# GLOBAL TRENDS IN POLLUTION & CLIMATE I

# Agenda

- Awareness of atmospheric pollution and assessment of causes: correlation with fossil-fuel burning

- Evidence for trends in natural systems, atmosphere, oceans extreme weather events

- Long-term correlations of global climate parameters
  sudden changes (tipping points), blocking events

Next: Earth as a planet in solar system, blackbody radiation
Radiation balance of surface and troposphere

# Problem Awareness → Assessment → Adaptation/Mitigation


Successful mitigation or adaptation entails a continuing risk evaluation. With this approach, individuals and organizations become aware of and assess risks and vulnerabilities from climate and other drivers of change, take actions to reduce those risks, and learn over time. The gray arced lines compare the current status of implementing this process with the status reported by the Third National Climate Assessment in 2014; darker color indicates more activity.

(Source: adapted from National Research Council, 2010.)

# Air Quality In California

Smog hangs over the city on a day rated as having 'moderate' air quality in downtown Los Angeles, on June 11, 2019. Mario Tama/Getty Images

Smog in LA before 2019

Downtown freeways are empty of traffic as the spread of the coronavirus disease (COVID-19) continues, in Los Angeles on April 7, 2020.

Clean air in LA after traffic reduction in 2019

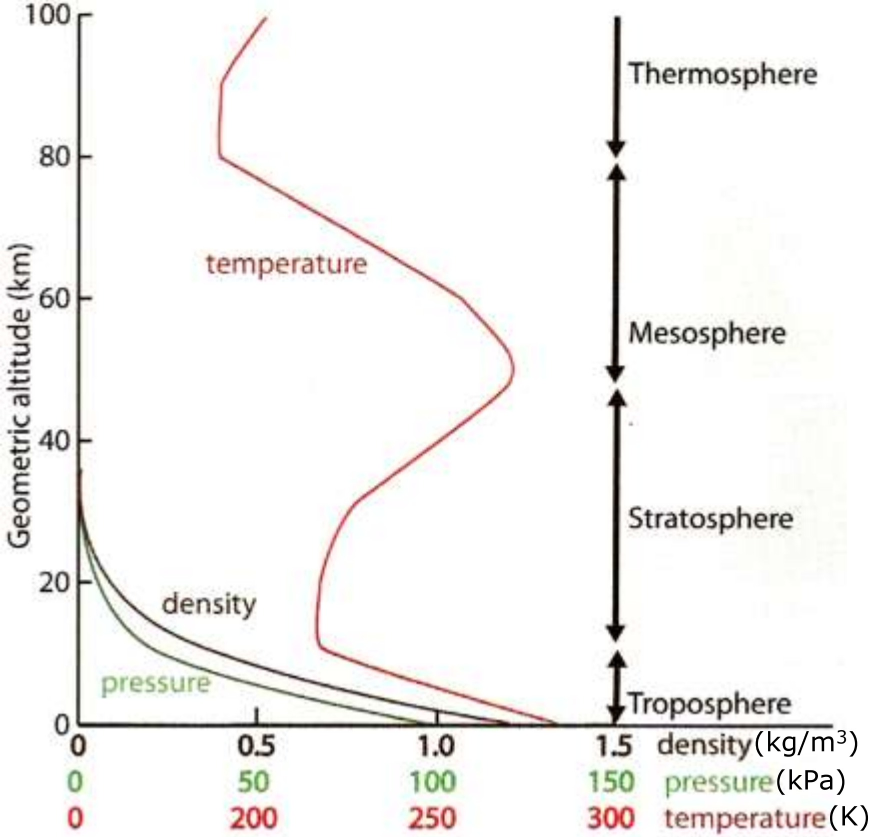
Attribution: individual and commercial transport

# Pollution Produced by Fossil Fuel Combustion

Evaluation of implementing mitigating methods → Compelling observations/conclusions require 'controlled' experiments:

- Frequent smog emergencies in industrial areas around the world (UK, USA, Europe, Asia,…) occurred mainly as long as coal and oil (diesel) were primary energy carrier.
- Reduced problem by implementing emission control and by switching to cleaner energy carriers (oil, nat. gas).
- Smog increases with increased automobile traffic. Positive correlation: also increased emission in $SO_2$, $NO_x$,..
- Reduction in $SO_2$, $NO_x$, emission enforced for power plants and automobiles reduced "acid rain" and $NO_x$ problems in the US and Europe.
- Reduction in use of specific Cl compounds (CFC) in the US has measurable effect on stratosphere on south polar region.

# Standard Earth Atmosphere




| Gas | Volume (ppm) | Mixing Ratio<br>Volume (%) |
|---|---|---|
| Nitrogen | 781,000 | 78 |
| Oxygen | 209,500 | 21 |
| Argon | 9,340 | 0.934 |
| Carbon dioxide | ~~394~~ 416 | 0.0~~39~~46 |
| Neon | 18 | 0.0018 |
| Helium | 5.24 | 0.0005 |
| Methane | ~~1.79~~ 1.9 | ~~0.00018~~ 1.9 |
| Krypton | 1.14 | 0.00011 |
| Hydrogen | 0.55 | 0.000055 |
| Nitrous oxide | 0.33 | 0.000033 |
| Carbon monoxide | 0.1 | 0.00001 |
| Xenon | 0.09 | 0.000009 |
| Ozone | 0–0.07 | 0–0.000007 |

These numbers are for a dry atmosphere; the water content of the atmosphere is on average 0.4% (1–4% at the surface).

Pressure units: 1 Pa (Pascal) = 1 kg/ms$^2$
1 atm = $1.013\cdot10^5$ Pa =100kPa= 760 Torr,
1 bar =$1.0\cdot10^5$ Pa,
R= 8.3144598 J/(mol·K)

*Barometric Law*

$$P(z) = P(0)\cdot e^{-z/H}$$

Boltzmann Factor

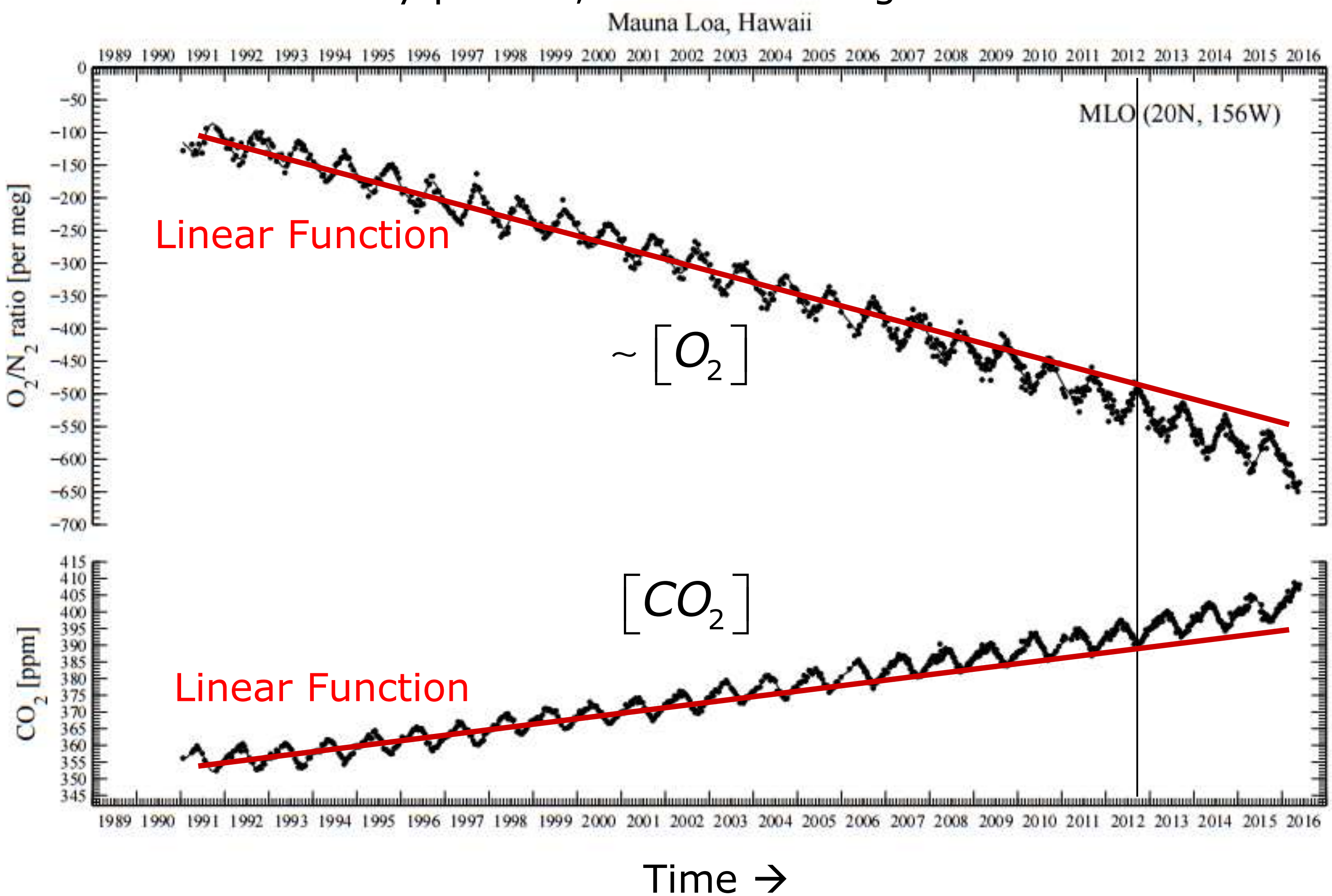
*height scale*

$$H = \frac{R\cdot T}{M_{air}\cdot g}$$

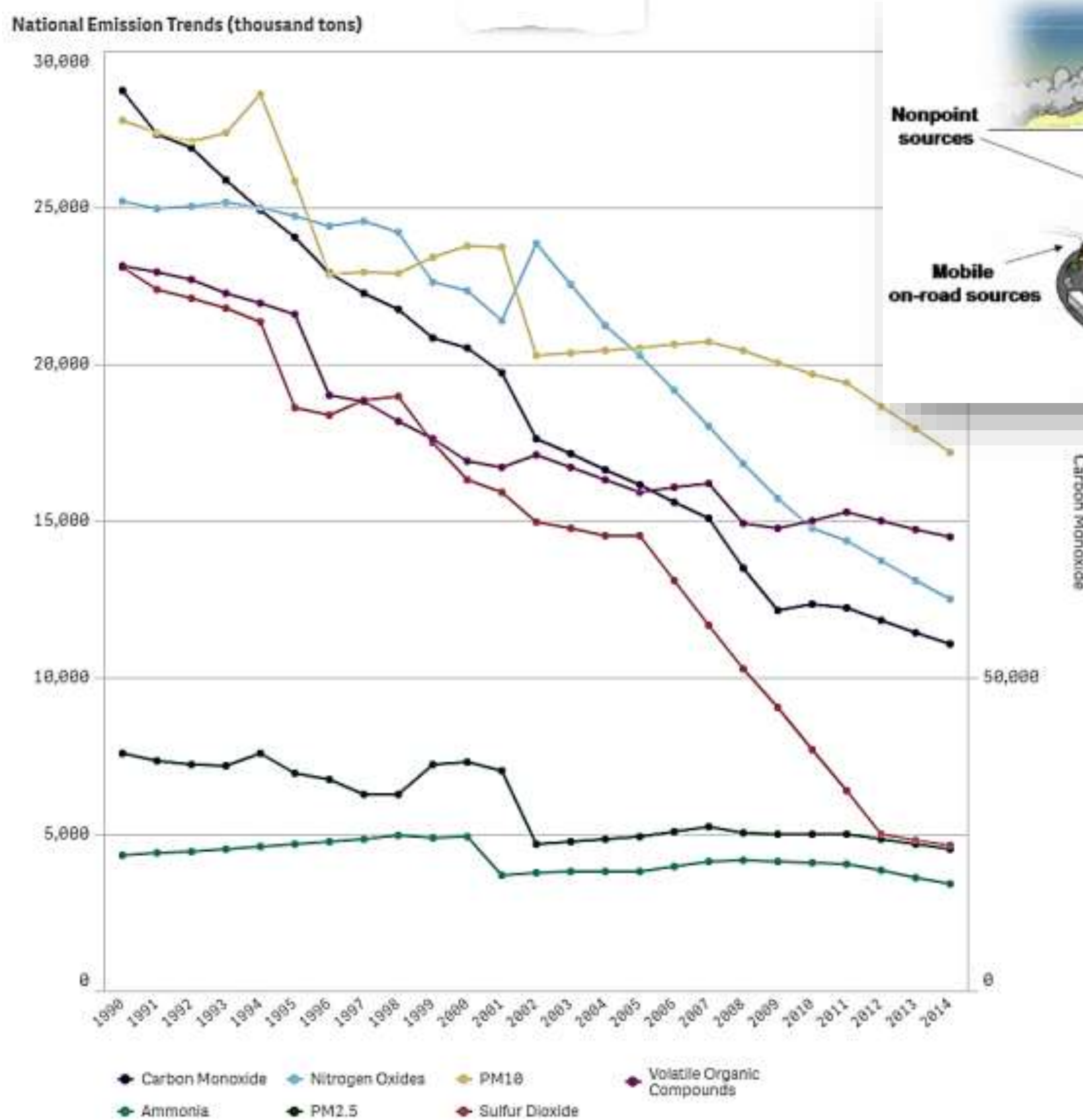
# Correlated Changes in Atmospheric Composition

Other changes of Earth atmosphere: $O_2$ depletion → correlation with $CO_2$ ?

Both have oscillatory pattern, non-linear long-term trends.



# US National Emission Trends 1990-2014





Hazardous gases:

NOx, $NH_4$, $SO_2$, Organic compounds

Particulates (PM10, PM2.5).

All emissions have been reduced, enforcing emission standards. Emitters

Industry, transportation, construction agriculture

# Observation Of Global Climate Trends

Previously proven: Some man-made pollution effects on global upper atmosphere was/can be halted and reversed !

Are these valid examples for attacking an even larger (global) problem (climate change) ? → Scale !

