Fourth WCRP International Conference on Reanalysis

Silver Spring, 7 May 2012

Challenges of Reanalysis: Past, present and future

Adrian Simmons

Consultant, European Centre for Medium-Range Weather Forecasts

Chair, Steering Committee for the Global Climate Observing System

GCOS
GLOBAL CLIMATE OBSERVING SYSTEM

ECMWF

Objectives of this presentation

To provide a basic introduction

- to atmospheric data assimilation and reanalysis
- to evolution of the atmospheric observing system
- to various reanalysis activities in progress worldwide
- giving some common background to the other talks in this opening session
- identifying a number of general questions or challenges to be faced relating to the coordination and conduct of reanalysis

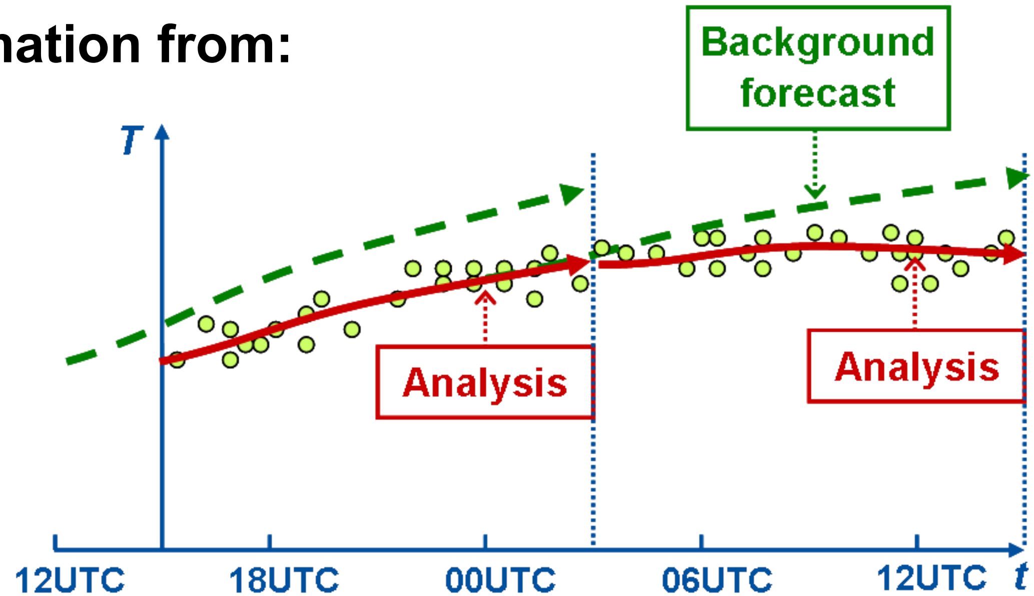
To present some recently updated results from ECMWF's ERA-40 and ERA-Interim reanalyses

- related to low frequency variability and trends
- identifying a number of more specific questions or challenges to be faced
- linking with several other talks and posters to be presented this week
- and presented with thanks to ERA team members past and present

Data assimilation

Data assimilation blends information from:

- observations
- a short “background” model forecast from previous analysis
- estimates of observational and background errors
- dynamical relationships built into the representation of background errors



4D variational assimilation as used in ERA-Interim

to produce an estimate of the atmospheric state

Model carries information from earlier observations forward in time and spreads it in space

Information is spread from one variable to another by the model and by background-error relationships

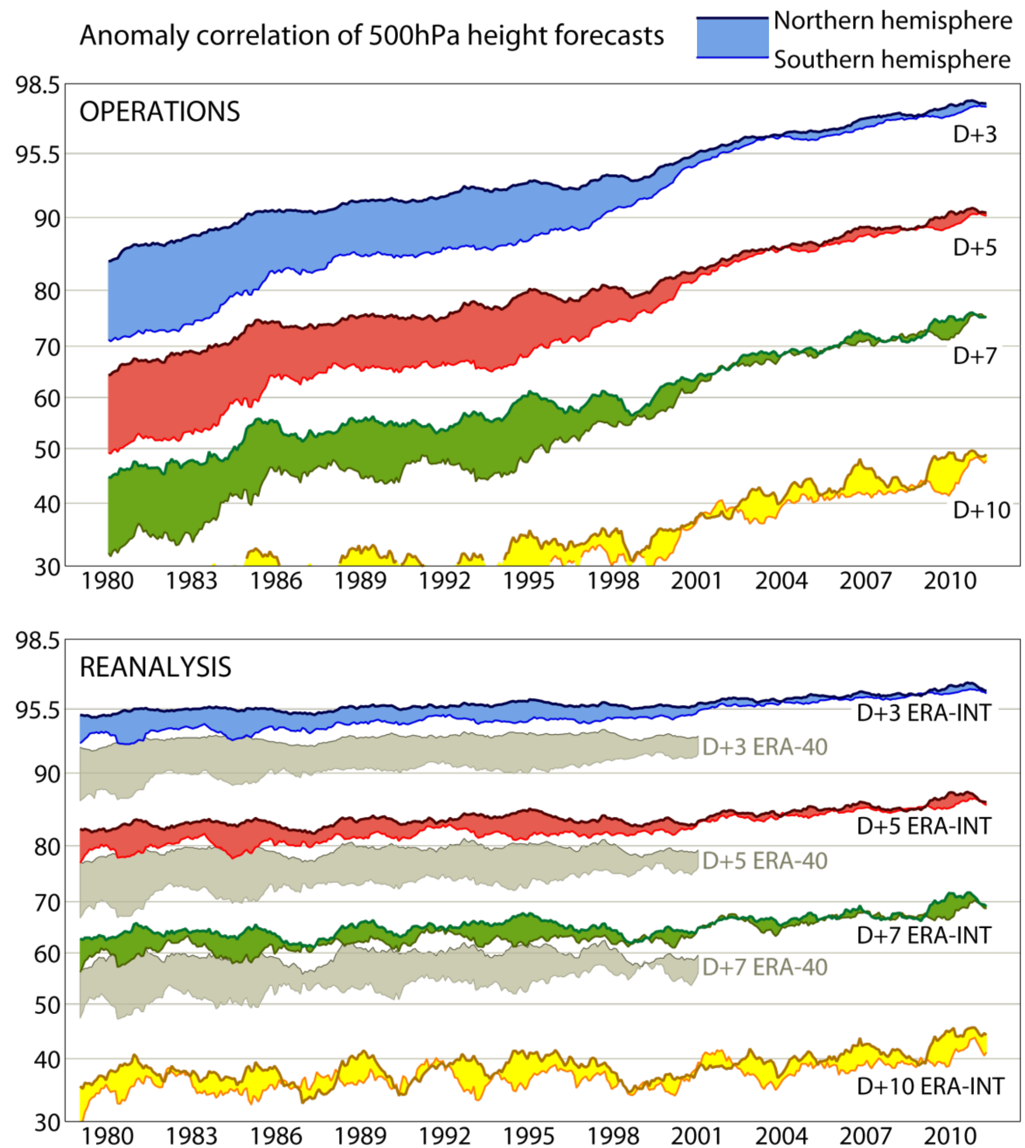
Data assimilation and reanalysis

Data assimilation was developed to provide estimates of the state of the atmosphere, “analyses”, needed to start operational numerical weather forecasts

Large improvements in forecasts have stemmed from better data assimilation and observations

Improvement from 1980 to 2000 comes mostly from improvement to forecasting system

Improvement since 2000 comes from improvement to forecasting system and to observations



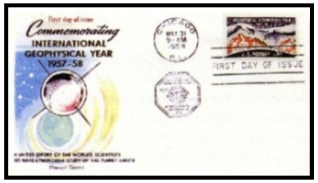
Development of the observing system

Early years Growth of network of surface measurements
Development of measurements from balloons

1940s Establishment of network of radiosonde measurements from North Atlantic and North Pacific Weather Ships

