Royal Netherlands
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*Ministry of Infrastructure
and Water Management*

Detection and Attribution of Climate Change

- What is D&A?
- Global Mean Temperature
- Extreme Event Attribution

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Definitions

Detection:

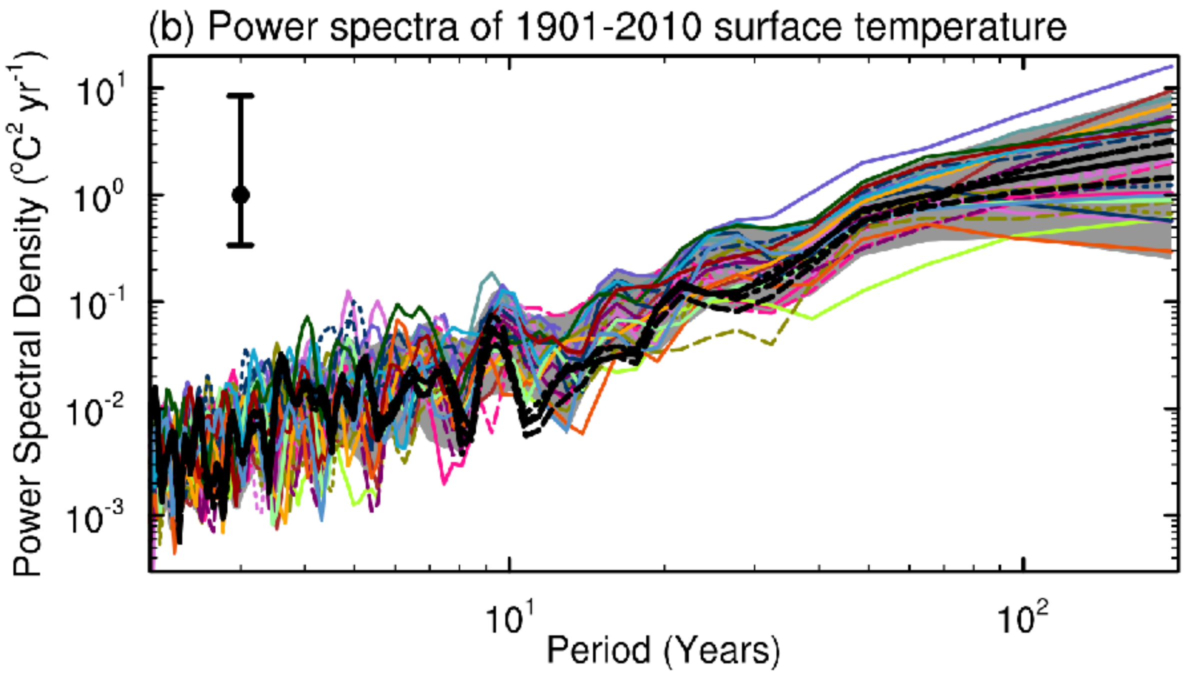
- demonstrating that climate or a system affected by climate has changed in some defined statistical sense without providing a reason for that change.

Attribution:

- evaluating the relative contributions of multiple causal factors to a change or event with an assignment of statistical confidence.

Detection: change is outside natural variability

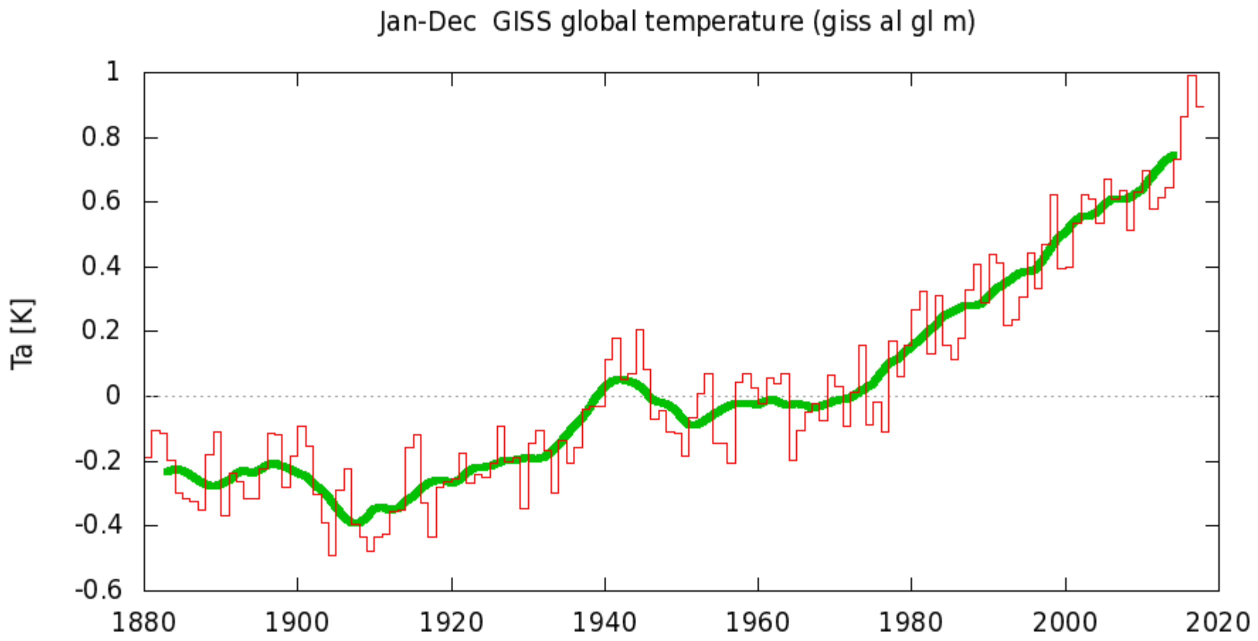
- Natural variability usually taken from climate models, as the observed record is too short to determine century-scale variability
- Up to those scales models and observations are consistent.
- Spectra include the trend but not the annual cycle.



IPCC WG1 AR5 (2013), Fig. 9.33. The spectra have been computed using a Tukey–Hanning filter of width 97 years.

Detection: change is outside natural variability

- Since the late 1990s the trend is not compatible with natural variability.

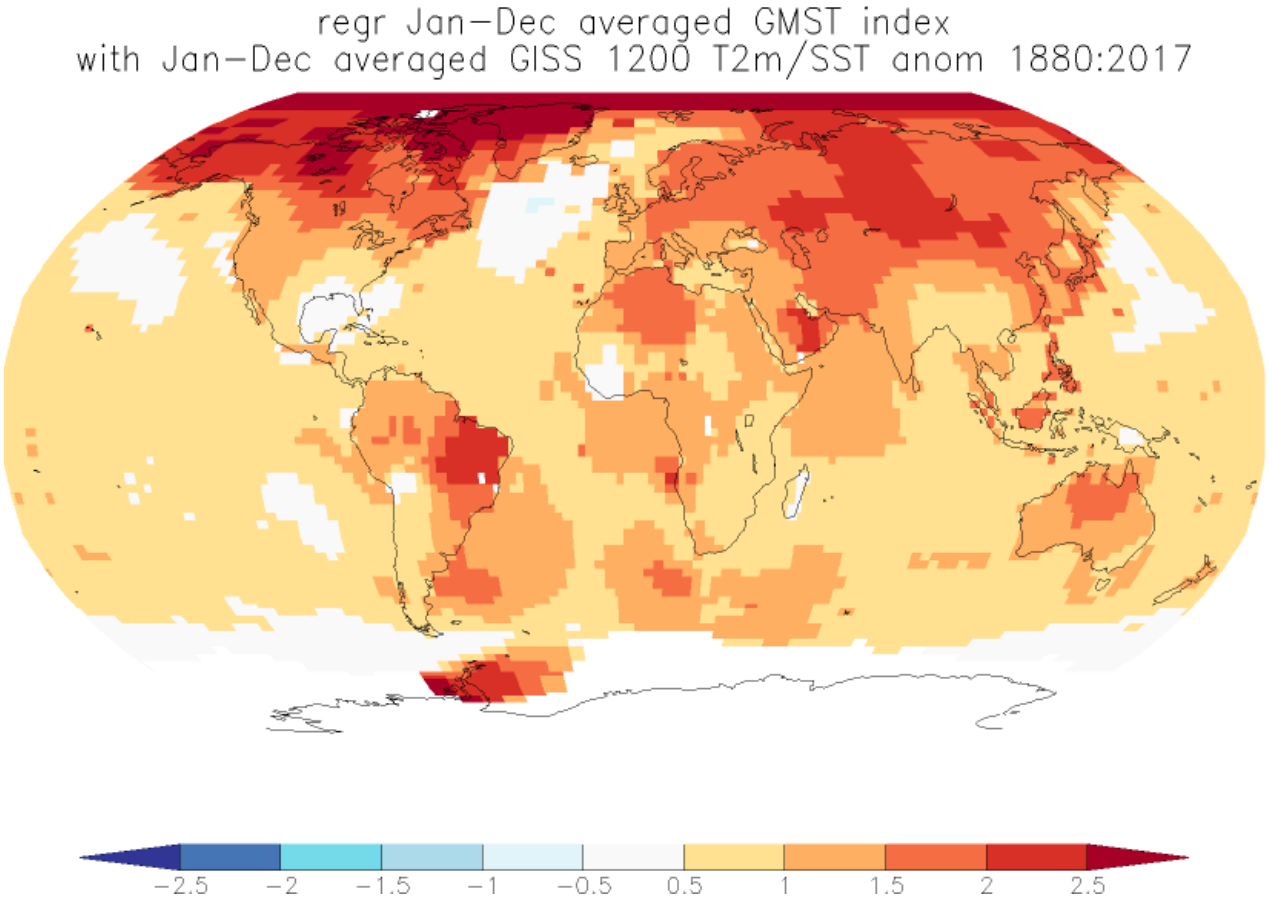


Many plots from public climate analysis web application climexp.knmi.nl

GISTEMP, anomalies relative to 1951–1980

Detection: change is outside natural variability

- Temporally, the change is almost linear with the global mean change
- Spatially, the amplitude differs due to noise and local factors (lapse rate feedback, albedo feedback, Atlantic overturning, ...).

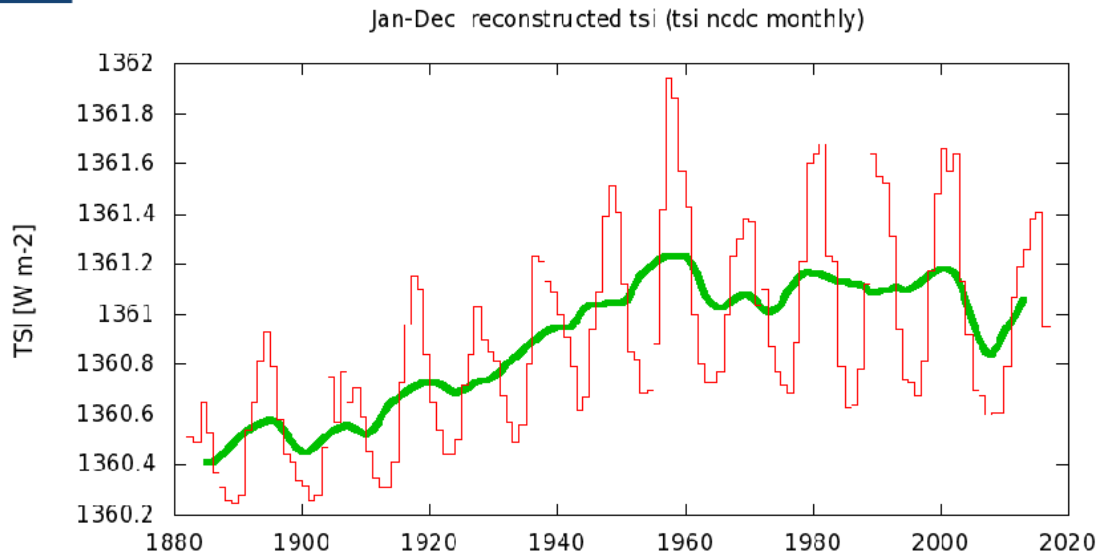


Attribution: what causes these changes?

