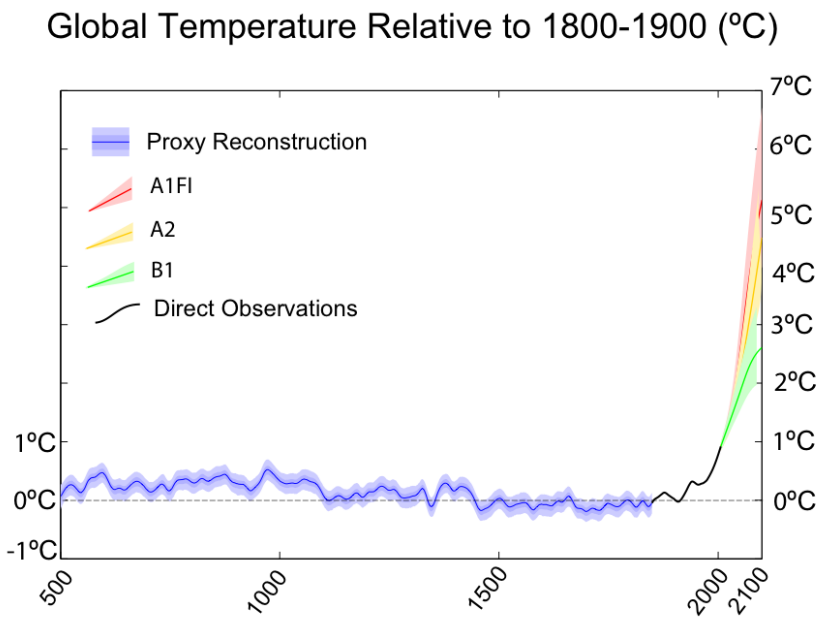
Developments in climate reanalysis at ECMWF

Dick Dee

Many contributions from the ECMWF reanalysis team, including A. Simmons

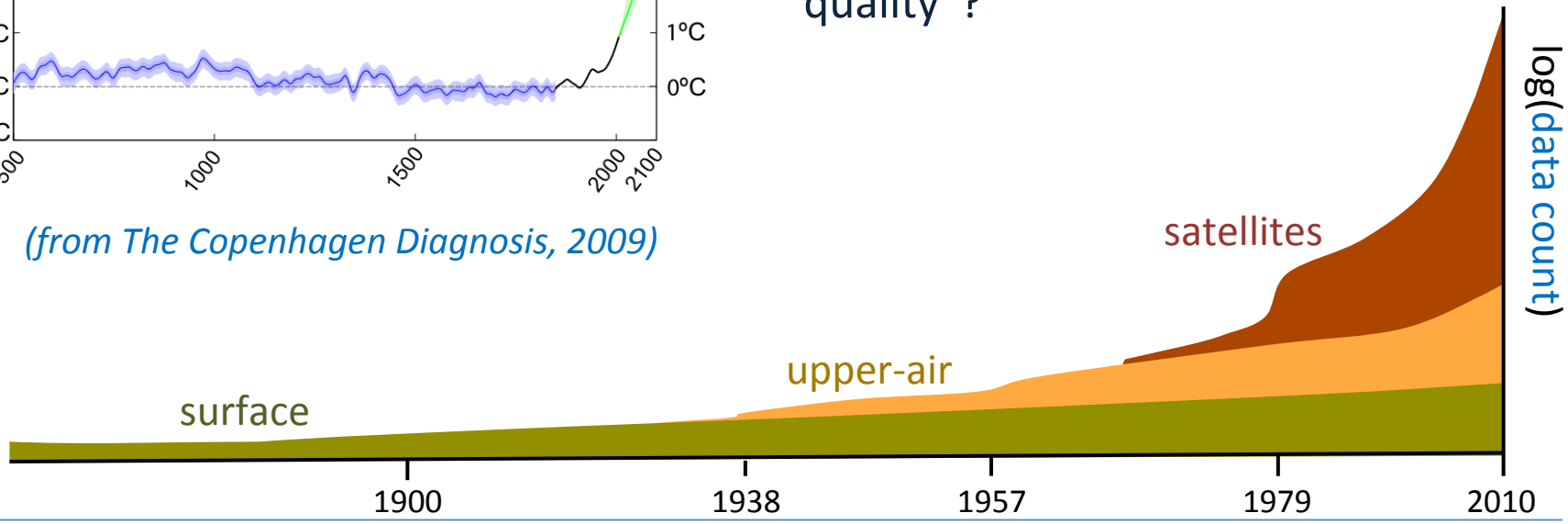
WCRP Open Science Conference
24-28 October 2011
Denver, Colorado

Reanalysis of the instrumental data record



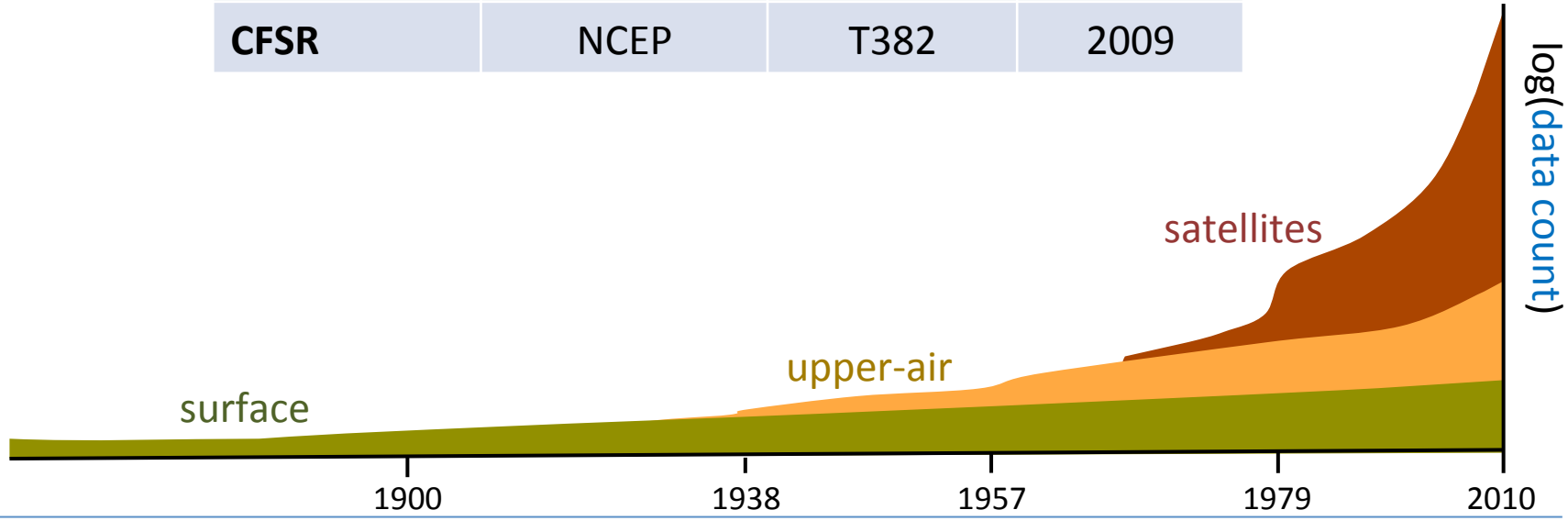
(from The Copenhagen Diagnosis, 2009)

- Which observations are available?
- How can we best make use of them?
- Can we reliably estimate parameters other than temperature?
- What is the role of models?
- Can reanalysis achieve “climate quality”?



Current reanalyses of the satellite era

	Produced by	Resolution	Model
NRA2	NCEP/DOE	T62	2001
JRA-25	JMA	T106	2006
ERA-Interim	ECMWF	T255	2006
MERRA	GMAO	½° ×⅔°	2009
CFSR	NCEP	T382	2009



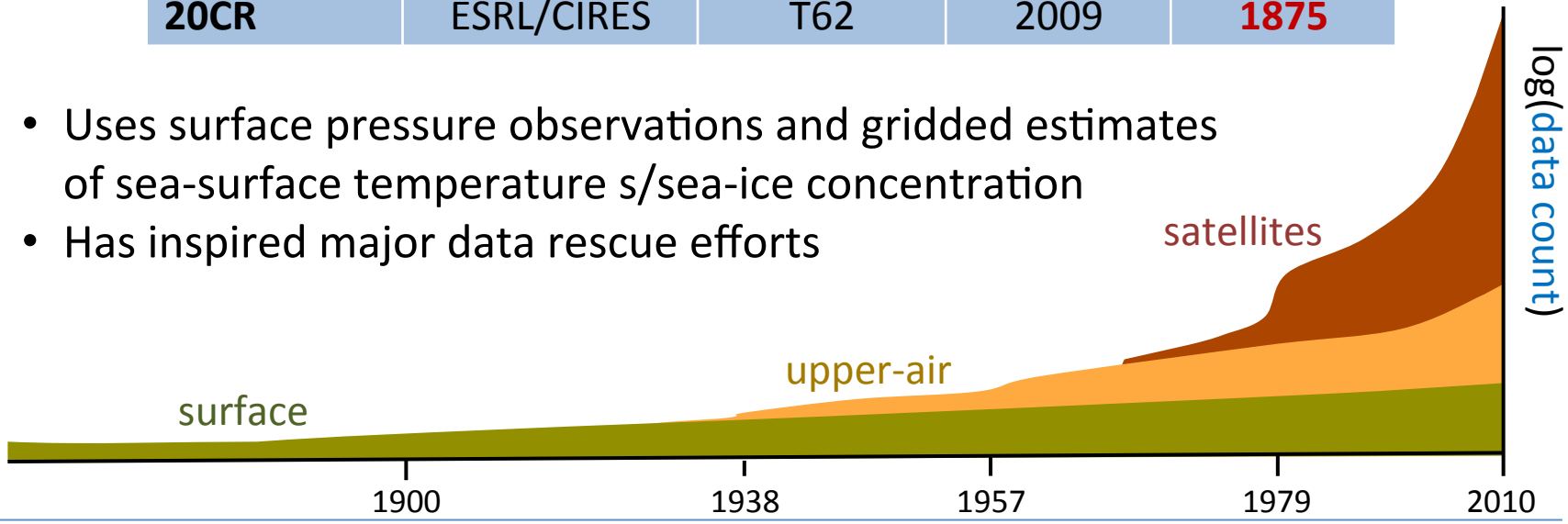
Reanalyses extending to the pre-satellite era