Strategy:

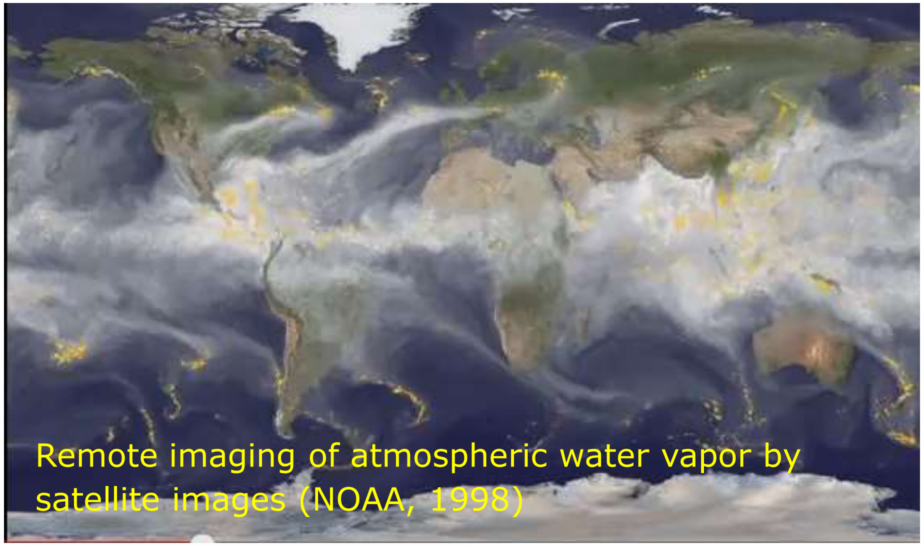
First (Awareness): Deterioration of human/animal systems (declining health, lifetime, # population) ?

Second (Assessment): What are (likely) causes, natural or man-made, e.g., natural climate cycles, anthropogenic (CC from fossil fuel burning)?

Third (Plans, Implement, Monitor): Can effects be halted/reversed ?

Our Investigative Tools

# Weather, Climate, Land, Atmosphere, Oceans


Remote imaging of atmospheric water vapor by satellite images (NOAA, 1998)


One of the many weather stations (Albany) of US Network.


Ice cores stored in the U.S. Geological Survey **National Ice Core Lab** Denver, CO (NAS 2010)

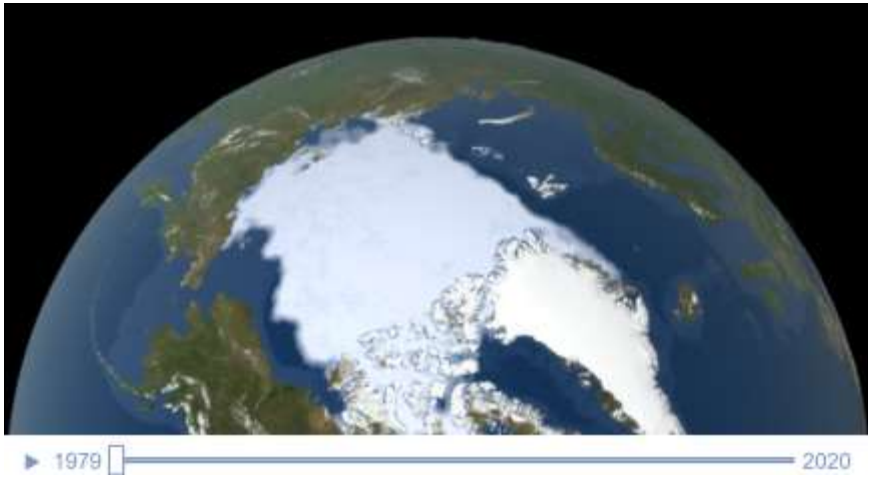
Excellent weather/climate information provided by several national/international agencies allows systematic climate evaluation and projection→ Research efforts in Nat'l Labs/Univ.

Examples:

1. U.S. *Historical Climatology Network* (USHCN): 1221 observing stations in the 48 contiguous states (Europe equiv).
2. Complex, remote measurements of atmospheric temperatures, composition, flows, ocean temperatures, etc., via NOAA/NASA/ESA/EUMETSAT satellites.
3. Check theoretical models against known history.

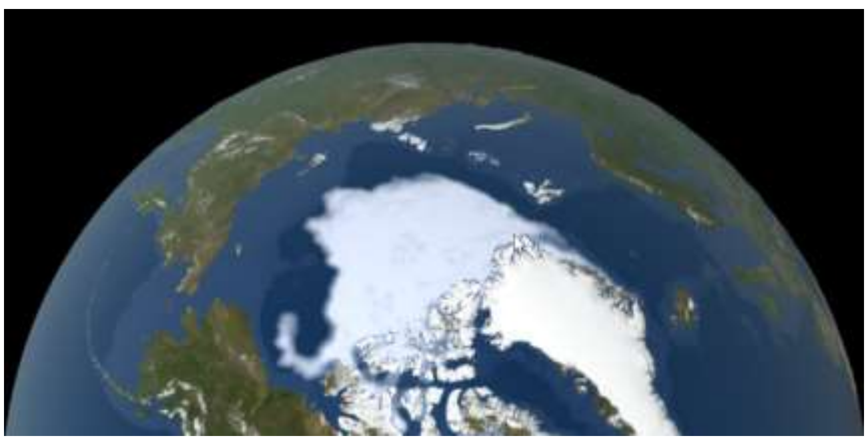
Paleo-climate information: air bubbles in Greenland or Antarctic ice cores, tree rings, coral reefs, historical records.

# Polar Regions Reduced Ice Cover




NASA sim from satellite+ surface observations.

Ice cover in winter of 1979 northern hemisphere

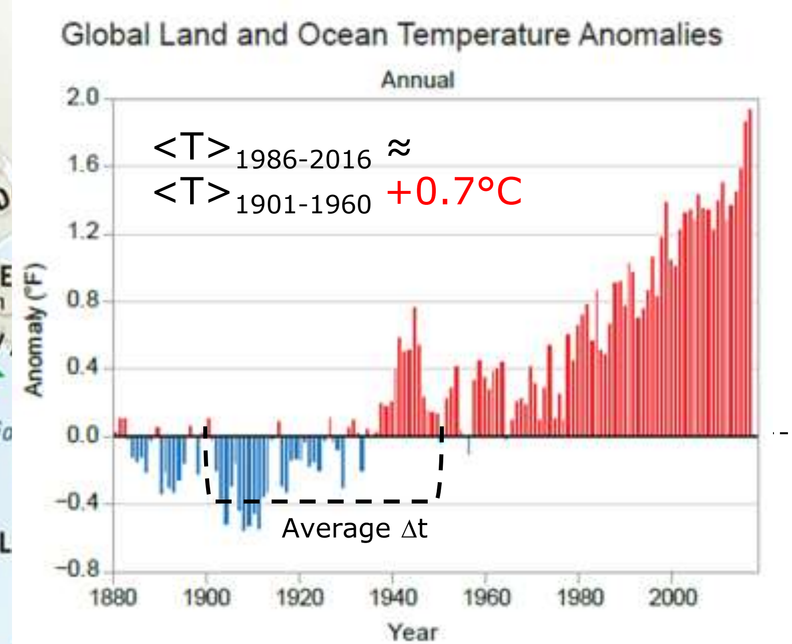


Ice cover in winter of 2020 northern hemisphere

Breaking ice shields in Antarctica

# Evidence for Large-Scale Changes

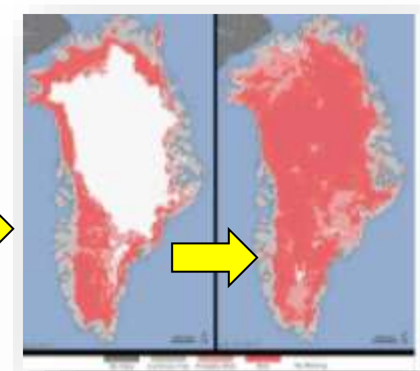

From: IPCC 5th Assessment Report (2014)



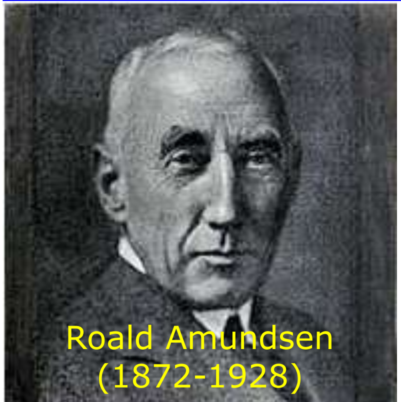

$\langle T \rangle_{1986-2016} \approx \langle T \rangle_{1901-1960}$ +0.7°C

**Important Q:**
**Natural vs. man-made**
**→**
**Economic Implications**

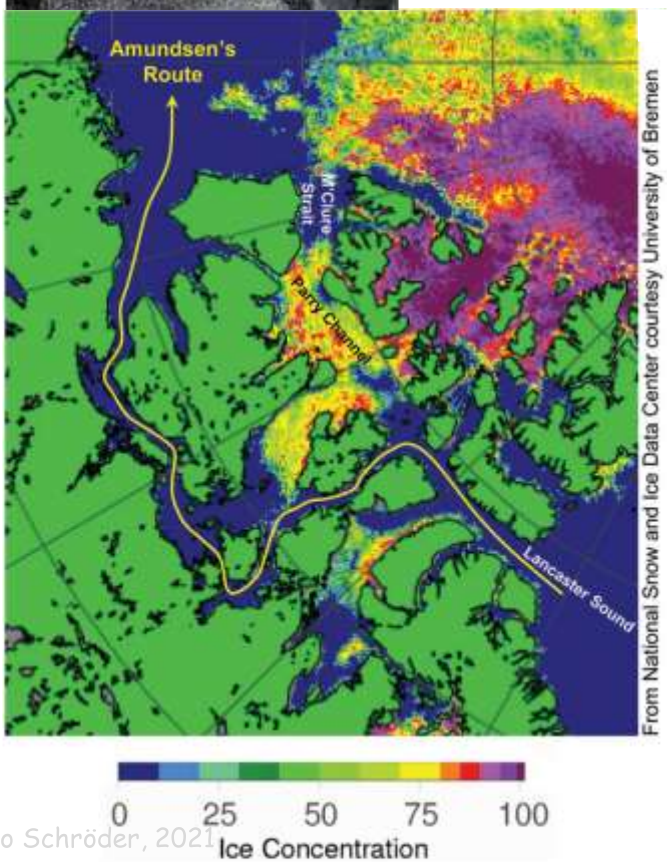
Greenland surface ice layer melts within 4 days:
July 8–July 12, 2011
NASA/NOAA satellite image.

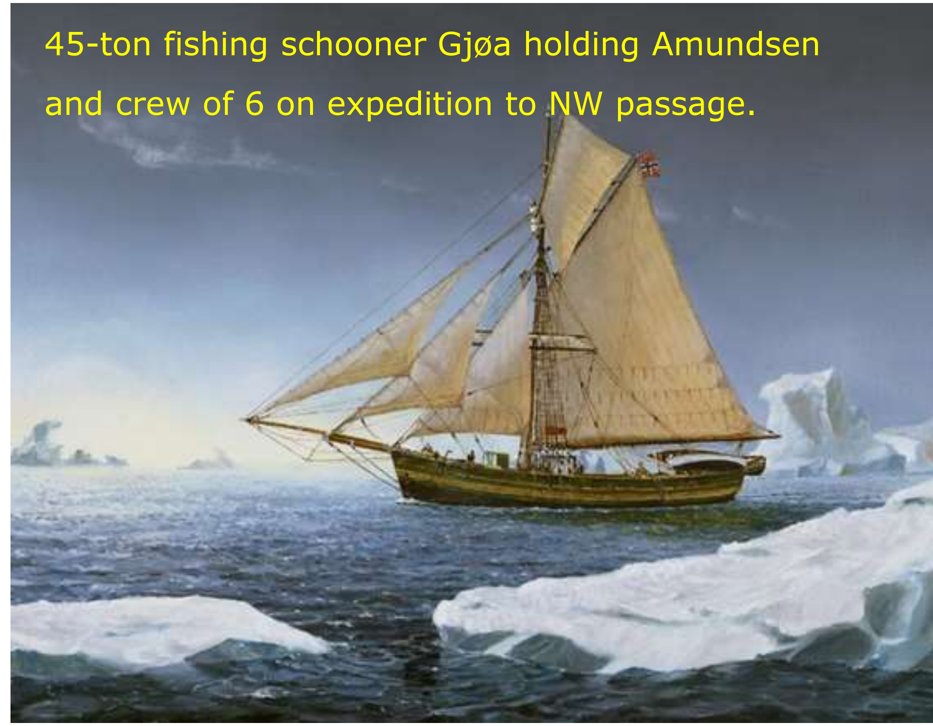


# Some Hard Facts: Opening of Northwest Passage




Old folklore: Northwest Passage exists between Atlantic & Pacific Oceans. True? Perhaps when Vikings in Greenland?



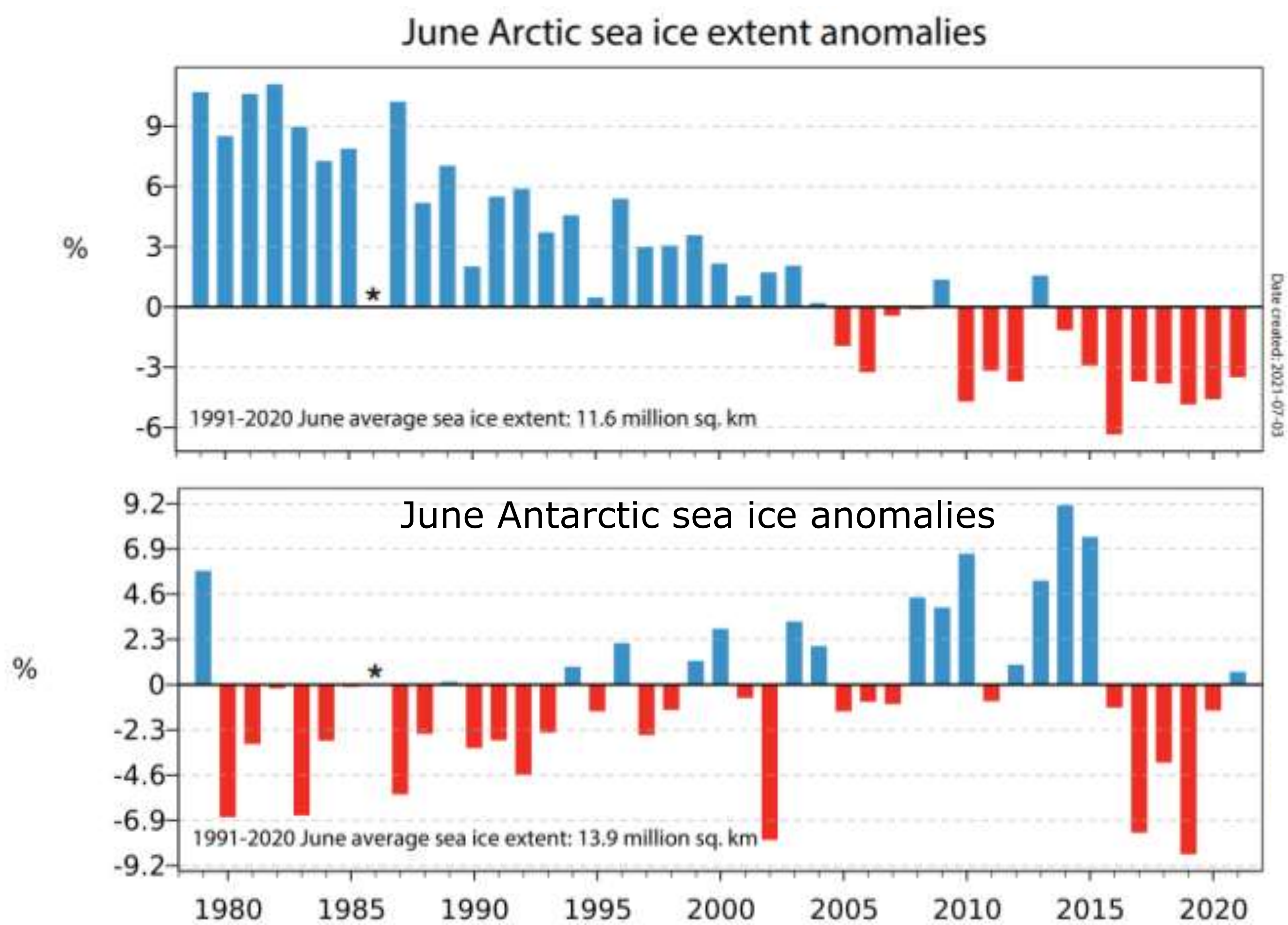




1903: Amundsen led the first expedition to successfully trans-navigate Northwest Passage connecting Atlantic and Pacific Oceans. Navigated small one-mast schooner with auxiliary gasoline engine close to coast.

