
ERA-Interim data products and plans for future ECMWF reanalyses

Dick Dee

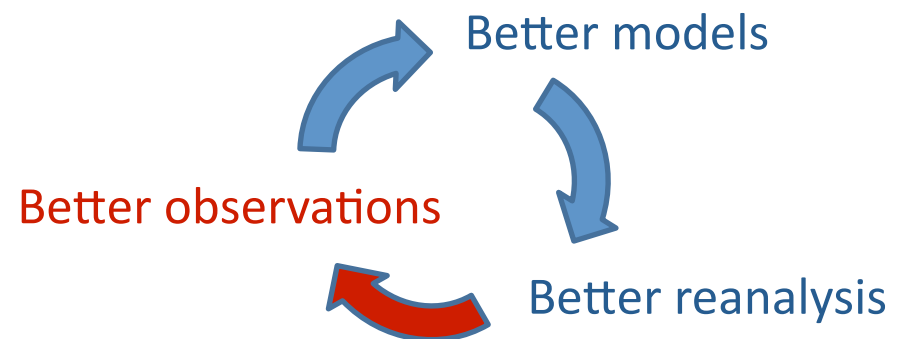
Topics:

- Successive generations
- ERA-Interim performance
- Bias: Progress and limitations
- Climate monitoring
- Stratospheric aspects
- ERA-Interim extension to 1979
- The ERA-CLIM project

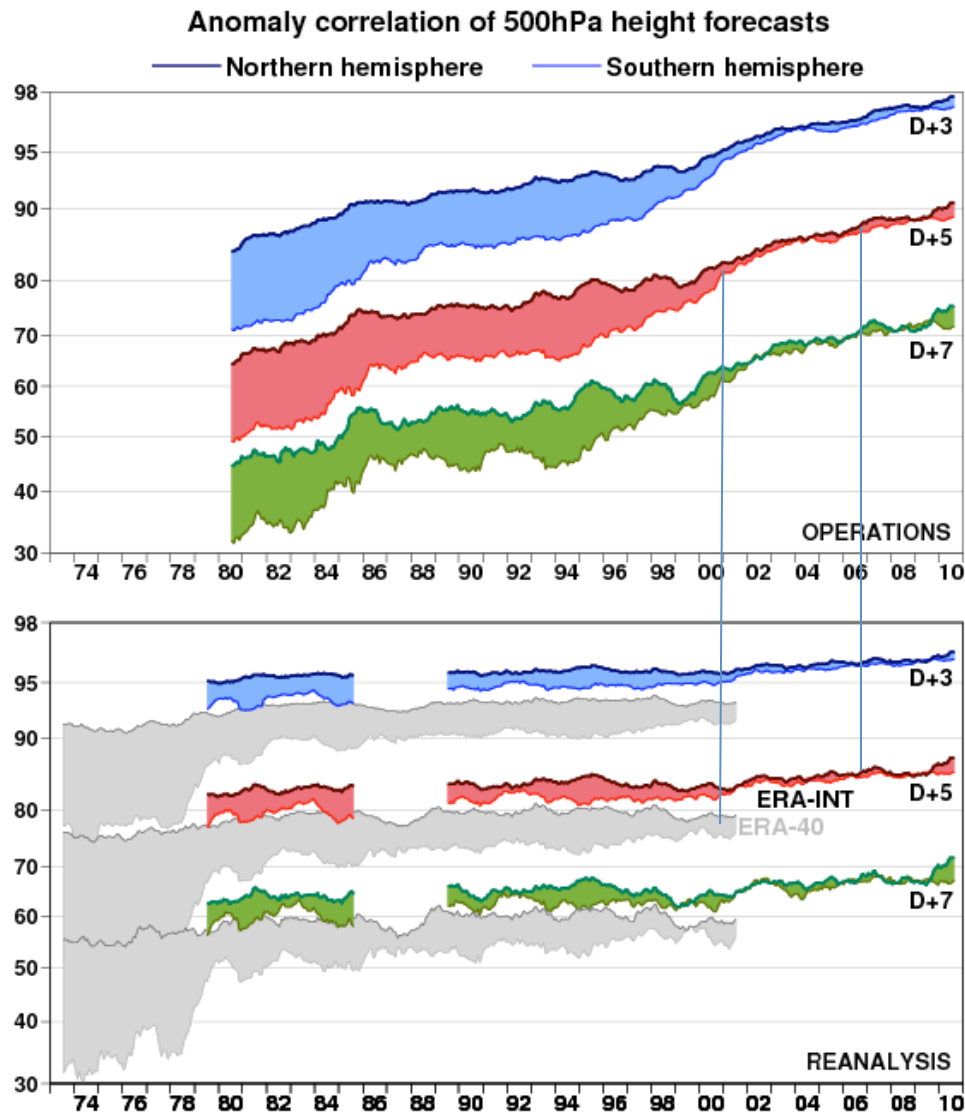
ECMWF atmospheric reanalysis projects

FGGE → ERA-15 → ERA-40 → ERA-Interim → ERA-CLIM

- **ERA-40** (1957-2002):
Very large user base; science and downstream applications
- **ERA-Interim** (from 1979 onward):
Near-real time updates; better trends; better data services
- **ERA-CLIM**: An EU project to prepare the next generation reanalysis
Longer period; higher resolution; better input data; uncertainty information



ERA-Interim



ECMWF forecasts: 1980 – 2010

Changes in skill are due to:

- improvements in modelling and data assimilation
- evolution of the observing system
- atmospheric predictability

ERA-Interim: 1979 – 2010

- uses a 2006 forecast system
- ERA-40 used a 2001 system
- forecast quality is more uniform
- improvements in modelling and data assimilation outweigh those due to the observing system

Access to reanalysis data at www.ecmwf.int/research/era

Public data server:
~7000 registered users

Data products are
updated monthly

By summer 2011:

- Full resolution
- Data on model levels
- Dates from 1979

Climate change
monitoring tools in
development


The screenshot shows the ECMWF website interface for the ERA Project. At the top, there is a navigation bar with links for Home, Your Room, Login, Contact, Feedback, Site Map, and a search box. Below this are several menu categories: About Us, Products, Services, Research, Publications, and News&Events. The main content area is titled "ERA Project" and includes a sidebar with links to Research (Demeter, ERA, IFS, Monthly Forecasting, Seasonal, SMDA, Physical Aspects), Areas (Reanalysis at ECMWF, ERA-Interim, ERA-40, ERA-15, Publications), and ERA Project (Area Admin, New Item). The main content area features "ERA Areas" with sub-sections for Climate monitoring, ERA Interim, ERA-40, ERA-15, and Publications. A green box highlights "Product availability as of 2 September 2010: ERA-Interim data are now available for dates from 1 January 1989 to 30 June 2010." Below this, there is a section for "NEW: Climate monitoring products" which includes a time series plot of global 2m-temperature anomalies and a description of the data.

Product availability as of 2 September 2010:
ERA-Interim data are now available for dates from 1 January 1989 to 30 June 2010.


NEW: Climate monitoring products

Time series of global 2m-temperature anomalies, and many other [climate indicators](#) produced from ERA-Interim and ERA-40 monthly data. Plots are updated monthly. The most recent two months of ERA-Interim data shown are provisional and therefore subject to change.

Time series of monthly averaged products



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Single-level accumulated forecast parameters

Parameter ▲▼▶

Total precipitation

- Total precipitation
- Evaporation
- Precipitation minus evaporation
- Surface thermal radiation (upward)
- Surface thermal radiation (downward)
- Surface solar radiation (upward)
- Surface solar radiation (downward)
- Surface sensible heat flux
- Surface latent heat flux
- TOA thermal radiation (net)
- TOA solar radiation (net)

Which ▲▼▶

Anomaly

Area ▲▼▶

20S-20N

Period ▲▼▶

197901-201012

0.3

0

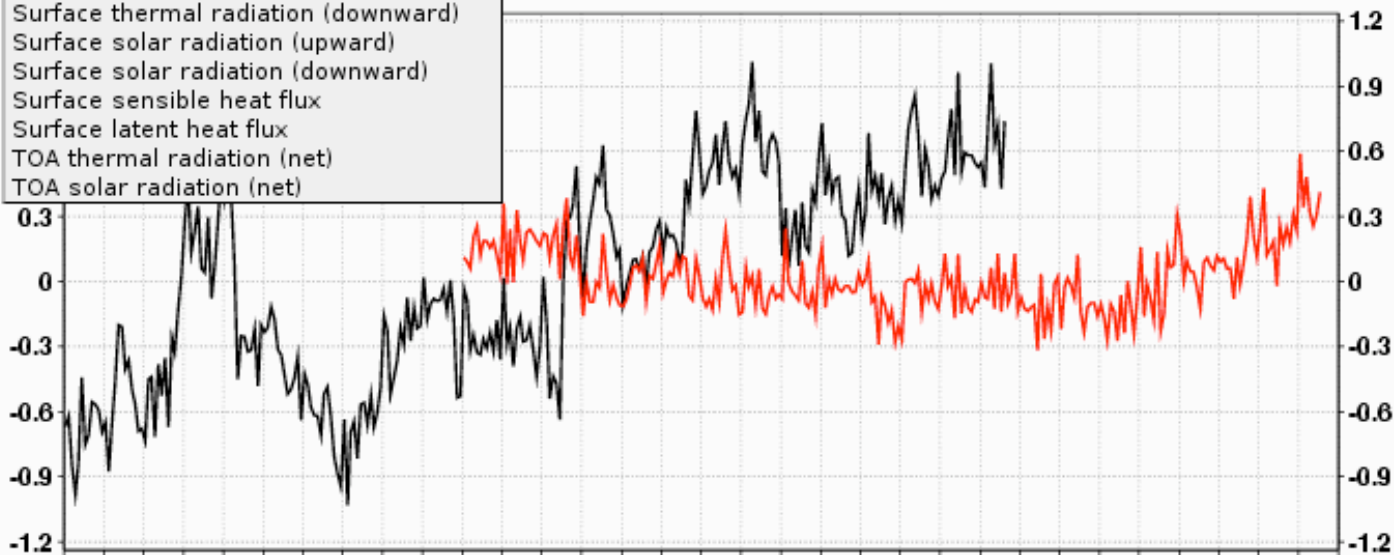
-0.3

-0.6

-0.9

-1.2

*-1) 20S-20N



1.2

0.9

0.6

0.3

0

-0.3

-0.6

-0.9

-1.2

Your Room

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[Parameter](#)


[Which](#)

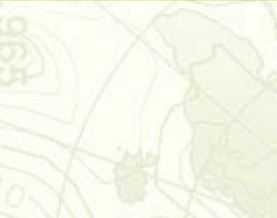
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Parameter

Nino3.4 SST Index

North Atlantic Oscillation Index
Pacific-North America Oscillation Index
Southern Oscillation Index
Nino3.4 SST Index
Quasi-biennial Oscillation Index at 50 hPa

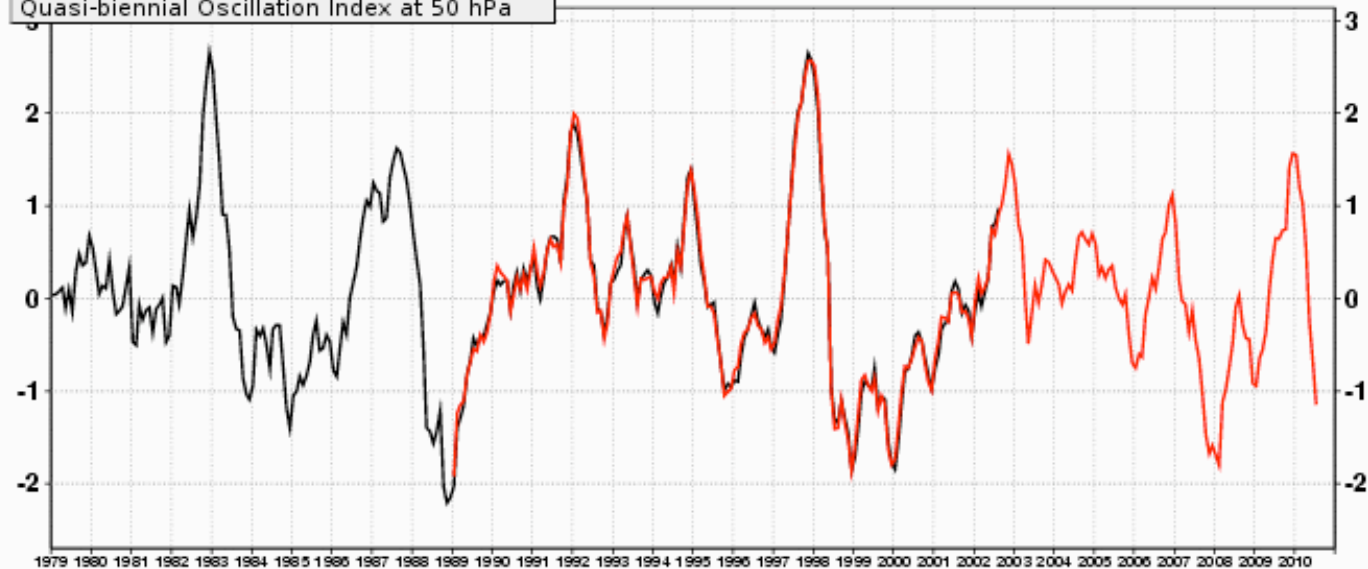
Which

Index

The entire Globe

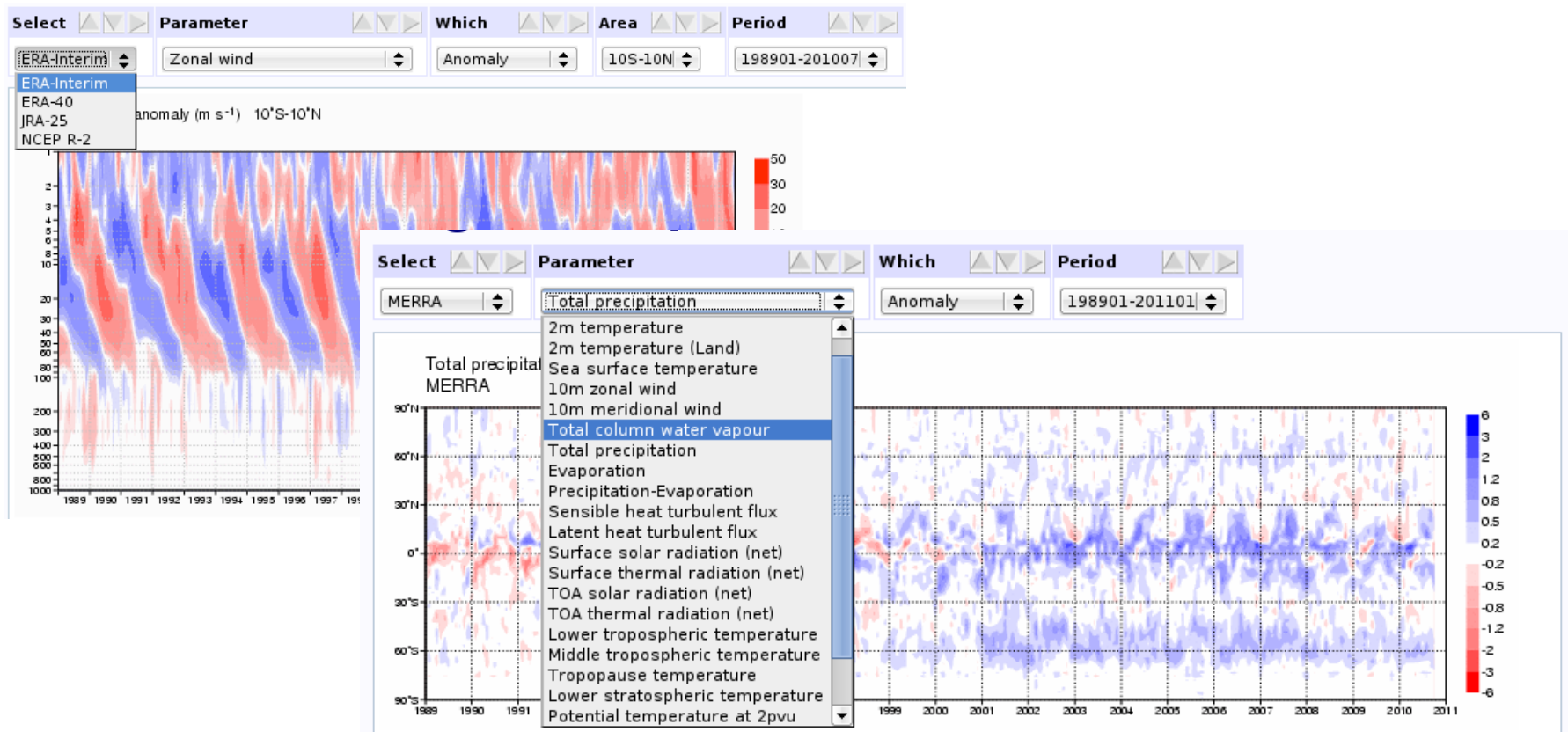
Period

197901-201012



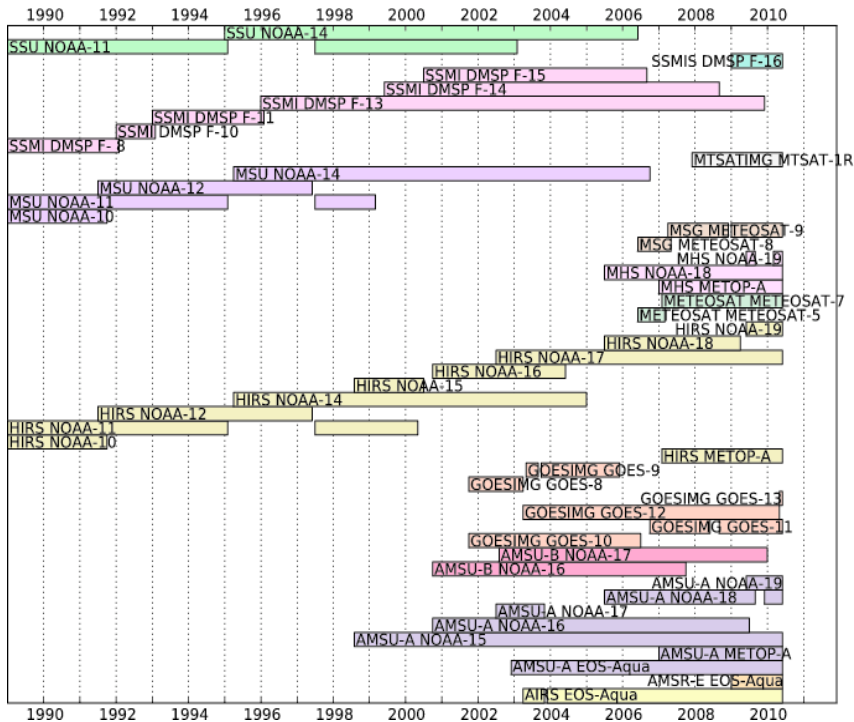
Additional climate monitoring products in development

- Two-dimensional time series (height/latitude/longitude)
- Global maps of Essential Climate Variables and climate anomalies
- Comparisons with other available reanalyses (JMA, NCEP, ...)
- Comparisons with other observational products (GPCP, CCI, ...)