Ship Alpha

1957 Radiosonde network enhanced in southern hemisphere for the International Geophysical Year



1972 Operational sounding of temperature and humidity from polar-orbiting satellite
Some data from commercial aircraft

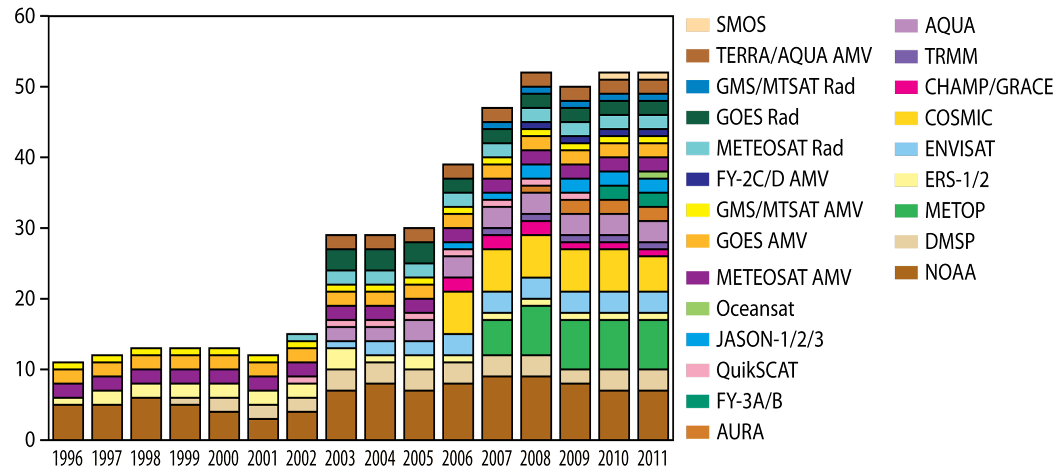
NOAA-2
15 Oct 1972

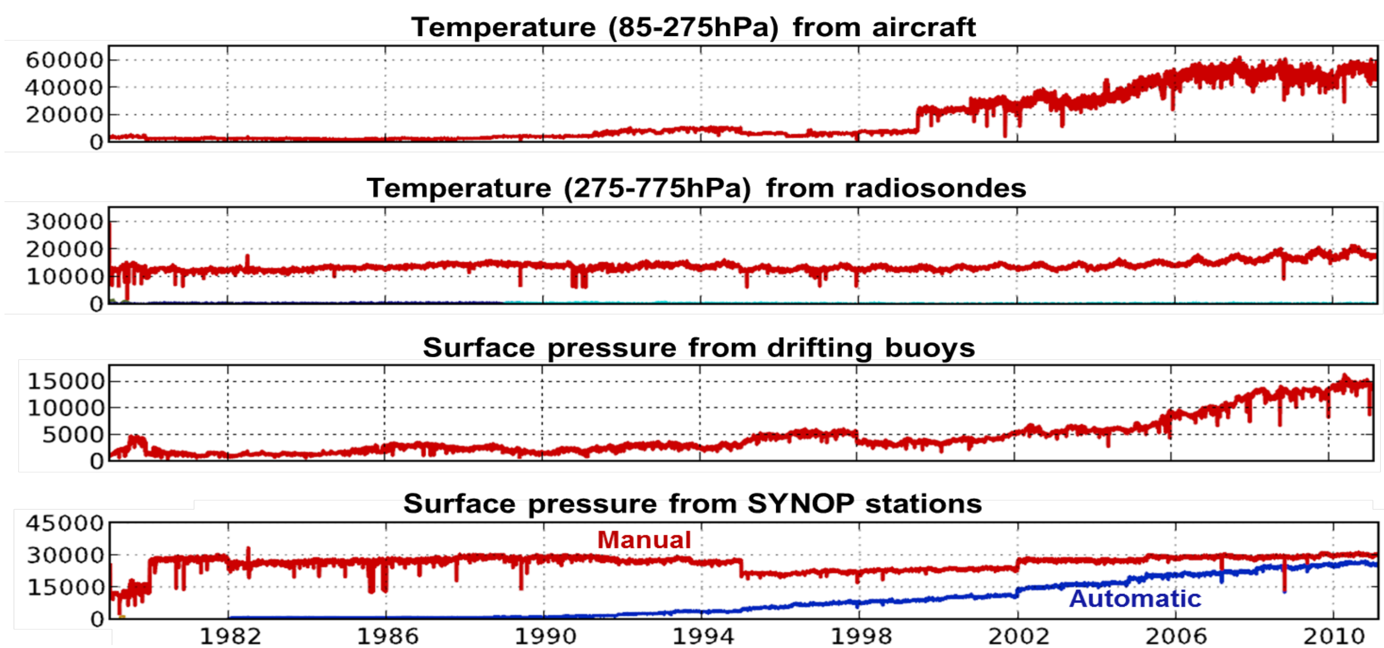
1979 Improved sounding from polar orbiters
Winds from geostationary orbit
Much more data from commercial aircraft
Drifting buoys

Increases in observational types and numbers

Number of satellite instruments from which data were passed through the ECMWF assimilation system from 1996 to 2011

ERA-Interim did not process some of these data. The number increases if atmospheric composition data are included





Examples of daily counts of *in situ* data used in ERA-Interim from 1979 to 2011

Observational metadata products

Atmospheric reanalysis generates not only

- gridded meteorological, ocean-wave and land-surface products

but also

- quality-control information on each observation
- fits of background forecast and analysis to each observation
- estimates of biases of some types of observation

The observational metadata support informed use for climate purposes

- of products (e.g. enabling inferences from drifts in background and analysis fits to observations over time)
- of observational data (e.g. through use of quality control or bias information)

Enabling this fully is a technical and data-policy challenge

- and pursuing this in the past has been a user challenge, met for example by Haimberger in determining break points for homogenising radiosonde data

Atmospheric reanalysis

Proposed in 1988 by Bengtsson & Shukla and Trenberth & Olson

– for climate studies, following ECMWF and GFDL “FGGE” reanalyses for 1979

Three responses in the mid 1990s

– ERA-15 (1979 - 93), NASA/DAO (1980 - 93) and NCEP/NCAR (1948 - …)

Second round followed

– ERA-40 (1958 - 2001), JRA-25/JCDAS (1979 - …) and NCEP/DOE (1979 - …)

Now towards end of third generation of comprehensive global reanalysis

– CFSR (1979 – 2010?), ERA-Interim (1979 - …), JRA-55 (1958 - 2012) and MERRA (1979 - …)

With more diverse contributions

– 20th Century reanalysis (1871 – 2010) using surface pressure and SST data

– Reanalyses focused on atmospheric composition, regional reanalyses, …

Organisational questions

How do producers secure funding with a sufficient time horizon?

- to enable appropriate planning, preparation and execution of reanalyses
- to allow appropriate international coordination

How many comprehensive global reanalyses do users need?

- covering which periods, how often refreshed, when to be terminated?
- are three or four main centres producing for global consumption enough?
- how many from around the Capital Beltway?
- is regional reanalysis a better focus for potential new entrants?

To what extent is international coordination needed?

- over development of input datasets (observations, forcing fields, emissions, …)
- over timing of mainstream production
- over running of supplementary data assimilations and model integrations
- over linking of activities with climate modelling

and how formal can or should this be?

Implementational challenges

Ongoing business remains challenging and important

- recovery of observational data from past years
- improvement of assimilating models
- improvement of assimilation methods, including the treatment of model error

But we tend to shift from direct use of tried-and-tested NWP systems

- adjusting (statically or dynamically) background errors for earlier, more poorly observed periods
- developing longer-window data assimilation, in which reanalysis can benefit from additional observations made after the analysis time

And there are questions to be asked

- should we expect a single method to be optimal across the centuries?
- how quickly and fully should coupling be introduced with the ocean circulation, with atmospheric chemistry, …?
- should global producers provide global downscaling to higher resolution?
- …

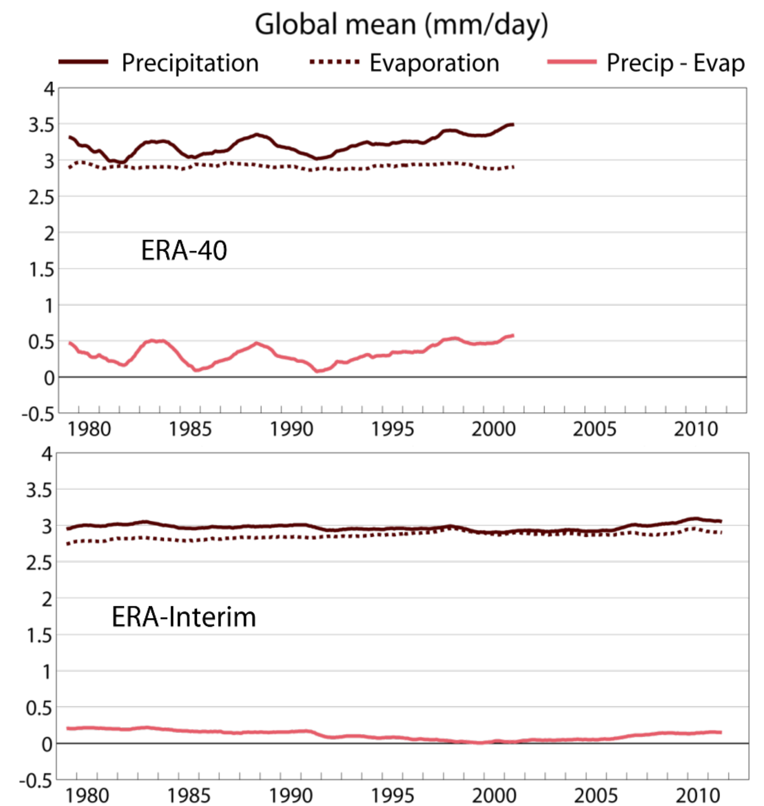
Capturing realistic low-frequency variations and trends: challenges

Observations have biases, and these biases change over time

e.g. daytime warm bias in radiosonde measurements of stratospheric temperature

Models have biases, and changes over time in observational coverage change the extent to which these biases are corrected by the assimilation process

e.g. 1970s transition of observing system in southern hemisphere; introduction and later changes in availability of SSMI humidity data

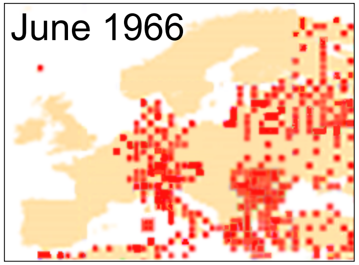


Data assimilation can introduce biases that depend on observational coverage

e.g. humidity/rainfall problem over tropical oceans in ERA-40

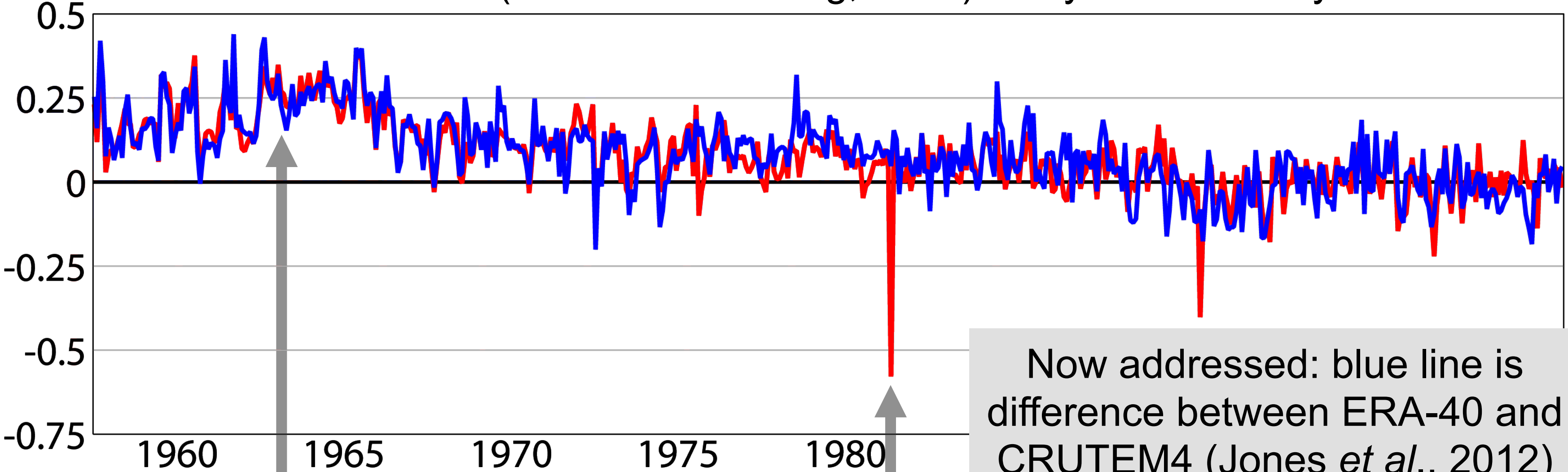
Should balance be enforced, or used as a diagnostic?

