ARC CENTRE OF EXCELLENCE FOR CLIMATE SYSTEM SCIENCE

Australian Government
Australian Research Council

Climate extremes:

Data issues

Lisa Alexander
Climate Change Research Centre and ARC Centre of Excellence for Climate Systems Science, University of New South Wales

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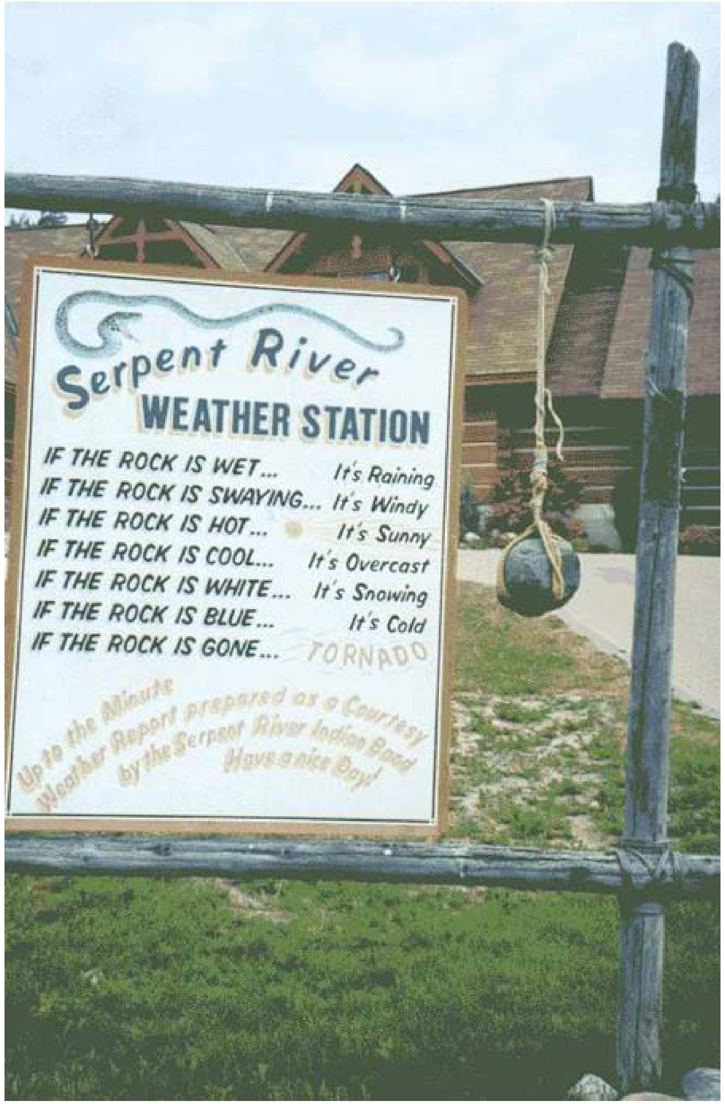
WCRP Grand Challenge on Extremes

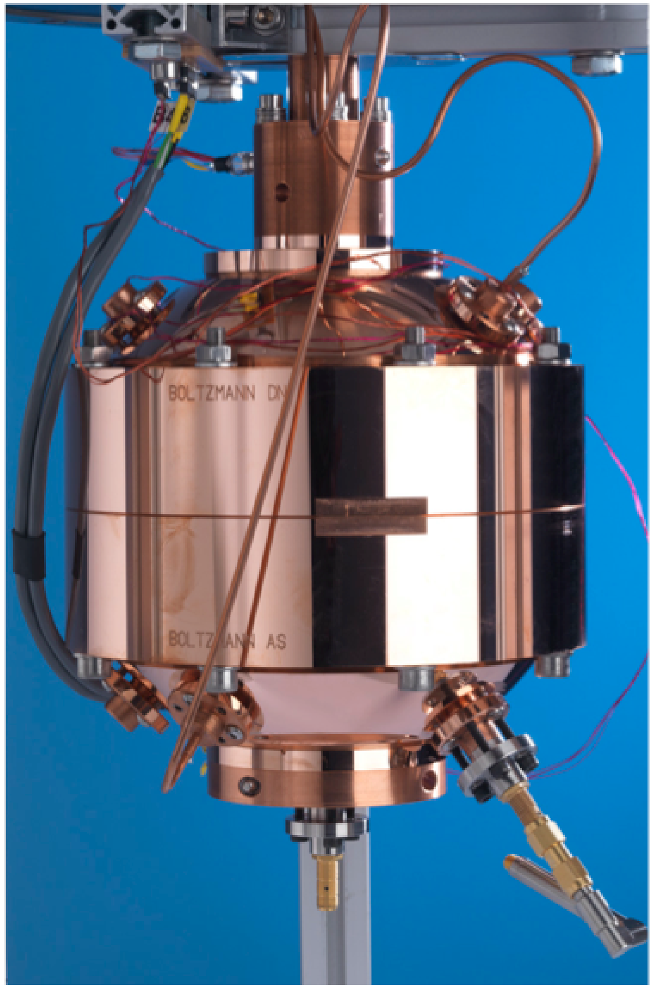
- 8 key scientific questions have been posed to the scientific community over the coming decade

Q1: How can we improve the collation, dissemination and quality of observations needed to assess extremes and what new observations do we need?

Why observe the climate?



How do we observe the climate?



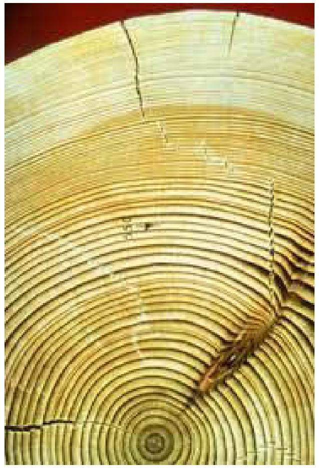
This is not the lab!

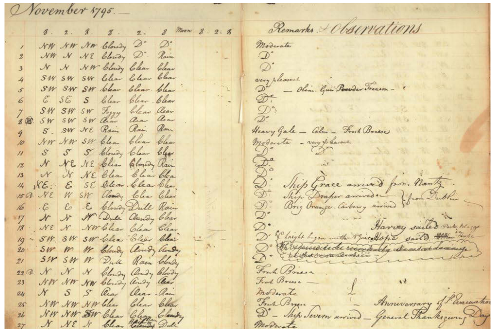
Michael de Podesta's 'Instrument of real beauty' for determining the Boltzmann constant

Observations in some in really challenging environments …

Image courtesy BAS via CIMSS AWS website (Fossil Bluff station)

Many different observations

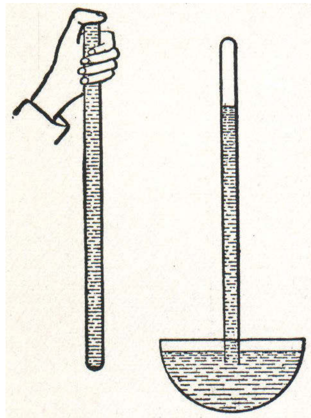



November 1795
Remarks & Observations

Thatched Shed.

History of instrumentation and observations

- Between 16th and 17th C instruments started to be constructed to measure weather variables e.g. temperature (Galileo, Santorio), pressure (Torricelli)
- 18th and 19th century
  - ➢ 1724 - Farenheit introduces first standardised scale
  - ➢ 1742 - Celcius introduces scale based on freezing and boiling point of water
  - ➢ 1848 – Kelvin introduces scale based on 'absolute temperature'
- Military realises benefit of weather observations (first daily forecast produced - 1860)



20^{th} century

Late 1800s/Early 1900s – National Weather Services formed

1930 – first weather balloon released

1941 – first radar network

1959 – first weather satellite launched (Vanguard 2)

1975 – first GOES satellite launched

Data requirements for extremes

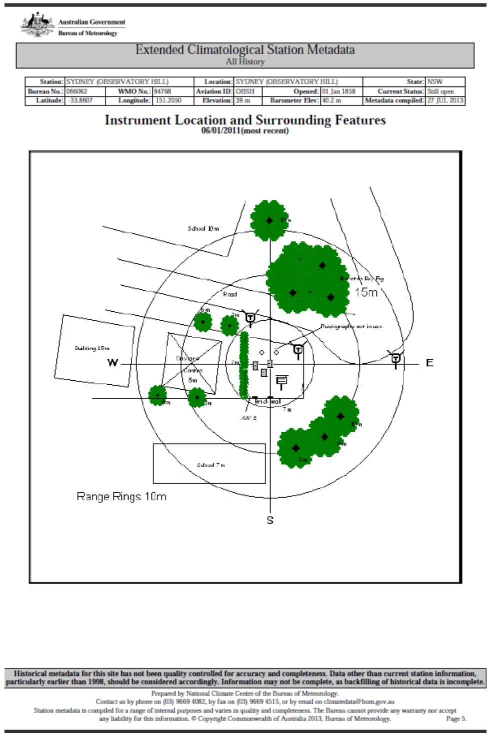
- Quality, consistency and availability of observations underpin analysis of climate extremes and attribution analyses
- Errors in data are likely to show up as 'extreme'
- But what we want/need versus what we get can be very different

Quality – what we want

Quality – what we get

Consistency – what we want

Artificial changes are well documented (metadata) and have been accounted for over all time periods (traceability)



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Extended Climatological Station Metadata
All History

Station:	SYDNEY (OBSERVATORY HILL)			**Location:**	SYDNEY (OBSERVATORY HILL)			**State:**	NSW
Bureau No.:	066062	**WMO No.:**	94768	**Aviation ID:**	OBSH	**Opened:**	01 Jan 1858	**Current Status:**	Still open
Latitude:	-33.8607	**Longitude:**	151.2050	**Elevation:**	39 m	**Barometer Elev:**	40.2 m	**Metadata compiled:**	27 JUL 2013

Instrument Location and Surrounding Features
06/01/2011(most recent)

Historical metadata for this site has not been quality controlled for accuracy and completeness. Data other than current station information, particularly earlier than 1998, should be considered accordingly. Information may not be complete, as backfilling of historical data is incomplete.

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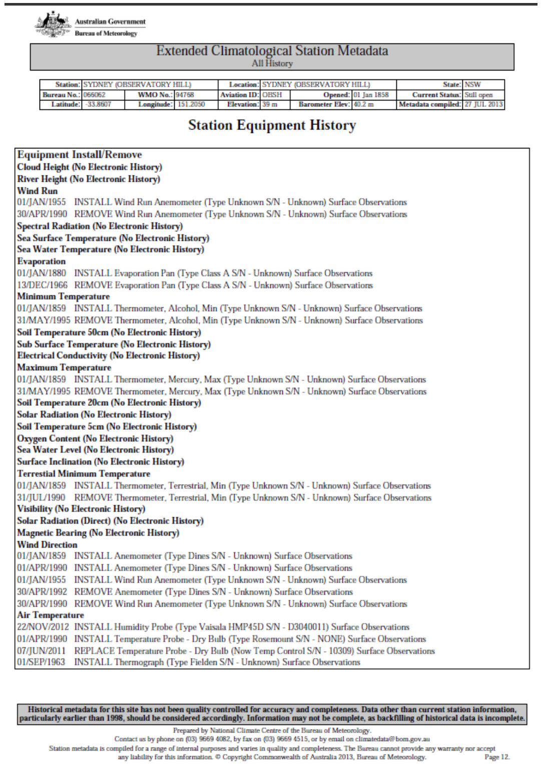

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Station Equipment History

Equipment Install/Remove
Cloud Height (No Electronic History)
River Height (No Electronic History)
Wind Run
01/JAN/1955 INSTALL Wind Run Anemometer (Type Unknown S/N - Unknown) Surface Observations
30/APR/1990 REMOVE Wind Run Anemometer (Type Unknown S/N - Unknown) Surface Observations
Spectral Radiation (No Electronic History)
Sea Surface Temperature (No Electronic History)
Sea Water Temperature (No Electronic History)
Evaporation
01/JAN/1880 INSTALL Evaporation Pan (Type Class A S/N - Unknown) Surface Observations
13/DEC/1966 REMOVE Evaporation Pan (Type Class A S/N - Unknown) Surface Observations
Minimum Temperature
01/JAN/1859 INSTALL Thermometer, Alcohol, Min (Type Unknown S/N - Unknown) Surface Observations
31/MAY/1995 REMOVE Thermometer, Alcohol, Min (Type Unknown S/N - Unknown) Surface Observations
Soil Temperature 50cm (No Electronic History)
Sub Surface Temperature (No Electronic History)
Electrical Conductivity (No Electronic History)
Maximum Temperature
01/JAN/1859 INSTALL Thermometer, Mercury, Max (Type Unknown S/N - Unknown) Surface Observations
31/MAY/1995 REMOVE Thermometer, Mercury, Max (Type Unknown S/N - Unknown) Surface Observations
Soil Temperature 20cm (No Electronic History)
Solar Radiation (No Electronic History)
Soil Temperature 5cm (No Electronic History)
Oxygen Content (No Electronic History)
Sea Water Level (No Electronic History)
Surface Inclination (No Electronic History)
Terrestial Minimum Temperature
01/JAN/1859 INSTALL Thermometer, Terrestrial, Min (Type Unknown S/N - Unknown) Surface Observations
31/JUL/1990 REMOVE Thermometer, Terrestrial, Min (Type Unknown S/N - Unknown) Surface Observations
Visibility (No Electronic History)
Solar Radiation (Direct) (No Electronic History)
Magnetic Bearing (No Electronic History)
Wind Direction
01/JAN/1859 INSTALL Anemometer (Type Dines S/N - Unknown) Surface Observations
01/APR/1990 INSTALL Anemometer (Type Dines S/N - Unknown) Surface Observations
01/JAN/1955 INSTALL Wind Run Anemometer (Type Unknown S/N - Unknown) Surface Observations
30/APR/1992 REMOVE Anemometer (Type Dines S/N - Unknown) Surface Observations
30/APR/1990 REMOVE Wind Run Anemometer (Type Unknown S/N - Unknown) Surface Observations
Air Temperature
22/NOV/2012 INSTALL Humidity Probe (Type Vaisala HMP45D S/N - D3040011) Surface Observations
01/APR/1990 INSTALL Temperature Probe - Dry Bulb (Type Rosemount S/N - NONE) Surface Observations
07/JUN/2011 REPLACE Temperature Probe - Dry Bulb (Now Temp Control S/N - 10309) Surface Observations
01/SEP/1963 INSTALL Thermograph (Type Fielden S/N - Unknown) Surface Observations

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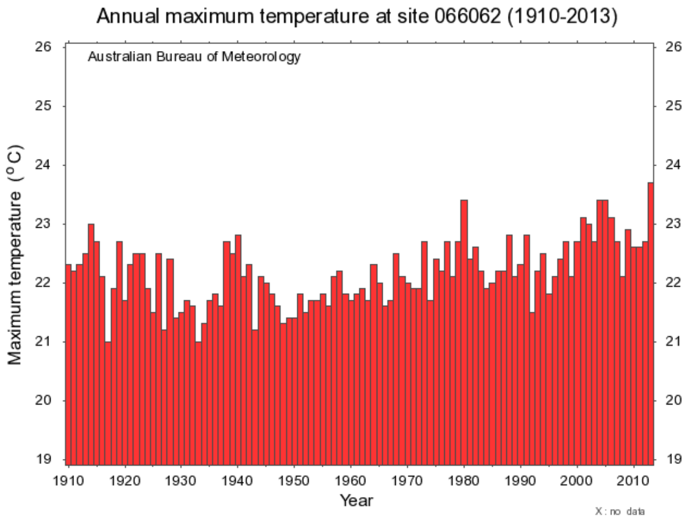