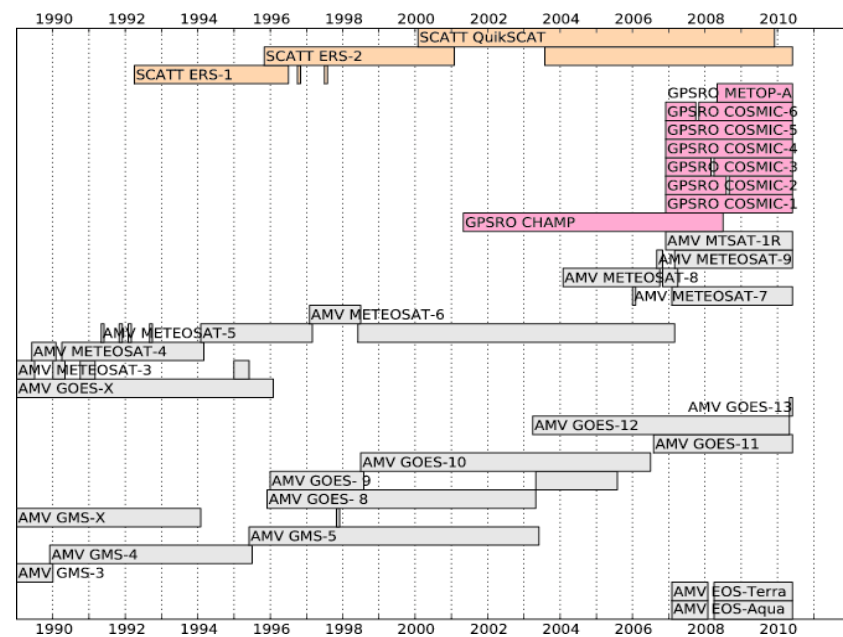


Observations used in ERA-Interim: Instruments

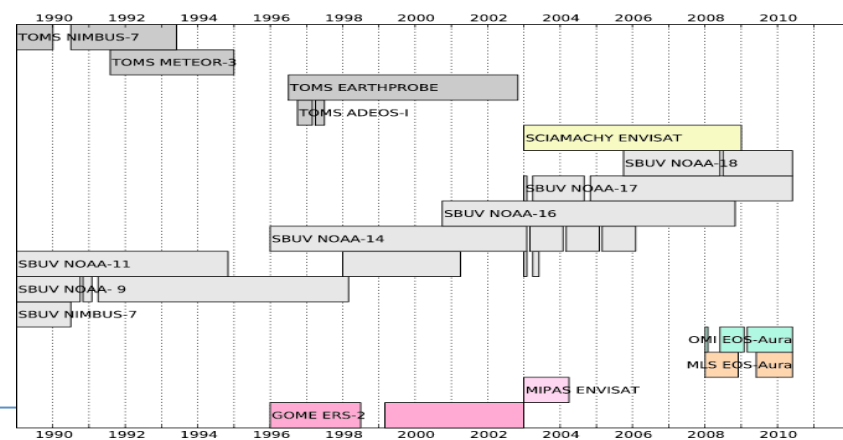
Radiances from satellites



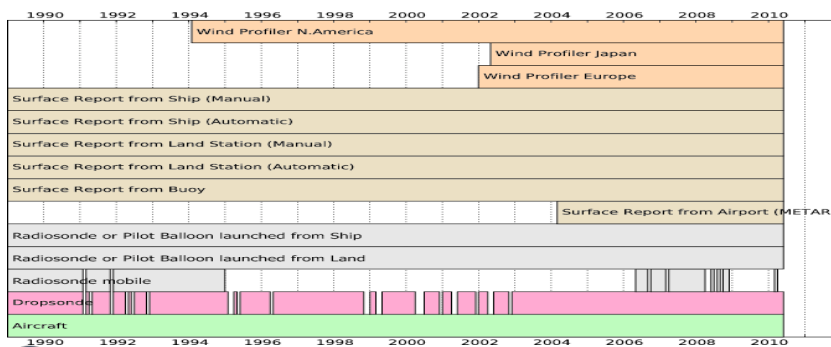
Backscatter, GPSRO, AMVs from satellites



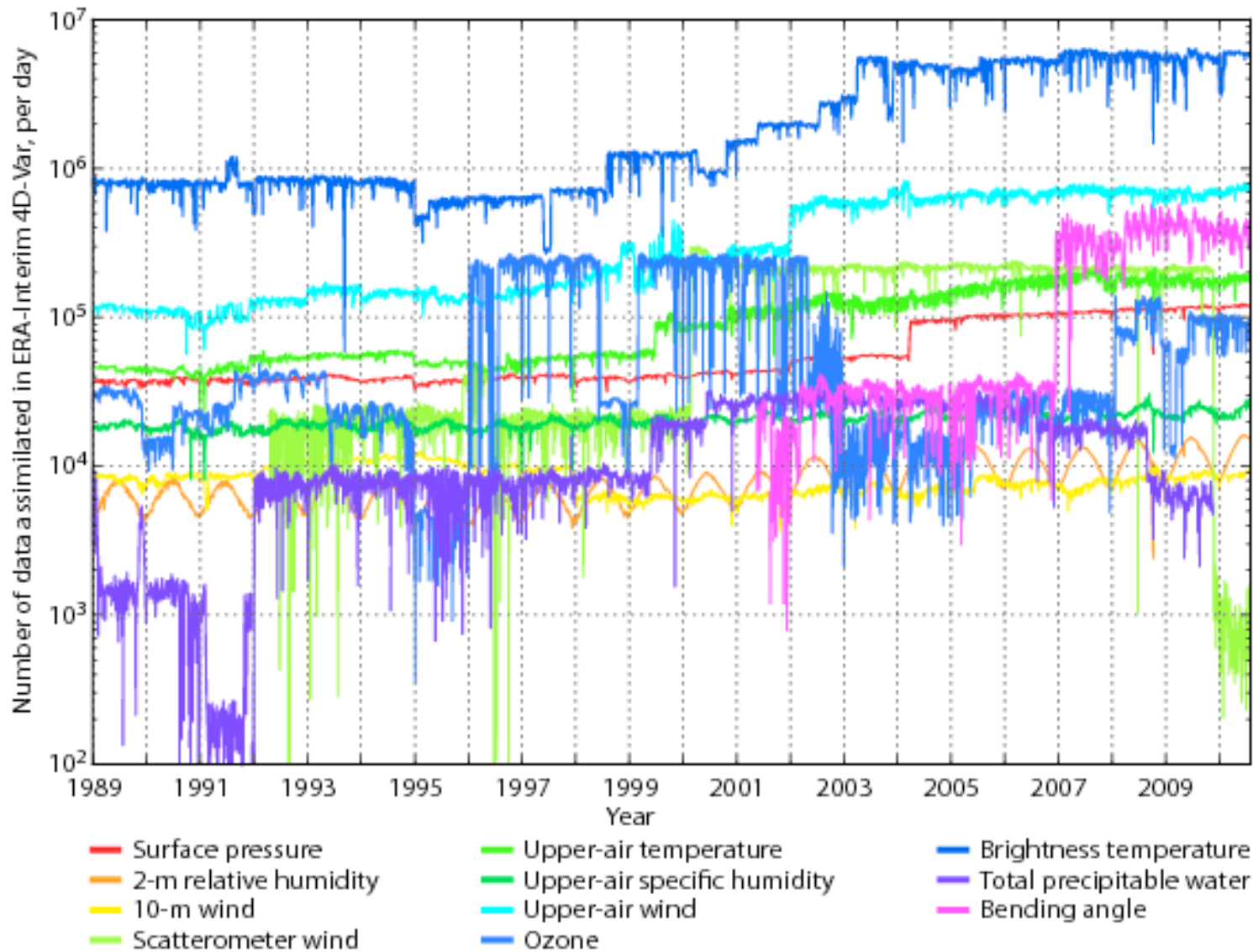
Ozone from satellites



Sondes, profilers, stations, ships, buoys, aircraft

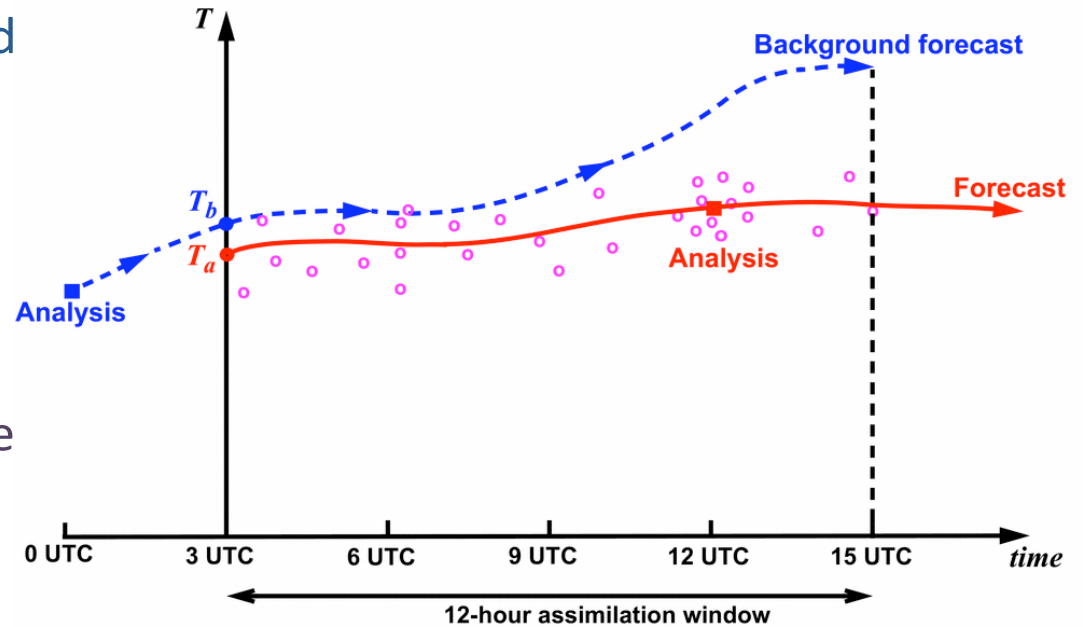


Observations used in ERA-Interim: Data counts



Variational data assimilation

- The model equations are used to fill gaps and to propagate information forward in time
- Observations are used to constrain the model state
- Additional parameters may be used to adjust for data biases



prior state constraints

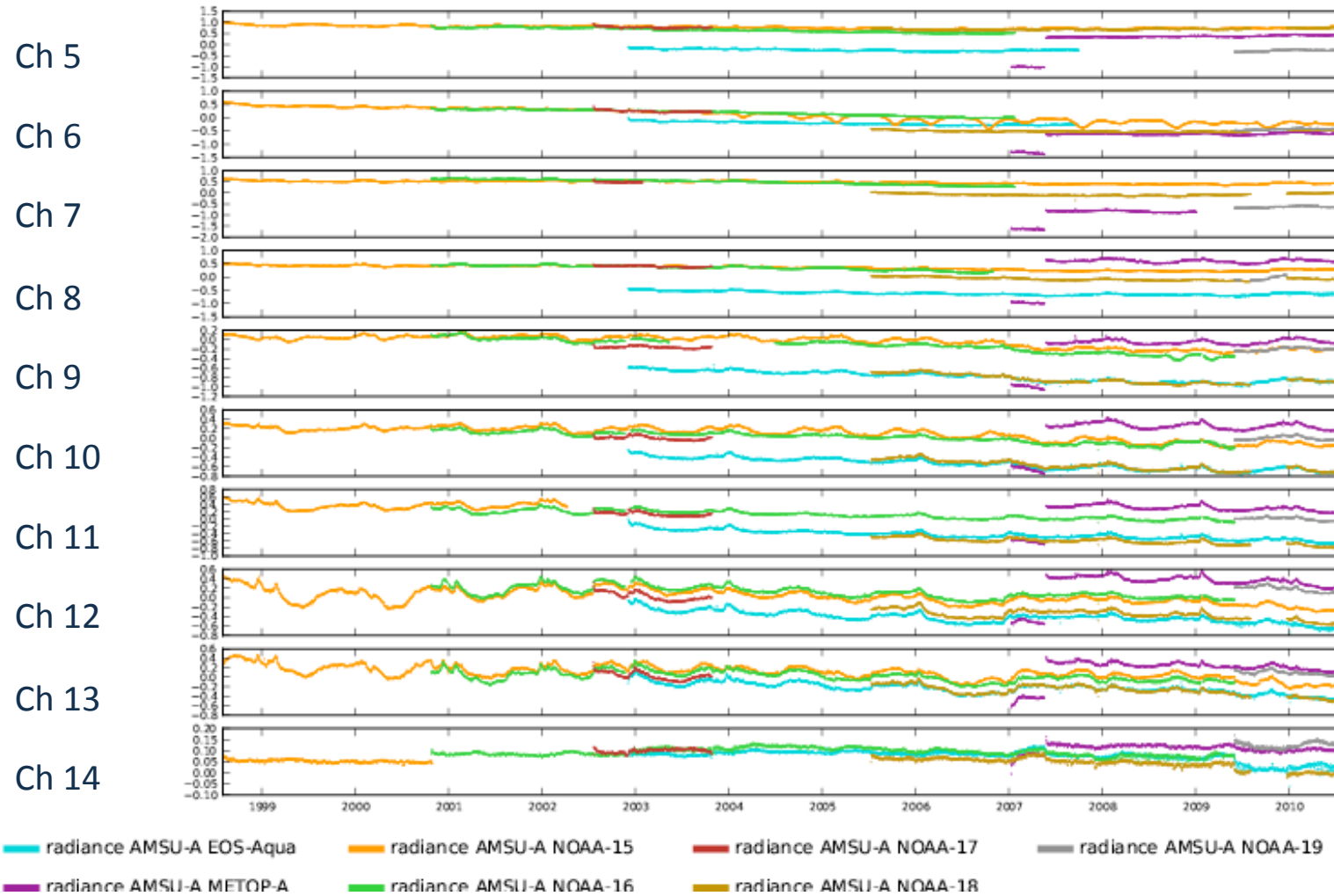
prior parameter constraints

$$\begin{aligned}
 \mathbf{J}(\mathbf{x}, \boldsymbol{\beta}) = & \underbrace{(\mathbf{x}_b - \mathbf{x})^T \mathbf{B}_x^{-1} (\mathbf{x}_b - \mathbf{x})}_{\text{prior state constraints}} + \underbrace{(\boldsymbol{\beta}_b - \boldsymbol{\beta})^T \mathbf{B}_\beta^{-1} (\boldsymbol{\beta}_b - \boldsymbol{\beta})}_{\text{prior parameter constraints}} \\
 & + \underbrace{[\mathbf{y} - \mathbf{b}_o(\mathbf{x}, \boldsymbol{\beta}) - \mathbf{h}(\mathbf{x})]^T \mathbf{R}^{-1} [\mathbf{y} - \mathbf{b}_o(\mathbf{x}, \boldsymbol{\beta}) - \mathbf{h}(\mathbf{x})]}_{\text{observational constraints}}
 \end{aligned}$$

observational constraints

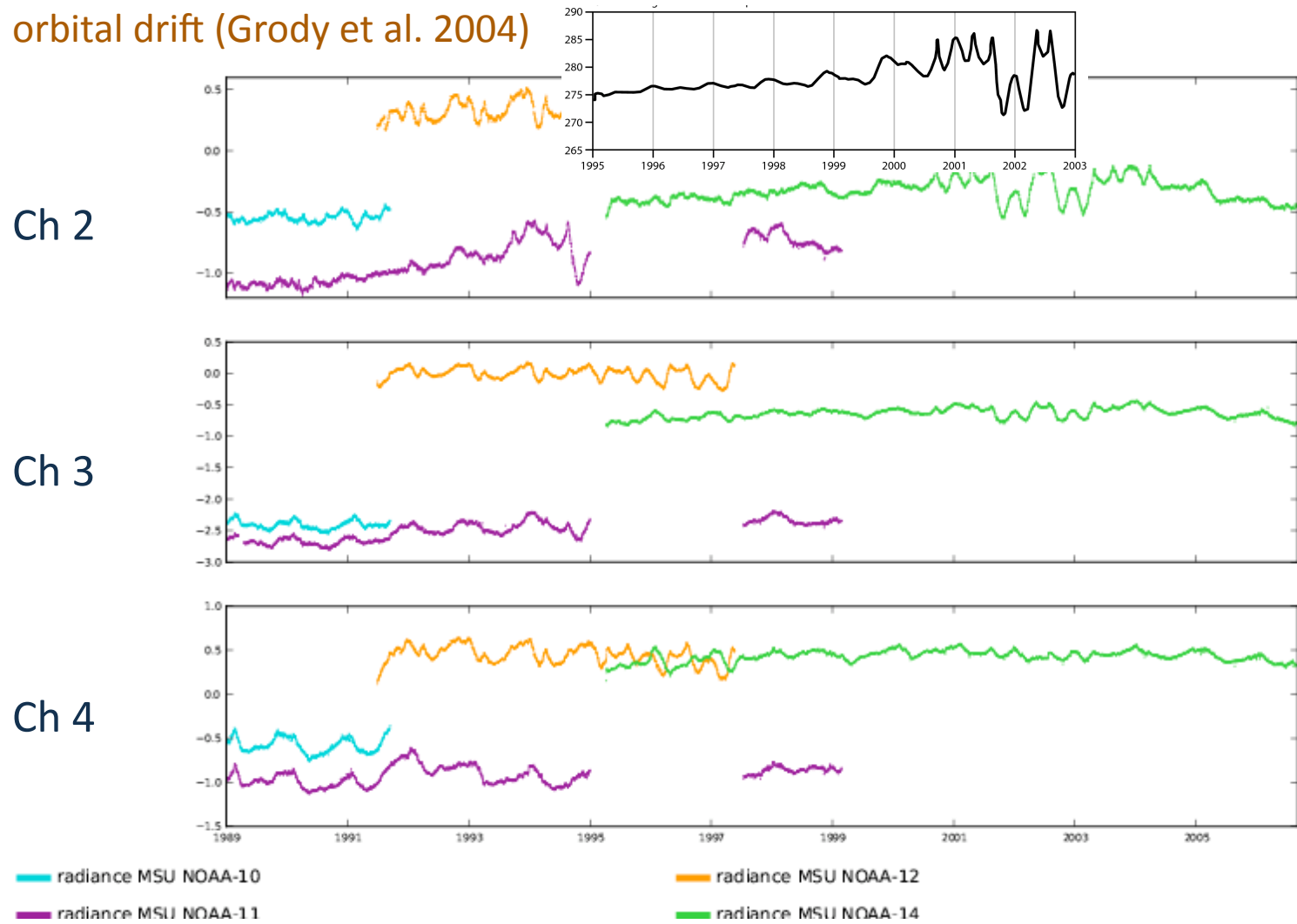
Variational bias adjustments for satellite radiances

Globally averaged bias estimates, for all AMSU-A channels used



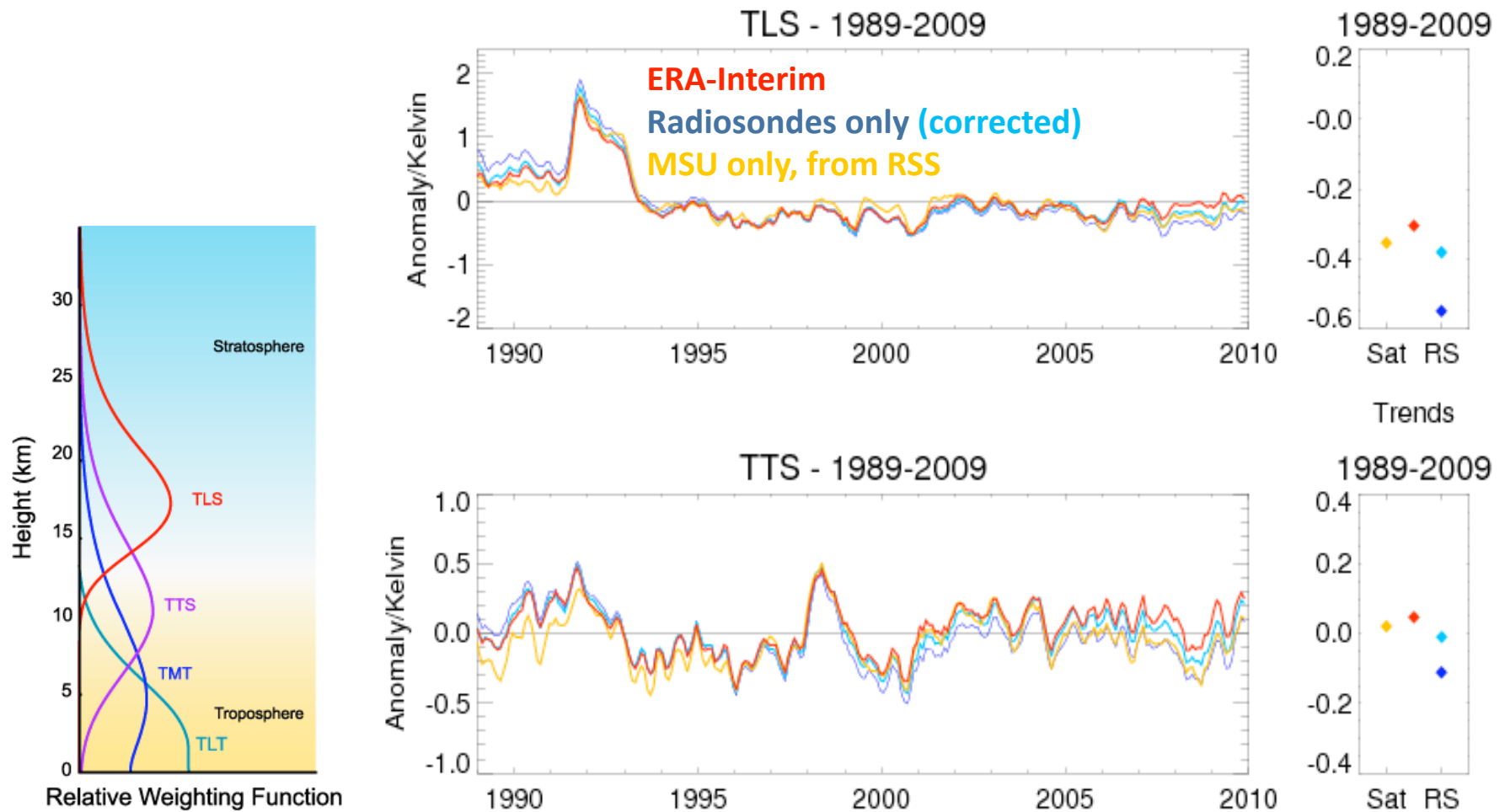
Independent verification of MSU bias estimates

Record of on-board warm-target temperature changes for NOAA-14, due to orbital drift (Grody et al. 2004)



How accurate are trend estimates from reanalysis?