Surface air temperature anomaly (K) with respect to 1987-2001



Many gaps in SYNOP coverage in ERA-40 prior to 1967

Red line is average difference over Europe between ERA-40 analysis of synoptic data and CRUTEM2v (Jones and Moberg, 2003) analysis of monthly station data



Now addressed: blue line is difference between ERA-40 and CRUTEM4 (Jones *et al*., 2012)

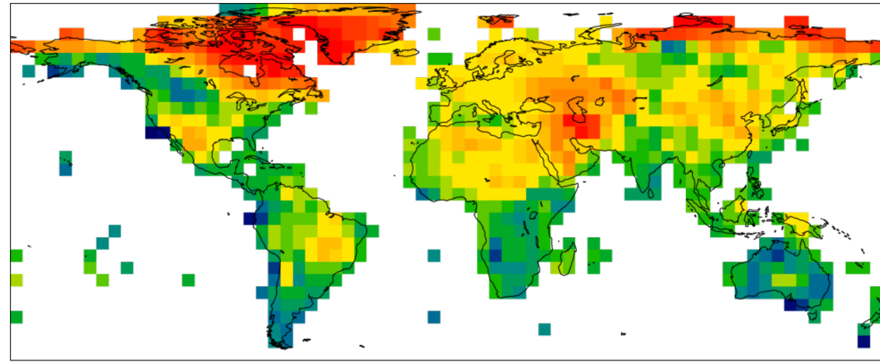
Warm bias in ERA-40 due to inadequate SYNOP coverage

Warm bias in CRUTEM2v due to erroneous station data

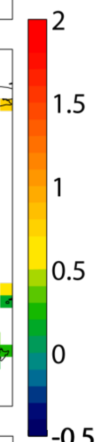
Monitoring large-scale temperature change

Differences in 16-year means of 2m temperature (K)

(1995 to 2010) – (1979 to 1994)

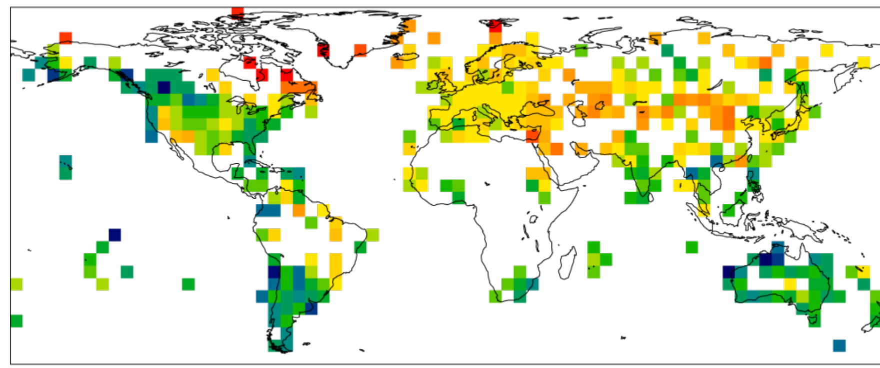


ERA-Interim (averaged onto CRU grid)



ERA-Interim analyses synoptic observations using a model background

CRUTEM analyses monthly station data using station climate as the background

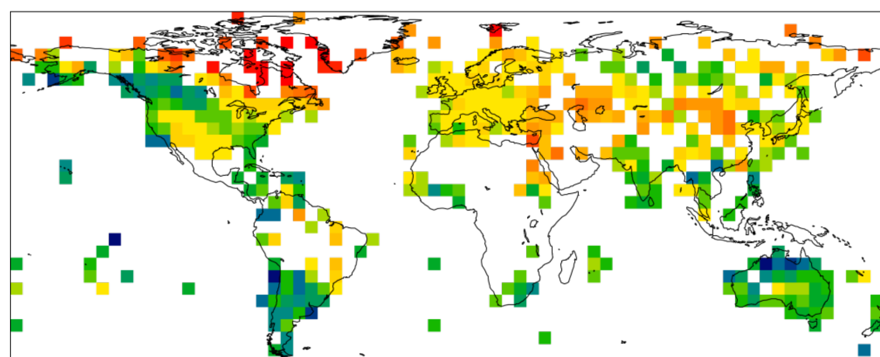


CRUTEM3 (Brohan *et al.*, 2006)

At common grid boxes, RMS differences between ERA-Interim and CRUTEM are:

0.241K for CRUTEM3

0.227K for CRUTEM4



CRUTEM4

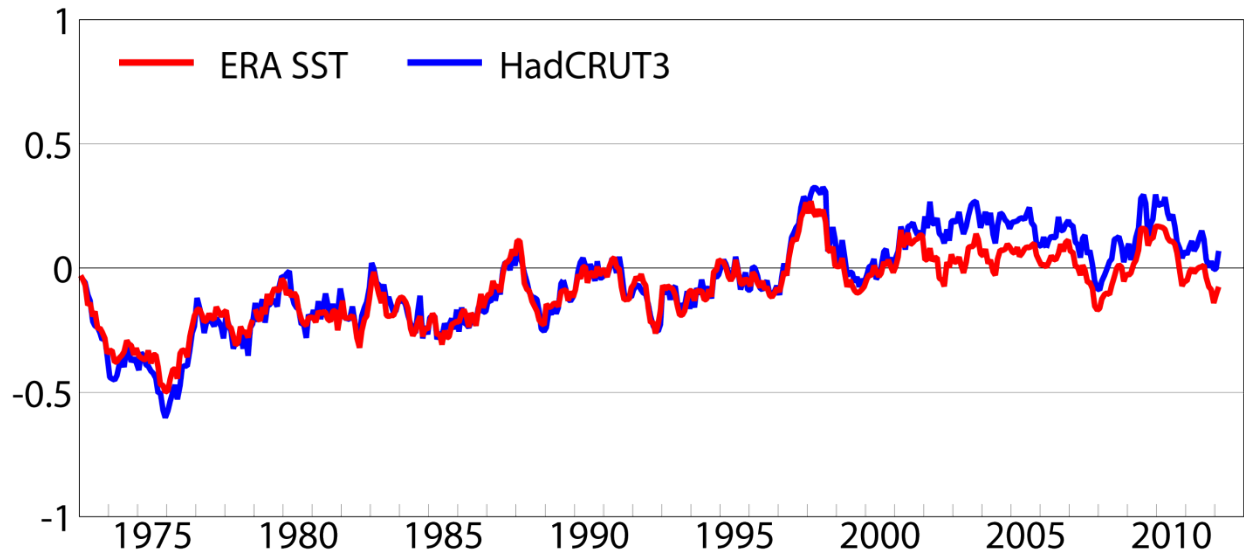
Consistency over time of global sea-surface temperature analysis

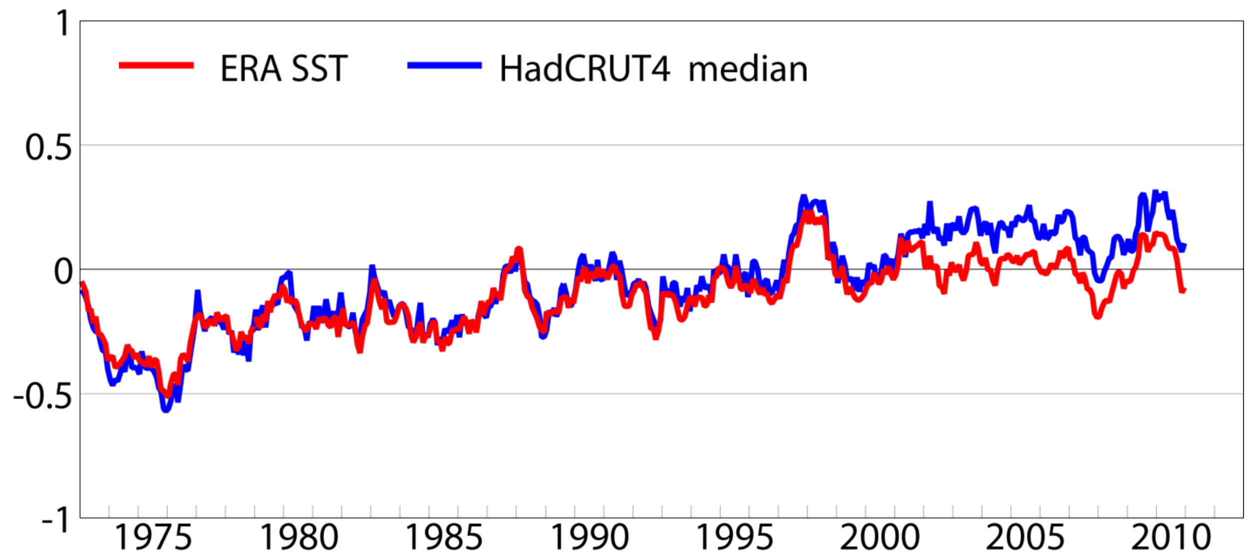
HadCRUT3 is effectively HadSST2

Global averages (K) over model sea areas are shown. ERA used :

- HadISST1 to Nov 1981
- NCEP 2D-Var to Jun 2001
- NCEP ops to Sept 2008
- Met O. OSTIA thereafter

HadCRUT4 is effectively HadSST3





Consistency over time of tropical sea-surface temperature analysis

HadCRUT3 is effectively HadSST2

Tropical averages (K) over model sea areas are shown. ERA used :