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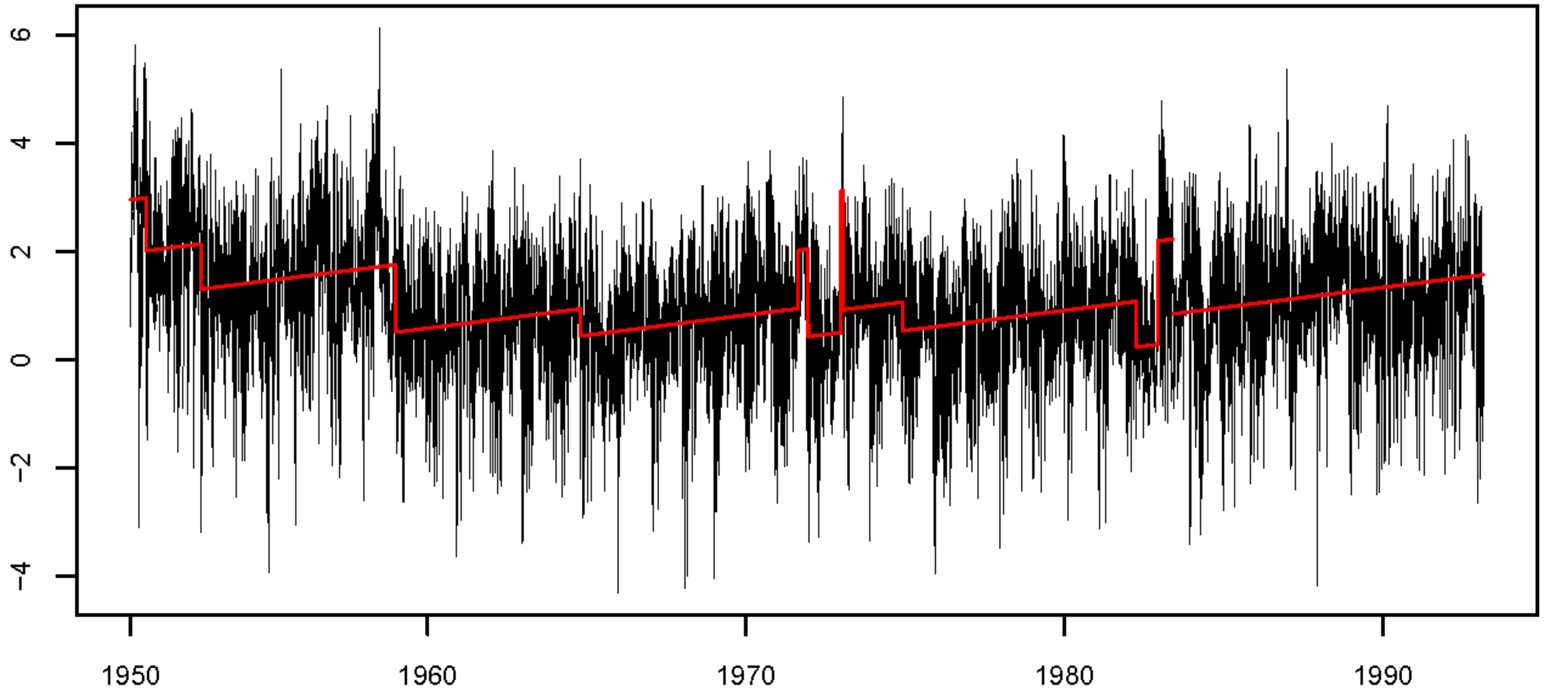
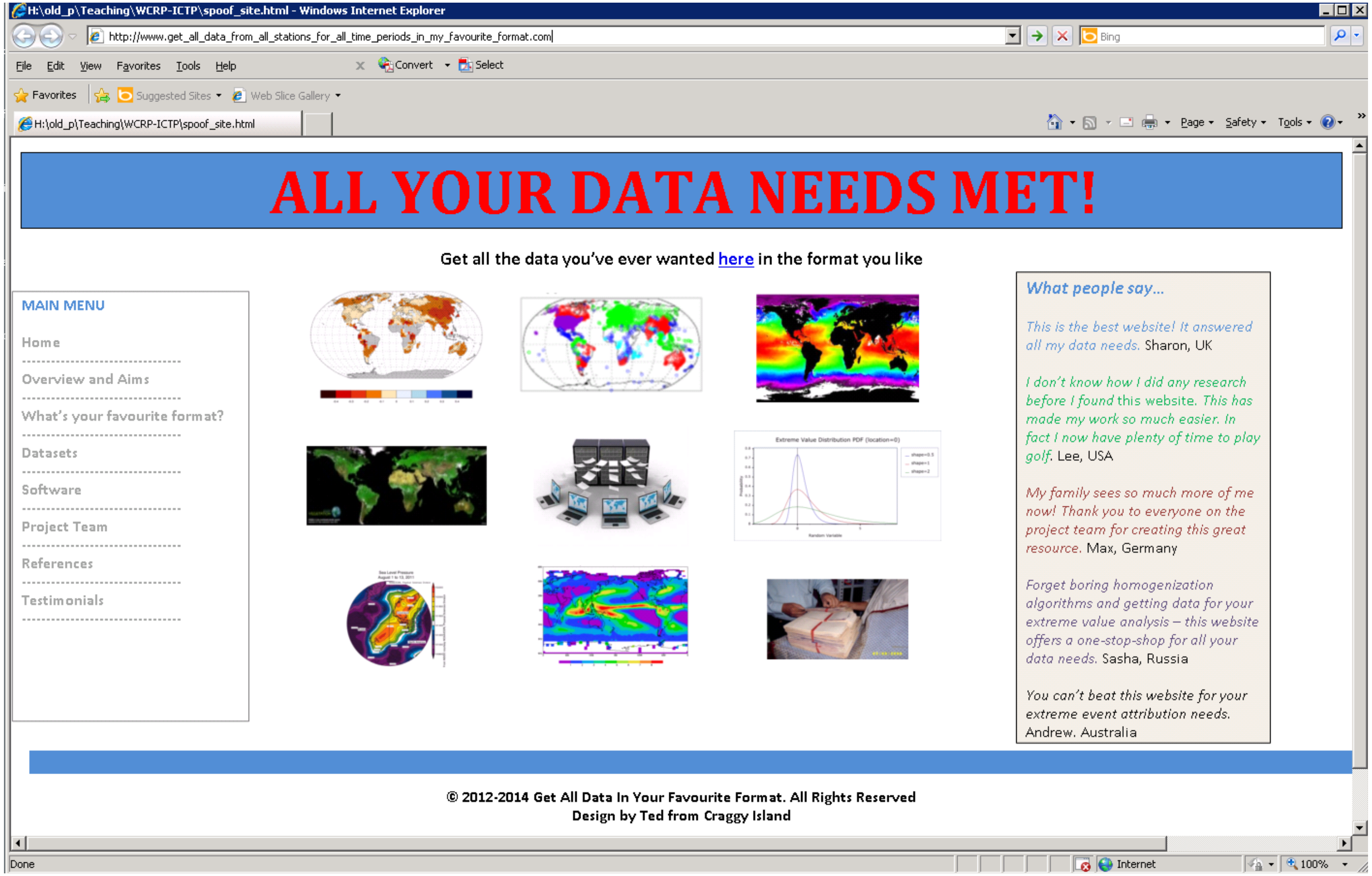
Consistency – what we get

Base anomaly series and regression fit



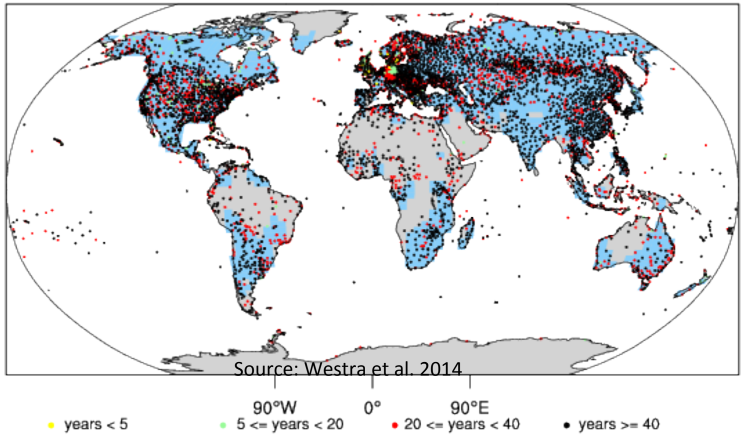
Availability – what we want

www.get_all_data_from_all_stations_for_all_time_periods_in_my_favorite_format.com



Availability – what we get

Sub-daily precip stations (HadISD) and SDII coverage (HadEX2)

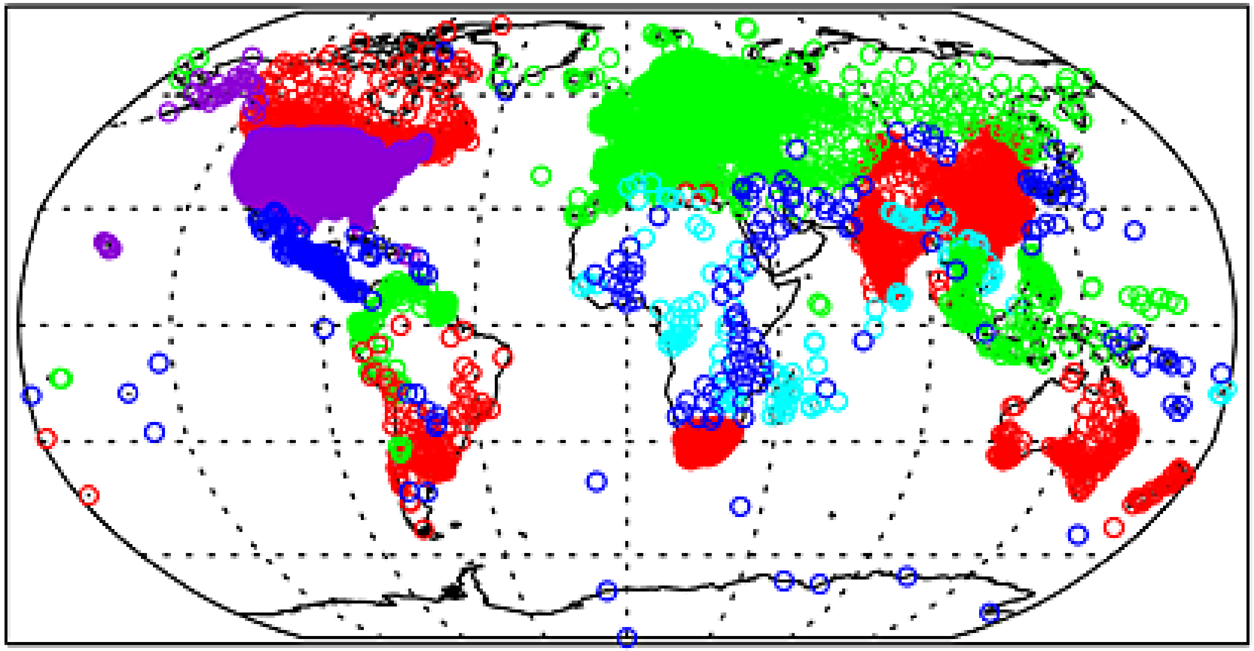


"We estimate the world loses 500,000 old records each day". Rick Crouthamel, IEDRO

Issues and uncertainties – 1. station error

uncertainty of individual station measurements

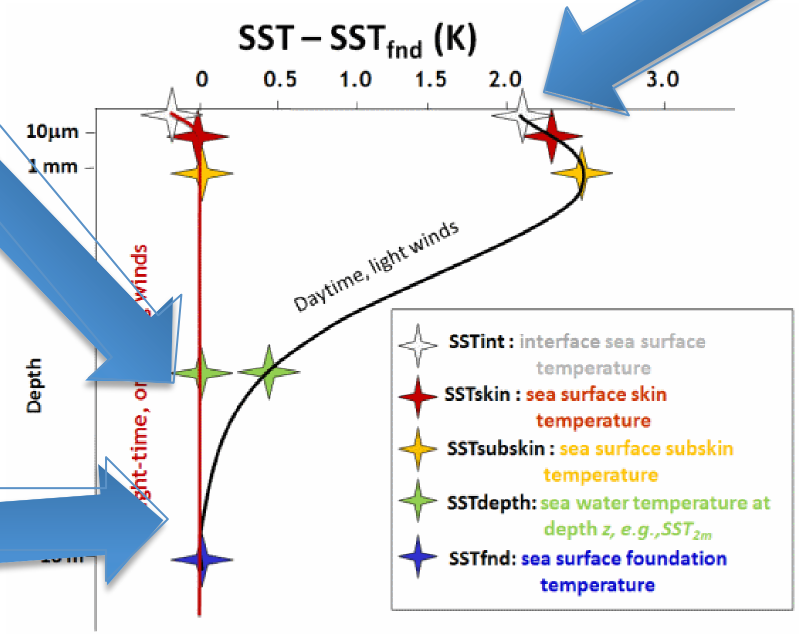
Issues and uncertainties: 2. sampling error



Source: Donat et al. 2013

uncertainty in area mean caused by sampling small number of point values

Issues and uncertainties: 3. bias error



uncertainty in large-scale values caused by systematic changes in measurement methods

..also coverage error…

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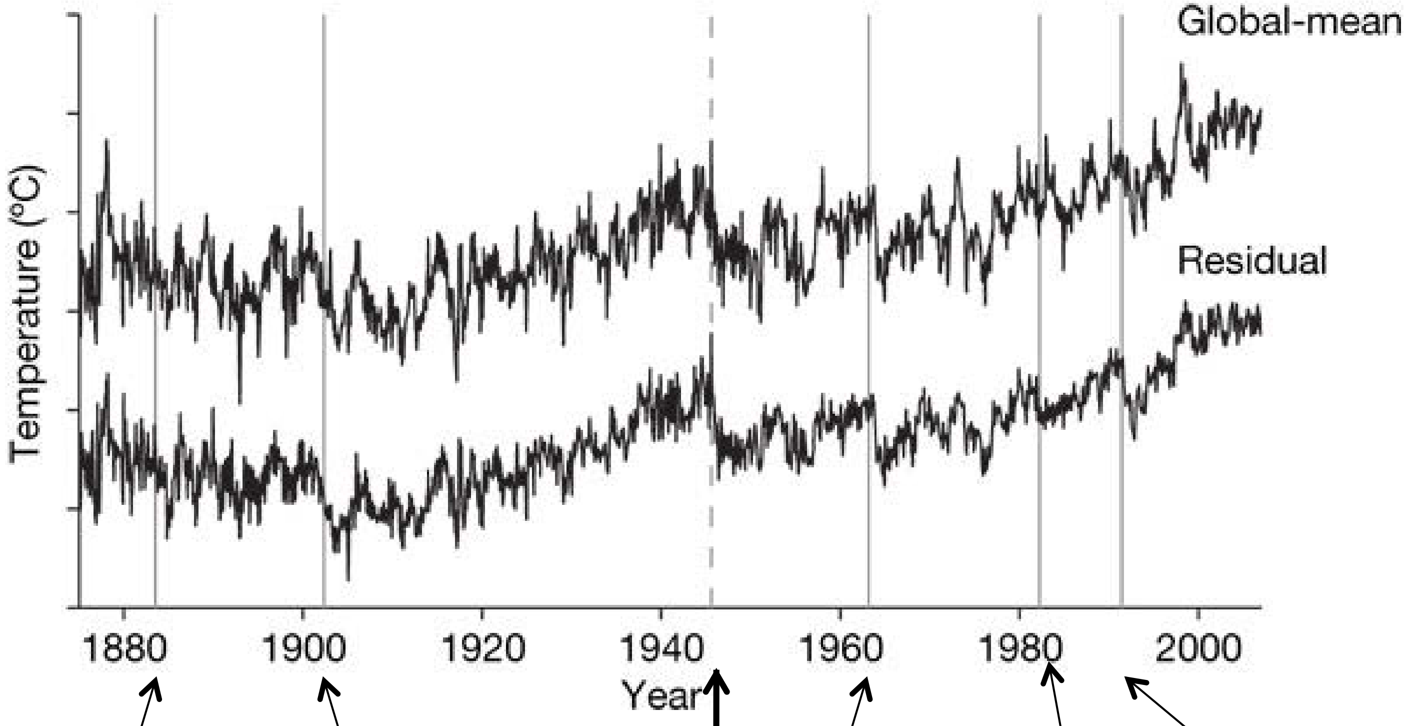
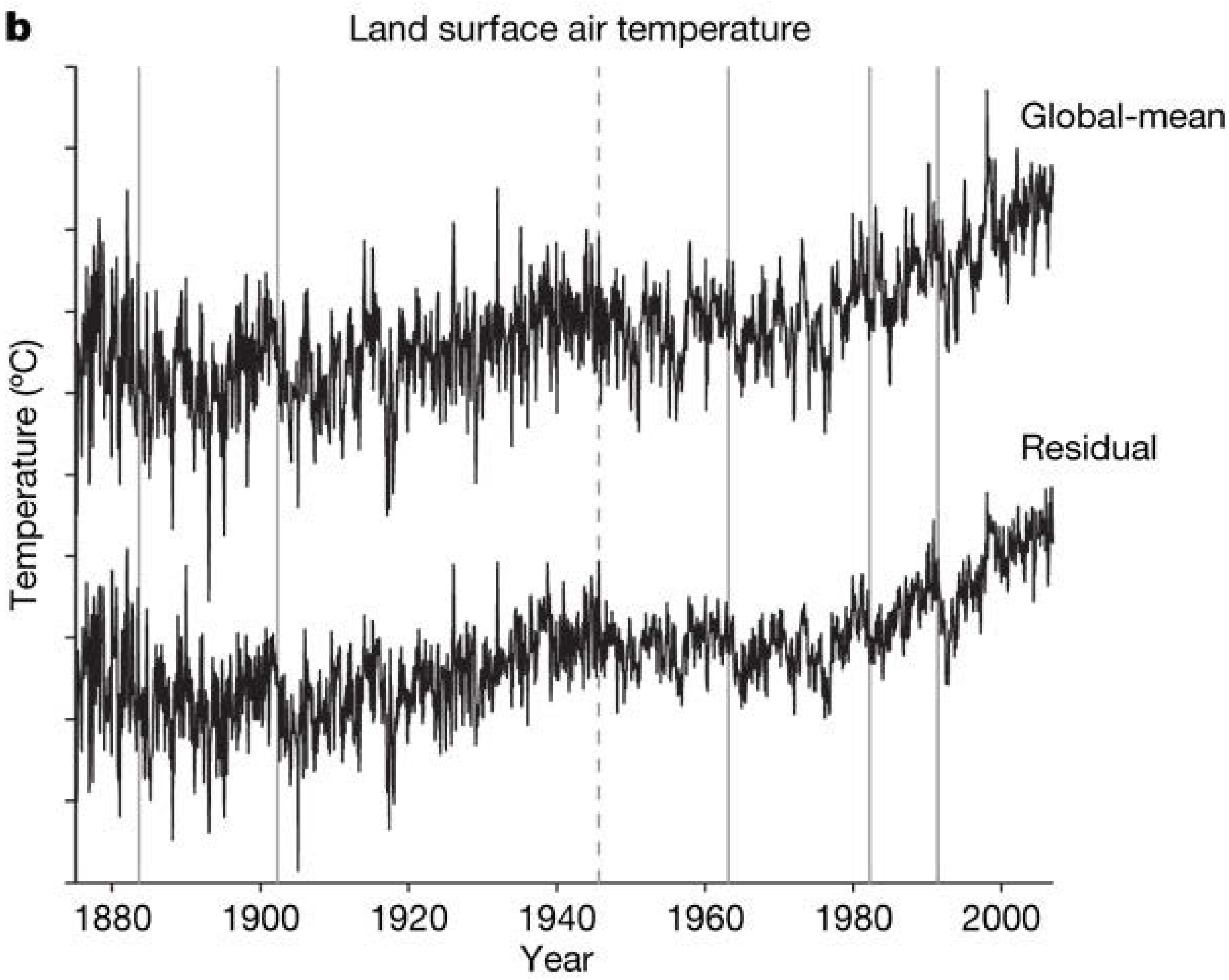
Global SST measurements