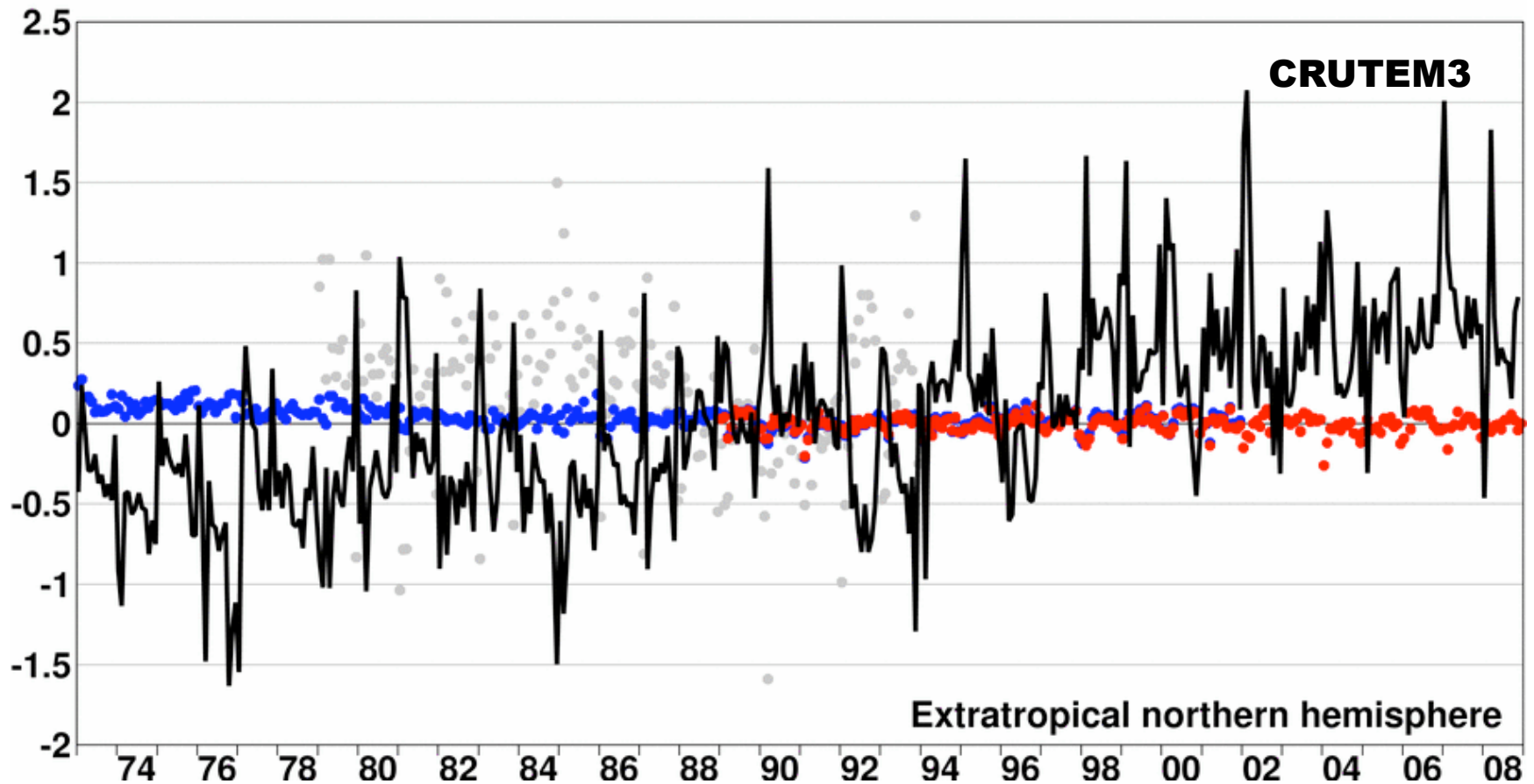
Global mean temperatures, for MSU-equivalent vertical averages:



Time series of 2m land temperature anomalies (K)

Differences of monthly values from CRUTEM3

• ERA-15 • ERA-40 • ERA-Interim

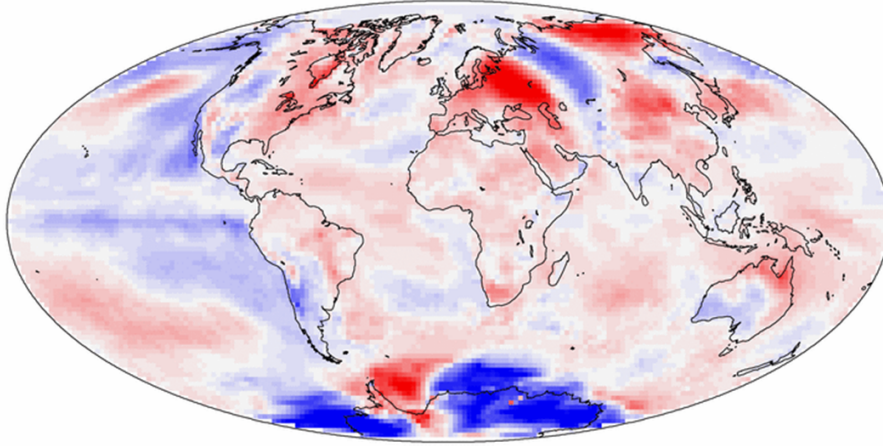


ERA sampled as CRUTEM3 (Brohan et al., 2006) following Simmons et al. (2004)

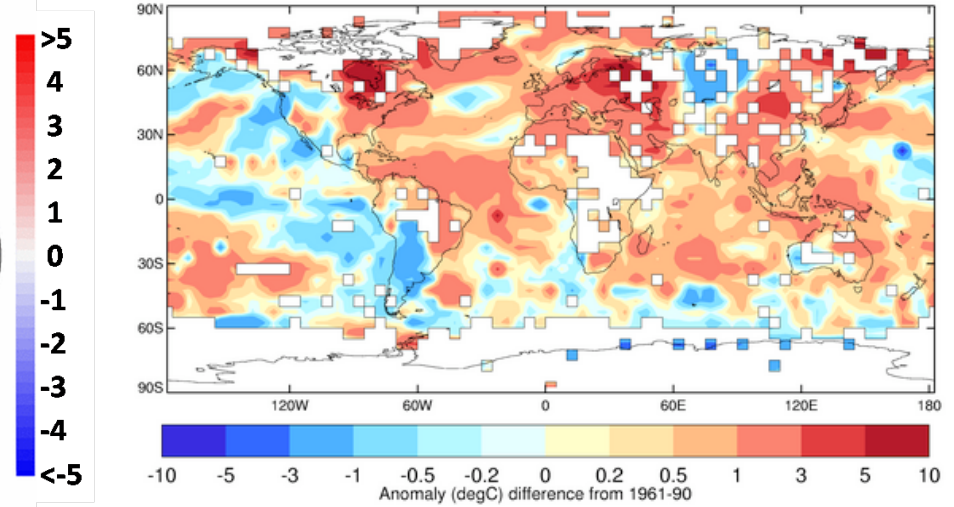
Climate change monitoring

ERA-Interim

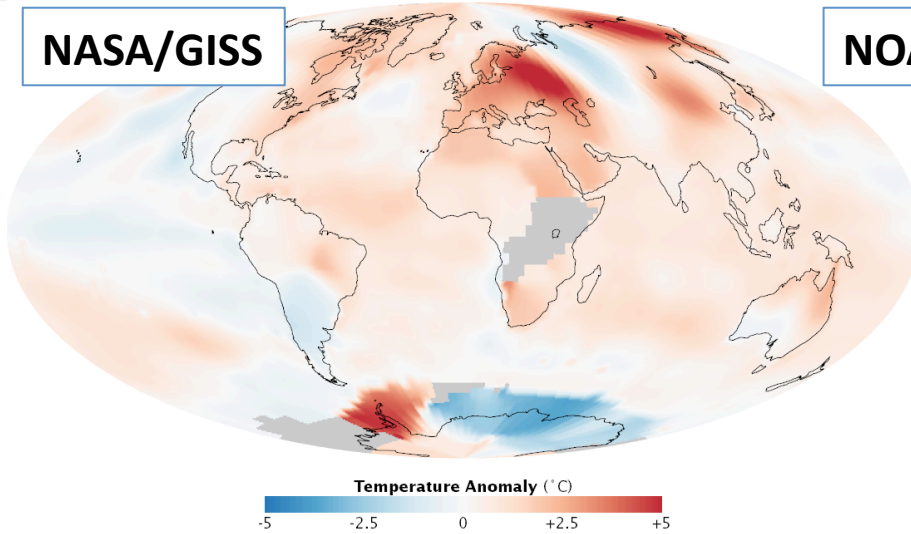
Two-metre temperature anomaly (C; relative to 1989-2009) for July 2010



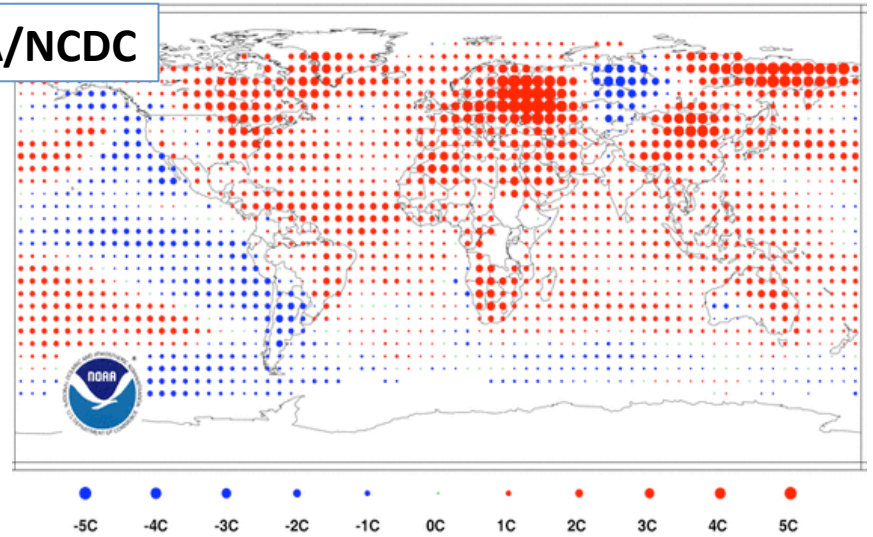
Hadley Centre



NASA/GISS

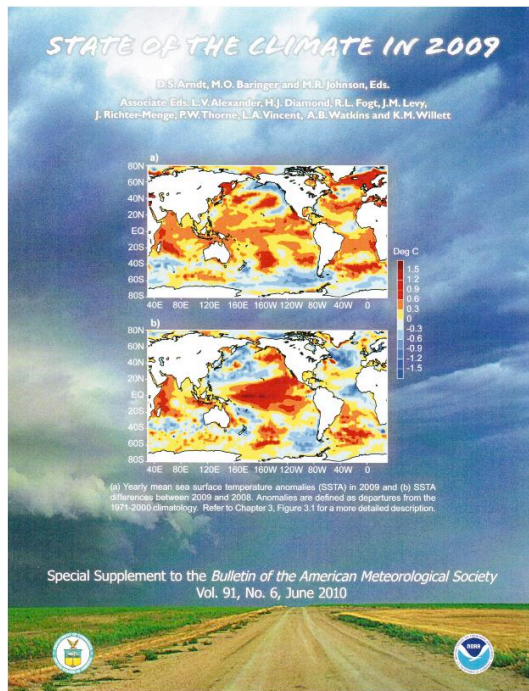


NOAA/NCDC

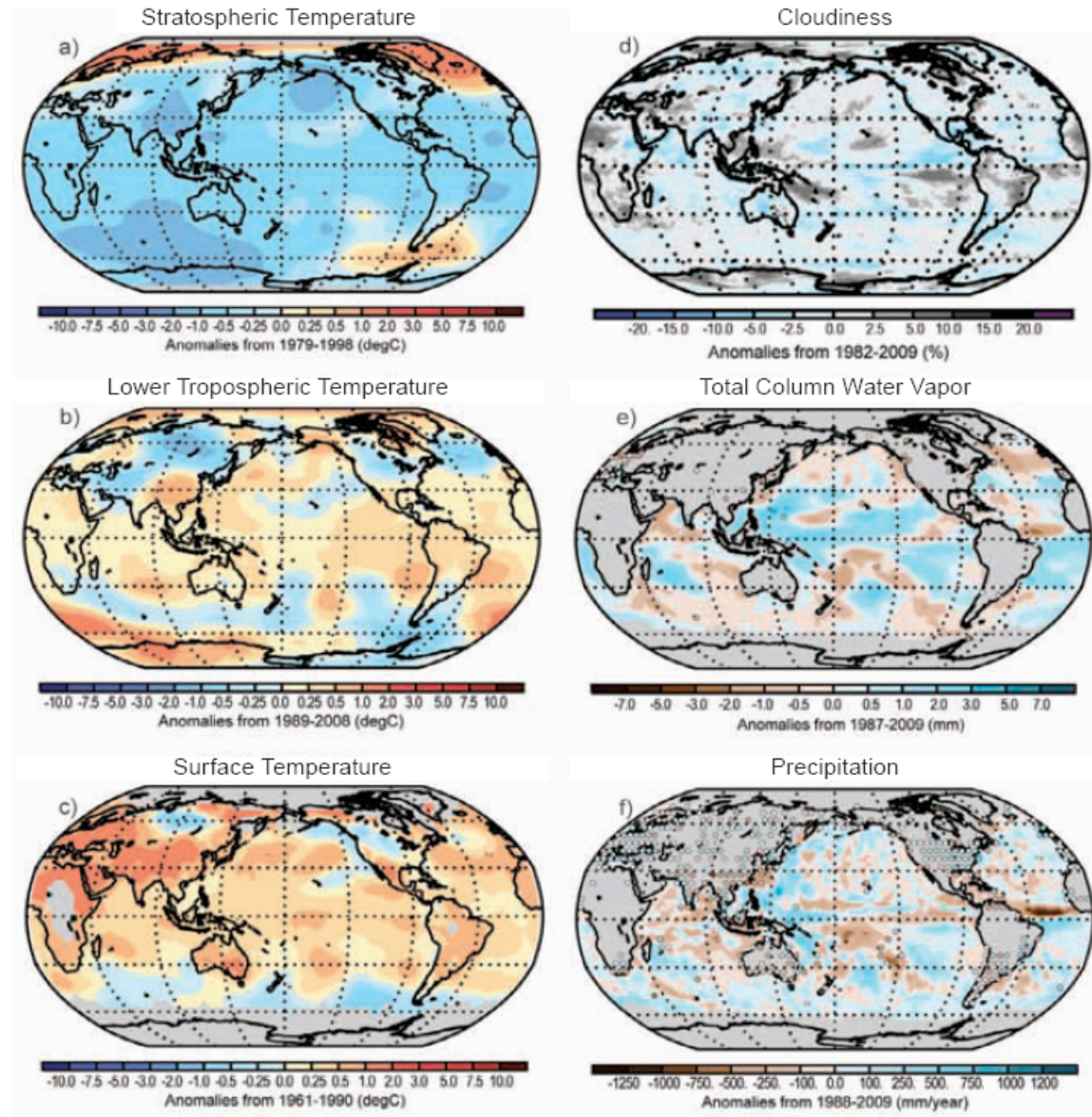


BAMS State of the Climate

Growing use of reanalysis for climate monitoring



Caution is still advised!

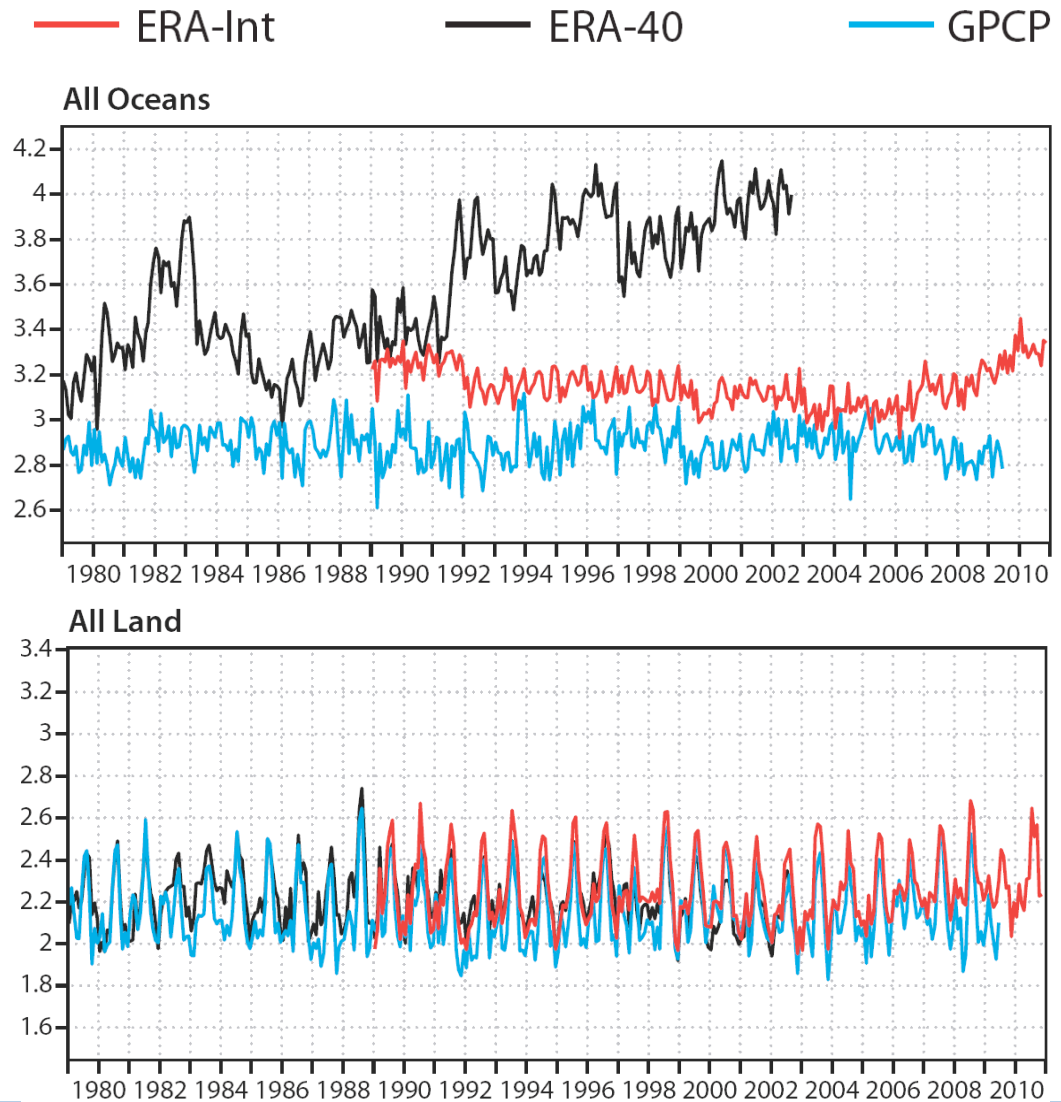


Larger uncertainties in precipitation trends

Comparison of monthly averaged rainfall with combined rain gauge and satellite products (GPCP)