	Produced by	Resolution	Model	Back to
NRA1	NCEP/NCAR	T62	1995	1948
ERA-40	ECMWF	T159	2001	1957
JRA-55	JMA	T319	2009	1958

Pushing the envelope: *The 20th-Century Reanalysis Project (next talk)*

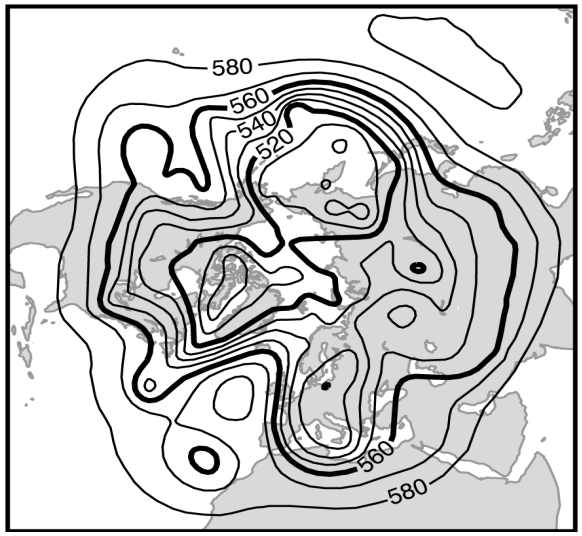
20CR	ESRL/CIRES	T62	2009	**1875**

- Uses surface pressure observations and gridded estimates of sea-surface temperature s/sea-ice concentration
- Has inspired major data rescue efforts

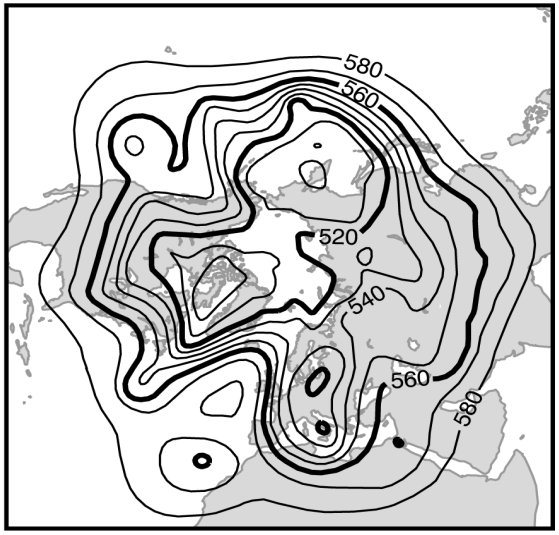


The early period: Model information is key

Two modern analyses of geopotential height at 500hPa

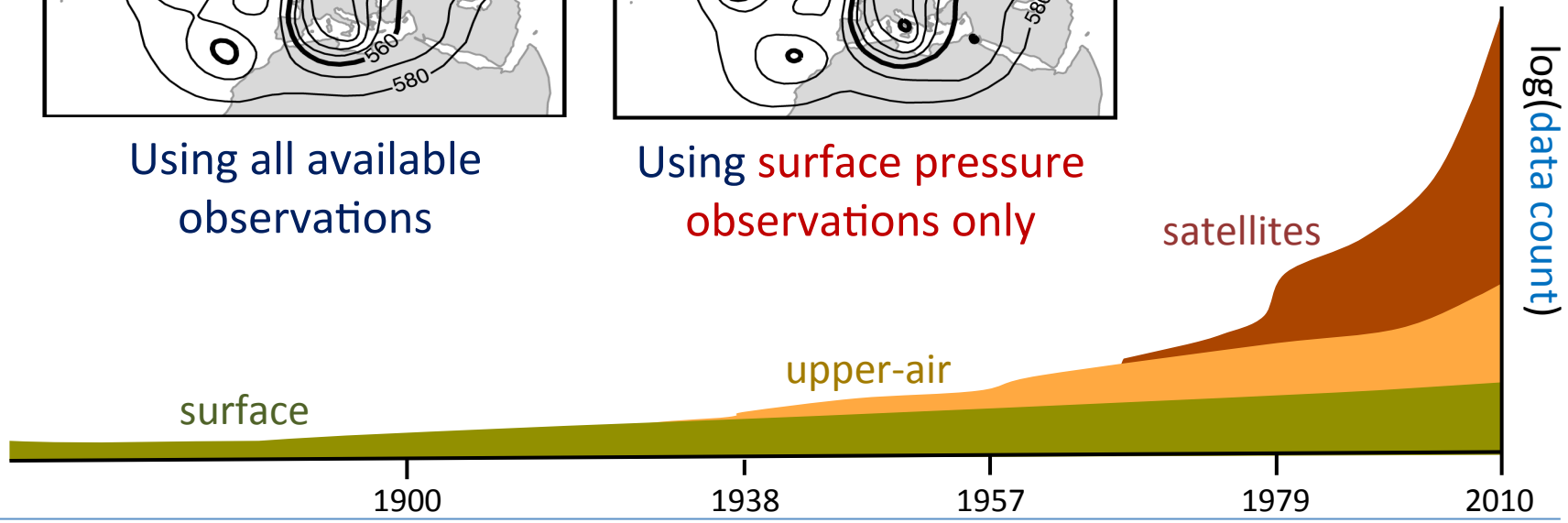


Using all available observations



Using surface pressure observations only

Whitaker, Compo, and Thépaut 2009



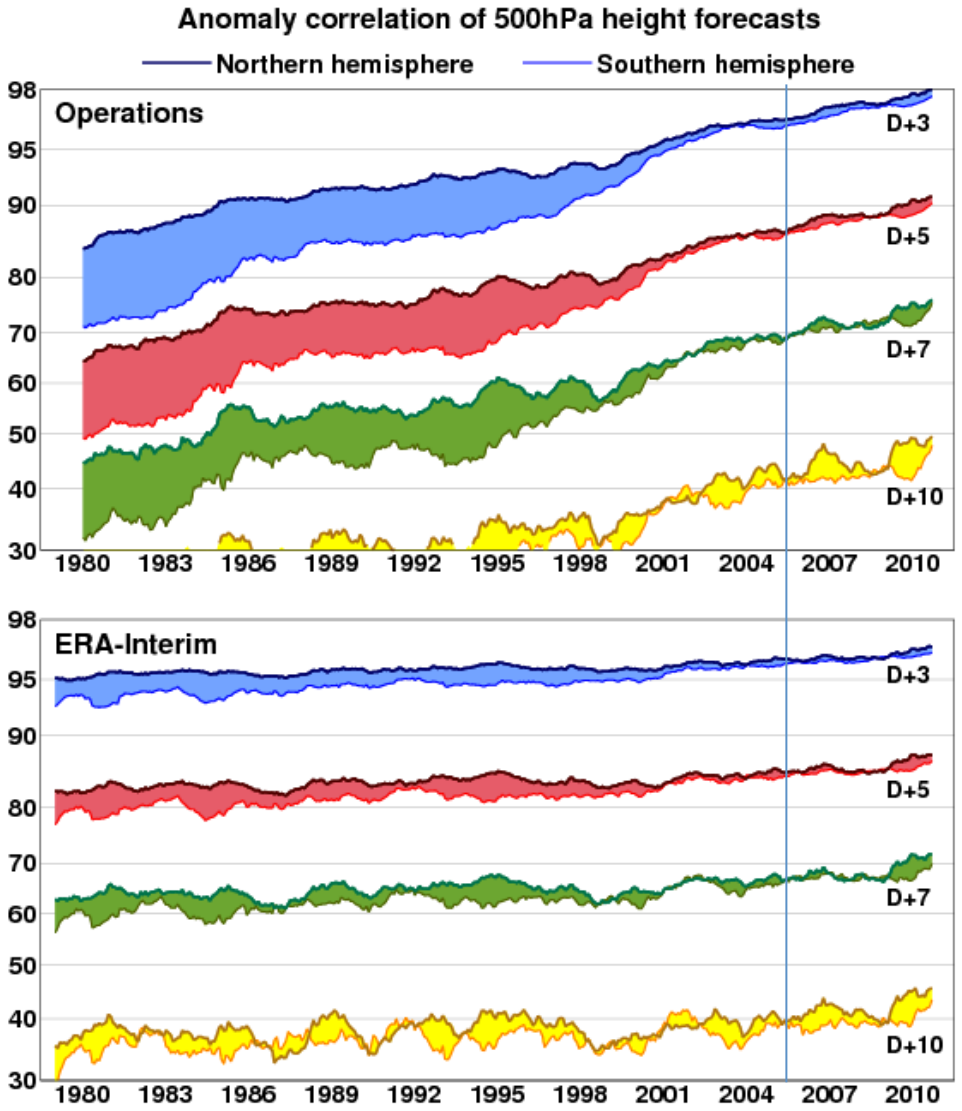
Reanalysis and Numerical Weather Prediction

Reanalysis makes use of data assimilation systems designed for weather forecasting

It uses a single model and analysis method for a consistent re-analysis of past observations

