Increase of Extreme Events in a Warming World

Stefan Rahmstorf
Potsdam Institute
for Climate Impact Research

Foto: Wolfgang Cramer

Alexander von Humboldt, 1843

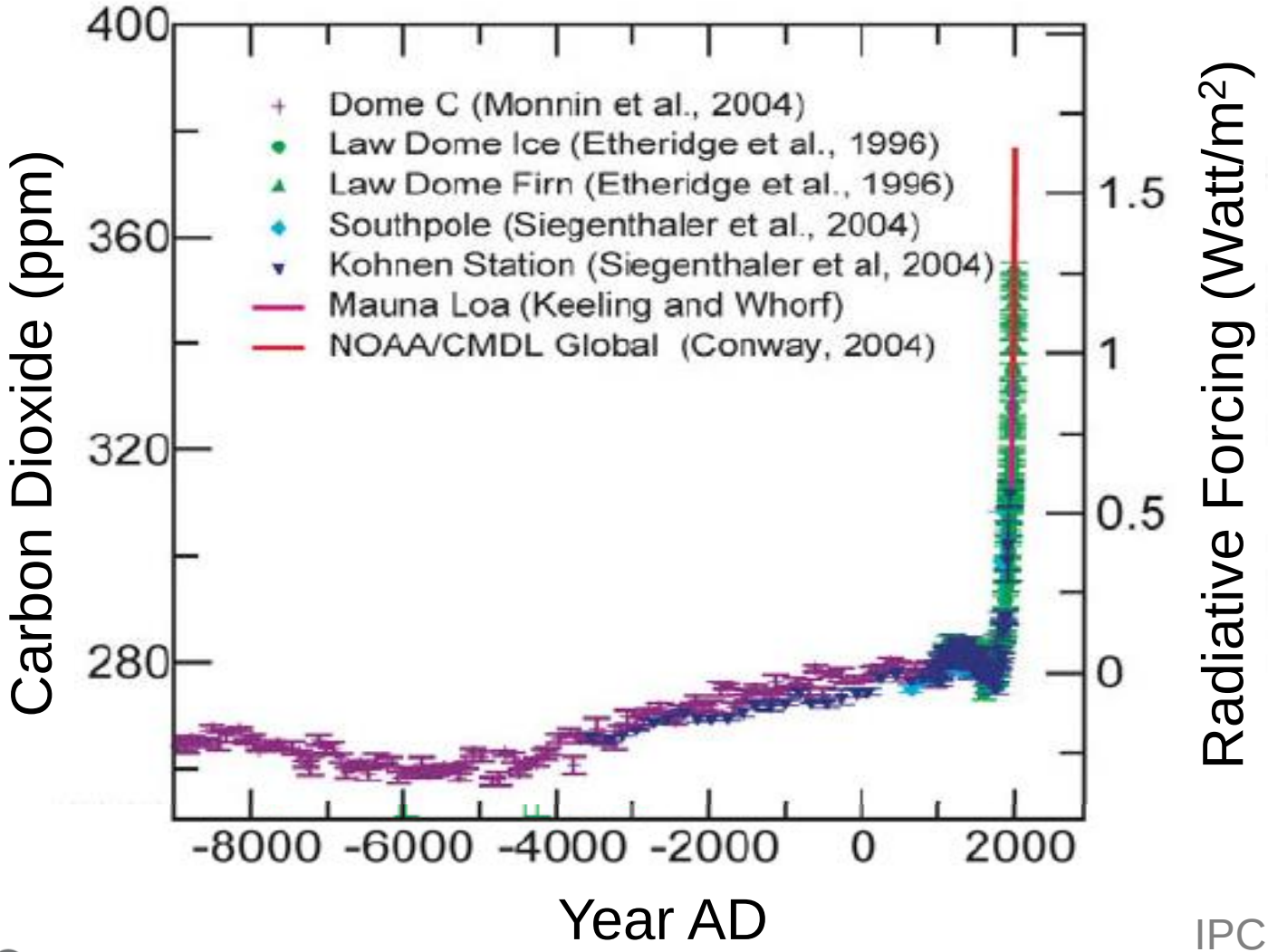
Man changes climate „by cutting forests [...] and by emitting large amounts of steam and gas at the centers of industry"

John Tyndall, 1859

„The atmosphere admits of the entrance of solar heat, but checks its exit; and the result is a tendency to accumulate heat at the surface of the planet.“

John Tyndall

Rising CO2-Concentration

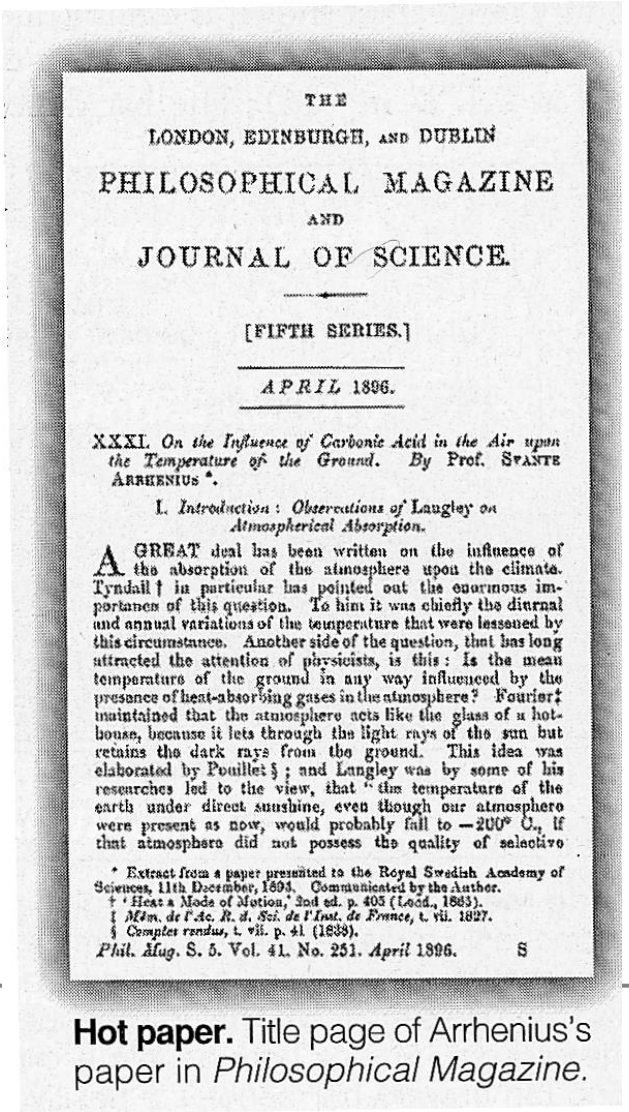


IPCC 2007

Climate Effect of CO2

Arrhenius 1896 (4-6 ºC)

Svante Arrhenius



THE
LONDON, EDINBURGH, AND DUBLIN
PHILOSOPHICAL MAGAZINE
AND
JOURNAL OF SCIENCE.

[FIFTH SERIES.]

APRIL 1896.

XXXI. *On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground.* By Prof. SVANTE ARRHENIUS *.

I. *Introduction: Observations of* Langley *on Atmospherical Absorption.*

A GREAT deal has been written on the influence of the absorption of the atmosphere upon the climate. Tyndall † in particular has pointed out the enormous importance of this question. To him it was chiefly the diurnal and annual variations of the temperature that were lessened by this circumstance. Another side of the question, that has long attracted the attention of physicists, is this: Is the mean temperature of the ground in any way influenced by the presence of heat-absorbing gases in the atmosphere? Fourier‡ maintained that the atmosphere acts like the glass of a hot-house, because it lets through the light rays of the sun but retains the dark rays from the ground. This idea was elaborated by Pouillet §; and Langley was by some of his researches led to the view, that "the temperature of the earth under direct sunshine, even though our atmosphere were present as now, would probably fall to −200° C., if that atmosphere did not possess the quality of selective

* Extract from a paper presented to the Royal Swedish Academy of Sciences, 11th December, 1895. Communicated by the Author.
† 'Heat a Mode of Motion,' 2nd ed. p. 405 (Lond., 1863).
‡ *Mém. de l'Ac. R. d. Sci. de l'Inst. de France*, t. vii. 1827.
§ *Comptes rendus*, t. vii. p. 41 (1838).

Phil. Mag. S. 5. Vol. 41. No. 251. *April* 1896. S

Hot paper. Title page of Arrhenius's paper in *Philosophical Magazine*.

Effect of CO_2-doubling:

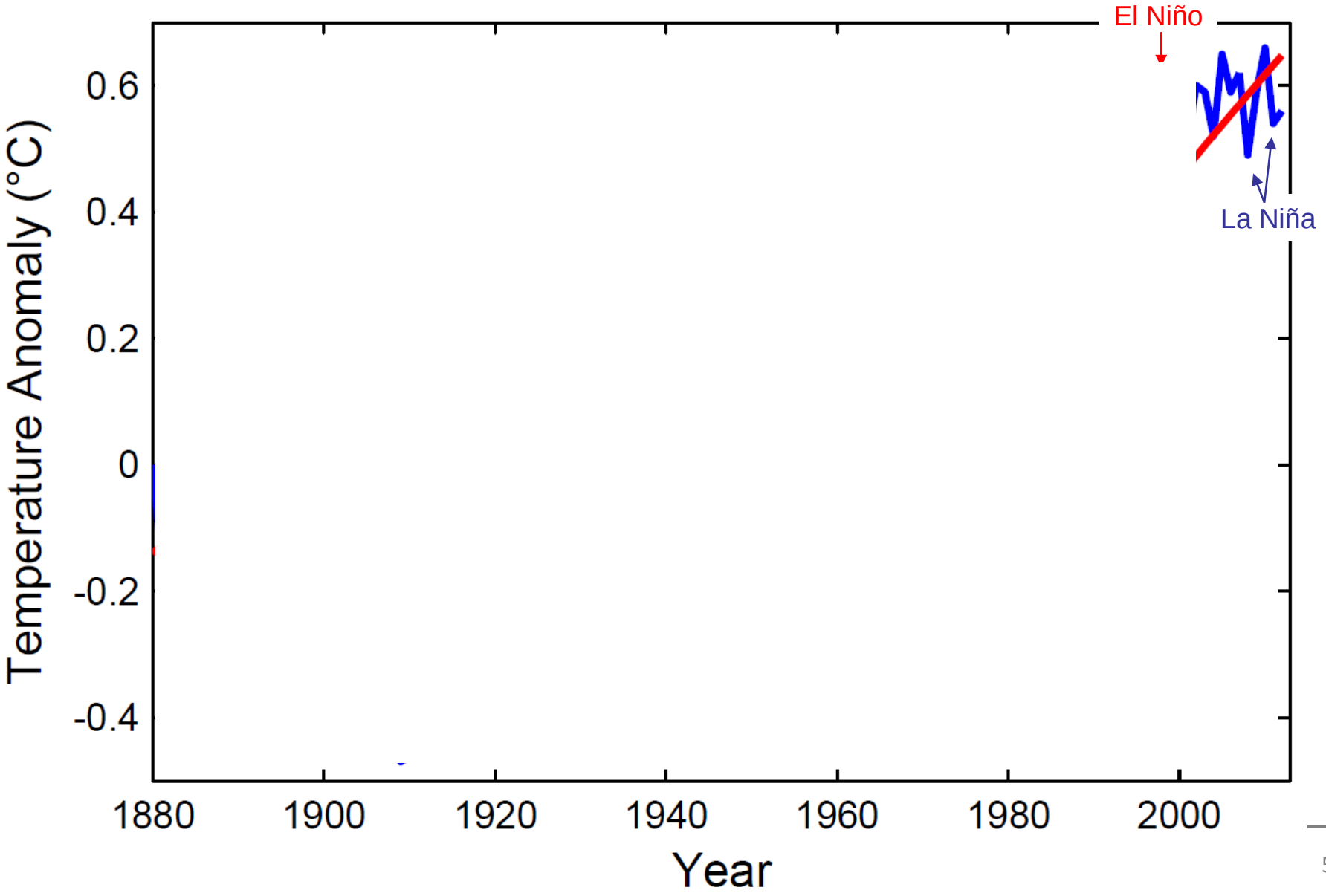
"climate sensitivity"