Reanalysis estimates of rainfall over ocean are still problematic

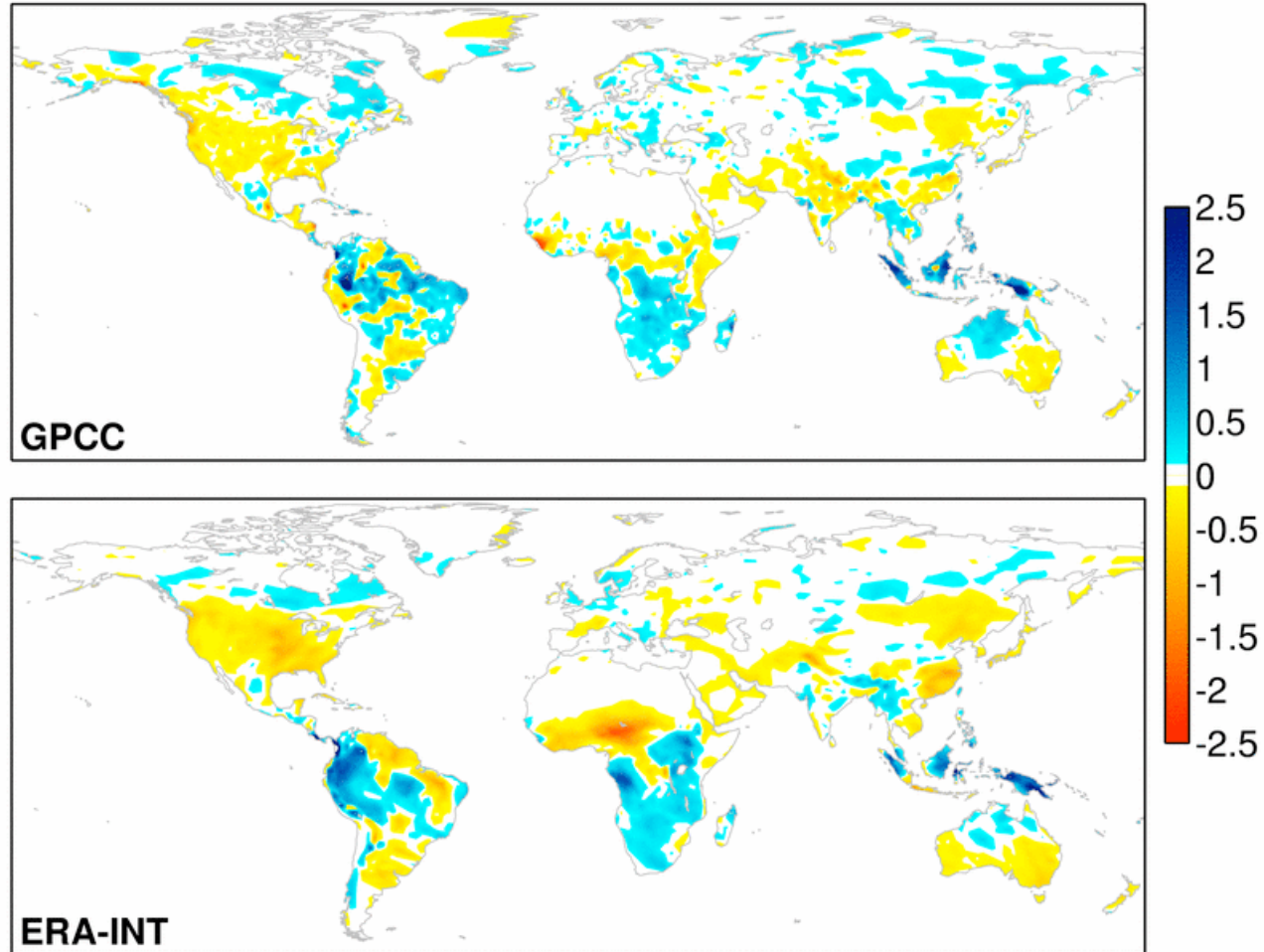
Results over land are much better



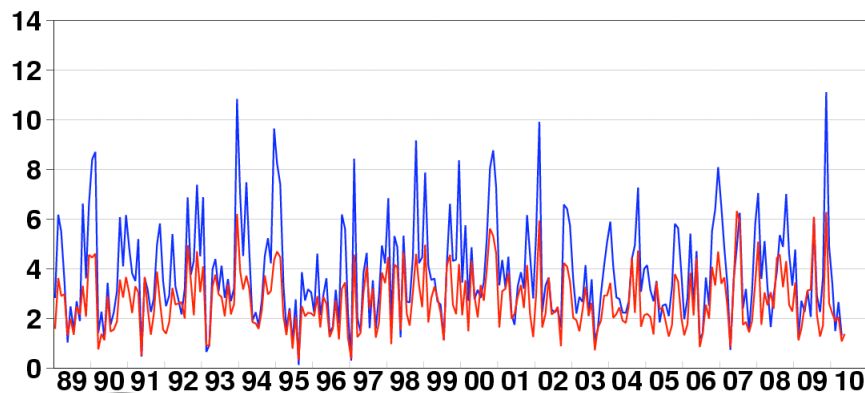
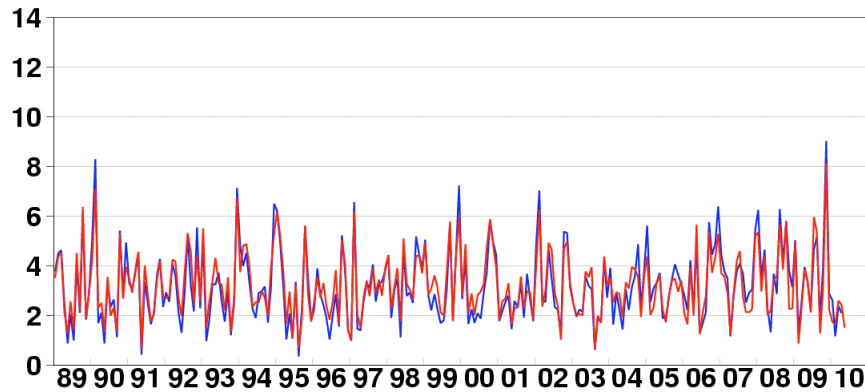
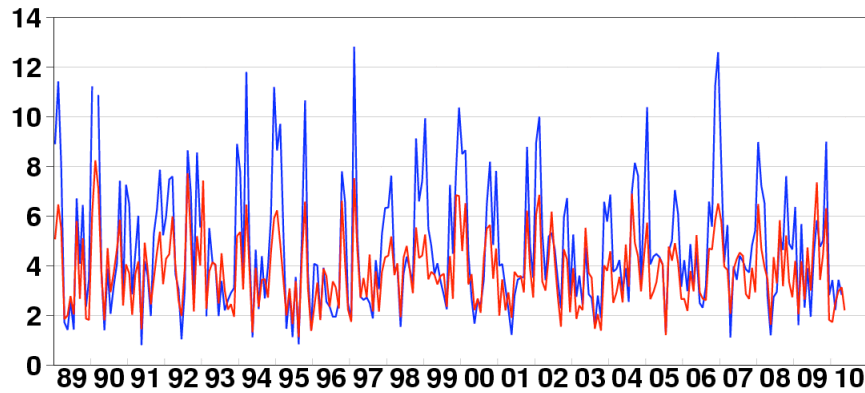
Larger uncertainties in precipitation trends

Decadal trends in precipitation, from GPCC estimates and from ERA-Interim:

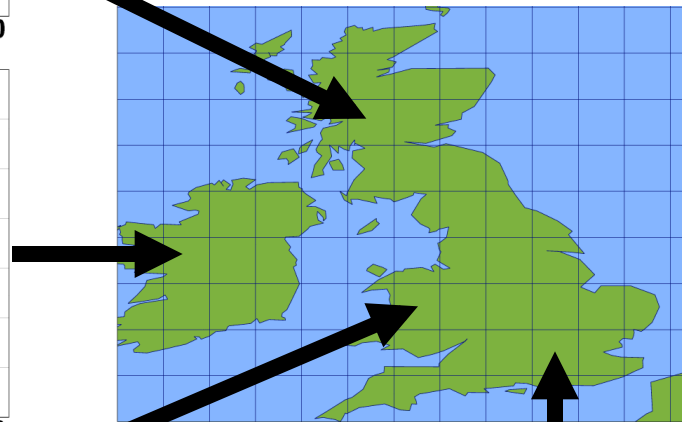
Mean precipitation difference ((2000-2009) - (1990-1999)) (mm/day)



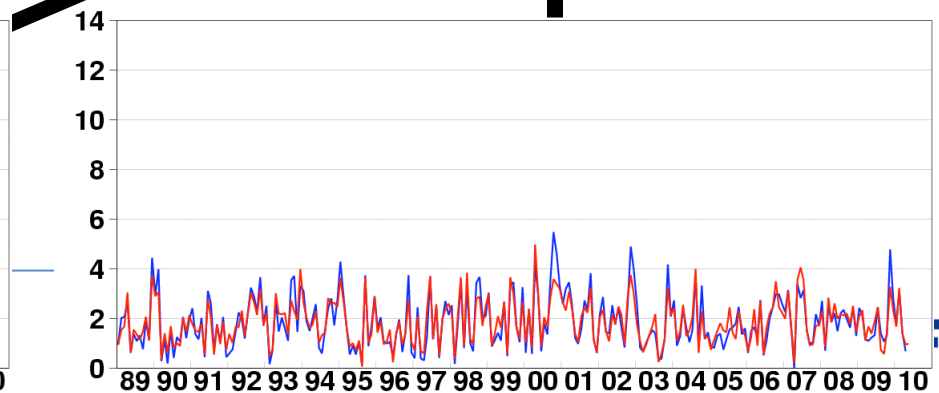
Monthly precipitation rates for 1°x1° grid boxes



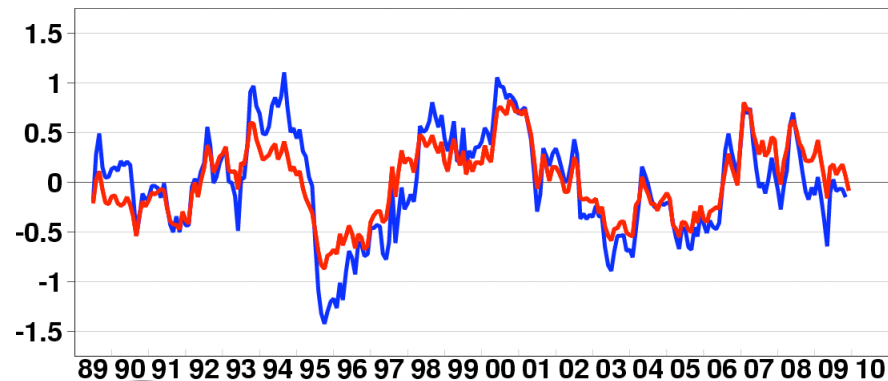
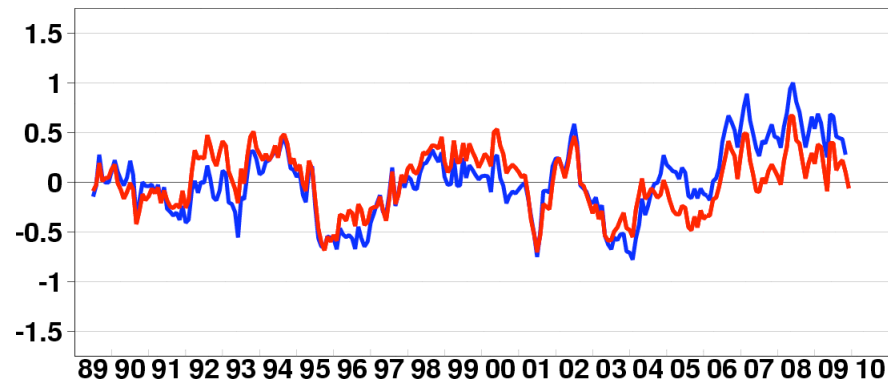
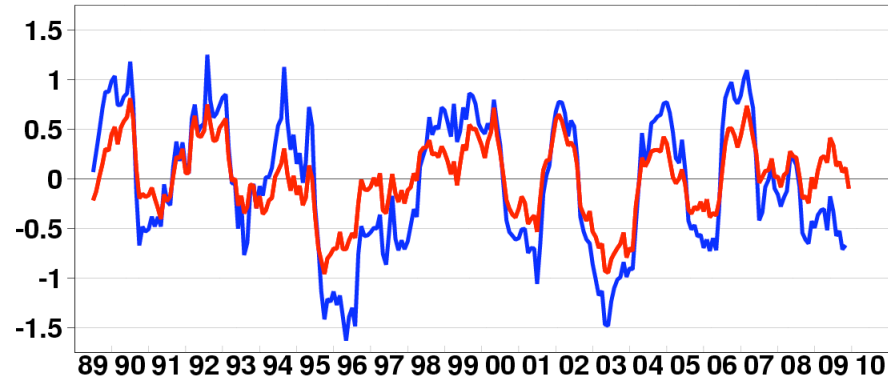
ERA values are interpolated from ~80km model grid to 1° grid of GPCP product
ERA values underestimate precipitation maxima for mountainous regions of Wales, Scotland and northern England



— ERA-Interim
— GPCP
(mm/day)

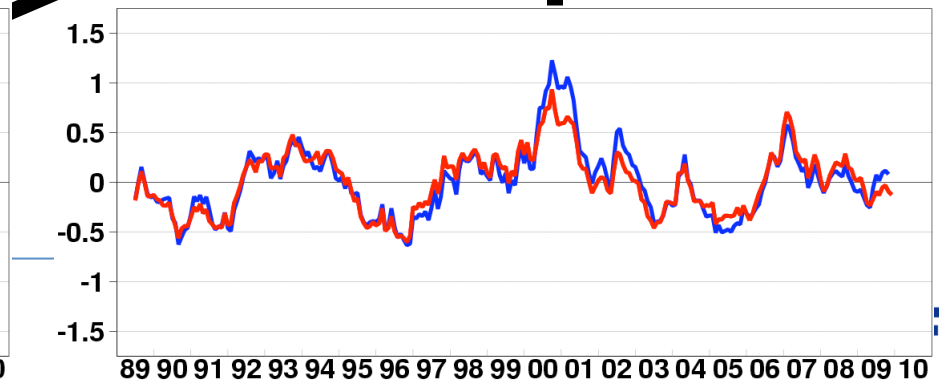
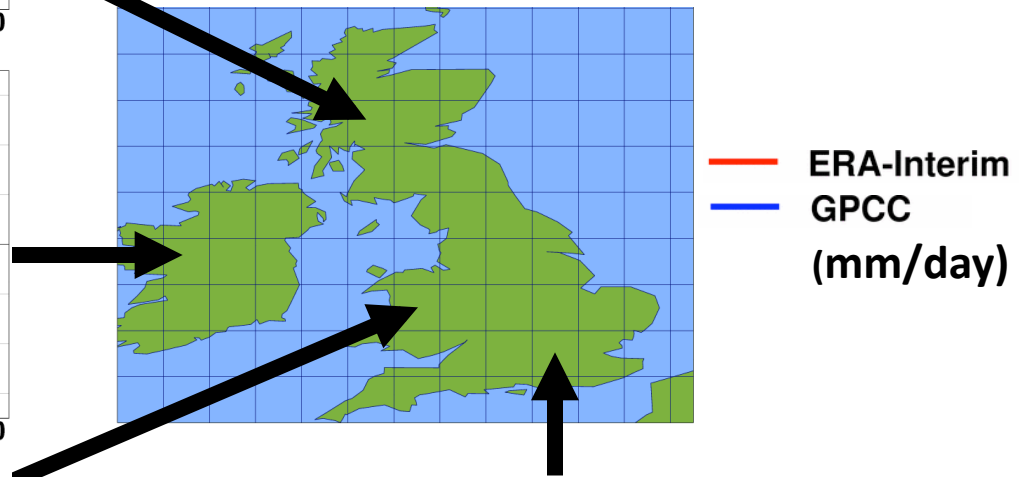


Precipitation anomalies for 1°x1° grid boxes



Anomalies are computed with respect to (1989-2009) means for each month from ERA and GPCC respectively.

Time series of 12-month running means are shown here.



Stratosphere

Topics:

- Stratospheric circulation
- Response to Pinatubo
- Temporal consistency of the upper stratosphere
- Effect of model biases
- Ozone assimilation

Particle dispersion

Particle distributions after 50 days of backward kinematic trajectories using TOMCAT CTM

Are stratospheric winds produced by data assimilation good enough for long-term transport calculations? (Schoeberl *et al.* 2003)

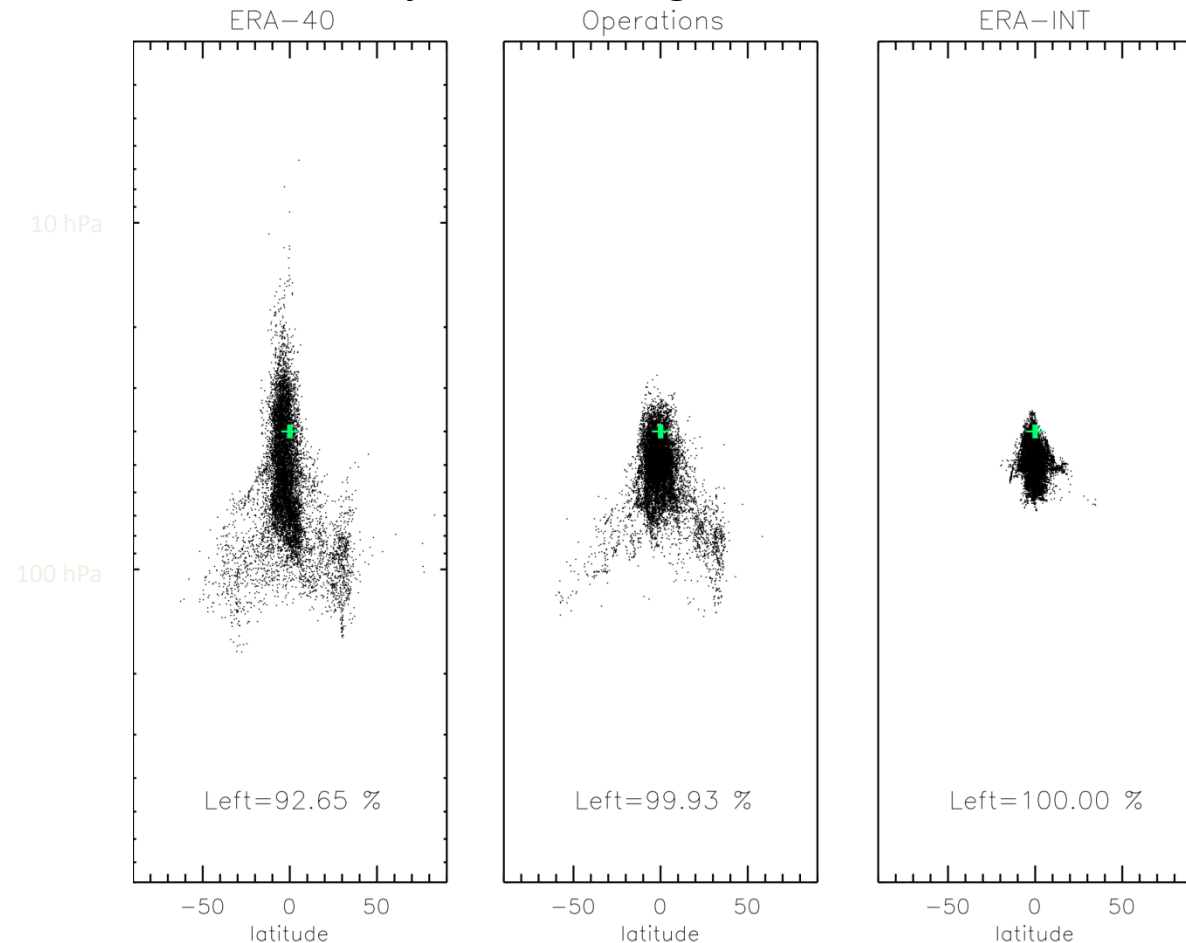


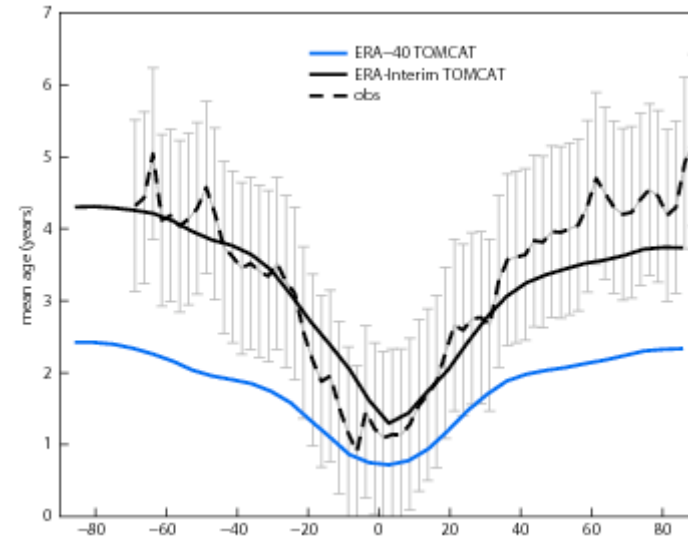
Figure updated from Monge-Sanz *et al.* 2007

Stratospheric circulation

Evidence of improved Brewer-Dobson circulation (*too strong in ERA-40*)

