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):

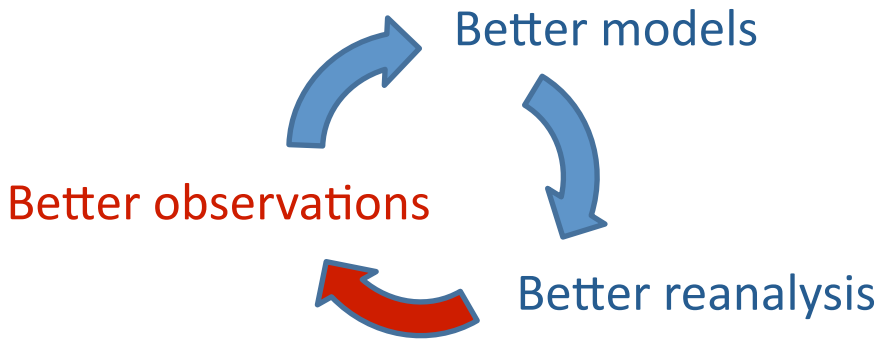
  Very large user base; science and downstream applications

- **ERA-Interim** (from 1979 onward):

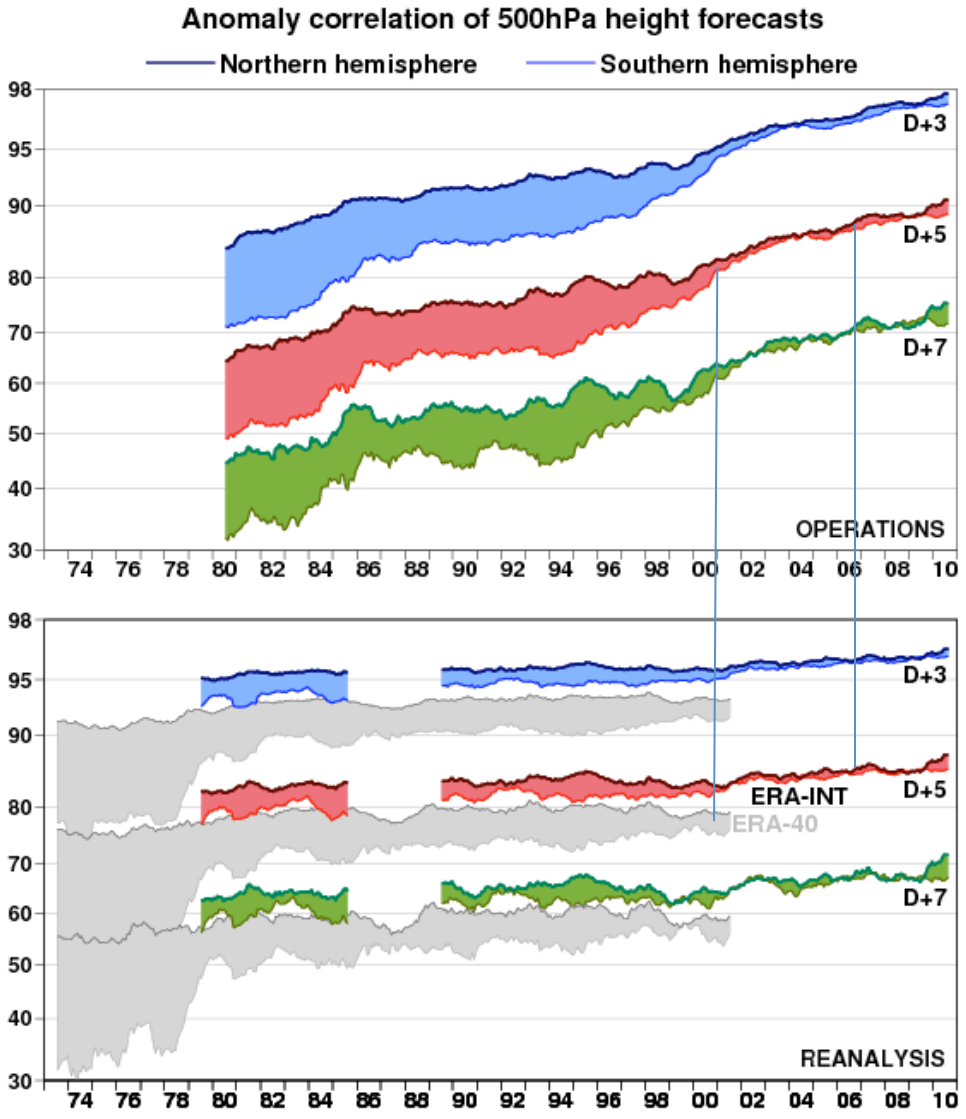
  Near-real time updates; better trends; better data services

- **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

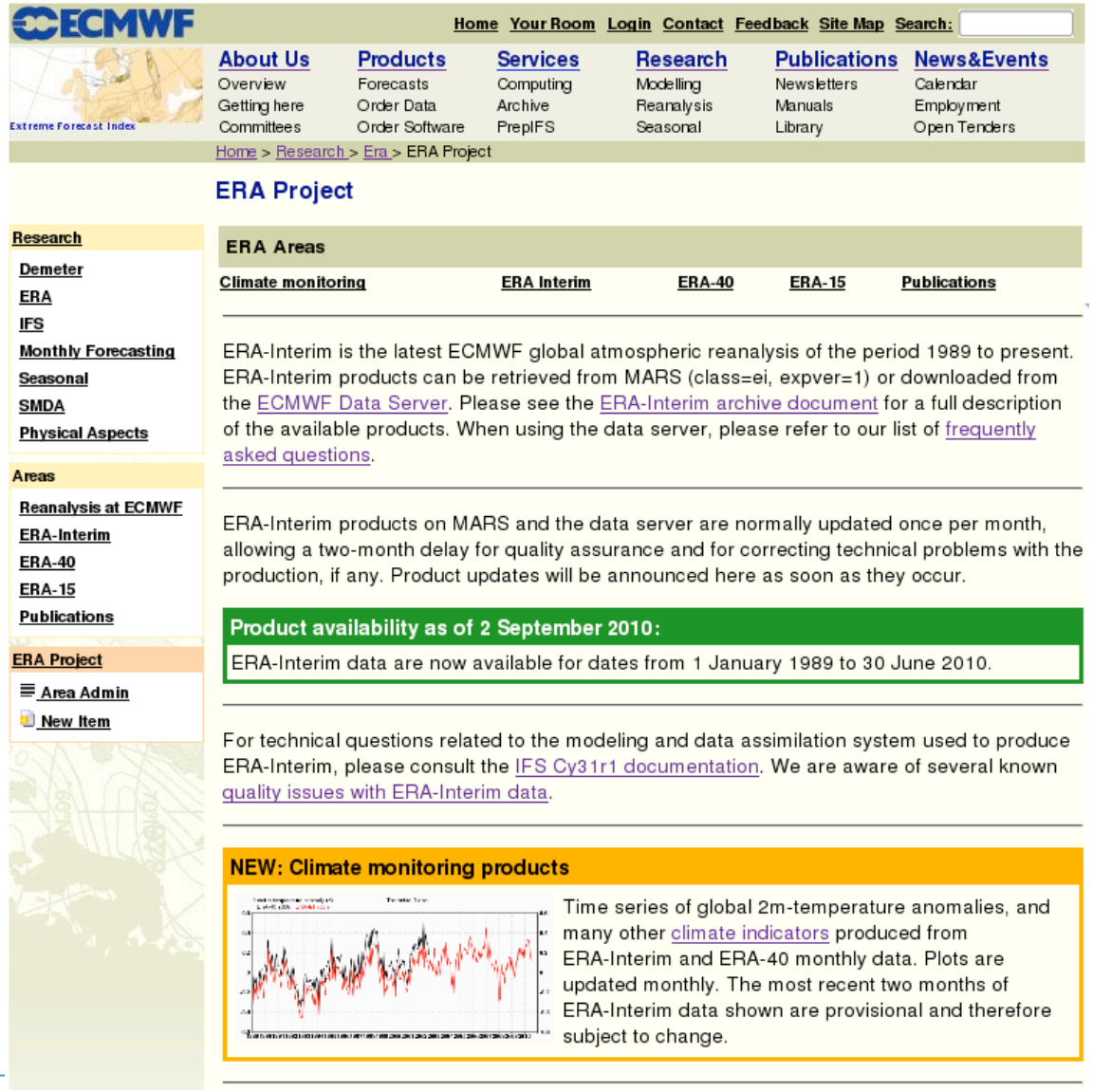
Access to reanalysis data at www.ecmwf.int/research/era

Public data server:
~7000 registered users

Data products are updated monthly

By summer 2011:
- Full resolution
- Data on model levels
- Dates from 1979

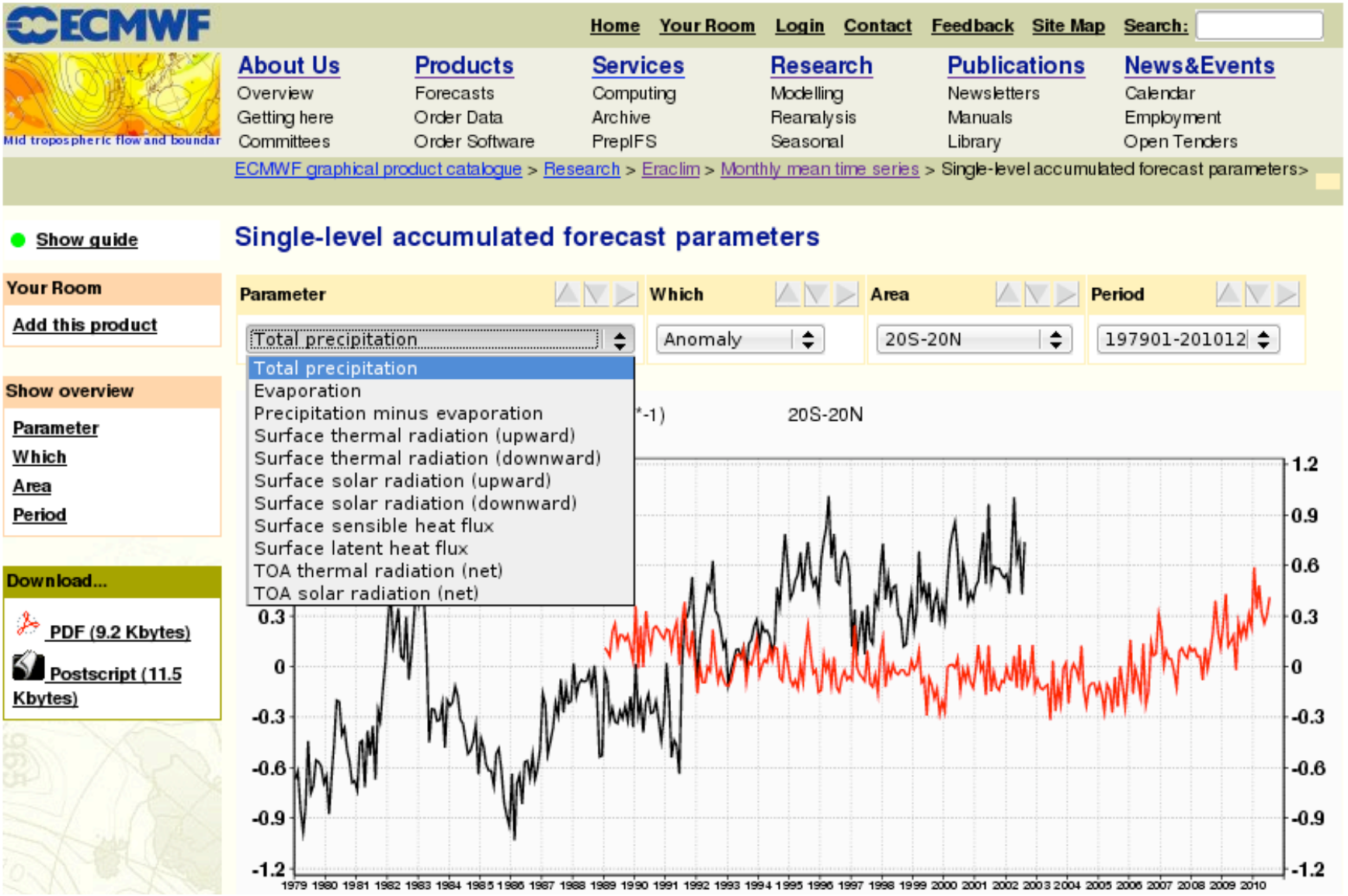
Climate change monitoring tools in development



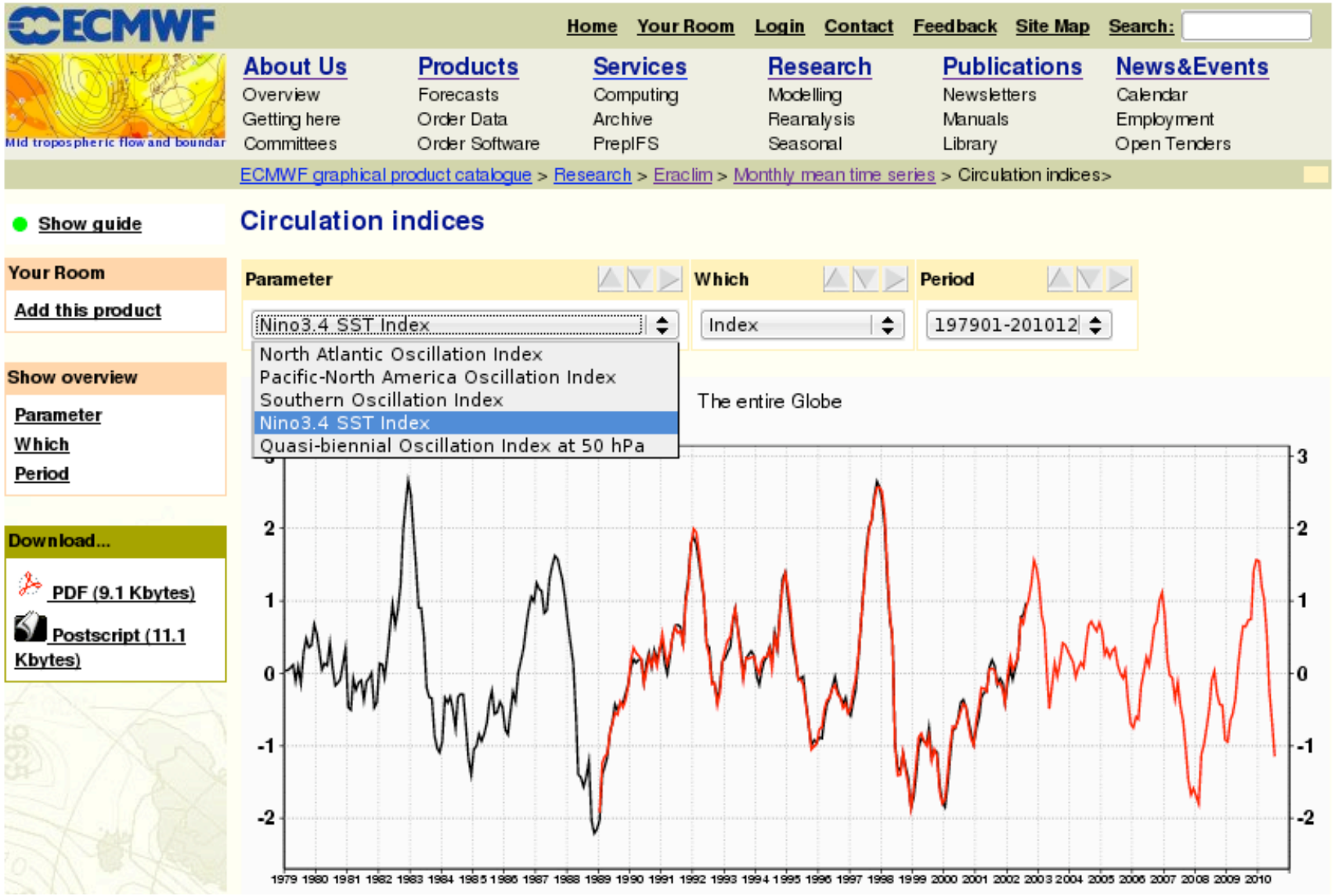
ERA CLIM

ECMWF

Time series of monthly averaged products

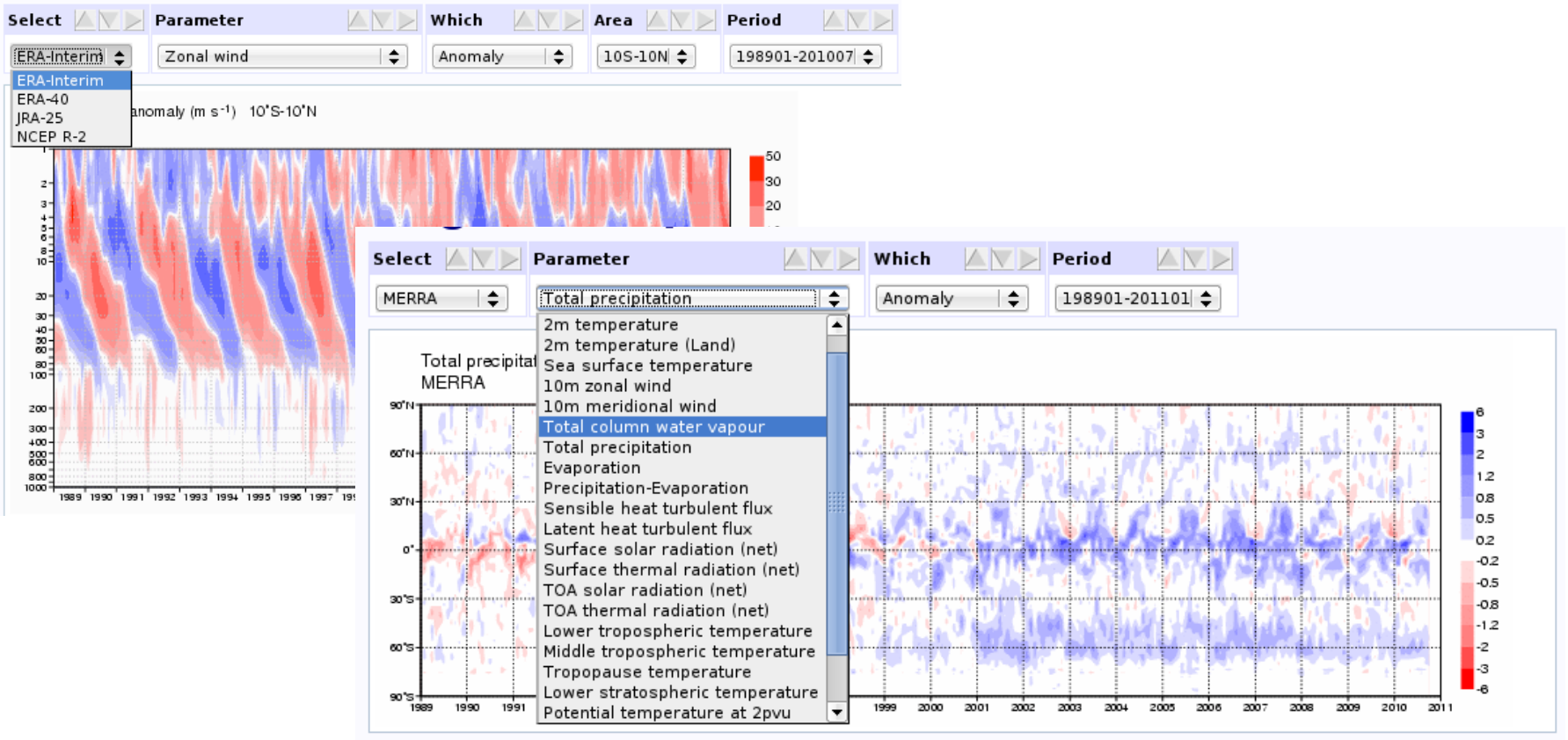


Large-scale circulation indices



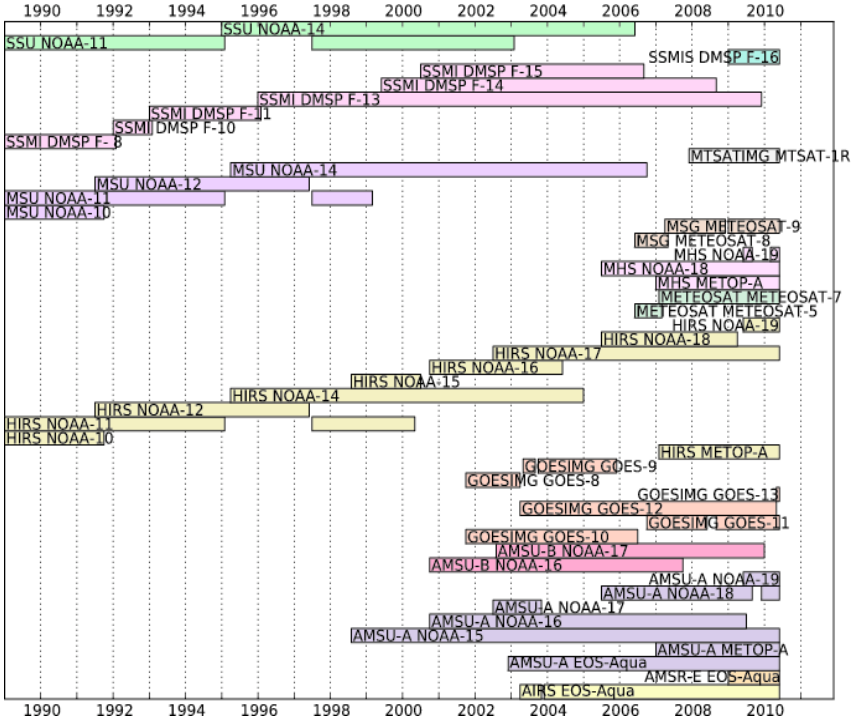
Additional climate monitoring products in development

