



# About Climate Change

Dr. Michael Friedman



Unitarian Universalist Society of Rockport, September 2018

Climate change (global warming) is happening.

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Anyone who says it is not is knowingly  
lying to you.

Humans are responsible for most of the climate change we are seeing now and that will affect us in the future.

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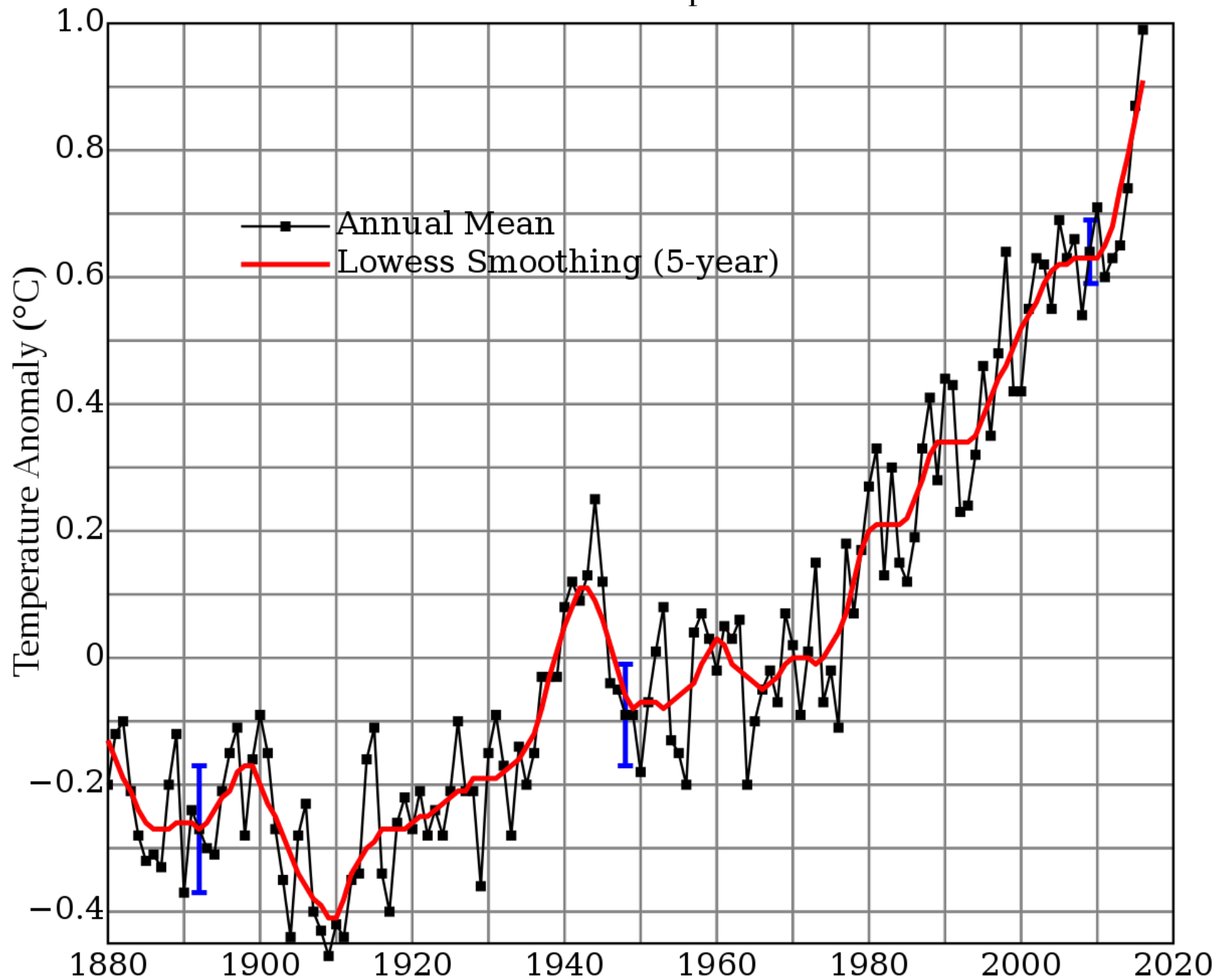
Anyone who says this is not the case is, at best, uninformed by the overwhelming scientific evidence. Many who say this is not the case are knowingly lying.

Climate change will have important impacts.

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Anyone who says the impacts will be minor (or even beneficial on the whole) is, at best, uninformed by the overwhelming scientific evidence. (And, again, some are knowingly lying.)

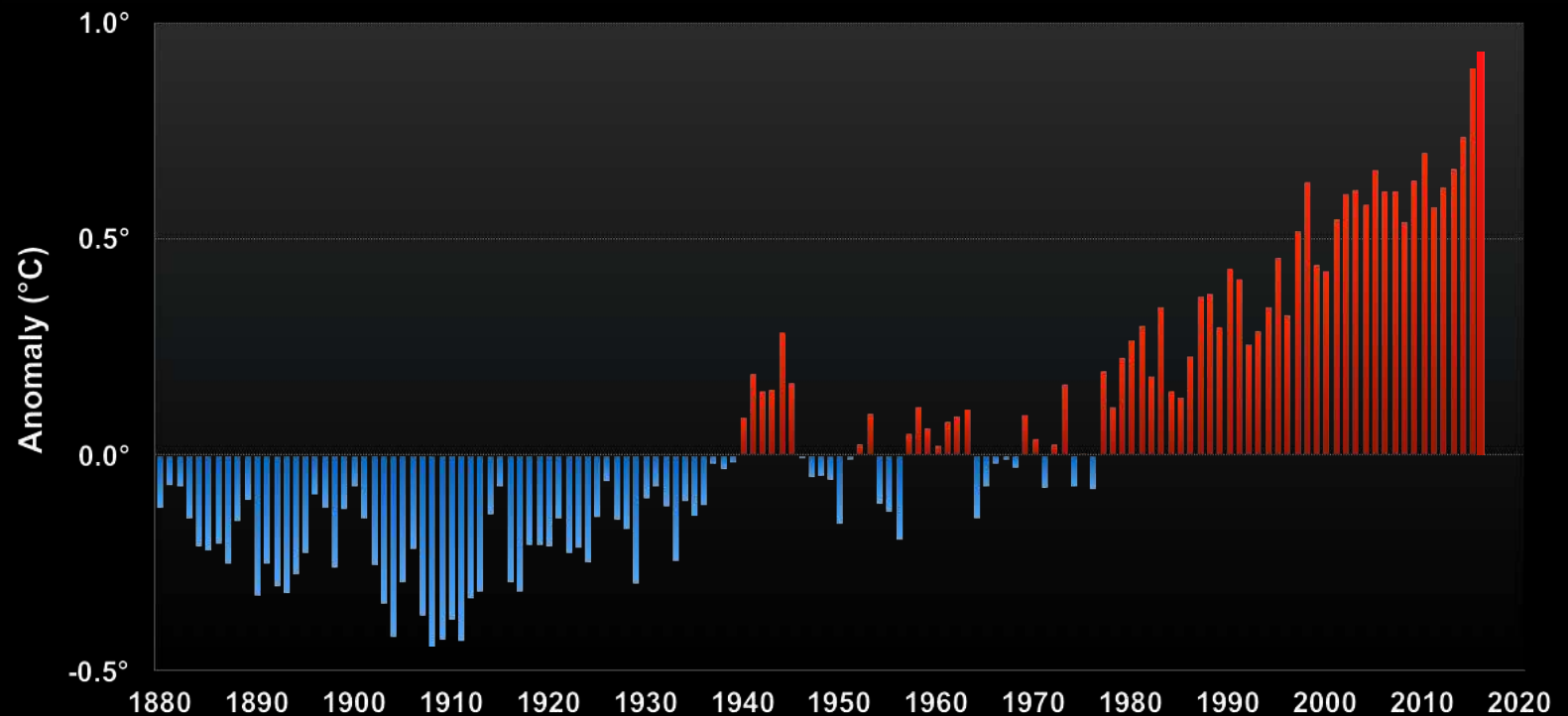
Global Land–Ocean Temperature Index





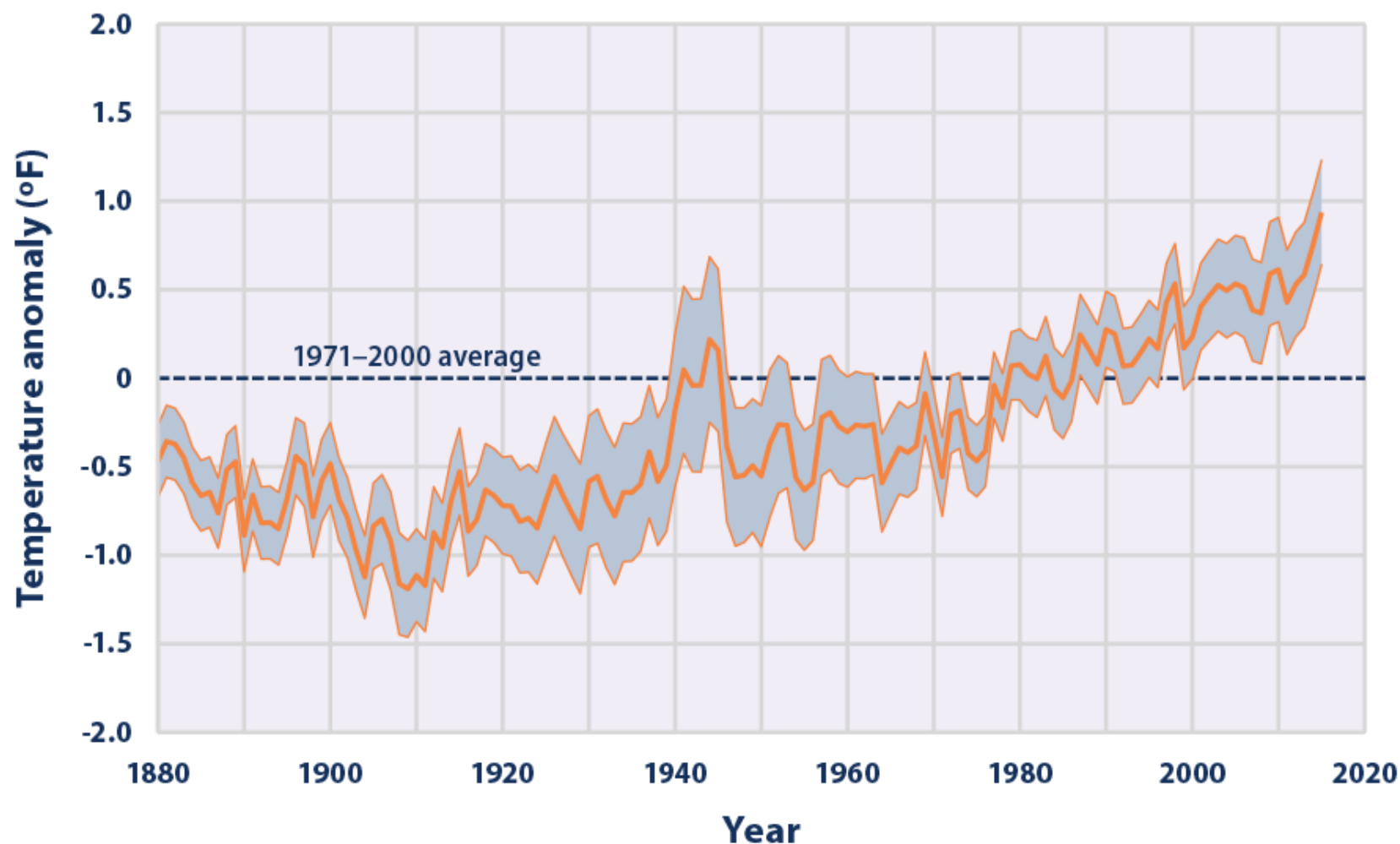
# Global Surface Temperature – Departure from Average

