Climate change and extreme weather events

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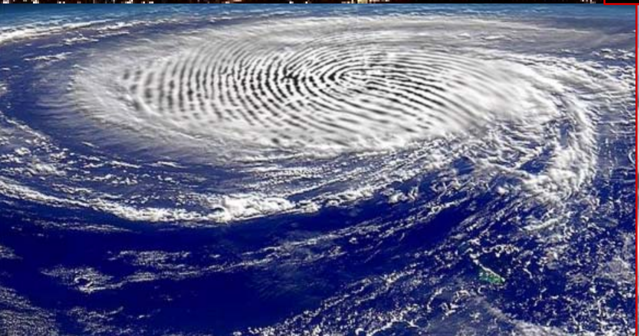
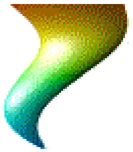
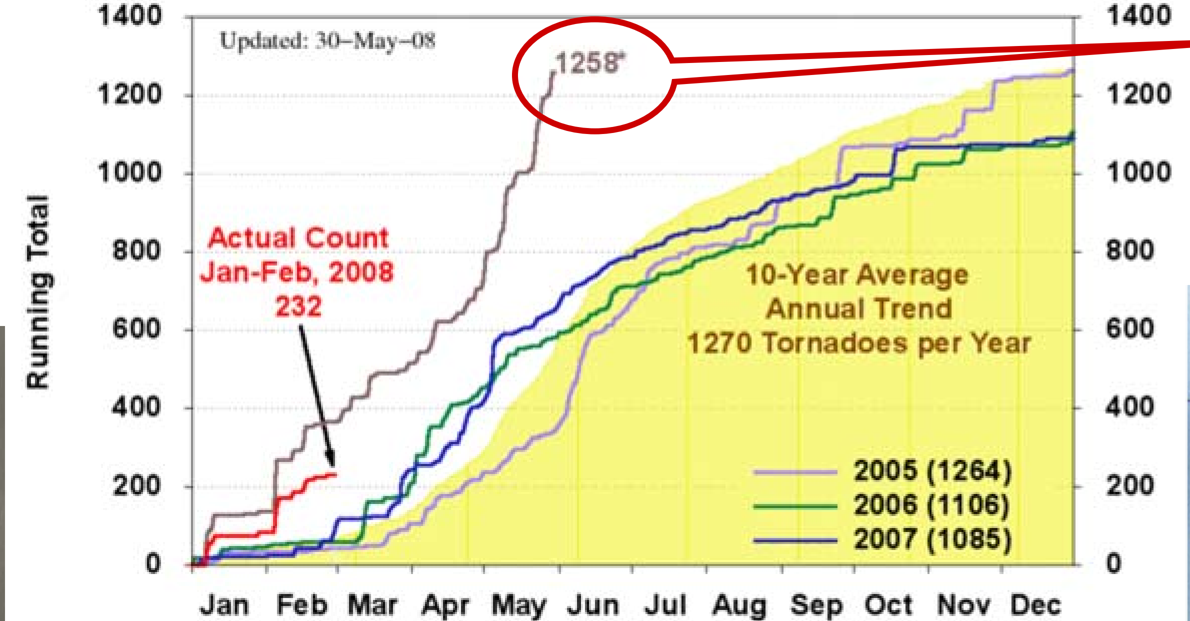


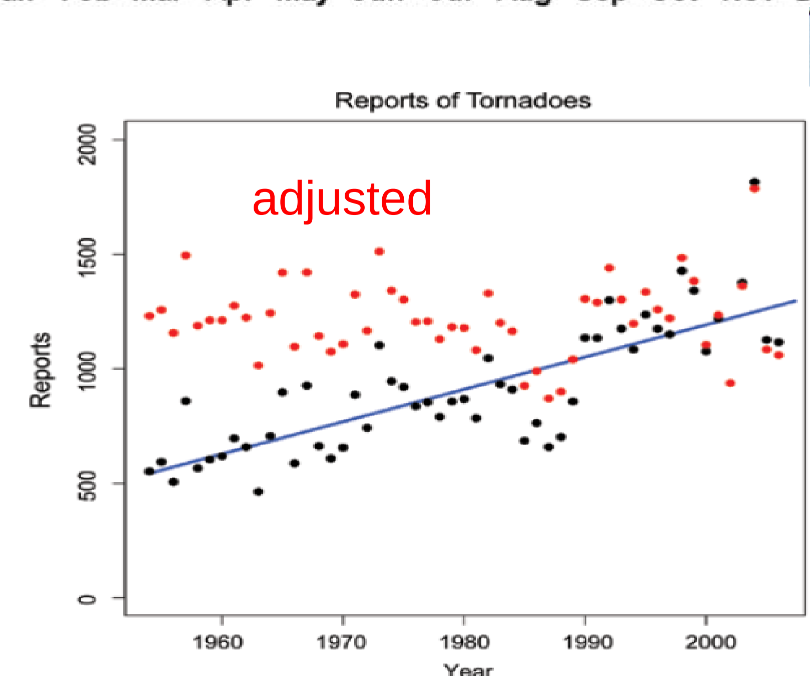

U.S. Annual Tornadoes

*2008: preliminary count, may include duplicates; Corrected through February





2008:
111 deaths
547 May
(prelim)

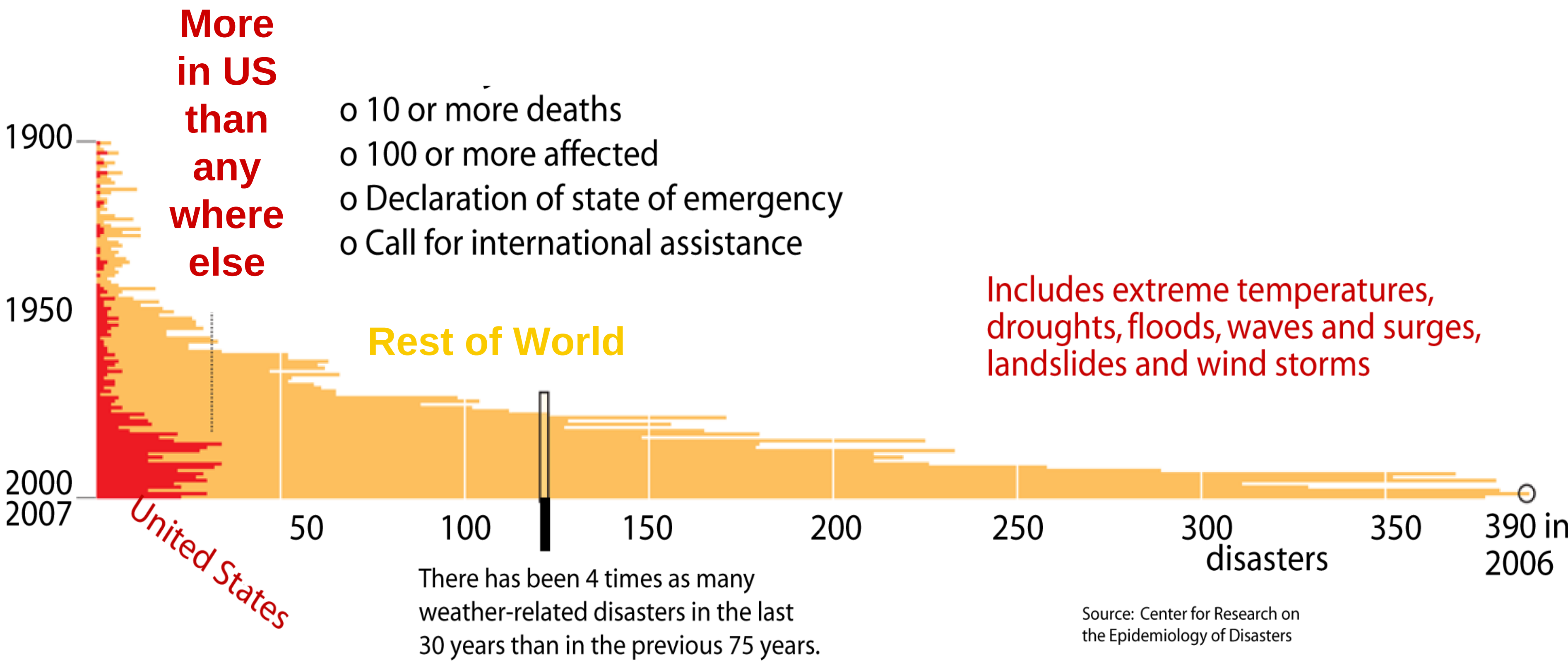


Climate change and extreme weather events

Changes in extremes matter most for society and the environment

- With a warming climate:
  - More high temperatures, heat waves
  - Wild fires and other consequences
  - Fewer cold extremes.
- More extremes in hydrological cycle:
  - Drought, heavy rains, floods
  - Intense storms

A century of weather-related disasters



Ask the right question!

- Is it global warming?
- Is it natural variability?

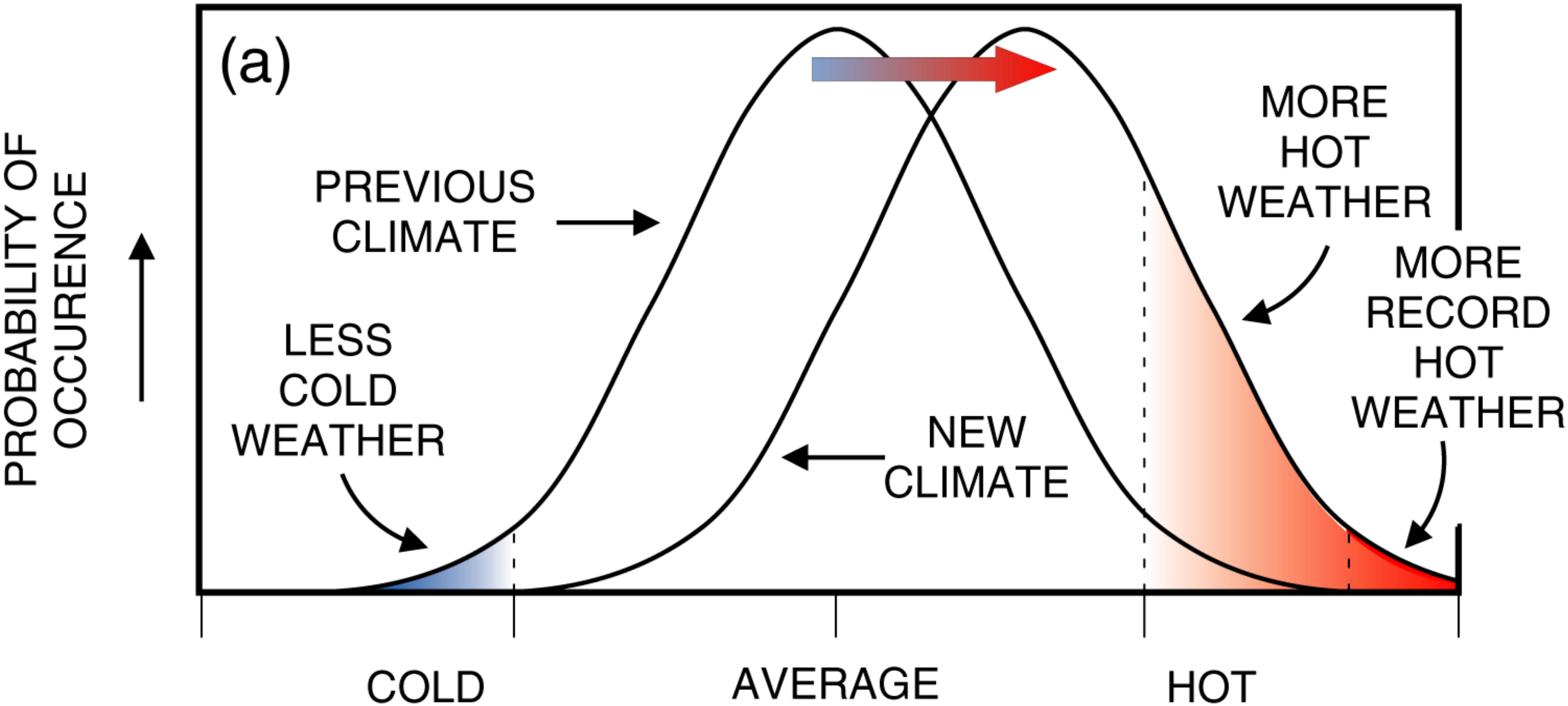
These are **not** the right questions: do not have answers.

We can estimate how rare an event was based solely on observations (requires good long data and assumptions of stationary climate)

We may be able to state that the odds are remote that the event could have occurred without warming (or without natural variability).