- 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, …)

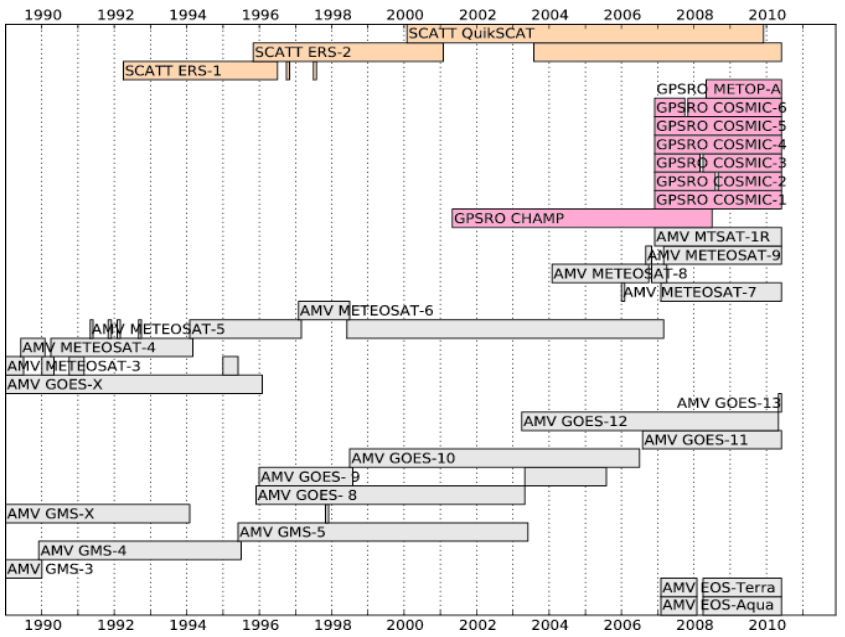


Observations used in ERA-Interim: Instruments

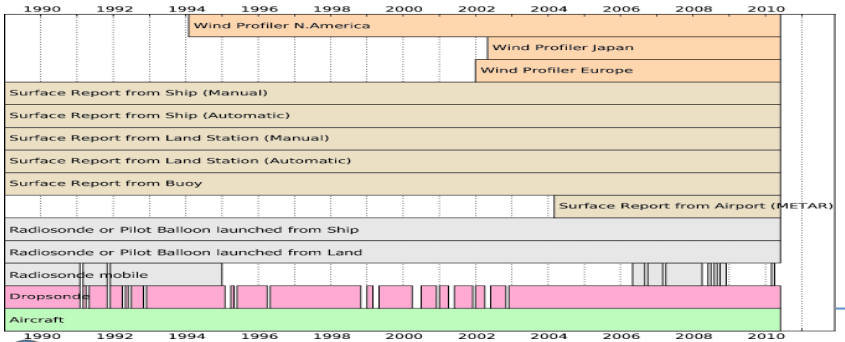
Radiances from satellites



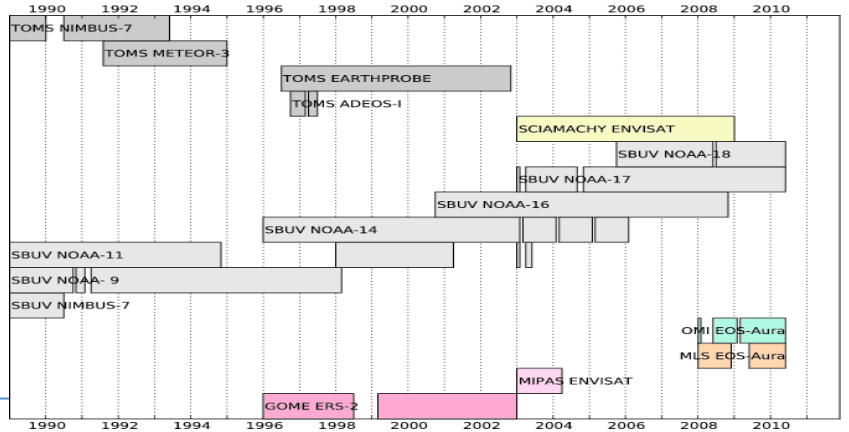
Backscatter, GPSRO, AMVs from satellites



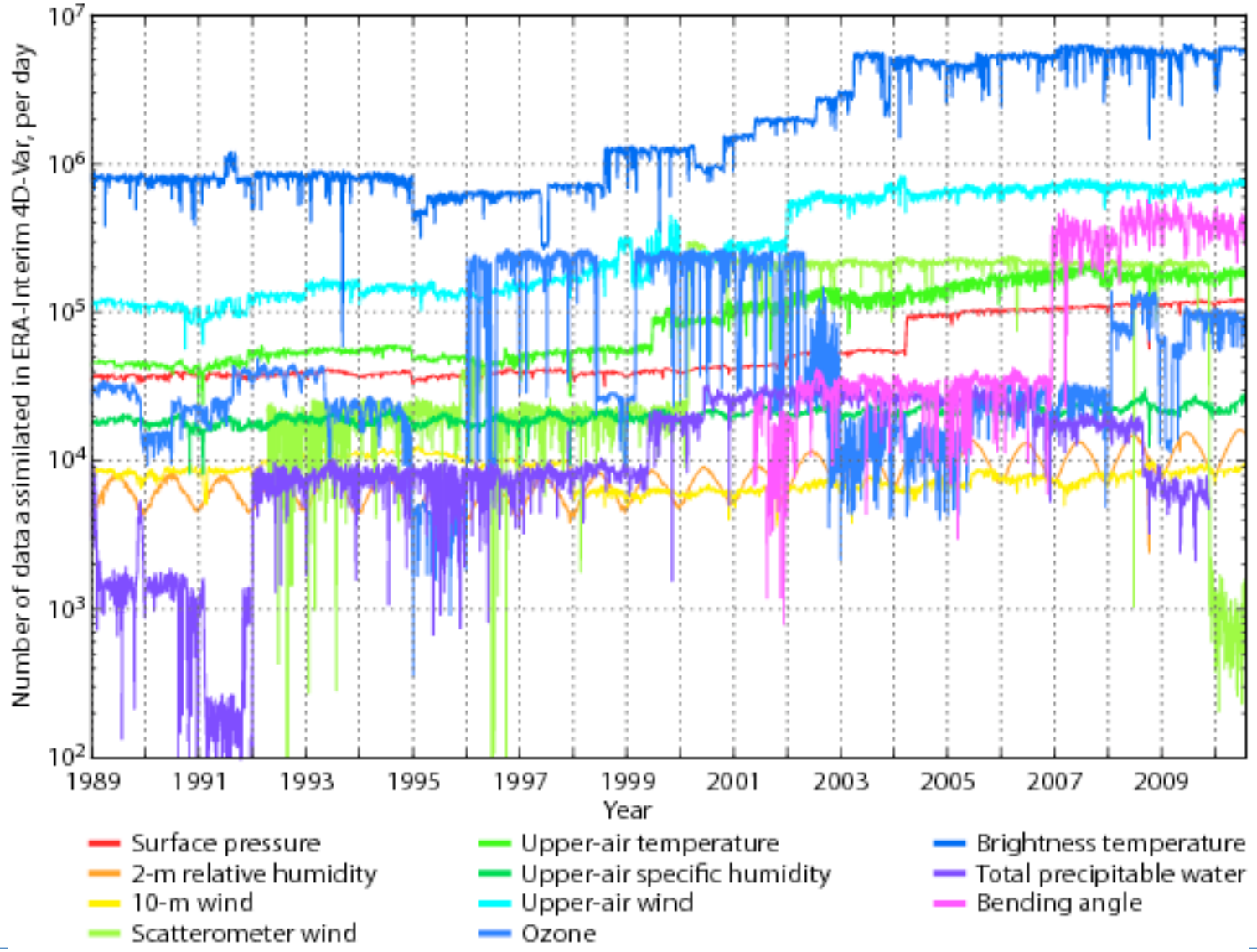
Sondes, profilers, stations, ships, buoys, aircraft



Ozone from satellites

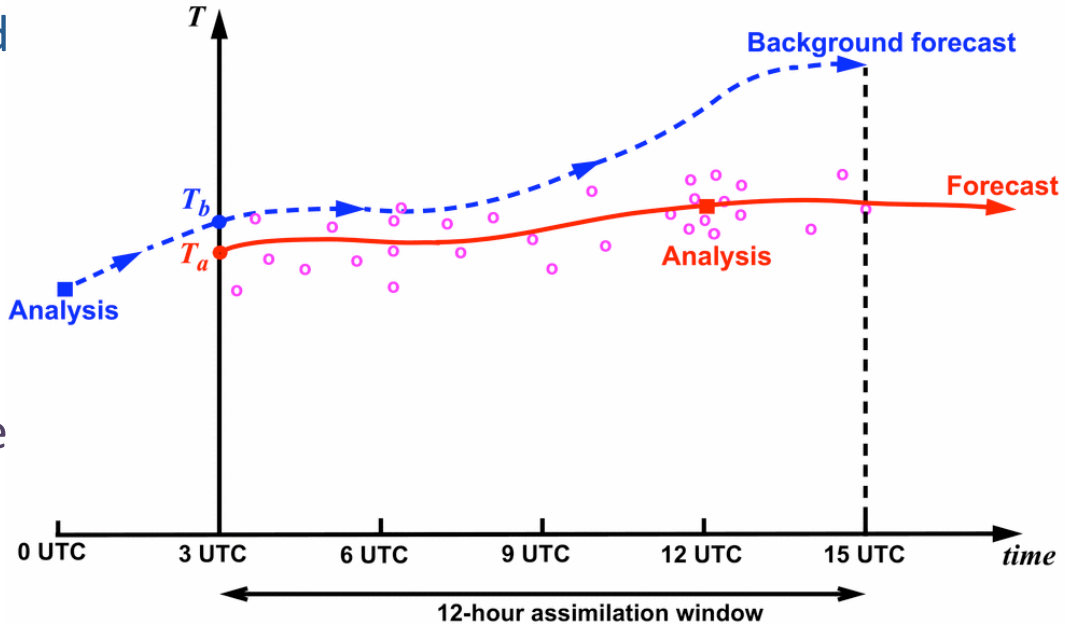


Observations used in ERA-Interim: Data counts



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



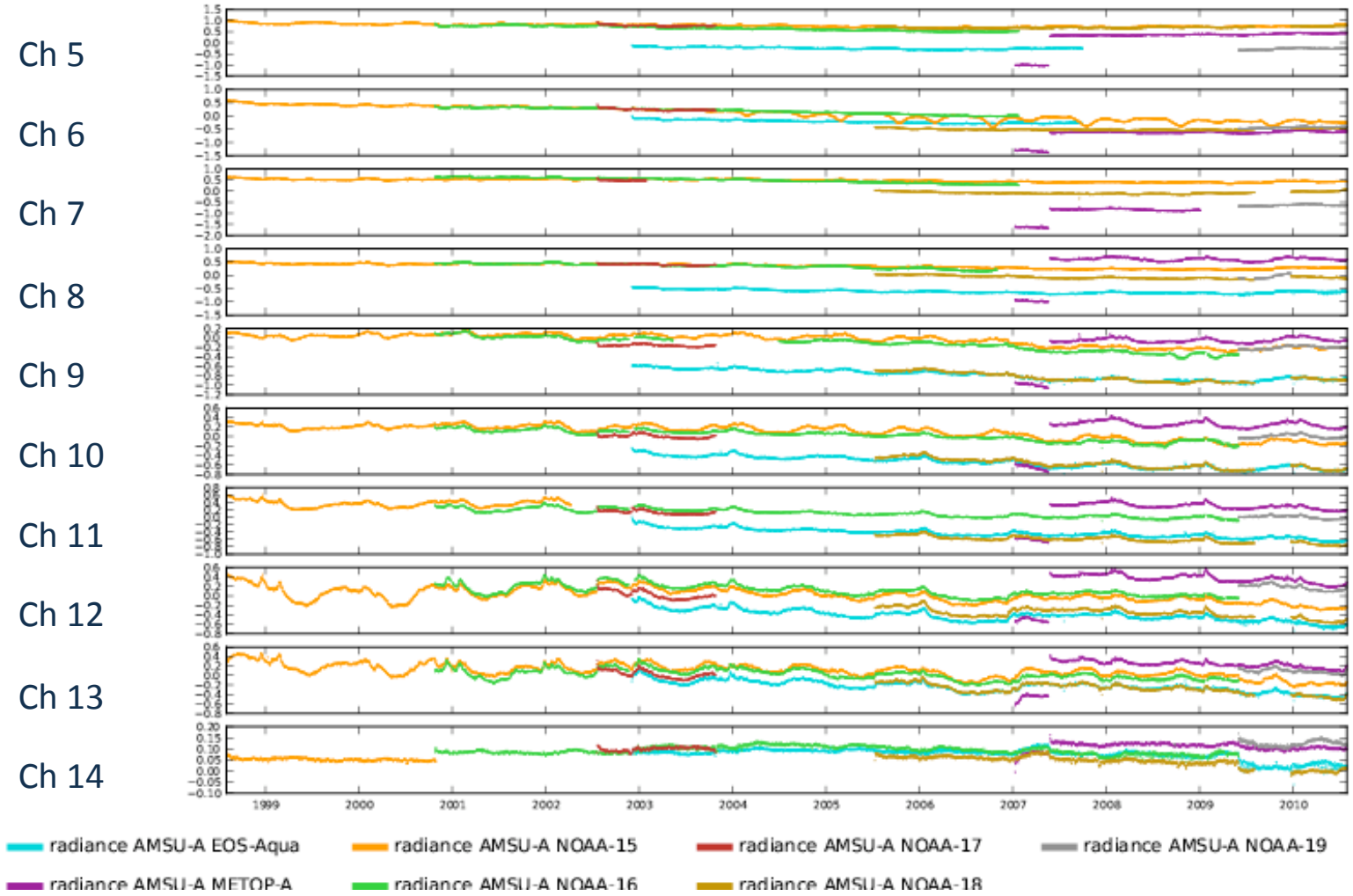
prior state constraints — prior parameter constraints

$$\mathbf{J(x,\beta)} = (\mathbf{x_b} - \mathbf{x})^{\mathrm{T}}\mathbf{B_x^{-1}}(\mathbf{x_b} - \mathbf{x}) + (\boldsymbol{\beta_b} - \boldsymbol{\beta})^{\mathrm{T}}\mathbf{B_\beta^{-1}}(\boldsymbol{\beta_b} - \boldsymbol{\beta}) + \left[\mathbf{y} - \mathbf{b_o}(\mathbf{x},\boldsymbol{\beta}) - \mathbf{h(x)}\right]^{\mathrm{T}}\mathbf{R^{-1}}\left[\mathbf{y} - \mathbf{b_o}(\mathbf{x},\boldsymbol{\beta}) - \mathbf{h(x)}\right]$$

observational constraints

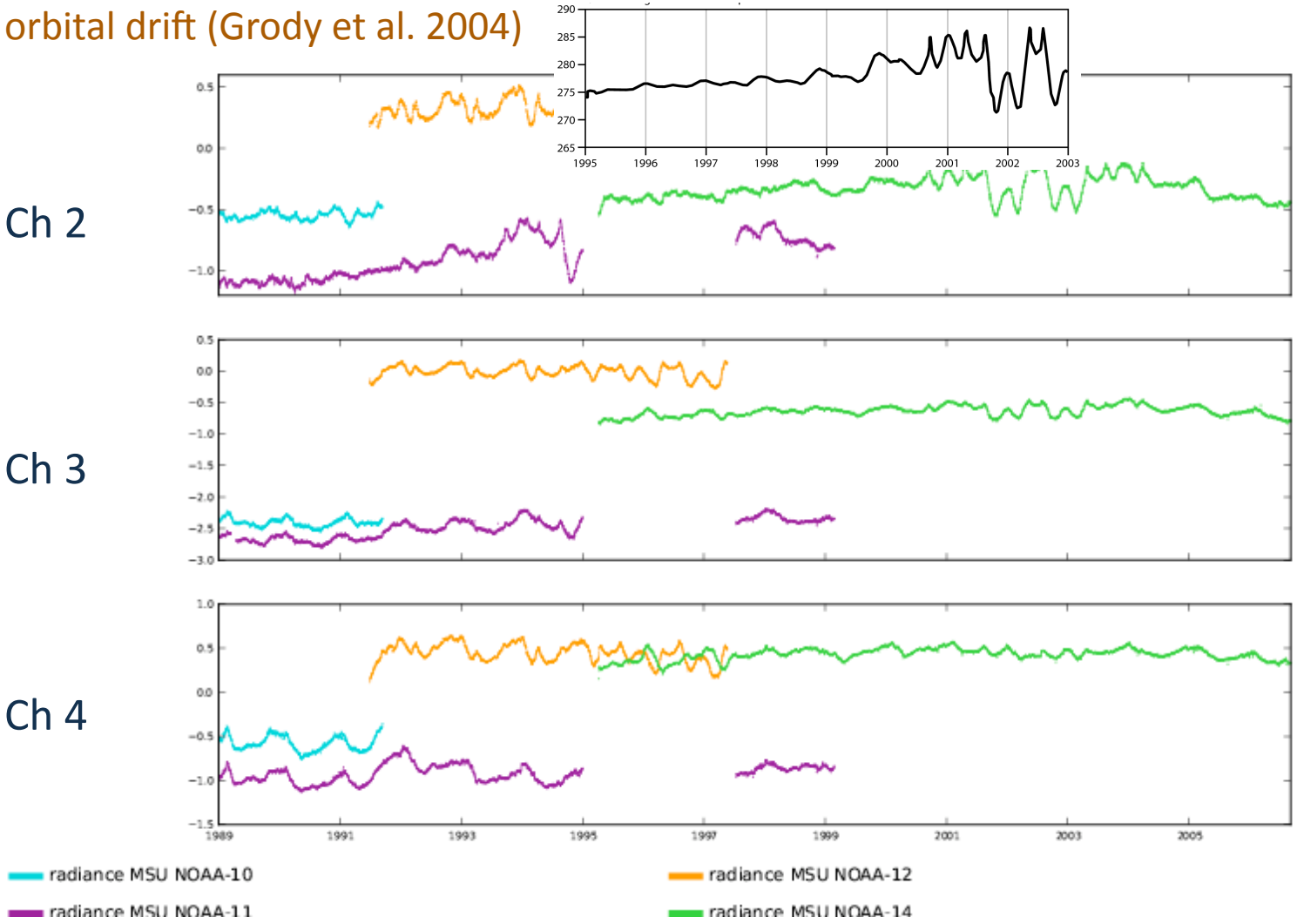
Variational bias adjustments for satellite radiances

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



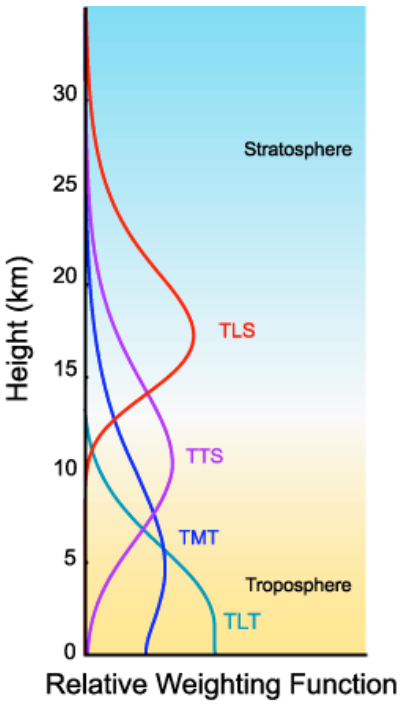
Independent verification of MSU bias estimates

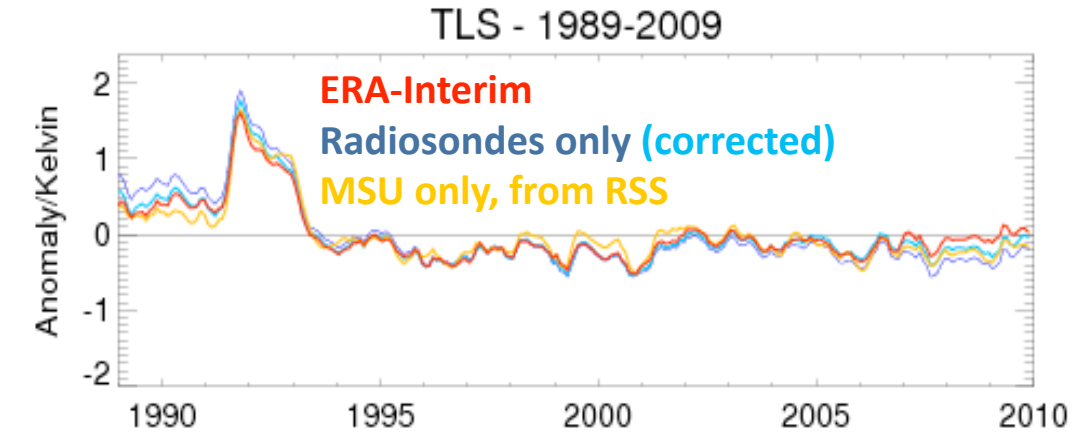
Record of on-board warm-target temperature changes for NOAA-14, due to orbital drift (Grody et al. 2004)

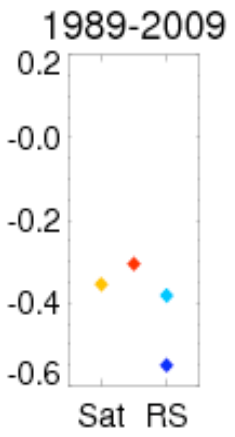


How accurate are trend estimates from reanalysis?

