Data assimilation requirements for climate reanalysis

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Example of specific climate issues where re-analysis data would be most useful

- To clarify the large climate variations in the 20th century with the warm period in the 1930s and 1940s followed by a cooler period in the 1960s and 1970s
- To clarify the multi-decadal variations in the behavior of ENSO
- To determine by which accuracy the climate can be reconstructed for the last 100 years or so.
- To clarify how well three-dimensional trends of key meteorological parameters (say over 30, 60 and 100 years) can be determined and how they are related to each other
- To determine energy and water fluxes between atmosphere and the surface (ocean and land). How well can this be done?

Potential limitations in present reanalysis in climate applications

- Principal difficulties due to major changes in the observational system

- Incorrect or incomplete determination of the surface conditions (sea-ice, snow and vegetation)

- Lack of long-term conservation conditions for the assessment of energy and water fluxes

- Need to assure consistency between dynamical and heat processes (the net heating field must be consistent with the 3-dimensional flow field)

The need for a Dynamical Climate Reanalysis

Summary from a workshop at ESSC

22-23 January 2005

Lennart Bengtsson, Phil Arkin, Paul Berrisford, Philippe Bougeault, Chris K. Folland, Chris Gordon, Keith Haines, Kevin I. Hodges, Phil Jones, Per Kallberg, Nick Rayner, Adrian J. Simmons, Detlef Stammer, Peter W. Thorne, Sakari Uppala and Russell S.Vose

The need for a Dynamical Climate Reanalysis
What do we need it for?

- Understanding the atmospheric circulation
- Assessment of climate trends
- The hydrological cycle
- Reanalysis fluxes over the oceans

- Ocean reanalysis

Global forecasts DJF 90/91

- 7- day forecasts, every 6hr.
- Later ECMWF model T159/L60

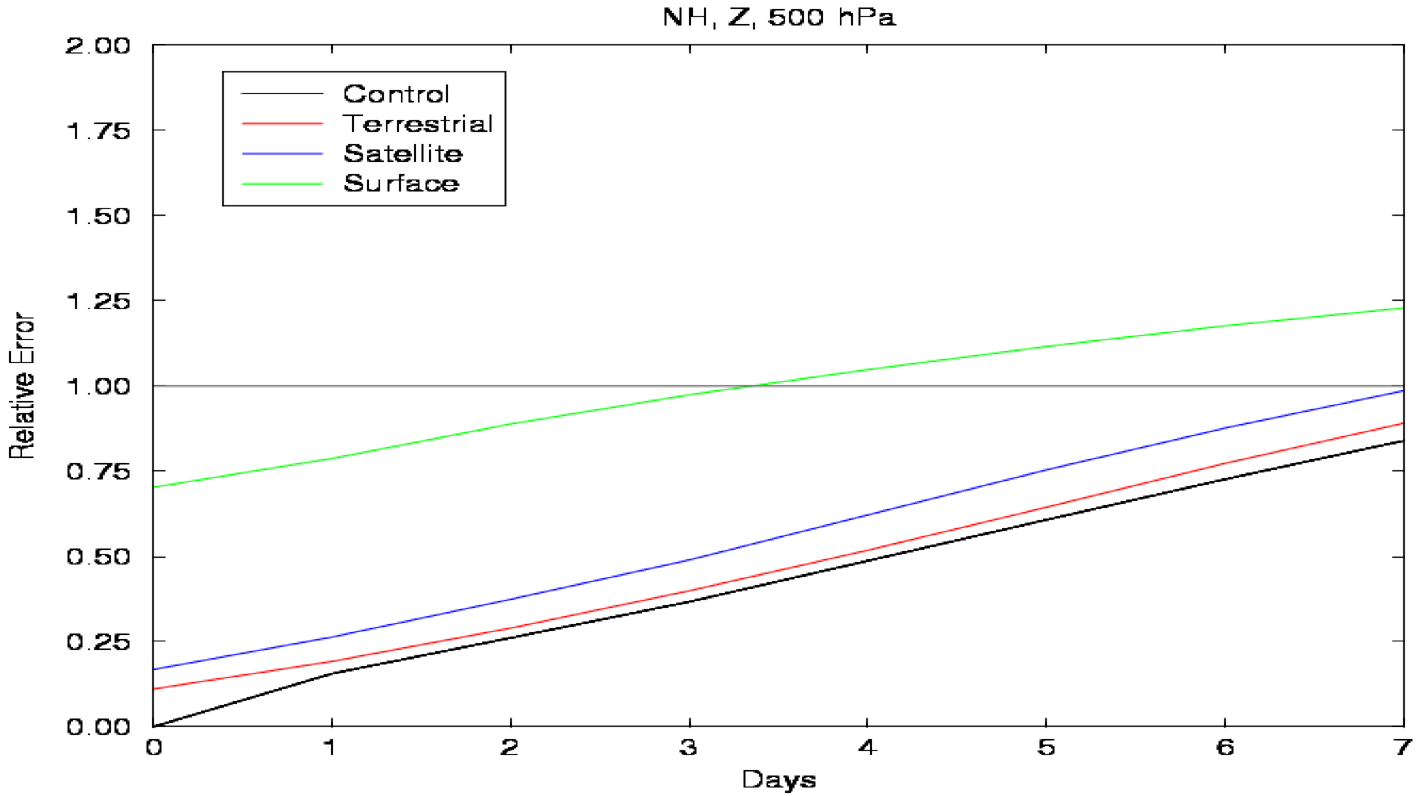
- Extra-tropics 20-90N and 20-90S
- 500 hPa **Z**, normalized SD for the period

- Tropics 20N-20S
- **Wind vector** field 850 and 250hPa

Observing systems and predictive skill

Northern Hemisphere extra-tropics

Bengtsson and Hodges, 2004

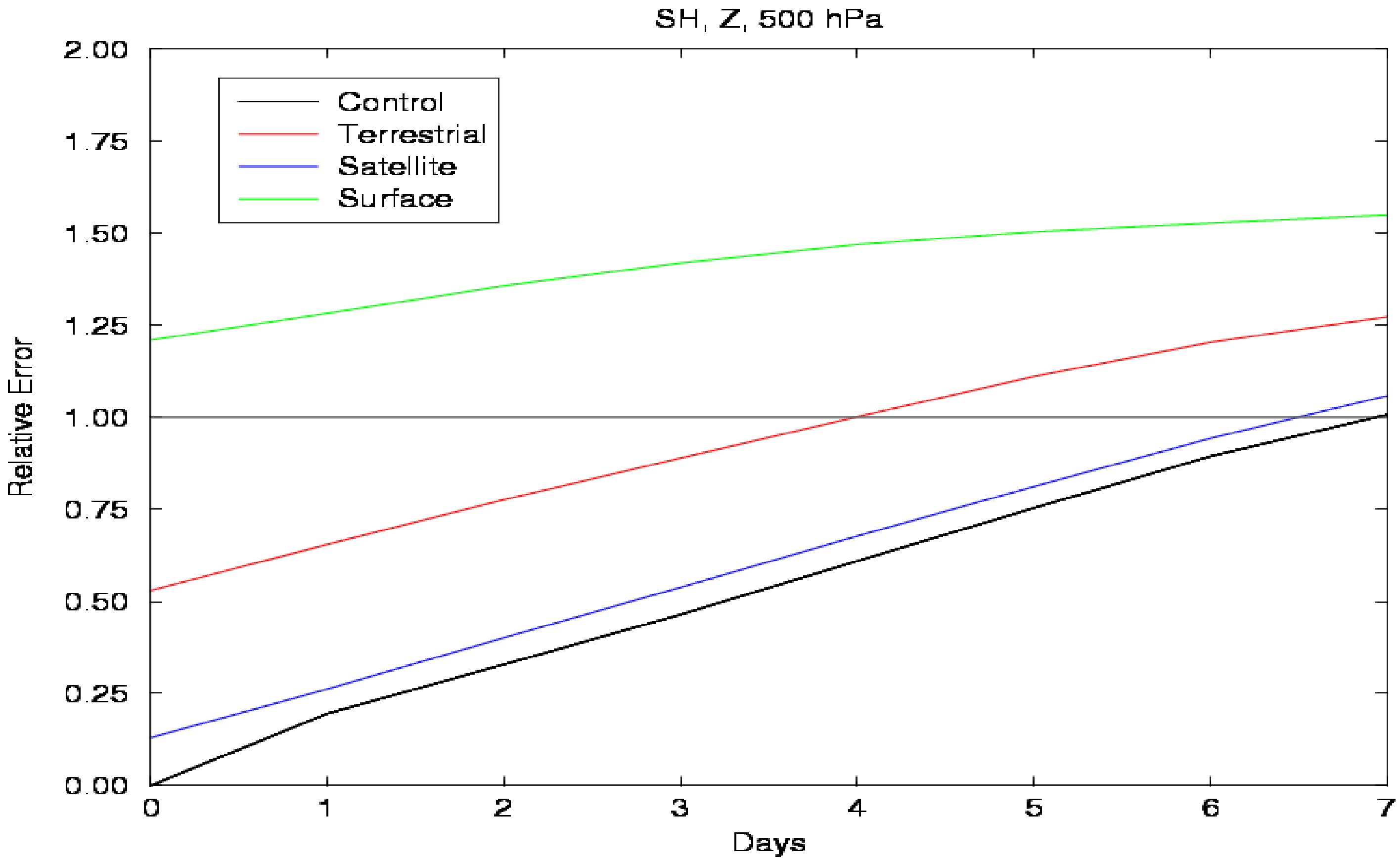


Reanalysis workshop

Observing systems and predictive skill

Southern Hemisphere extra-tropics

Bengtsson and Hodges, 2004



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Forecast skill and observations

Bengtsson and Hodges (Tellus: 2004)

- The terrestrial system is the best at the NH extra-tropics
- The satellite system is crucial for the SH extra-tropics
- In the tropics the terrestrial system and the satellite system are equally useful and highly complementary
- Between 1990 and 2000 the satellite system has increased its information content and the terrestrial system has decreased it

The impact of specific observations on forecast skill
Experiment with ERA40

Bengtsson and Hodges (Tellus:2005)