1880 – 2016



Data: NOAA

## Average Global Sea Surface Temperature, 1880–2015

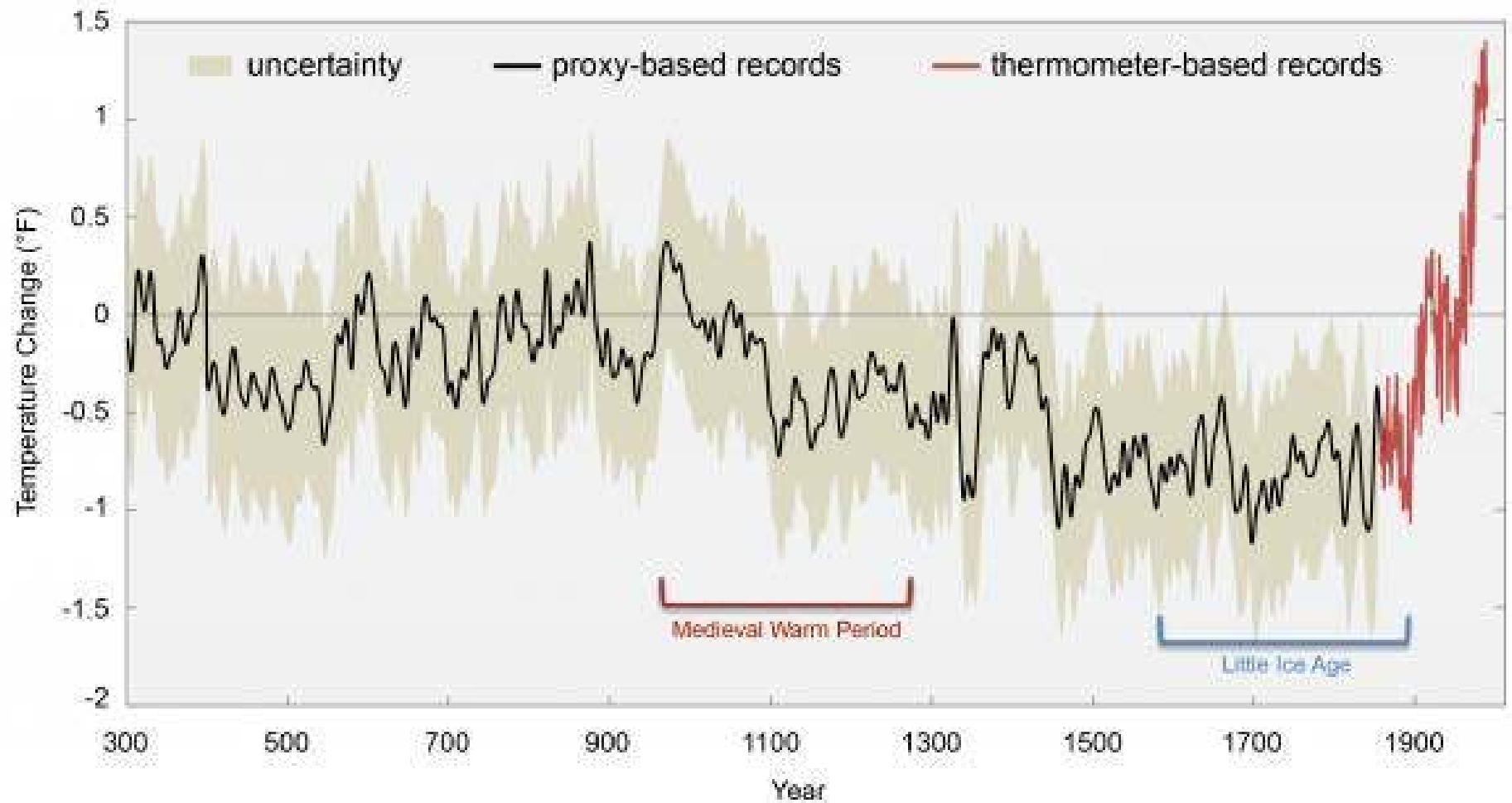


Data source: NOAA (National Oceanic and Atmospheric Administration). 2016. Extended reconstructed sea surface temperature (ERSST.v4). National Centers for Environmental Information. Accessed March 2016.

[www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst](http://www.ncdc.noaa.gov/data-access/marineocean-data/extended-reconstructed-sea-surface-temperature-ersst).

For more information, visit U.S. EPA's "Climate Change Indicators in the United States" at [www.epa.gov/climate-indicators](http://www.epa.gov/climate-indicators).

## 1700 Years of Global Temperature Change from Proxy Data

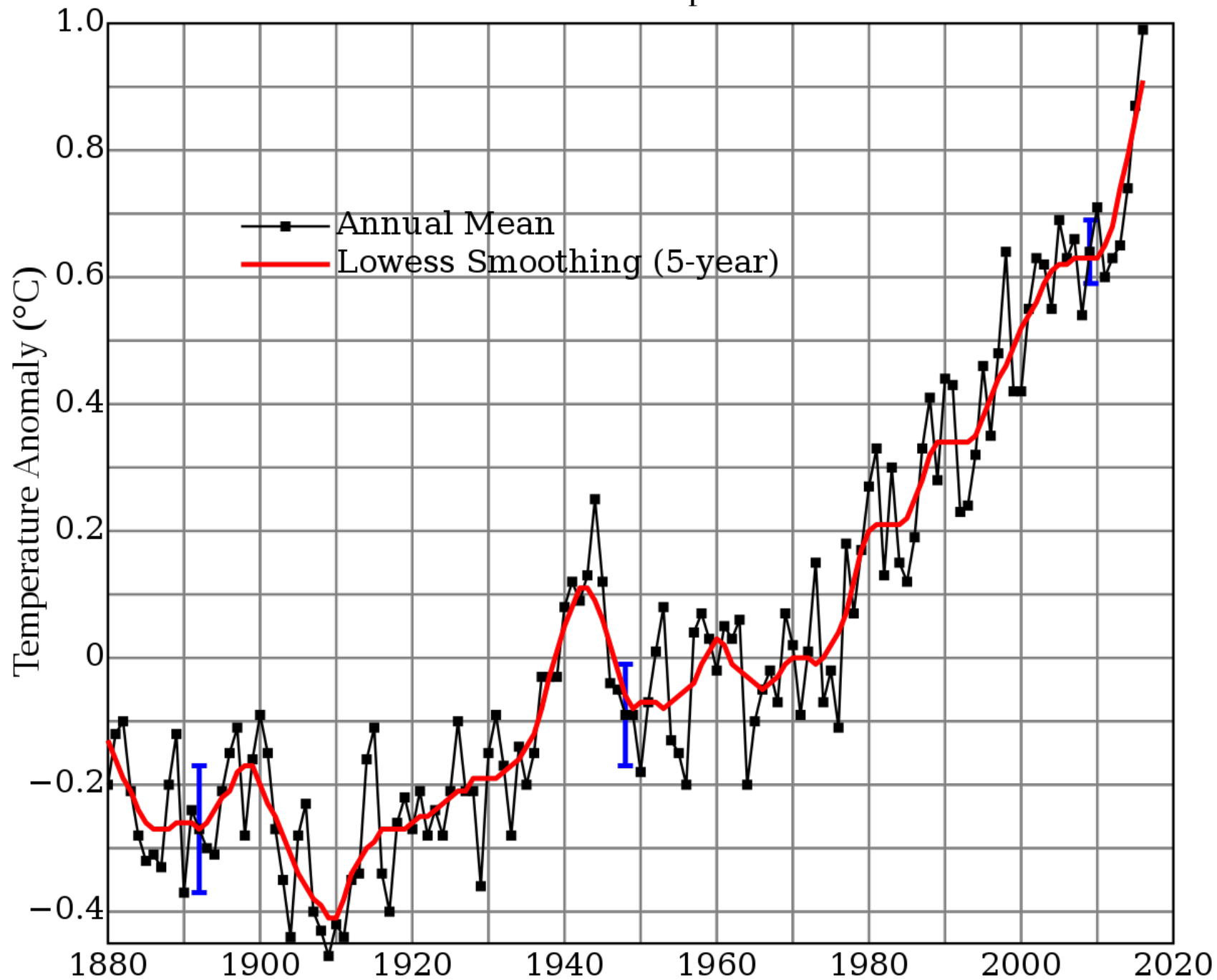


## 16 of the 17 Hottest Years on Record Have Occurred Since the Year 2001



Data: NASA/GISS

Global Land–Ocean Temperature Index



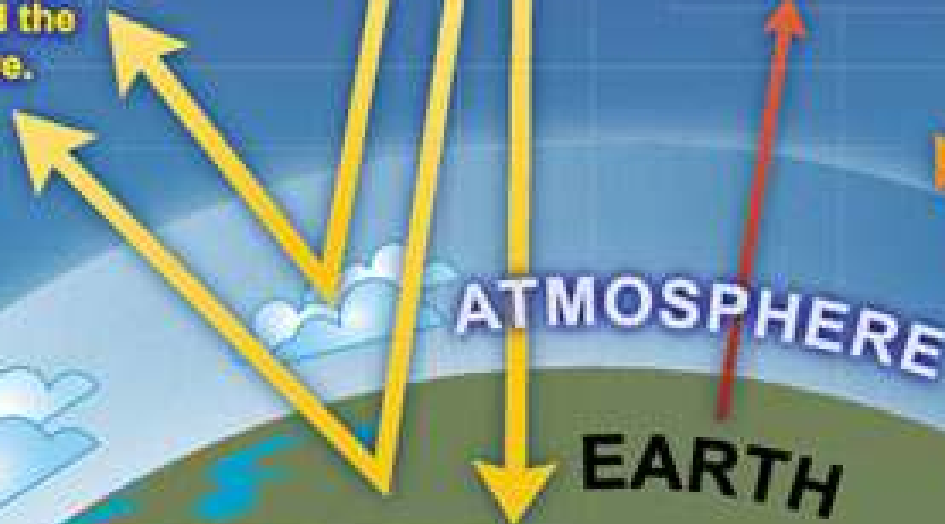
# The Greenhouse Effect

Some of the infrared radiation passes through the atmosphere but most is absorbed and re-emitted in all directions by greenhouse gas molecules and clouds. The effect of this is to warm the Earth's surface and the lower atmosphere.

Solar radiation powers the climate system.



Some solar radiation is reflected by the Earth and the atmosphere.



About half the solar radiation is absorbed by the Earth's surface and warms it.

Infrared radiation is emitted from the Earth's surface.



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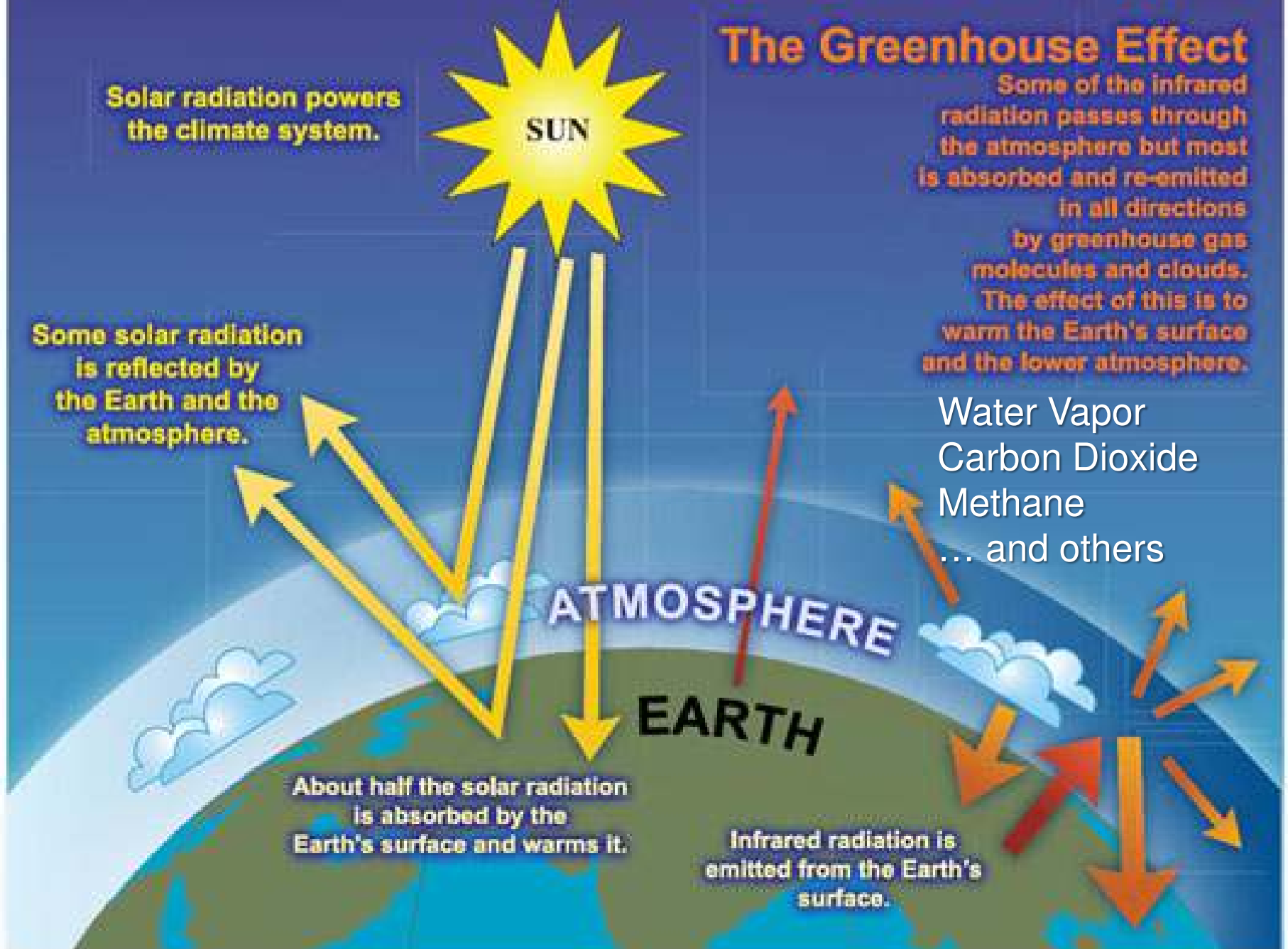
Water Vapor  
Carbon Dioxide  
Methane  
... and others

Solar radiation powers the climate system.