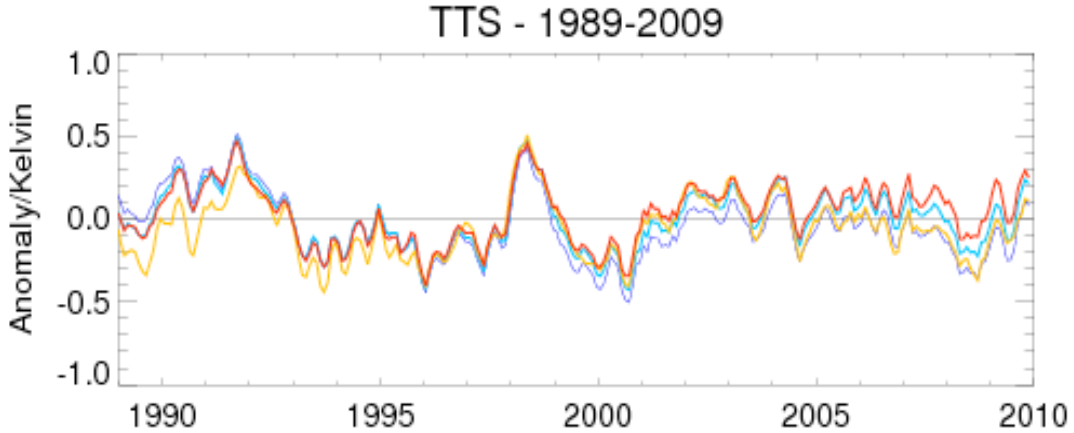
Global mean temperatures, for MSU-equivalent vertical averages:

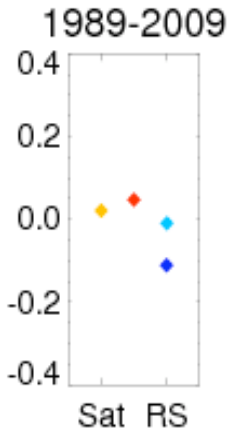






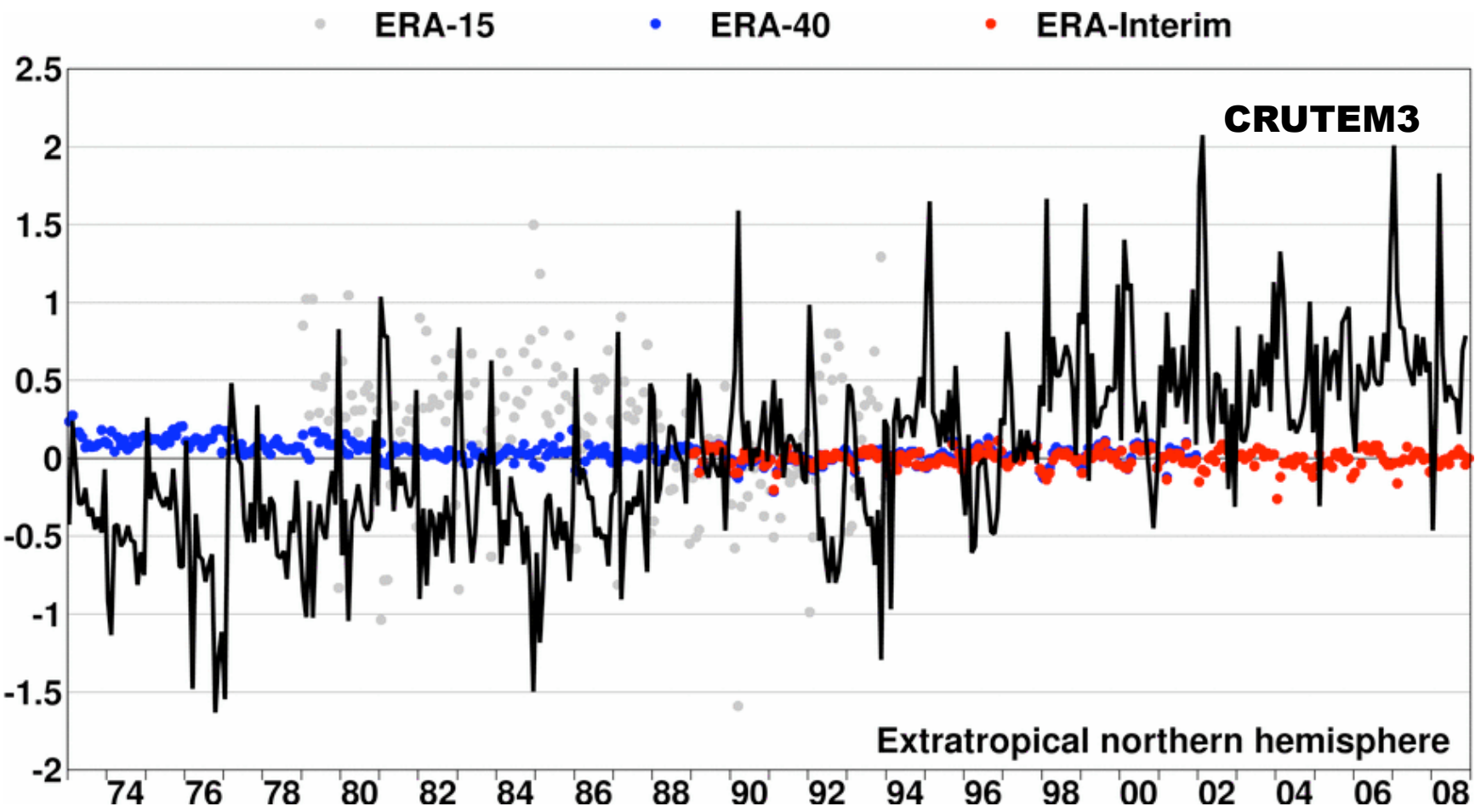
Trends





Time series of 2m land temperature anomalies (K)

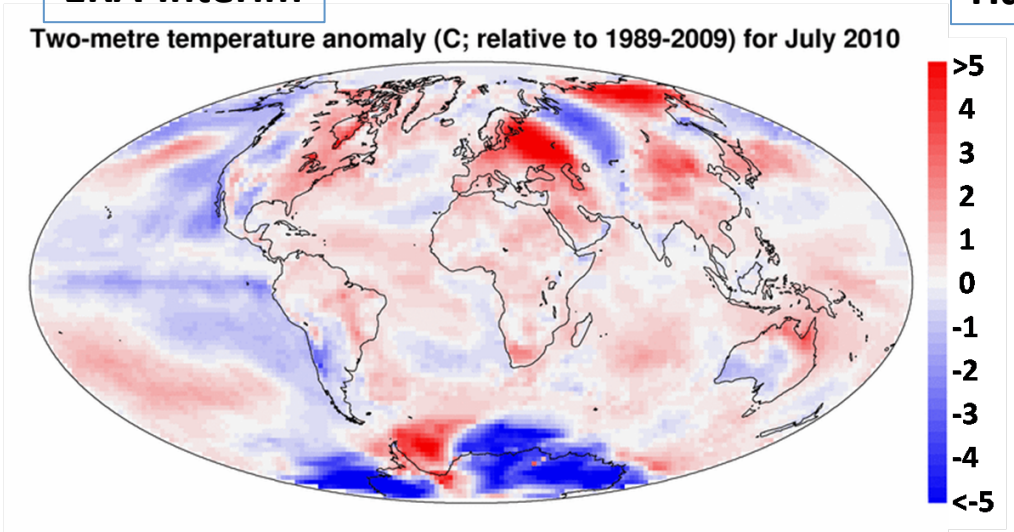
Differences of monthly values from CRUTEM3



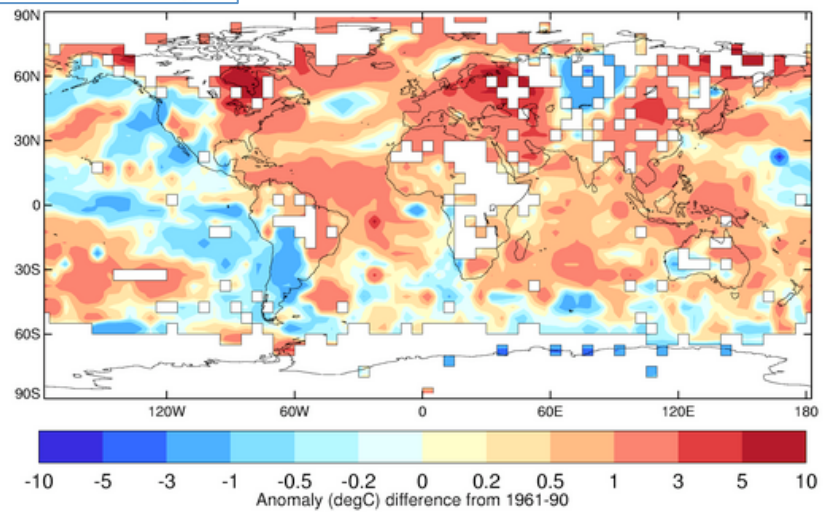
ERA sampled as CRUTEM3 (Brohan et al., 2006) following Simmons et al. (2004)

Climate change monitoring

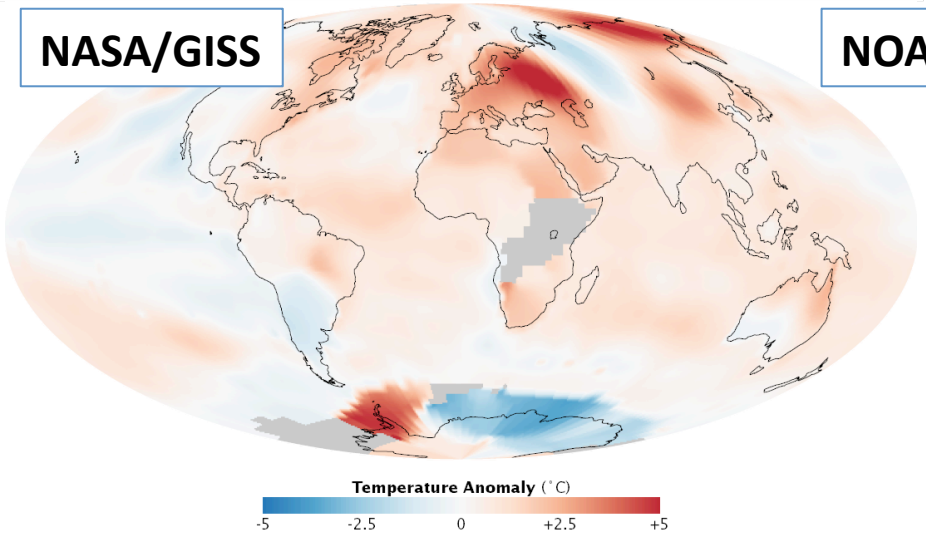
ERA-Interim



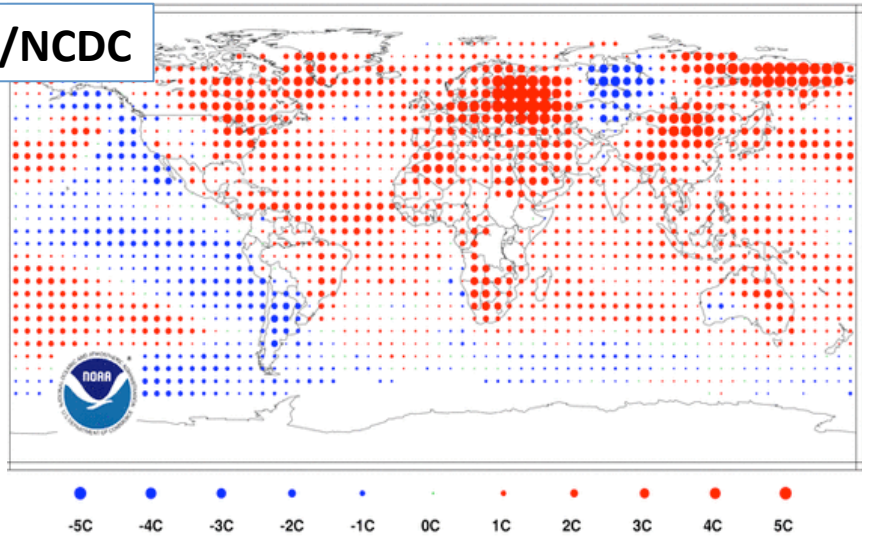
Hadley Centre



NASA/GISS

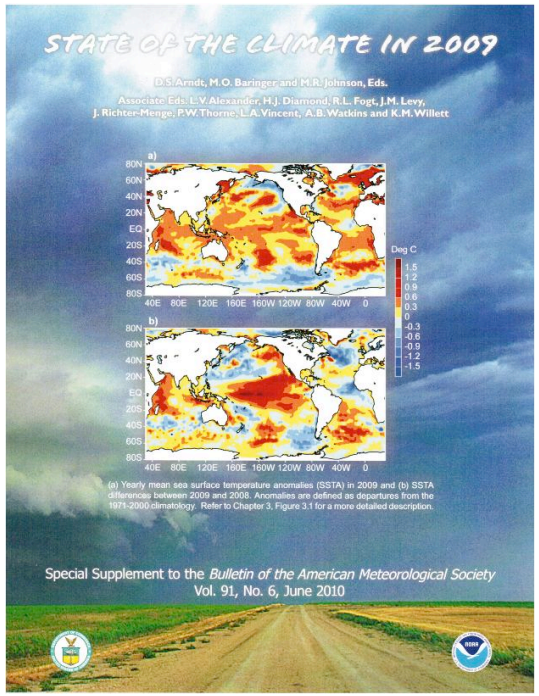


NOAA/NCDC

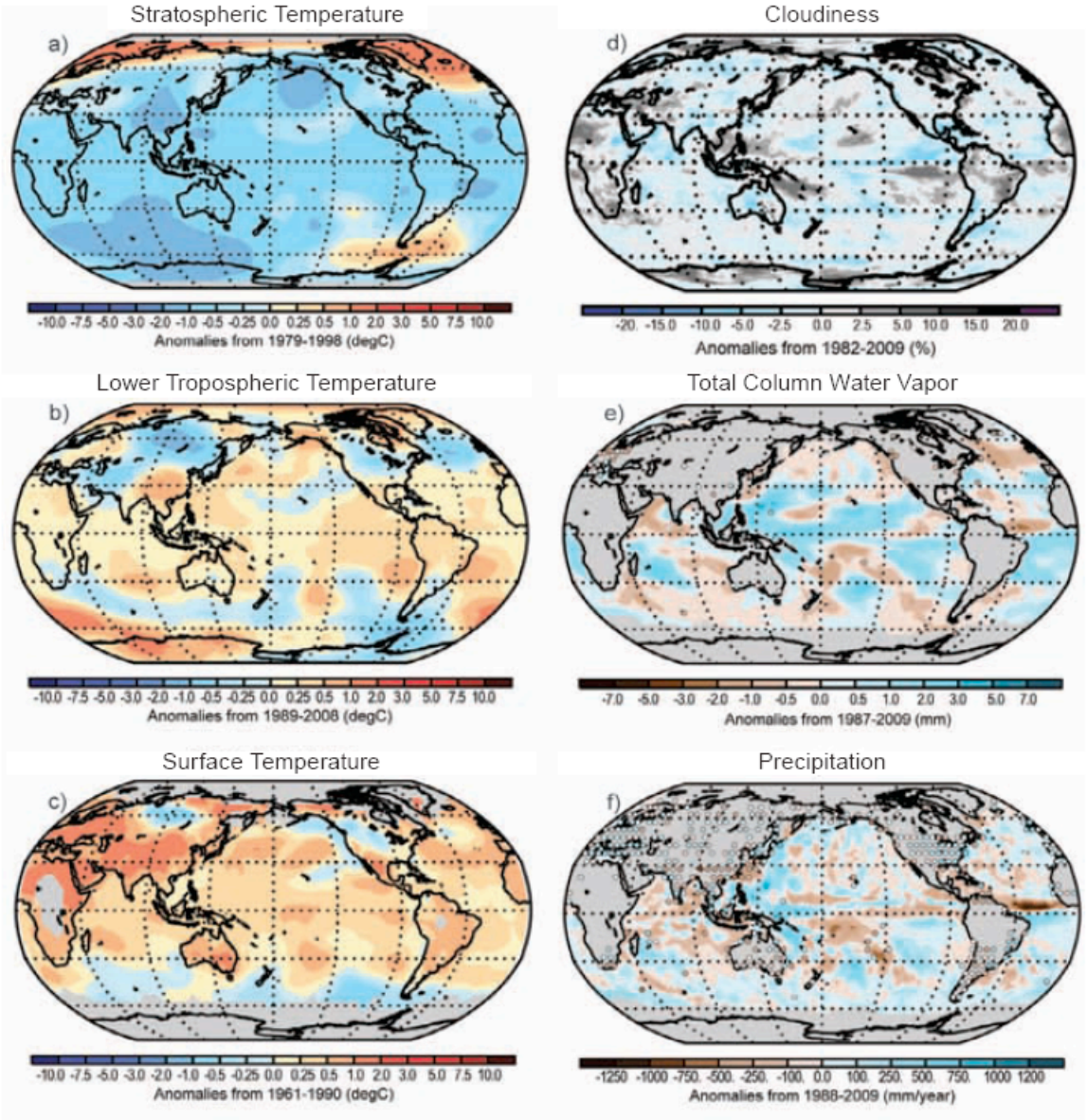


BAMS State of the Climate

Growing use of reanalysis for climate monitoring



Caution is still advised!