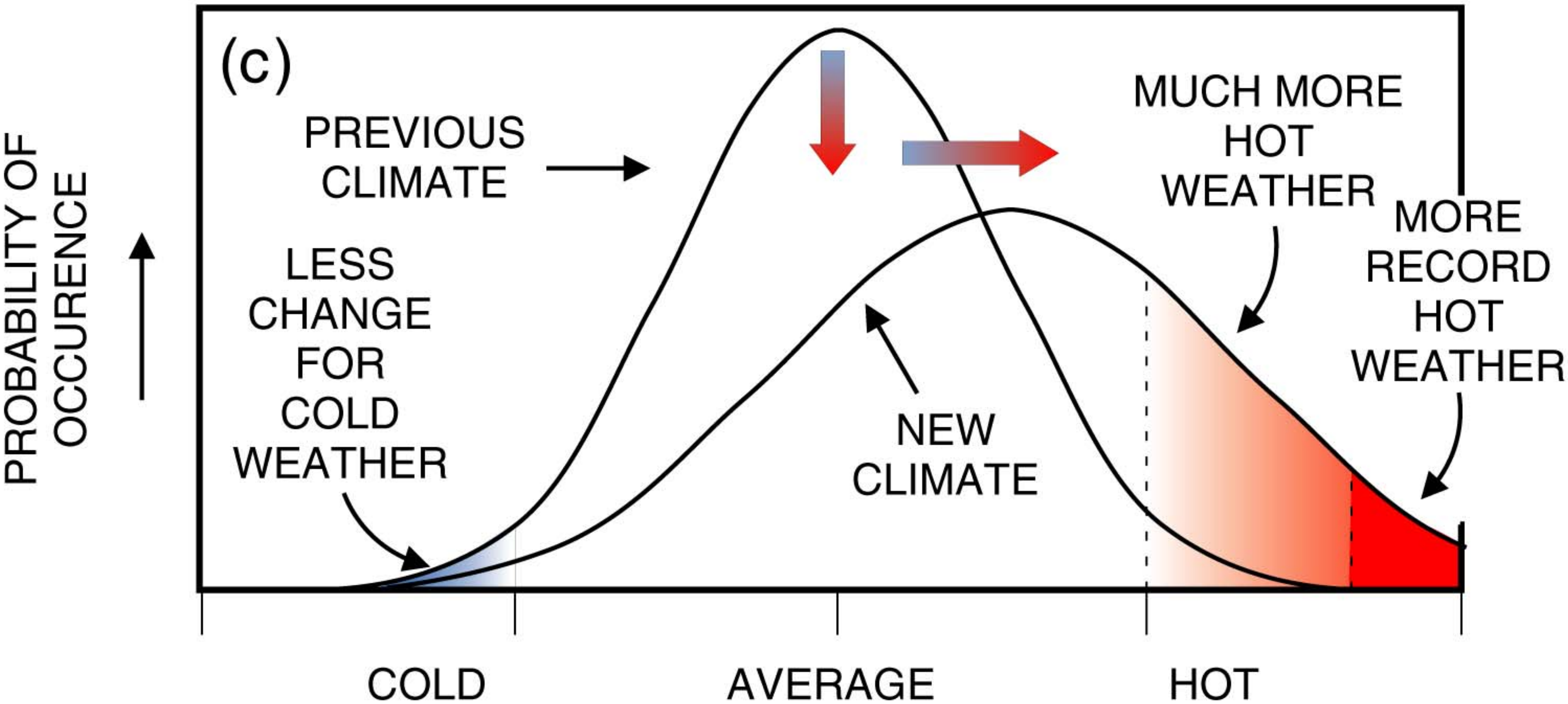
Always a combination of both.

Increase in Mean



Much bigger percentage changes in extremes

INCREASE IN MEAN AND VARIANCE



Much bigger percentage changes in extremes

Issues for extremes

- Data are “messy”
- Often data are not available with right sampling
- Spatial scales vary: tornadoes to droughts
- Extremes are inherently rare
- Terminology: High impact but not really extreme?
- Model definitions are often different
- Model grid box value may not be comparable to mean of grid box from observations

Estimating extremes in data and models

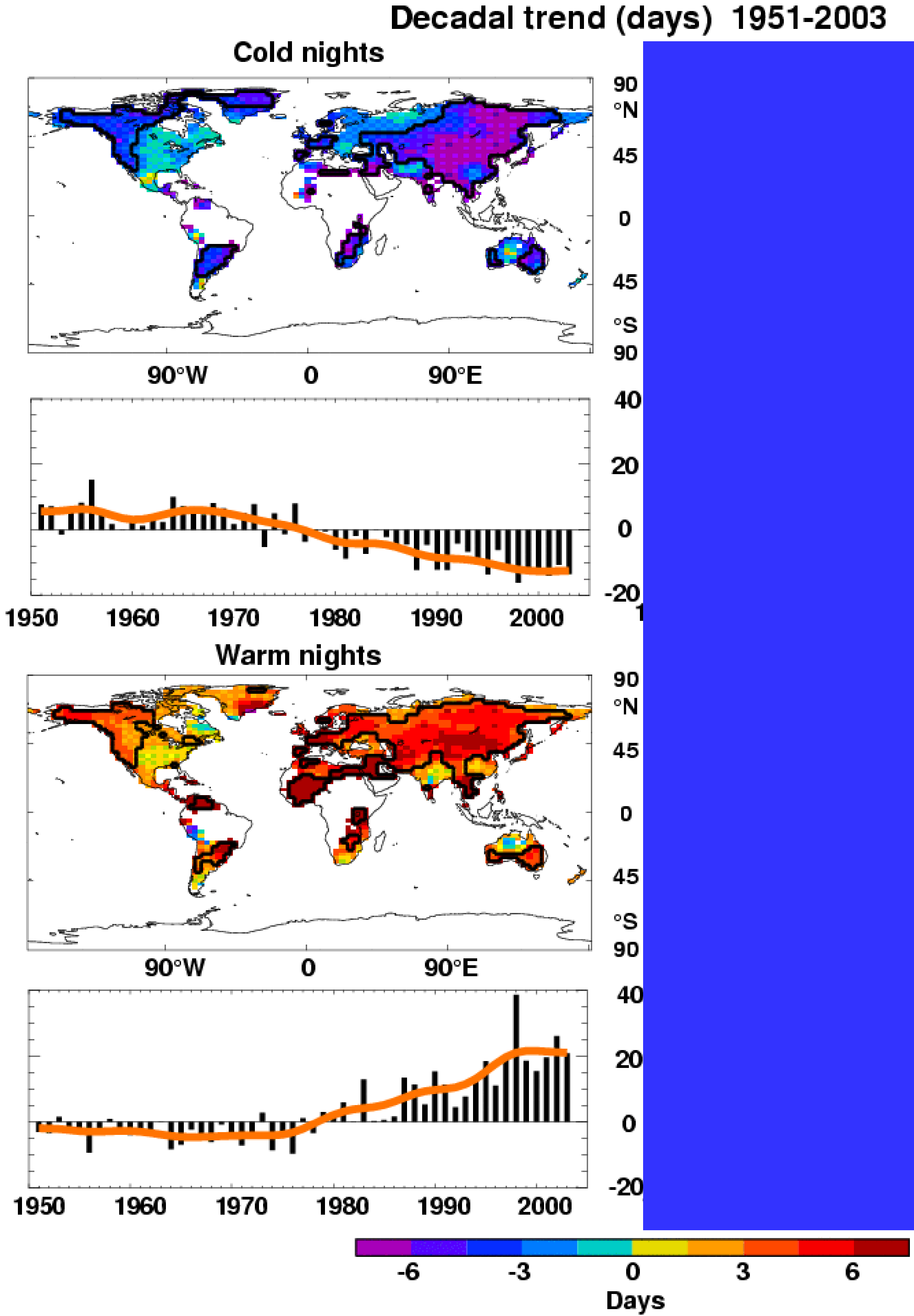
P1: probability of event under current conditions
P0: probability of event with external driver removed
(requires model)
FAR: Fraction of Attributable Risk = 1-P0/P1

Use coupled models to estimate attributable effect
Use statistical methods to estimate FAR (e.g. Stott et al 2004)
Use GCMs to estimate FAR (e.g. Pall et al 2007)
Extend to other regions and variables (e.g. Hoerling et al 2007)

Assumes model depicts real world.

Heat waves and wild fires

Impacts on human health and mortality, economic impacts, ecosystem and wildlife impacts



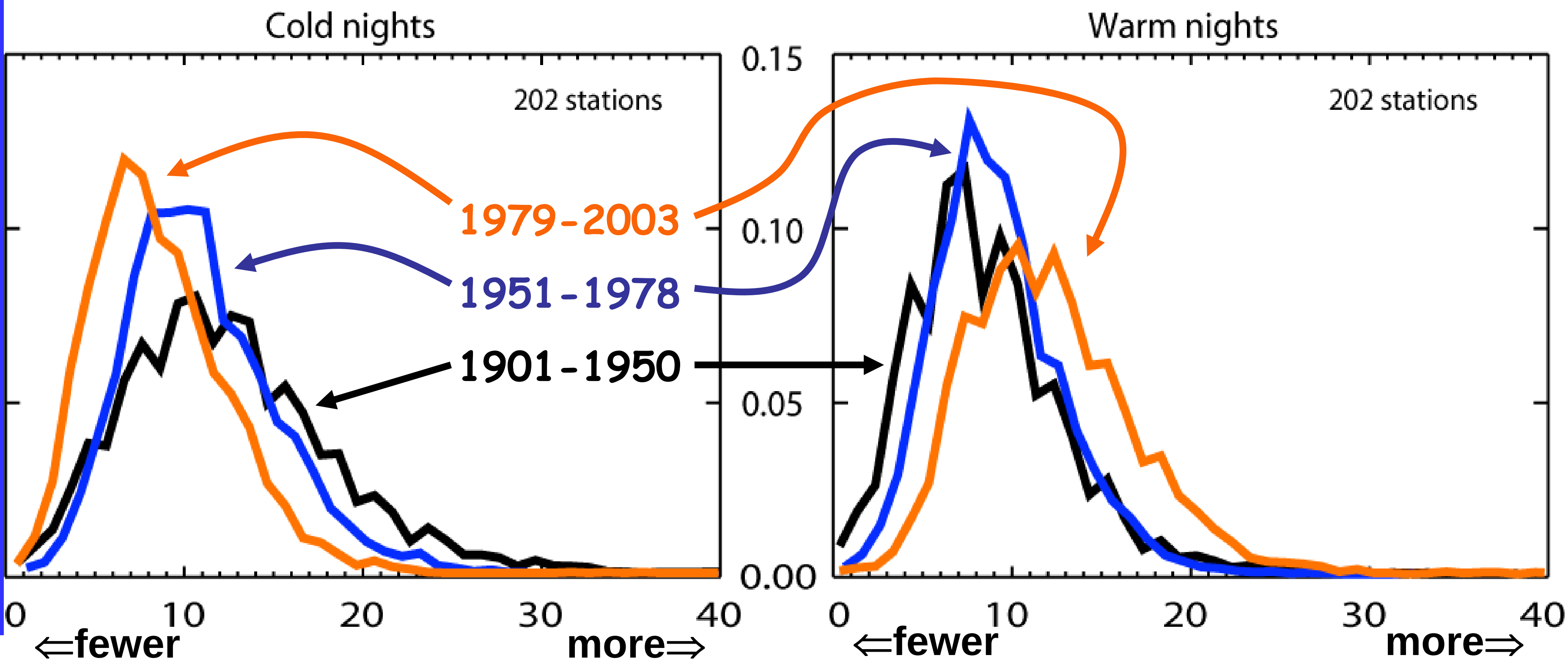
Extremes of temperature are changing!