Route: Baffin Bay → Parry Channel → south through Peel Sound → James Ross Strait → Simpson Strait → Rae Strait. Two winters at King William Island (today's Gjoa Haven, Nunavut/CA).

**>2016: Passage much easier for larger ships**

# Arctic/Antarctic Sea-Ice Development



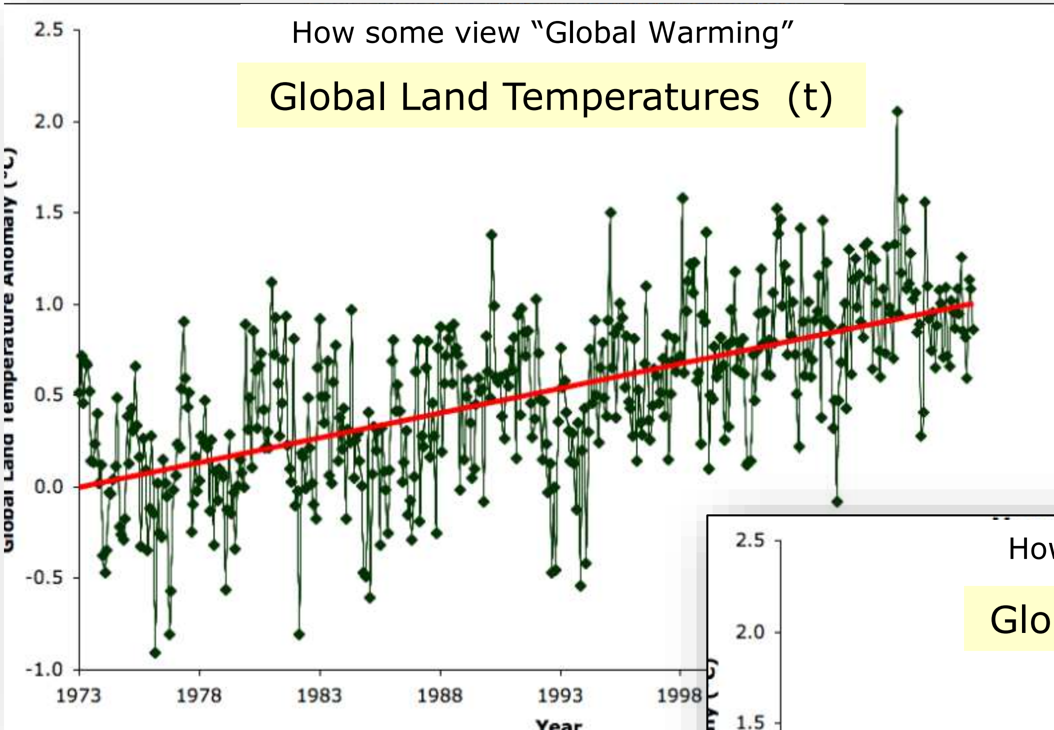

Temporal fluctuations, seasonal dependence, complex trends

Climate skeptical attitudes

# Awareness: What Climate Change, Who's Done It?


In US and Canada, debate over climate politics is split along partisan lines. Gallup 2018: Democrats (>80 %) believe global warming exists and (87%) is caused by human activities. Republicans are more skeptical: only 40 % believe effects exist and humans have caused it.

# Selective “Alternative” Climate Data




Individuals and political action groups challenge “Global Warming” assertion by UN-IPCC climate scientists.

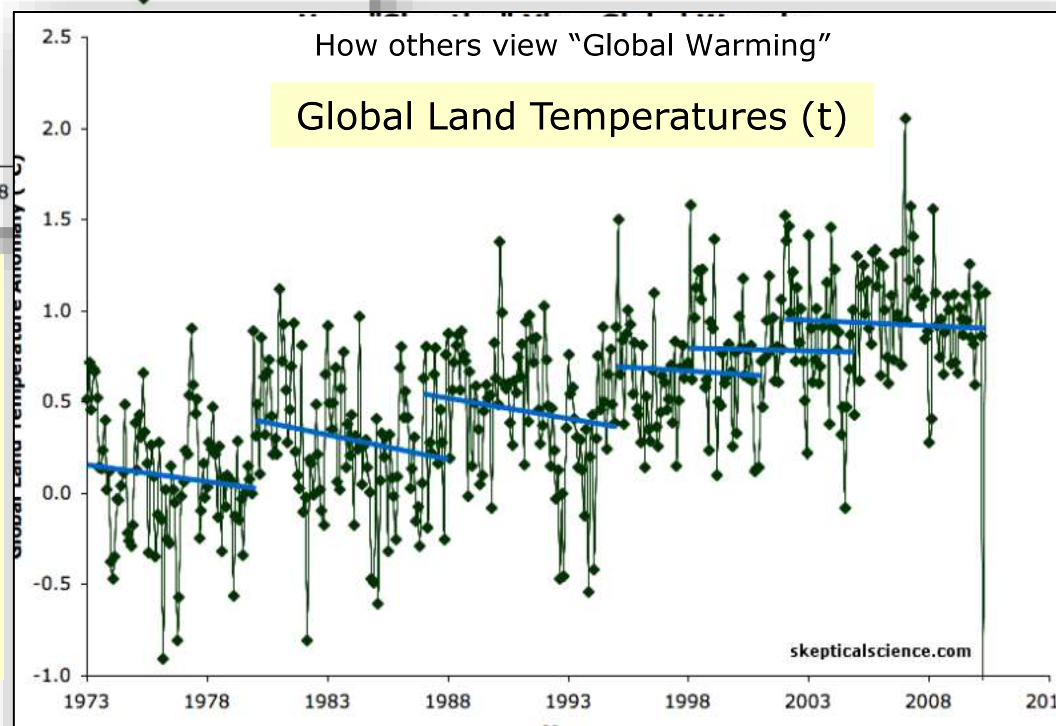
→ Do statistics data “lie” ?

Is the truth only “in the eye of the beholder” ? (“truthiness”)

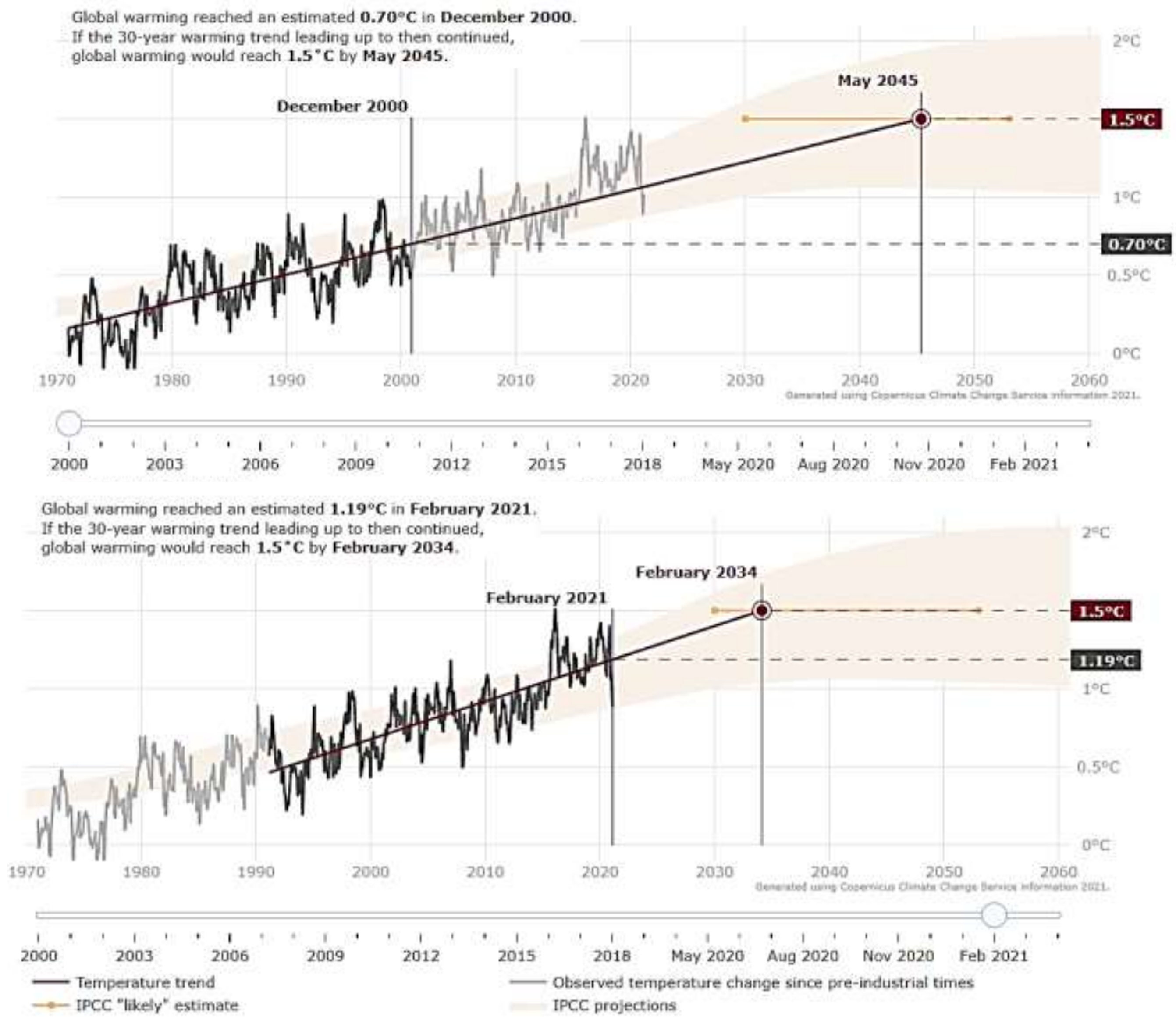
Do statistics **data** “lie” ? No!

But, if consideration is limited to certain, e.g., short-term aspects (= half-truths) and omits longer-term trends → **biased sampling**.

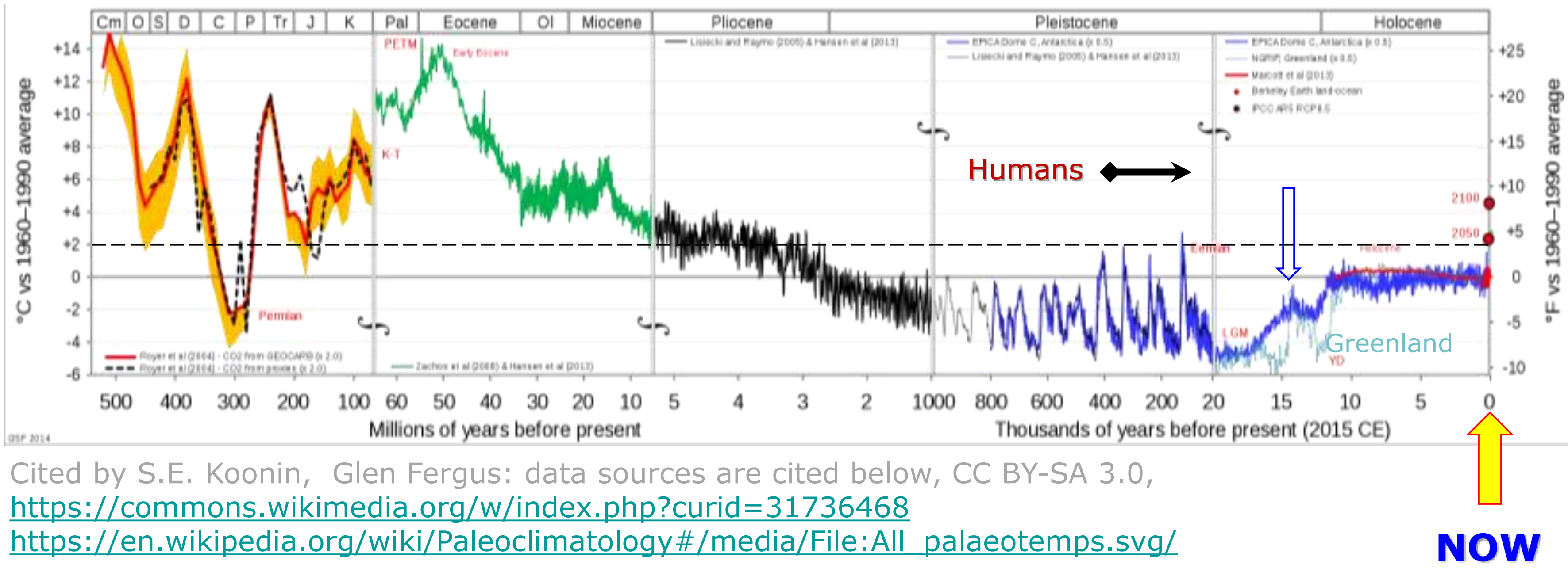
Complete analysis points out both behaviors of data (short-term fluctuations superimposed on long-term trend).