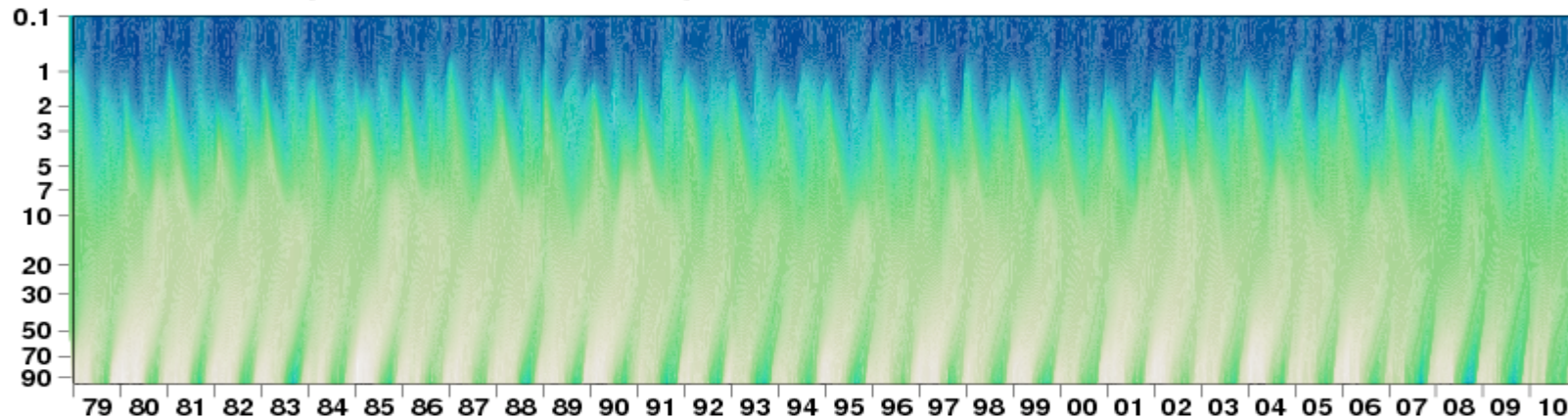
Likely due to 4D-Var and VarBC

Mean age of air at 20km



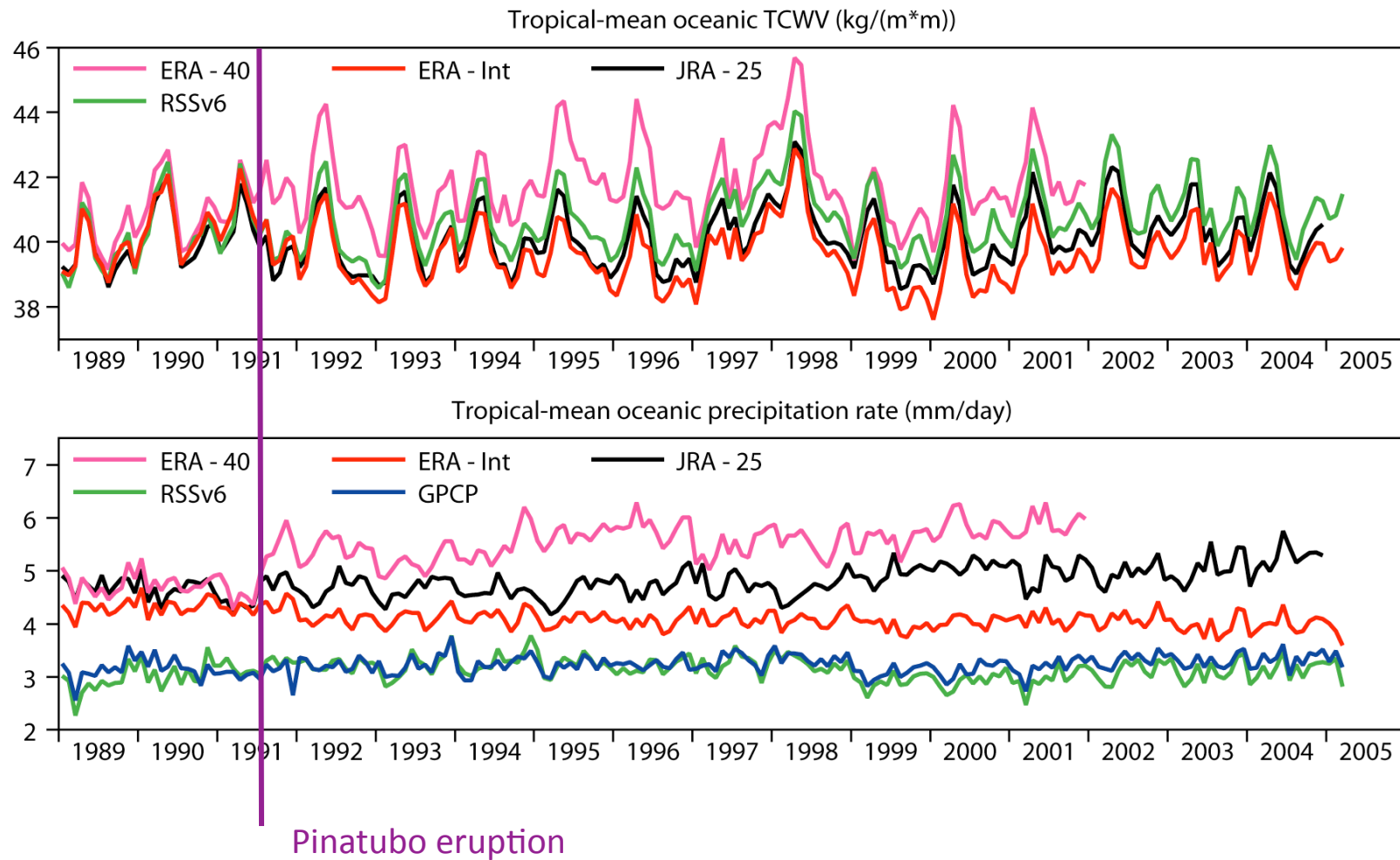
Equatorial (10N-10S) specific humidity

ERA-Interim



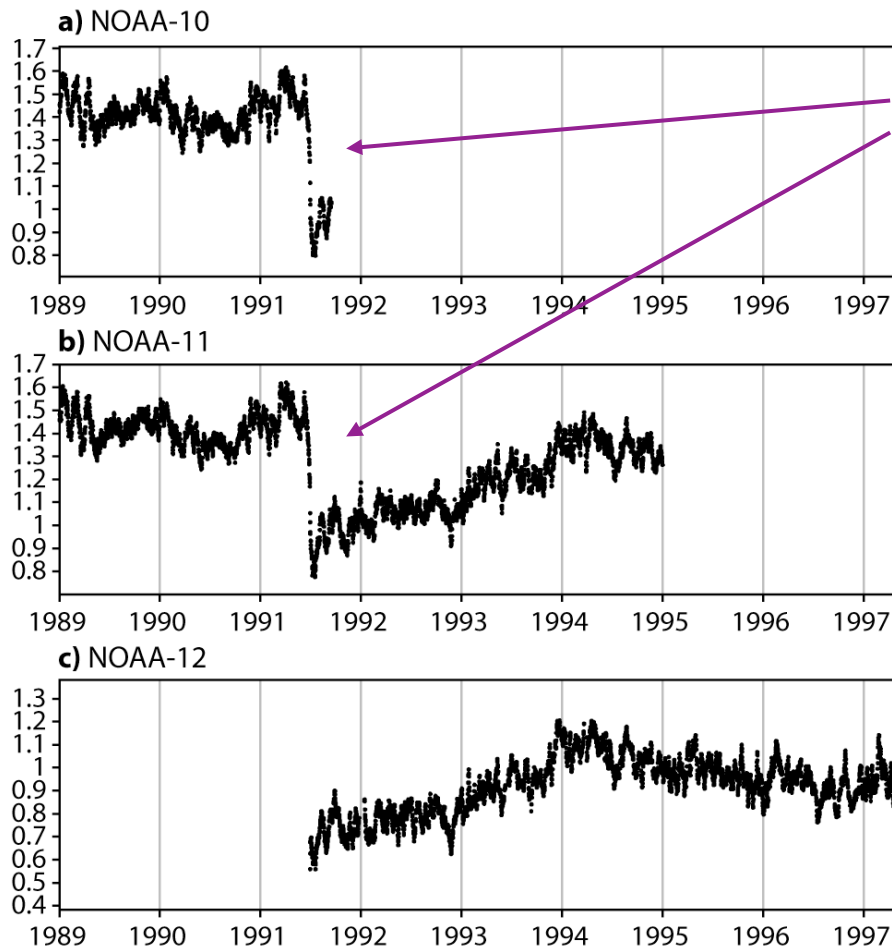
Response to Pinatubo eruption

ERA-40: Excessive precipitation over tropical oceans – worse after Pinatubo



Response to Pinatubo: HIRS Ch11

Bias corrections for HIRS Ch11 (tropical averages)



Volcanic aerosols in the lower stratosphere:

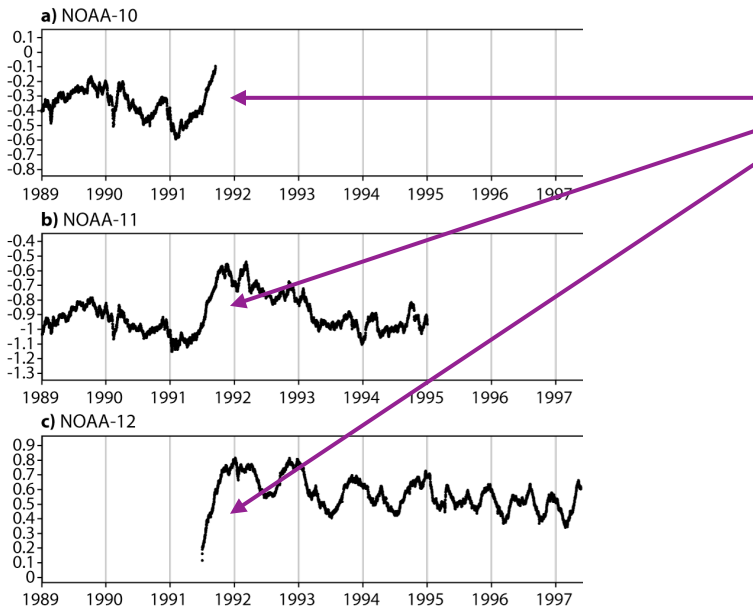
- Cooling effect on radiances
- Not in the radiative transfer model
- ERA-Interim: Change the bias correction
- ERA-40: Change the humidity increments

Bias corrections for NOAA-12:

- In ERA-Interim, correct initialisation followed by gradual recovery
- In ERA-40, bias was held fixed

Response to Pinatubo: MSU Ch4

Bias corrections for MSU Ch4 (tropical averages)



Volcanic aerosols in lower stratosphere:

- Microwave radiances are insensitive to aerosol, but correctly measure warming of the stratosphere
- The effect of aerosol changes on radiation is not accounted for in the forecast model (biased cold)
- This causes a (false) bias adjustment for MSU

The result is a **slight damping of the Pinatubo signal** in ERA-Interim

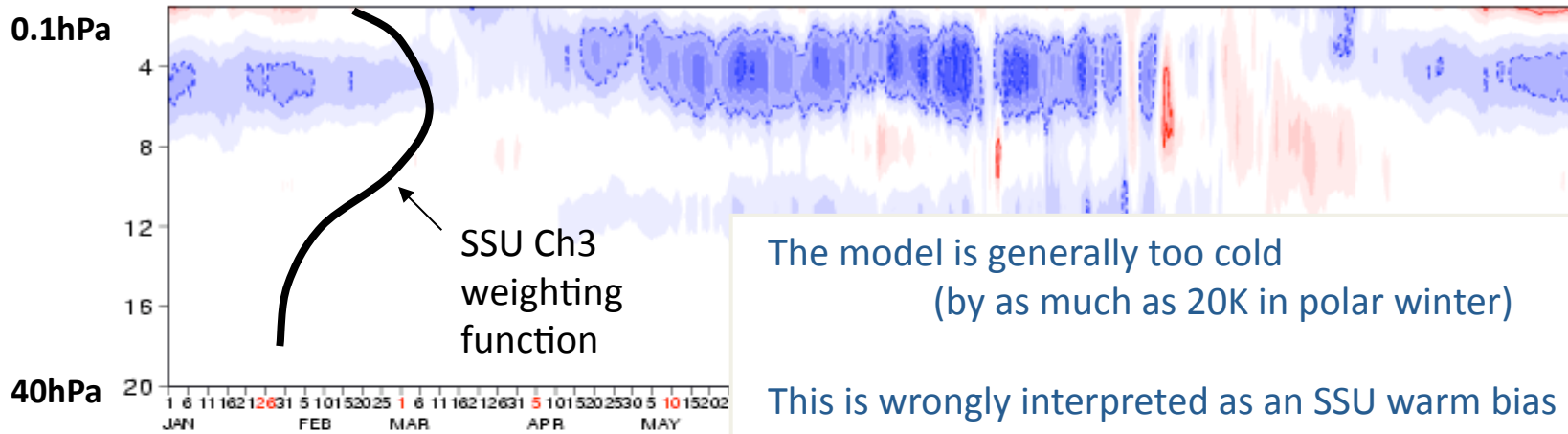
Still the best option, given large variations in the MSU biases

Fundamental limitation of variational bias correction:

- bias parameters are used to minimise mean departures, regardless of the cause
- variational bias correction may not work well in poorly observed regions with large model biases

More on VarBC: Interaction with model bias

Mean temperature [K] 120-hour forecast errors for experiment 1112 : Antarctica

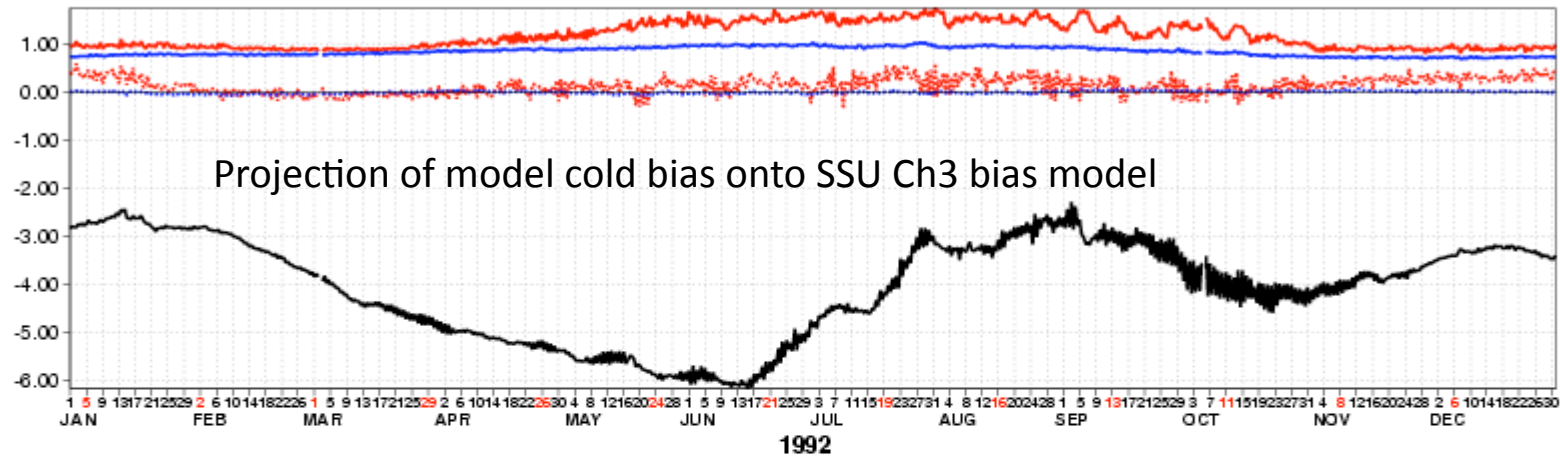


The model is generally too cold
(by as much as 20K in polar winter)

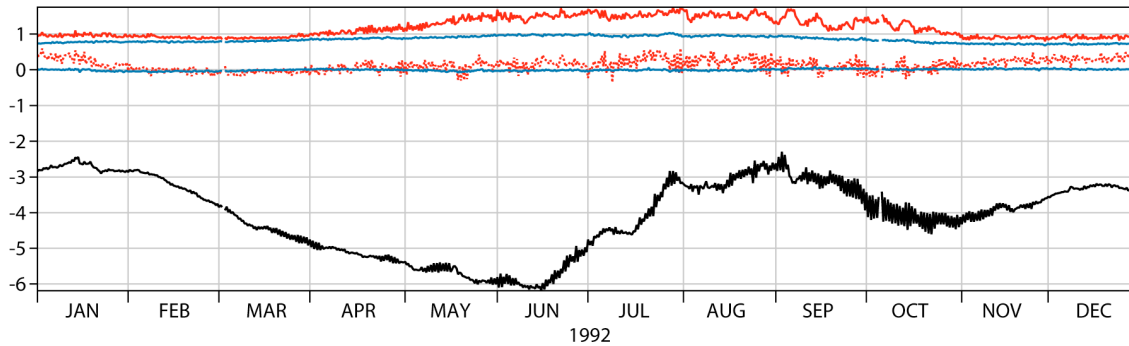
This is wrongly interpreted as an SSU warm bias

SSU is then “corrected” to agree with the model

1112 (DA) : TOVS-1C_NOAA-11_SBU_Tb Ch
rms and bias (K) OB-FG (red) OB-AN (blue) BIASCOR (mean)



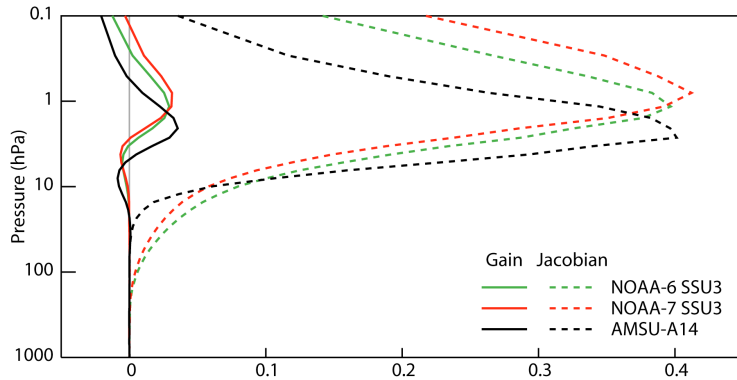
How to constrain model biases in the upper stratosphere?