Consistency in time is the key challenge for climate reanalysis

The difficulties are due to biases in models and observations

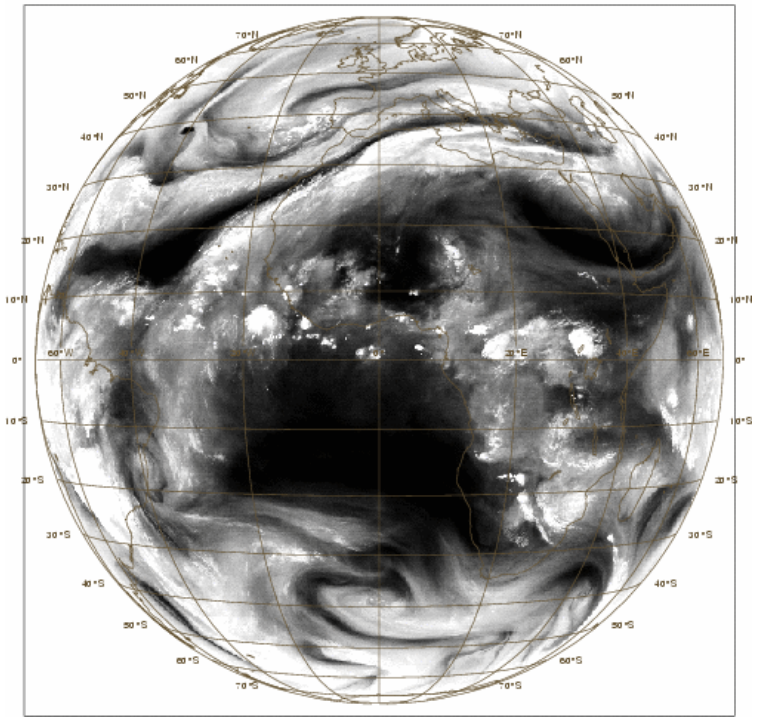


Variational assimilation of satellite radiances

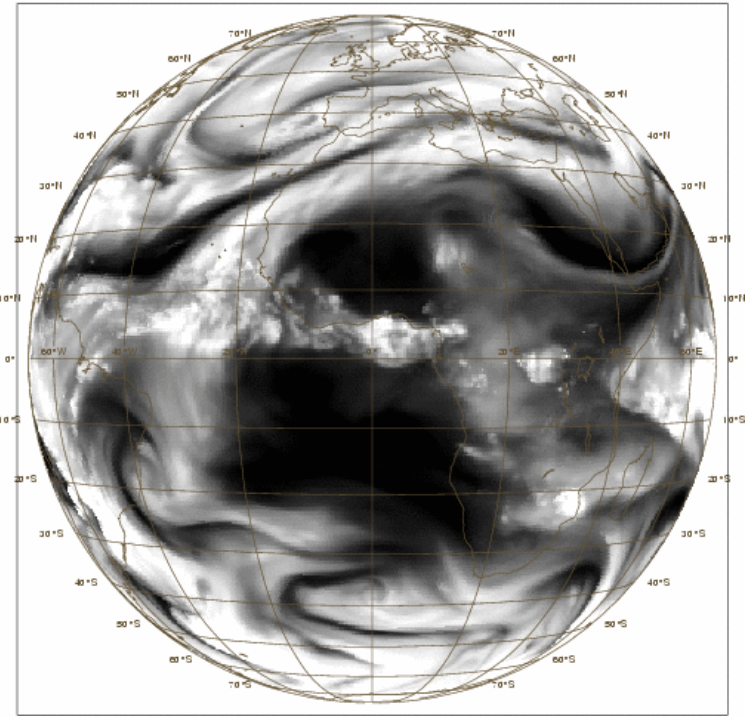
Adjust the model state to improve the match with observations:

$$\mathbf{J(x) = (x_b - x)^T B^{-1} (x_b - x) + \left[y - h(x)\right]^T R^{-1} \left[y - h(x)\right]}$$

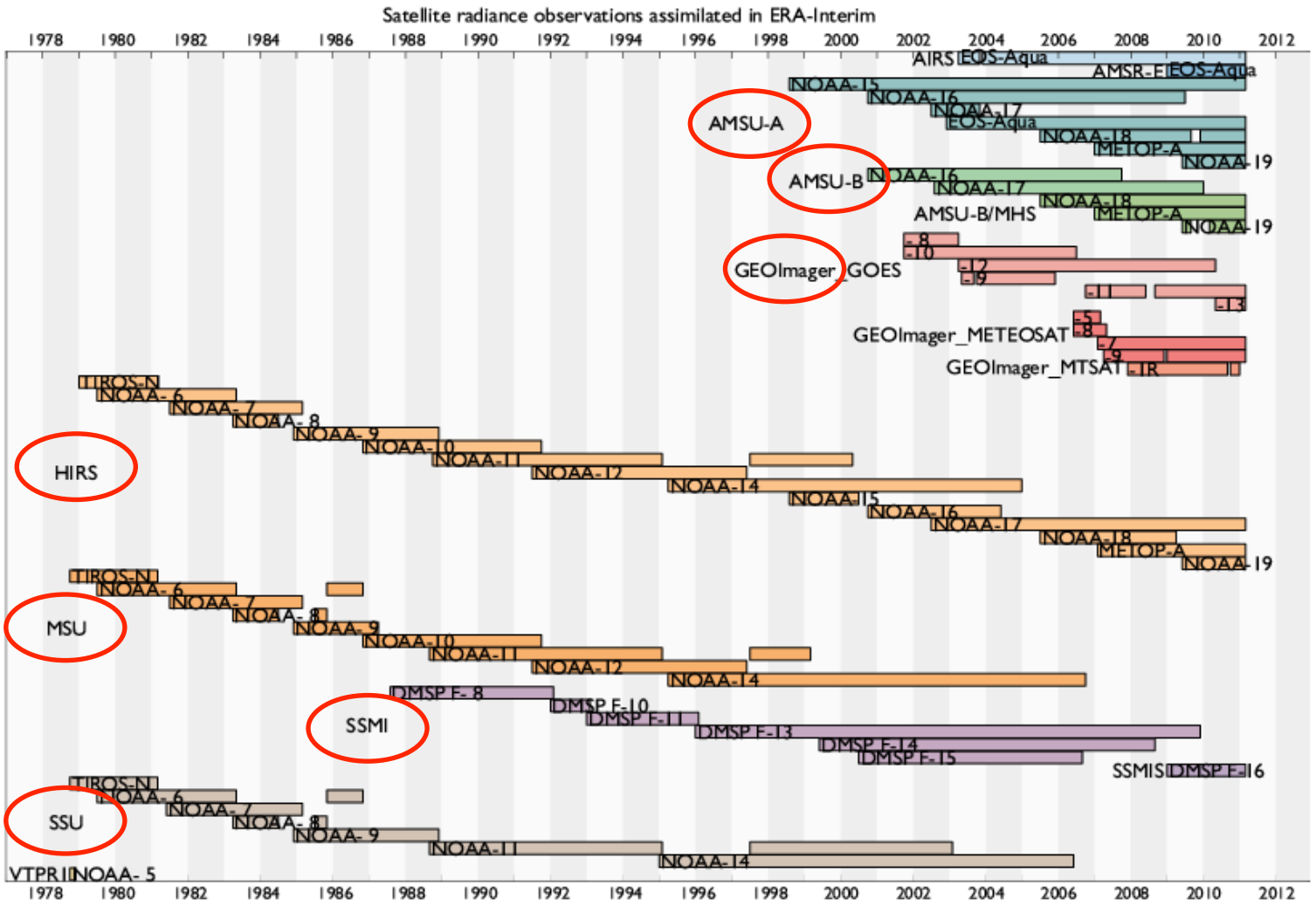
y : observed radiances



h(x) : model-simulated radiances



Satellite radiance data used in modern reanalyses

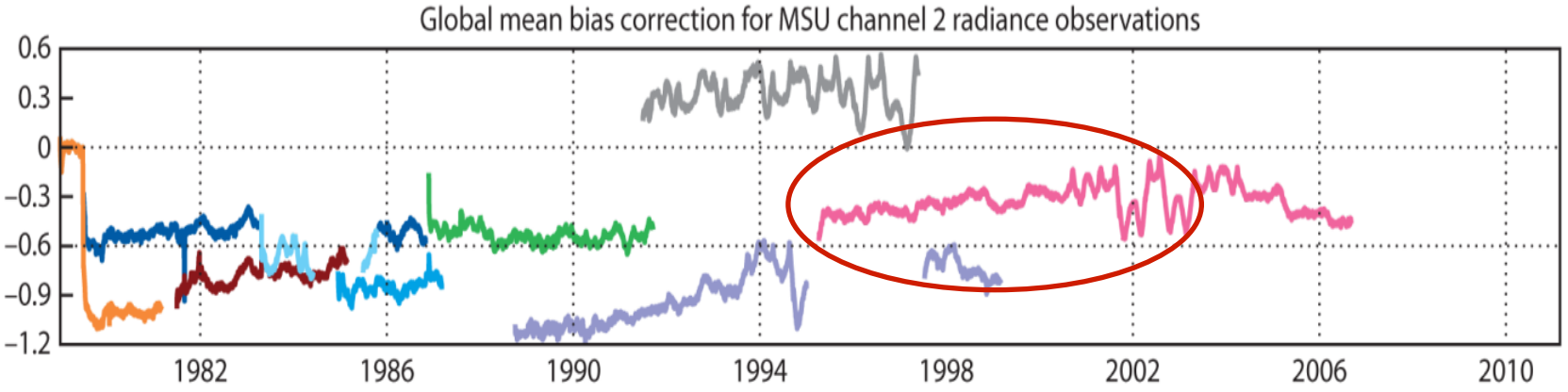


Variational bias correction of satellite radiances

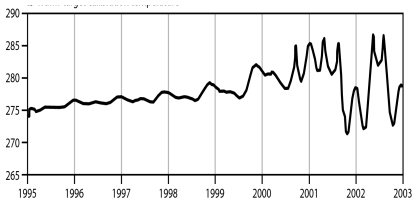
Satellite observations have instrument-dependent biases that change over time, e.g. due to calibration errors, orbit drift

The biases can be estimated in the variational analysis:

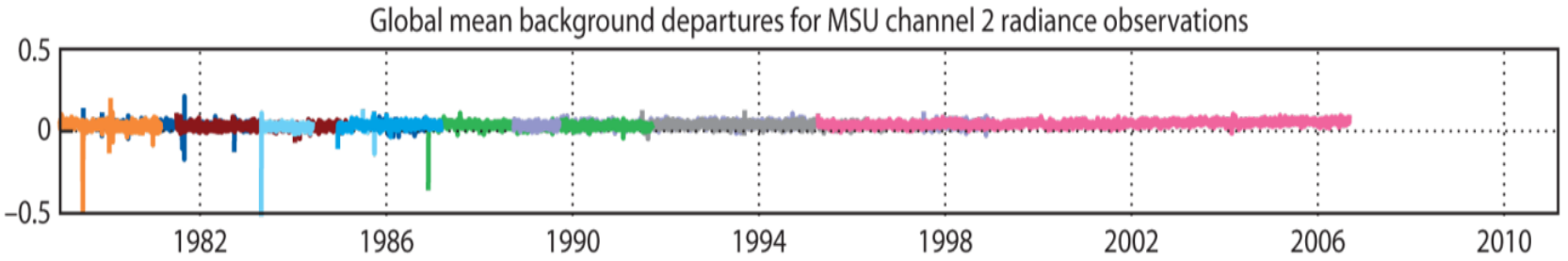
$$\mathbf{J}(\mathbf{x},\beta) = (\mathbf{x}_b - \mathbf{x})^T \mathbf{B}^{-1}(\mathbf{x}_b - \mathbf{x}) + \left[\mathbf{y} - \mathbf{h}(\mathbf{x},\beta)\right]^T \mathbf{R}^{-1}\left[\mathbf{y} - \mathbf{h}(\mathbf{x},\beta)\right]$$