3 ± 1 ºC

Anthropogenic emissions should have caused 0.7 to 0.9 ºC warming to date

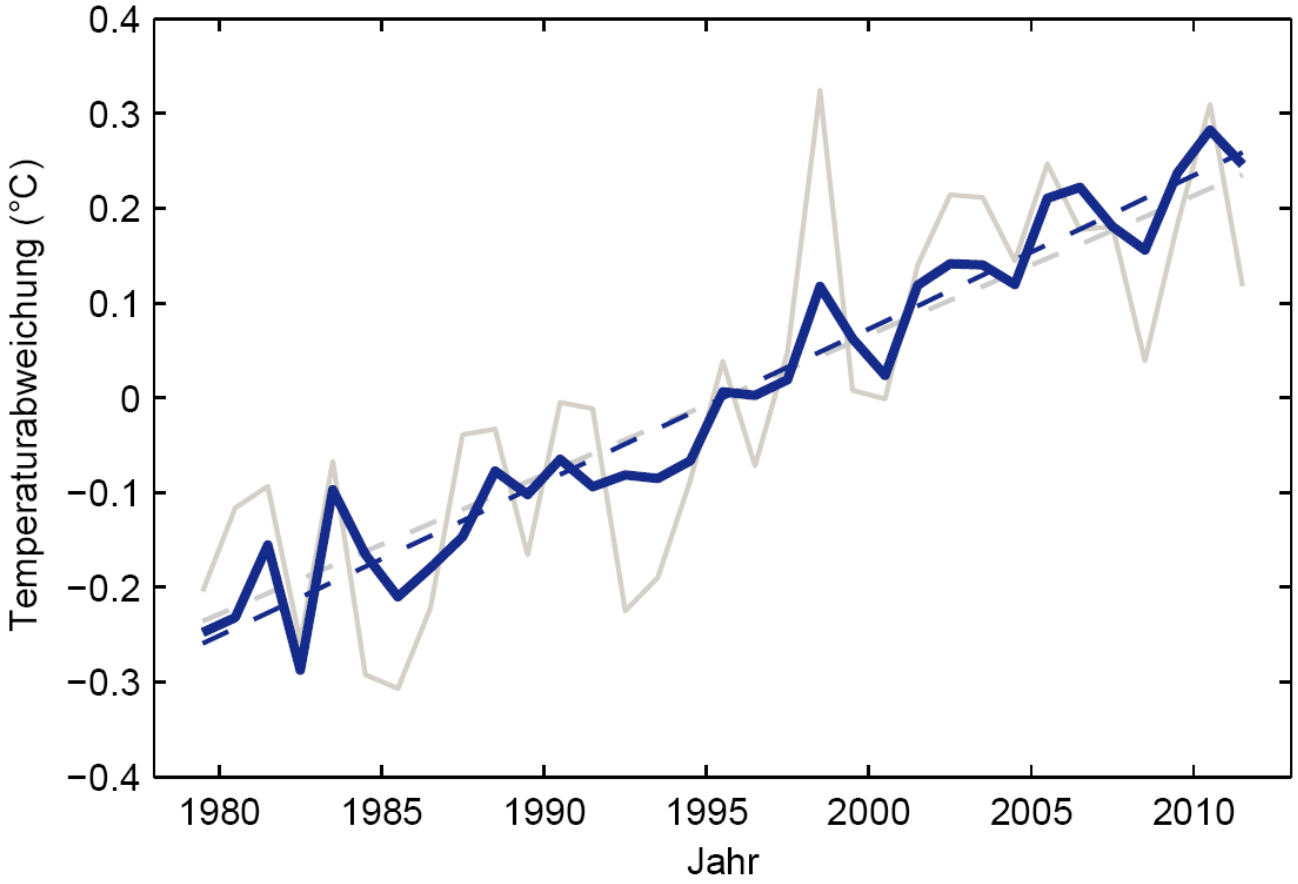
PIK

Global Temperature



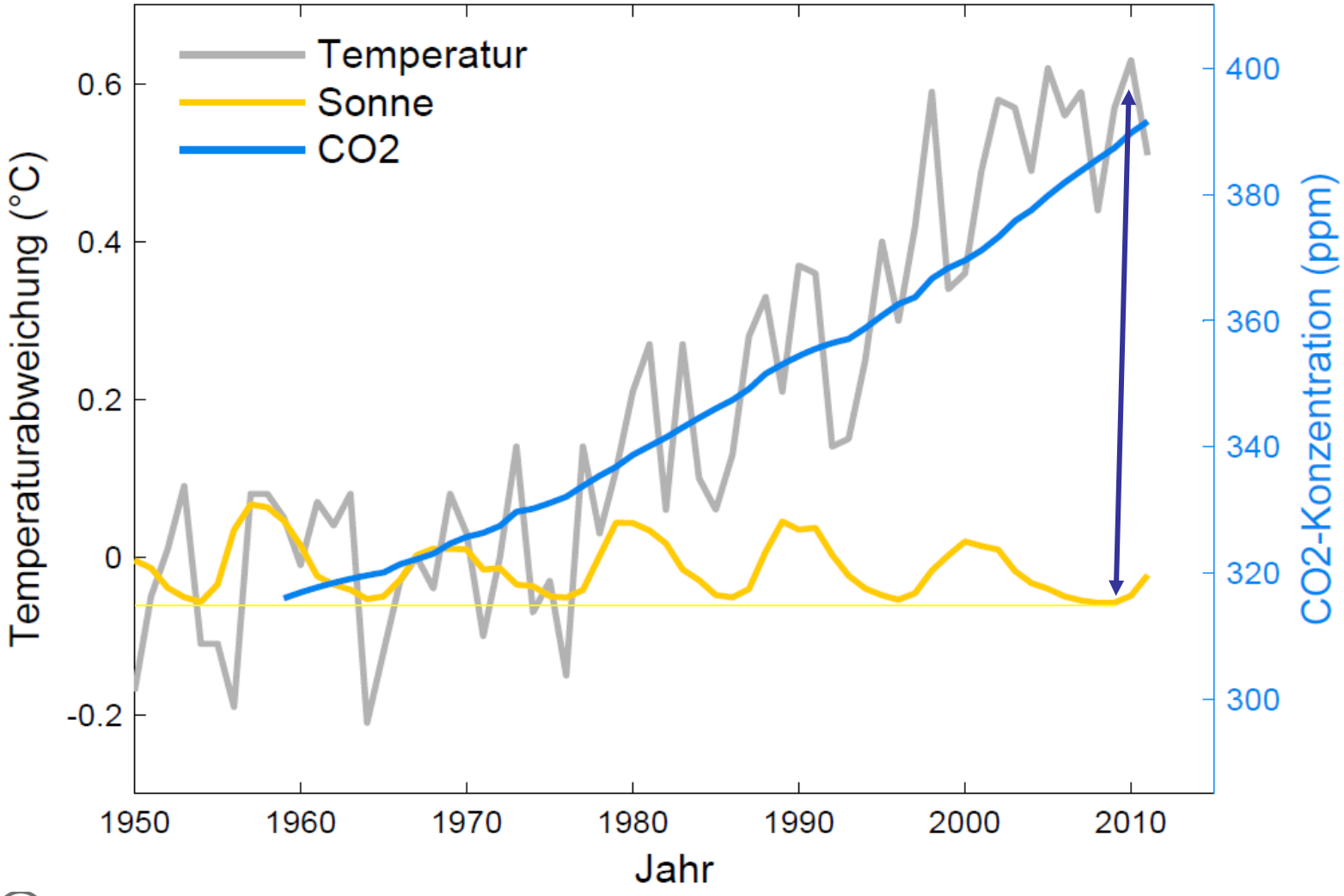
Global Temperature

- **With effect of El Niño, volcanos und solar activity removed**

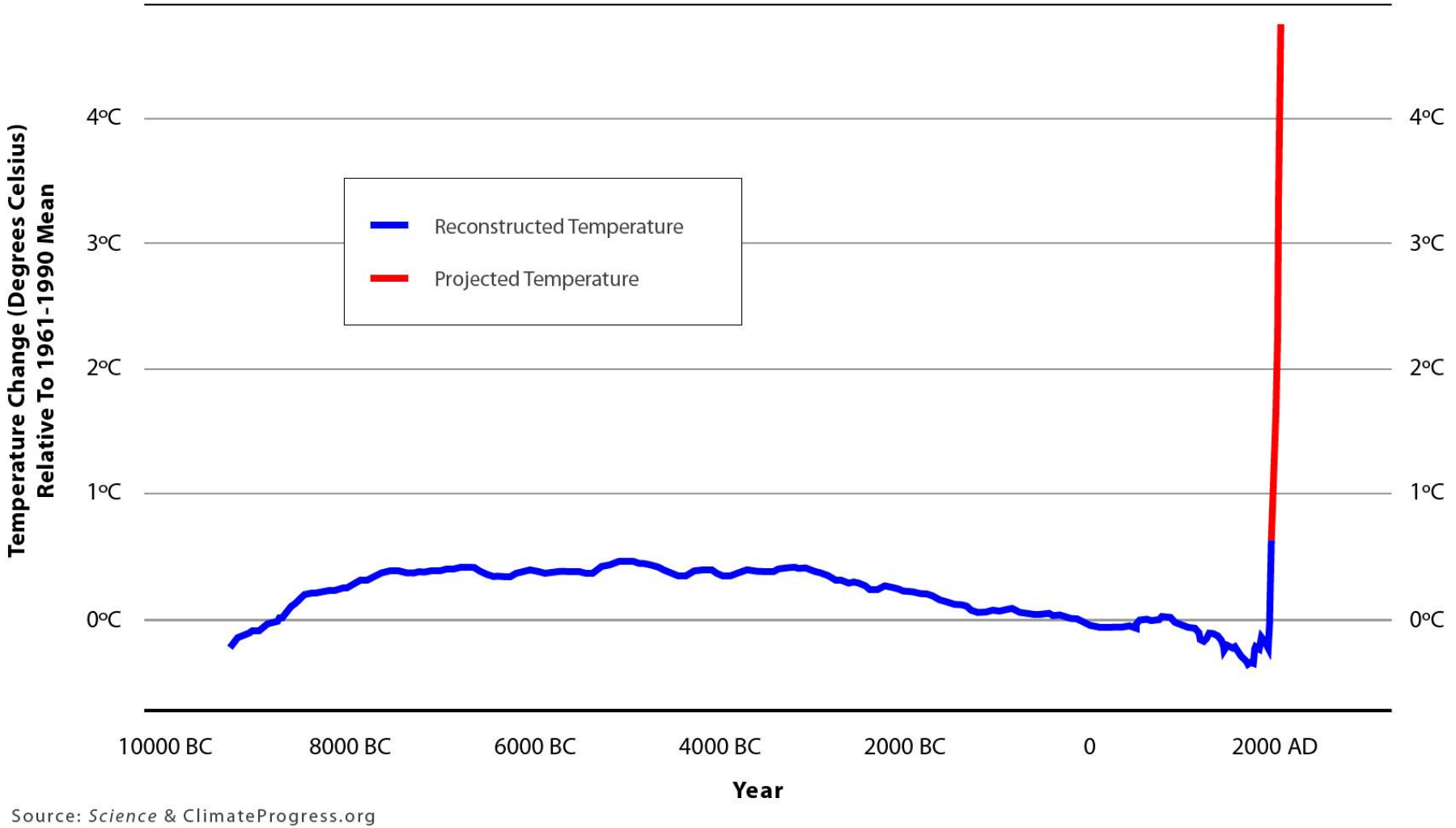


Foster & Rahmstorf, ERL 2011

Global Temperature und Solar Activity



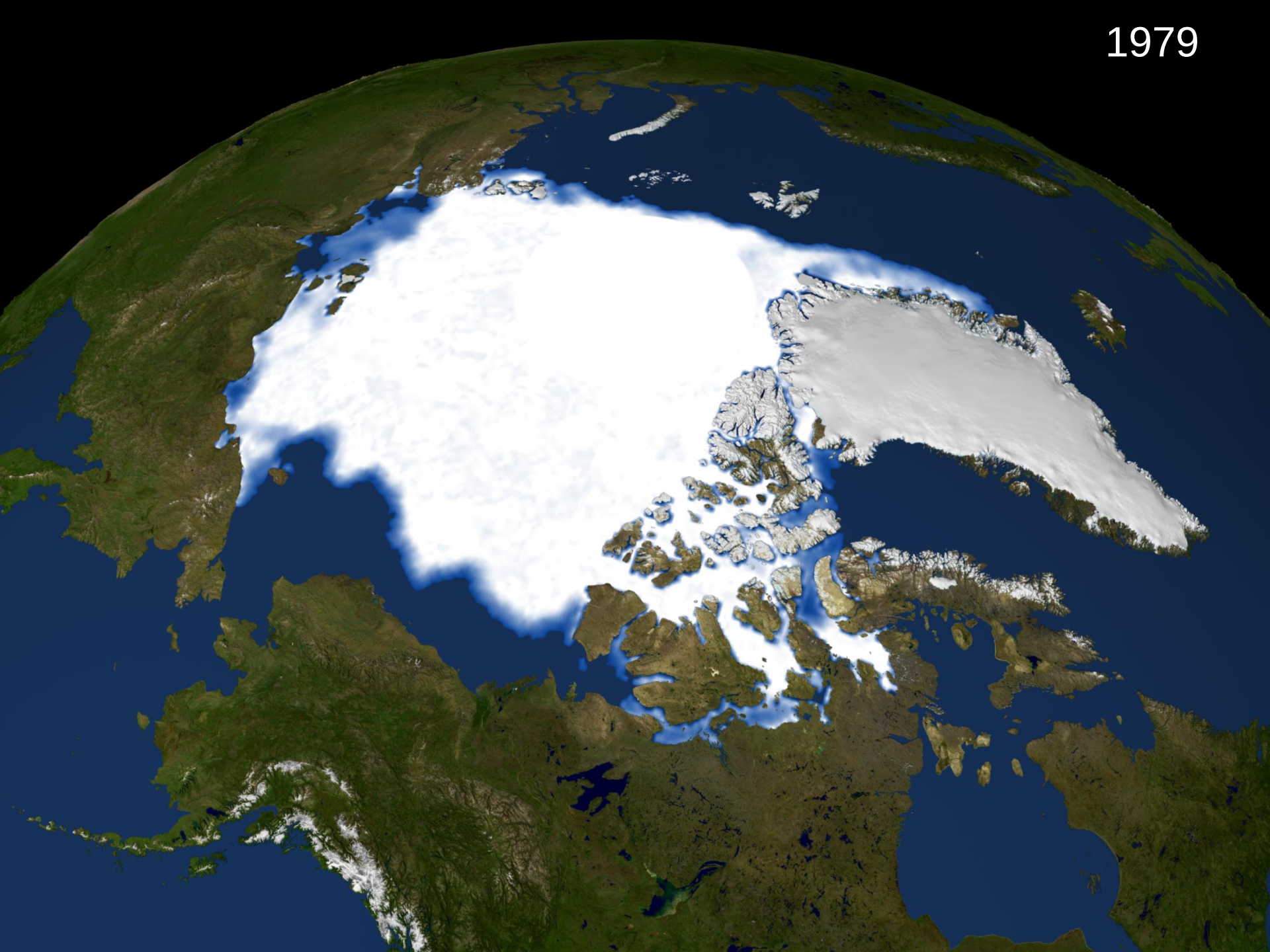
Global Temperature during the Holocene

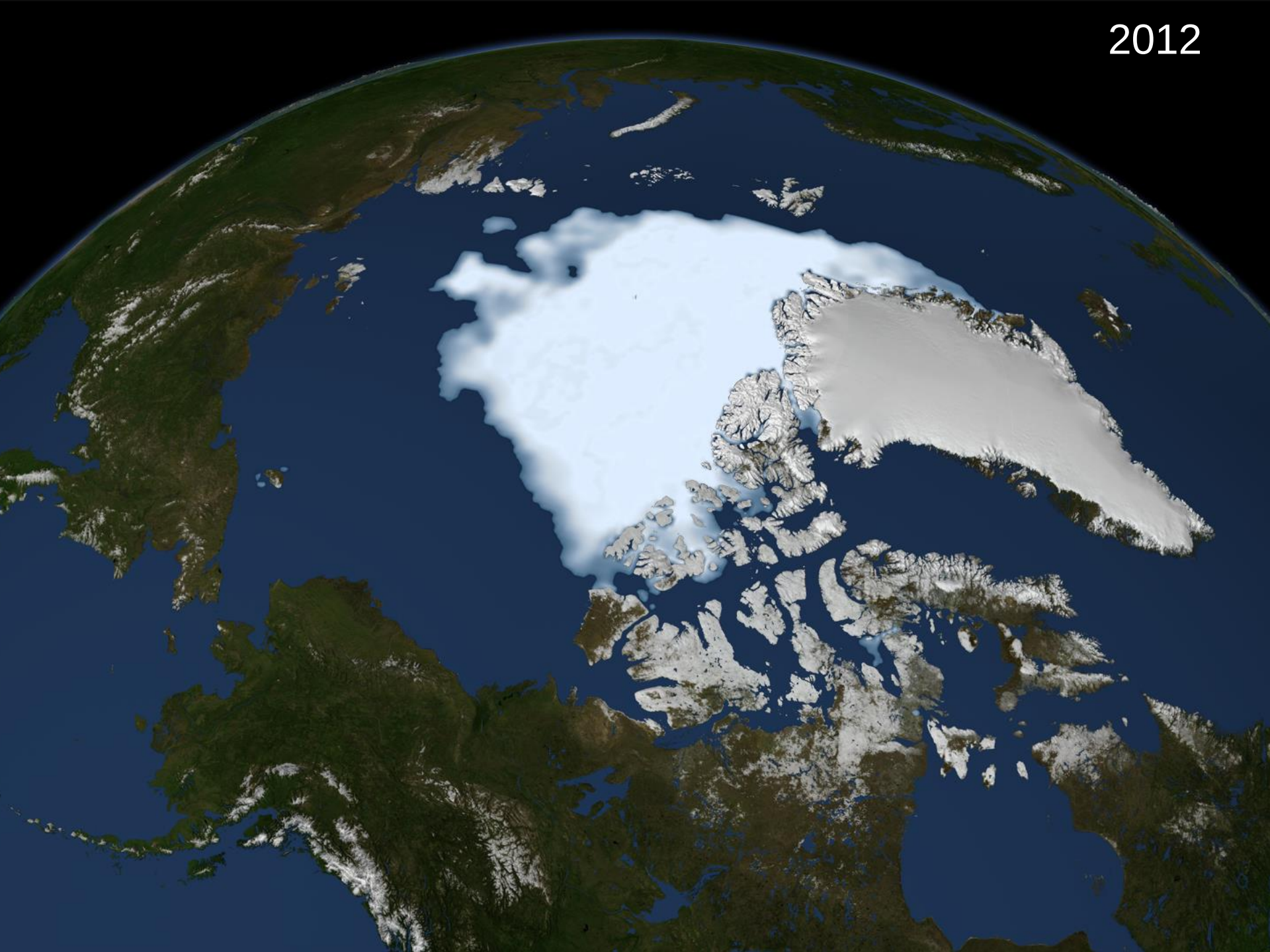


Source: *Science* & ClimateProgress.org

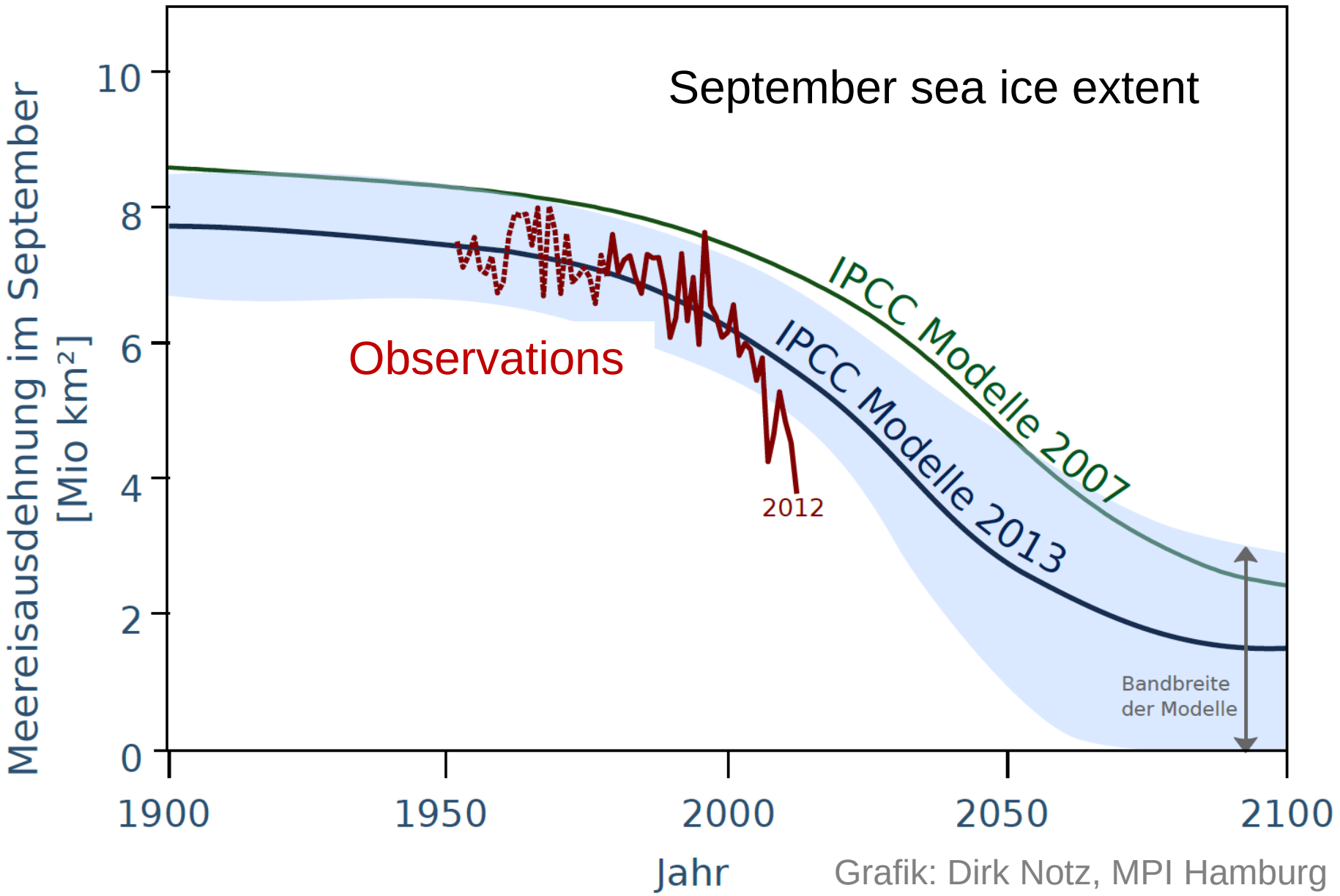
Marcott et al., Science 2013


Mueller Glacier


1979

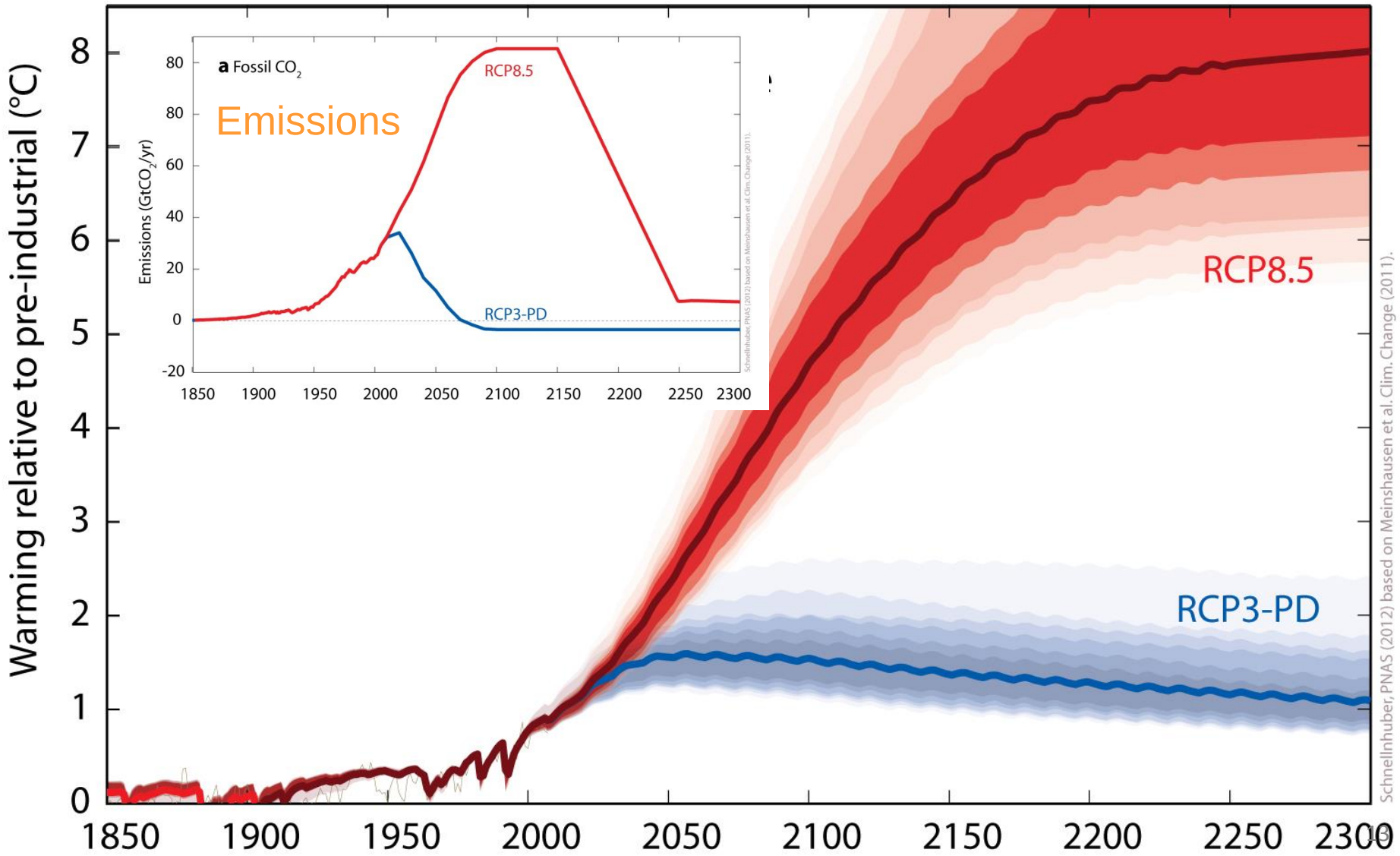

2012

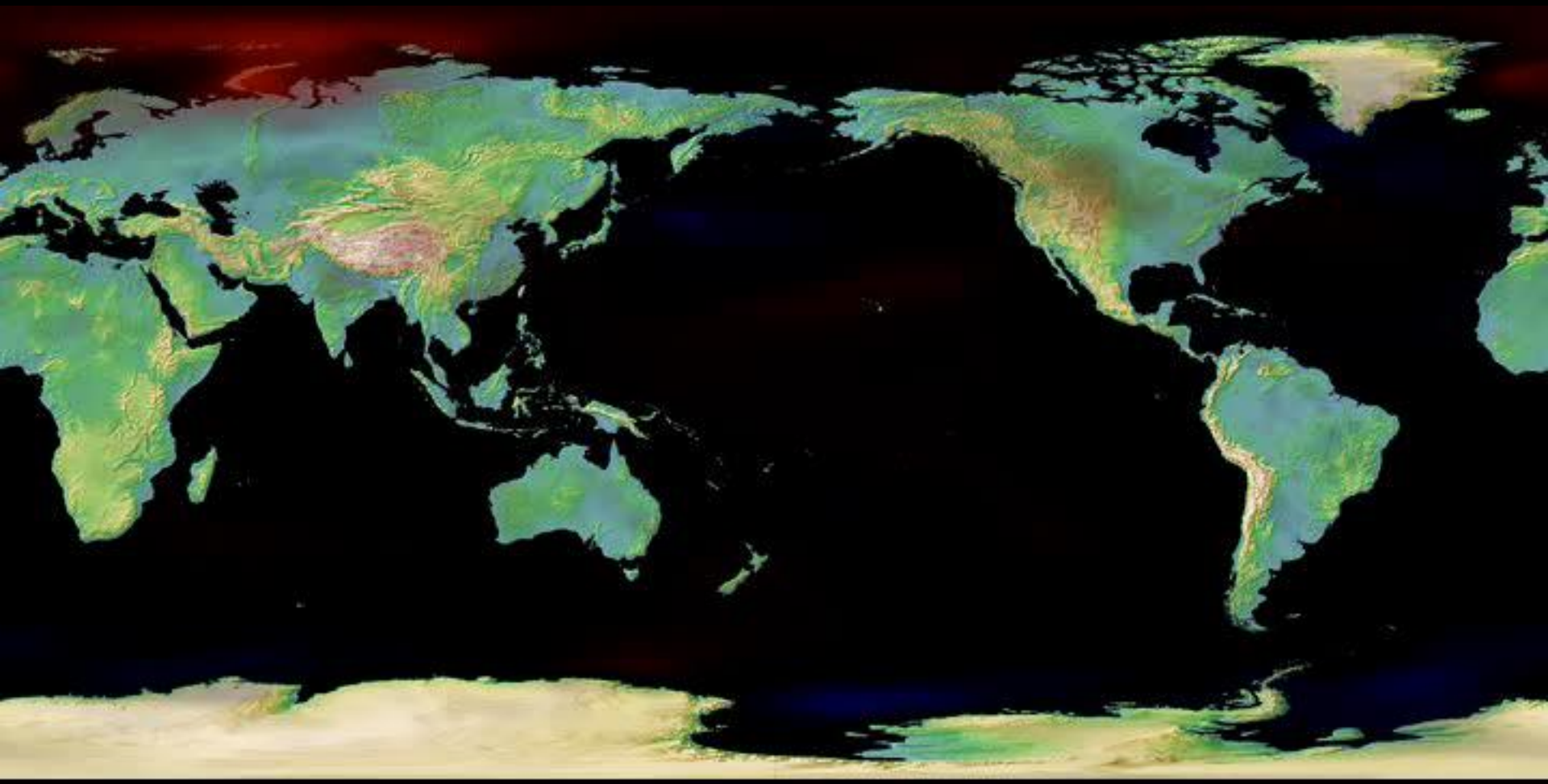
Loss of Arctic Sea Ice Cover



Grafik: Dirk Notz, MPI Hamburg

Future Global Temperature





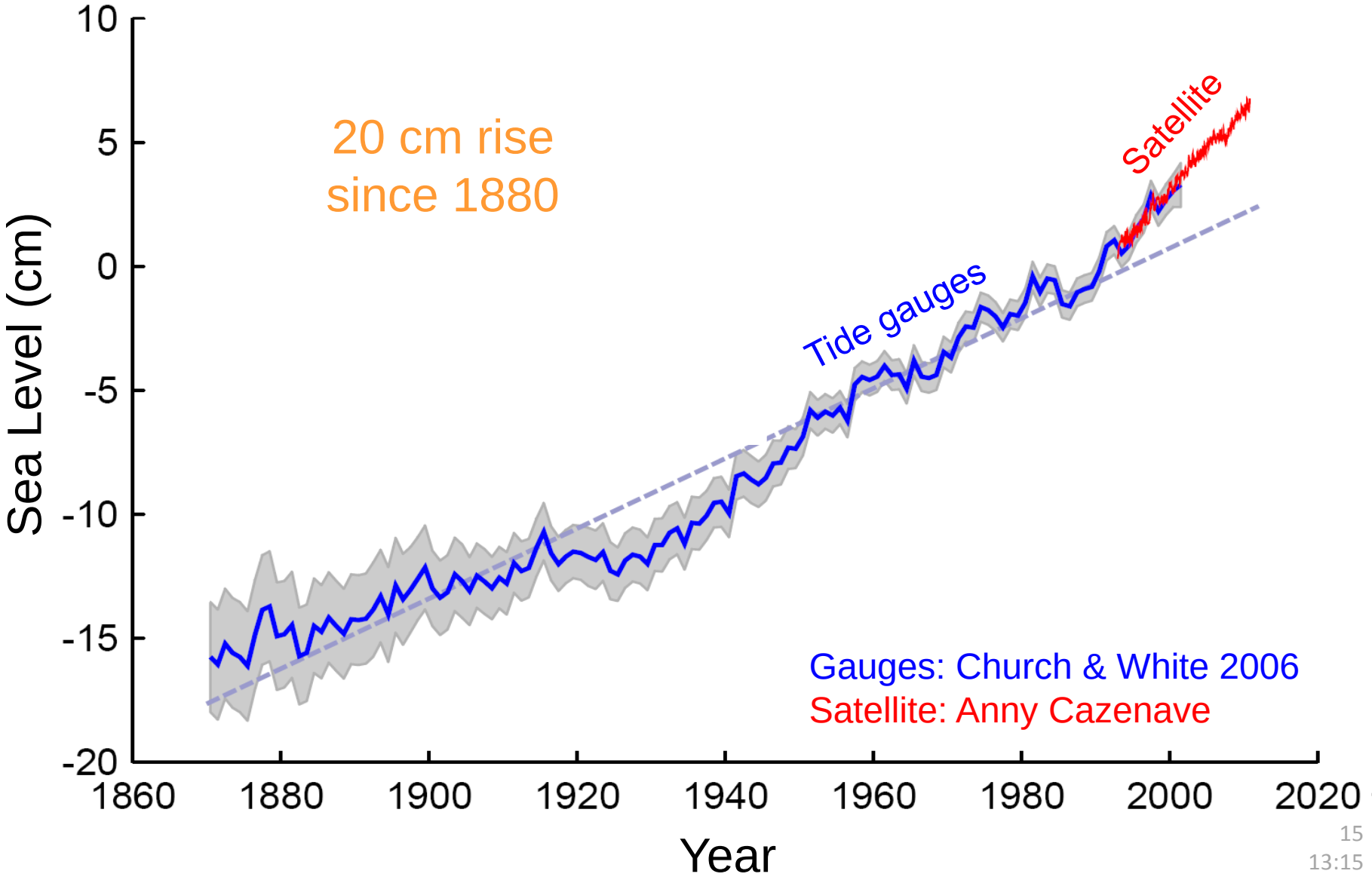
1950

-12 K -6 K +0 K +6 K +12 K

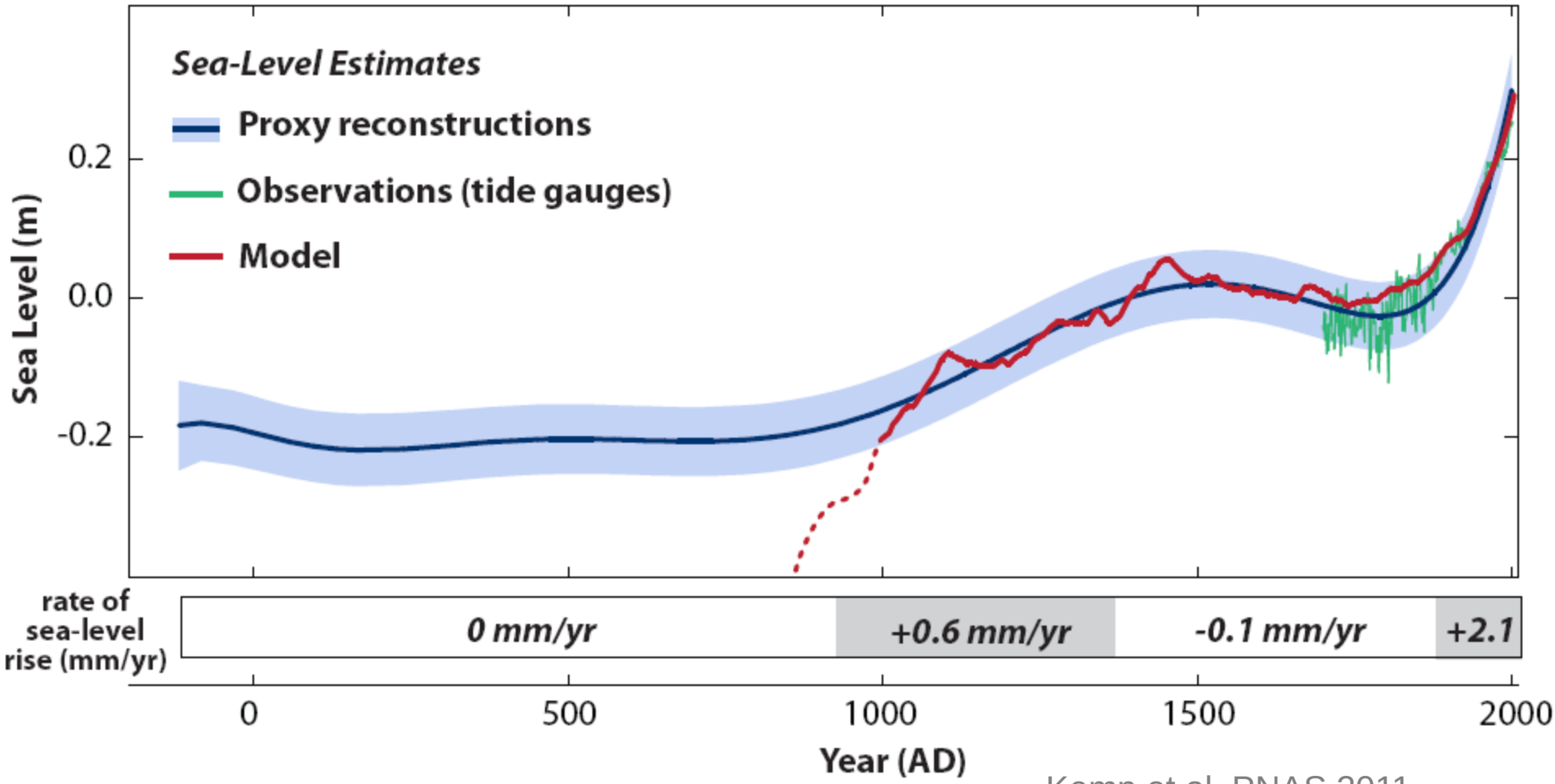
2m temperature change (A1B / MIROC-hi)

CCSR/NIES/FRCGC
MEXT RR2002

Sea Level Rise

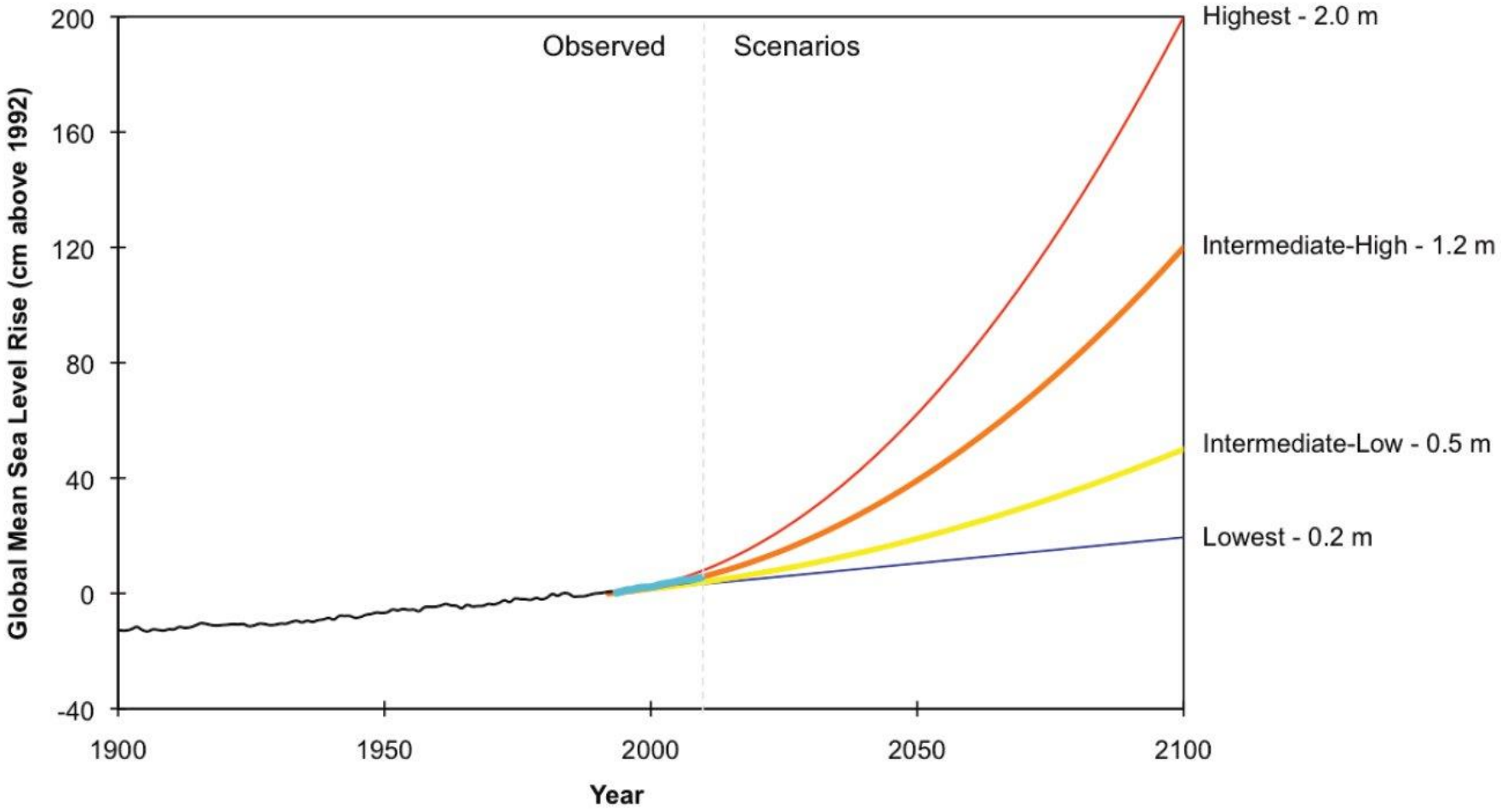


2000 Years of Sea Level

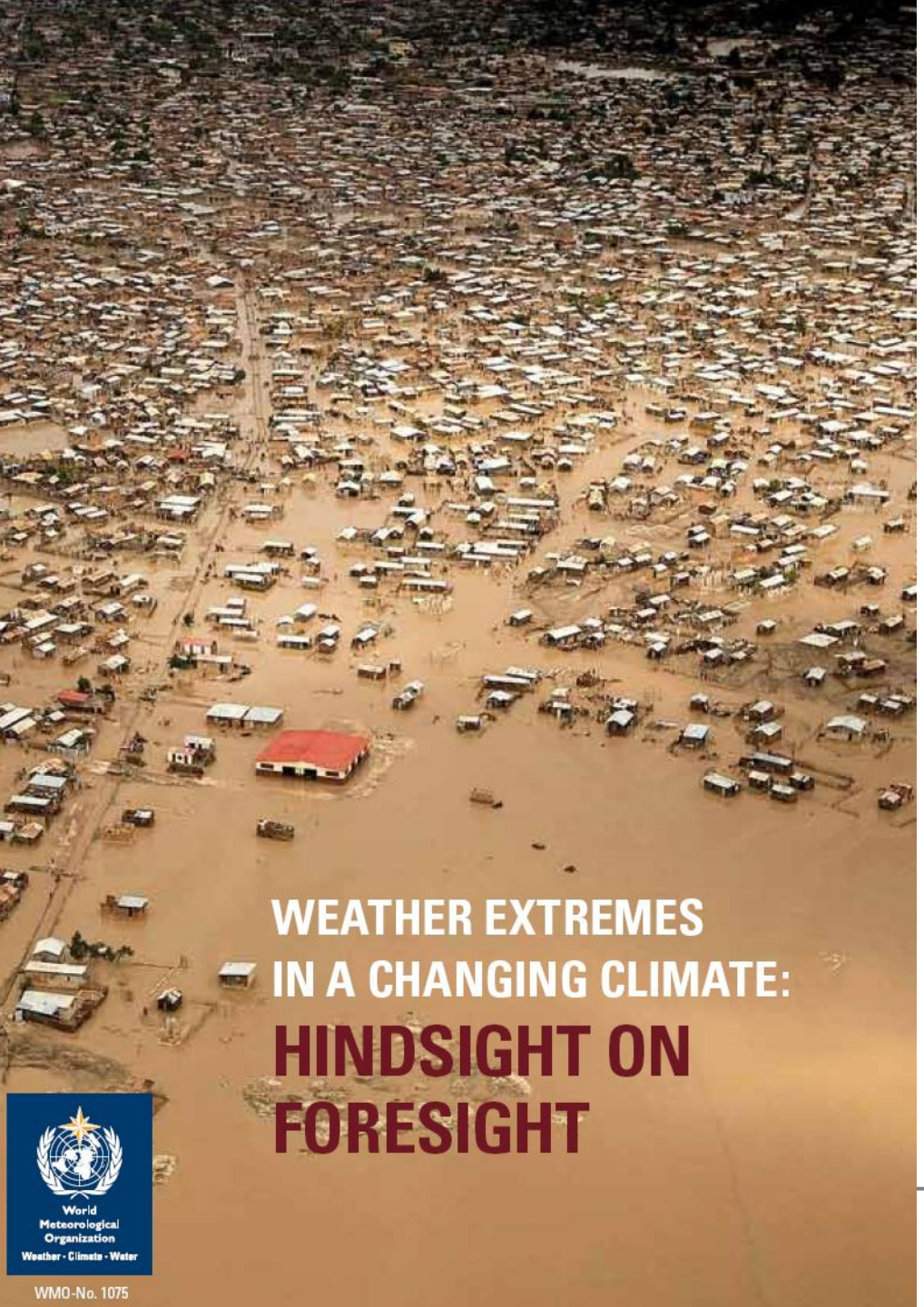


Kemp et al. PNAS 2011

Latest Gobal Sea Level Projections



Global Sea Level Rise Scenarios for the
United States National Climate Assessment, NOAA (2012)