Observed trends (days) per decade for 1951 to 2003:

5th or 95th percentiles

From Alexander et al. (2006) and IPCC

Warm nights are increasing; cold nights decreasing



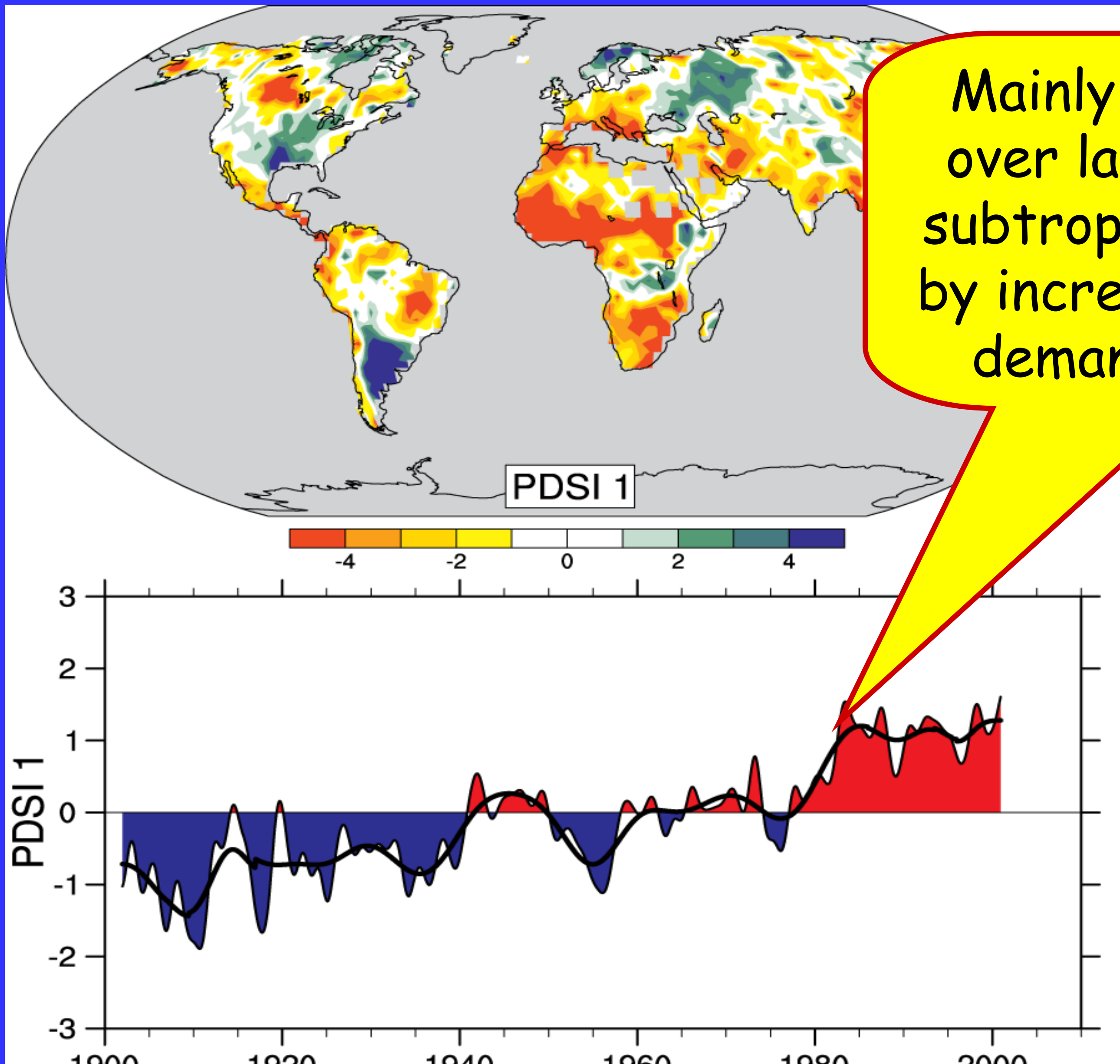
10th (left) and 90th (right) percentiles

Frequency of occurrence of cold or warm temperatures for 202 global stations with at least 80% complete data between 1901 and 2003 for 3 time periods:

1901 to 1950 (black), 1951 to 1978 (blue) and 1979 to 2003 (orange).

IPCC

Drought is increasing most places



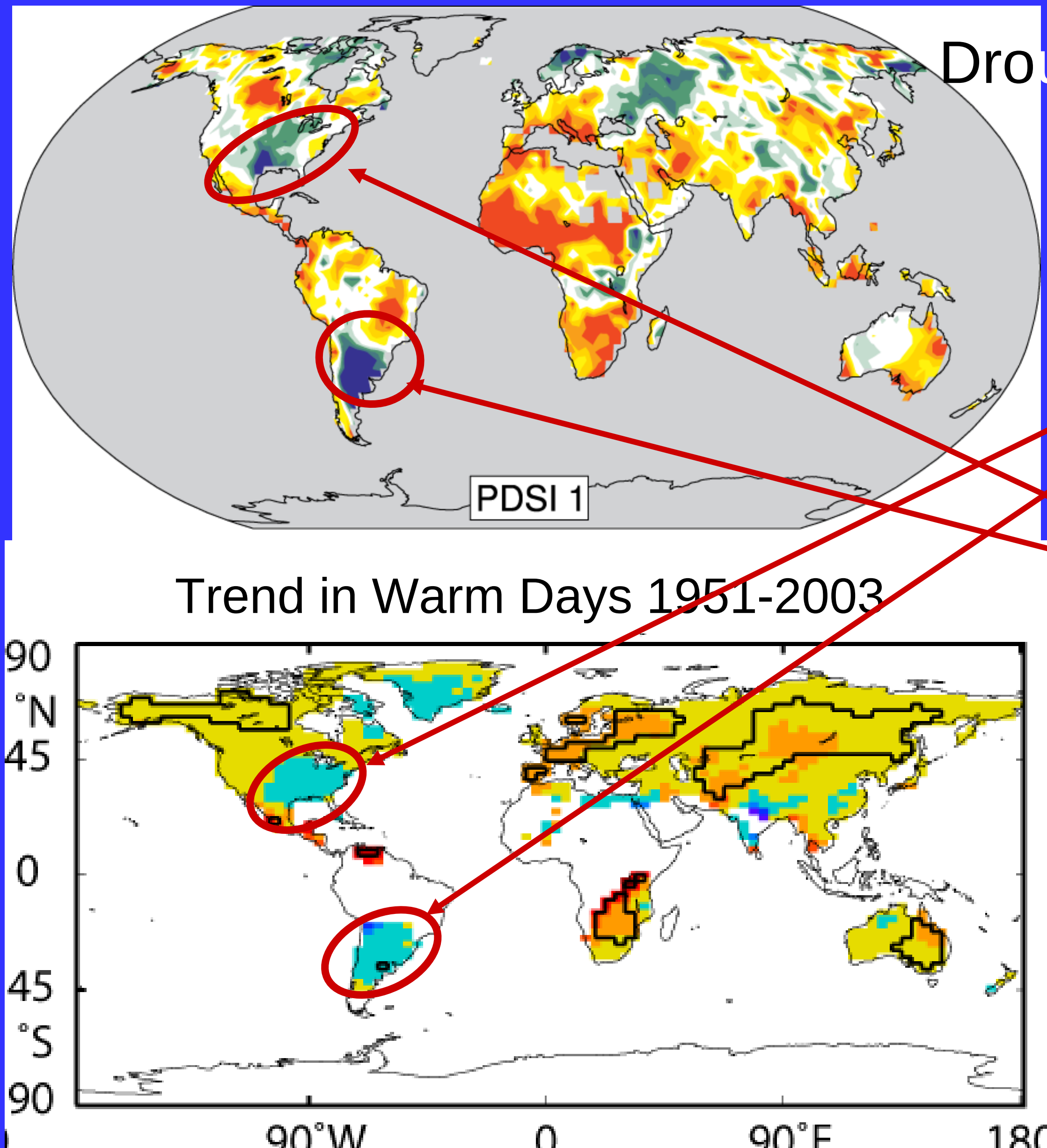
Mainly decrease in rain over land in tropics and subtropics, but enhanced by increased atmospheric demand with warming

Severity Index (PDSI) for 1900 to 2002.

The time series (below) accounts for most of the trend in PDSI.

AR4 IPCC

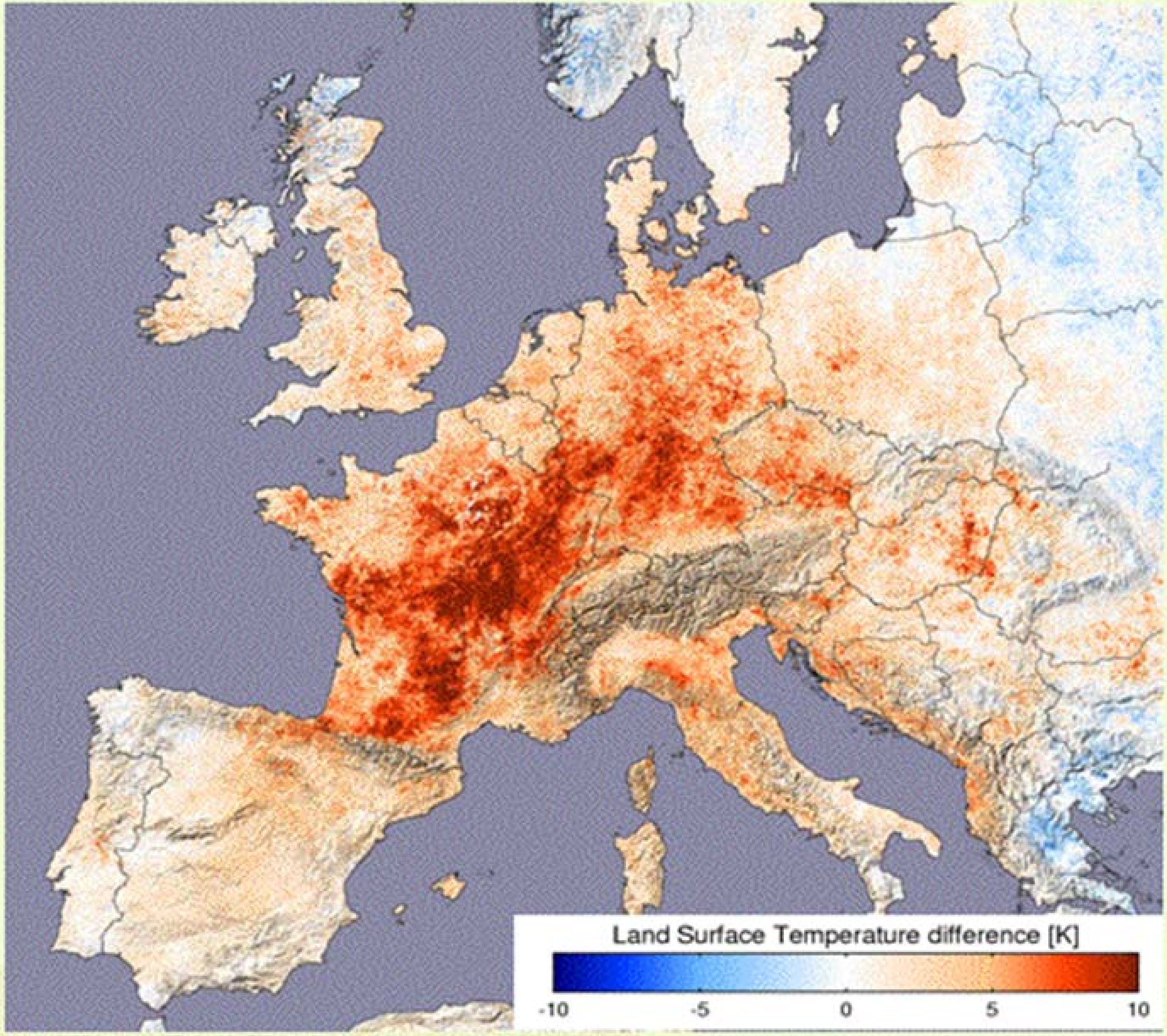
Increases in rainfall and cloud counter warming



Absence of warming by day coincides with wetter and cloudier conditions

IPCC 2007

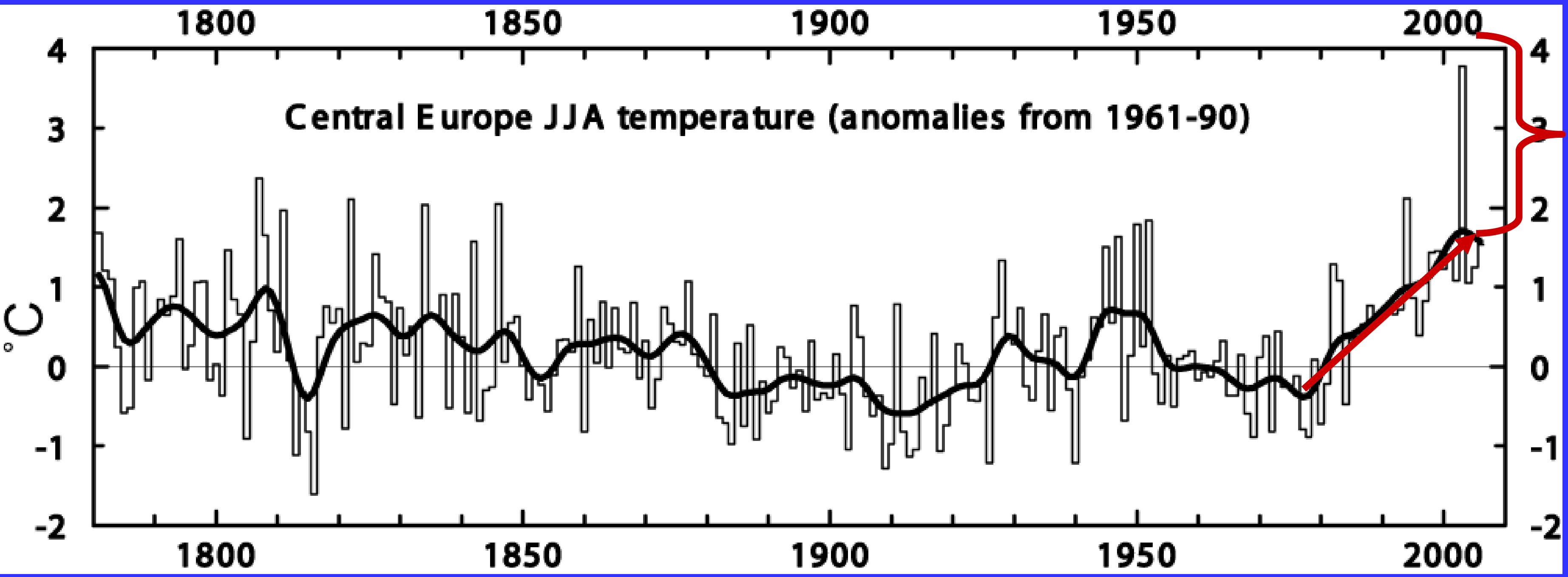
The European heat-wave of summer 2003



European temperatures in early August 2003, relative to 2001-2004 average

From NASA's MODIS - Moderate Resolution Imaging Spectrometer, courtesy of Reto Stöckli, ETHZ