# Effect on Extrapolation



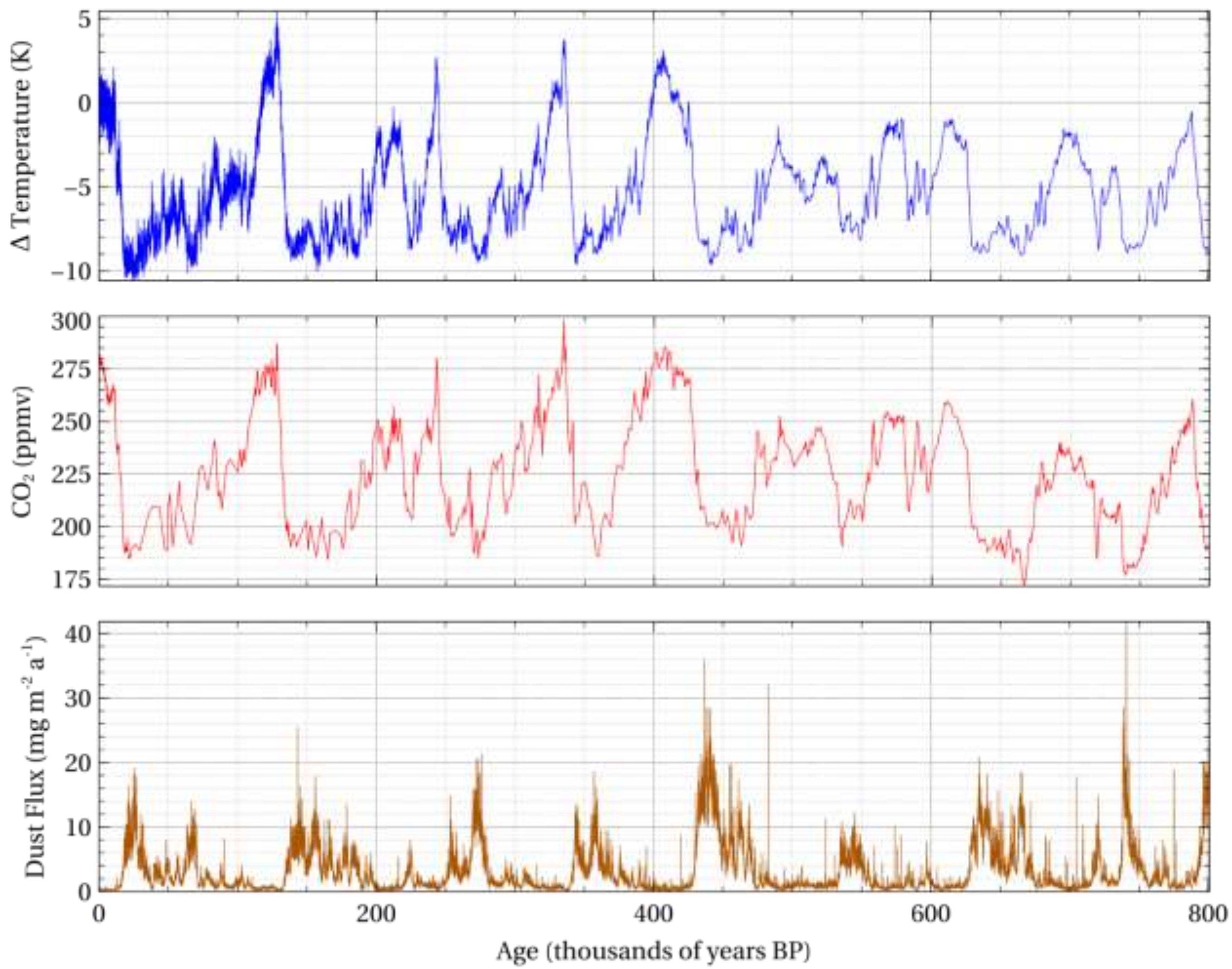
# Context Paleo-Climate: Mean Global Surface Temps




Cited by S.E. Koonin, Glen Fergus: data sources are cited below, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=31736468
https://en.wikipedia.org/wiki/Paleoclimatology#/media/File:All_palaeotemps.svg/

Different methods to determine temperatures (etc.) of paleoclimate, ice cores (≈3Ma), isotopic ratios, ocean sediments (≈100Ma) → direct satellite T measurements (±0.1$^0$C)

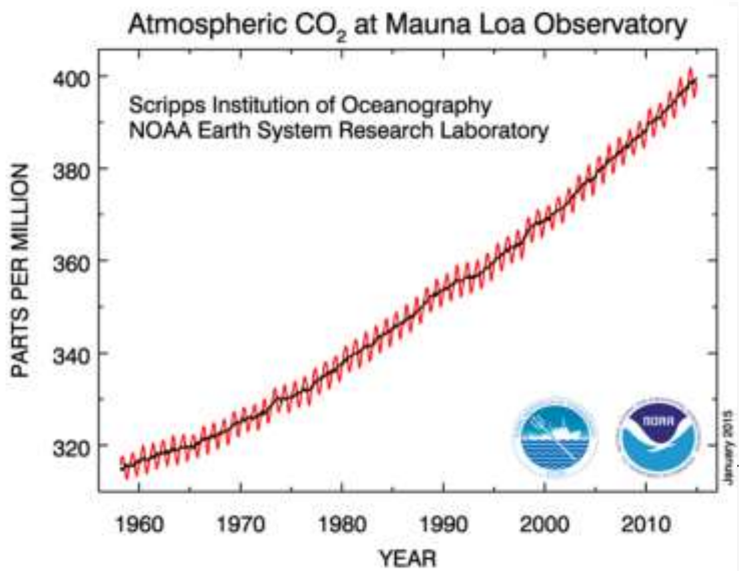
# Correlations of Atmospheric Data with *T*

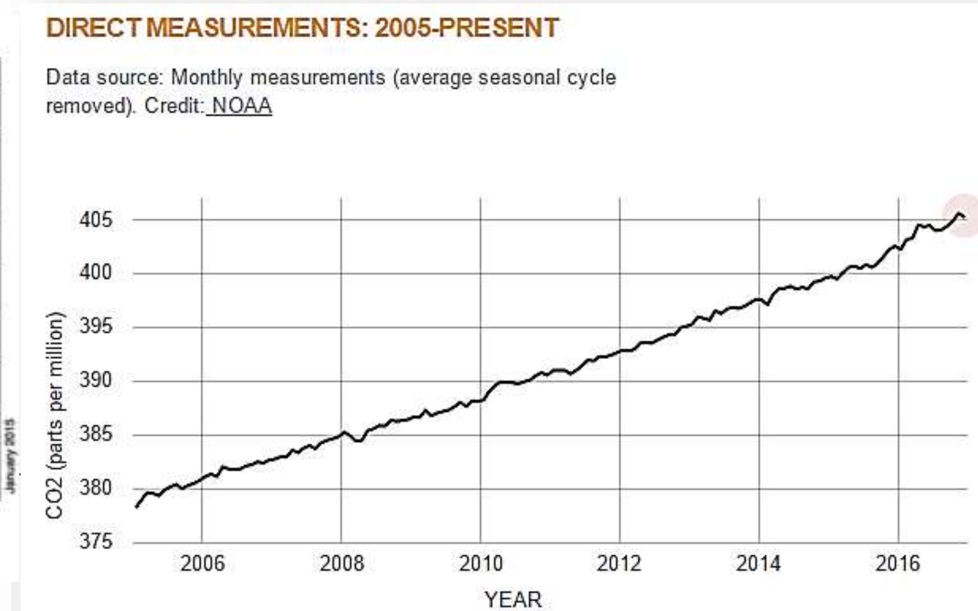



Ice core data for the past 800,000 years (x-axis values represent "age before 1950", so today's date is on the left side of the graph and older time on the right). Blue curve is temperature,[26] red curve is atmospheric CO2 concentrations,[27] and brown curve is dust fluxes.[28][29] Note length of glacial-interglacial cycles averages ~100,000 years.

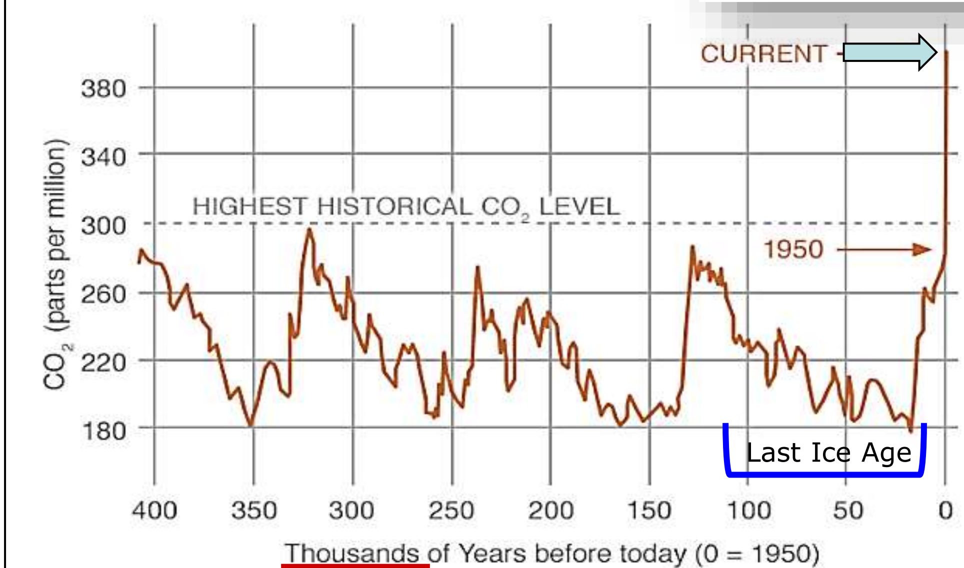
Back to shorter time scales

# A Changing Atmosphere: $CO_2$ Levels




http://www.esrl.noaa.gov/gmd/ccgg/trends/)




Direct measurements show detailed increase of atmospheric and oceanic $CO_2$ levels.

Paleoclimatic measurements show unusually high levels during the past 150 years (since industrial revolution).

Does CC prevent next ice age ?

# Recent Temperature-$CO_2$ Correlations

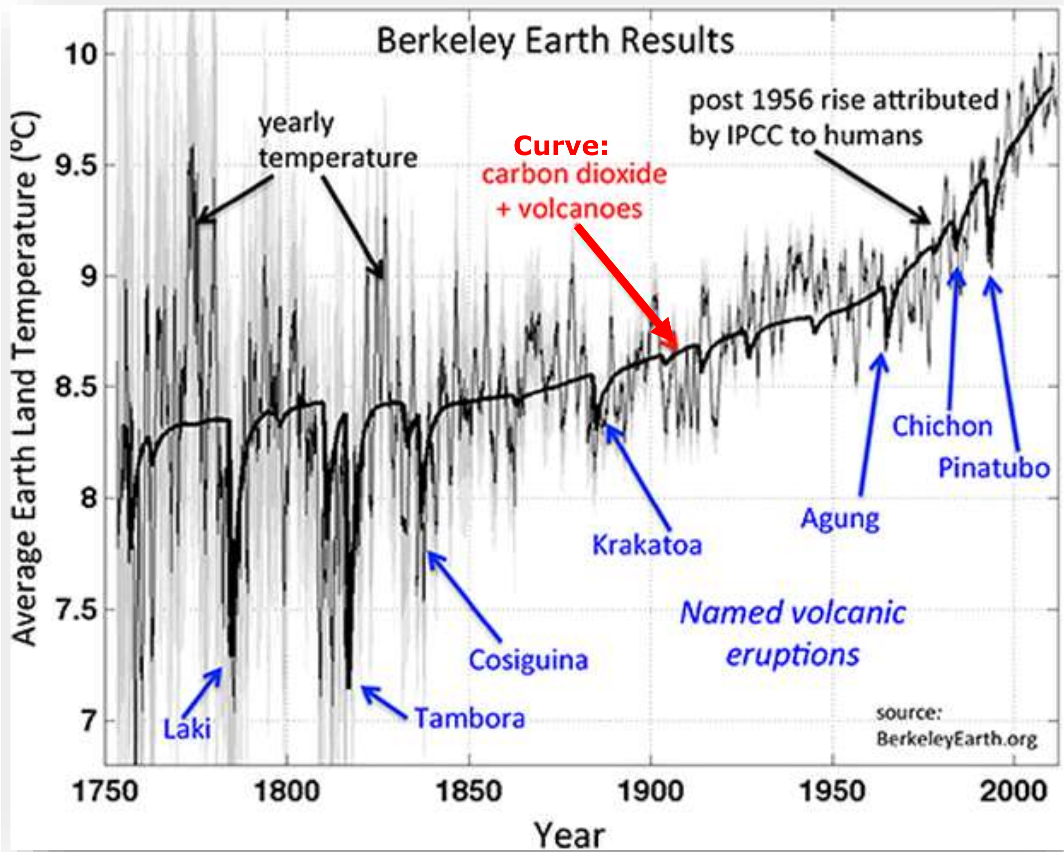
Dips in the observed historic temperature pattern match in time of occurrence and amplitude the emissions of known explosive volcanic eruptions.

Particulate clouds from volcanic events reflect sunlight and cool the Earth's surface for a few years.

Small rapid variations are attributable to El Nino and other ocean currents such as the Gulf Stream.

(From BerkelyEarth Project )

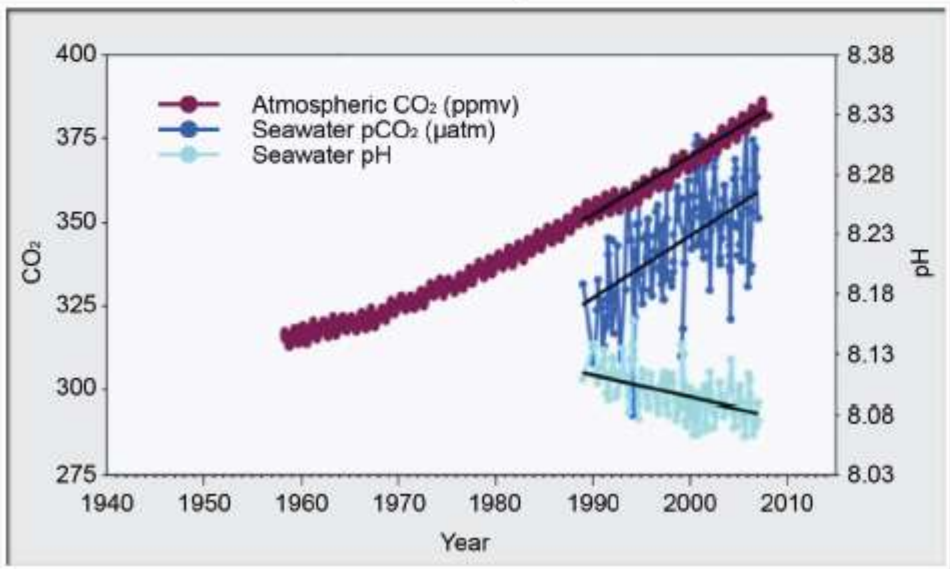
Last 250 years (anthropogenic activities?):
Systematic gradual rise of $\Delta T = 1.5^0C$ correlates with experimental record of atmospheric $CO_2$, as measured from atmospheric samples and air trapped in polar ice.
Modified $CO_2$ concentration is strongly correlated with T.
Solar variation not seen to impact *mean* temperature trend much.
(Berkeley Earth Surface Temperature study, 2012)




**Atmospheric GHG gases ($CO_2$) → increasing *T* trends. GHG influence is countered by aerosols (dust particles), volcanic emissions!**

# $CO_2$ Equilibrium

As Oceans Absorb $CO_2$, They Become More Acidic




Shells Dissolve in Acidified Ocean Water


Increasing atmospheric concentration of $CO_2$ → increasing $CO_2$ solvation in sea water → decreasing pH value (increasing $[H^+]$, complex set of rxns)
NCADAC Report 2013

**Consequence** (Example):
Pteropod, "sea butterfly":
Tiny sea creature (size of pea).
Pteropods = food for marine species from krill to whales, major food for North Pacific salmon.
Photos show progree of dissolution of a pteropod's shell in seawater with pH and carbonate levels projected for the year 2100.
The shell slowly dissolves after 45 days.