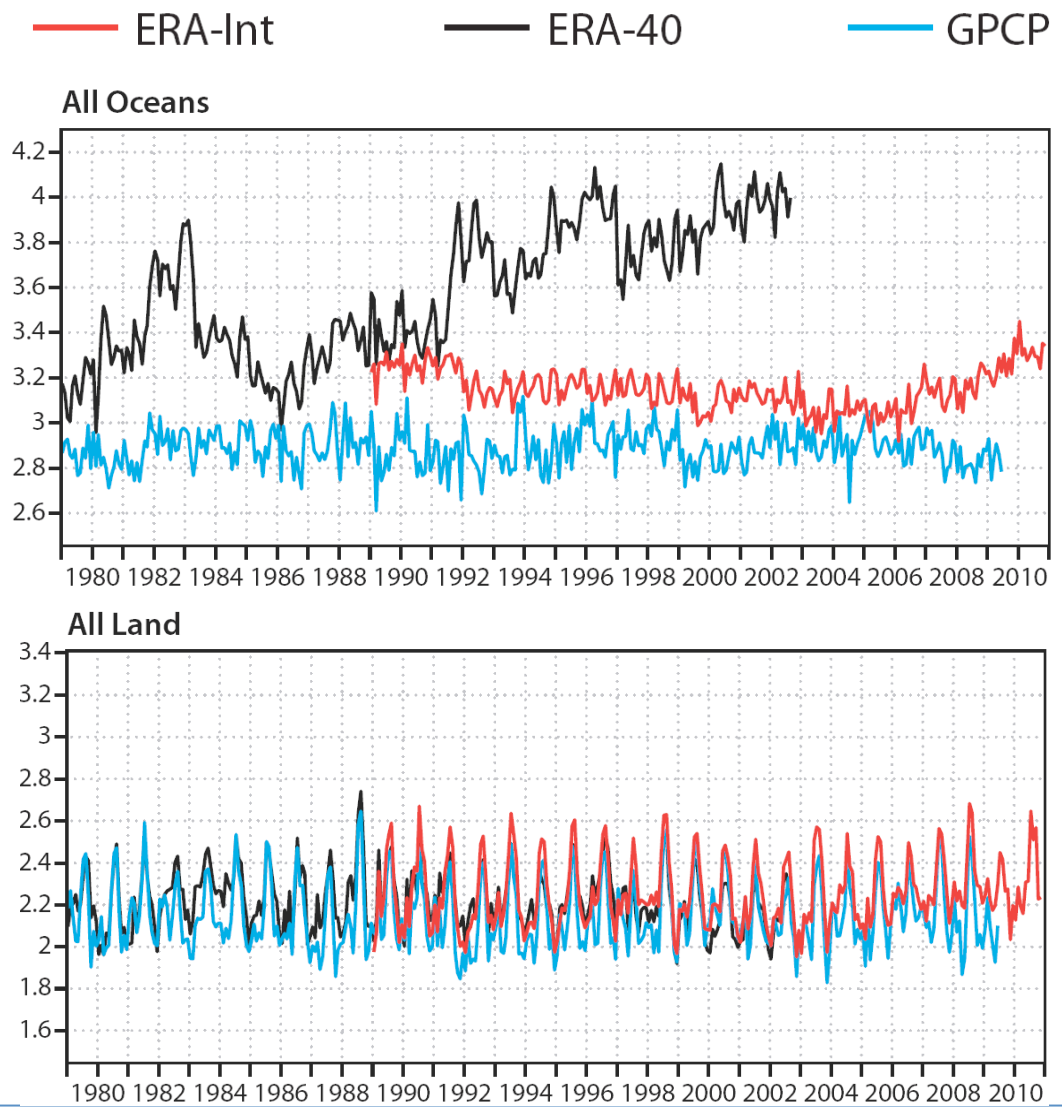


Larger uncertainties in precipitation trends

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

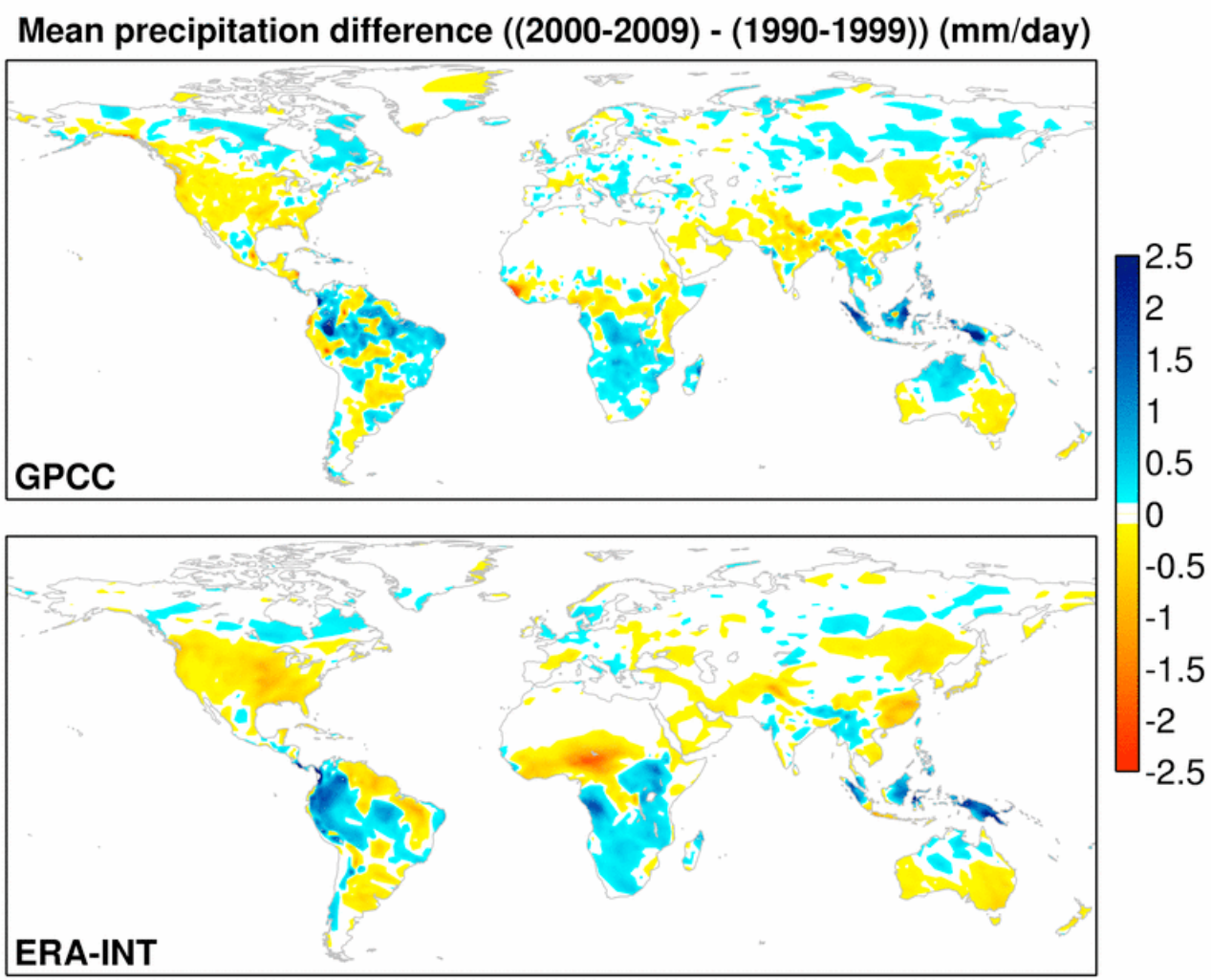
Reanalysis estimates of rainfall over ocean are still problematic

Results over land are much better

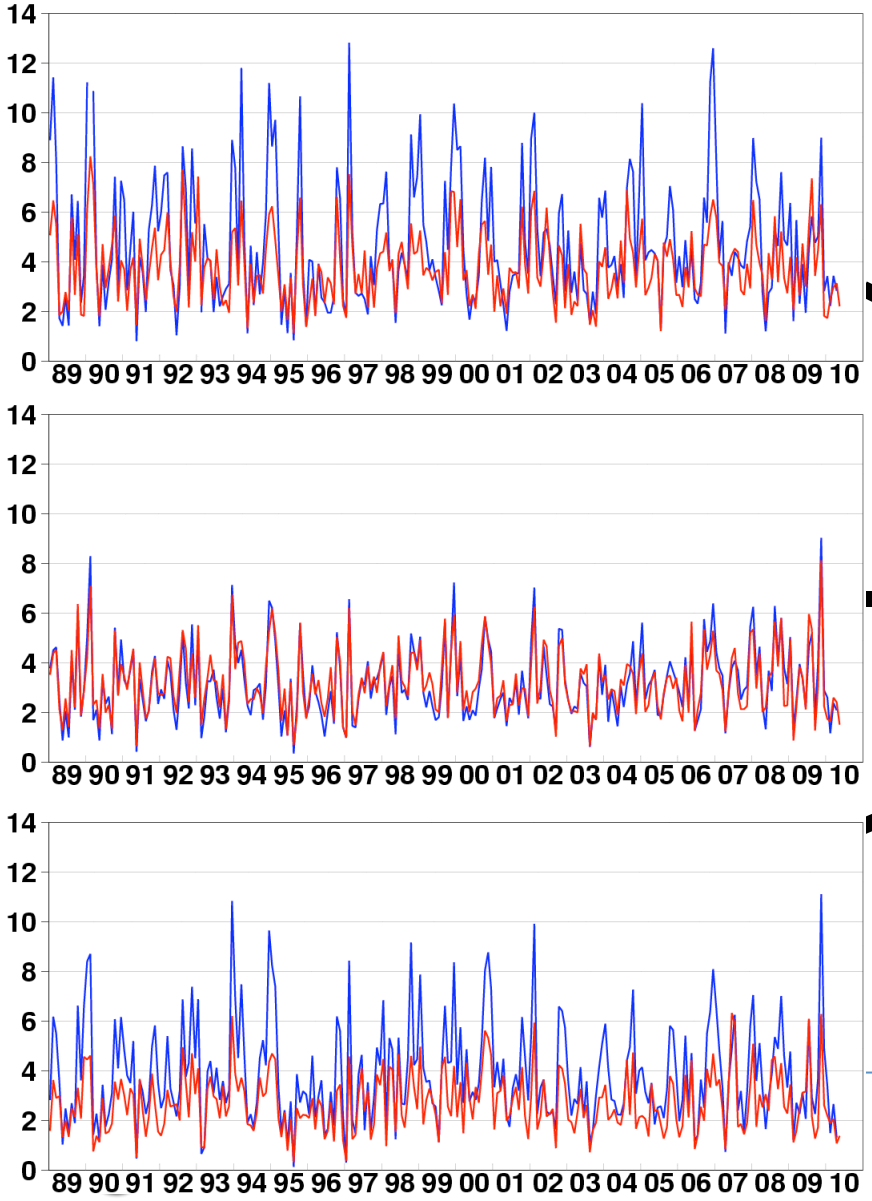


Larger uncertainties in precipitation trends

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

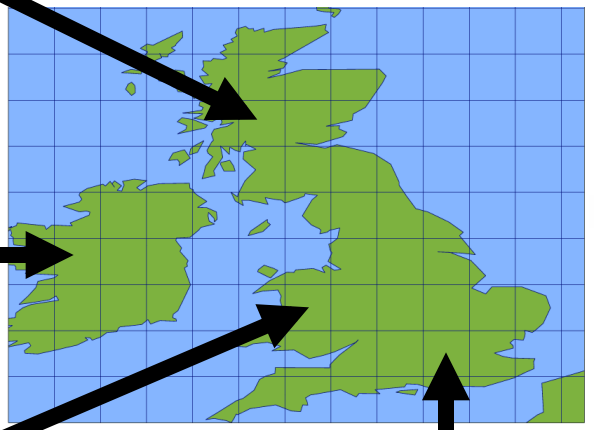


Monthly precipitation rates for 1^{O}x1^{O} grid boxes

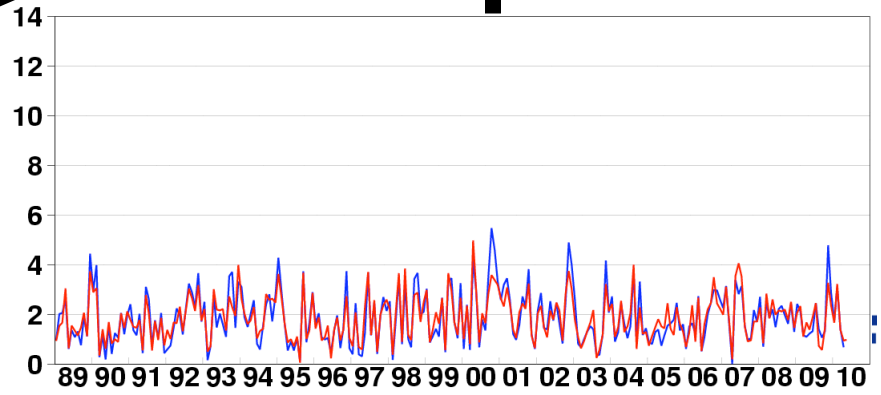


ERA values are interpolated from ~80km model grid to 1^{O} grid of GPCC product

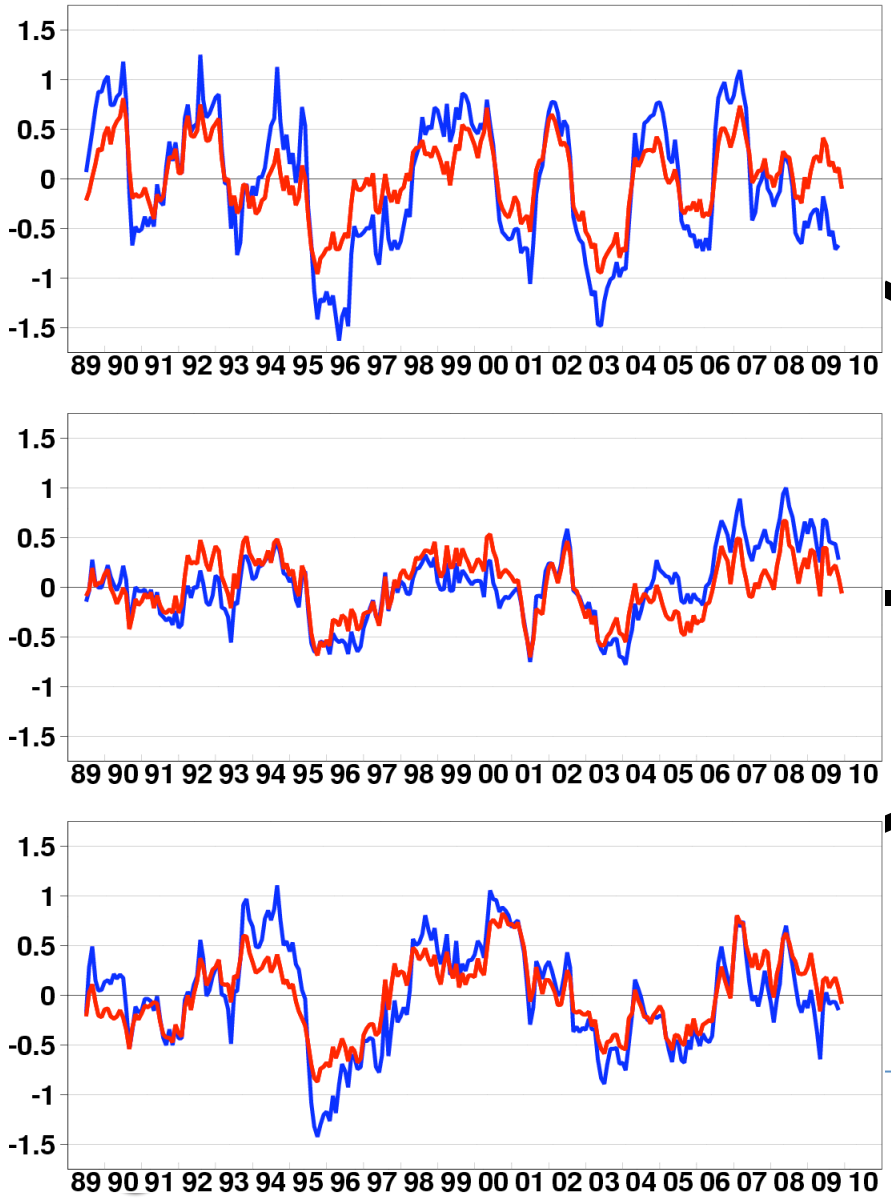
ERA values underestimate precipitation maxima for mountainous regions of Wales, Scotland and northern England



ERA-Interim
GPCC
(mm/day)

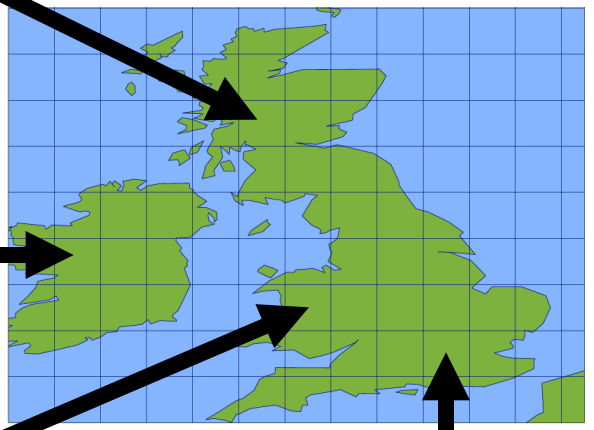


Precipitation anomalies for $1^{O}x1^{O}$ grid boxes



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.