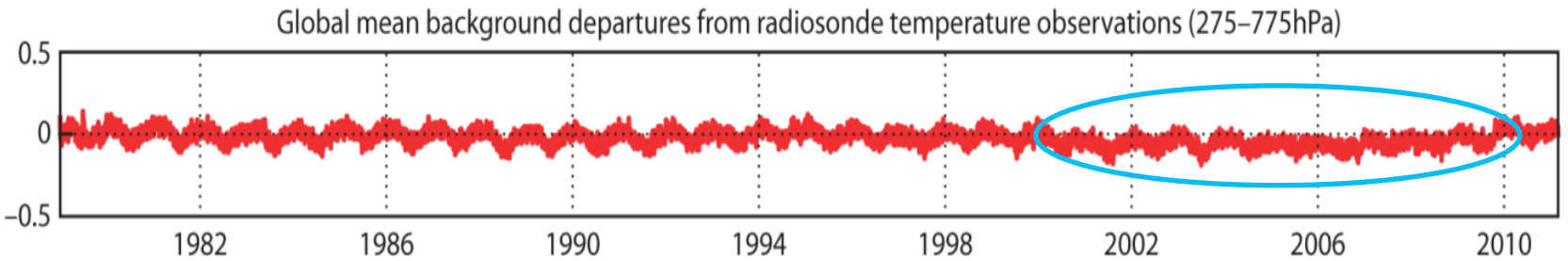
On-board warm target variations for MSU NOAA-14 *(Grody et al. 2004)*



ERA-Interim mean state controlled by radiosondes



Mean tropospheric temperatures are (mostly) consistent with radiosondes:



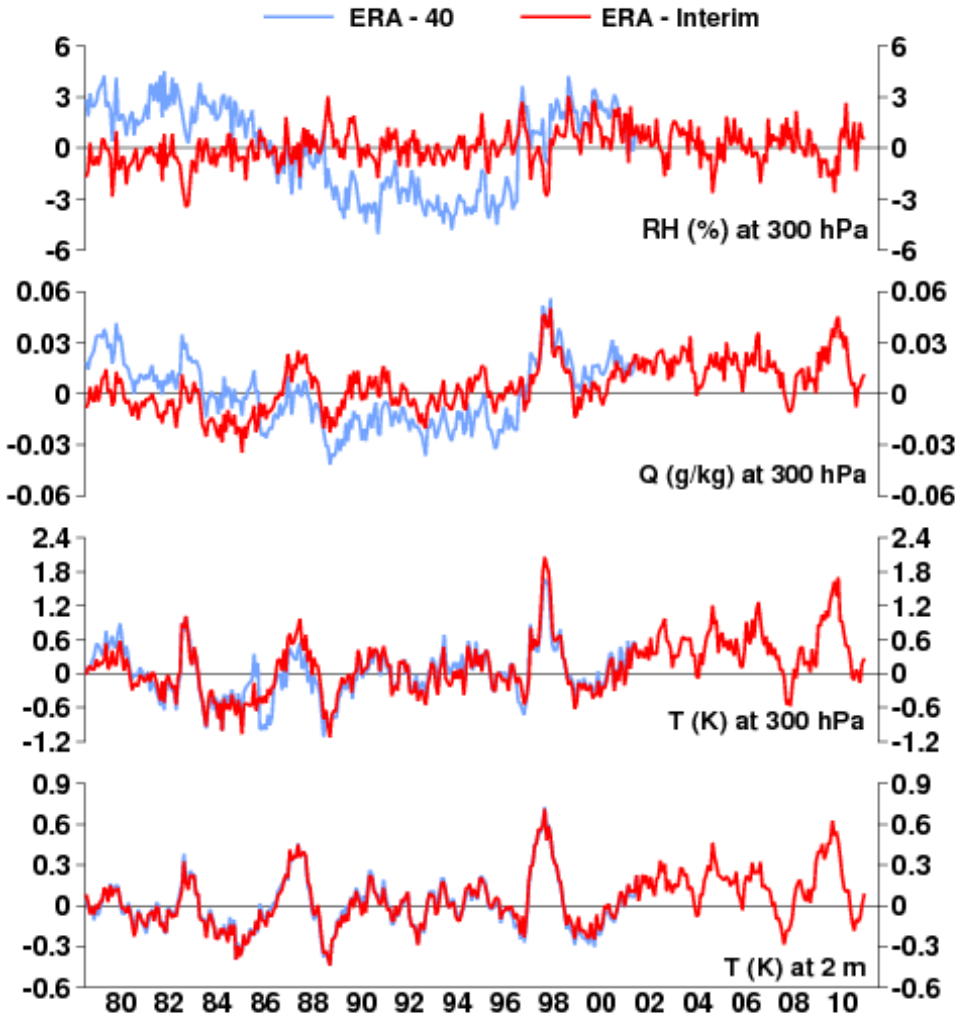
- Slight excess warming in last decade, due to warm bias in aircraft data
- Cancelled after end 2006 by introduction of GPS RO data
- **Choice of "anchoring data" controls the mean state (hence trends).**
  For ERA-Interim this is essentially RAOBCORE 1.4 *(Haimberger, 2007)*

Coherent representation of tropical anomalies

Uniform relative humidity

Coherent anomalies of T and Q in the upper troposphere

Amplification of T anomaly with height (factor 2.2 at 300 hPa)



(A. Simmons, ECMWF)

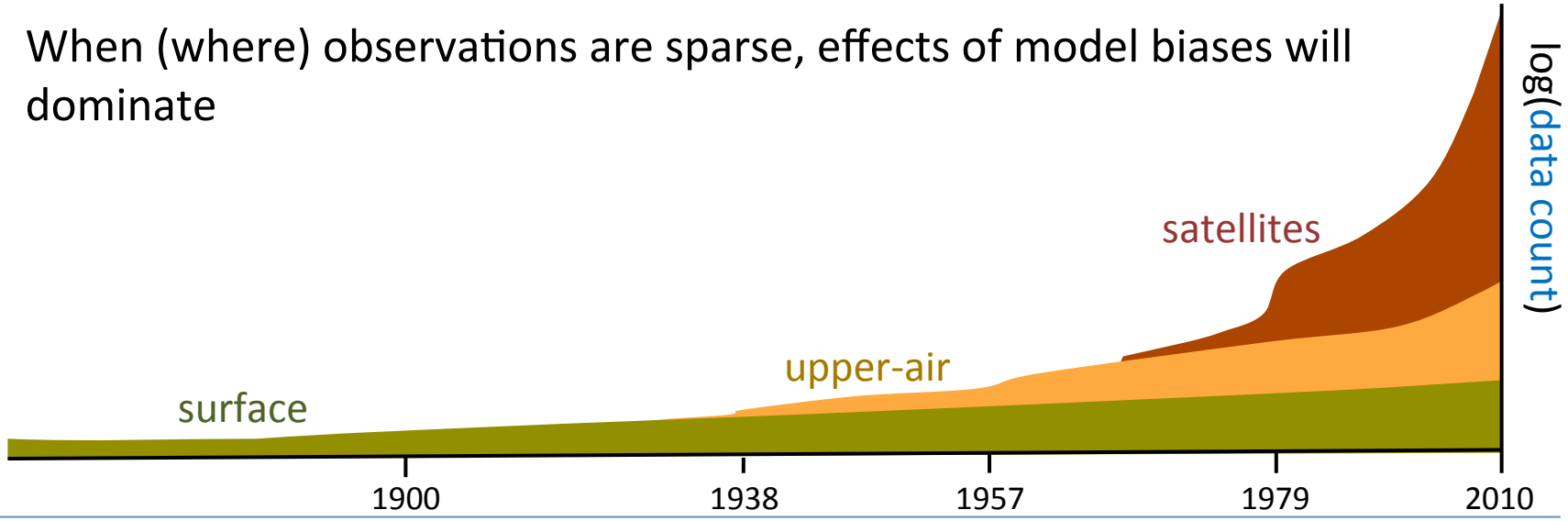
Limitations: Reaching further back in time?

Tropospheric mean temperatures are controlled by:

model ⟷ model + radiosondes ⟷ radiosondes + satellites

We can reconcile the mean signals from different observing systems when (where) these are plentiful

When (where) observations are sparse, effects of model biases will dominate



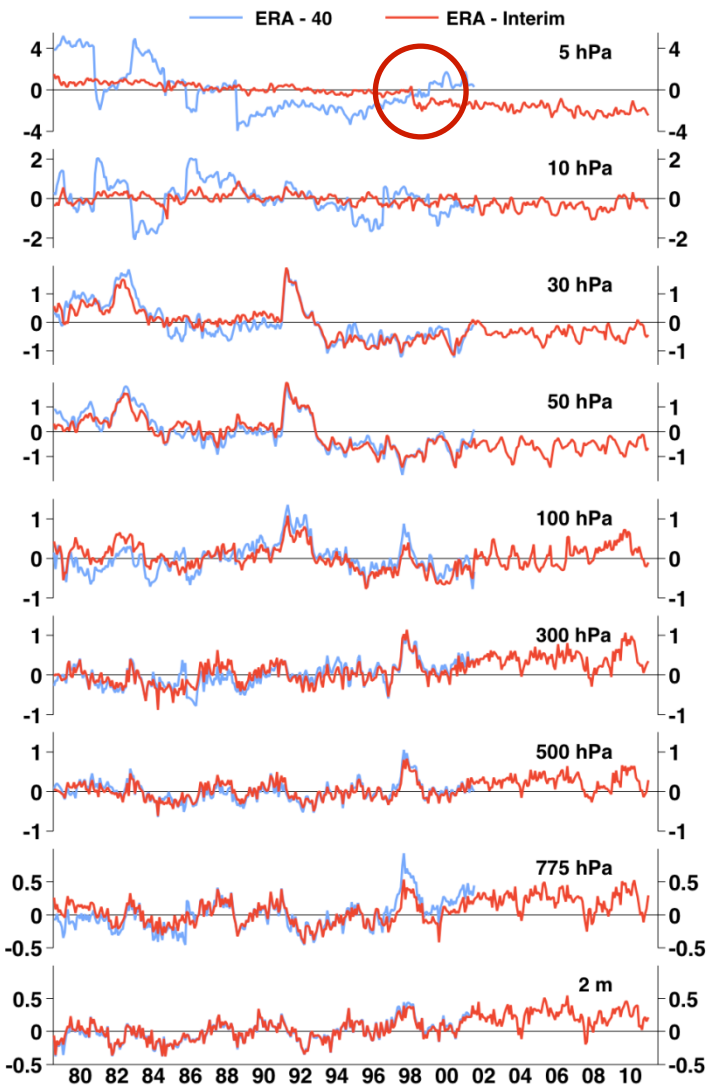
Globally averaged temperature anomalies

Upper stratosphere: Large model bias, partly constrained by SSU prior to 1998, then by AMSU-A