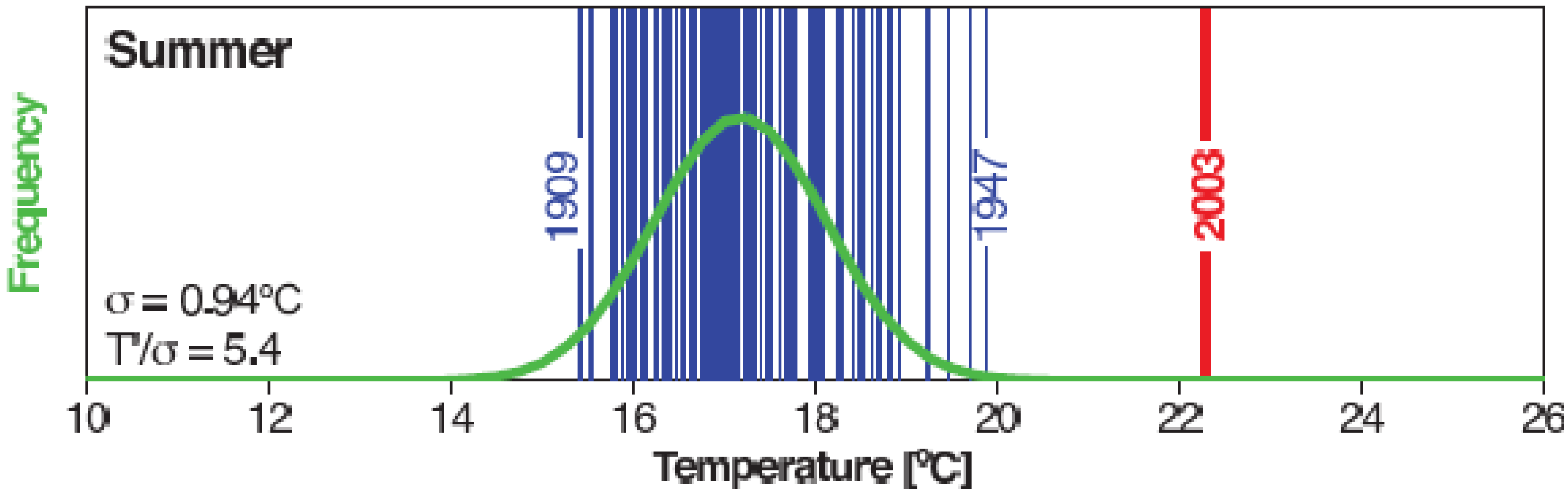
Heat waves are increasing: an example



Extreme Heat Wave
Summer 2003
Europe
30,000 deaths IPCC AR4

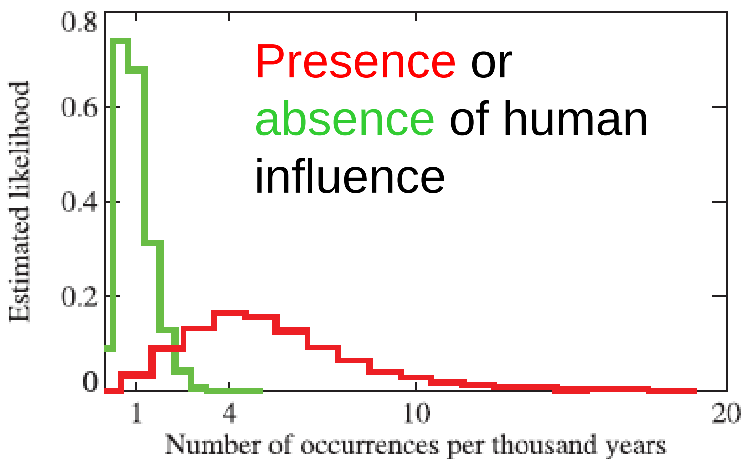
Trend plus variability?

Humans have affected temperatures



Summer temperatures in Switzerland from 1864 to 2003. During the extremely hot summer of 2003, average temperatures exceeded 22°C, as indicated by the red bar (a vertical line is shown for each year in the 137-year record).

The odds of the 2003 value, given the rest of the record is about **1 in 10 million**.

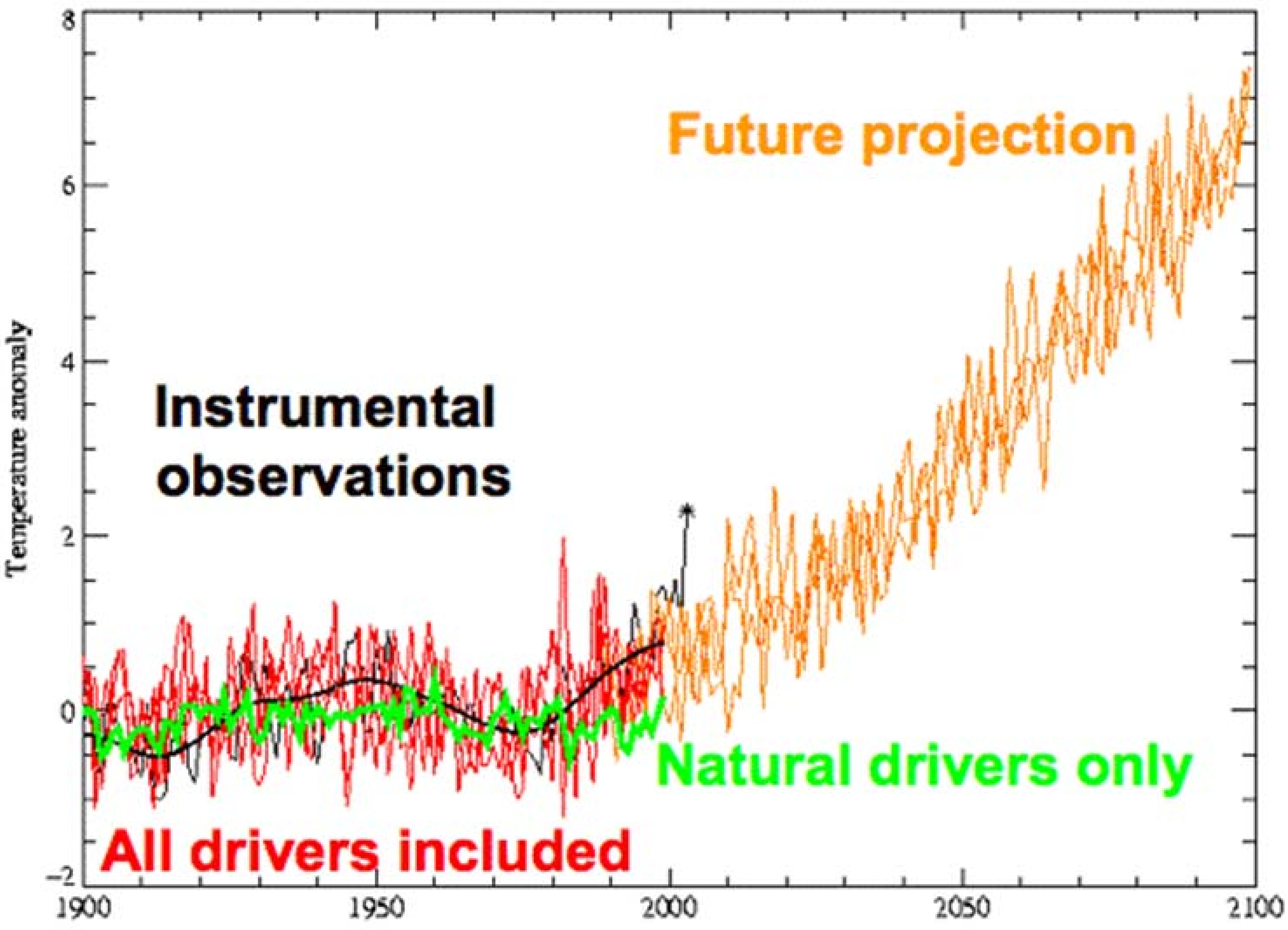


Change in risk of mean European summer temperatures exceeding 1.6°C above 1961 to 1990 means.

Stott et al. 2004

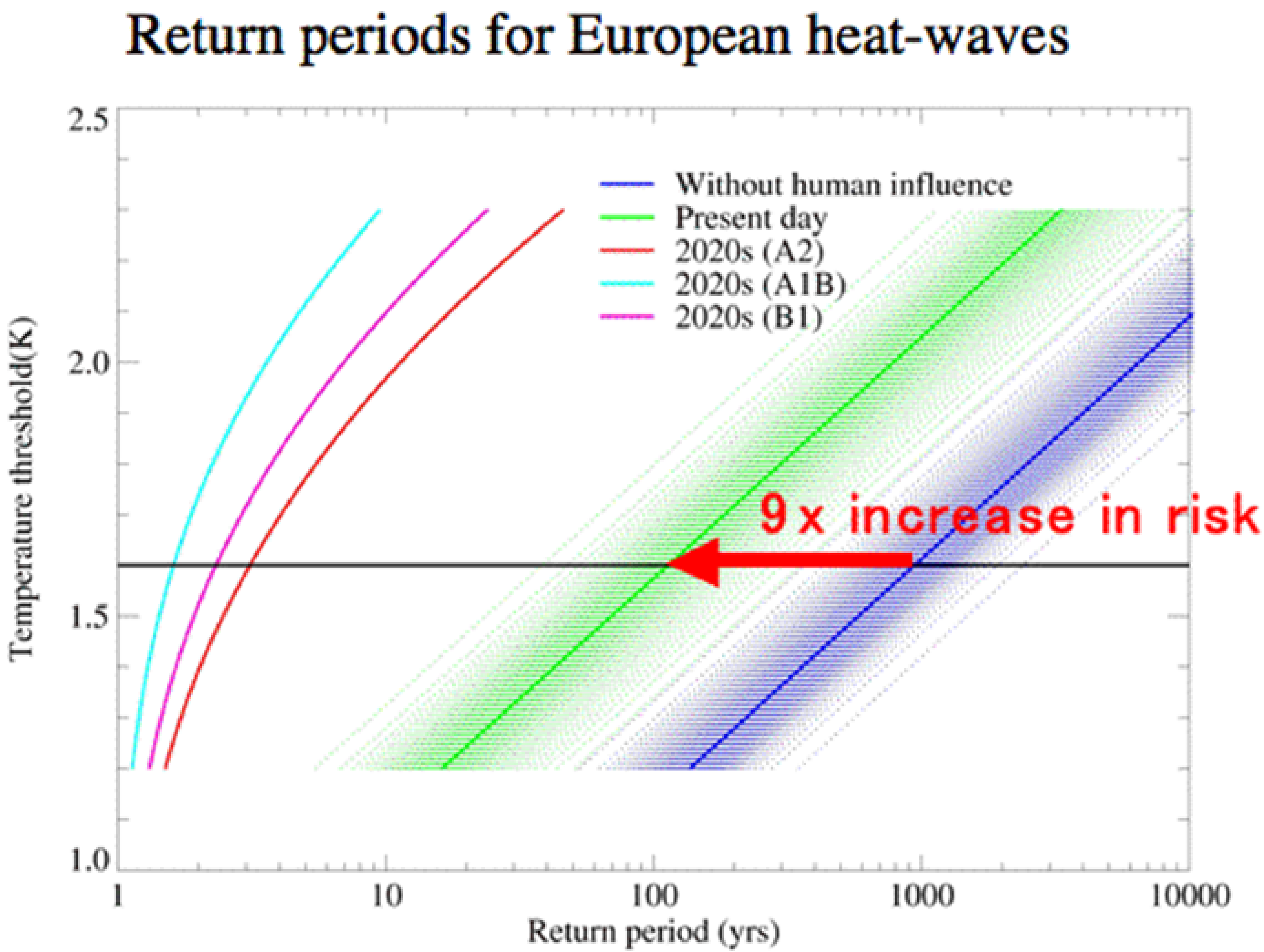
IPCC AR4

Modeling southern European JJA temperatures



Stott et al 2004

Changing risk of European heat waves



Stott et al 2004

The observed heat wave in Europe in 2003 becomes commonplace by 2020s

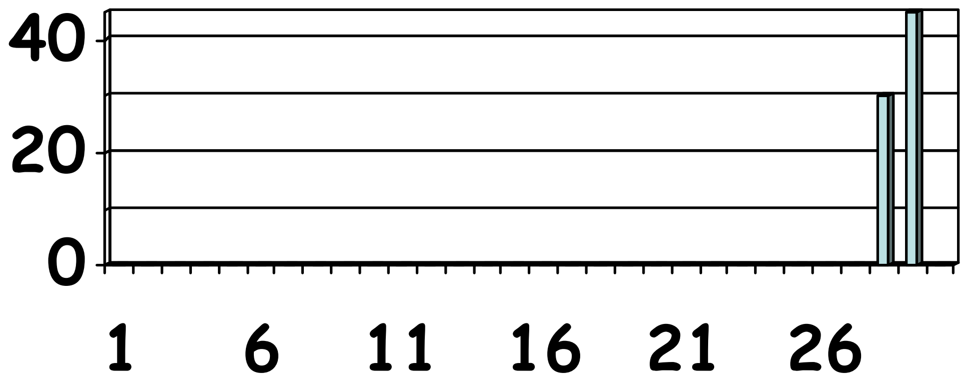
Flooding and extremes of precipitation

Photo Dave Mitchell, Courtesy Myles Allen

Role of character of precipitation:

Daily Precipitation at 2 stations

A



drought
wilting plants

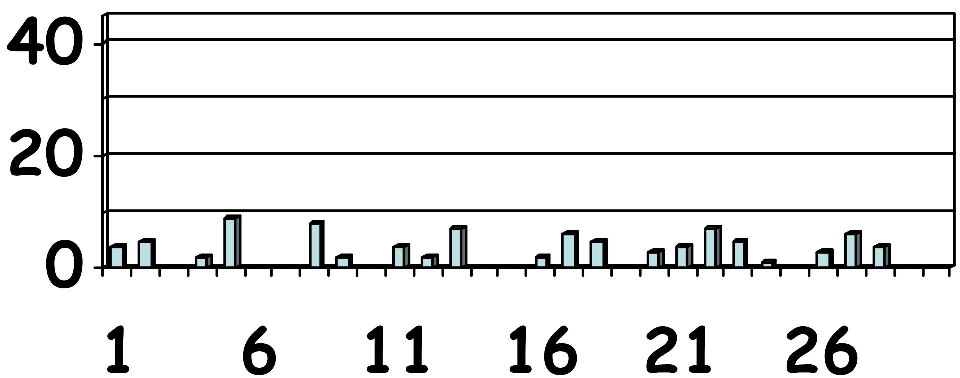
wild fires

local
floods

Monthly
Amount 75 mm

Frequency 6.7%
Intensity 37.5 mm

B



soil moisture replenished
virtually no runoff

Amount 75 mm
Frequency 67%
Intensity 3.75 mm

Moderate or heavy precipitation:

- Can not come from local column.
- Can not come from E, unless light precipitation.
- Has to come from transport by storm-scale circulation into storm.

On average, rain producing systems
(e.g., extratropical cyclones; thunderstorms)
reach out and grab moisture from distance about
3 to 5 times radius of precipitating area.

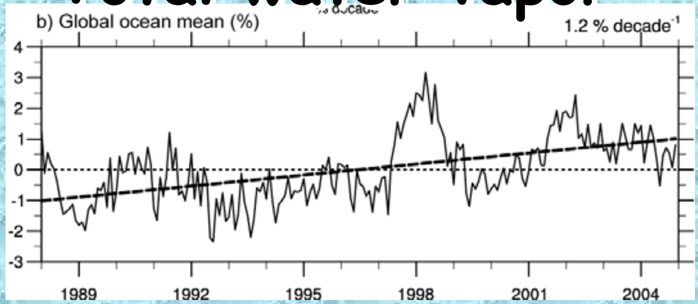
Air holds more water vapor at higher temperatures

A basic physical law tells us that the water holding capacity of the atmosphere goes up at about 7% per degree Celsius increase in temperature. (4% per °F)

Observations show that this is happening at the surface and in lower atmosphere: 0.55°C since 1970 over global oceans and 4% more water vapor.

This means more moisture available for storms and an enhanced greenhouse effect.

Total water vapor



How should precipitation P change as the climate changes?

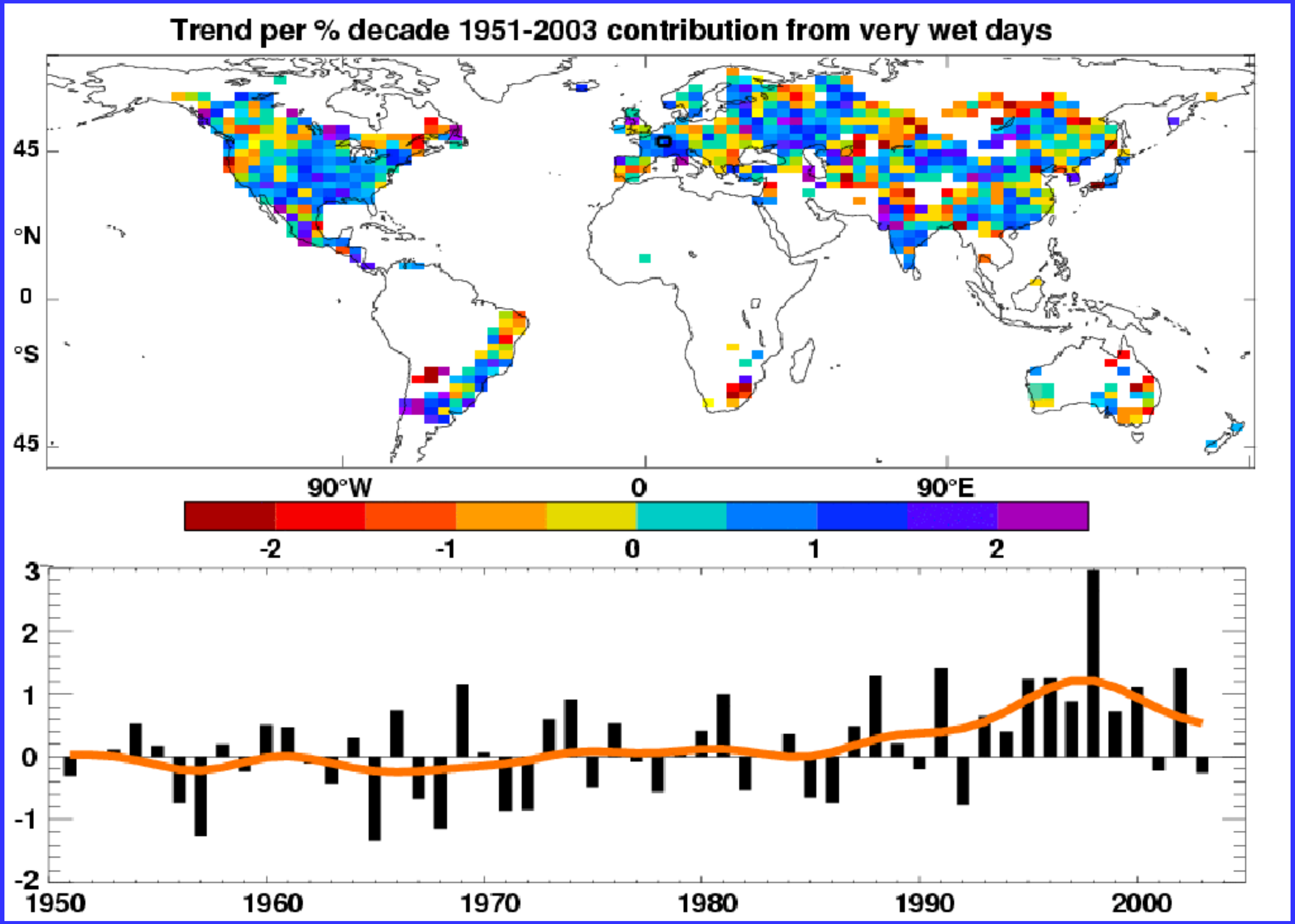
- With increased GHGs: increased **surface** heating evaporation E⇑ and P⇑
- With increased aerosols, E⇓ and P⇓
- **Net global effect is small and complex**

- Warming and T⇑ means water vapor ⇑ as observed
- Because precipitation comes from storms gathering up available moisture, **rain and snow intensity** ⇑ : **widely observed**
- But this must reduce lifetime and frequency of storms
- Longer dry spells

Trenberth et al 2003

How should precipitation P change as the climate changes?

- "The rich get richer and the poor get poorer". More water vapor plus moisture transports from divergence regions (subtropics) to convergence zones. Result: **wet areas get wetter, dry areas drier** (Neelin, Chou)
- "Upped ante" precip decreases on edges of convergence zones as it takes more instability to trigger convection: more intense rains and upward motion but broader downward motion. (Neelin, Chou)
- "More bang for the buck": The moisture and energy transport is a physical constraint, and with increased moisture, the winds can be less to achieve the same transport. Hence the divergent circulation weakens. (Soden, Held et al)

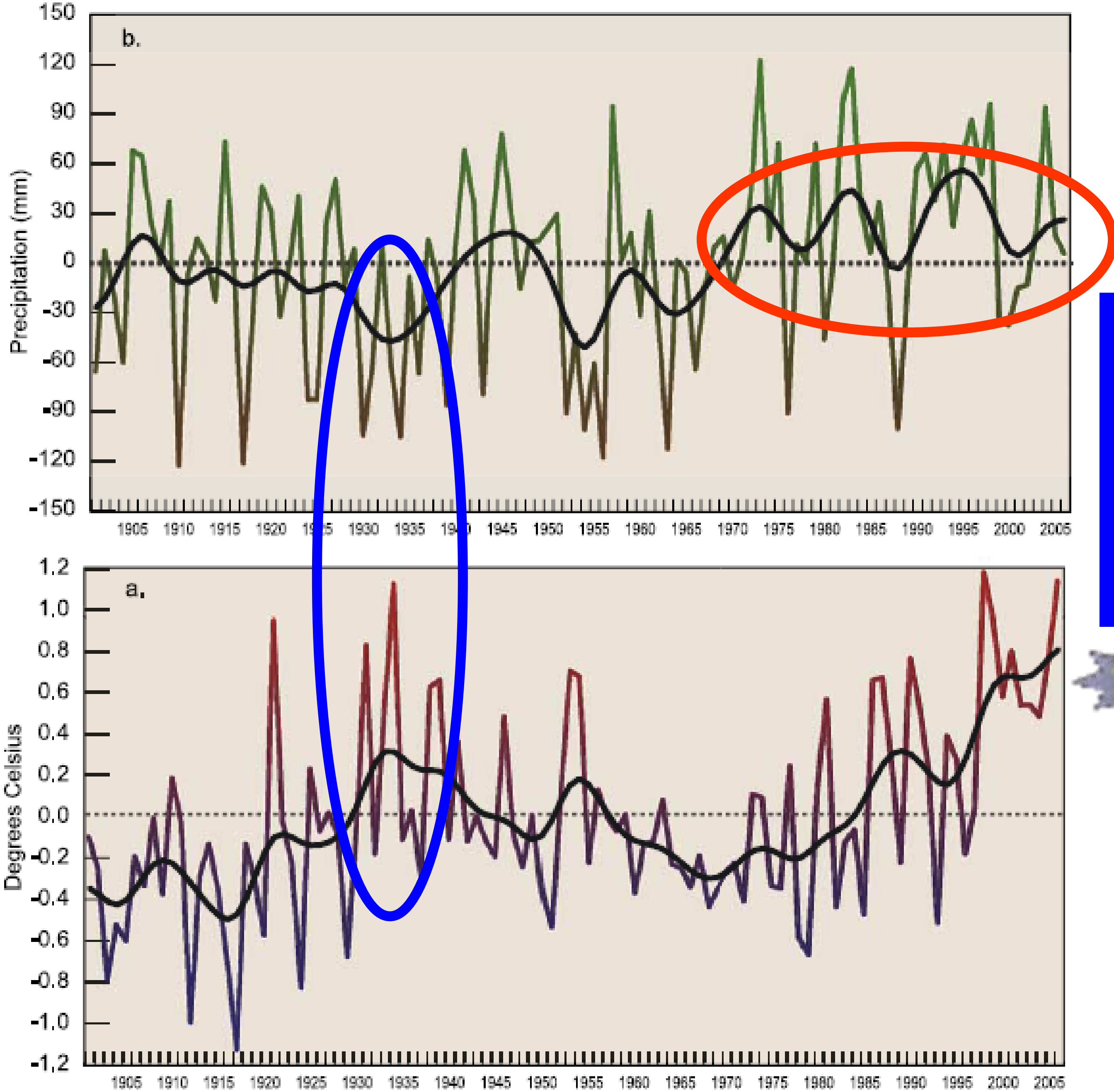


Precipitation

Observed trends (%) per decade for 1951-2003 contribution to total annual from **very wet days** > 95th %ile.

Alexander et al 2006
IPCC AR4

Heavy precipitation days are increasing even in places where precipitation is decreasing.