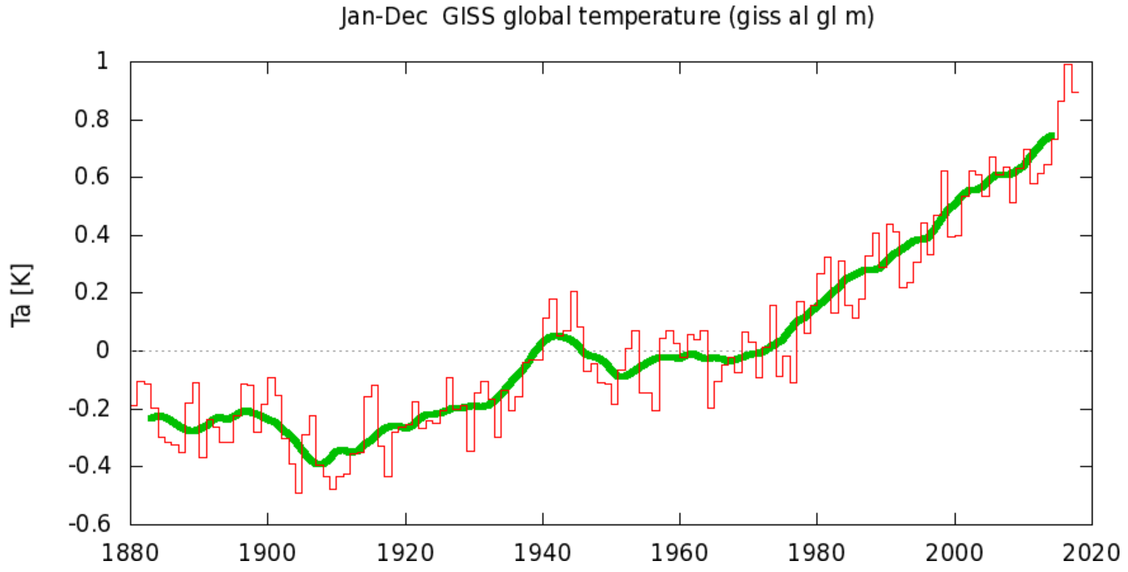
- External forcings of the climate system:
- Natural forcings ΔF_N: solar variability, volcanic aerosols
- Anthropogenic forcings ΔF_A: Greenhouse gases (CO_2, CH_4, …), aerosols (sulphate, black carbon, …), land-use changes, …

- Run climate model with only natural forcings $M(\Delta F_N)$, only anthropogenic forcings $M(\Delta F_A)$
- Fit $\Delta T = \beta_N M(\Delta F_N) + \beta_A M(\Delta F_A)$
- (usually optimise S/N by projecting on fingerprints first)

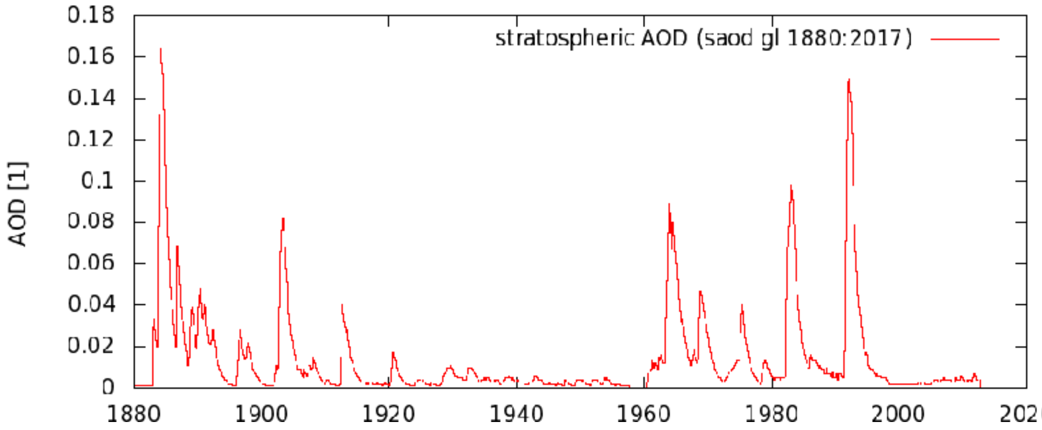
Natural forcings



NOAA Climate Data Record (CDR) of Total Solar Irradiance (TSI), NRLTSI Version 2

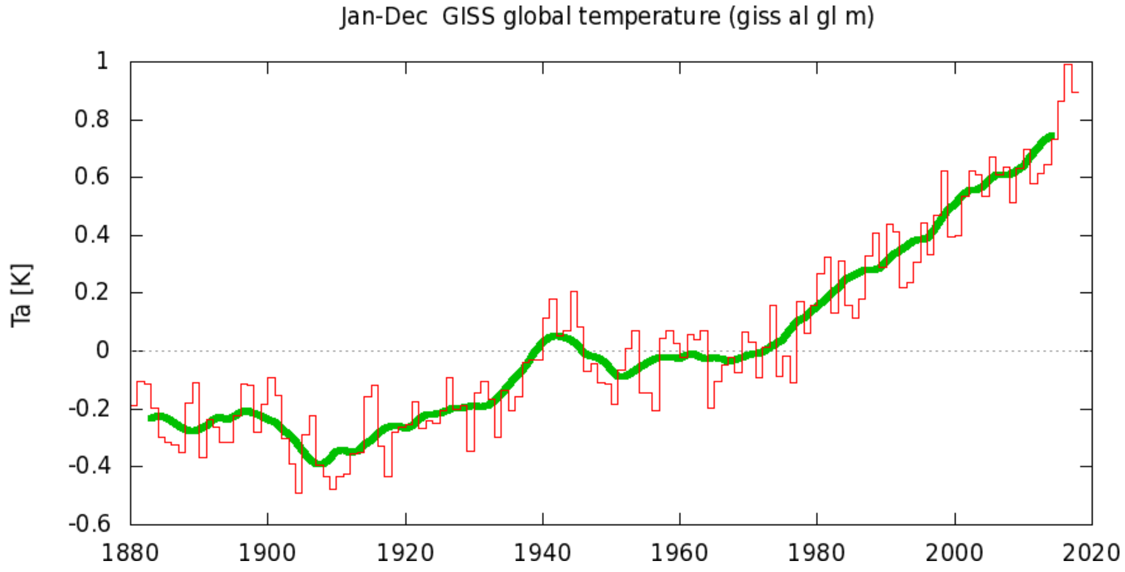


GISTEMP merged land-ocean temperature

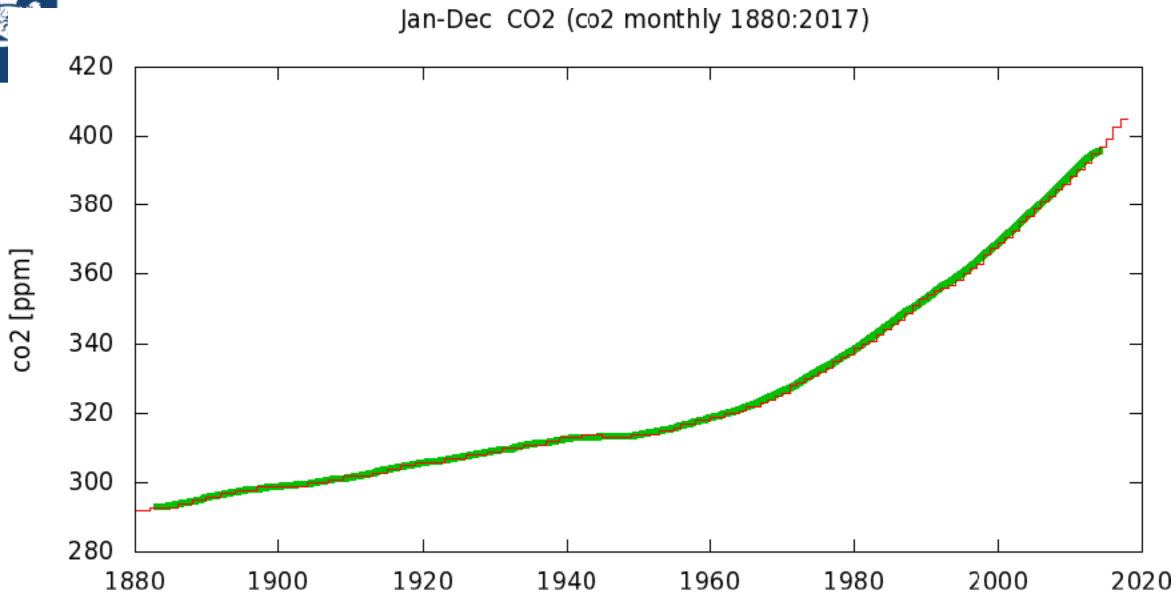


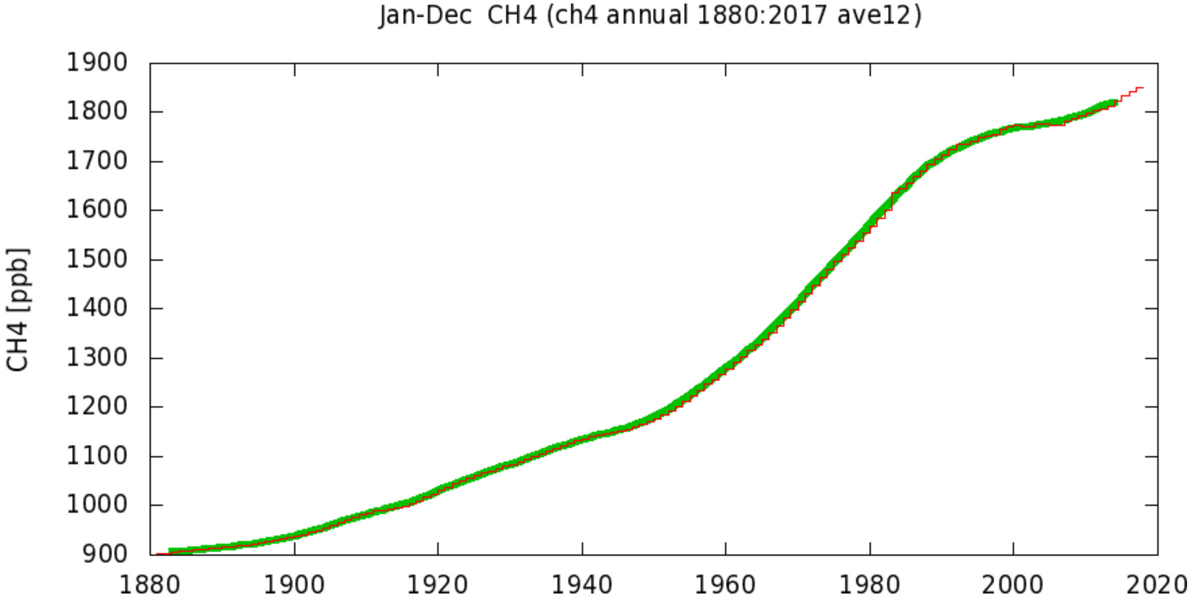
Sato et al stratospheric aerosol depth, NASA/GISS