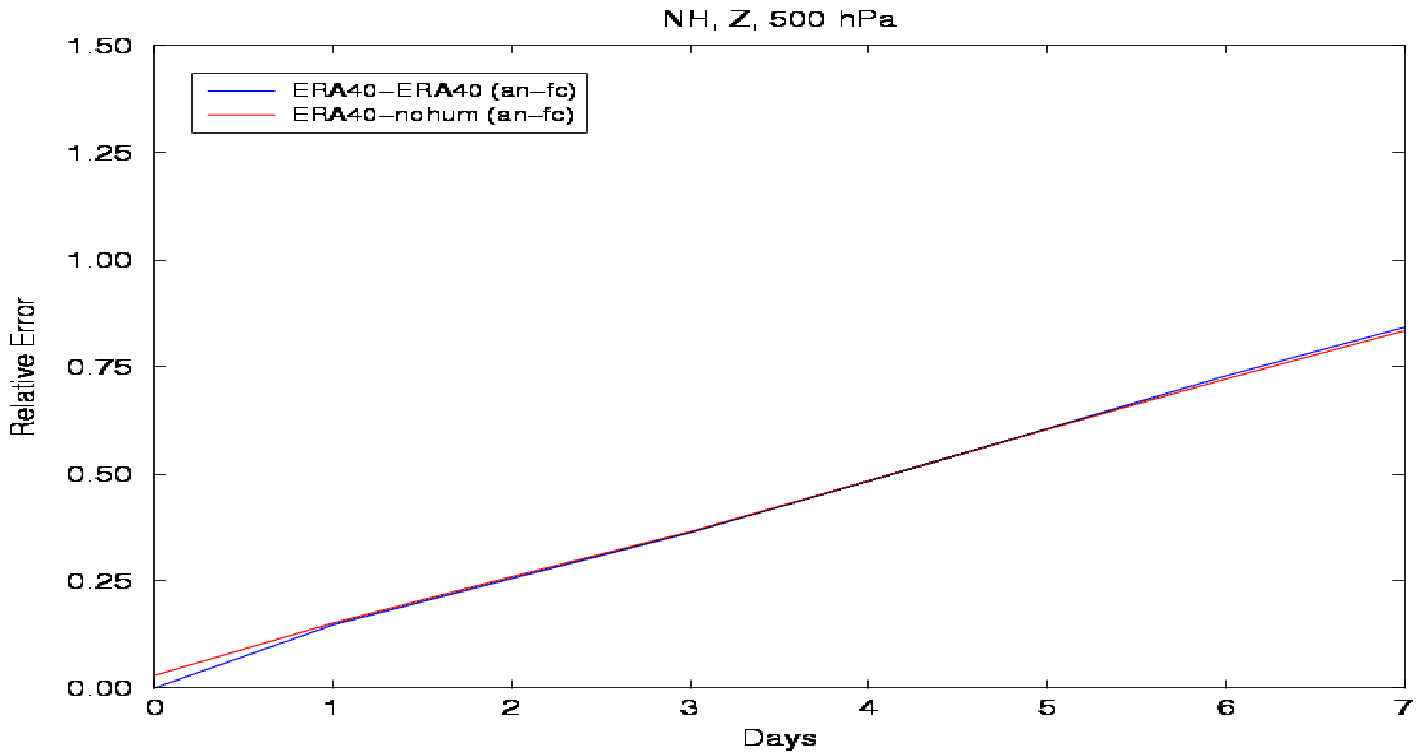
The impact of observations of humidity on NWP

360 global forecasts DJF 1990/91

Impact of humidity observations
NH Z 500 hPa

Full observing system

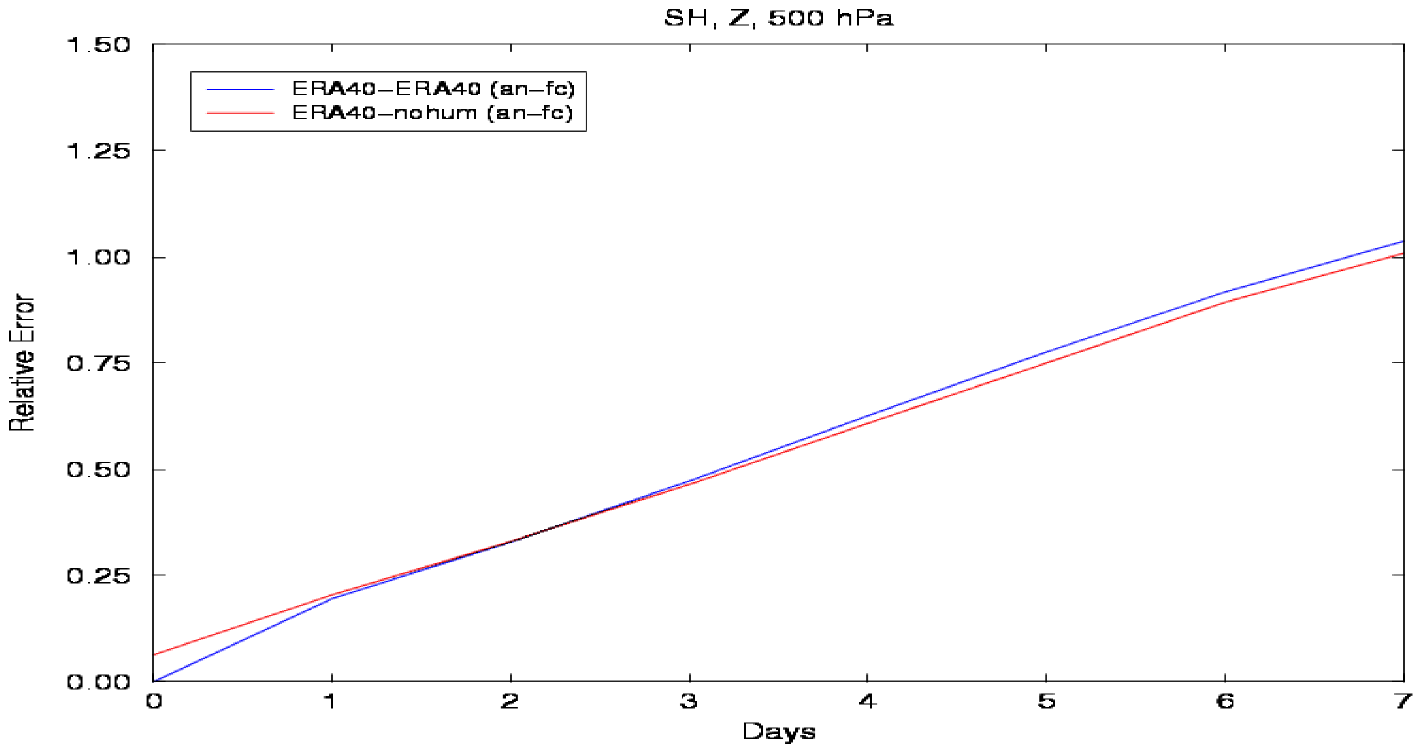
No humidity observations in data-assimilation



Impact of humidity observations
SH Z 500 hPa

Full observing system

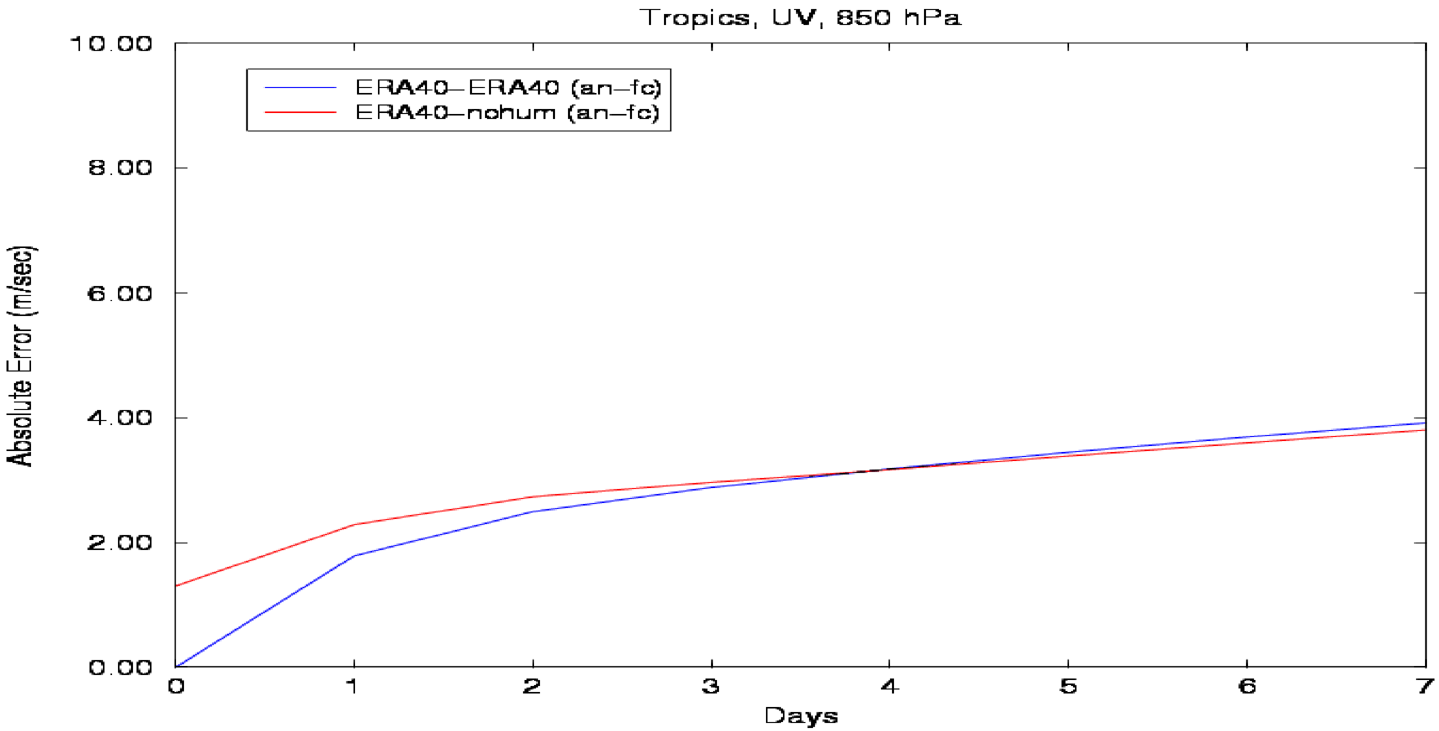
No humidity observations in data-assimilation