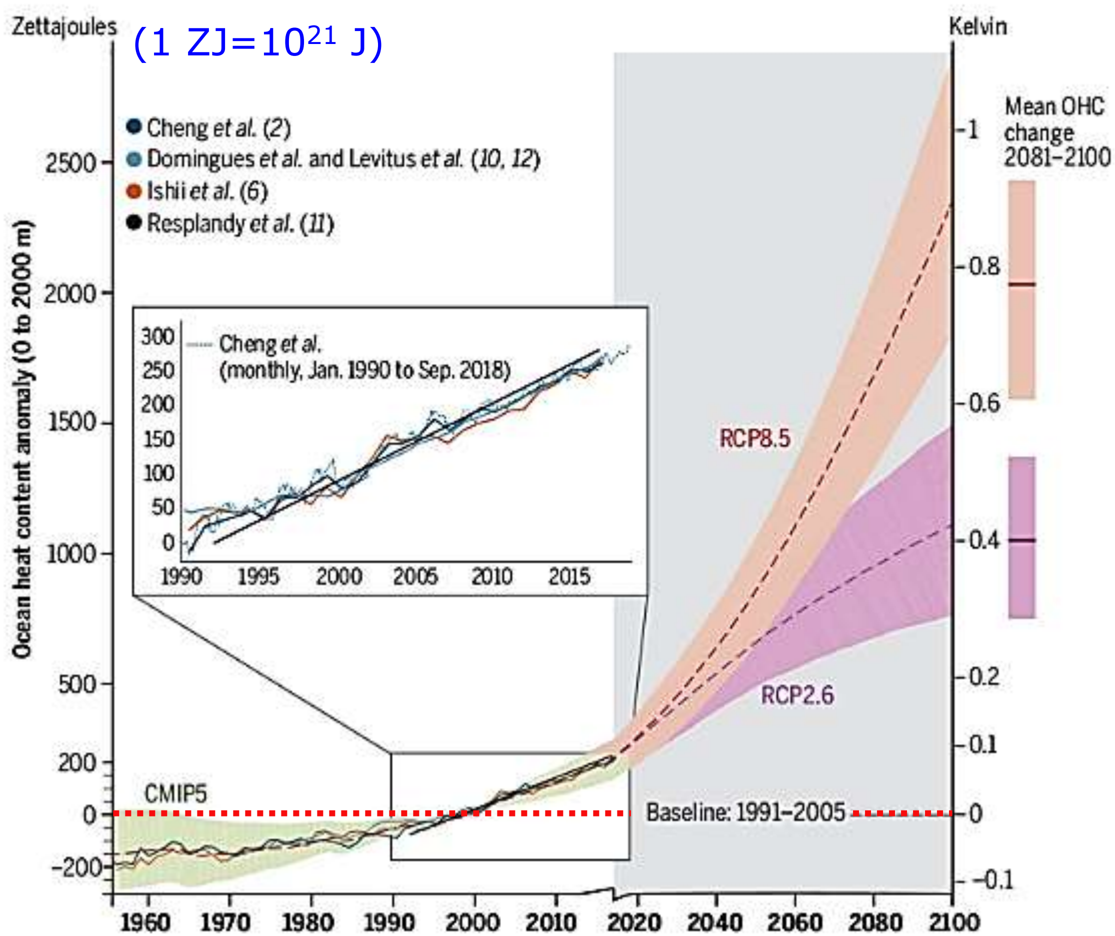
(Photo credit: National Geographic Images)

**Q**: Is there a causal relation $CO_2$ ←→ T ?

# Ocean Warming Trends

Increased ocean heat content (OHC): 1971-2010: $\Delta P=(0.39\pm0.07)\mathrm{W/cm^2}$ for upper 2km ocean.

2018 [Cheng *et al.* (2)], along with the other annual observed values superposed.

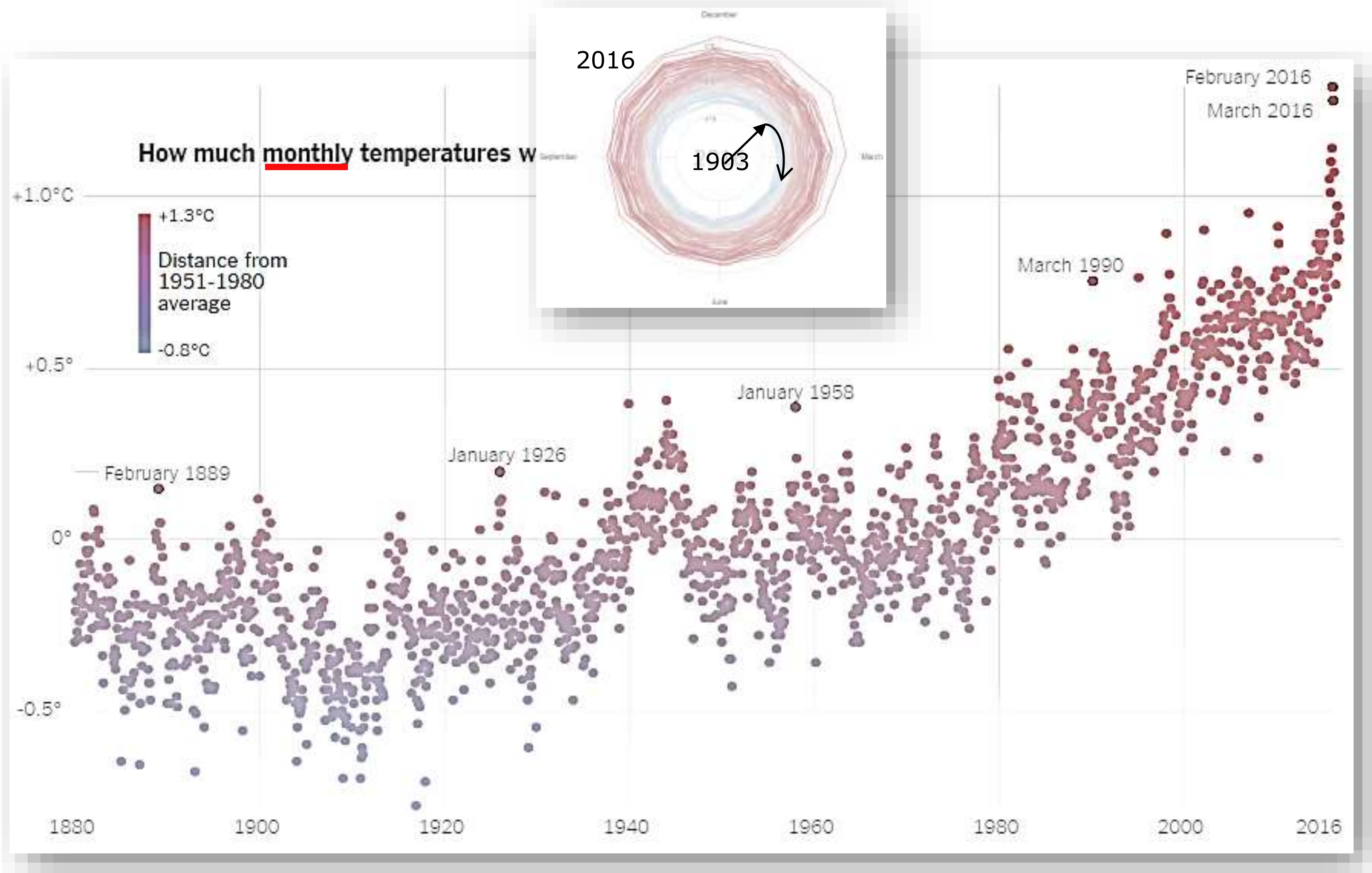



L. Cheng: Science Mag. Jan 11, 2019

Most (>90%) excess heat energy is absorbed by oceans. Many different methods of measurement: Direct contact with drone floats,…, satellites.

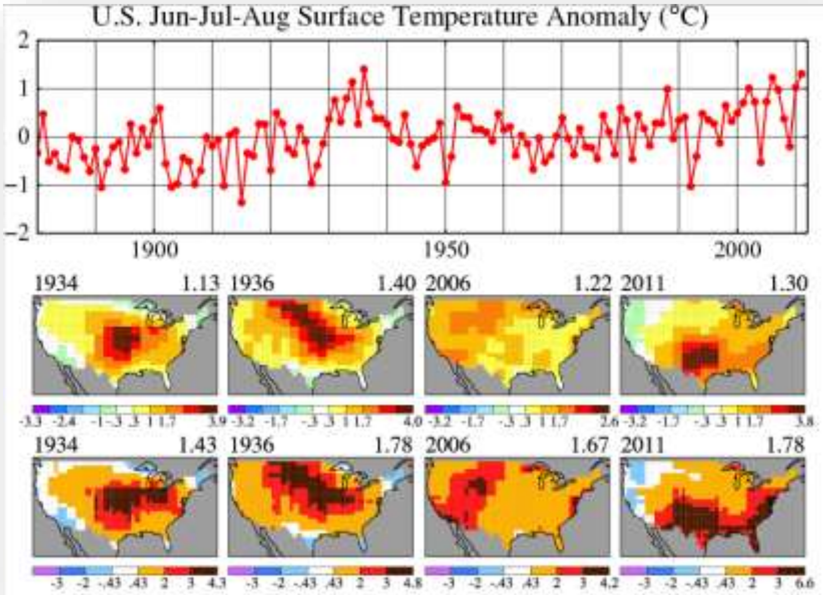
Predictions: For BAU
$\Delta E$=2300ZJ
$\Delta T$= +0.9 K by 2100.
→ outgassing, sea level rise (by how much?)

# Mean Global Temperature Trends = F(time)




Interactive Graphics (NYT Jan 18, 2017): https://www.nytimes.com/interactive/2017/01/18/science/earth/2016-hottest-year-on-record.html?emc=eta1&_r=0

# Evidence for Systematically Changing Climate

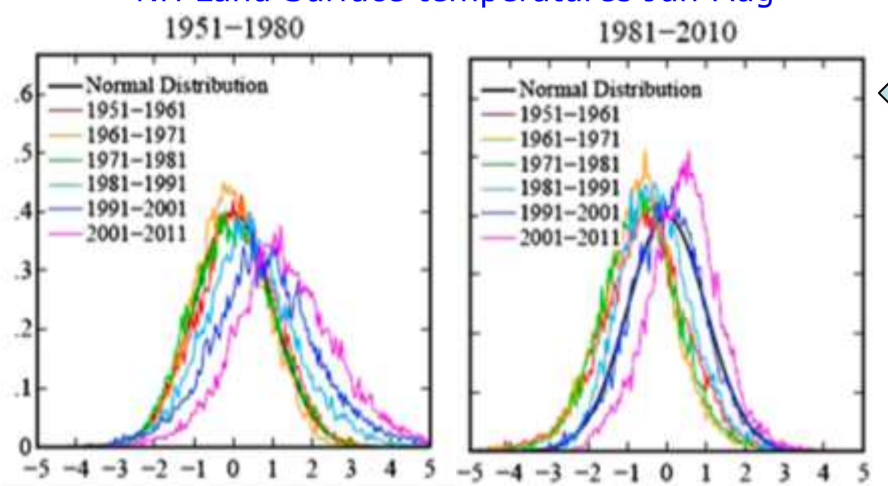



US: world's most extensive weather/climate records, publicly available.

2012 statistical study of changing temperature patterns:

Report *Perception of climate change* by James Hansen et al., (NASA Goddard Institute for Space Studies and Columbia University Earth Institute

NH Land Surface temperatures Jun-Aug




30-y period 1951–1980 with relatively stable climate defines a near-normal climatological temperature distribution, (Figure).

In time, T distribution shifts to higher means and becomes broader.

Less visible when compared to different (more recent time period) normal standard (Figure right).

<T(t)> How systematic ?

# National Climate Assessment and Development Advisory Committee

**Summary Findings** (edited):

1) Global climate is changing, apparent in a wide range of observations. The climate change of the past 50 years due primarily to human activities (burning of fossil fuels).

2) Extreme weather and climate events have increased in recent decades, evidence is mounting for human activities as dominant cause.

3) Human-induced climate change will accelerate significantly if emissions of heat-trapping gases continue to increase.

4) Impacts of climate change, evident in many sectors, become increasingly challenging.

5) Threats to human health and well-being from extreme weather events, wildfire, dangerous air quality, diseases transmitted by insects, food, and water, and threats to mental health.

6) Infrastructure adversely affected by climate change: sea level rise, storm surge, heavy downpours, extreme heat.

7) Lower reliability of water supplies, affecting ecosystems and livelihoods in many regions, particularly the Southwest, the Great Plains, the Southeast, the islands of the Caribbean and the Pacific, including the state of Hawai.