Much wetter

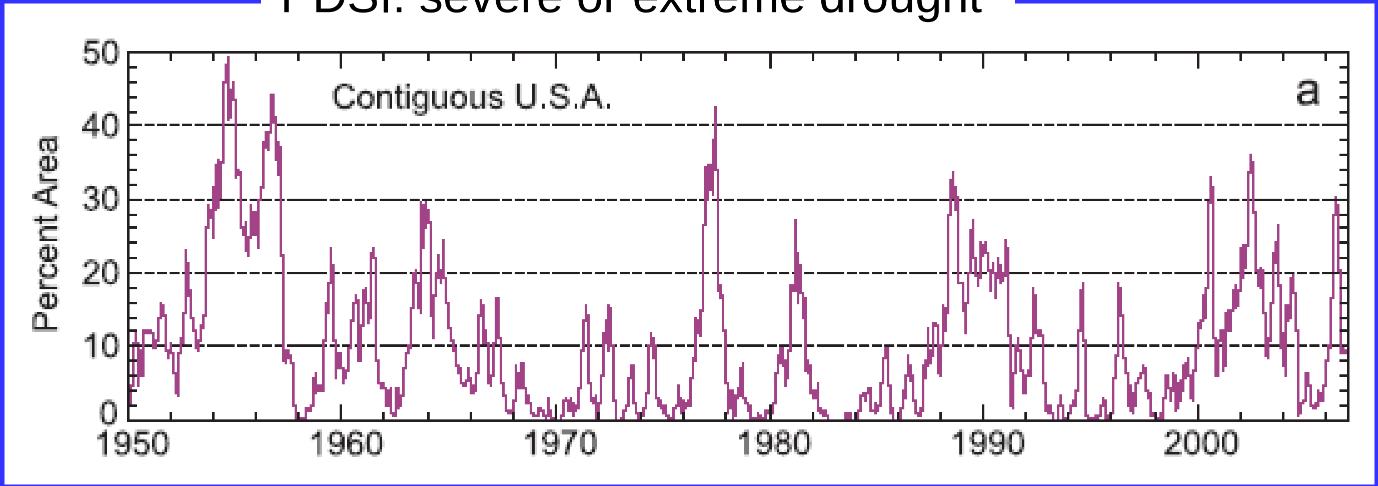
US changes in

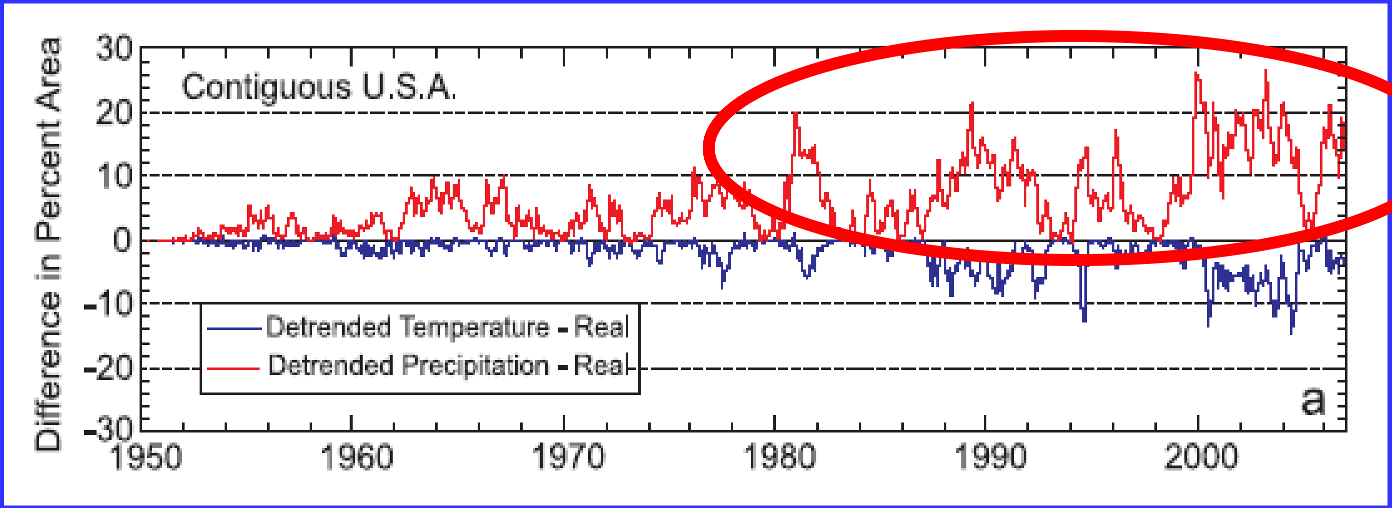
Precipitation

Temperature

1930s:
Hot and dry

PDSI: severe or extreme drought



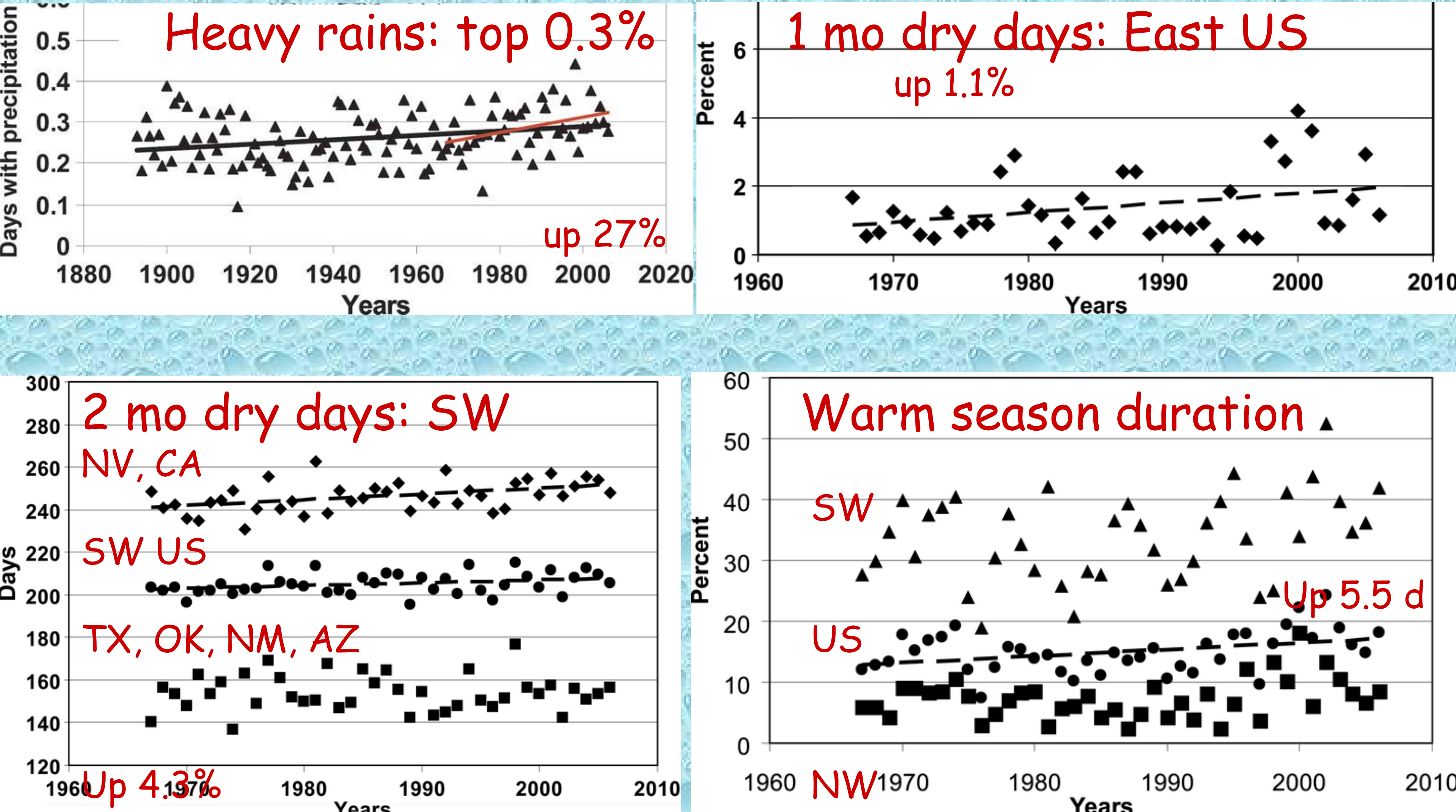


The warmer conditions suggest that drought would have been much worse if it were not for the much wetter conditions.

And it would have been much warmer too!

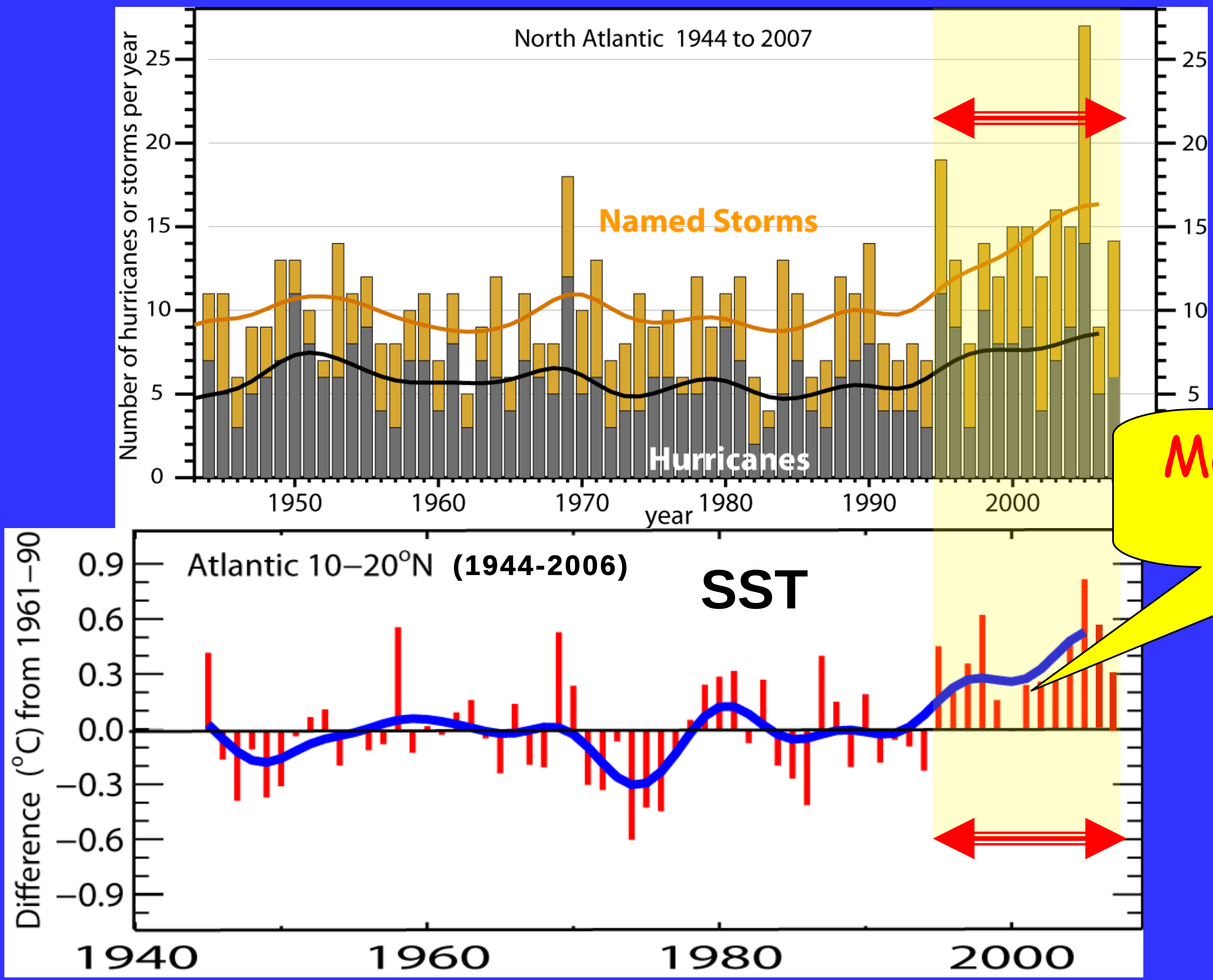
Change in area of PDSI in drought using detrended temperature and precipitation:
Red is no trend in precipitation: **Would be much more drought!**
Blue is no trend in temperature. **Modest warming** has contributed
Easterling et al 2007

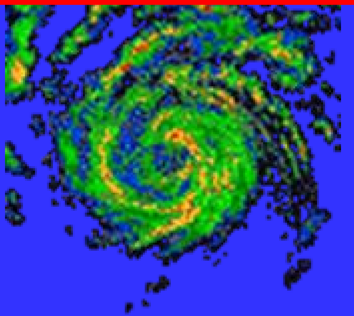
Increases in extremes in U.S.