Anthropogenic forcings



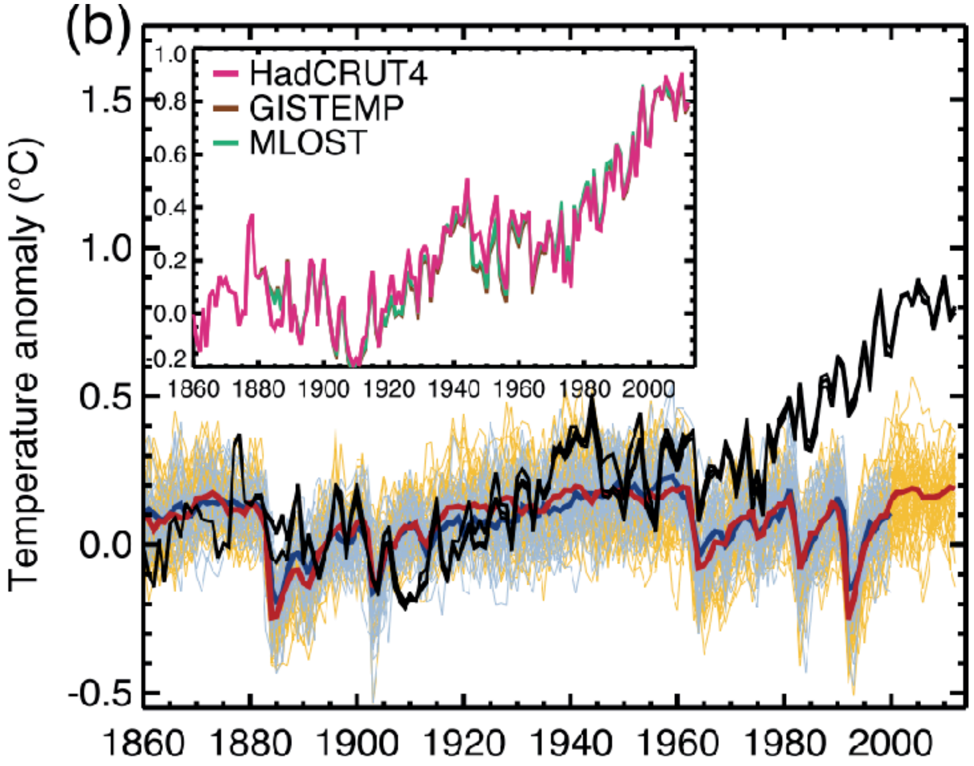
GISTEMP merged land-ocean temperature



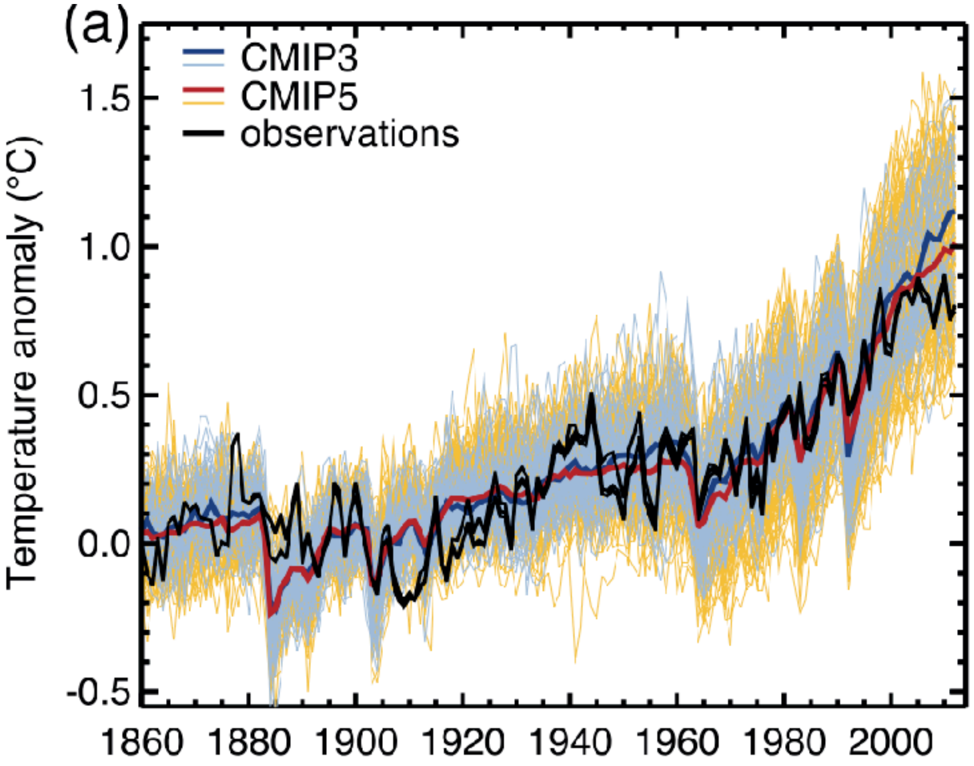


CO2, CH4 concentration from ice cores, instruments

Attribution



Natural forcing only



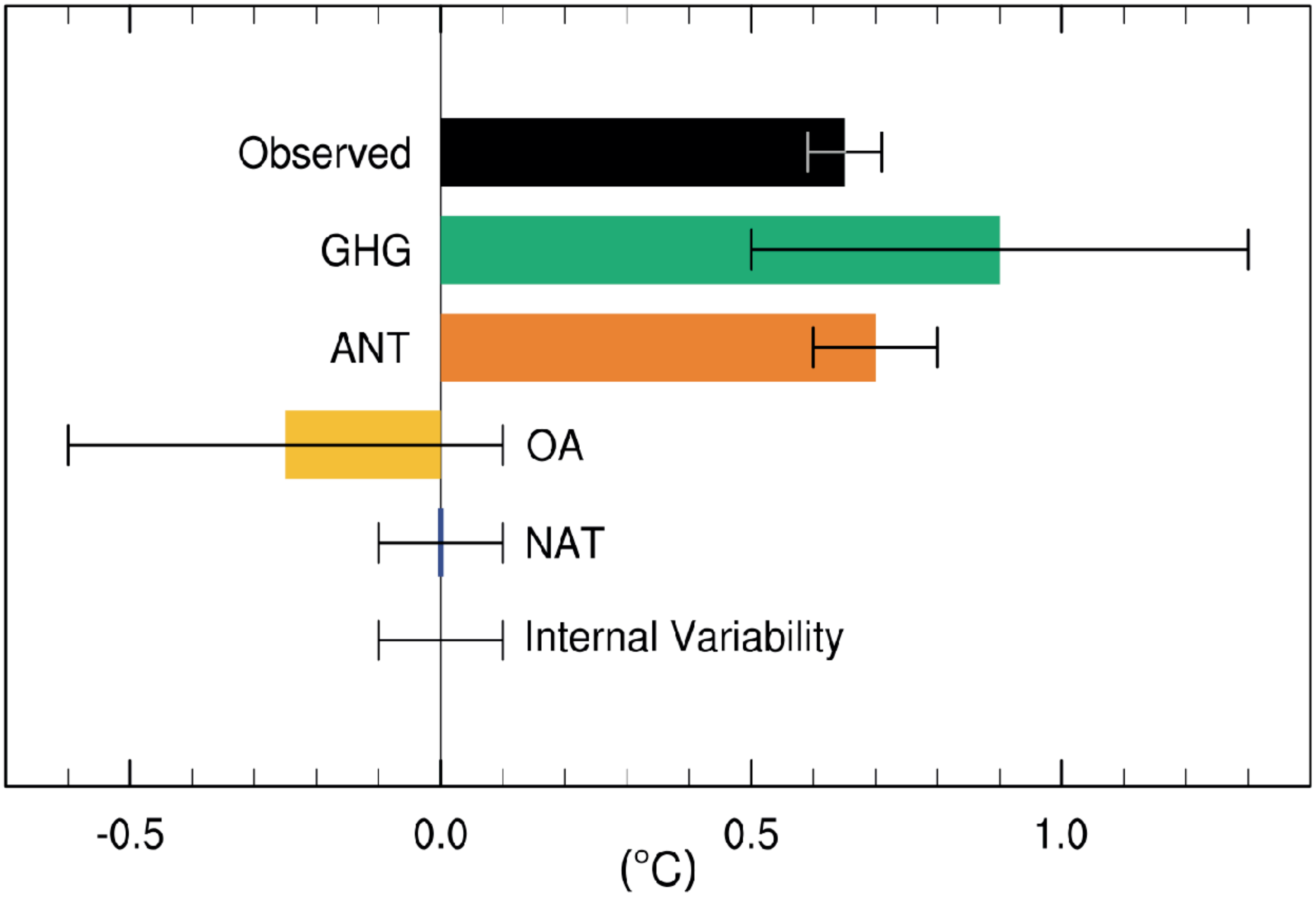
Natural plus anthropogenic forcing

Attribution

Global mean
temperature change
1951–2010

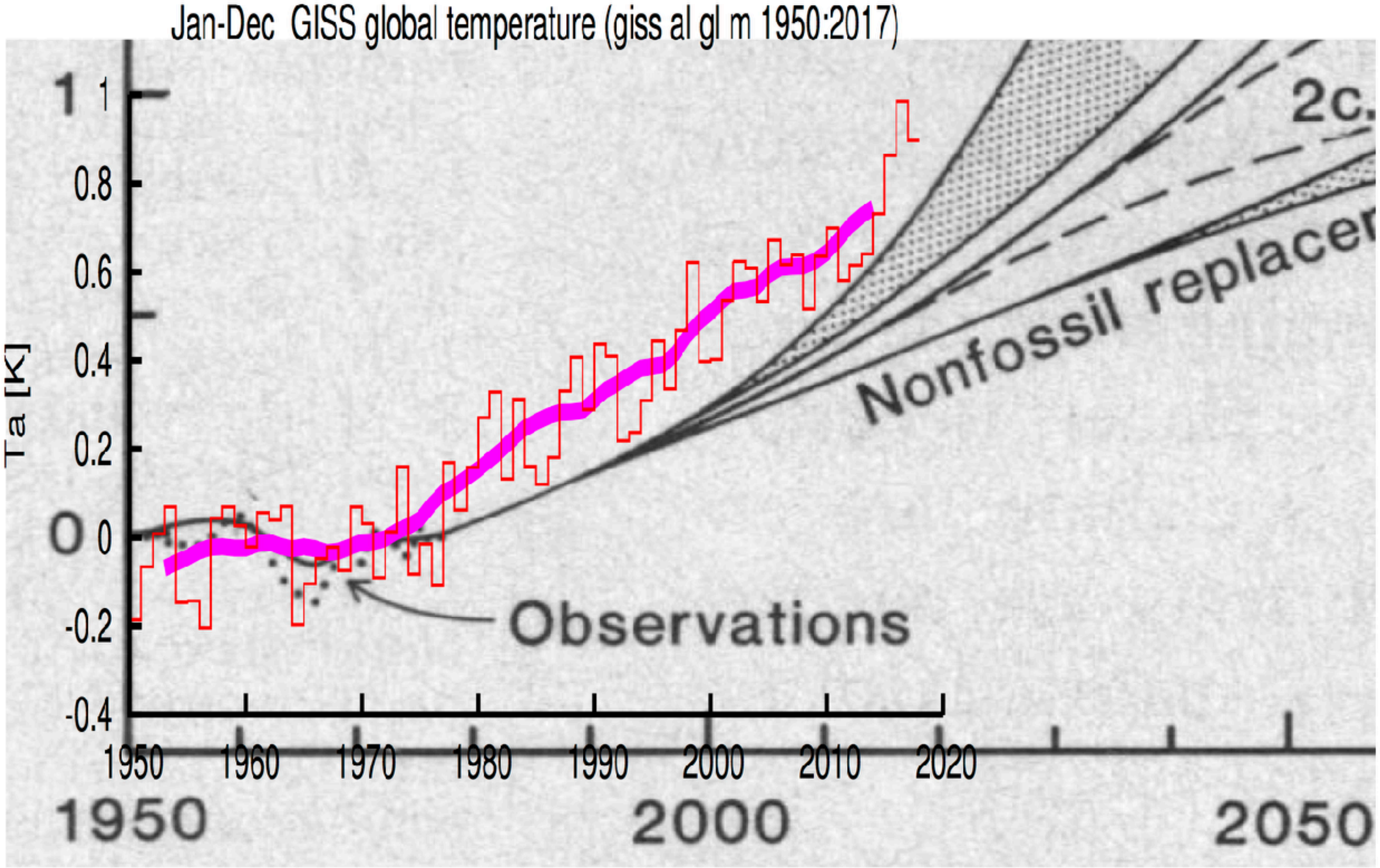
IPCC WG1 AR5
Fig. 10.5

GreenHouse Gases
Other Anthropogenic
ANThropogenic
NATural



Verification

Hansen et al, 1981:
a bit too low
(note: no trend at
time of publication)



