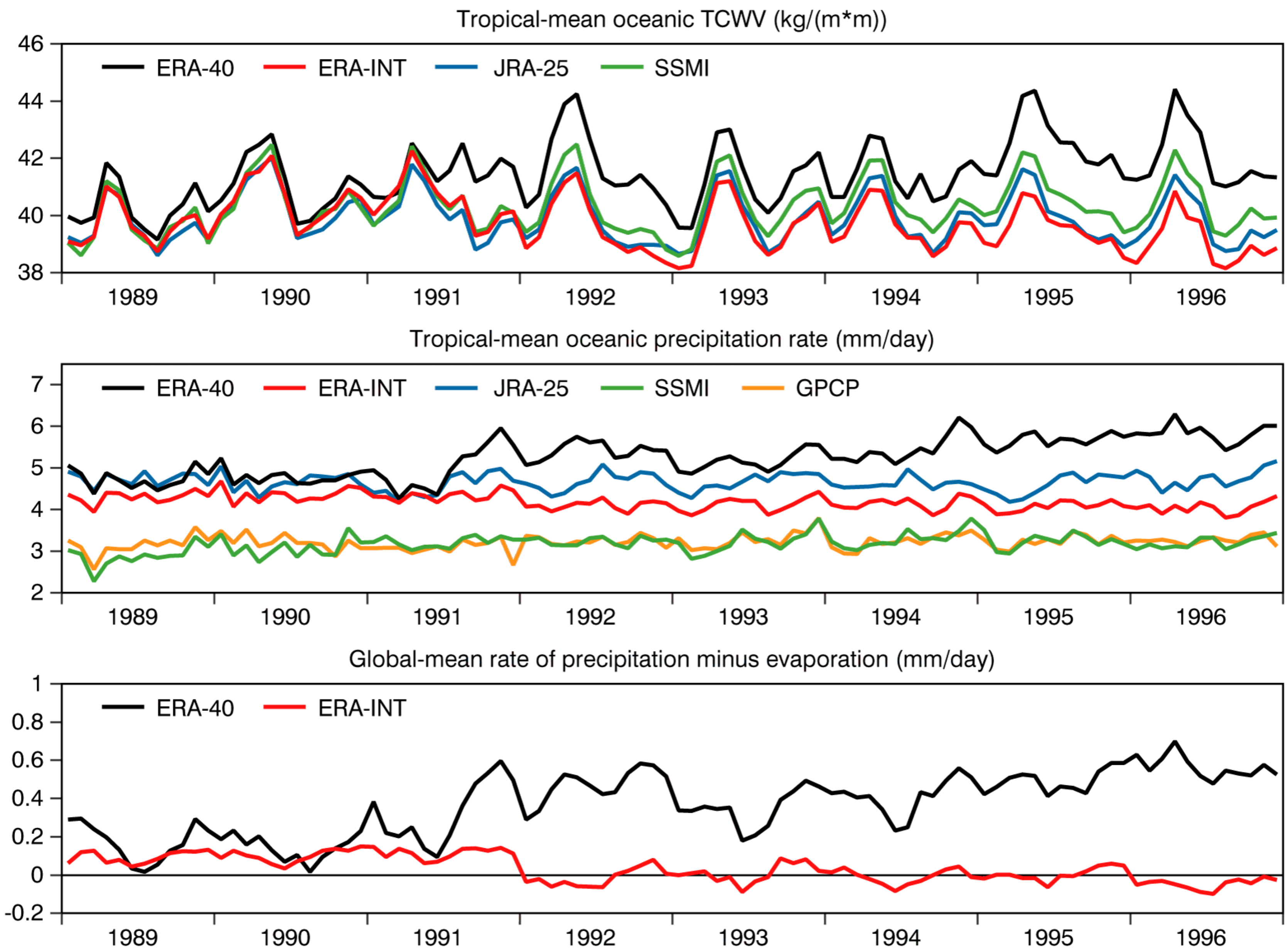
  Better RTTOV and improved use of radiances especially IR and AMSU

