



**WEATHERING  
CHANGE**



**Strengthen communities to prepare, respond and recover  
in the face of climate impacts and other disruptions  
through collaborative, innovative solutions.**

[communityresilience-center.org](https://communityresilience-center.org)

Abigail Abrash-Walton  
Co-Director

# Local Solutions for Strong Communities

... a series of online courses focused on the fundamentals of climate change resilience.

- Engage in each course for 4 weeks
- Enroll for graduate credit or audit the course
- Increase your skill set in climate resilience for better outcomes
- Discover solutions to local issues you face on the job or in your community.
- Register for one course or the whole series.

<http://www.communityresilience-center.org/climate-change-resilience-series/>



# Local Solutions for Strong Communities

... a series of online courses focused on the fundamentals of climate change resilience.

Join us for our next online course in this series

## Climate Change: The Science, Uncertainty, and Risk

Sunday, September 8 – October 5, 2019

<http://www.communityresilience-center.org/climate-change-resilience-series/>



Instructor: Michael Simpson, MS





**Meet the challenges of a changing climate by finding information and tools to help you understand and address your climate risks.**

[toolkit.climate.gov](https://toolkit.climate.gov)

Ned Gardiner,  
Engagement Manager

# Logistics



If you have a question, please write it in the Q&A section (not Chat) and select to All Panelists, so we can see the questions.



If you are having technical difficulty, please use Chat and send to Host, so we can address the issue with you directly.



The presentation will be recorded and posted to the Antioch website within a week [www.communityresilience-center.org](http://www.communityresilience-center.org)

# Climate Change

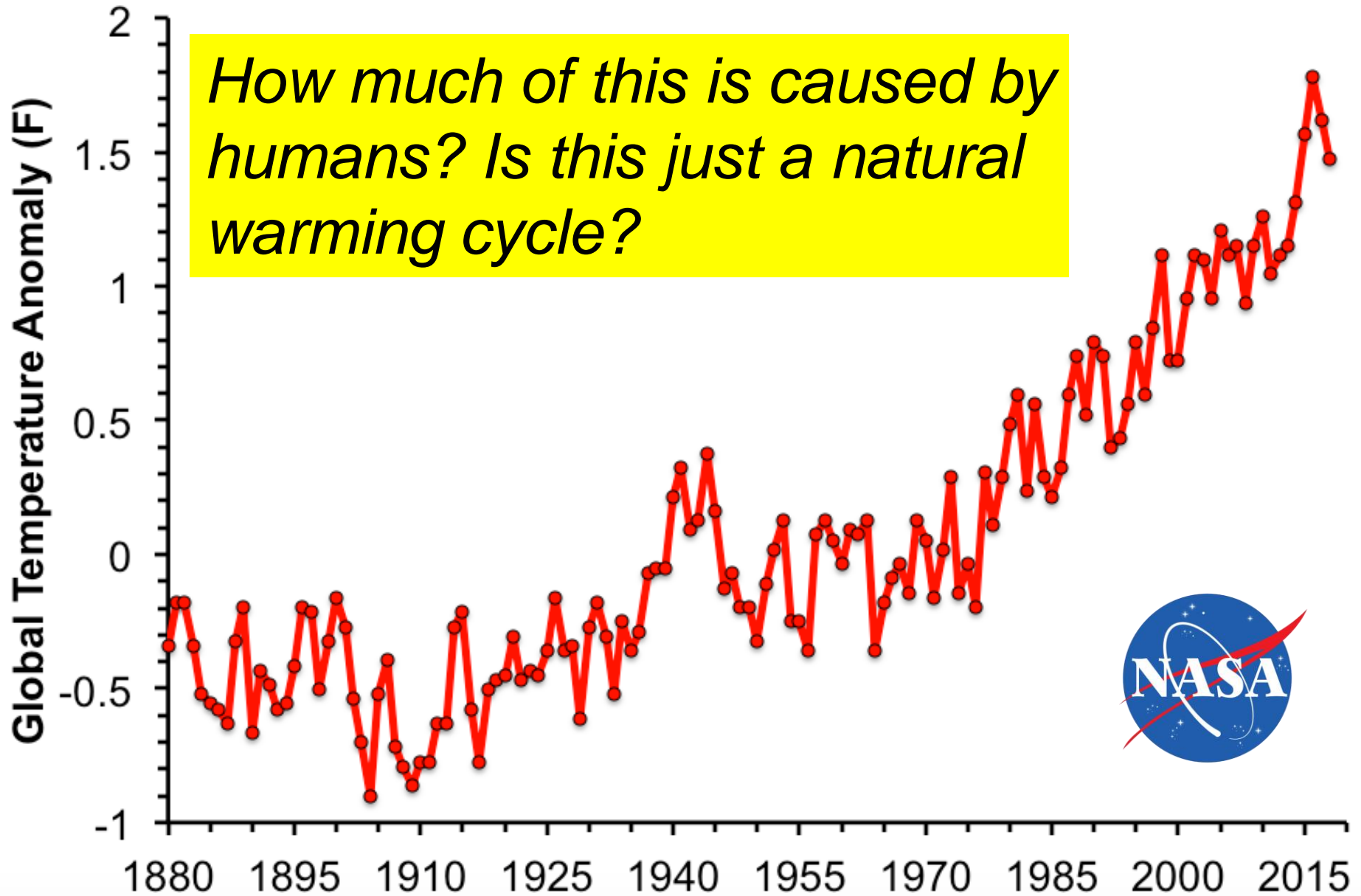
- **What's natural?**
- **What's human-caused?**
- **And how do we know?**

**Erich Osterberg, PhD**

Associate Professor of Earth Sciences,  
Dartmouth College

# The Earth has Warmed 2°F Since 1900

*How much of this is caused by humans? Is this just a natural warming cycle?*



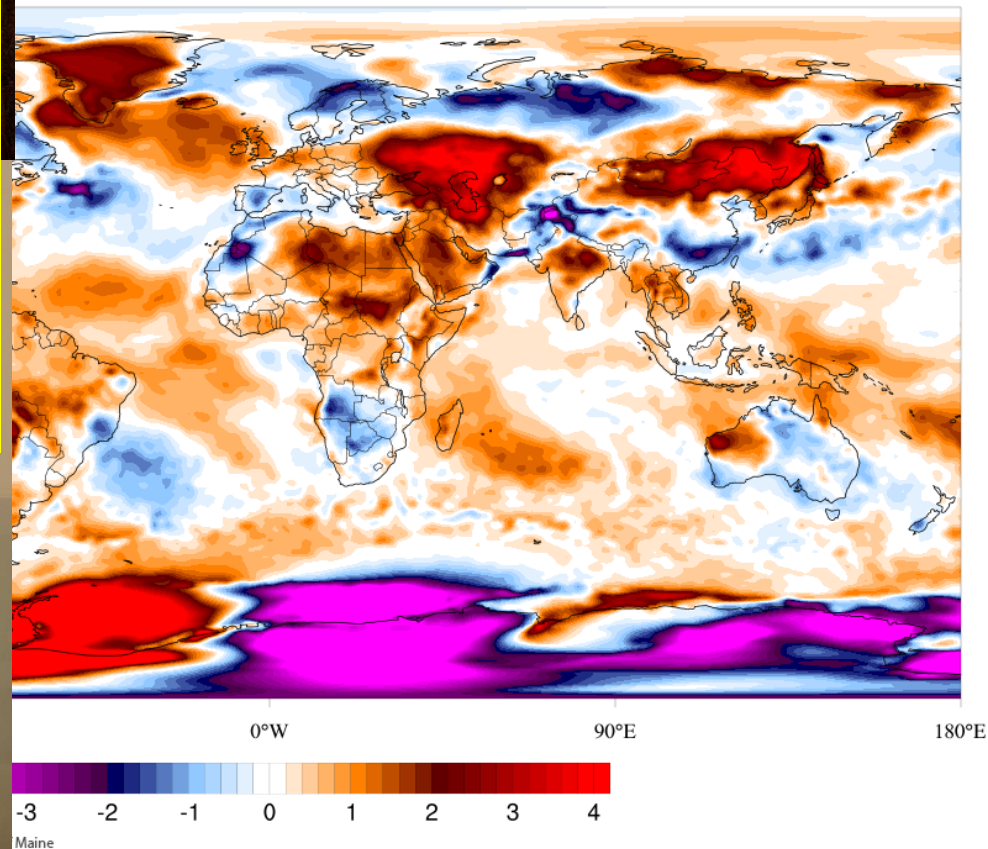
# 2010 Russian Heat Wave & Fires: 55,000+ Deaths, 15% Decreased Crop Production & \$15 billion



*Russian heat wave 3x  
more likely due to  
climate change  
(Rahmstorf and Coumou,  
2011)*

Heat wave from June-July 2010  
set all-time temp records.  
Deaths from heart & respiratory  
distress, drownings

Jun 2010 minus 1979-2015





# Greenland's ice sheet just lost 11 billion tons of ice -- in one day

By Mark Tutton, CNN

🕒 Updated 10:35 PM ET, Thu August 15, 2019





# Sunny Day High Tide in Miami Beach



Credit: Joe Raedle

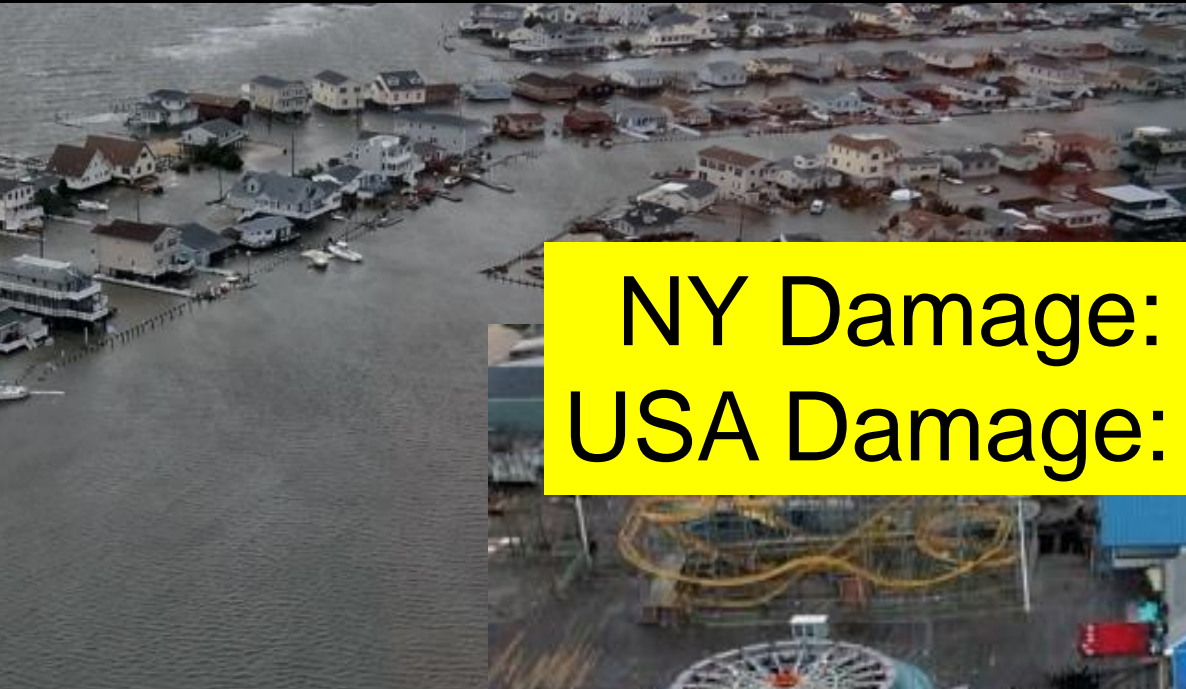
# 2018 Boston Nor'easter Flooding

- January 4, 2018
- ~100-year flood
- 4.5 feet above high tide
- #1 record flood level
- >\$1 billion in losses

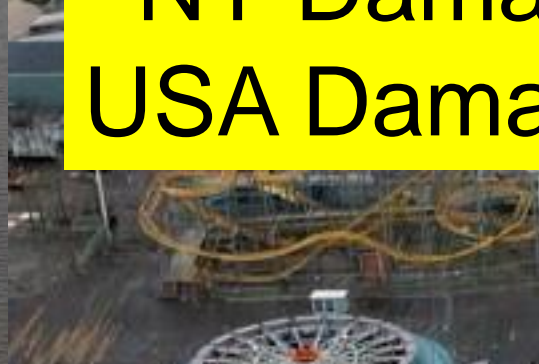




# 2012: Hurricane Sandy



**NY Damage: \$33 Billion**  
**USA Damage: \$65 Billion**



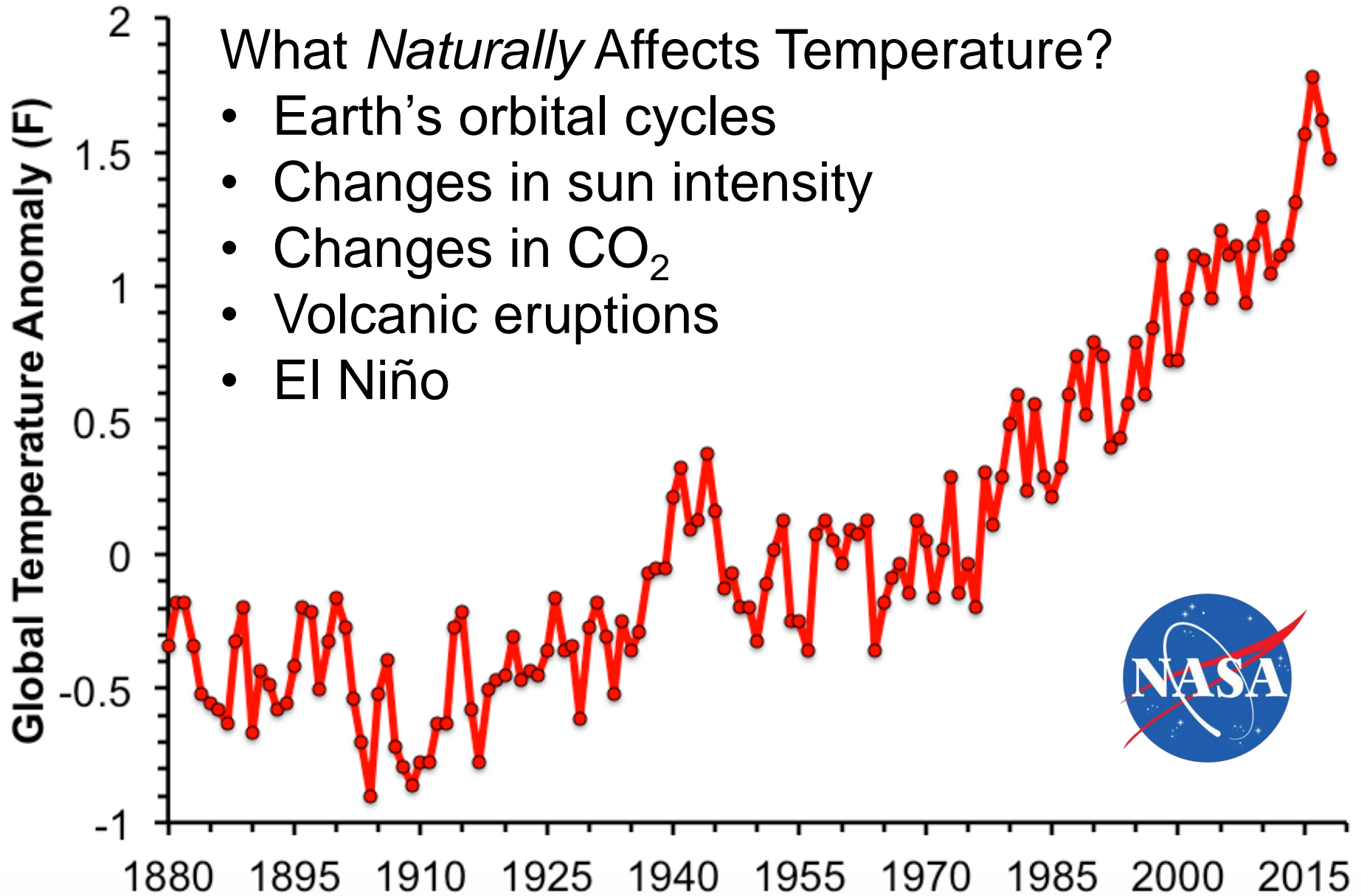
# How Do We Know What's Natural and What's From Humans?

- **Strategies**
  - Understand the natural cycles
  - Create long records of climate from ice cores
  - Use climate models to create human-free climate simulations
- **Case Studies**
  - Global warming since ~1900
  - Greenland melting and sea level rise
  - Extreme storms in the Northeast US

# The Earth has Warmed 2°F Since 1900

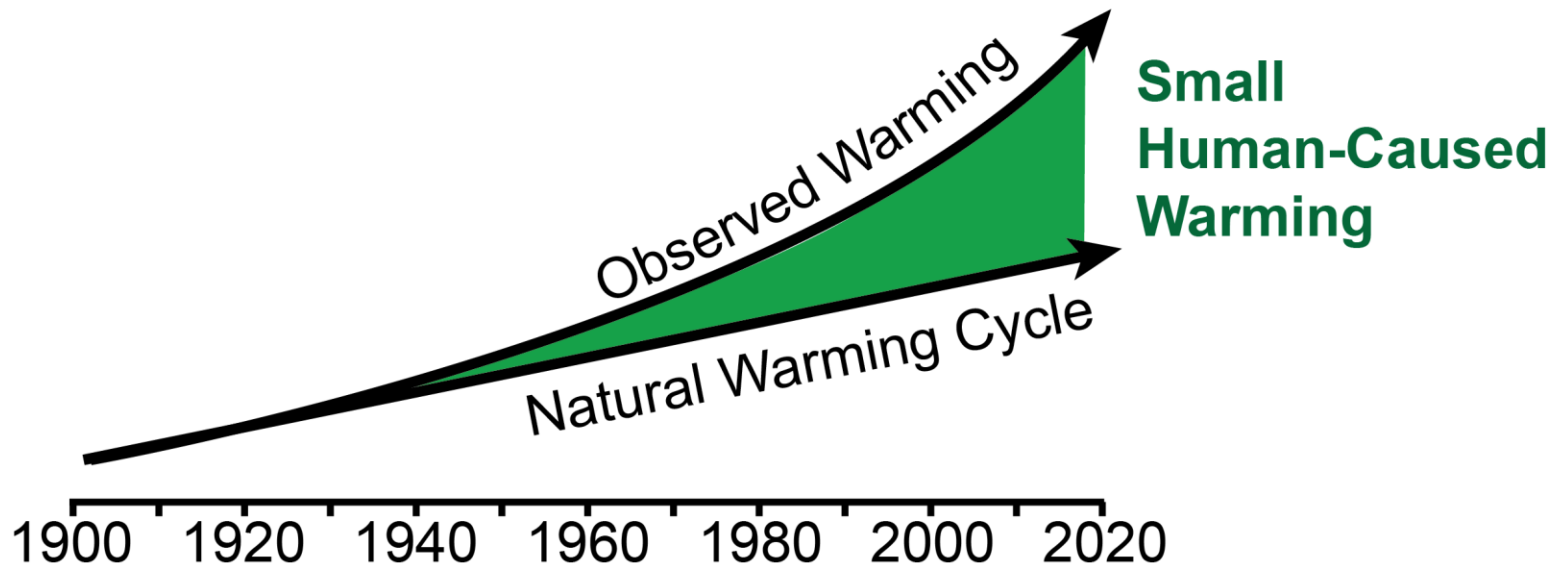
What *Naturally* Affects Temperature?

- Earth's orbital cycles
- Changes in sun intensity
- Changes in CO<sub>2</sub>
- Volcanic eruptions
- El Niño



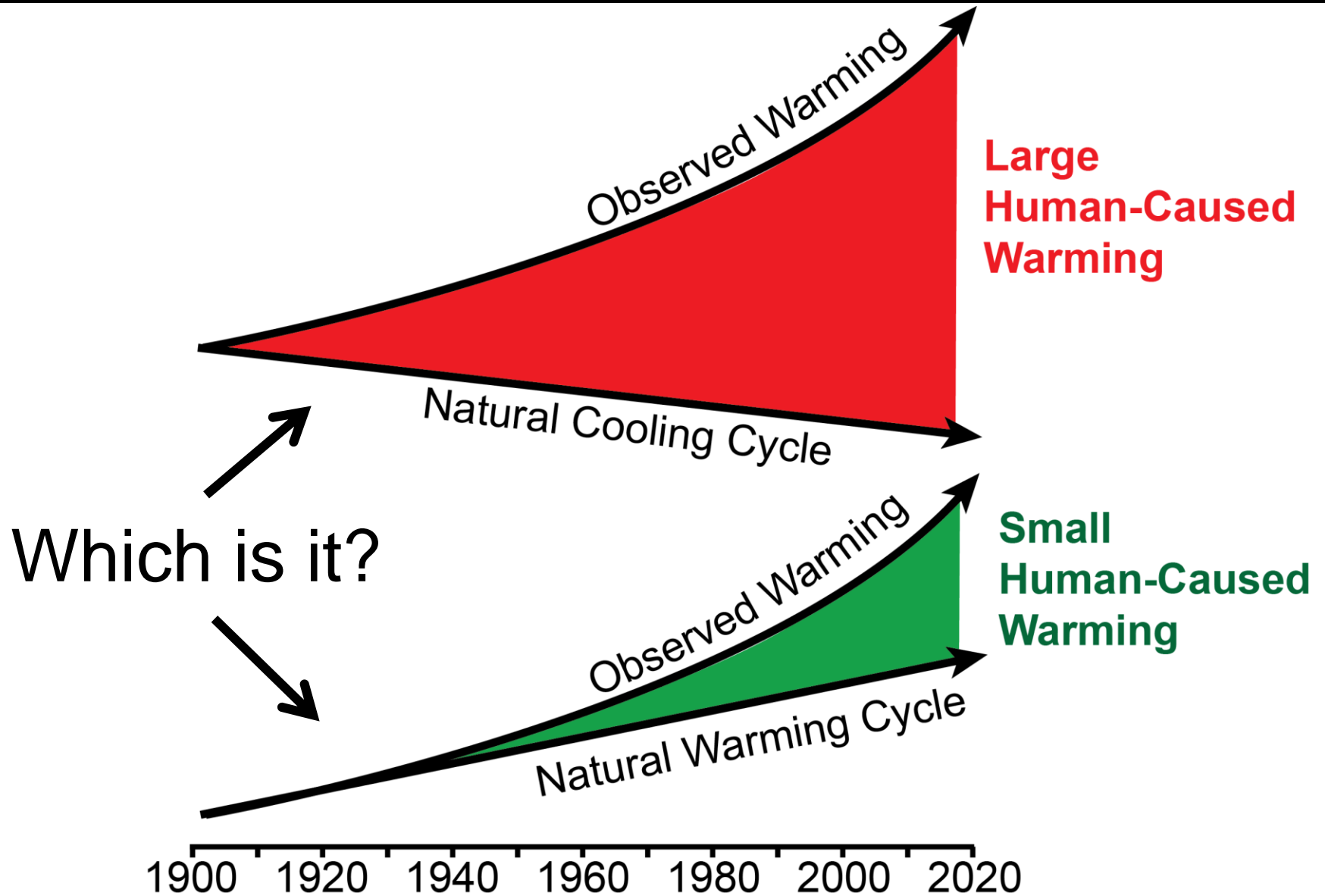


# Natural vs. Human-Caused Warming



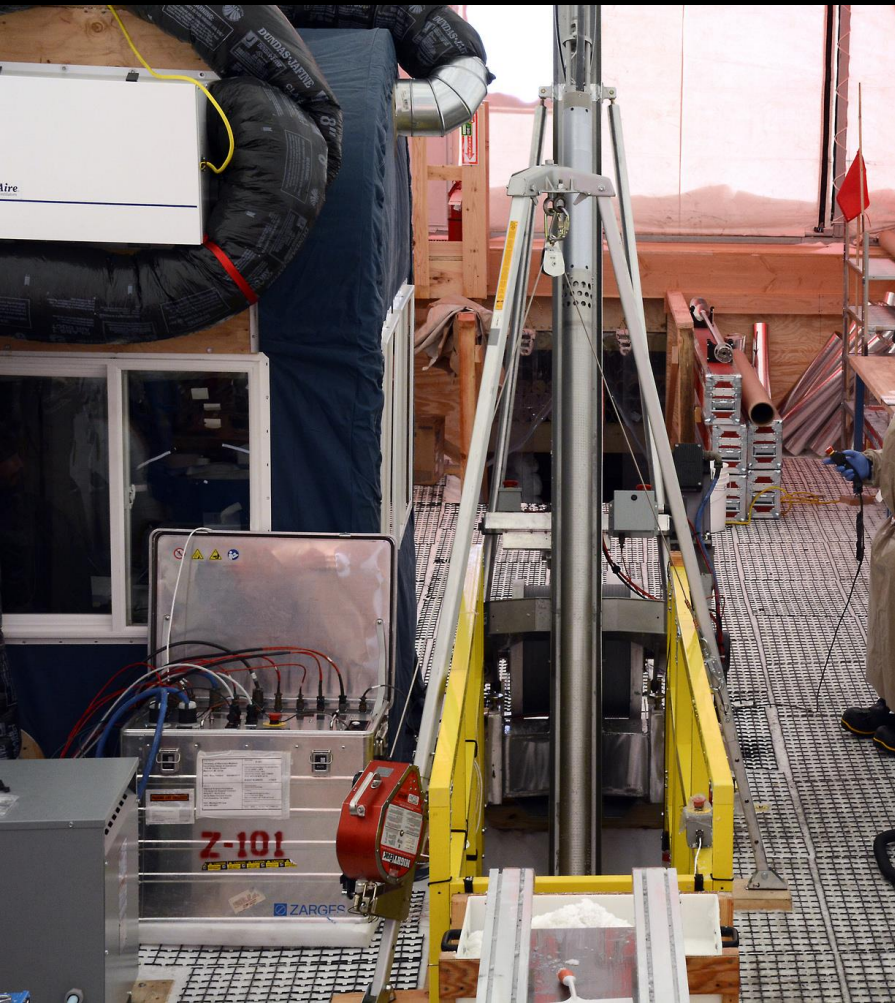
Based on Ruddiman, 2008

# Natural vs. Human-Caused Warming



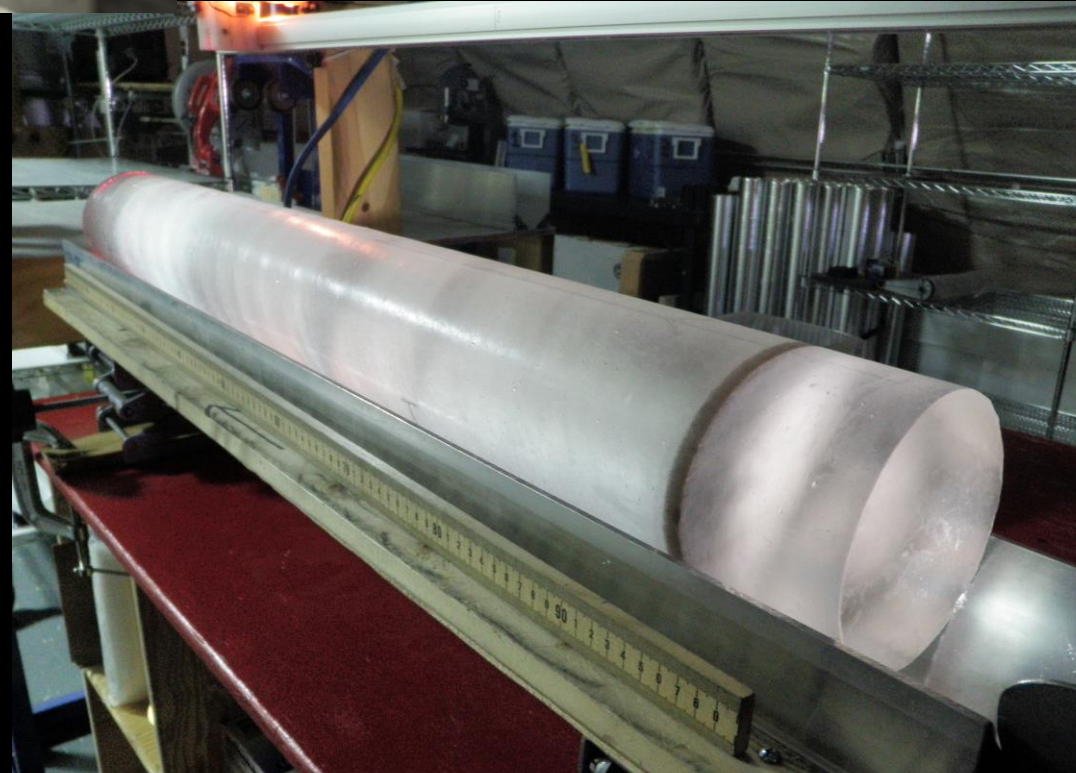
Based on Ruddiman, 2008

# South Pole Ice Coring 2015

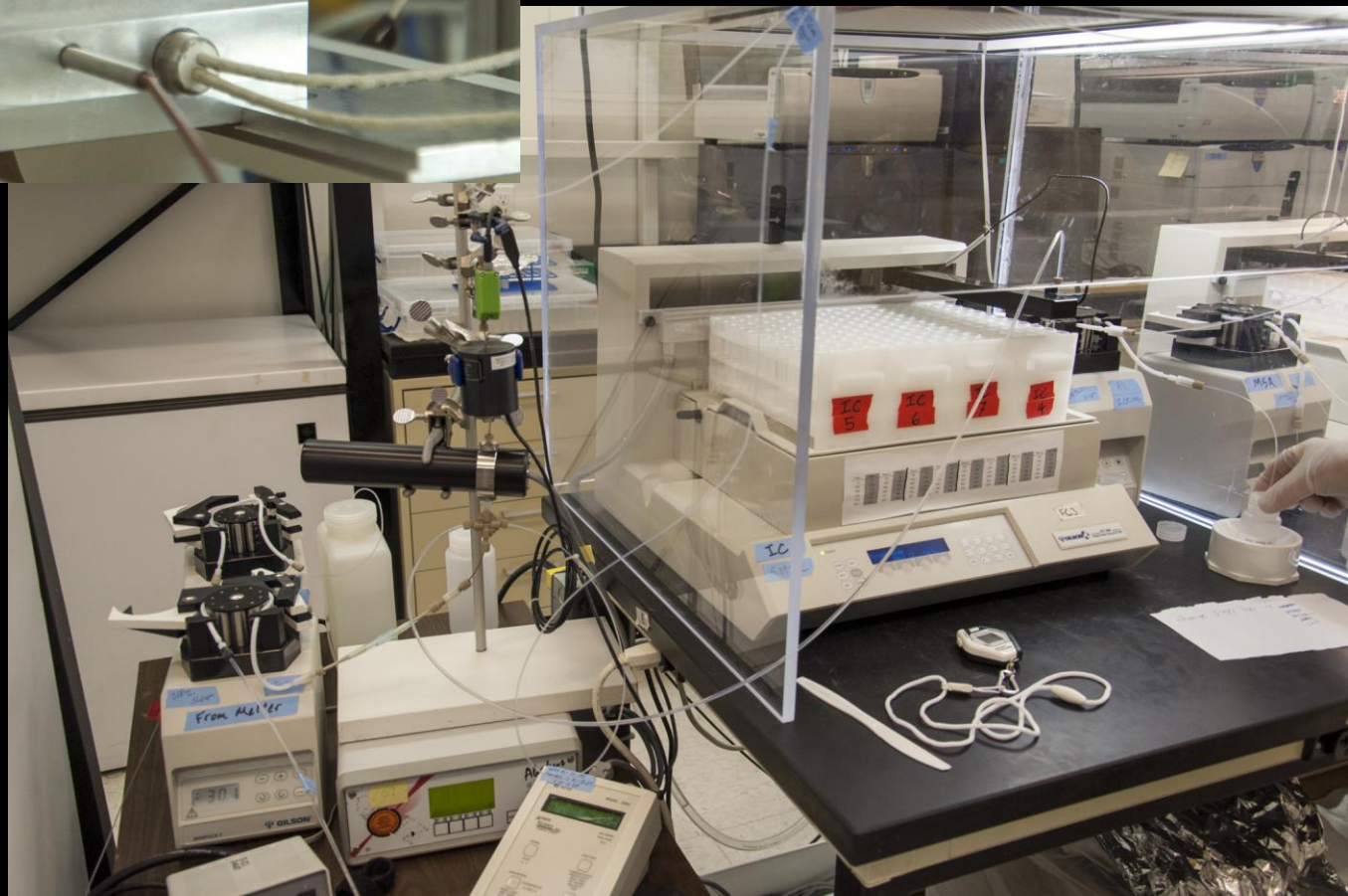
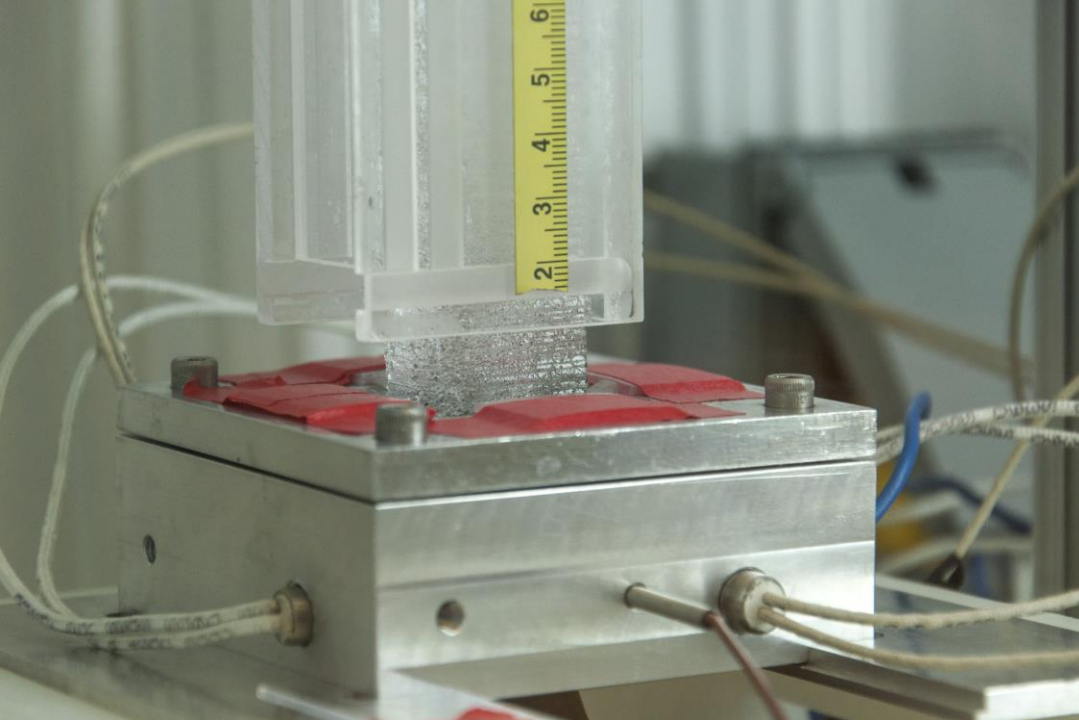




# South Pole Ice Coring 2015



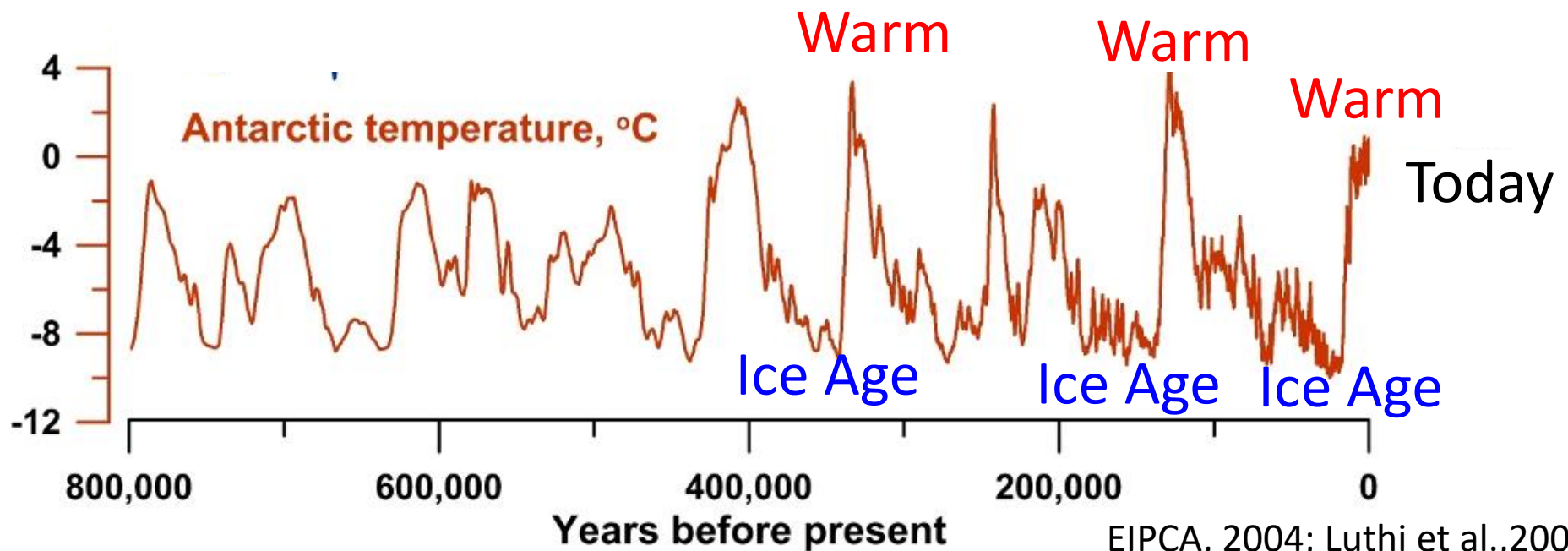
# Dartmouth Ice Core Lab





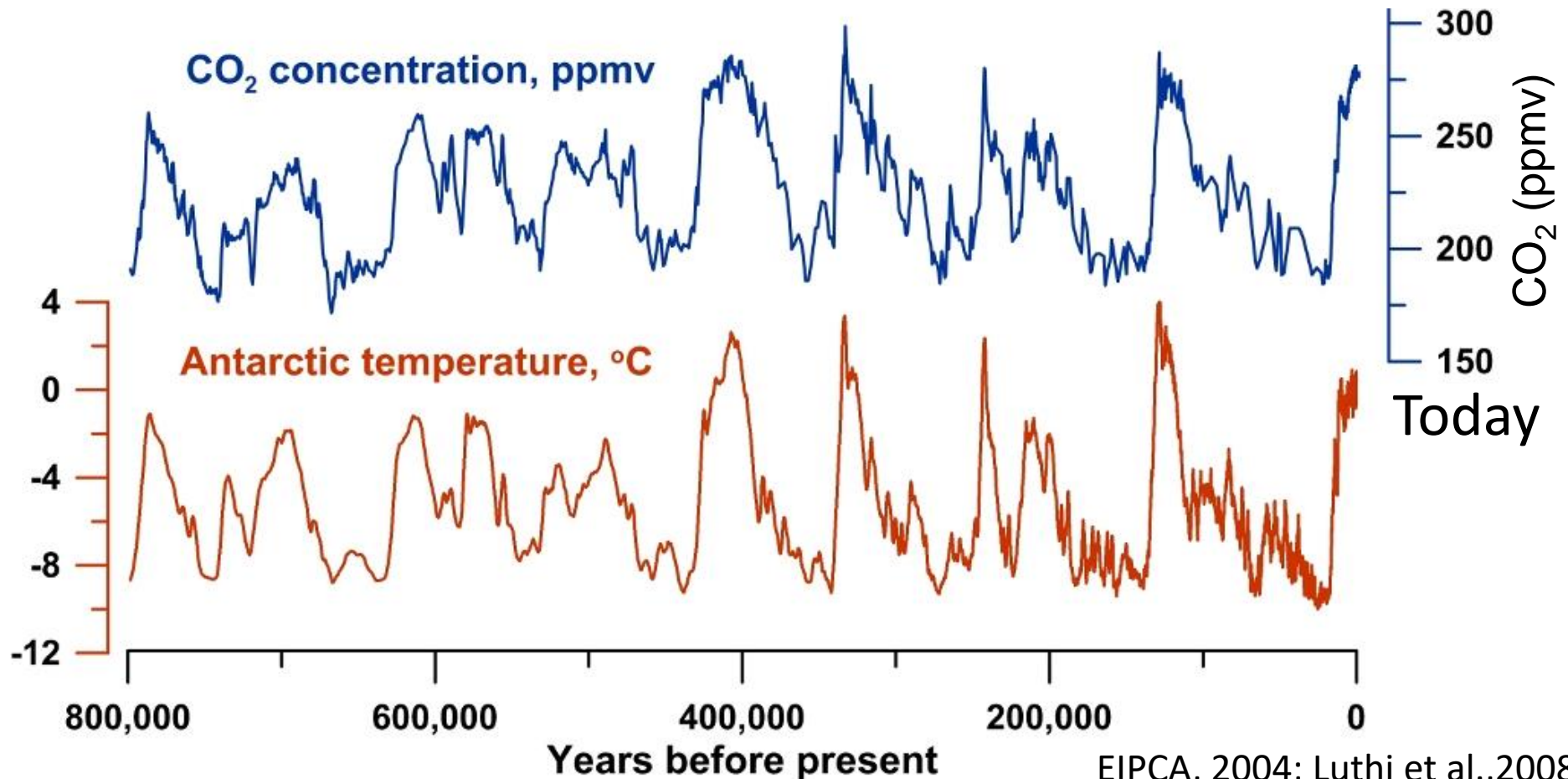
# Ice Age Cycles Caused by Orbital Changes and Natural CO<sub>2</sub>

- Ice ages are paced every 100,000 years

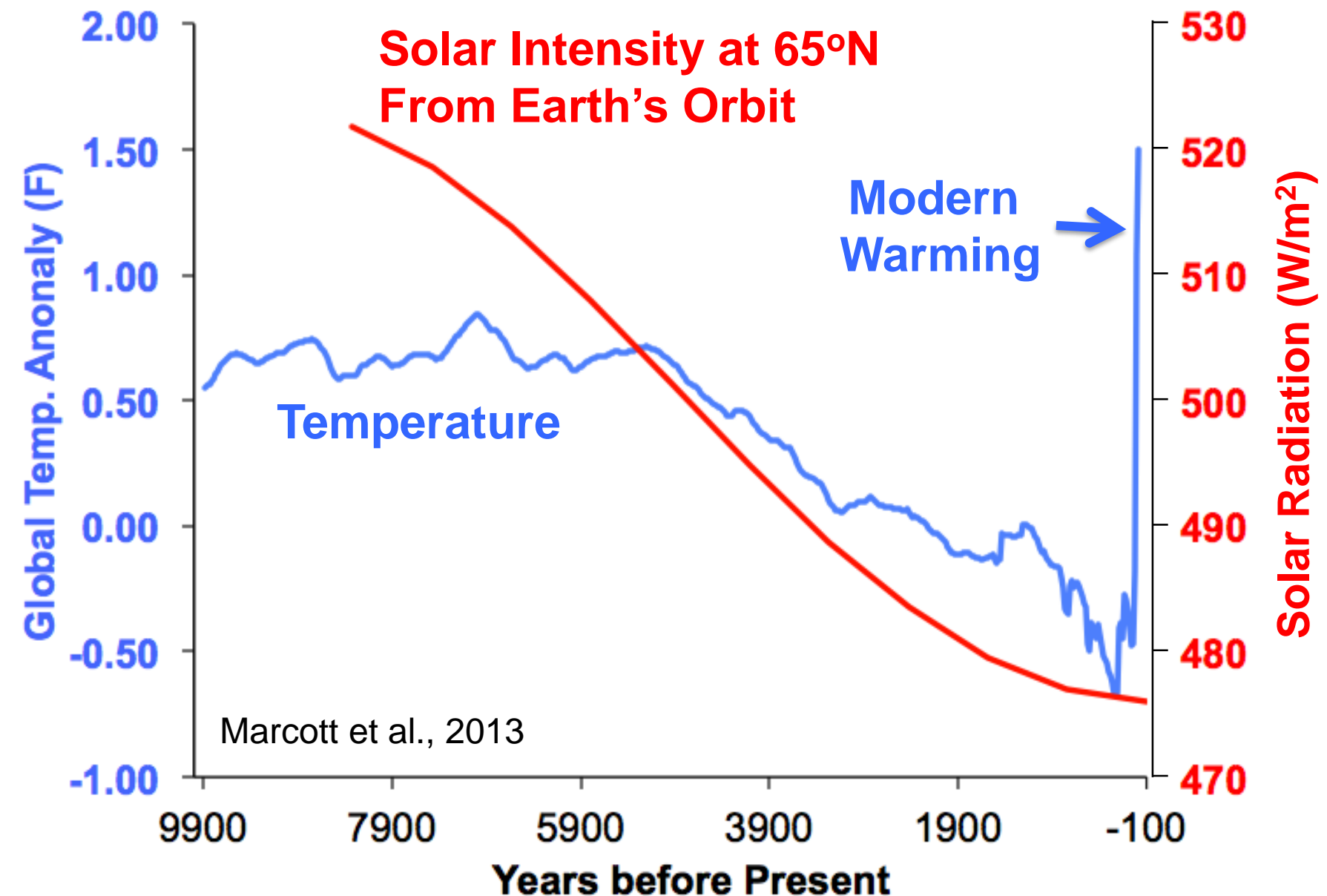


# Ice Age Cycles Caused by Orbital Changes and Natural CO<sub>2</sub>

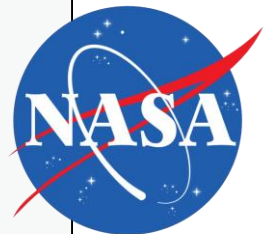
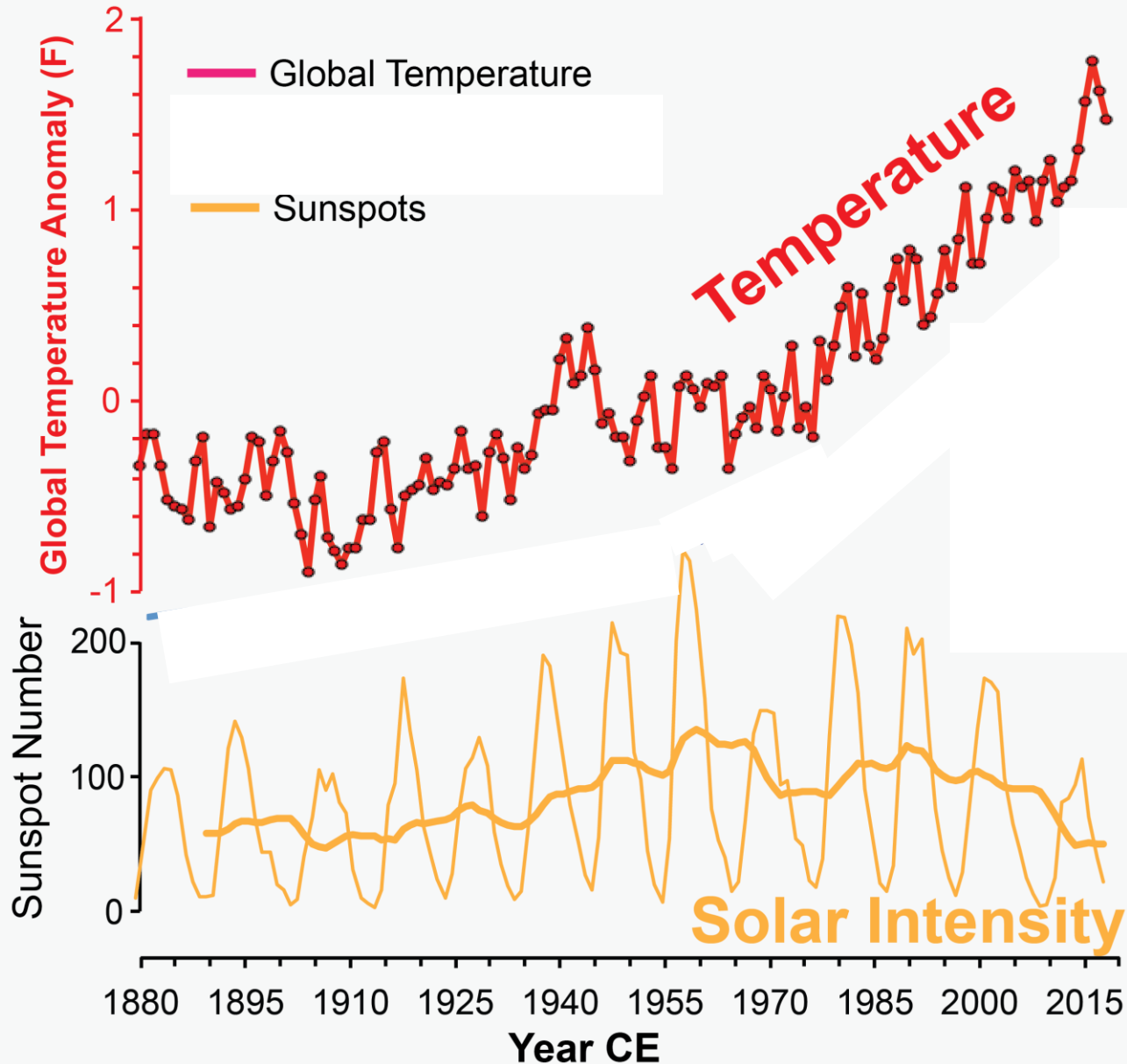
- Ice ages are paced every 100,000 years
- Pacing started by Earth's orbital cycles and then CO<sub>2</sub> reinforces the change (positive feedback)



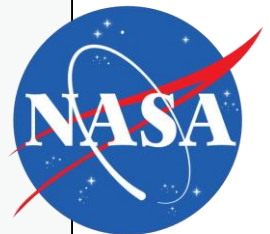
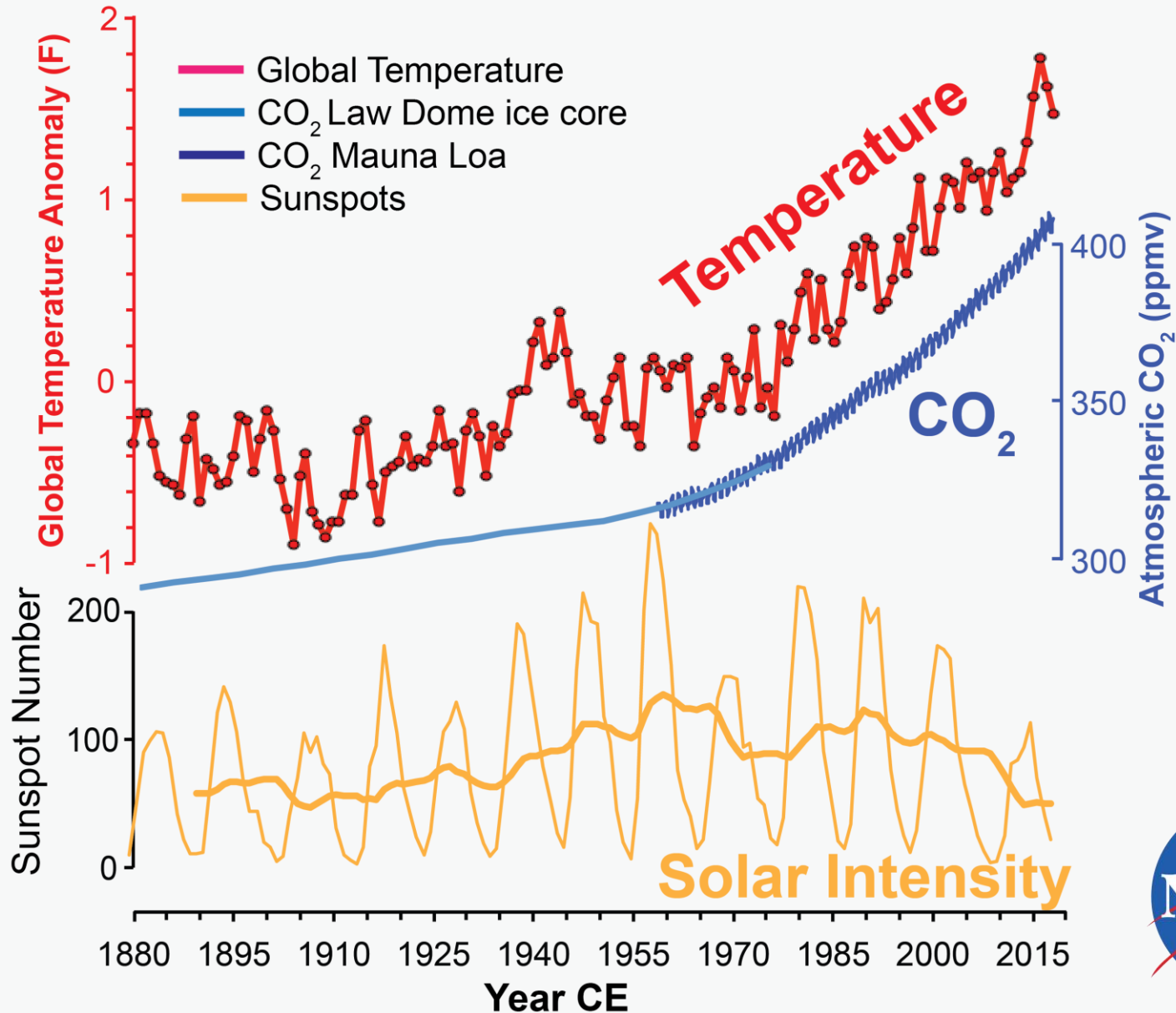
# Earth's Orbital Changes Have Caused Cooling over Past 5,000 Years – until the 20<sup>th</sup> Century!



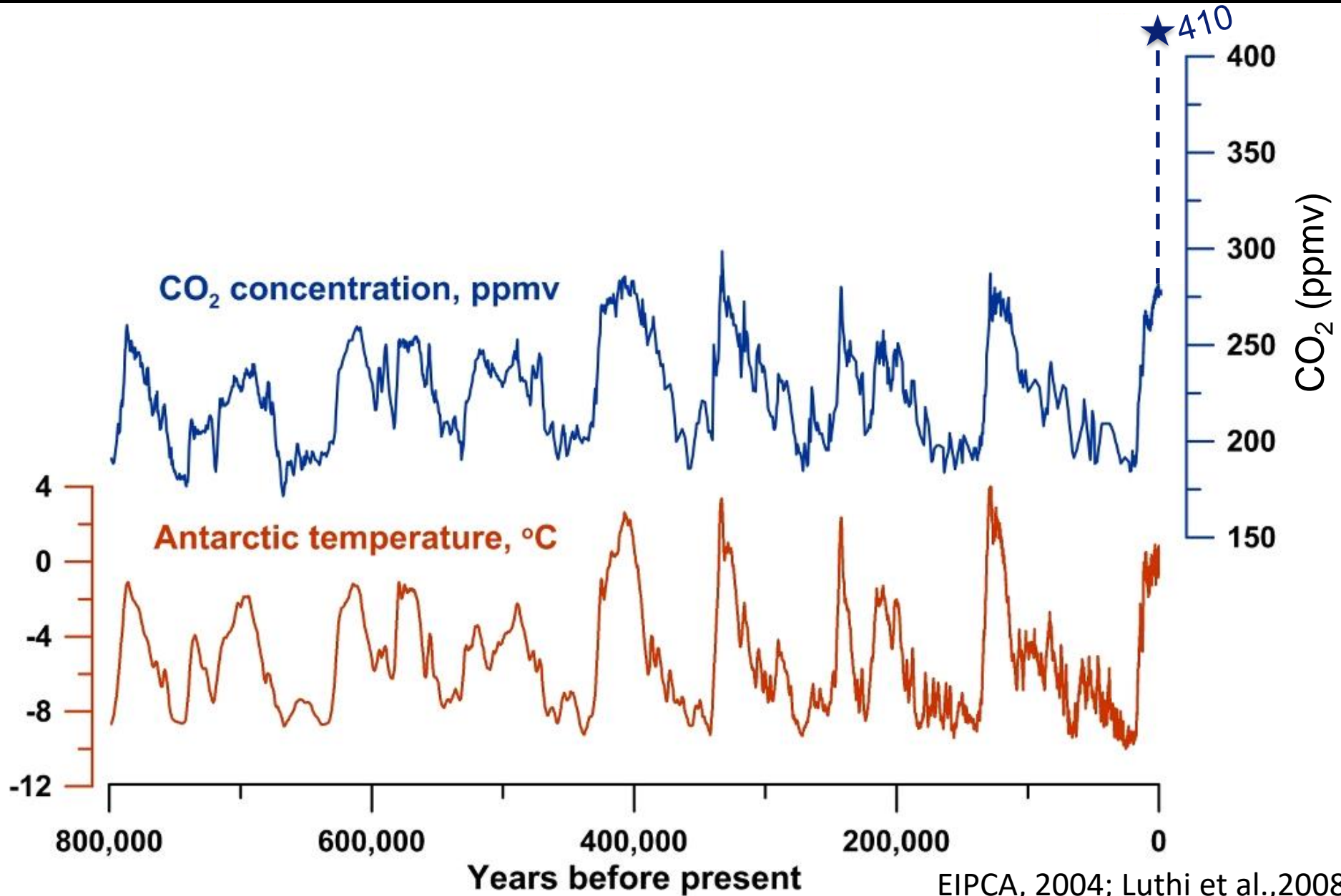
# Solar Intensity is Going DOWN - Temps are Going UP



# Solar Intensity is Going DOWN - Temps are Going UP with CO<sub>2</sub>



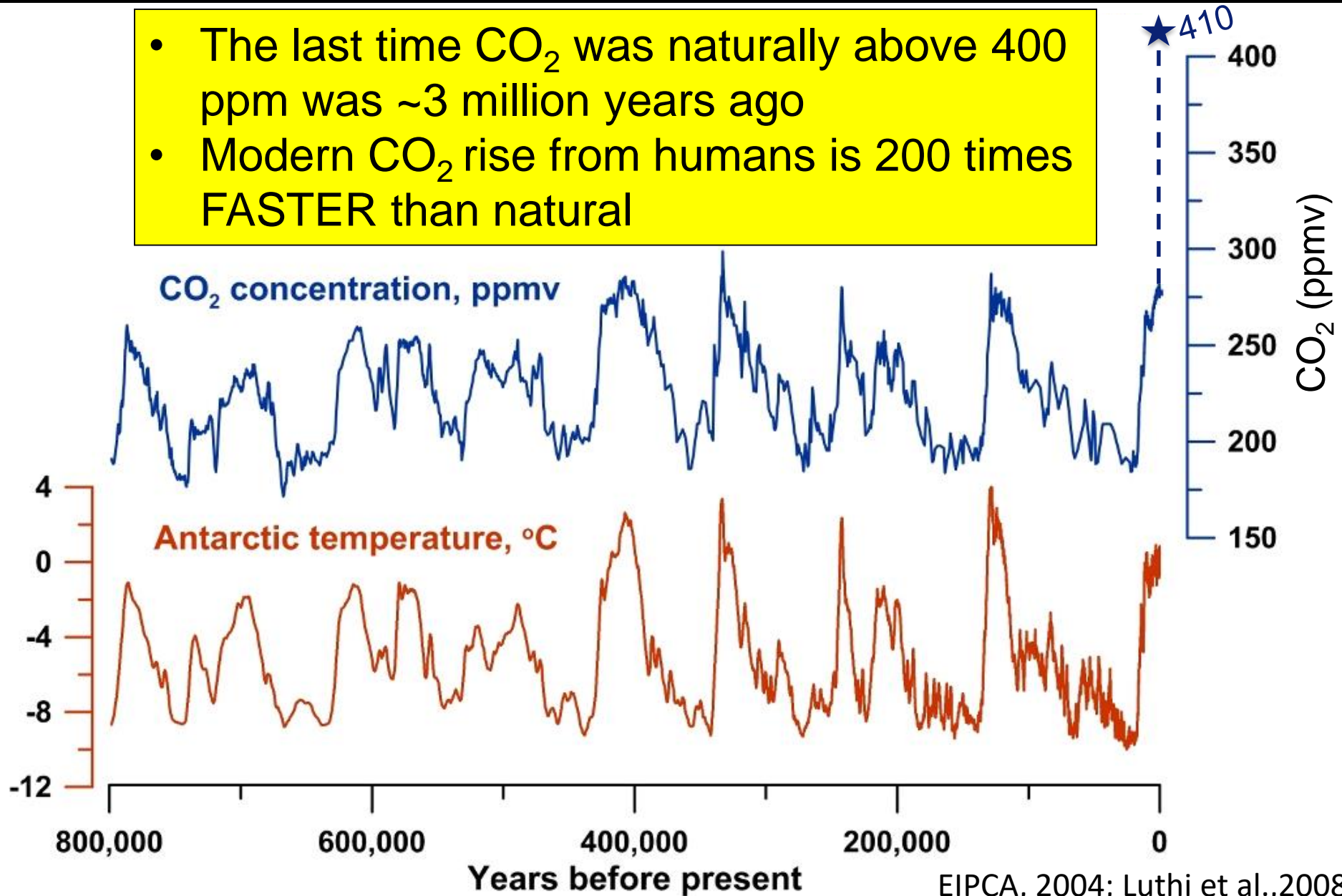
# CO<sub>2</sub> Rise from Humans is Off the Charts and Super Fast!