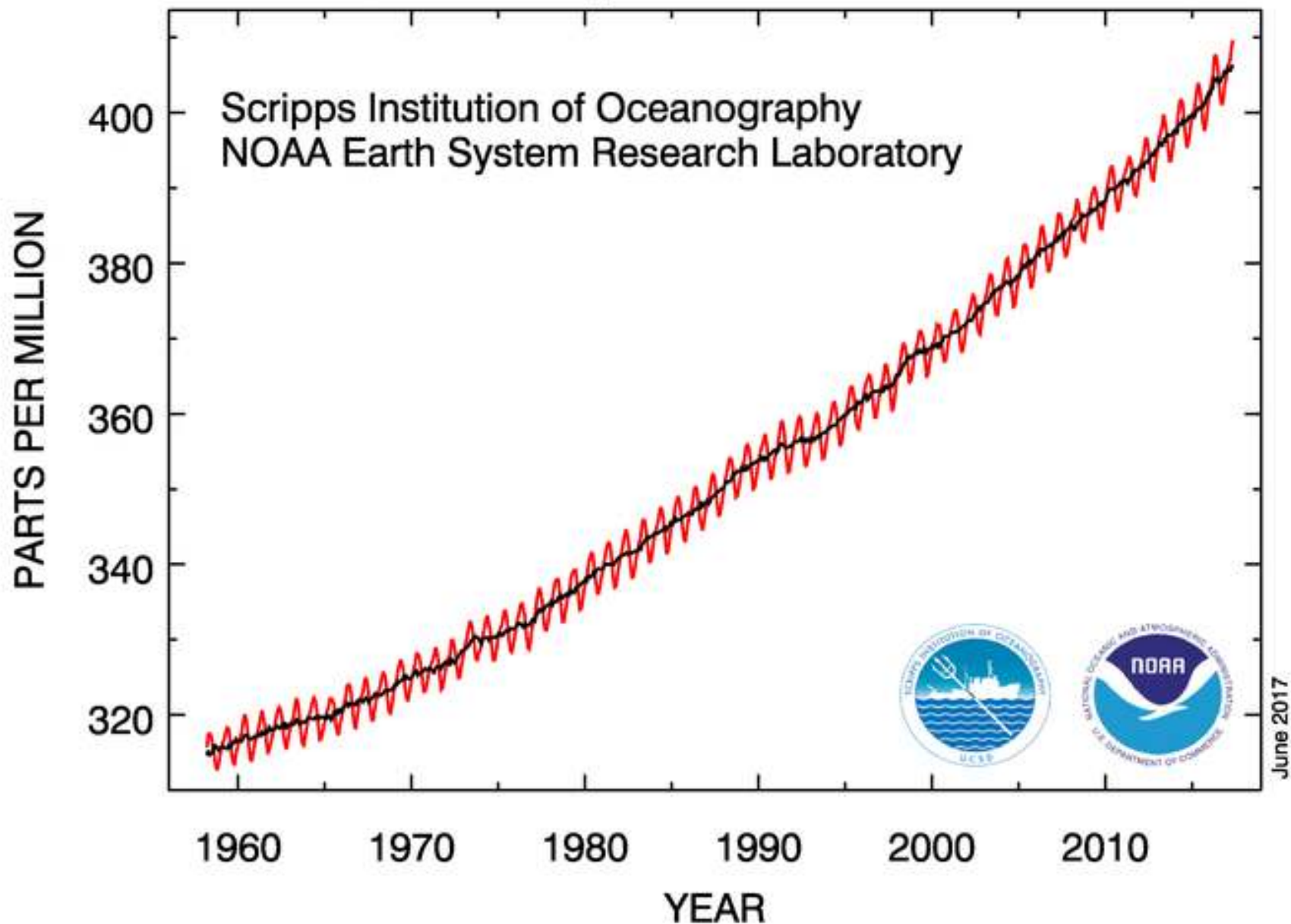
Some solar radiation is reflected by the Earth and the atmosphere.

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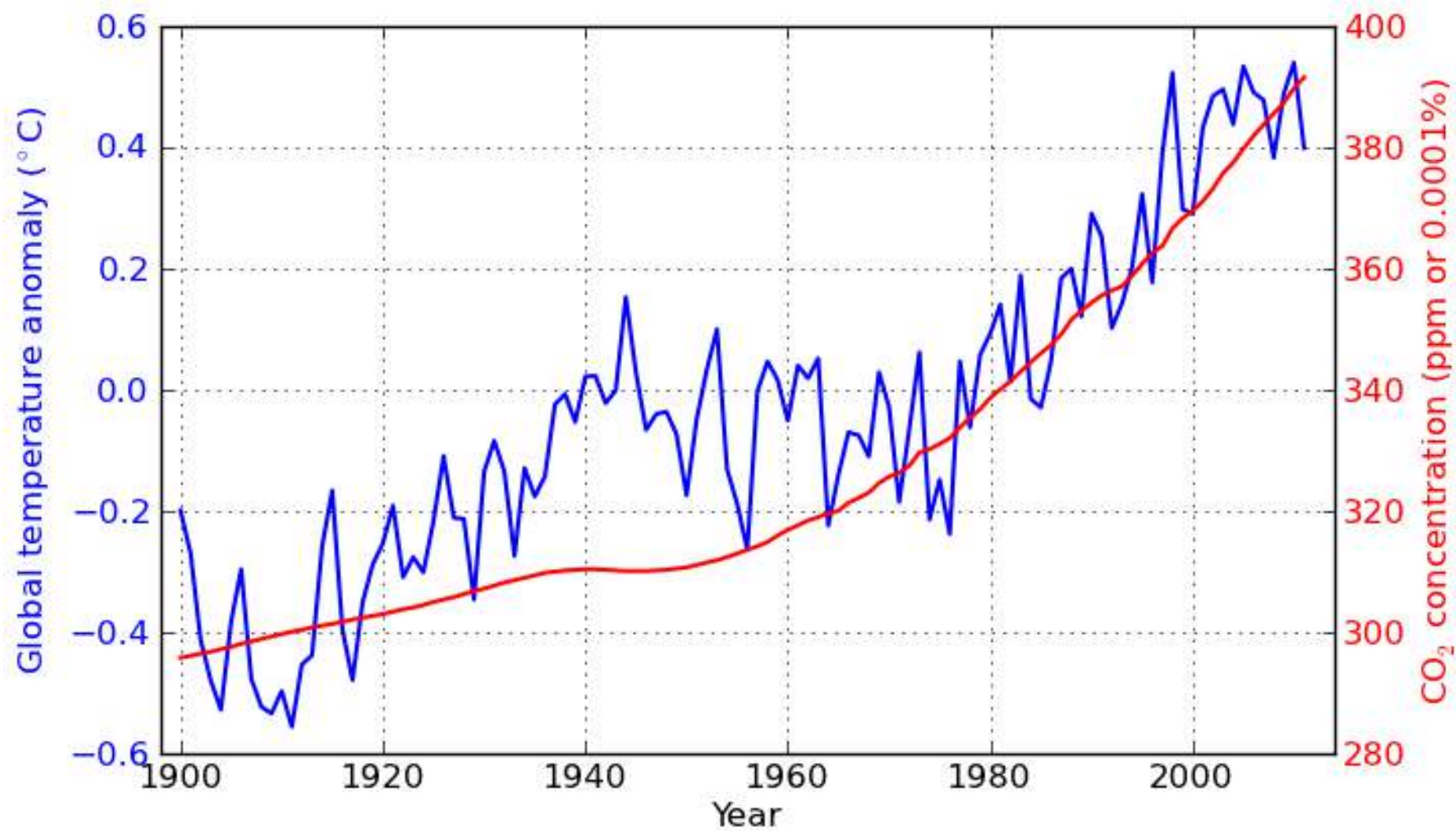
Infrared radiation is emitted from the Earth's surface.



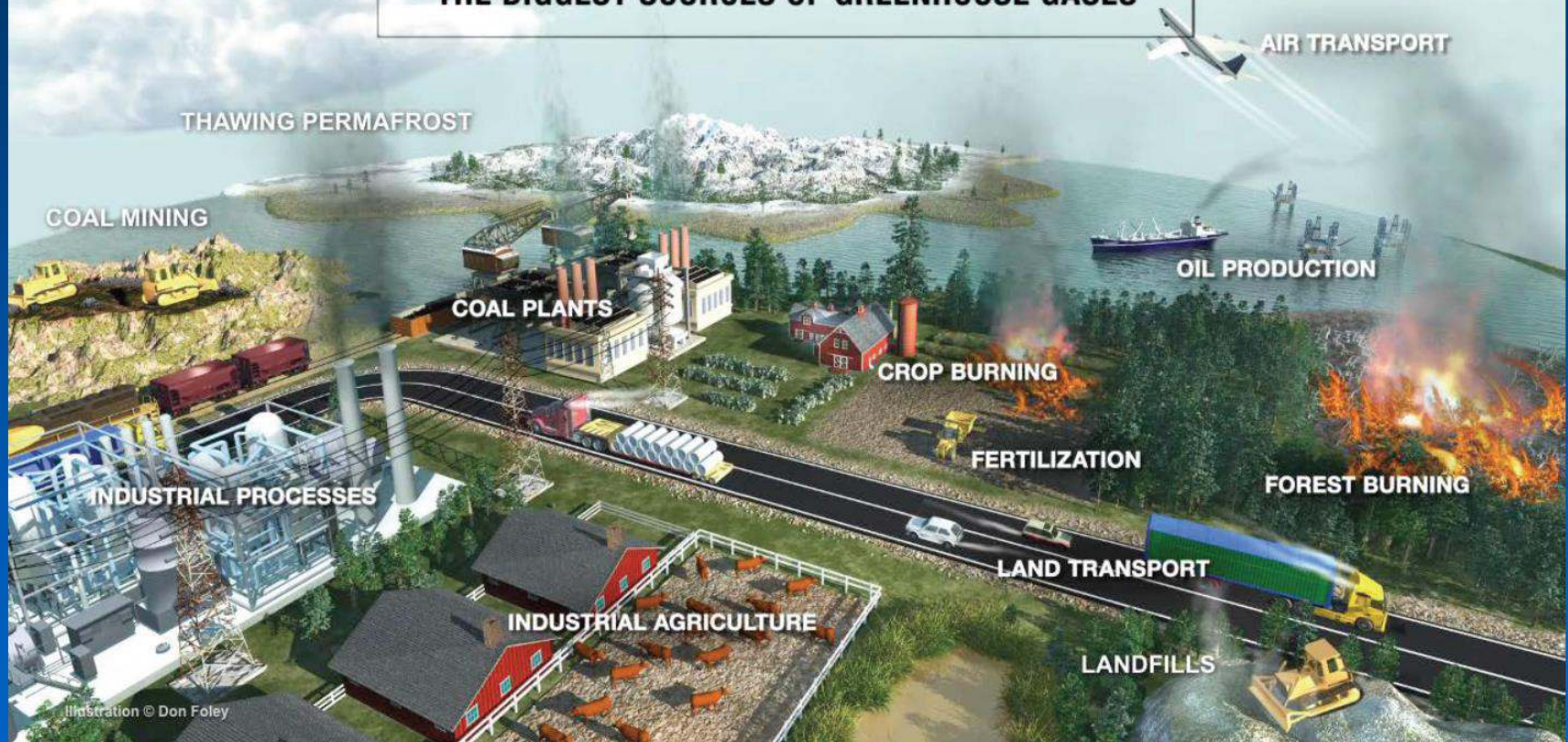
# Atmospheric CO<sub>2</sub> at Mauna Loa Observatory







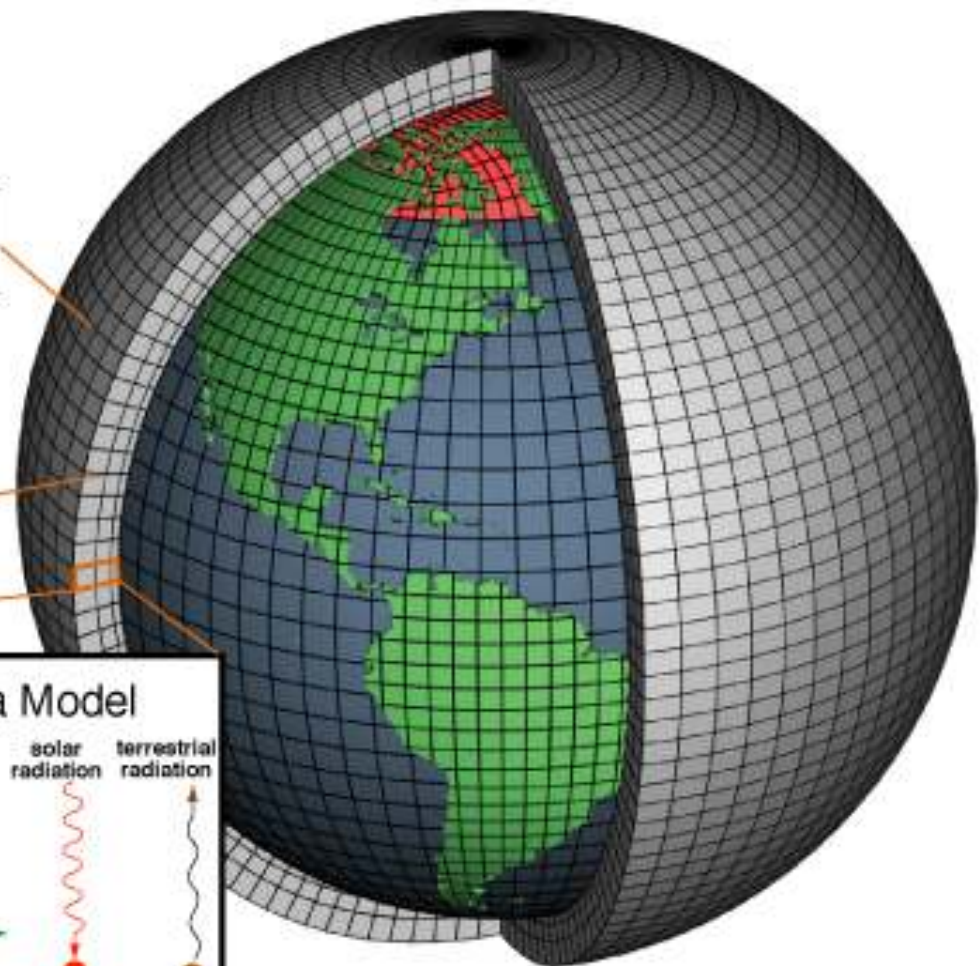
## THE BIGGEST SOURCES OF GREENHOUSE GASES