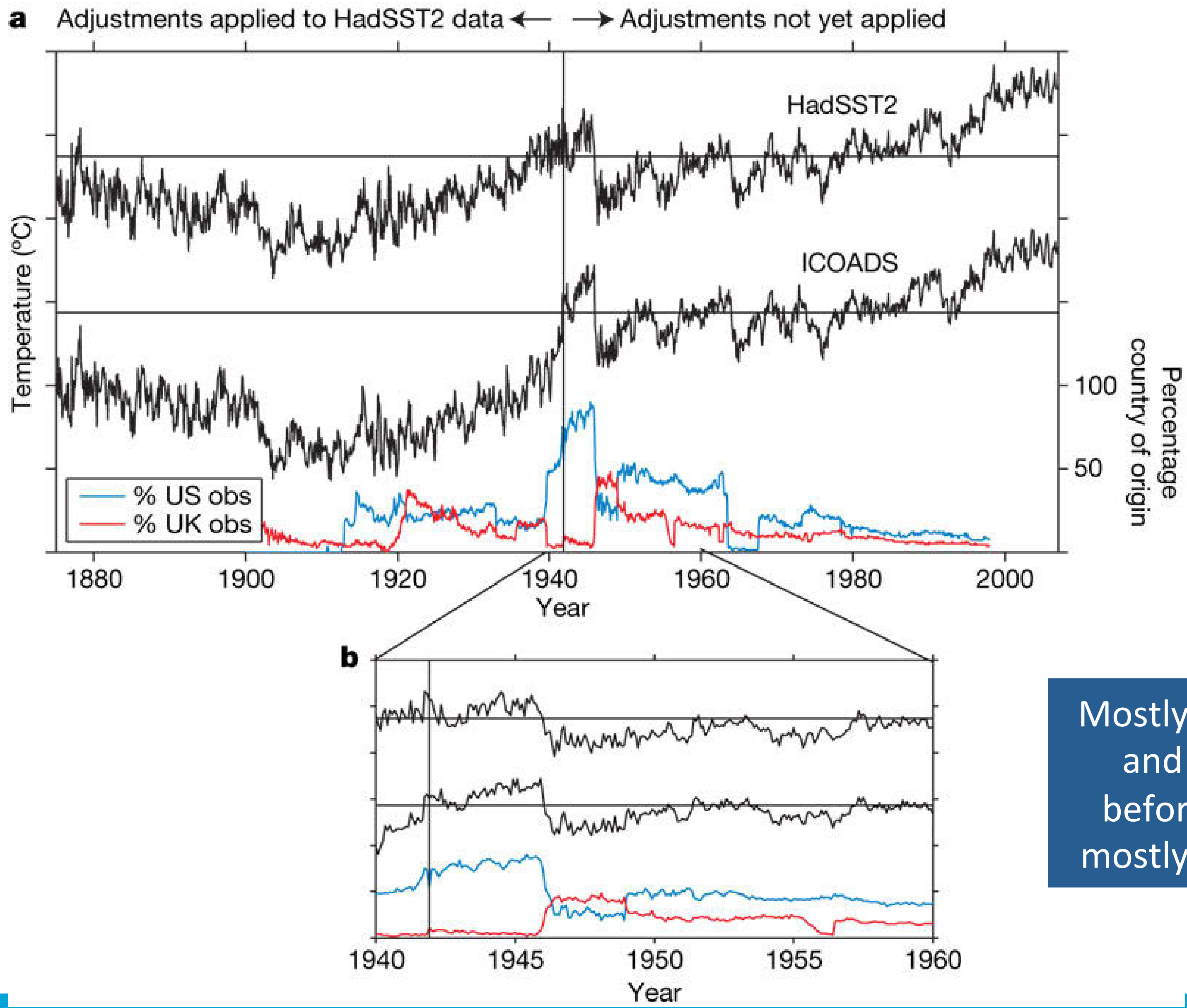
Krakatoa Santa Maria Agung El Chichón Pinatubo

But what about 1945?

No evidence of change over land



Source: Thompson et al. 2008



Mostly US ships and buoys before 1945, mostly UK after

Source: Thompson et al. 2008

Inhomogeneities

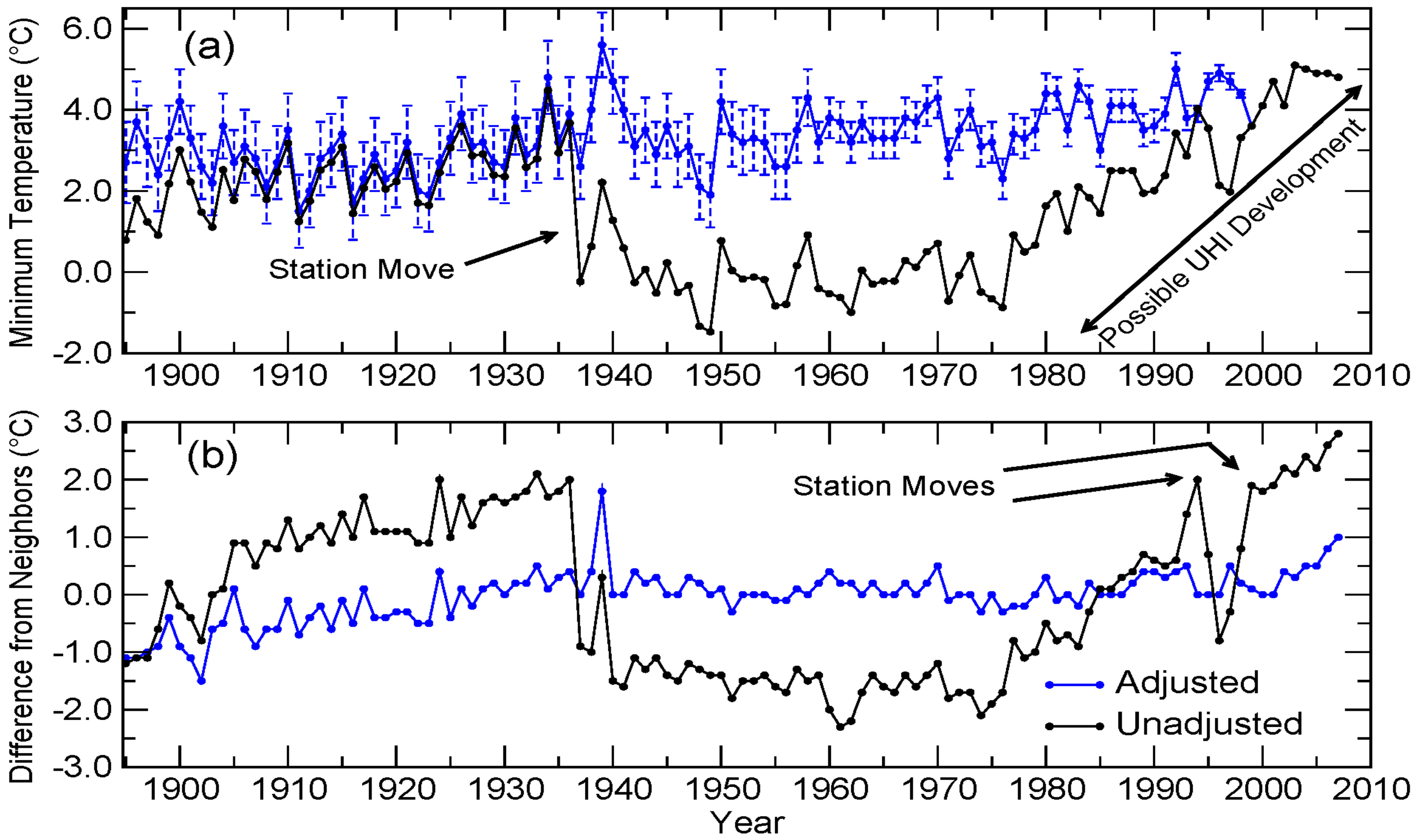
Artificial changes in the observed record that are not due to changes in climate

Can be introduced through changes in e.g.

- observation source or observing practice
- number of observations
- station relocation
- instrumentation change
- site environment

Inhomogeneities can be sudden or gradual

Statistical tests can adjust data for inhomogeneities



$$T_{obs} + C_H = T_{true} + \varepsilon_{obs} + \varepsilon_H$$

Homogenisation correction

Error in applied homogenisation correction

Random measurement error

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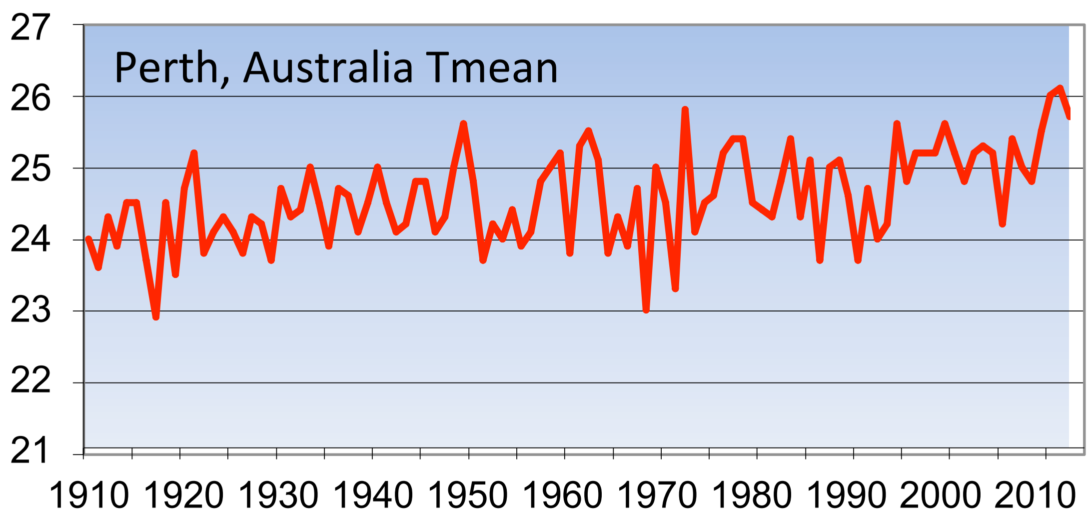
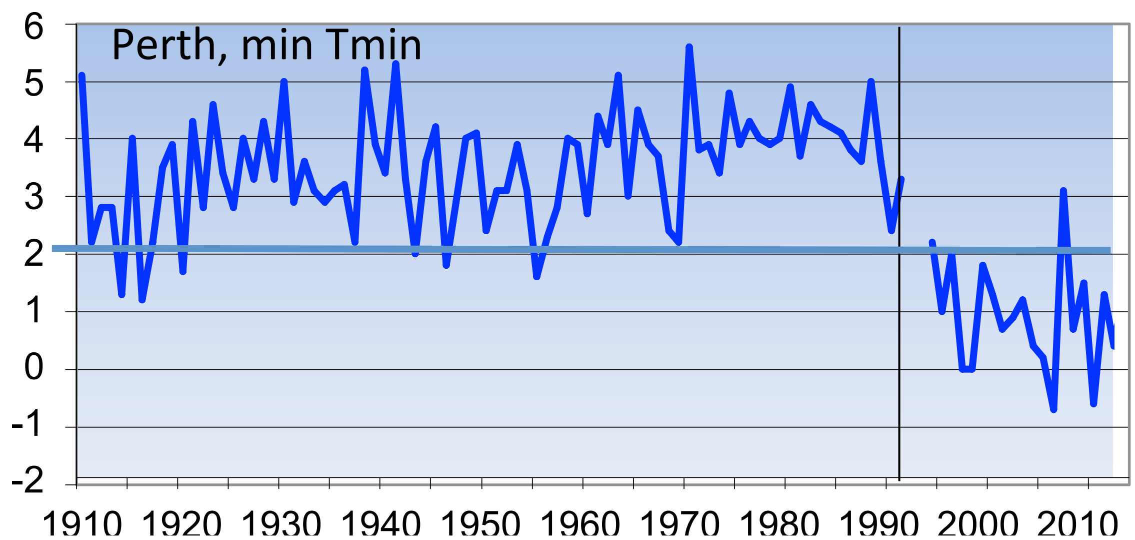
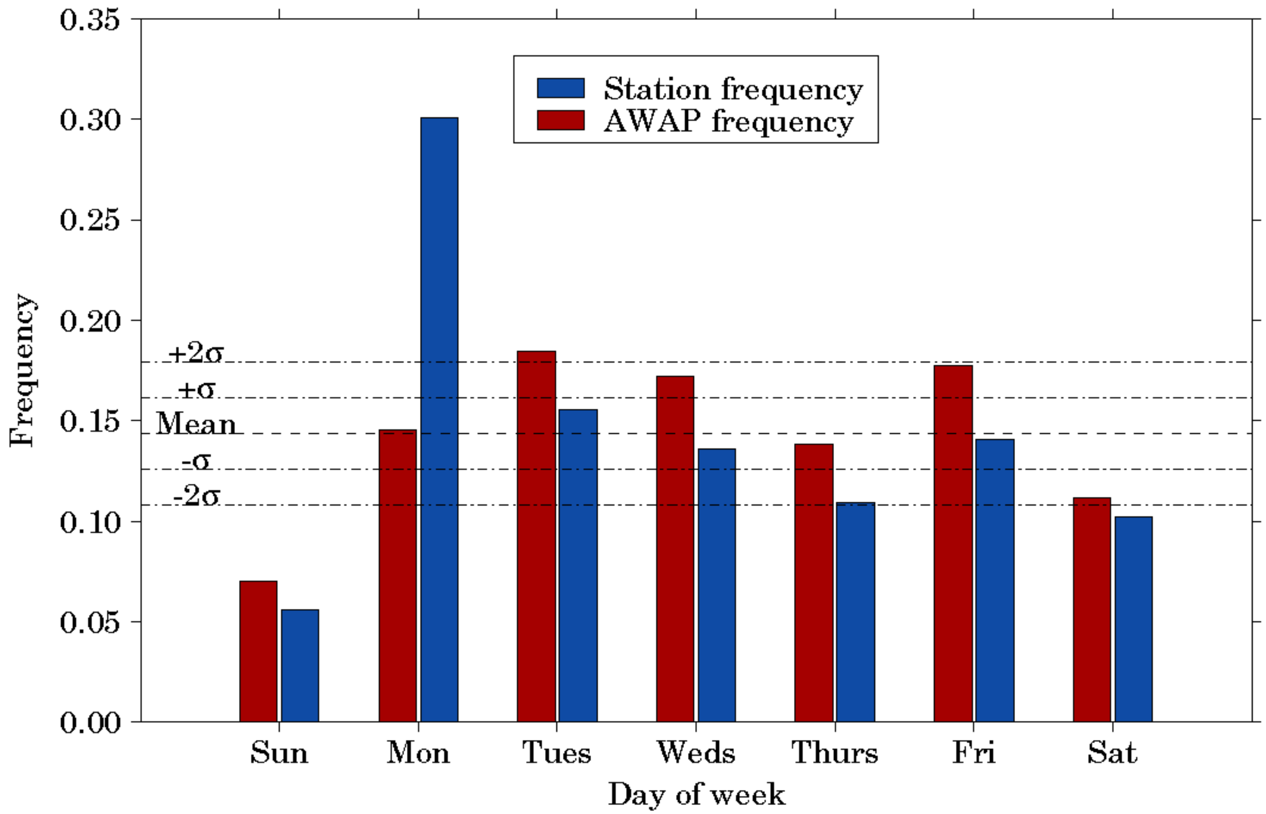
Is this different for extremes?