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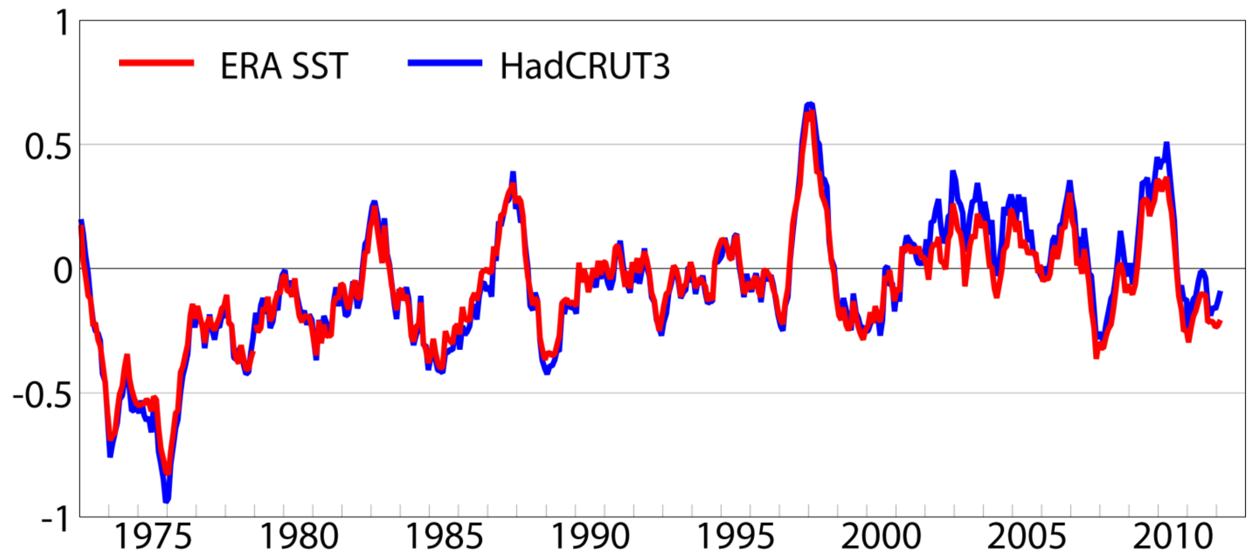
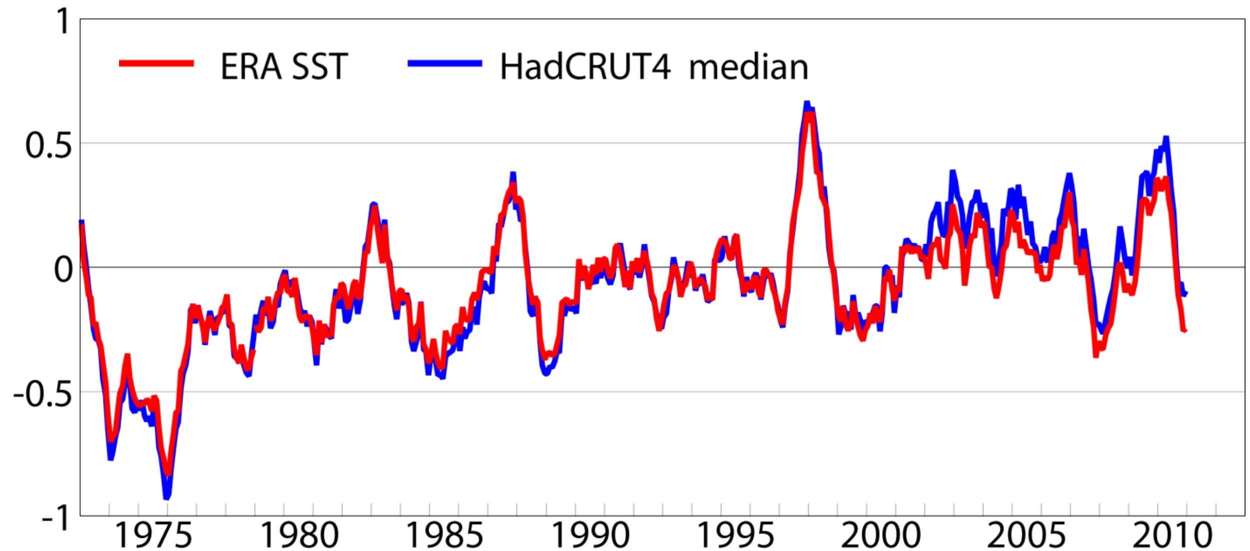
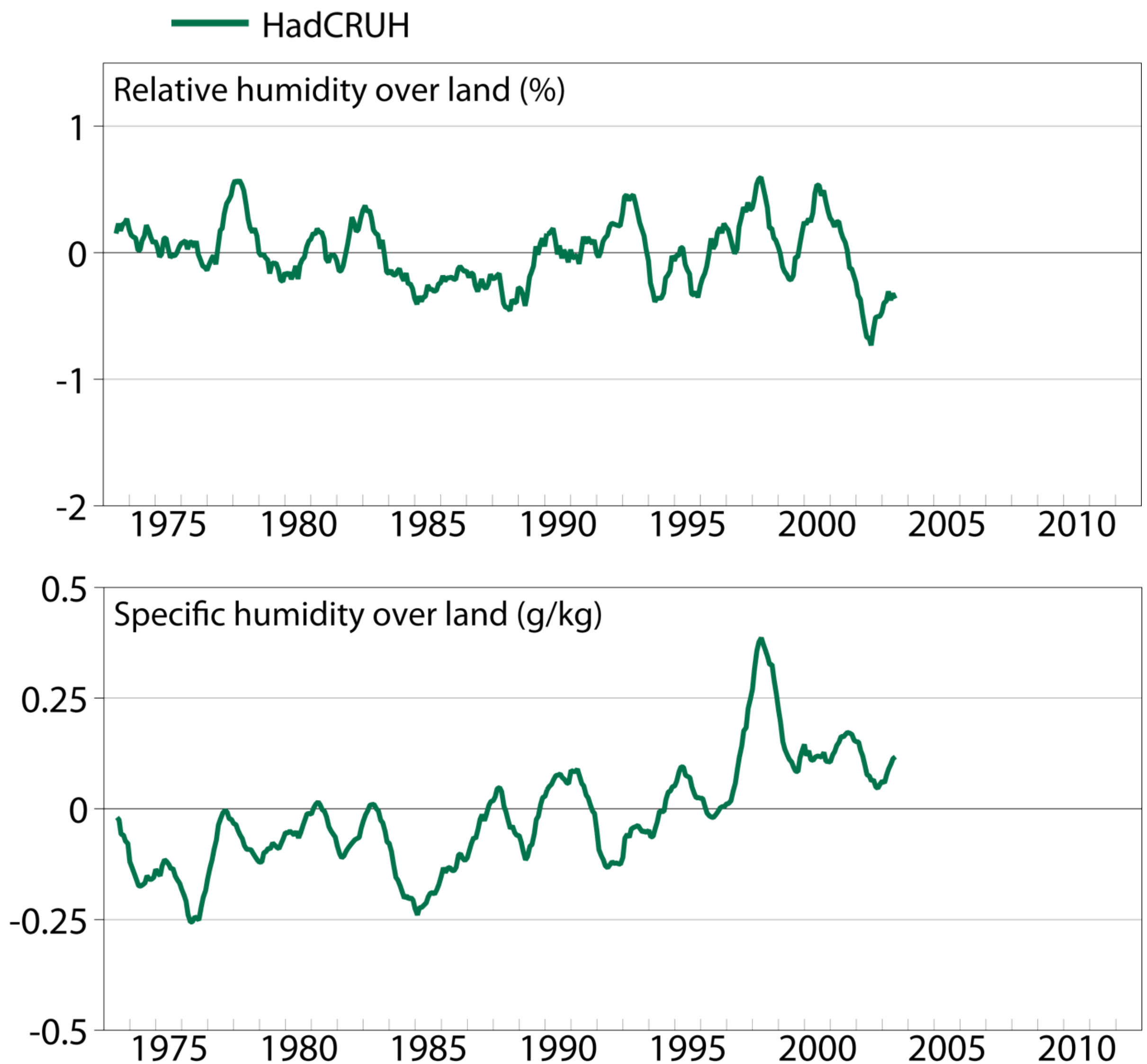
HadCRUT4 is effectively HadSST3





Global average of near-surface humidity over land

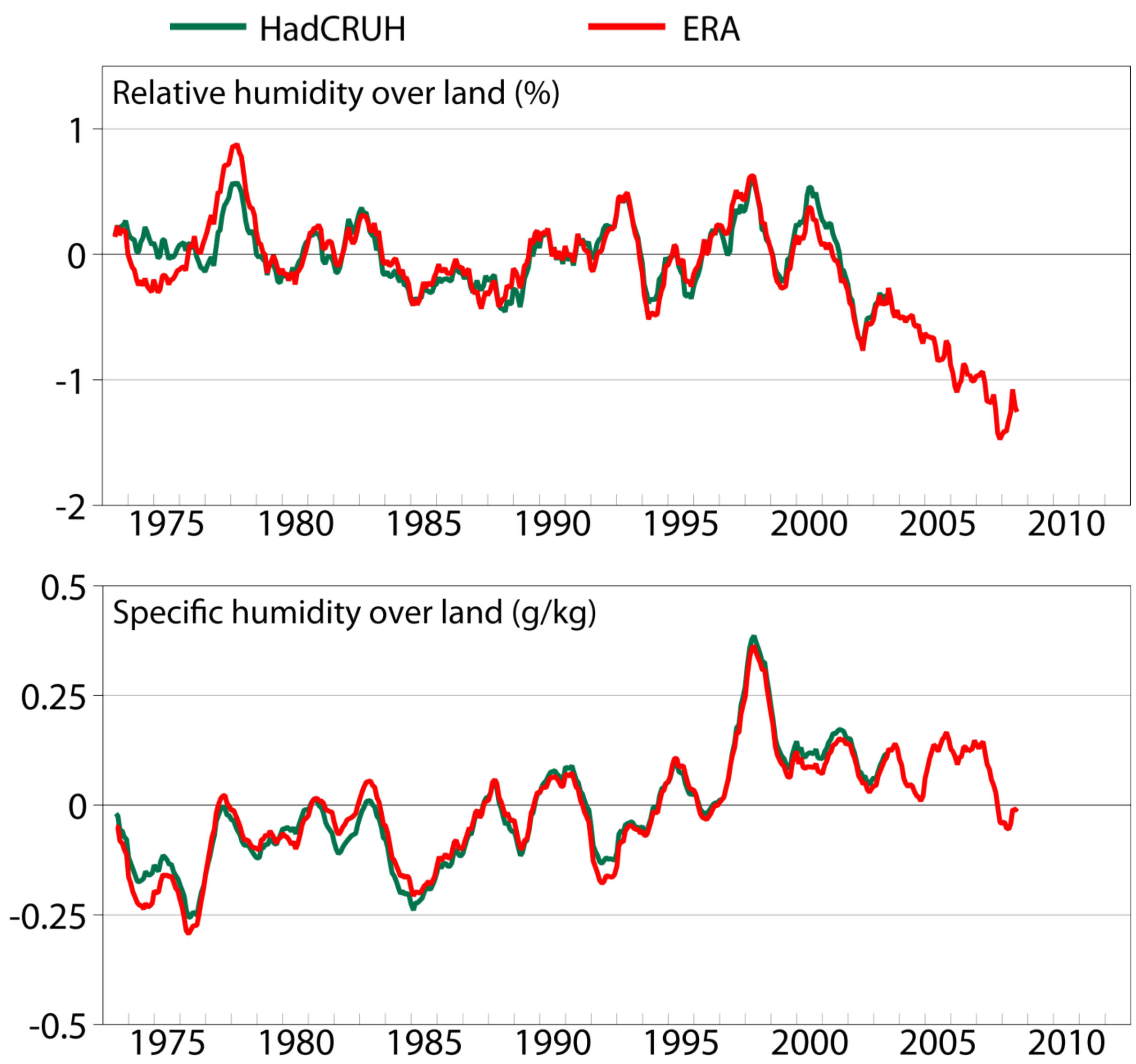
Global averages of relative humidity (%) and specific humidity (g/kg) over land are shown for the HadCRUH (Willett *et al*. 2008) dataset of gridded anomalies from synoptic observations



Global average of near-surface humidity over land

Global averages of relative humidity (%) and specific humidity (g/kg) over land are shown for the HadCRUH (Willett *et al*. 2008) and ERA datasets of gridded anomalies from synoptic observations