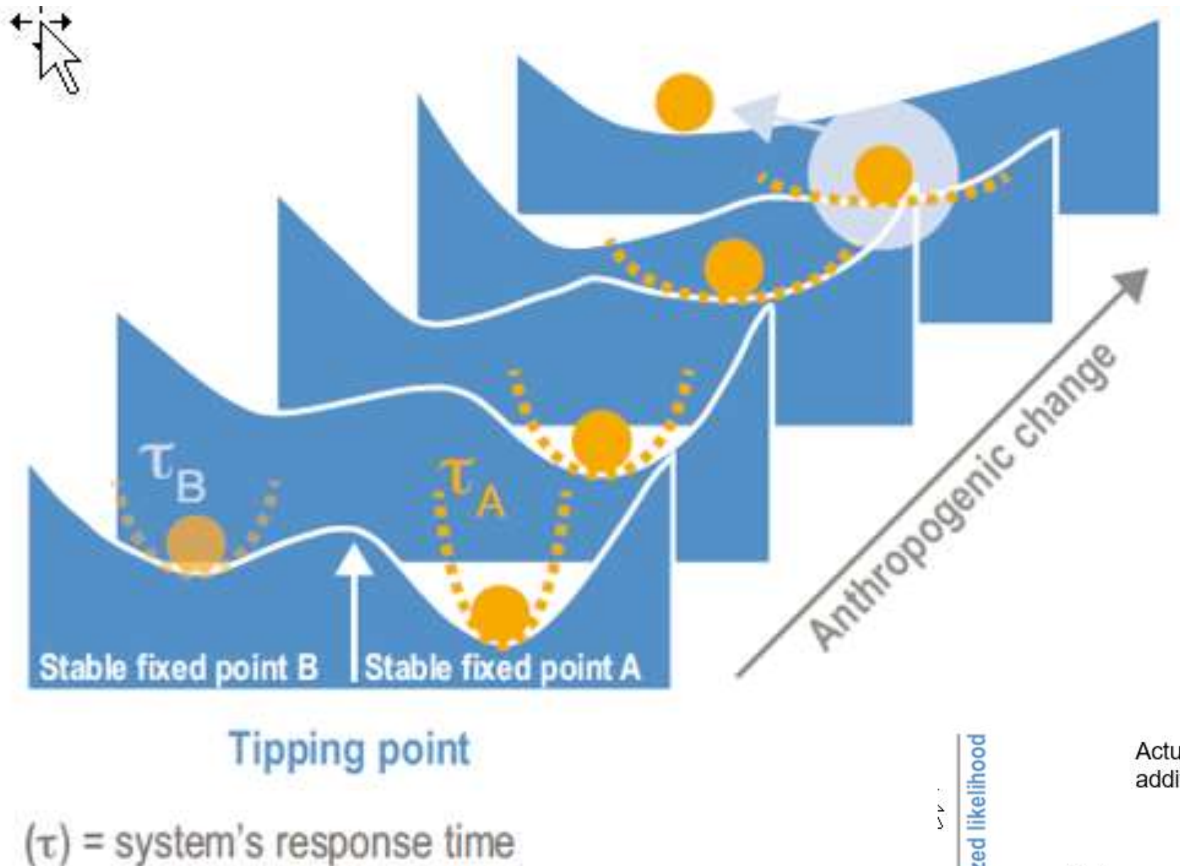
8) Adverse impacts to crops and livestock over the next 100 years, increasing disruptions from extreme heat, drought, and heavy downpours.

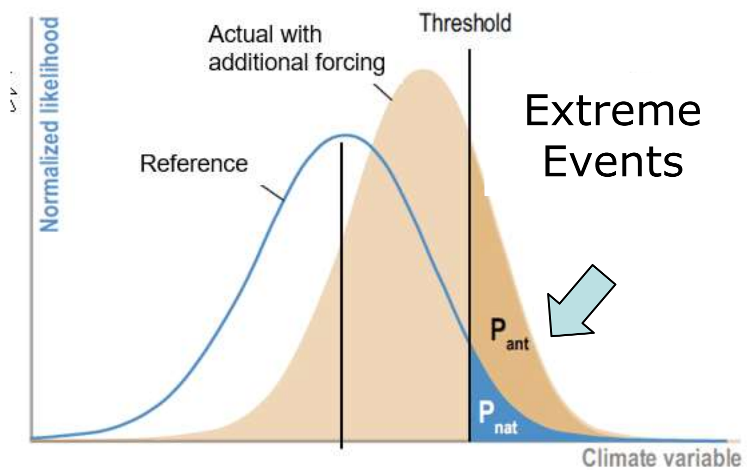
9) Natural ecosystems directly affected, changes in biodiversity and location of species.

10) Life in the oceans is changing as ocean waters become warmer and more acidic.

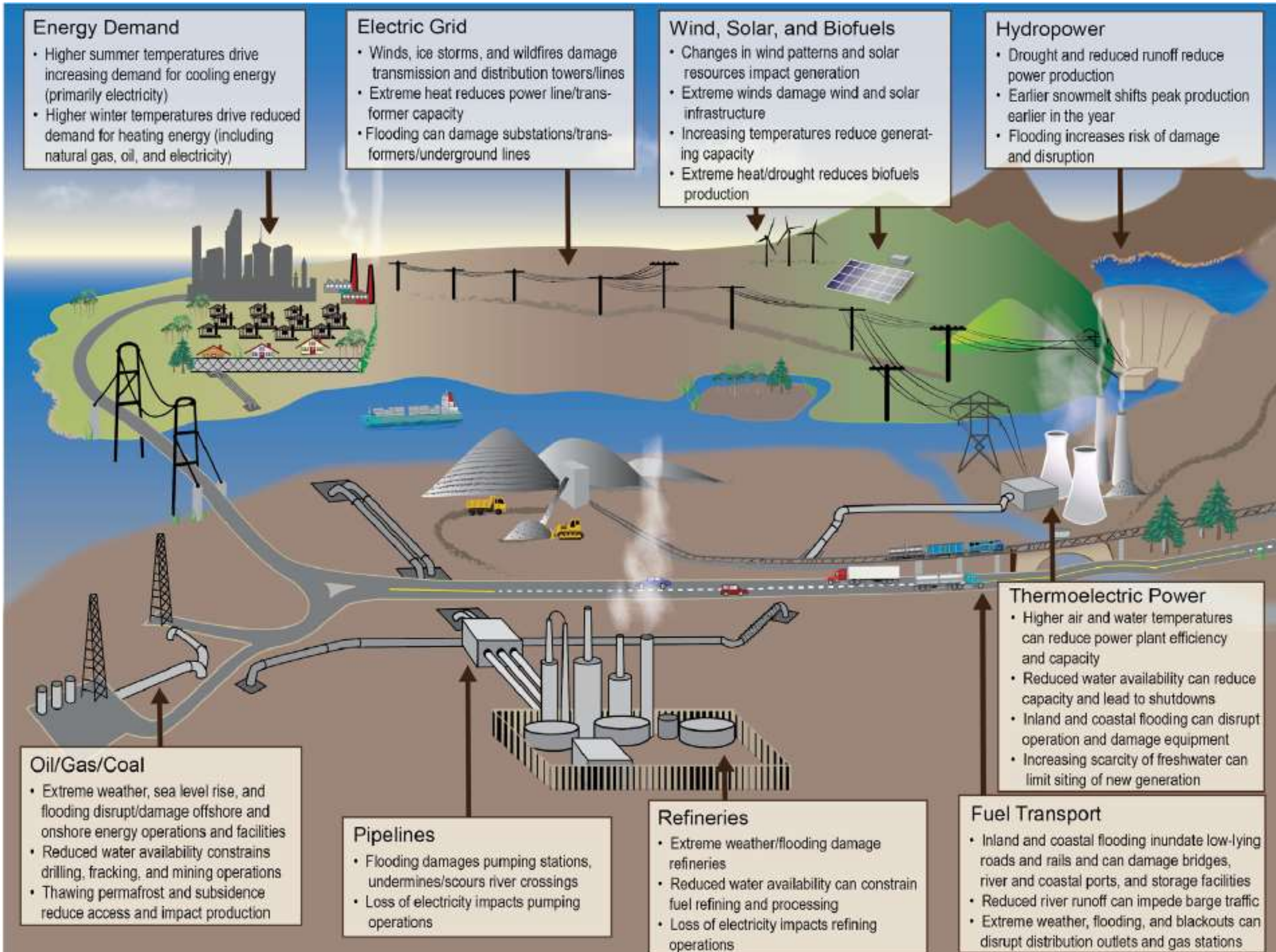
11) Planning for adaptation (address and prepare for impacts) and mitigation (reduce emissions) is increasing, but progress with implementation is limited.

# Tipping Points for Complex Systems

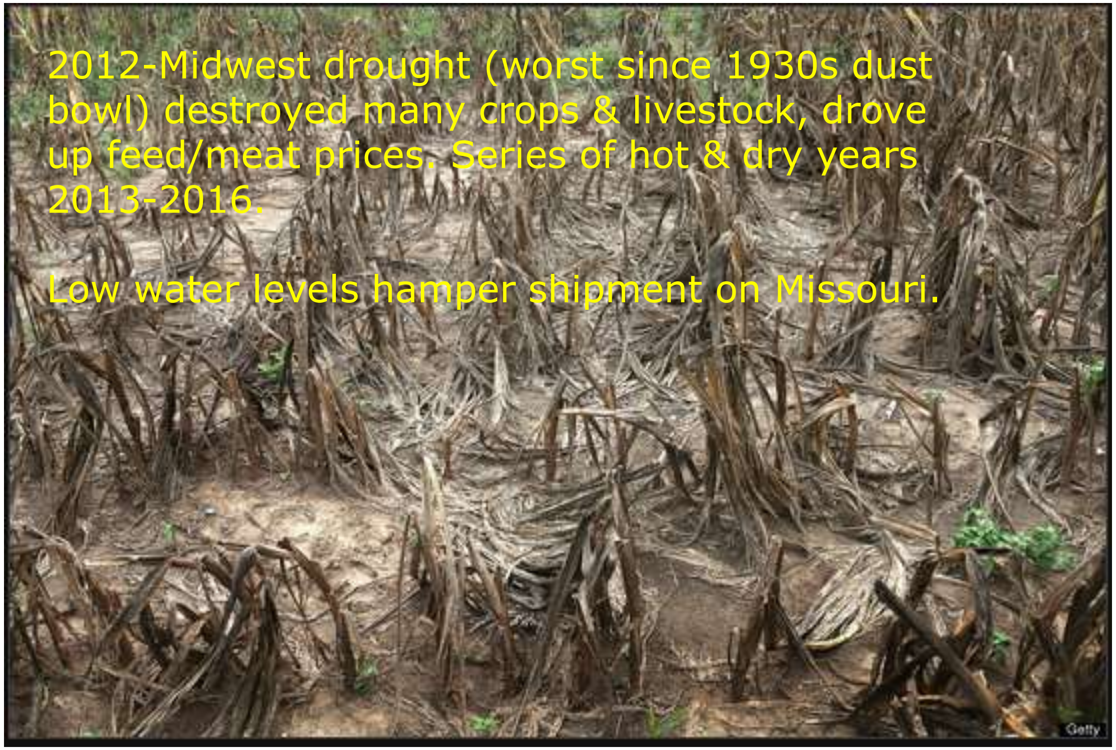


# Impacts of Extreme Weather (CC)



# Extreme Weather Events



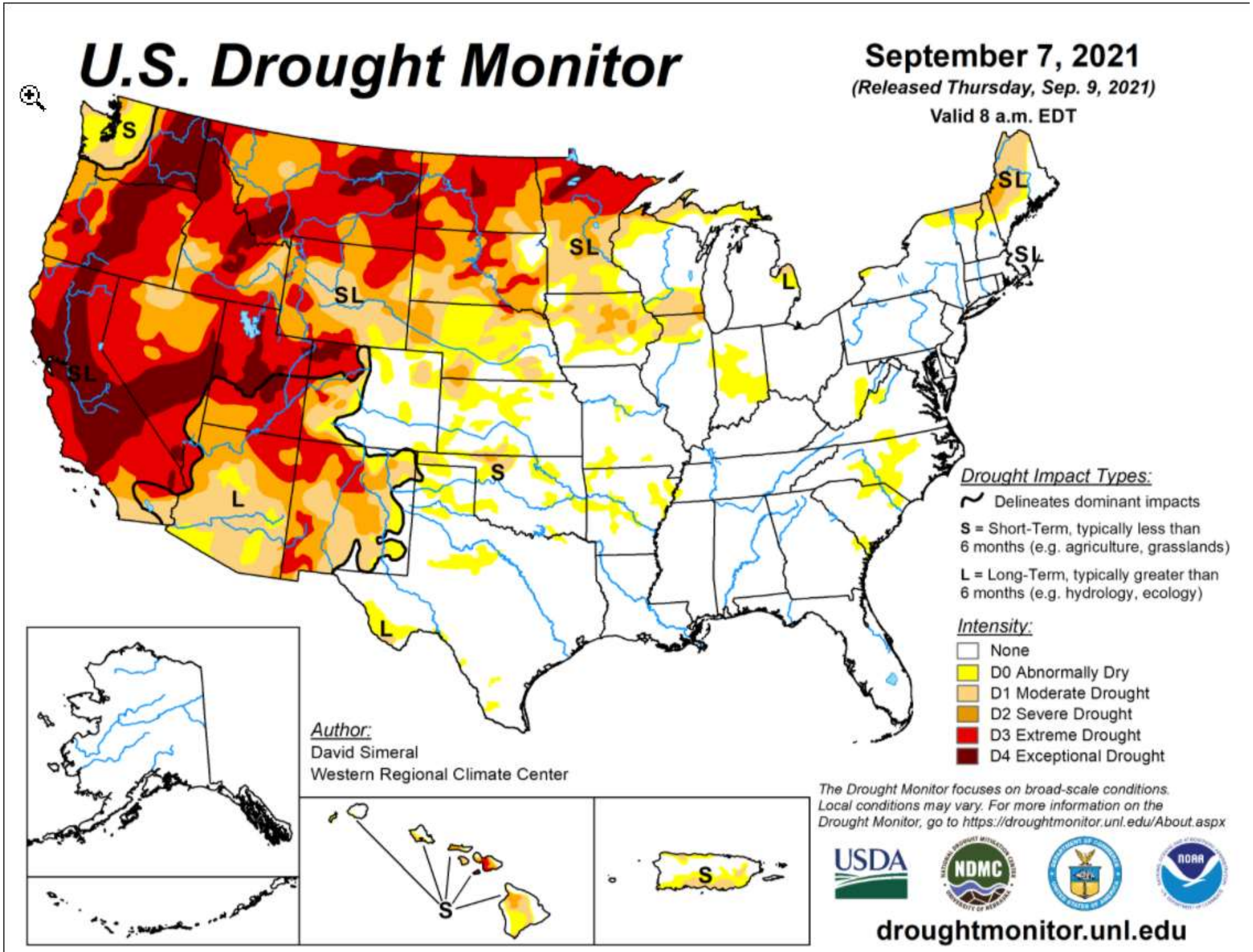

Lives lost in heat waves:
≈ 750 in Chicago 1995.
≈ 3,000/15,000 in Paris/F 2003.
2010 Moscow heat wave (many ?)
2012 Chicago Heat Wave: 3 days of continuous >$100^0$F (first since 1947).
Now better prepared facilities.