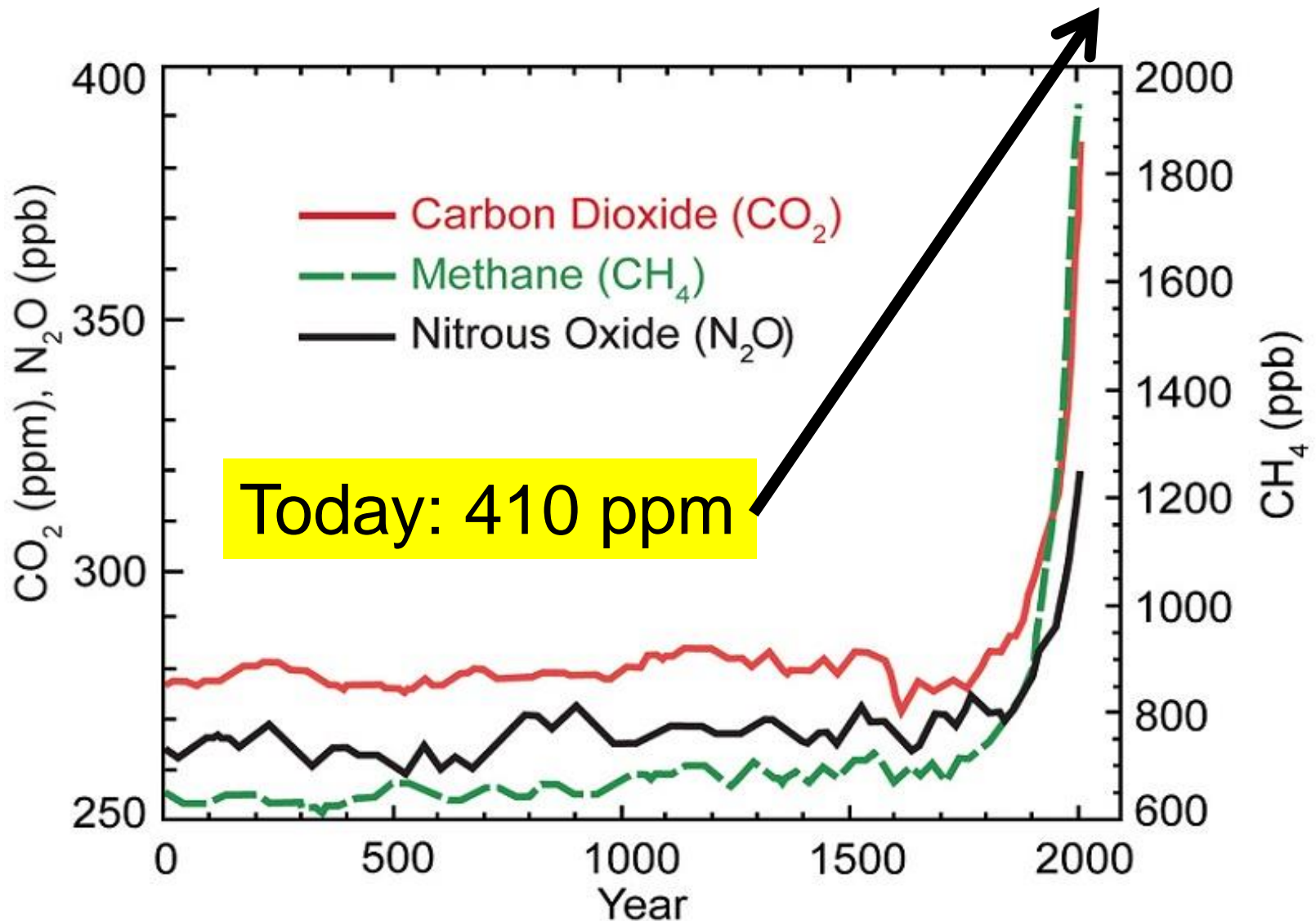


# CO<sub>2</sub> Rise from Humans is Off the Charts and Super Fast!

- The last time CO<sub>2</sub> was naturally above 400 ppm was ~3 million years ago
- Modern CO<sub>2</sub> rise from humans is 200 times FASTER than natural

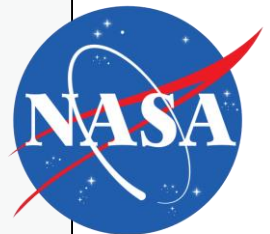
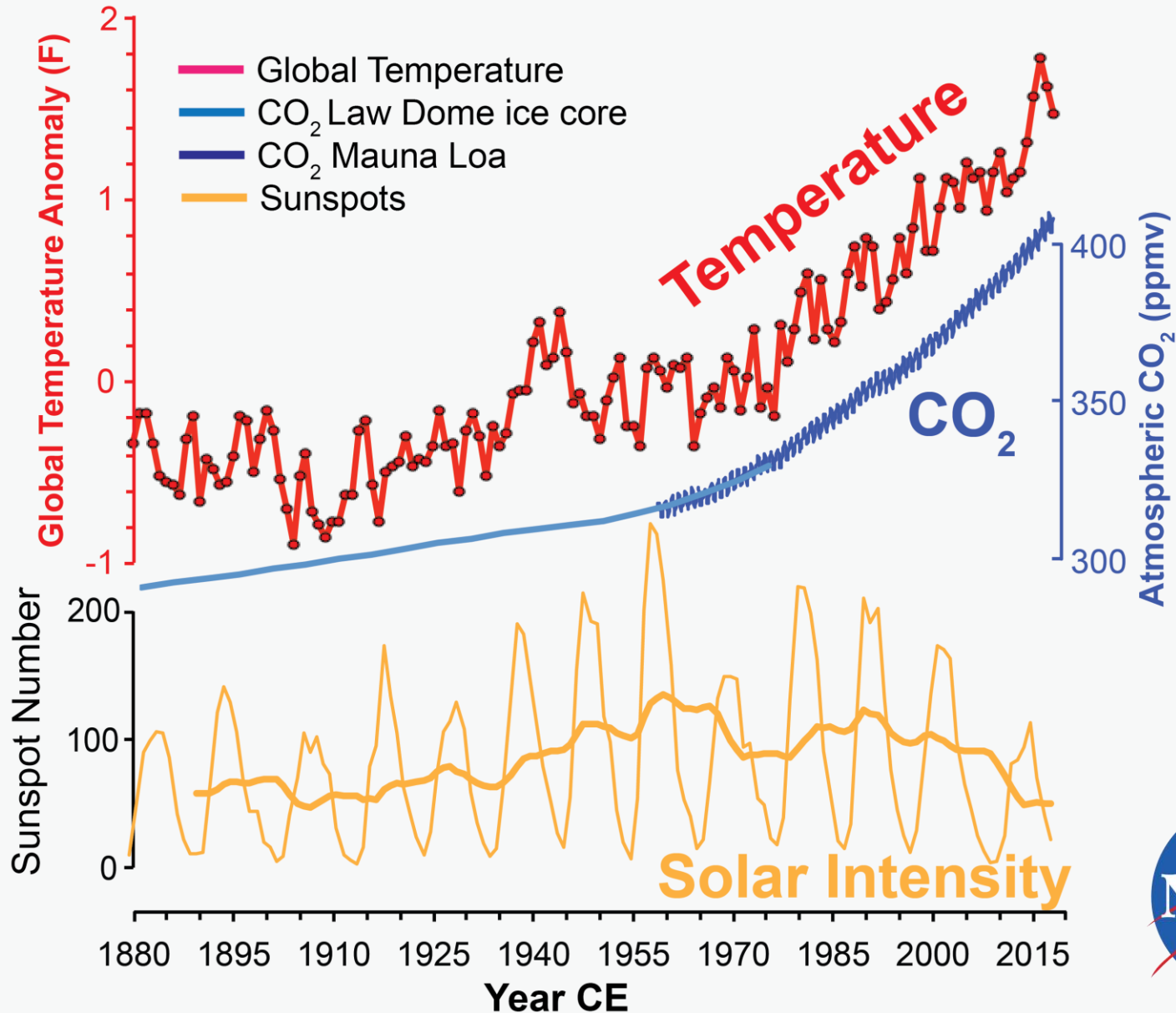


# Human CO<sub>2</sub> Rise is Unprecedented in Speed





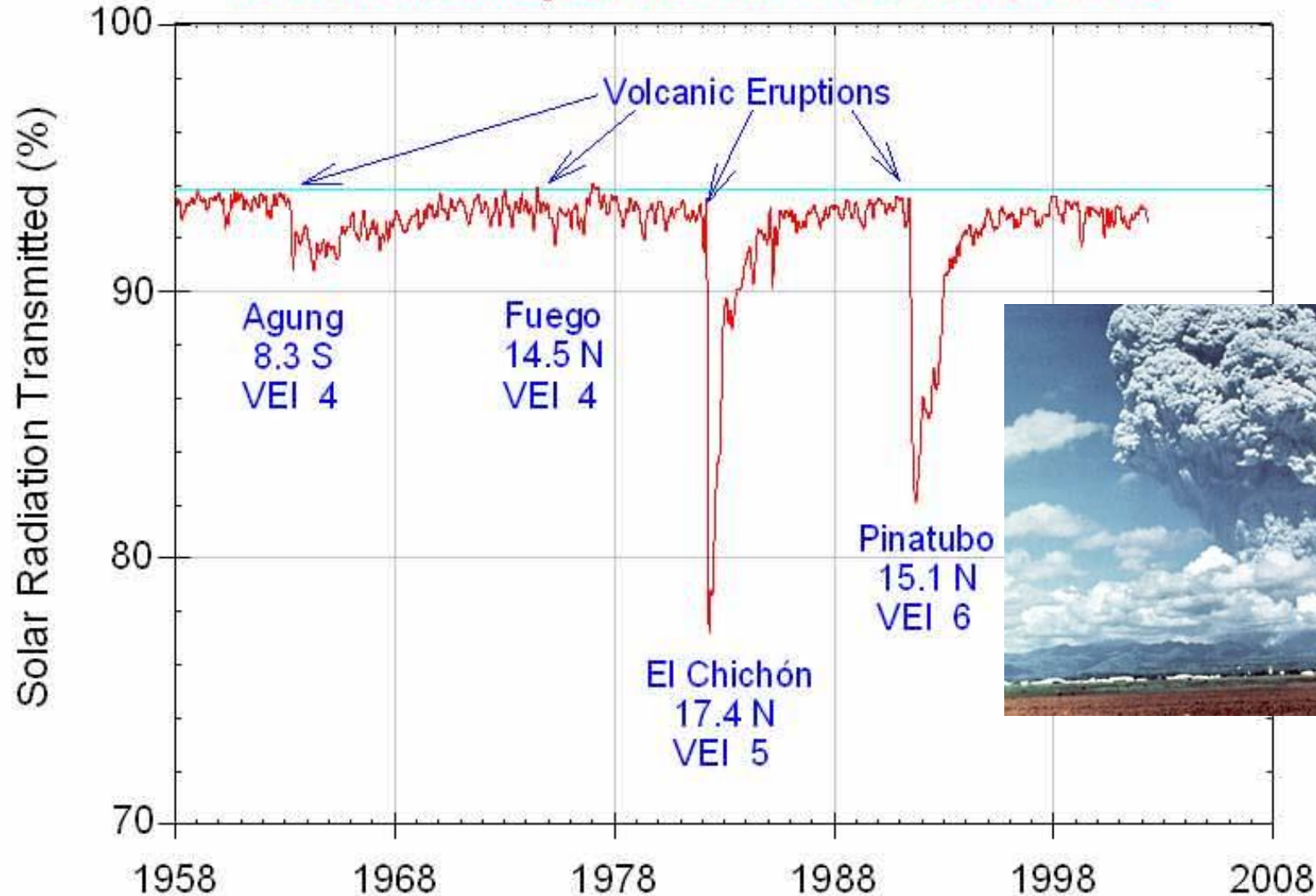
# Solar Intensity is Going DOWN - Temps are Going UP with CO<sub>2</sub>



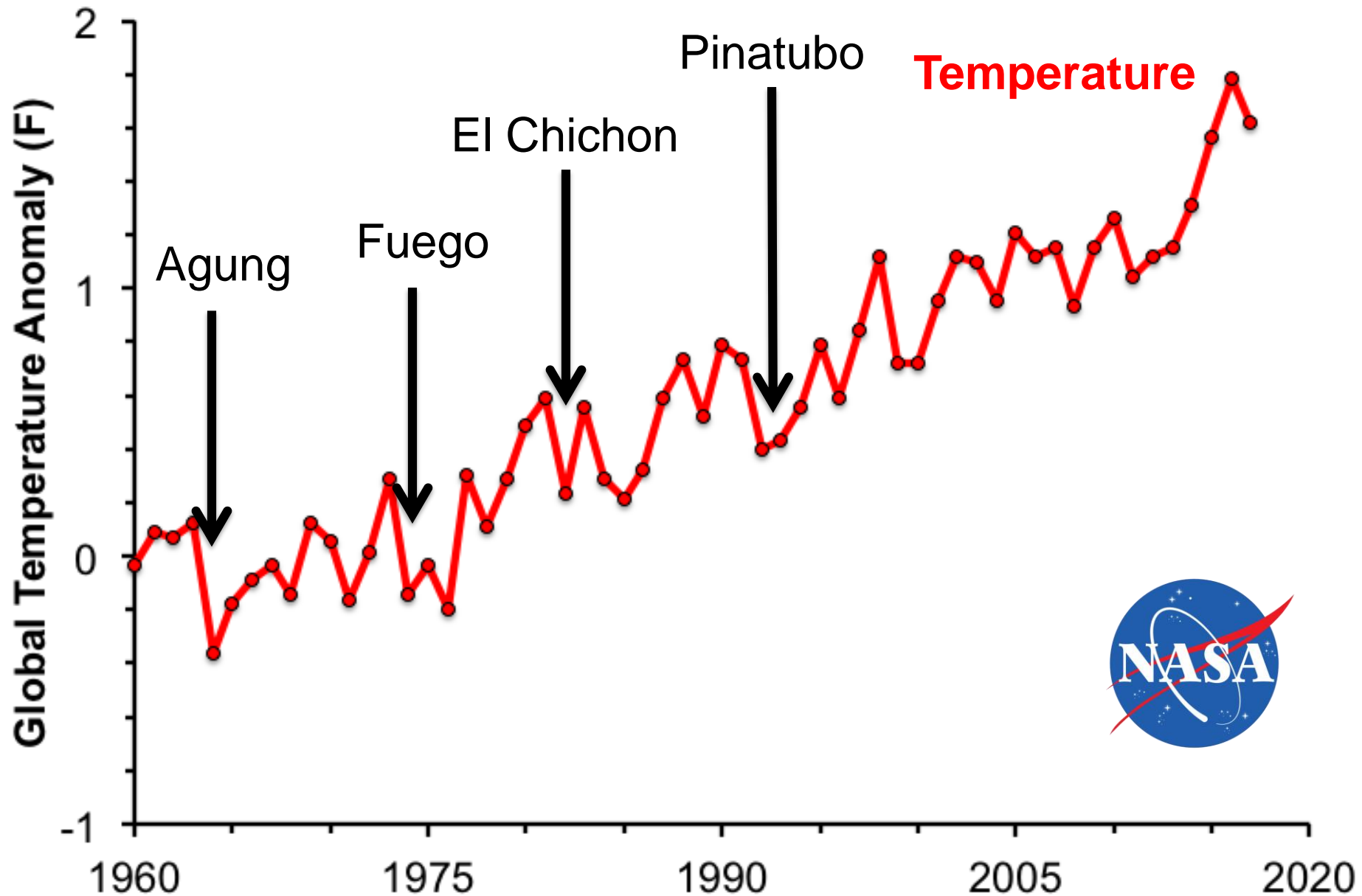
# Large Volcanic Eruptions Cause Cooling for a Couple Years by Reflecting More Sunlight Back to Space

## Large Volcanic Eruptions Reduce Global Sunlight

*Mauna Loa Observatory Solar Radiation % Transmission Since 1958*

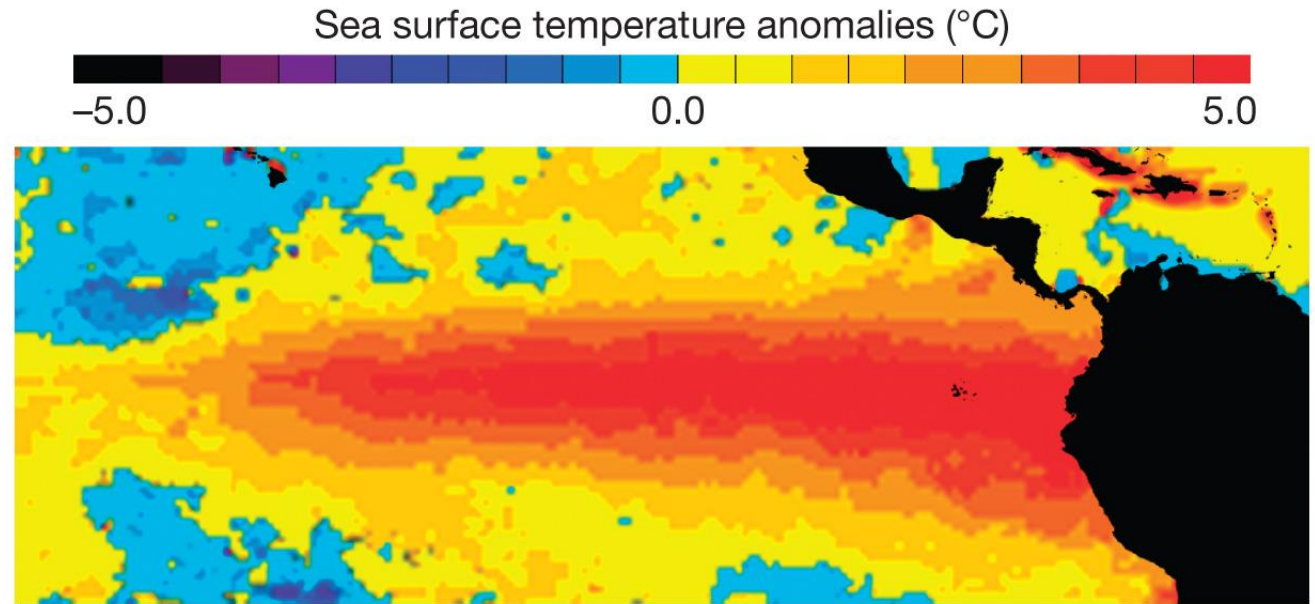


# Large Volcanic Eruptions Cause Cooling for a Couple Years by Reflecting More Sunlight Back to Space



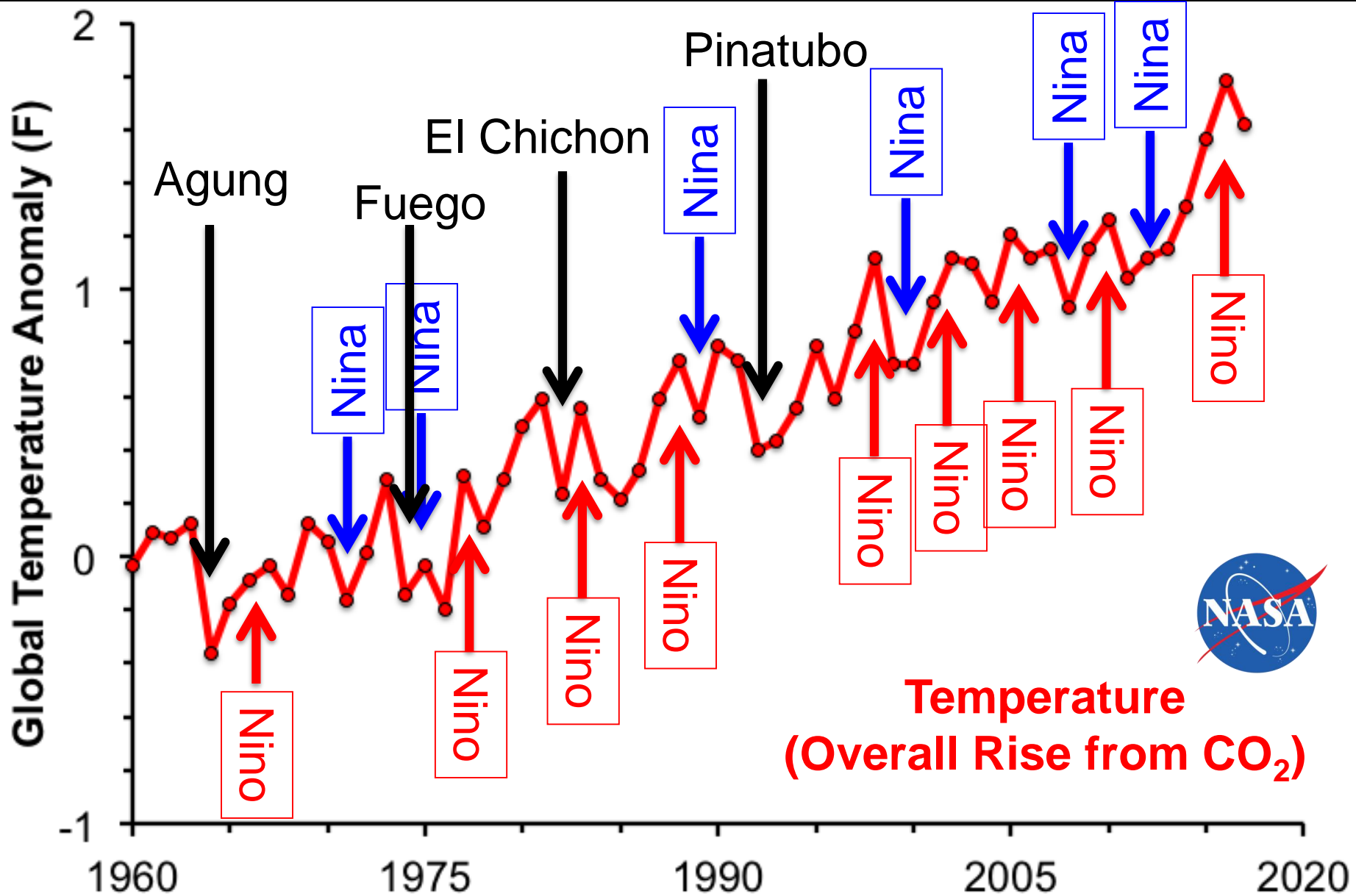
# El Niño and La Niña Sea Surface Temp Anomalies

El Niño  
Causes  
Warming

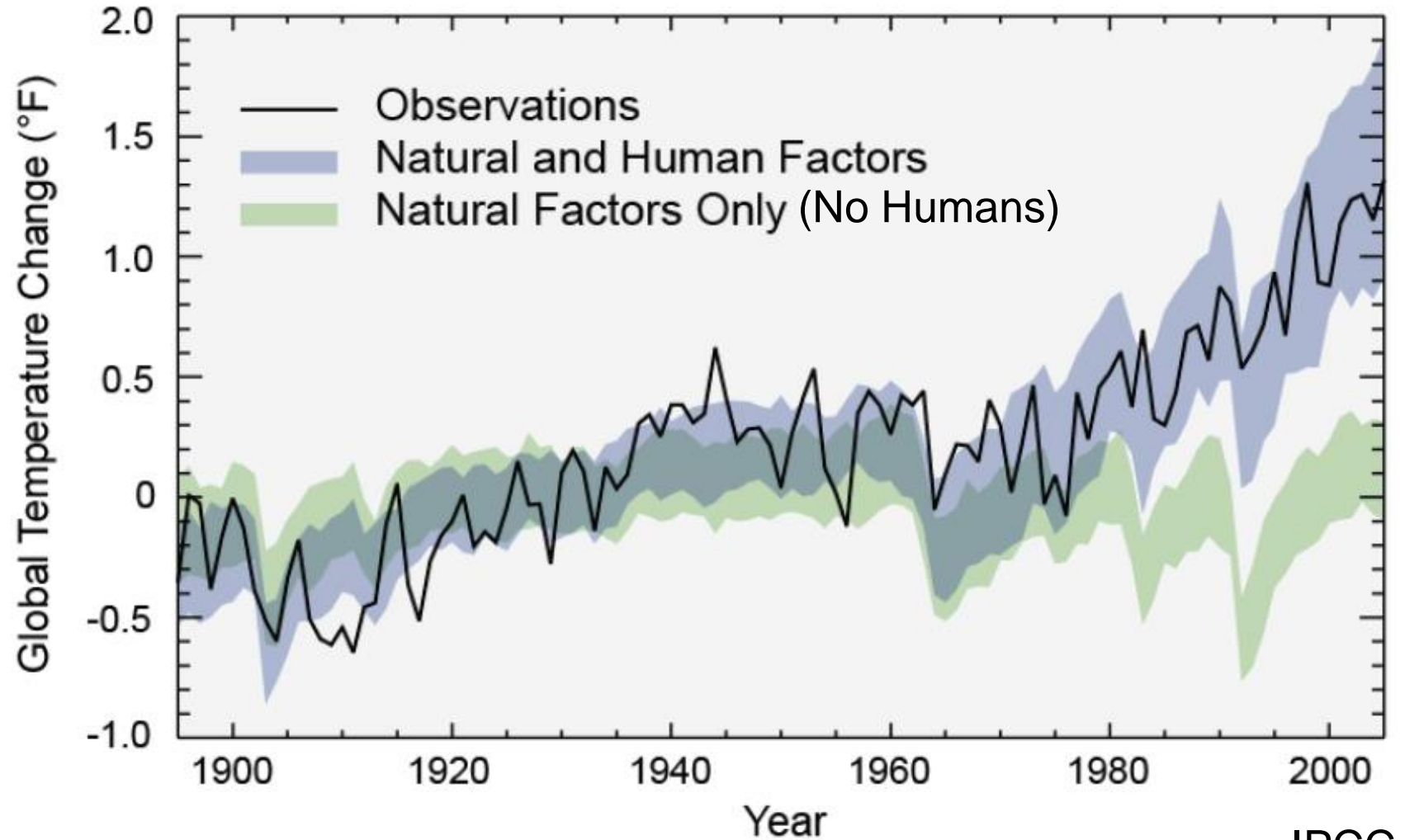


(a) El Niño (December 1997)

# El Nino's Make it a Little Bit Warmer; La Nina's and Volcanic Eruptions Make it a Little Bit Cooler

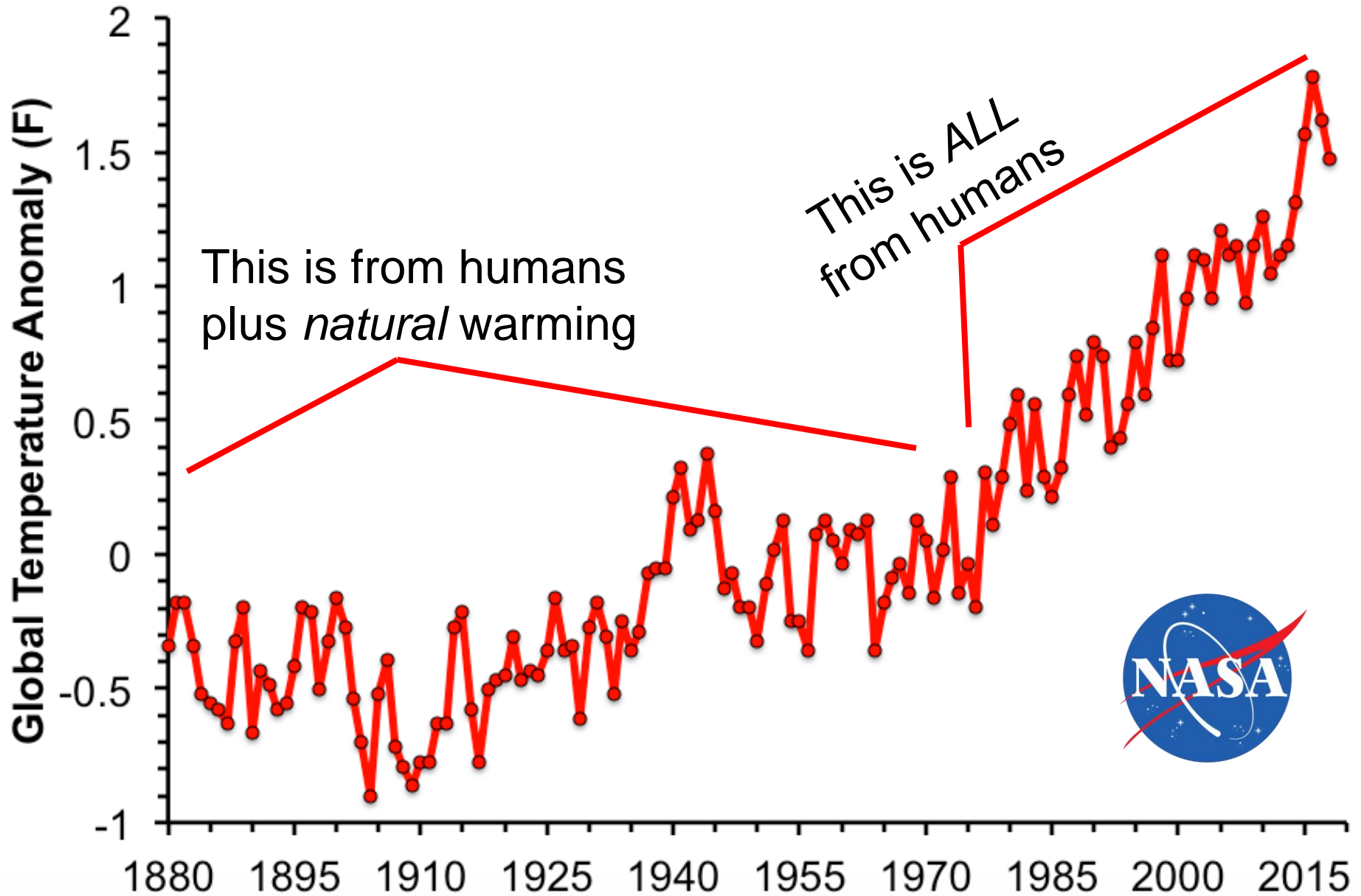


# Using a Climate Model to Create a Human-Free World





# The Warming since ~1975 is ALL from Humans



# Greenland's ice sheet just lost 11 billion tons of ice -- in one day

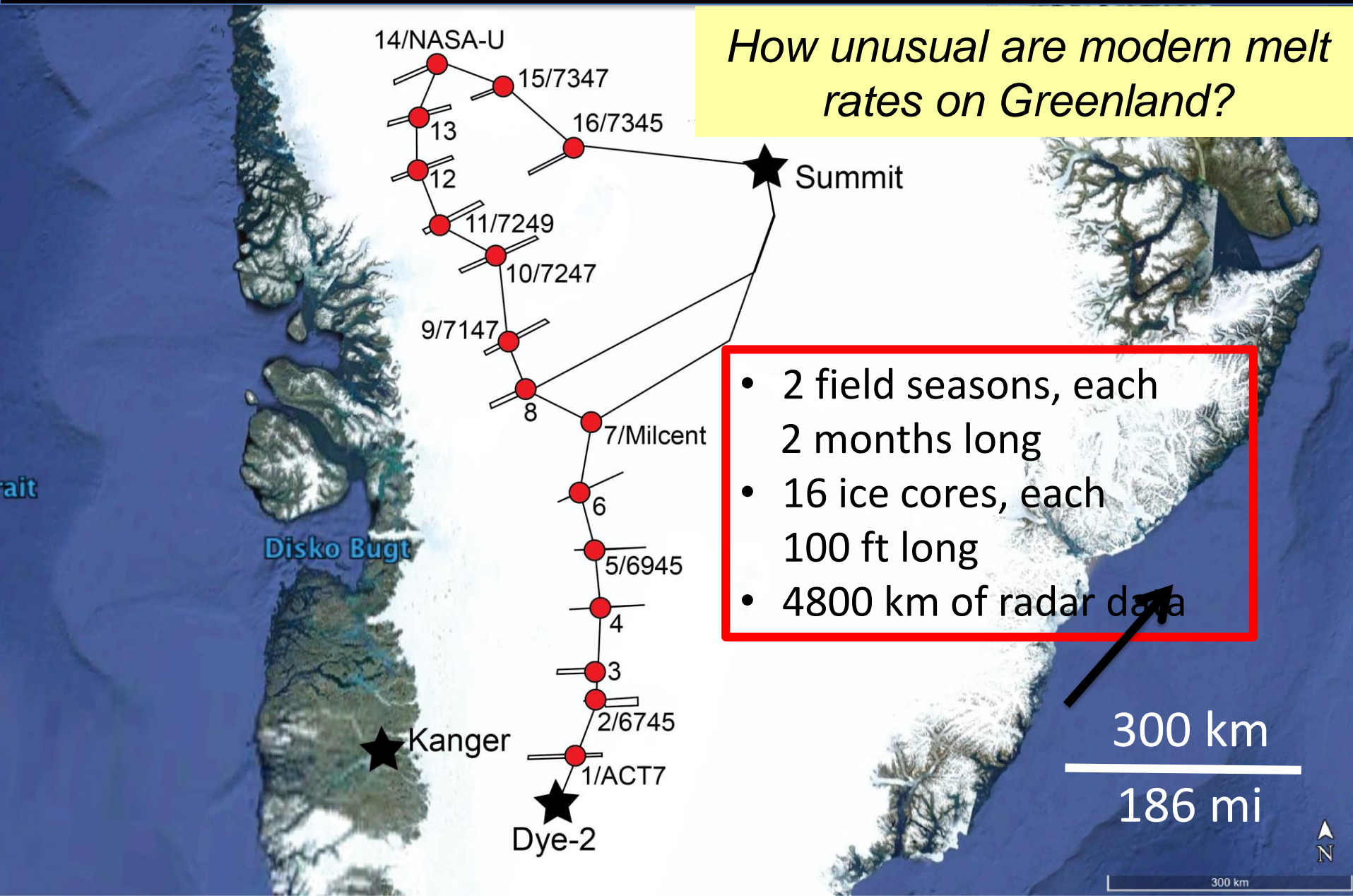
By Mark Tutton, CNN

🕒 Updated 10:35 PM ET, Thu August 15, 2019





# Dartmouth's GreenTrACS 2016 and 2017 Traverses

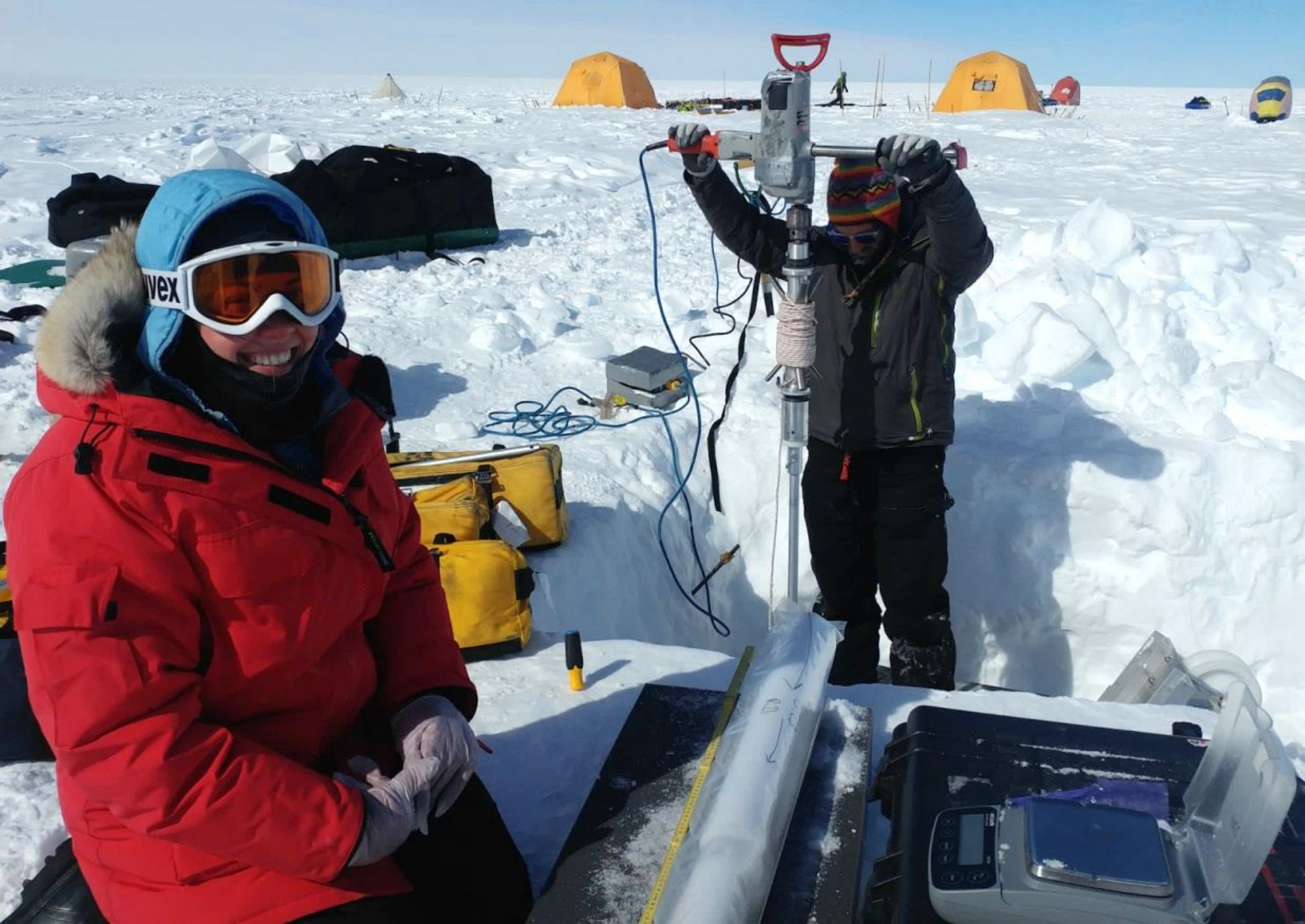






# Dartmouth's "Greenland Campus"



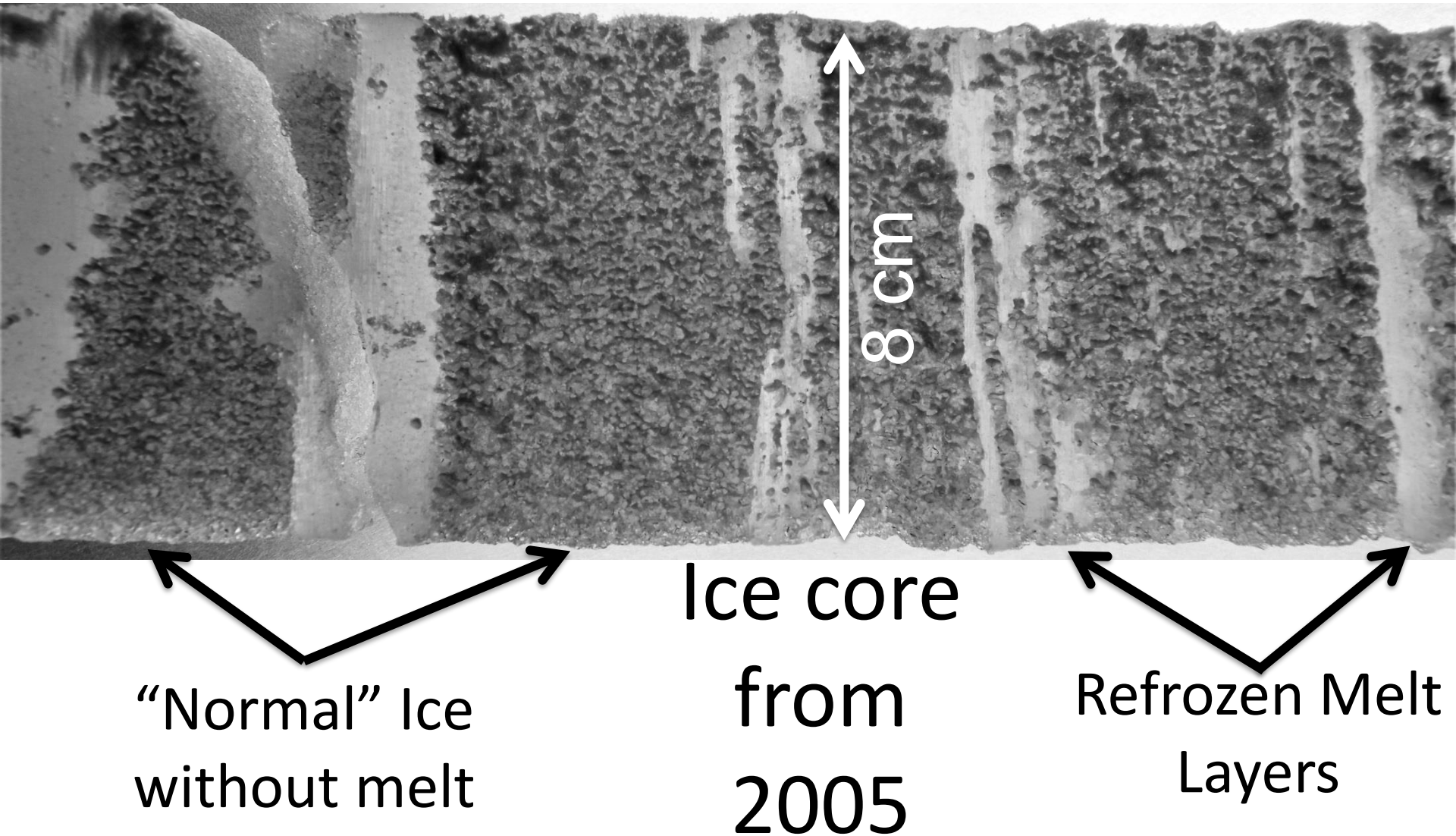






Dartmouth's "Greenland Campus"

# Rise in Glacier Melt Preserved in the Ice Core As Refrozen Melt Layers



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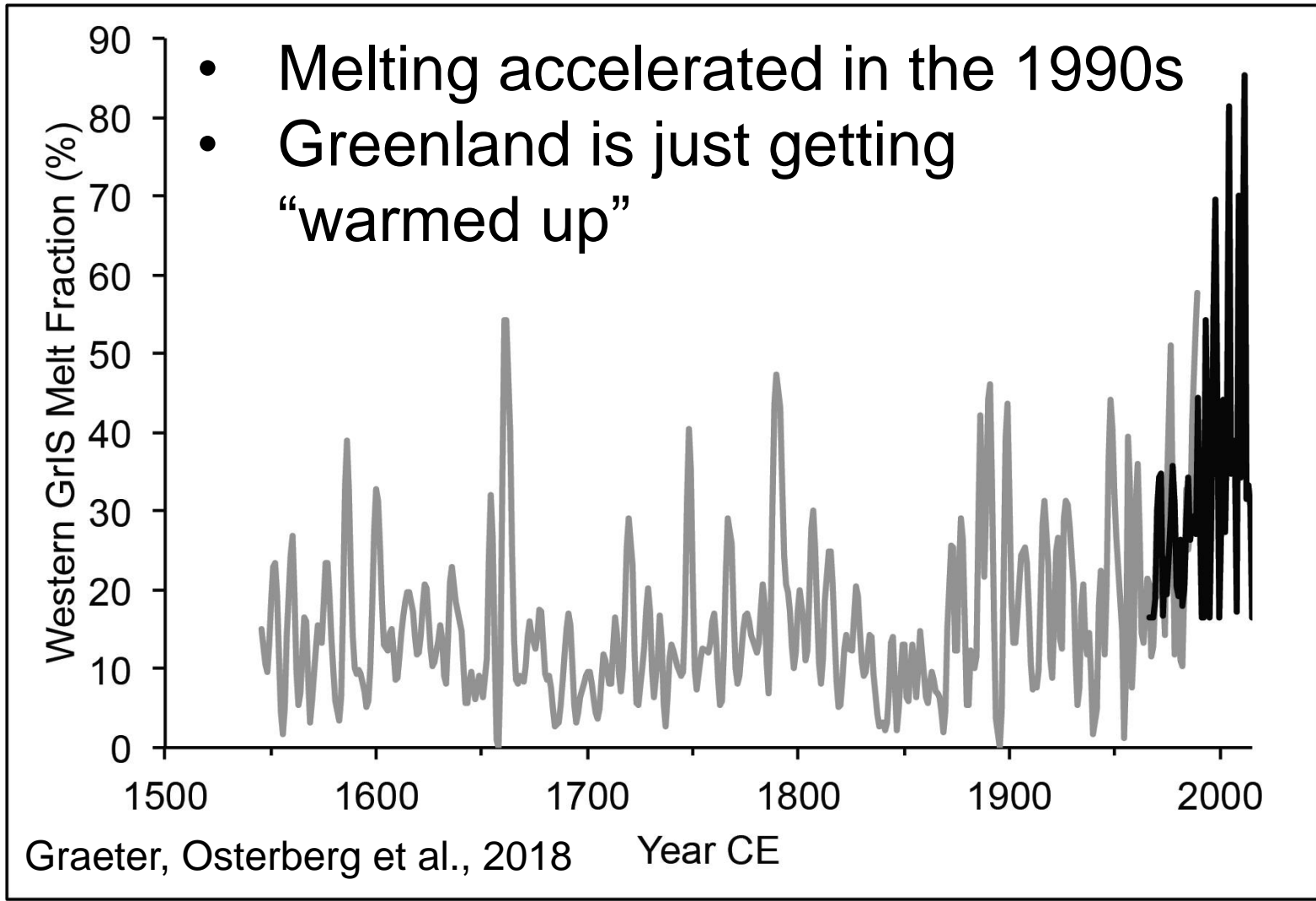
Ice core from 1866  
All "Normal" Ice without melt

# Greenland Is Melting Faster Than at Any Time in the Last 400 Years

*The Washington Post*

**SCIENTIFIC  
AMERICAN**

And the melt of the massive ice sheet is only picking up speed





# Sea Level Rise is Accelerating

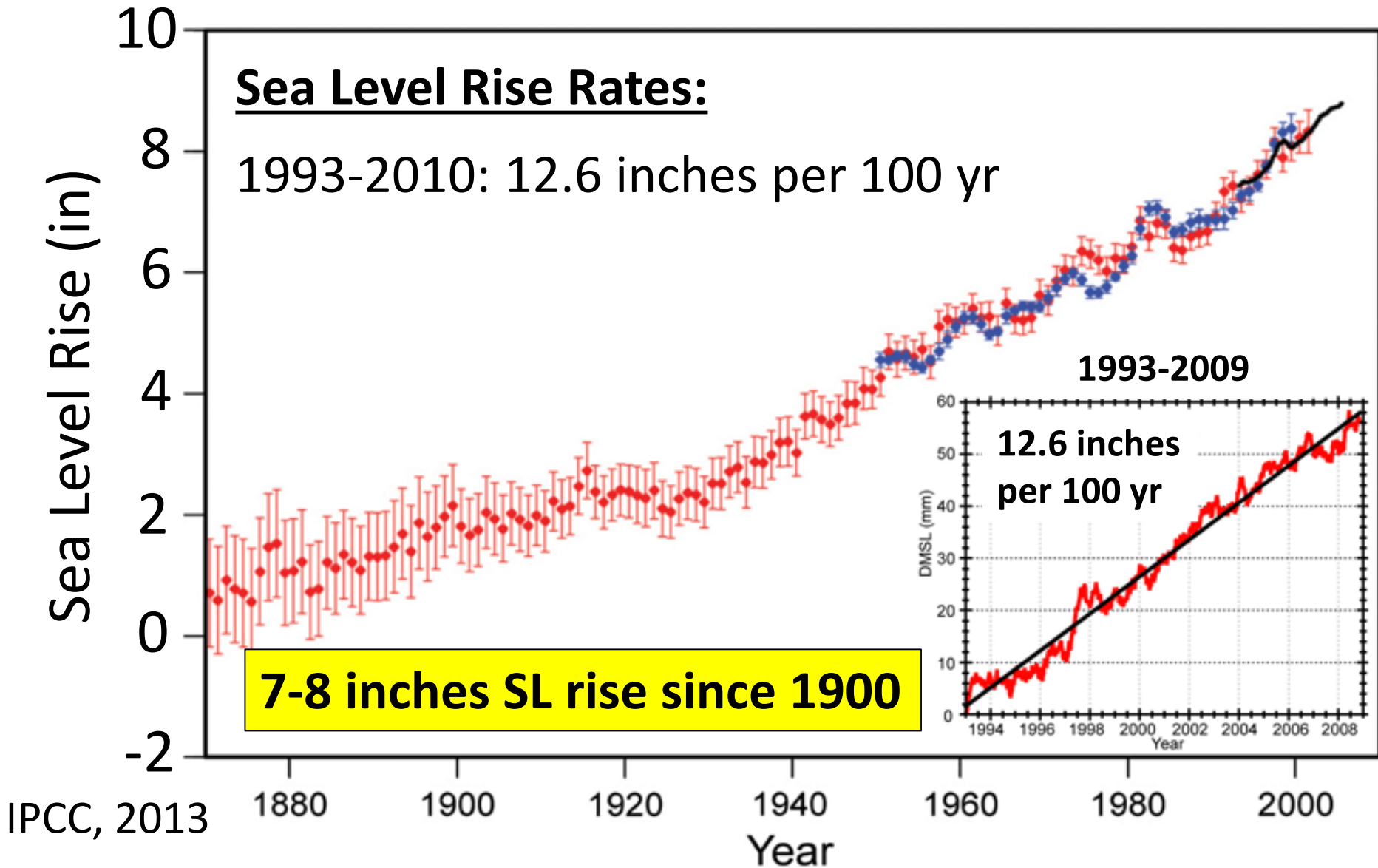
## Sea Level Rise Rates:

1993-2010: 12.6 inches per 100 yr

**7-8 inches SL rise since 1900**

1993-2009

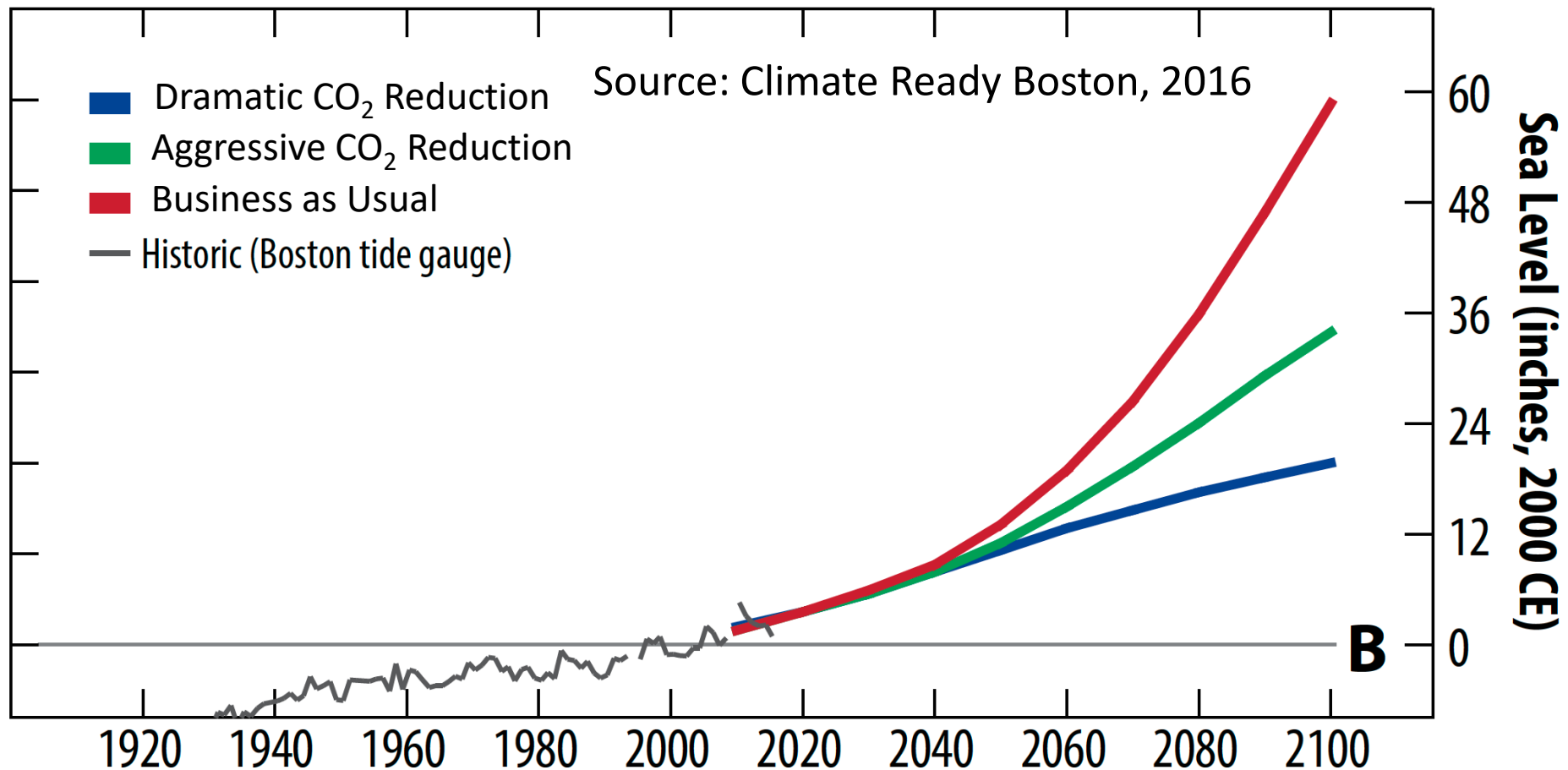
12.6 inches  
per 100 yr

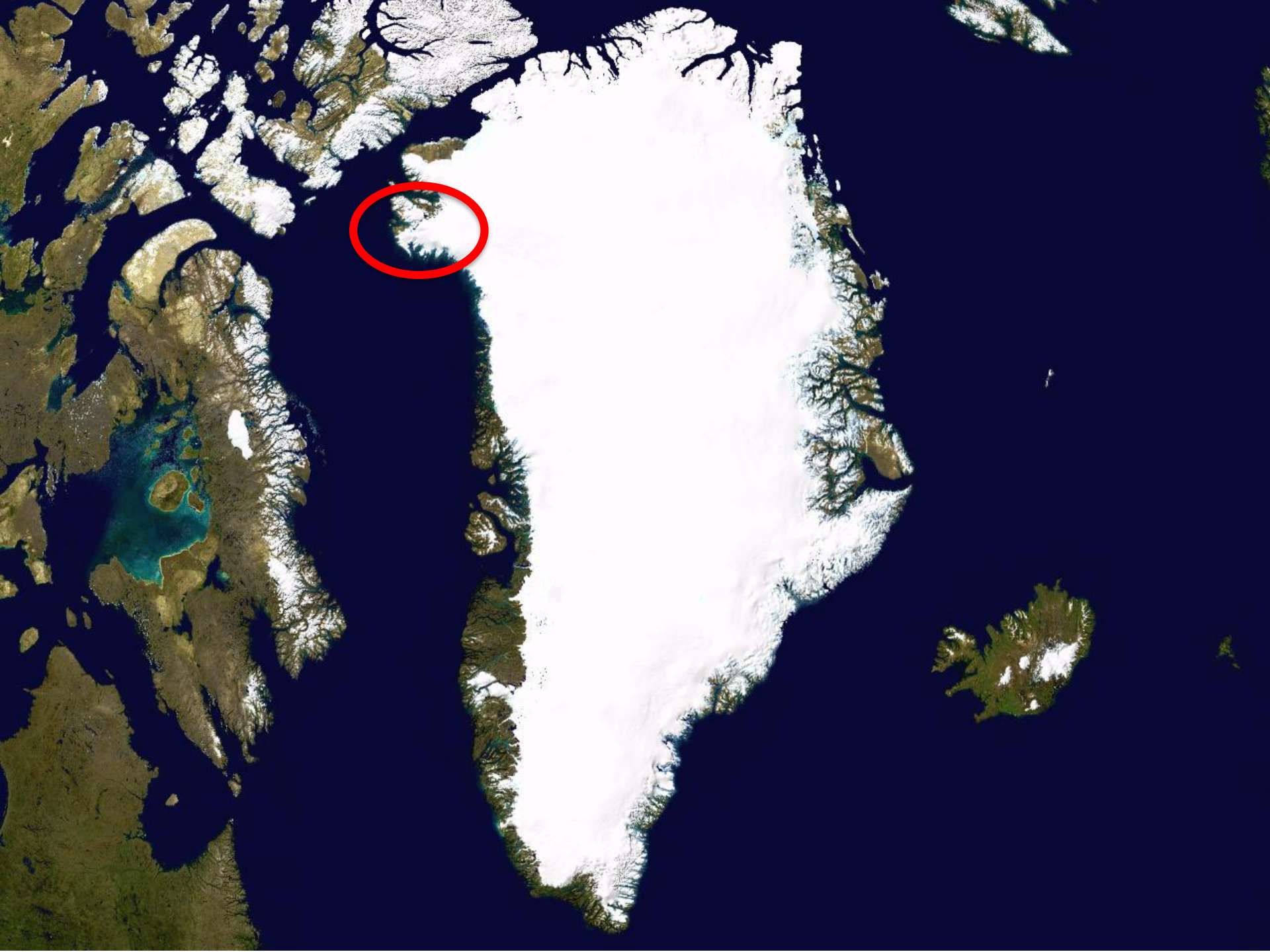


# Our Choice: 2-5+ Feet of SL Rise by 2100

- Our decisions about carbon emissions WILL MATTER
- Disruptive sea level rise will occur regardless
- Calls for a combination of mitigation and adaptation

## Relative Sea Level at Boston, MA









Camp

2 km



Before: August 5, 2012



Credit: Meredith Kelly



After: August 15, 2012



Credit: Erich Osterberg



After: August 15, 2012



Credit: Erich Osterberg



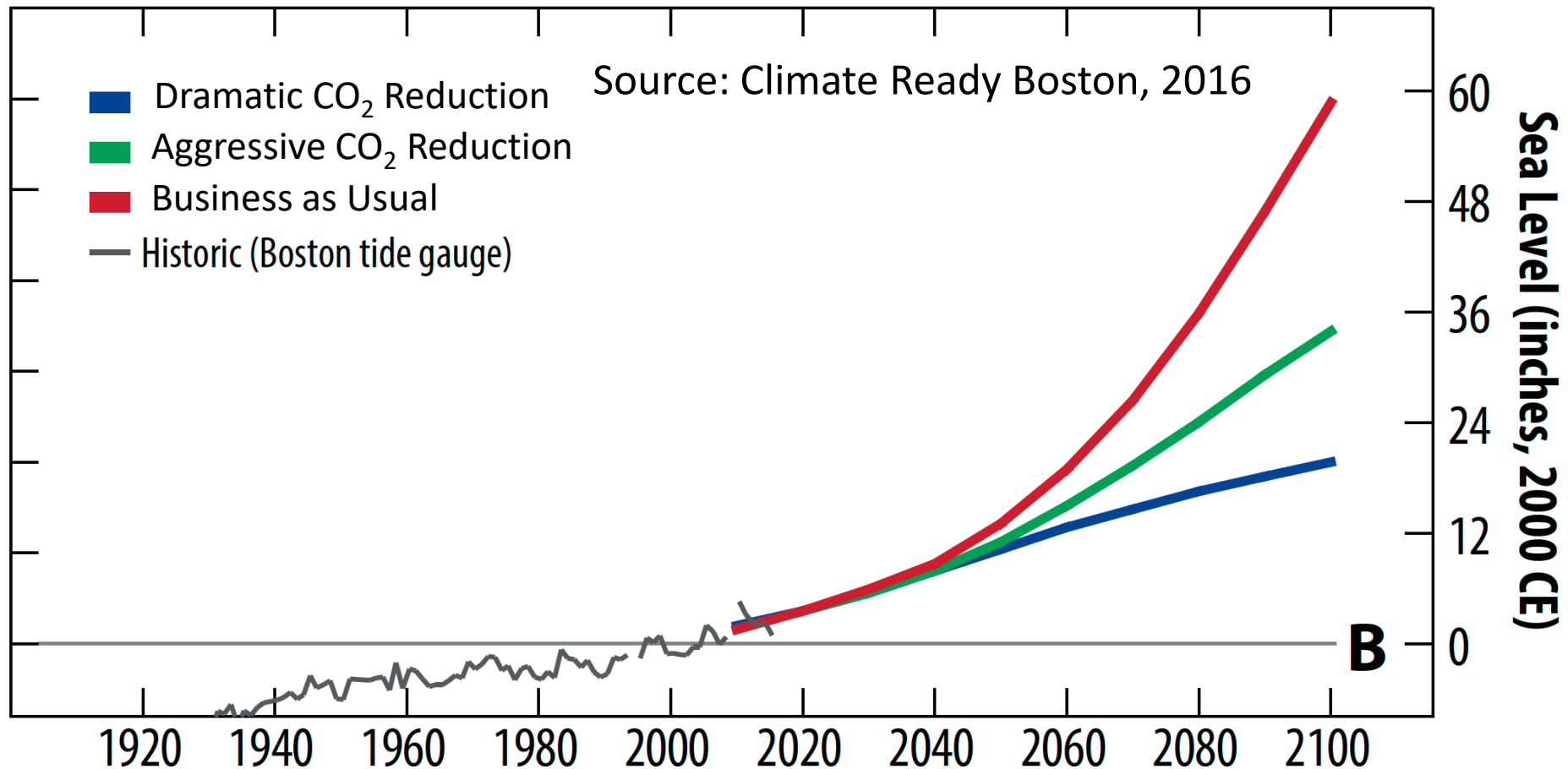
Credit: Erich Osterberg



# Our Choice: 2-5+ Feet of SL Rise by 2100

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## Relative Sea Level at Boston, MA



Florida 125,000 Years Ago:  
Sea Level was 16-26 Feet Higher  
Temperatures only 2-4° F Warmer





# New York City: Sea Level 23 Feet Higher



In 2200?