Before a site move in 1993 an 'extreme' Tmin < 2°C occurred only 5 times in Perth but almost every year since then



Observing practice – it never rains on a Sunday



Source: King et al. 2012

The long list of issues to be considered

- Station moves
- Instrument changes
- Observer changes
- Automation
- Time of observation biases
- Microclimate exposure changes
- Urbanization
- And so on …
- And that's just for the land records, similar laundry lists for satellites, radiosondes, marine …

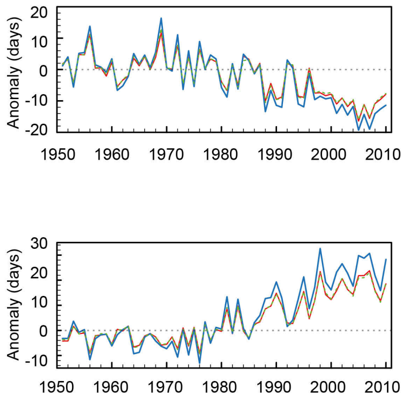
Underlying which are two absolutely fundamental issues …

- A lack of traceability to absolute or even relative standards for most of the historical (and present day) records
- A lack of adequate documentation of the (ubiquitous) changes sufficient to characterize in an absolute sense the time-varying measurement characteristics.

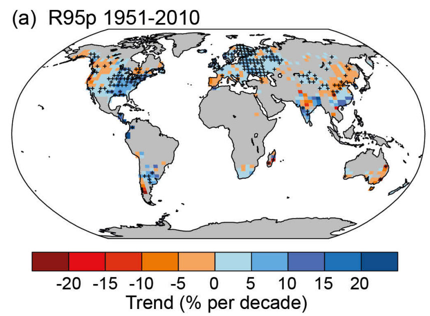
All data have problems and uncertainties

- Which are different from (climate) models
- Which require expertise to minimize
  - E.g. not all data sets were created equal
- Fortunately, there are experts in almost all types of observational data who would be happy to share their insights
  - As these data are often their life's work

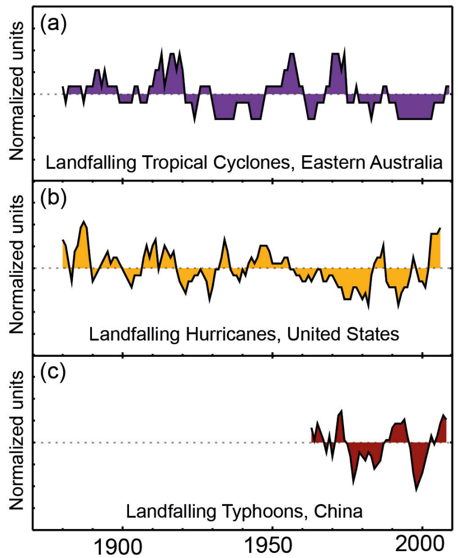
IPCC AR5 observed extremes assessment



Very likely decreases in cold days and nights and increases in warm days and nights



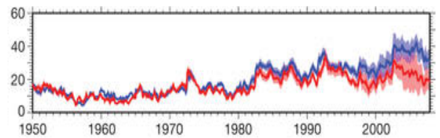
Likely more land regions where the number of heavy precipitation events has increased than where it has decreased



Low confidence in long-term increases in intense tropical cyclone activity

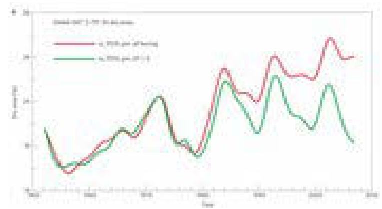
Virtually certain North Atlantic since 1970s

Little change in drought over the past 60 years



Low confidence in increasing drought duration/intensity

Increasing drought under global warming in observations and models



Likely increases and decreases in some regions

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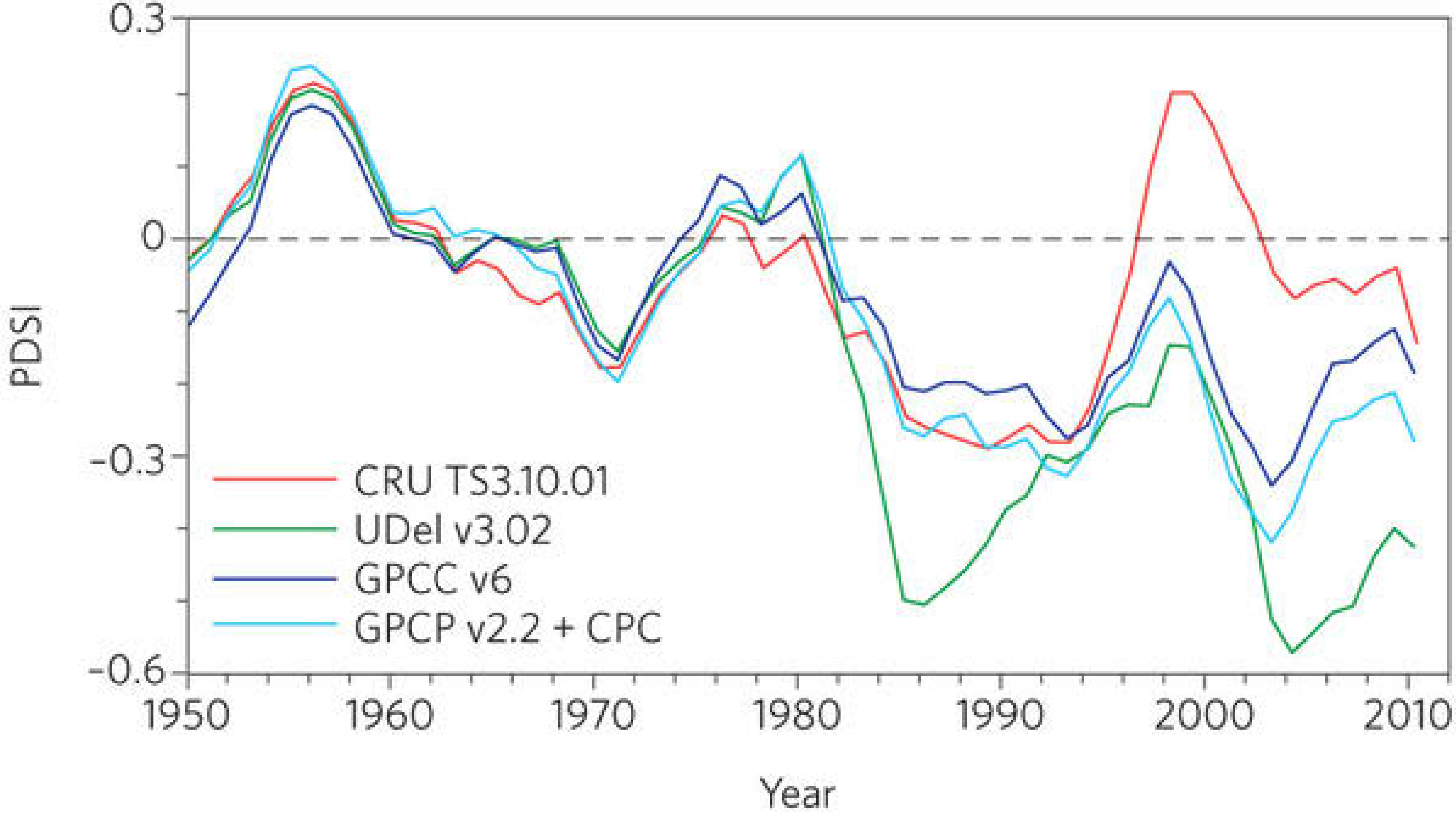
Recent attempts to reconcile differences



Source: Trenberth et al. 2014

Scaling issues

Fundamental mismatch?

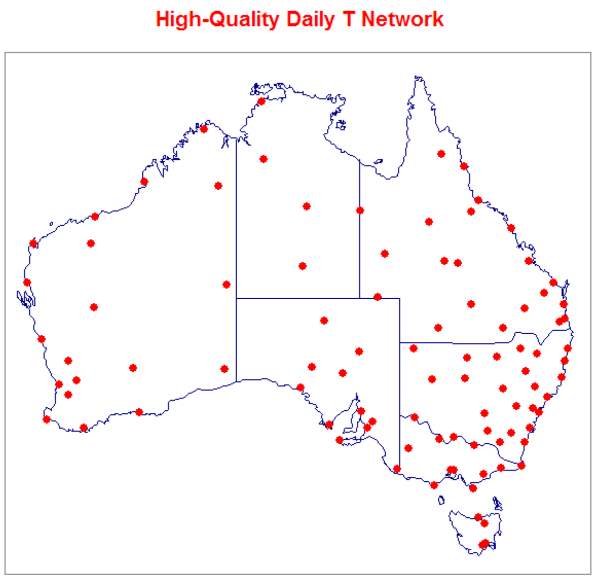
- The spatial representativeness of in situ observations which are gridded using interpolation techniques may not 'mean' the same as climate model output of extremes

- Scale mismatch (or 'problem of change in support') more importantly affects phenomena whose spatial features are discontinuous or have short temporal scales
  - e.g. sub-daily precipitation, extreme events

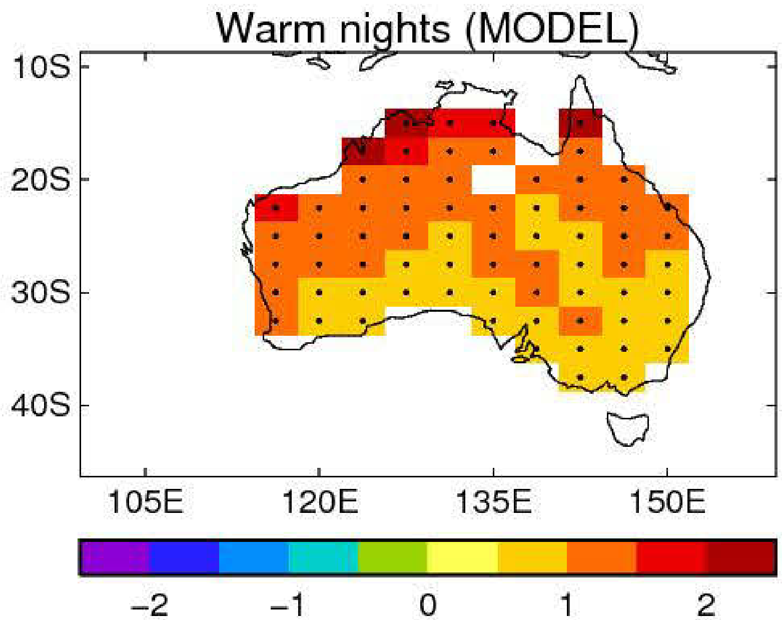
- Alternative data sets are available (e.g. reanalyses) but come with their own problems

Points versus grids

1. Observations are taken at points locations
2. Climate model output represents an areal average

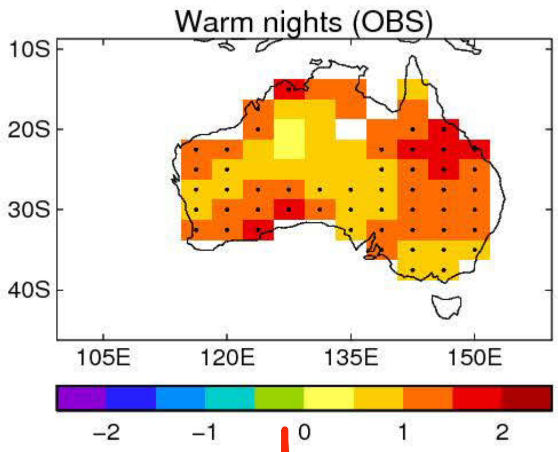


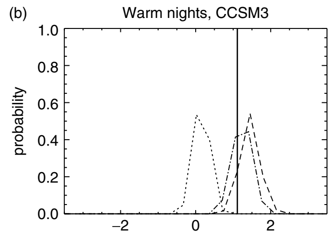
?



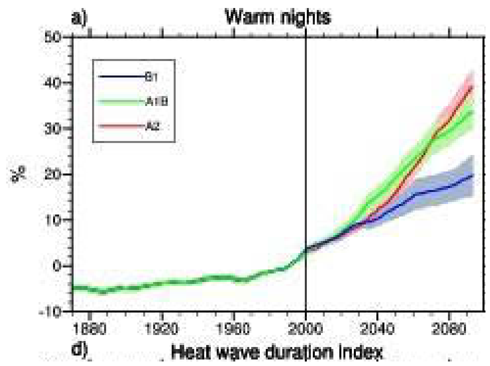
How can we compare 1. and 2.?