Variational bias correction of SSU Ch3 would result in large temperature biases near the stratopause

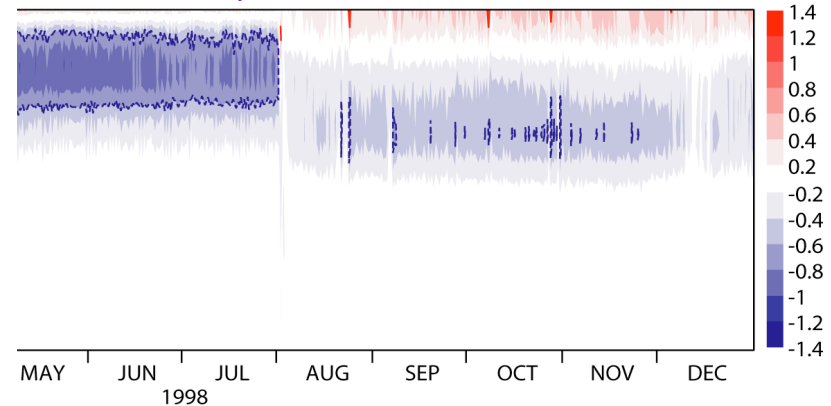
The top of the model must be constrained by uncorrected observations:
SSU Ch3 (available until 2006), **AMSU-A Ch14** (available from 1998)

Jacobians for SSU3 and AMSUA-14



The constraints provided by each sensor are fundamentally different

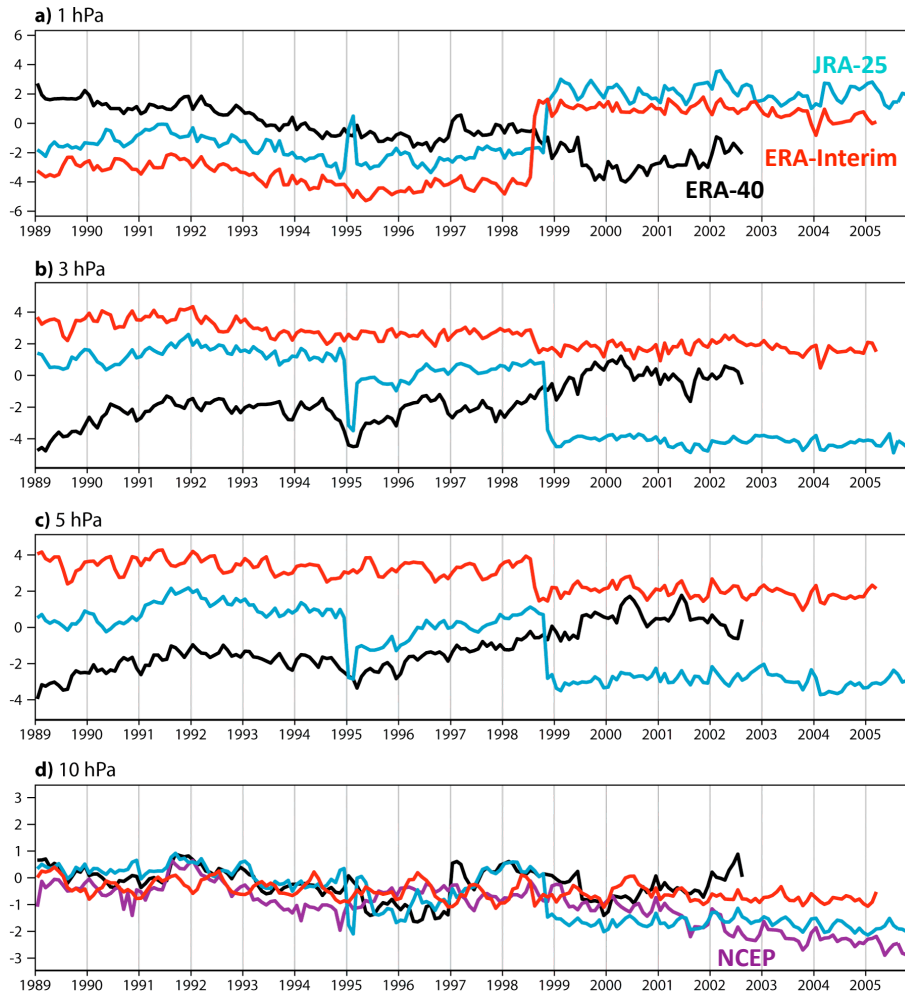
Global mean temperature increments above 40hPa



Both sensors result in systematic (but partial) corrections to the model background

Shifts in upper-stratospheric temperatures

Global mean temperature anomalies in the upper stratosphere



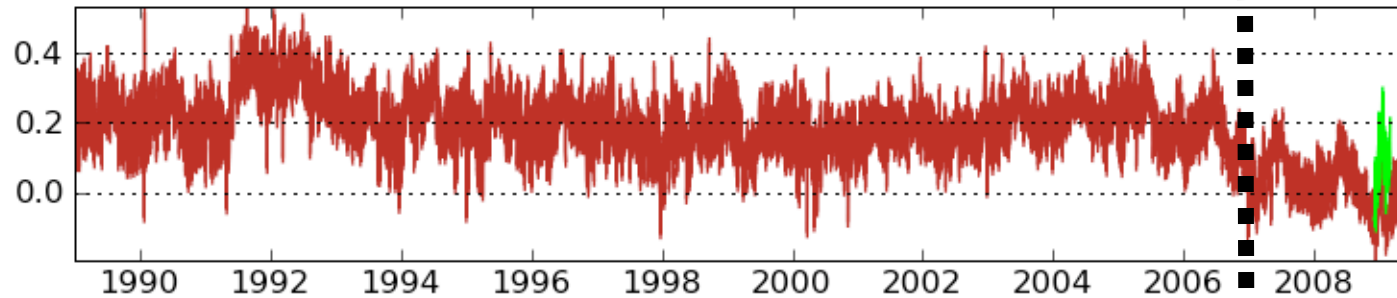
The transition from SSU Ch3 to AMSU-A Ch14 is clearly visible in global mean temperatures at 5hPa and above

Weak-constraint 4D-Var can help but not solve the problem

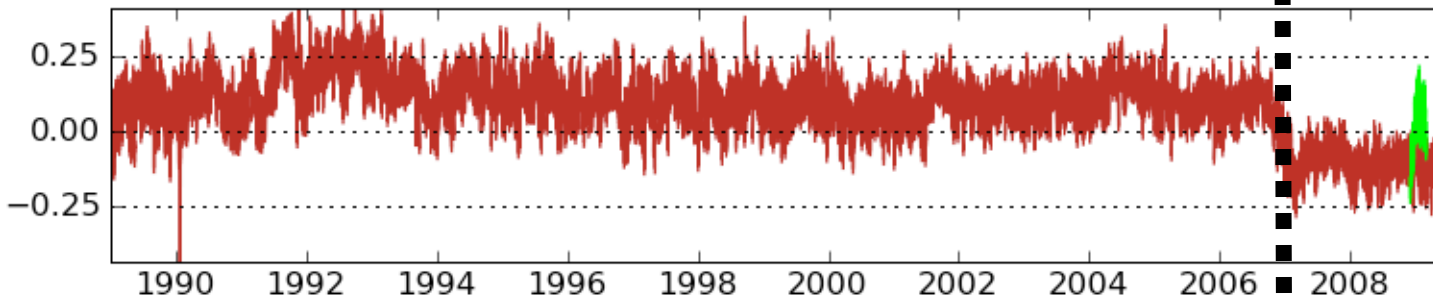
This problem cannot be completely solved unless the forecast model is free of bias

Introduction of GPSRO (COSMIC)

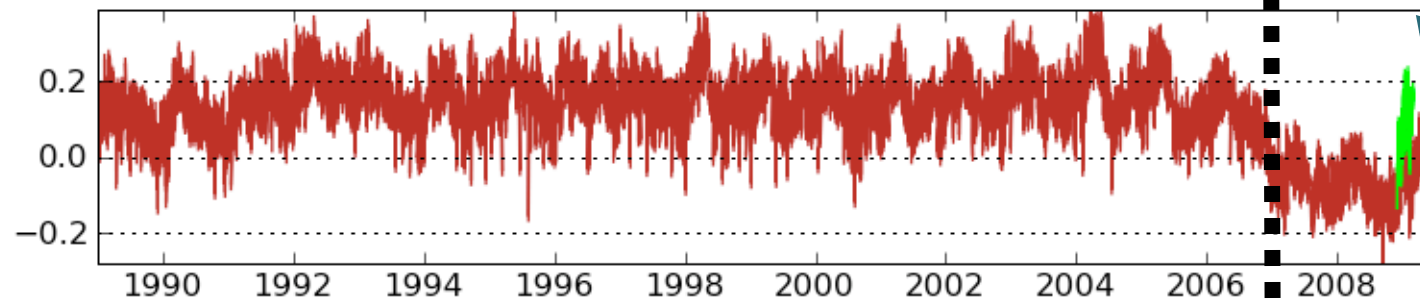
(a) Temper. diff. NH land RS minus ERA-Interim (in K), Pressure layer 60-40hPa



(b) Temper. diff. NH land RS minus ERA-Interim (in K), Pressure layer 85-60hPa



(c) Temper. diff. NH land RS minus ERA-Interim (in K), Pressure layer 125-85hPa

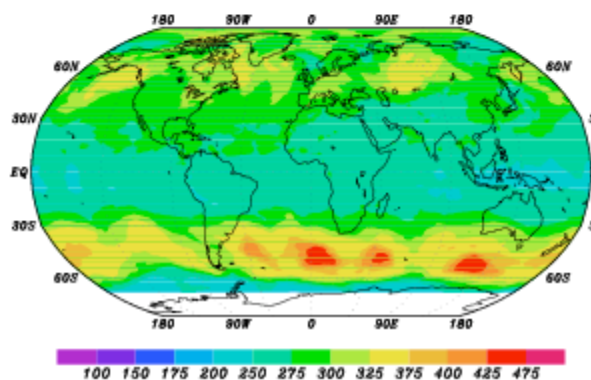


Observing System Experiment, in which GPSRO data were withdrawn

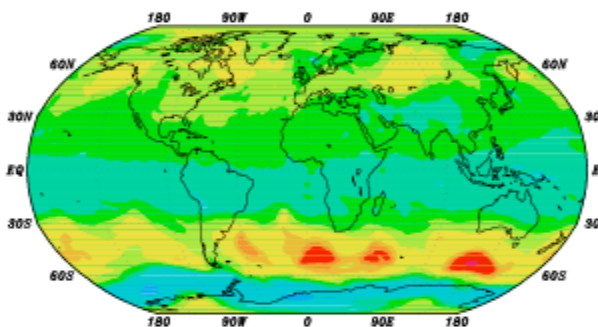
Ozone assimilation

Can ozone data be used to infer stratospheric winds?

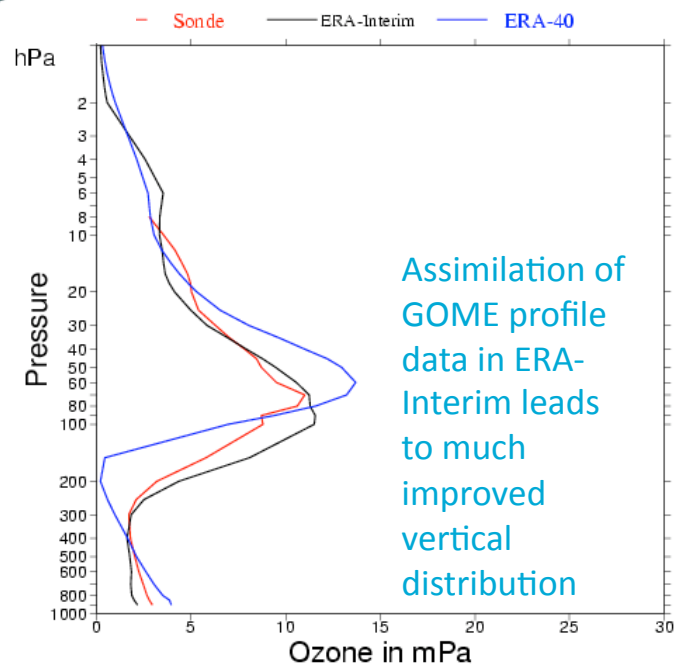
Total ozone from TOMS
(August 1996)



ERA-Interim
(TOMS + SBUV + GOME)



Ozone profiles from sondes and reanalyses
NEUMAYER (Lat = -70.7, Lon = -8.3)
Month = 199608

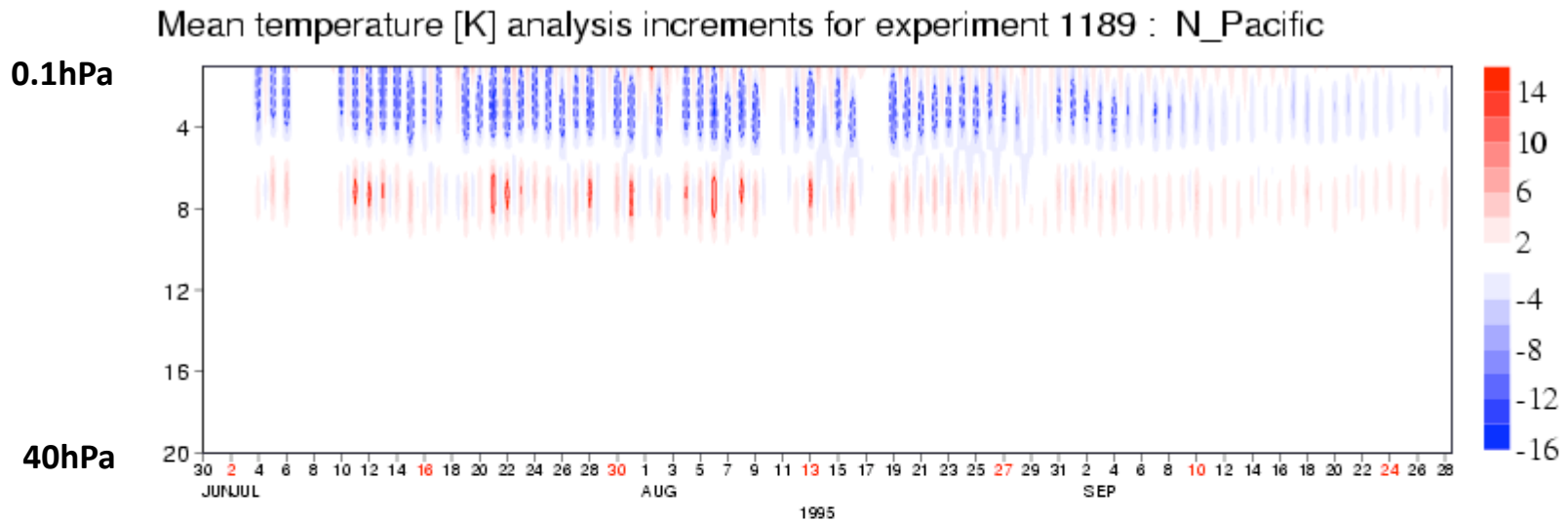
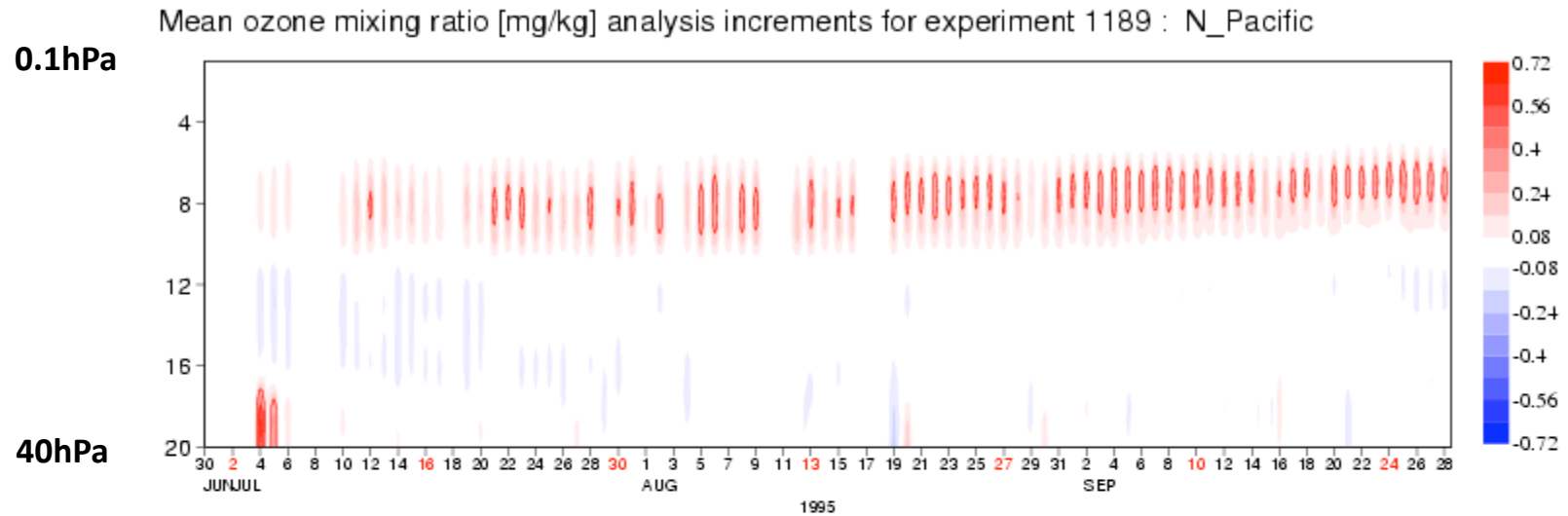


Ozone observations contain information about the flow
4D-Var should be able to extract this information, since it uses the forecast model as a dynamical constraint

How well does this work in practise ?

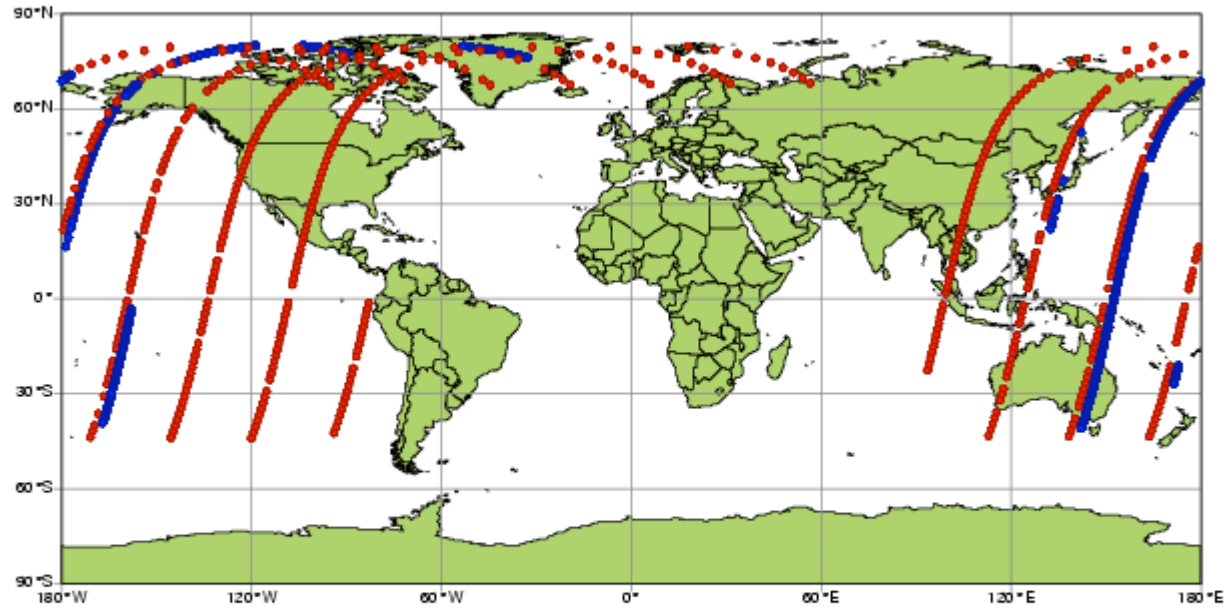
Introduction of GOME ozone profile data in ERA-Interim