  Assimilation of rain affected radiances through 1D-Var

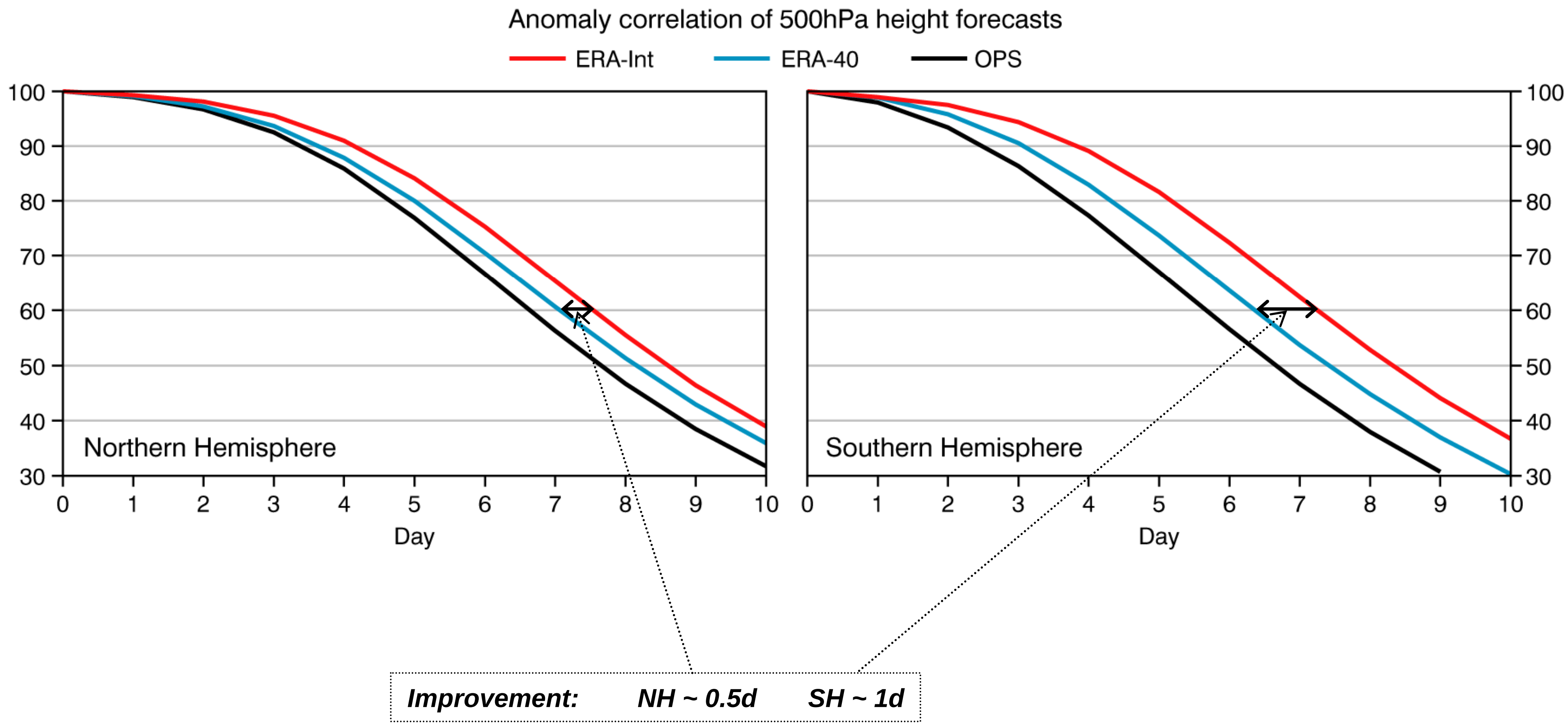
  Variational bias correction
- Improved use of radiosondes

  Bias correction and homogenization based on ERA-40
- Correction of SHIP/ SYNOP surface pressure biases
- Use of reprocessed
  - Meteosat winds
  - GPS-RO data CHAMP / UCAR 2001 →, GRACE and COSMIC
  - GOME O3 profiles 1995 →
- New set of Altimeter wave height data 1991→