Impact of humidity observations
Tropics wind at 850 hPa

Full observing system

No humidity observations in data-assimilation



Impact of humidity observations

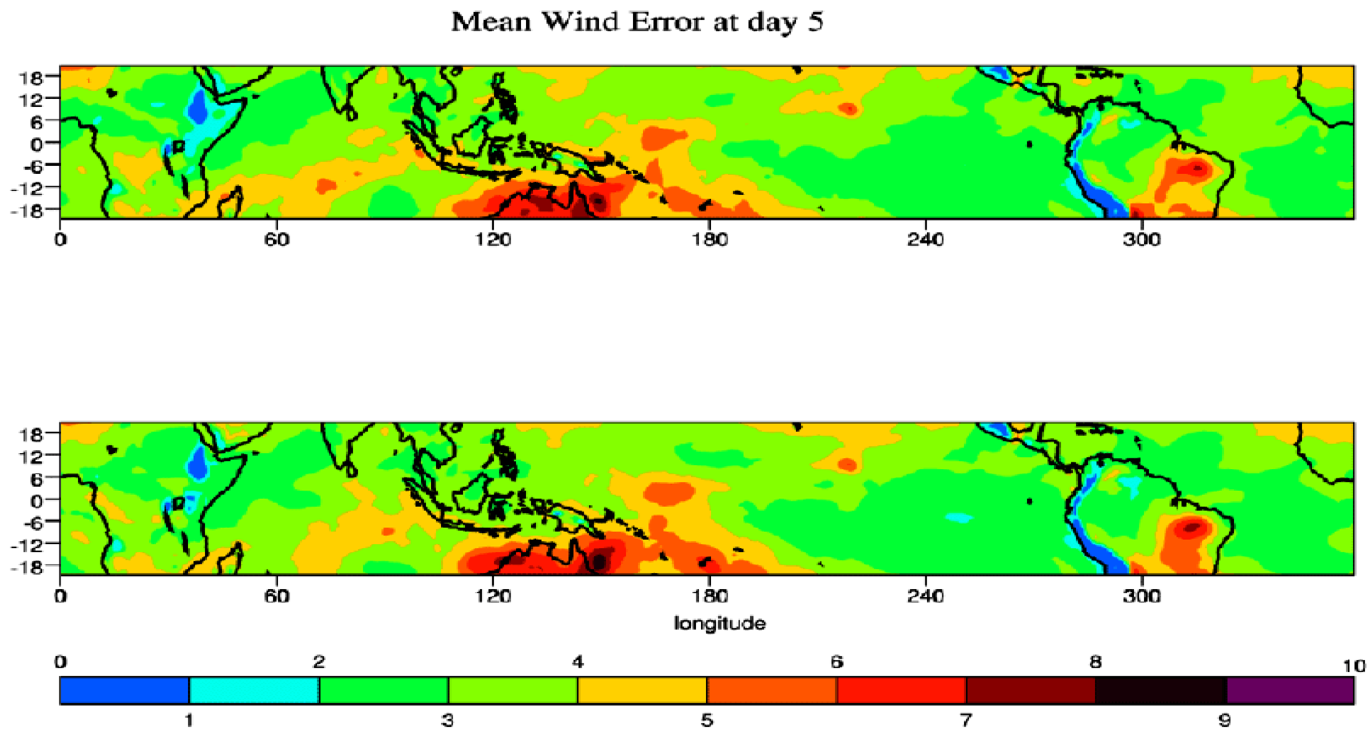
Tropics wind at 850 hPa (mean error at day 5)

Full observing system

No humidity observations in data-assimilation

Control

No humidity



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Humidity observations
in present data-assimilation

- Moisture observations have no detectable influence on the overall large scale predictive skill

- During the cause of the data-assimilation the large scale moisture field is mainly controlled by the model dynamics

- There is an urgent need to develop techniques for a better assimilation of humidity observations

Global trend calculations

- Precipitation
- Tropospheric temperatures
- Column water vapor
- Kinetic energy

Global water balance
DJF 90/91 unit:1000qkm

	Total	Dec.	Jan.	Feb.
P-E ERA40 (control)	12.8	4.3	4.9	3.6
P-E ERA40 (no moisture)	12.8	4.0	5.1	3.7
Ocean P-E ERA40 (control)	0.9	-0.6	1.6	-0.1
P-E ERA40 (no moisture)	-13.4	-5.1	-4.1	-4.2

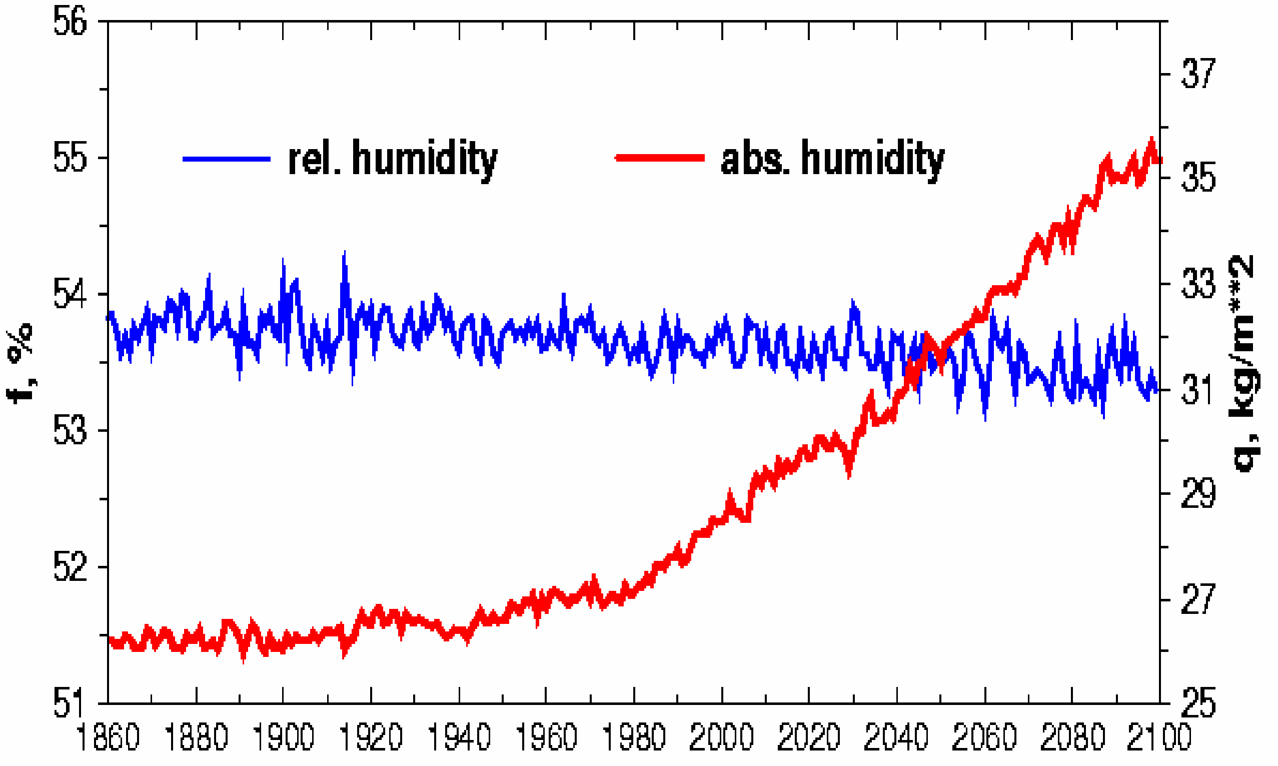
TLT Decadal trends
1958-2001

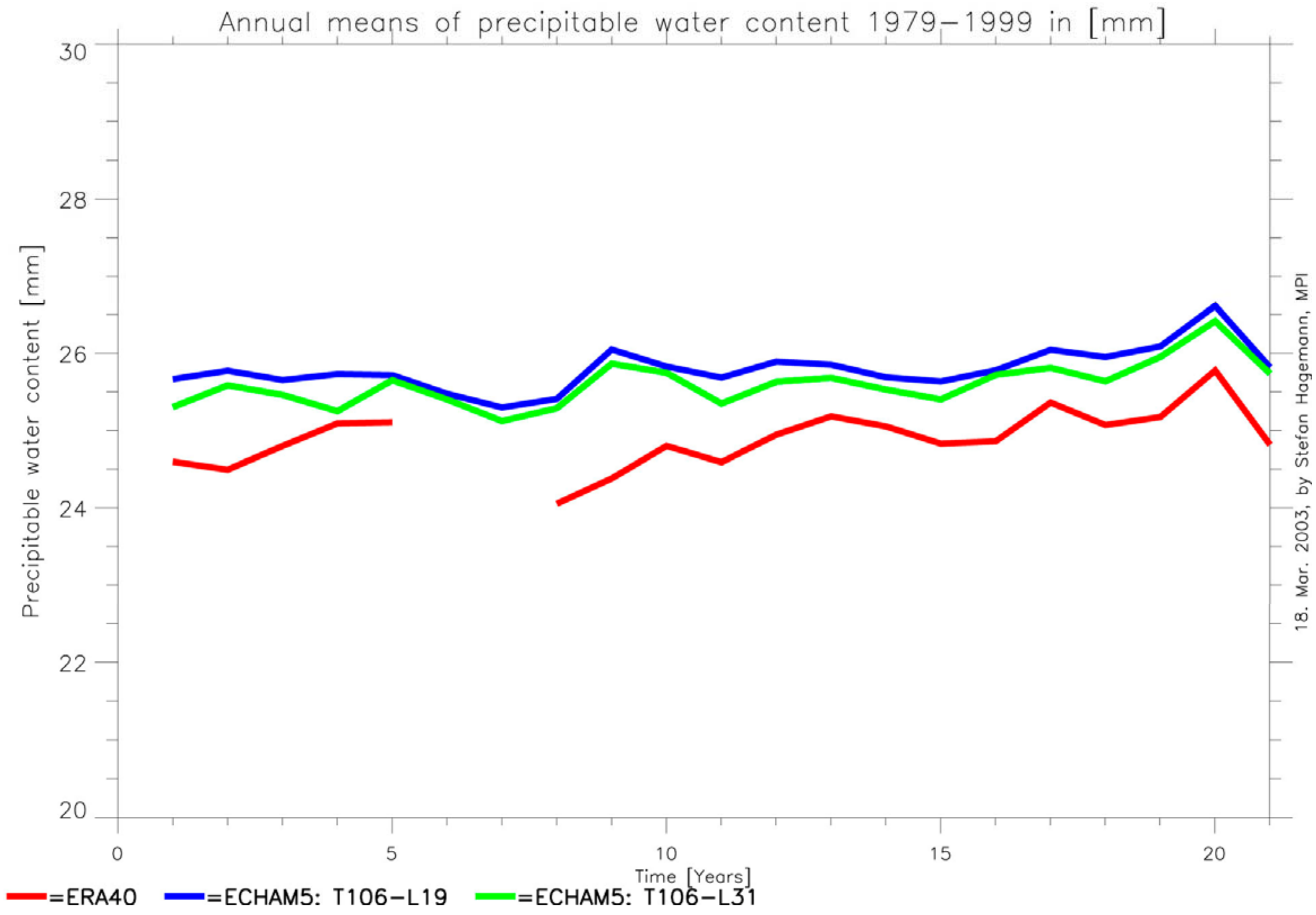
- ERA-40: + 0.142 C
- SST: + 0.080 C
- ERA 40 (corr) : + 0.100 C (1958-2001 **0.43C**)

- (corrections by modifing the data before 1979 with the difference ERA-40 and the NOSAT experiment)

- GISS: 1958-2001 **0.45C**

Annual mean global values of relative humidity *f* (in %) vertically averaged for 850-300 hPa and vertically integrated absolute humidity *q* (in kg/m^2).