2012: Large parts of France are under high (yellow) alert following record high temperatures. Some towns report highest temperatures in 90 years.

Elsewhere ? 2012: African heat wave swept Turkey > $55^0$C (133 F) ? (Blogs, web casts)
Since 1960, Africa has warmed $\Delta T = +0.5°C$, expect further + (1.5 - 4)°C in 21st century.
Heat decreases cereal crop yields (especially maize) by ≈(10-20)% per 1°C rise.
Shifting rainfall patterns also influence crop.

Many African countries: cultivation of few varieties of crops, no irrigation. Vulnerable to climate change (global warming). → More conflicts expected, human migration waves ? African boat people to Spain/Italy/France.

# Current U.S. Droughts 2021

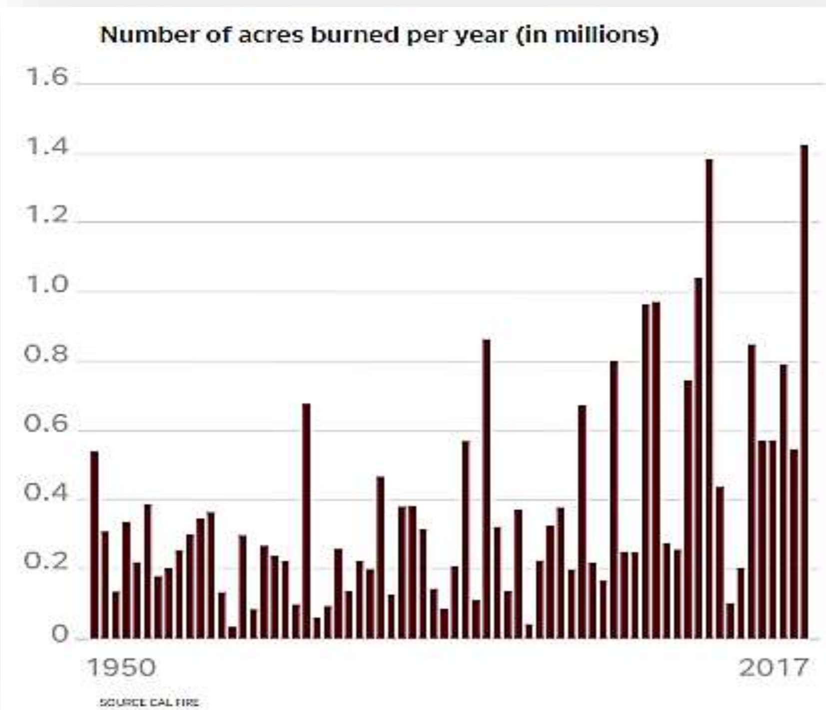


# California Wildfires

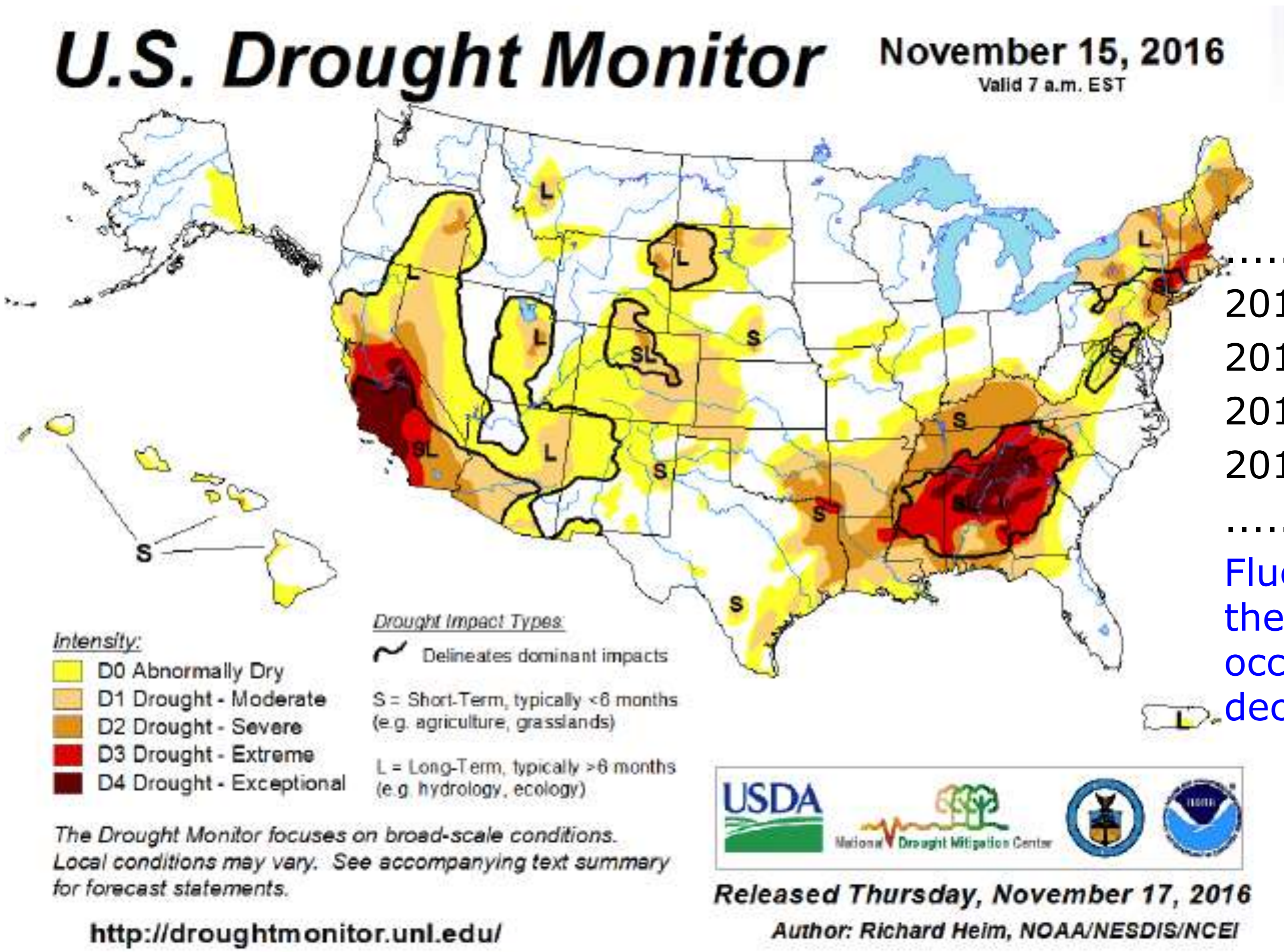
Multi-year droughts in CA: water problem, increased # and severity of wildfires

Paradise/Ca lost town, < 23 fatalities.

Role of electrical lines (PG&E)




# Current U.S. Droughts

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2016 Hottest year recorded

2015 Hottest year recorded

2014 Hottest year recorded

2013 Hottest year recorded

.......

Fluctuations, but most of the hottest years ever occurred during the last decade

25.2% of Contiguous U.S. in Drought ( ~+10.7 percentage points since early October)

Degradation: Tennessee Valley into lower Ohio Valley, Southern Appalachians, upper mid-Atlantic into Northeast, Central Plains into Southern and Central Rockies

Improvements: Pacific Northwest, northern California, Northern Rockies and parts of Northern Plains

# Elsewhere: Australian Heat Wave 2019

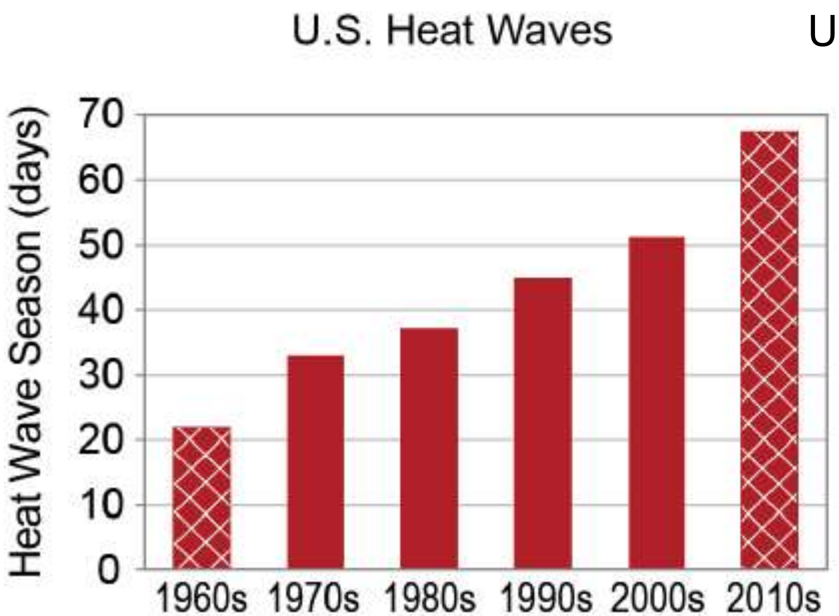
Several years of drought in Australia.

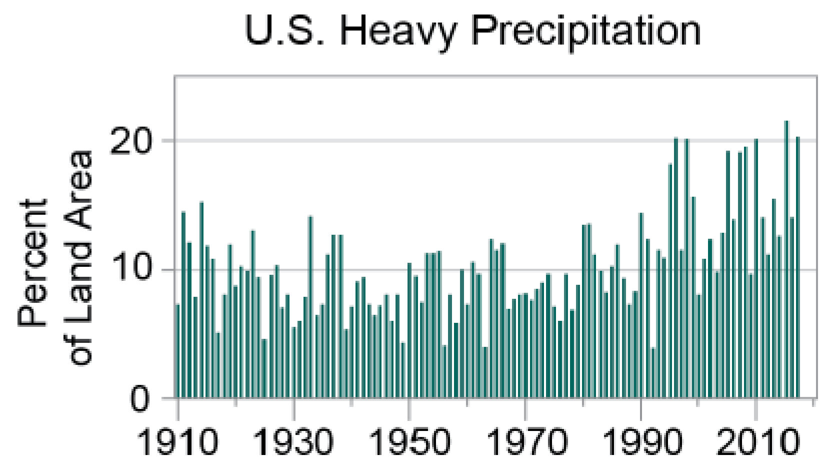
Excessive heat during Summer 2019,
T >116 $^0$F   Loss of farm land, livestock


Many African regions suffer extensive droughts for years. Some fluctuating effects due to global El Nińo weather patterns are superimposed.

# Trends in Significant Weather Events

US Fourth National Climate Assessment



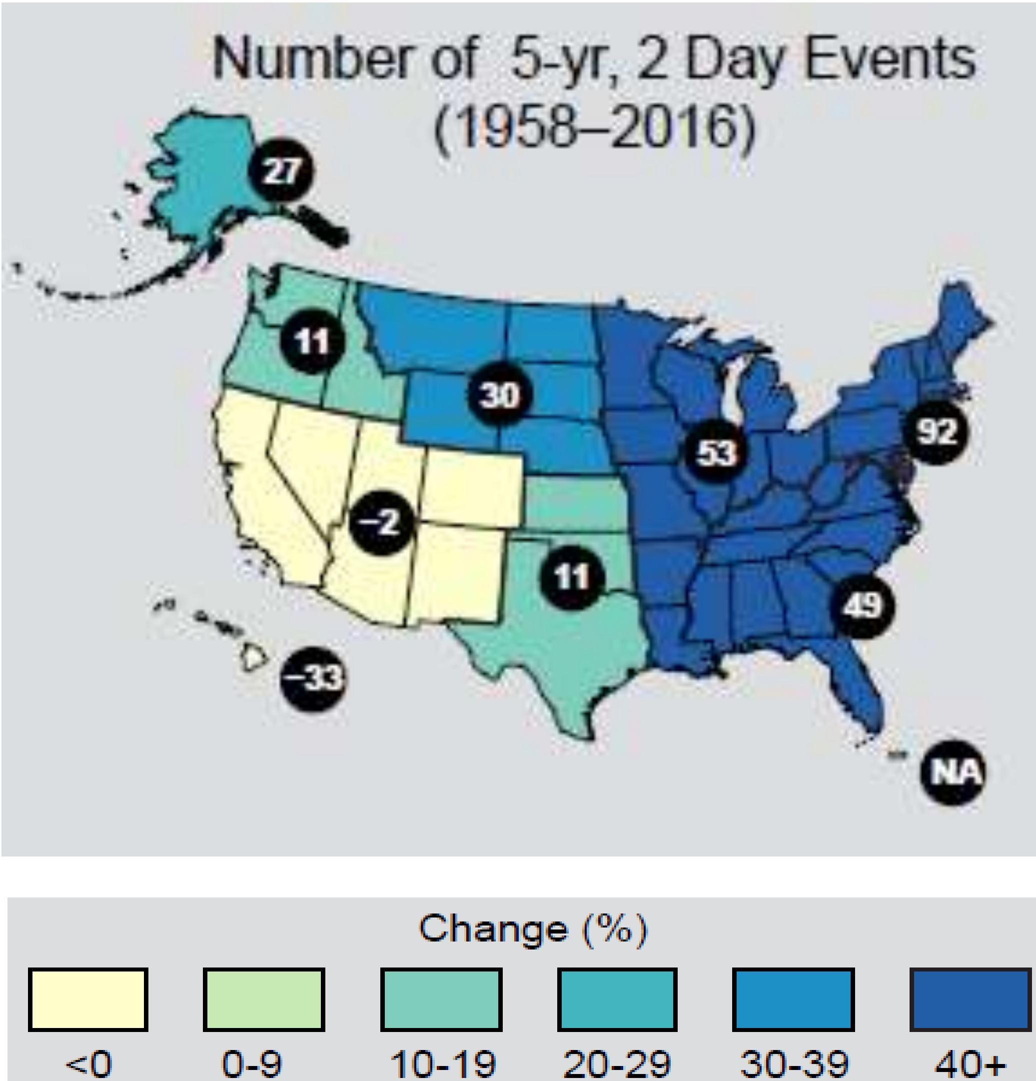

| Storm (Cat) | Landfall (t) | Affected | Fatalities |
| --- | --- | --- | --- |
| Maria (V) | **9/20/2017** | Puerto Rico | >500 (?) |
| Irma (V) | **9/10/2017** | Florida Barbuda, St. Martin | 134(US 90) |
| Harvey (V) | **8/25/2017** | Houston | 90 |