ERA is sampled to match the sampling of HadCRUH



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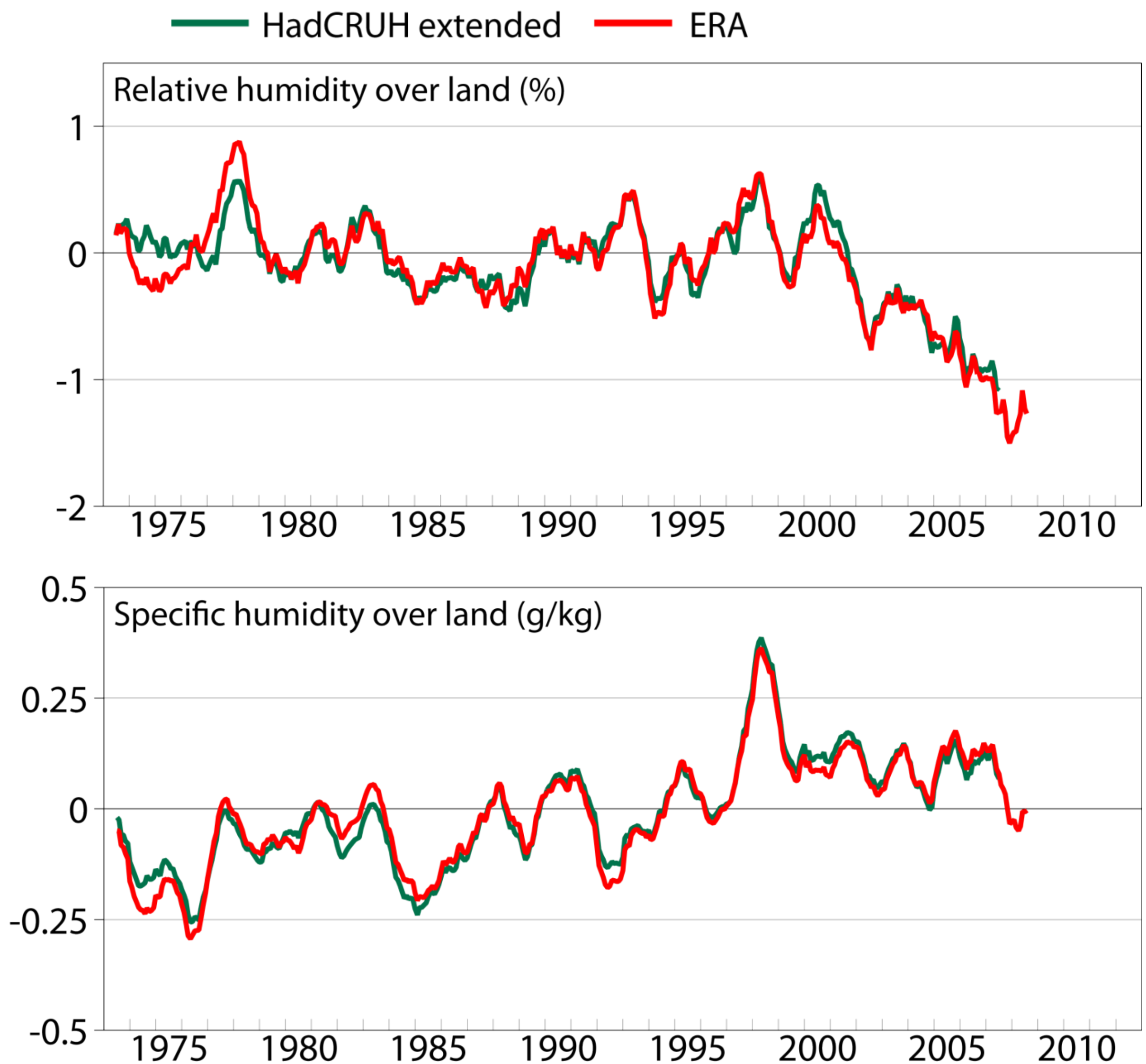
HadCRUH is extended by four years (Simmons *et al*., 2010)

ERA is sampled to match the sampling of HadCRUH

Comment: Full updating of HadCRUH is needed



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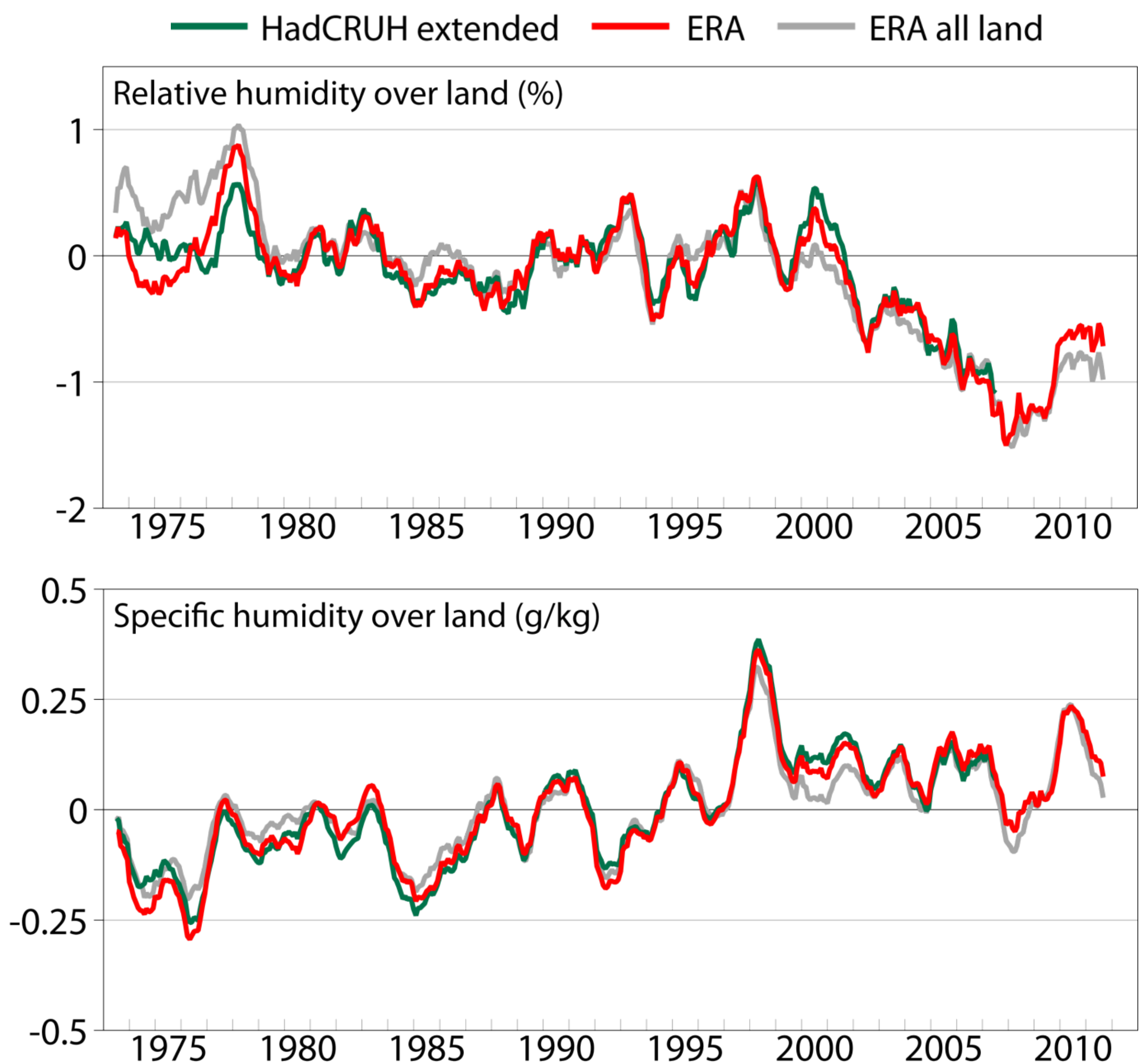
HadCRUH is extended by four years (Simmons *et al*., 2010)

ERA is shown with/without HadCRUH sampling

Comment: Full updating of HadCRUH is needed



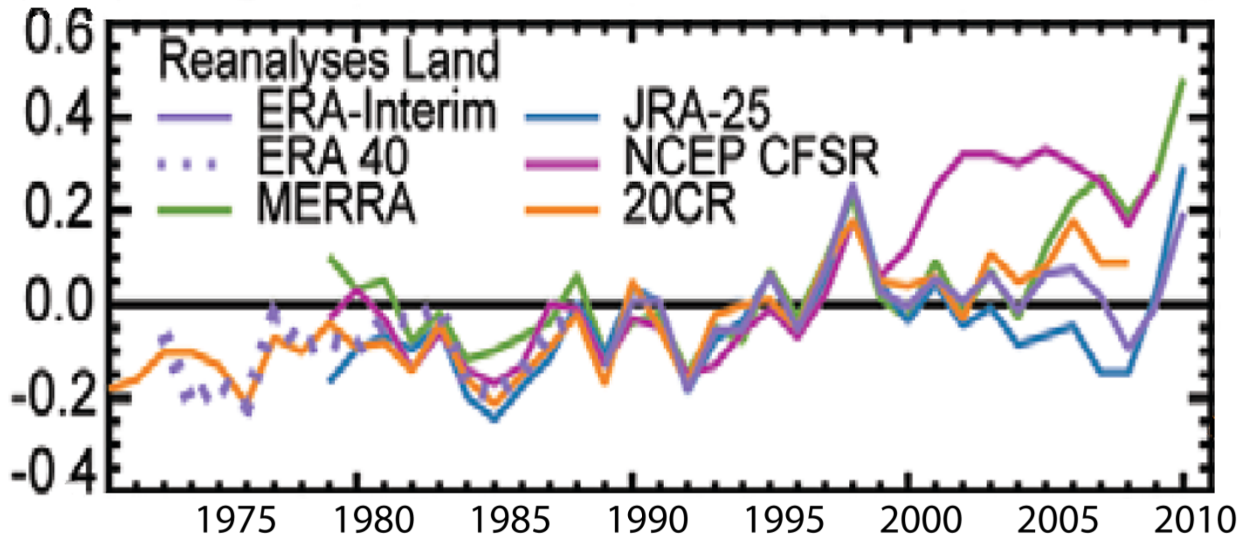
Global average of near-surface humidity over land