Verification

Hansen et al, 1988:
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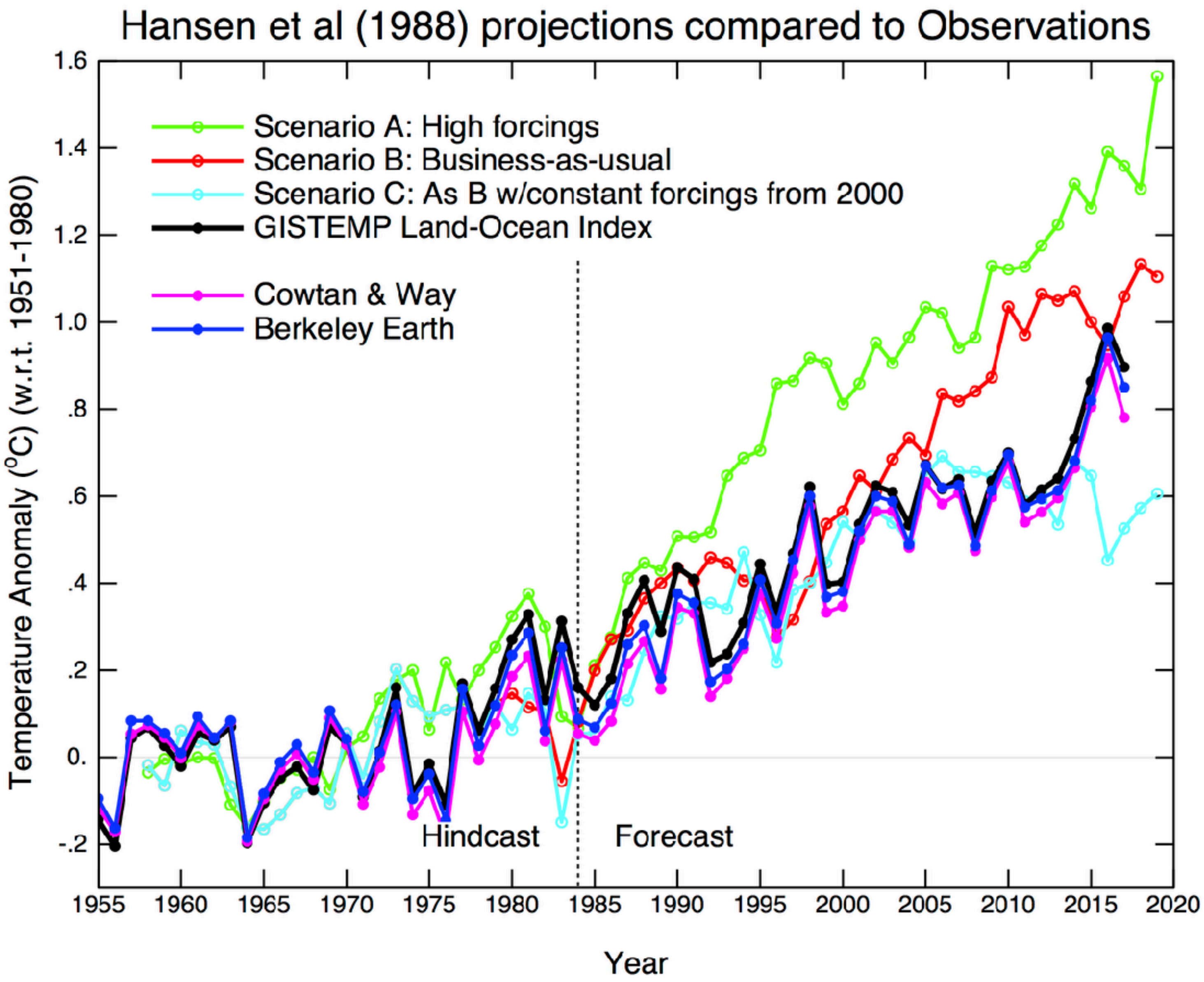
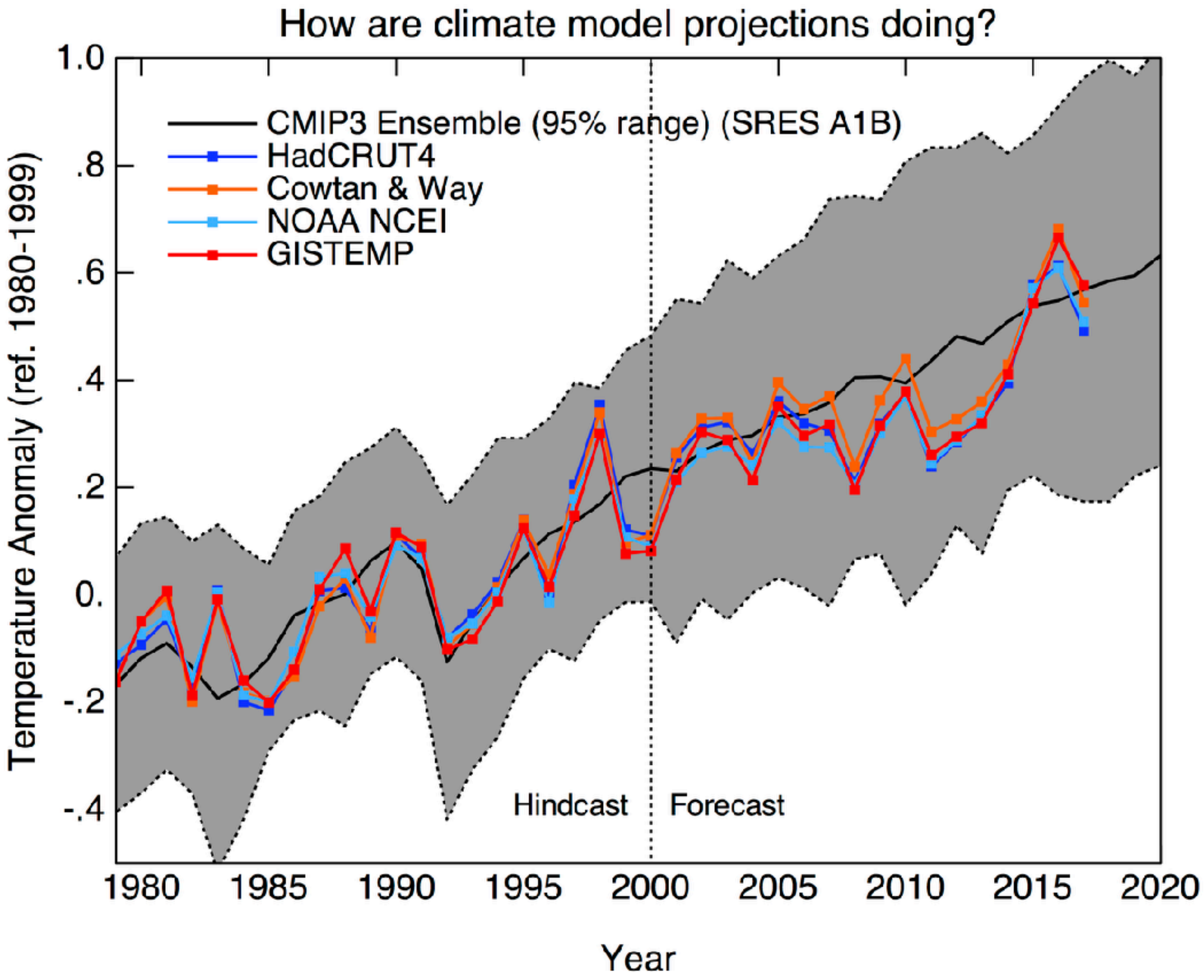


Verification

CMIP3 (2001)