The decade 2001–2010 was the warmest ever recorded. The decade was marked by numerous weather and climate extremes, unique in strength and impact.

(WMO 2011)

Nature Climate Change, March 2012:

nature climate change

PERSPECTIVE

PUBLISHED ONLINE: 25 MARCH 2012 | DOI: 10.1038/NCLIMATE1452

A decade of weather extremes

Dim Coumou and Stefan Rahmstorf*

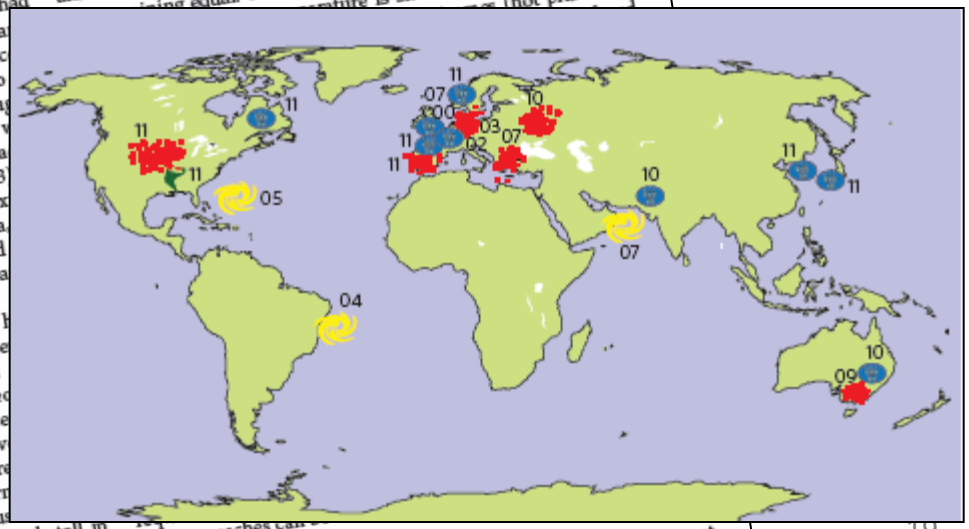
The ostensibly large number of recent extreme weather events has triggered intensive discussions, both in- and outside the scientific community, on whether they are related to global warming. Here, we review the evidence and argue that for some types of extreme — notably heatwaves, but also precipitation extremes — there is now strong evidence linking specific events or an increase in their numbers to the human influence on climate. For other types of extreme, such as storms, the available evidence is less conclusive, but based on observed trends and basic physical concepts it is nevertheless plausible to expect an increase.

For the United States, 2011 was a year of extreme weather, with 14 events that caused losses in excess of US$1 billion each[1]. The US National Oceanic and Atmospheric Administration spoke of "a year seemingly full of weather extremes" after July had set new monthly heat records for Texas, Oklahoma and Delawa... The period from January to October was the wettest on rec... for several northeastern states, with wet soils contributing to severe flooding when Hurricane Irene hit the region in Au... During spring, the southern United States had been hit by the ... recorded tornado outbreak in history: April saw 753 torna... beating the previous monthly record of 542 (from May 2003) ... large margin[2]. Other regions in the world were affected by ex... weather in 2011 as well: rainfall records were set in Australia, ... and Korea, whereas the Yangtze Basin in China experienced ... drought[1]. In western Europe, spring was exceptionally hot a... setting records in several countries (Table 1)[1].

But 2011 was not unique: the past decade as a whole h... an exceptional number of unprecedented extreme weathe... some causing major human suffering and economic ... (Table 1 and Fig. 1). In August 2010, the World Meteo... Organization issued a statement on the "unprecedented se... extreme weather events", stating that it "matches Intergov... Panel on Climate Change (IPCC) projections of more fre... more intense extreme weather events due to global warr... Moscow heatwave and Pakistan flooding that year illus... destructive extreme weather can be to societies: the death toll in ... estimated at 11,000 and drought caused grain- ... government to ban wheat ... flooding in ...