ERA-Interim
GPCC
(mm/day)

Stratosphere

Topics:

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

Particle dispersion

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

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

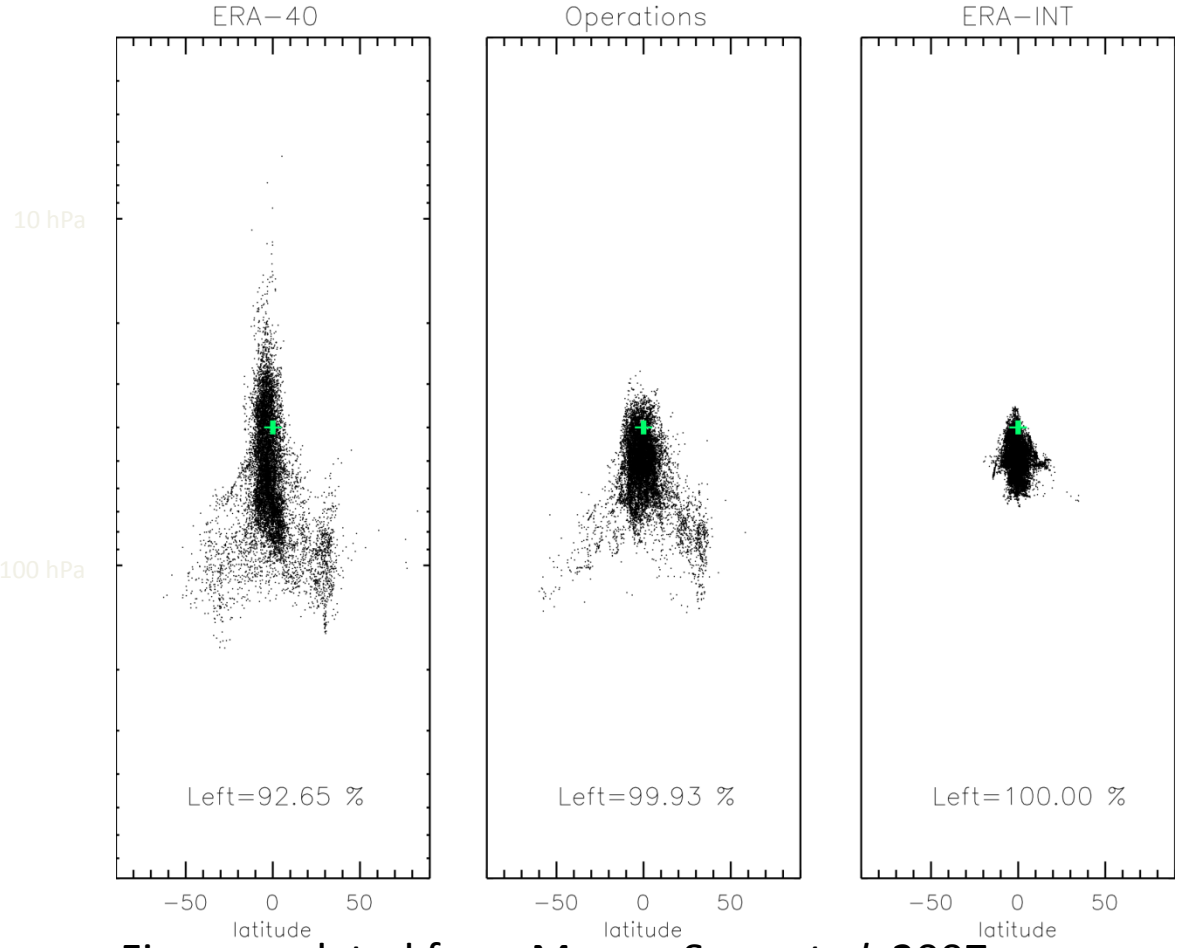


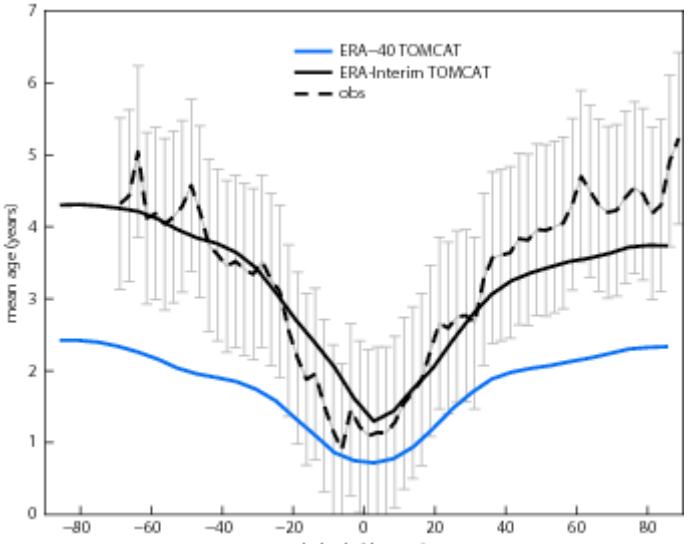
Figure updated from Monge-Sanz *et al.* 2007

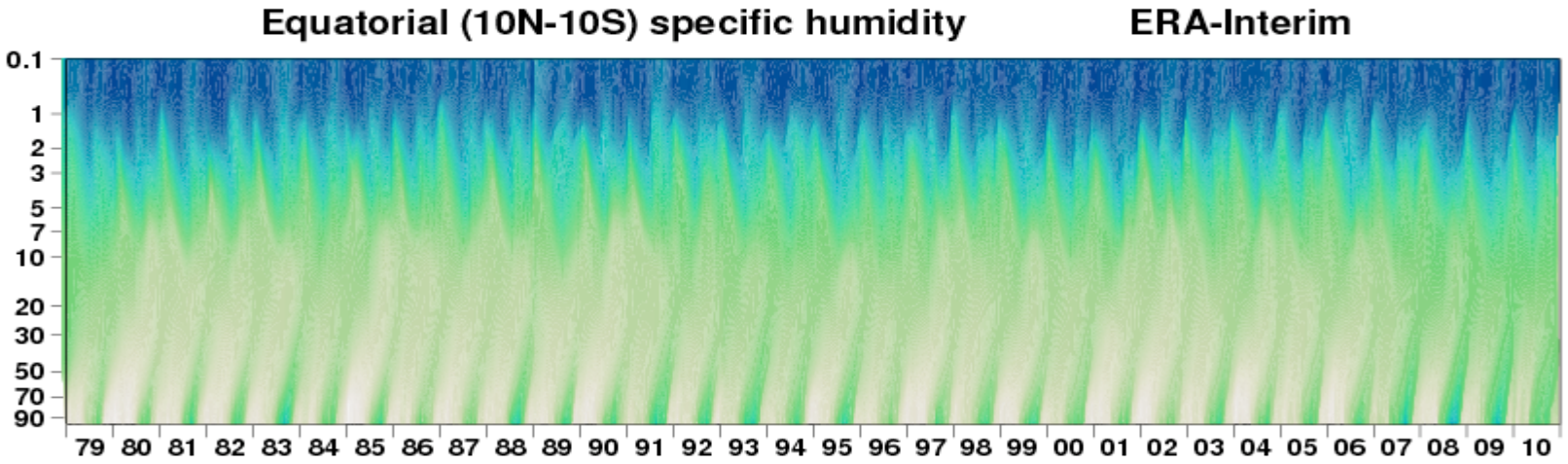
Stratospheric circulation

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

Likely due to 4D-Var and VarBC

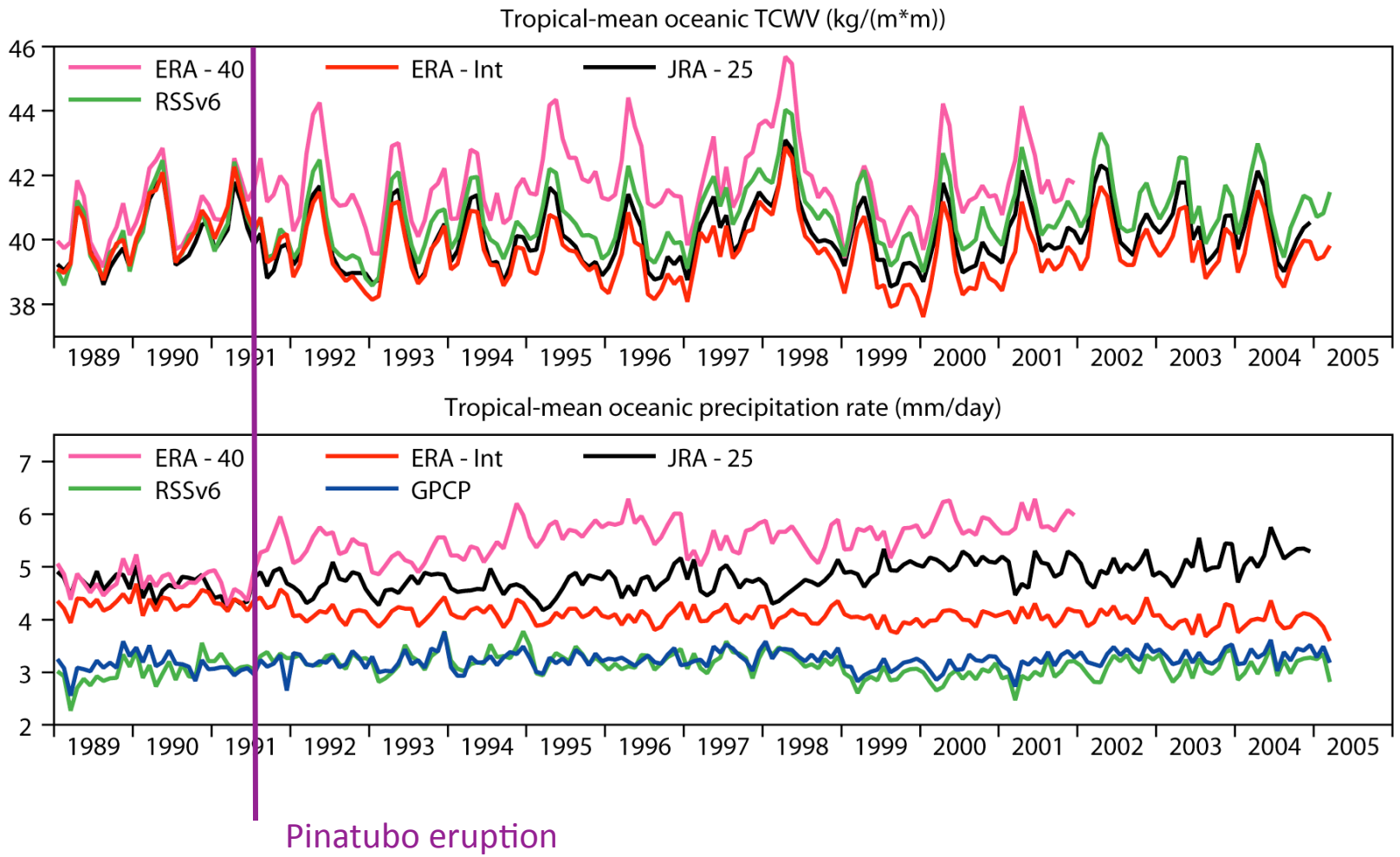
Mean age of air at 20km





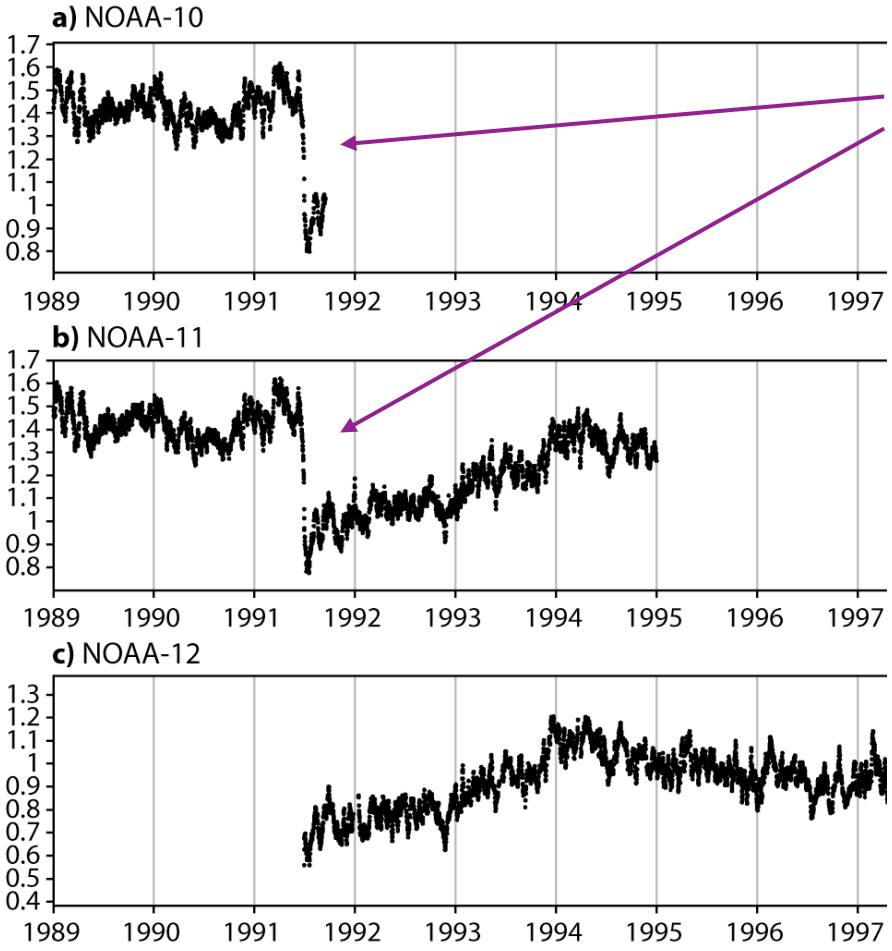
Response to Pinatubo eruption

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:

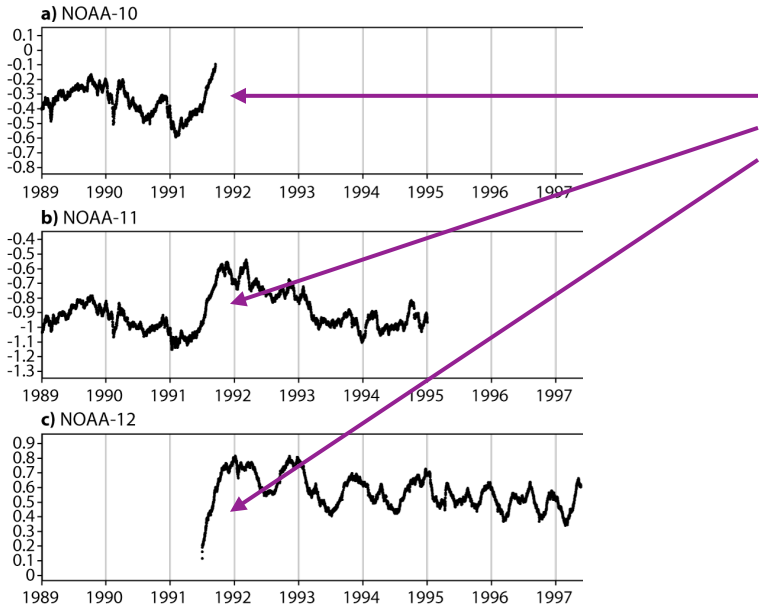
- Cooling effect on radiances
- Not in the radiative transfer model
- ERA-Interim: Change the bias correction
- ERA-40: Change the humidity increments

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

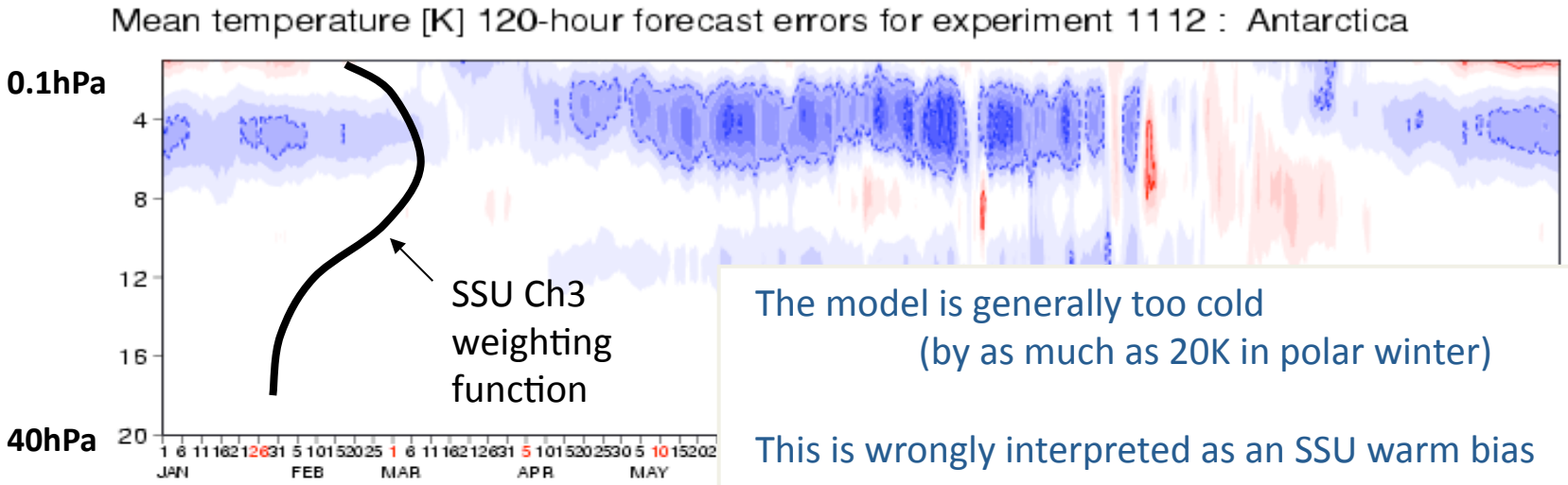
The result is a **slight damping of the Pinatubo signal** in ERA-Interim

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

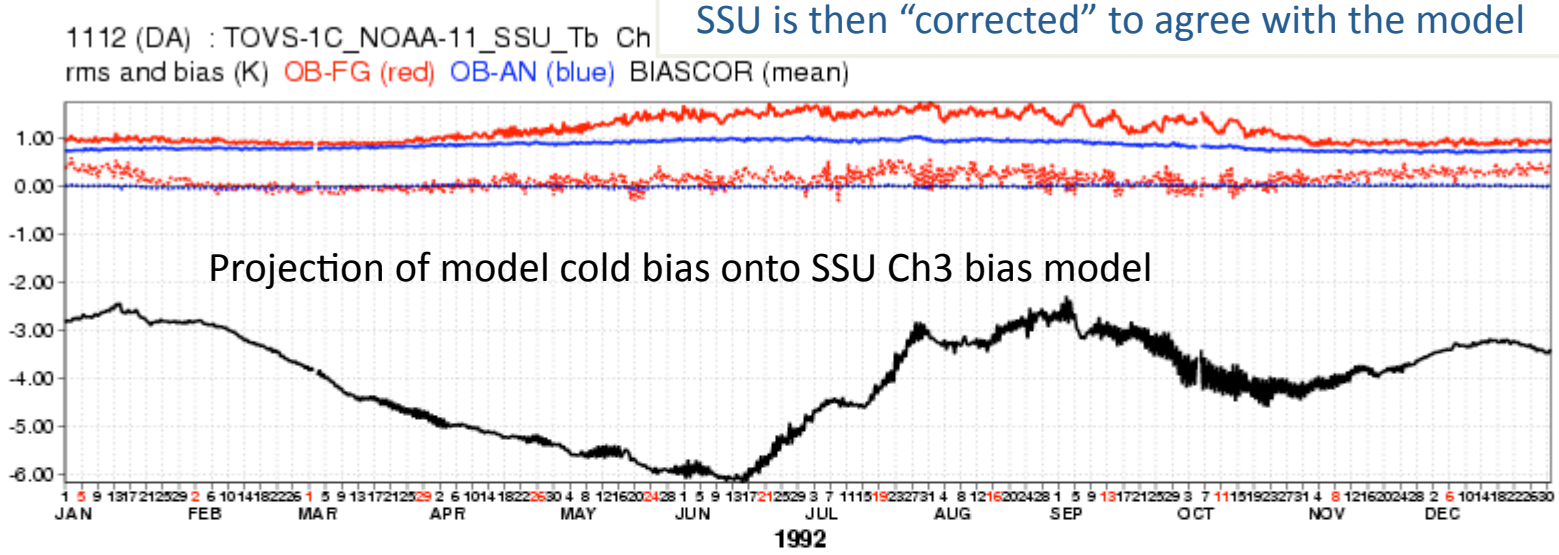
More on VarBC: Interaction with model bias



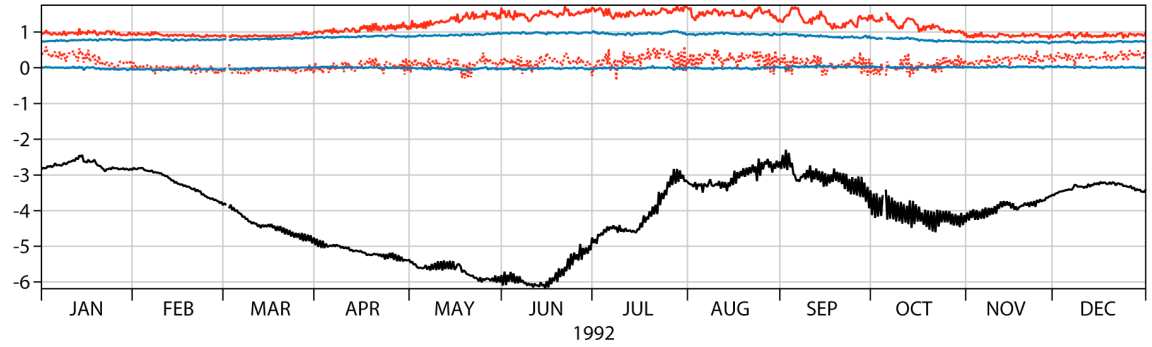
The model is generally too cold
(by as much as 20K in polar winter)

This is wrongly interpreted as an SSU warm bias

SSU is then "corrected" to agree with the model



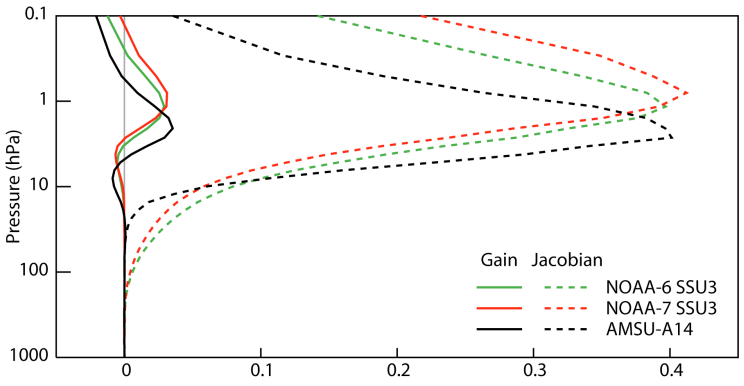
How to constrain model biases in the upper stratosphere?