Note: model data is air temperature, observations use SST over ocean

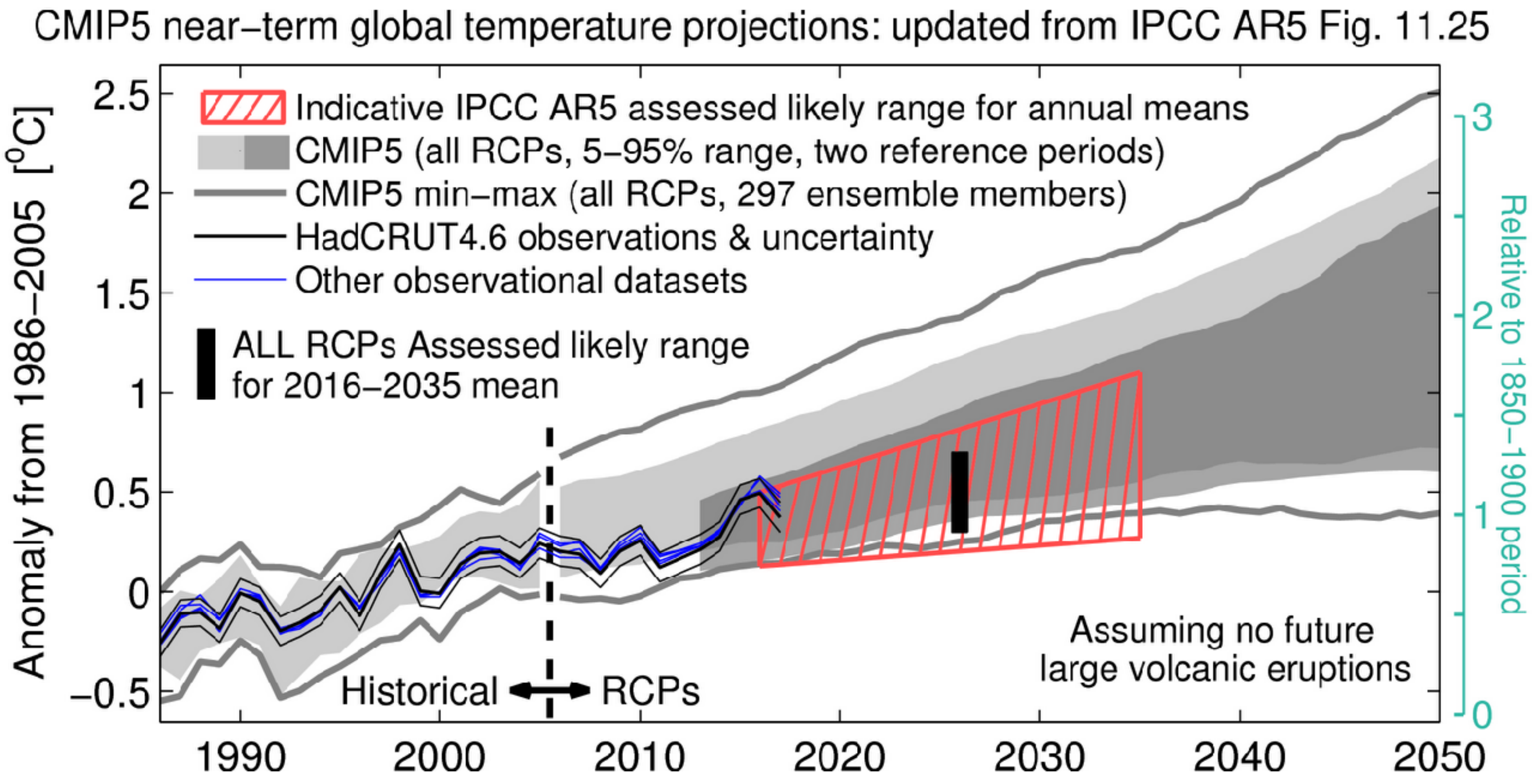


Verification

IPCC WG1 AR5 (2013), updated Fg. 11.25b

Note: model data is air temperature, observations use SST over ocean

Note: HadCRUT4 underestimates trend



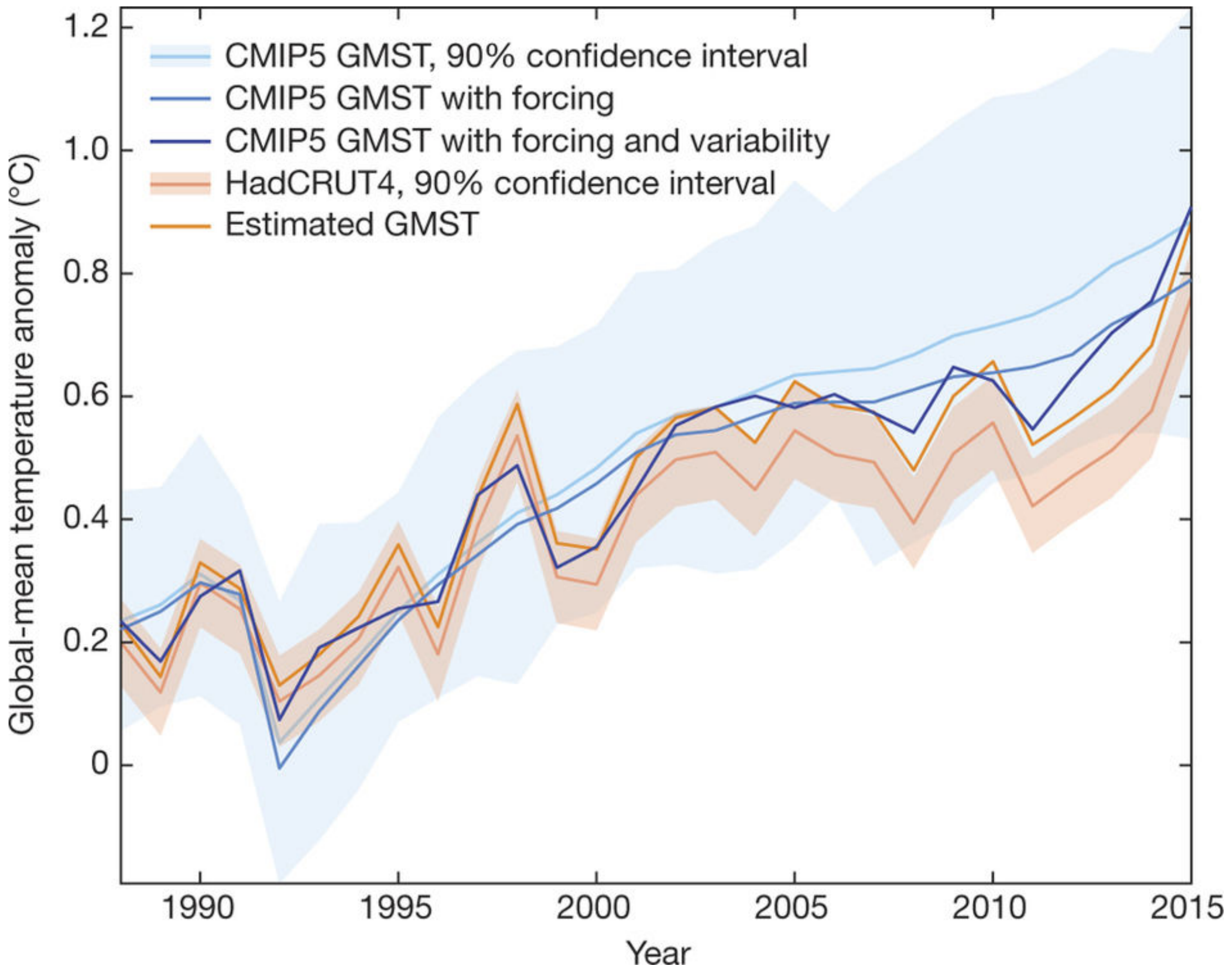
CMIP5 vs observations: good agreement

Forcings were lower than assumed in CMIP5 protocol

Reference period happened to be warm in observations

HadCRUT4 underestimates trend by excluding the Arctic

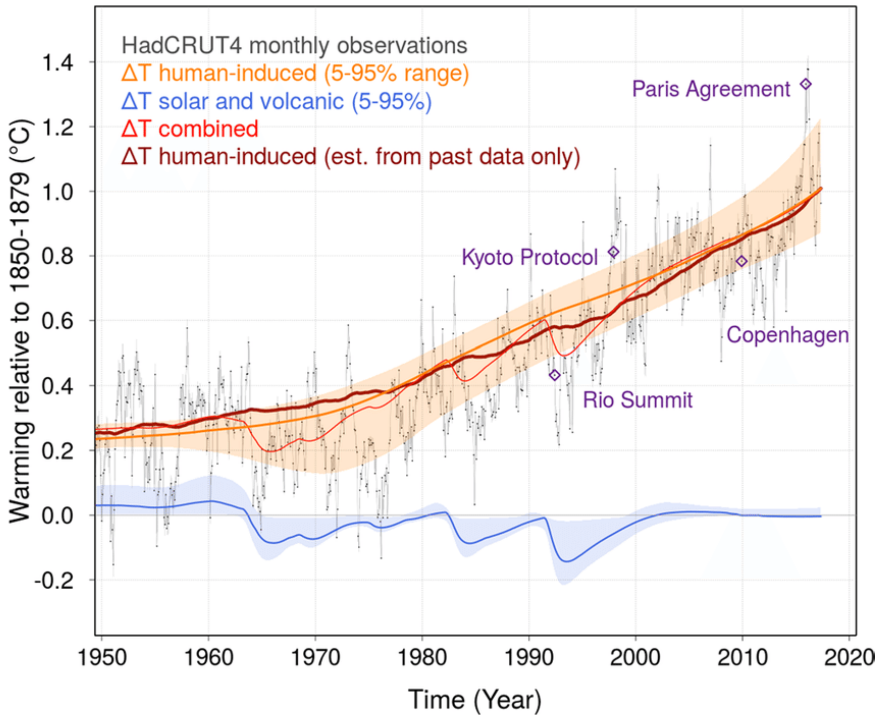
Observations use SST over sea, models T2m



Global mean temperature trend: conclusions

- Detection: is far outside the range of natural variability

Global Warming Index 1950 - 2017



- Attribution: is a bit over 100% due to anthropogenic emissions (greenhouse gases and aerosols partly cancelling)
- (Projection: the trend up to now is not strongly connected to climate sensitivity)

Extreme Event Attribution

- After an extreme weather or climate event the question is raised how it was influenced by climate change
- We can now answer this question.

Event definition, methodology

Traditional D&A:

- Large-scale (continent), long time scale (season)
- Optimise S/N ratio using fingerprints
- Consider influence of external forcings

Extreme Event Attribution:

- Impact-related: small-scale spatially and temporally (eg, 50 km / 3 days precipitation)
- No fingerprints, S/N natural variability main concern
- Consider other factors that can cause trends, neglect solar and volcanic forcings

Framing

How has the risk of the event changed due to climate change?

Prescribed boundary condition:

- Land use
- Sea Surface Temperature
- Large-scale circulation
- ...

Risk Ratio:

p_1 = Probability in current climate

p_0 = Probability in counterfactual or past climate

$RR = p_1/p_0$

$(FAR = 1-p_0/p_1)$

Framing, event definition

- We use a class-based definition: probability of events with "impact" $X \geq X_{obs}$
- Well-defined, easy to use
- Examples: highest 3-day temperature of year, highest daily precipitation, highest/lowest wind speed, highest run-off
- Physical parameters
- Demand physically plausible connection

Observed trend

- Obtain long homogeneous observational record until yesterday
- Fit Extreme Value Function with covariate to relevant extreme
- (Use spatial pooling to increase S/N ratio)
- Compute *p*-value

Assumptions:

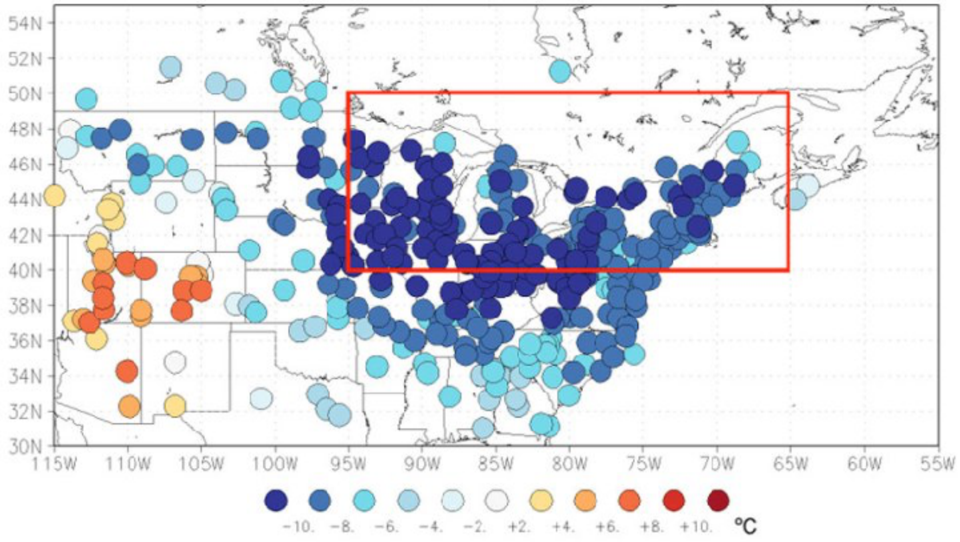
- PDF shifts with smoothed global mean temperature (temperature)
- PDF scales with smoothed global mean temperature (precipitation, wind)
- Check in model output

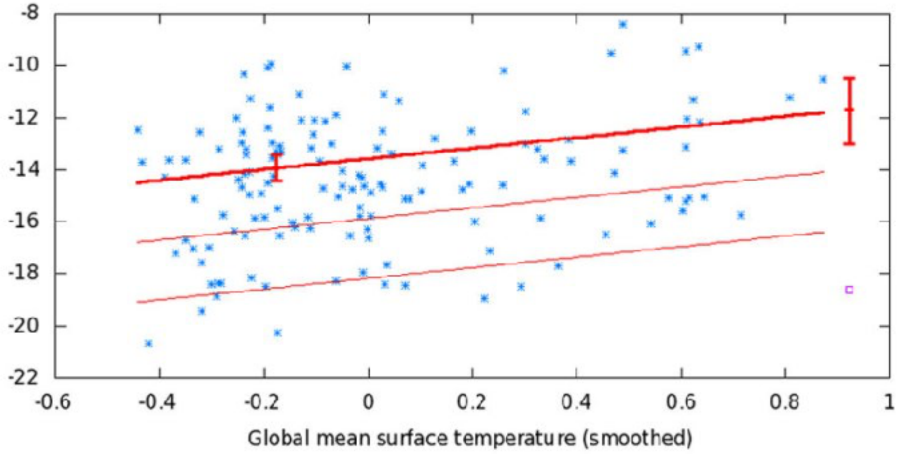
$$F(x) = \exp\left[-\left(1+\xi\frac{x-\mu}{\sigma}\right)^{1/\xi}\right]$$

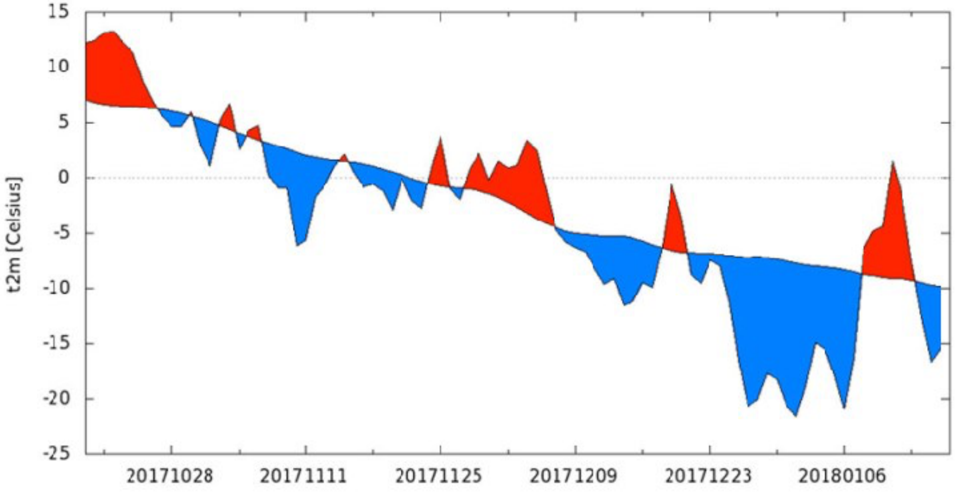
$$\mu = \mu_0 \exp\left(\frac{\alpha T'}{\mu_0}\right),$$

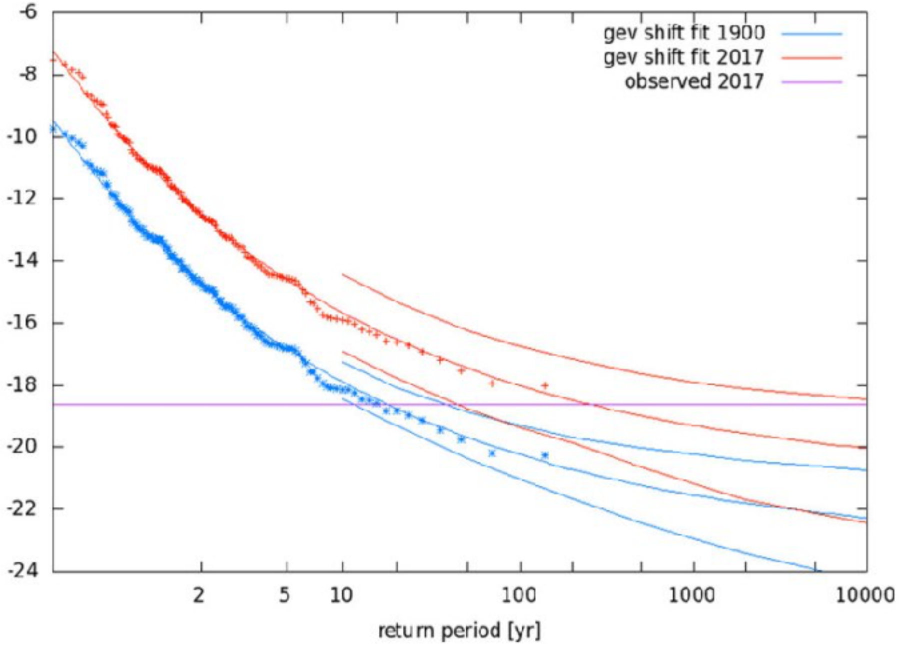
$$\sigma = \sigma_0 \exp\left(\frac{\alpha T'}{\mu_0}\right),$$