Annual means of precipitable water content 1979–1999 in [mm]
Precipitable water content [mm]
30
28
26
24
22
20
0
5
10
15
20
Time [Years]
18. Mar. 2003, by Stefan Hagemann, MPI
=ERA40
=ECHAM5: T106–L19
=ECHAM5: T106–L31

Integrated Water Vapor
1979-1999

ECHAM5: **T106/L31** using AMIP2 boundary conditions

Preliminary results:

Globally averaged results vary between 25.10 mm (1985) and 26.42 mm (1998)

Mean value for the 1990s is 1% higher than in the 1980s

Interannual variations are similar to ERA-40

Variations follow broadly temperature observations from MSU (tropospheric channel) under unchanged relative humidity (1°C is equivalent to some 6% of IWV).

Determination of integrated water vapour, IWV

Methodology

Zenith path delay, ZPD, from GPS measurements

Obtain temperature from operational weather prediction model

Surface pressure from met. observations

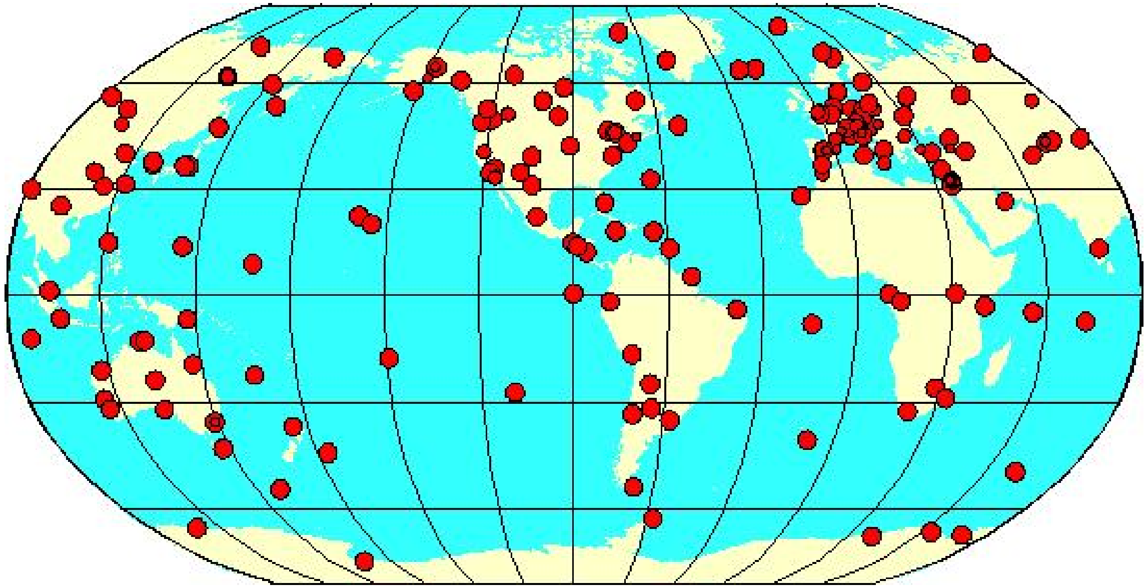
Calculate IWV

Independent test of IWV using GPS

Hagemann, Bengtsson and Gendt JGR, 2003

Using the IGS Network

The IGS network of ground-based GPS stations



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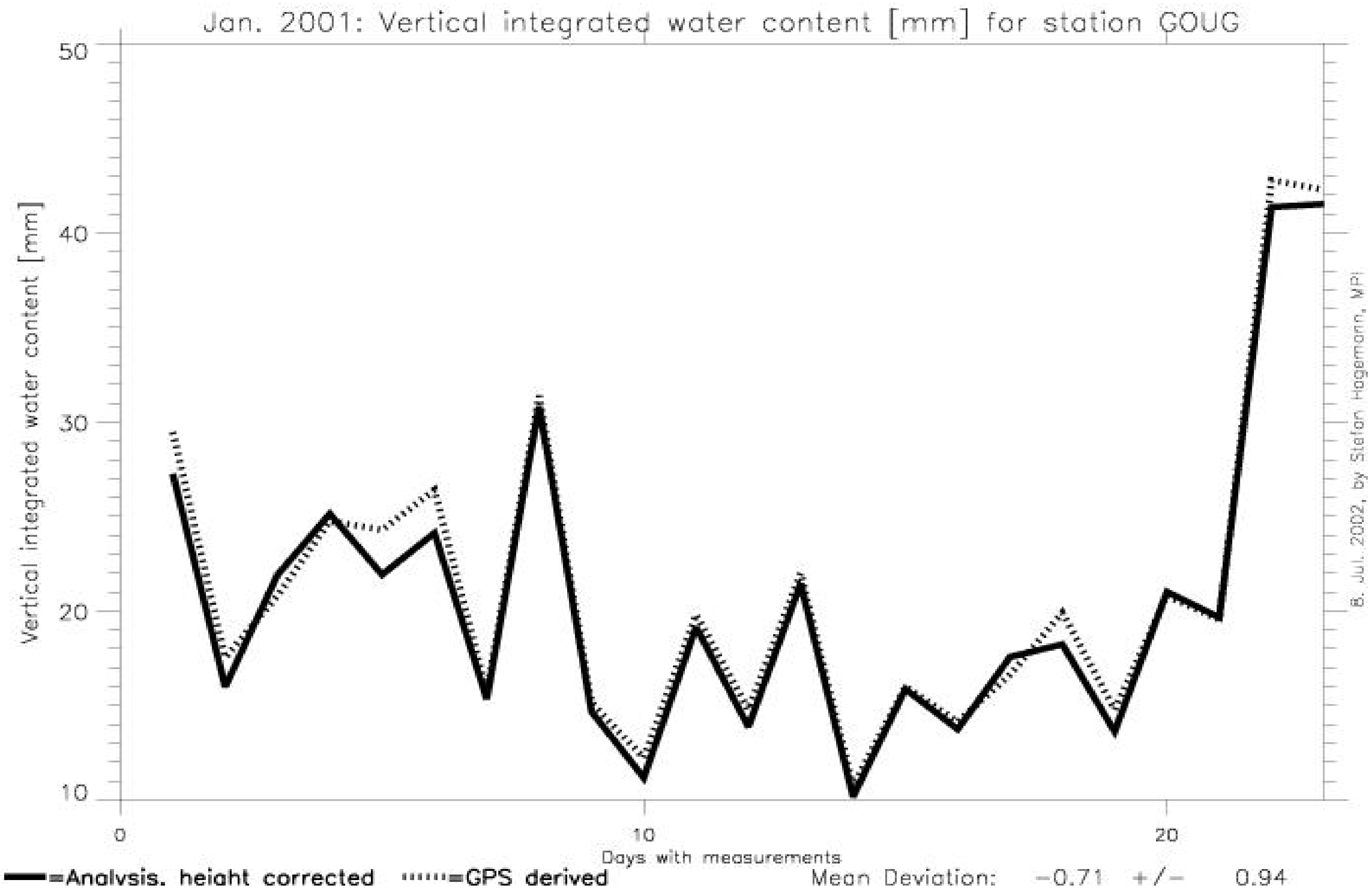
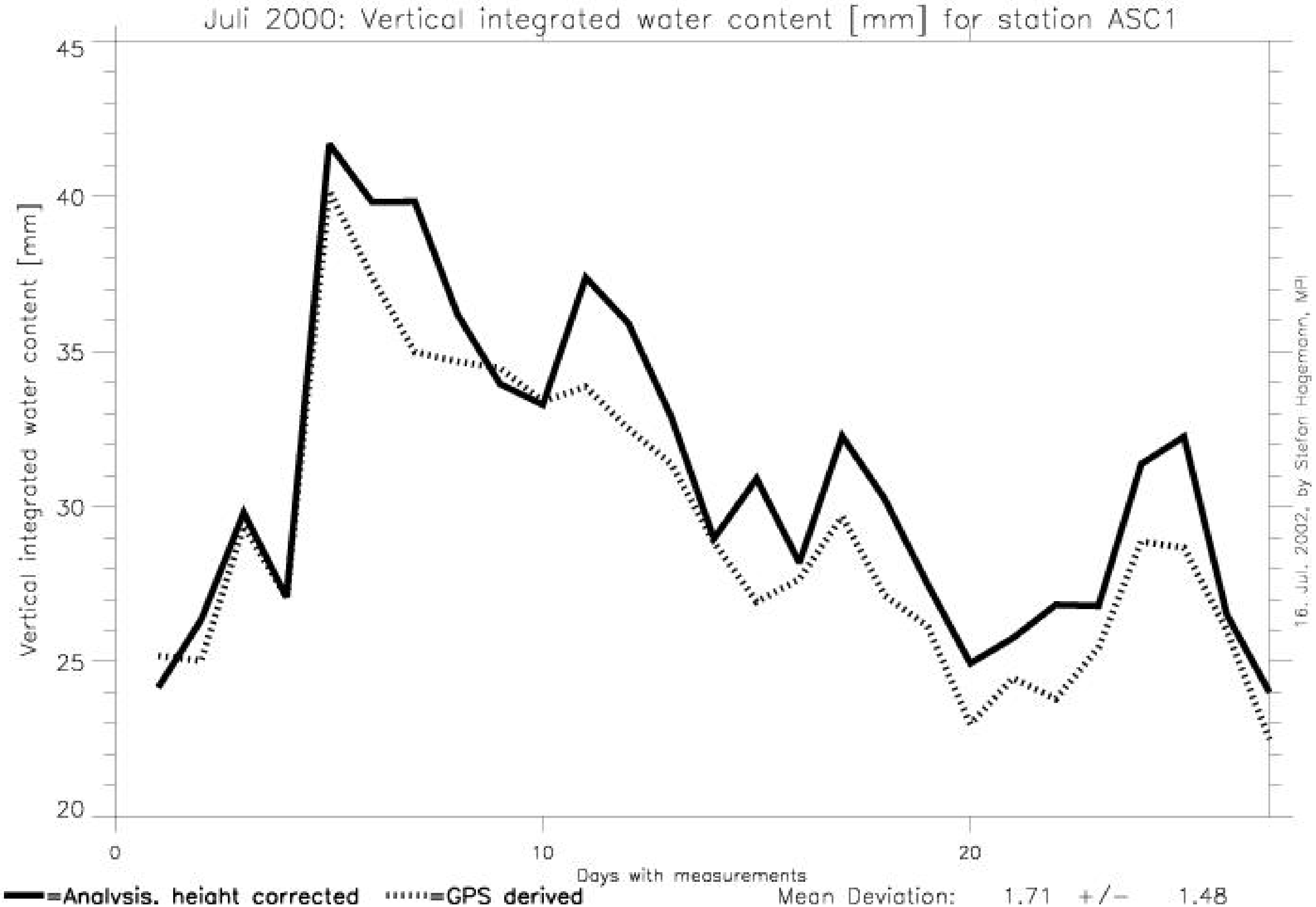
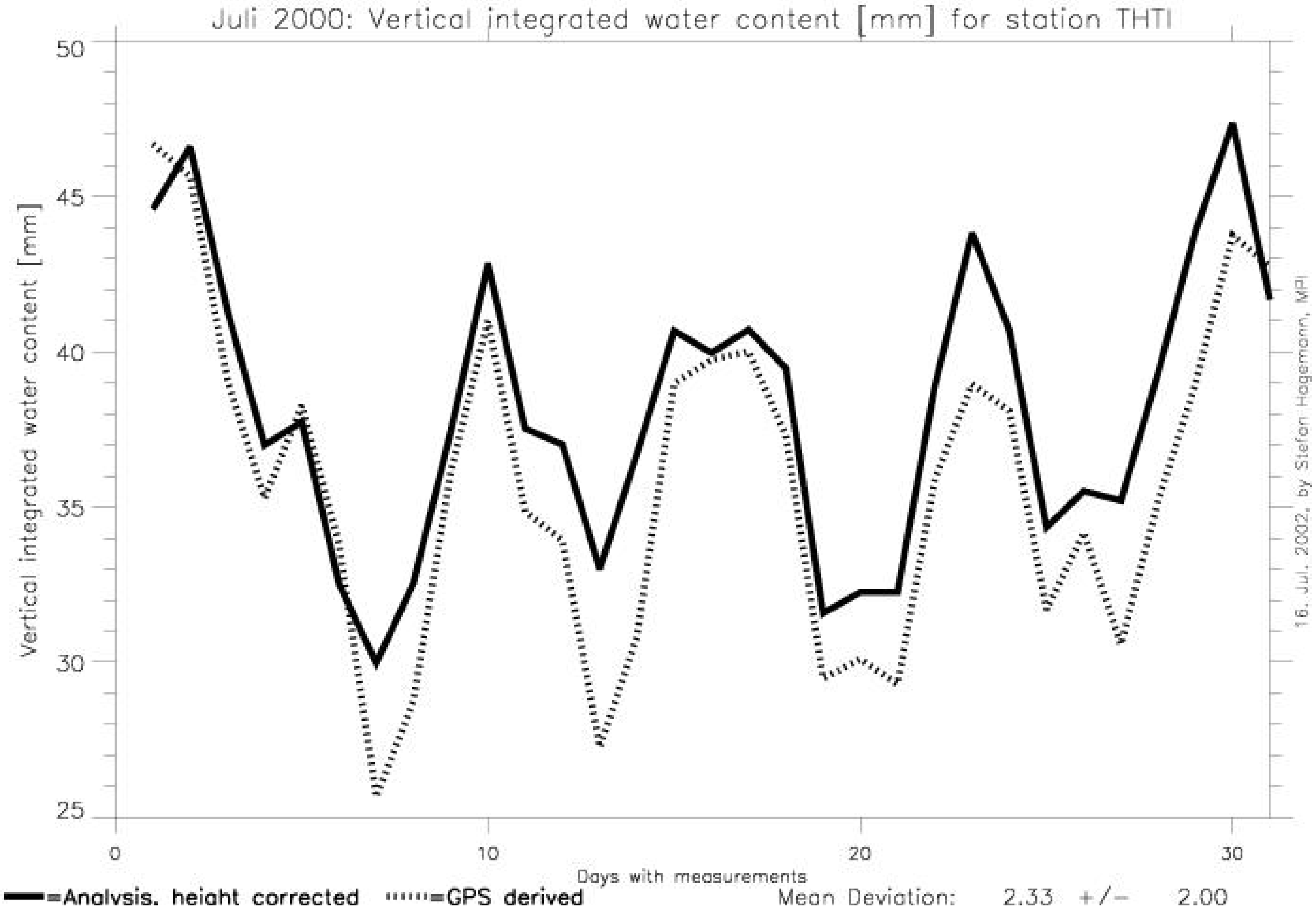
January 2001: IWV [mm] for station Gough Island (South Atlantic)