A spurious shift is inevitable in this case unless the model is unbiased

Model biases can be corrected in data assimilation – but that requires accurate observations

The fundamental limitations on reanalysis accuracy **always** have to do with the observing system

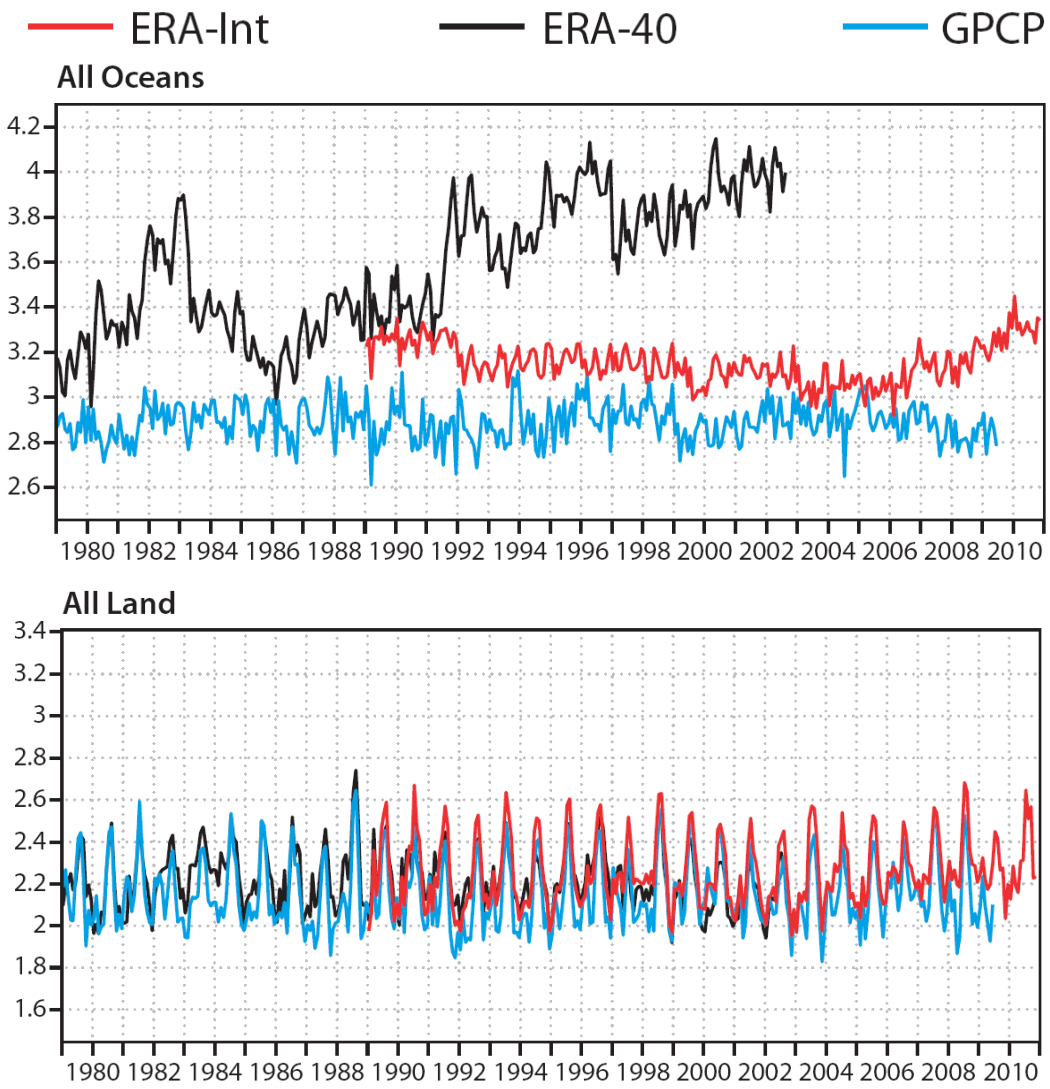


Larger uncertainties in precipitation trends

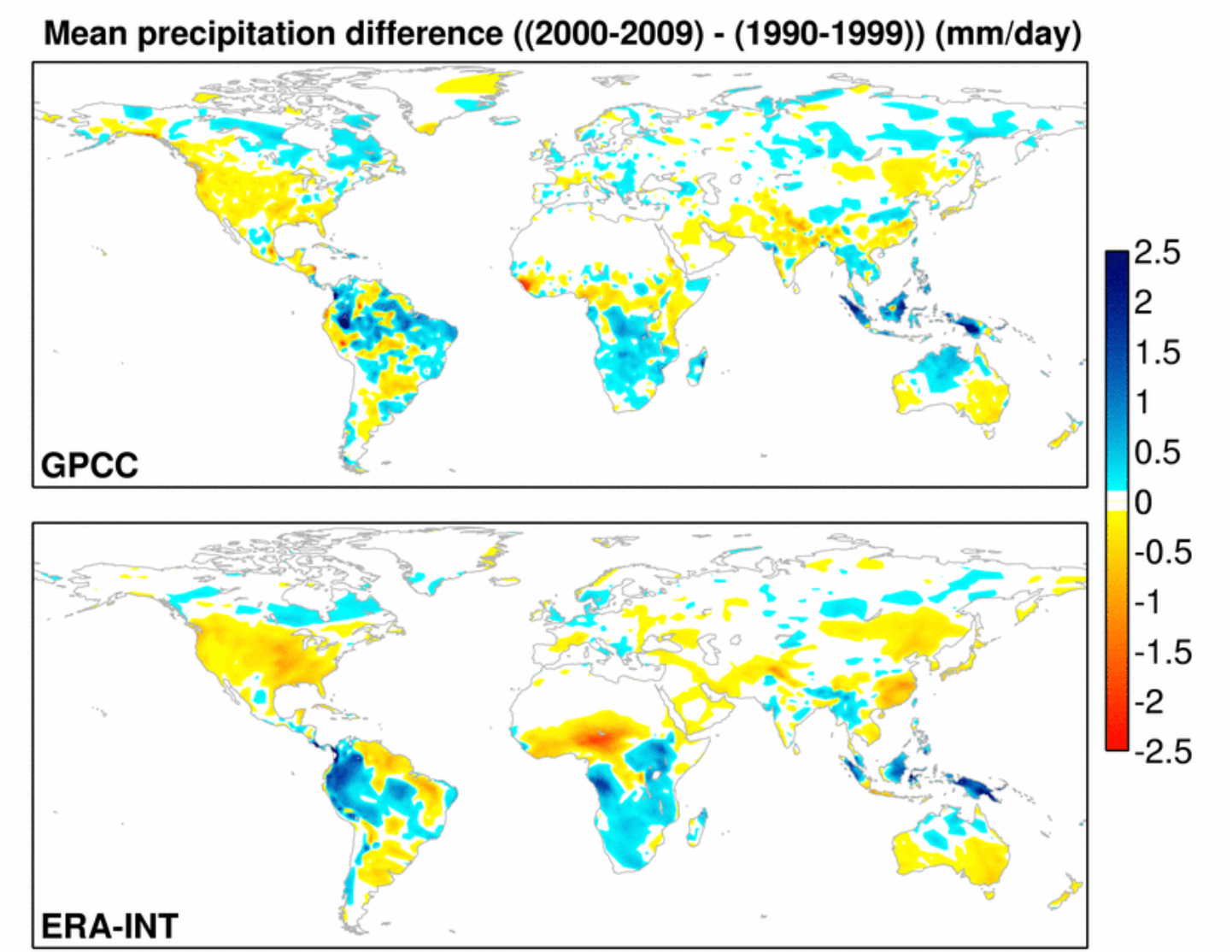
Comparison of monthly averaged rainfall with combined rain gauge and satellite products (GPCP)

Reanalysis estimates of rainfall over ocean are still problematic *(but see Dee et al 2011)*