Per 40 years **1967-2006** Groisman, Knight 08

North Atlantic hurricanes have increased with SSTs



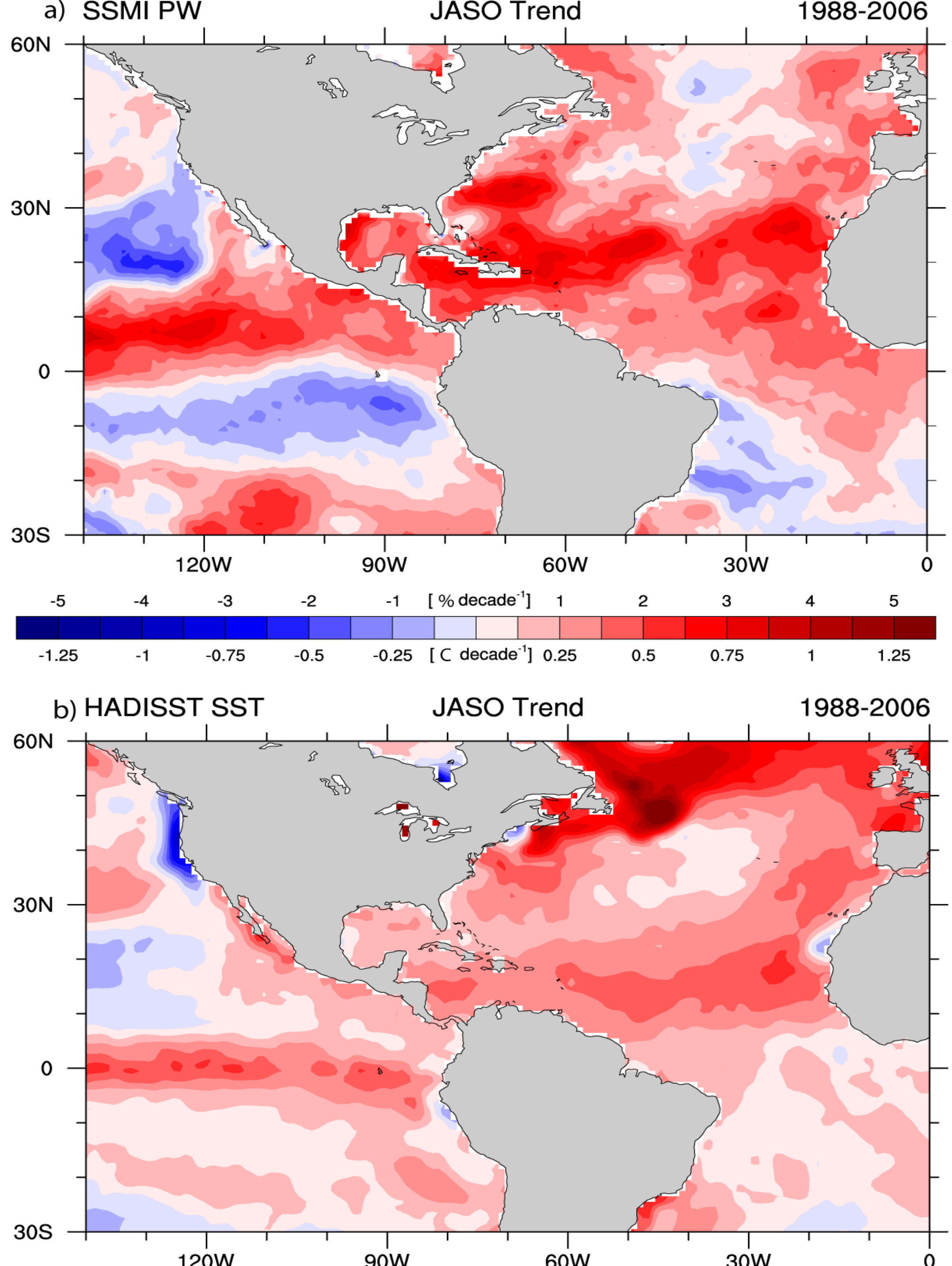


N. Atlantic hurricane record best after 1944

Marked increase after 1994

Global number and percentage of intense hurricanes is increasing

IPCC



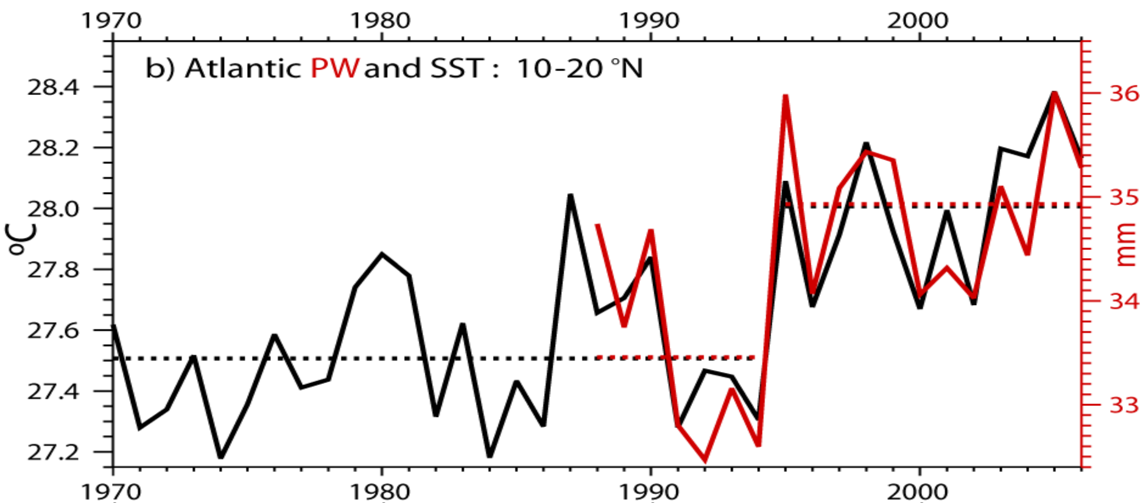
Precip Water

Atlantic JASO Linear trends

SSTs

Higher SSTs and
Higher water vapor

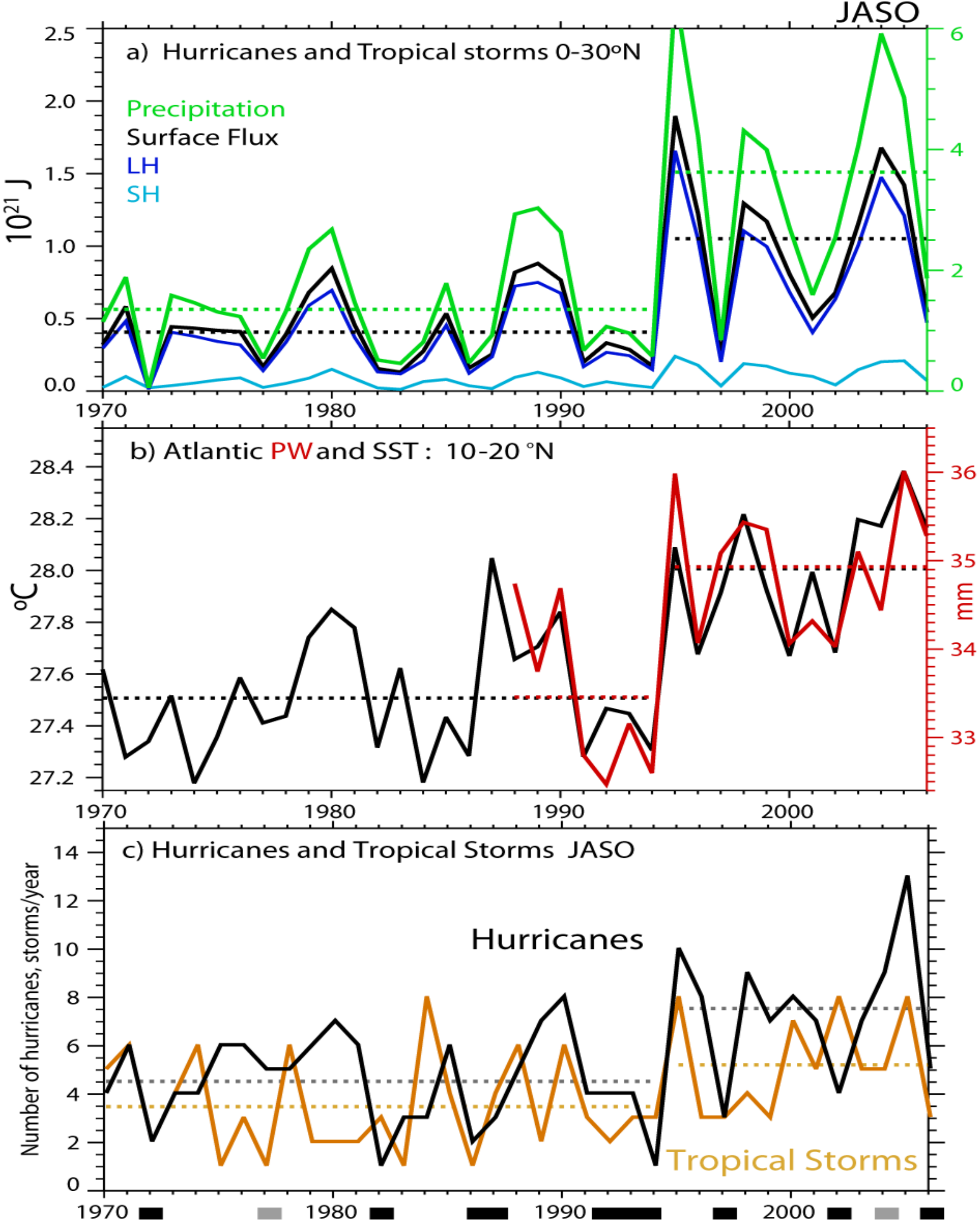
JASO Atlantic



Higher SSTs and
Higher water vapor
after 1994

Means more:

Ocean evaporation
Rainfall,
Tropical storms, and
Hurricanes



JASO Atlantic

Sfc Fluxes

123%/K (total)

90%/K (precip)

Precip water

SST

7%/K

Numbers:

TS

Hurricanes

Changes across 1994/95

JASO: 1995-2006 vs 1970-1994

	1970-1994	1995-2006	Diff	%	Units
SSTs	27.5	28.0	0.5		°C (10-20N)
Wv	33.5	34.9	1.4	4.1/K	mm
TS	3.4	5.2	1.8	45	No.
Hurr	4.5	7.5	3.0	55	
Total	7.9	12.7	4.8	43	
Sfc Flux	0.41	1.05	0.64	105	10^{21} J
	0.04	0.10			PW
Precip	1.36	3.63	2.27	109	10^{21} J
	0.13	0.34			PW

Downscaling of hurricanes

- Emanuel 2008 *BAMS*
- Knutson et al 2008 *Nature Geoscience*

Use climate models projections of the environmental state

- SST
- Vertical temperature structure (stability)
- Wind shear

Hoskins says: "*If the large scale is rubbish, then the detail is rubbish, too*."

--New Scientist, 7 May 2008

Downscaling of hurricanes

Knutson et al 2008 Nature Geoscience

Good replication of number of tropical storms

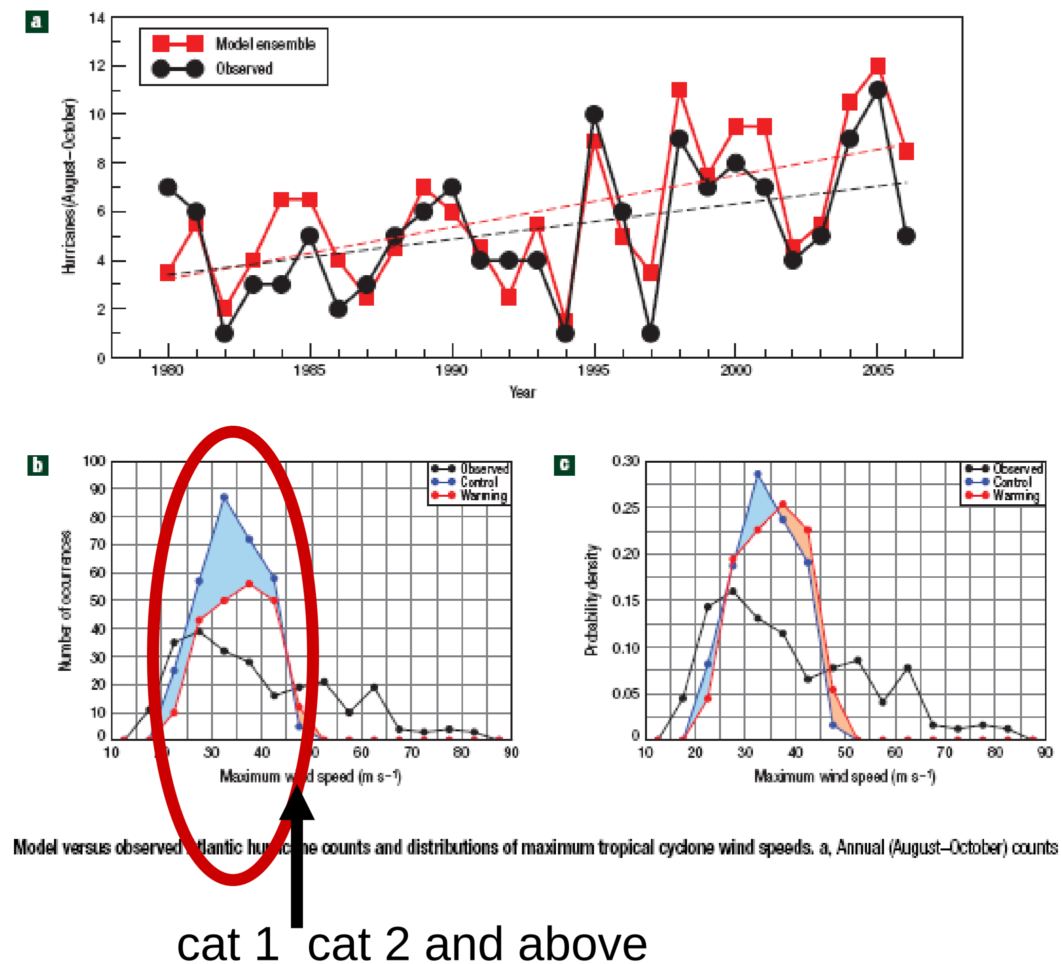
But no storms cat 2 or higher

Why?