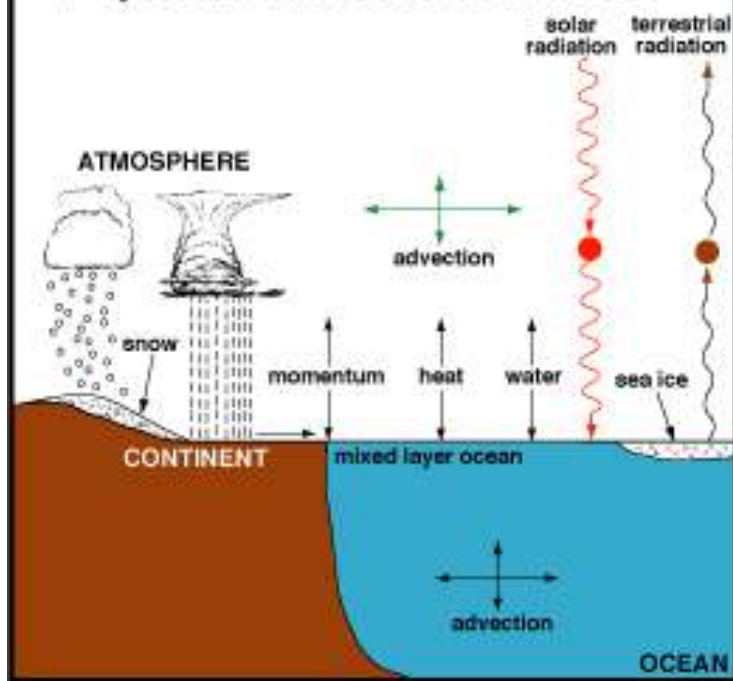


Horizontal Grid  
(Latitude-Longitude)

Vertical Grid  
(Height or Pressure)



### Physical Processes in a Model



$$w_e = A_1 \frac{V_{\text{sum}}^3/z_{\text{ml}} + g\tilde{\beta}_T\alpha_t\Delta_F}{\Delta b + c_TV_{\text{sum}}^2/z_{\text{ml}}},$$

$$\left(\frac{\partial \overline{w'w'}}{\partial t}\right)_{\text{diss}} = -C_1 \frac{\overline{w'w'}}{\tau} = -C_{\text{ww}} \frac{[\sigma(1-\sigma)(w_{\text{up}} - w_{\text{dn}})^2]}{\tau}. \quad (4)$$

$$\overline{w'q'_t}|_{z_0} = -K_h|_{z_0} \frac{\Delta q_t}{\Delta z} \Big|_{z_0} = -w_e \Delta q_t|_{z_0}. \quad (3)$$

$$\begin{aligned} \frac{\partial q'_v}{\partial t} = & -m^2 \left( u^* \frac{\partial q_v}{\partial x} + v^* \frac{\partial q_v}{\partial y} \right) - \dot{\sigma} \frac{\partial q_v}{\partial \sigma} + F_{qv}^{\text{vdif}} \\ & + F_{qv}^{\text{hdif}} + F_{qv}^{\text{impl}} + F_{qv}^{\text{expl}} - \frac{\partial q_v^{\text{base}}}{\partial t}, \end{aligned} \quad (1)$$

$$\begin{aligned} \frac{\partial q'_{ci}}{\partial t} = & -m^2 \left( u^* \frac{\partial q_{ci}}{\partial x} + v^* \frac{\partial q_{ci}}{\partial y} \right) - \dot{\sigma} \frac{\partial q_{ci}}{\partial \sigma} \\ & + F_{qci}^{\text{hdif}} + F_{qci}^{\text{expl}} - \frac{\partial q_{ci}^{\text{base}}}{\partial t}, \text{ and} \end{aligned} \quad (2)$$

$$\begin{aligned} \frac{\partial q'_{rs}}{\partial t} = & -m^2 \left( u^* \frac{\partial q_{rs}}{\partial x} + v^* \frac{\partial q_{rs}}{\partial y} \right) - \dot{\sigma} \frac{\partial q_{rs}}{\partial \sigma} \\ & + F_{qrs}^{\text{hdif}} + F_{qrs}^{\text{expl}} - \frac{\partial q_{rs}^{\text{base}}}{\partial t} - \frac{g}{p_s} \frac{\partial \rho q_{rs} V_t}{\partial \sigma}. \end{aligned} \quad (3)$$

$$\begin{aligned} (1) \quad \frac{\partial S}{\partial t} = & -\frac{u_r}{\Delta x_i} \left[ \frac{\Delta x_{i+1} S_i + \Delta x_i S_{i+1}}{\Delta x_{i+1} + \Delta x_i} - \frac{1}{8} \text{CURV}_{ra} \right] \\ & + \frac{u_l}{\Delta x_i} \left[ \frac{\Delta x_i S_{i-1} + \Delta x_{i-1} S_i}{\Delta x_{i-1} + \Delta x_i} - \frac{1}{8} \text{CURV}_{la} \right] \\ & + \frac{|u_r|}{16 \Delta x_i} \text{CURV}_{rd} - \frac{|u_l|}{16 \Delta x_i} \text{CURV}_{ld}. \end{aligned} \quad (7)$$

$$\begin{aligned} \frac{\partial T'_p}{\partial t} = & -m^2 \left( u^* \frac{\partial T_p}{\partial x} + v^* \frac{\partial T_p}{\partial y} \right) - \sigma^\kappa \dot{\sigma} \frac{\partial T_p \sigma^{-\kappa}}{\partial \sigma} \\ & + \kappa T_p \left[ \frac{\partial Q}{\partial t} + m^2 \left( u^* \frac{\partial Q}{\partial x} + v^* \frac{\partial Q}{\partial y} \right) \right] + F_T^{\text{vdif}} \\ & + F_T^{\text{hdif}} + F_T^{\text{rad}} + F_T^{\text{impl}} + F_T^{\text{expl}} - \frac{\partial T_p^{\text{base}}}{\partial t}, \end{aligned} \quad (4)$$

$$\theta_{\text{vl}}^{\text{par}} = \theta_{\text{vl}}^{\text{top}} + \frac{w_e \Delta \theta_{\text{vl}} - \Delta_F}{V_{\text{Sc}}},$$

$$\tau_B = \frac{L_B}{M_c/m} = \frac{L_B}{\sigma(1-\sigma)(w_{\text{up}} - w_{\text{dn}})}. \quad (13)$$

$$\mathbf{C}_0 = \frac{1}{N-1} \sum_{n=1}^{N-1} \mathbf{x}_n \mathbf{x}_n^{\text{T}}, \quad \mathbf{C}_1 = \frac{1}{N-1} \sum_{n=1}^{N-1} \mathbf{x}_{n+1} \mathbf{x}_n^{\text{T}} \quad (9)$$

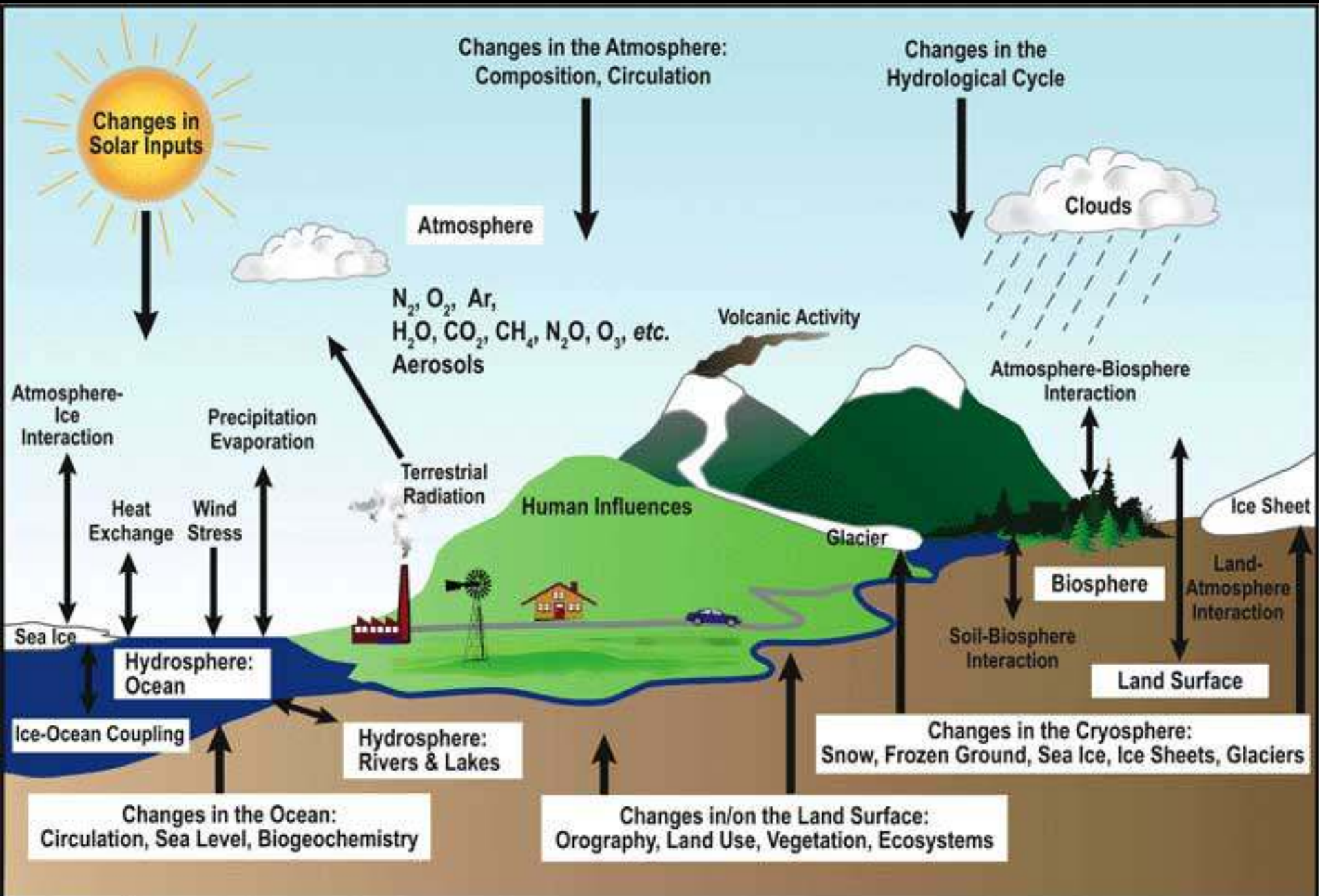
$$\overline{w'\chi'} = -\max[(K_\chi^{\text{surf}} + K_\chi^{\text{Sc}}), K_\chi(\text{Ri})] \frac{\partial \overline{\chi}}{\partial z} + K_\chi^{\text{surf}} \gamma_\chi, \quad (6)$$