Example: cold wave North America 2017/2018



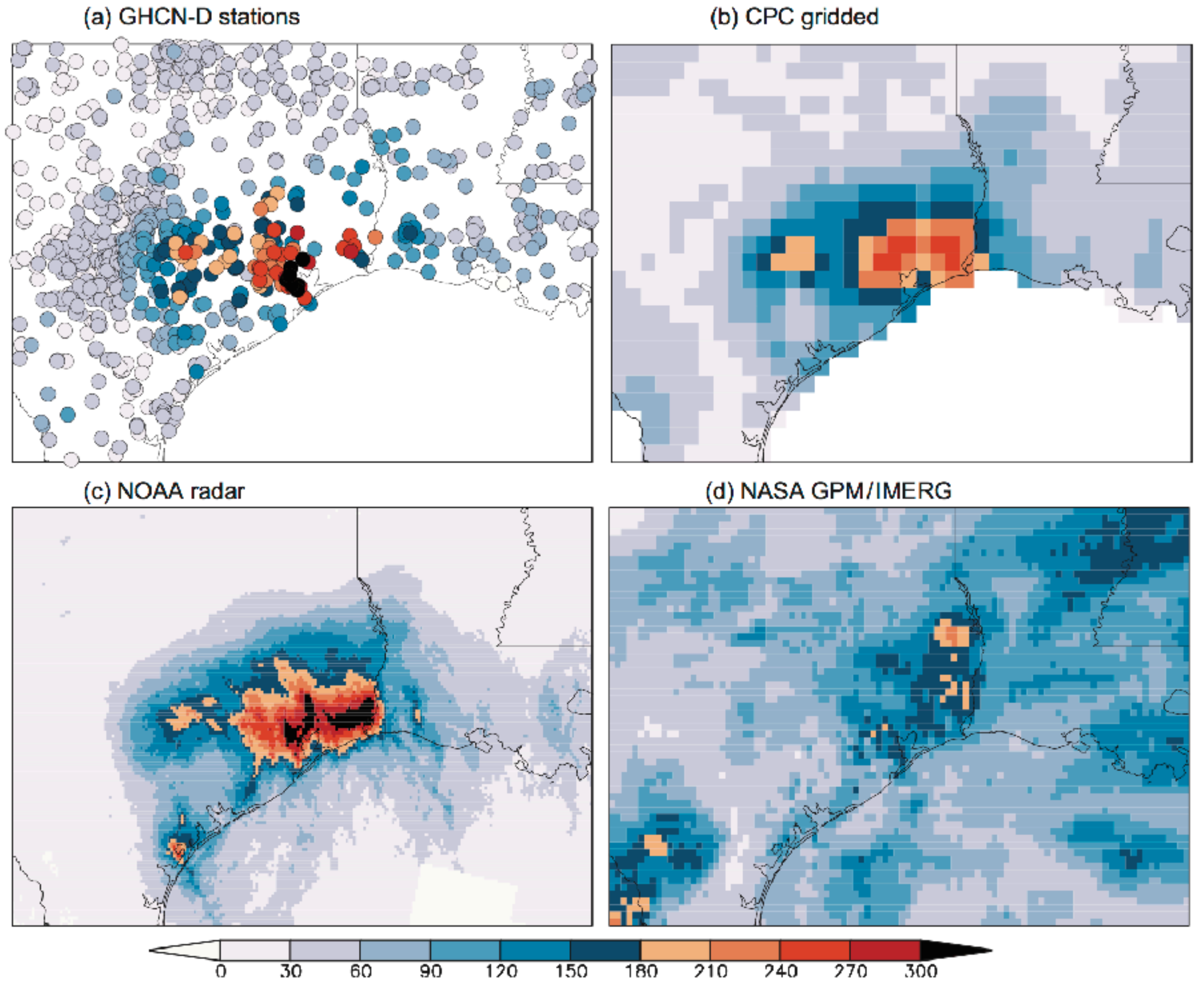




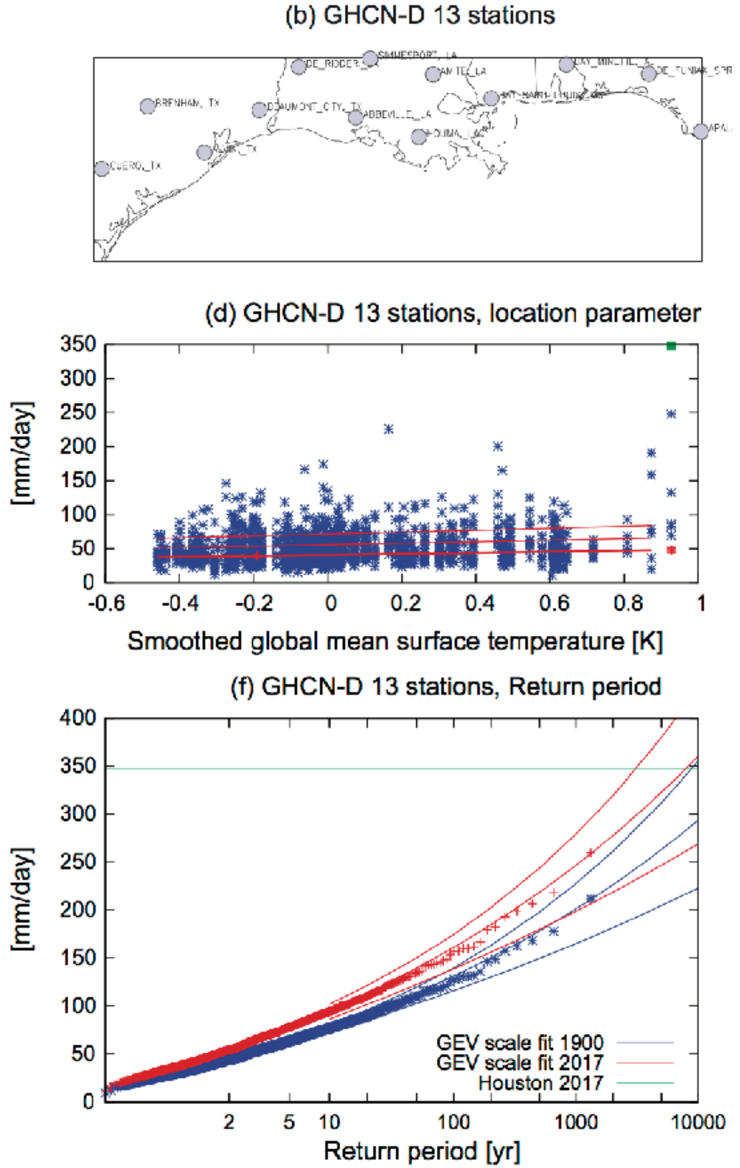


Based on van Oldenborgh et al, BAMS, 2015

Example: precipitation Hurricane Harvey 2017

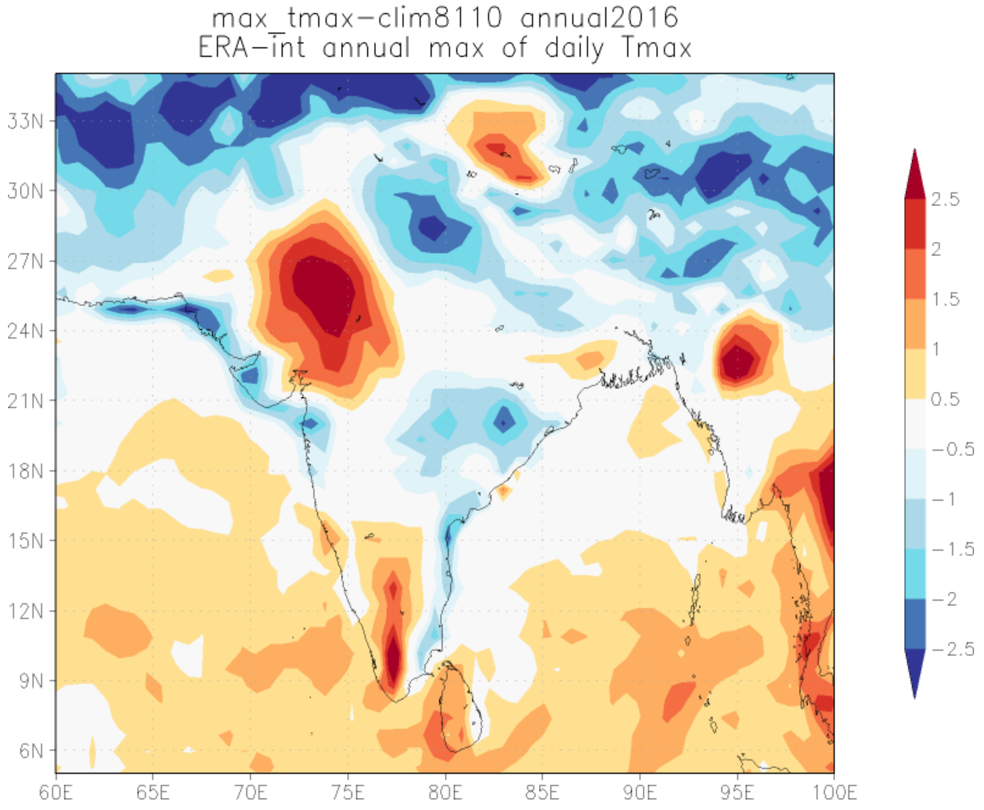


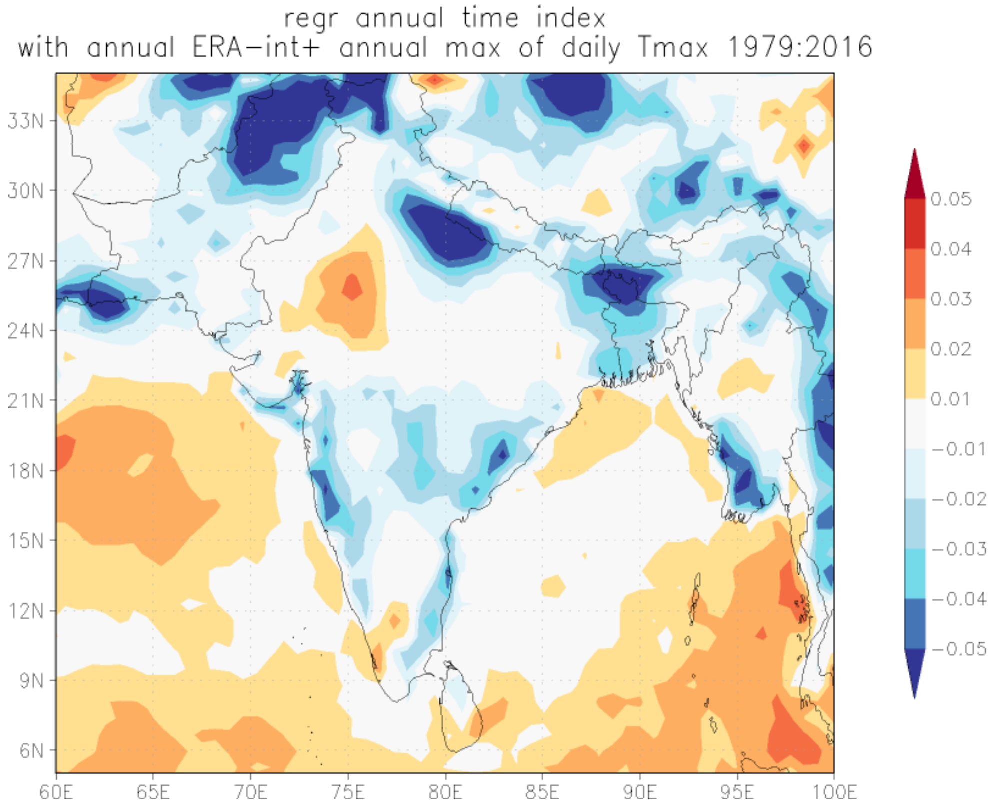
Various estimates of 3-day rainfall [mm/dy]