July 2000: IWV [mm] for station Ascension (Tropical Atlantic)



July 2000: IWV [mm] for station Tahiti (Polynesia)



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IWV Decadal trend
1979-2001

- ERA-40: + 0362 mm
- IWV/TLT: 3.15 mm/C
- (presumably only half as much)

- ECHAM 5 (1979-1999): + 0.290 mm
- IWV/TLT: 1.54 mm/C

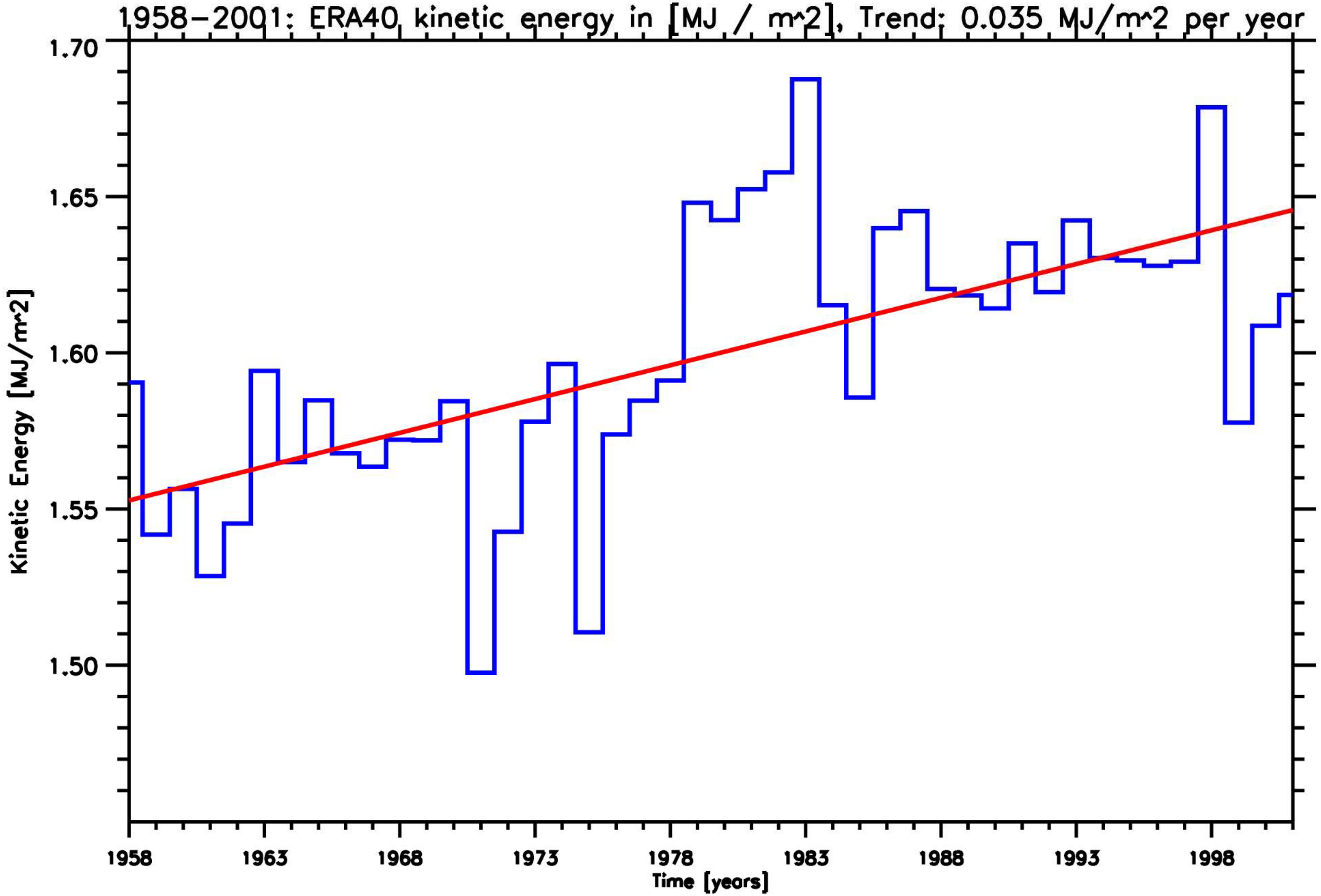
IWV Decadal trends
1958-2001

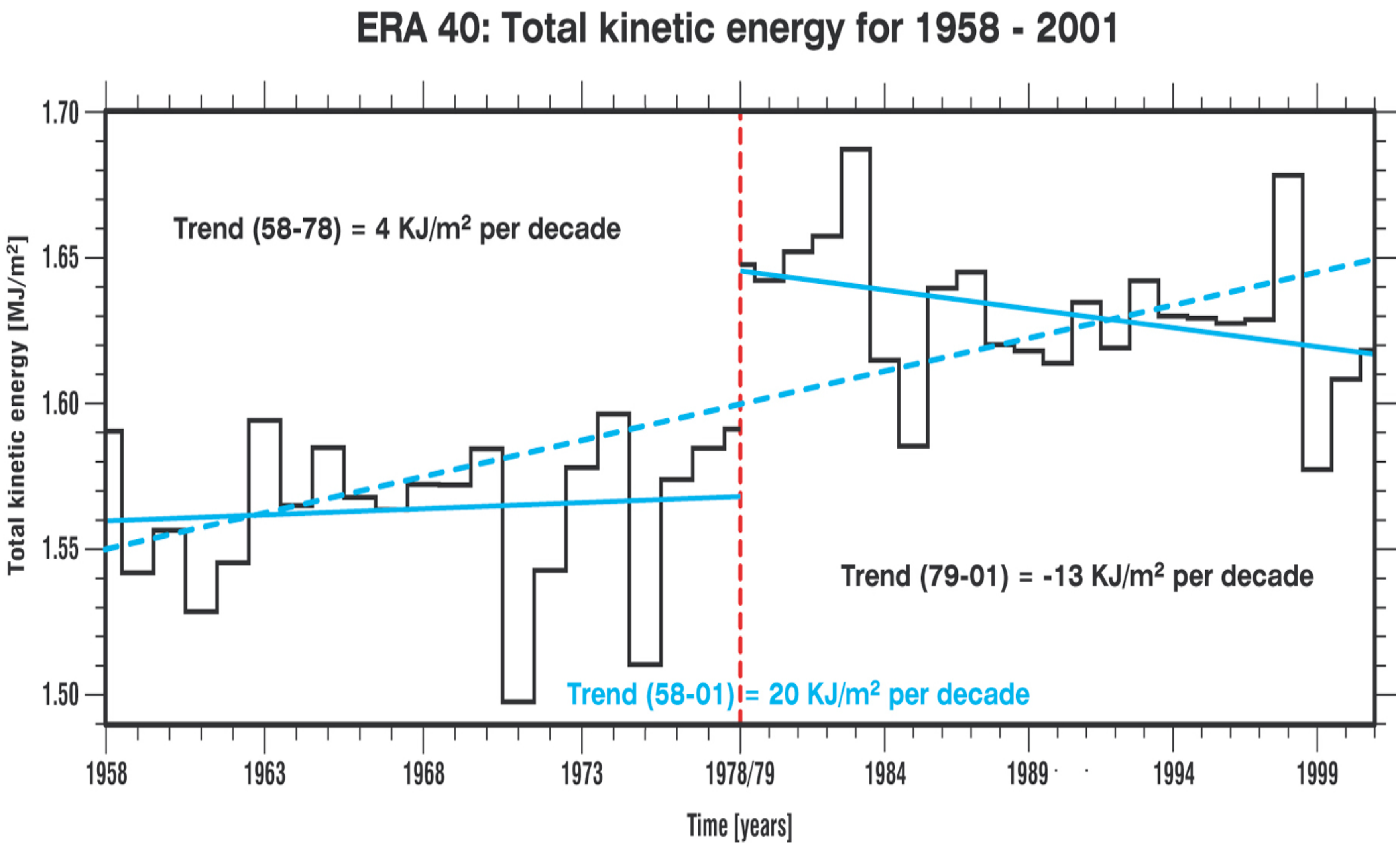
- ERA-40
- IWV/TLT : 2.85 mm/C
- (4.05 mm/C)

- ERA 40 (corr)
- IWV/TLT : 1.55 mm/C

Total kinetic energy

Globally and vertically integrated


1958–2001: ERA40 kinetic energy in [MJ / m^2], Trend: 0.035 MJ/m^2 per year
Kinetic Energy [MJ/m^2]
1.70
1.65
1.60
1.55
1.50
1958
1963
1968
1973
1978
1983
1988
1993
1998
Time [years]



ERA 40: Total kinetic energy for 1958 - 2001
Trend (58-78) = 4 KJ/m² per decade
Trend (79-01) = -13 KJ/m² per decade
Trend (58-01) = 20 KJ/m² per decade
Total kinetic energy [MJ/m²]
1.70
1.65
1.60
1.55
1.50
1958
1963
1968
1973
1978/79
1984
1989
1994
1999
Time [years]

Total kinetic energy
DJF 90/91

ERA-40 (global): 1.75 MJ/sqm

NOSAT(global): 1.68 MJ/sqm

ERA-40 (SH): 2.18 MJ/sqm

NOSAT(SH): 1.98 MJ/sqm

Summary
ERA-40 trends 1958-2001

- TLT trend is likely to be overestimated by some 40%
- IWV trend is much too high by a factor of almost three
- Kinetic energy trend is most likely zero

Reanalysis fluxes over oceans

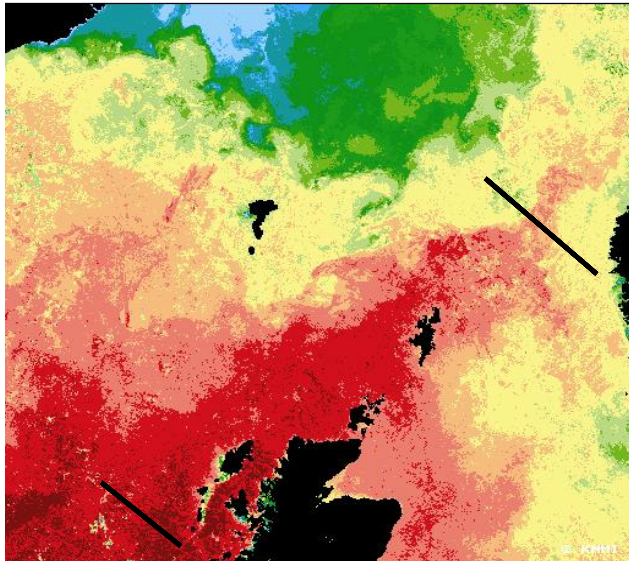
- There is evidence that smaller spatial scales in SST leads to stronger turbulence in the atmosphere effecting heat and evaporative fluxes
- There is a strong non-linear effect from leads requiring higher resolution
- Spin-up times for flux products in general. What time delay is needed to get better balanced E-P fields? How much better will it work with longer time window in 4DVar?
- Constraints on global radiation balance?
- Reducing large surface heat flux biases using a mixed layer model?

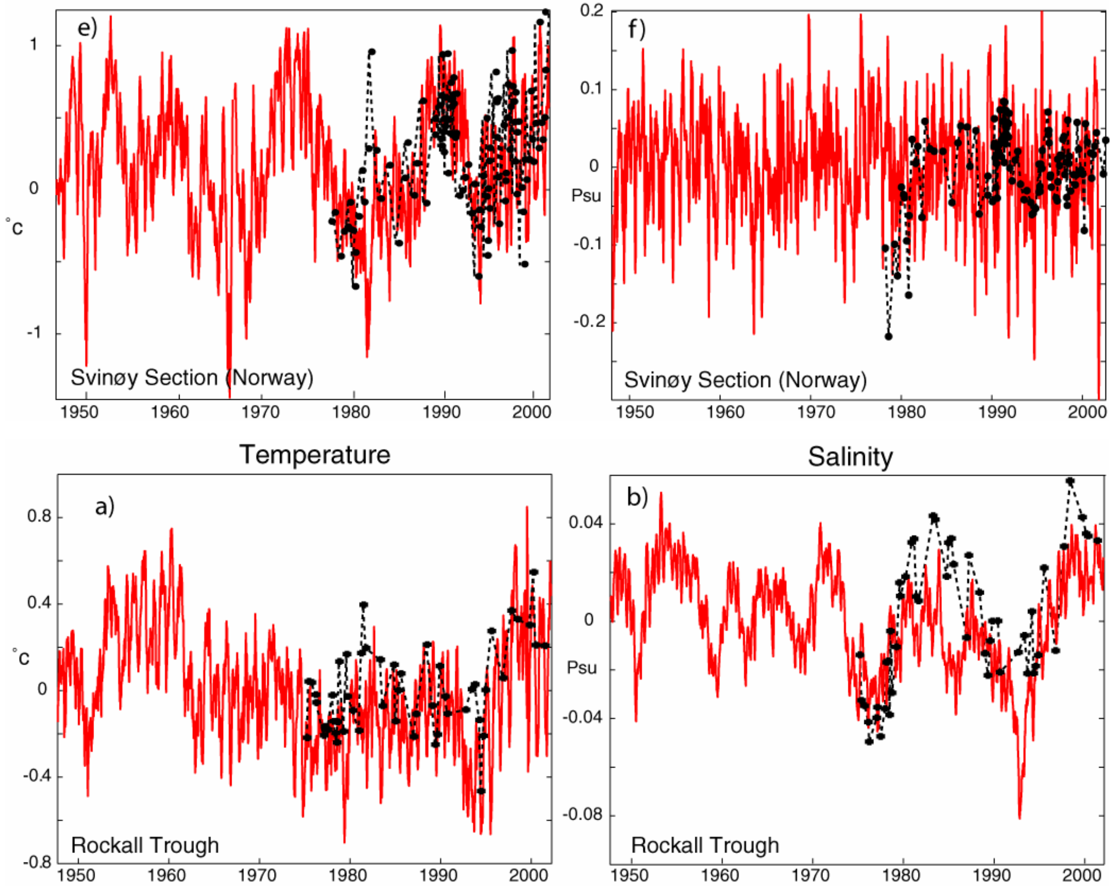
- Development of coupled model data assimilation!