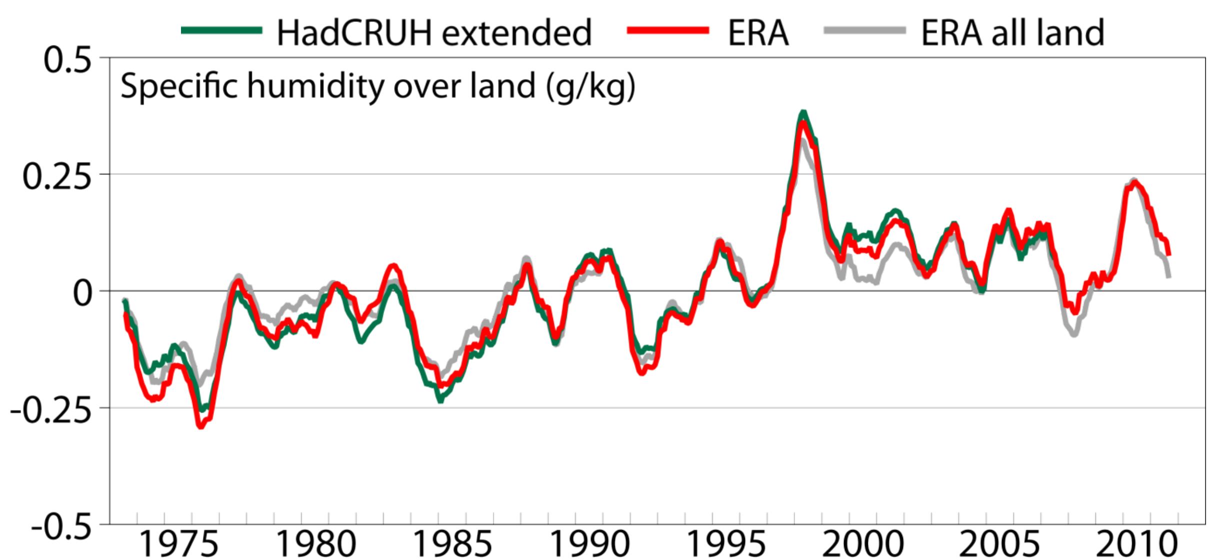
Global averages of specific humidity (g/kg) over land are shown for reanalyses as presented in the BAMS State of the Climate 2010 article

Corresponding plots for ERA and the extended HadCRUH are also shown

Question:

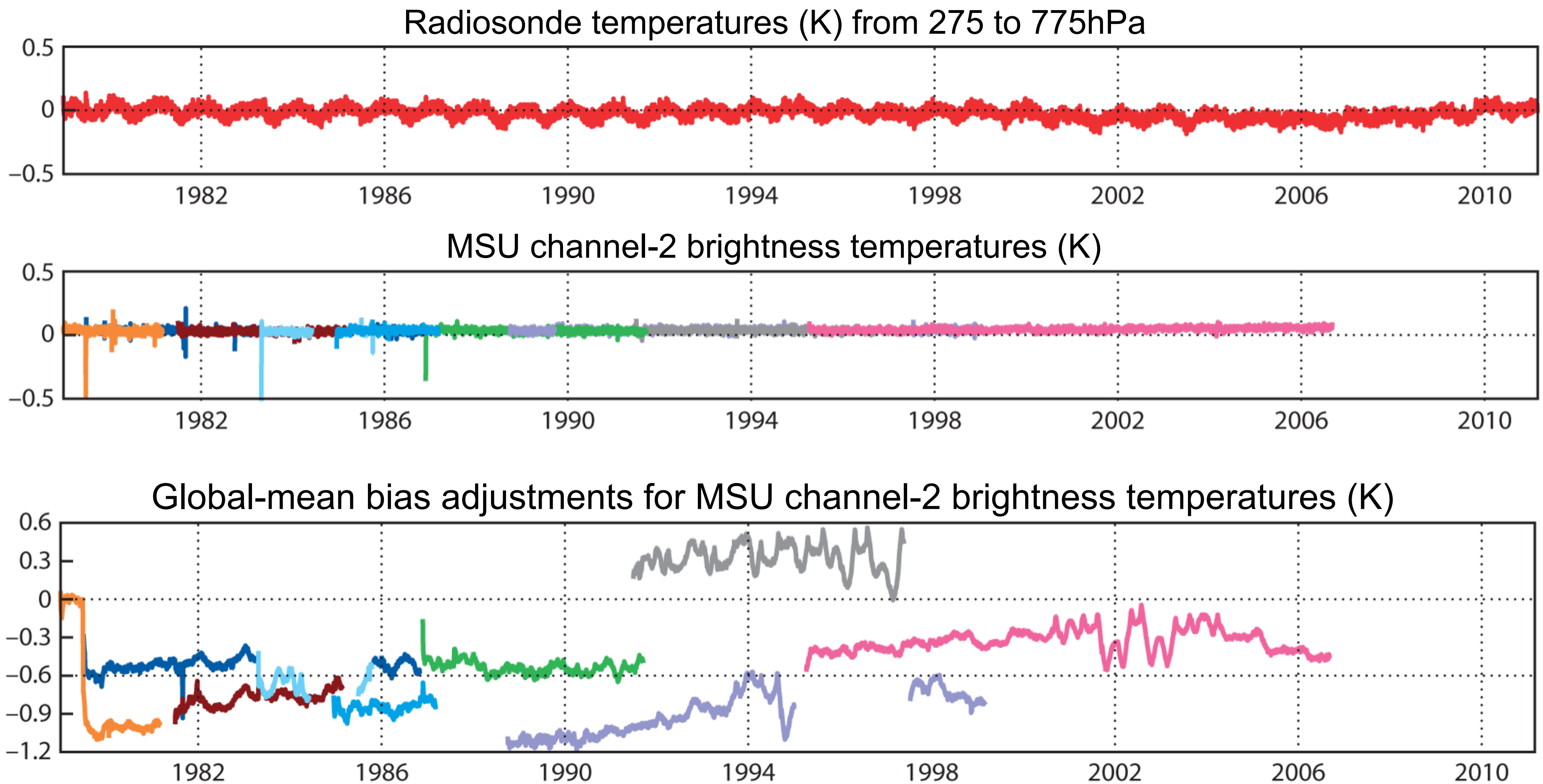
Should all submitted results from reanalyses be accepted for SoC article regardless of demonstrated quality?





Temporal consistency of ERA-Interim

Global-mean differences between background forecasts and observations

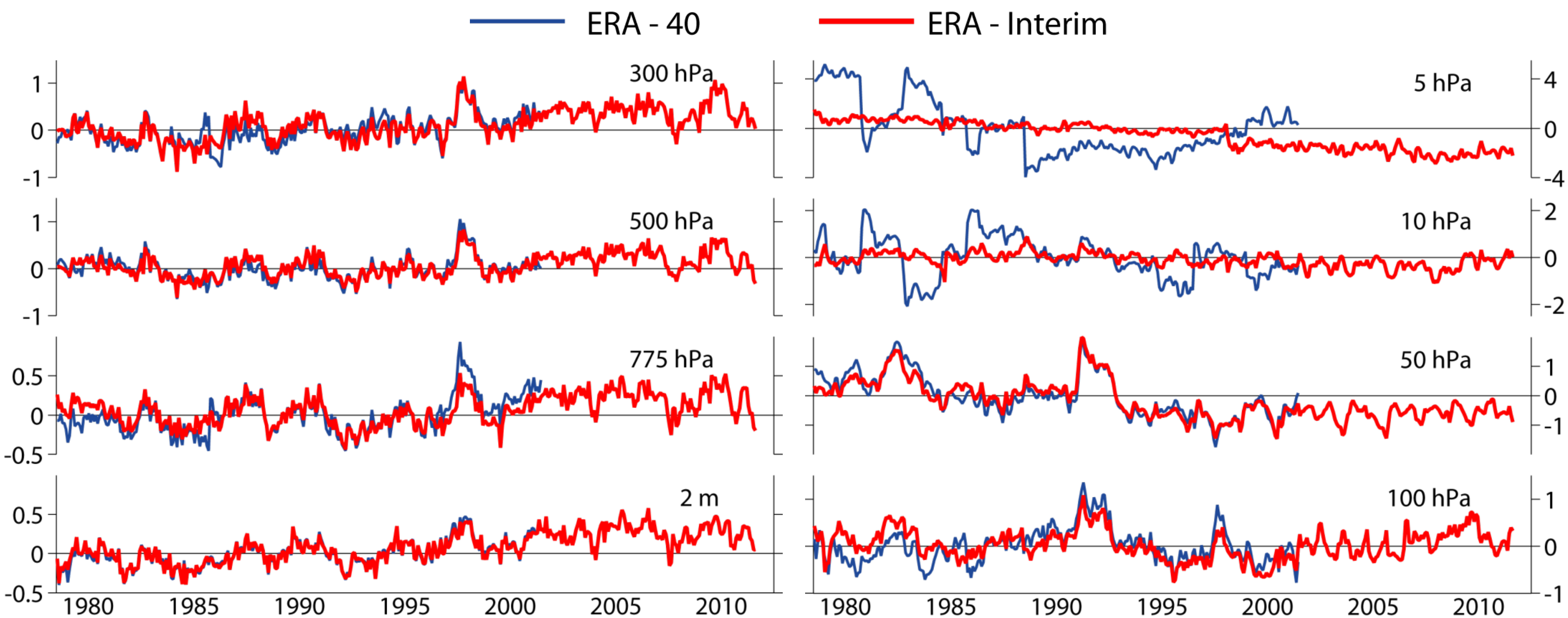


Radiosonde temperature adjustments follow Haimberger *et al*. (2008) and Andrae *et al*. (2004)

Global-mean near-surface, tropospheric and stratospheric temperature anomalies (K)