Simple physical considerations

For some types of extreme, there are simple physical reasons why they would increase in a warming climate. If the average temperature rises, then obviously so will the number of heat records, all ... equal. Cold extremes will decrease, but if the prob- ... ature is shifted unchanged towards ... (hot plus cold) ...



... ling approaches can ...

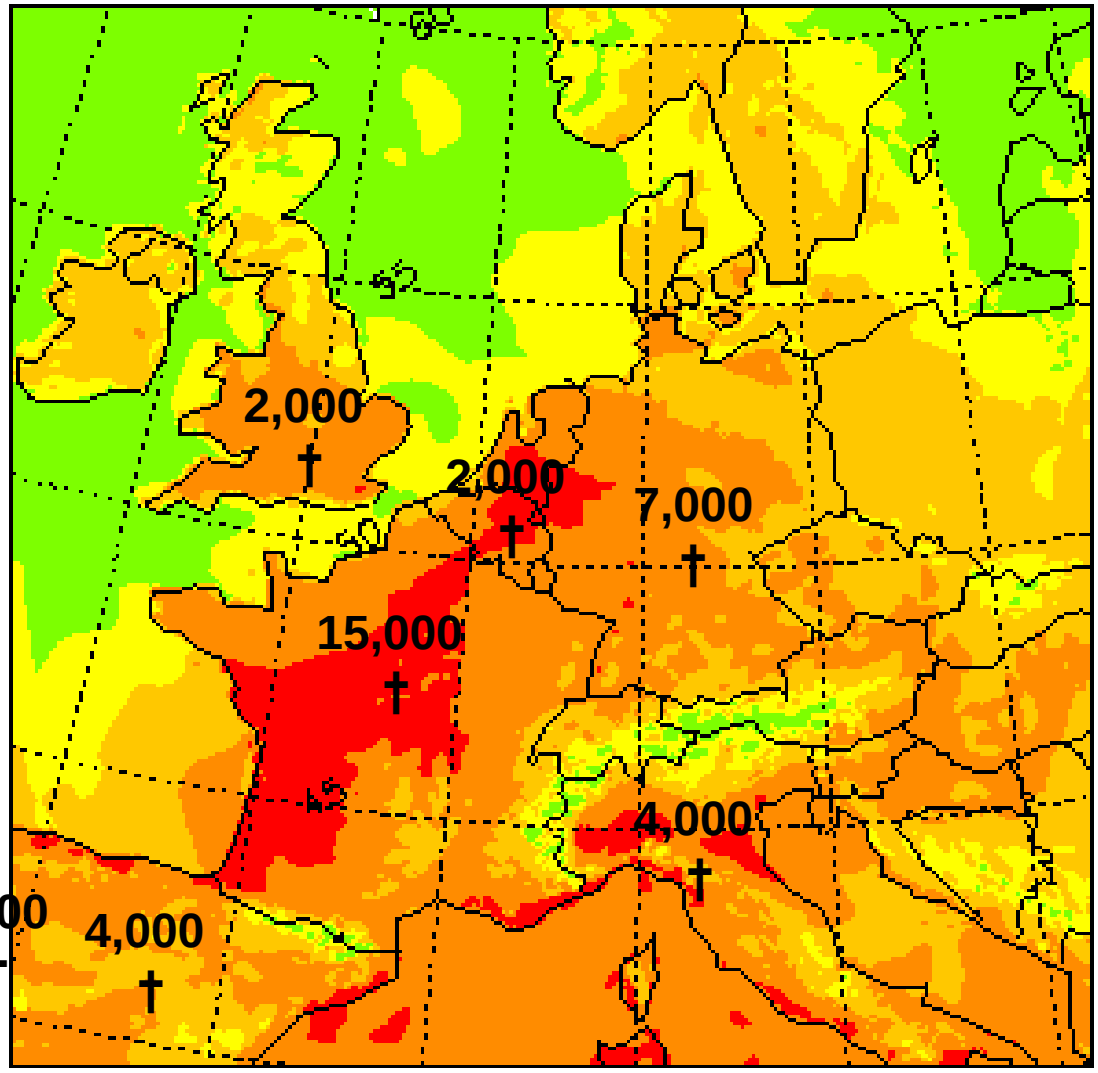
Statistics and the detection problem

... statistics, scientists can analyse whether the number of recent ... ificantly larger than expected in a stationary ... methods thus may link ...

Some unprecedented extremes since 2000

Region (Year)	Meteorological Record-breaking Event	Confidence in attribution to climate change	Impact, costs
England and Wales (2000)	Wettest autumn on record since 1766. Several short-term rainfall records[2]	Medium based on[3–5]	~£1.3 billion[3]
Europe (2003)	hottest summer in at least 500 years[6]	High based on[7,8]	Death toll exceeding 70,000[9]
England and Wales (2007)	May to July wettest since records began in 1766[10]	Medium based on[3,4]	Major flooding causing ~£3 billion damage
Southern Europe (2007)	Hottest summer on record in Greece since 1891[11]	Medium based on[8,12–14]	Devastating wildfires
Eastern Mediter-ranean, Middle-East (2008)	Driest winter since 1902 (see Fig. 20)	High based on[15]	Substantial damage to cereal production[16]
Victoria (Aus) (2009)	Heat wave, many station temperature records (32–154 years of data)[17]	Medium based on[8,14]	Worst bushfires on record, 173 deaths, 3,500 houses destroyed[17]
Western Russia (2010)	Hottest summer since 1500[18]	Medium based on[8,13,14,19]	500 wildfires around Moscow, crop failure of ~25%, death toll ~55,000, ~US$15B eco-nomic losses[18]
Pakistan (2010)	Rainfall records[20]	Low to Medium based on[21,22]	Worst flooding in its history, nearly 3000 deaths, affected 20M people[23].
Colombia (2010)	Heaviest rains since records started in 1969[26]	Low to Medium based on[21]	47 deaths, 80 missing[26]
Western Amazon (2010)	Drought, record low water level in Rio Negro[27]	Low[27]	Area with significantly increased tree mortality spanning3.2 million km[27]
Western Europe (2011)	Hottest and driest spring on record in France since 1880[28]	Medium based on[8,14,29]	French grain harvest down by 12%
4 US states (TX, OK, NM, LA) (2011)	Record-breaking summer heat and drought since 1880[30,31]	High based on[13,14,31,32]	Wildfires burning 3 million acres (preliminary impact of $6 to $8 billion)[33]
Continental U.S. (2012)	July warmest month on record since 1895[34] and severe drought conditions	Medium based on[13,14,32]	Abrupt global food price increase due to crop losses[35]

Heat Waves



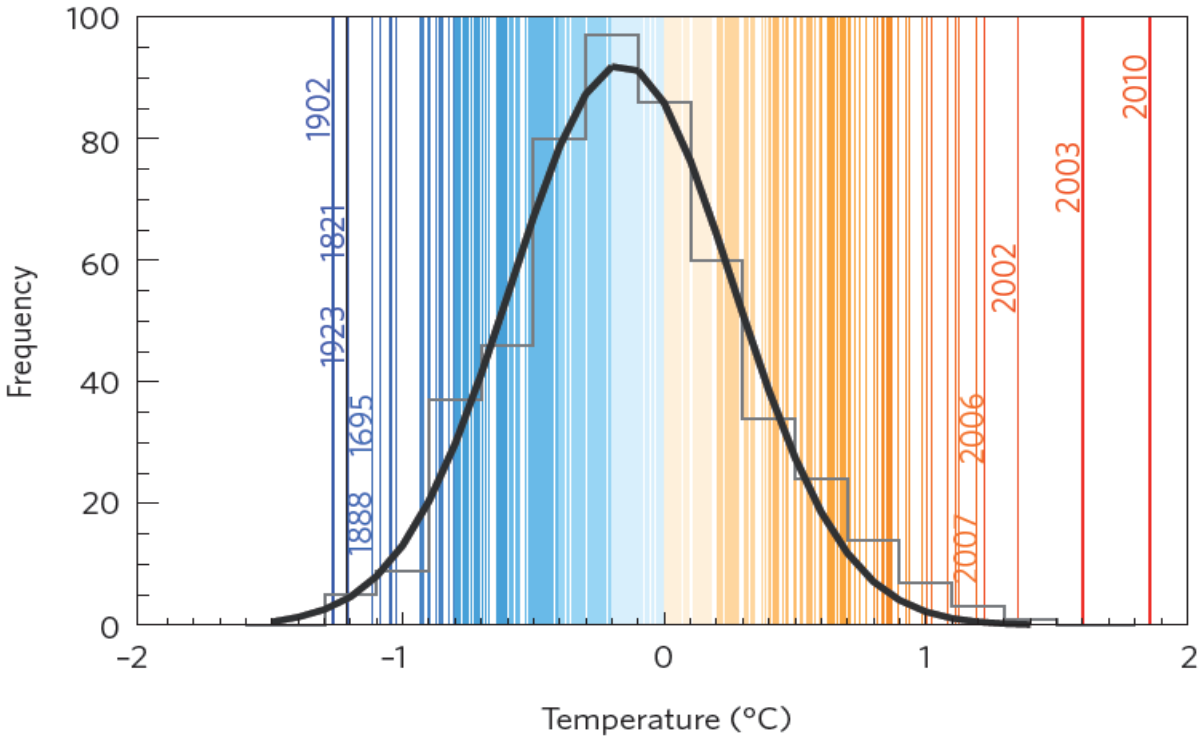
Summer 2003:
greatest natural desaster in Europe

ca. 70.000 fatalities

Heat Stress

Mortality data: Earth Policy Institute
Heat Stress: Deutscher Wetterdienst

Heat Waves



Alex Aminev, Reuters

Hottest summers in Europe since 1500 AD:

2010

2003

2002

2006

2007

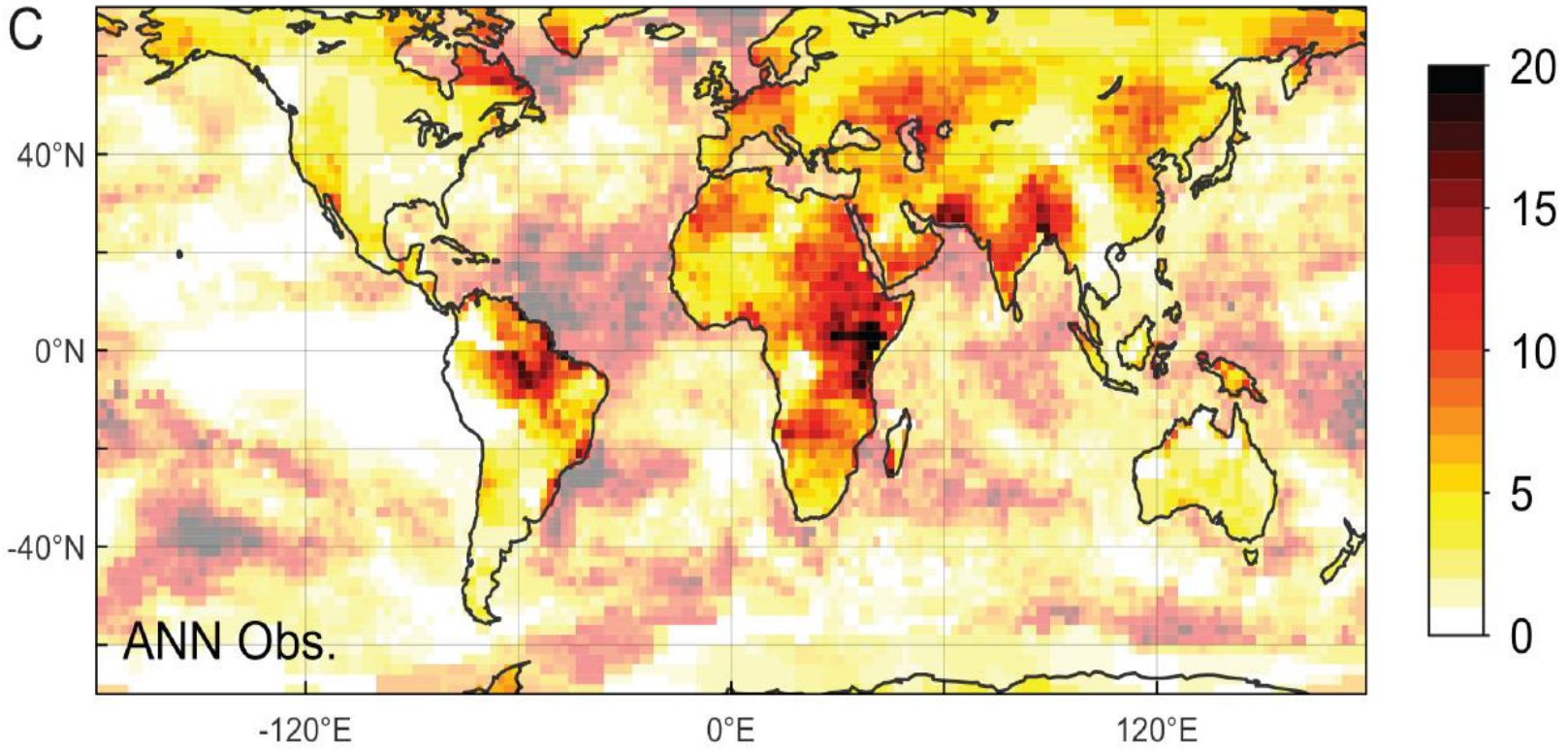
Distribution of European summer temperatures AD 1500 - 2010

(Barriopedro et al. Science 2011)

Heat Waves

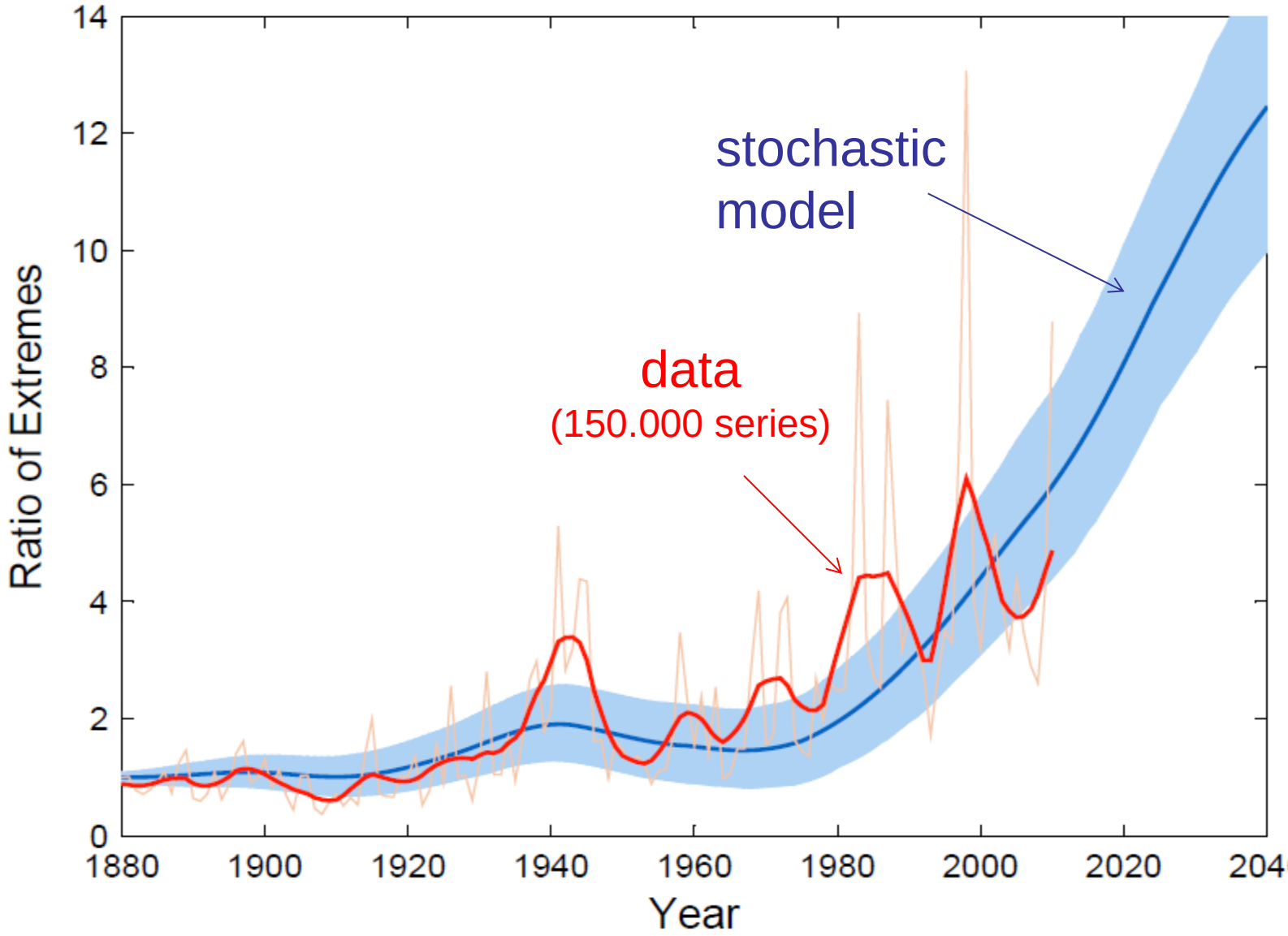
Observed increase in monthly heat records