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

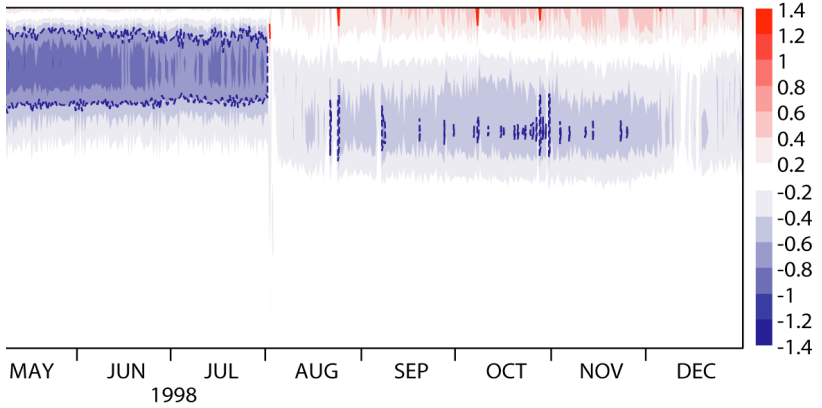
The top of the model must be constrained by uncorrected observations:
SSU Ch3 (available until 2006), AMSU-A Ch14 (available from 1998)

Jacobians for SSU3 and AMSUA-14



The constraints provided by each sensor are fundamentally different

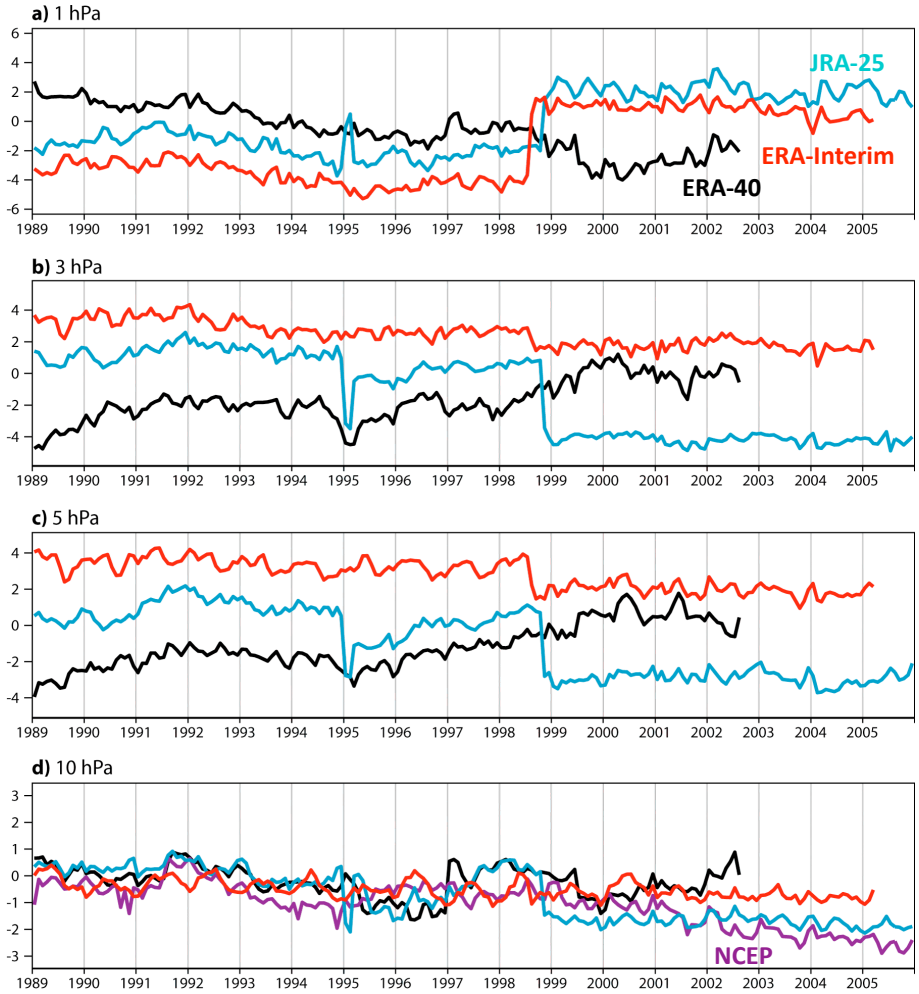
Global mean temperature increments above 40hPa



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

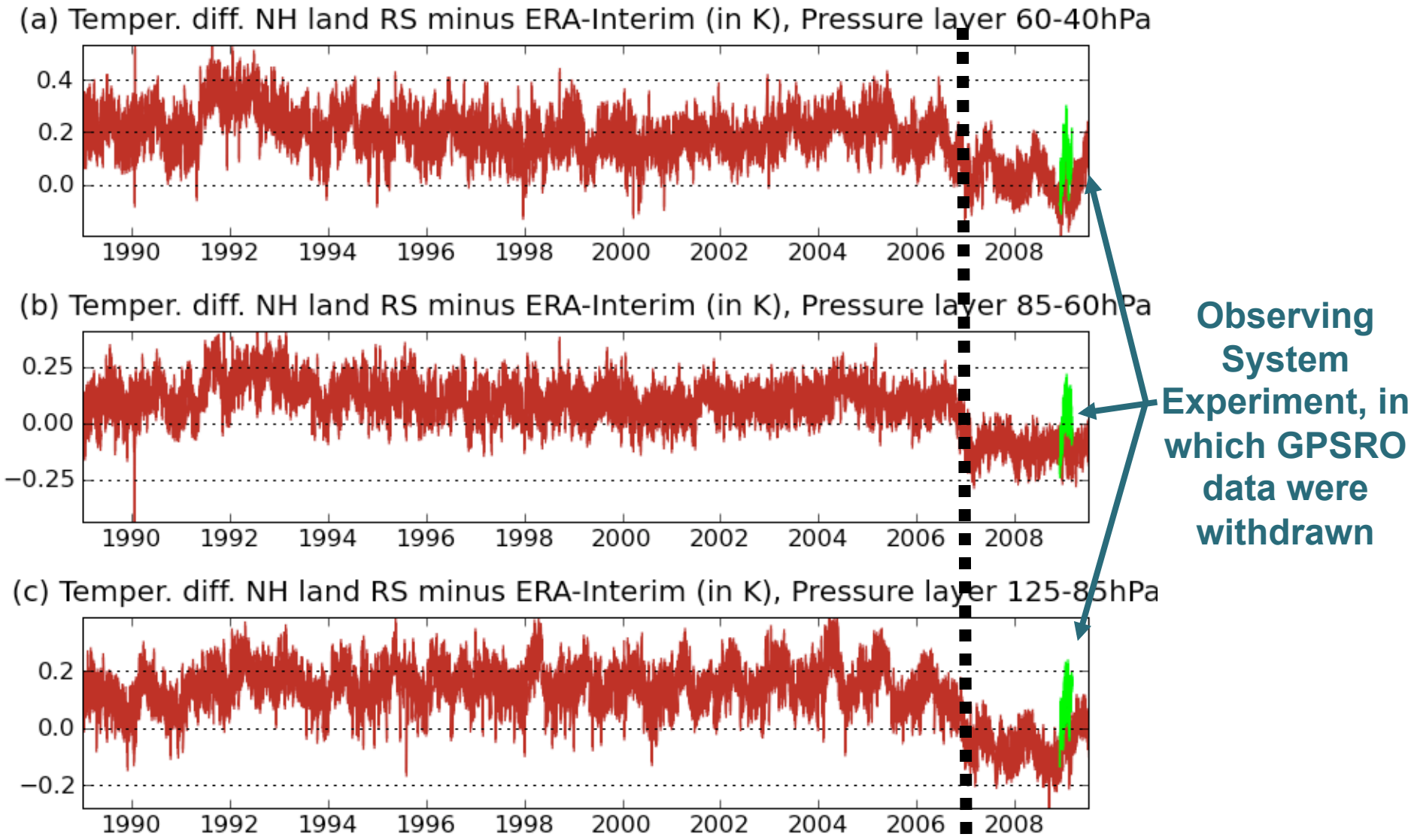


The transition from SSU Ch3 to AMSU-A Ch14 is clearly visible in global mean temperatures at 5hPa and above

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)

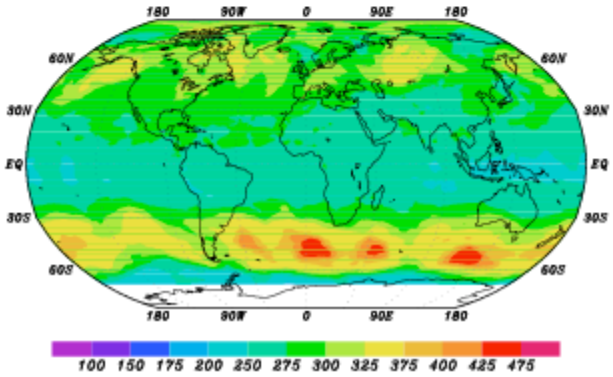


Observing System Experiment, in which GPSRO data were withdrawn

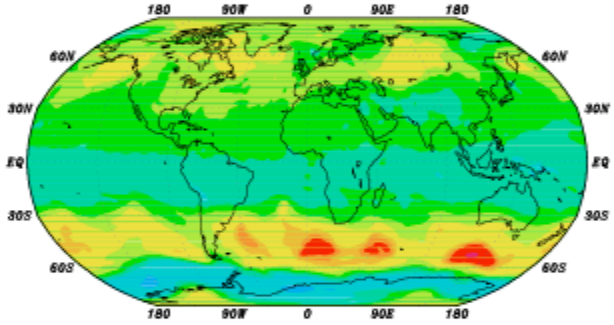
Ozone assimilation

Can ozone data be used to infer stratospheric winds?

Total ozone from TOMS
(August 1996)



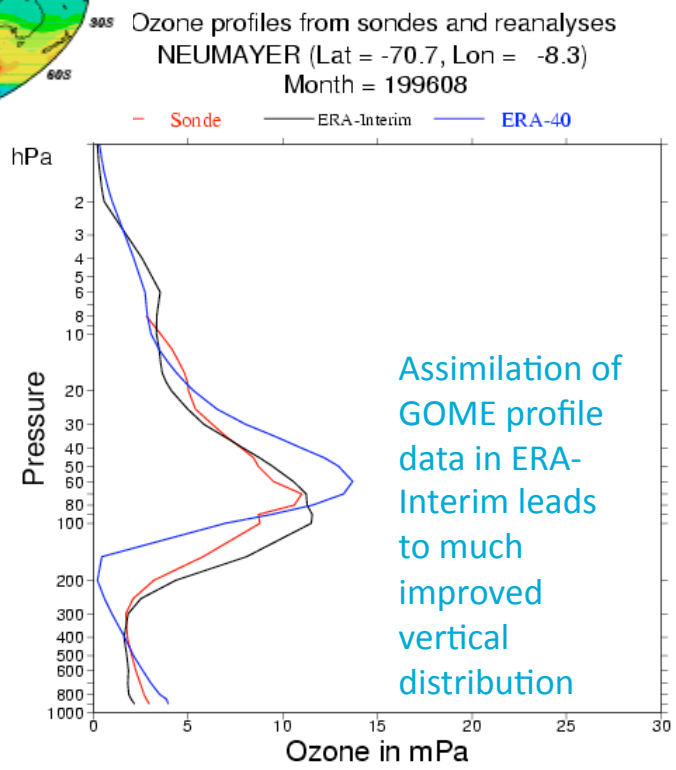
ERA-Interim
(TOMS + SBUV + GOME)



Ozone 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

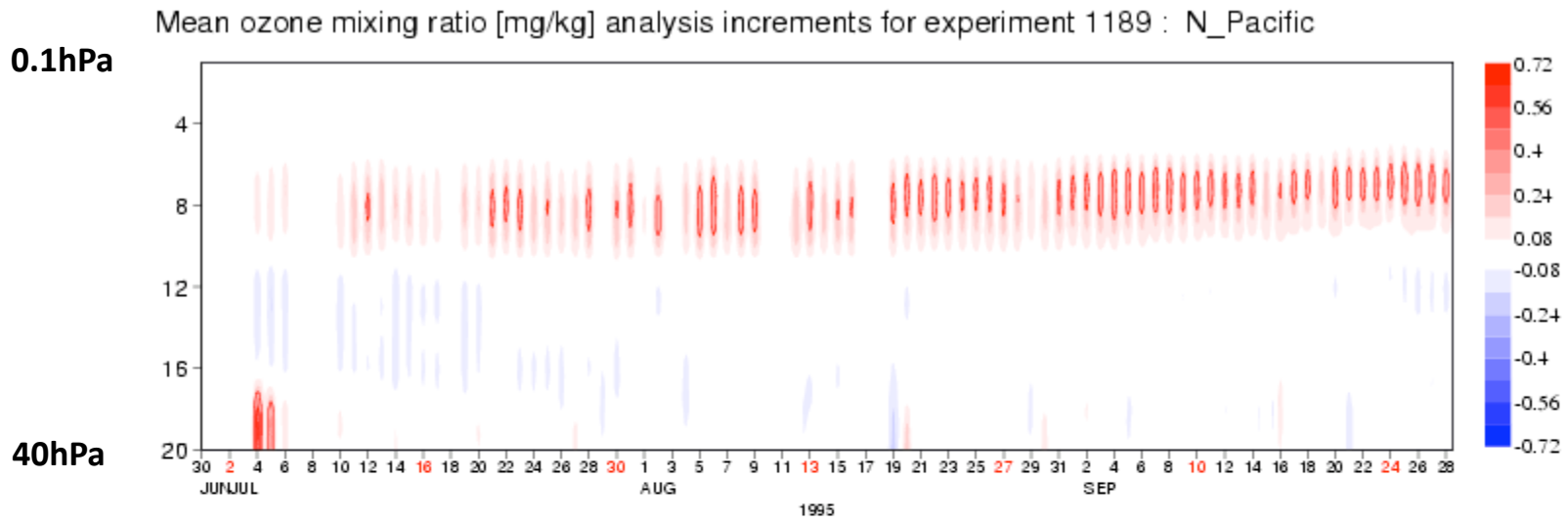
How well does this work in practise ?

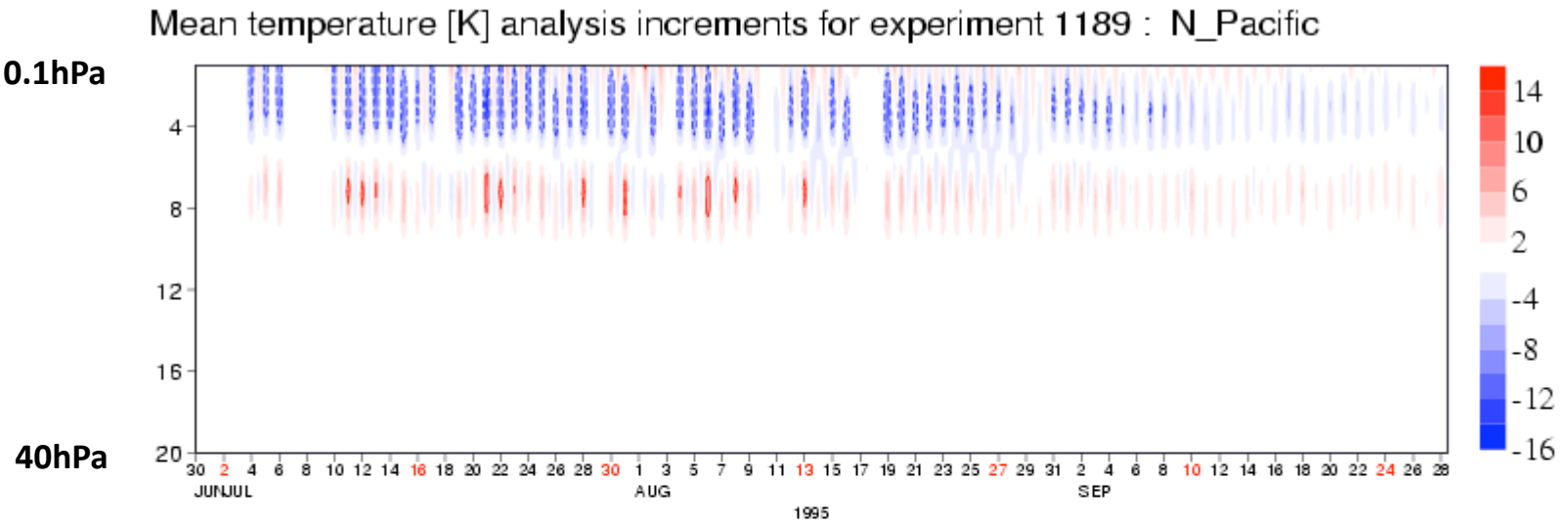


Assimilation of GOME profile data in ERA-Interim leads to much improved vertical distribution

Introduction of GOME ozone profile data in ERA-Interim

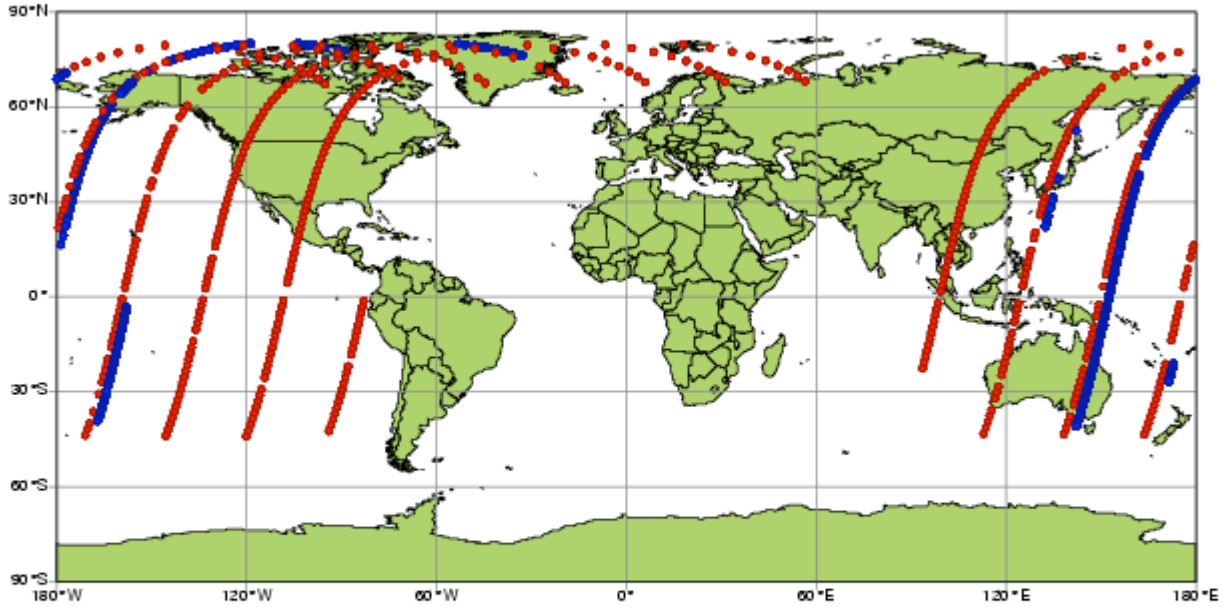
Ozone and temperature increments in the upper stratosphere