Results over land are much better



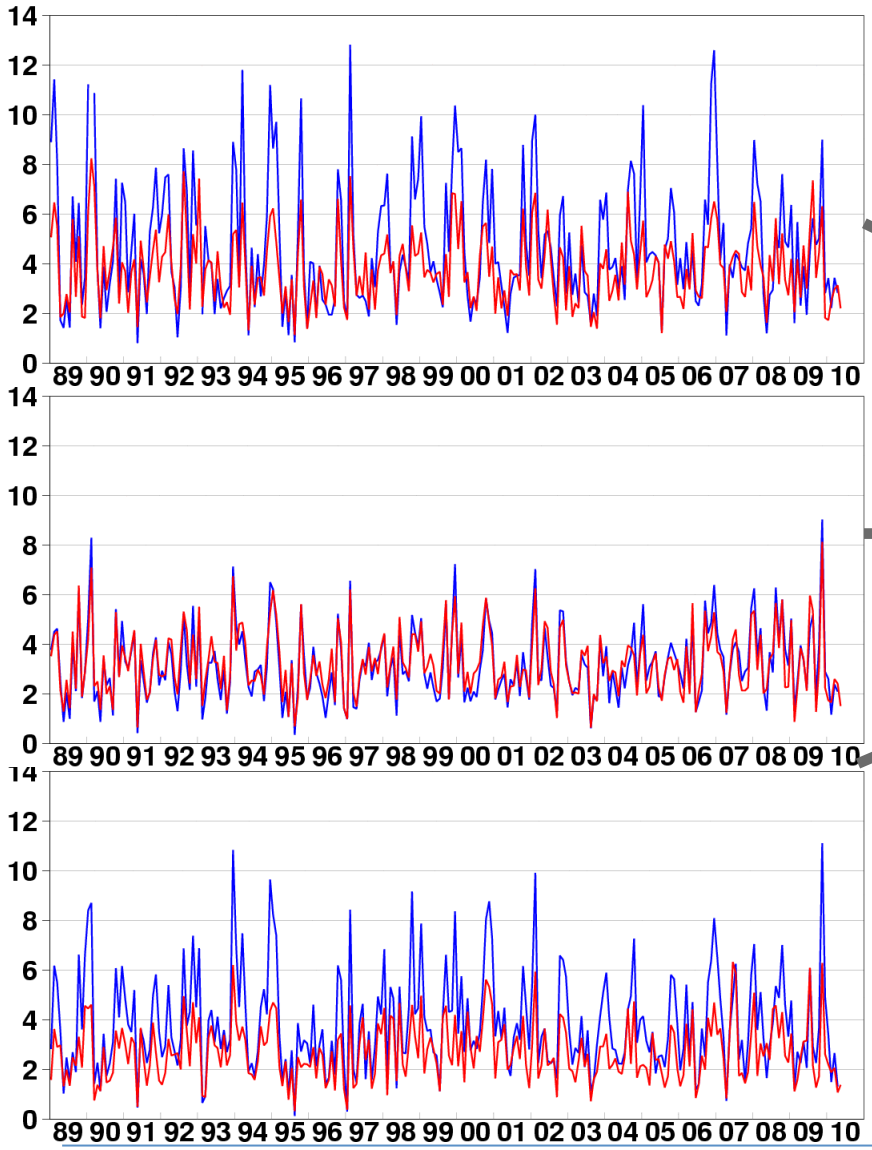
Decadal trends in GPCC and ERA-Interim

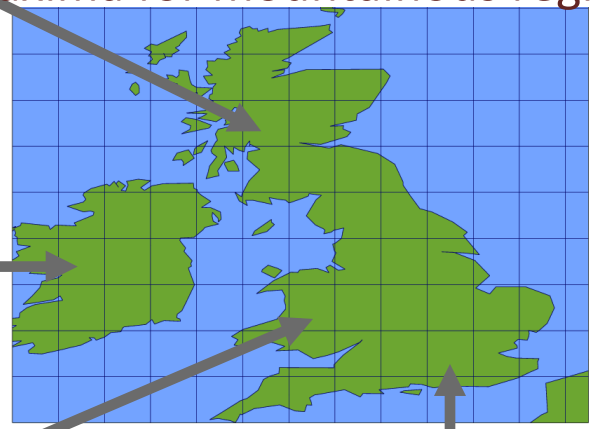


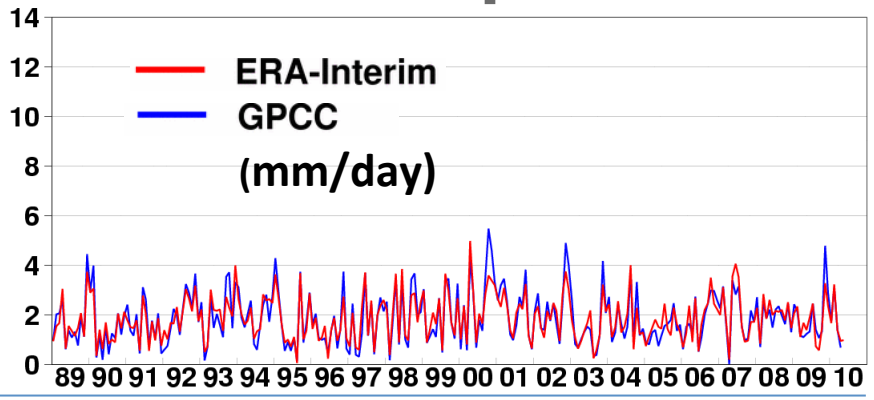
Monthly precipitation rates for 1^{O}x1^{O} grid boxes

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

ERA values underestimate precipitation maxima for mountainous regions



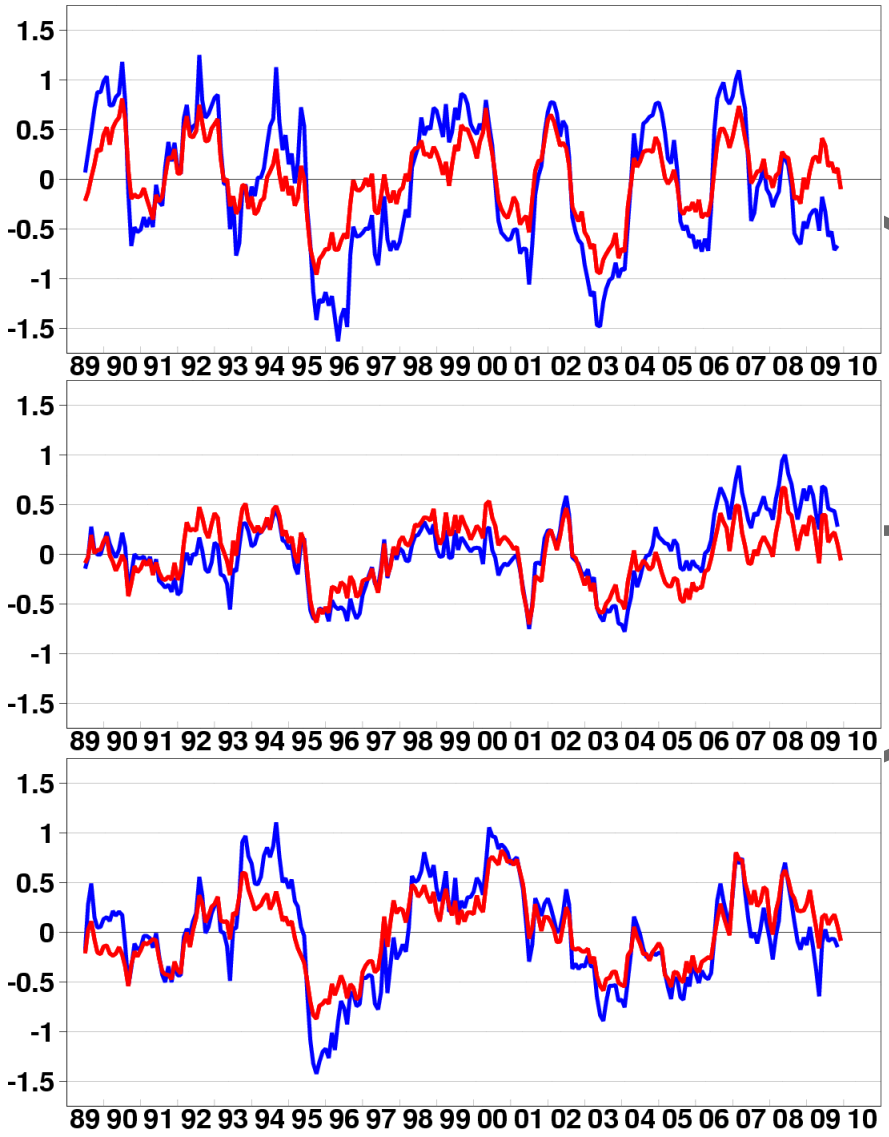


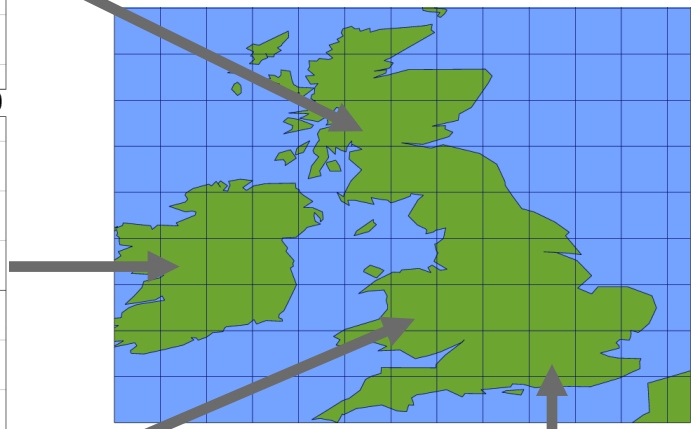


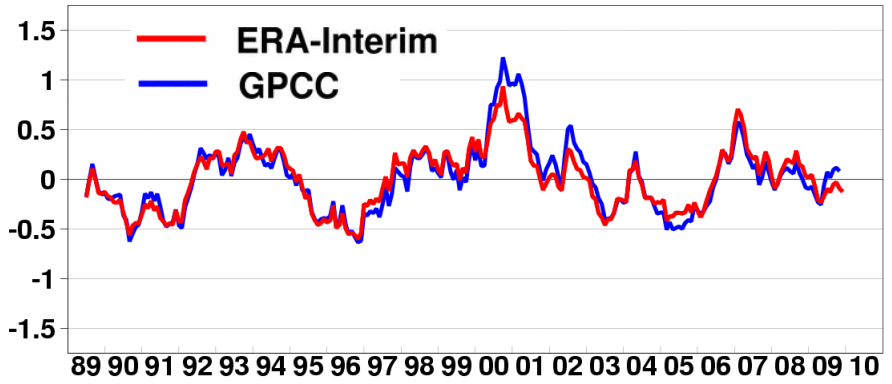
Precipitation anomalies for 1^{O}x1^{O} grid boxes

Anomalies relative to (1989-2009) means for each month from ERA and GPCC.

Time series show 12-month running means.