Ocean Reanalysis

Thanks to *Helge Drange*, NERSC, Bergen

Observed and simulated de-seasoned T & S in Rockall Through and along the Svinøy Section





Hatun et al., 2005

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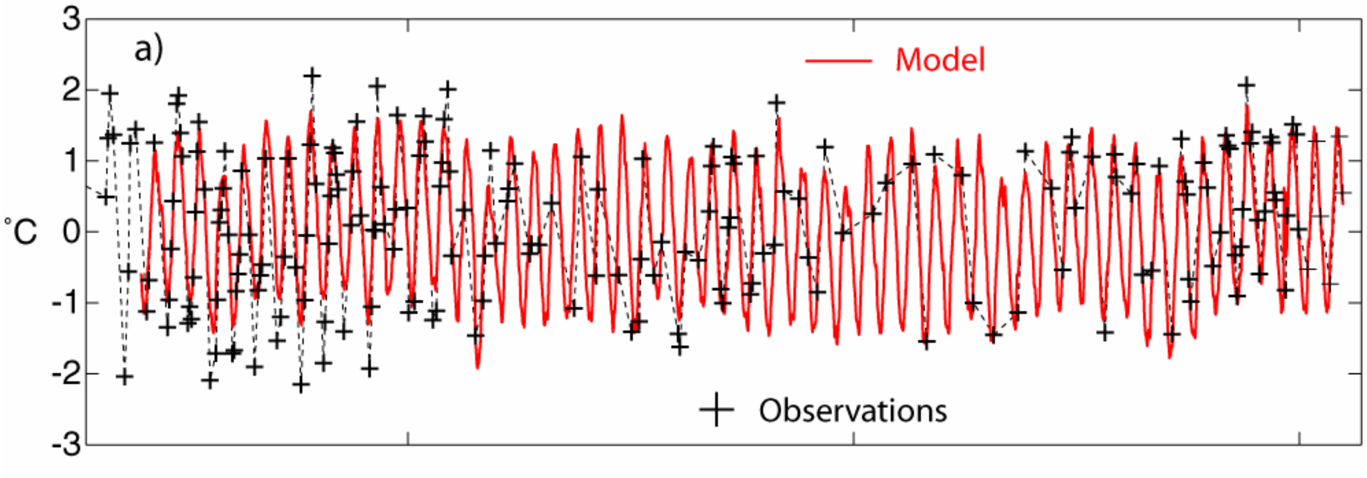
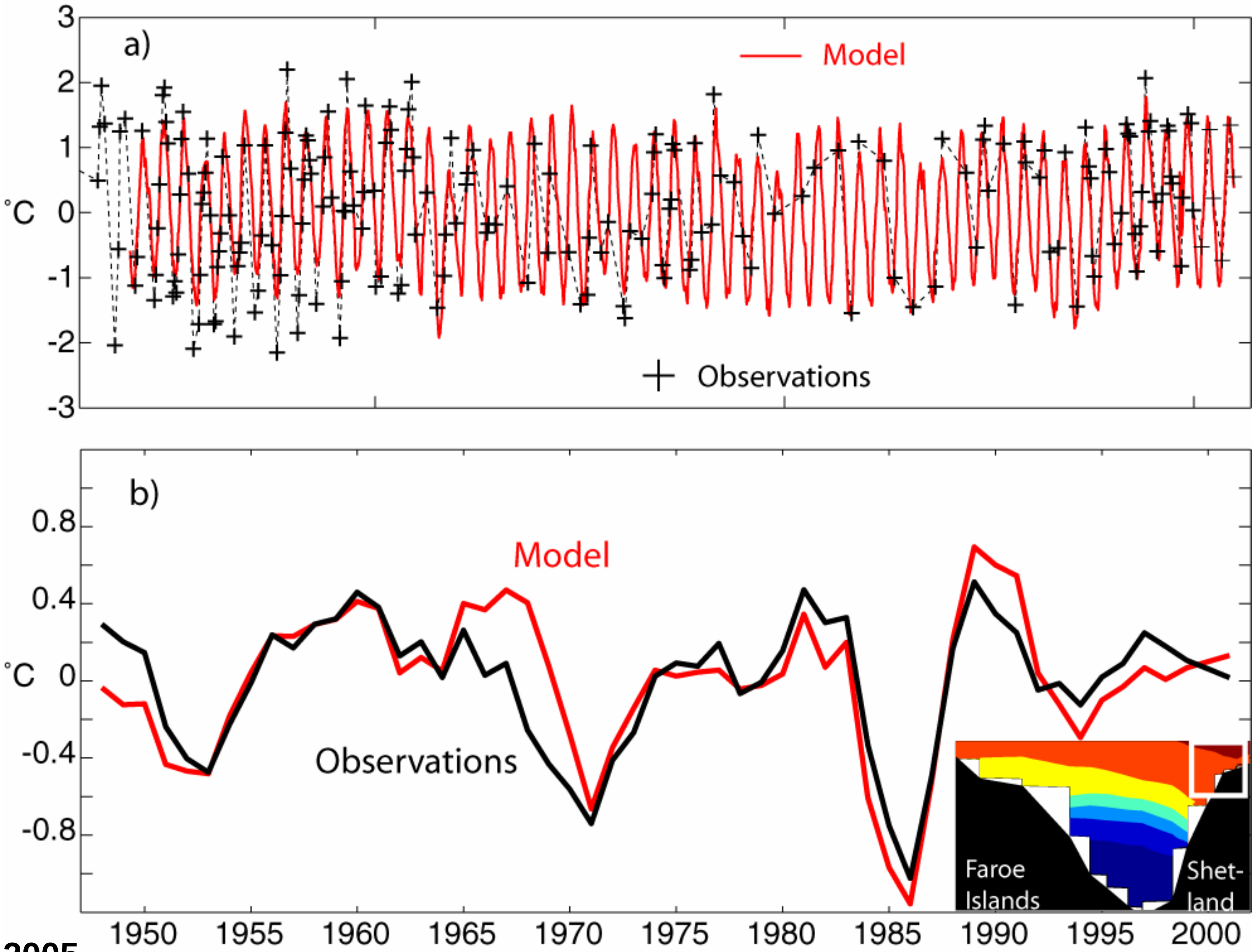
Observed and simulated T on the Scottish Shelf