4D-Var ozone-only analysis experiment

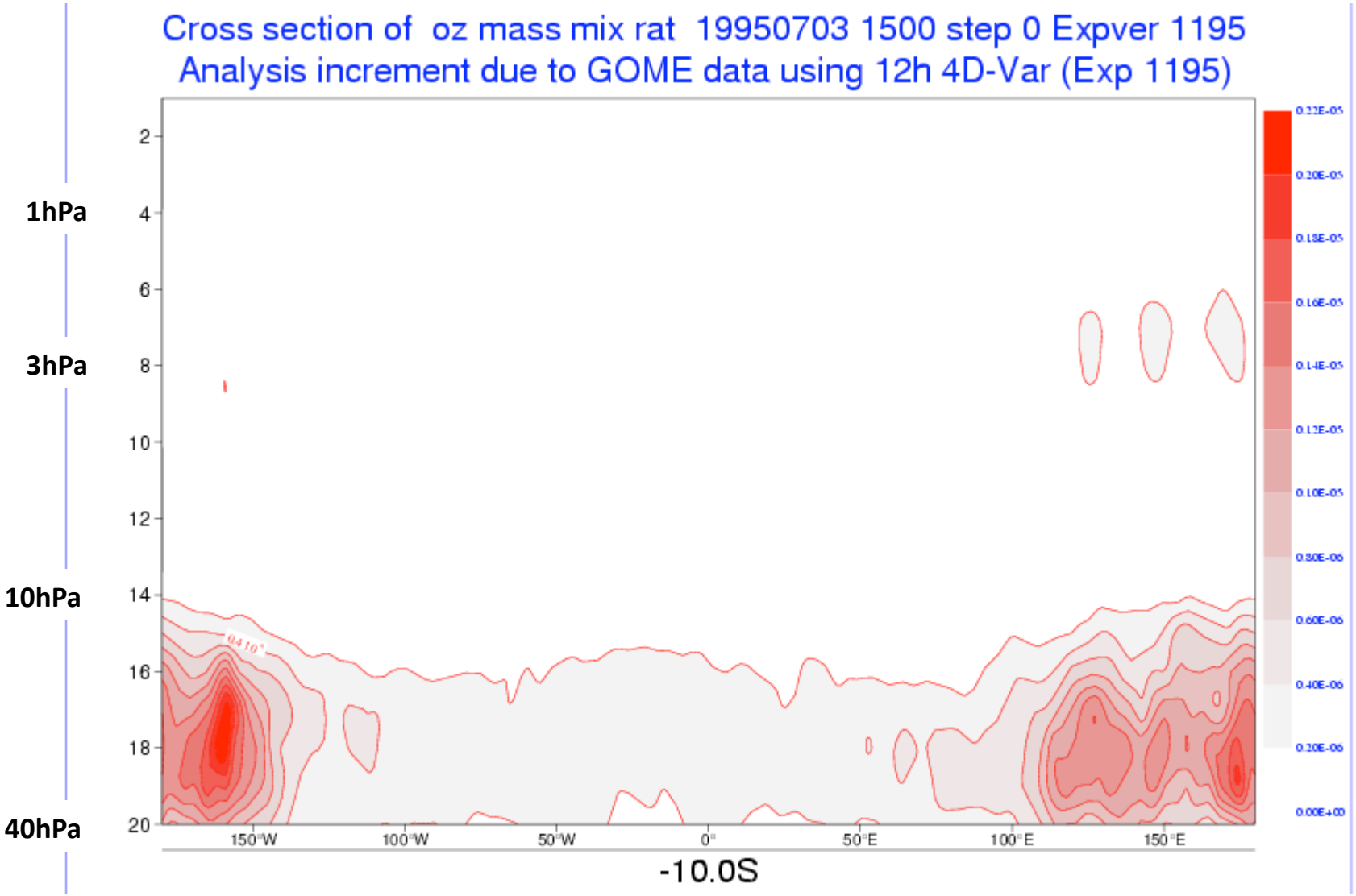
Ozone observation locations on 4 July 1995, 0 UTC



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

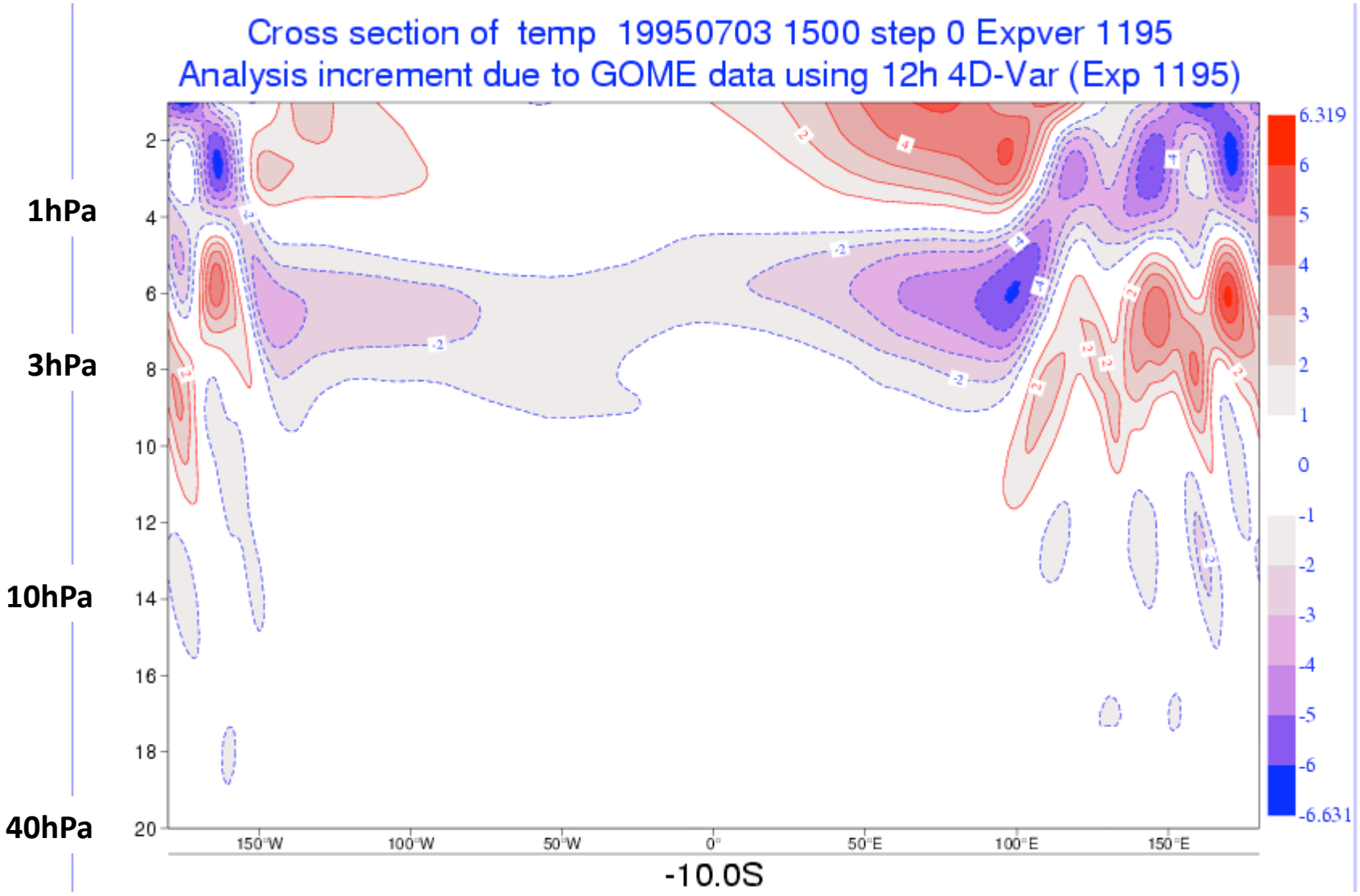
4D-Var ozone-only analysis experiment

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

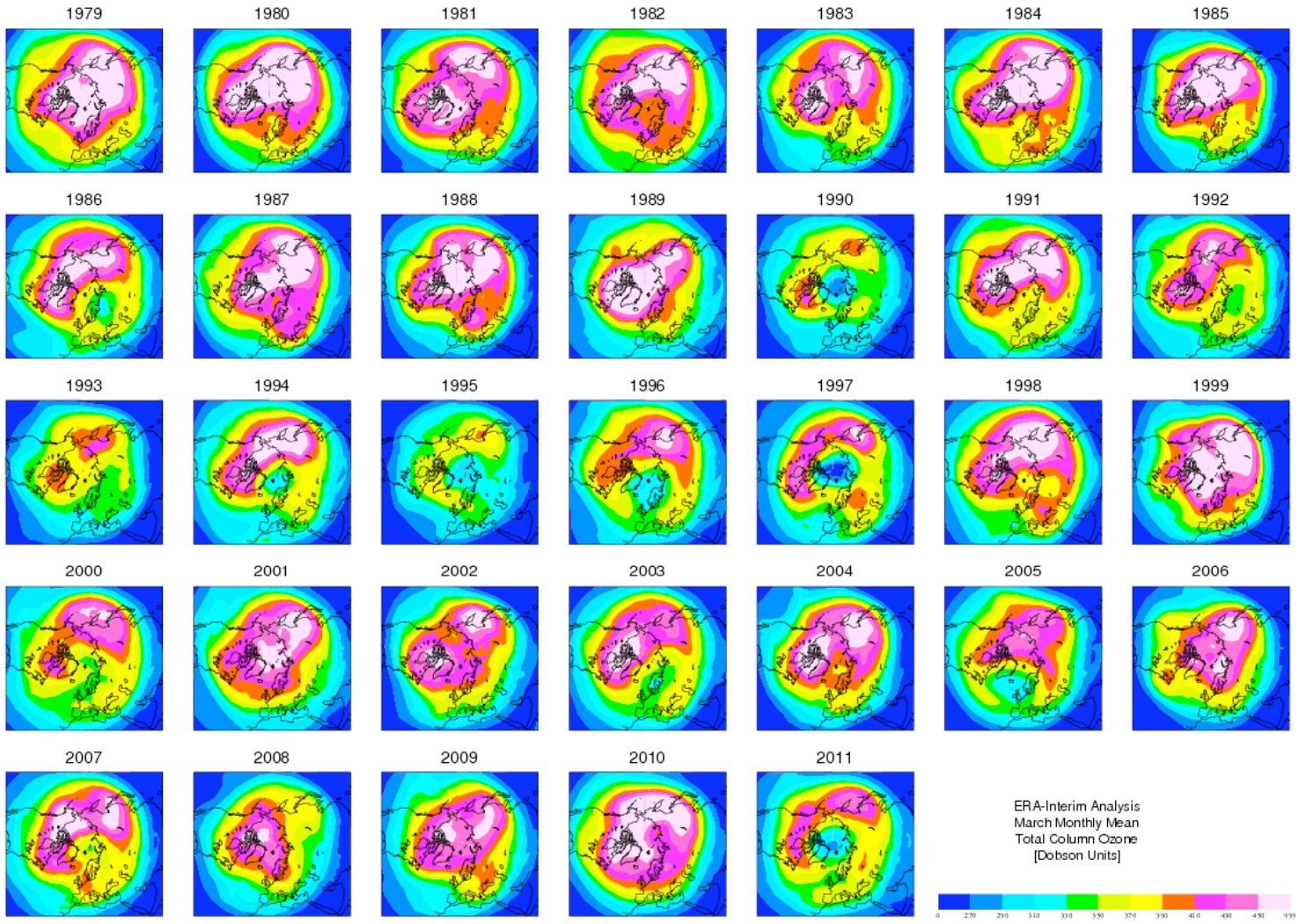


Ozone assimilation

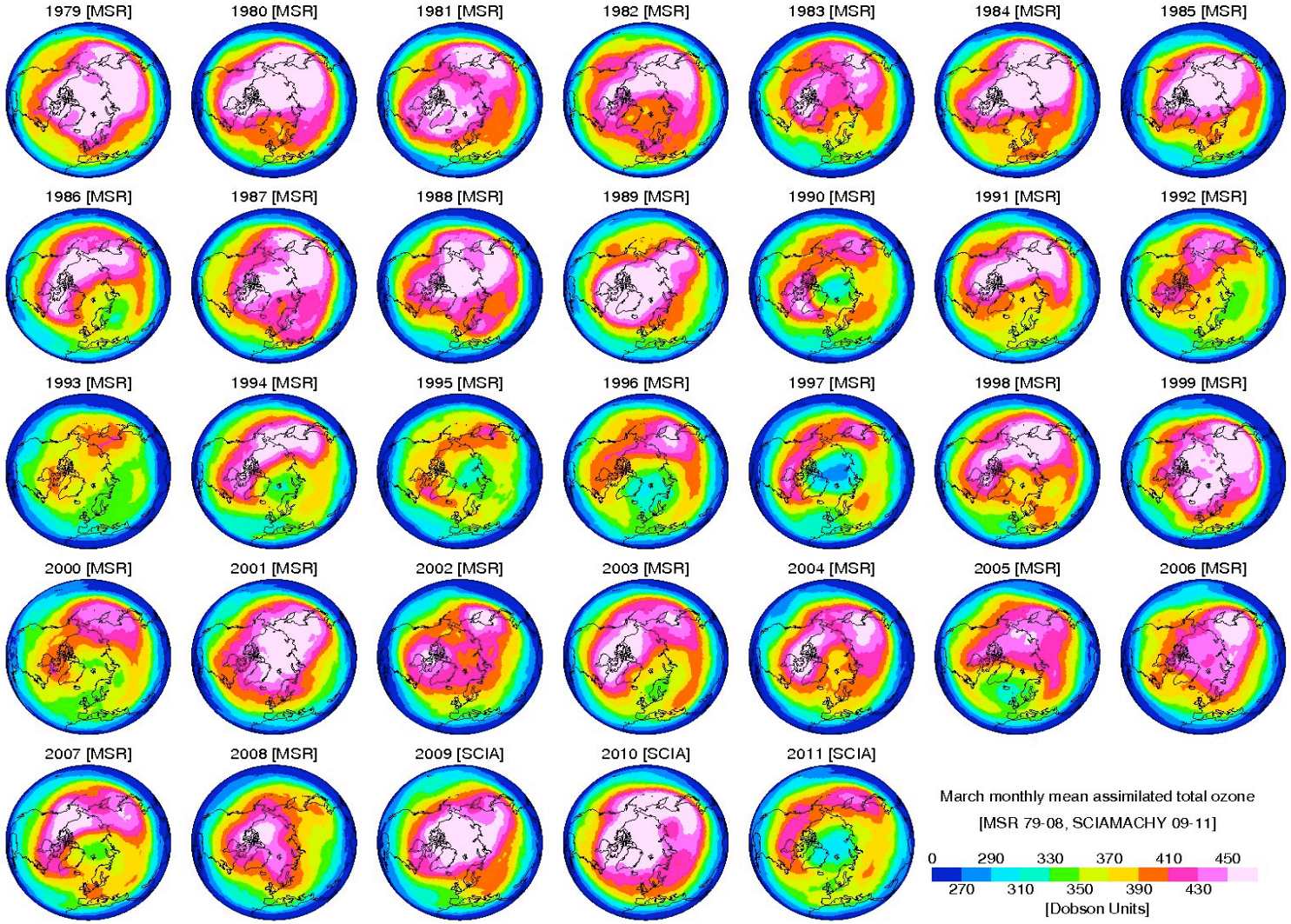
Can 4D-Var infer stratospheric winds from ozone data?

- 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

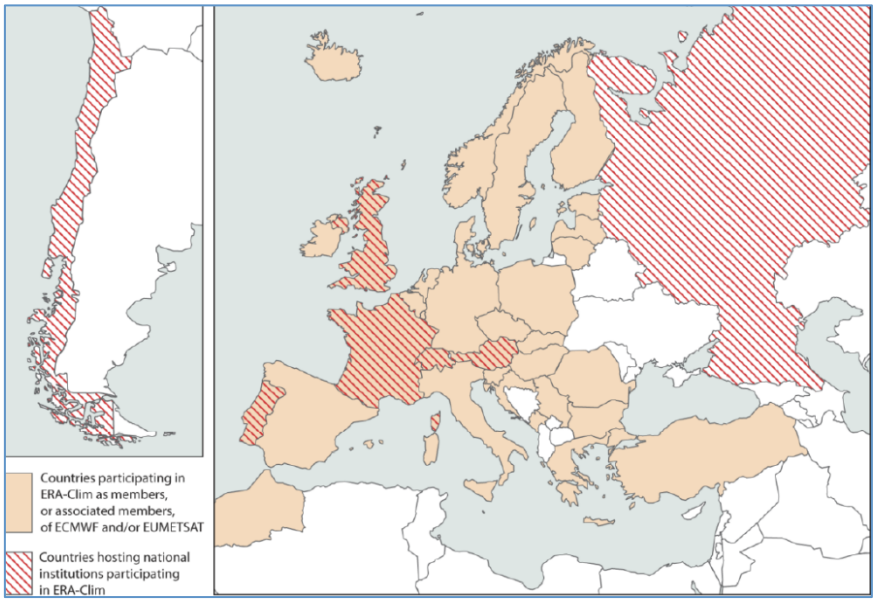


Estimates from KNMI



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 20th century	Inventories; database for metadata, web-based digitising tools	WP1
	Digitized, quality-controlled instrumental records for the early 20th 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 20th-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	

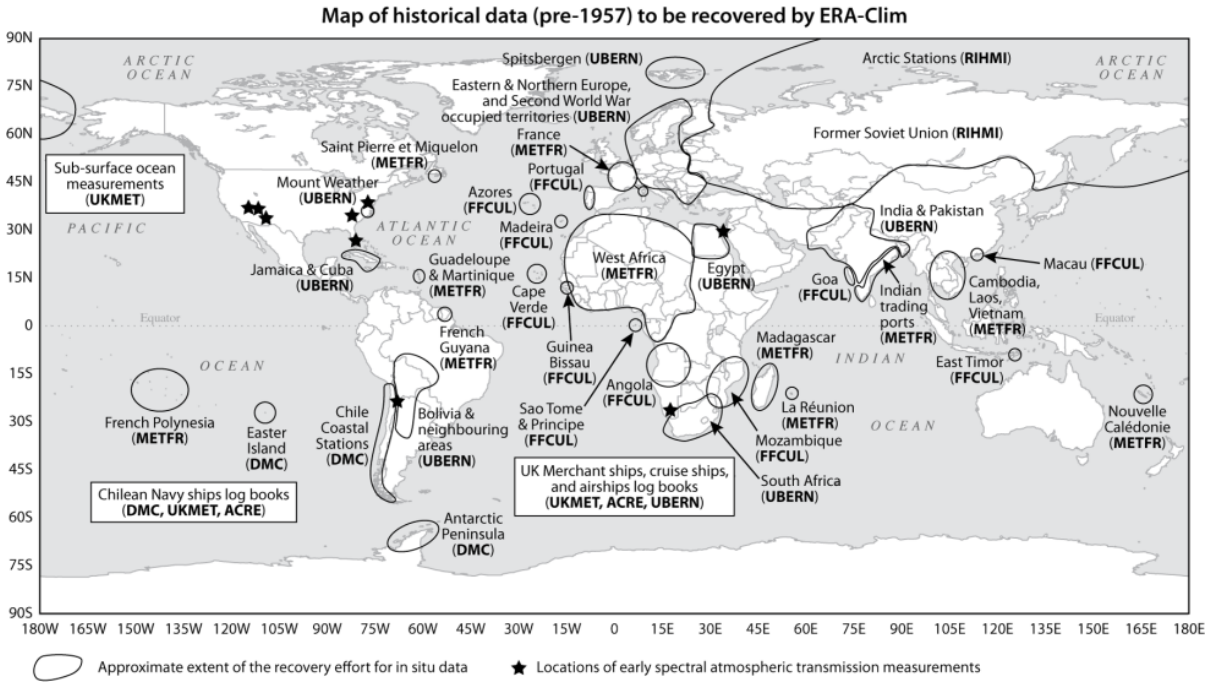
WP1: Data recovery and digitisation

Objectives	Deliverables	
Development of the observational record for the early 20th century	Inventories; database for metadata, web-based digitising tools	WP1
	Digitized, quality-controlled instrumental records for the early 20th 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..)