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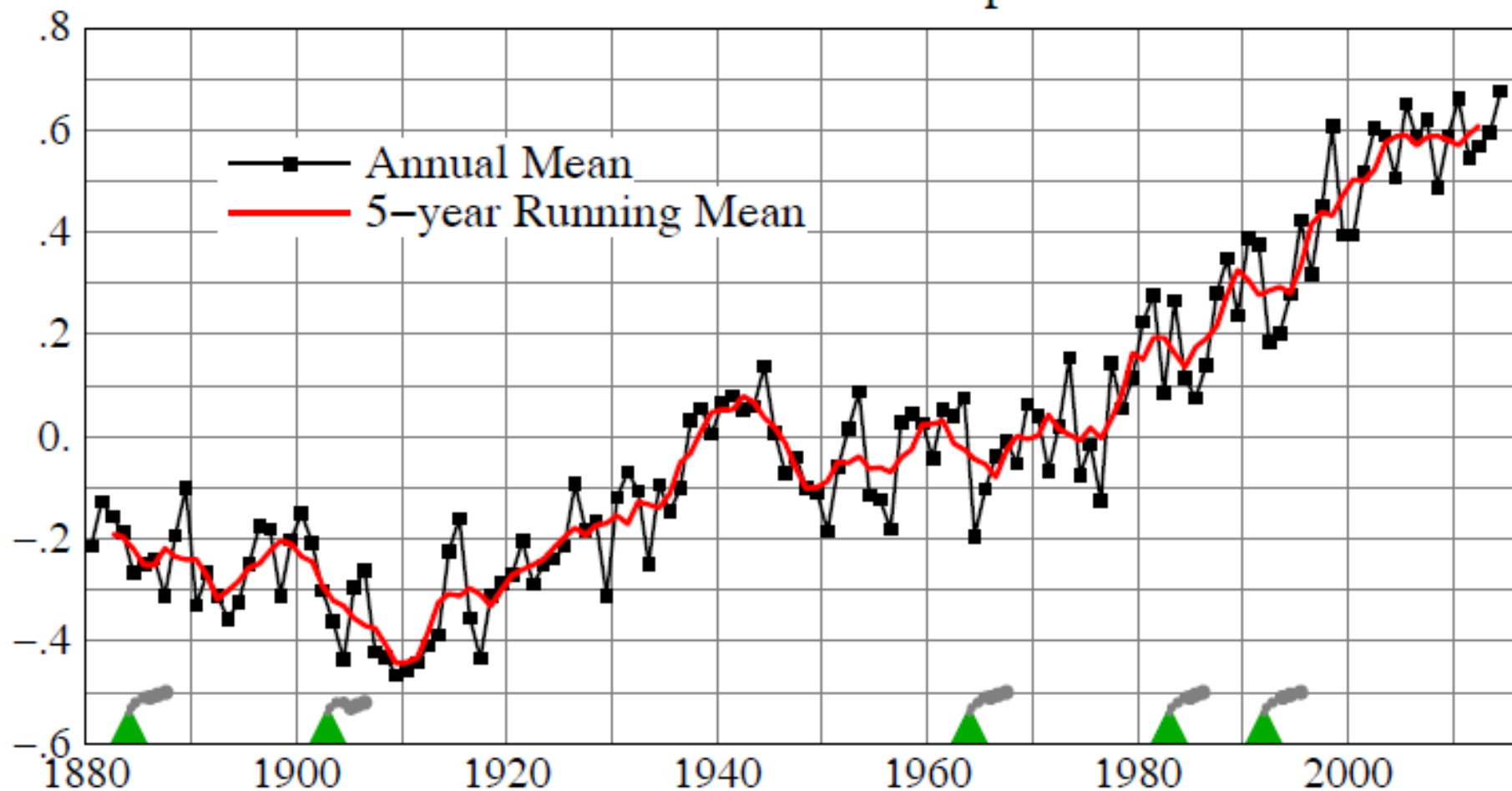


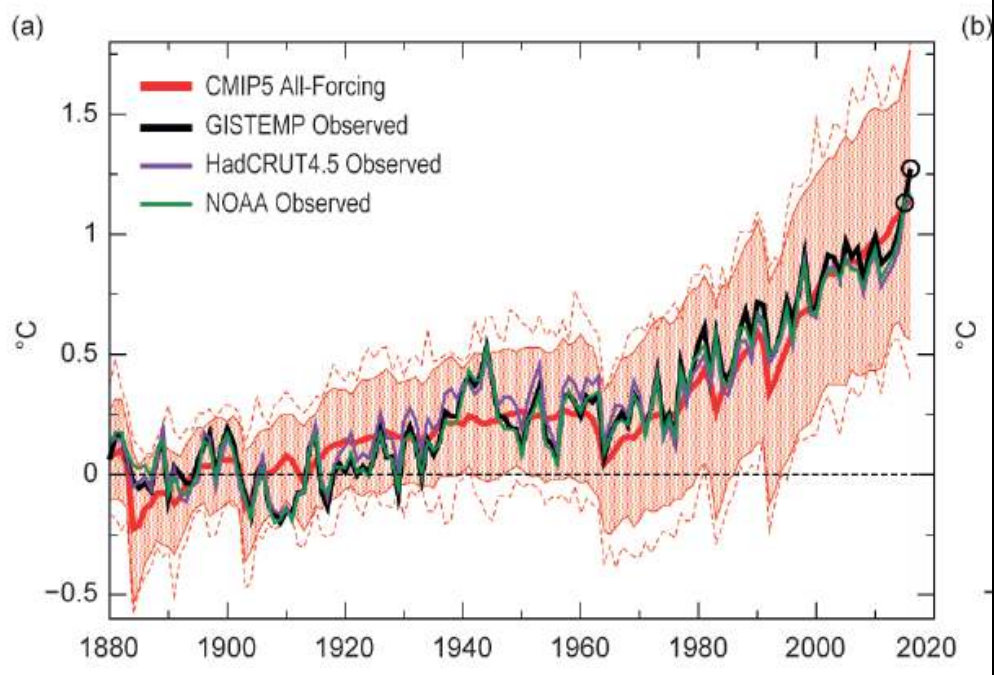




# Global Land–Ocean Temperature

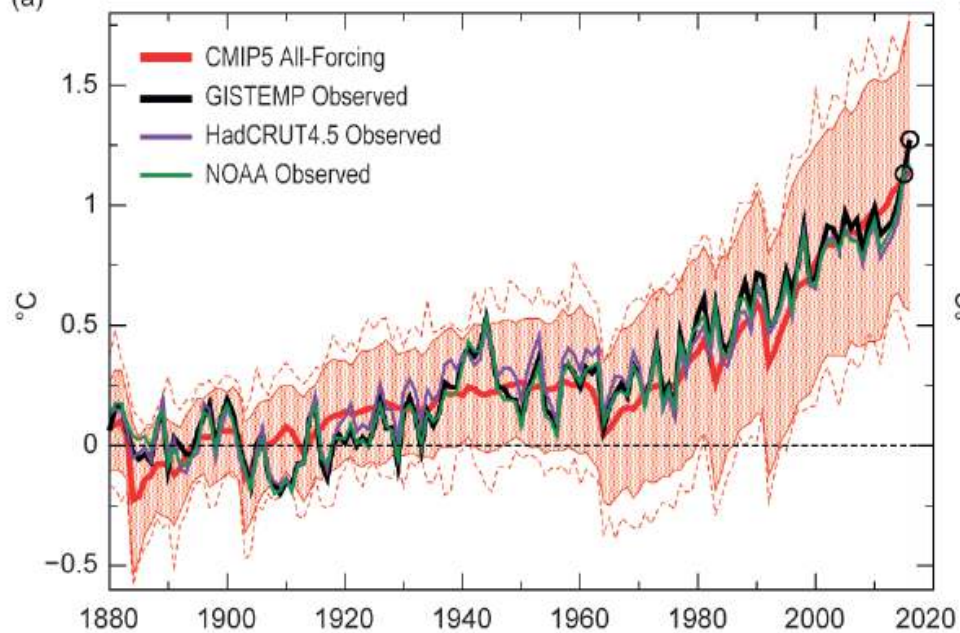
Temperature Anomaly ( $^{\circ}\text{C}$ )



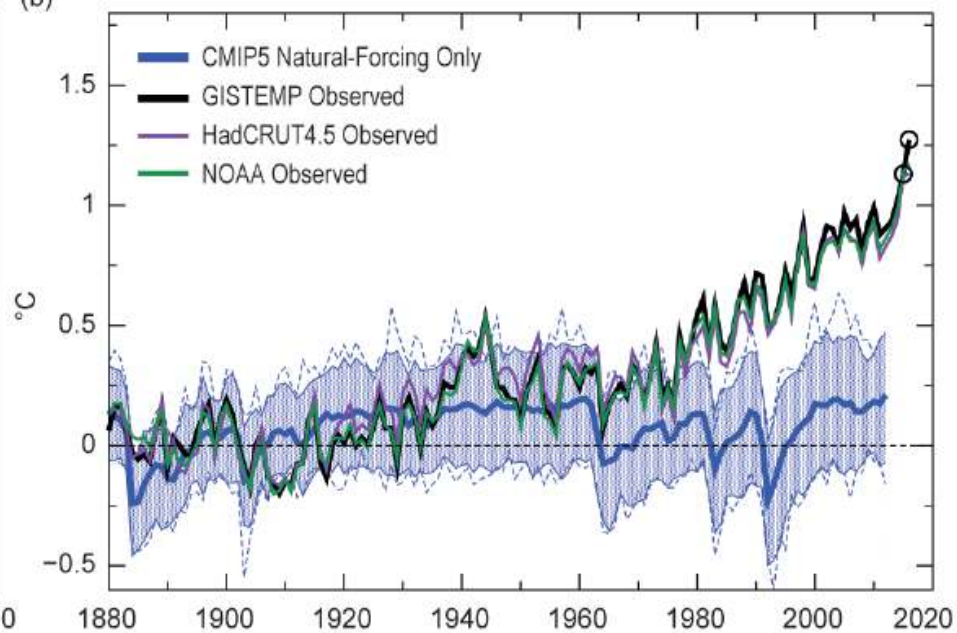




(a)

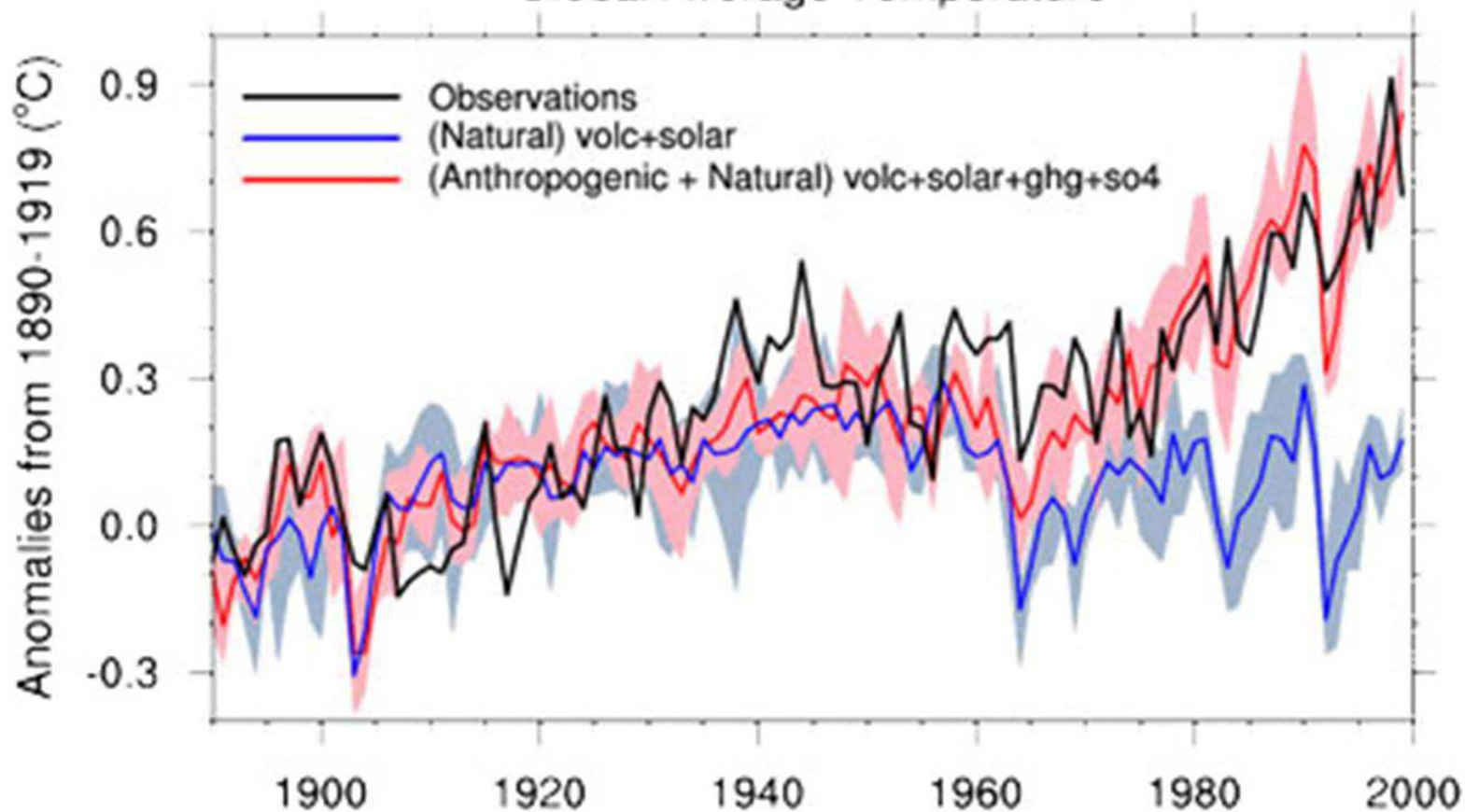


(b)



# PCM Ensembles

## Global Average Temperature



Global average temperature since 1890 as reproduced by the NCAR/DOE Parallel Climate Model.