Gridding allows comparison with climate models

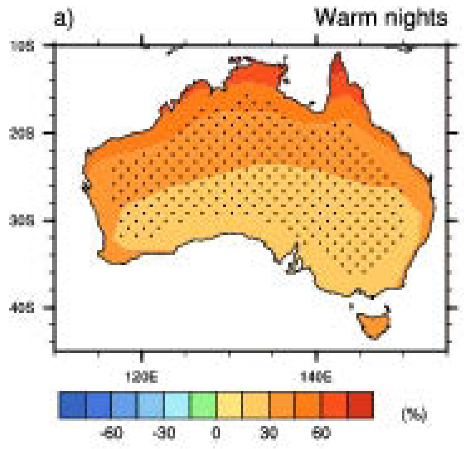




D&A

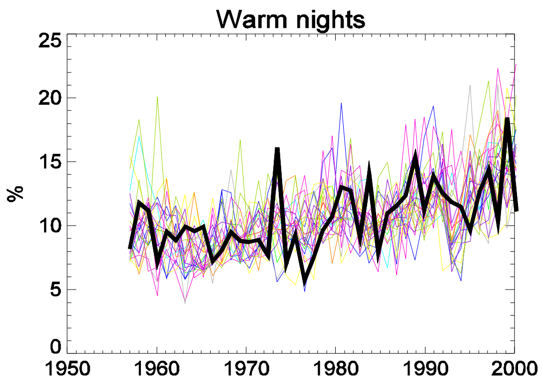


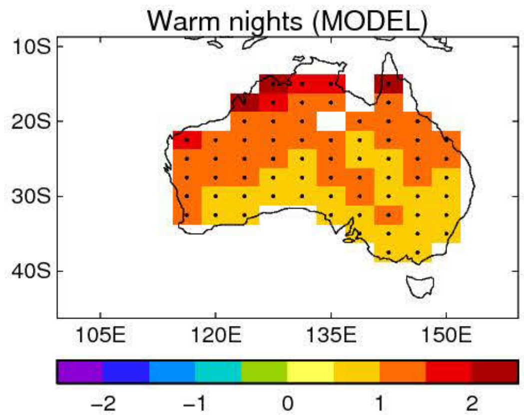
Project



Difference end 21st C compared to 20th C

Compare





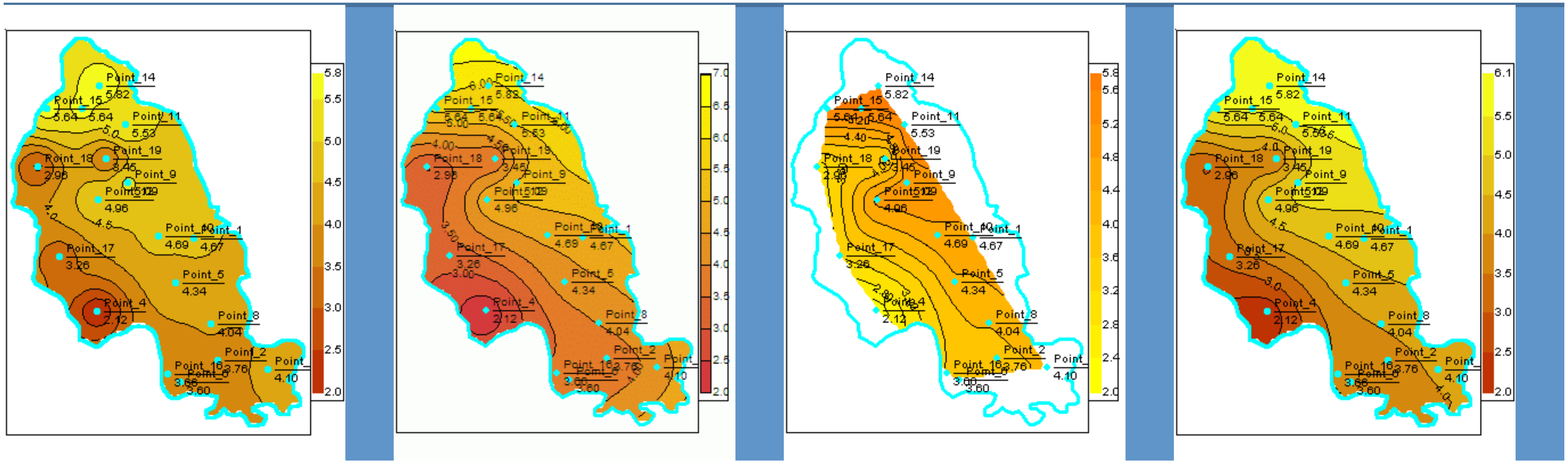
Source: Alexander and Arblaster, 2009

Gridding versus downscaling

- Gridding methods usually work by assigning values to unknown points by means of a weighted average of a number of known points
- Downscaling is the means of converting of areally averaged data to point data. There are two main types:
  - Statistical
  - Dynamical

Gridding methods

- There are many techniques that convert point observations to areal averages (grids). These include:
  - Kriging
  - Natural neighbours
  - Minimum curvature
  - Inverse distance weighting
  - Angular distance weighting
  - Radial Basis Functions
  - …



Example: Angular Distance Weighting (ADW)

- Requires knowledge of the correlation structure of the data i.e. how the chosen climate variable varies across space and time

- A correlation function, f, is defined for each i^{th} station:

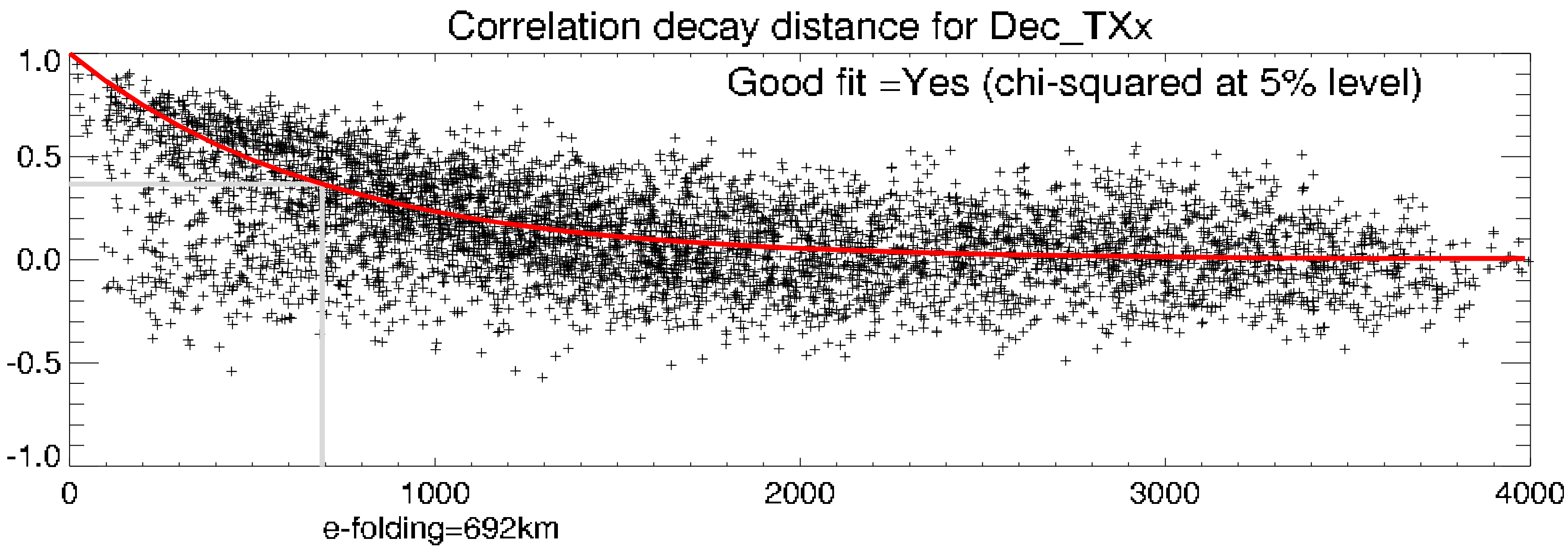
$$f_i = e^{-r_i / L}$$

r_i: Distance from i^{th} station to gridbox centre

L: Decorrelation length scale

Decorrelation length scale

- Also referred to as the *e-folding distance*
  - i.e. the time it takes the fitted function to fall away with distance to 1/e



Calculating weighting functions

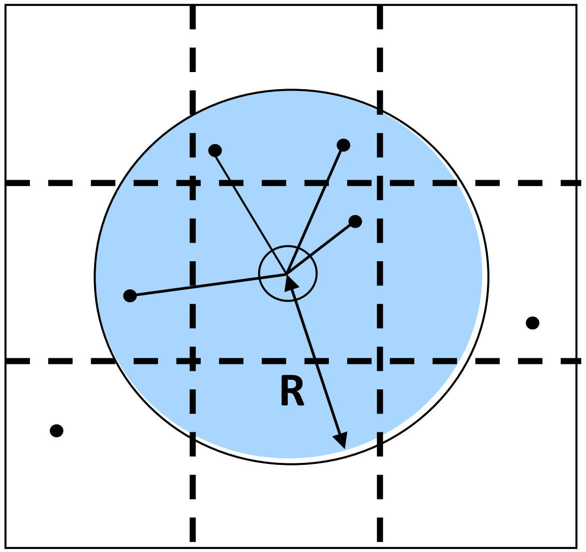
Bearing of i^{th} and k^{th} stations

$$\omega_i = f_i^{\,m}\left\{1 + \frac{\sum_k f_k^{\,m}\left[1 - \cos(\theta_k - \theta_i)\right]}{\sum_k f_k^{\,m}}\right\}, \qquad i \neq k$$

Adjusts function decay

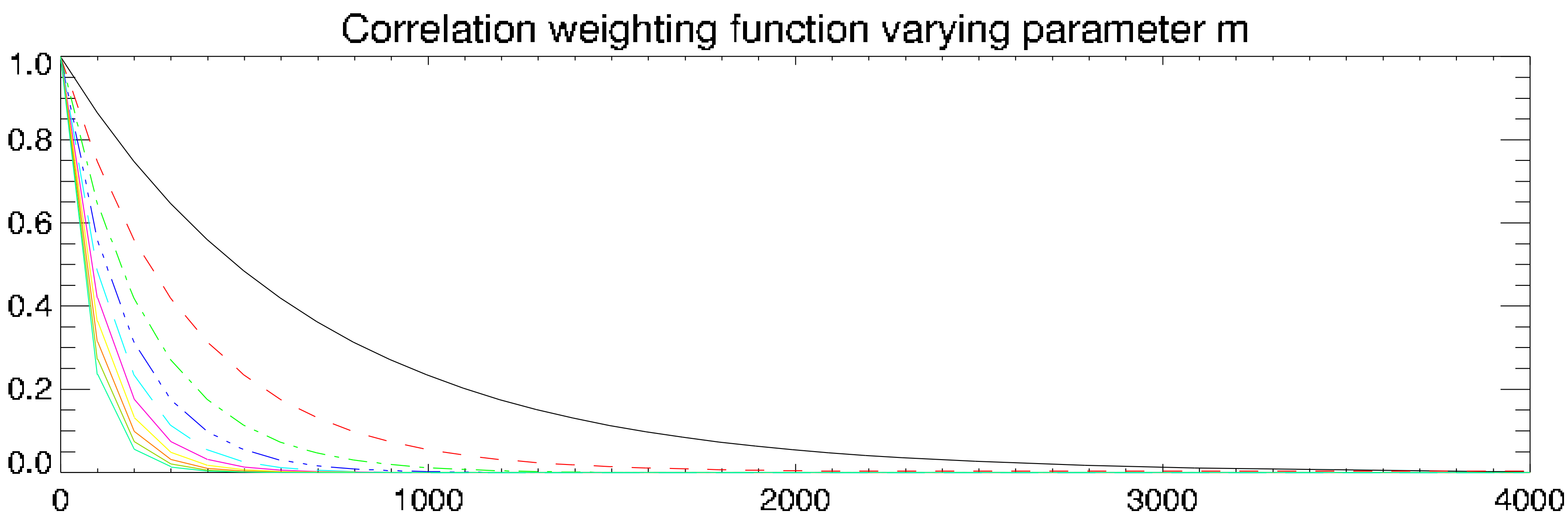
k sums over all stations within circle of influence (R)

R is determined by the correlation function (usually the e-folding distance)



Testing values of *m*

- The parameter that determines the exponential decay of station weights

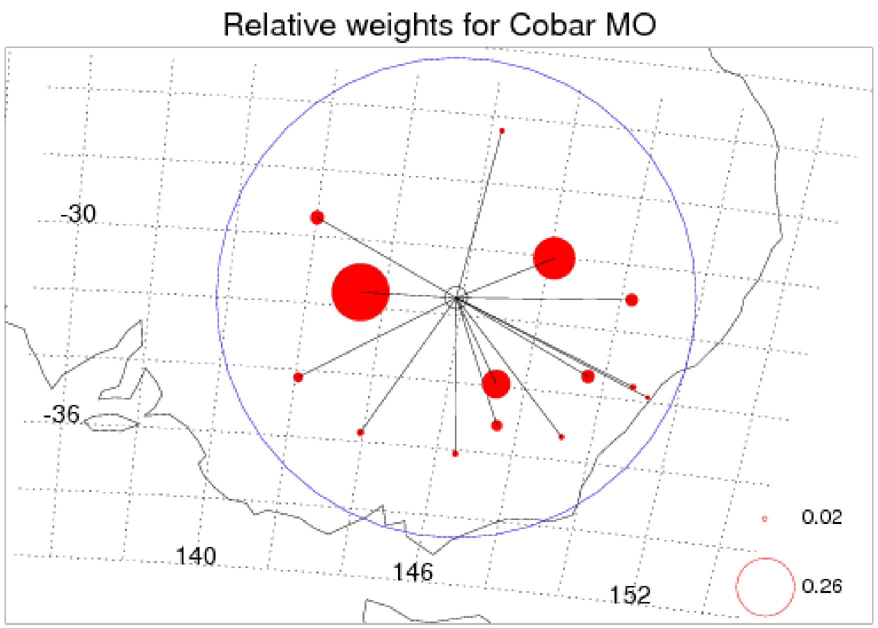


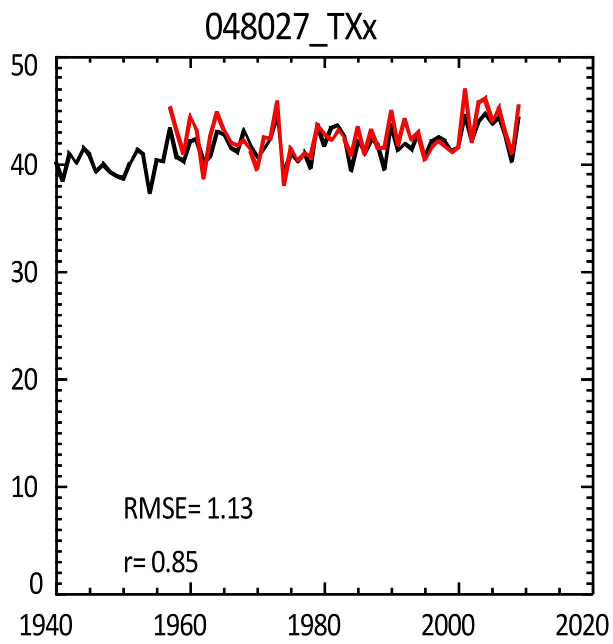
Parameter choices

- Period over which correlation is performed (all years, subset of years)
- Value of m (multiple tests can determine 'best' value)
- Distance over which function is fitted
- Ultimately parameter choices necessarily have to reflect compromises (don't have data points for all space and time periods, don't have all information)

Testing the 'goodness of fit' of the chosen method

- The method can be tested by trying to simulate the station data rather than an unknown grid point location



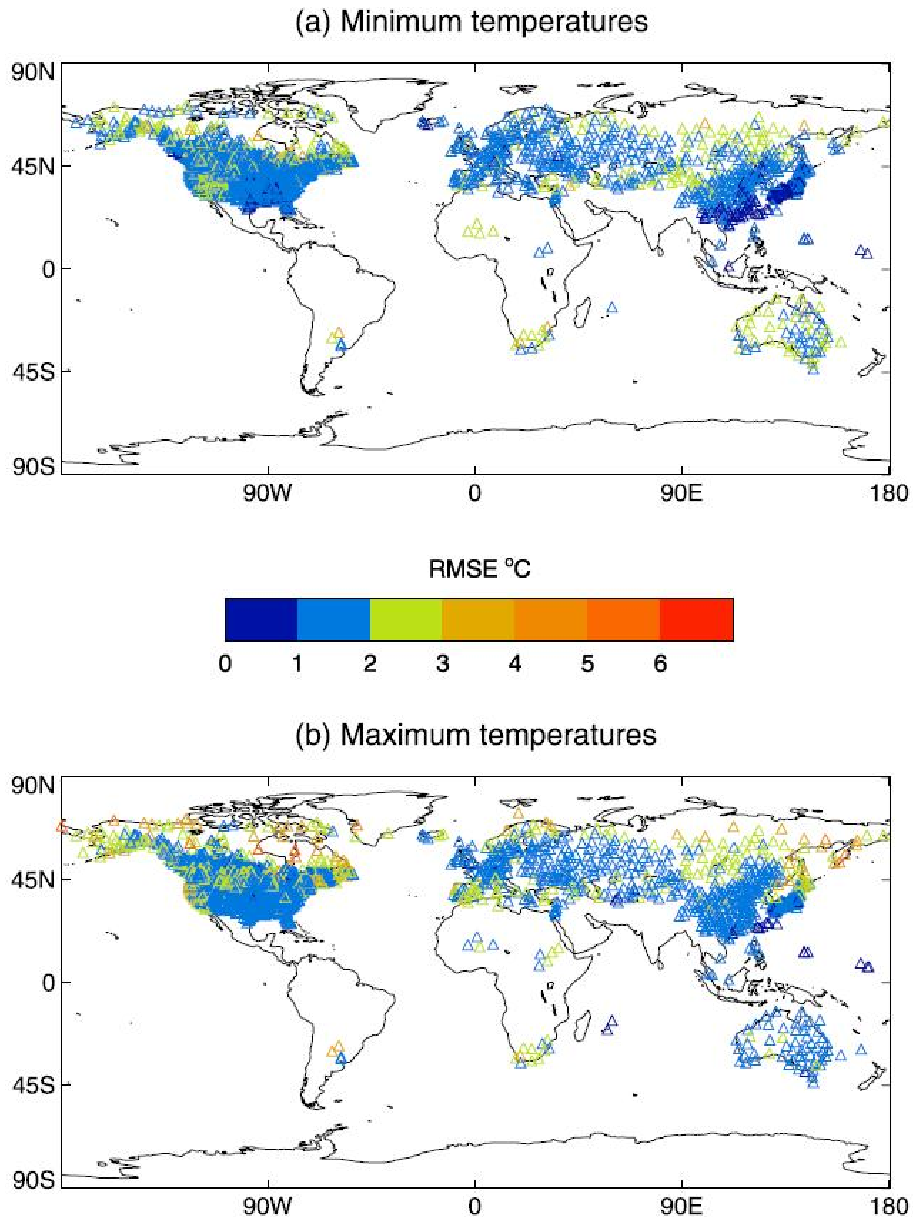


Error fields

•Possible to determine regions where you have more/less confidence in the gridded product