In 2300?



# Hurricane Irene: August, 2011

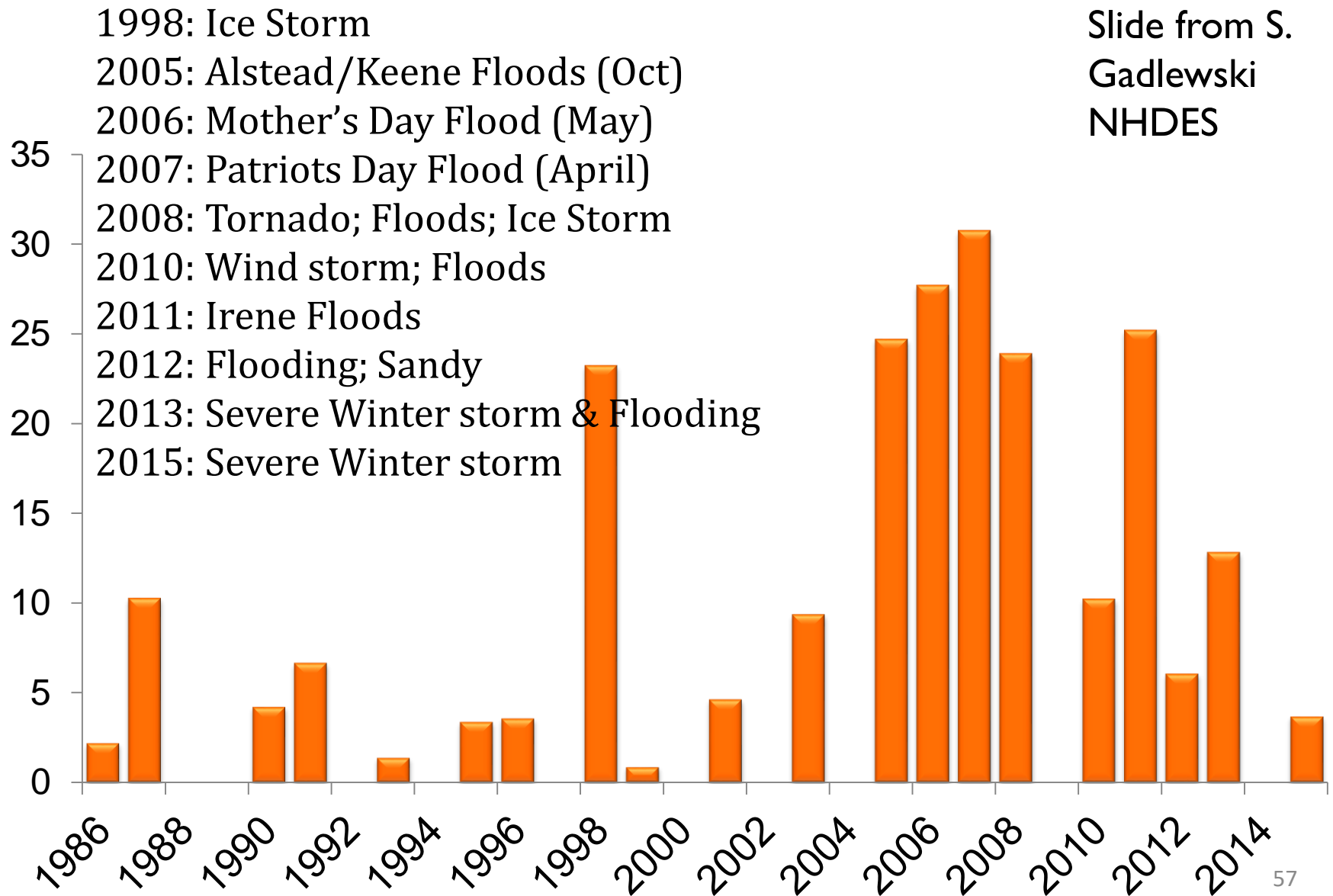


47 US Deaths

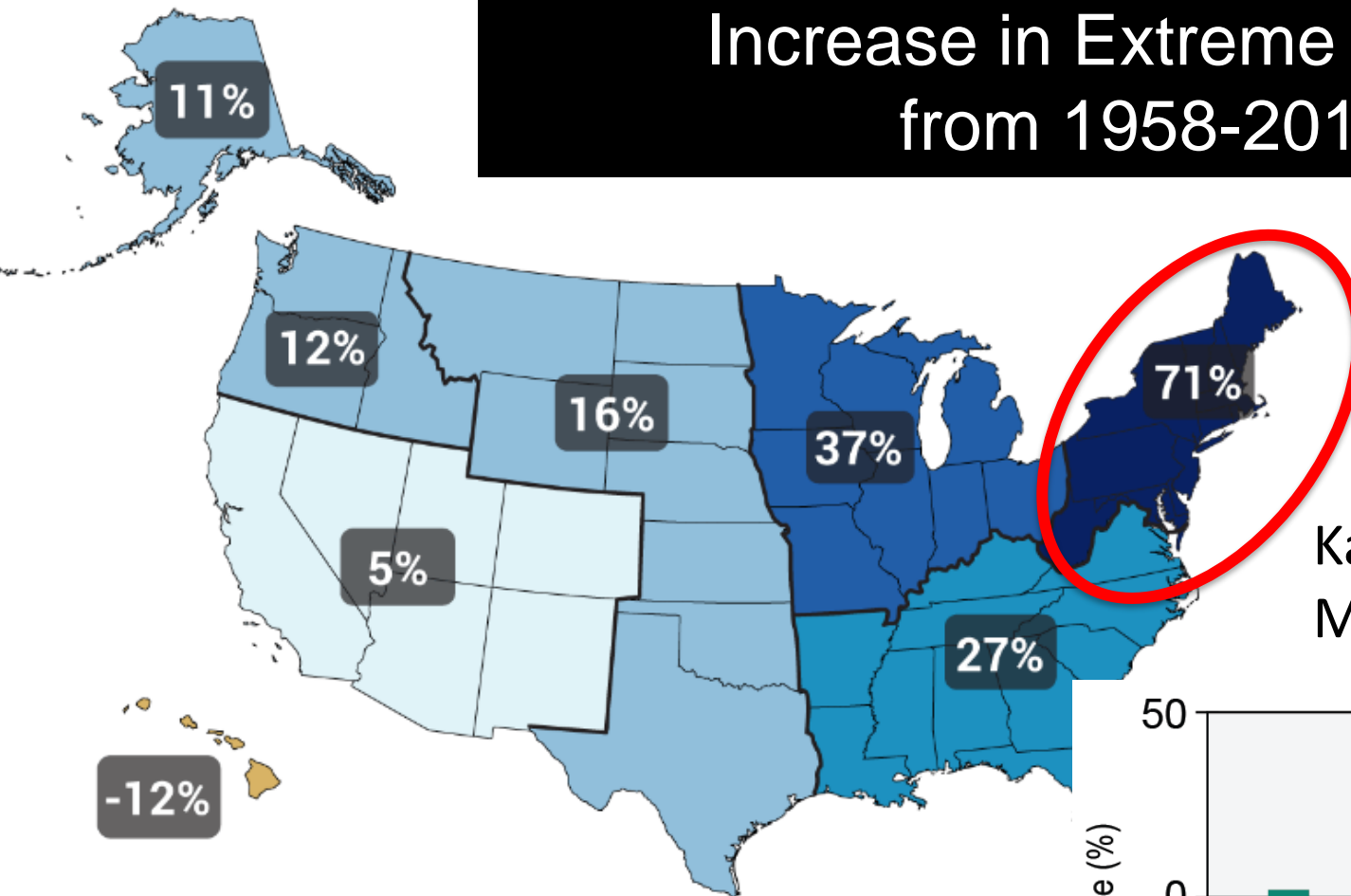
\$13.5 billion in  
damages

# Federal Disaster Spending in New Hampshire

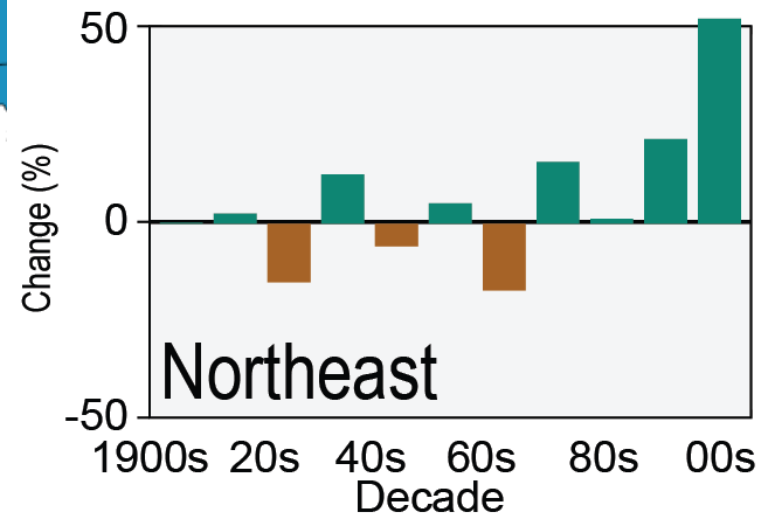
Slide from S.  
Gadlewski  
NHDES



# Increase in Extreme Rainfall from 1958-2012



Karl et al., 2009  
Melilo et al., 2014

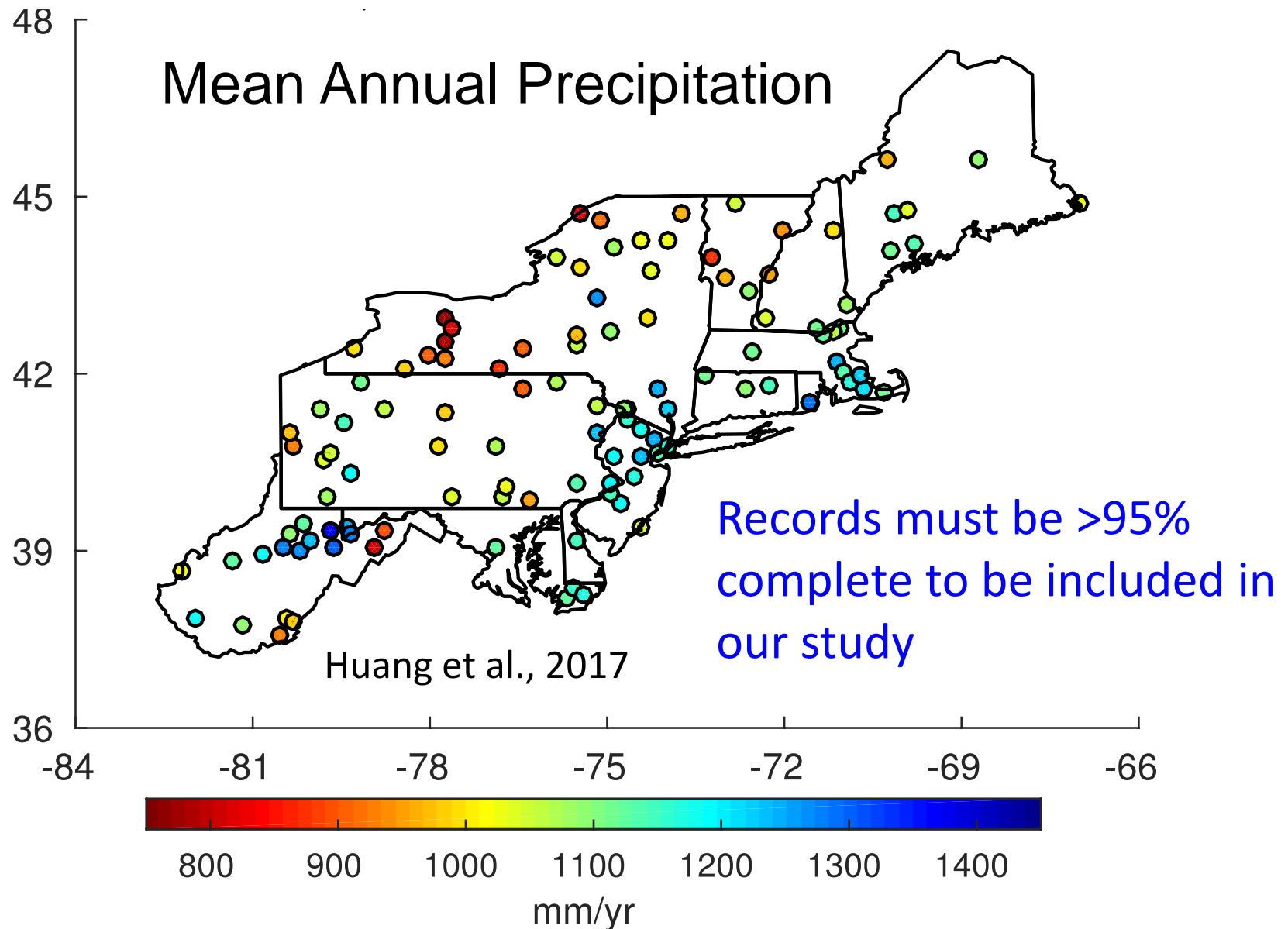


Change (%)

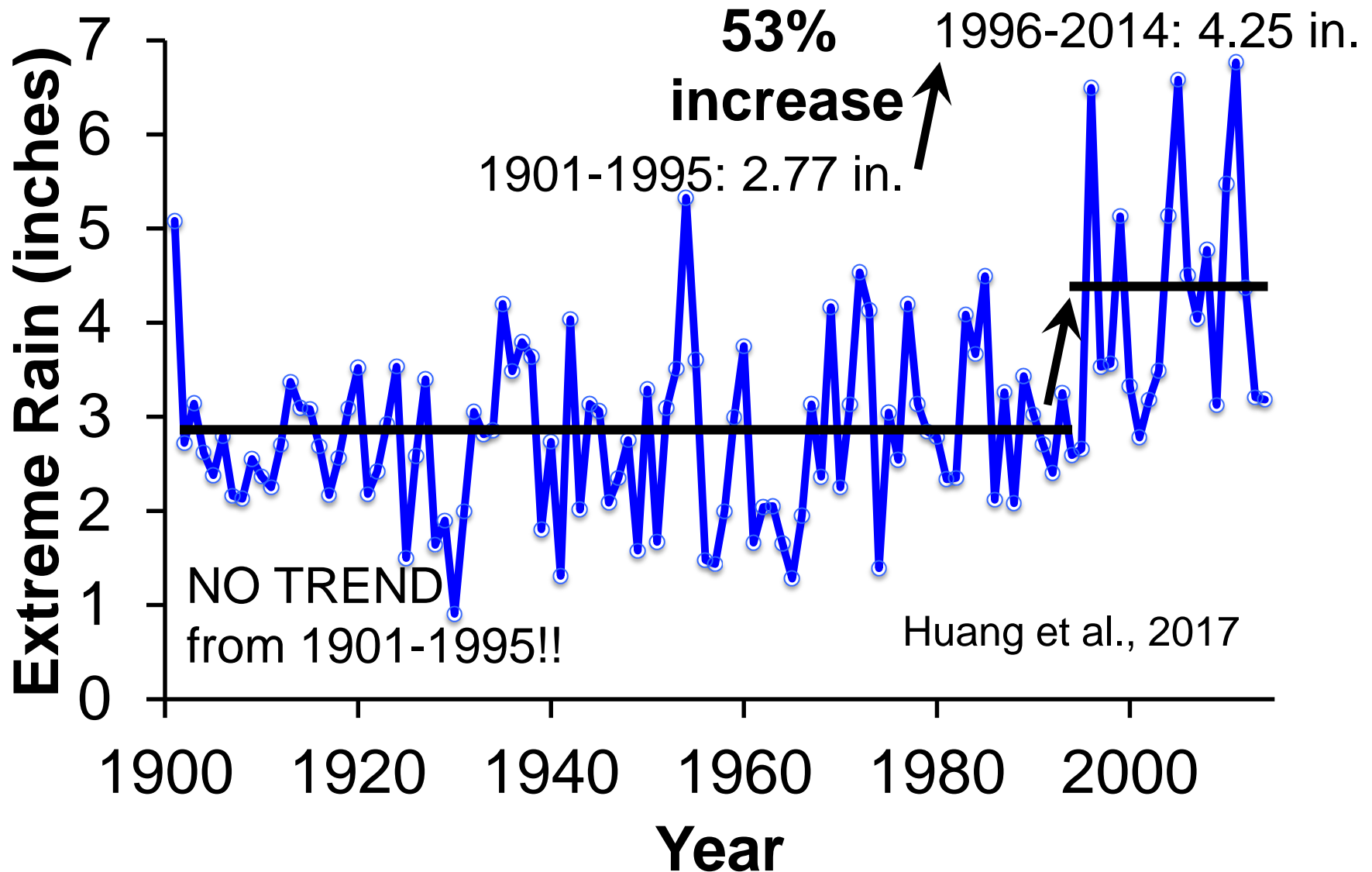




# We Used 116 High-Quality Daily Weather Station Records from 1901-2014



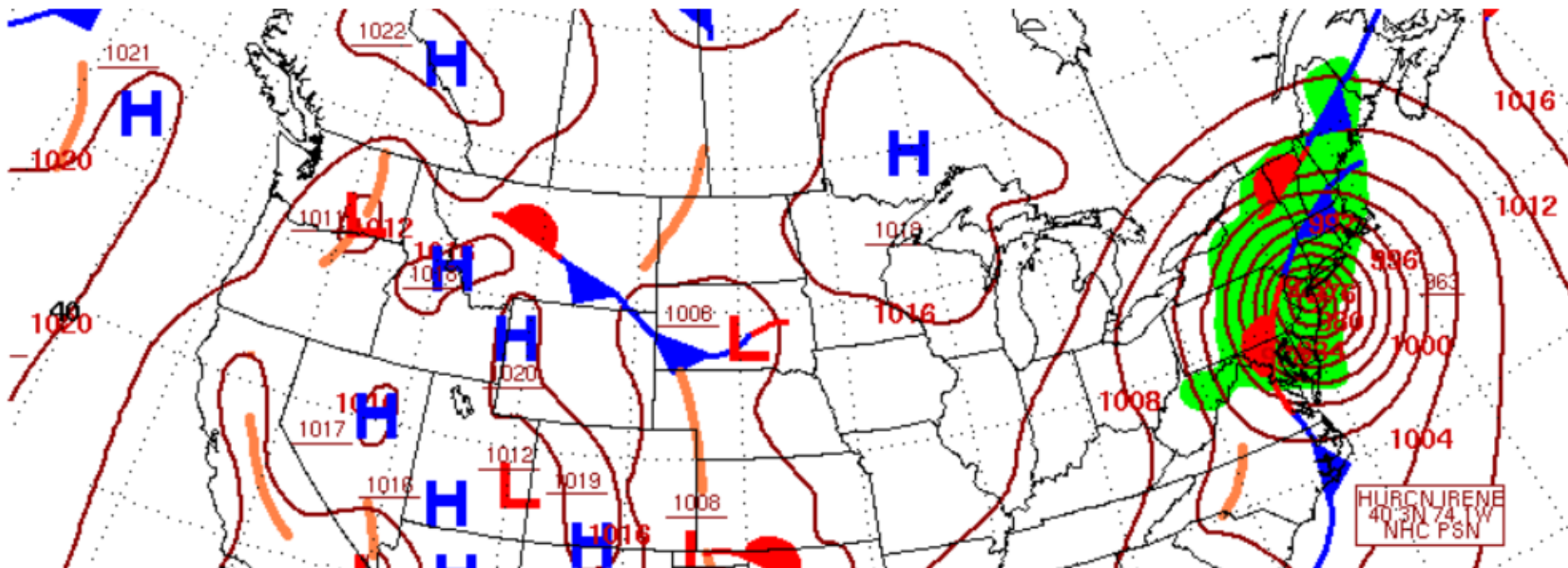
# Extreme Storms JUMPED 53% in the Northeast US in 1996



# We then Categorized 273 Extreme Storms from Daily Weather Maps

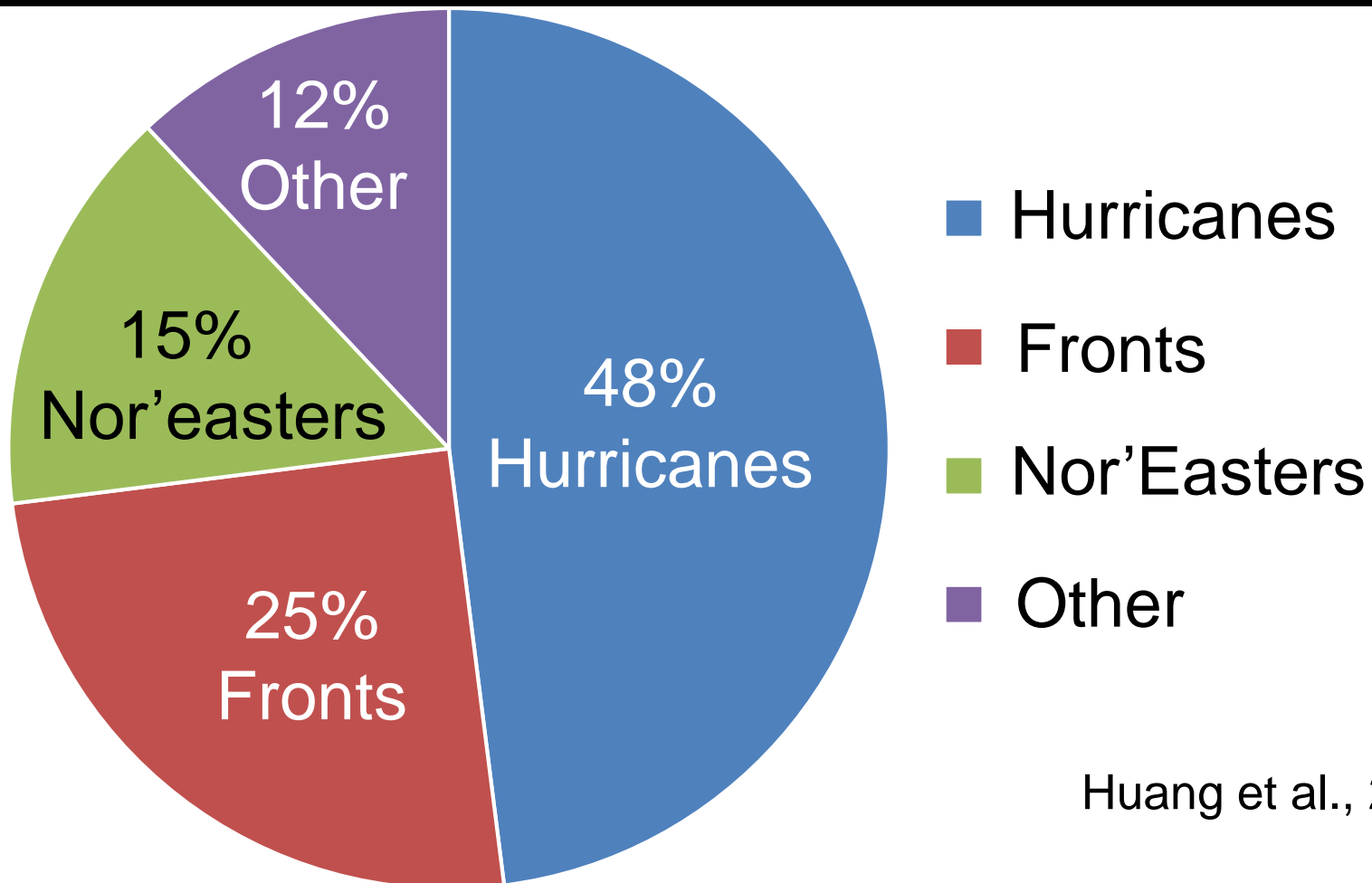
- 3 Categories:
  - Tropical Cyclones
  - Fronts
  - Extratropical Cyclones (Nor'easters)

**SUNDAY AUGUST 28, 2011**





# What Types of Storms Have Become More Frequent since 1996?



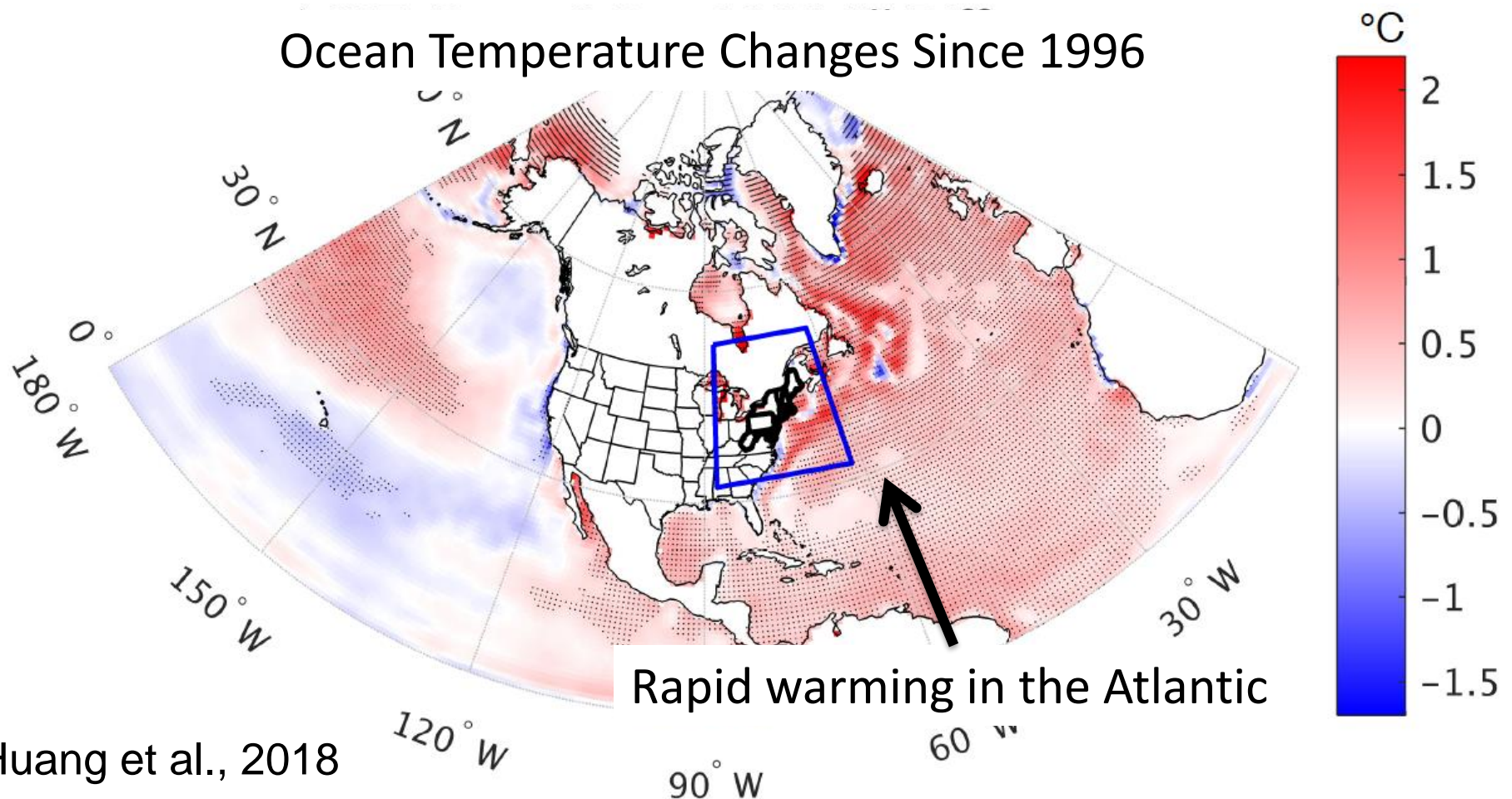
Huang et al., 2018

- Hurricanes are the primary driver (48%)
- Fronts (25%) and Nor'easters (15%) also important

# Warmer Ocean Water Causes More Frequent Extreme Hurricanes in NE since 1996

- Extreme hurricane events 3.9x more likely since 1996
- Extreme rainfall during hurricanes 4.2x higher since 1996!

Ocean Temperature Changes Since 1996

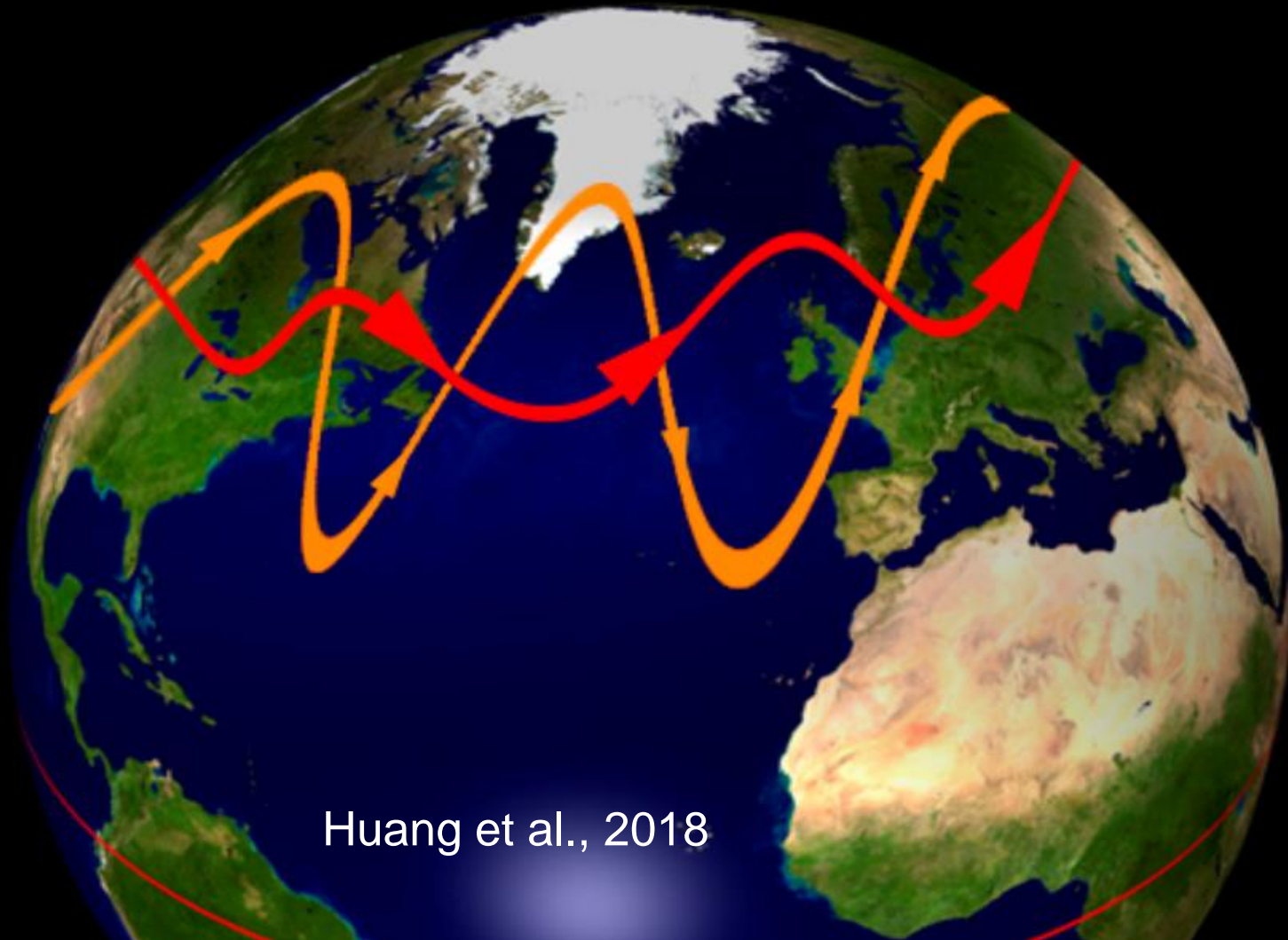


Huang et al., 2018

# More Frequent Severe Frontal Thunderstorms since 1996 due to a Wavier Jetstream

➡ = Before 1996

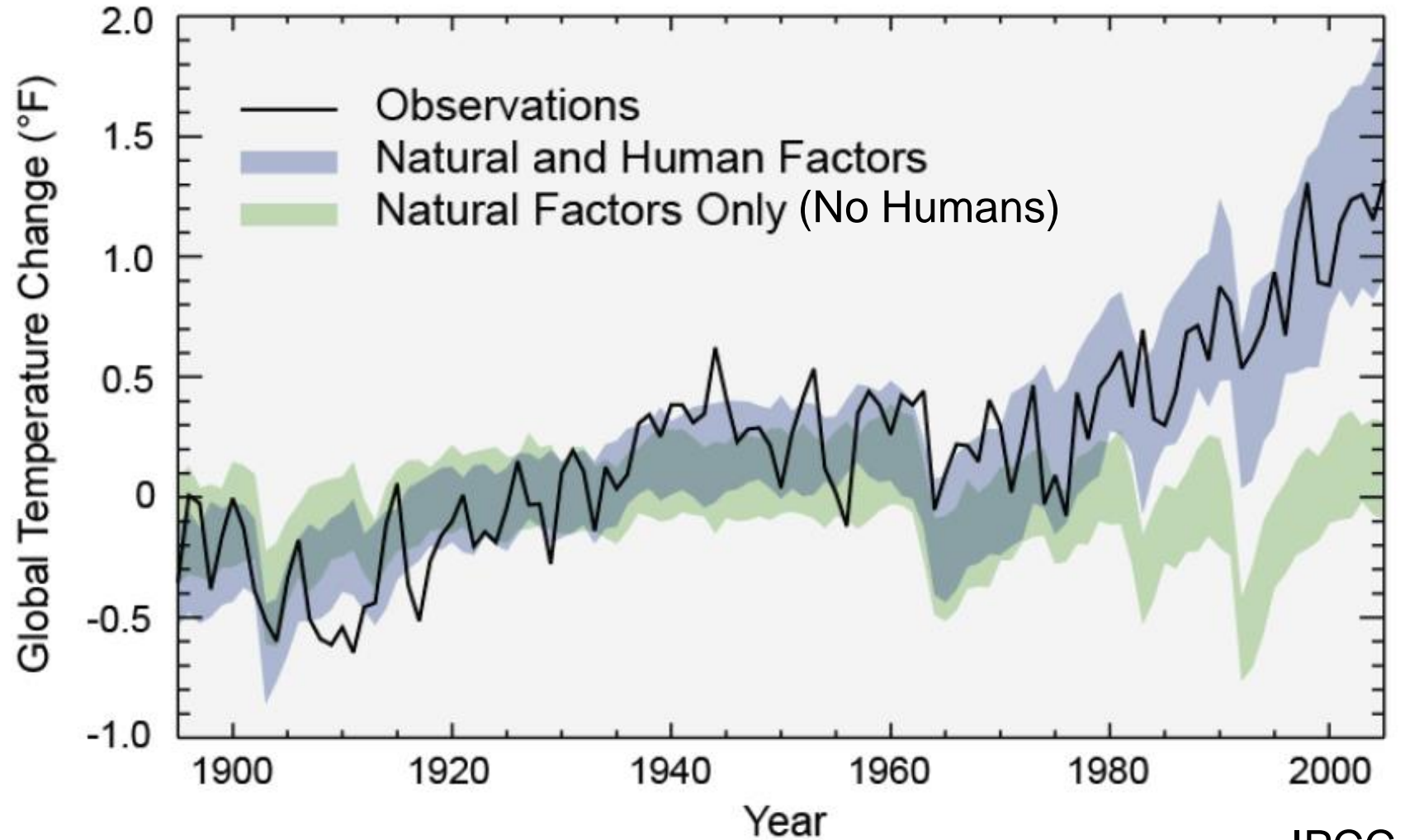
➡ = After 1996



Huang et al., 2018



# Using a Climate Model to Create a Human-Free World



IPCC

# 2018 Record Rainfall and Flooding In PA, MD, WV and NJ



Ellicott City, MD  
May 27, 2018

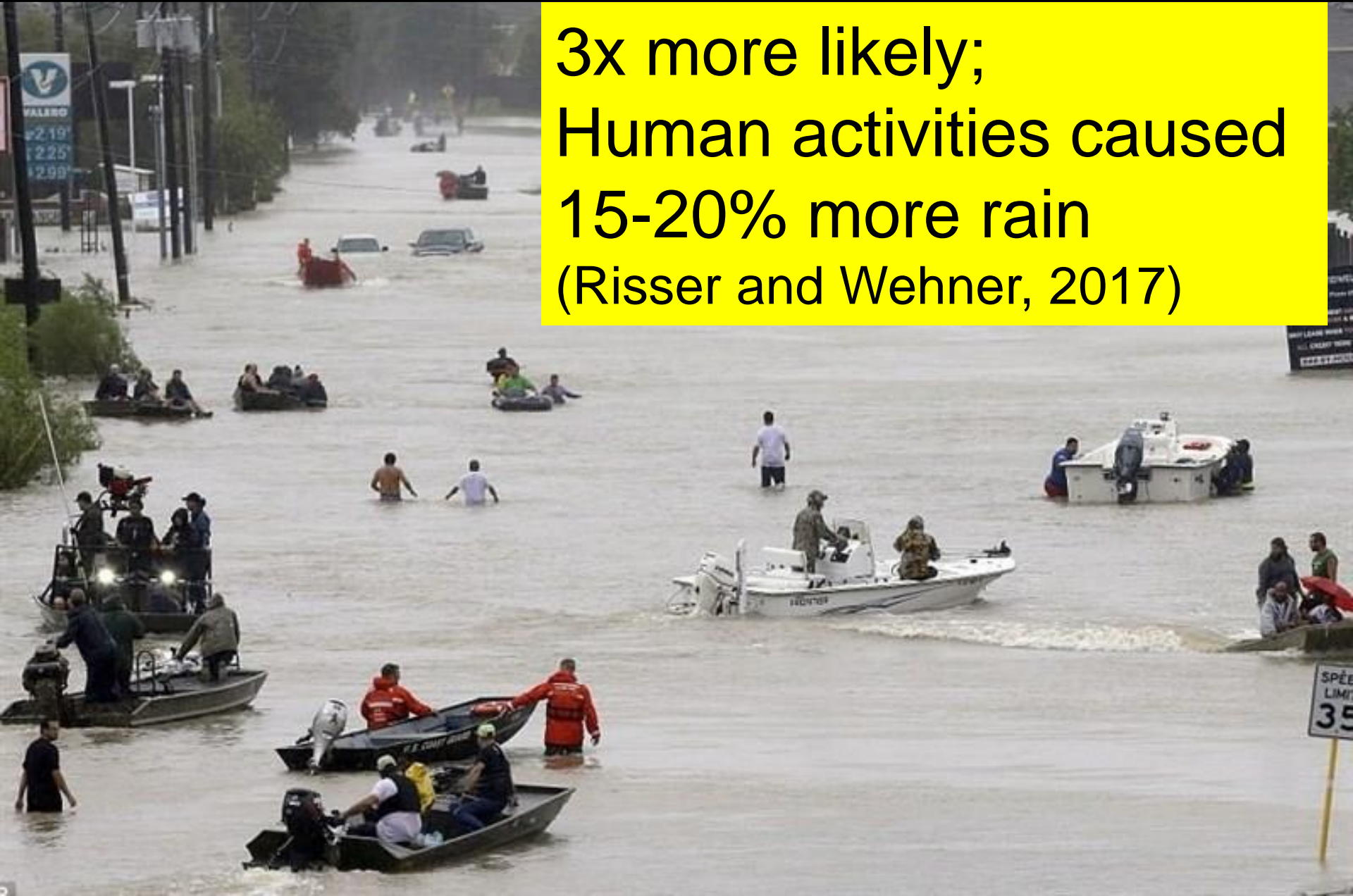
Human activities  
made it 1.5x more  
likely  
(Winter et al., in review)





# 2017: Record Breaking Hurricane Harvey

3x more likely;  
Human activities caused  
15-20% more rain  
(Risser and Wehner, 2017)





# Take-Home Messages

- **Warming since ~1975 is ALL from human activities**
  - **We should be in a natural cooling cycle**
- **Human activities are causing rapid ice sheet melt and sea level rise, and it's accelerating**
  - **Can we avoid catastrophic (20+ feet) sea-level rise?**
- **Human activities are already causing storms and extreme rainfall to become more frequent**

# Upper Valley Adaptation Workgroup

Building climate-resilient communities in the Upper Valley through collaboration, research, information sharing, education, and action.



## Climate Change Leadership Academy

October 2019 – April 2020

[Learn More and Apply >](#)

**Application Deadline: Sept. 15**



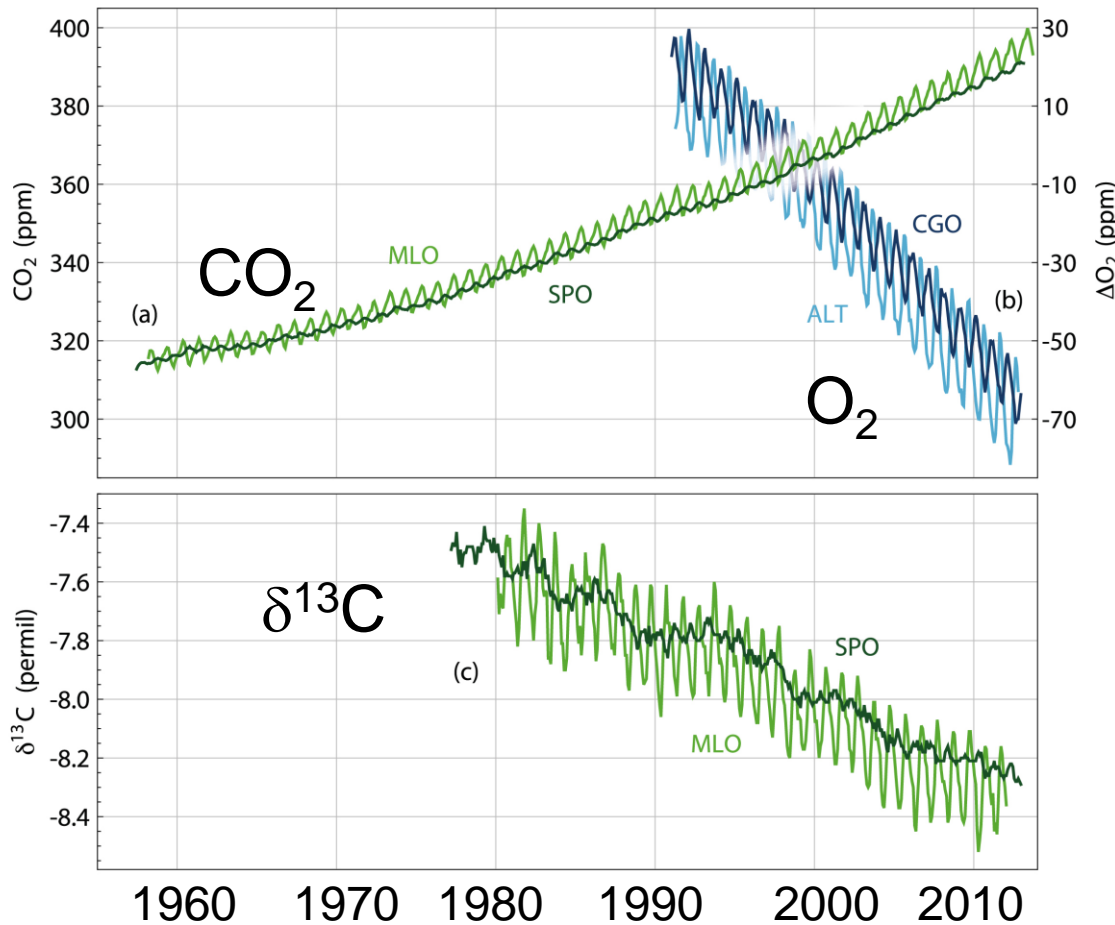
# Take-Home Messages

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# Warming is from CO<sub>2</sub> and the CO<sub>2</sub> is Ours



- Humans emit **100+ TIMES** more CO<sub>2</sub> than
- CO<sub>2</sub> has a fossil fuel chemical fingerprint
- CO<sub>2</sub> traps heat, raising temp.
- Without CO<sub>2</sub> Earth's average temp = -5°F!! (today = 57°F)

# Which Season Drives the 1996 Shift?

## Percent Contribution to the 1996 Shift

	Sept.–Oct.	Jun.–Jul.	Feb.–Mar.
Tropical cyclone	41%	8%	N/A
Front	17%	6%	3%
Extratropical cyclone	3%	6%	6%
Total	61%	20%	9%

Fall is the Dominant Driver of the 1996 shift

- Fall 61%
- Summer 20%
- Winter 9%



# The Earth has Warmed 2°F Since 1900

## *Warmest 12 Years:*

**2016: #1**

**2017: #2**

**2015: #3**

**2018: #4**

**2014: #5**

**2010**

**2005**

**1998**

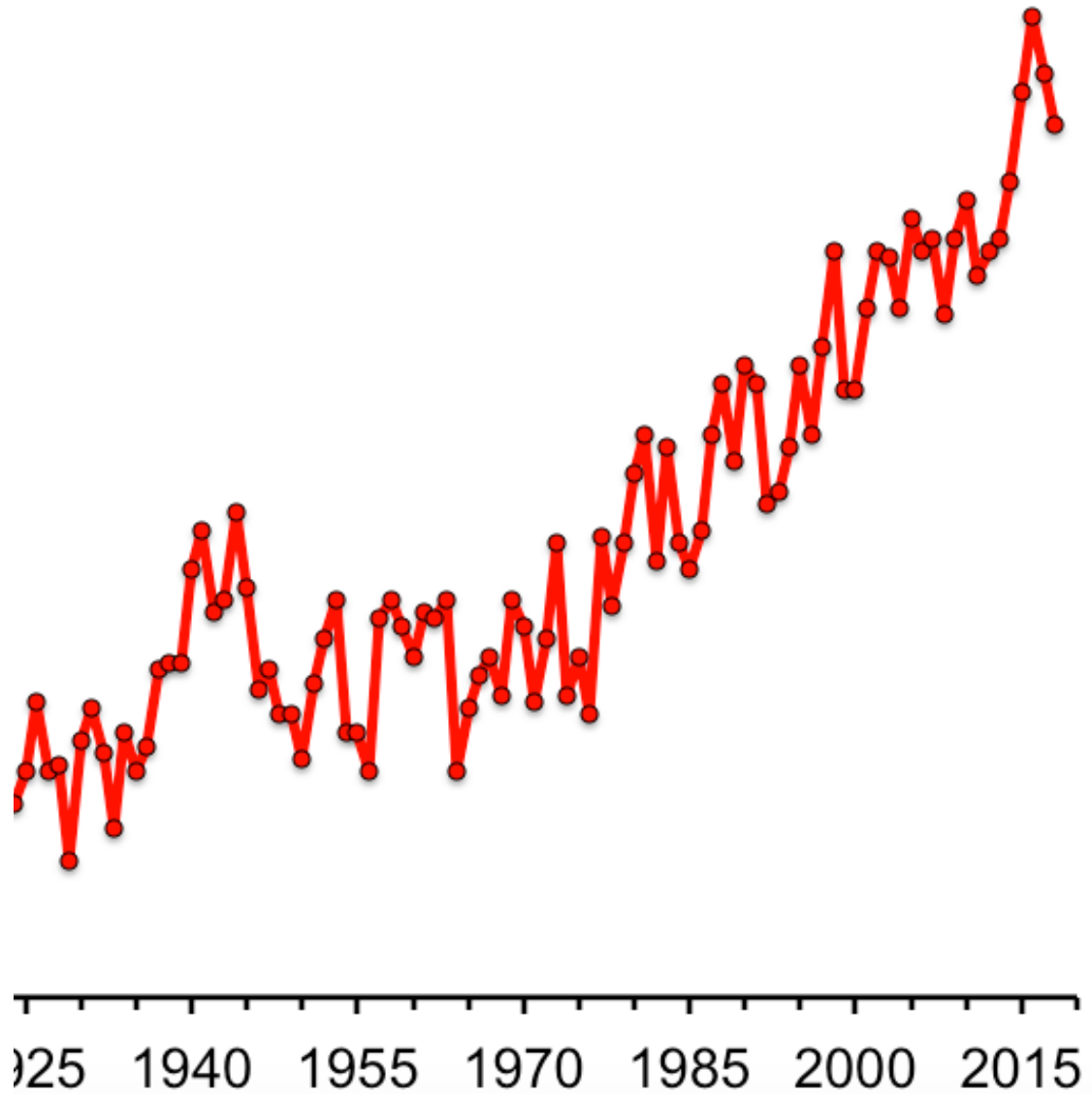
**2013**

**2003**

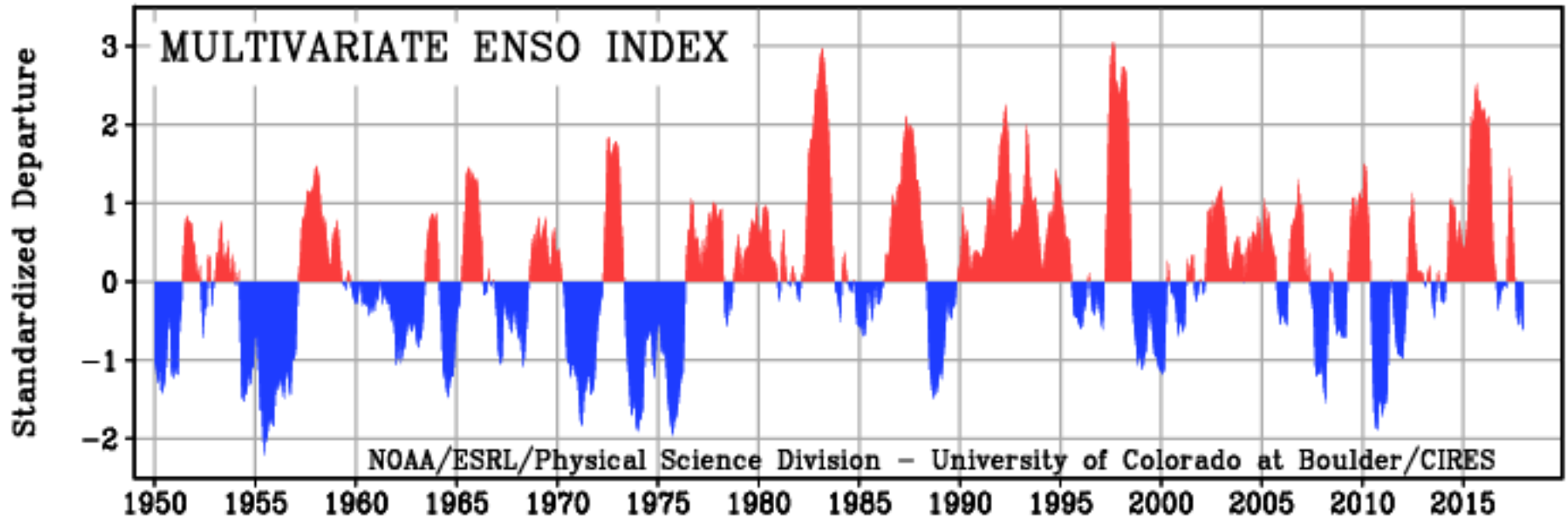
**2002**

**2006**

**2009**



# El Nino Timeseries over Past 60 years



- Dominant periodicity is 2-7 years, with possible longer-period changes as well
- ENSO in a global warming world?