# Three extreme events directly tied to anthropogenic warming for the first time

From “Explaining Extreme Events of 2016 from a Climate Perspective”, a special supplement to the *Bulletin of the American Meteorological Society*, vol. 99, no. 1, January 2018

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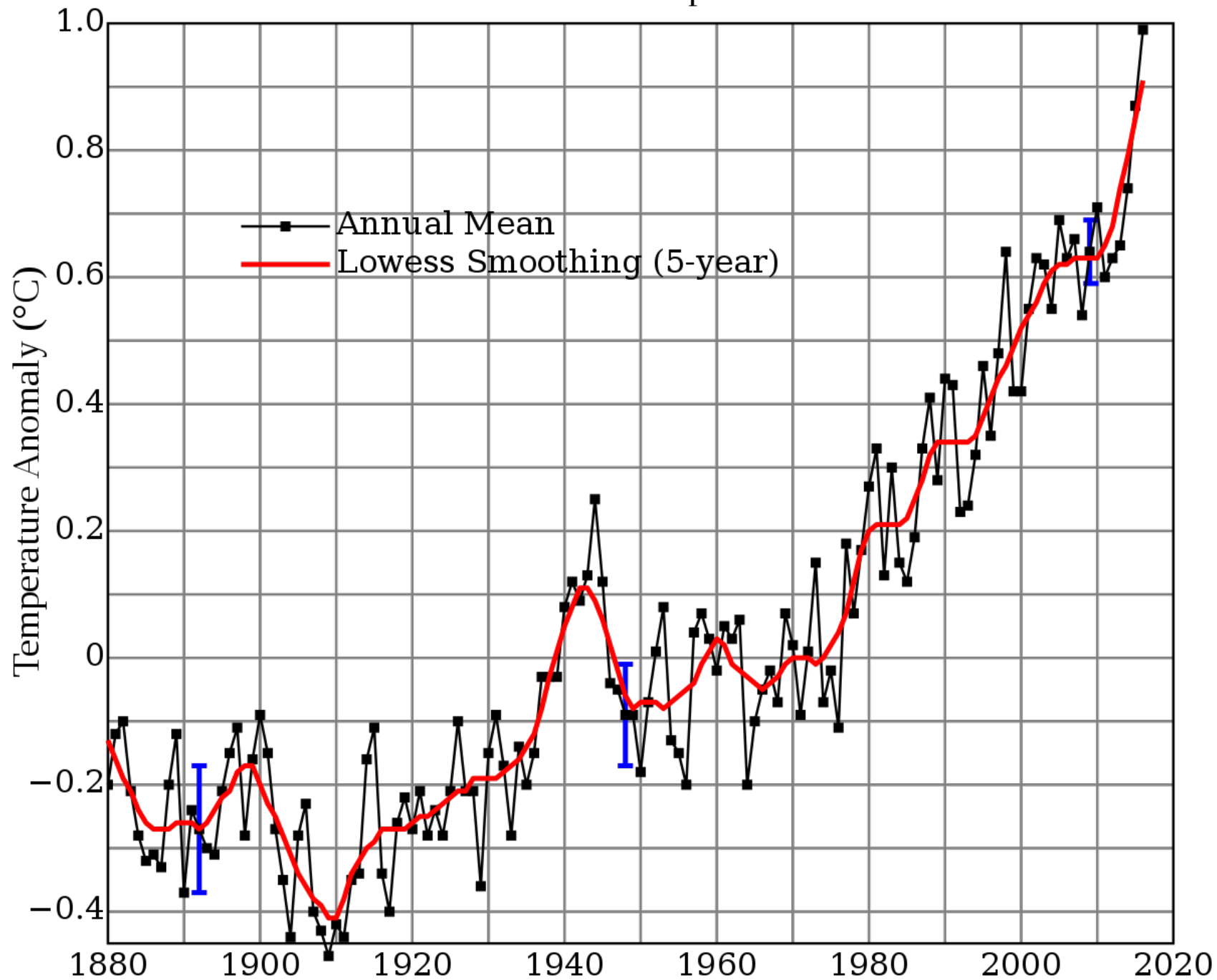
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- 2016 record global warmth (Knutsen et al.)
- 2016 extreme warmth across Asia (Imada et al.)
- Alaska marine heat wave, aka “blob” (Walsh et al.)

From “Explaining Extreme Events of 2016 from a Climate Perspective”, a special supplement to the *Bulletin of the American Meteorological Society*, vol. 99, no. 1, January 2018

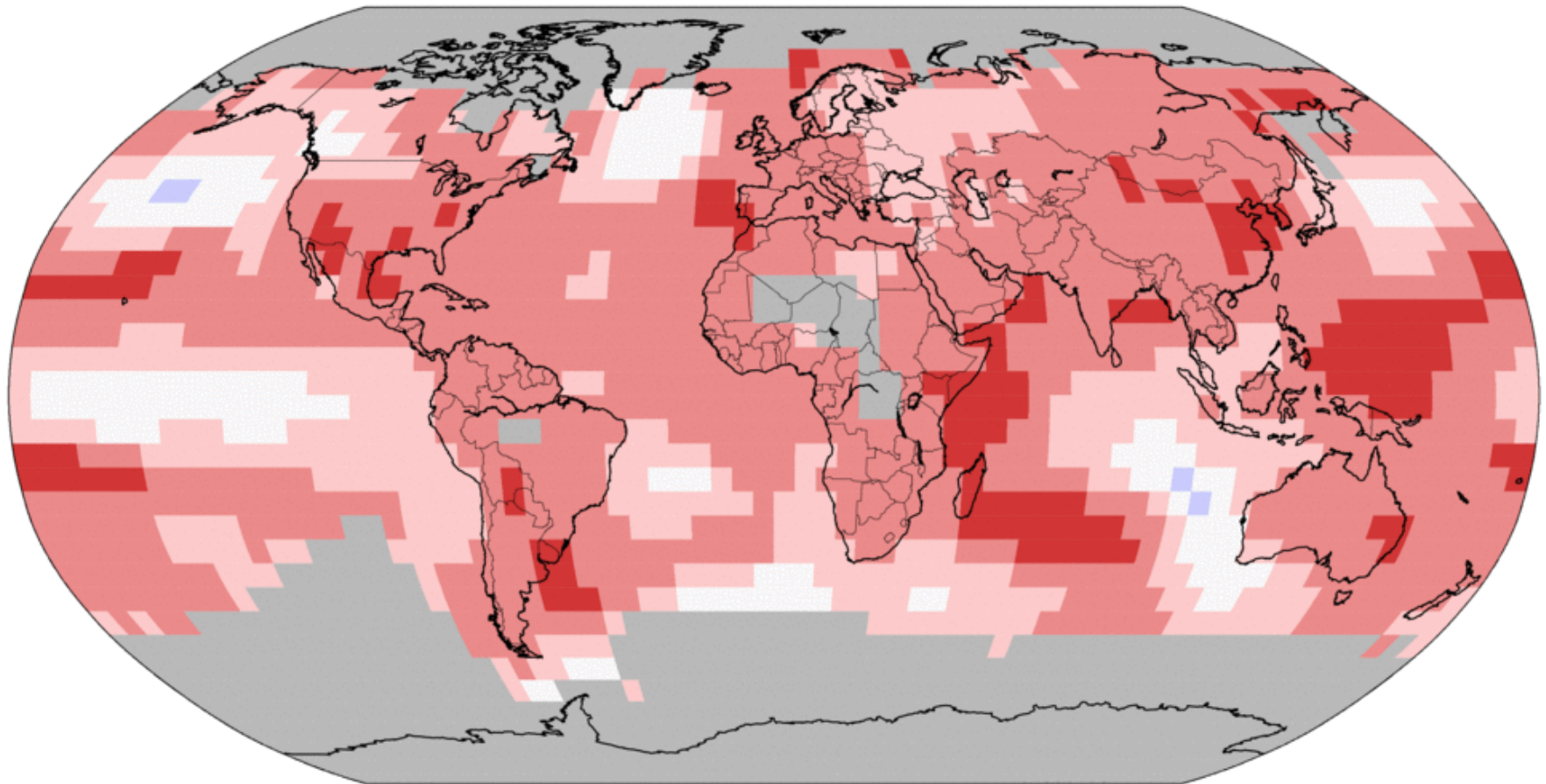
Global Land–Ocean Temperature Index



# Land & Ocean Temperature Percentiles Jan–Nov 2017

NOAA's National Centers for Environmental Information

Data Source: GHCN–M version 3.3.0 & ERSST version 4.0.0



**Record  
Coldest**



**Much  
Cooler than  
Average**



**Cooler than  
Average**



**Near  
Average**



**Warmer than  
Average**



**Much  
Warmer than  
Average**



**Record  
Warmest**



Wed Dec 13 07:33:33 EST 2017



## Actual Highs

Jul 21 2016



**The Weather Channel**

weather.com

22 Jul 2016 01:00 GMT / 21 Jul 2016 09:00 PM EDT



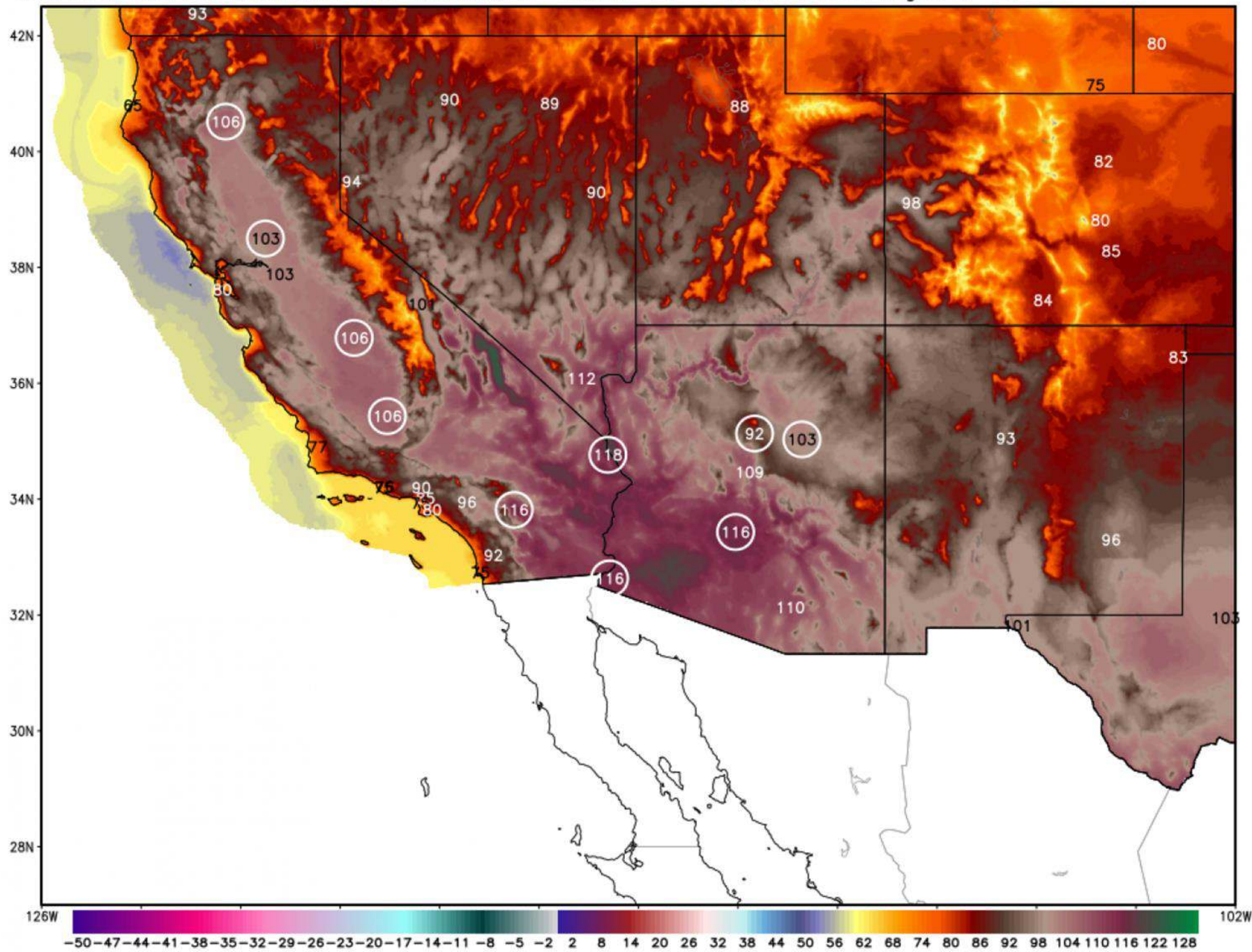
# NWS NDFD 2-m MAXIMUM TEMPERATURE [°F]