•Enables 'error bars' to be placed on gridded observational data

•Important for climate model evaluation



Parametric versus structural uncertainties

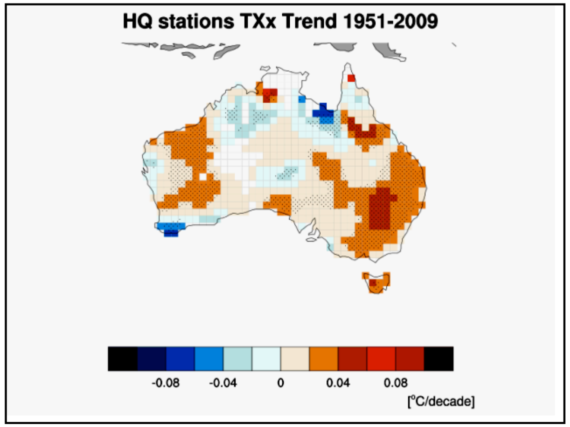
- Parametric uncertainties can be calculated by testing our choices within our model framework e.g.
  - Parameter settings
  - Minimum number of 'points' to consider
  - Type of function to fit and maximum distance over which to fit function
  - Value of function decay
- Structural uncertainties can be calculated by using multiple gridding methods
  - Questioning your methodological framework
  - E.g. Kriging versus ADW
- Need to understand uncertainties before appropriate evaluation of climate models

Comparison of the different data sets

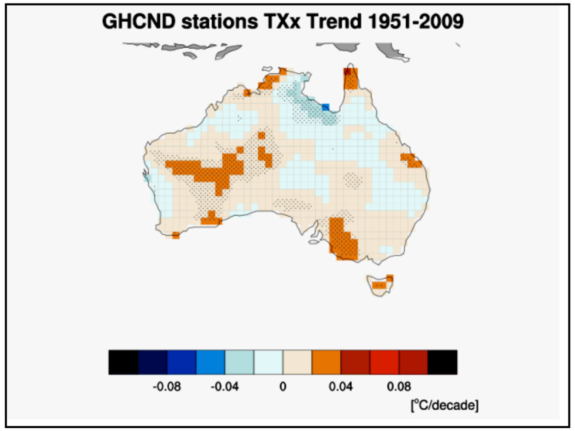
Hottest day of the year

(1° grid, fixed parameters)

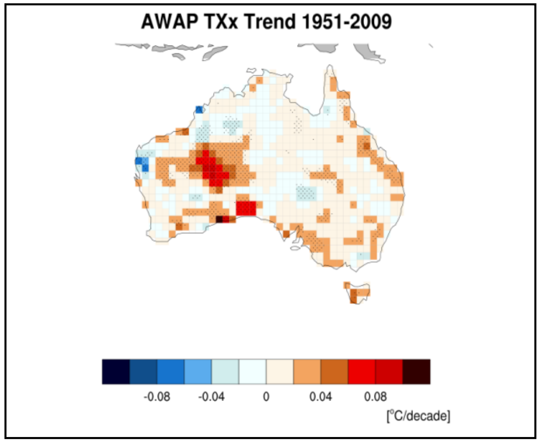
HQ stations



ALL stations



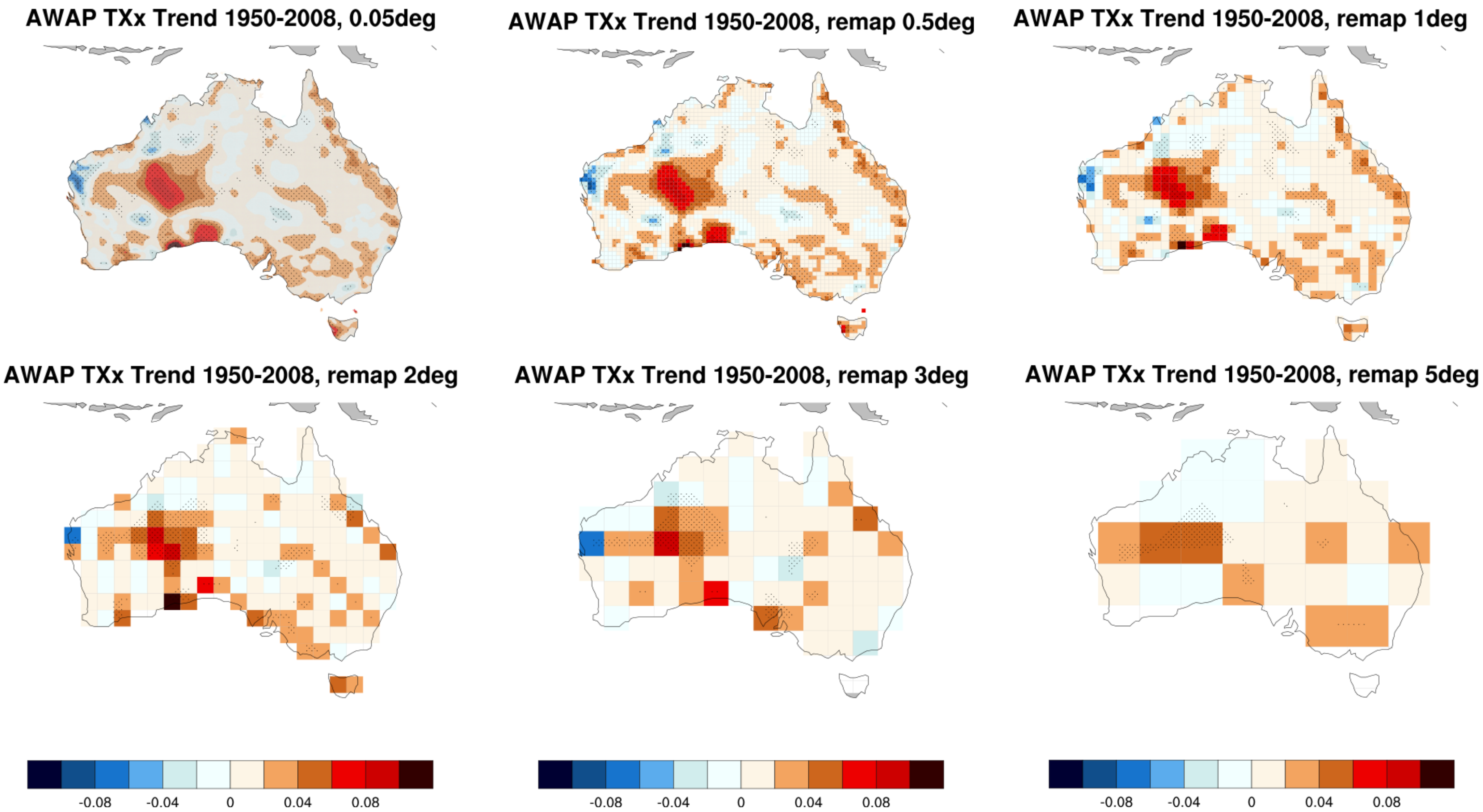
AWAP



Same gridding method
Different input data

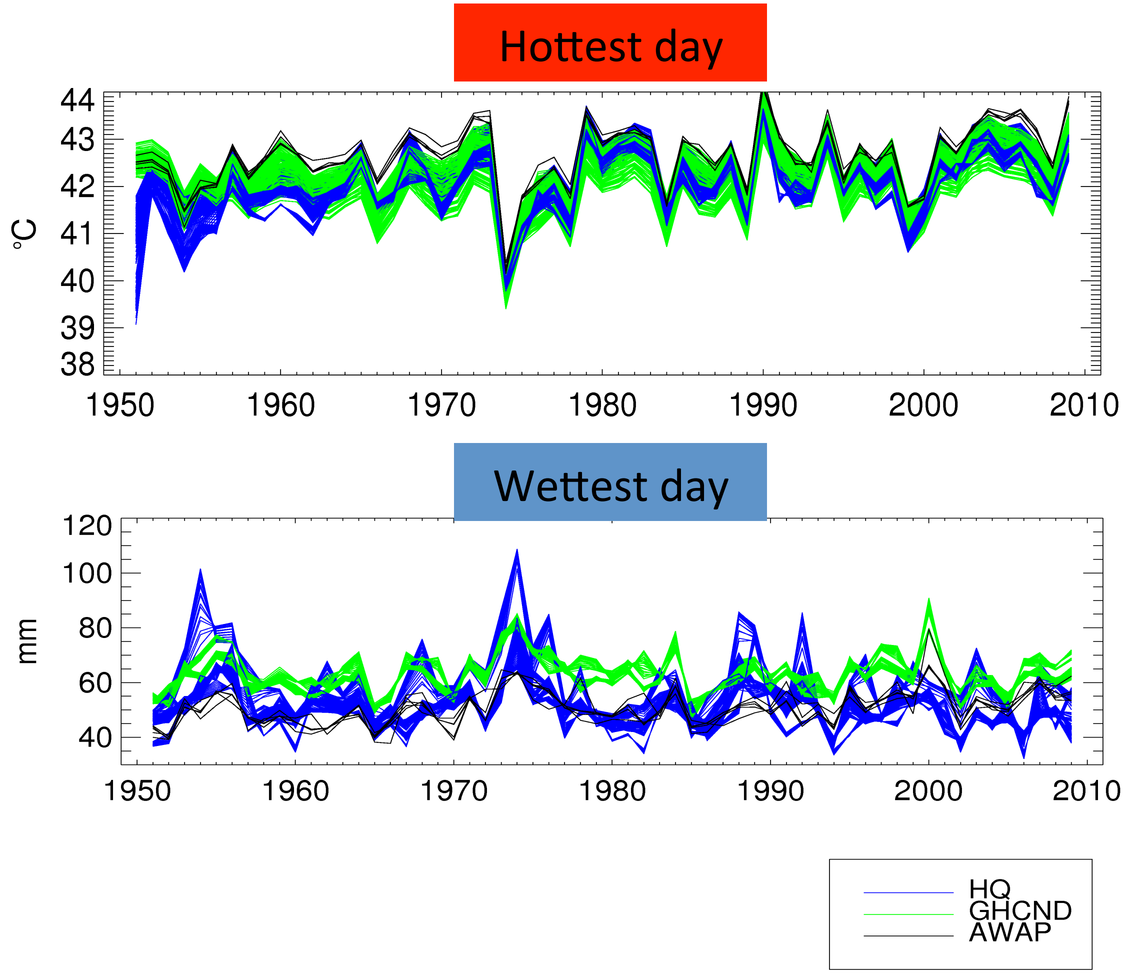
Same input data
Different gridding method

Also does grid size matter...?



How large is this uncertainty?