Models fail to replicate tropical disturbances of all sorts: convective parameterization.

Main reason for reduction in Atlantic is wind shear: state more "El Nino-like"

Does not apply elsewhere



Some model studies of extremes

- Frosts: Meehl et al 2004
- Heat waves: Meehl and Tebaldi 2004
- 2003 European heat wave: Stott et al 2004
- Precipitation, dry days: Tebaldi et al 2007
- Many indices Frich et al. 2002

  defined 10 standard extremes indices derived from observed data, then from 9 CMIP3 models for AR4
- Precip: Meehl et al 2005

Extremes indices for temperature

Total number of **frost days**, defined as the annual total number of days with absolute minimum temperature below 0ºC

- Intra-annual **extreme temperature range**, defined as the difference between the highest temperature of the year and the lowest

- **Growing season length**, defined as the length of the period between the first spell of five consecutive days with mean temperature above 5ºC and the last such spell of the year

- **Heat wave** duration index, defined as the maximum period of at least 5 consecutive days with maximum temperature higher by at least 5ºC than the climatological norm for the same calendar day

- **Warm nights**, defined as the percentage of times in the year when minimum temperature is above the 90th percentile of the climatological distribution for that calendar day

Frich et al 2002 Clim. Res.

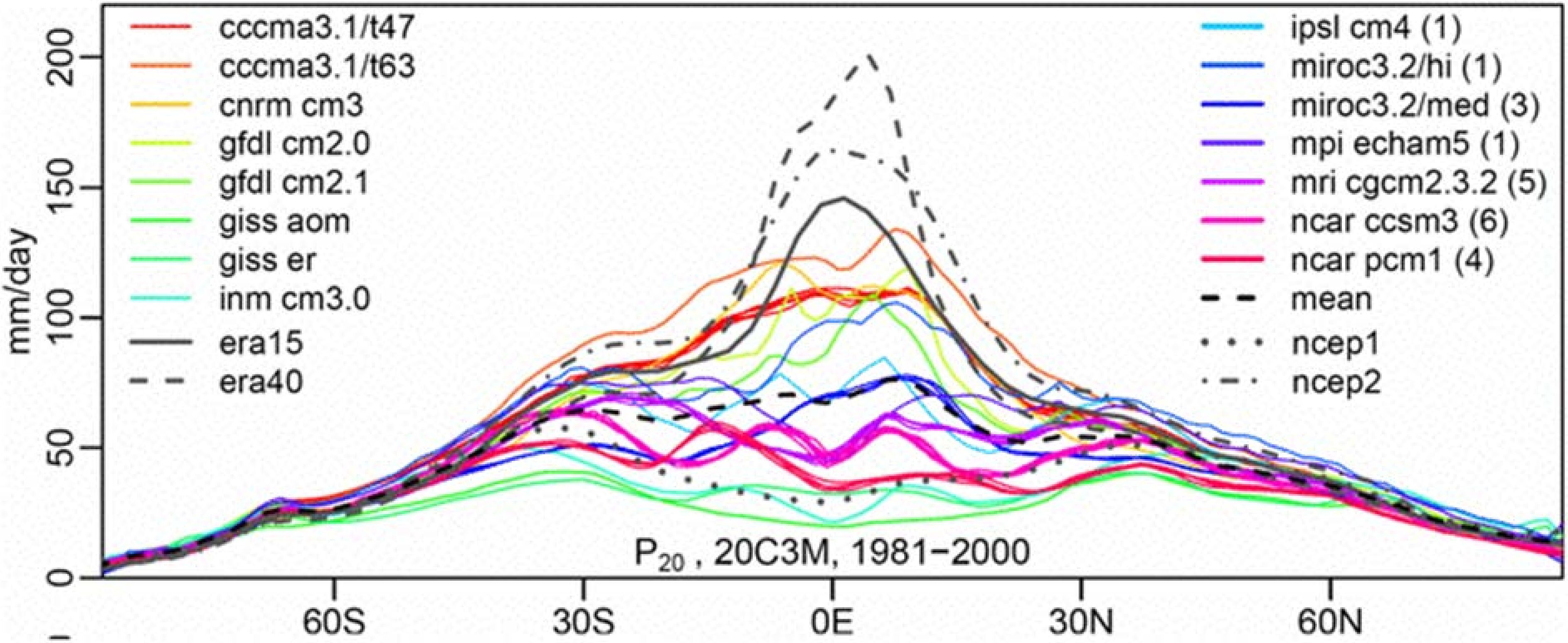
Extremes indices for precipitation

- Number of days with **precipitation greater than 10mm**
- Maximum number of consecutive **dry days**
- Maximum **5-day precipitation** total
- Simple daily **intensity** index, defined as the annual total precipitation divided by the number of wet days
- Fraction of total precipitation due to events exceeding the 95th percentile of the climatological distribution for **wet day** amounts

Frich et al 2002 Clim. Res.

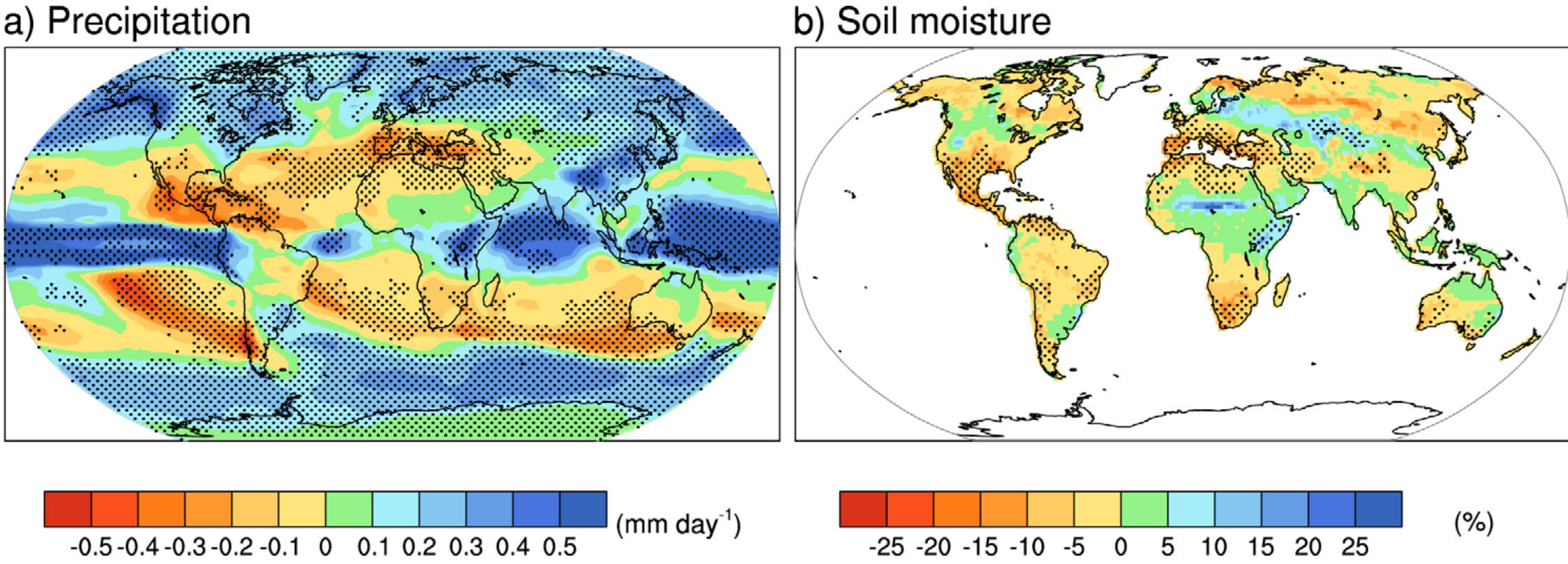
Environment Canada
Environnement Canada

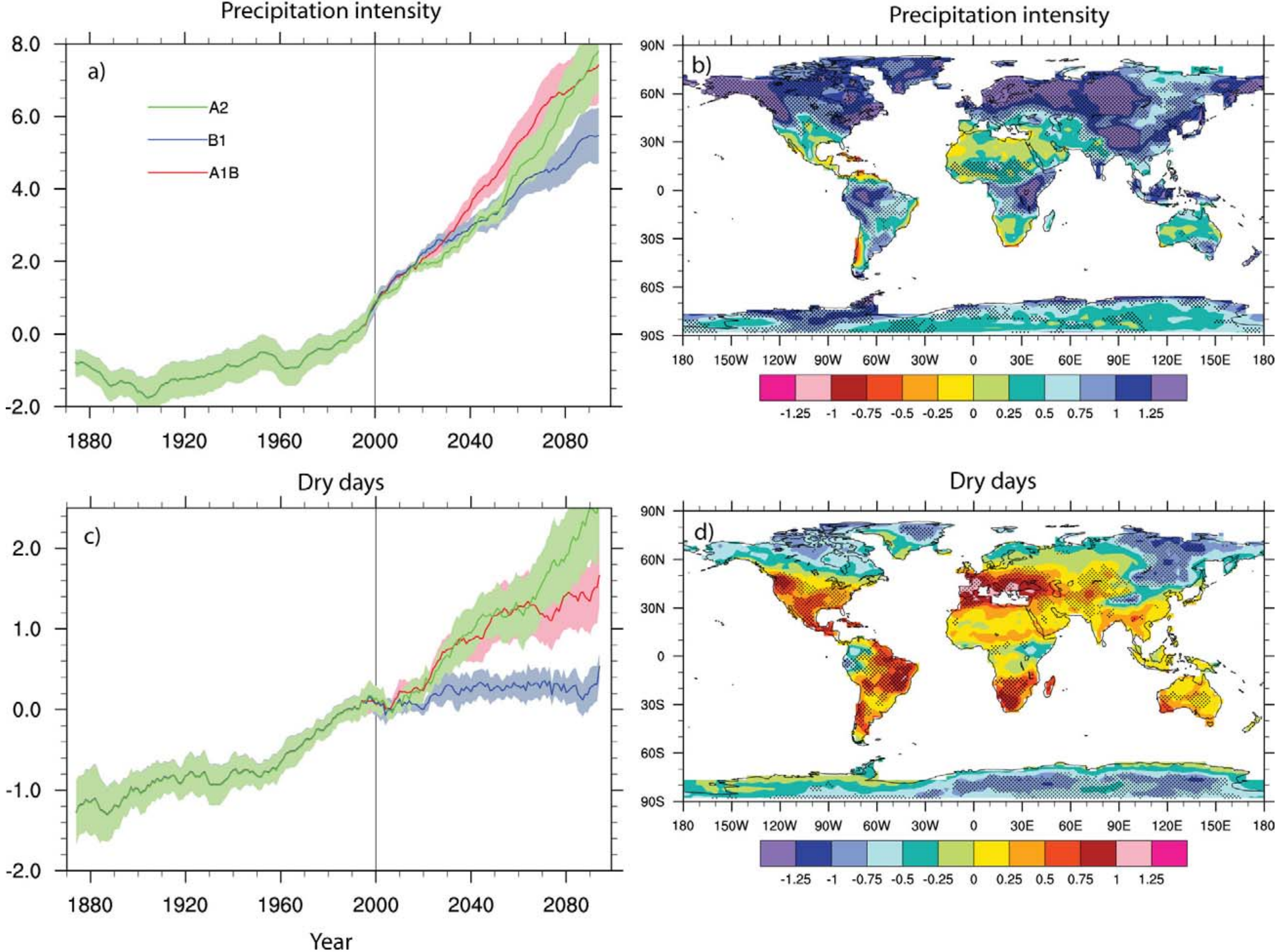
20-yr 24-hr PCP extremes – current climate



Courtesy Francis Zwiers

Combined effects of increased precipitation intensity and more dry days contribute to mean precipitation changes





(Tebaldi , C., J.M. Arblaster, K. Hayhoe, and G.A. Meehl, 2006: Going to the extremes: An intercomparison of model-simulated historical and future changes in extreme events. *Clim. Change*.)

Table SPM.2. *Recent trends, assessment of human influence on the trend and projections for extreme weather events for which there is an observed late-20th century trend. {Tables 3.7, 3.8, 9.4; Sections 3.8, 5.5, 9.7, 11.2–11.9}*

IPCC AR4

Phenomenon[a] and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend[b]	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	*Very likely*[c]	*Likely*[d]	*Virtually certain*[d]
Warmer and more frequent hot days and nights over most land areas	*Very likely*[e]	*Likely (nights)*[d]	*Virtually certain*[d]
Warm spells/heat waves. Frequency increases over most land areas	*Likely*	*More likely than not*[f]	*Very likely*
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	*Likely*	*More likely than not*[f]	*Very likely*
Area affected by droughts increases	*Likely* in many regions since 1970s	*More likely than not*	*Likely*
Intense tropical cyclone activity increases	*Likely* in some regions since 1970	*More likely than not*[f]	*Likely*
Increased incidence of extreme high sea level (excludes tsunamis)[g]	*Likely*	*More likely than not*[f,h]	*Likely*[i]