- **Based on 150.000 time series starting in the year 1880**

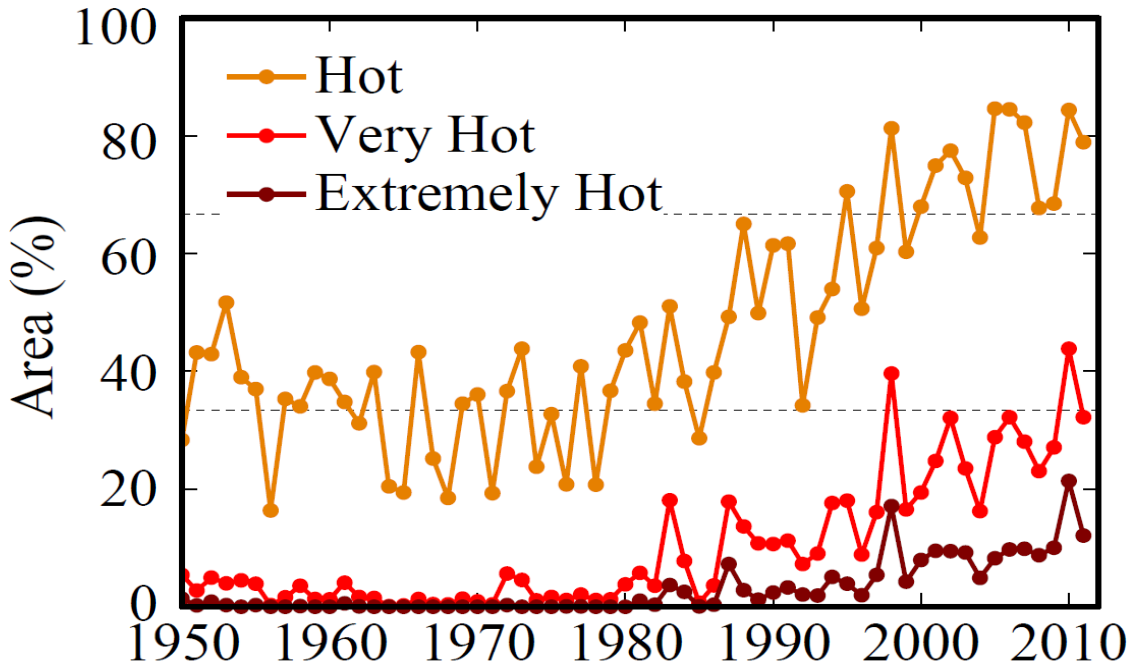


Source: Coumou et al. (2013)

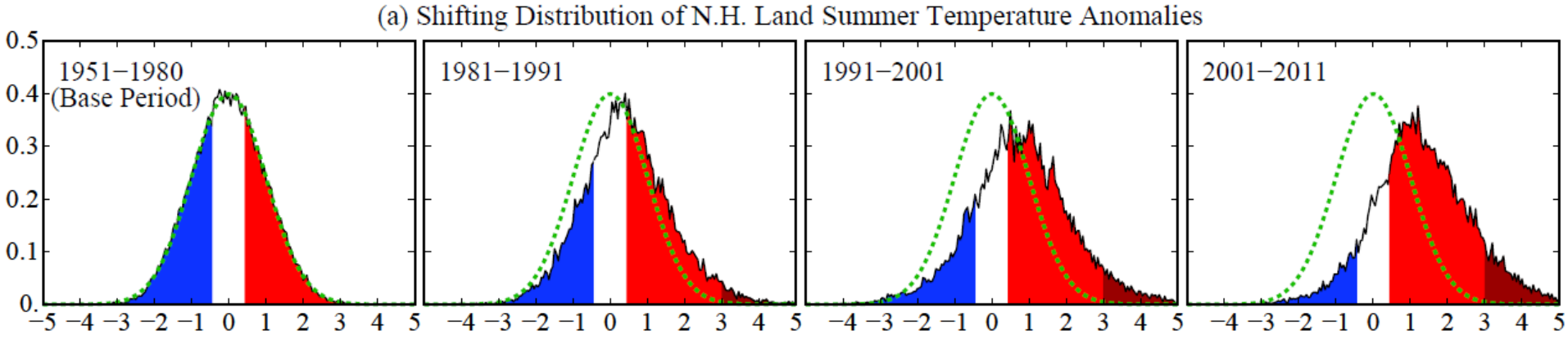
Future increase in record hot months



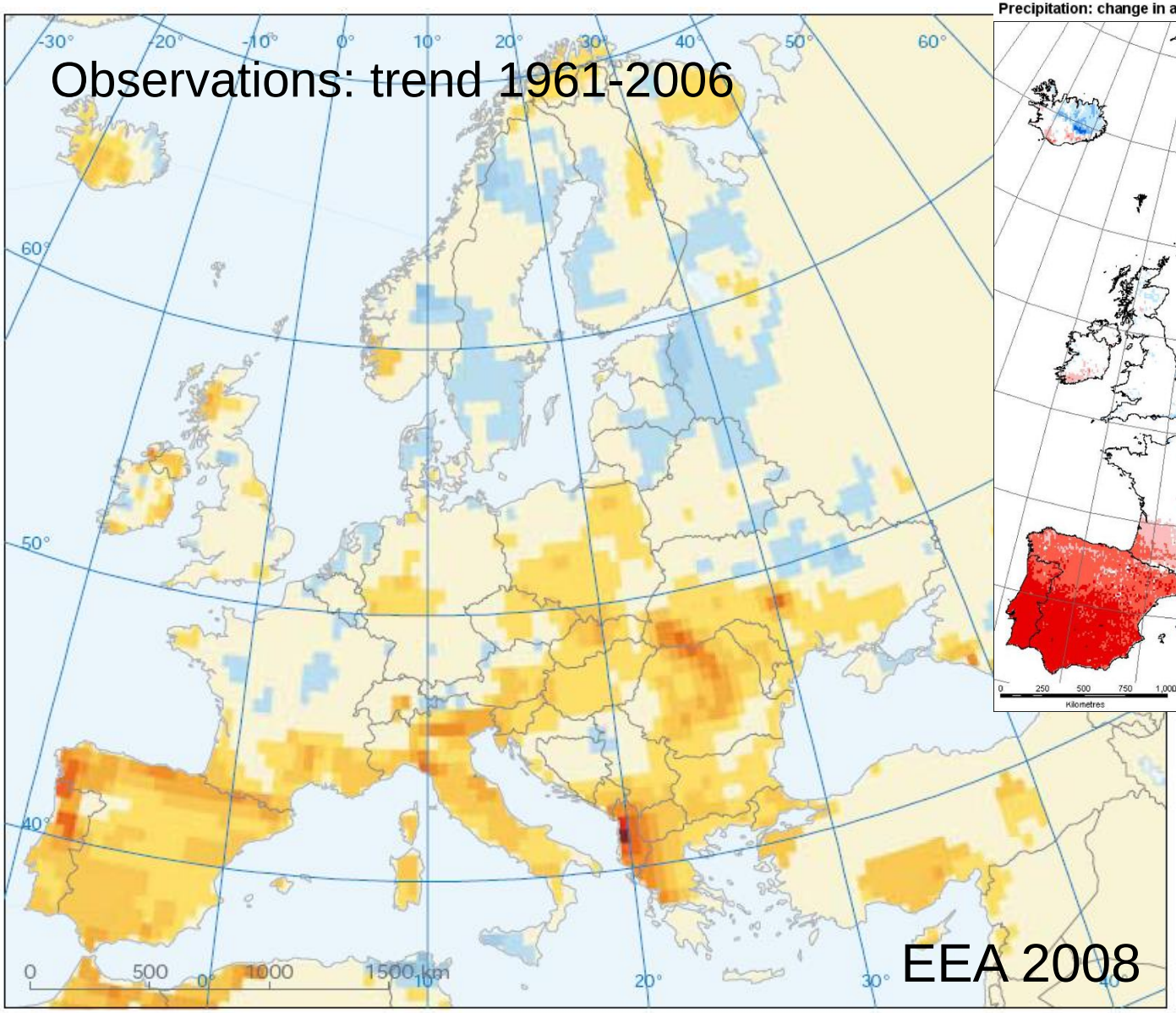
Increasing heat extremes

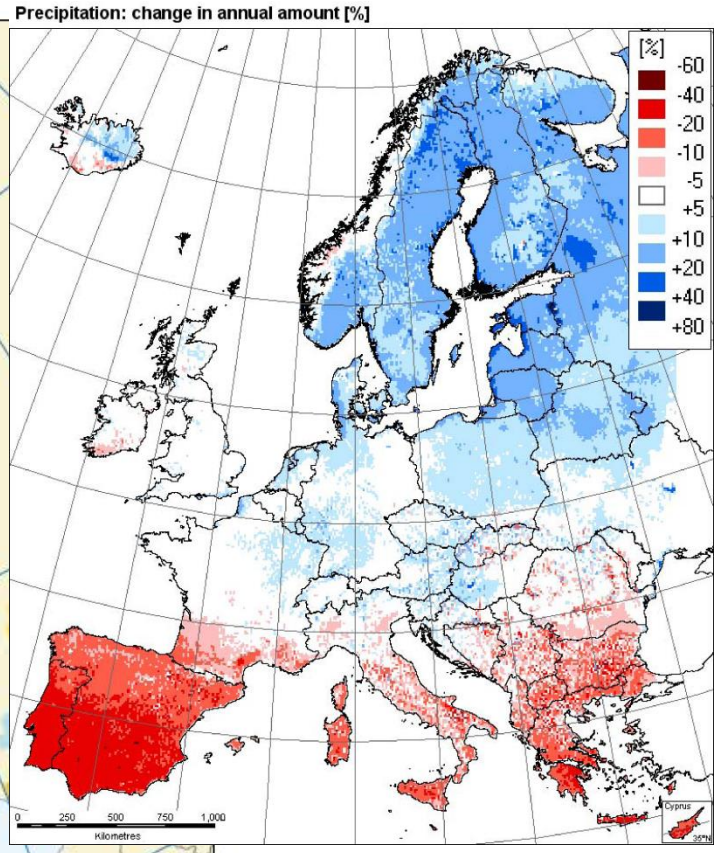


Hansen et al. 2012



Changes in Precipitation





Model simulation

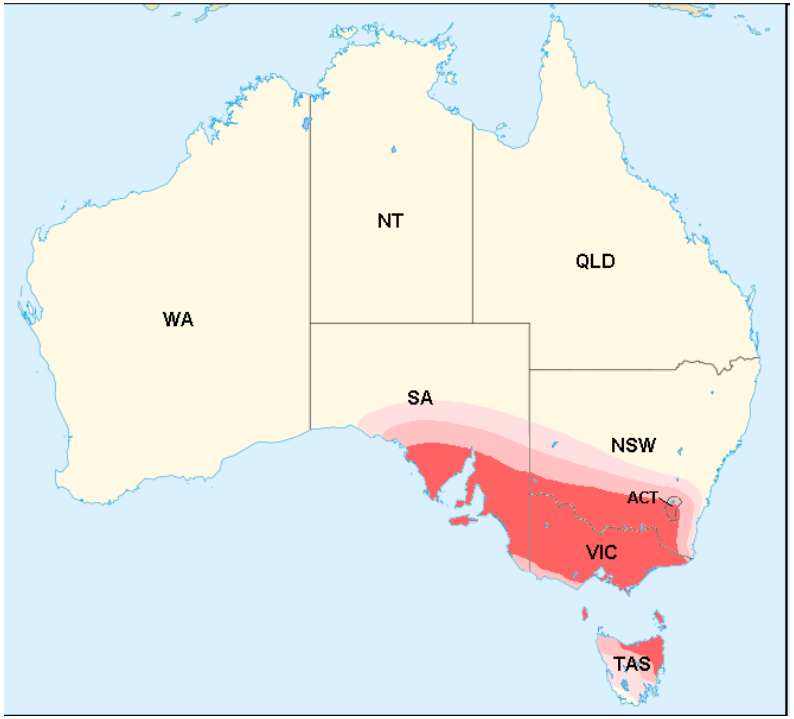
Southern Europe
Is drying out

Forest fires in Greece, August 2007

Source: spiegel.de

Australian bush fires – February 2009

- **Unprecedented Heat wave**



- **“Black Saturday” bush fires (worst on record) cost 173 lives and destroyed over 3,500 building**

Heat Raises Fire Risk

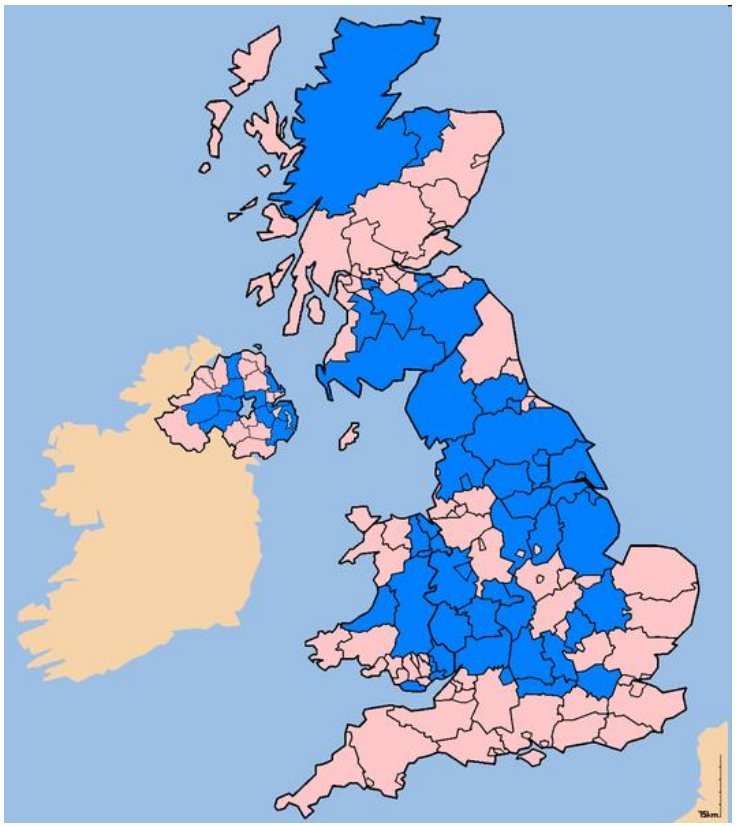
Extreme rainfall: Elbe flooding 2002

- Aug 2002: highest daily rainfall ever recorded in Germany

- Damages of ~$3 billion in Czech Republic, >$9 billion in Germany.
- Elbe river reached highest level since records began in 1275