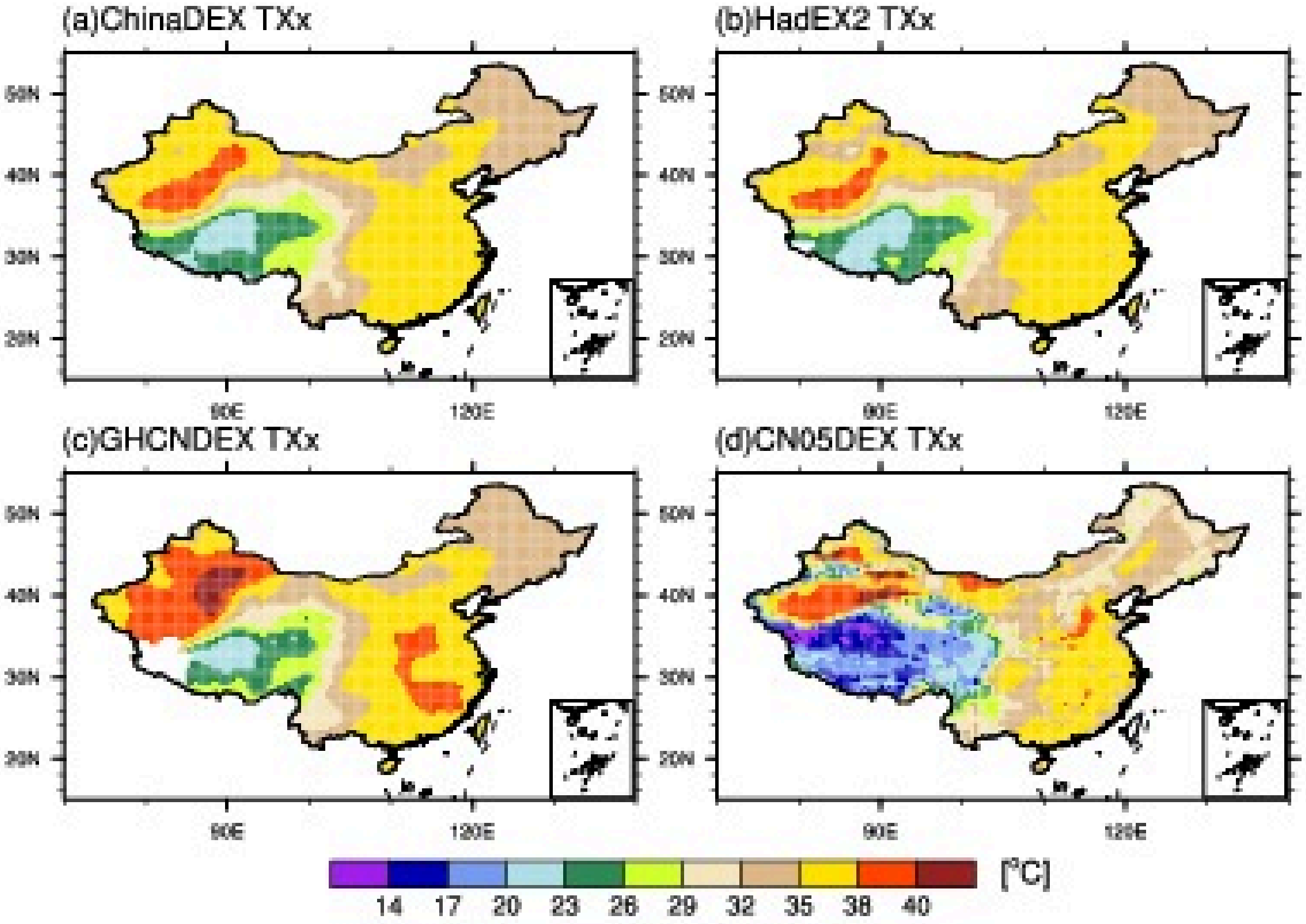
Example for Australia



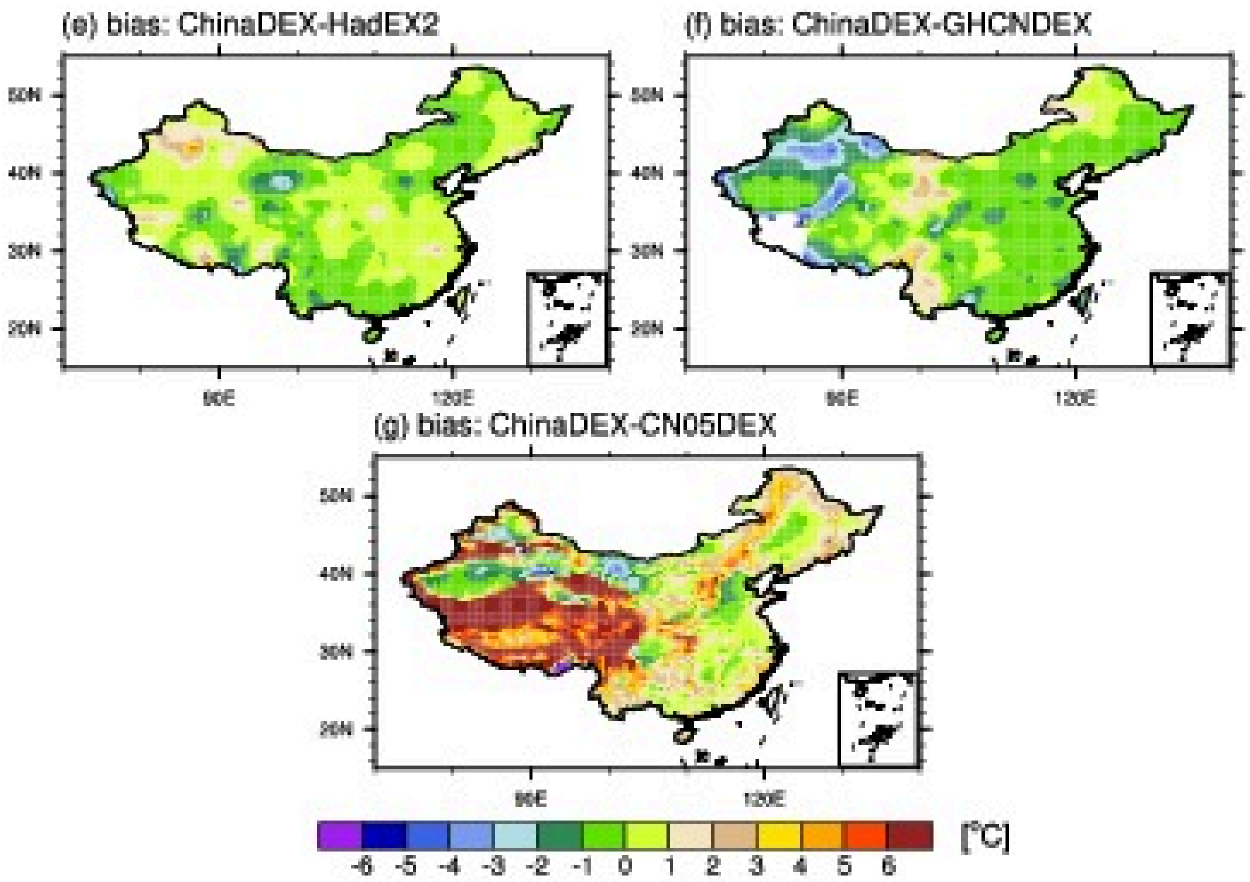
Several hundred realizations by varying:

- Grid size
- Parameters
- Network density
- Interpolation method
- Prior painstaking work on quality control and homogenisation of data

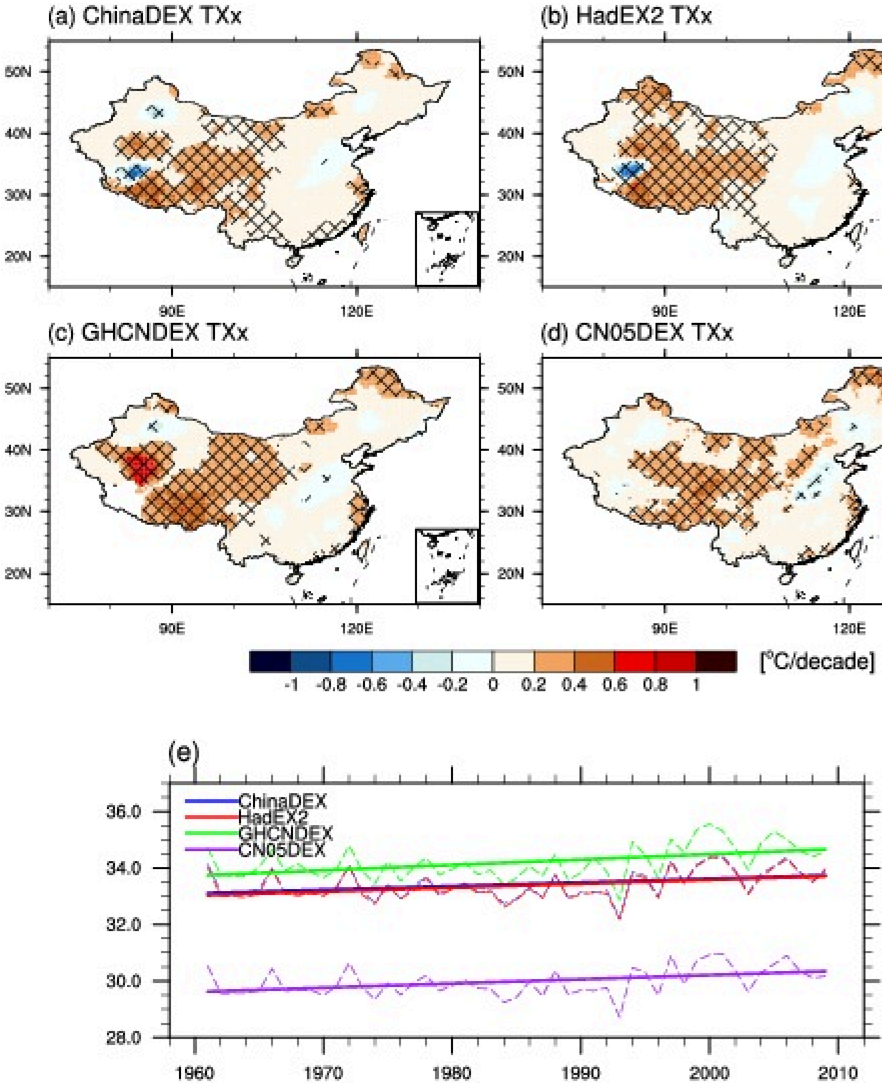
Can test multiple methods and regions



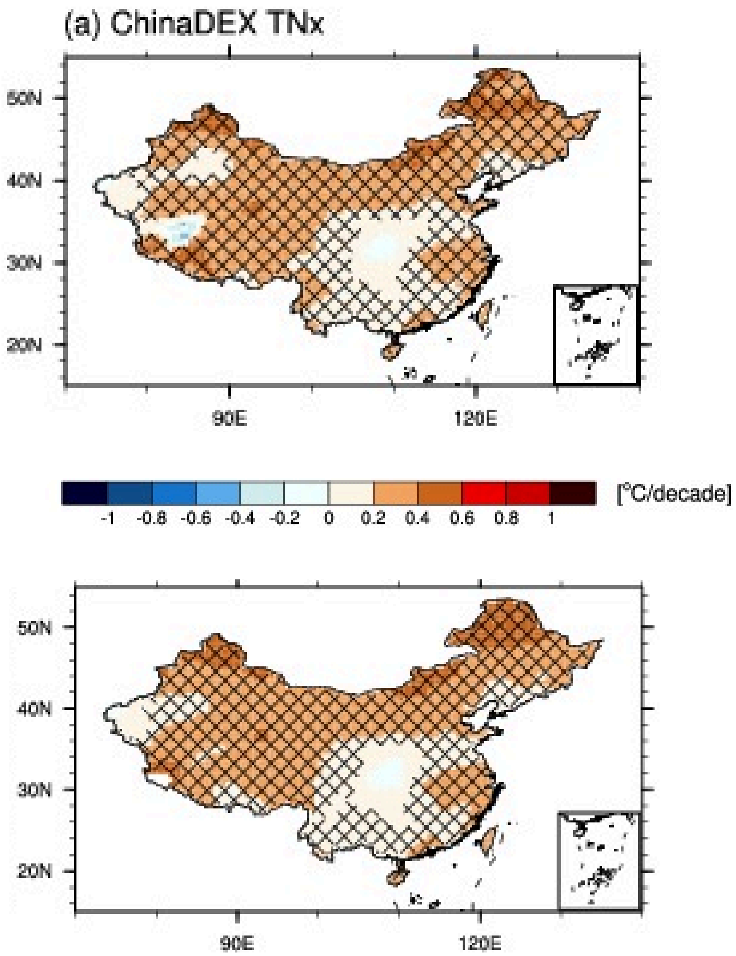
Bias estimation

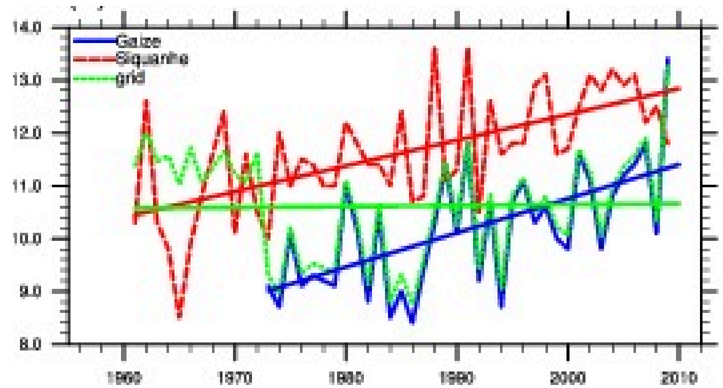


Trend estimation



For absolute extremes quality particularly important



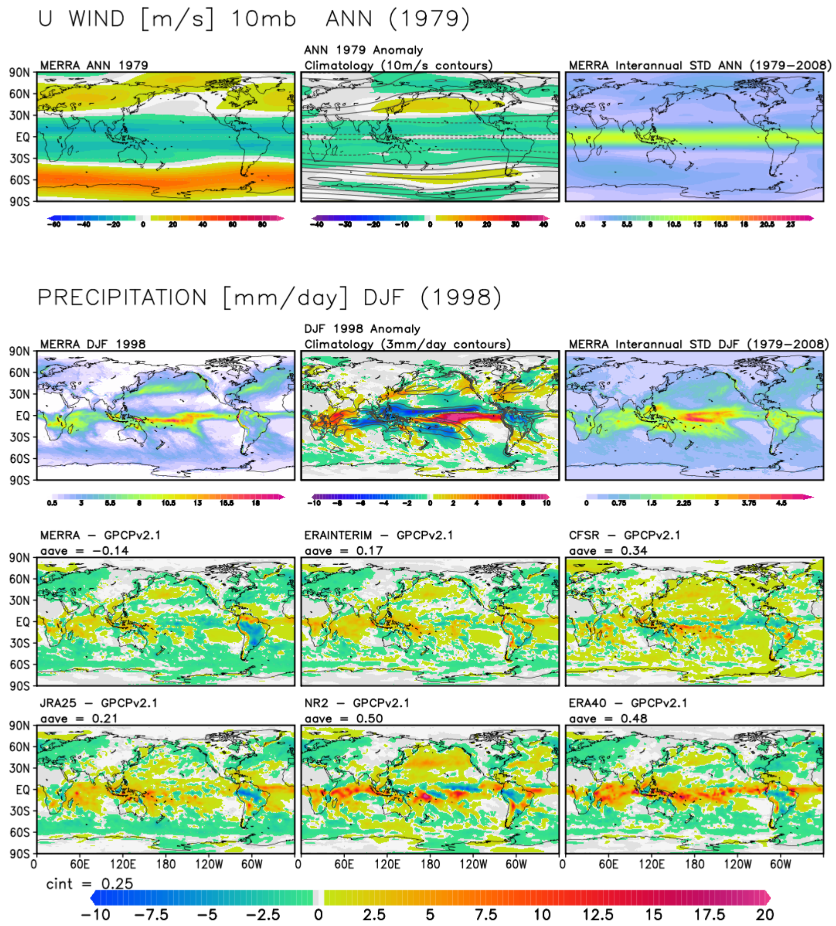


Why don't we just use reanalysis data?

- Reanalyses based on observational data assimilated into a NWP model
  - ✓ provide physically consistent fields
  - ✓ complete spatial coverage
  - x Usually shorter than in situ records
  - x Inhomogeneous especially since assimilation of satellite records

Advantages and disadvantages of reanalyses

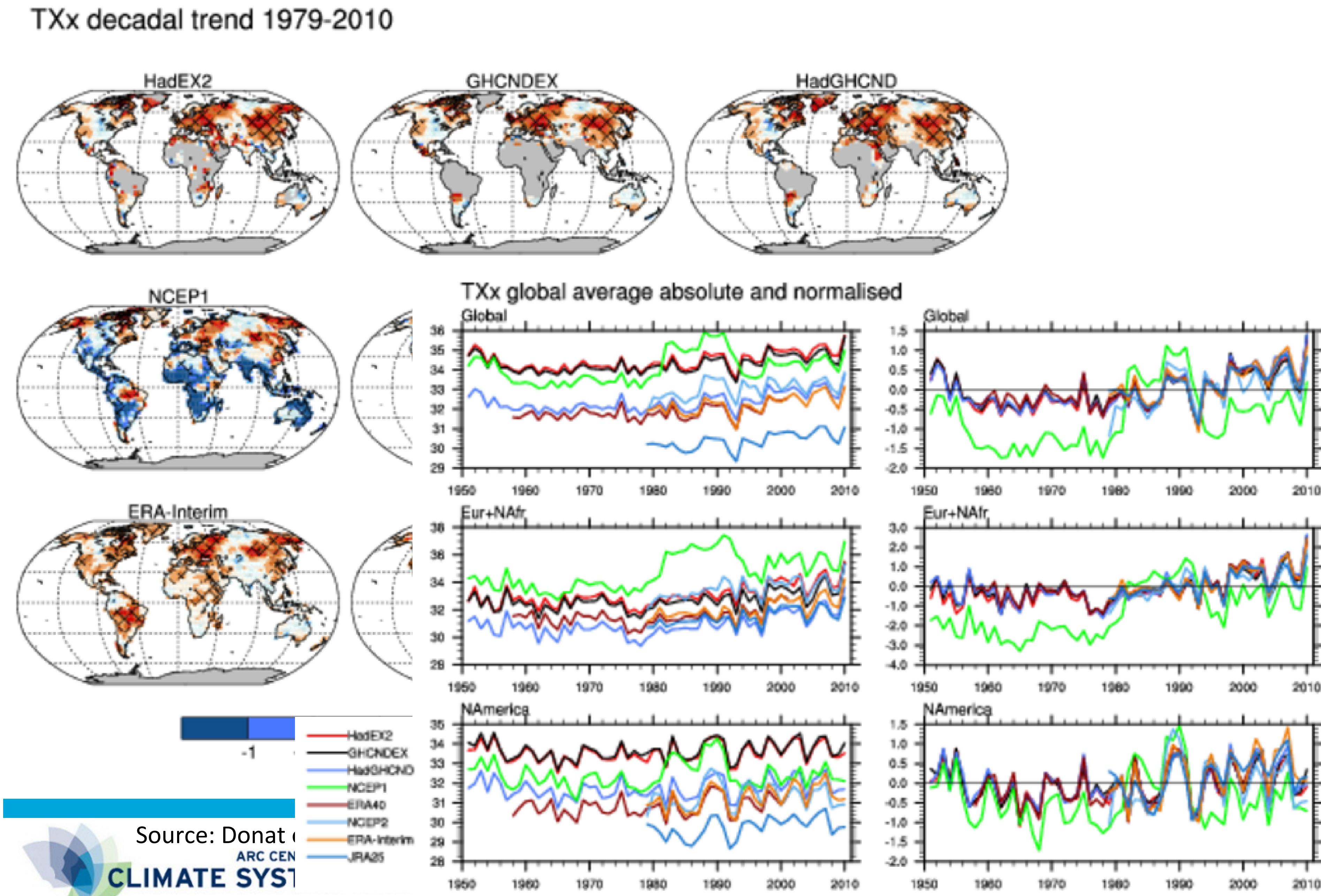
- Able to assess fields for which there are little or no observations
- Output may be more similar to GCMs
- Disagreement between products and between products and observations
- Inhomogeneous over time (especially due to inclusion of satellite data in late 1970s)



Types of reanalysis products

- European Centre for Medium-range Weather Forecasts (ECMWF) e.g.
  - ERA-40 (Sep 1957-Aug 2002)
  - ERA-interim (1979-present)
- USA e.g.
  - NCEP/NCAR reanalysis (1948/01/01 to present)
  - NASA MERRA (1979-present)
  - NOAA-CIRES 20th Century Reanalysis V2 (20CR): 1871-2008
- Japan e.g.
  - JRA-25 (1979-2004)