# Hurricane Irene: August, 2011



~50% of the jump since  
1996 is from MORE  
Hurricanes due to  
warmer ocean waters  
(Huang et al., 2018)



# July 2013 & 2017 Thunderstorms

+3" Rain for Each Event

Route 25A • Orford, N.H.  
July 1, 2017 • Courtesy Peter Bouchard

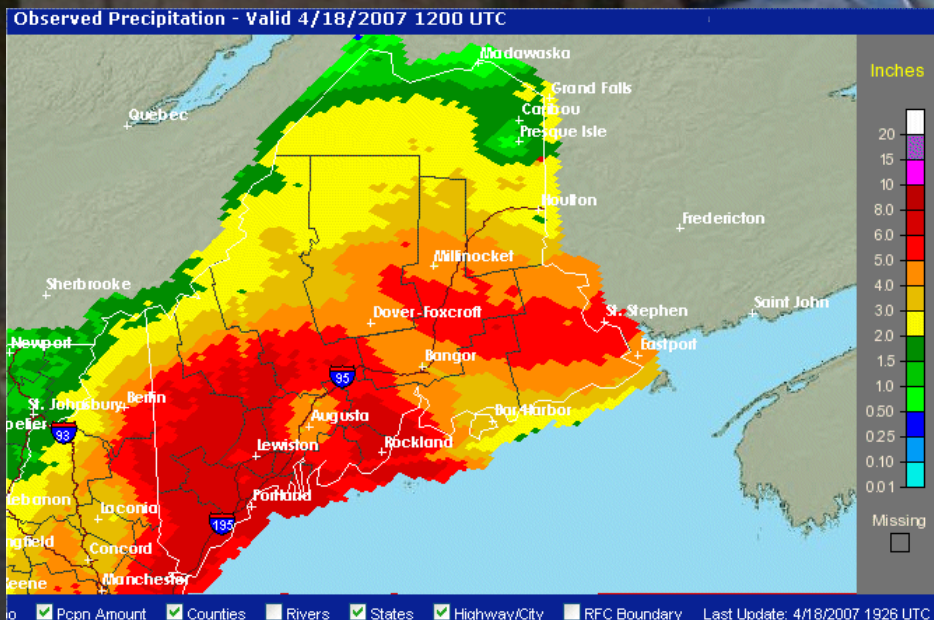


~25% of the jump  
since 1996 is from  
MORE cold fronts  
with wavier jet  
(Huang et al., 2018)



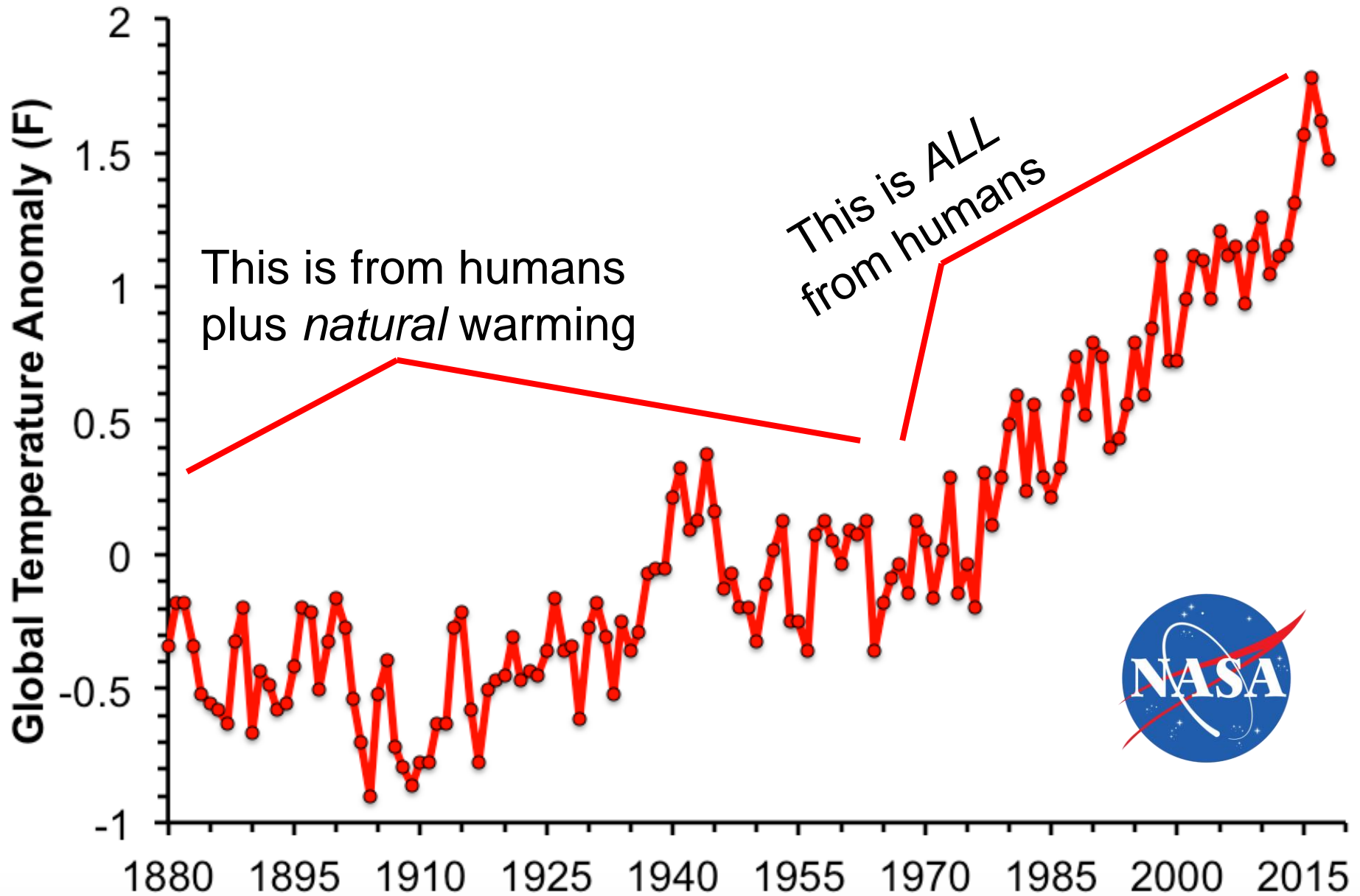
# President's Day 2007 Nor'easter

Newmarket, NH: 6"  
rain



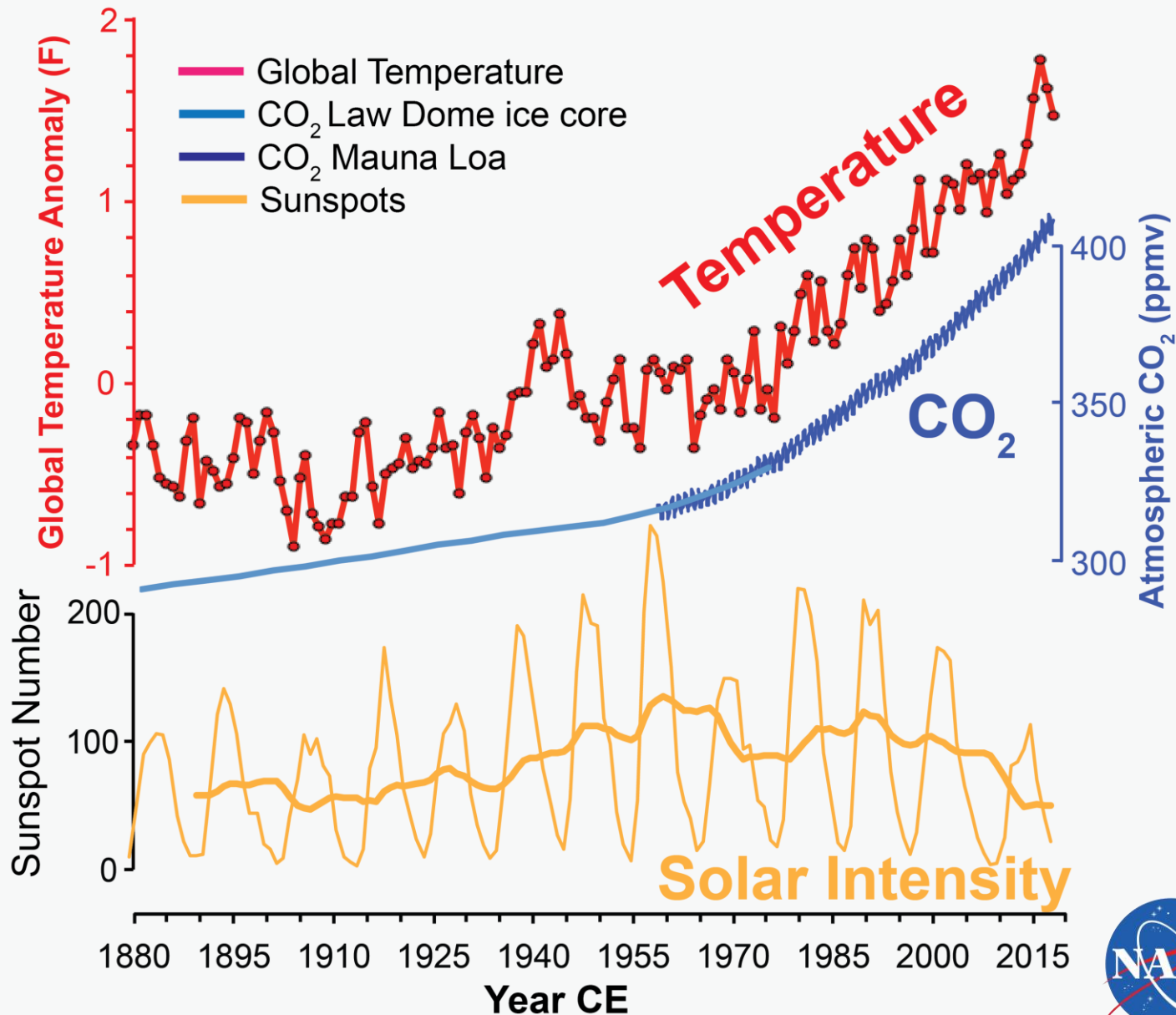
~15% of the jump  
since 1996 is from  
**MORE** Nor'easters  
from a wavier jet  
(Huang et al., 2018)

# The Earth has Warmed 2°F since 1900





# Warming is Caused by Human CO<sub>2</sub>, Not the Sun



# Greenland and Antarctica are the Real Threat



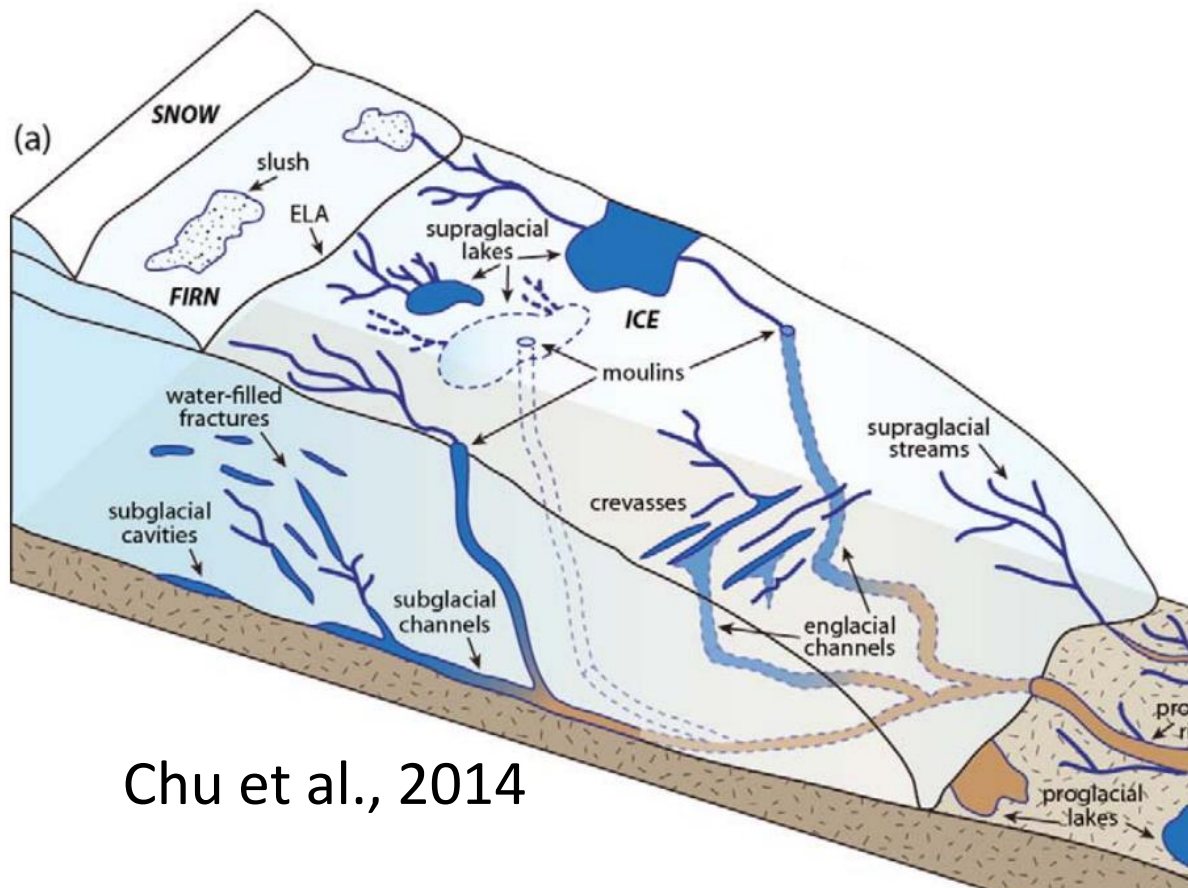
23 Feet



West: 16 Feet  
East: 190 Feet

# Greenland Melting Will be Really Hard to Stop Because:

1. Melting causes ice lowering, enhancing melting...
2. Melting makes the snow darker, enhancing melting...
3. Meltwater speeds up glacier flow into the ocean
4. Surprises.....

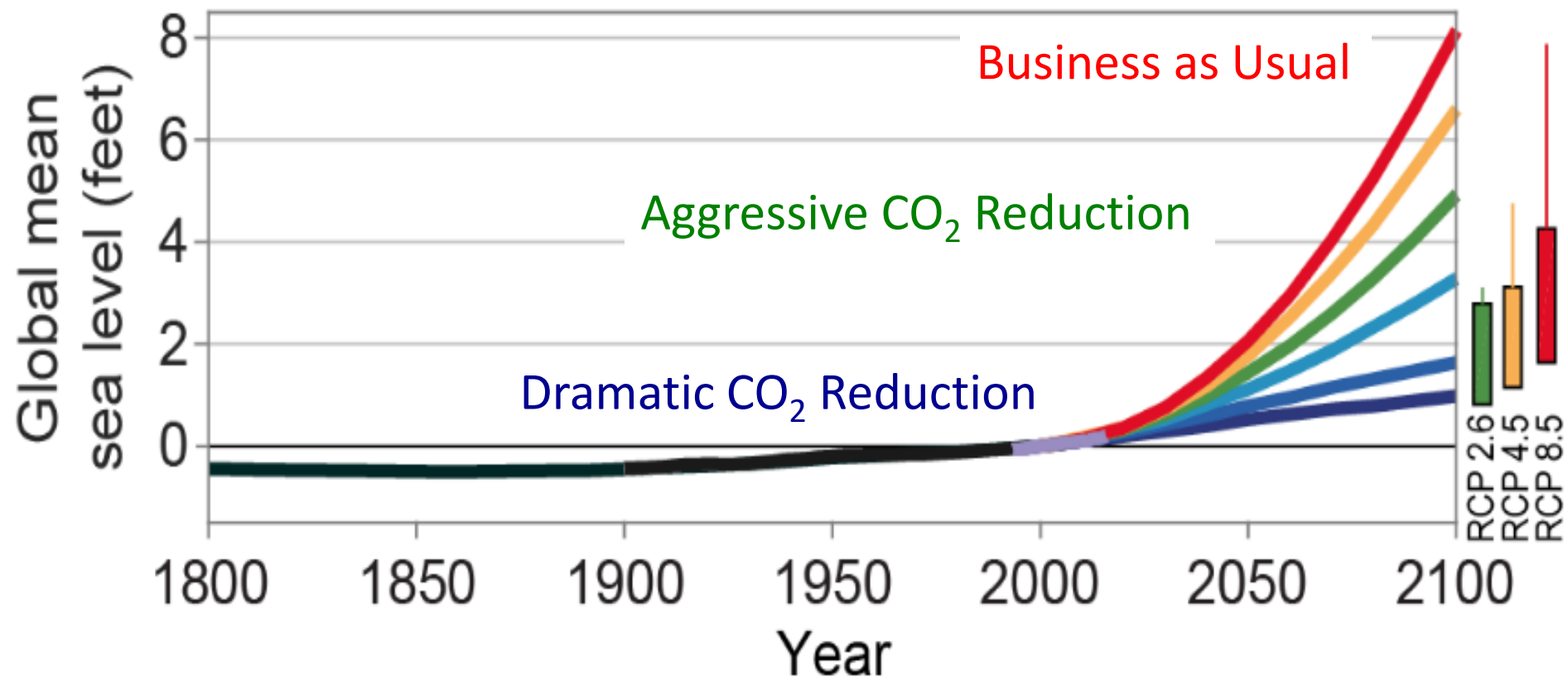


Chu et al., 2014

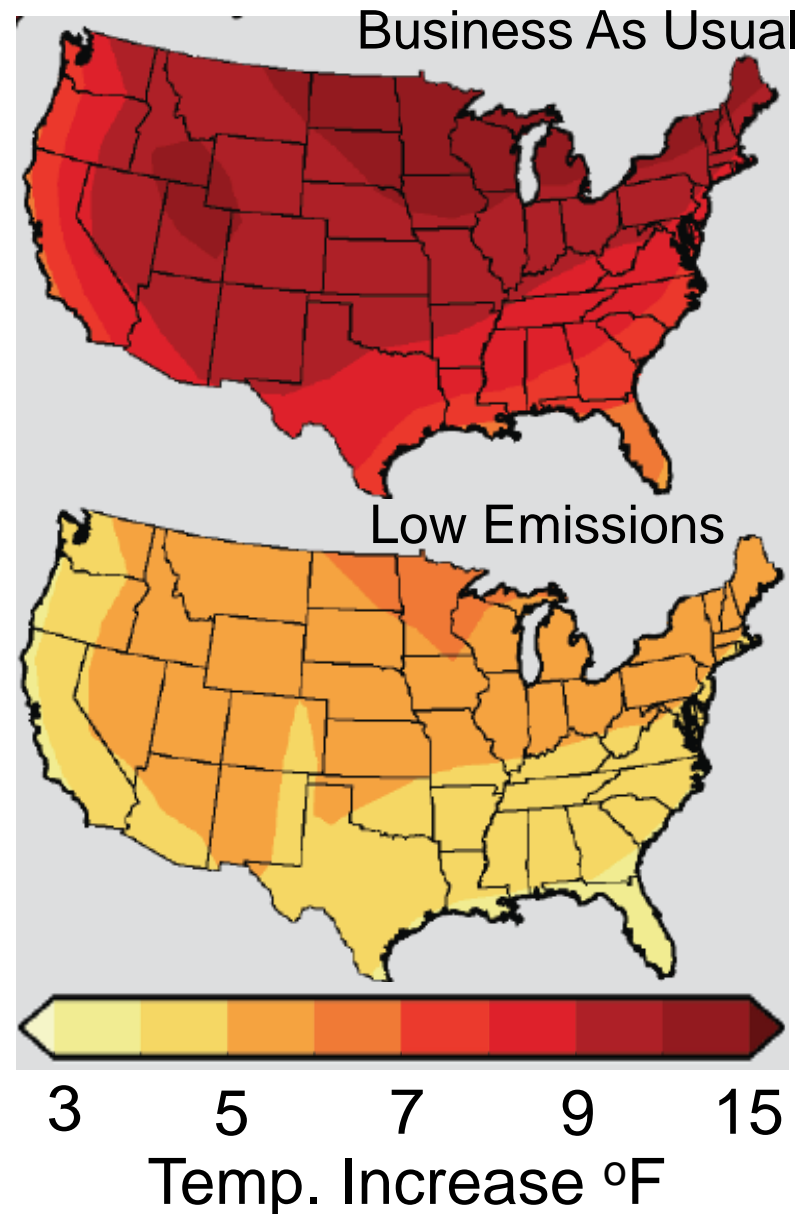
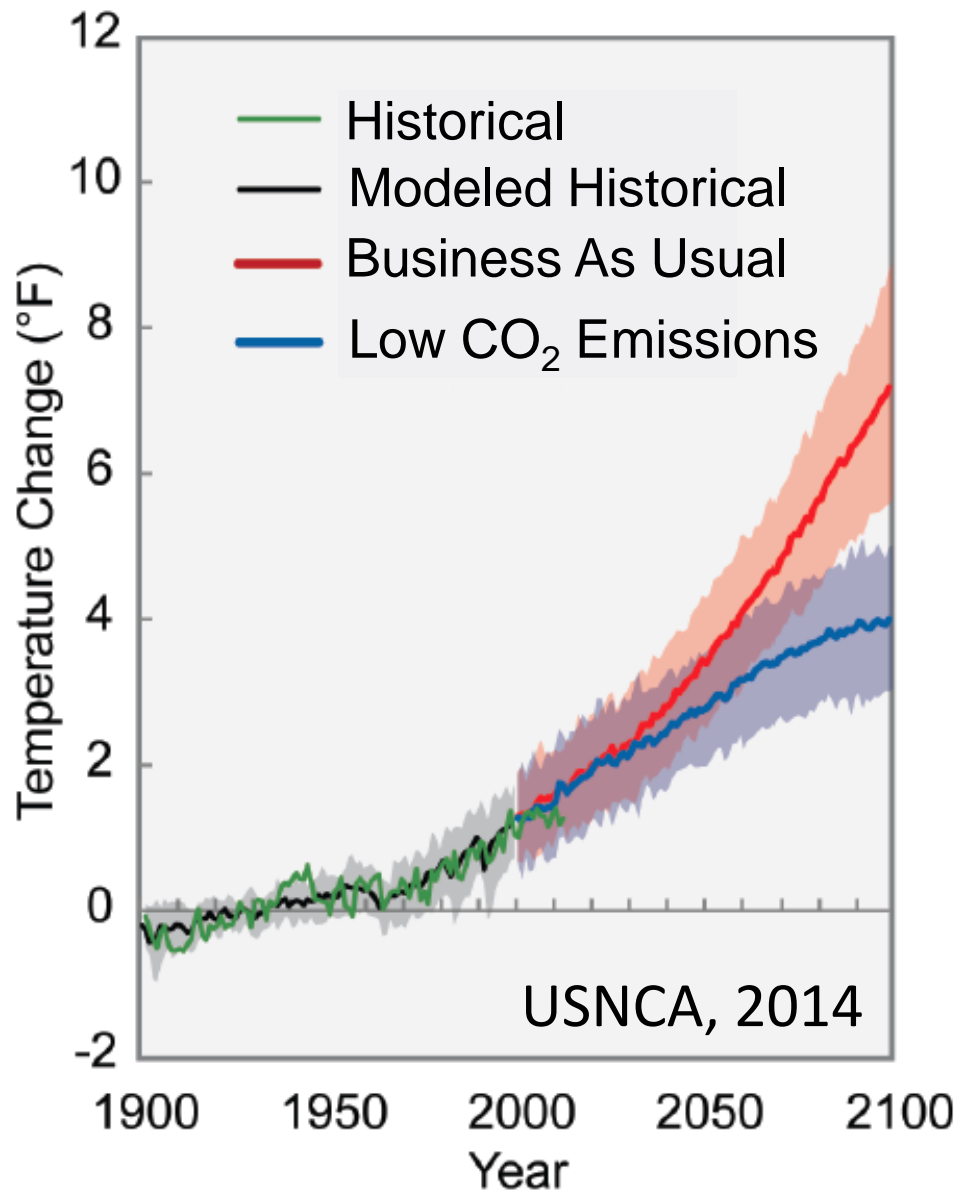


# Our Choice: 2-5+ Feet of SL Rise by 2100

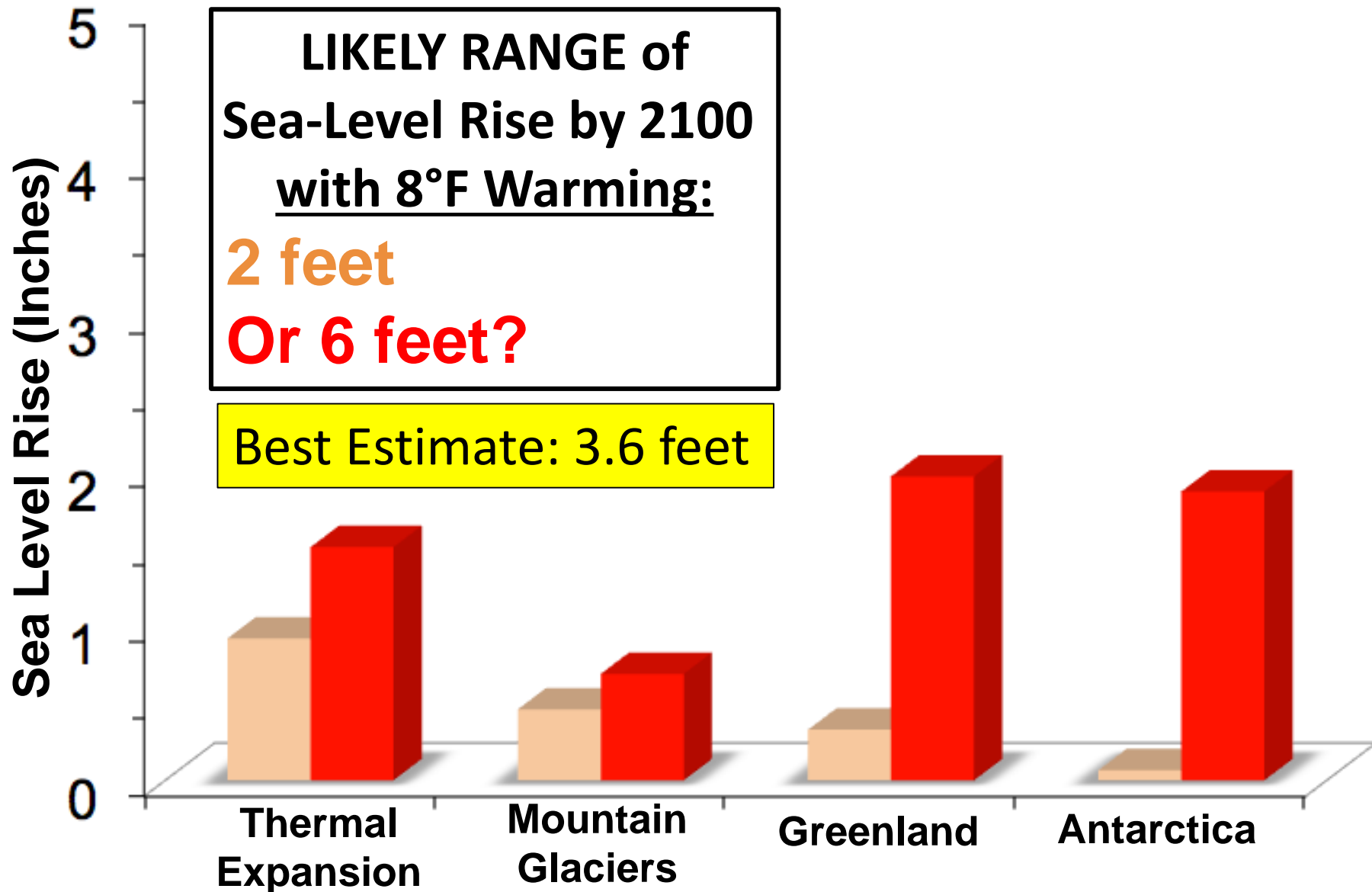
- Our decisions about carbon emissions WILL MATTER
- Disruptive sea level rise will occur regardless
- Calls for a combination of mitigation and adaptation



# Our Choice: Temperatures 4-8+ °F Warmer by 2100



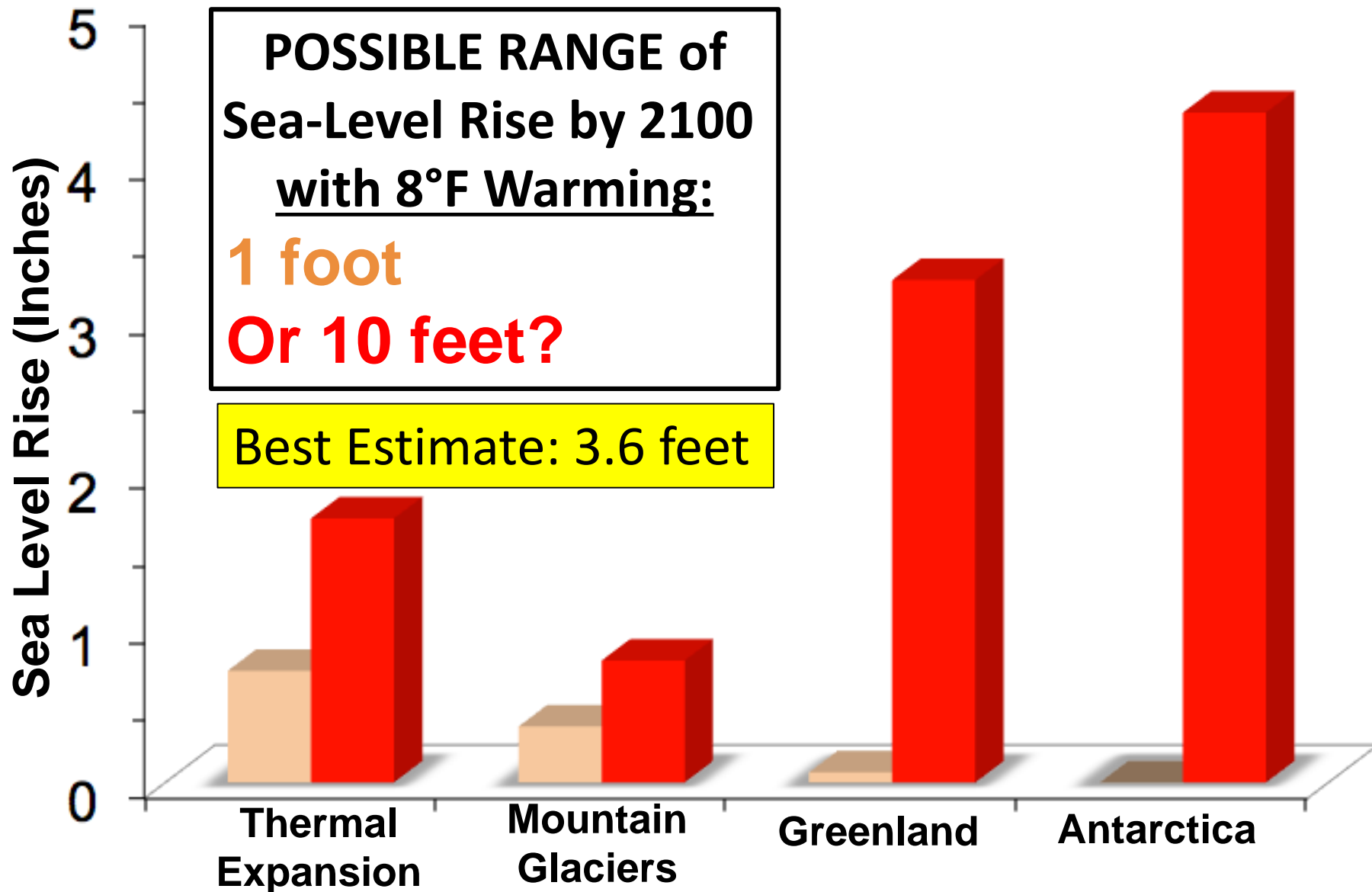
# Great Uncertainty about Future Sea Level Rise



Data from Kopp et al. 2014, Bamber et al., 2019



# Great Uncertainty about Future Sea Level Rise



Data from Kopp et al. 2014, Bamber et al., 2019

# Sunny Day High Tide in Annapolis, MD



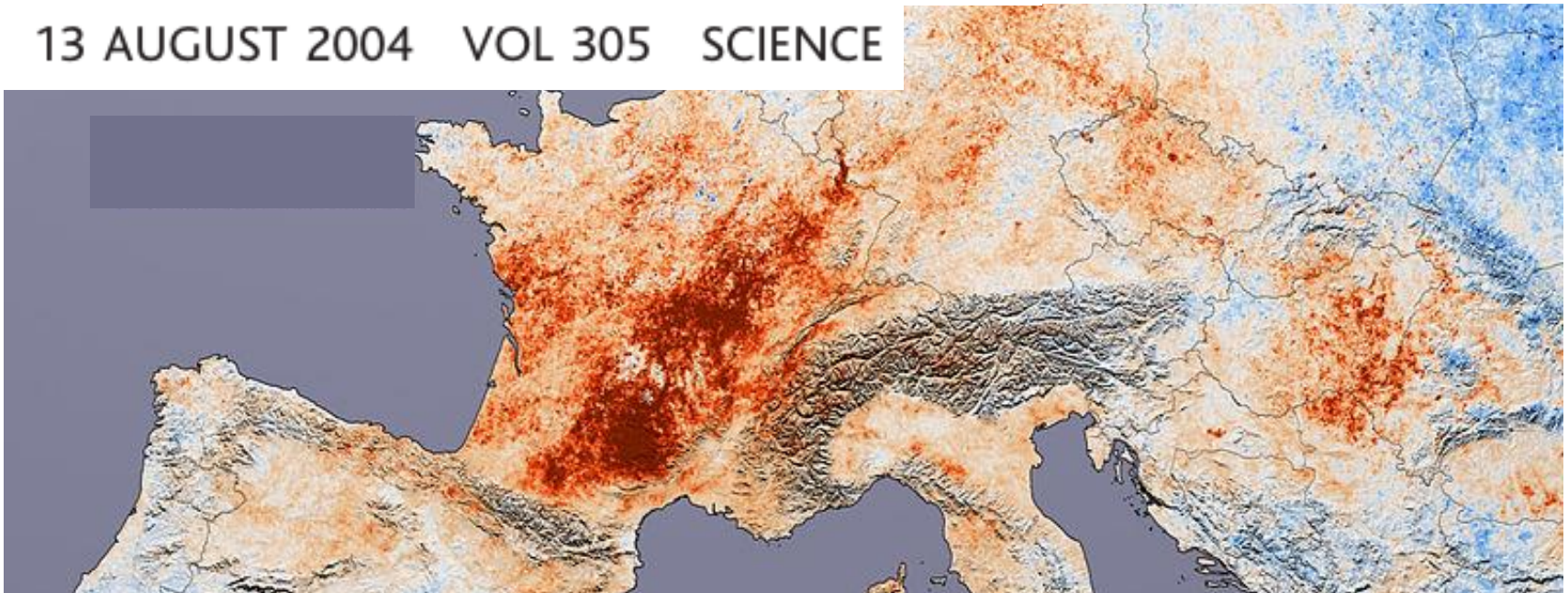
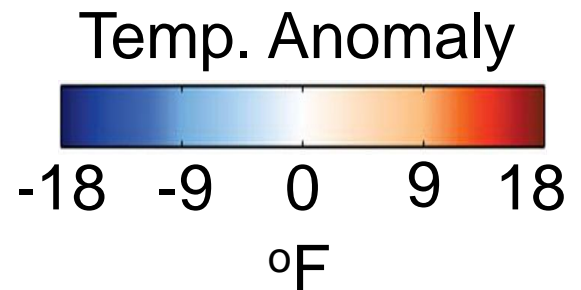


# 2003 European Heat Wave: 35,000+ Deaths

More Intense, More Frequent, and  
Longer Lasting Heat Waves in  
the 21st Century

Gerald A. Meehl\* and Claudia Tebaldi

13 AUGUST 2004 VOL 305 SCIENCE



*70% of the heat-related deaths in Paris  
were caused by climate change*

*(Mitchell et al., 2016)*



# Athabasca Glacier, Jasper Natl. Park, Canada

2017





# Athabasca Glacier, Jasper Natl. Park, Canada

2017



Dartmouth Students!





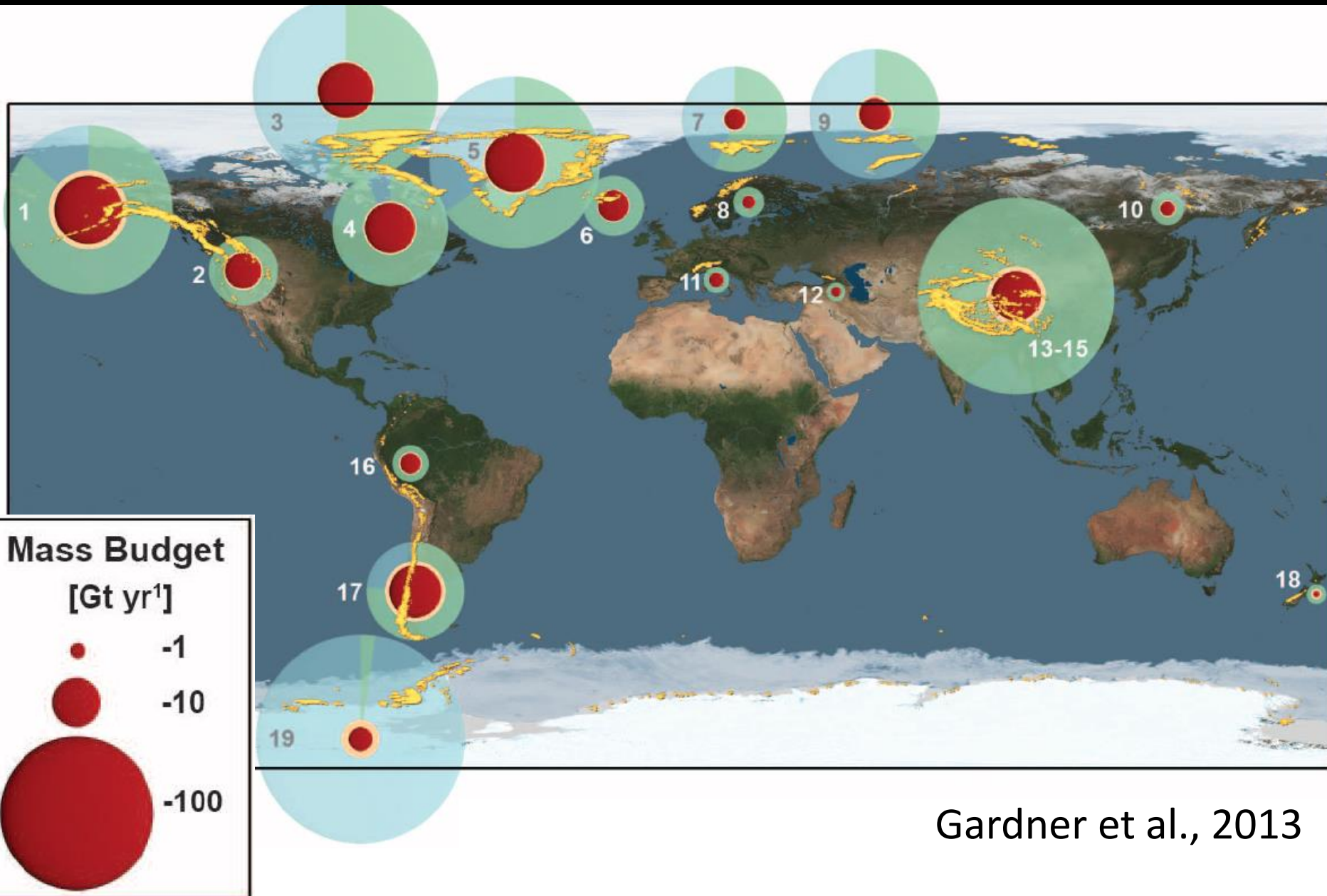
# Athabasca Glacier, Jasper Natl. Park, Canada

*The lower glacier will be gone in 2060*





# Mountain Glaciers are Melting in Every Region



Gardner et al., 2013







# Shepard Glacier

## Glacier National Park, MT



1913

*W. C. Alden photo  
Courtesy of GNP Archives*



2005

*Blase Reardon photo  
USGS*



# Toboggan Glacier

Prince William  
Sound, AK

1905

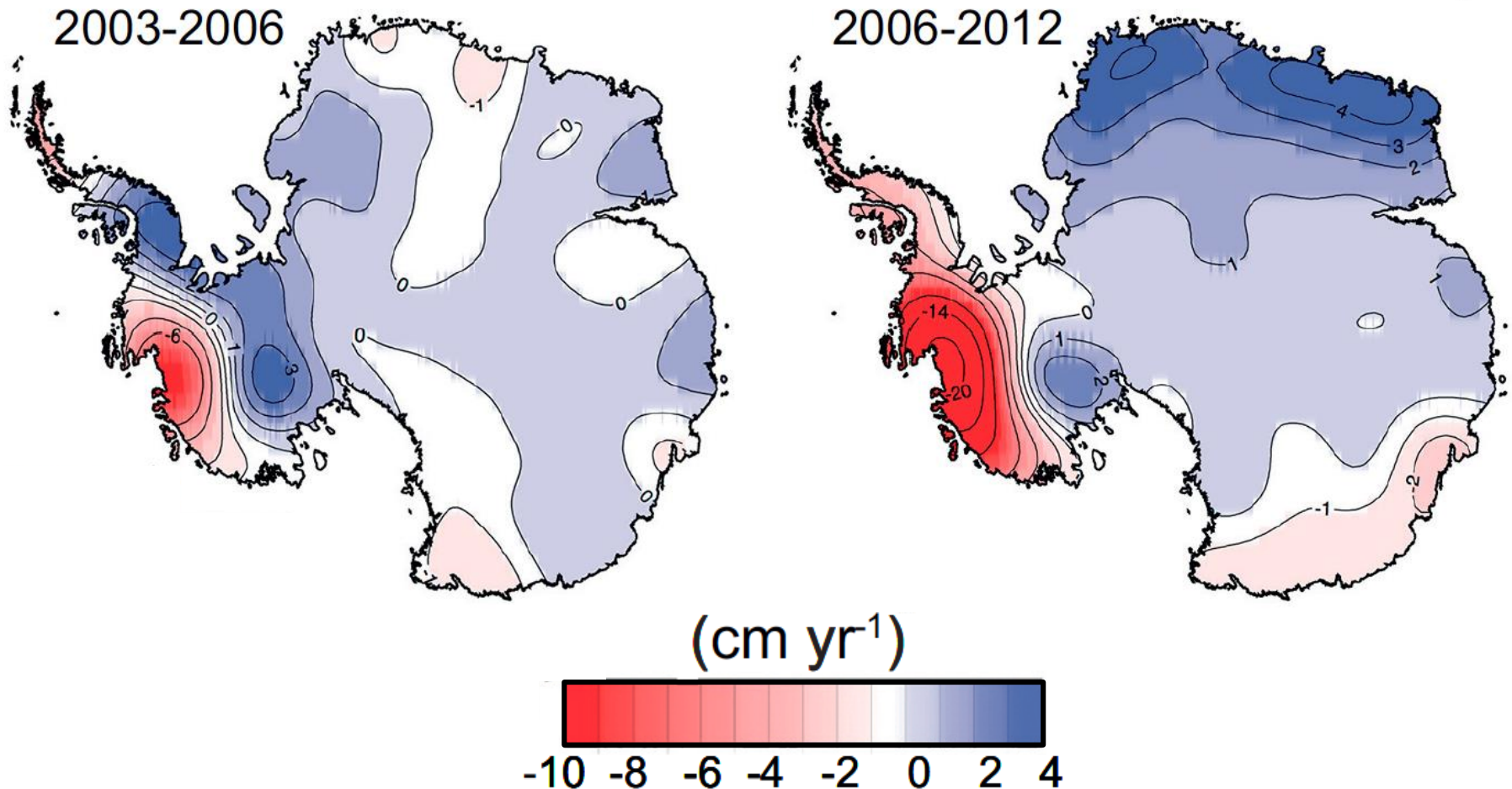


2000



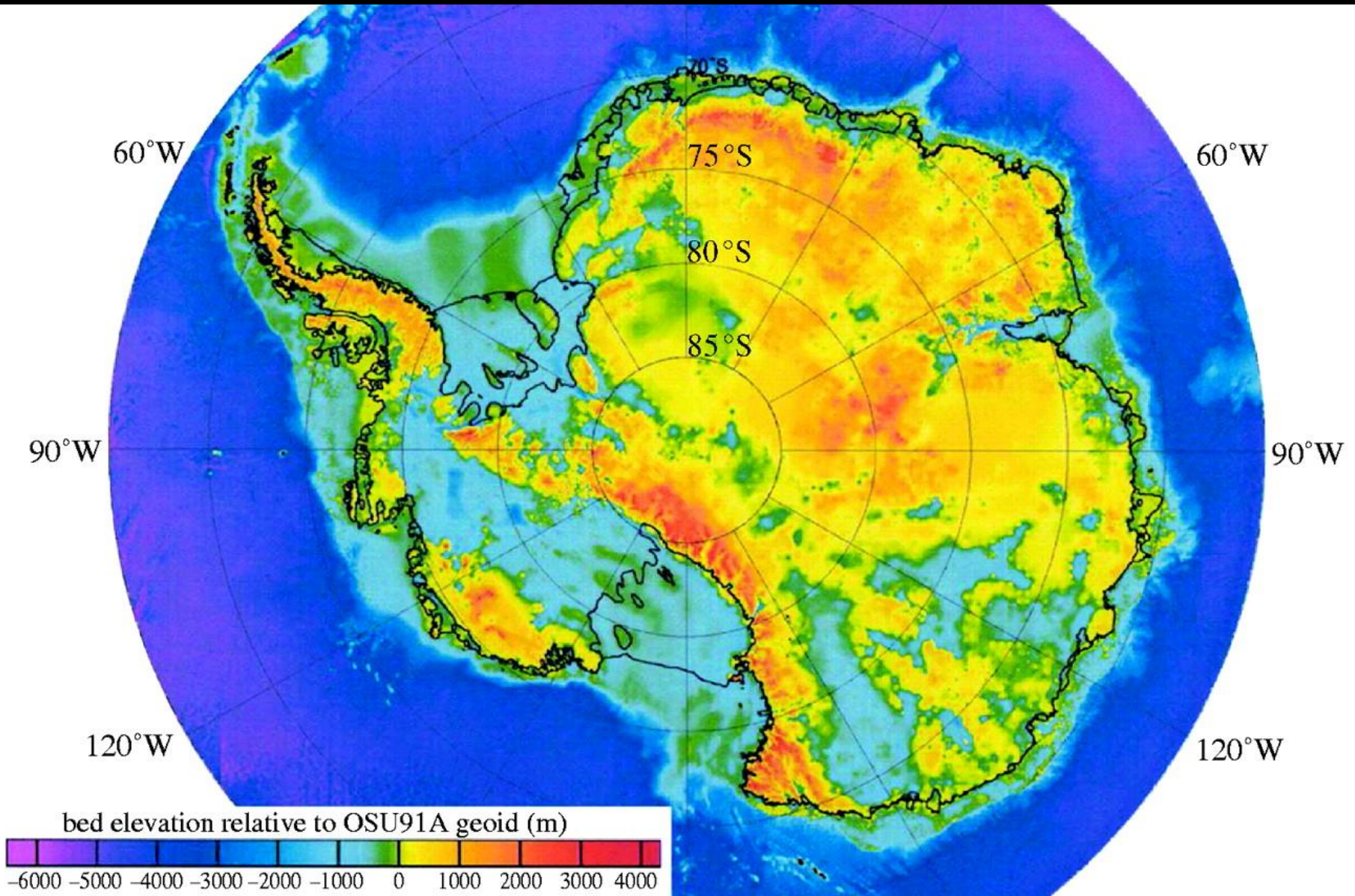
# Melting is Also Speeding Up in Antarctica

*...but because of OCEAN warming, not air warming!*





# West Antarctic Ice Sheet is Based Below Sea Level





# Warm Ocean Water is Melting Antarctica from Below

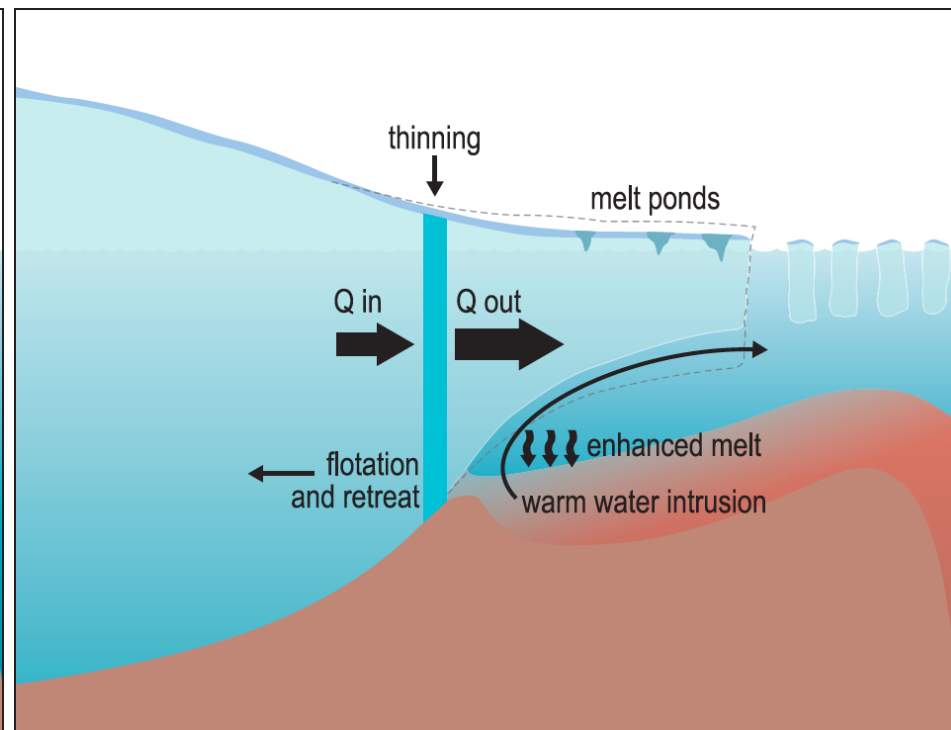
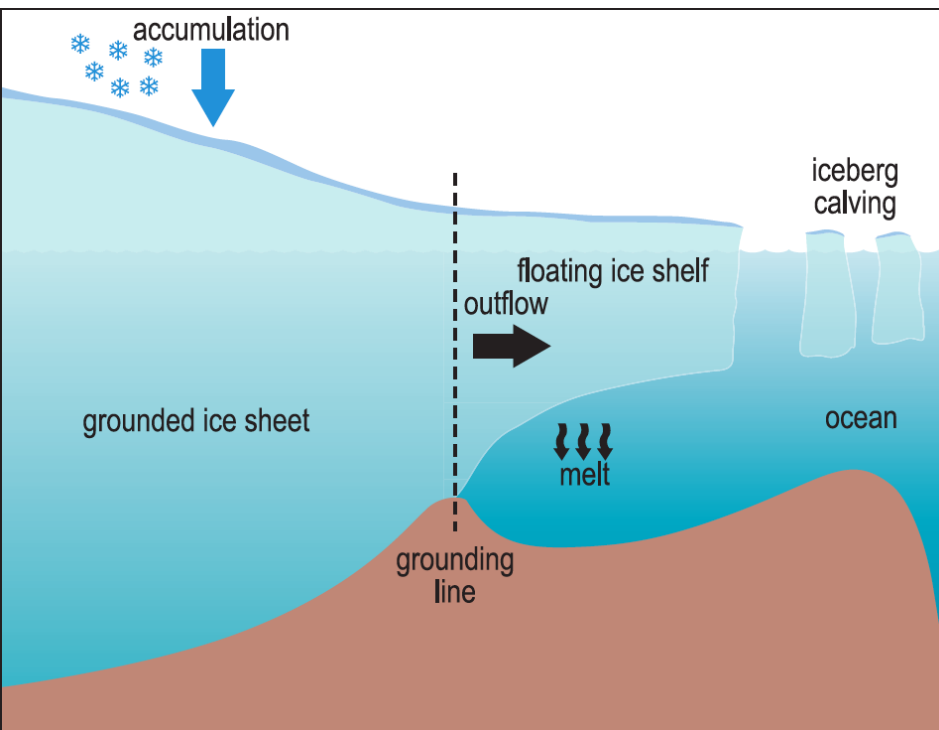
## Melting Of Antarctic Ice Sheet Might Be Unstoppable

by SCOTT NEUMAN

NEWS | MAY 12, 2014



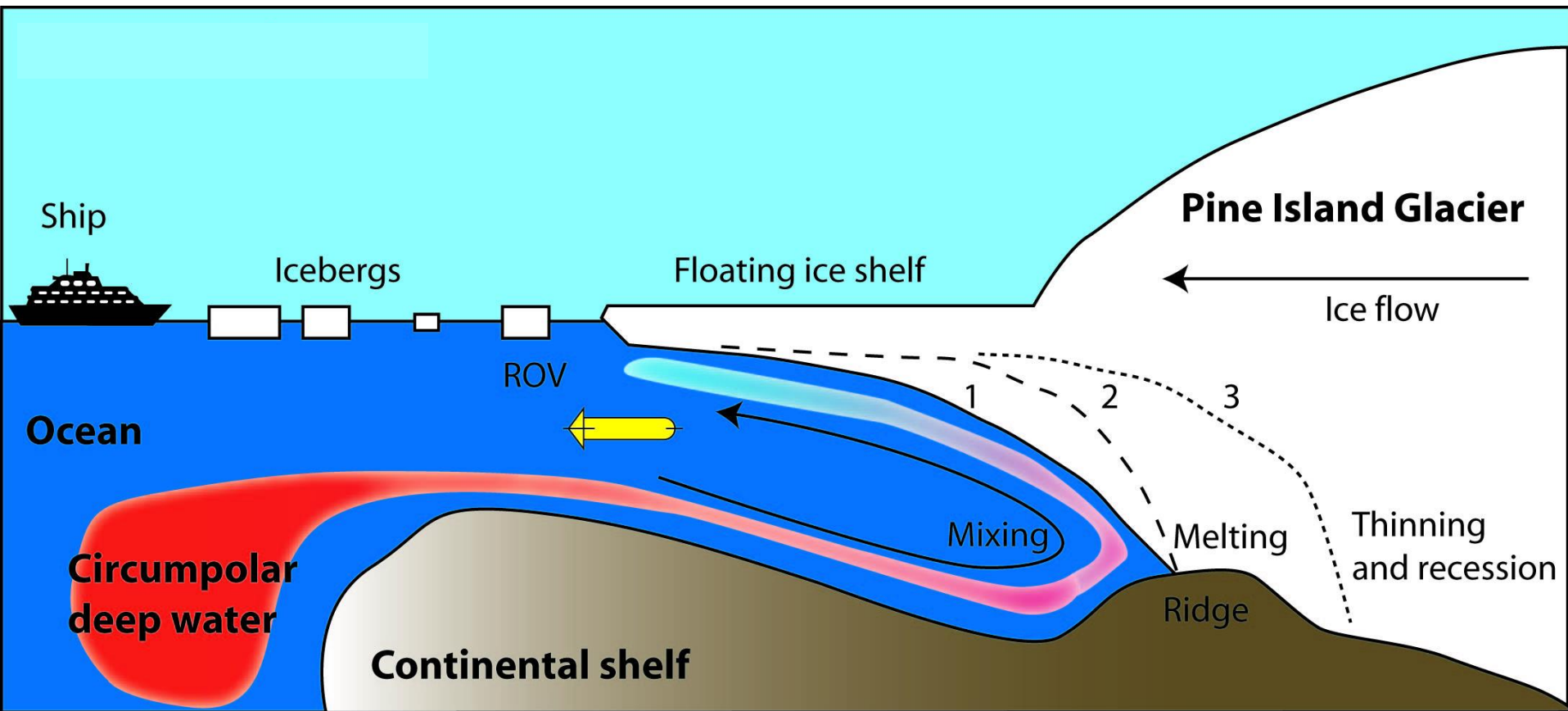
SCIENTIFIC  
AMERICAN™



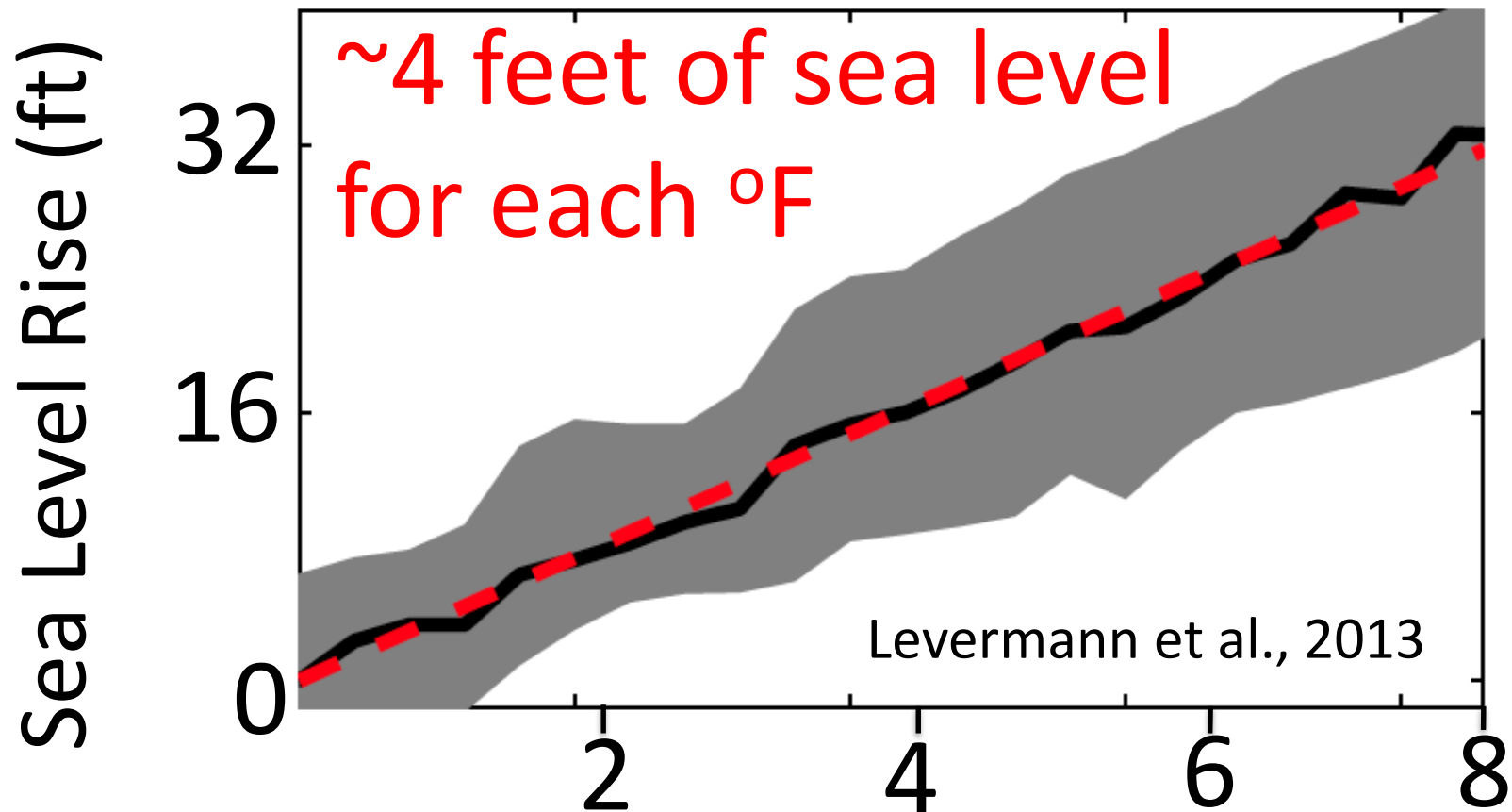
IPCC, 2013

# Warm Ocean Water is Melting Antarctica from Below

As the ice sheet melts from below, water seeps under the ice and speeds up its flow into the ocean, raising sea level



# Our Actions TODAY are Locking Us into MUCH Bigger Changes for Future Generations



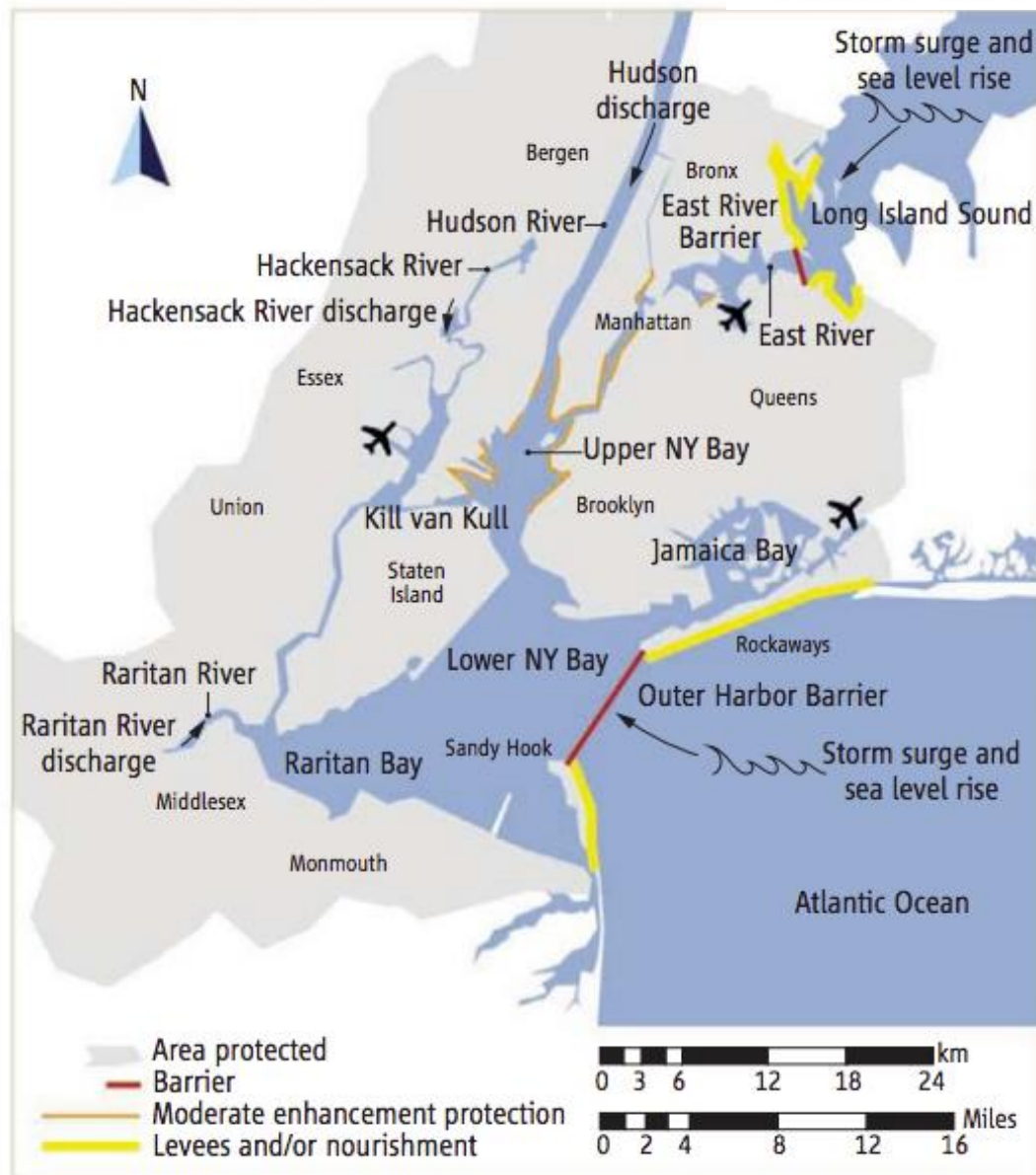
New Paper! “8 more inches of sea level rise in 2300 for every 5 year delay in peak CO<sub>2</sub>”



# Massive Seawall May Be Needed to Keep New York City Dry

May 5, 2014

SCIENTIFIC  
AMERICAN™



The Boston Globe

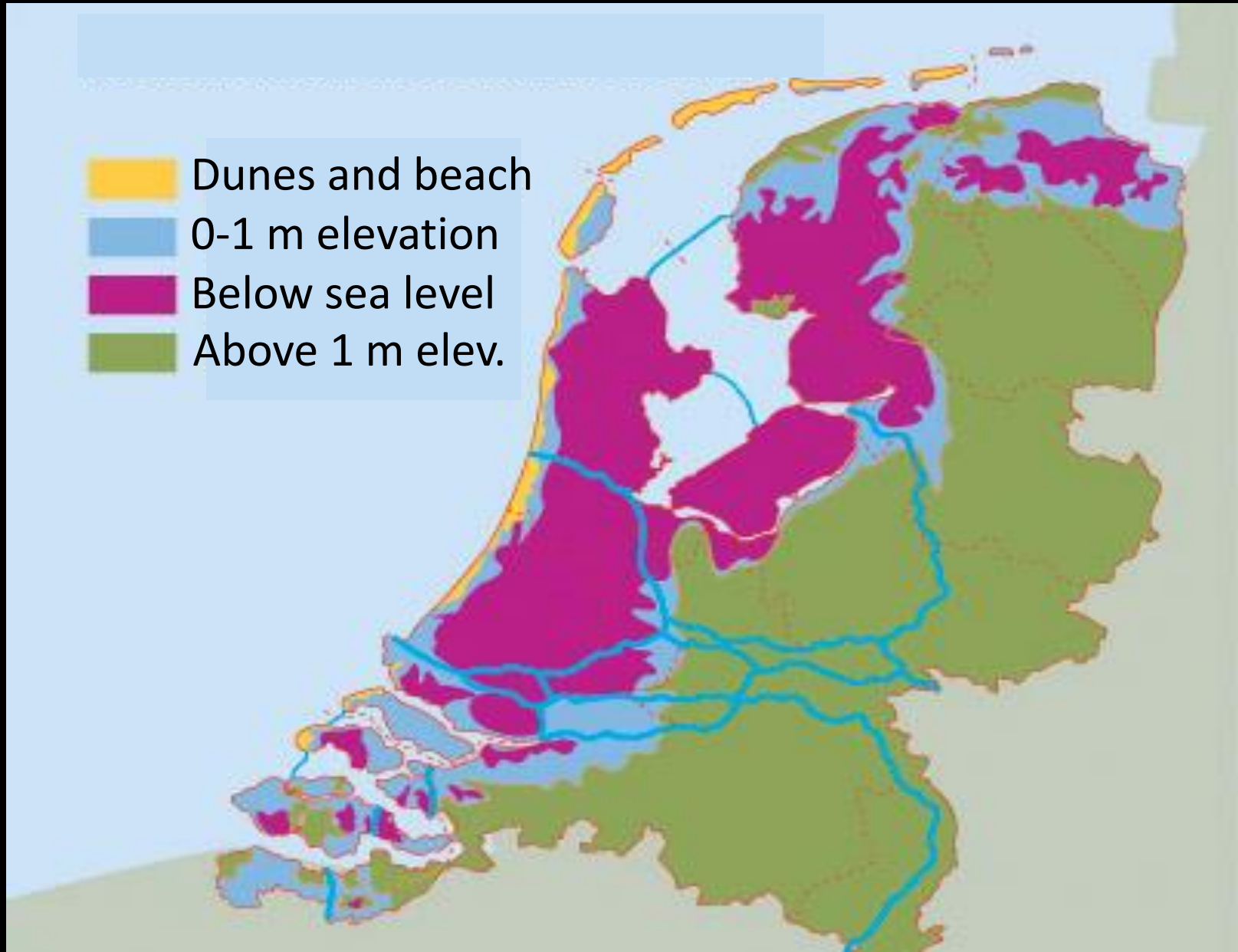
## As seas rise, city mulls a massive sea barrier across Boston Harbor