Flooding in Britain in 2007

- May to July by far wettest in England and Wales since 1766

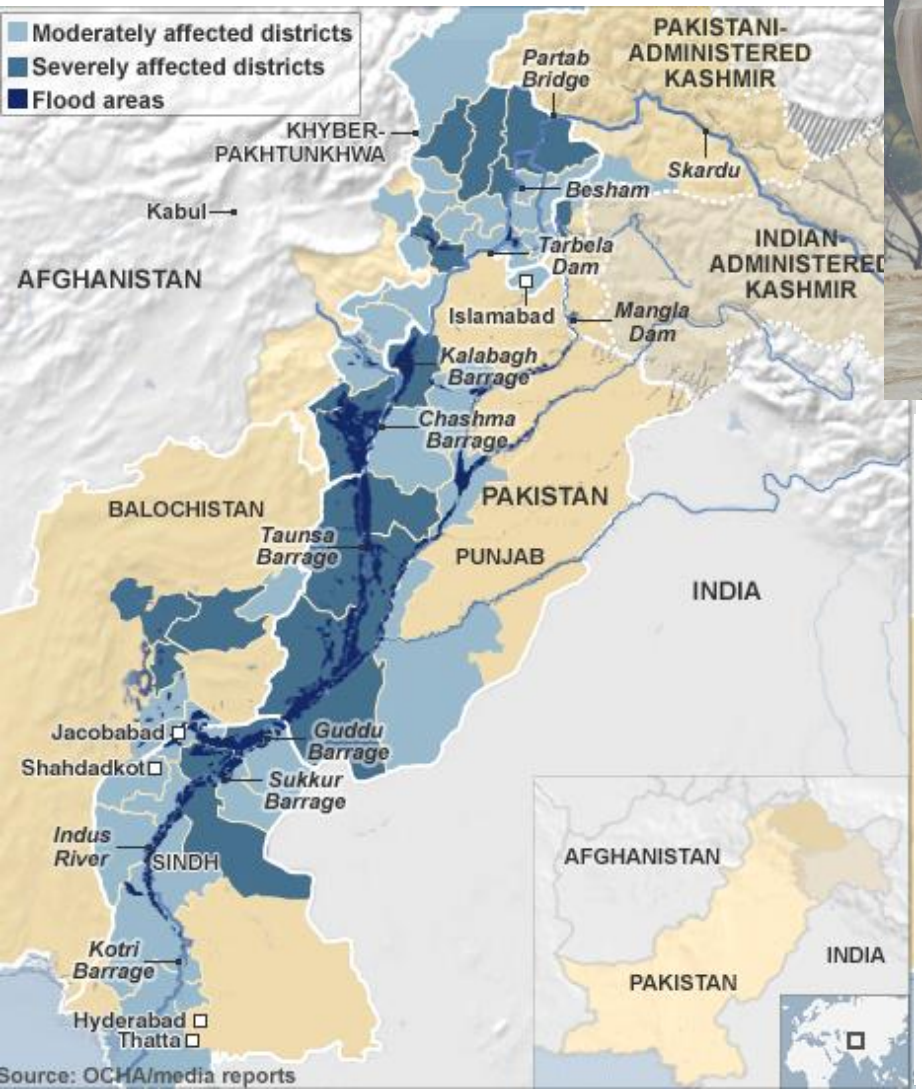


Areas affected by flooding

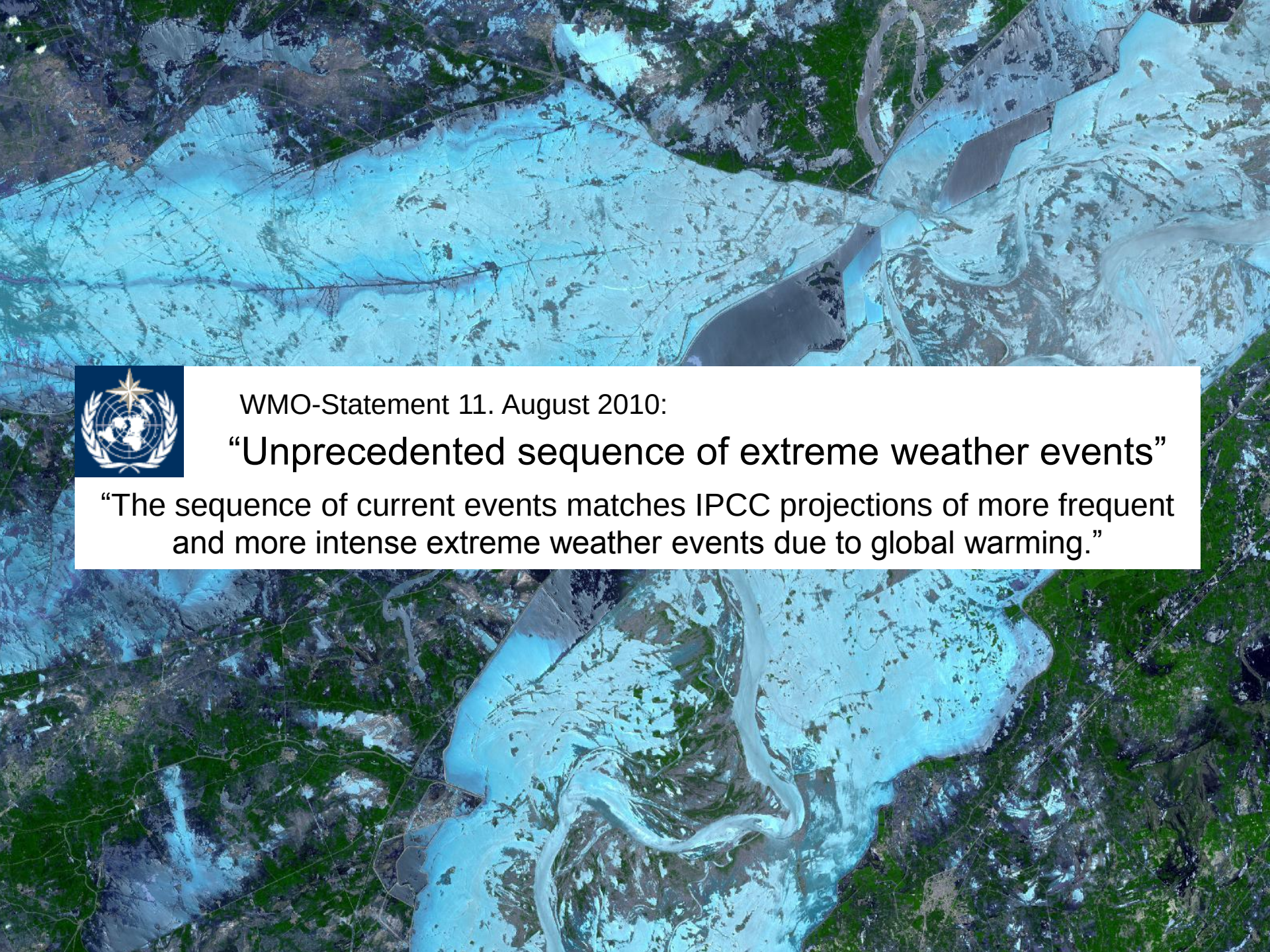
- Widespread crop damage
- Financial Damage: £3 billion

Unprecedented Rainfall in Pakistan 2010

- Pakistan flooding



- Rainfall records caused the worst flooding in history
- Approximately one-fifth of Pakistan's total land area was underwater
- Affected about 20 million people, death toll of close to 2,000



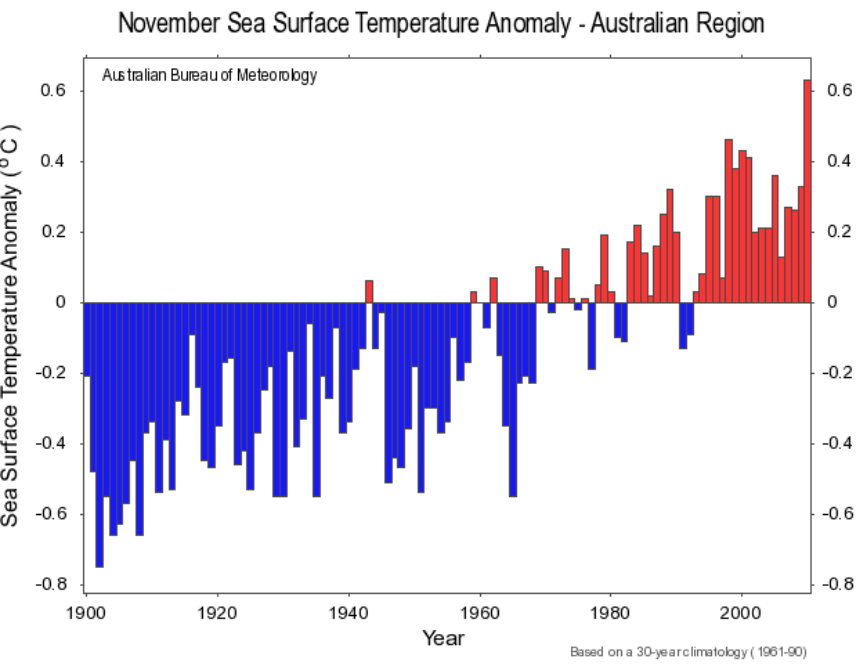
WMO-Statement 11. August 2010:

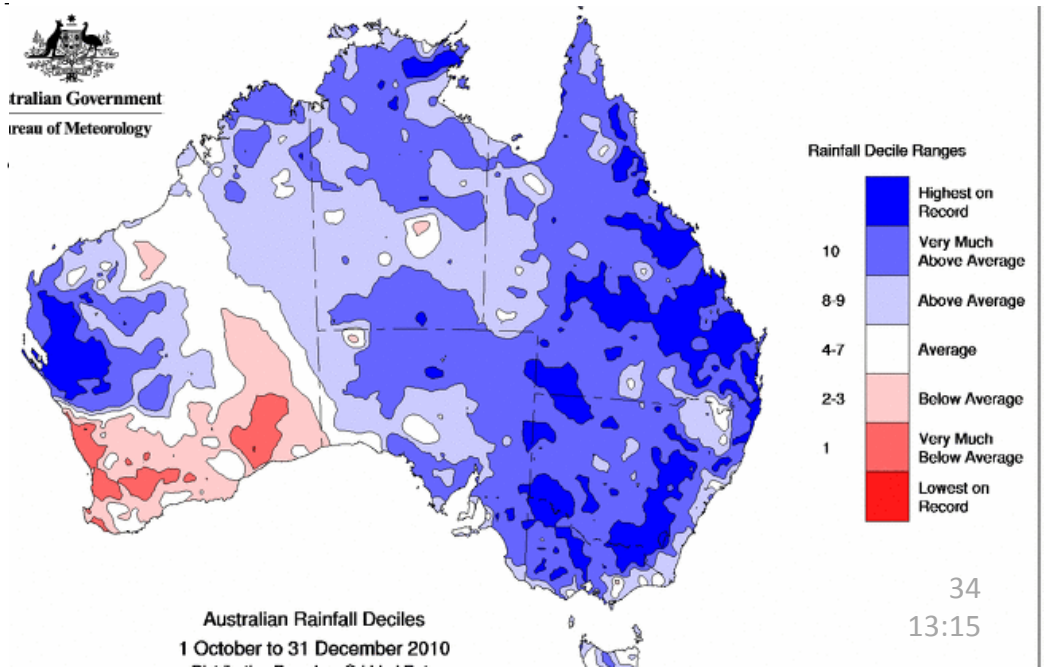
“Unprecedented sequence of extreme weather events”

“The sequence of current events matches IPCC projections of more frequent and more intense extreme weather events due to global warming.”

Unprecedented Extreme Rainfall Australia 2011

- Record rainfall causing flooding of large parts of Queensland, incl Brisbane
- Link to record high sea surface temperatures?
- Exceptional blip in global sea level!