Superstorms (1 in 50 a) in 2017 hitting US. Fatalities, substantial damage

Fewer in 2018

NOAA

# Significant Weather Trends

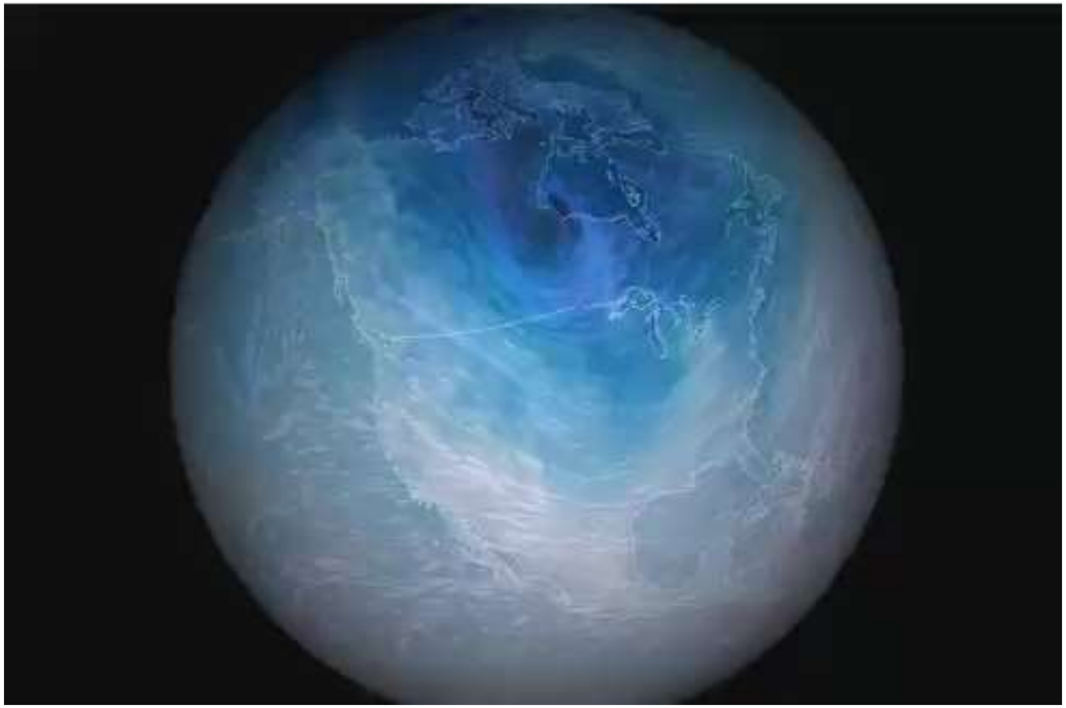



Excess precipitation and flooding events have increased.

Number of 2-day events with total precipitation exceeding the largest 2-day amount expected to occur, on average, only once every 5 years (calculated for 1958–2016)

US Global Change Research Program
Climate Science Special Report, 2018

# Sudden Bursts of Extreme (Chaotic) Weather



Jan 2019 US Midwest and NE: Extreme cold (-25$^0$C)

Northern Vortex: CC flow of upper atmospheric flow over North Pole.

Cold wave 2019: NV fractionated, driving cold air south.

Possible connection to smaller sea ice cover. Warmer ocean water generates upward convection tilting the NV. → chaotic dynamics (Edward Lorenz)

# Extreme Weather Events: Hurricanes in US


More frequent extreme weather: Hurricanes Irene, Katrina,.., Sandy,…

Hurricane Katrina '3' New Orleans (Aug. 29, 2005), Category 3 winds downtown, tidal surge. Center of Katrina missed city.

Oct 30, Nov. 1 2012: ~1,000-mile-wide "Superstorm" Sandy devastates NY, NJ, Connecticut,… More tornadoes (2016 US East Coast)

Sandy's Jersey City trail. Several 10,000 persons displaced, stranded. Millions without power in 17 states.

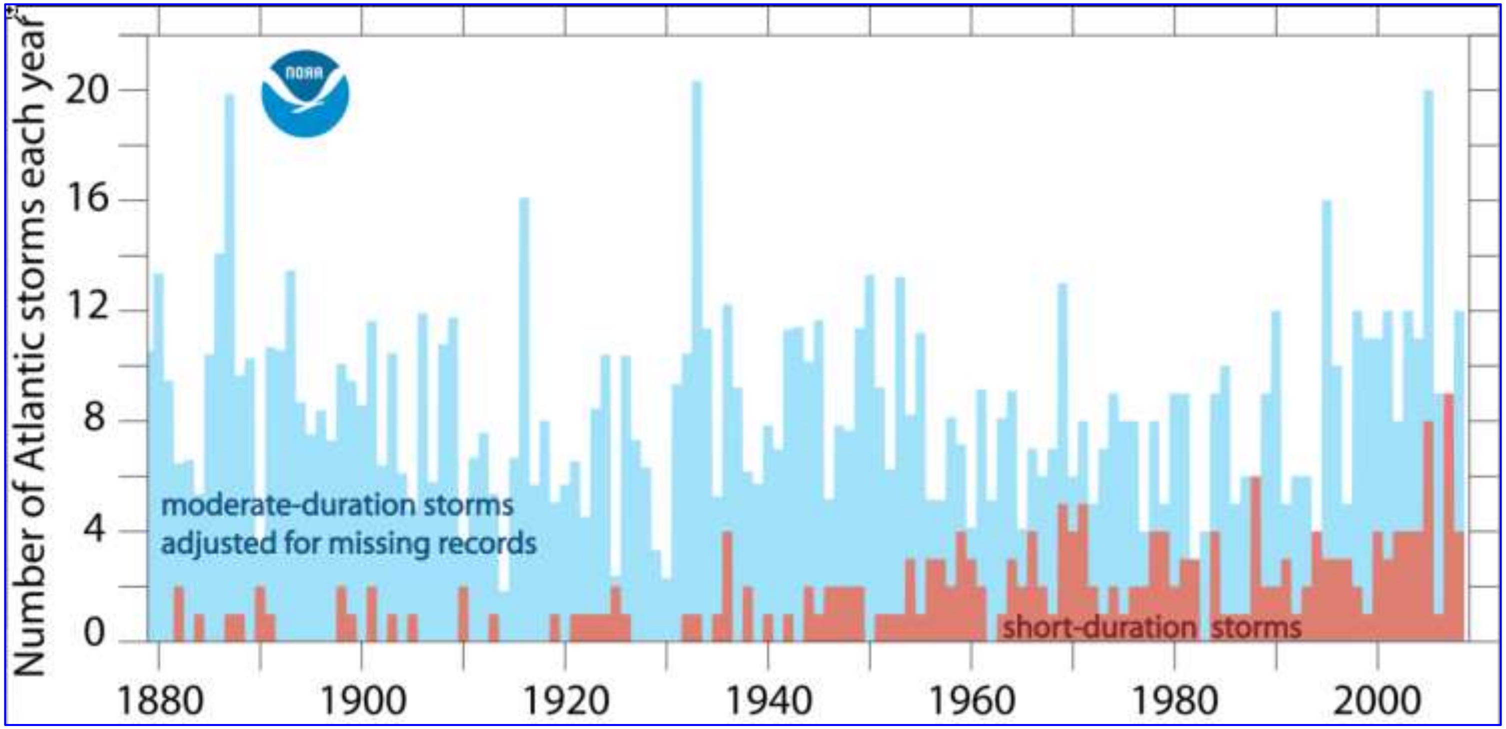
Photo: By Mark Lennihan, AP

Superstorm "Sandy" damages:

Significant economic losses : ~ $\$6\cdot10^{10}$ !

Extreme monsoons in Asia. Flooding (Bangladesh).

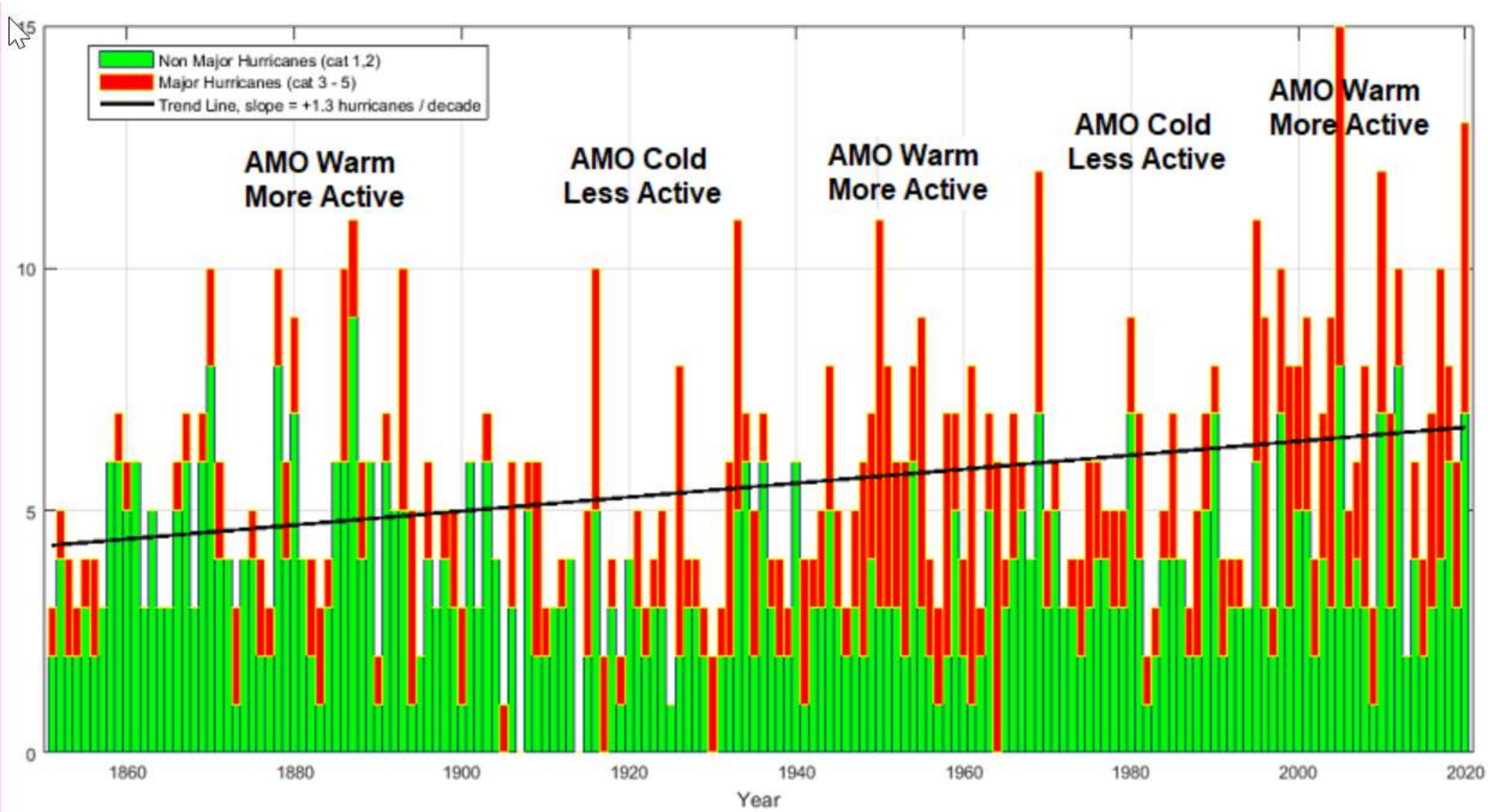
# Tropical Storms in Atlantic




# of Atlantic tropical storms lasting more than 2 days has not increased.
# of storms lasting less than two days has increased sharply,
likely due to better observations.

Figure adapted from Landsea, Vecchi, Bengtsson and Knutson (2009, J. Climate)

# Atlantic Multidecadal Oscillation (AMO) Hurricanes



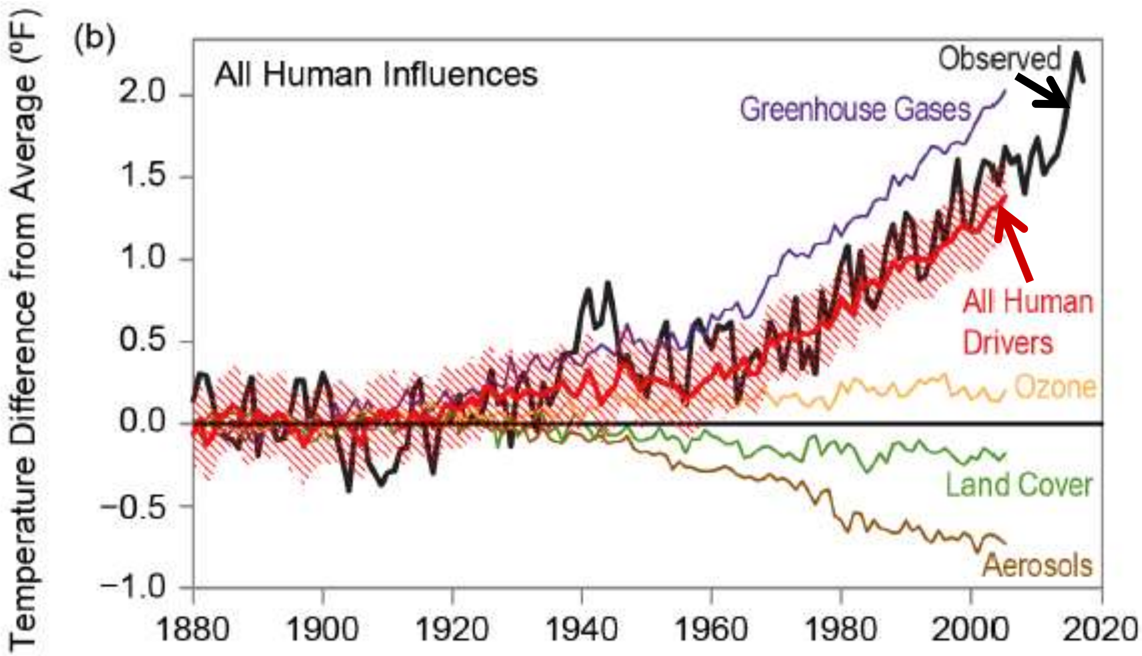

Influence of Atlantic Multidecadal Oscillation (AMO) Hurricanes

# Anthropogenic Influences

Many correlations exist between human caused pollution and global climate parameters: To what extent is there a causal relationship ?

→ Quantitative agreement between observation and robust physical models

→ Absence of plausible competing scenarios




Simulated changes in global temperature when considering only human influences (dark red line), including the contributions from emissions of greenhouse gases (purple line) and small particles (referred to as aerosols, brown line) as well as changes in ozone levels (orange line) and changes in land cover, including deforestation (green line). Changes in aerosols and land cover have had a net cooling effect in recent decades, while changes in near-surface ozone levels have had a small warming effect. These smaller effects are dominated by the large warming influence of greenhouse gases such as carbon dioxide and methane. Note that the net effect of human factors (dark red line)explains most of the long-term warming trend.