Ozone and temperature increments in the upper stratosphere



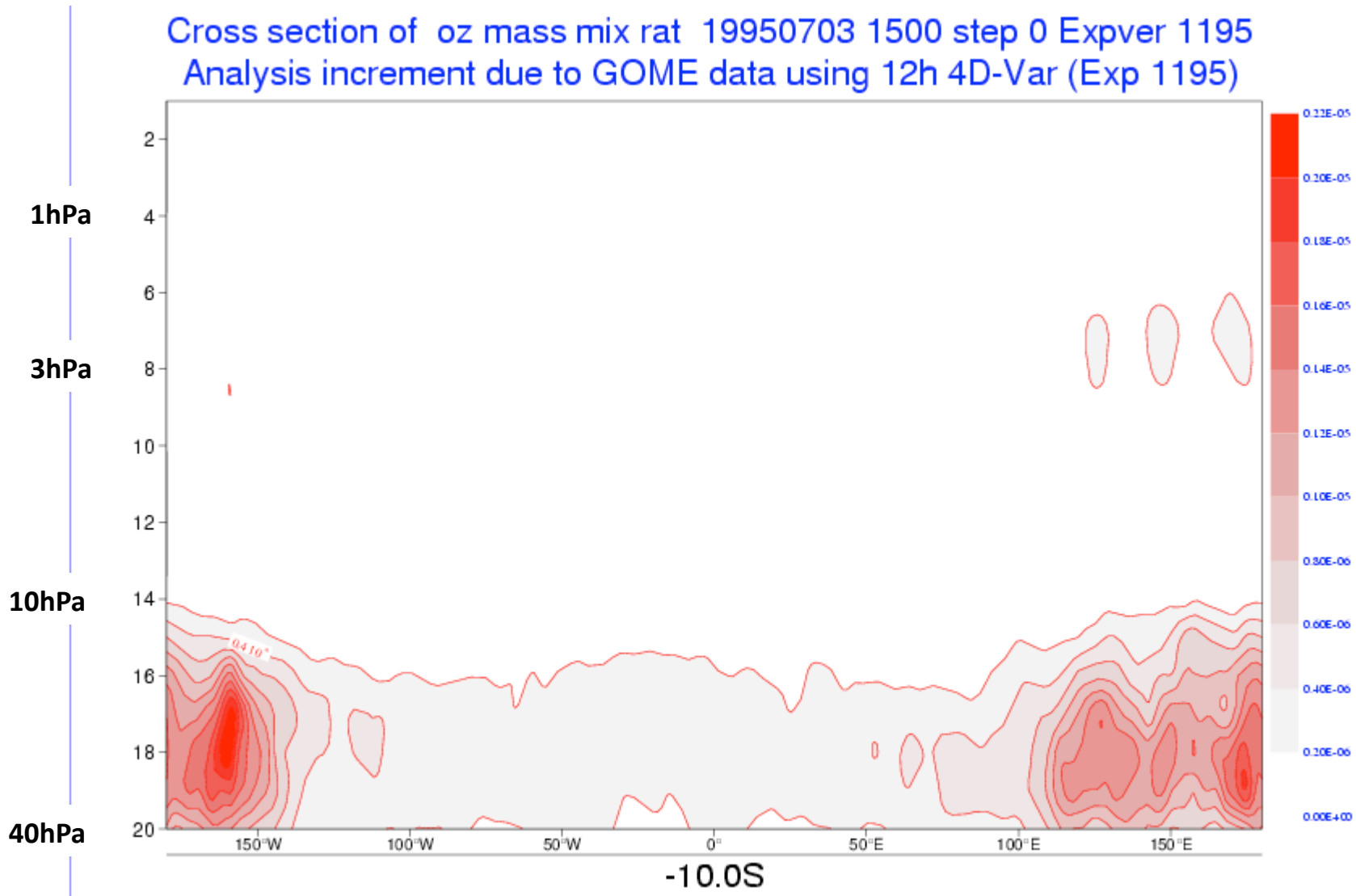
4D-Var ozone-only analysis experiment

Ozone observation locations on 4 July 1995, 0 UTC



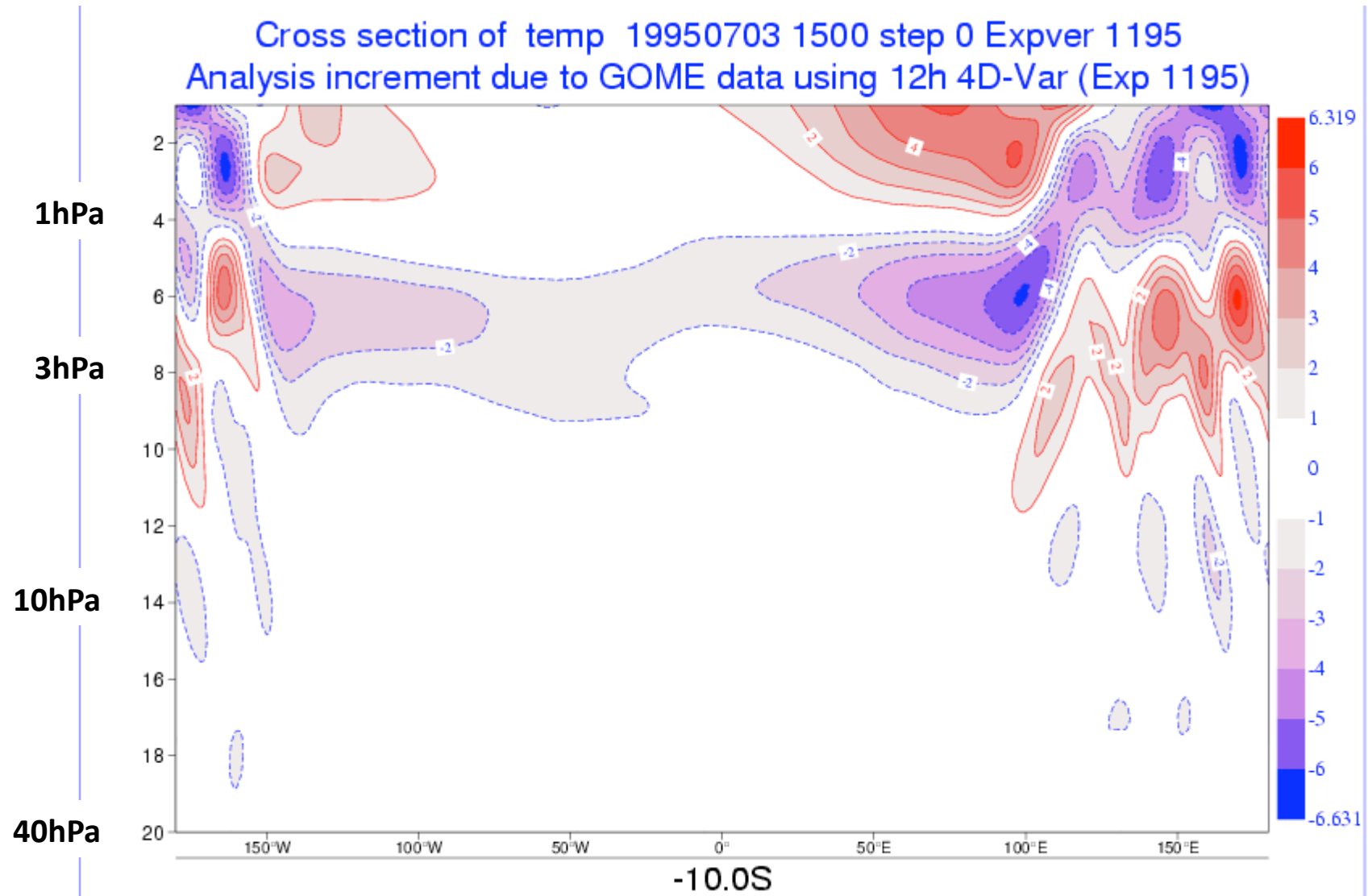
Blue: GOME 15-layer profiles (~15,000 per day)
Red: SBUV 6-layer profiles (~1,000 per day)

4D-Var ozone-only analysis experiment
The impact of the ozone data on the ozone analysis at 10S



4D-Var ozone assimilation

The impact of the ozone data on the temperature analysis at 10S

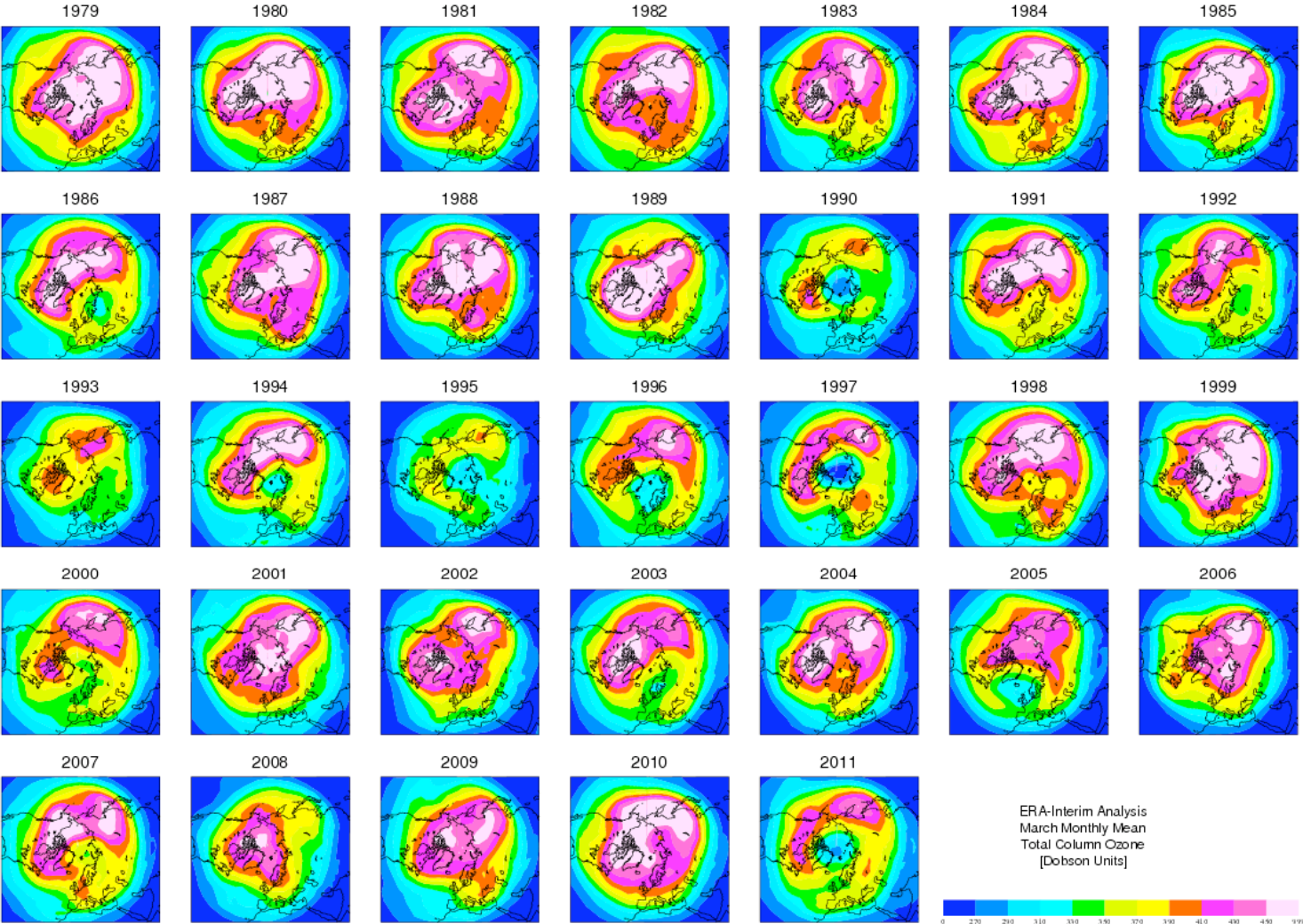


Ozone assimilation

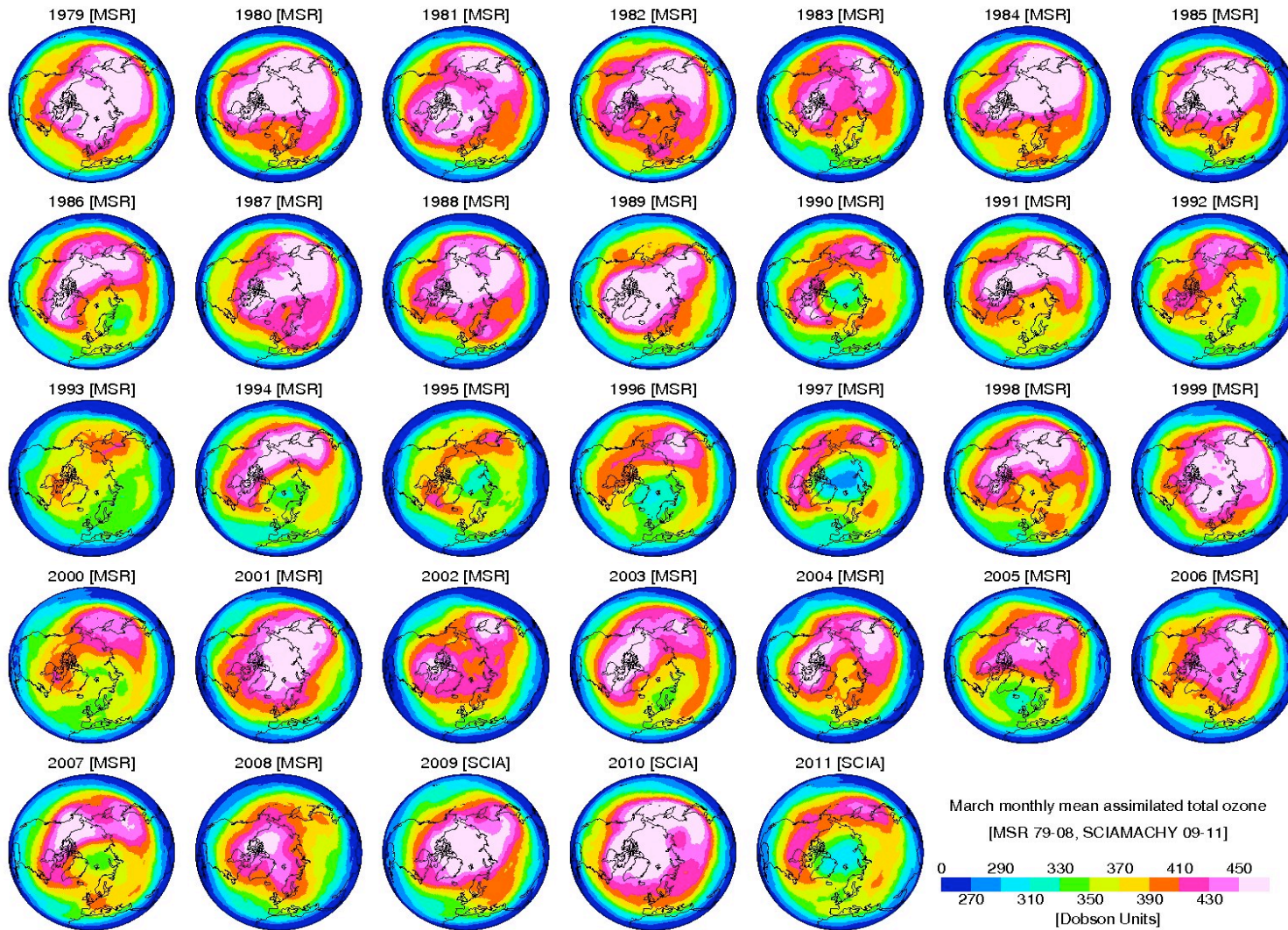
Can 4D-Var infer stratospheric winds from ozone data?

- Assimilation of ozone profile data causes large and unrealistic T/U/V increments near the stratopause to accommodate the observed discrepancies between background and data
- A large part of these discrepancies are due to biases (in both data and model)
- It is natural for 4D-Var to make adjustments to the flow where constraints are few:
 - Lack of wind observations
 - Large background uncertainties
- A short-term fix disables this feature for the assimilation of ozone and other trace gases (use the background flow for ozone transport during minimisation)
- Comprehensive ozone bias correction (as for radiances) will help.

ERA-Interim total ozone, March, NH

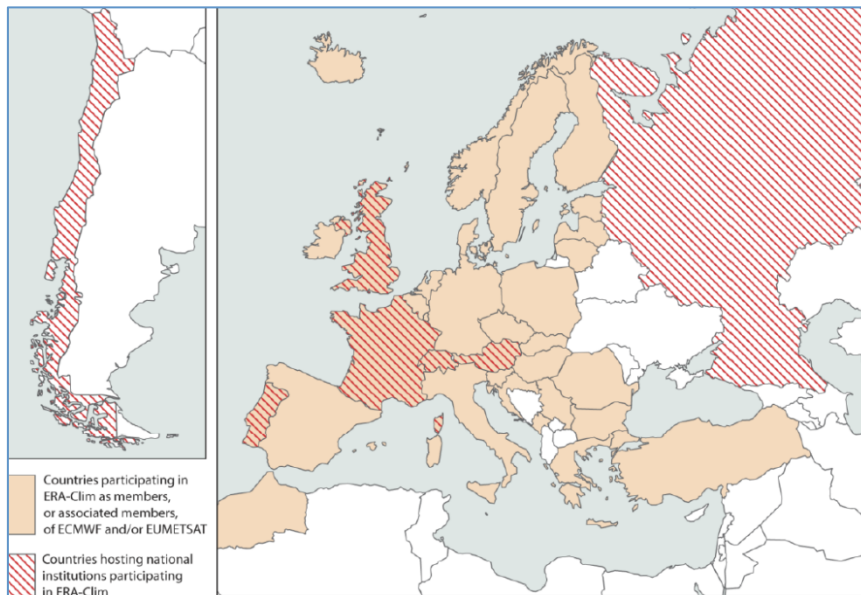


Estimates from KNMI



The ERA-CLIM Project

- **ERA-CLIM:** European Reanalysis of Global Climate Observations
- A 3-year collaborative research project (2011 - 2013)
- Funded by EU research FP7 (Environment)
- Total cost €4.9M; EC contribution €3.5M
- 9 partners, 59 person-years, 50 deliverables



Consortium:

- ECMWF
- Met Office
- EUMETSAT
- Univ. Bern
- Univ. Lisbon
- Univ. Vienna
- Météo-France
- RIHM (Russia)
- DMC (Chile)

ERA-CLIM Objectives

Addressing ENV.2010.4.1.2-1:

Building observational datasets for the predictability of global atmospheric, oceanic and terrestrial processes using reanalysis techniques

Key objectives:

- Improvement of the **observational record** for the early 20th century
- Preparation of satellite observations, boundary conditions, and forcing data for a global **atmospheric reanalysis of the 20th century**
- Production of **pilot case reanalyses** and data quality information
- Development of an **Observation Feedback Archive** for reanalysis
- Assessment and reduction of **data uncertainties**

Additional goals:

- **Improving access** to climate data, data quality, and transparency
- Developing a **sustainable capability** for data recovery and reanalysis
- Meeting requirements for future GMES **climate services**

Key deliverables

Objectives	Deliverables	
Development of the observational record for the early 20 th century	Inventories; database for metadata, web-based digitising tools	WP1
	Digitized, quality-controlled instrumental records for the early 20 th century	
	Access to observations and metadata via international data centres	
Preparation of reprocessed satellite observations, boundary conditions, and forcing data	Reprocessed satellite data sets for input to reanalysis; early satellite records	WP2
	Ensemble of consistent sea-surface boundary conditions for the 20 th -century	
	Atmospheric forcing data (solar, aerosols, GHG, land surface...)	
Development of an Observation Feedback Archive (OFA)	Database facility for input observations with quality feedback from reanalyses	WP3
Production of pilot reanalyses and data quality information	A series of long test reanalyses at various resolutions	
	All reanalysis products and input observations available via web services	
Assessment and reduction of data uncertainties	Homogenized in-situ data and bias correction techniques	WP4
	Improved ocean observations for reanalysis	
	Tools for quality assessment of reanalysis products	

WP1: Data recovery and digitisation

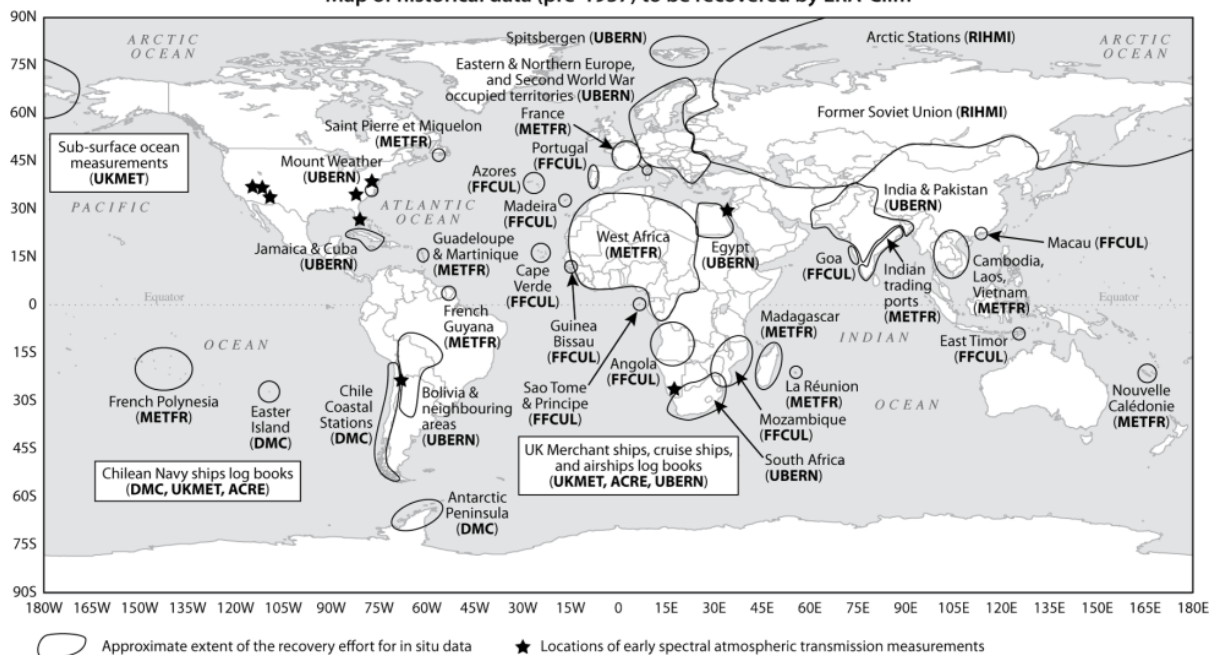
Objectives	Deliverables	
Development of the observational record for the early 20 th century	Inventories; database for metadata, web-based digitising tools	WP1
	Digitized, quality-controlled instrumental records for the early 20 th century	
	Access to observations and metadata via international data centres	

Partners:

- Univ. Bern (lead)
- Hadley Centre
- Univ. Lisbon
- Météo-France
- RIHM
- DMC

Leverage on many existing data recovery efforts (NCDC, ACRE, IEDRO..)