Key deliverables

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	Improved ocean observations for reanalysis	
	Tools for quality assessment of reanalysis products	

WP3: Data integration (global reanalysis)

Partners:

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

ERA-CLIM pilot reanalyses:

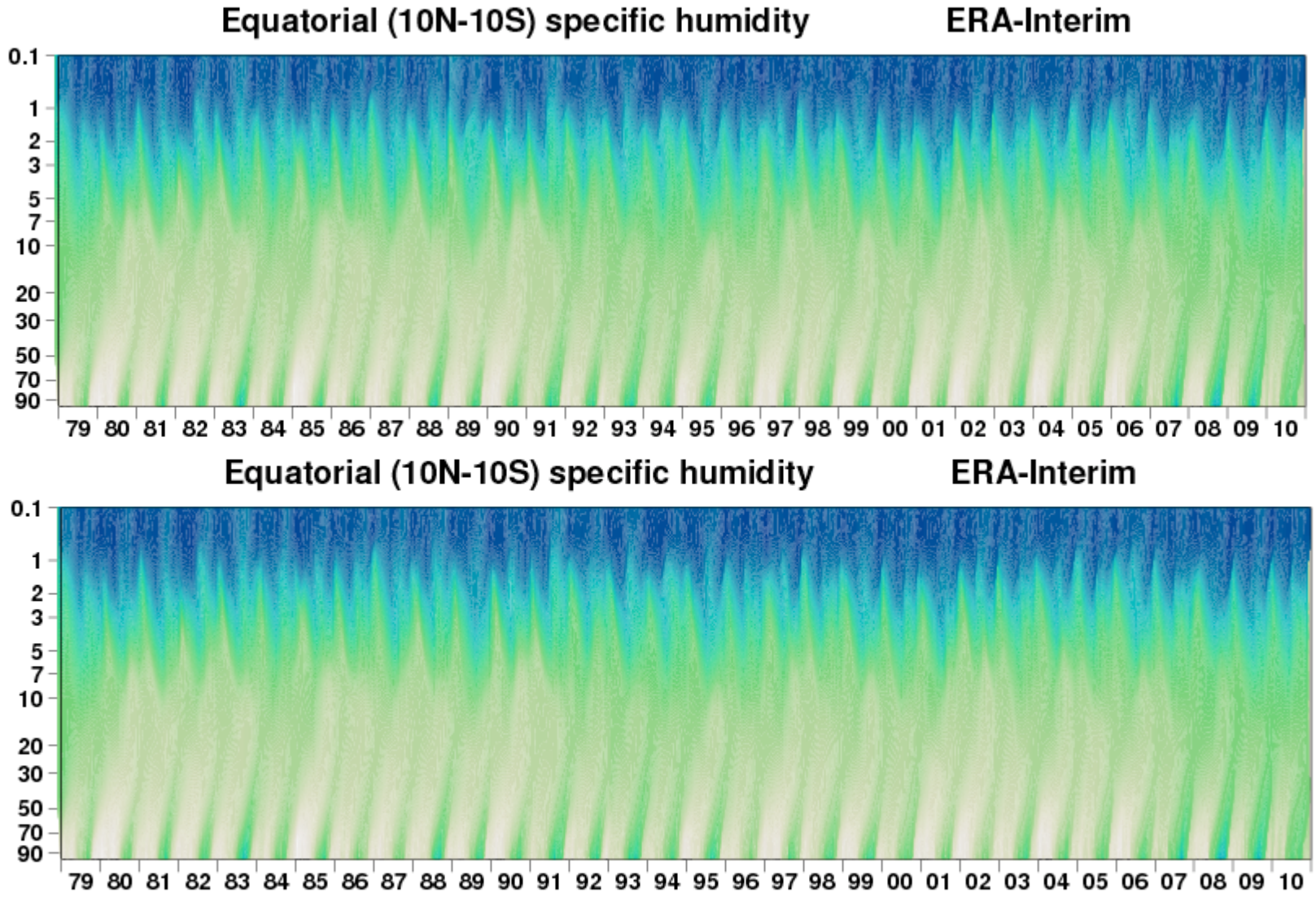
ERA-20C: 3D atmosphere from 1900 (125km)
ERA-20CL: Land surface only from 1900 (25km)
ERA-SAT: 3D atmosphere from 1979 onward (40km)

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 O_3 (10S-10N)

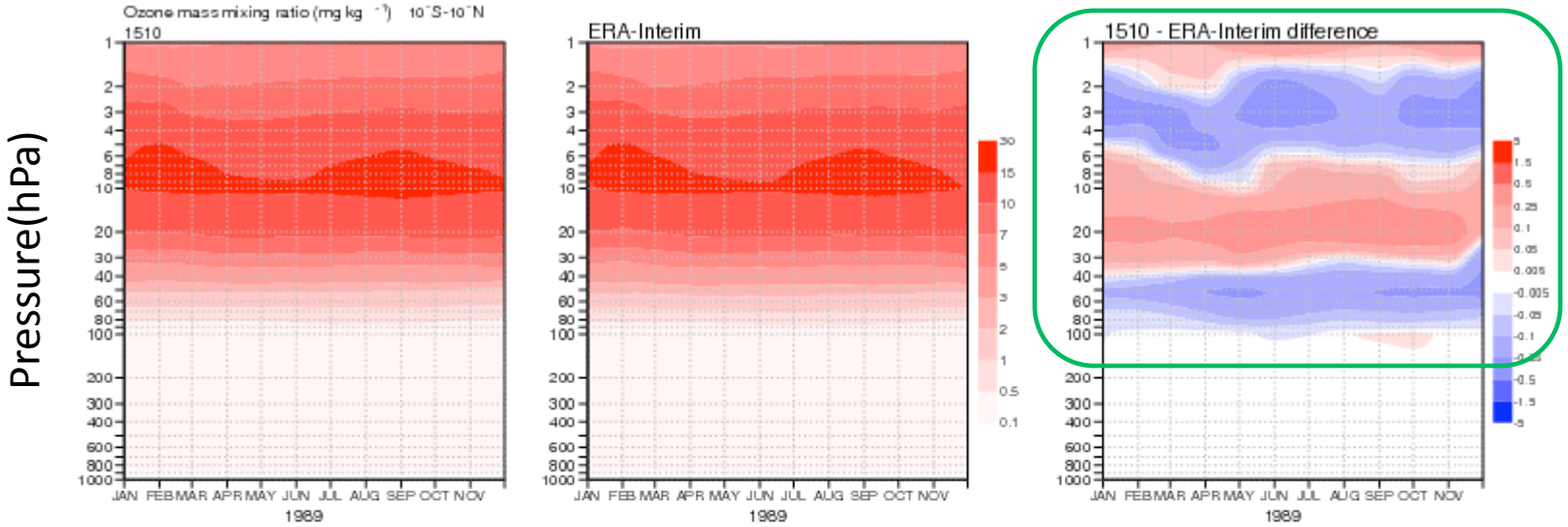
Total

1510

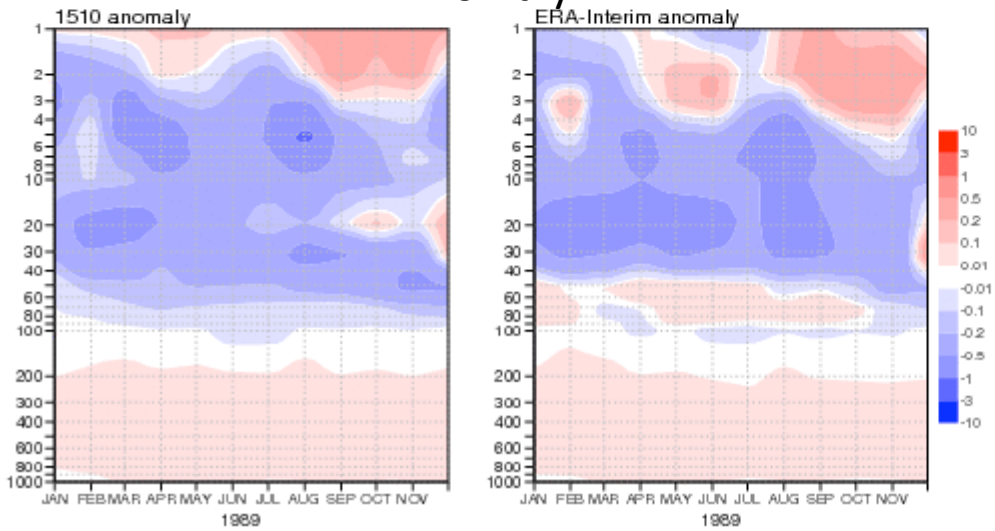
ERA-Interim

Diff.

1510 – ERA-Interim



Anomaly



Zonal mean Q (10S-10N)

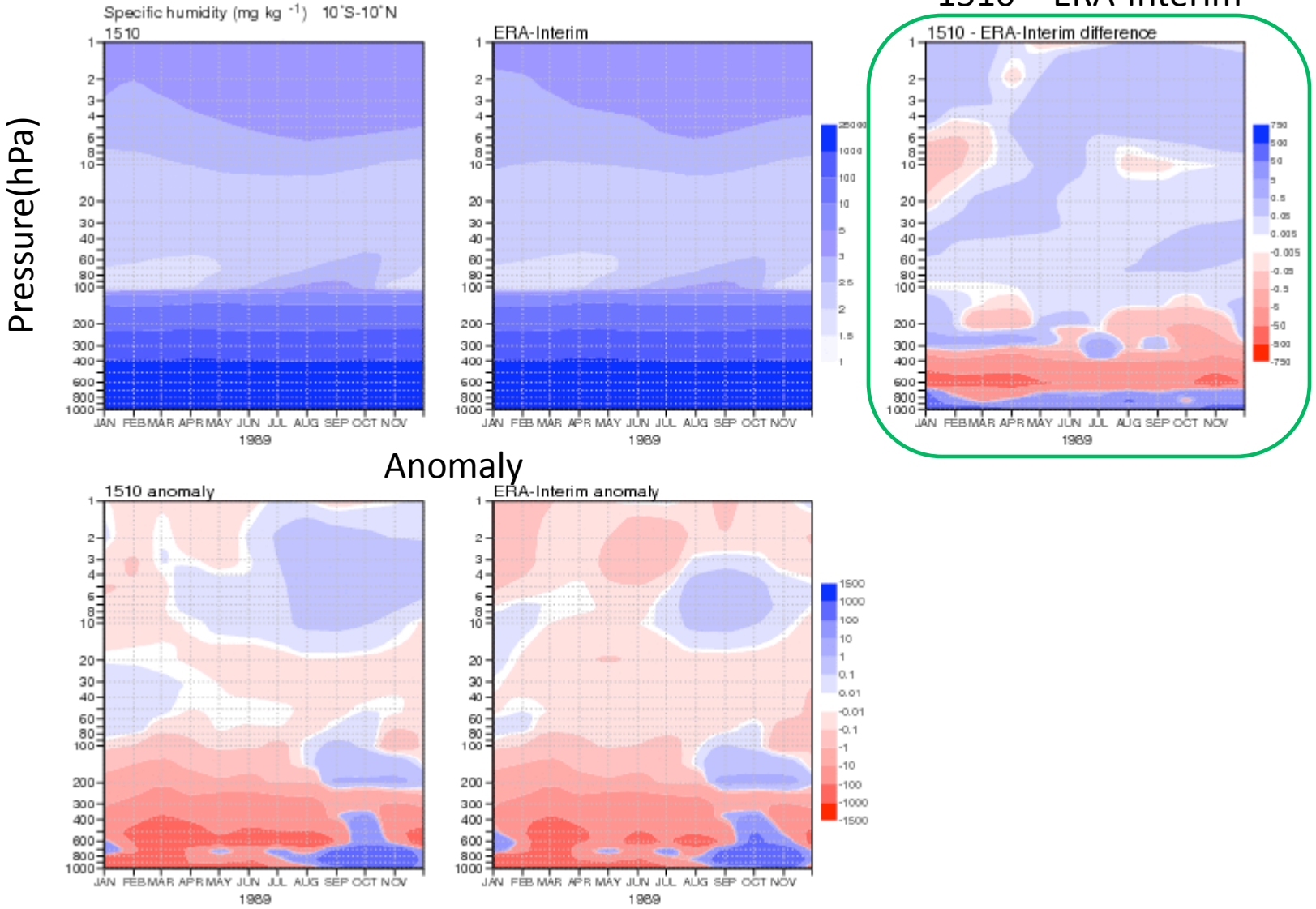
Total

1510

ERA-Interim

Diff.

1510 – ERA-Interim



Anomaly

Zonal mean T (10S-10N)

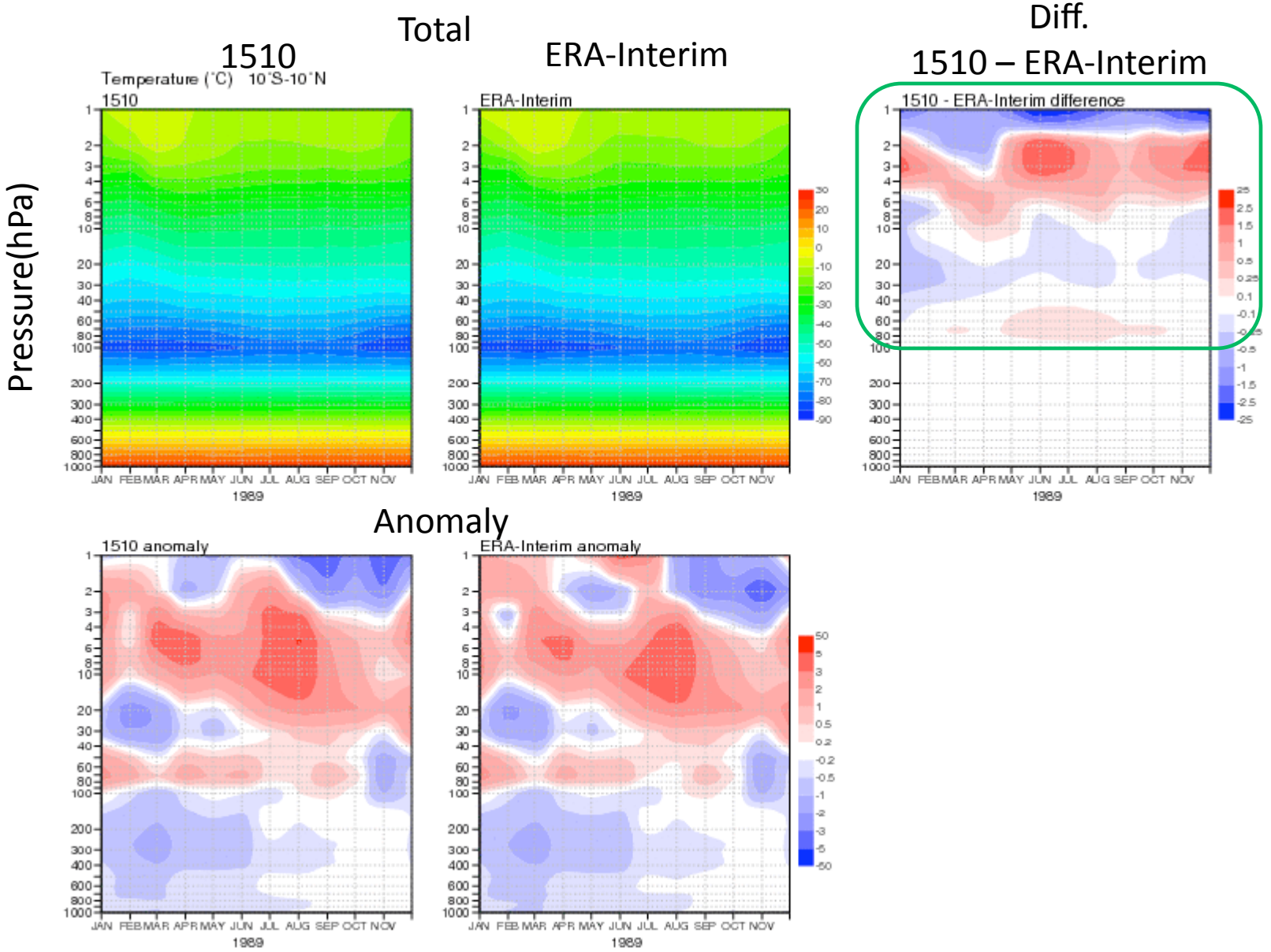
Total

1510

ERA-Interim

Diff.

1510 – ERA-Interim



Anomaly

Zonal mean U (10S-10N)

Total

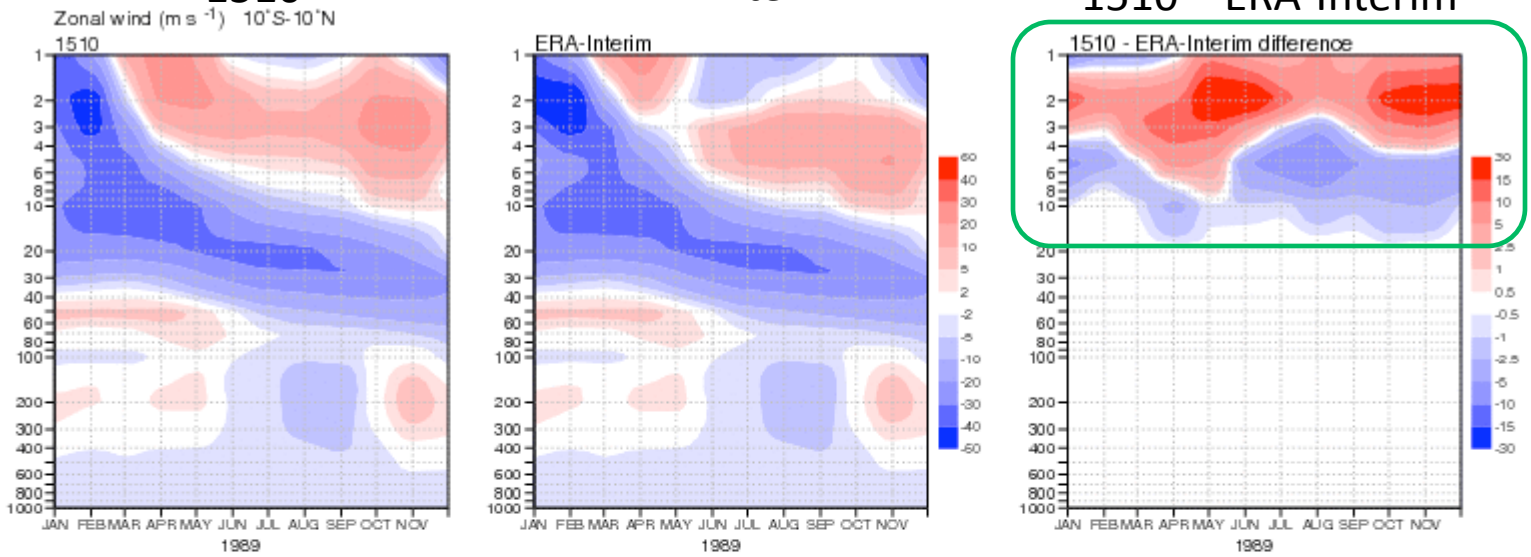
1510

ERA-Interim

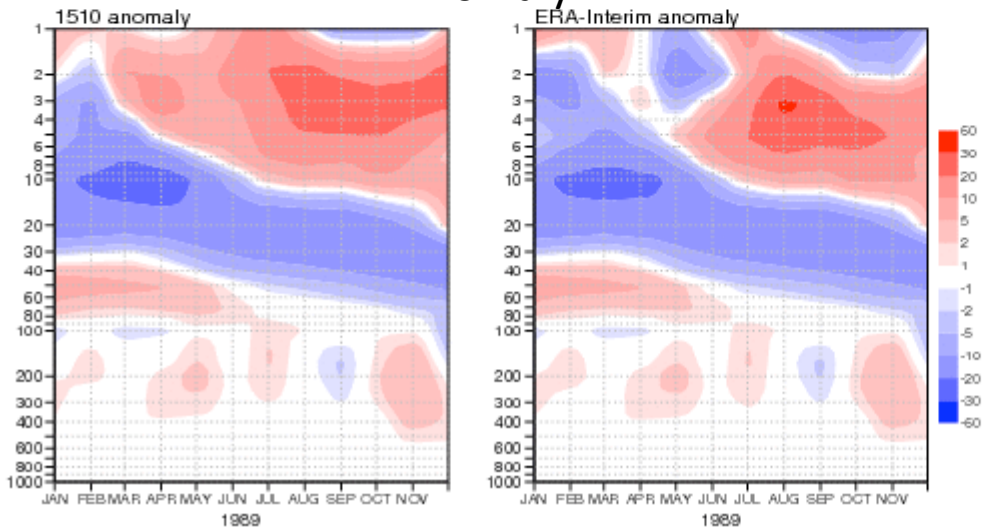
Diff.

1510 – ERA-Interim

Pressure(hPa)



Anomaly



Climatology: ERA-Interim 1989-2001