February 18, 2017



“Sapphire Necklace”

# ~25% of the Netherlands is Below Sea Level







North Sea



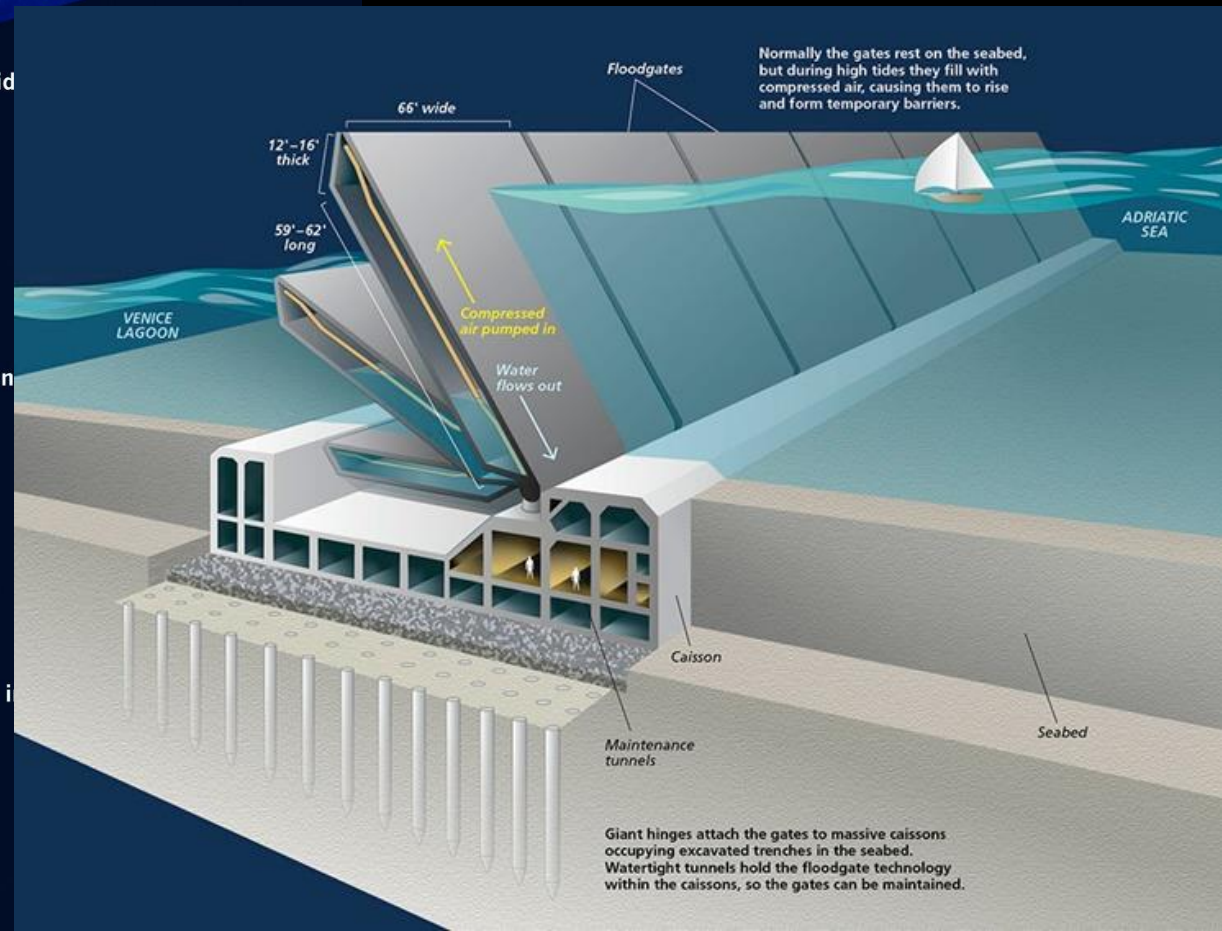
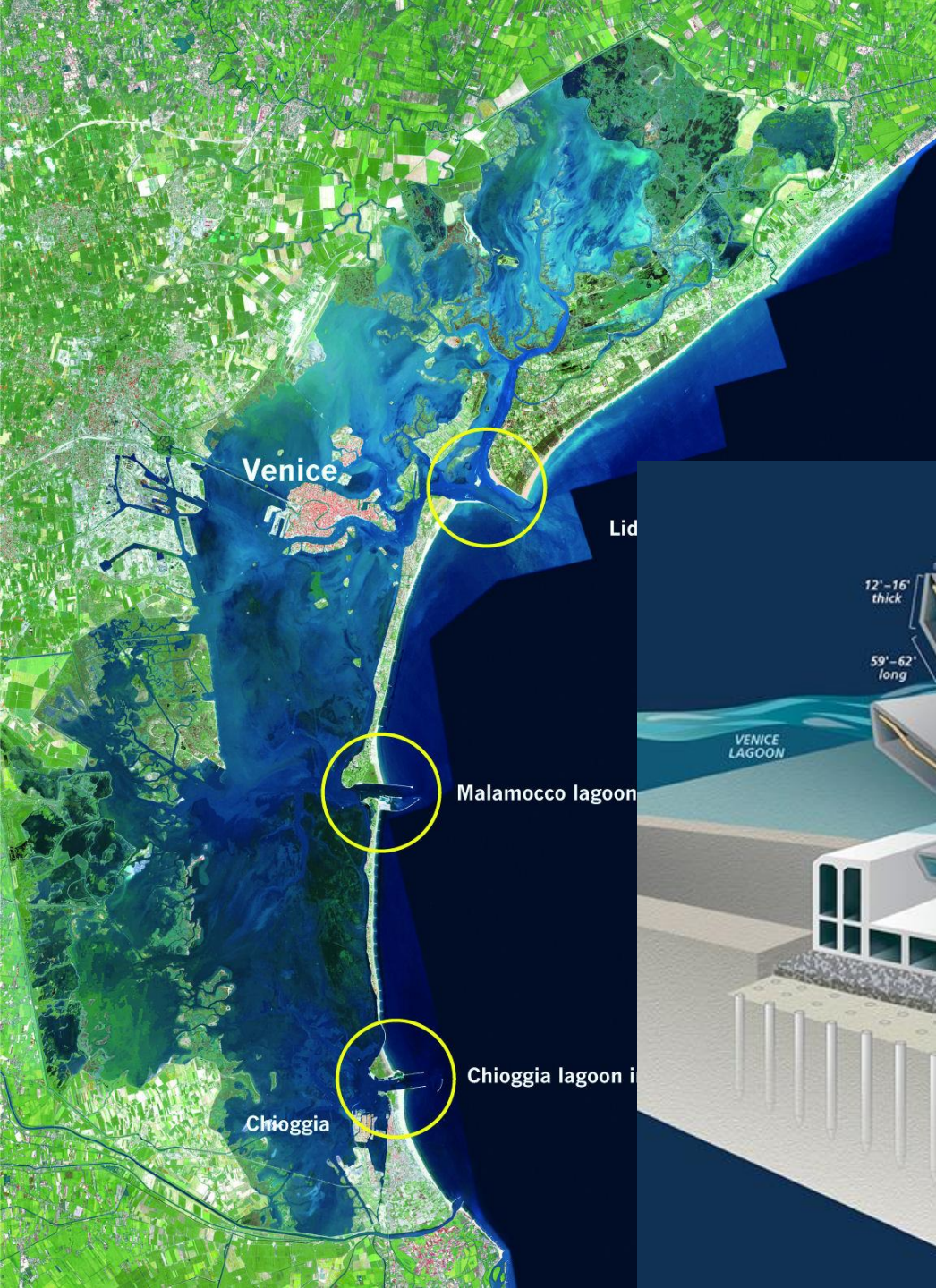
Netherlands  
Delta Works  
50 Years  
\$6 Bill.





# Venice "MOSE"

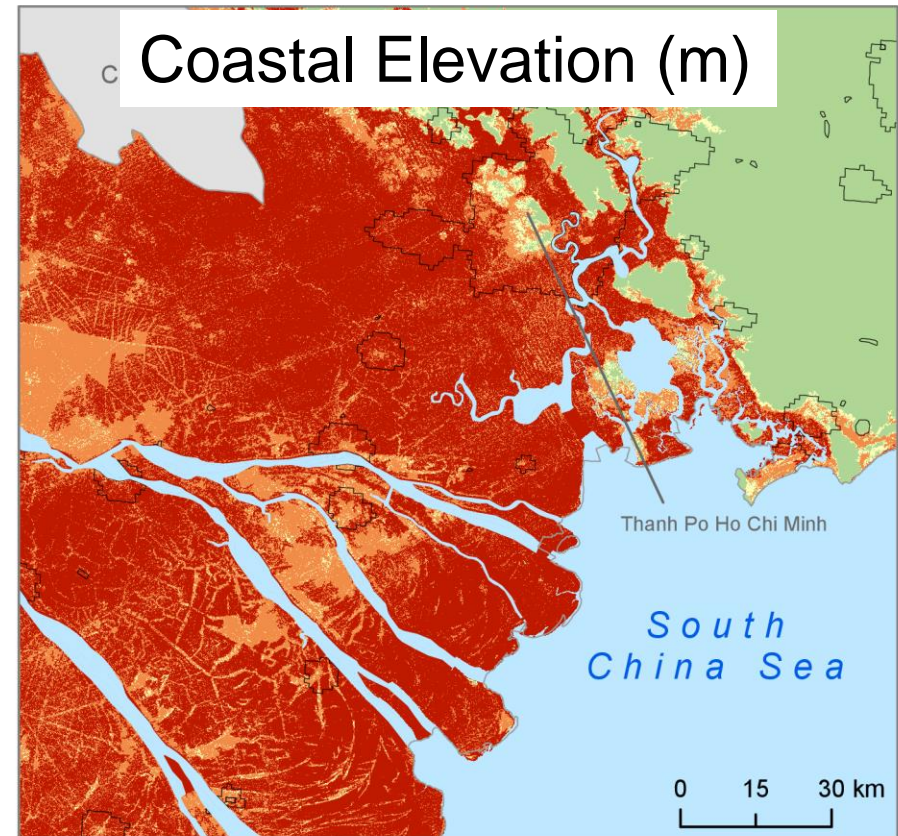
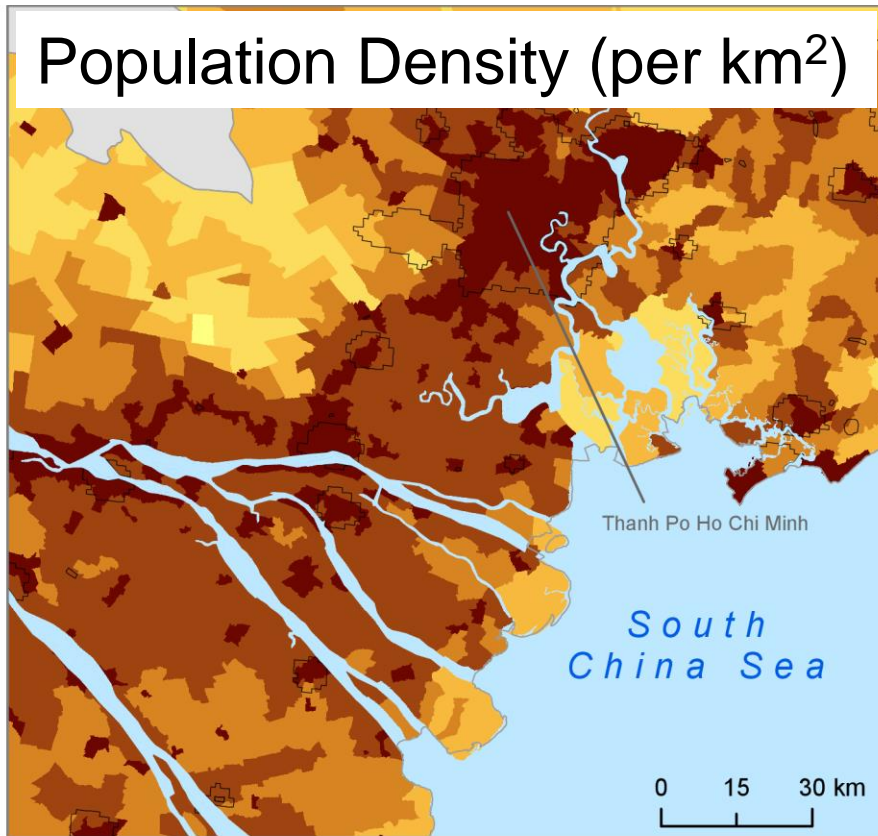
15 Years  
\$6+ Billion



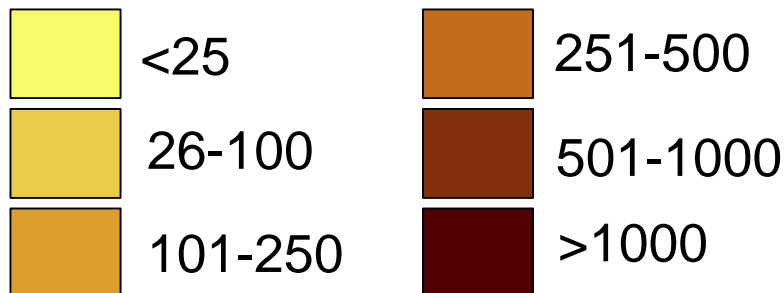


# Developing Countries Will be Hit Harder

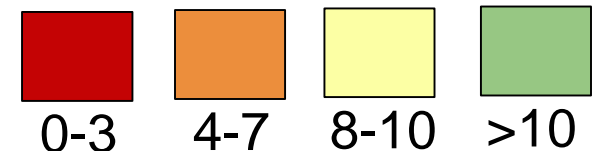
Mekong Delta, Vietnam: 2-7 Million displaced by 2050



Map Credit: CIESIN Columbia University, November 2013

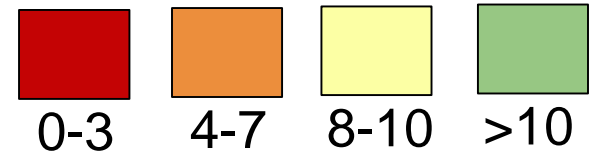
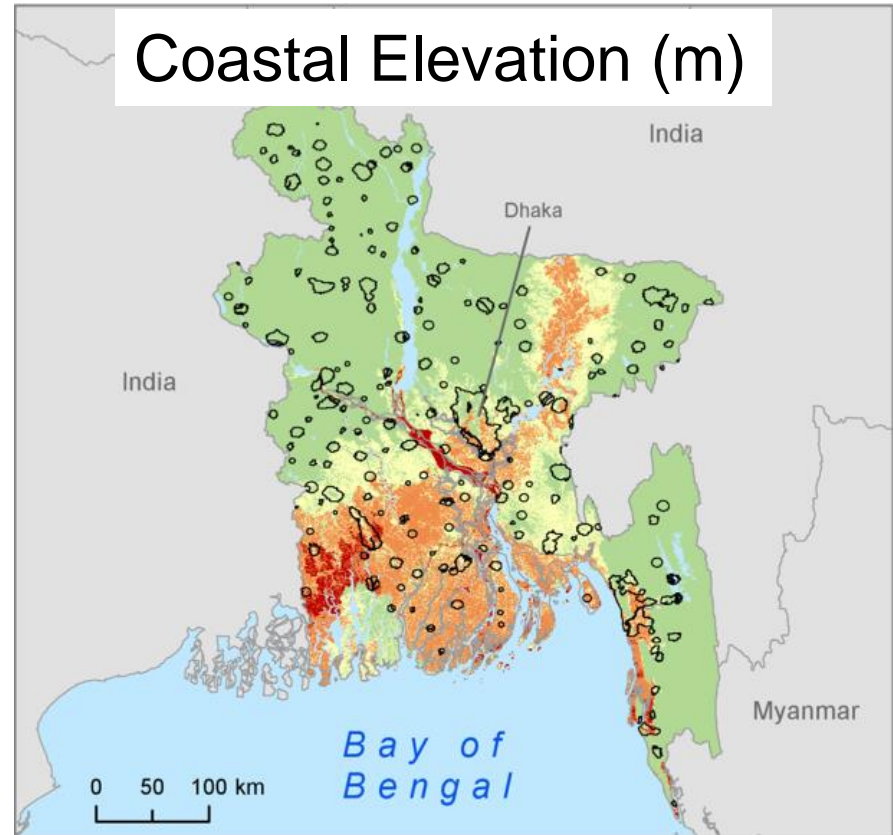


Center for International Earth



# 1970 Bhola Bangladesh Cyclone (Cat 3)

**~500,000 lives lost**





# Dutch court rules that government must help stop climate change

**nature**

*Appeals court upholds earlier ruling that the government is accountable for efforts to combat global warming.*

## Cities Sue Big Oil for Damages from Rising Seas

**SCIENTIFIC  
AMERICAN®**

Oakland and San Francisco want oil companies to pay for climate change adaptation programs

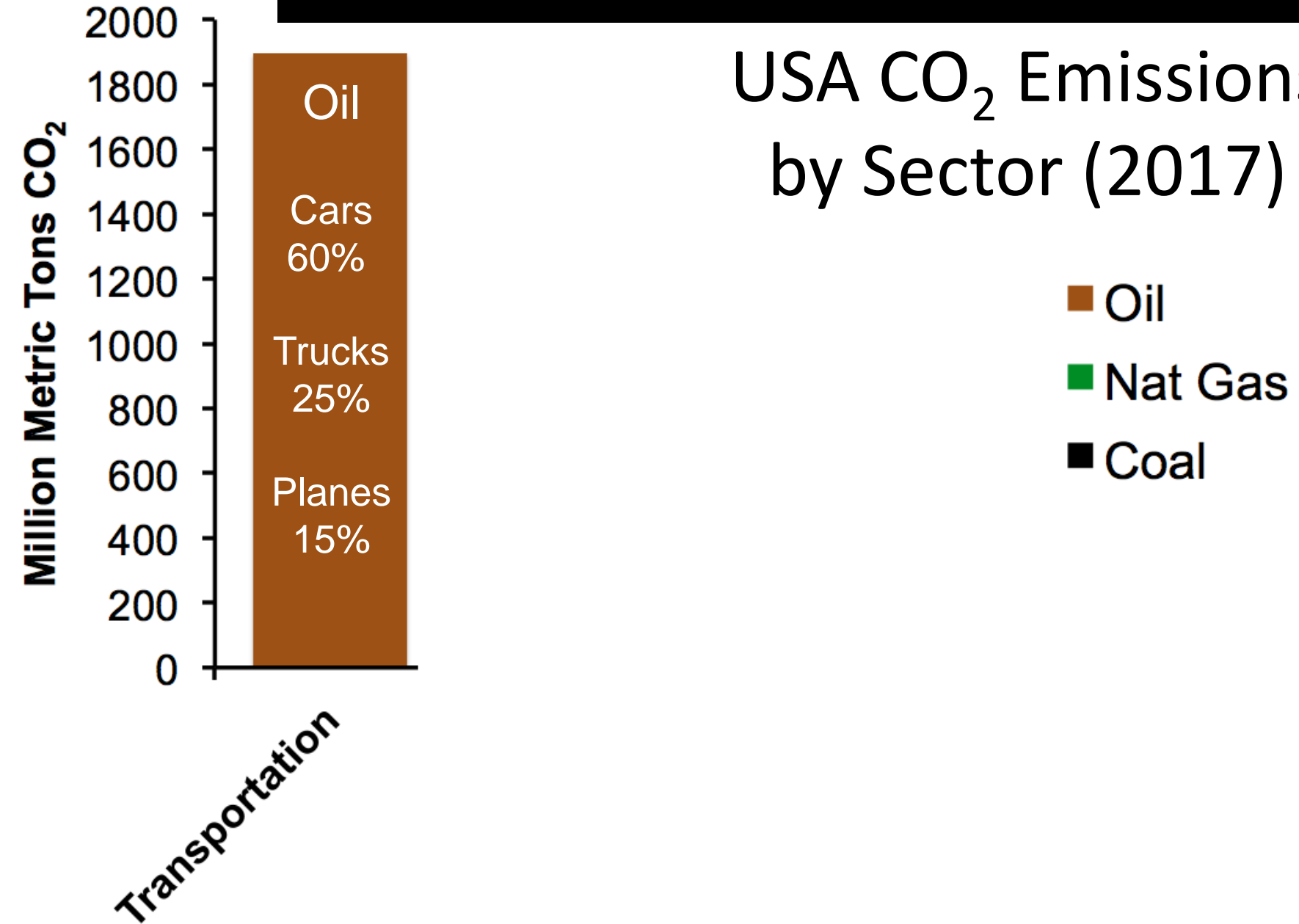
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## Support is surging for teens' climate change lawsuit

The U.S. Constitution protects the right to a safe climate, say 30,000 kids and eight members of Congress in support of the suit.

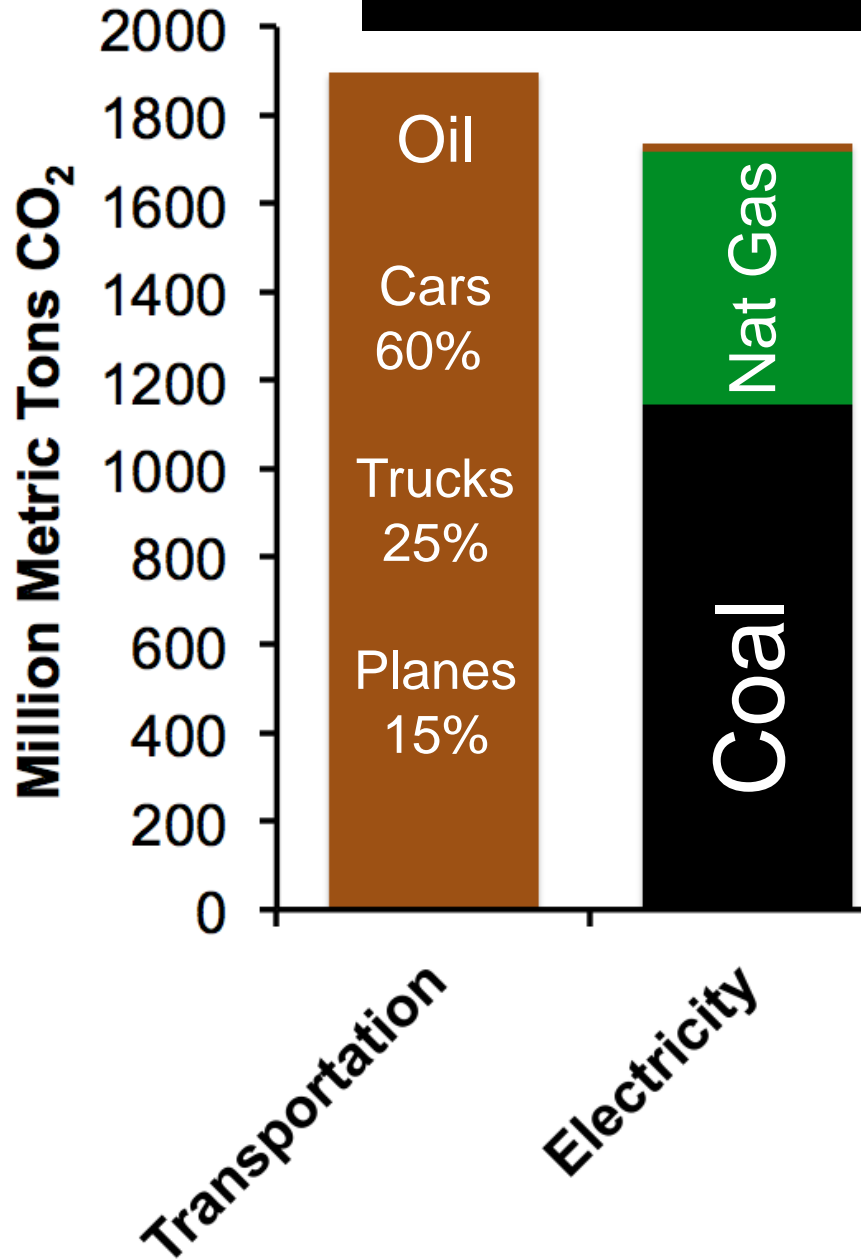
# We Must Declare War on CO<sub>2</sub>

## USA CO<sub>2</sub> Emissions by Sector (2017)



# We Must Declare War on CO<sub>2</sub>

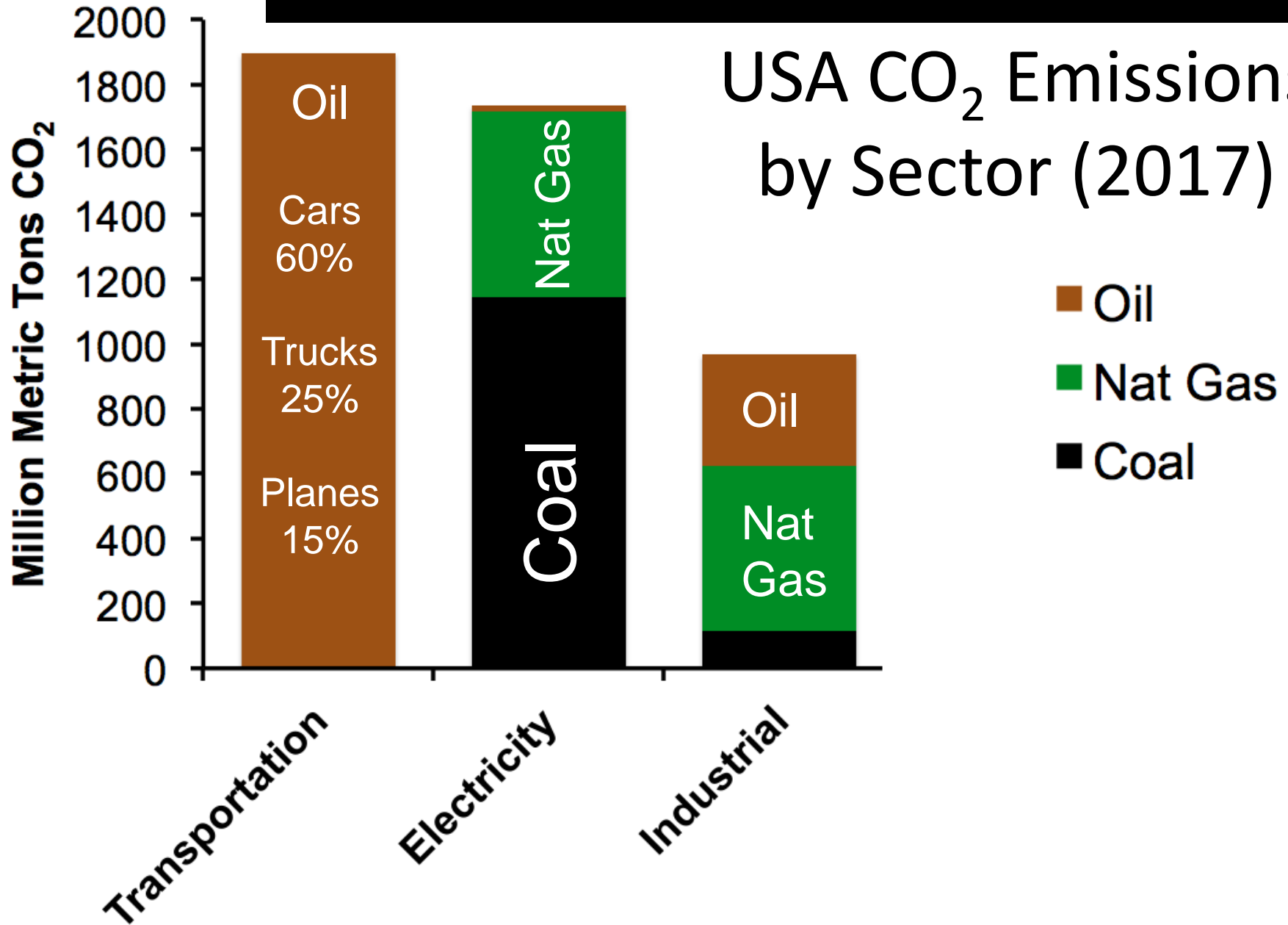
## USA CO<sub>2</sub> Emissions by Sector (2017)





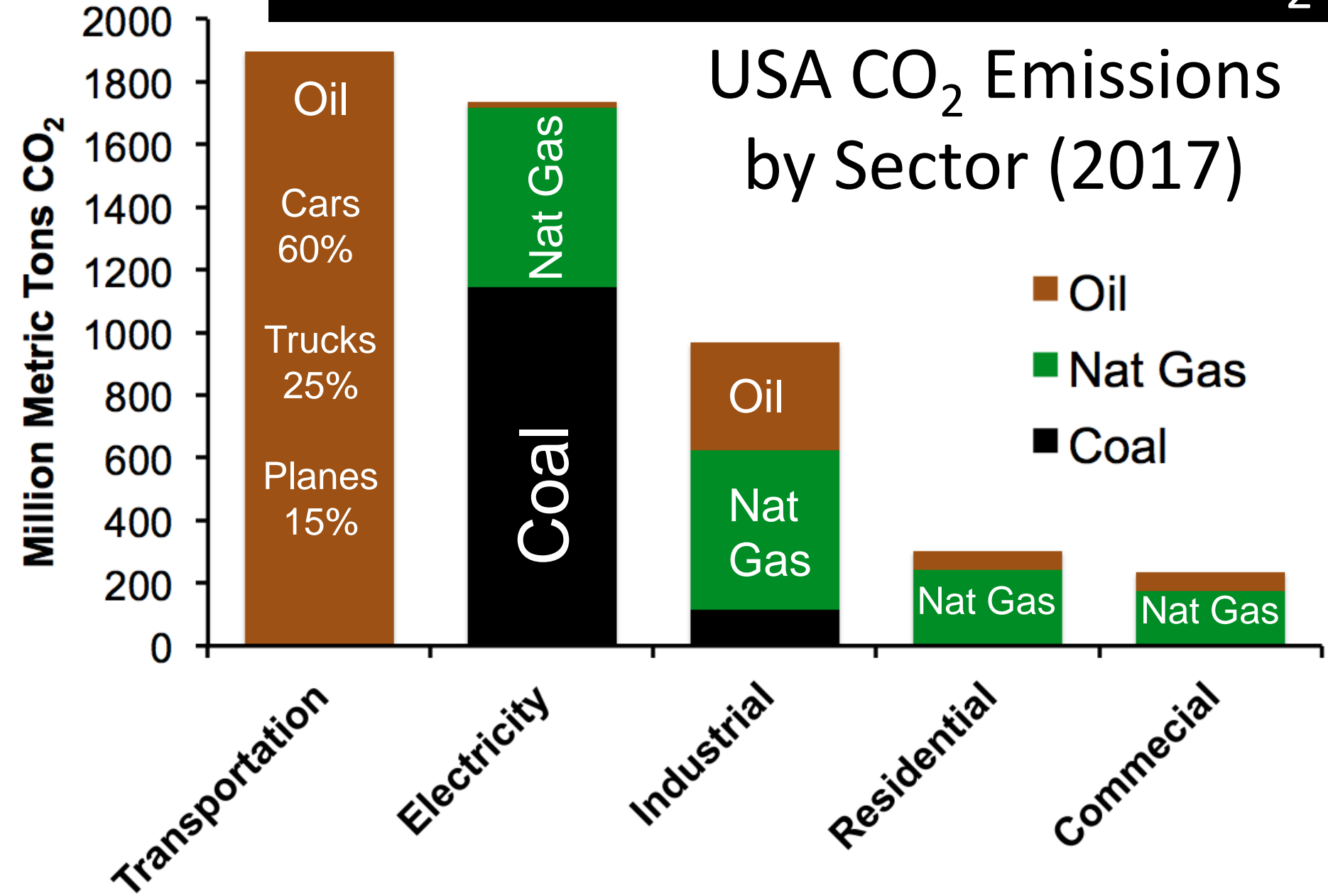
# We Must Declare War on CO<sub>2</sub>

## USA CO<sub>2</sub> Emissions by Sector (2017)



# We Must Declare War on CO<sub>2</sub>

## USA CO<sub>2</sub> Emissions by Sector (2017)



Mercedes-Benz pours \$1 billion into electric car production in the U.S.

## **Volkswagen Will Launch Its Last Gas-Powered Cars in 2026**

VW is ready to shift its focus to electric vehicles.

Kristin Houser

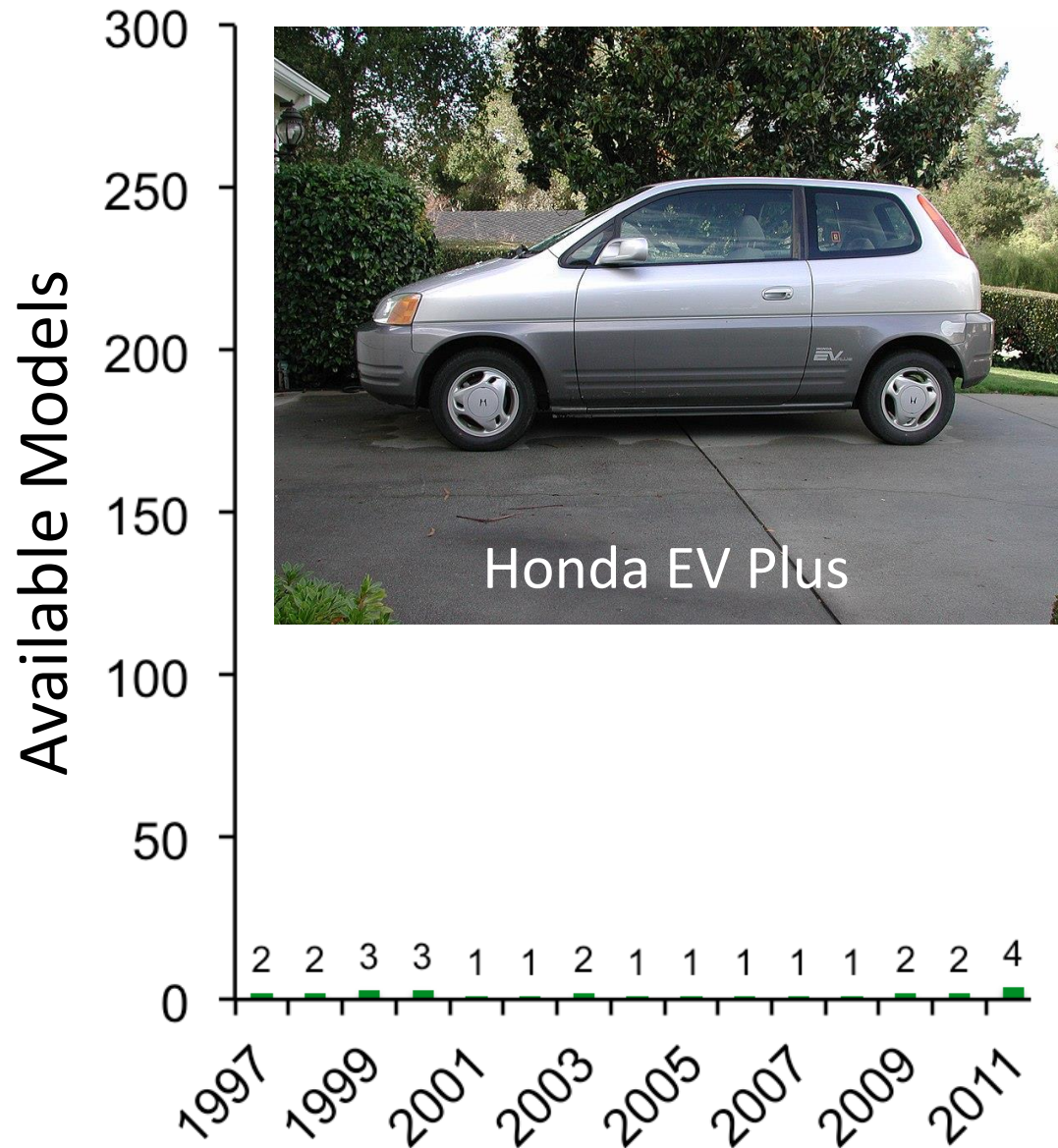
| December 5th 2018

ALEX DAVIES TRANSPORTATION 10.02.17 12:01 PM

## **GENERAL MOTORS IS GOING ALL ELECTRIC**

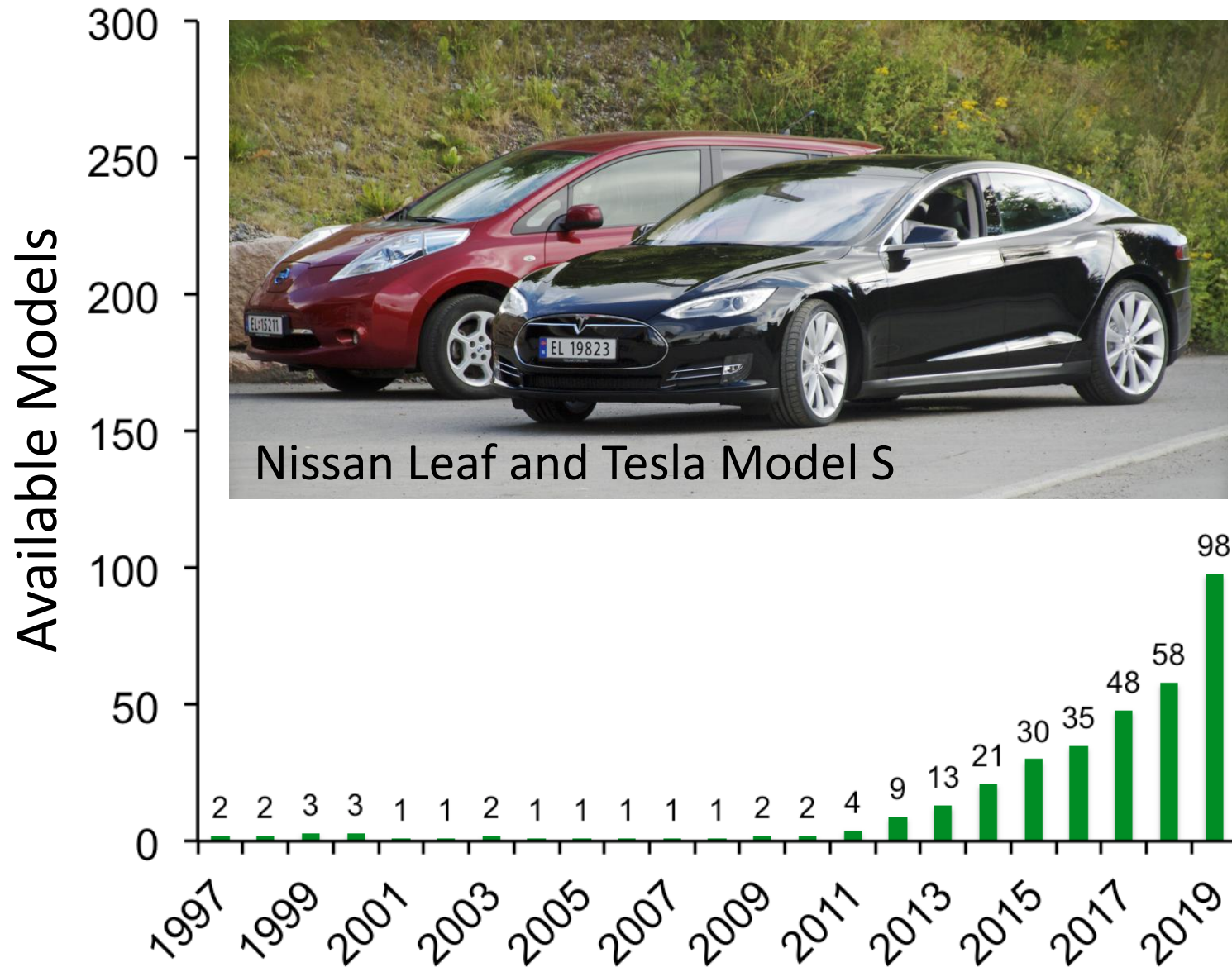


# A Rapid Rise in Electric, Plug-in Hybrid and Fuel Cell Car Models in the USA



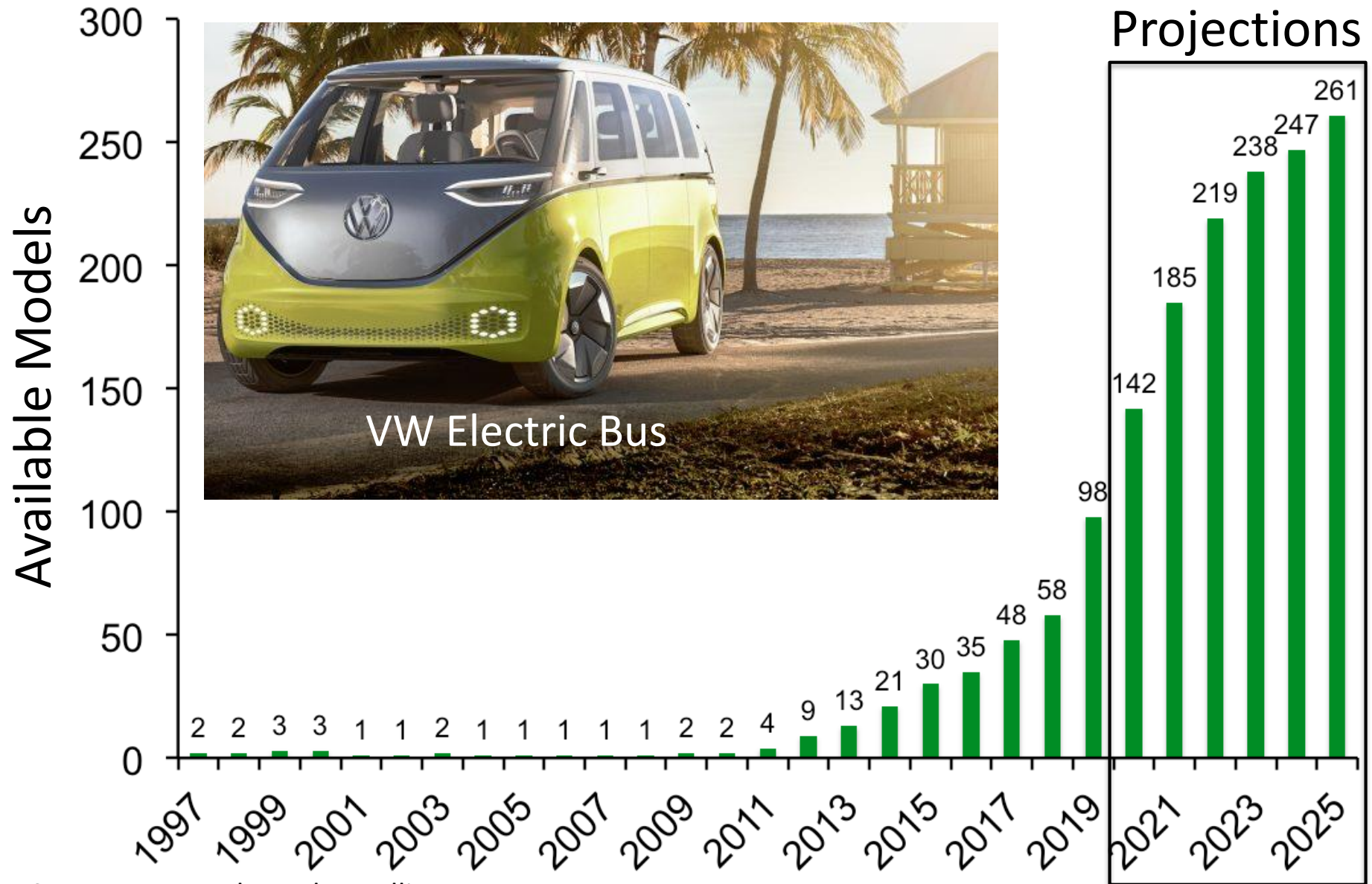
Source: NPR and Wards Intelligence

# A Rapid Rise in Electric, Plug-in Hybrid and Fuel Cell Car Models in the USA



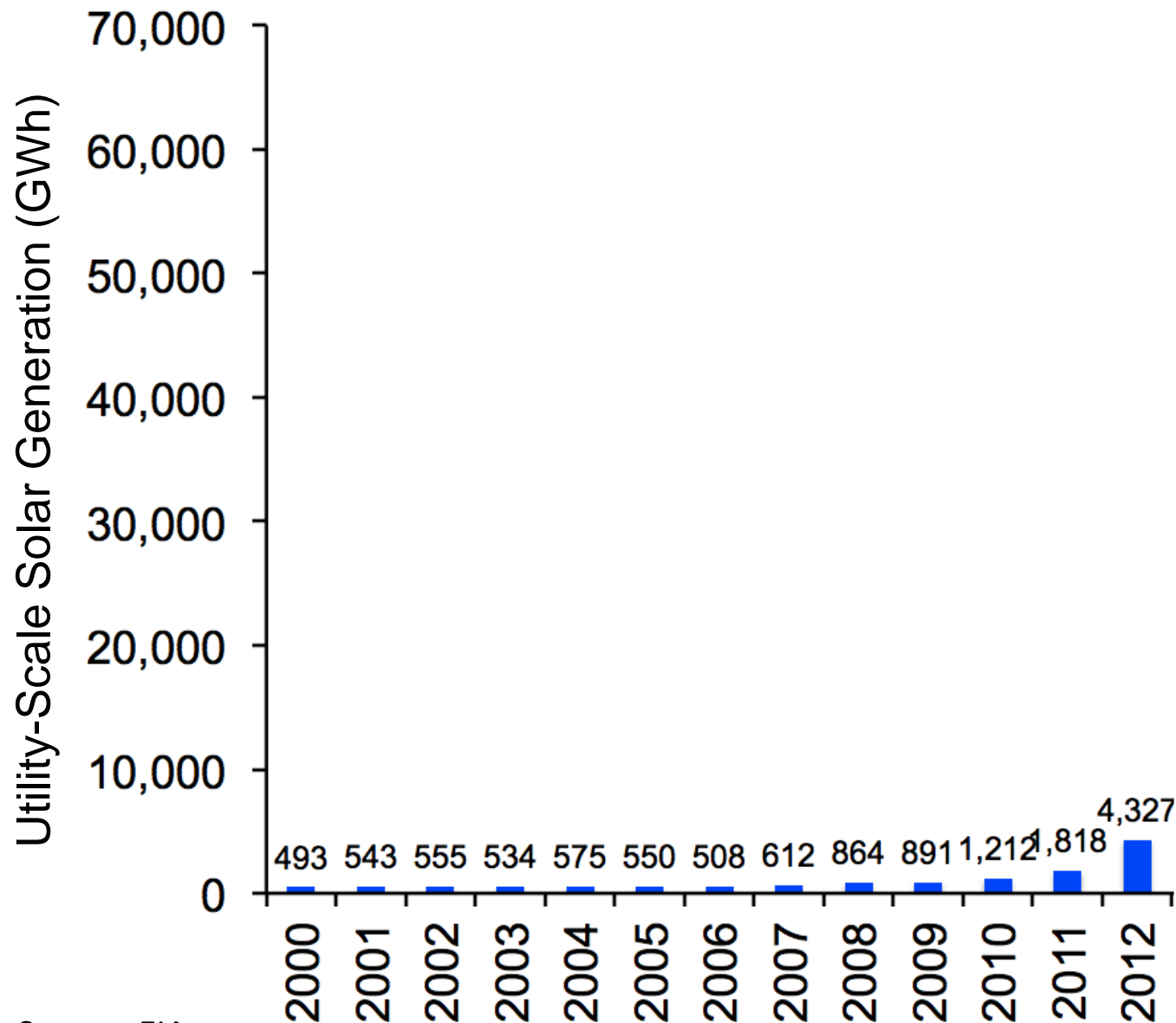
Source: NPR and Wards Intelligence

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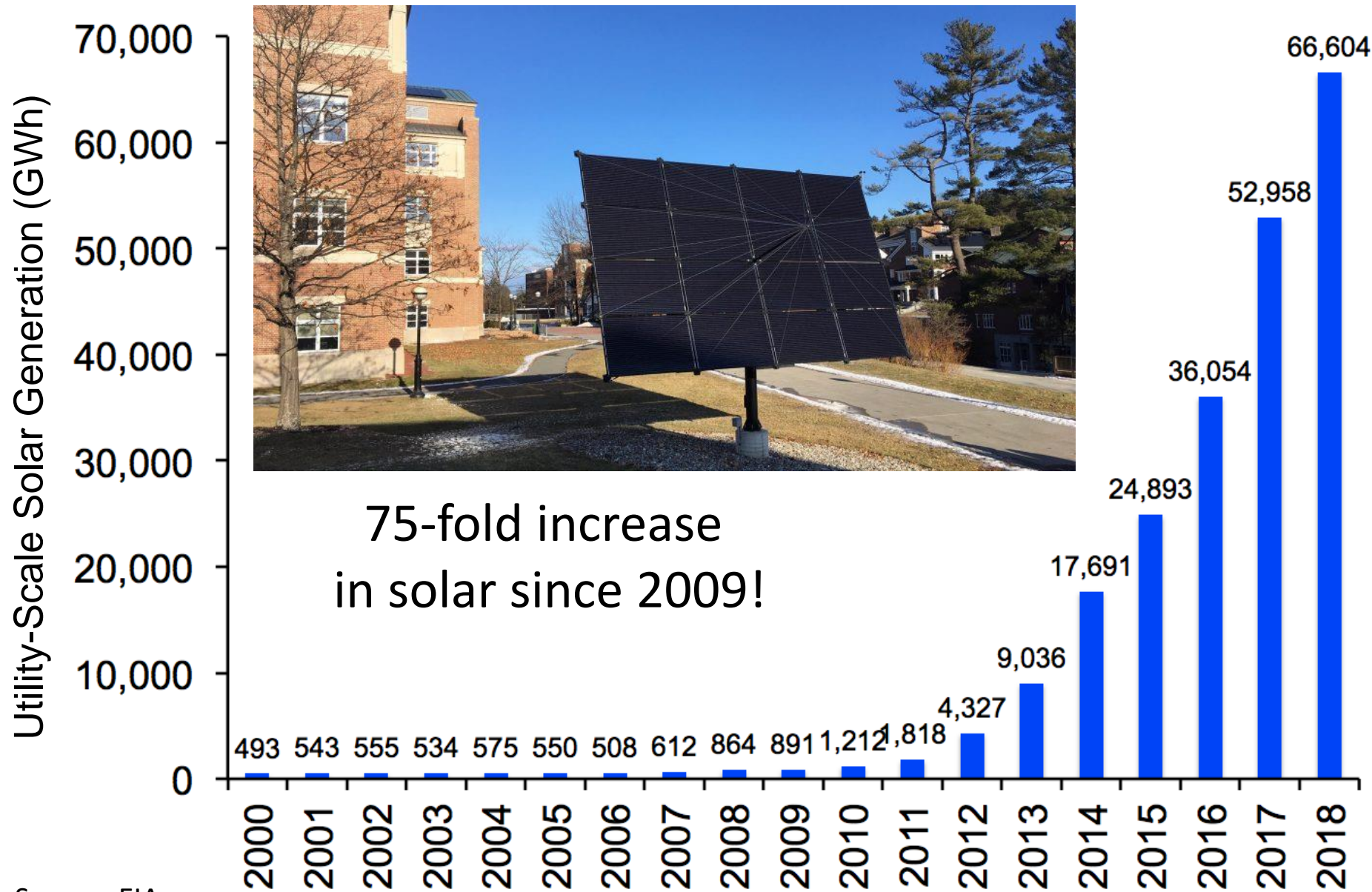