Init: 2017061419 Maximum Sun 18JUN2017

Within 1°F

Total Record Highs n=10

Domain Min/Max 44.5° - 124.0°F



**The same extra heat that evaporates more water from the ocean, causing bigger downpours and floods...**



**...pulls moisture even more quickly from the soil, causing longer and deeper droughts.**



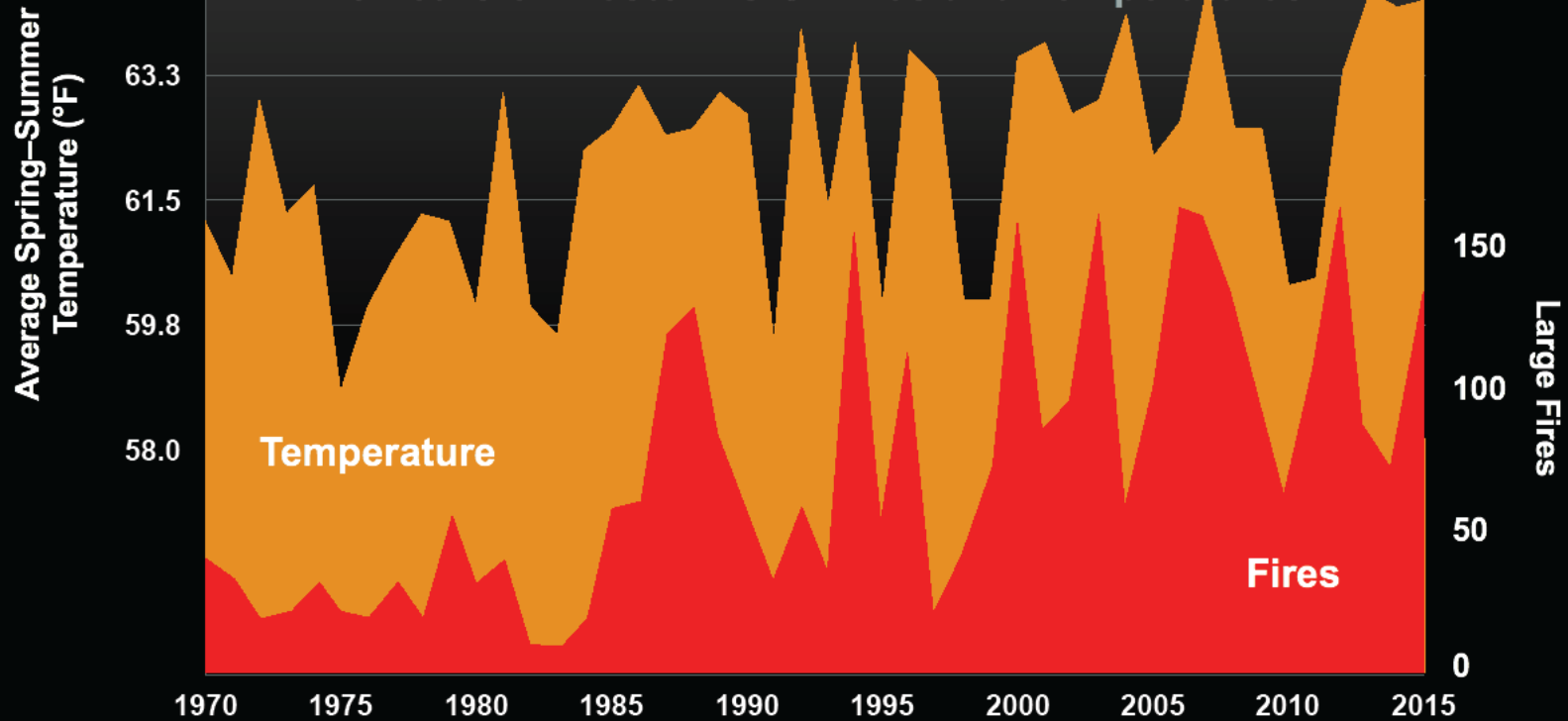






# Hotter Years Typically Have More Fires

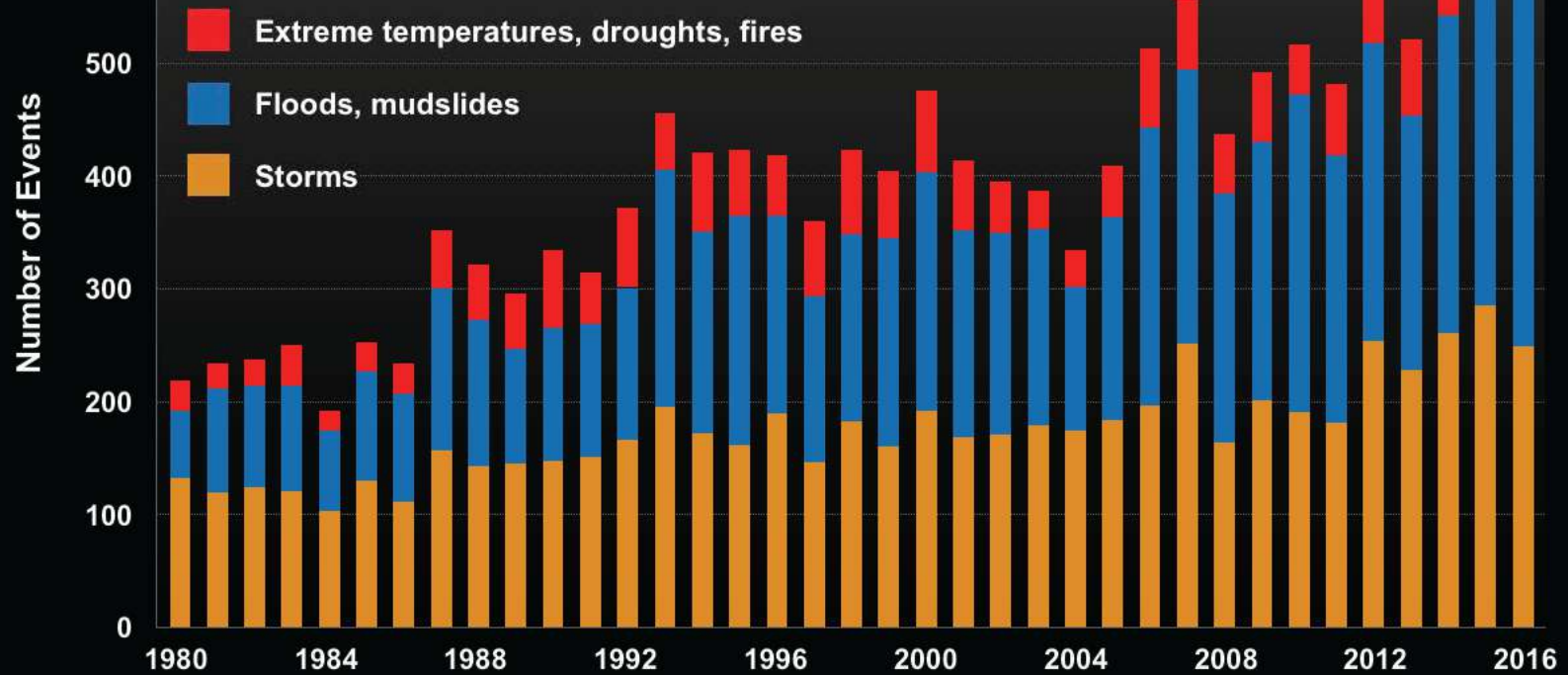
45 Years of Western U.S. Fires and Temperatures



Source: NOAA, USFS/Climate Central

# Worldwide Extreme Weather Catastrophes

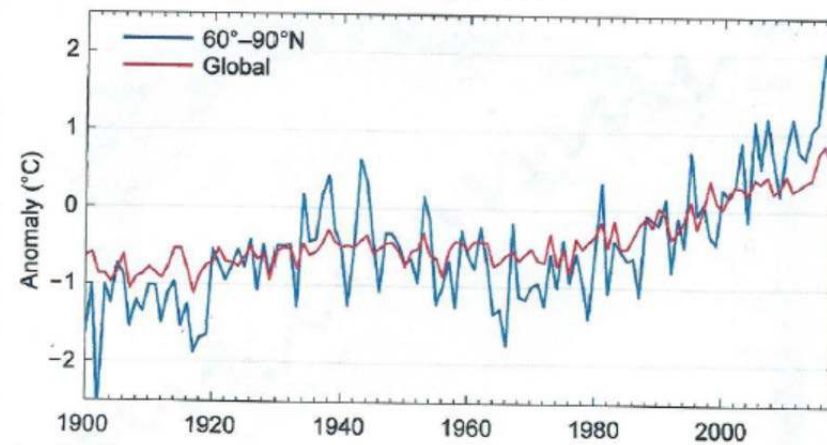
1980 – 2016



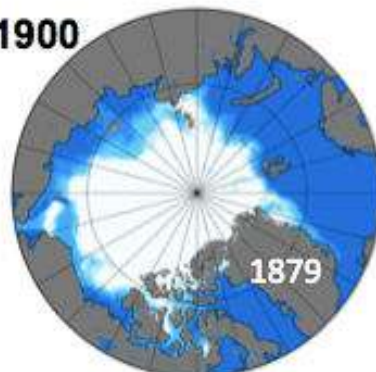
Data: Insurance Information Institute, January 2017



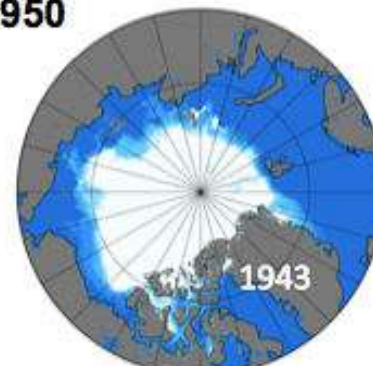
## Arctic Amplification Seen in Temperature



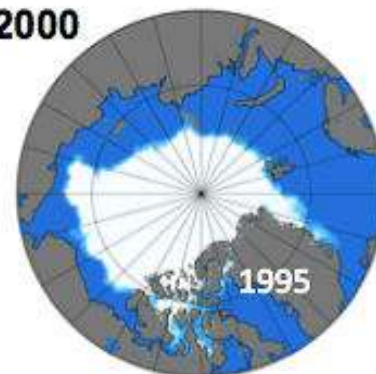
**1850-1900**



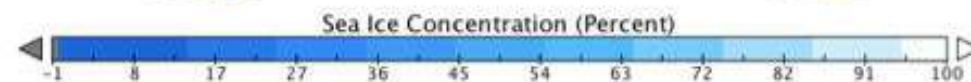
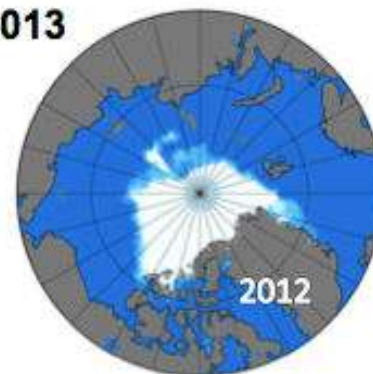
**1901-1950**



**1951-2000**

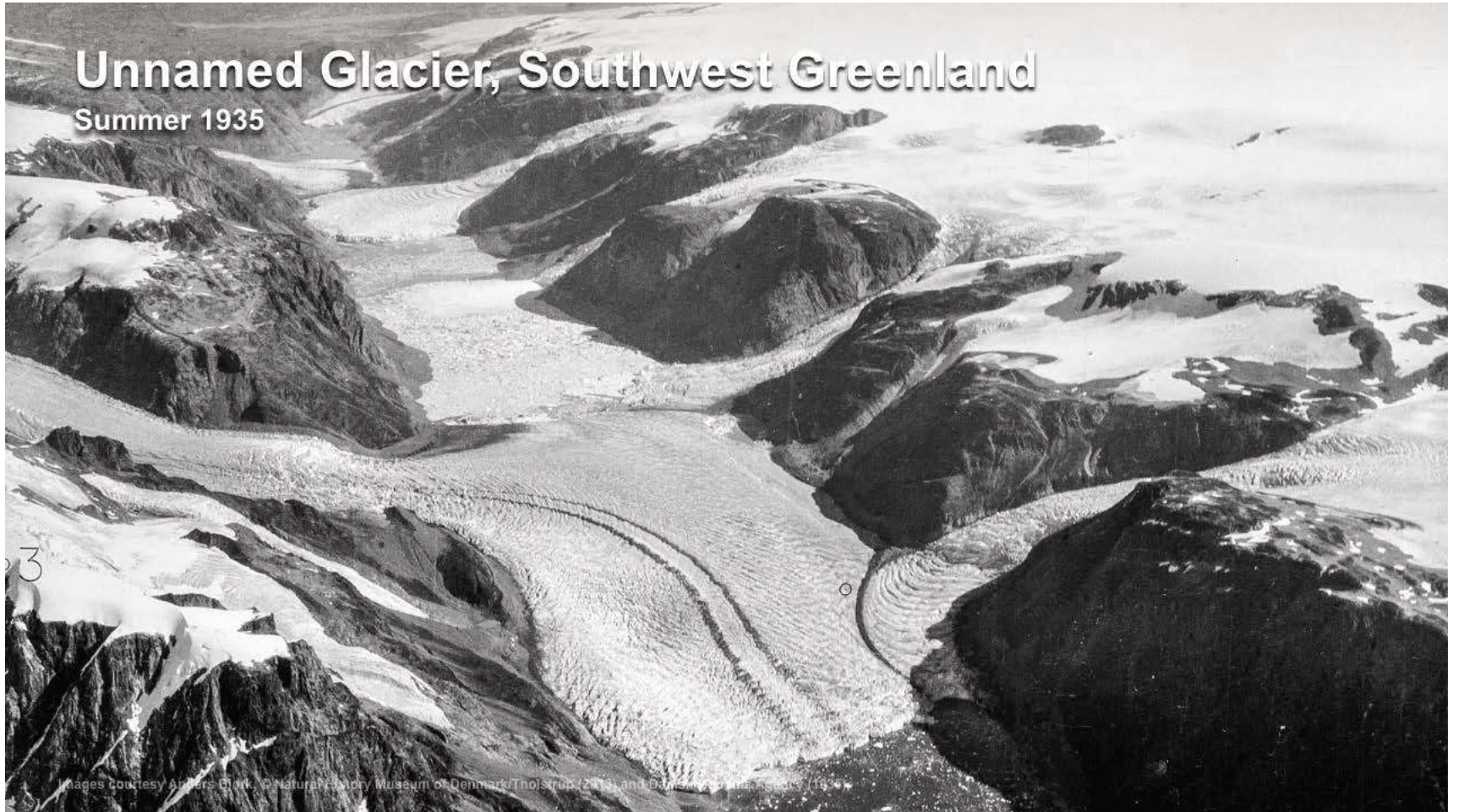


**2000-2013**



# Unnamed Glacier, Southwest Greenland

Summer 1935



Images courtesy Arthur Clark. © Natural History Museum of Denmark/Thorstrup (2013) and Danish Polar Research (1935)