GCOS

ECMWF

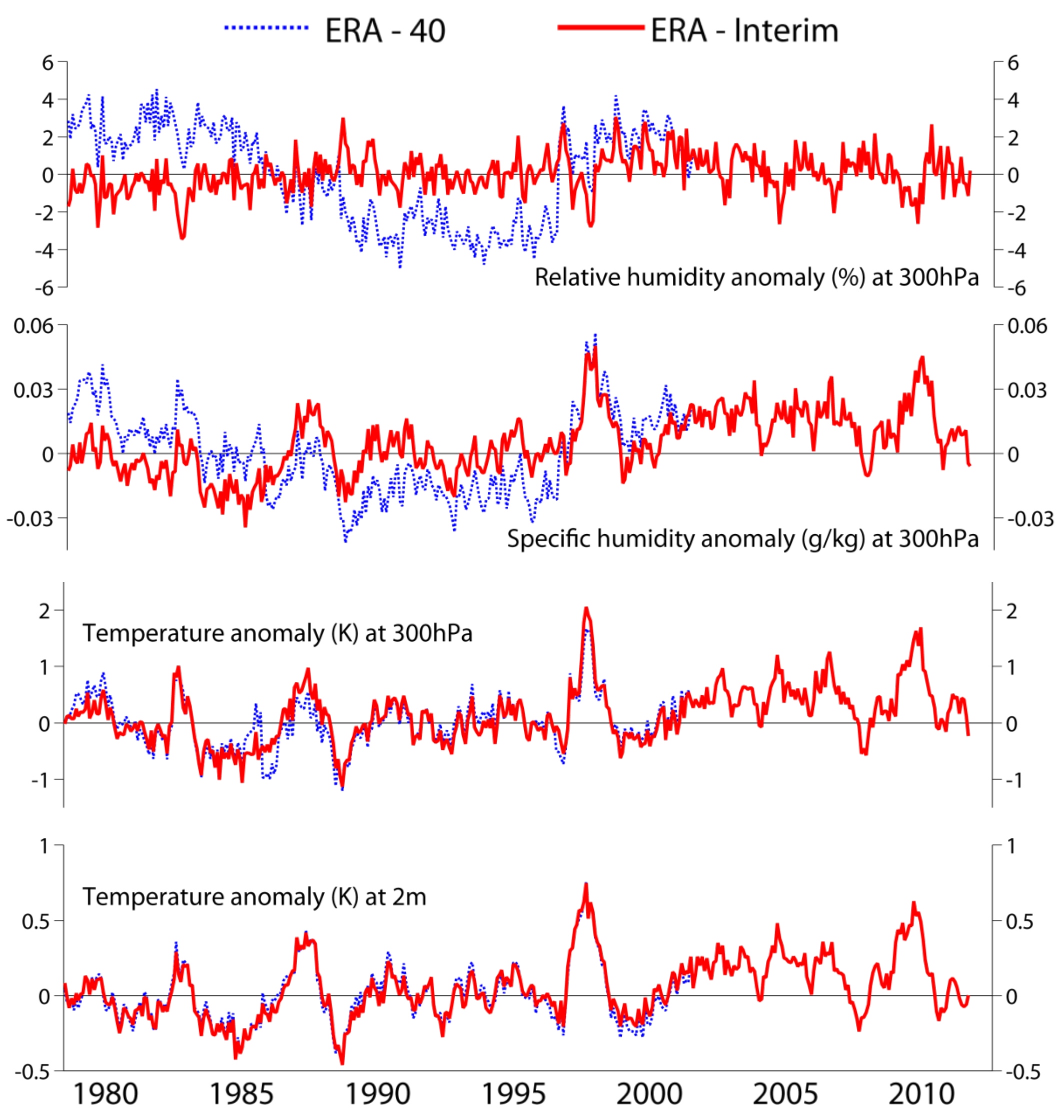


Tropospheric time series do not much from ERA-40 to ERA-Interim, but improve a little

ERA-Interim is much more consistent over time in mid to upper stratosphere, but it is hard to avoid a shift at high levels due to the change from SSU to AMSU

ERA-Interim also shifts near the tropopause due to increasing amounts of biased aircraft data and due to correction of model bias by recently available GPS occultation data

Near-surface and upper-tropospheric tropical temperature and humidity anomalies



ERA shows strong correlation and amplification of tropical temperature anomalies by factor ~2.2 from surface to upper troposphere

Consistent with longstanding model results but not raw radiosonde data, to be discussed later by Haimberger

ERA-Interim shows strong correlation between temperature and specific humidity anomalies in the tropical upper troposphere

Relative humidity is quite uniform over time in ERA-Interim, especially early on

Comment: Looks good, but ERA-Interim satellite bias adjustments need to be checked against independent estimates

Annual anomalies in precipitation (mm/day) for 2011 relative to the 1981-2010 mean

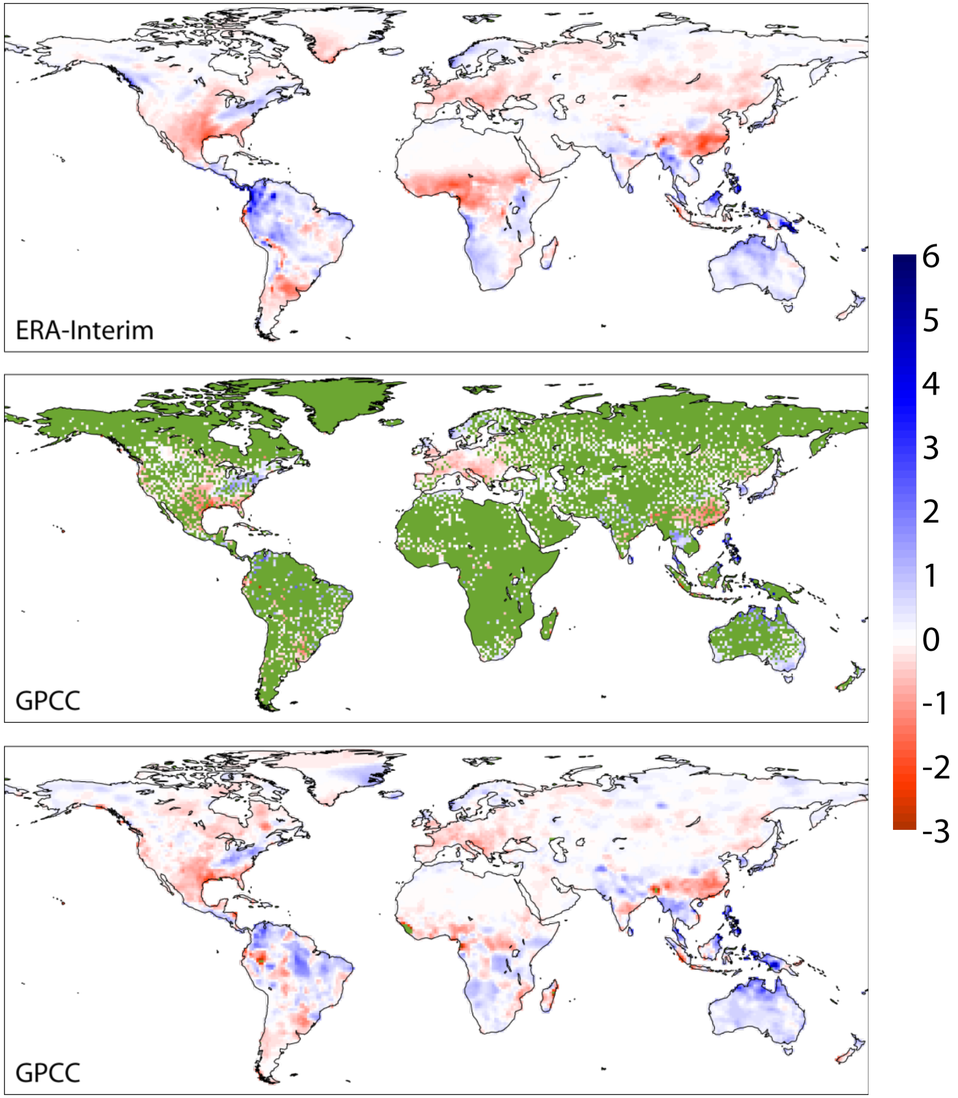
ERA-Interim uses no rain-gauge data

Anomalies in 12-24h forecast precipitation from ERA-Interim are compared with analyses of rain-gauge data produced by the Global Precipitation Climatology Centre (GPCC) at Deutscher Wetterdienst

GPCC analyses are plotted

- for all $1^{O}x1^{O}$ grid boxes that contain data from at least one gauge for every month in 2011
- for all $1^{O}x1^{O}$ grid boxes for which values are provided by the GPCC

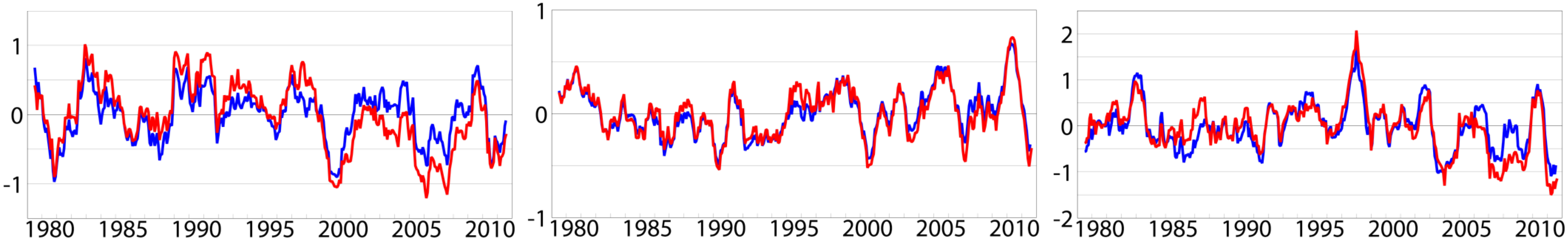
Version 6 of the GPCC Full-data Product is used up to 2010; the GPCC Monitoring Product is used for 2011

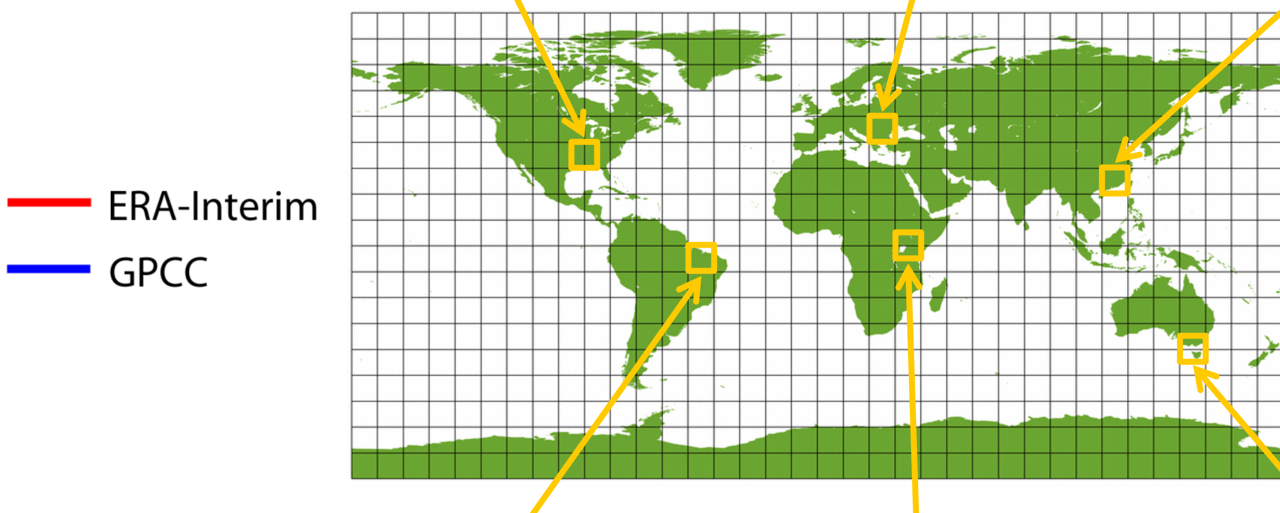


12-month running-mean precipitation anomalies (mm/day) for six 10^{o}x10^{o} domains