# Solar Power Generation is Exploding in the USA

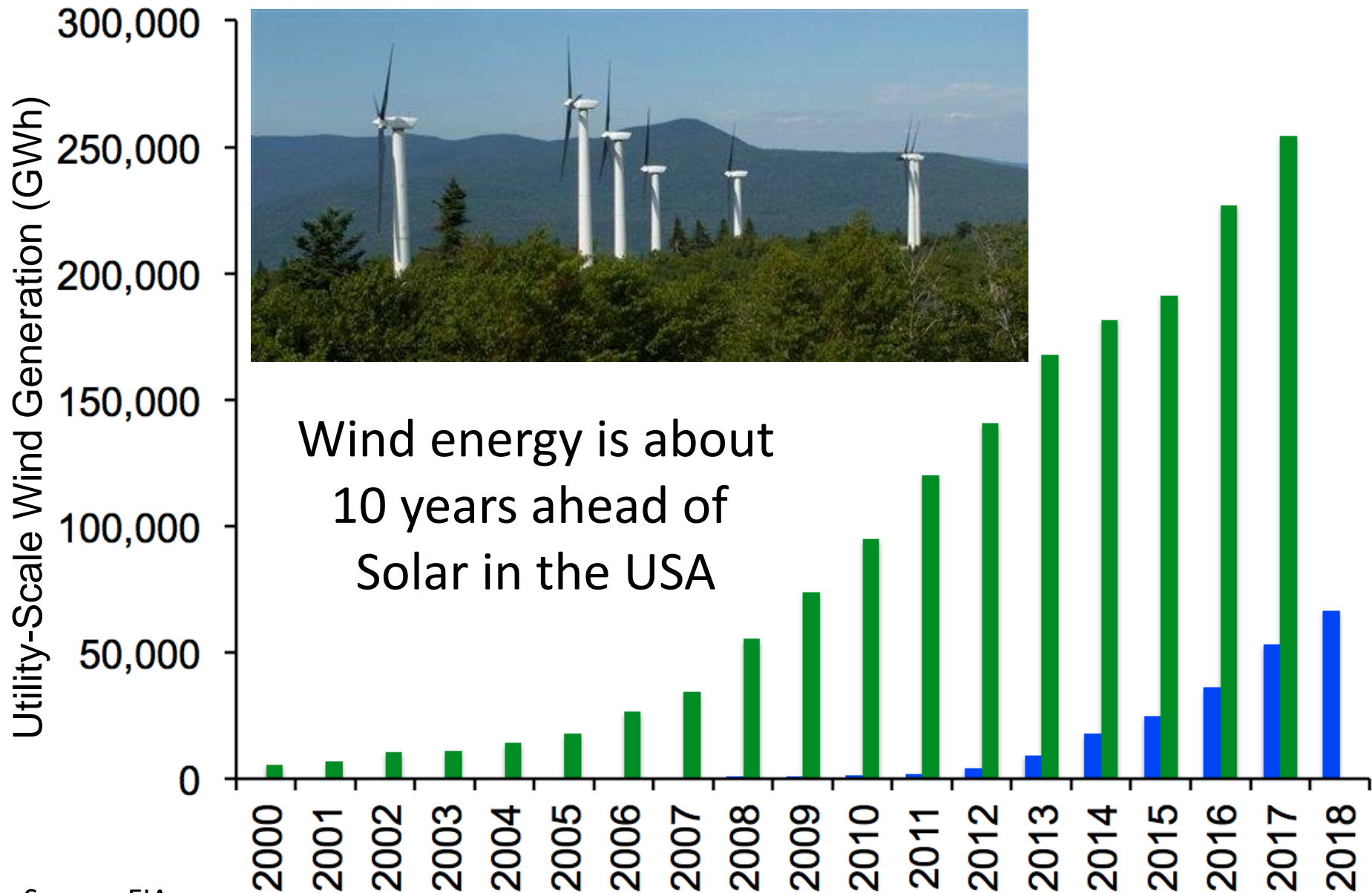


Source: EIA

# Solar Power Generation is Exploding in the USA

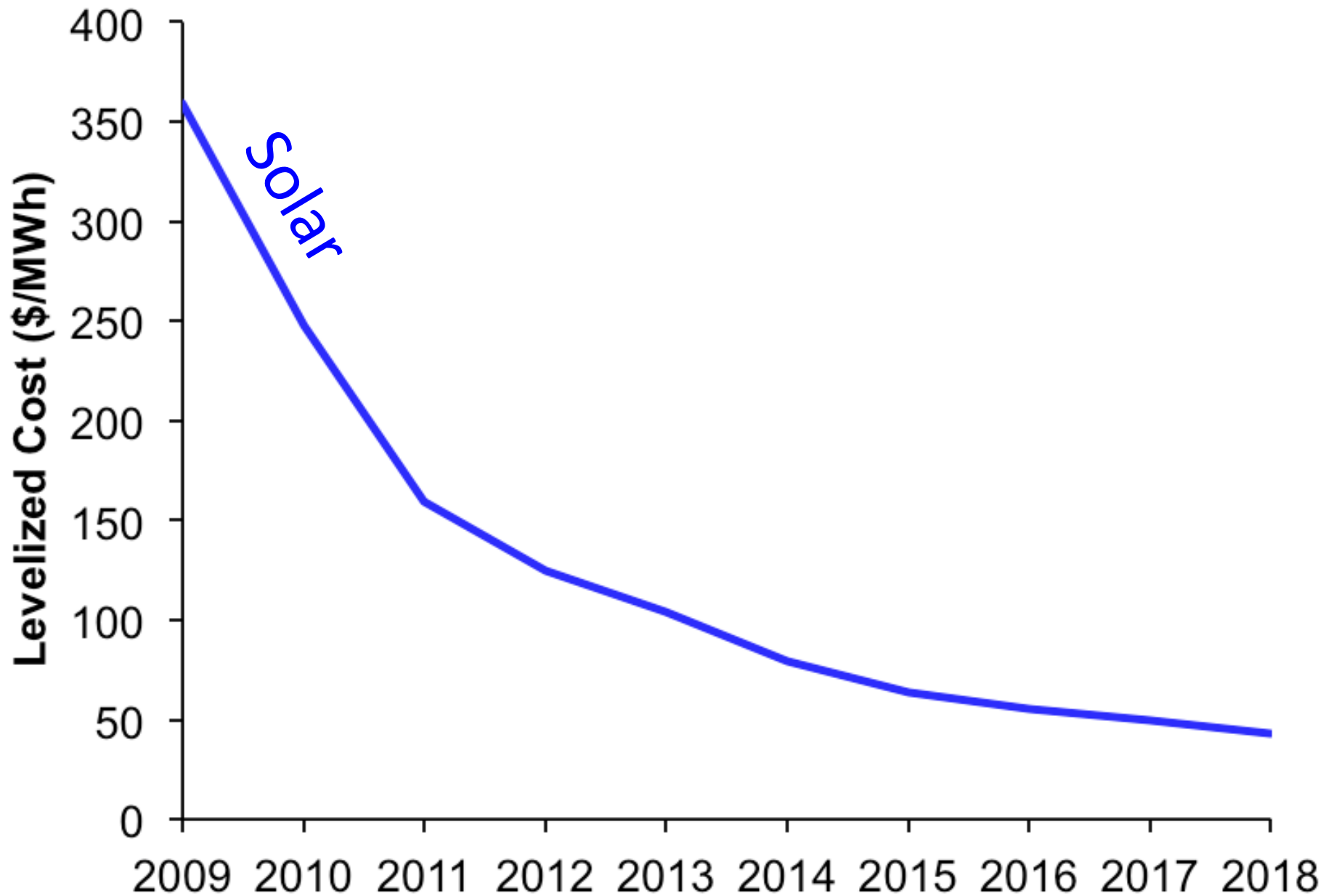


# Wind Power is Exploding Too

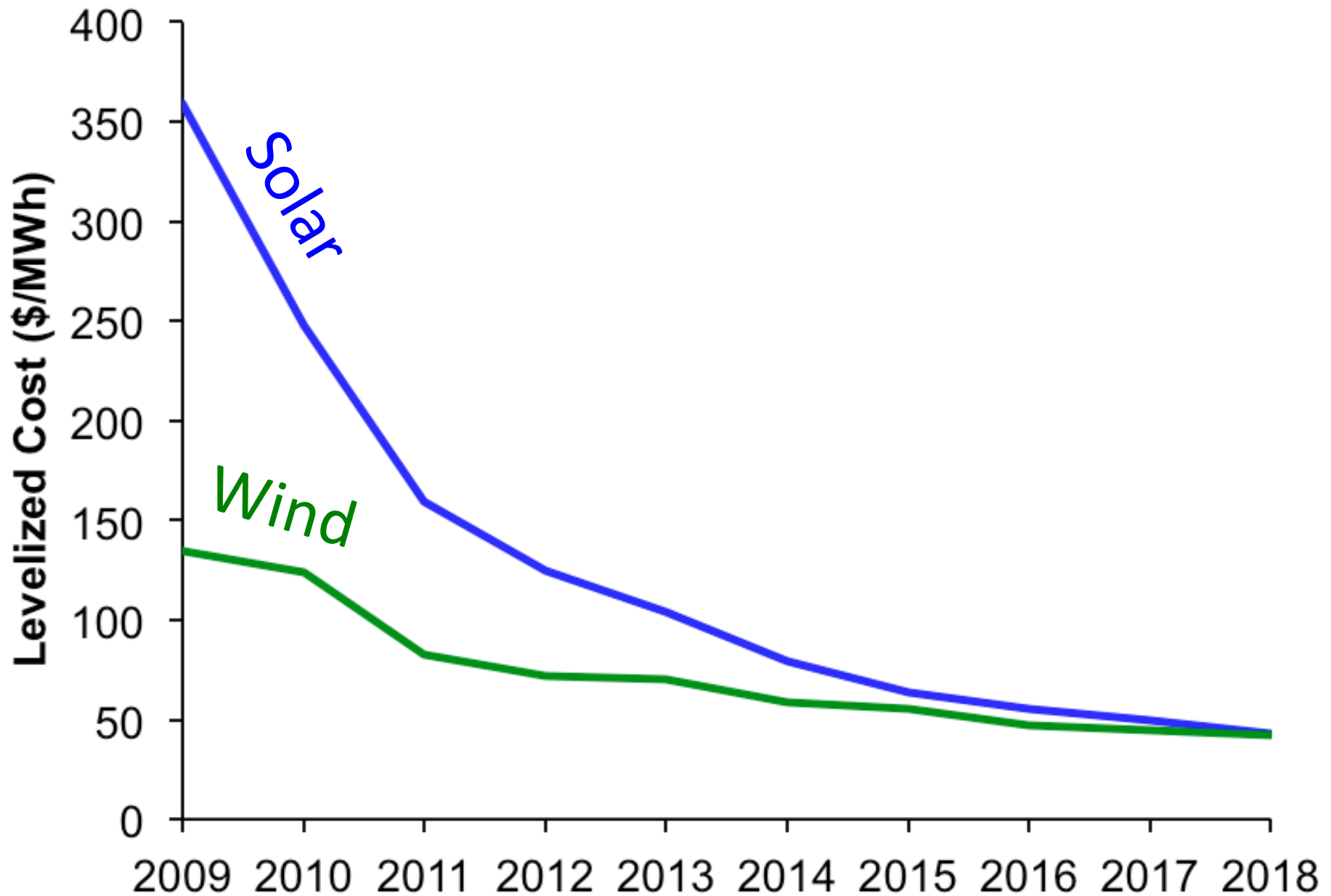




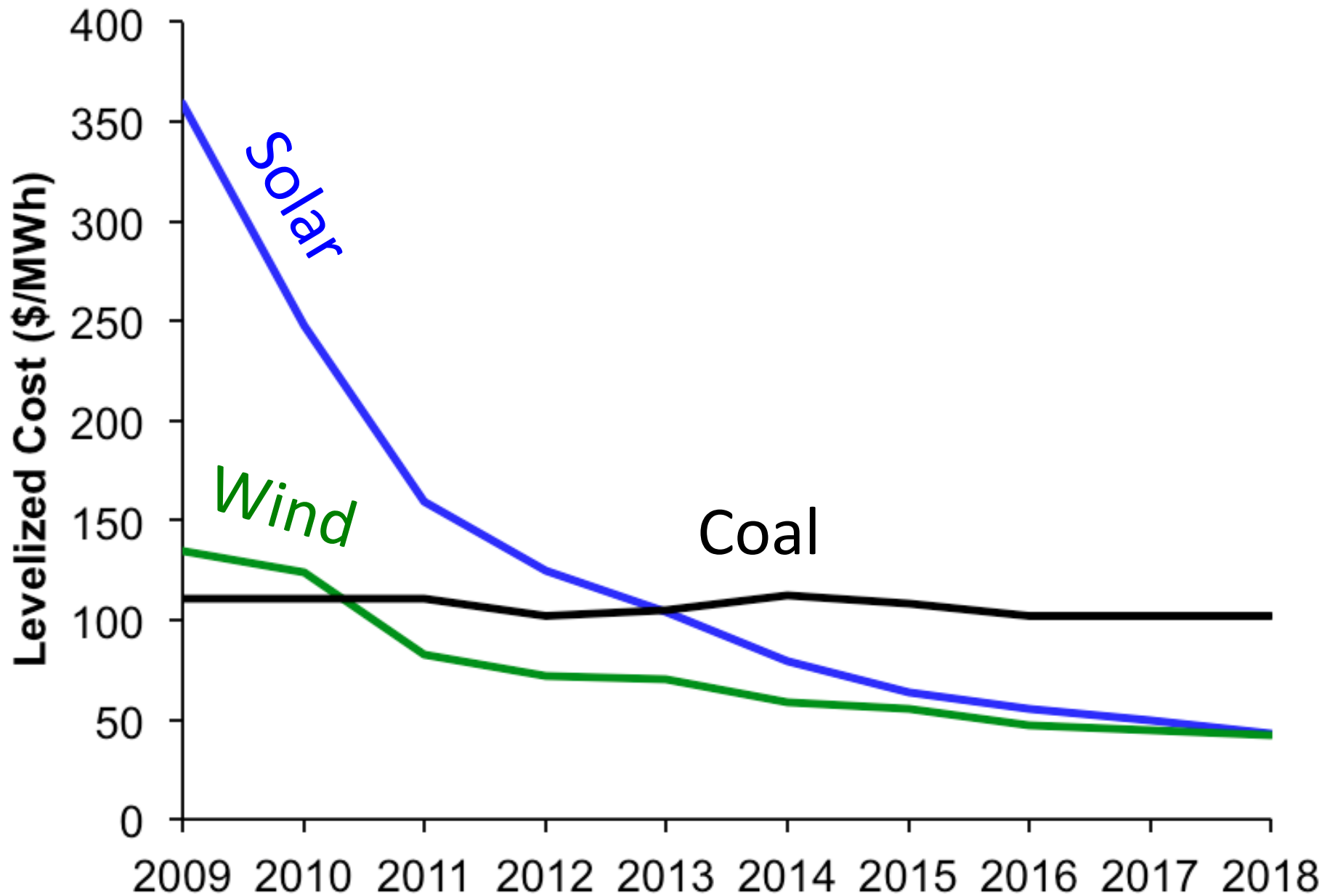
# Renewable Power Growth Driven By Falling Costs



# Renewable Power Growth Driven By Falling Costs

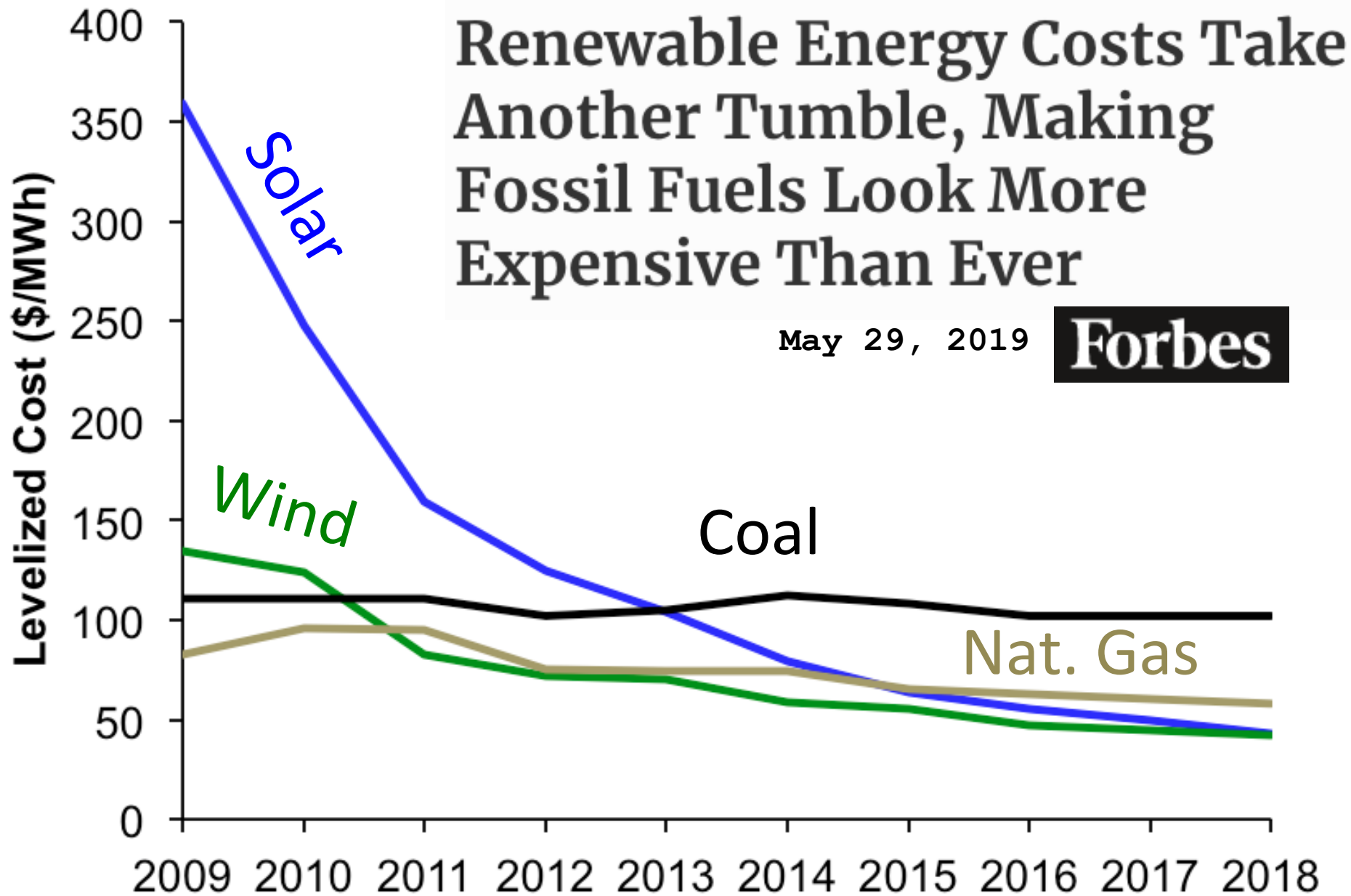


# Renewable Power Growth Driven By Falling Costs





# Renewable Power Growth Driven By Falling Costs



# U.S. companies could save \$78 billion by closing coal plants, finds new report



By Michelle Froese | December 5, 2018

The researchers say that China could save \$389 billion by closing plants in line with the Paris Climate Agreement instead of pursuing business as usual plans; the EU could save \$89 billion; the US could save \$78 billion; and Russia could save \$20 billion.

# What Can You Do?

- **Purchase renewable power**
- **Consider energy with your major, long-term purchases (homes, cars, appliances)**
- **Skip 1 airplane flight a year – Train? Skype?**
- **Support companies that prioritize sustainability, and shop local products**
- **Support political candidates who prioritize this energy transformation – and VOTE!**



# Miami Beach: Sea Level 23 Feet Higher



# London: Sea Level 23 Feet Higher



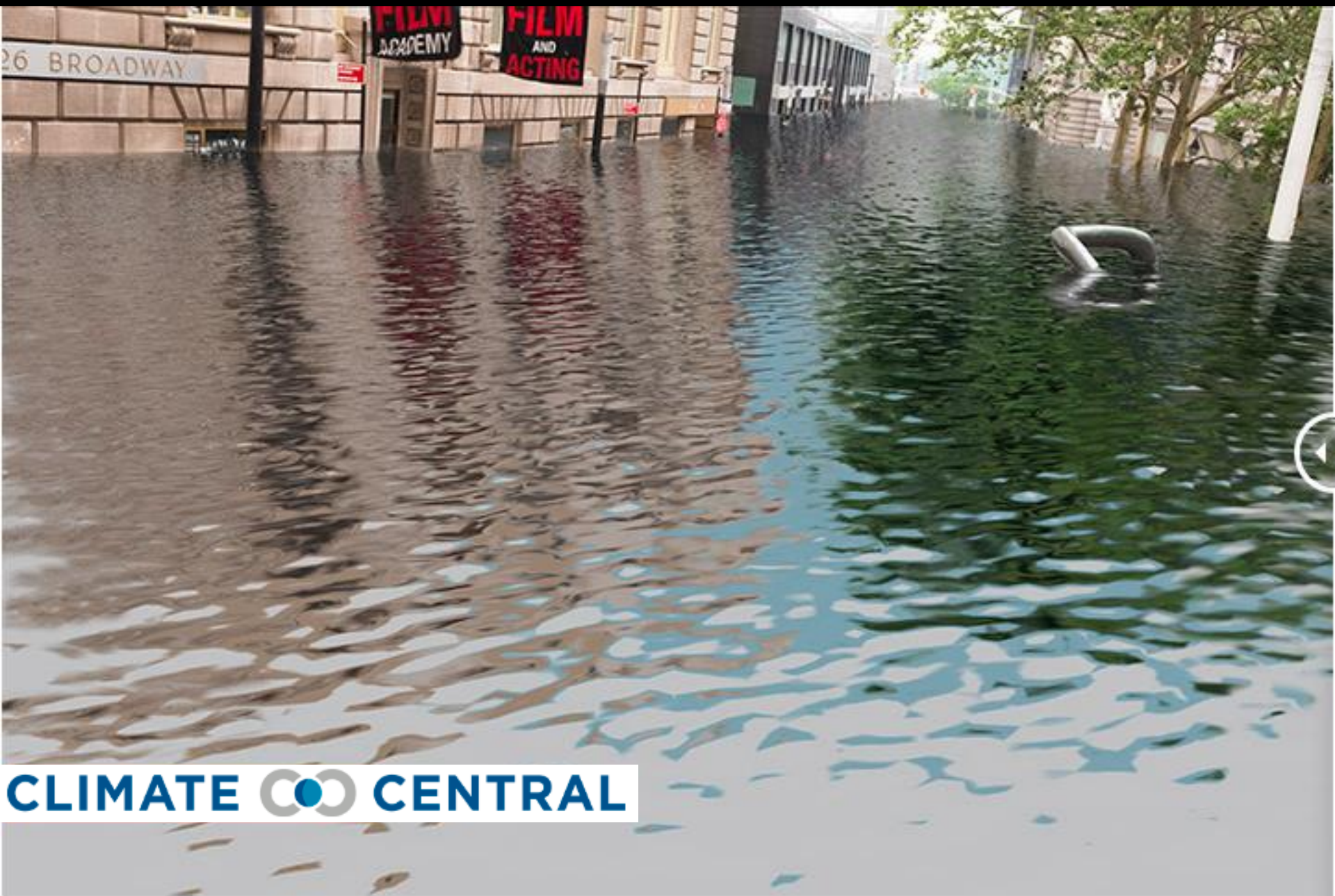
CLIMATE  CENTRAL





CLIMATE  CENTRAL





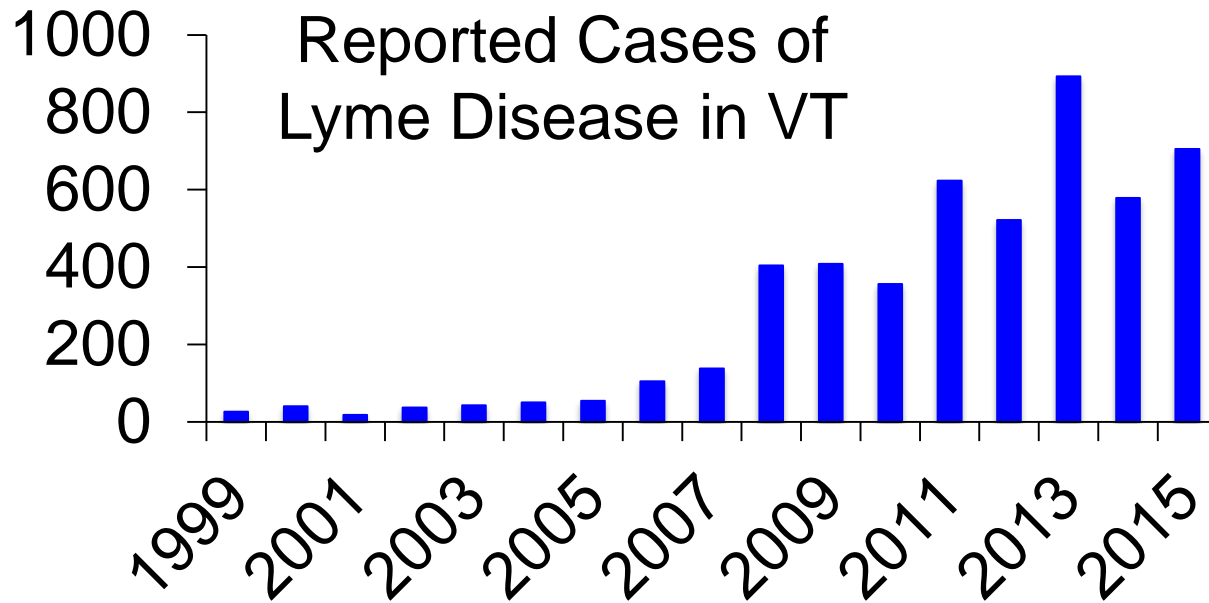
CLIMATE  CENTRAL



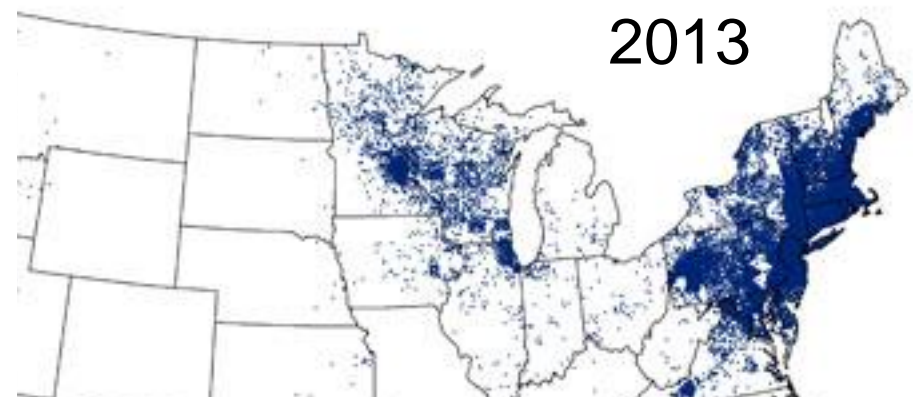
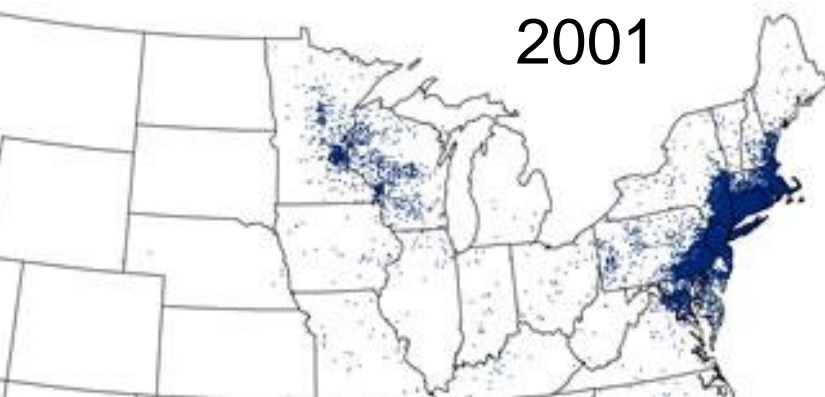
# New York: Sea Level 23 Feet Higher



# Increased Lyme Disease in NE with Warmer Winters



## Reported Cases of Lyme Disease



Centers for Disease Control and Prevention  
CDC 24/7: Saving Lives. Protecting People™



# Warmer Winters Allow the Ticks to Survive and Multiply





# 70% Of N.H. Moose Calves Died from Tick Infestation from 2014-2016 (Jones et al., 2018)





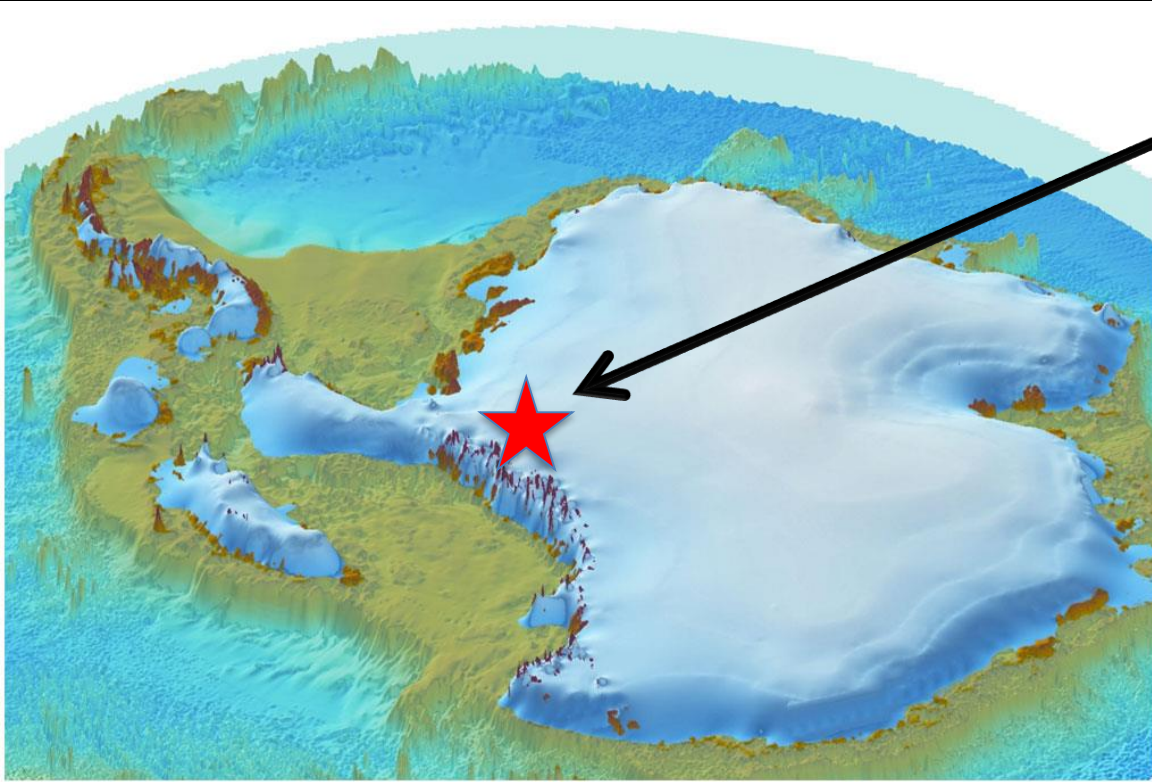






# How Fast did West Antarctica Melt during Past Naturally Warmer Times?

Antarctica: 6-12 Feet of Sea Level



## Our Plan:

Collect an ice core from Hercules Dome

Location was waterfront property 125,000 years ago!

125,000 Years Ago;  
Sea Level 16-20 Feet Higher  
Temperatures only 2-4° F Warmer



# How Fast did Greenland Melt during Past Naturally Warmer Times?

PNAS

**Pronounced summer warming in northwest Greenland during the Holocene and Last Interglacial**

Jamie M. McFarlin<sup>a,1</sup>, Yarrow Axford<sup>a</sup>, Magdalena R. Osburn<sup>a</sup>, Meredith A. Kelly<sup>b</sup>, Erich C. Osterberg<sup>b</sup>, and Lauren B. Farnsworth<sup>b</sup>

*New Paper!*

Two warm periods in Greenland:

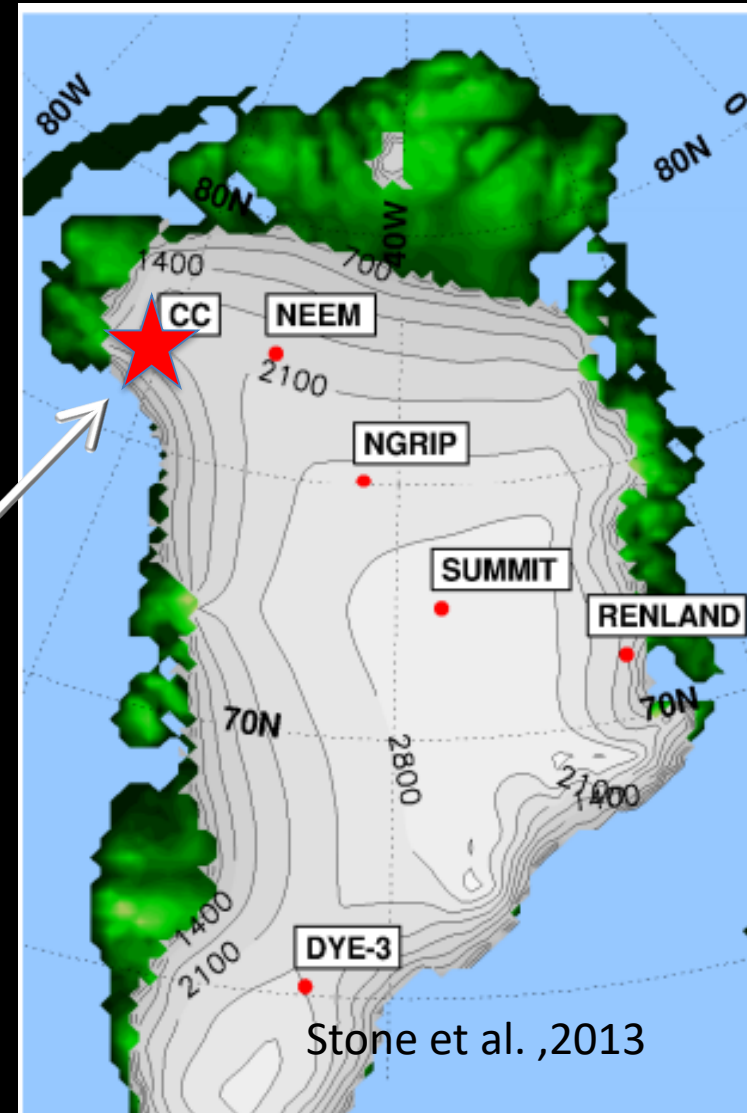
1. 7,000-10,000 years ago
2. 125,000 years ago

Summer temperatures similar to 2050-2100 projections

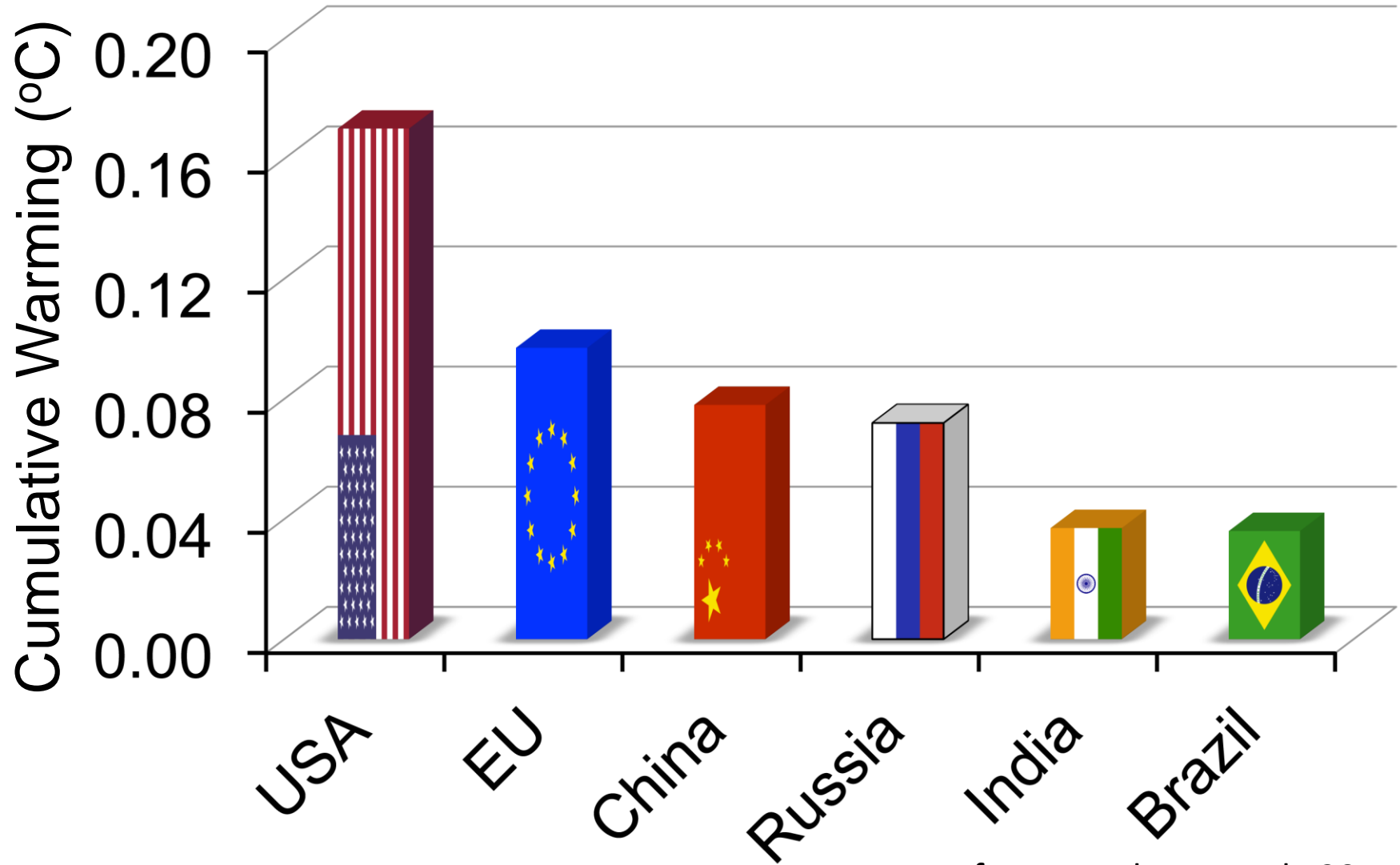
Our Plan:

Collect a new ice core (star) to see how quickly NW Greenland melted during both periods

Greenland: 3-6 Feet



# Cumulative Warming from CO<sub>2</sub> by Country



Data from Matthews et al., 2014

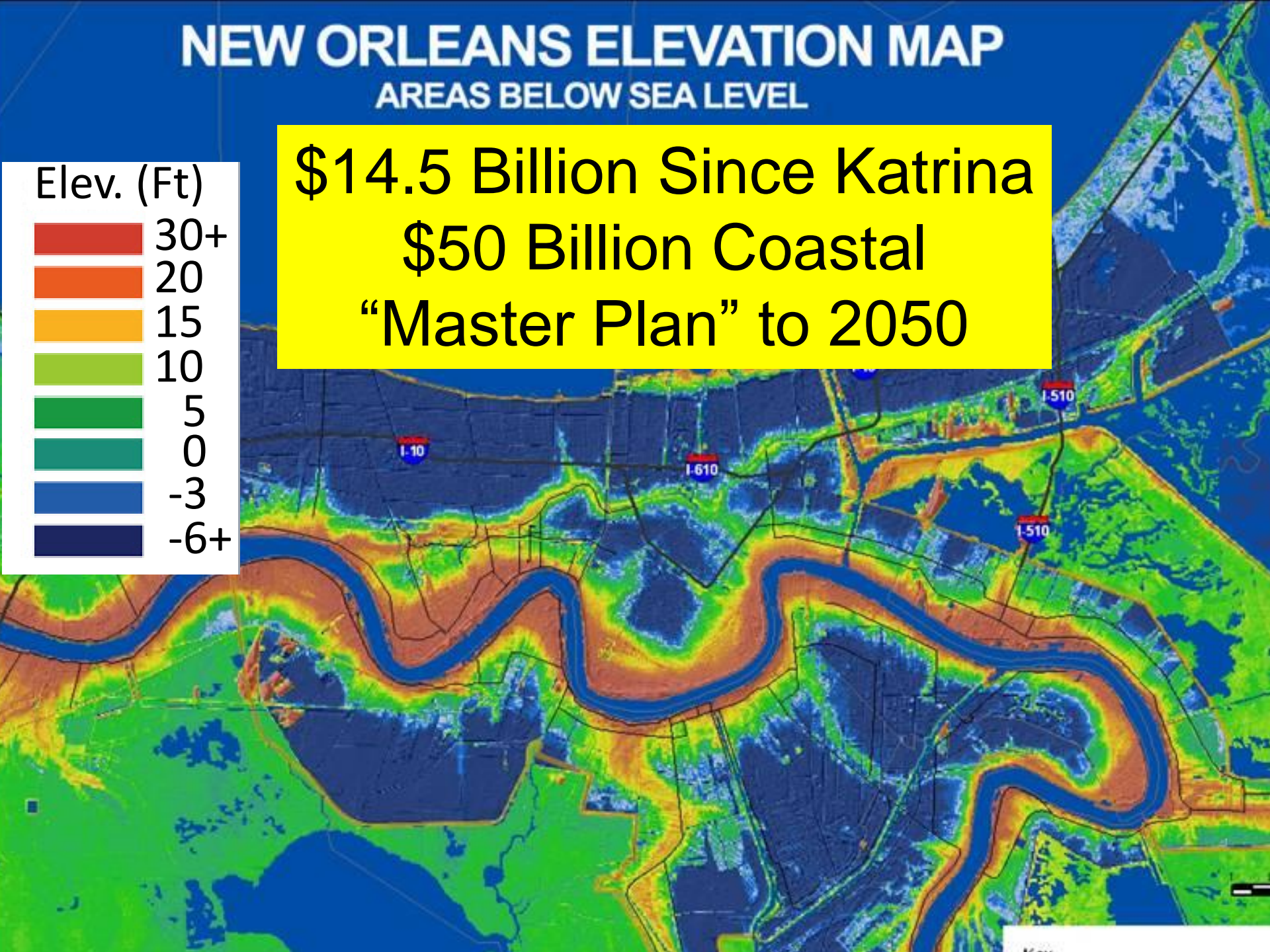
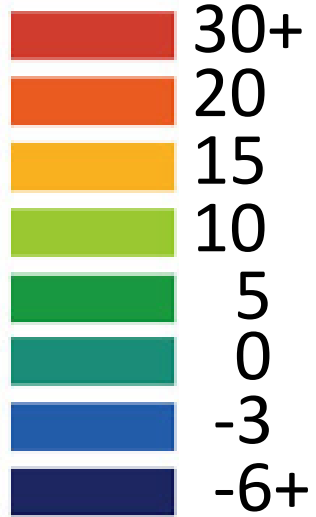


# NEW ORLEANS ELEVATION MAP

## AREAS BELOW SEA LEVEL

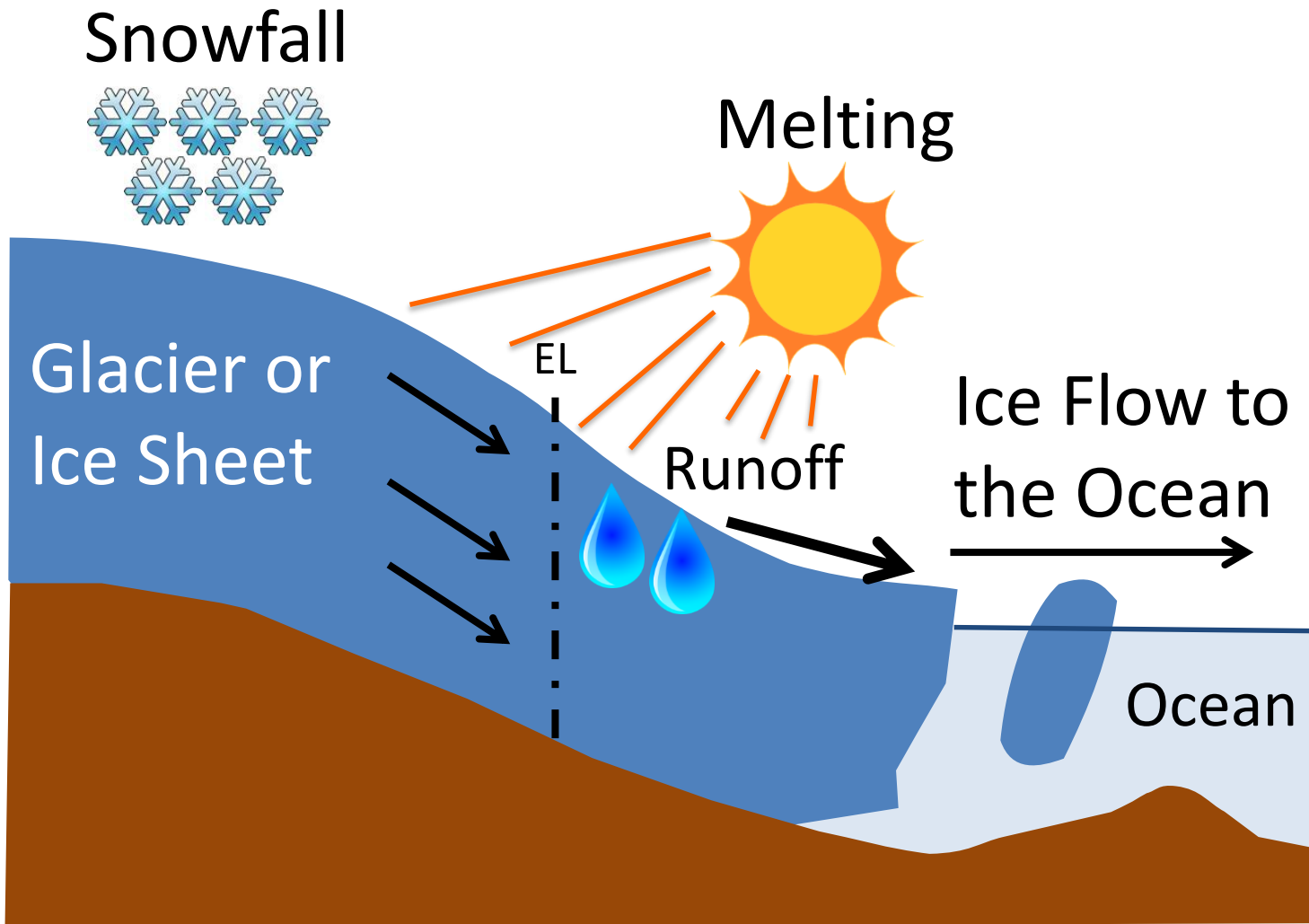
**\$14.5 Billion Since Katrina  
\$50 Billion Coastal  
“Master Plan” to 2050**

Elev. (Ft)

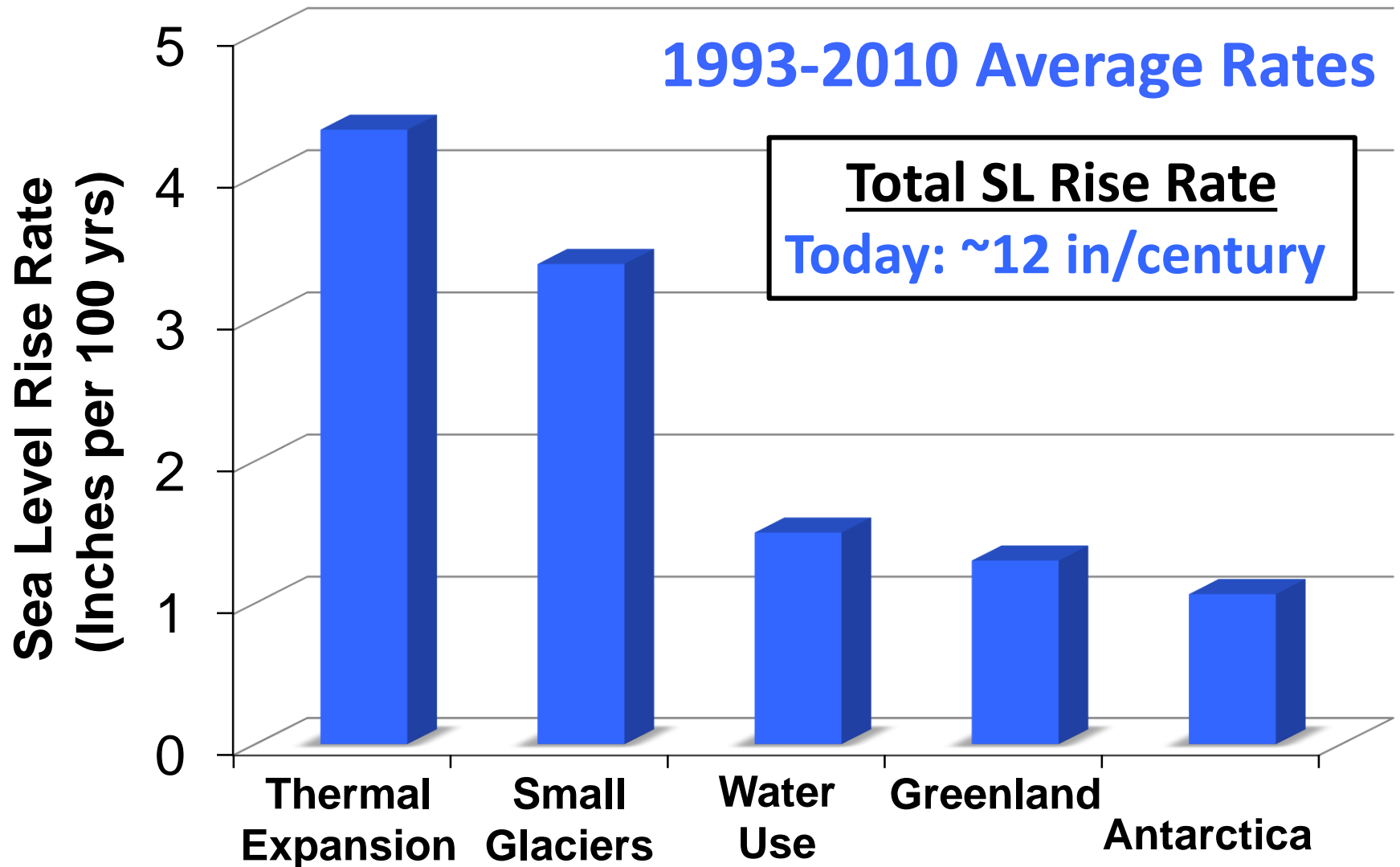


# Glaciers are a Balance Between Snowfall and Melting

Mass Balance:  $\text{Snowfall} \stackrel{?}{=} \text{Melting} + \text{Ice Flow}$



# Why is Sea Level Rising?



Data from IPCC, 2013



# Greenland and Antarctica are the Elephants

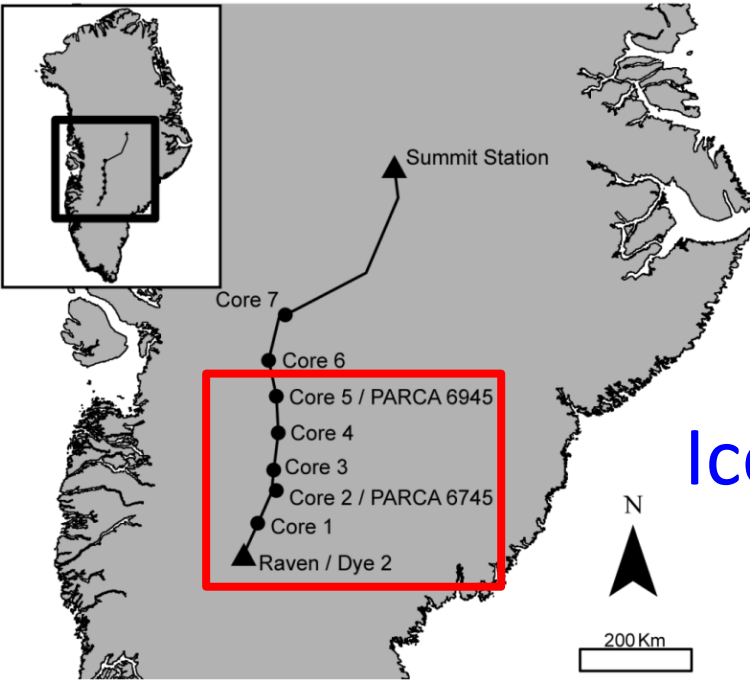


22 Feet



West: 16 Feet  
East: 190 Feet

# Greenland Melting Really Increased in 1997



Ice Core 3

1997

Amount of Melted Ice  
(m per year)

Amount of Melted Ice  
(m per year)

Ice Core 1

Graeter, Osterberg  
et al., in review

1965 1975 1985 1995 2005 2015



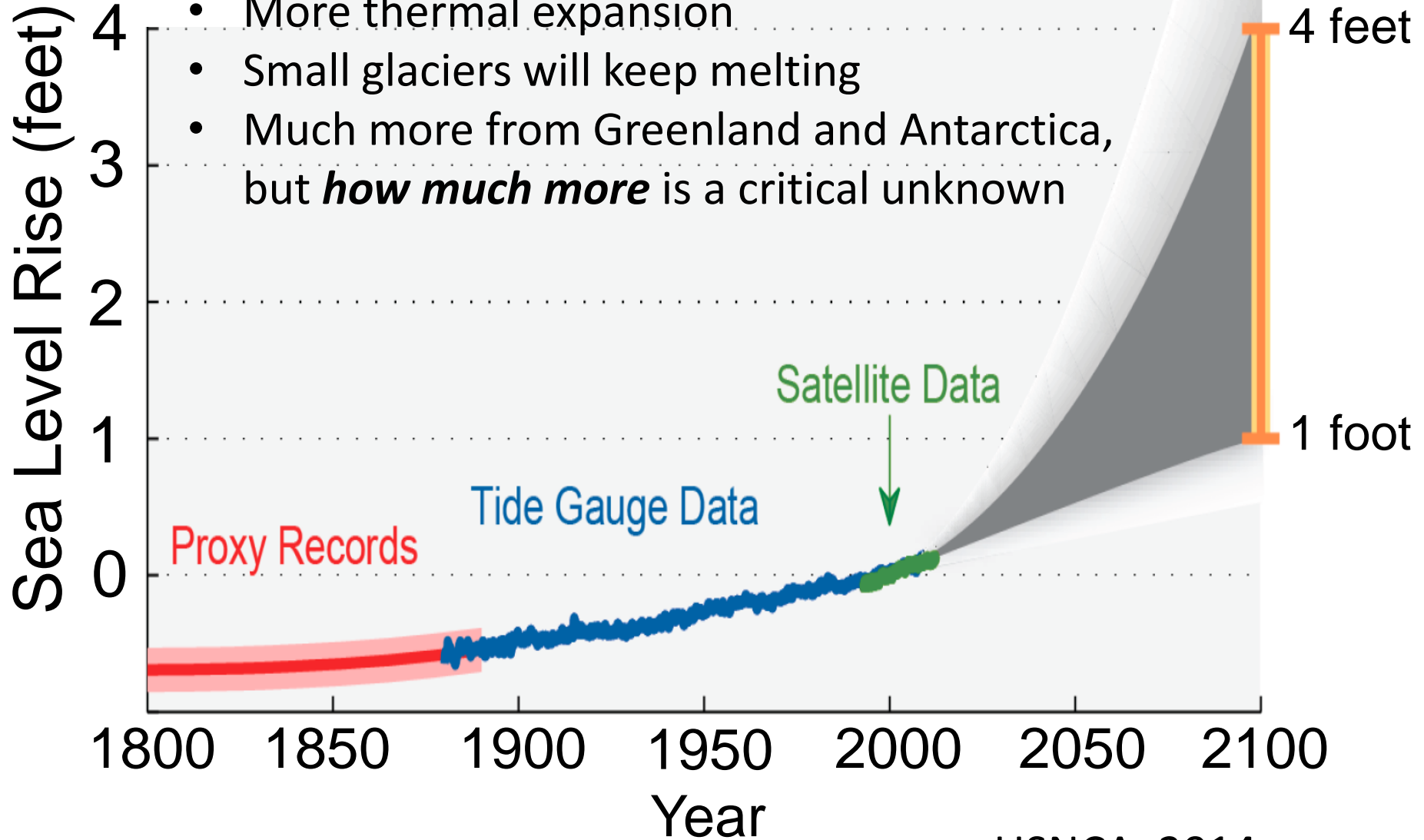
# Thule 2012 Expedition





# Our Choice: 1-4 Feet of Global SL Rise by 2100

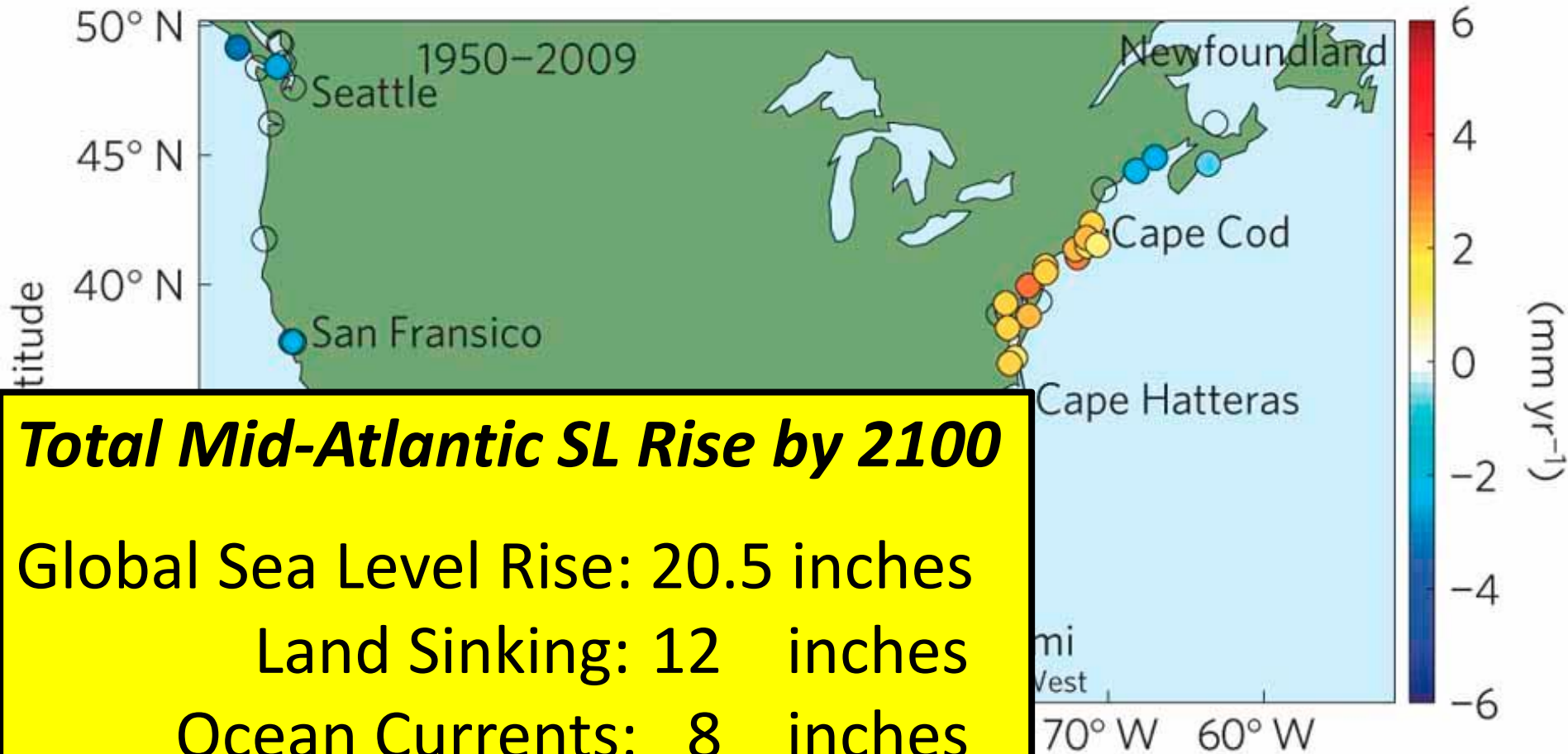
- More thermal expansion
- Small glaciers will keep melting
- Much more from Greenland and Antarctica, but ***how much more*** is a critical unknown



USNCA, 2014

# The US East Coast is a Sea Level Rise “Hotspot”

*Mid-Atlantic sea level is rising faster than average*



## ***Total Mid-Atlantic SL Rise by 2100***

Global Sea Level Rise: 20.5 inches

Land Sinking: 12 inches

Ocean Currents: 8 inches

---

**TOTAL: 40.5 inches**

Sallenger et al., 2012

# 2017 Hurricane Season: A Sign of Things to Come?

- ***Very likely more cat 3-5 hurricanes in the future***
- ***Possibly fewer weak hurricanes...jury still out***





New York: 100 yr flood (e.g. A Sandy!)  
every 10-22 years by 2100

NY Damage: \$33 Billion  
USA Damage: \$65 Billion



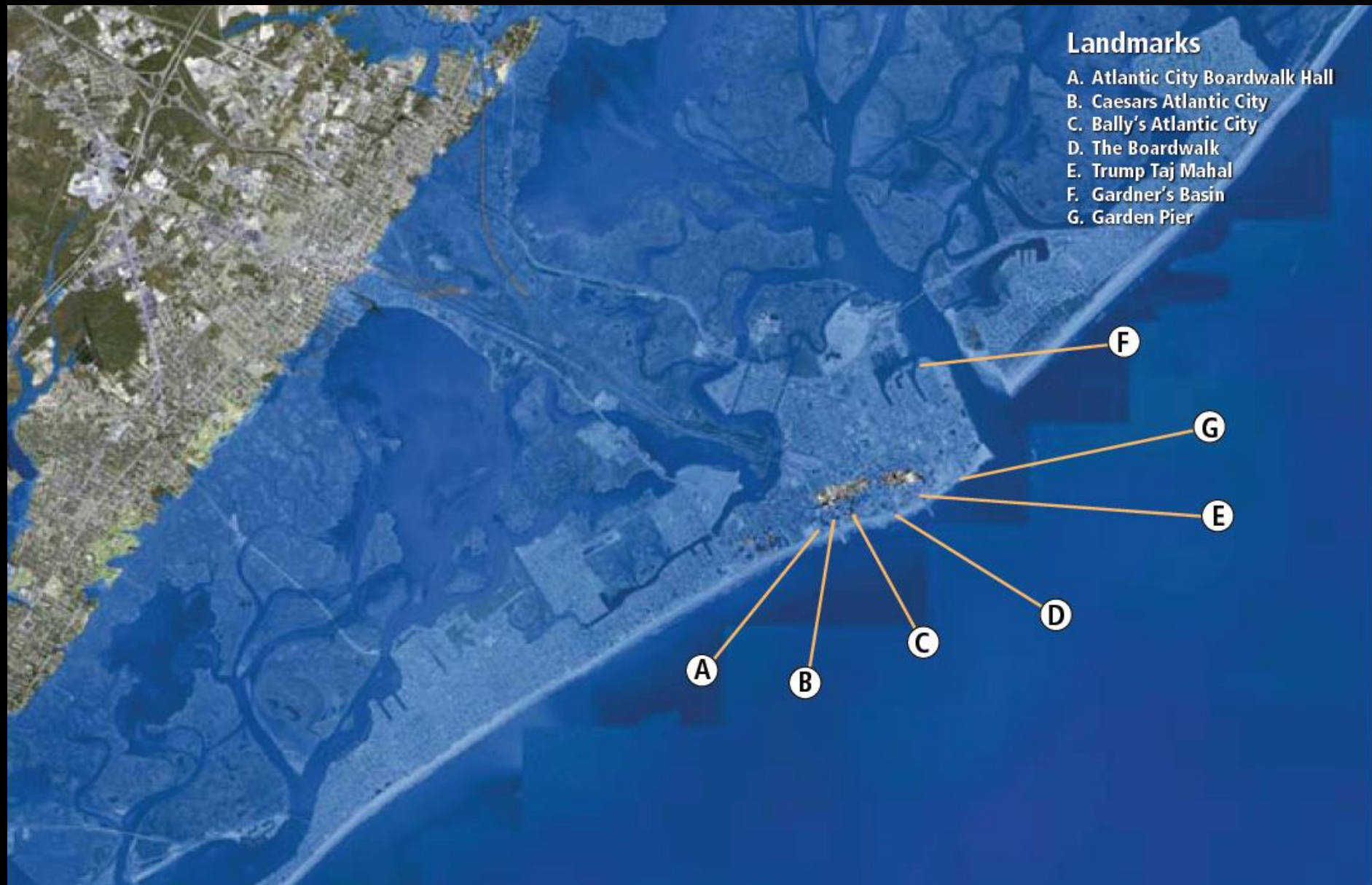
# New York: Actual Sandy Flooding





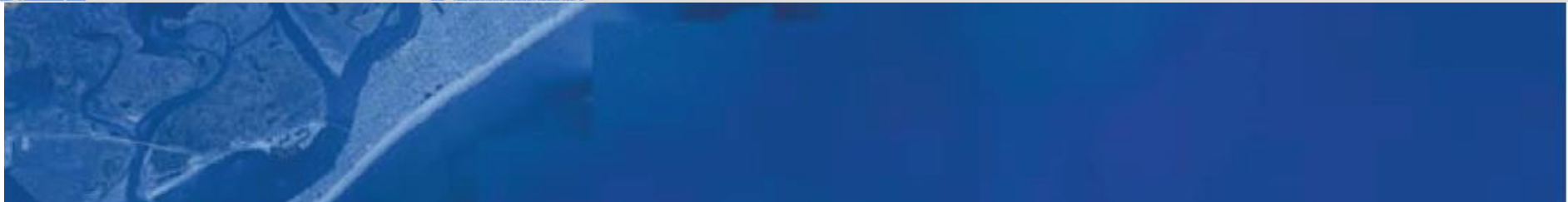
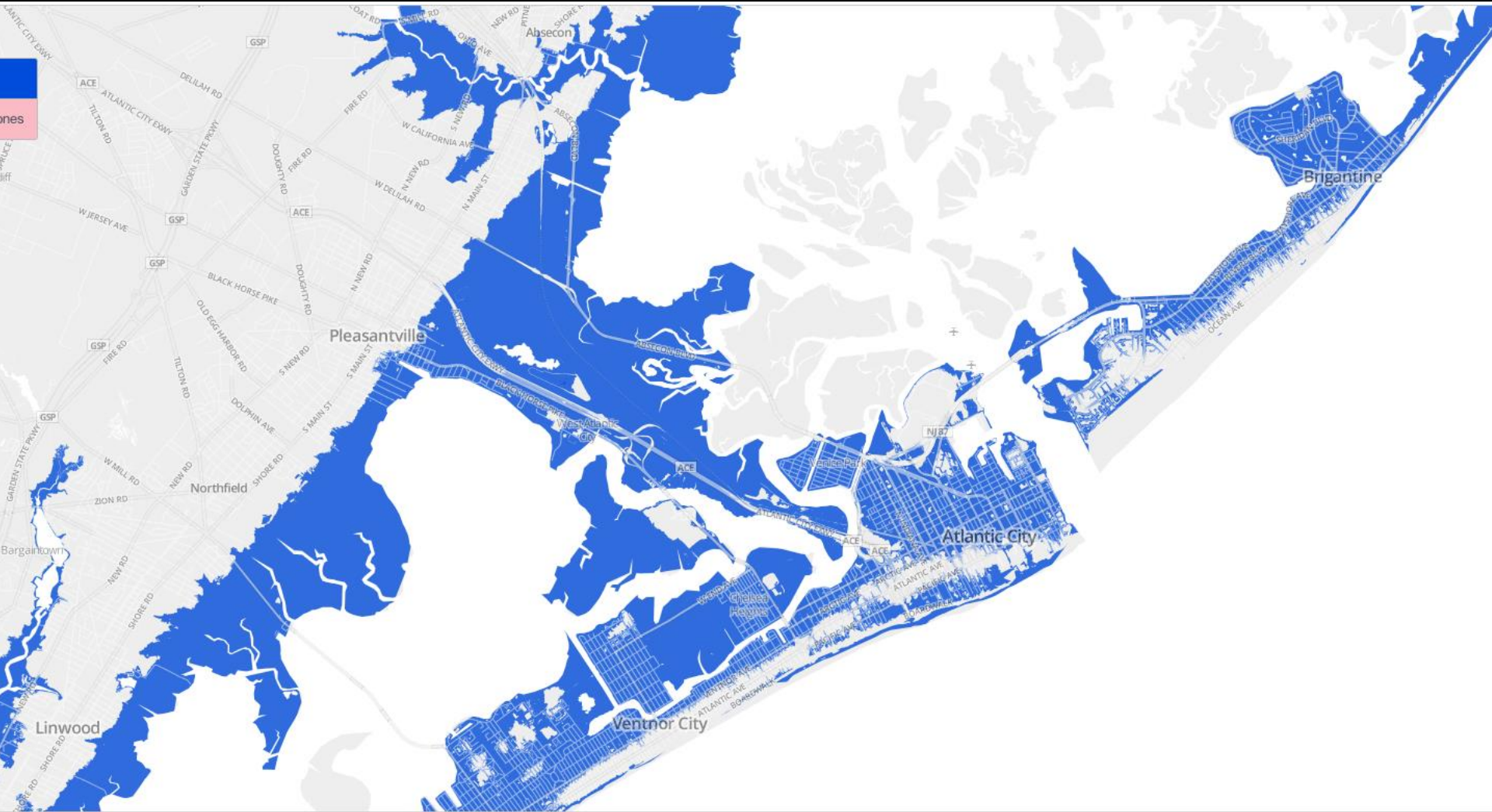
# Atlantic City: 100 year flood (a Sandy!)