Reanalysis data in comparison to gridded *in situ* data sets

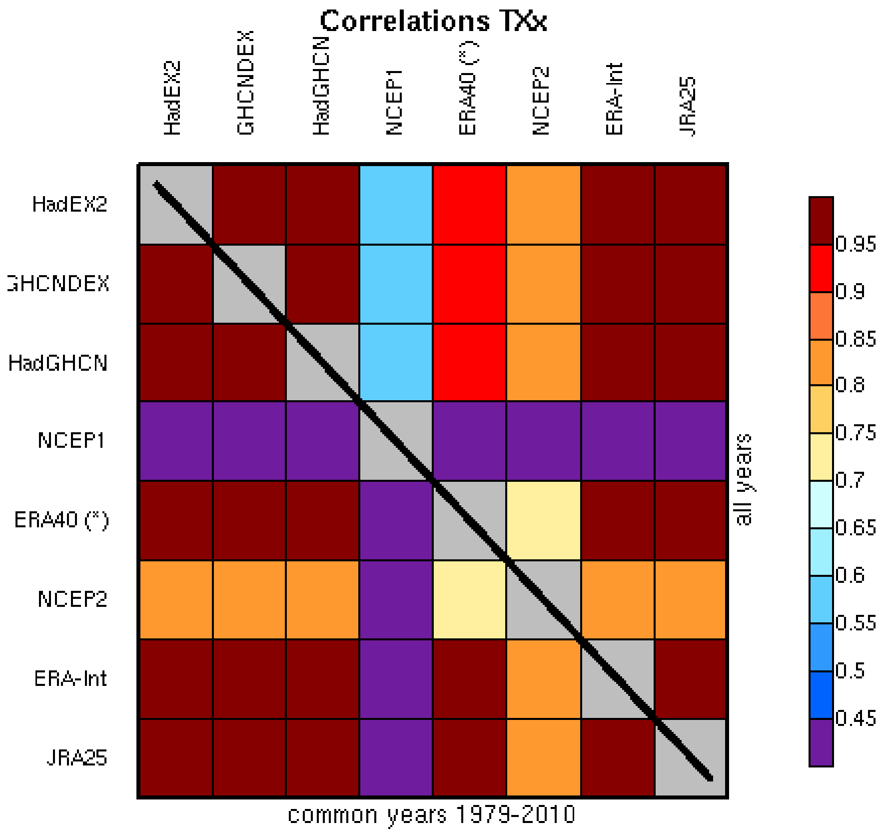


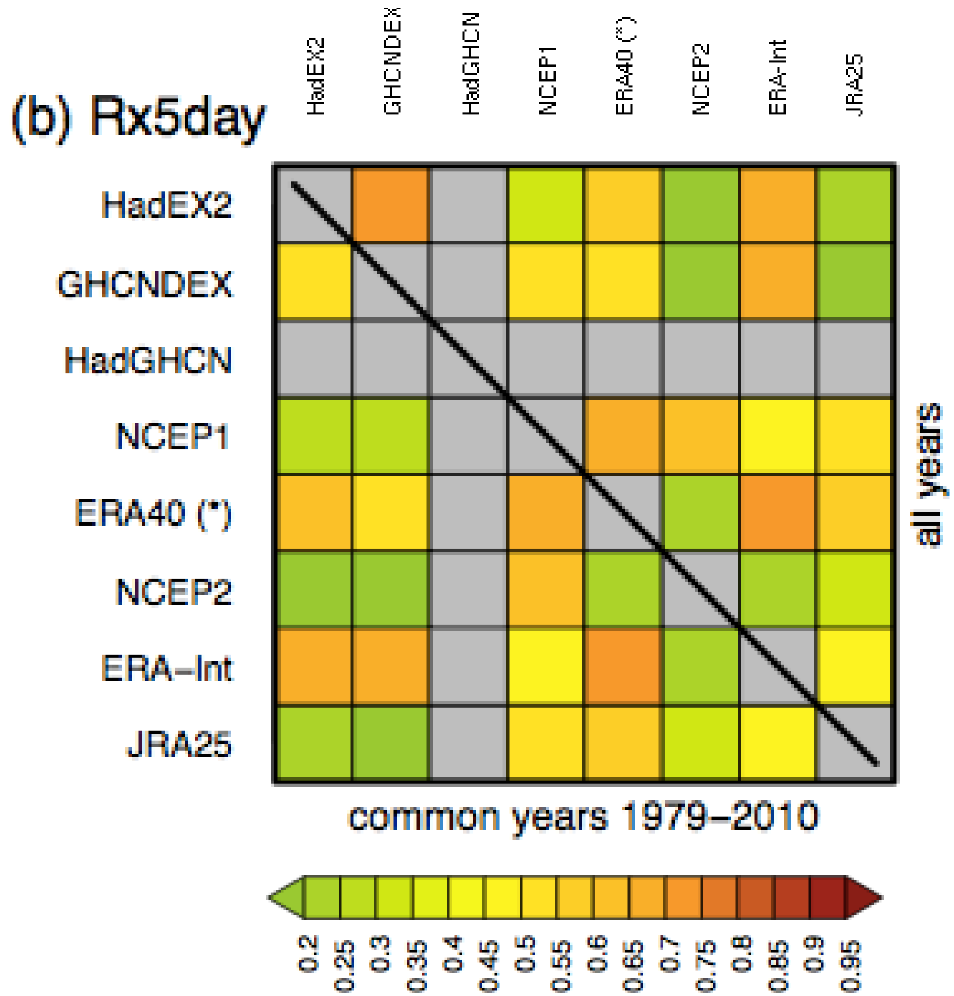
Source: Donat

ARC CEN

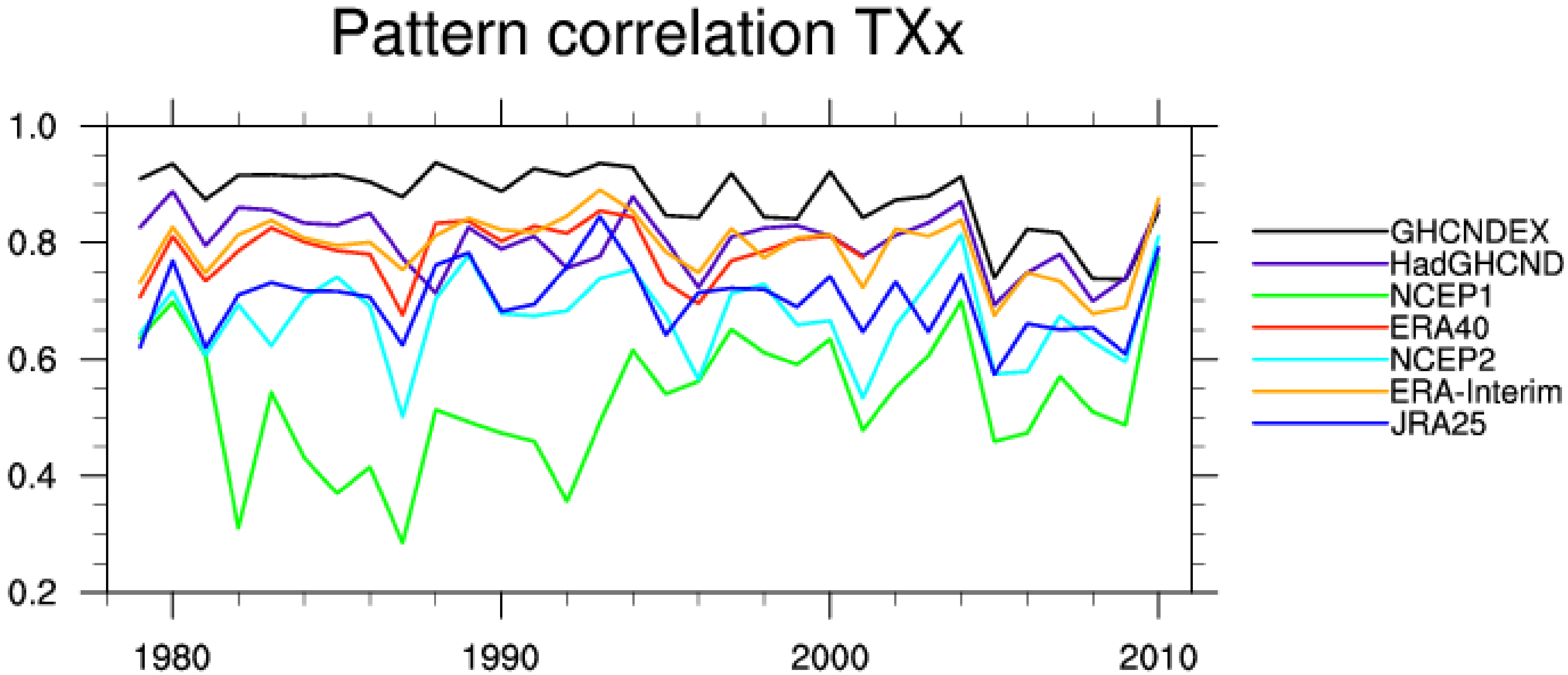
CLIMATE SYST

Example spatial correlation between datasets

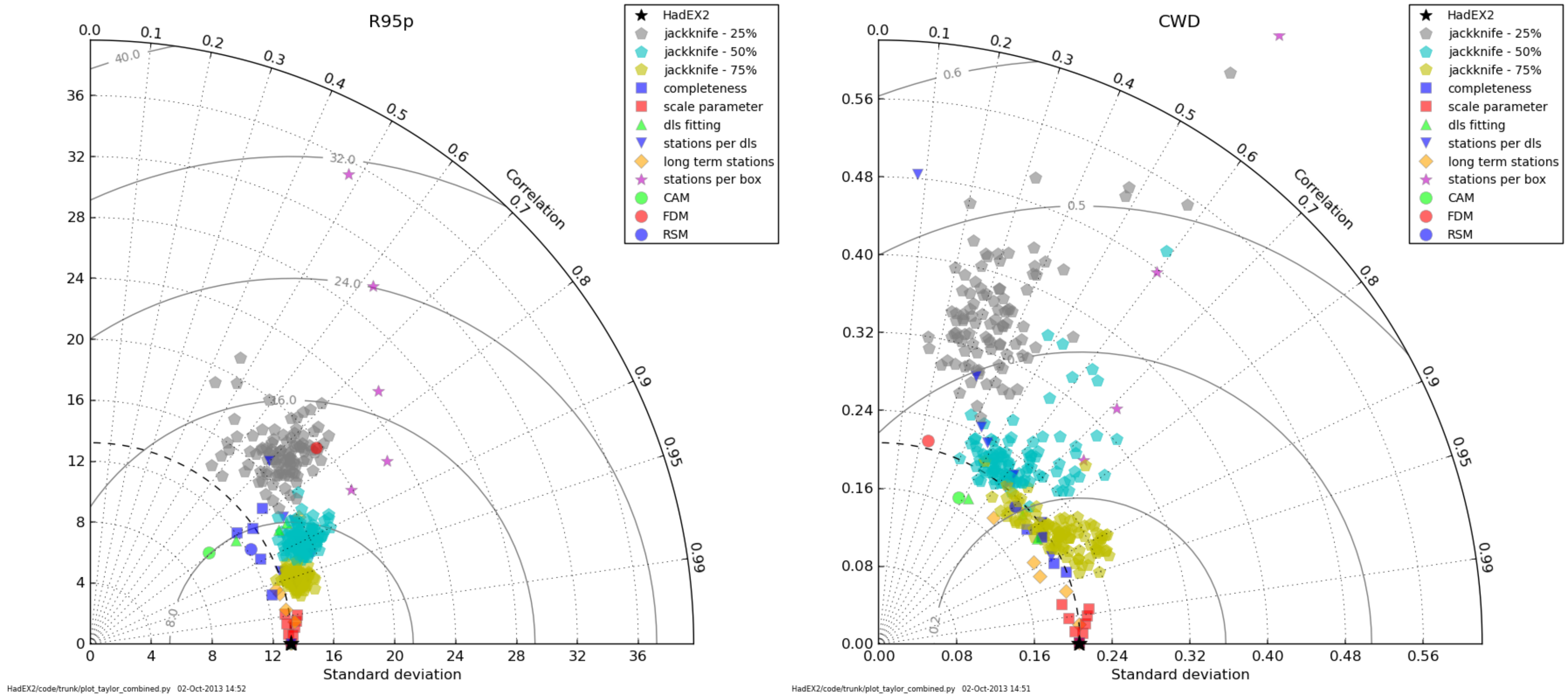




Example temporal correlation between datasets



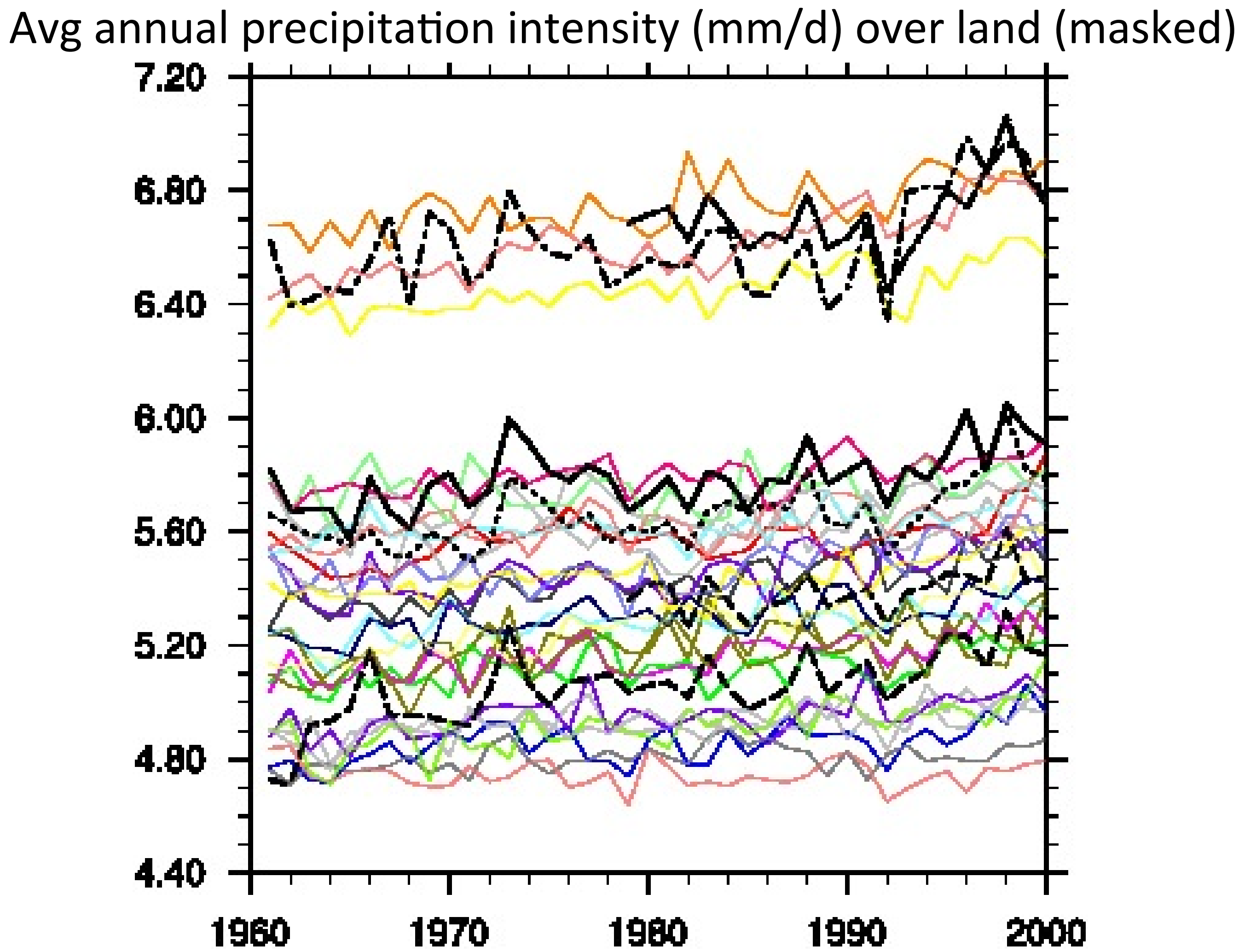
Calculating uncertainties for global datasets of extremes



Structural uncertainties are larger than parametric uncertainties
Some indices have larger uncertainties than others

Source: Dunn et al. (2014)

‘Observations’ versus models



Remember that observations are models

- "All models are wrong…"
- "..but SOME are useful"

G.E.P. Box

- "All models using erroneous data are wrong…"
- "…and NONE are useful"

L.V. Alexander