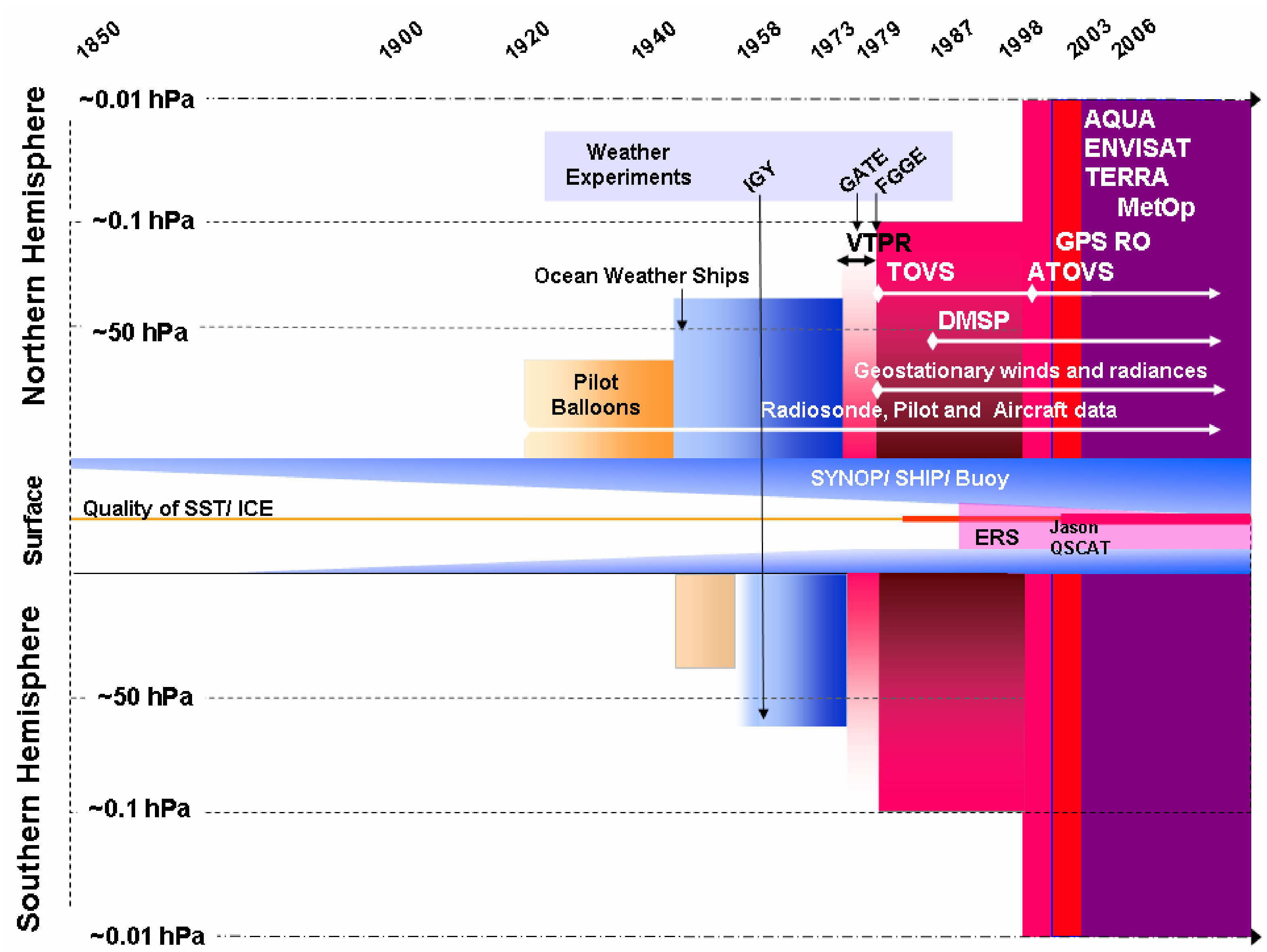

Mean daily precipitation rate
Mean total column water vapour
a ERA-Interim minus GPCP
b ERA-40 minus GPCP
c ERA-Interim minus ERA-40
d ERA-Interim minus RSS
e ERA-40 minus RSS
f ERA-Interim minus ERA-40
-25 -20 -16 -13 -10 -7 -5 -3 -2 -1 -0.2 0.2 1 2 3 5 7 10 13 16 20 25
mm/day
-20 -16 -13 -10 -7 -5 -4 -3 -2 -1 -0.5 0.5 1 2 3 4 5 7 10 13 16 20
kg/m²



Tropical-mean oceanic TCWV (kg/(m*m))
46
44
42
40
38
ERA-40
ERA-INT
JRA-25
SSMI
1989
1990
1991
1992
1993
1994
1995
1996
Tropical-mean oceanic precipitation rate (mm/day)
7
6
5
4
3
2
ERA-40
ERA-INT
JRA-25
SSMI
GPCP
1989
1990
1991
1992
1993
1994
1995
1996
Global-mean rate of precipitation minus evaporation (mm/day)
1
0.8
0.6
0.4
0.2
0
-0.2
ERA-40
ERA-INT
1989
1990
1991
1992
1993
1994
1995
1996



Anomaly correlation of 500hPa height forecasts
ERA-Int
ERA-40
OPS
100
90
80
70
60
50
40
30
0
1
2
3
4
5
6
7
8
9
10
Day
Northern Hemisphere
Southern Hemisphere
Improvement: NH ~ 0.5d SH ~ 1d



(Uppala S, A Simmons, D Dee, P Kållberg and J-N Thépaut, "Atmospheric reanalyses and climate variations" in the book "Climate variability and extremes during the past 100 years", Advances in Global Change Research, Springer (2007, in press, Eds. Brönnimann, S., J. Luterbacher, T. Ewen, H. F. Diaz, R. Stolarksi, and U. Neu)

ERA-75?

ERA-Interim

- Could start ~ 2011 depending on resources
- ~ 1938 → 2013 and continue as CDAS
- 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

  Coupled atmospheric-ocean reanalysis?

Summary

- Reanalyses have, in part, reached the level required for climate studies
- Satellite data have an increasing role in reanalysis
- The composite observing system improves over time
- Due to the use of satellite data reanalysis has substantially better and more uniform quality after 1978 especially over the Southern Hemisphere
- Reanalysis is seen as an iterative process, where improvements in the data assimilation/ bias adjustment/ increasing resolution bring new qualities to reanalyses and therefore to the applications
- Reprocessing/ recalibration of satellite data improves reanalysis quality and should also be done iteratively
- Improving the homogeneity of satellite data record is important
- Satellite missions with long period and overlapping important for reanalyses