## Every 1-2 years by 2100



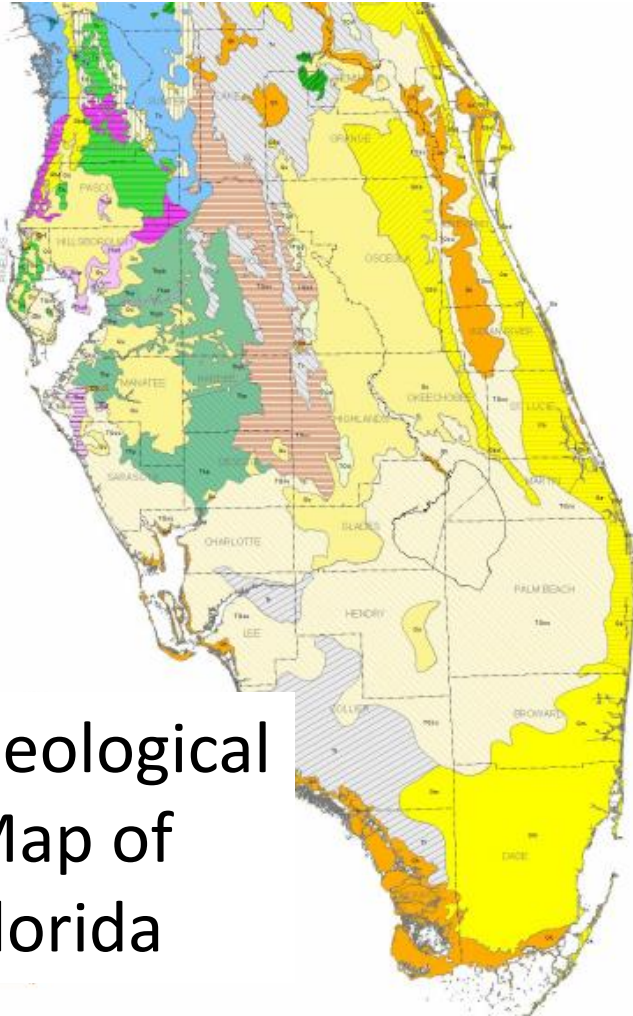


# Atlantic City: Actual Sandy Flooding



# What About Florida?

Miami: \$500 Million  
plan in process



Geological  
Map of  
Florida



## THE SIEGE OF MIAMI

*As temperatures climb, so, too, will sea levels.*

THE  
NEW YORKER

December, 2015



# When Rising Seas Transform Risk Into Certainty

Along parts of the East Coast, the entire system of insuring coastal property is beginning to break down.

By BROOKE JARVIS APRIL 18, 2017

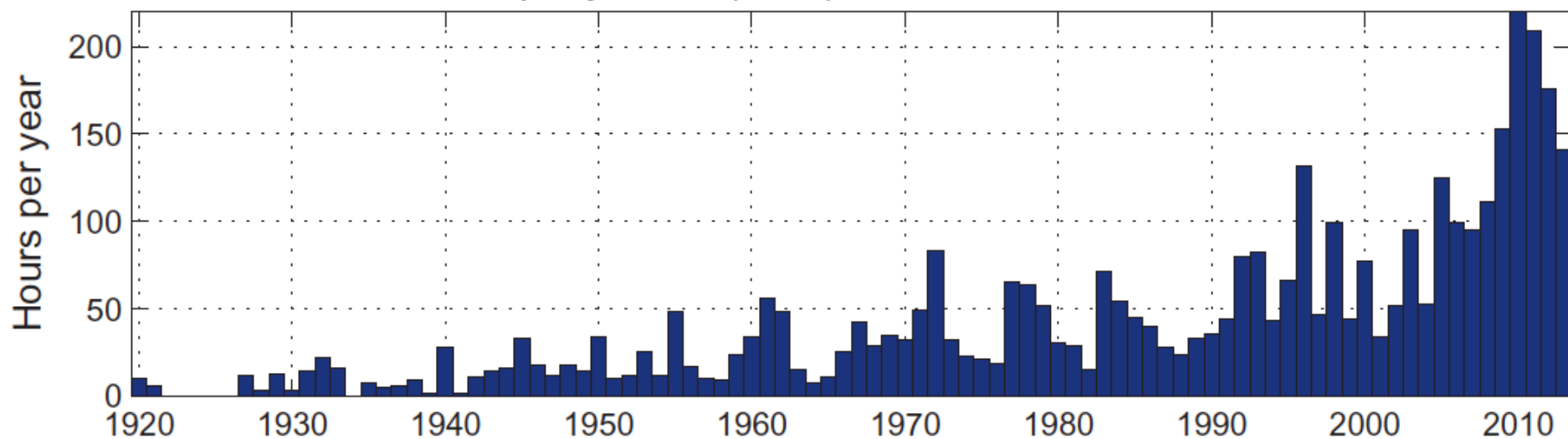
The New York Times



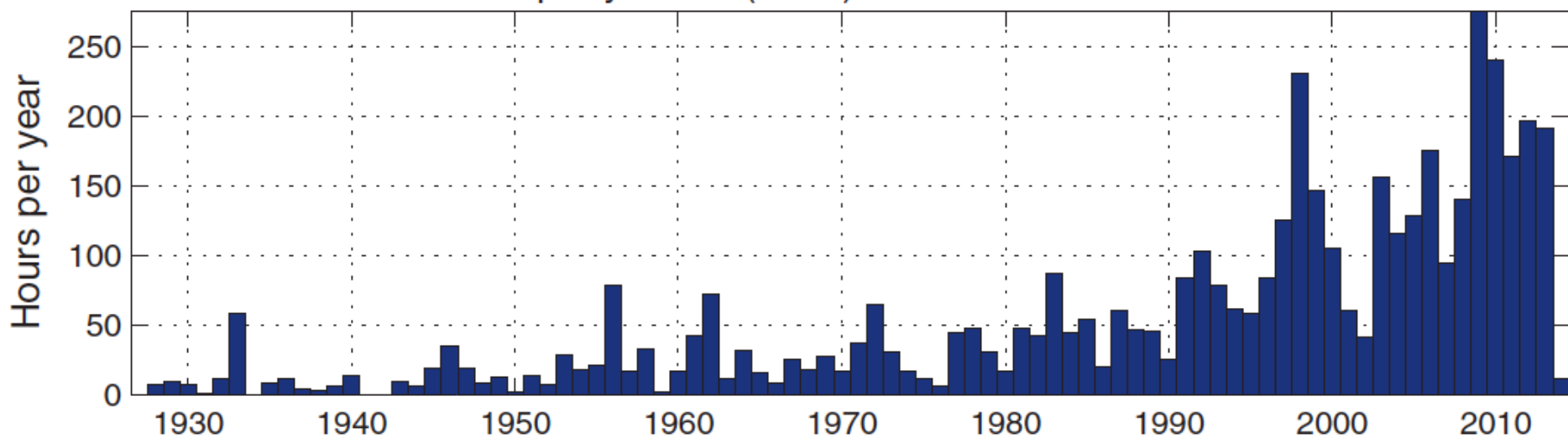


# Minor Flooding is already on the Rise

Hours per year 1ft (0.3m) above MHHW in New York

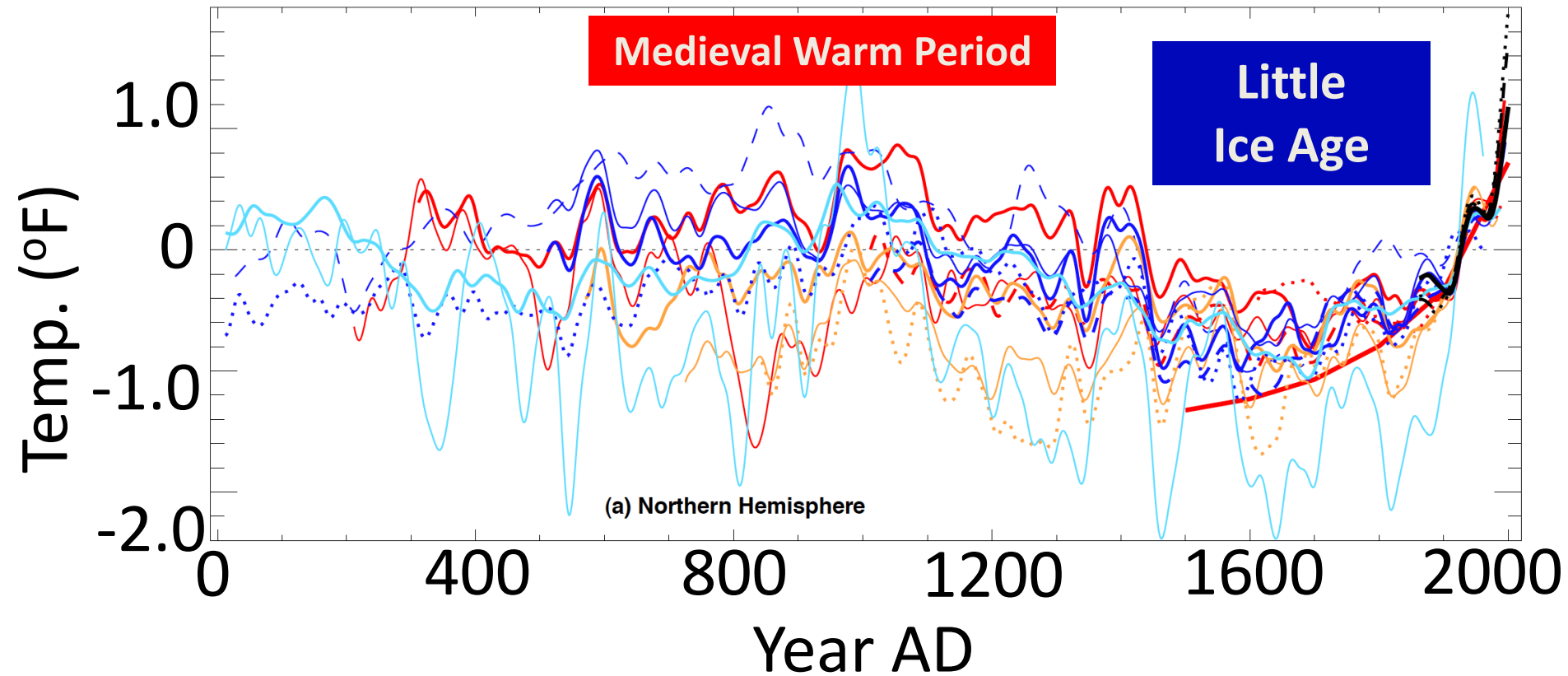


Hours per year 1ft (0.3m) above MHHW in Norfolk



# Temperature over the Past 2000 Years

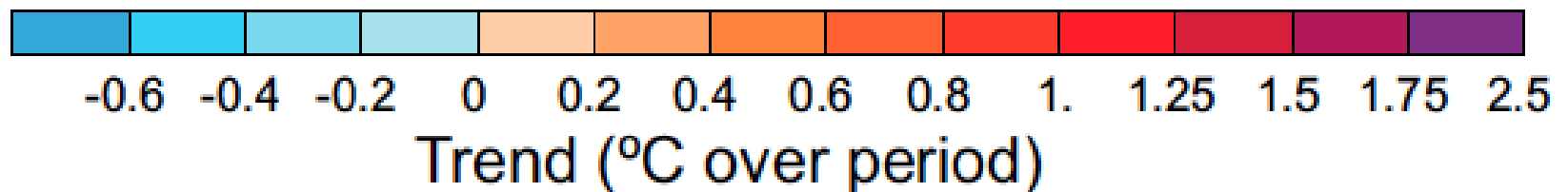
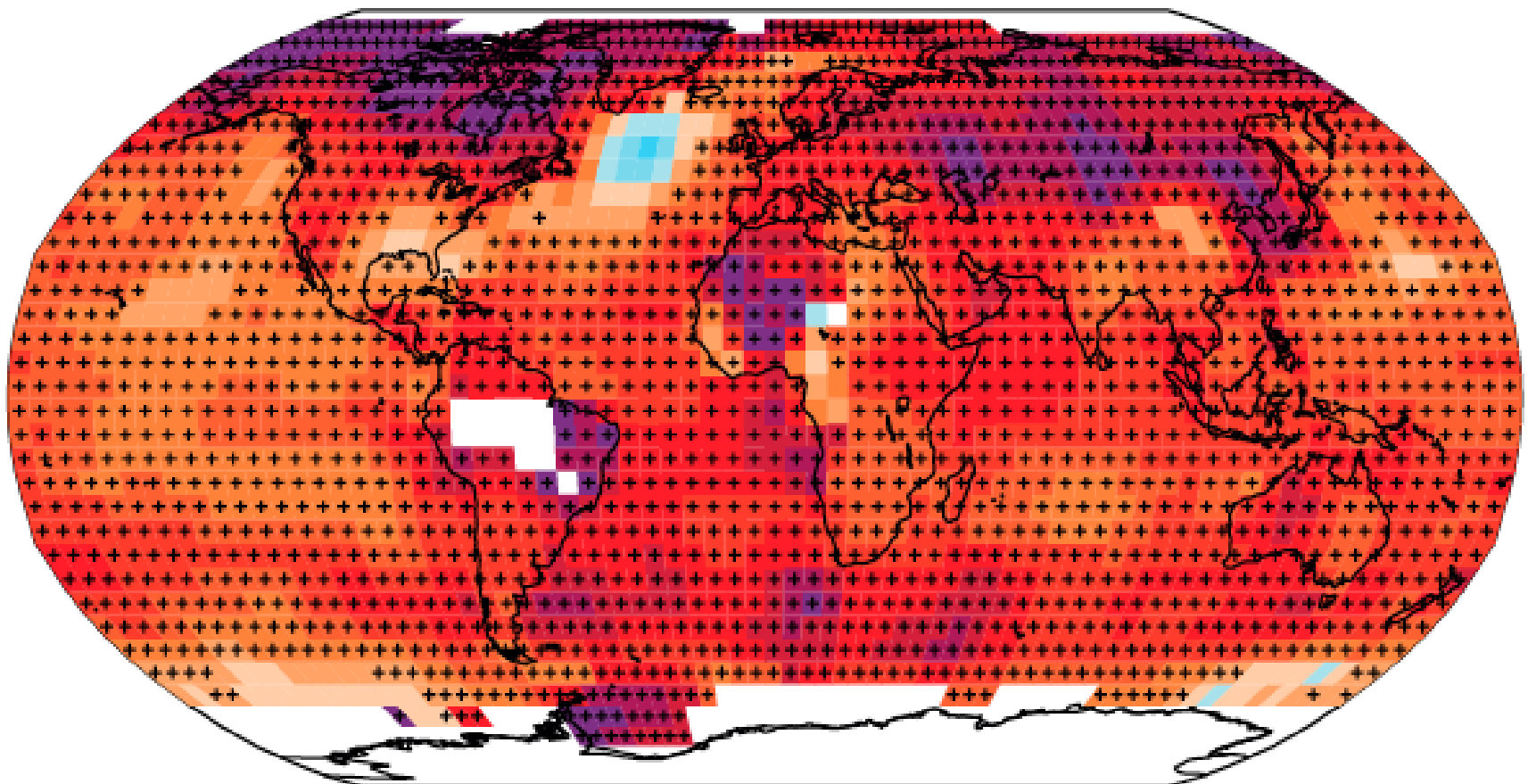
We came out of the (natural) Little Ice Age ~1850 AD



IPCC, 2013

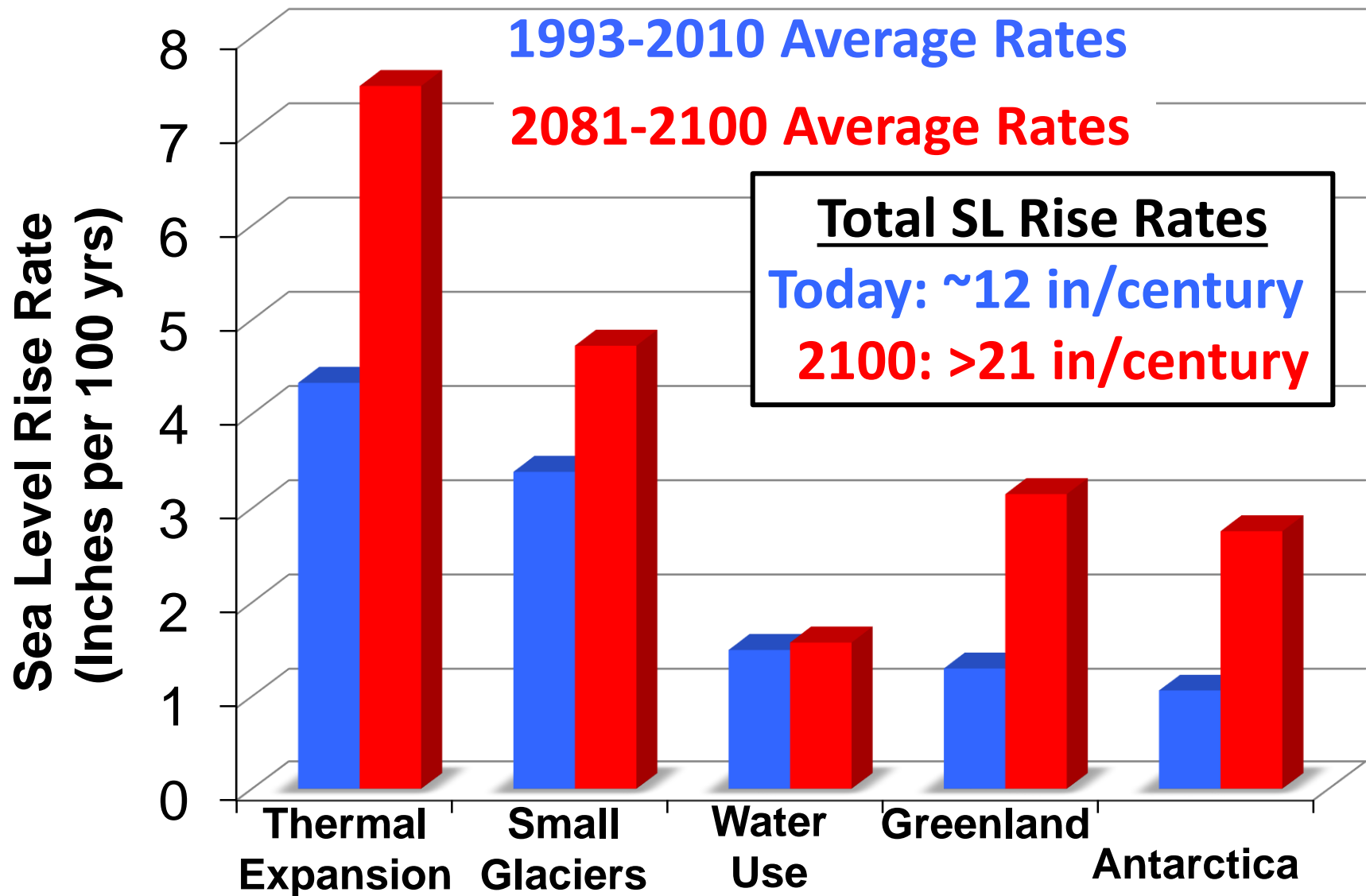
# Largest Warming in the Arctic Region

GISS 1901-2012

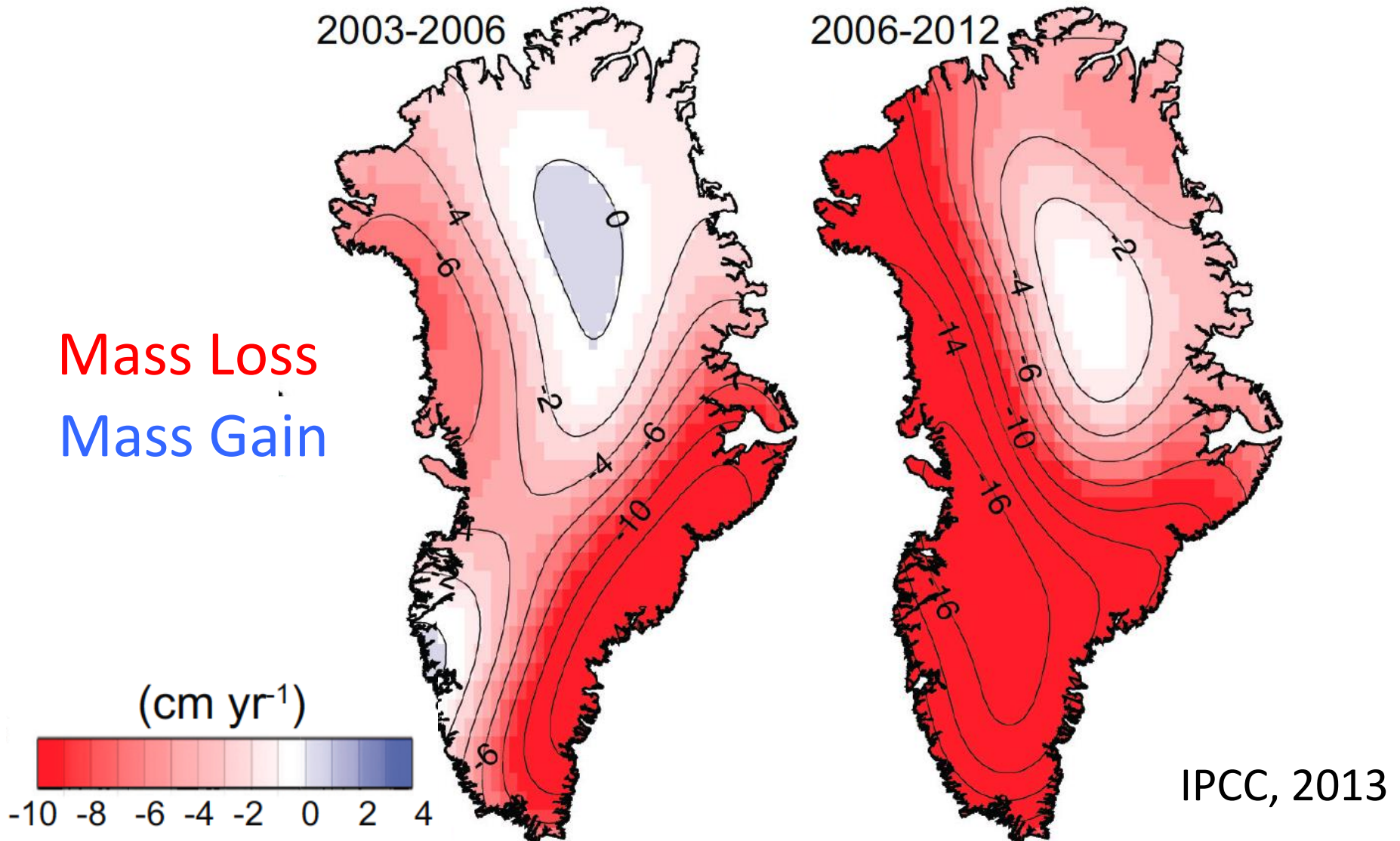




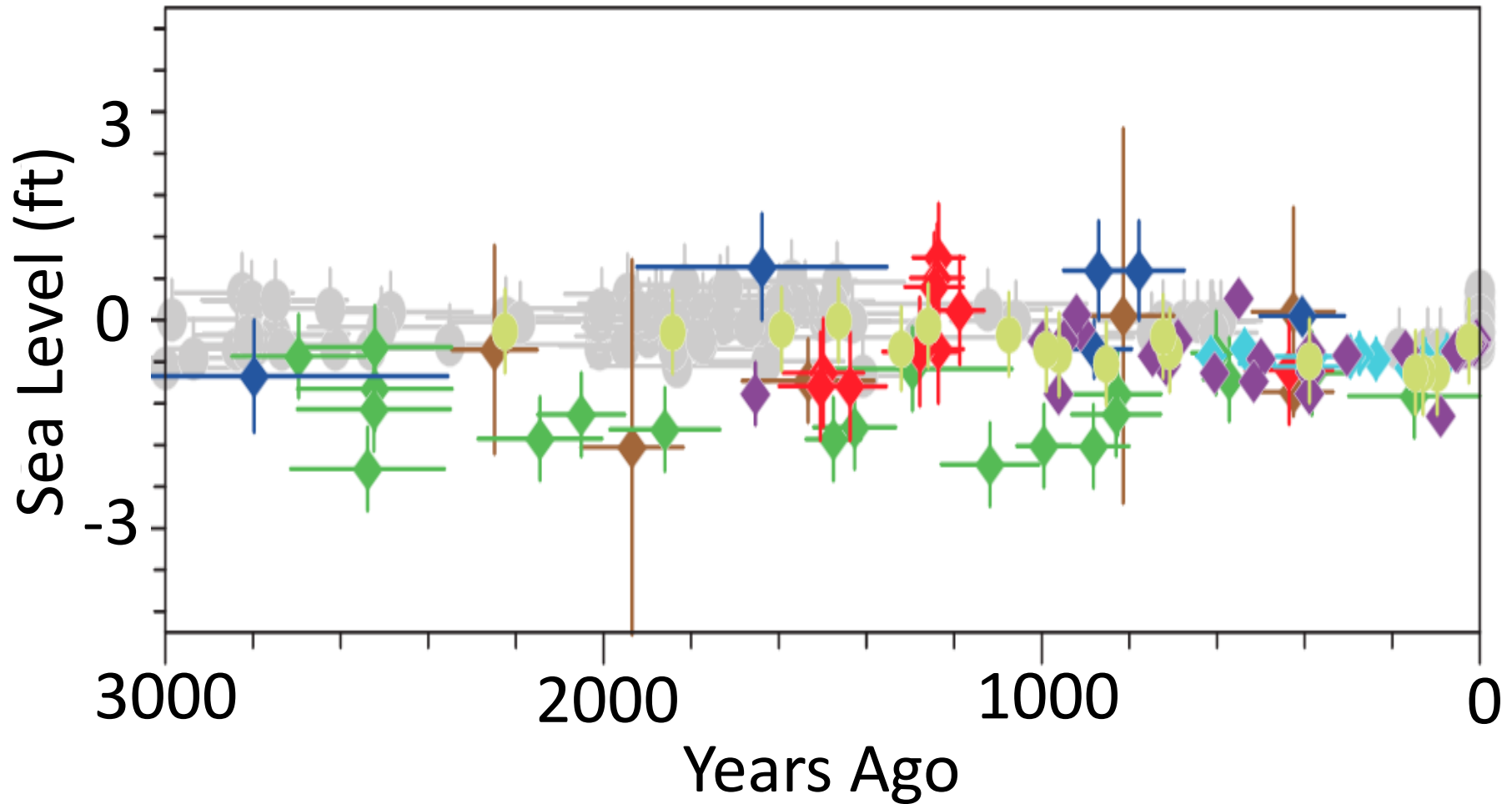
# Compare Sea Level Rise: Today vs. 2100



# Greenland Melting is Speeding Up

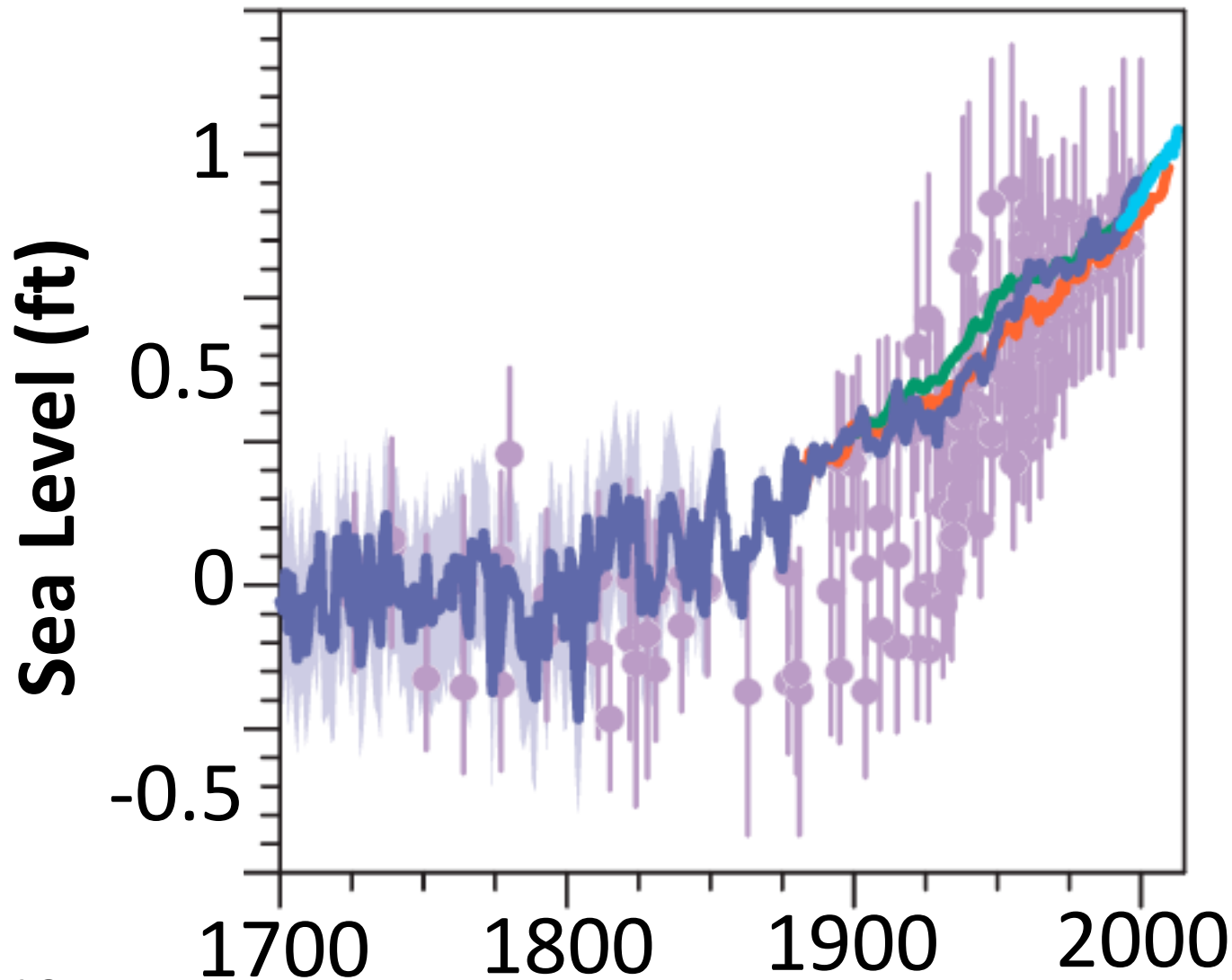


# Sea Level *had* been Stable for ~3000 Years...





...Until it Started Rising ~1900 AD



Mt. Hunter Ice Core Site  
13,000 Feet high  
Denali National Park,  
Alaska



Dartmouth's "Denali Campus"





Mt. Hunter Ice Core Site  
13,000 Feet high  
Denali National Park, Alaska





# Studying Denali Climate and Glaciers: Past 500 years



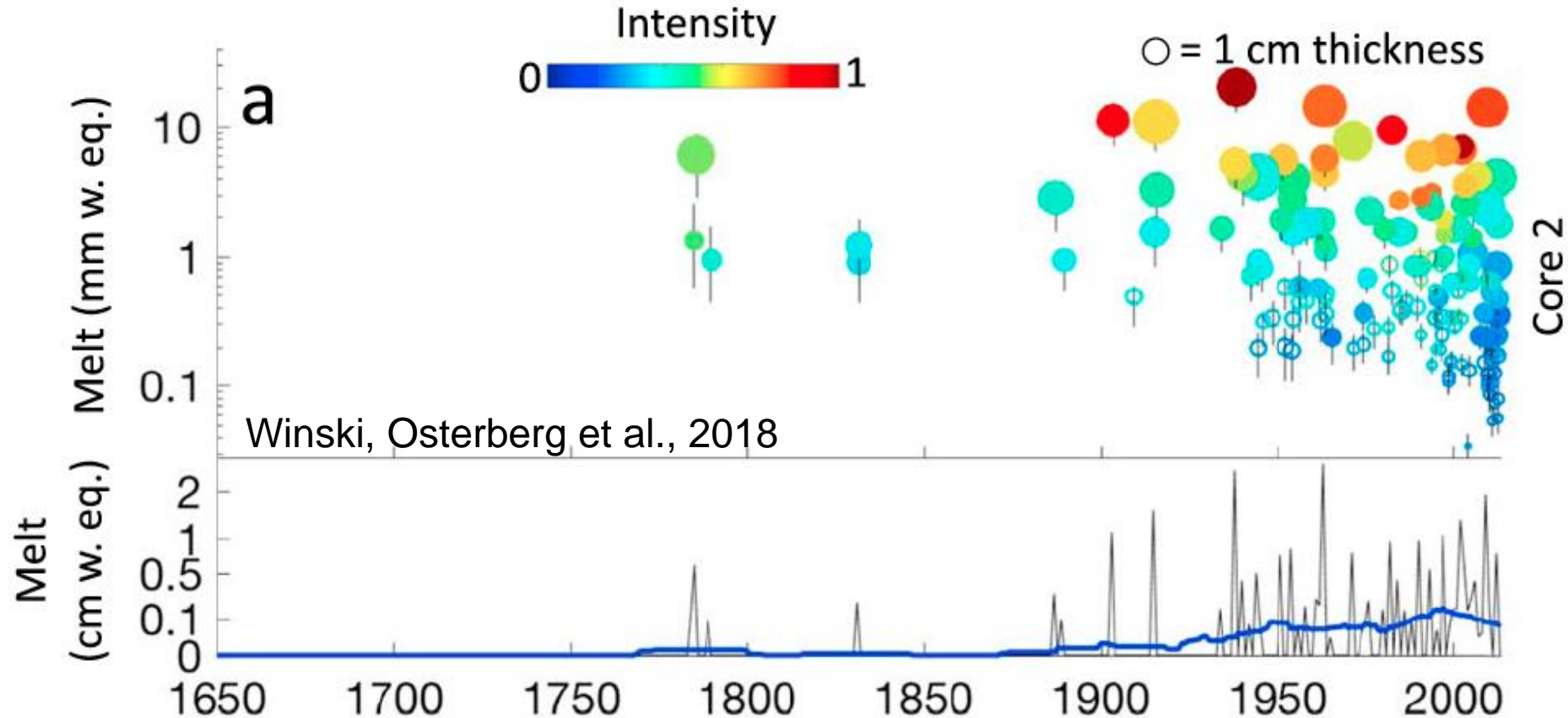
# Global warming is causing an Alaskan glacier to melt at the fastest pace in 400 years

Doyle Rice, USA TODAY

Published 12:22 p.m. ET April 11, 2018 | Updated 7:56 p.m. ET April 11, 2018

**USA  
TODAY**  
A GANNETT COMPANY

*60 times more melting today than in the 1800's*

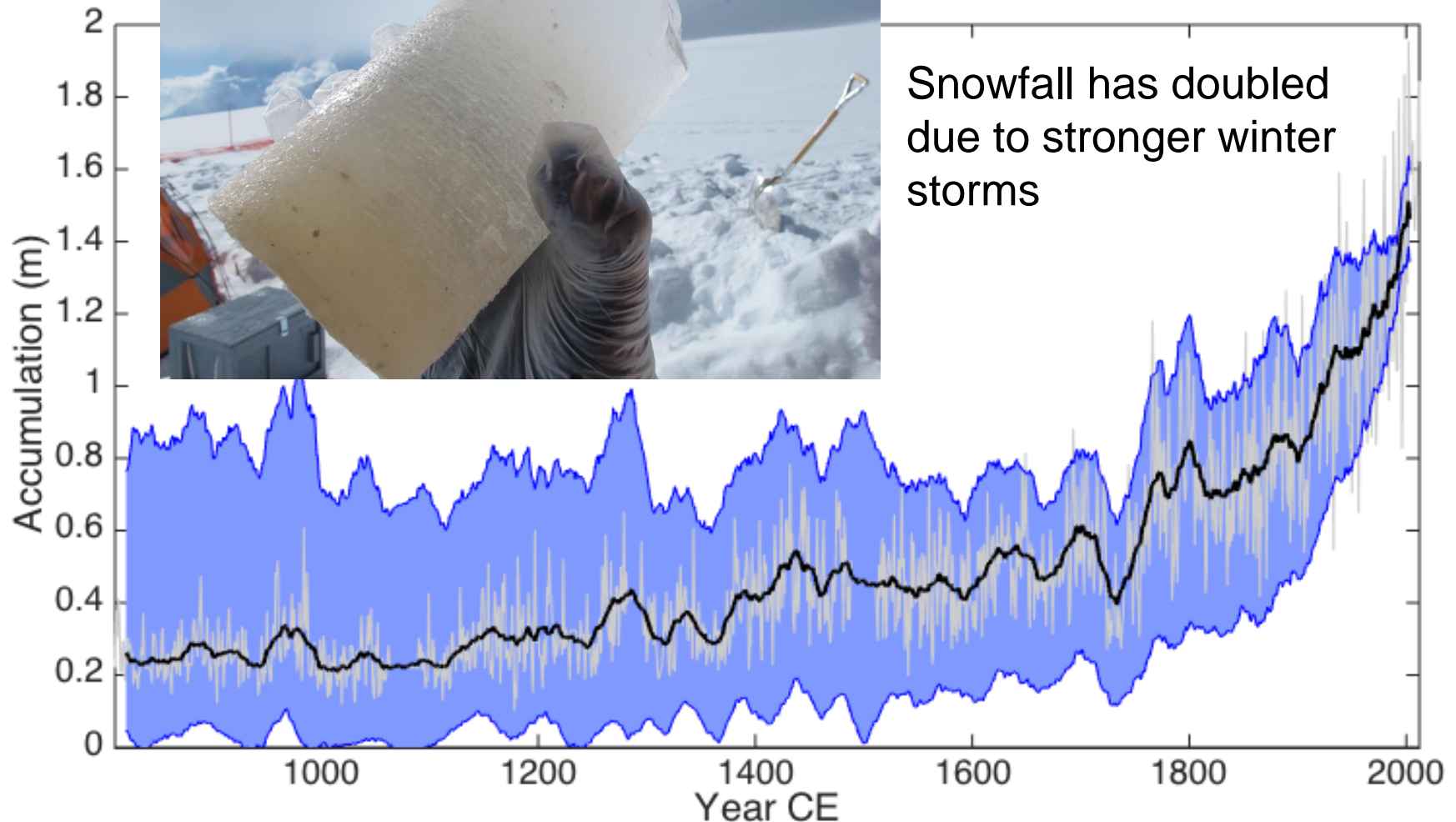




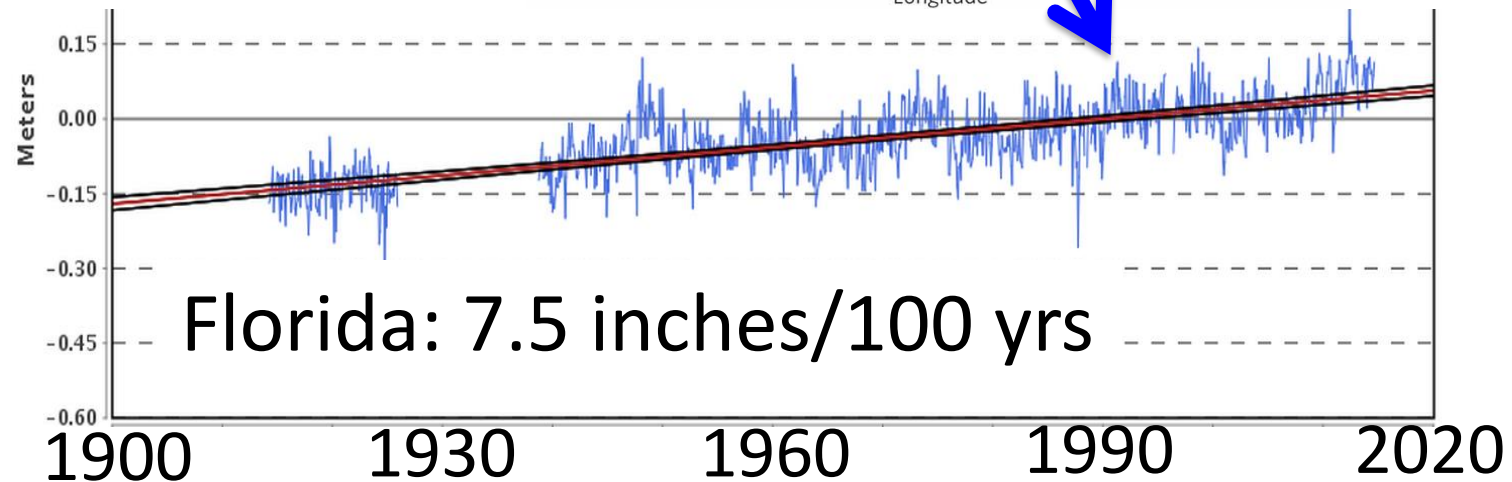
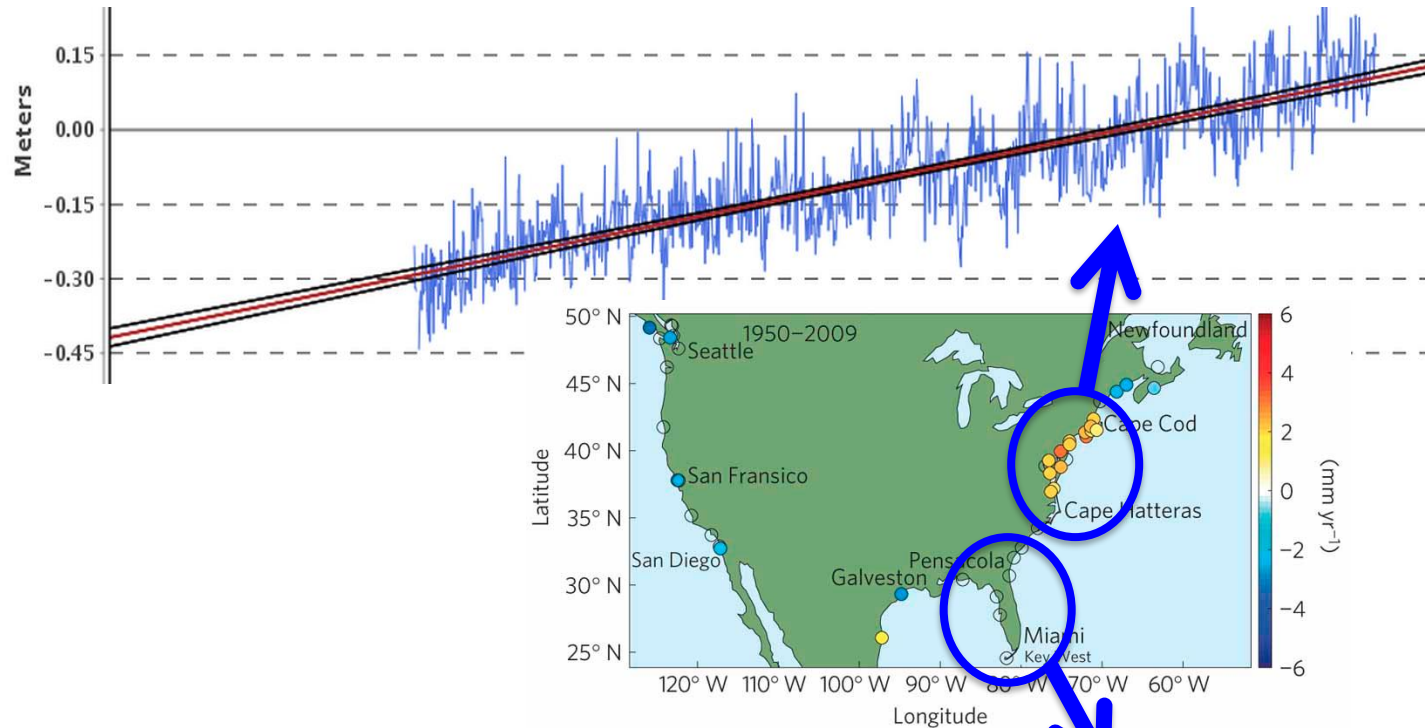
# Denali Glaciers are Melting Quickly from Warming Despite a Doubling of Snowfall since 1840!!



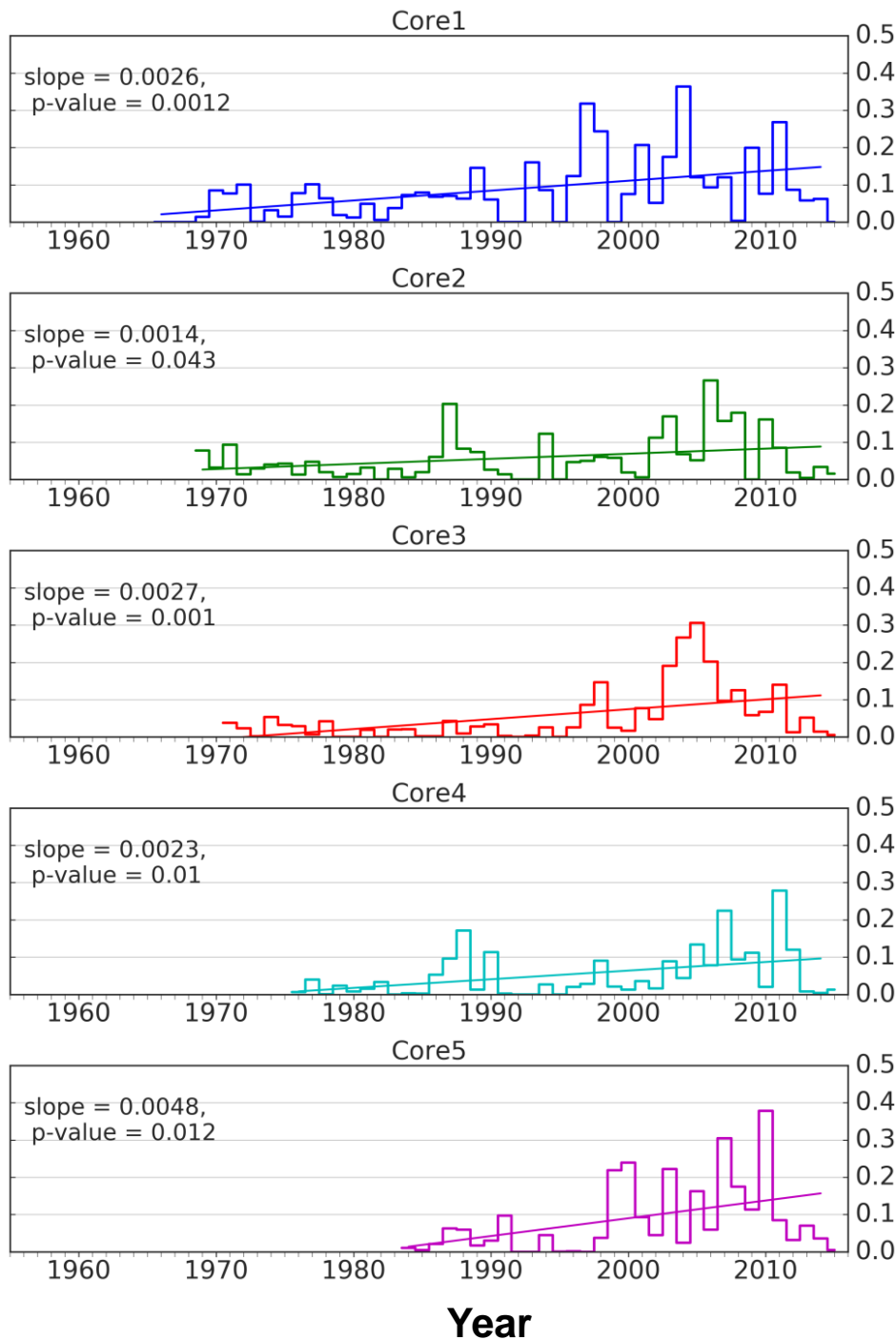
Winski, Osterberg et al., 2017  
Osterberg et al., 2017



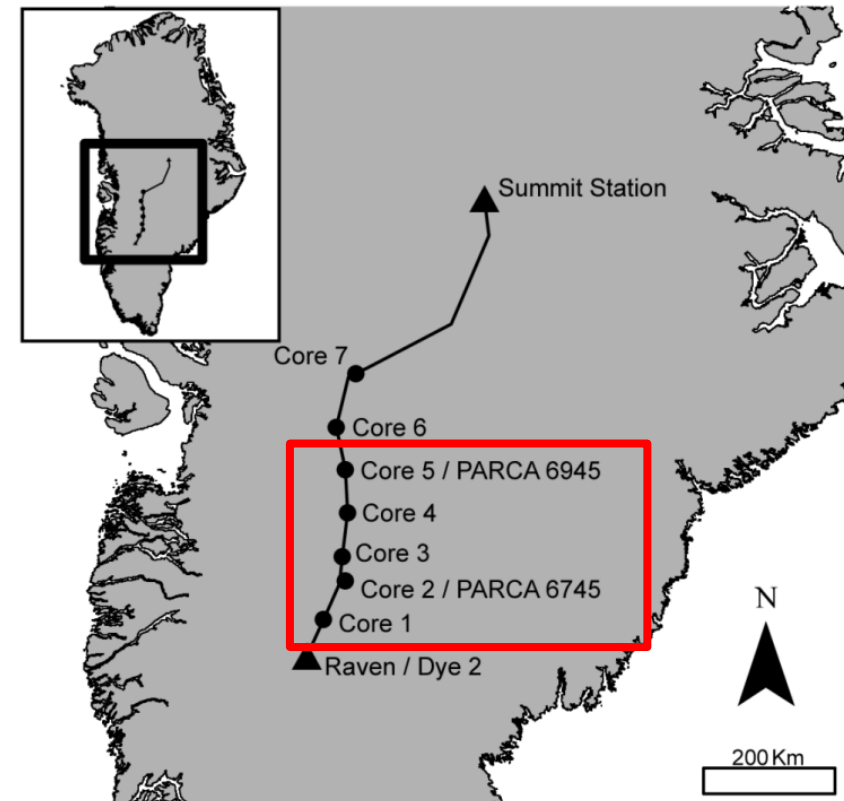
# Norfolk, VA: 15 inches/100 yrs



# Meltwater Refreeze



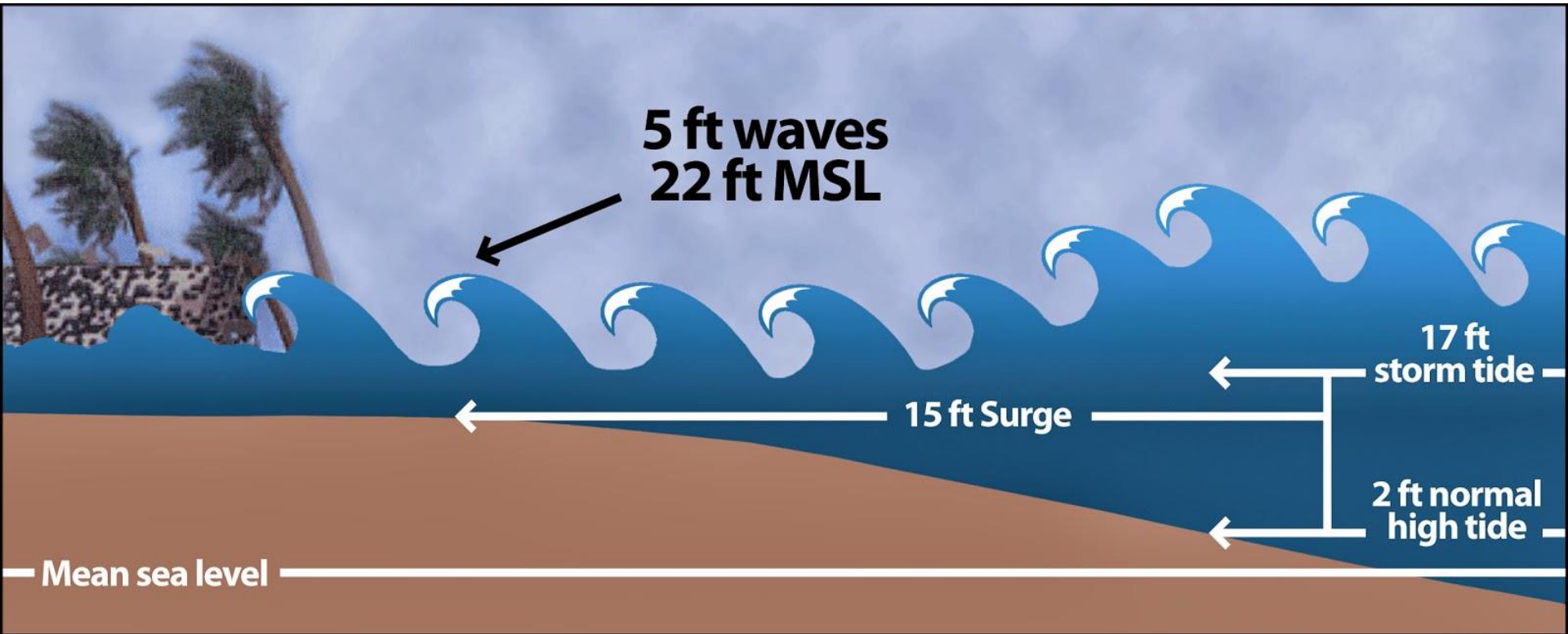
- Significant increases in total ice layer thicknesses in cores 1– 5



Graeter et al., in prep.