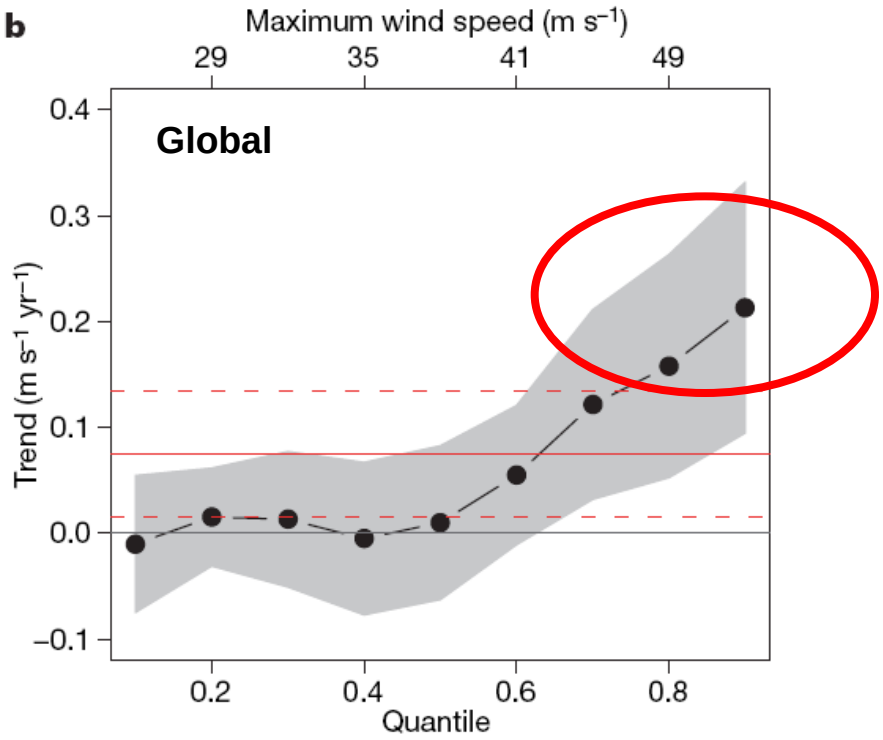




Tropical cyclones

Strongest cyclones are increasing globally

1 ºC warming corresponds to 30% increase in number of severe (cat. 4 & 5) storms



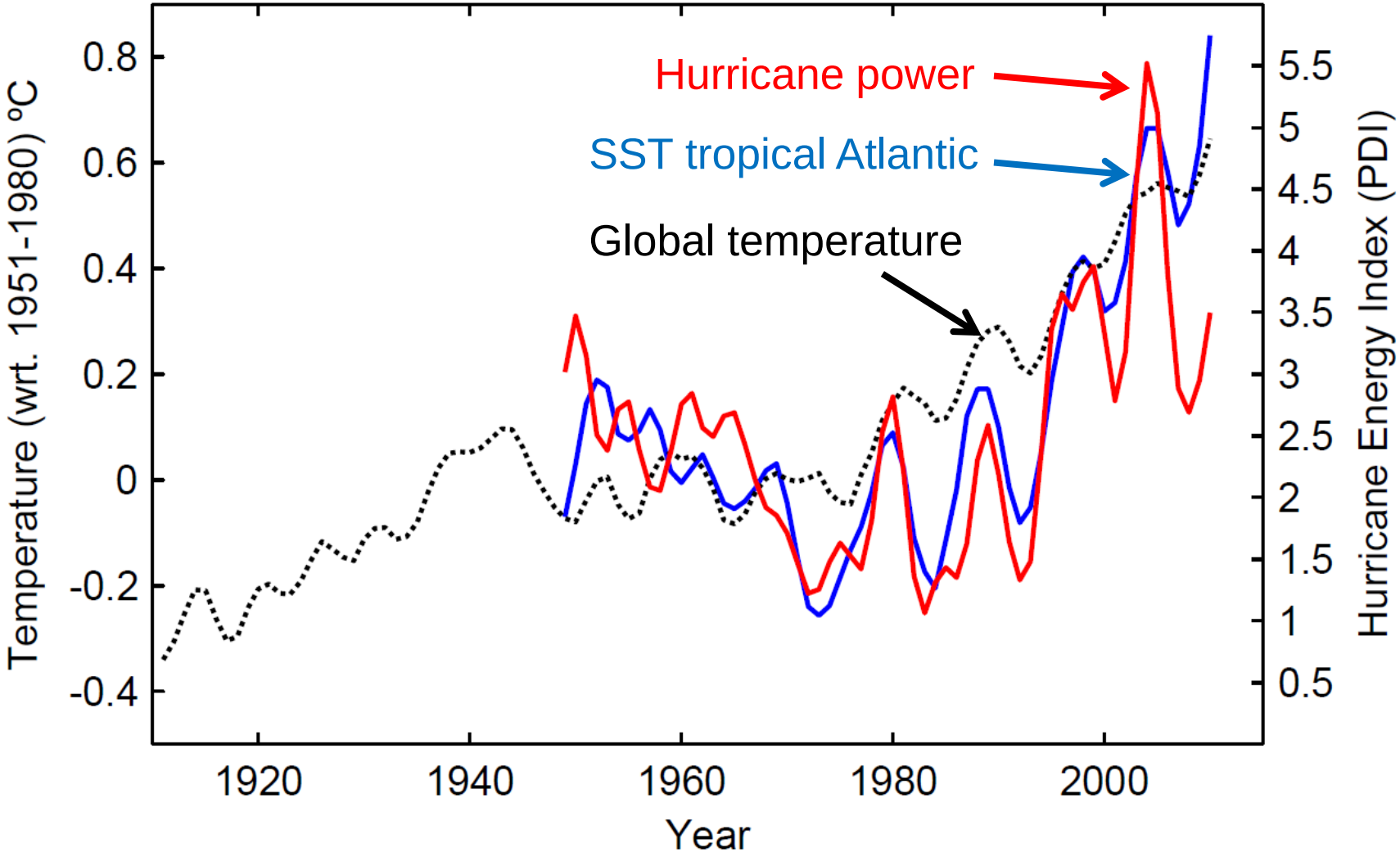
Elsner et al. Nature 2008

PIK

Unprecedented Atlantic hurricane season 2004

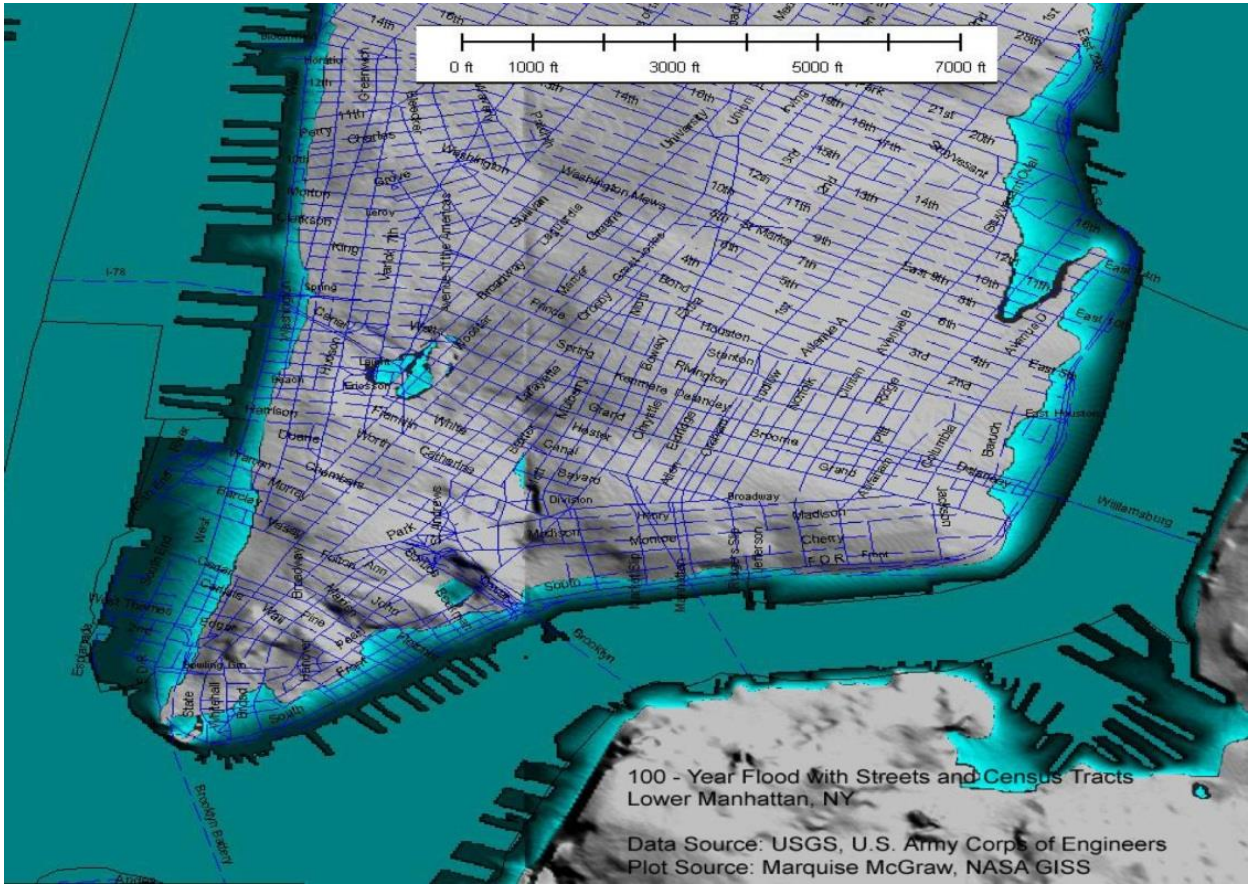
- 28 tropical storms (previous record 21), 15 reached hurricane strength (previous record: 12), 4 reached the max. category 5 (previous record: 2)
- hurricane *Wilma*, strongest ever recorded in the North Atlantic
- First ever hurricane in the South Atlantic

Atlantic hurricane power



Data: Kerry Emanuel, graph Coumou & Rahmstorf 2012

New York storm surges



- **Today: once in 100 years**
- **After 1 m rise: once in 3 years**

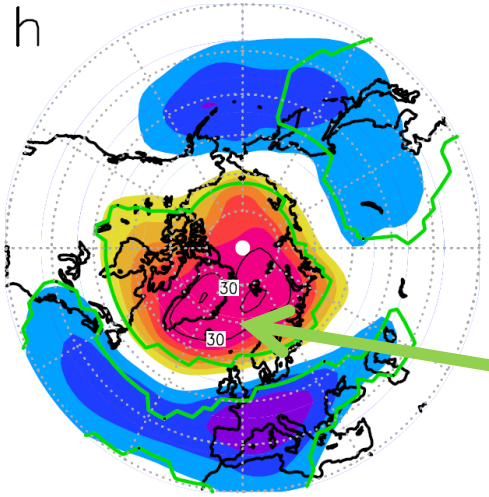
Rosenzweig and Solecki (2001)

Sandy

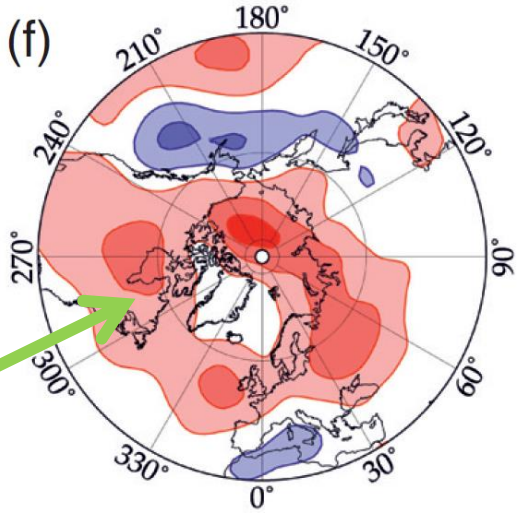
- Sea-level rise made storm surge worse
- Warm SST tends to sustain and strengthen storm
- Evaporation due to warm SST enhances precipitation

PIK

A connection of sea ice and pressure patterns?

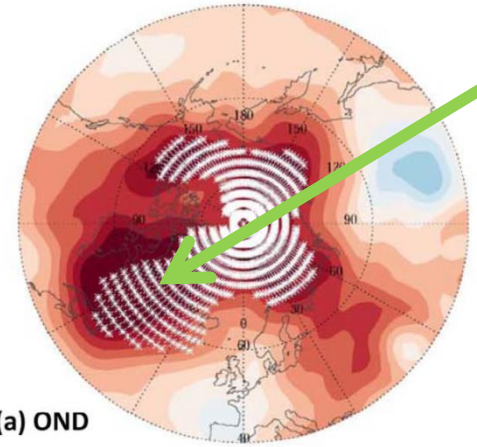


Petoukhov & Semenov JGR 2010
Simulation with ECHAM5 model
850 mb height response to reduce sea ice

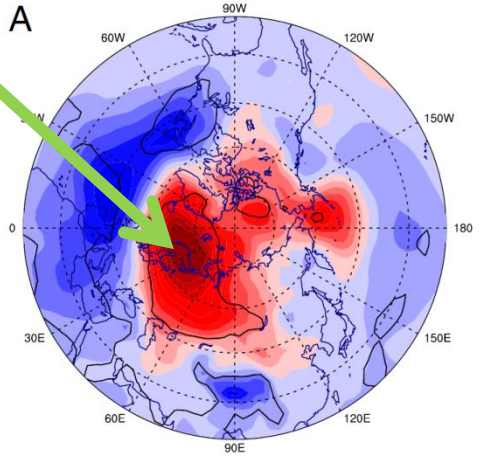


Jaiser et al. Tellus 2012 (OND)
Correlation of sea ice extent and 500 mb height
ERA reanalysis data vs HadISST sea ice

Less sea ice
▸ high pressure anomaly over high-latitude North Atlantic



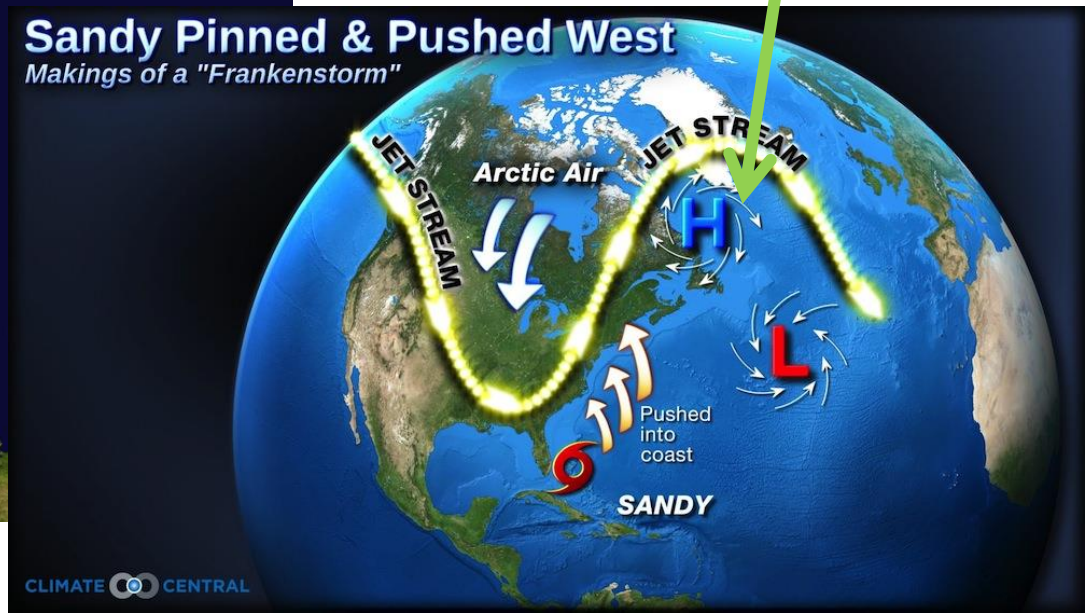
Francis & Vavrus GRL 2012
Comparing pressure patterns 2000-2010 vs 1970-1999 in NCAR-NCEP reanalysis



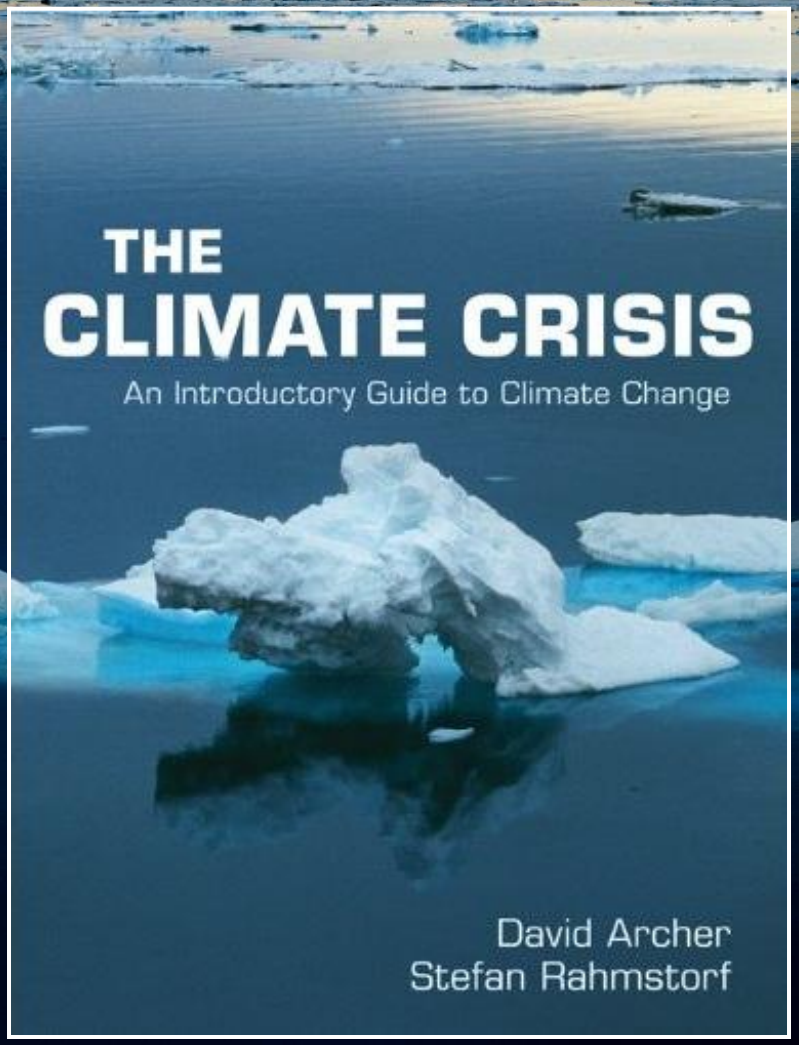
Liu et al. PNAS 2012
Linear regression winter sea level pressure vs NSIDC sea ice extent

The unusual track of Sandy

anomalous
high pressure over
high-latitude North
Atlantic blocks Sandy



Thank you for your attention!



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