Map of historical data (pre-1957) to be recovered by ERA-Clim



Key deliverables

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WP3: Data integration (global reanalysis)

Partners:

- ECMWF (lead)
- Univ. Vienna
- Univ. Bern
- RIHM

ERA-CLIM pilot reanalyses:

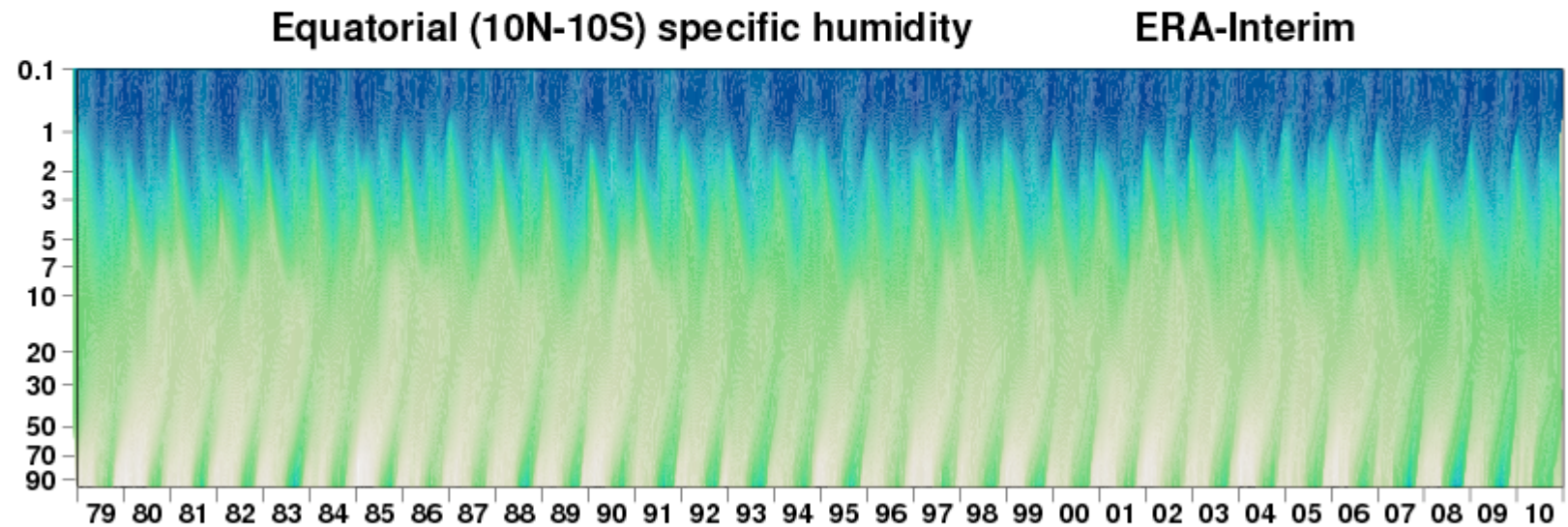
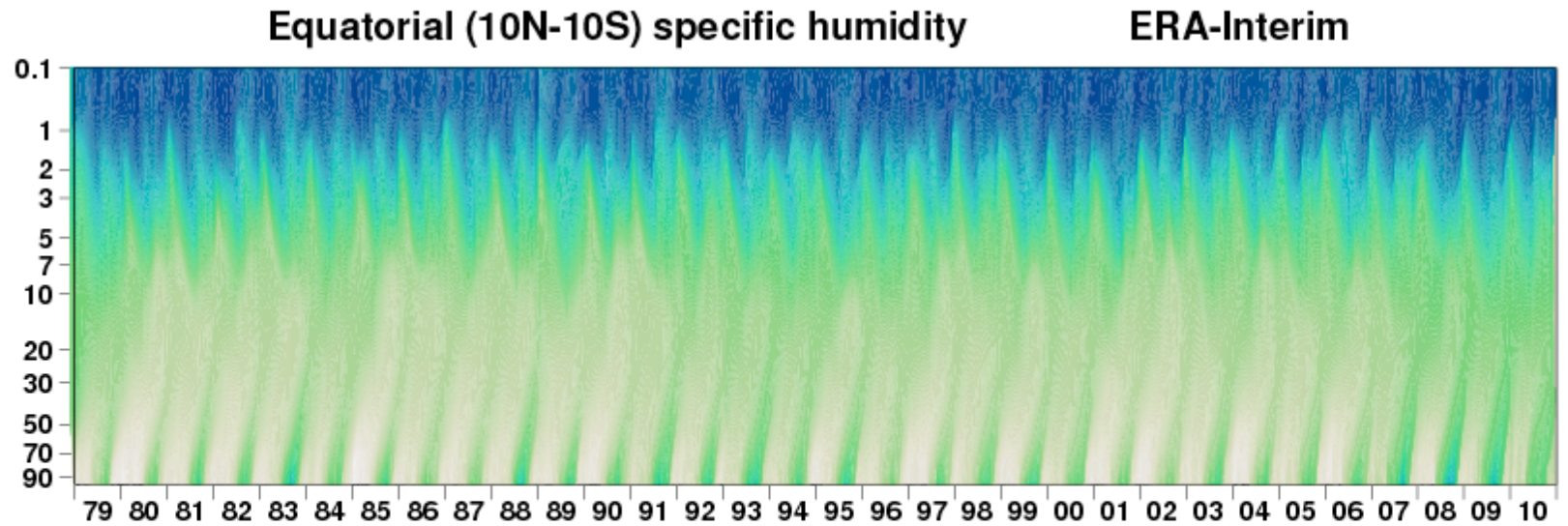
- ERA-20C: 3D atmosphere from 1900 (125km)
- ERA-20CL: Land surface only from 1900 (25km)
- ERA-SAT: 3D atmosphere from 1979 onward (40km)

Development of an Observation Feedback Archive (OFA)	Database facility for input observations with quality feedback from reanalyses	WP3
Production of pilot reanalyses and data quality information	A series of long test reanalyses at various resolutions	
	All reanalysis products and input observations available via web services	

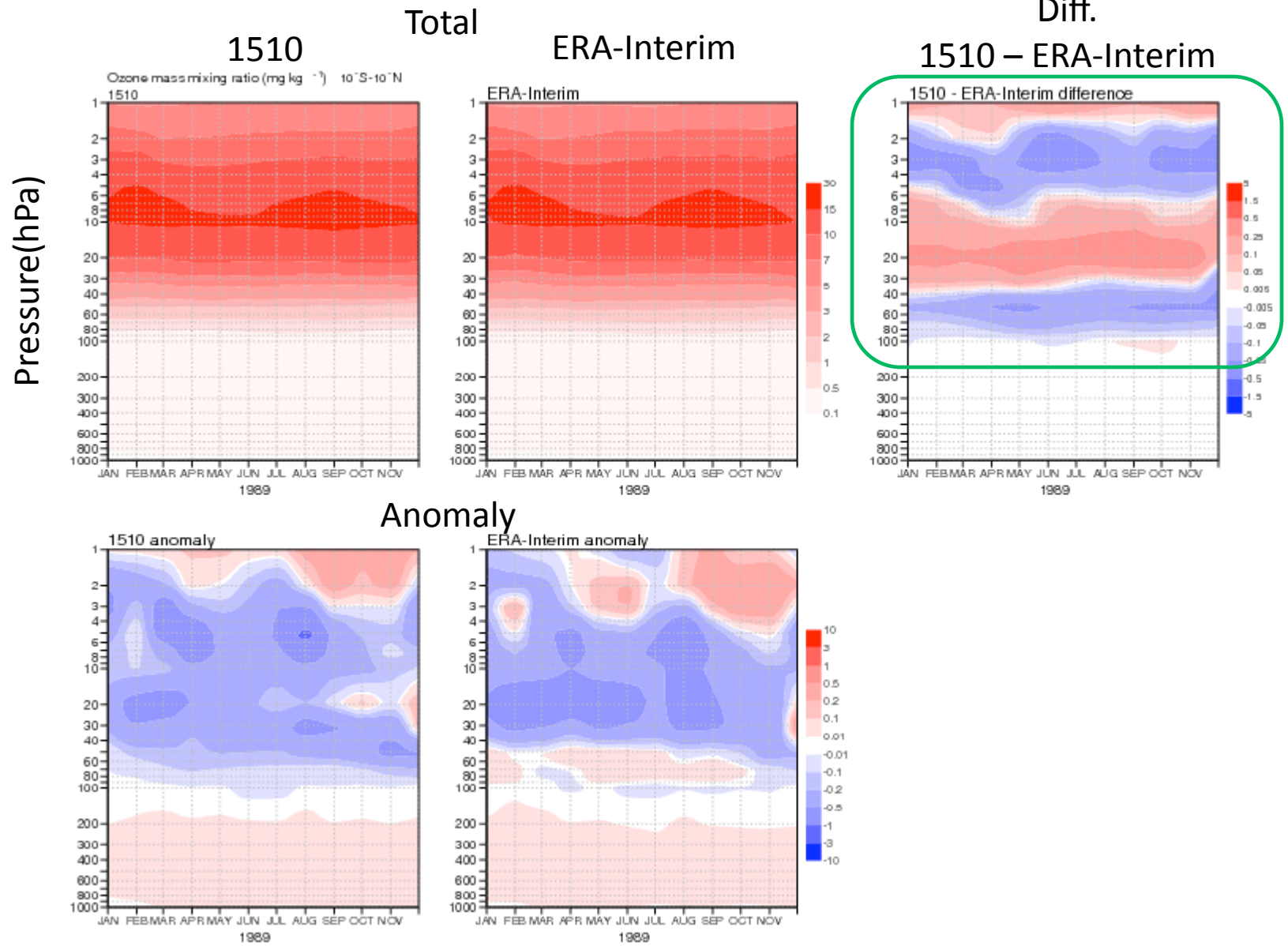
Observation Feedback Archive:

A new web-based facility for access to raw input observations, including uncertainty estimates from reanalysis

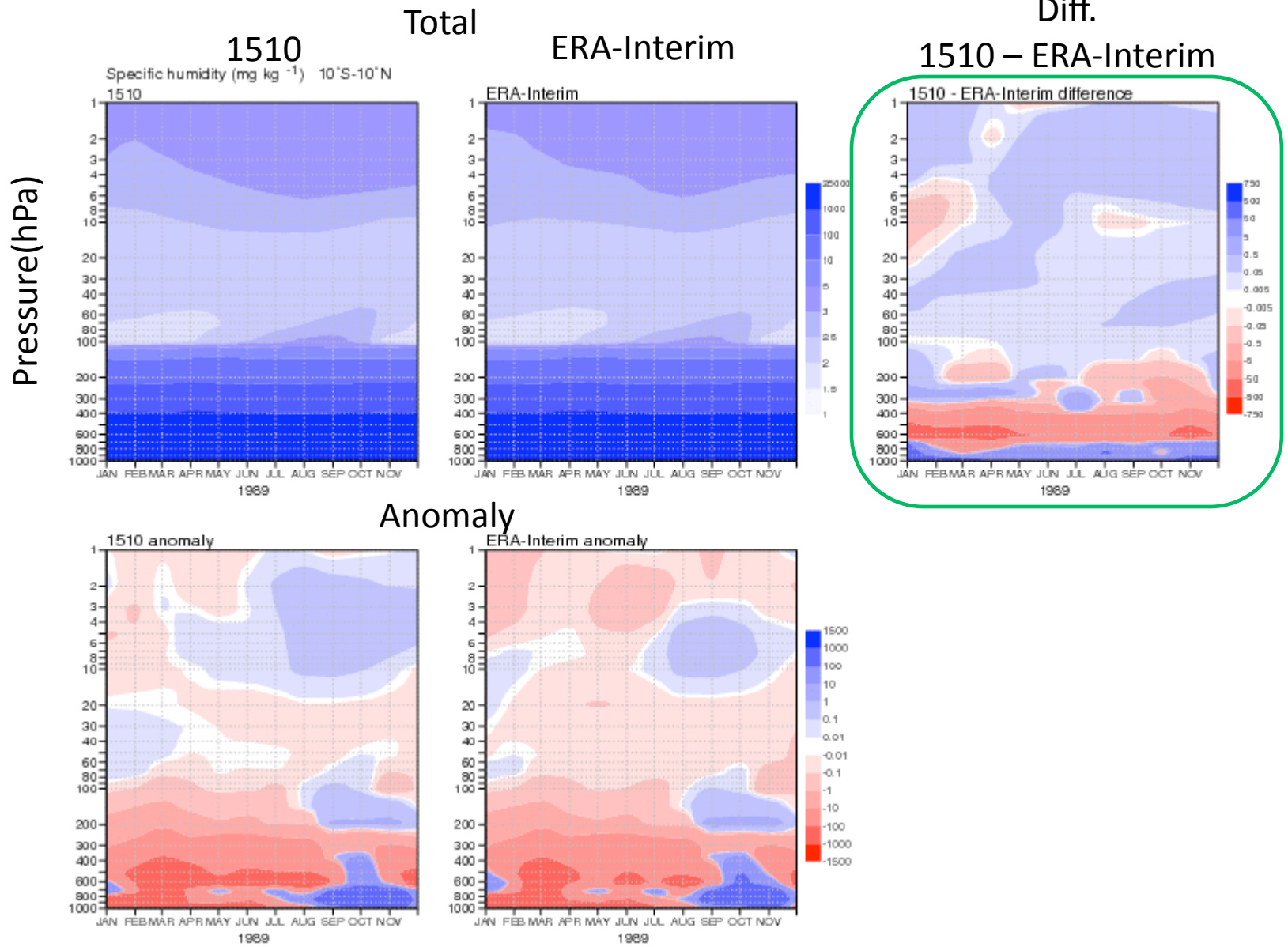
ERA-Interim 1979-1988 extension



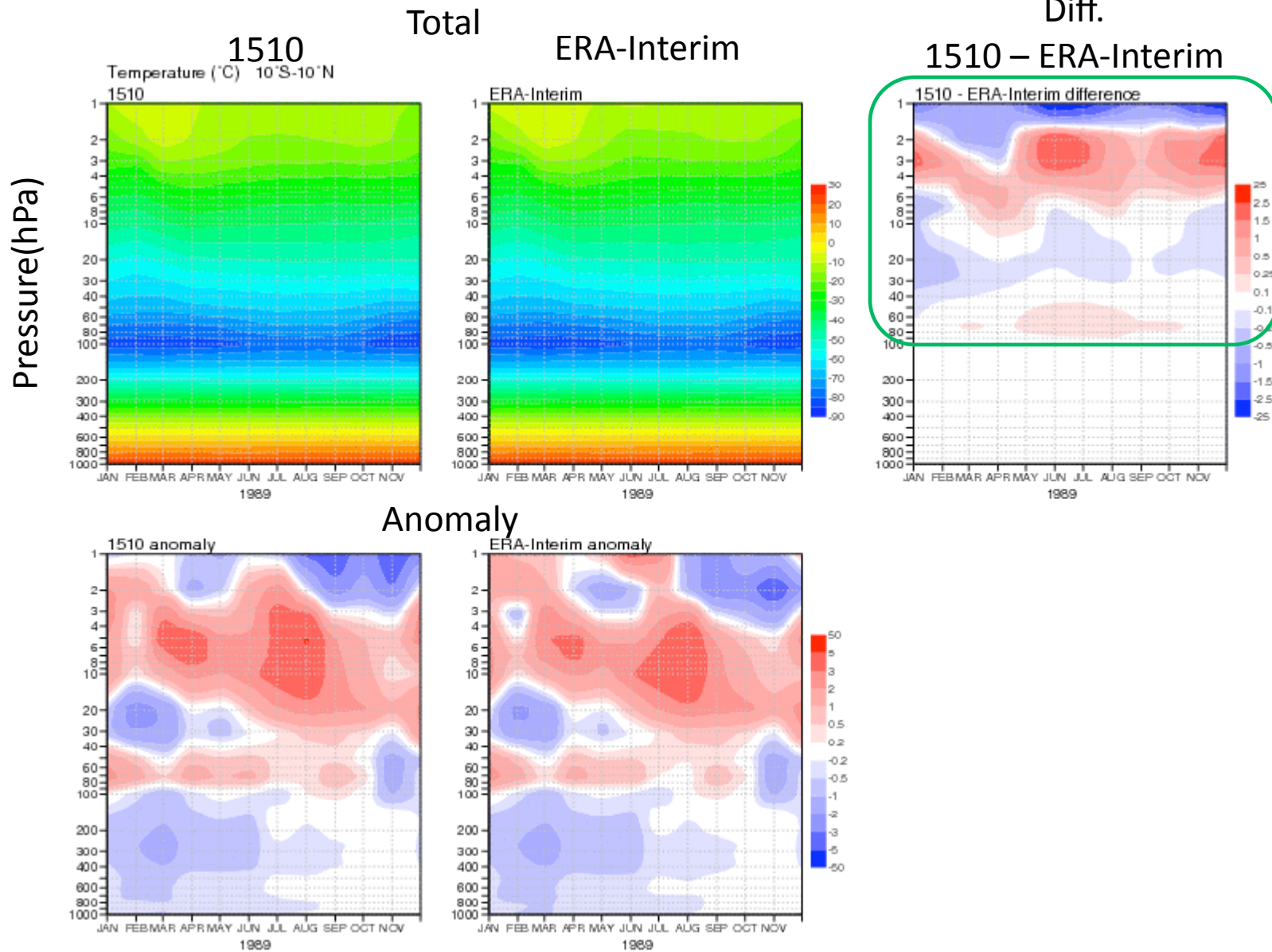
Zonal mean O₃ (10S-10N)



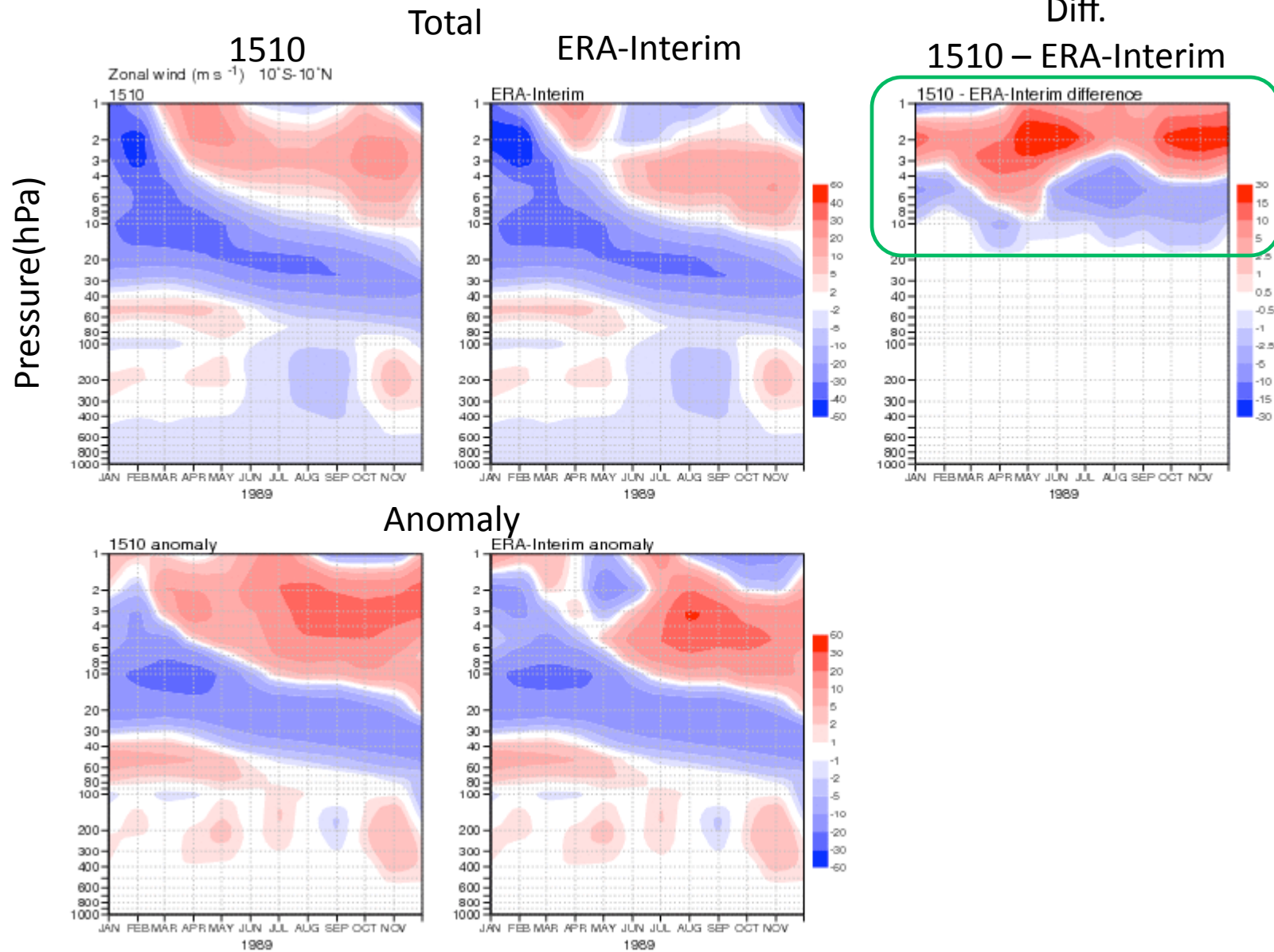
Zonal mean Q (10S-10N)



Zonal mean T (10S-10N)



Zonal mean U (10S-10N)



Climatology: ERA-Interim 1989-2001