GCOS

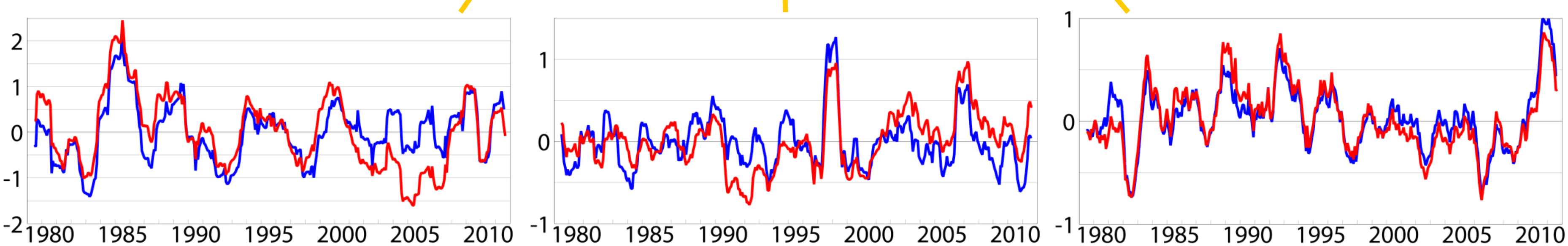
ECMWF





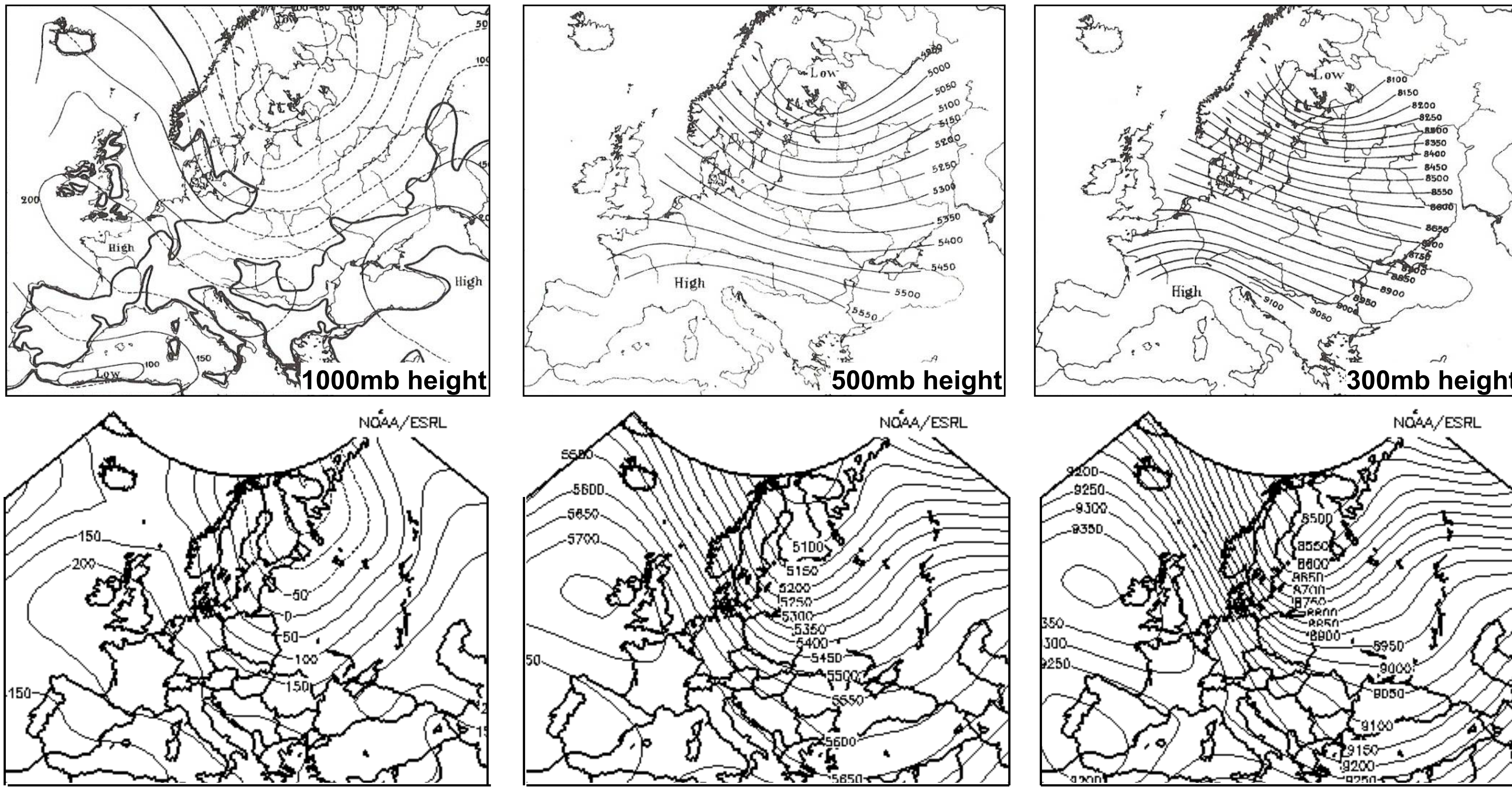
Standard deviations between ERA-Interim and GPCC Full Data versions over the period 1979-2007 are:

Version 4	1.416 mm/day
Version 5	1.404 mm/day
Version 6	1.398 mm/day



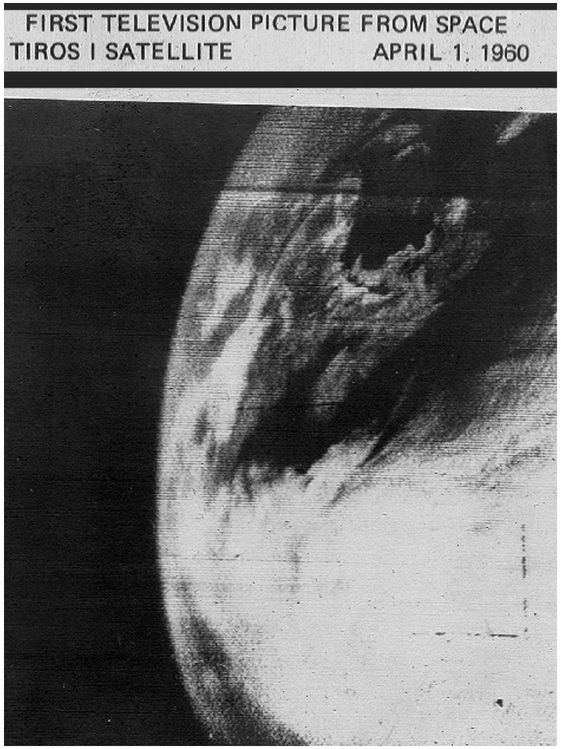
Revisiting Bjerknes and Sandström (1910)
Original isobaric maps for 7 November 1901

First demonstration of isobaric charts, using surface data, and balloon data from five locations



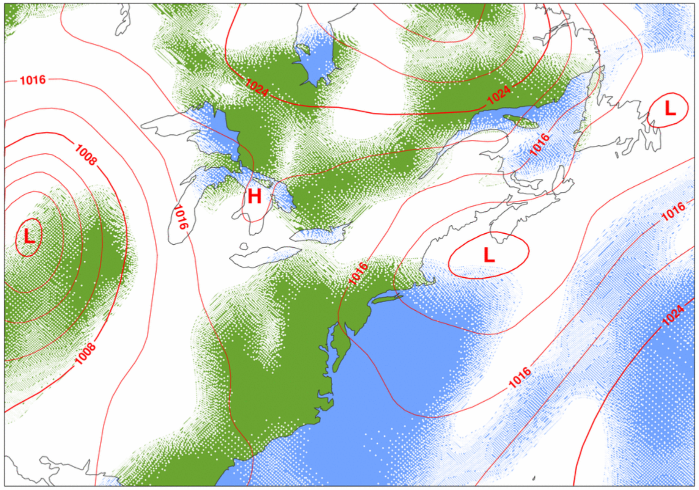
20th Century Reanalysis (Compo *et al.*, 2011) for 12UTC; contour intervals differ by factor ~0.98

Revisiting the early images from TIROS-1
Cloud cover on 1 and 2 April 1960

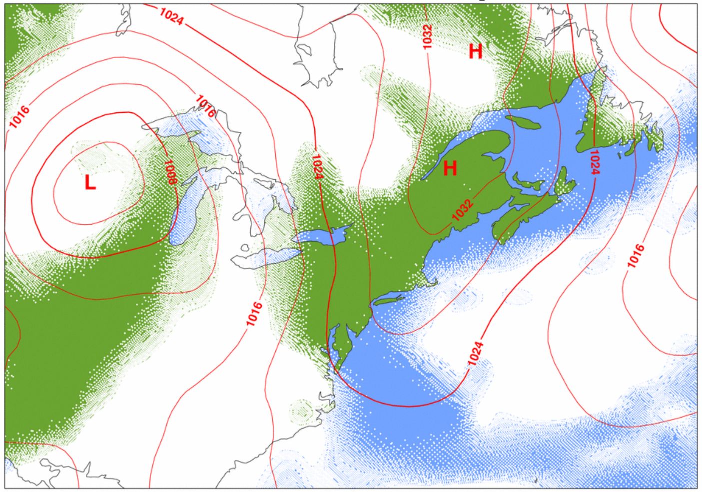


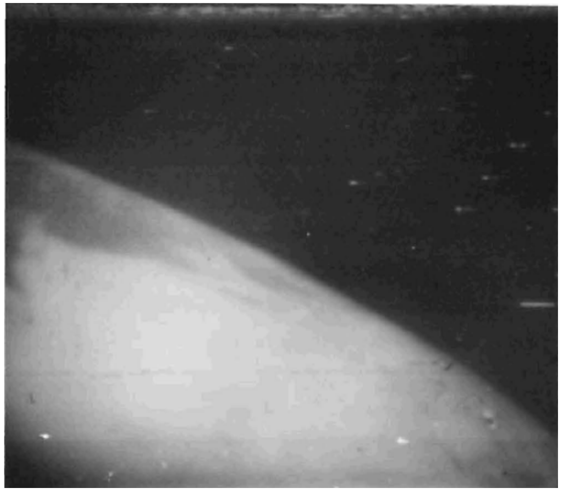
Now confirmed by NASA Goddard librarian as taken at 1608UTC 2 April 1960

ERA-40 1500UTC 1 April 1960



ERA-40 1500UTC 2 April 1960





Actual first TV picture from space, as supplied by NASA Goddard librarian

Anderson (2010)
Kållberg *et al*. (2010)

Concluding remarks

This has been an introduction

- to atmospheric data assimilation and reanalysis
- to evolution of the atmospheric observing system
- to various reanalysis activities in progress worldwide

and an illustration of some progress and issues

- related to low frequency variability and trends

Some questions have been raised, but it is the beginning of the week

- and we will learn much more this week on many topics
- and perhaps discuss some of the questions

So conclusions are for Friday …