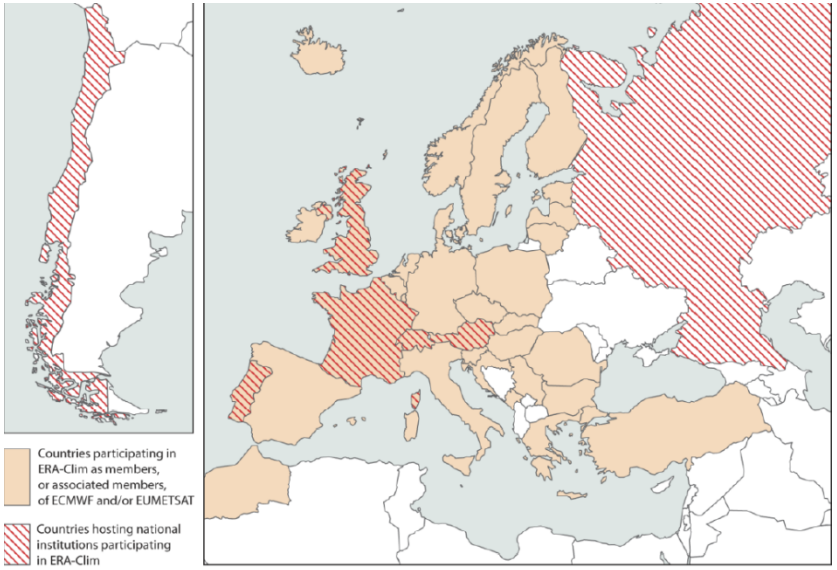




Current work at ECMWF: The ERA-CLIM project

ERA-CLIM: A 3-year collaborative research project coordinated by ECMWF, supported by the EU's FP7

Goal: Prepare input observations, model data, and data assimilation systems for a global atmospheric reanalysis of the 20th century – to begin production in 2014



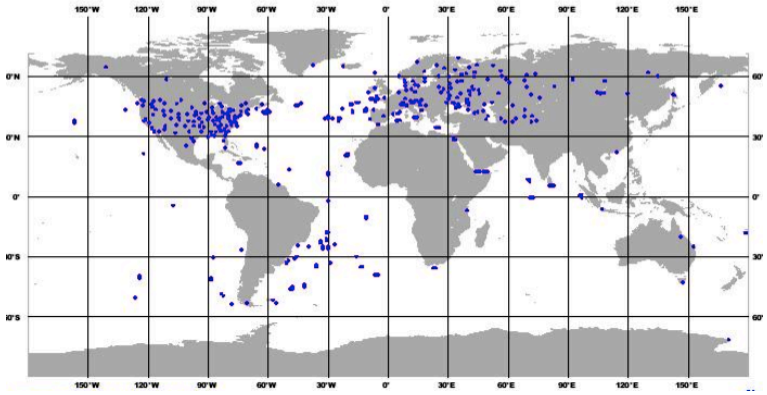
Work plan:

1. Data rescue efforts (in-situ upper-air and satellite observations)
2. Incremental development of new reanalysis products
3. Use of reanalysis feedback to improve the data record
4. Access to reanalysis data and observation quality information

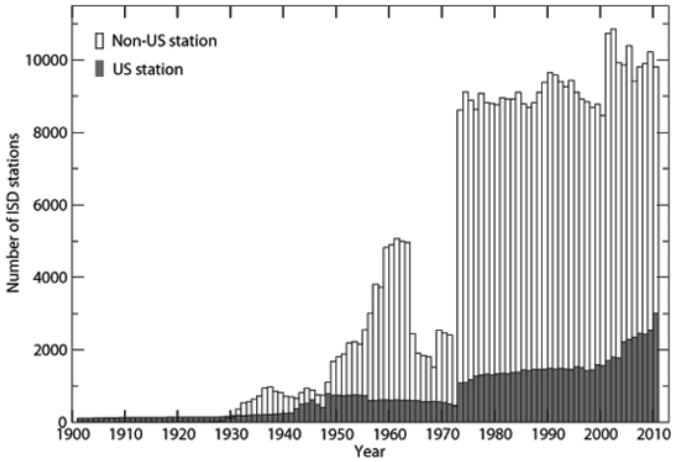
Data rescue: Surface weather observations

Major data collections: ICOADS; ISPD (from 1755); ISD (from 1901)

ISPD stations on a random date in 1900



ISD station counts over time

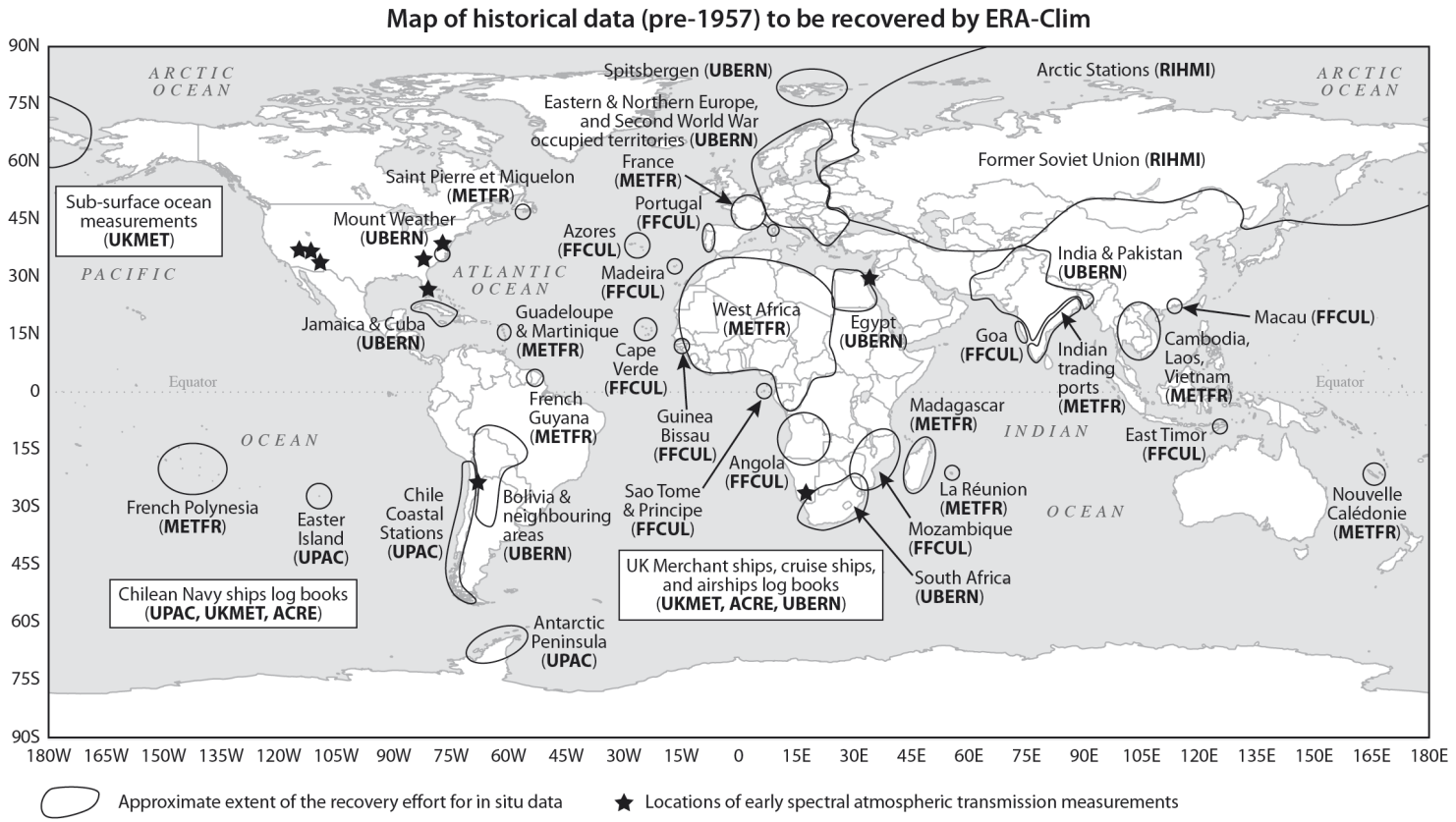


- Poor coverage outside Europe and North America
- Many data not yet in digital form: could easily disappear
- Sub-daily weather observations over land are not well organised (ISTI?)
- Restrictive data policies: precipitation, snow, ..

International Surface Temperature Initiative

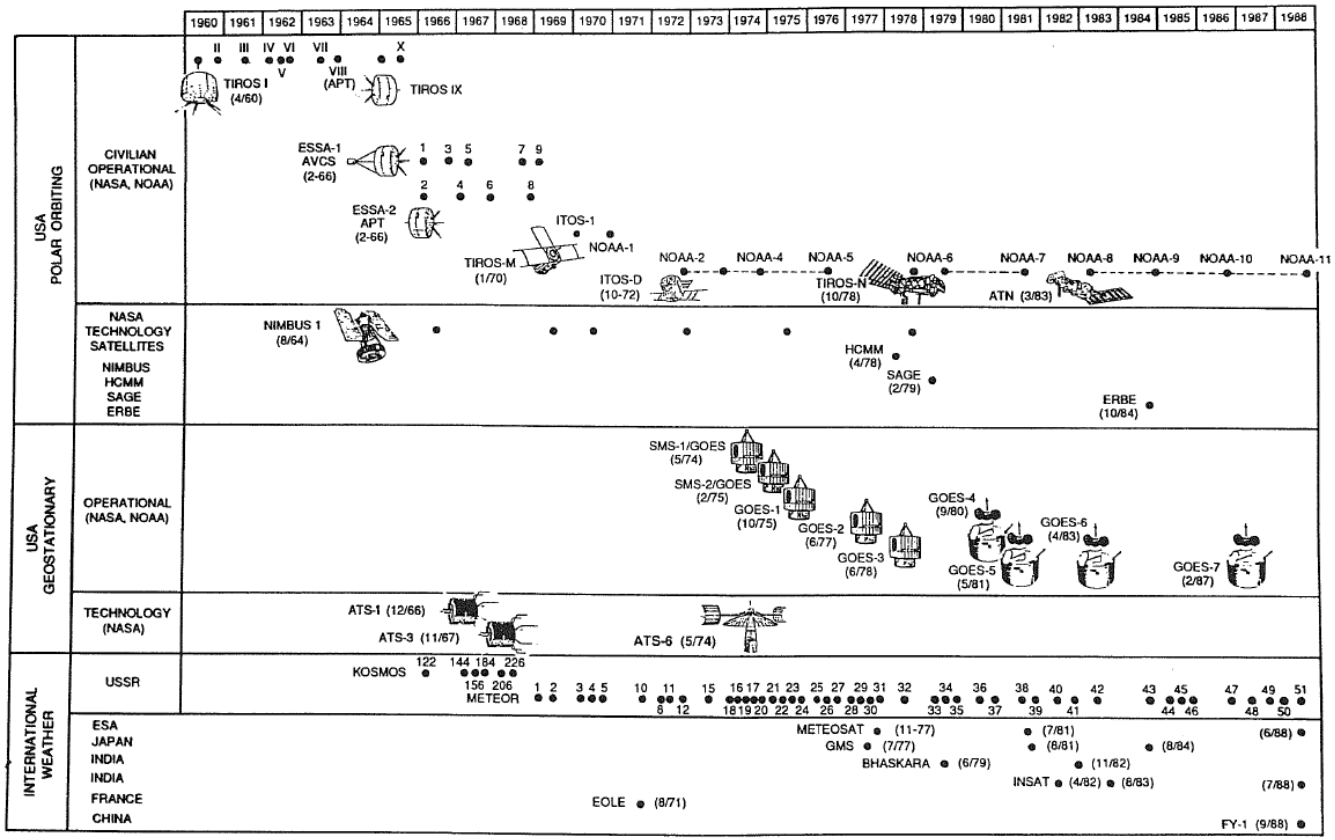
Data rescue in ERA-CLIM: In-situ observations