van Oldenborgh et al, ERL, 2017

Example: heat wave India 2016



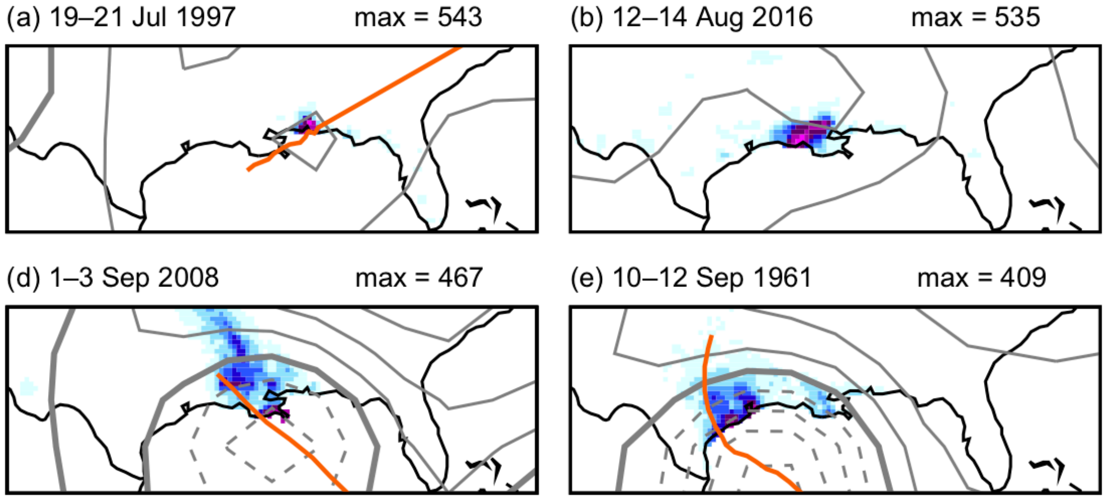


No detectable trends in highest maximum temperature of the year since 1970s

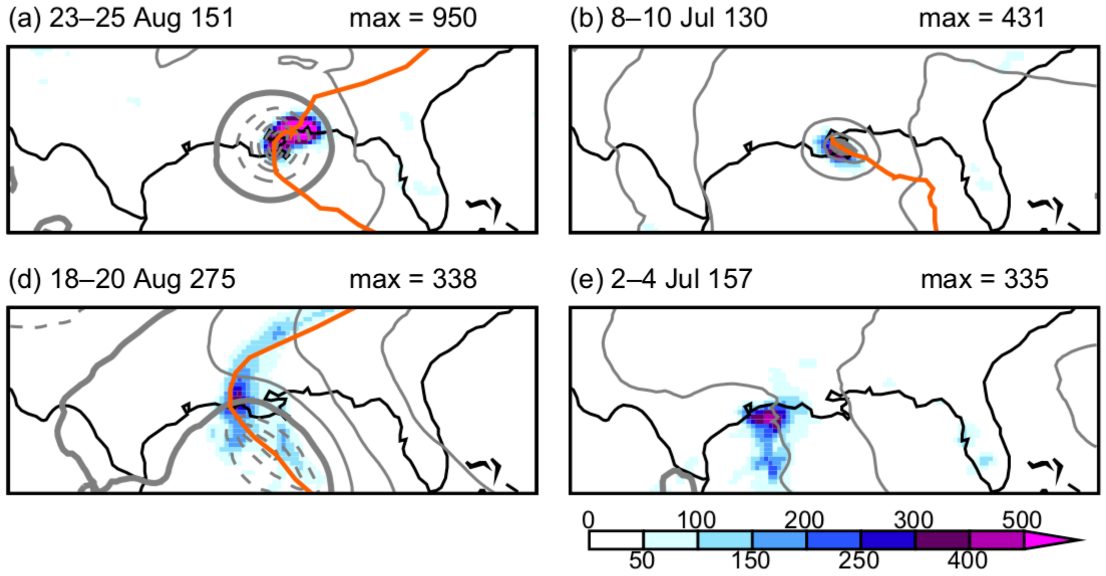
van Oldenborgh et al, NHESS, 2018

Model evaluation

- Can the model physically be expected to reproduce the extreme? E.g., need 25km resolution for hurricanes.
- Compare statistical properties of tail of distribution with observations (allowing for bias correction).
- Compare meteorological properties extremes with observations.



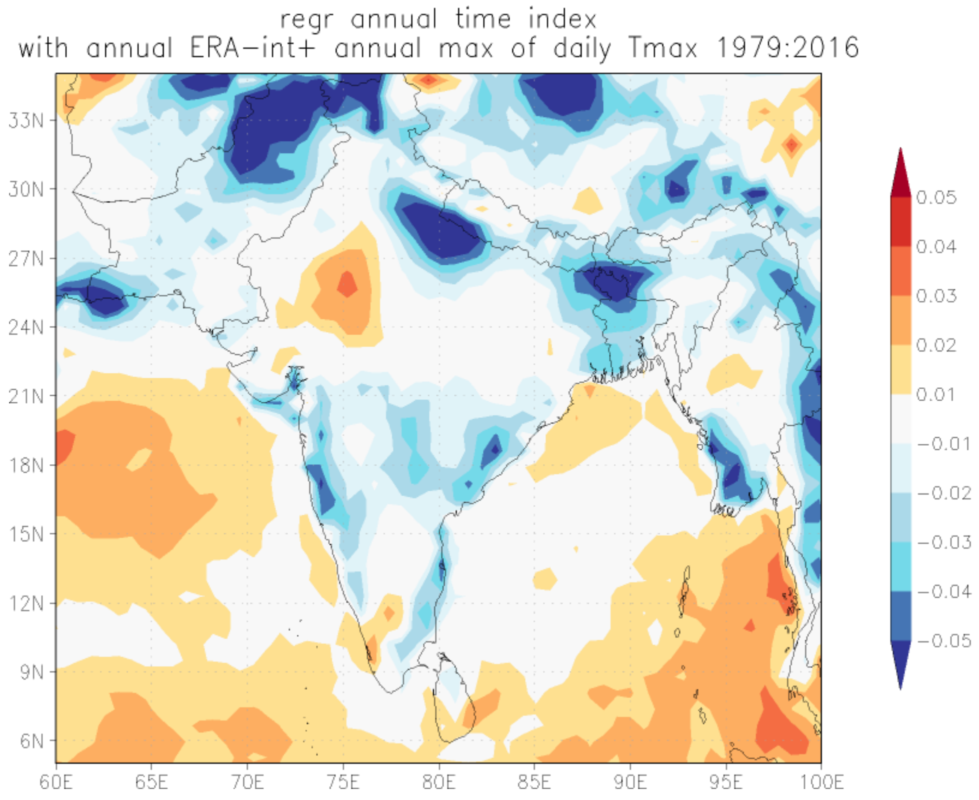
Four of the six highest 3-day precipitation events in CPC analysis



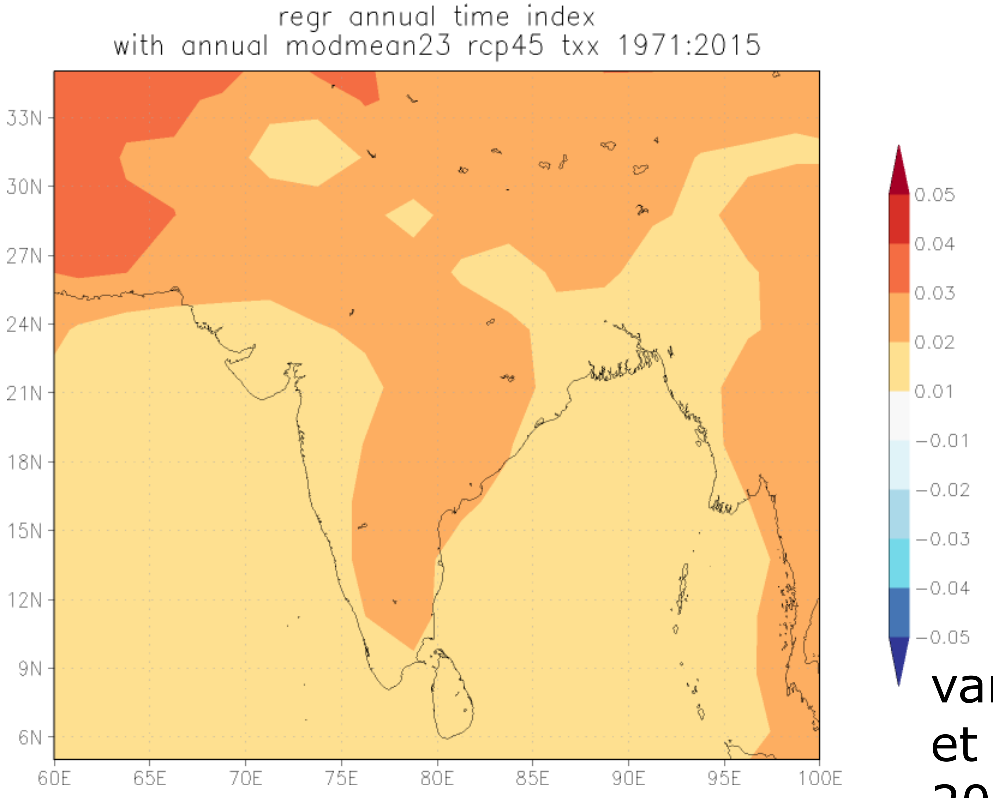
Four of the six highest 3-day precipitation events in HiFLOR