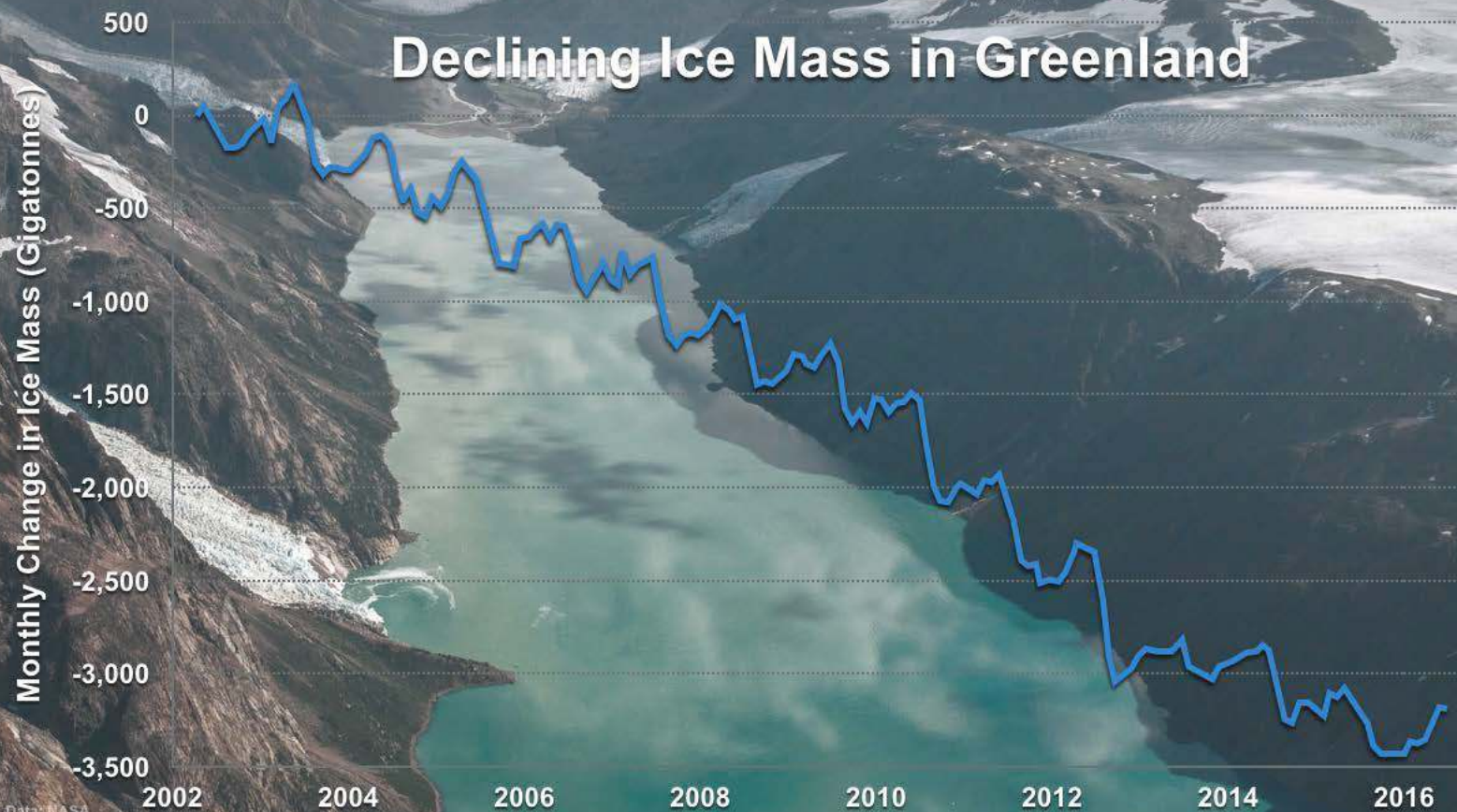
# Unnamed Glacier, Southwest Greenland

Summer 2013



Images courtesy Anders Bjørk, © Natural History Museum of Denmark/Tholstrup (2013) and Danish Geodata Agency (1935)

# Declining Ice Mass in Greenland



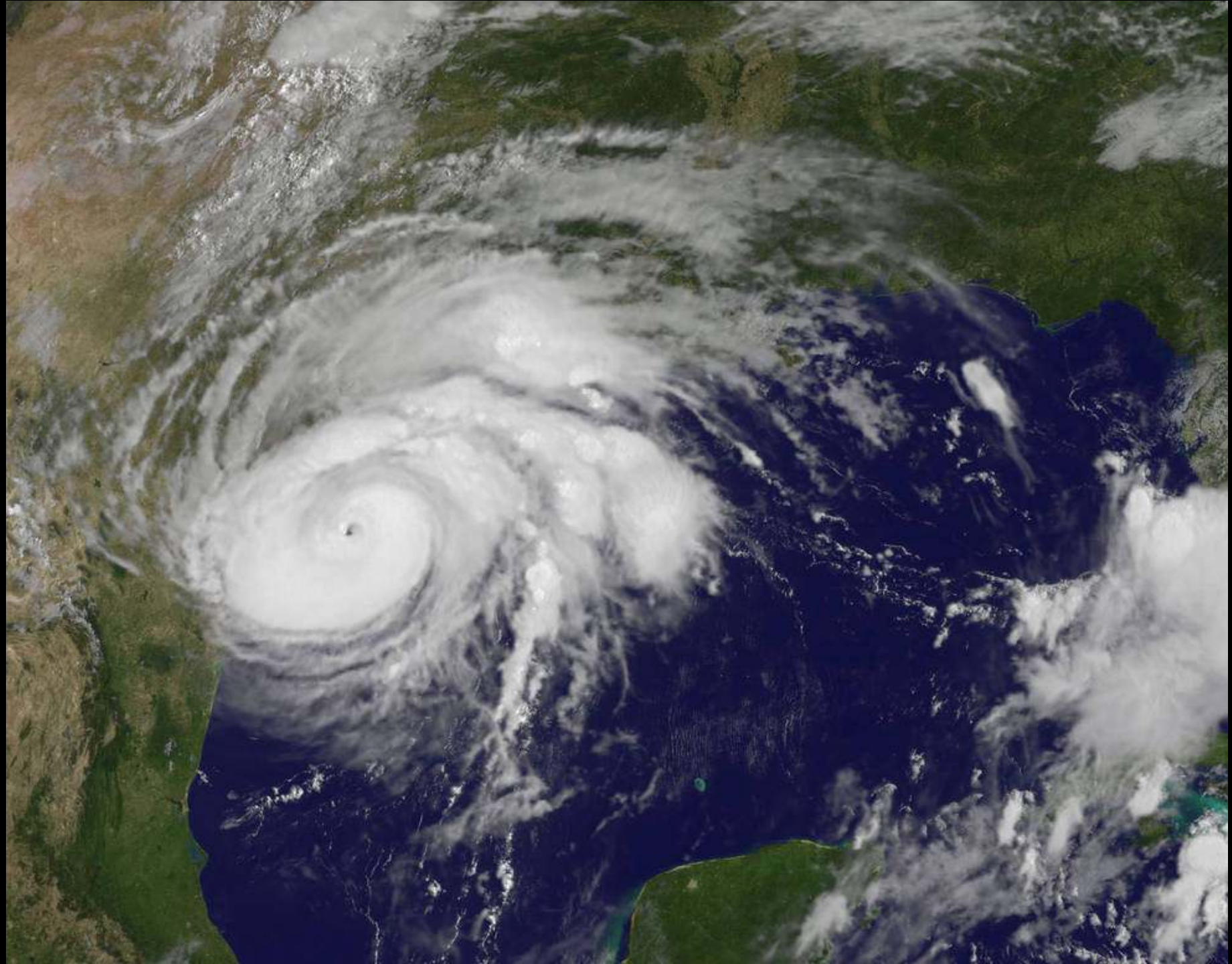
Data: NASA  
Images courtesy Anders Björk, © Natural History Museum of Denmark/Tholstrup (2013) and Danish Geodata Agency (1935)





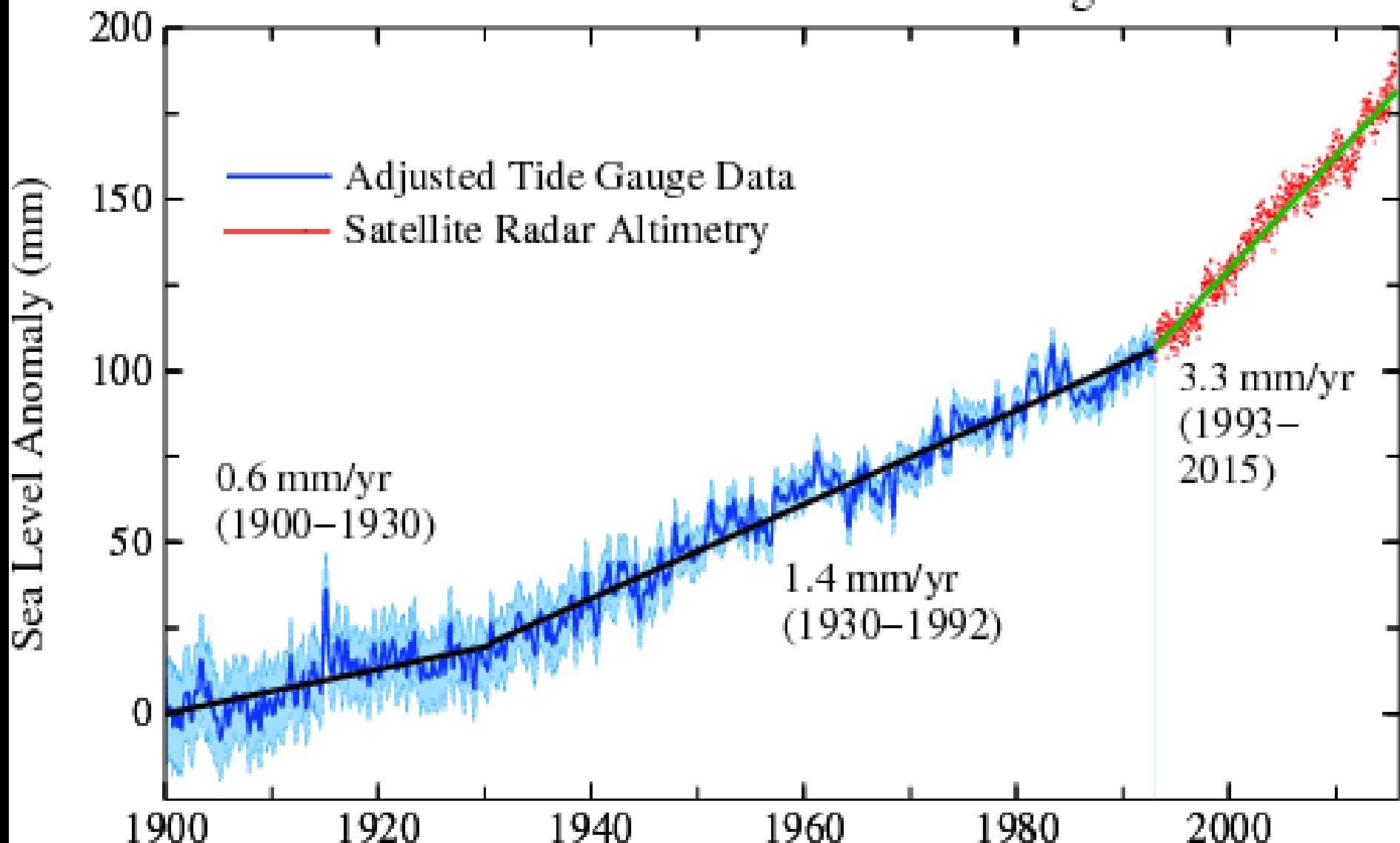








# Global Mean Sea Level Change





Scituate, Feb 2013

What do we do about climate change?

# What do we do about climate change?

- Mitigate
  - Reduce emissions of carbon dioxide and other greenhouse gases

# What do we do about climate change?

- Mitigate
  - Reduce emissions of carbon dioxide and other greenhouse gases
- Adapt
  - Plan for the impacts of a warmer world

# A few resources and links:

## General resources

[Union of Concerned Scientists](#)  
[350.Org](#)

AMS Annual Publications  
[State of the Climate](#)  
[Explaining Extreme Events](#)  
[AMS Statement on Climate](#)  
[Change](#)

Editorial in Boston Globe  
(3/11/18)

[A Must-do List for Climate](#)  
[Change in Greater Boston](#)

## State and Region

[Mass Executive Office of Energy](#)  
[and Environmental Affairs](#)

[Regional Greenhouse Gas](#)  
[Initiative](#)

[Environmental League of MA](#)

[Climate Ready Boston](#)

Article in the GHS Gillnetter  
[Gloucester under water in 100 yr](#)

Thank  
You!



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