- Focus on upper-air weather observations in poorly covered regions
- Data rescue, digitisation, and preliminary quality control



Data rescue in ERA-CLIM: Satellite observations

- Can we extend the usable satellite record back to the 1960's?
- Data rescue; development of observation operators; first screening



(from Rao et al., 1990)

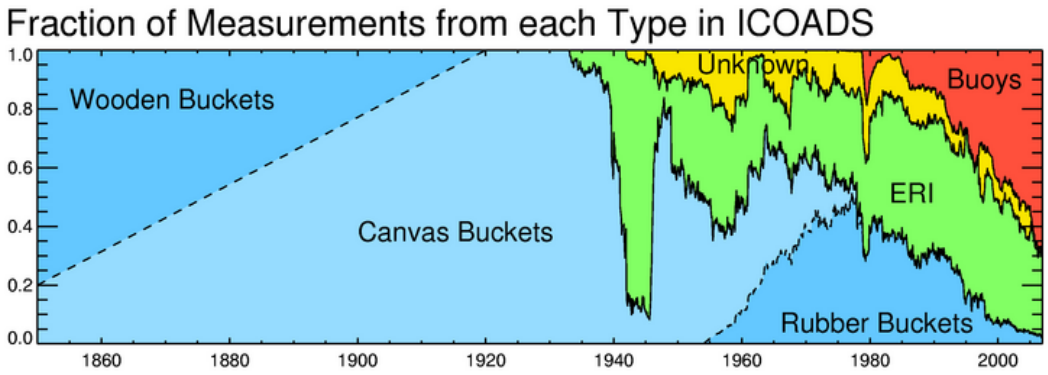
ERA-CLIM reanalysis development

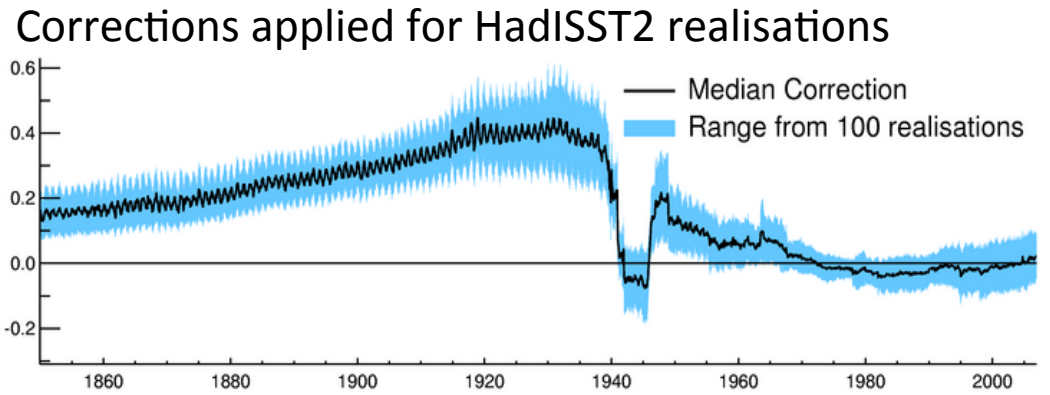
First step: An ensemble of (atmospheric) climate model integrations

- Atmospheric forcing based on CMIP5 input data
- An ensemble of SST/sea-ice estimates from HadISST2

HadISST2 will provide any number of equally plausible SST reconstructions

Key uncertainties arise from unknown error characteristics of SST measurements





(N. Rayner, MetOffice Hadley Centre)

ERA-CLIM reanalysis development

Next: A succession of new reanalysis products

- ERA-20C: 20th Century reanalysis using surface pressure observations only
- ERA-SAT: A new reanalysis of the satellite era (to replace ERA-Interim)

ERA-20CM	Ensemble of model integrations, using HadISST2 and CMIP5 forcing	T159 10 members	
ERA-20C	Reanalysis of surface pressure observations	T159 10 members	Available mid 2013
ERA-20CL	Land-surface only; forced by ERA-20C	T799 10 members	Available mid 2013
ERA-SAT	New reanalysis of the satellite era	T511 To replace ERA-Interim	Available mid 2014

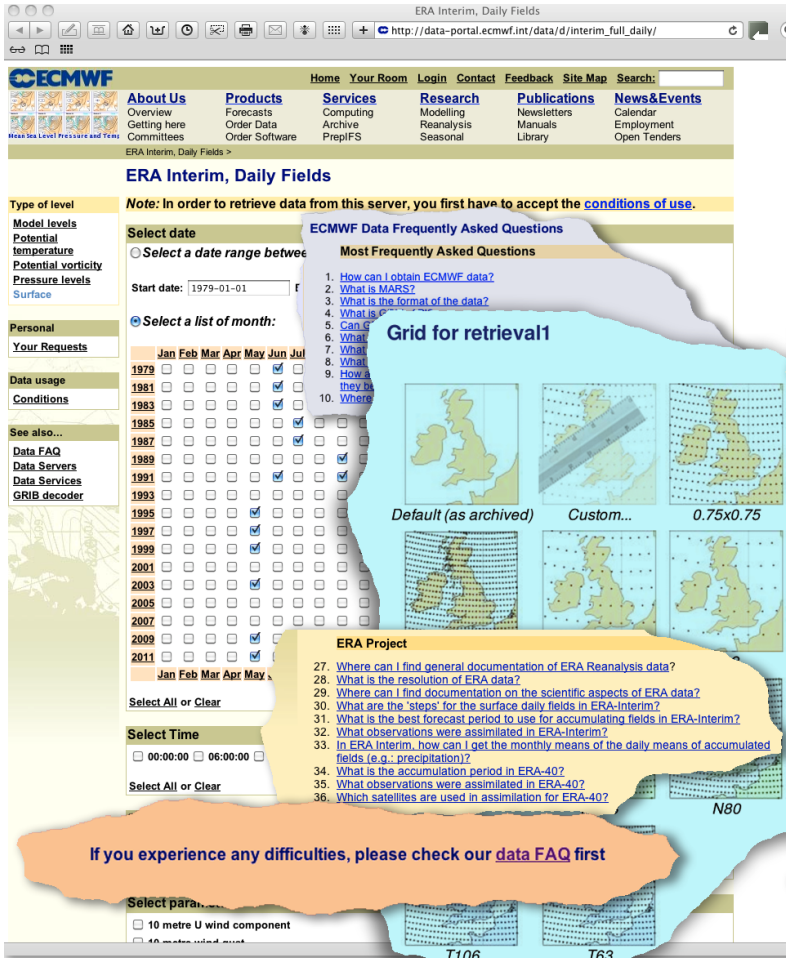
Improved access to reanalysis data

ERA-CLIM data will be freely available via the internet:

- All reanalysis products (1Pb by 2014)
- All input observations (used or screened)
- All quality feedback information (bias estimates, departures, QC flags)

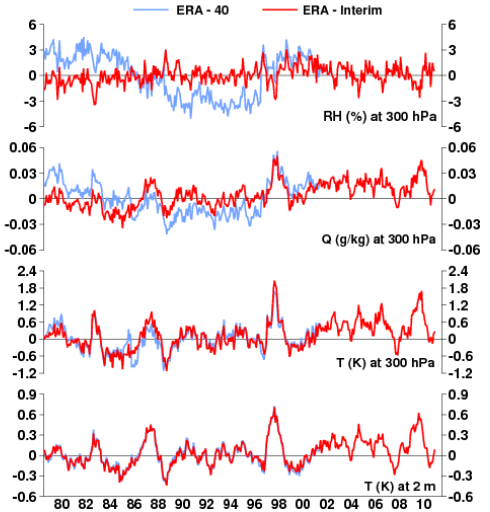
New ERA-Interim data server:

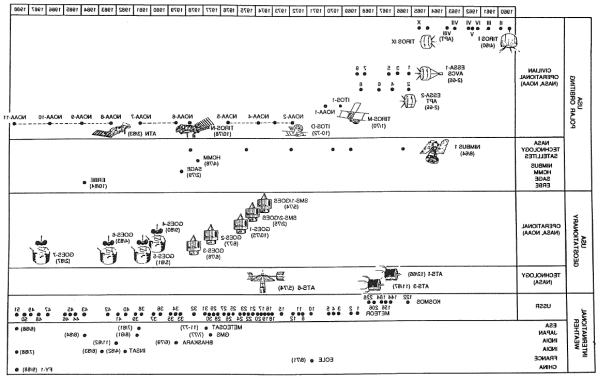
- www.ecmwf.int/research/era
- Data at full horizontal resolution and on model levels
- Options for regional selection and regridding, GRIB or NETCDF
- Less restrictive use conditions



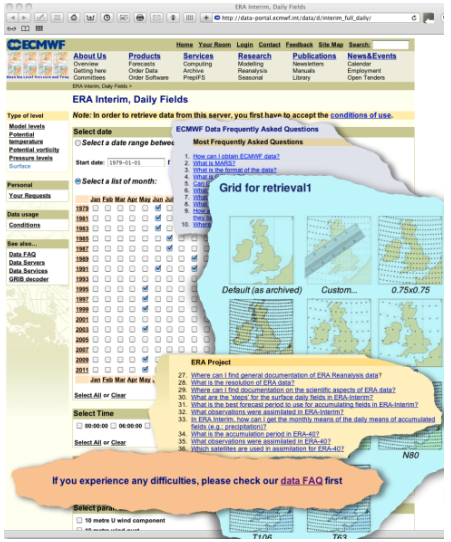
Summary of main points

- Reanalysis integrates the instrumental record
- Model information is key, more so in the early data-sparse period
- ERA-Interim: Good progress in dealing with biases in models and observations





The importance of data rescue efforts, also for the early satellite record



The need to improve access to data:
reanalysis products, observations, quality feedback information