mm/3dy

Model evaluation



Reanalysis trend in warmest maximum temperature 1979–2016

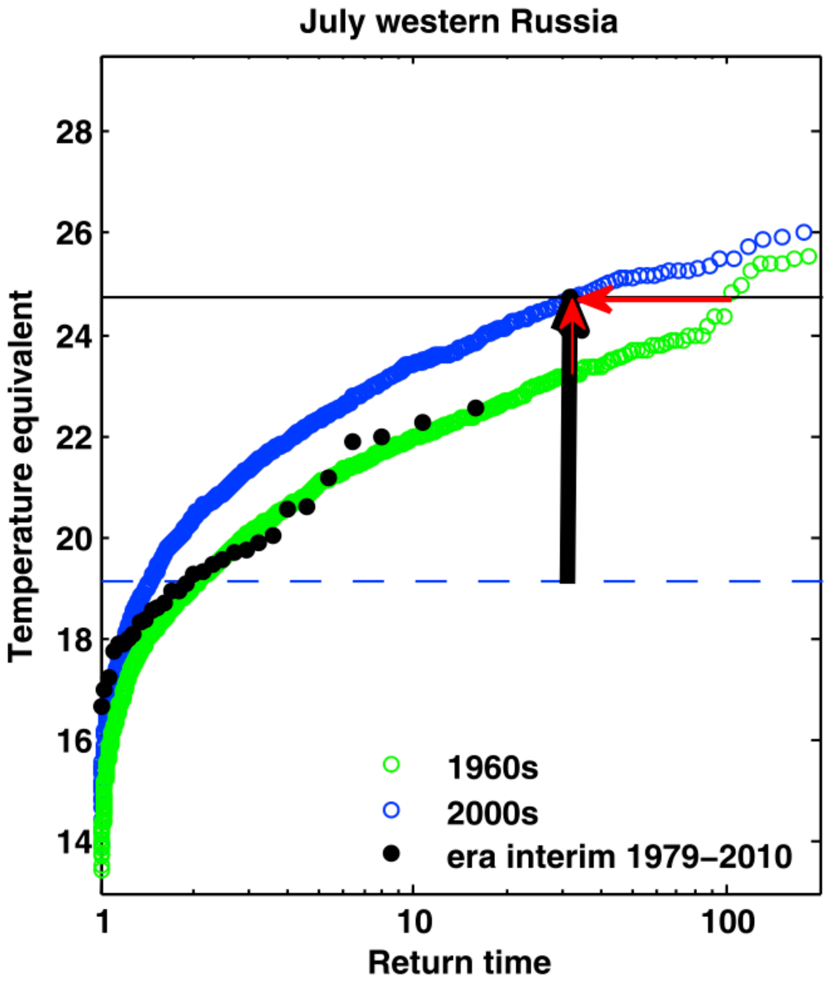


van Oldenborgh et al, NHESS, 2018

CMIP5 multi-model trend in warmest maximum temperature 1971–2015

Attribution: counterfactual world method

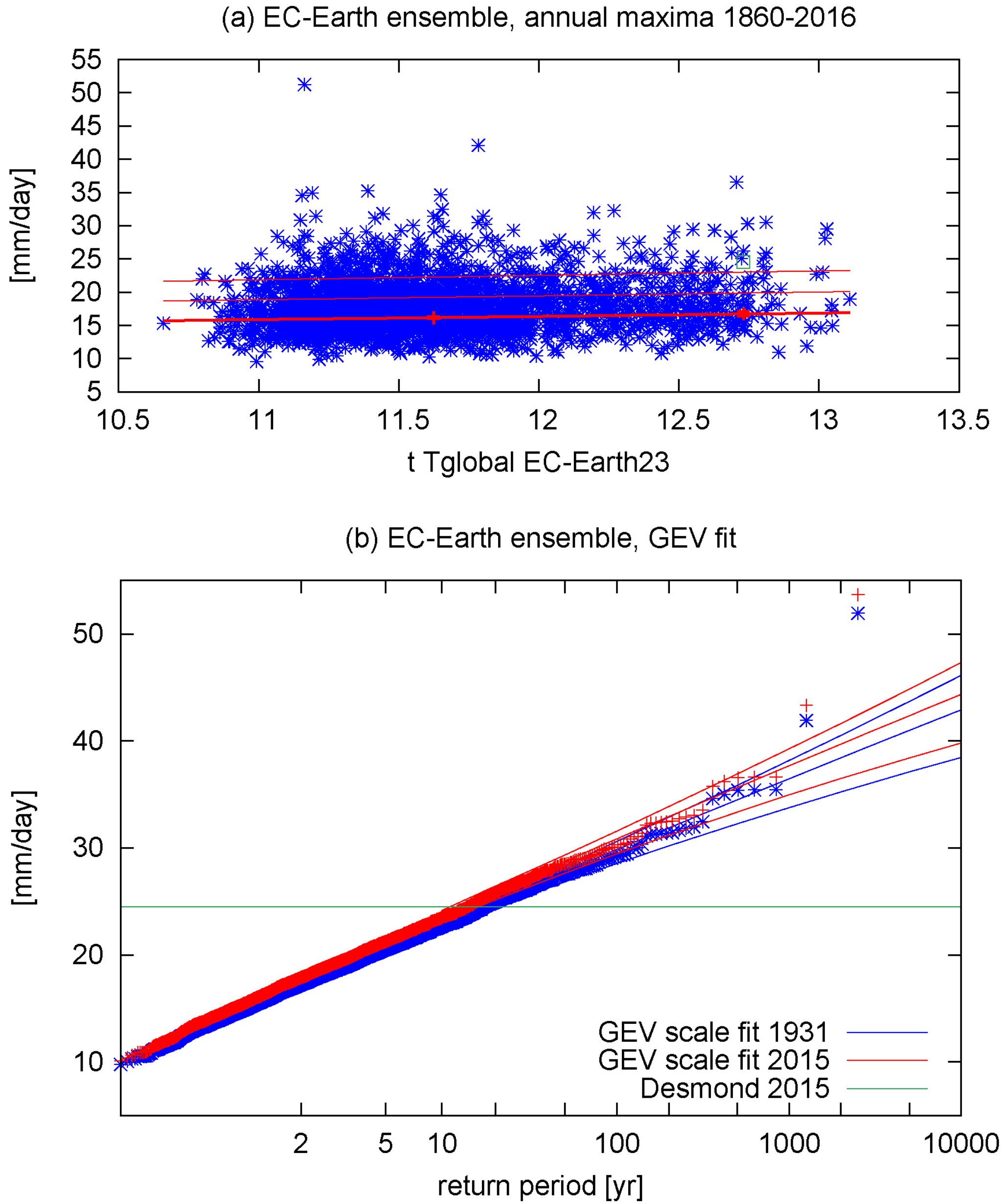
- Run two (large) ensembles: one with observed boundary conditions, one with boundary conditions without anthropogenic emissions (greenhouse gases, aerosols).
- Count how many times the event occurs on both ensembles
- $RR = p_1/p_0$
- $\Delta I = I_1 - I_0$
- "RR times more likely due to anthropogenic emissions"
- Allows check assumptions GEV fit



Otto et al, GRL, 2012

Attribution: trend method

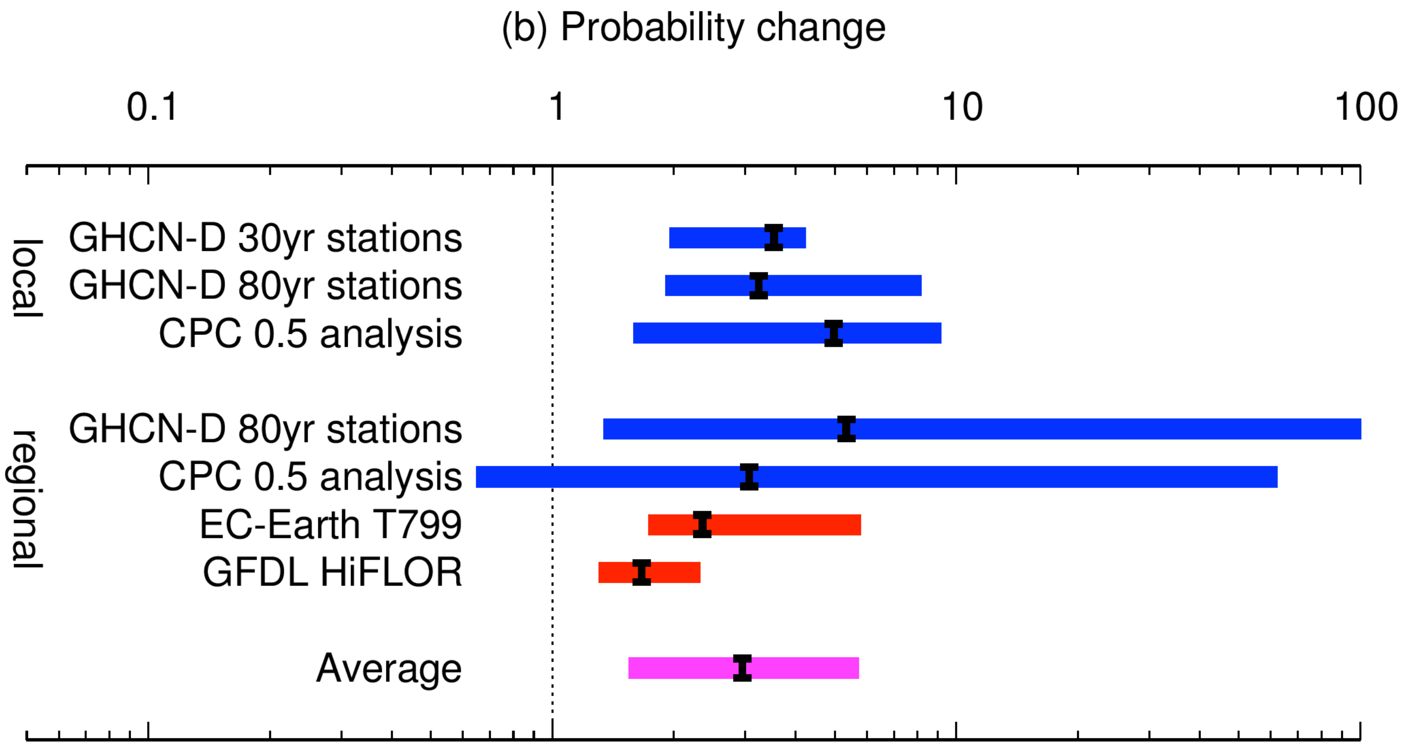
- Run (large) ensemble then–now, fit to GEV as observations.
- Assumes influence natural forcings is small compared to anthropogenic forcings and natural variability
- RR = p_{then}/p_{now}
- $\Delta I = I_{then} - I_{now}$
- "RR times more likely than a century ago"



UK precipitation Otto et al, ERL, 2018

Synthesis: combine all estimates

- Transform RRs to a common baseline
- Compute χ^2
- If dominated by noise (natural variability): weighted mean
- If contribution of model spread: inflate uncertainty range
- Under research



Harvey, van Oldenborgh et al, 2017

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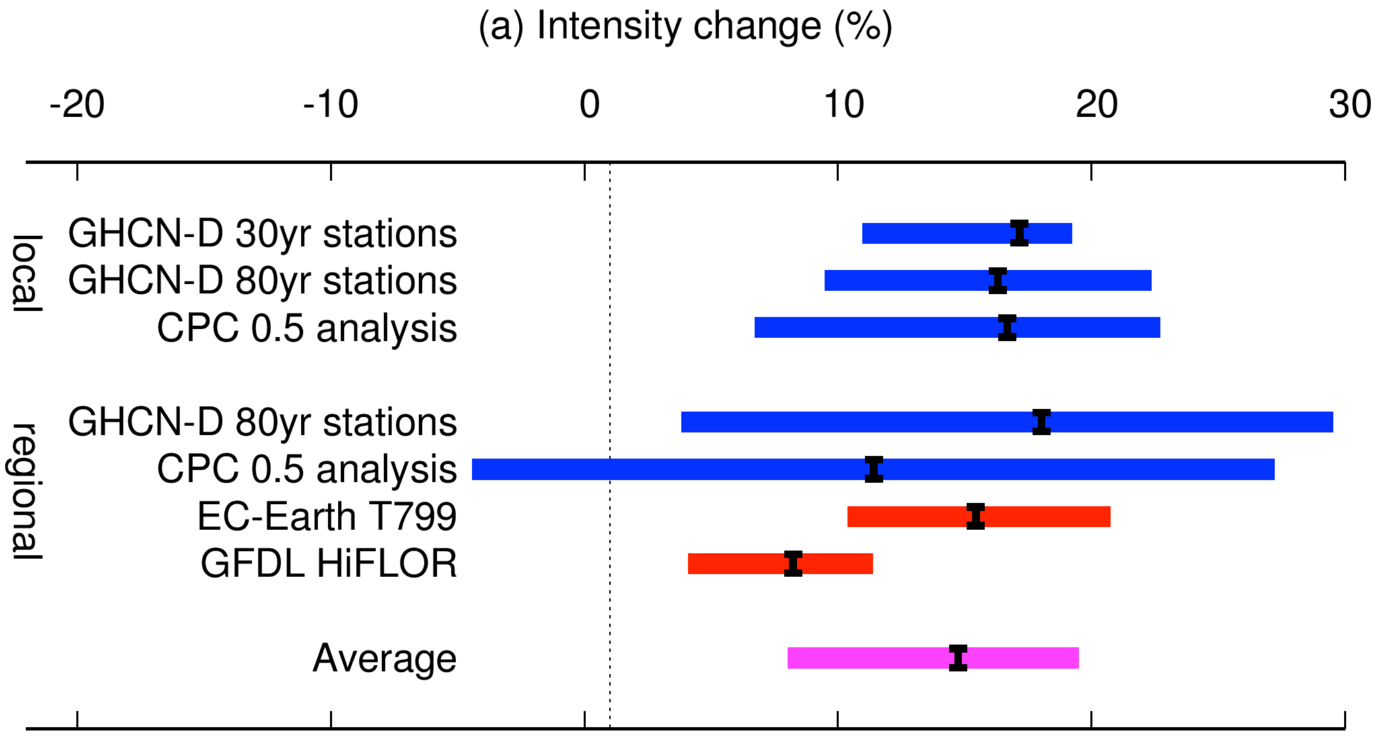

Harvey, van Oldenborgh et al, 2017

Attribution statement

- Harvey: "we conclude that global warming made the precipitation about 15% (8%–19%) more intense, or equivalently made such an event three (1.5–5) times more likely."
- US cold wave: "Temperatures like these are now about fifteen times rarer. This is equivalent to cold waves being about 4ºF (2ºC) warmer than they used to be."
- India heat wave: "Current climate models do not represent these processes well and hence cannot be used to attribute heat waves in this area."
- Ethiopian drought: "the drought cannot be clearly attributed to anthropogenic climate change"

Communication

That Recent Brutally Cold Weather? It's Getting Rarer

By HENRY FOUNTAIN JAN. 11, 2018

Hurricane Harvey

Global warming made Hurricane Harvey deadly rains three times more likely, research reveals

'Lucifer' heatwaves WORSE than this summer's weather will be normal in Europe in the next 30 years due to global warming

- **Climate change means Lucifer heatwaves are 10 times more likely to hit Europe**
- **Heatwaves on the continent this summer saw a spike in hospital admissions**
- **Experts say there is clear evidence of human influence on this summer's warmth**
- **Such weather will become typical in southern Europe by the 2050s if current greenhouse gas emissions continue**

By REUTERS and ASSOCIATED PRESS and HARRY PETTIT FOR MAILONLINE

Conclusions

- Detection & Attribution shows that most if not all global mean warming since the 1951 is anthropogenic
- Greenhouse gases contribute more than 100%, 2/3 CO_2, 1/3 CH_4
- Counteracted by aerosol cooling.
- We can now also detect and attribute the influence of anthropogenic emissions on extreme weather & climate events
- Temperature often easy, intense precipitation also.
- Other variables more difficult (drought, snow, wind, ...)