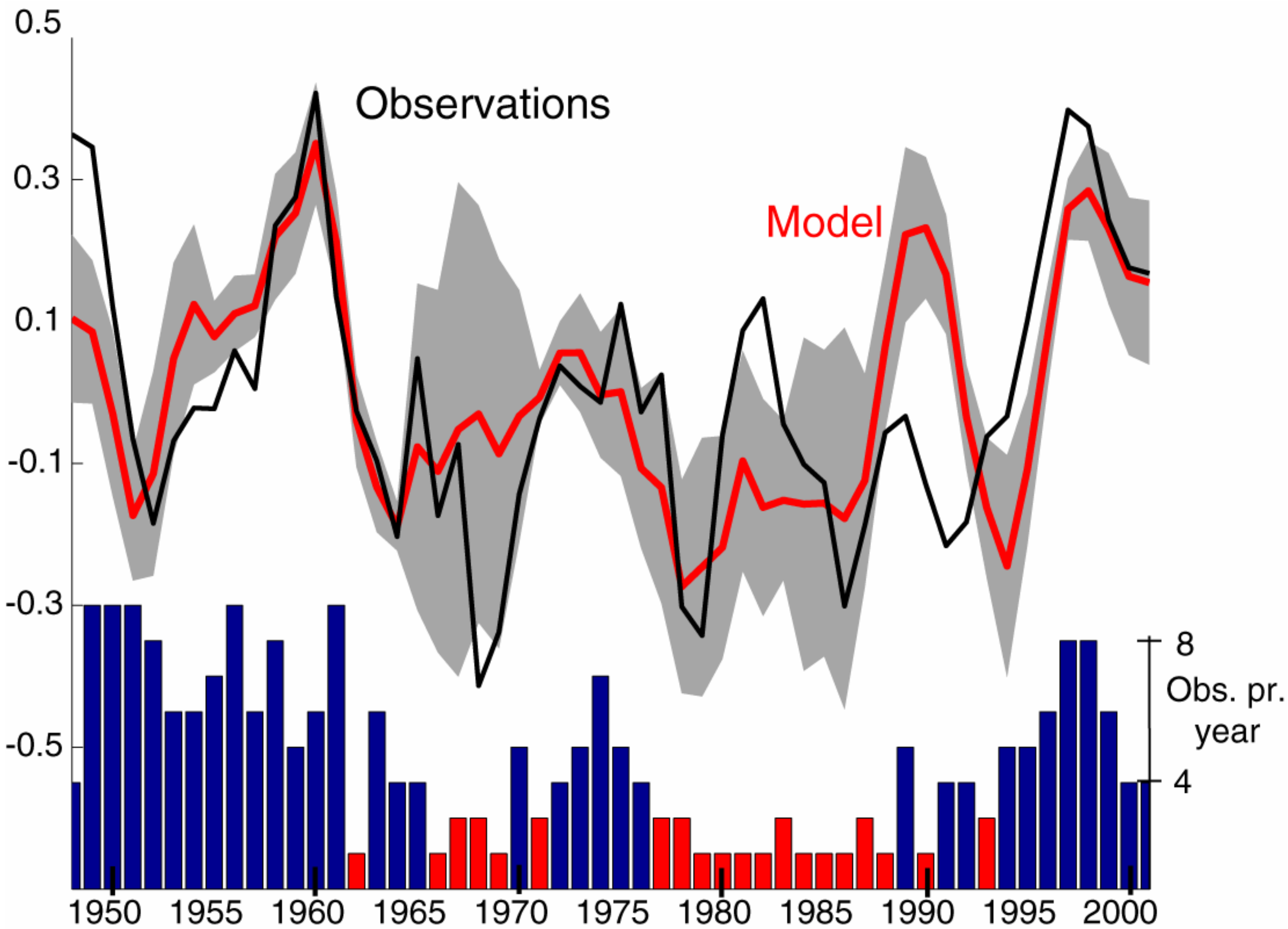
Hatun et al., 2005

Observed and simulated T on the Scottish Shelf



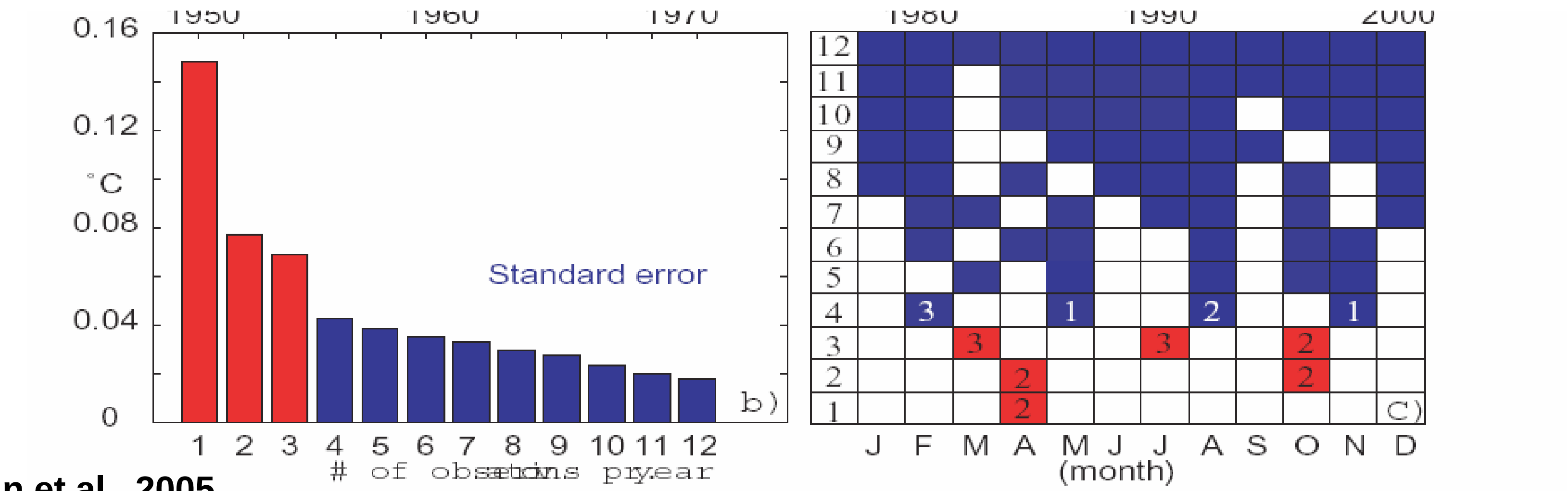
Hatun et al., 2005

Observed and simulated T on the Scottish Shelf



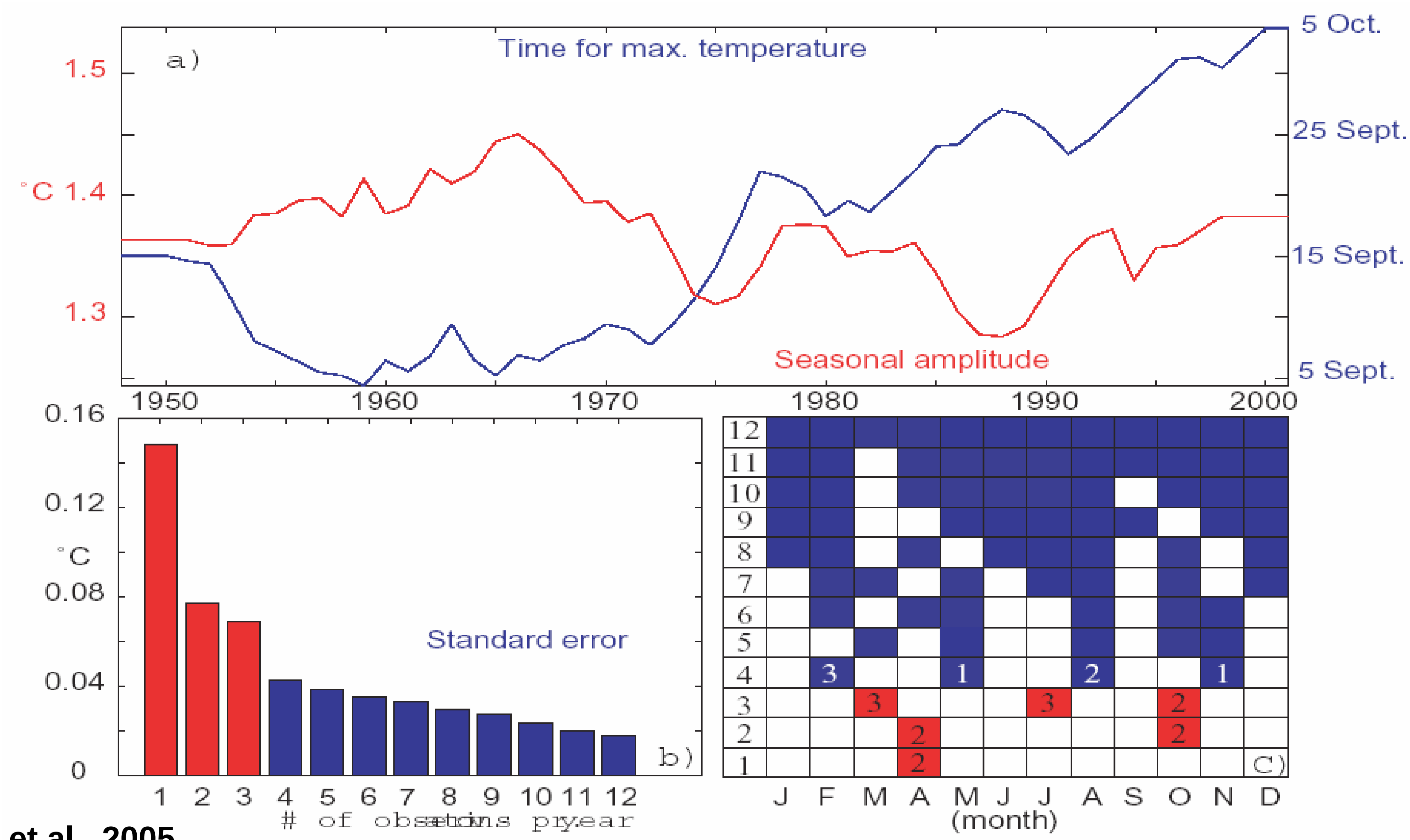
Hatun et al., 2005

Model derived optimal observation strategy



Hatun et al., 2005

Model derived optimal observation strategy



Hatun et al., 2005

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ECMW
19-22 June 2006

Developing reanalysis for climate research

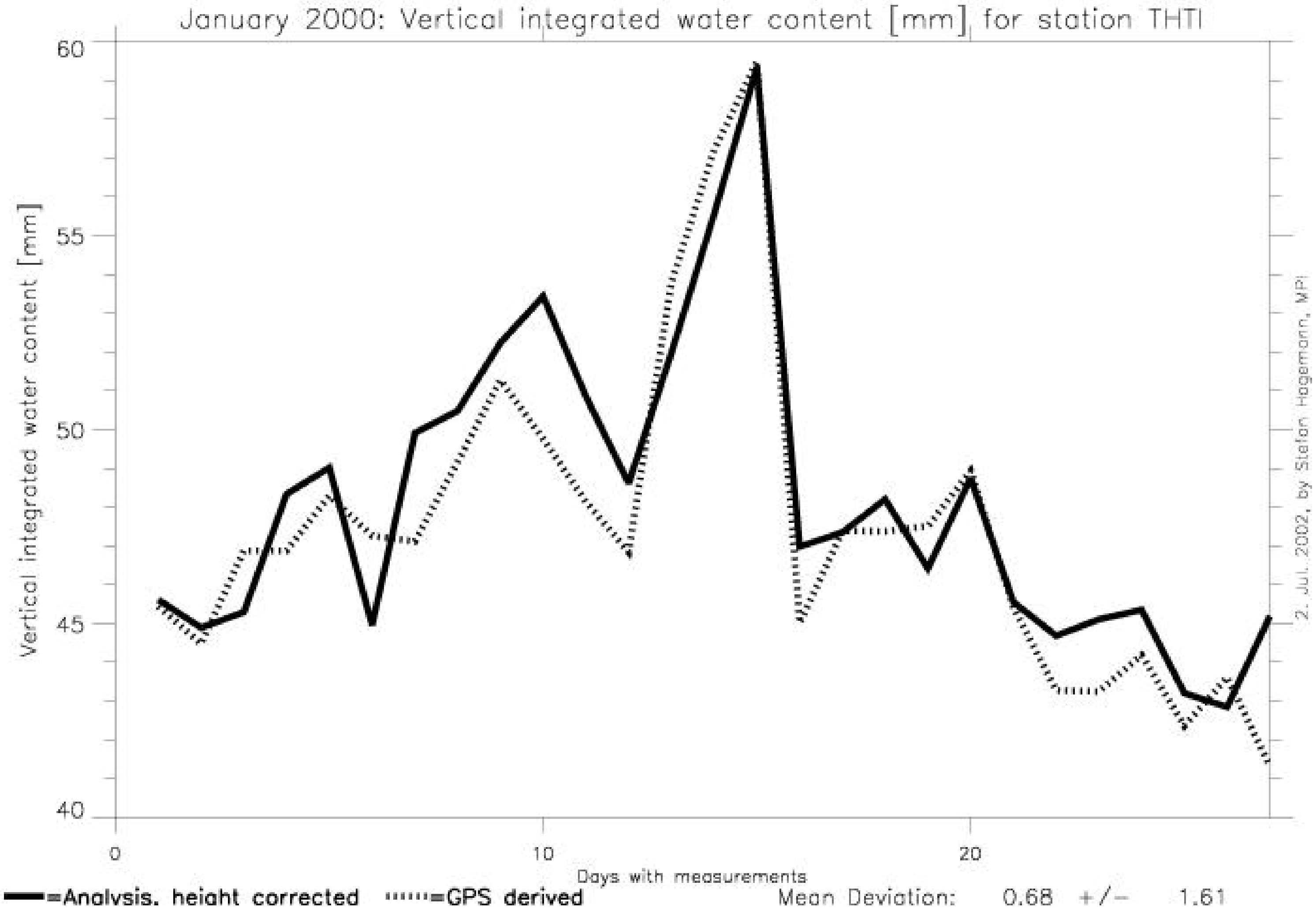
- To identify model and observational biases. Such biases preferably need to be identified prior to a reanalysis. Of particular importance are biases changing in time. This is not uncommon for upper air data.
- Further reductions in systematic model errors are needed including the handling of land surface and. parameterisation of processes of importance for the hydrological cycle.
- Further improvements in the horizontal resolution of the model to the order of some 50 km (T250 or similar) as well as employing a vertical resolution high enough to be able to handle QBO and other important stratospheric processes satisfactorily. (Giorgetta et al., 2002).
- Implementation of full four-dimensional data-assimilation systems similar to those increasingly used in operational NWP in order to handle non-synoptic and irregularly distributed observations more consistently. Using longest possible time-window.

A need for more active involvement by the climate community in the development of future reanalyses. This will include:

- The provision of best possible fields of SST and sea ice concentration including the assessed uncertainties. This will be of highest priority for a reanalysis addressing studies prior to the 1950s (Rayner et al., 2005). Incorrect or incomplete data can be misleading in estimating climate change. Similarly, better data sets for land surface conditions including snow cover are required.
- Recovery of synoptic surface meteorological data and radiosonde upper-air data to fill gaps in the observational records held by reanalysis centres. This is particularly important for the pre-satellite years.
- Much more accurately bias corrected radiosonde and satellite temperature data for the free atmosphere with assessed uncertainties that importantly include, and remove as far as possible, the structural uncertainties.
- Experimental reanalyses using selected sets of observations (Bengtsson et. al., 2004b) to explicitly assess the impact of different observations and provide quantitative justification for assimilation decisions and a focus for data rescue and homogenisation efforts. Such experimental studies can now be undertaken by remote research groups having high-speed access to advanced data-assimilation systems and databases made available by operational agencies such as ECMWF. An example, here, might be to omit satellite data for the period since 1979. Another might use the original and the bias-corrected sondes to see the impact of different adjustment procedures
- Experiments with the use of coupled models in data-assimilation drawing on the experiences in the oceanographic community.

END

January 2000: IWV [mm] for station Tahiti (Polynesia)



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January 2000: IWV [mm] for station Ascension (Trop. Atlantic)