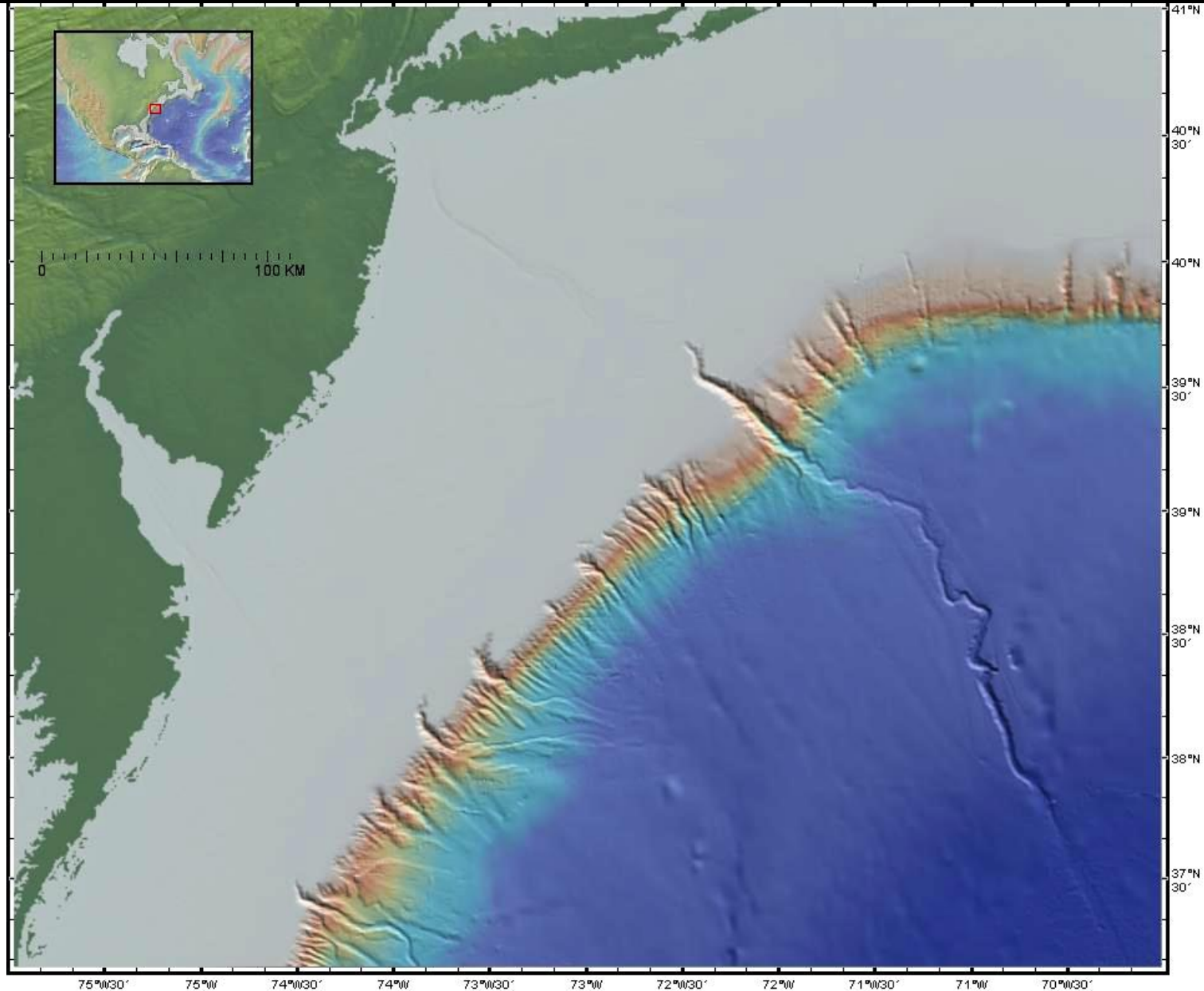
# Storm Surge



# Last Ice Age

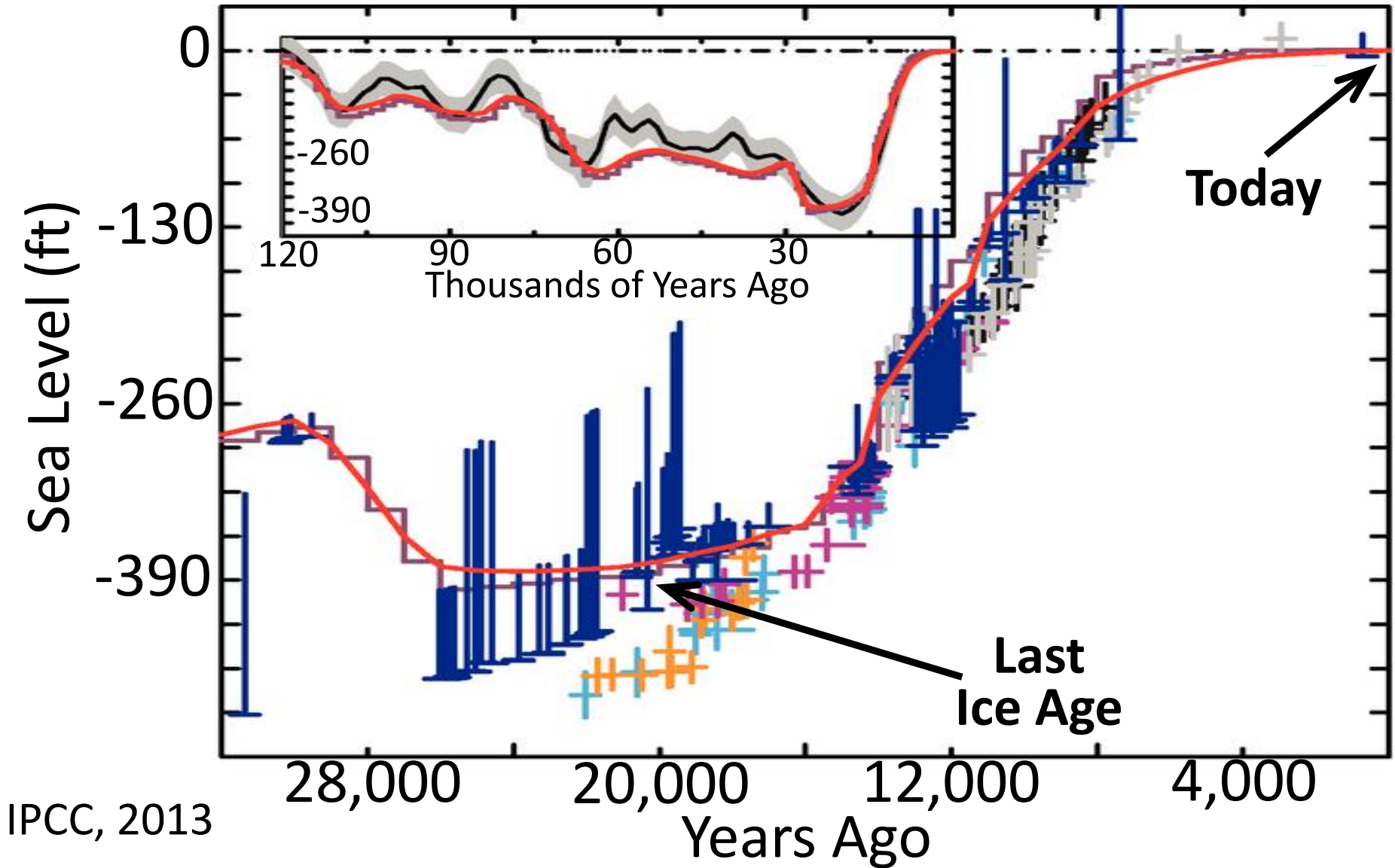


# Ice Age Sea Level was ~400 Feet Lower



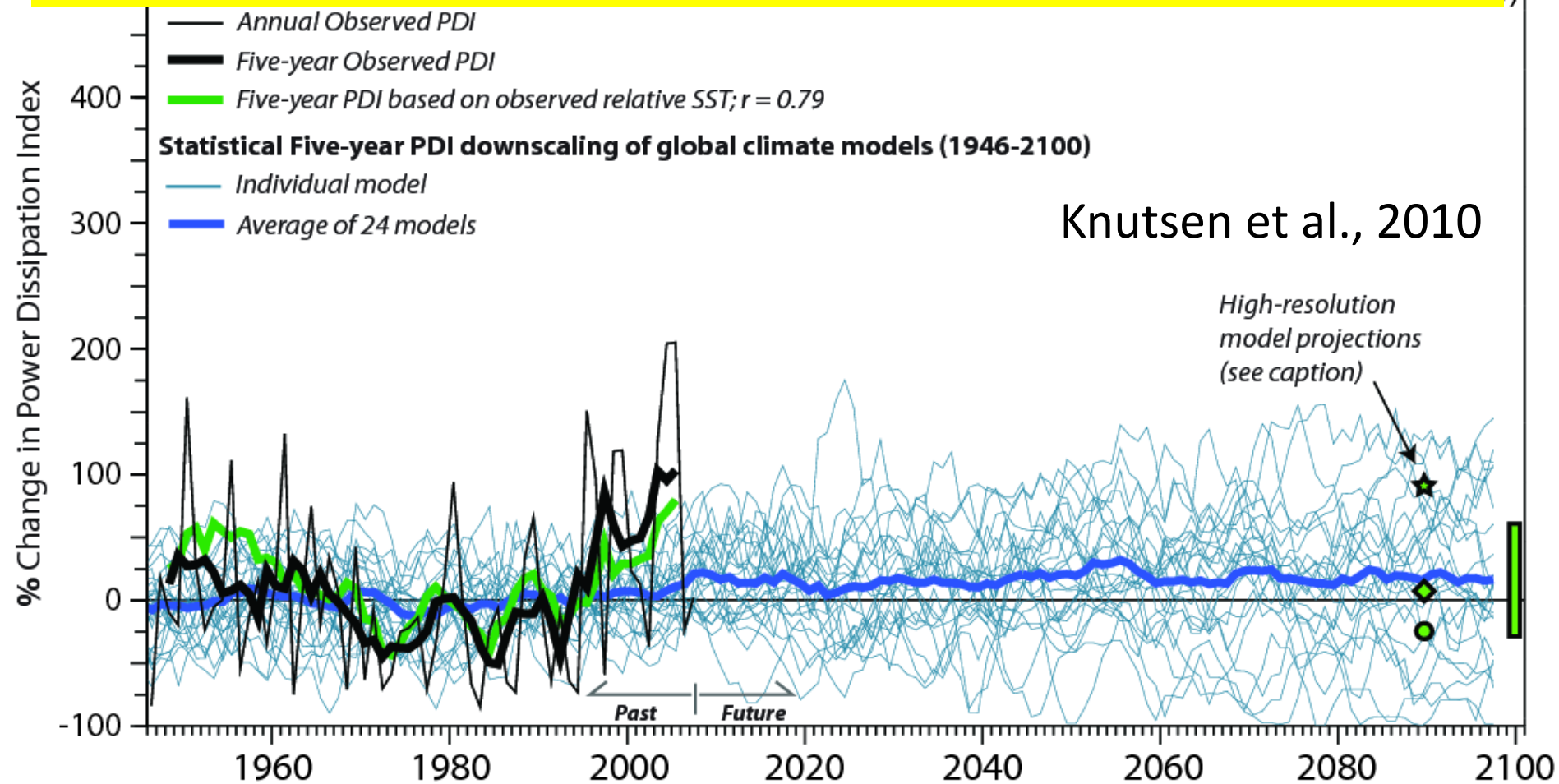


# Ice Age Sea Level was ~400 Feet Lower

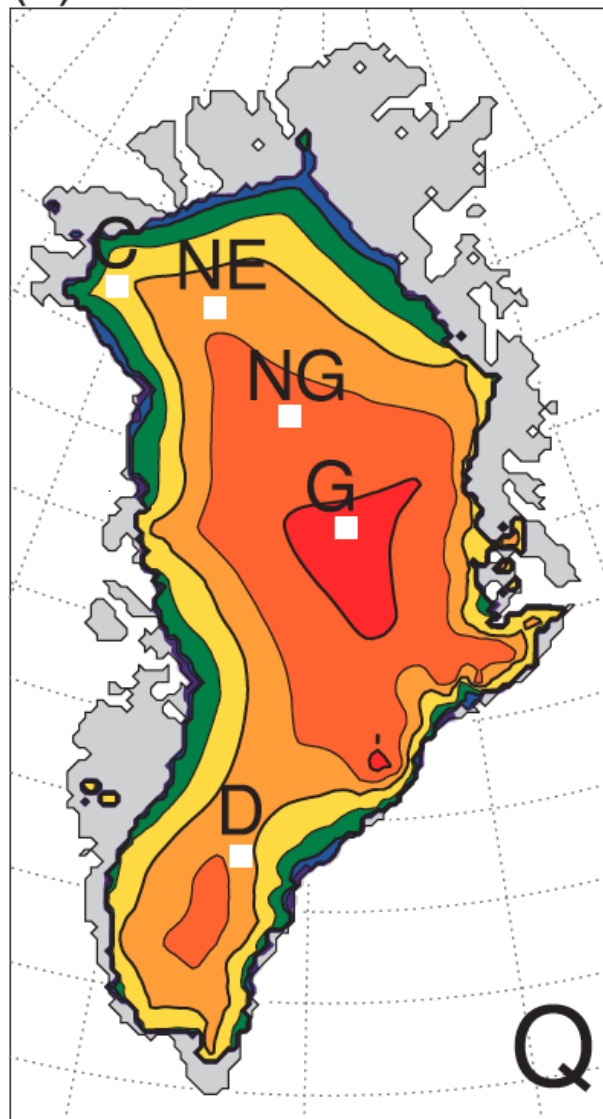


# Are Hurricanes Going to Become More Powerful?

***Very likely more cat 3-5 hurricanes***  
***Possibly fewer weak hurricanes...jury still out***

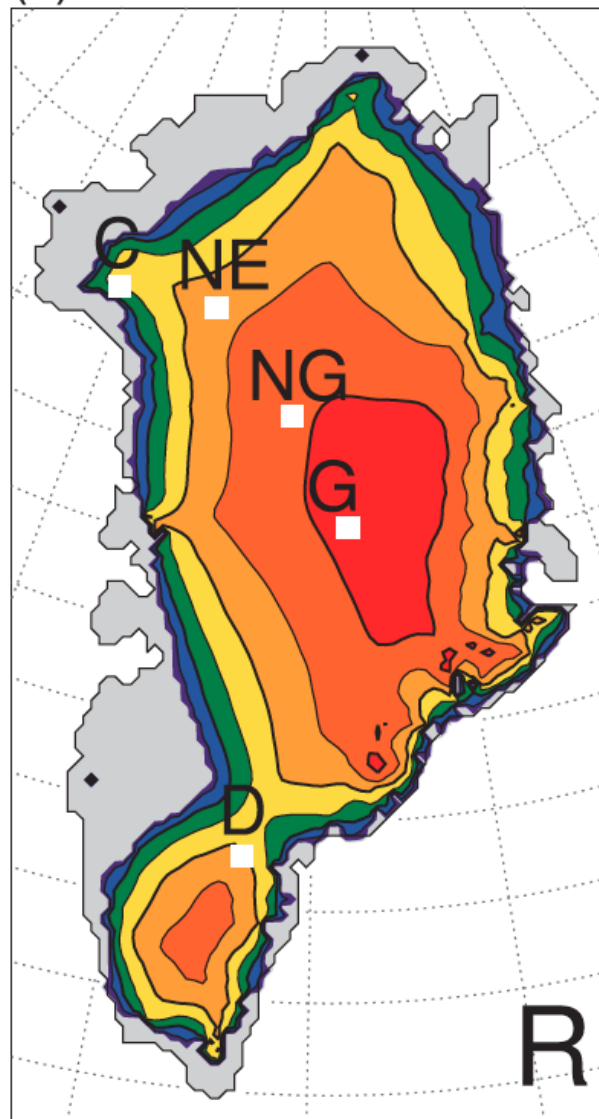


(a) IPSL4-GRISLI



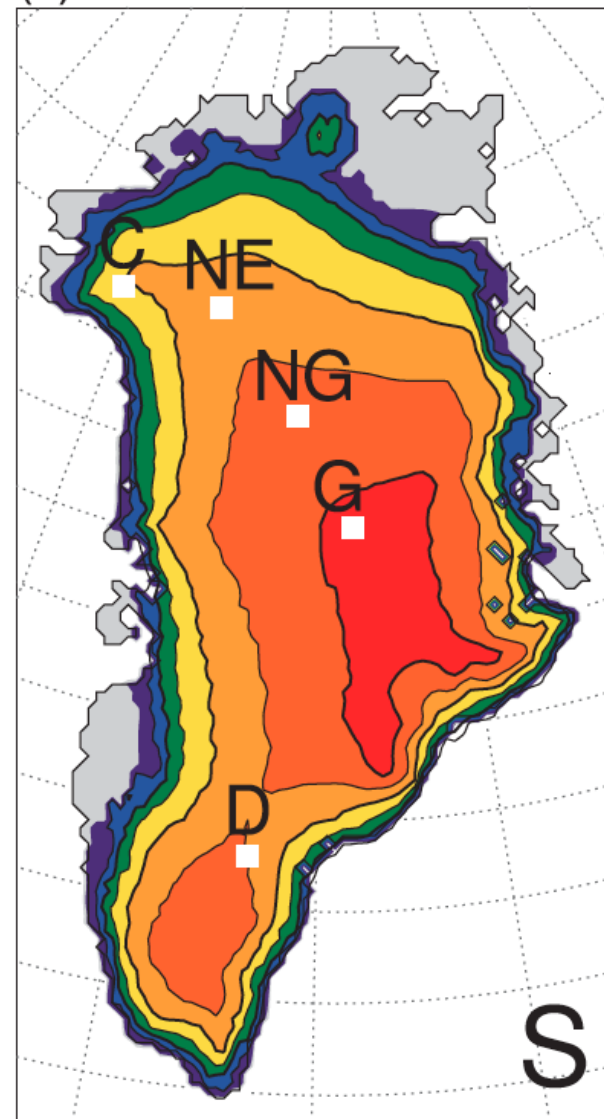
1.5 m at 121 ka : transient run

(b) CLIMBER2-SICOPOLIS



1.9 m at 123 ka : transient run

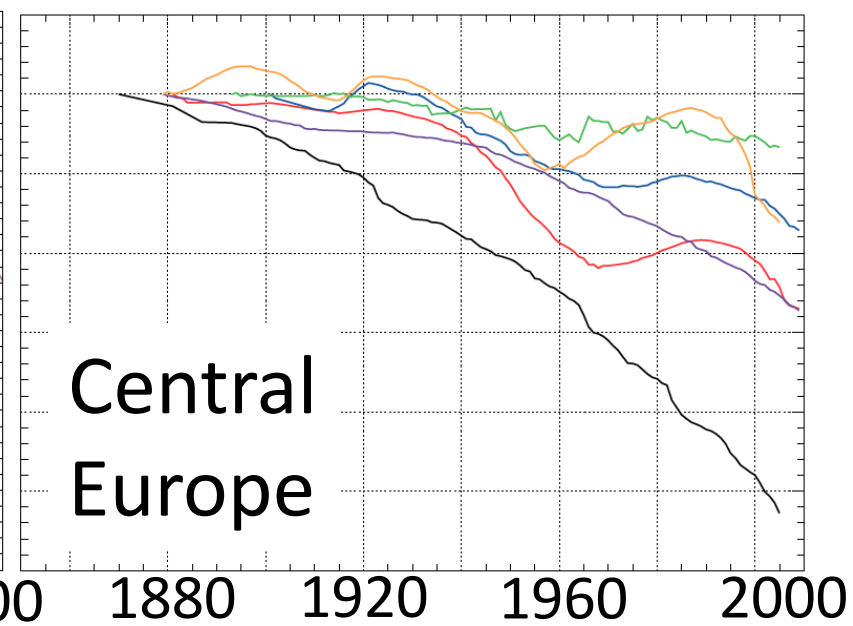
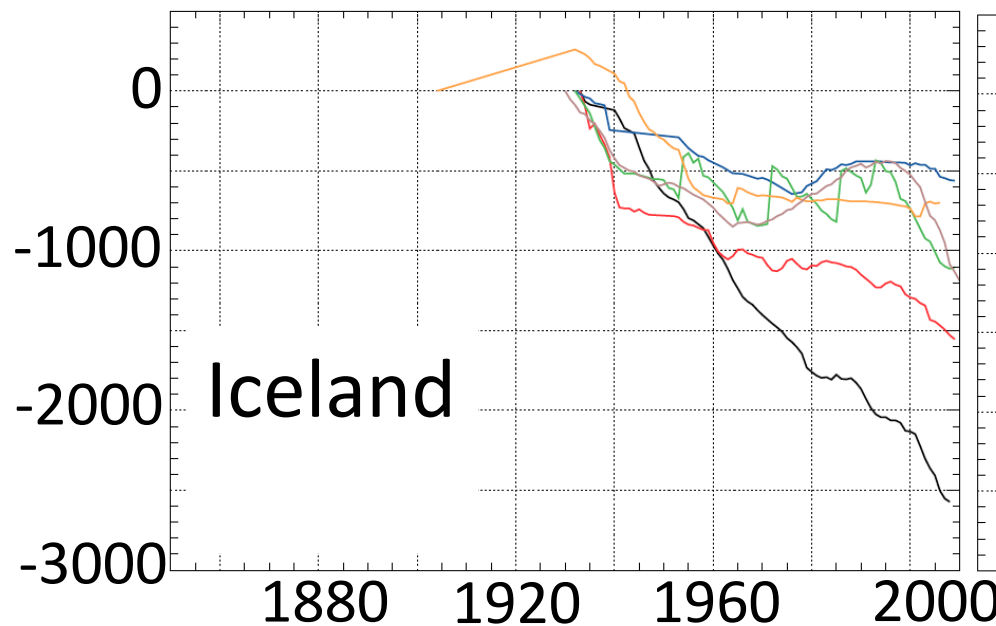
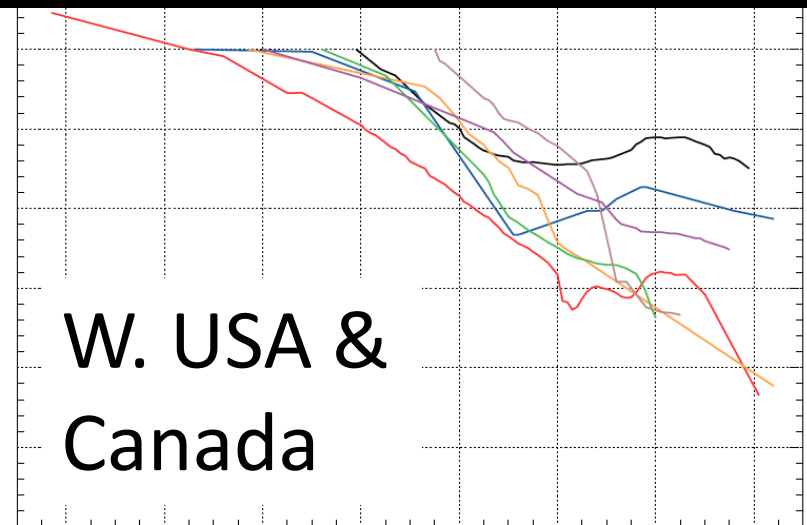
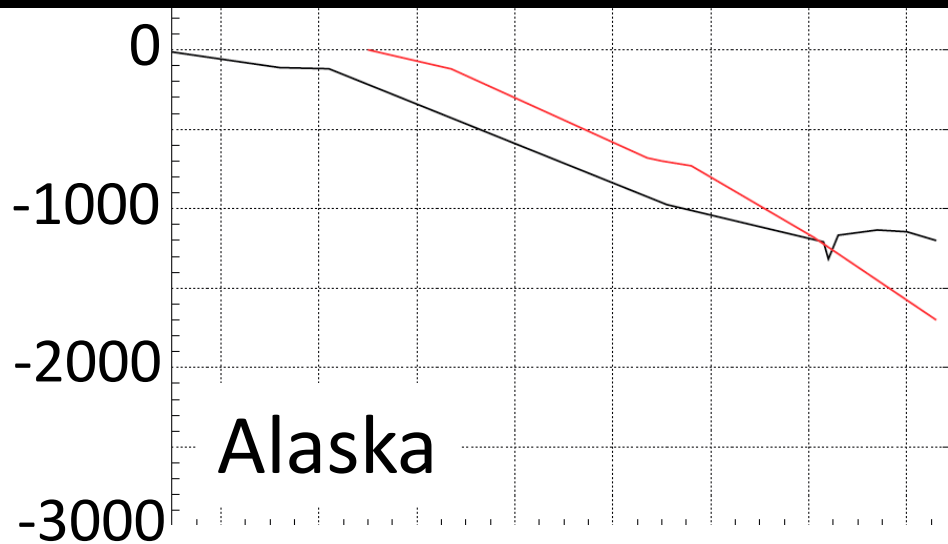
(c) HadCM3-Glimmer



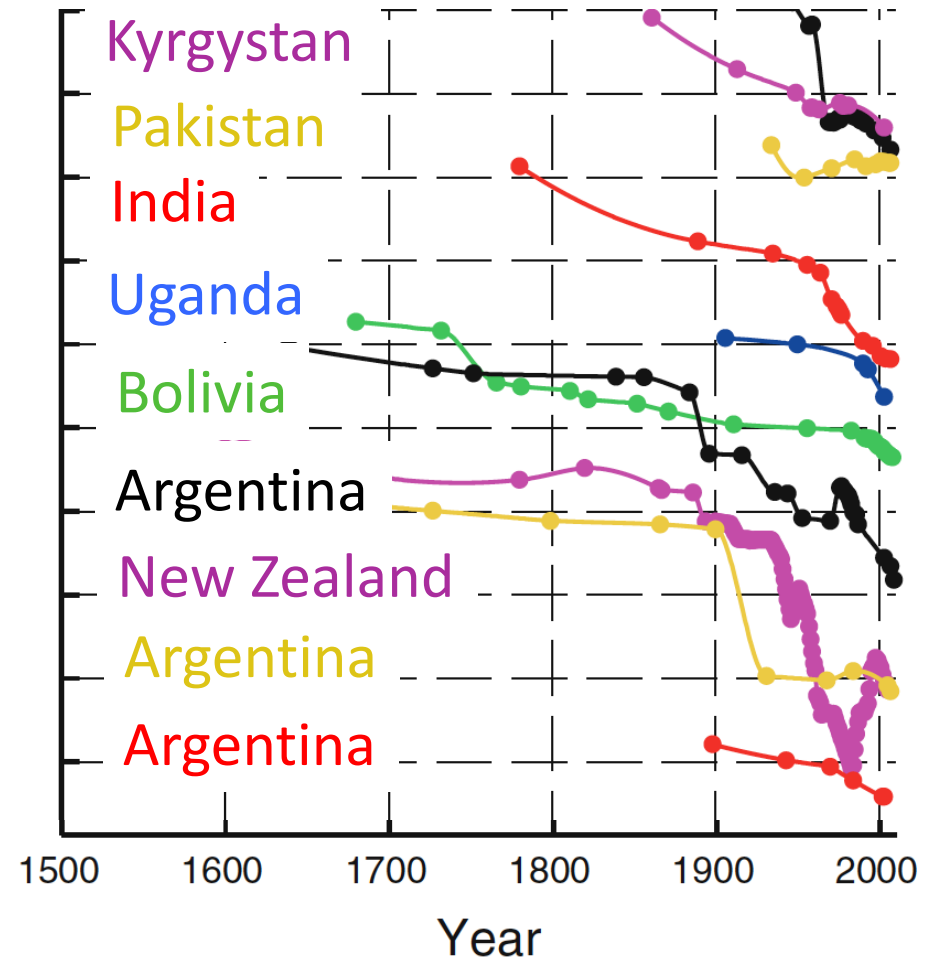
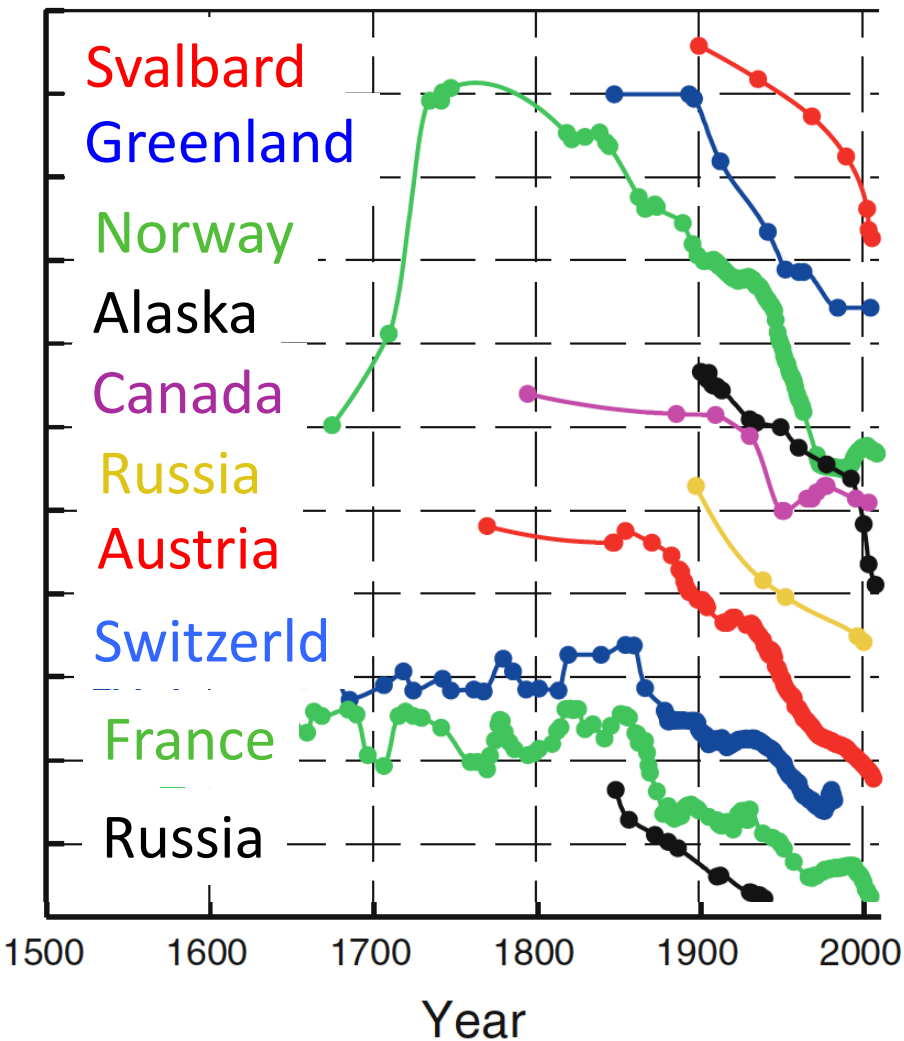
1.4 m at 124 ka : transient run



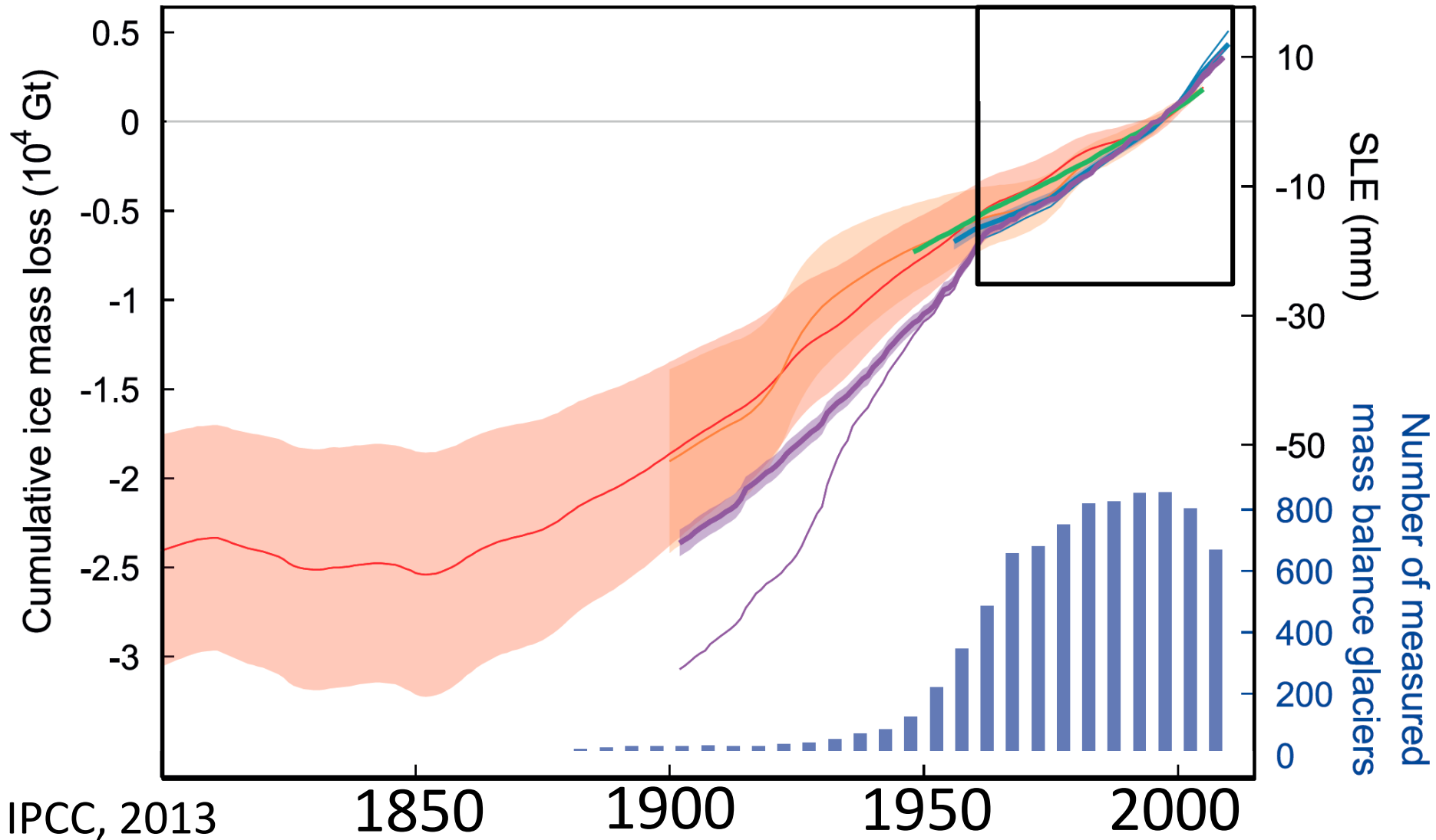
# "Small" Glaciers are Shrinking around the World



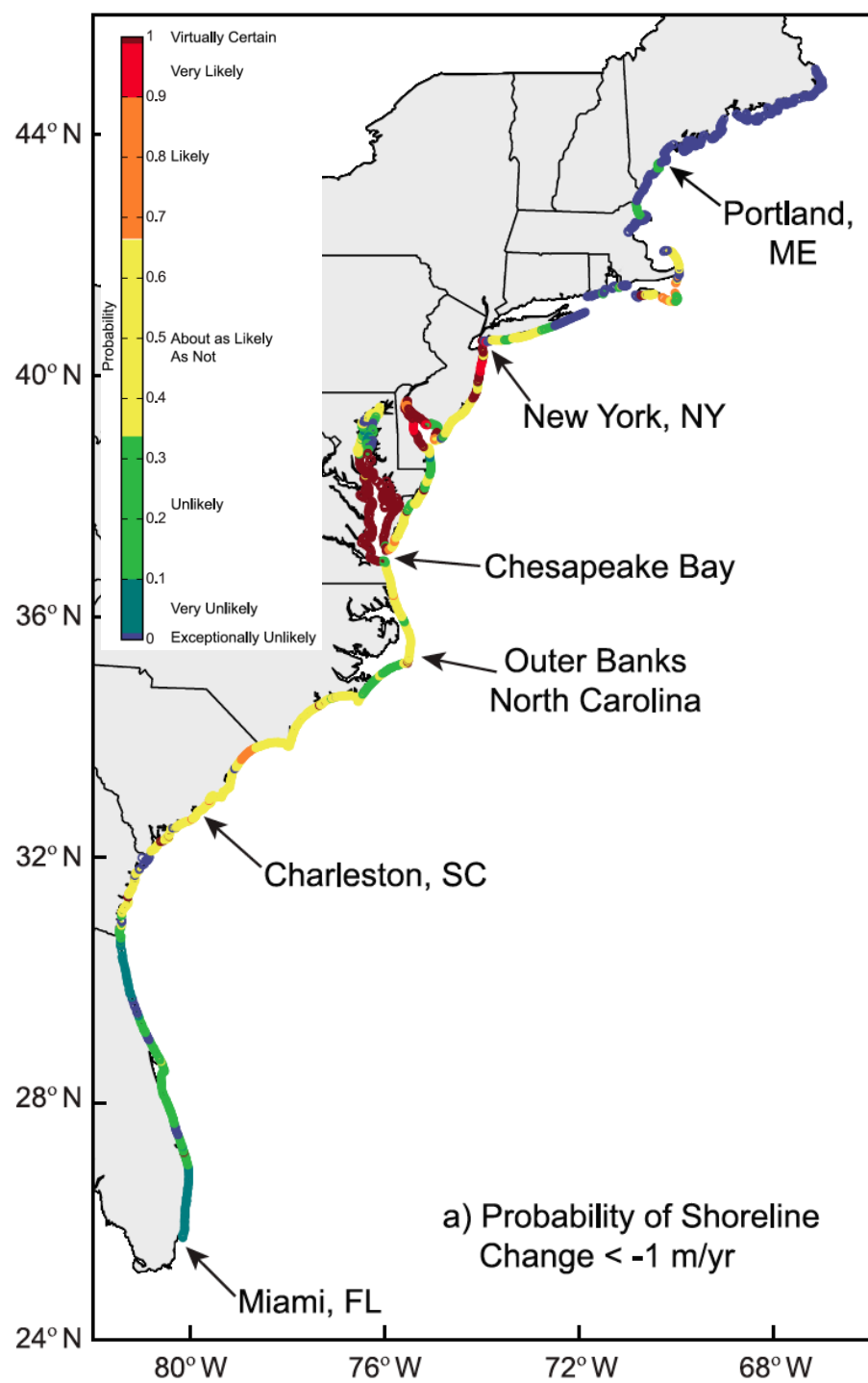
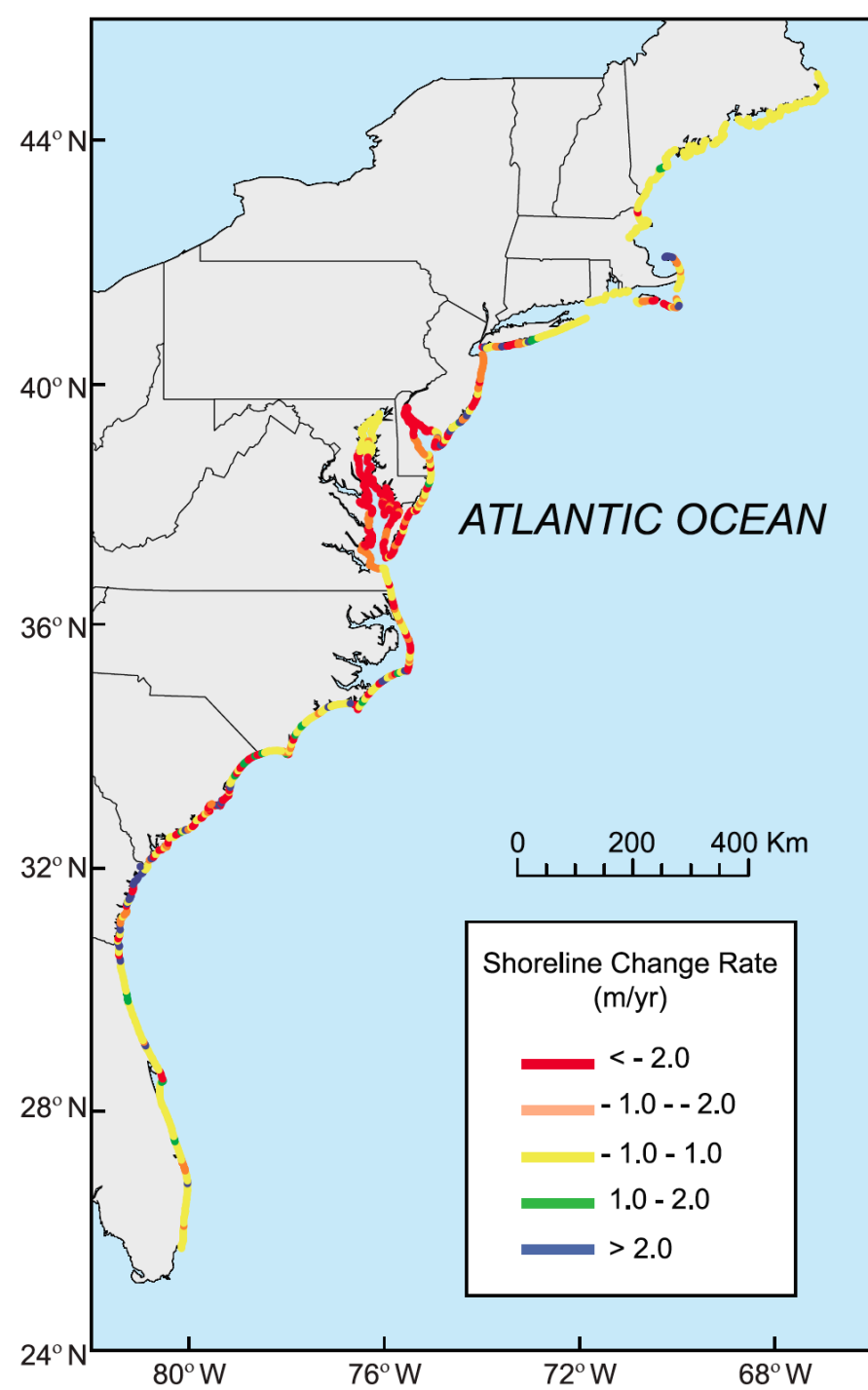
# “Small” Glaciers are Shrinking around the World



# Small Glaciers Have Been Melting Since ~1850

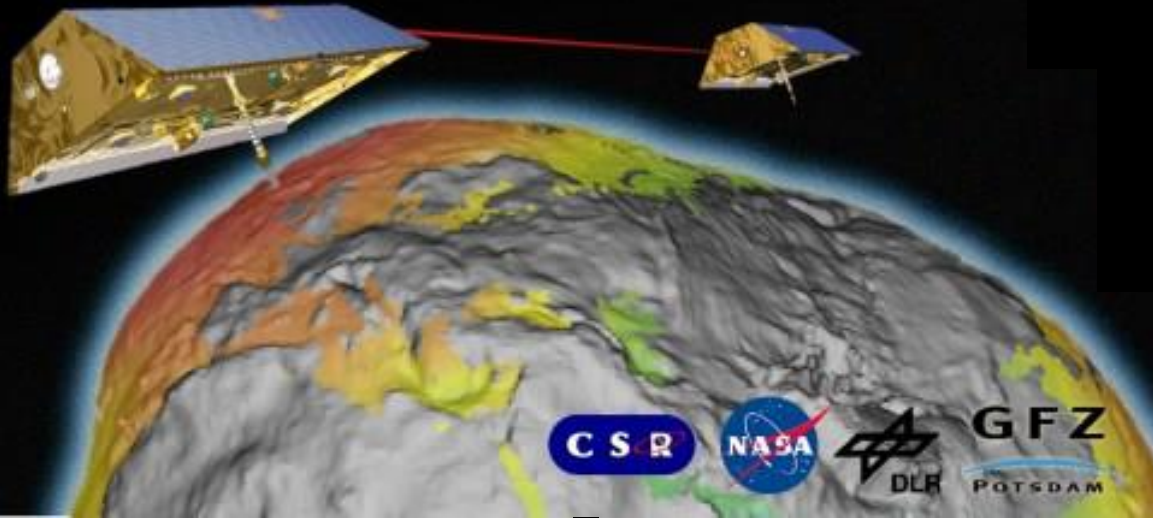




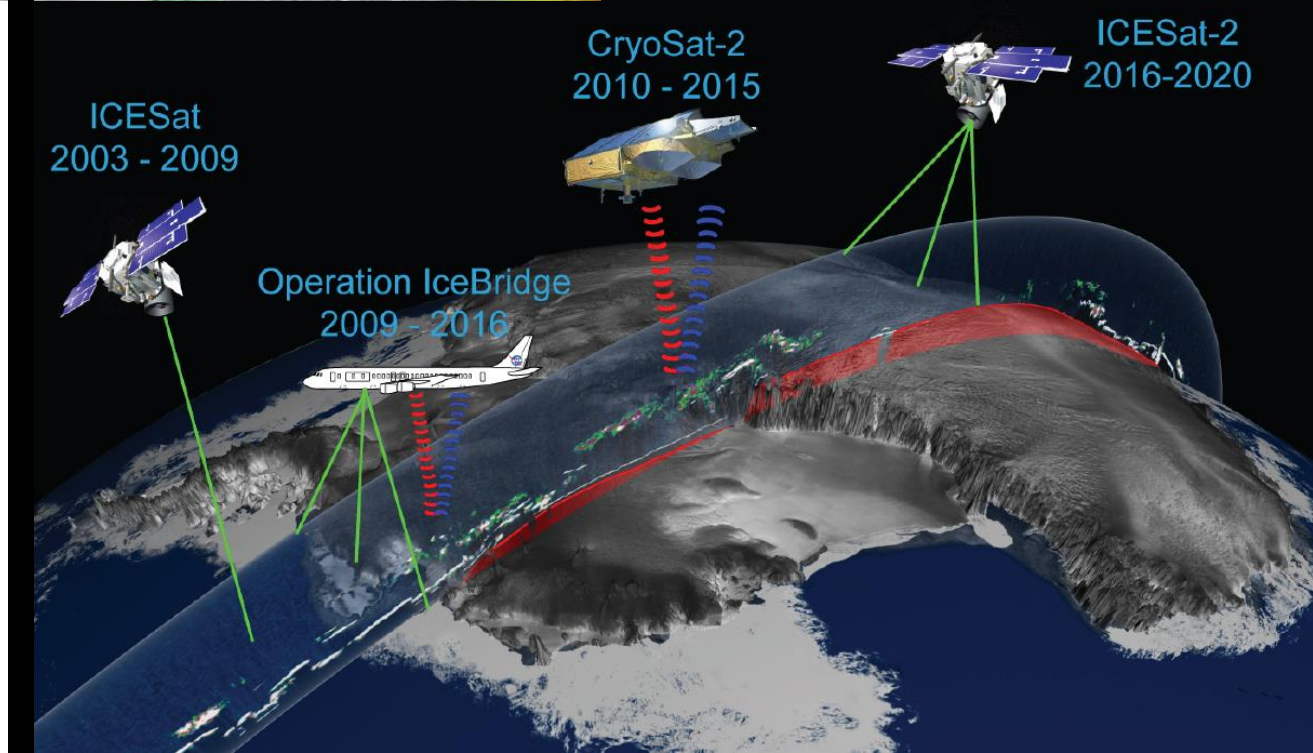
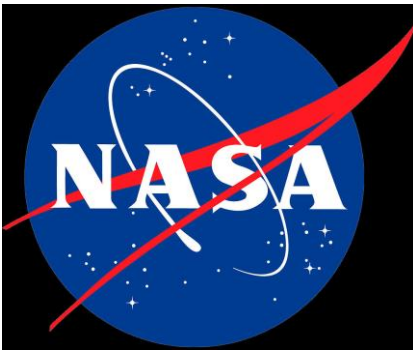


# GRACE

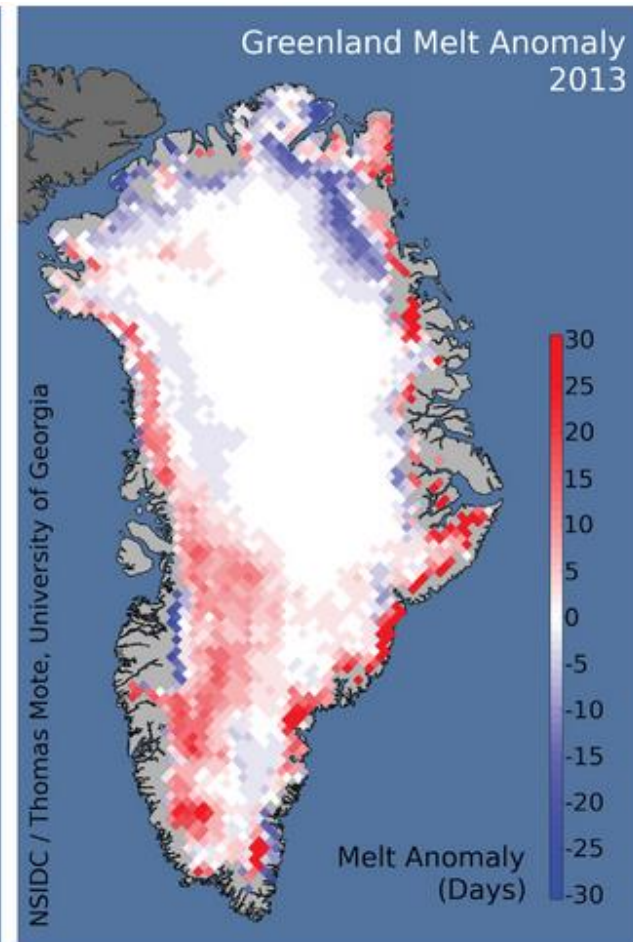
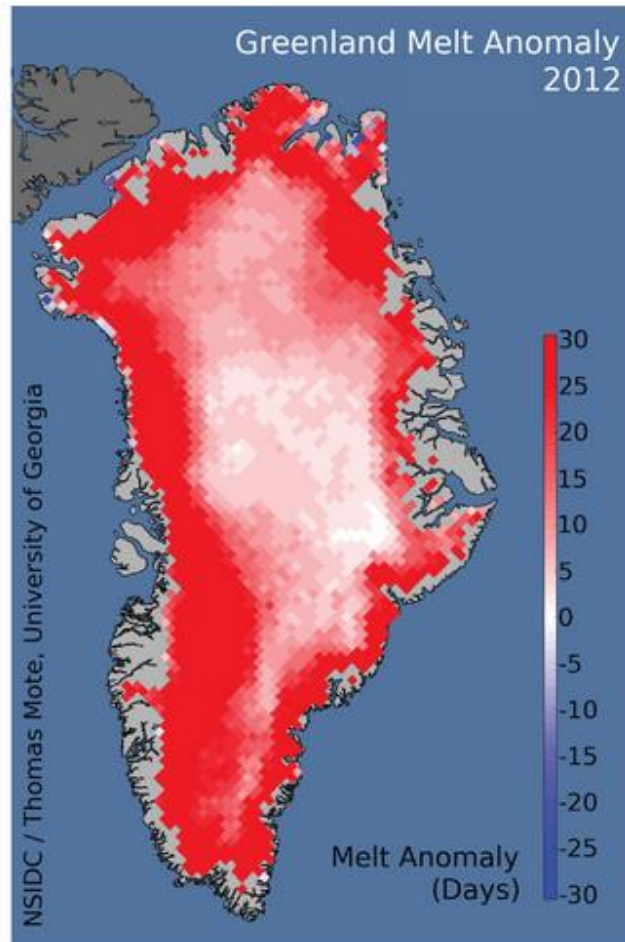
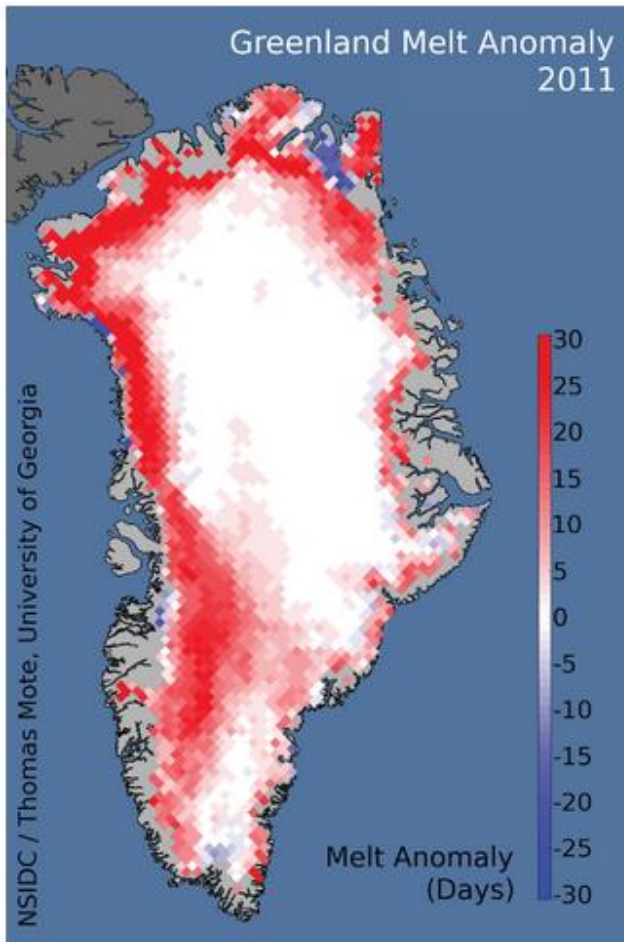
Gravity Recovery and Climate Experiment



## Remote Sensing of the Ice Sheets

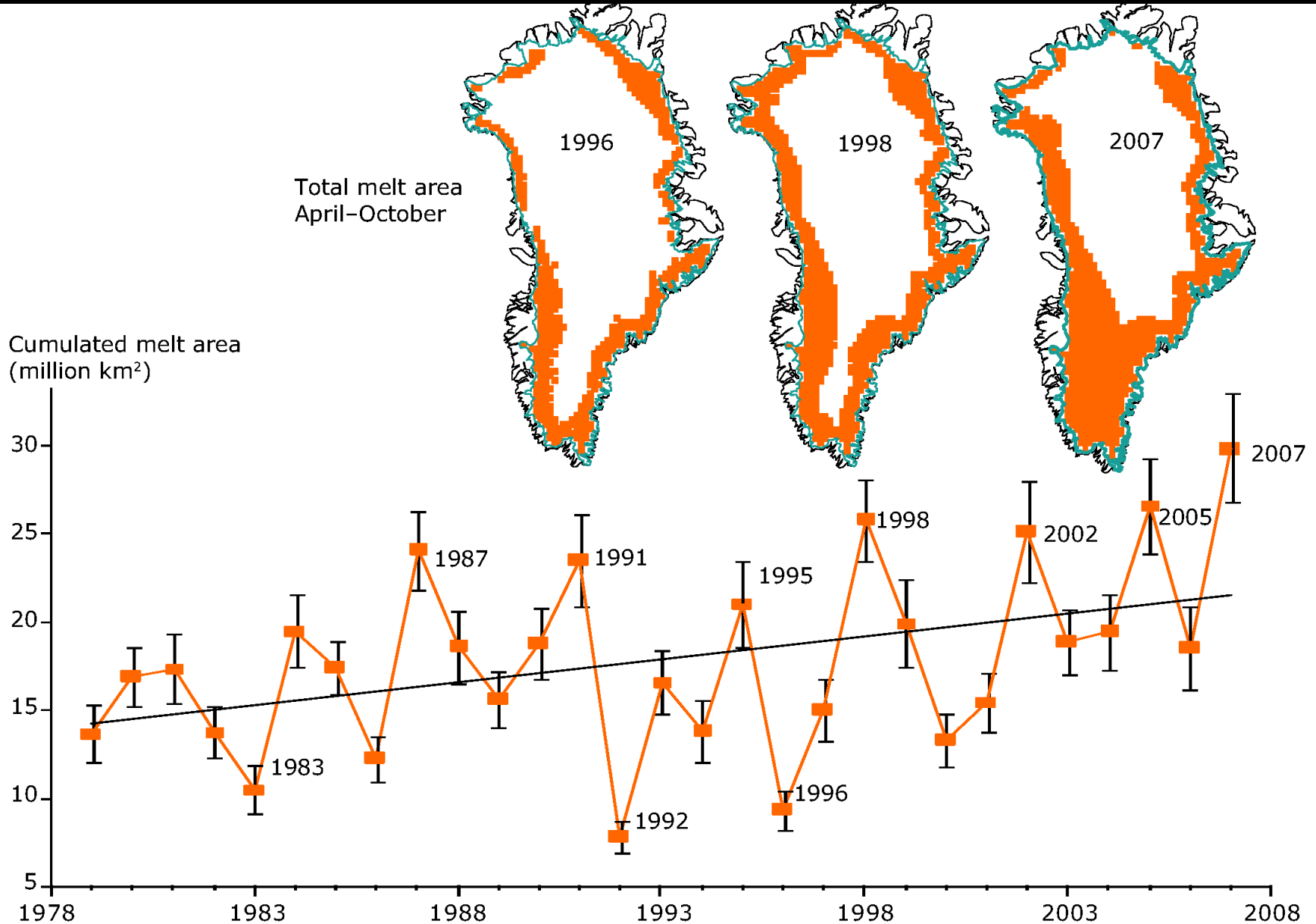


# 2012: Most Surface Melt for >100 years

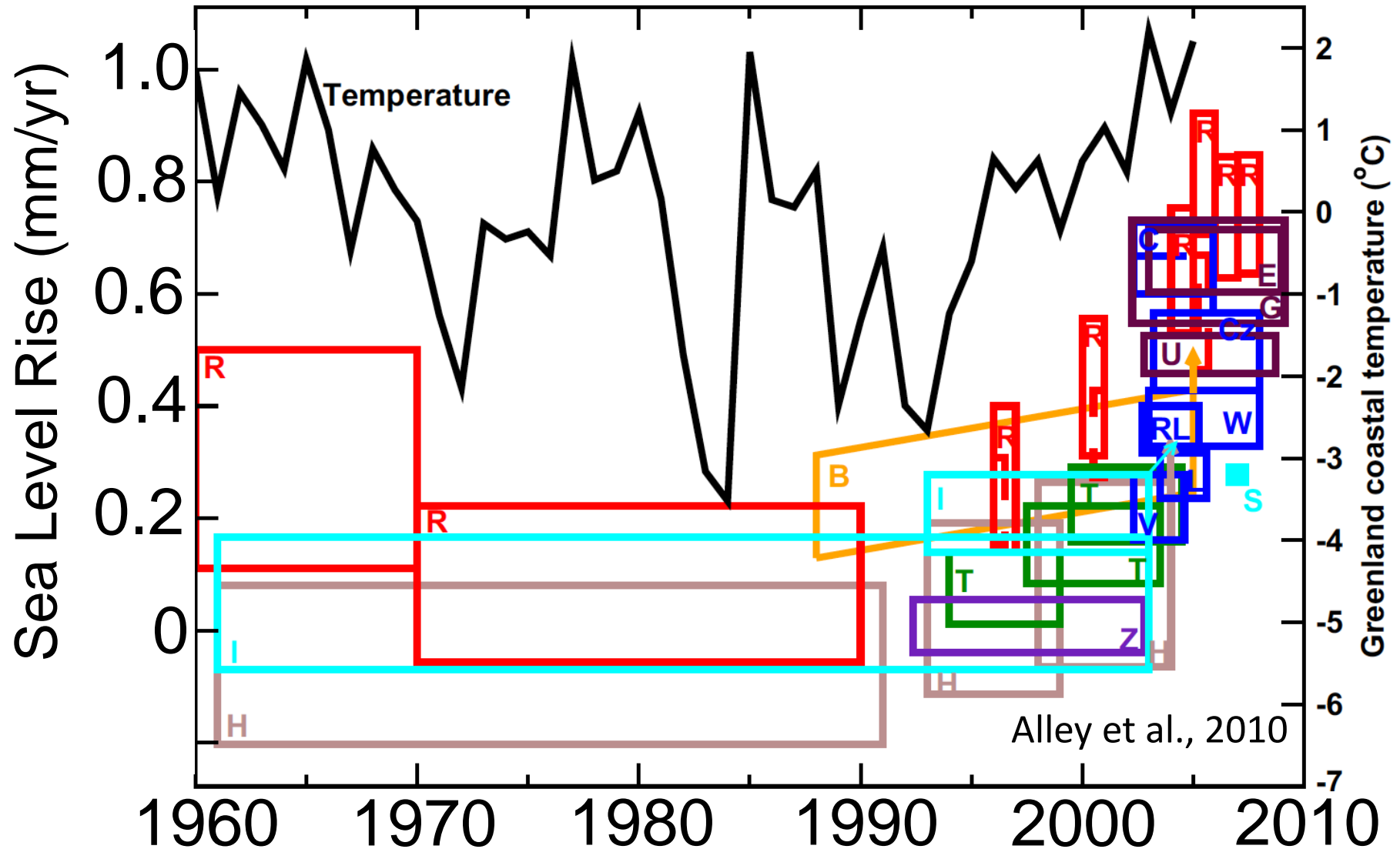




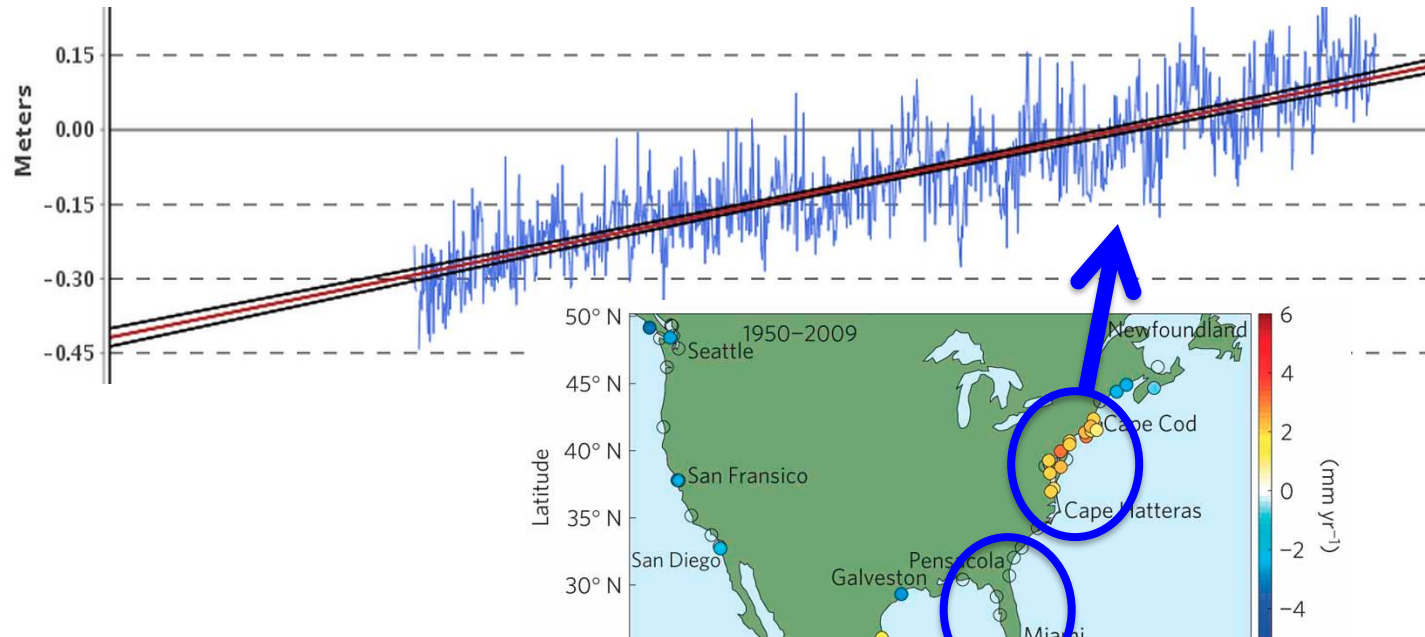
# Surface Melting is Spreading



# Greenland Melting is Just Starting to Speed Up!



# Norfolk, VA: 15 inches/100 yrs



## Mid-Atlantic Land Sinking

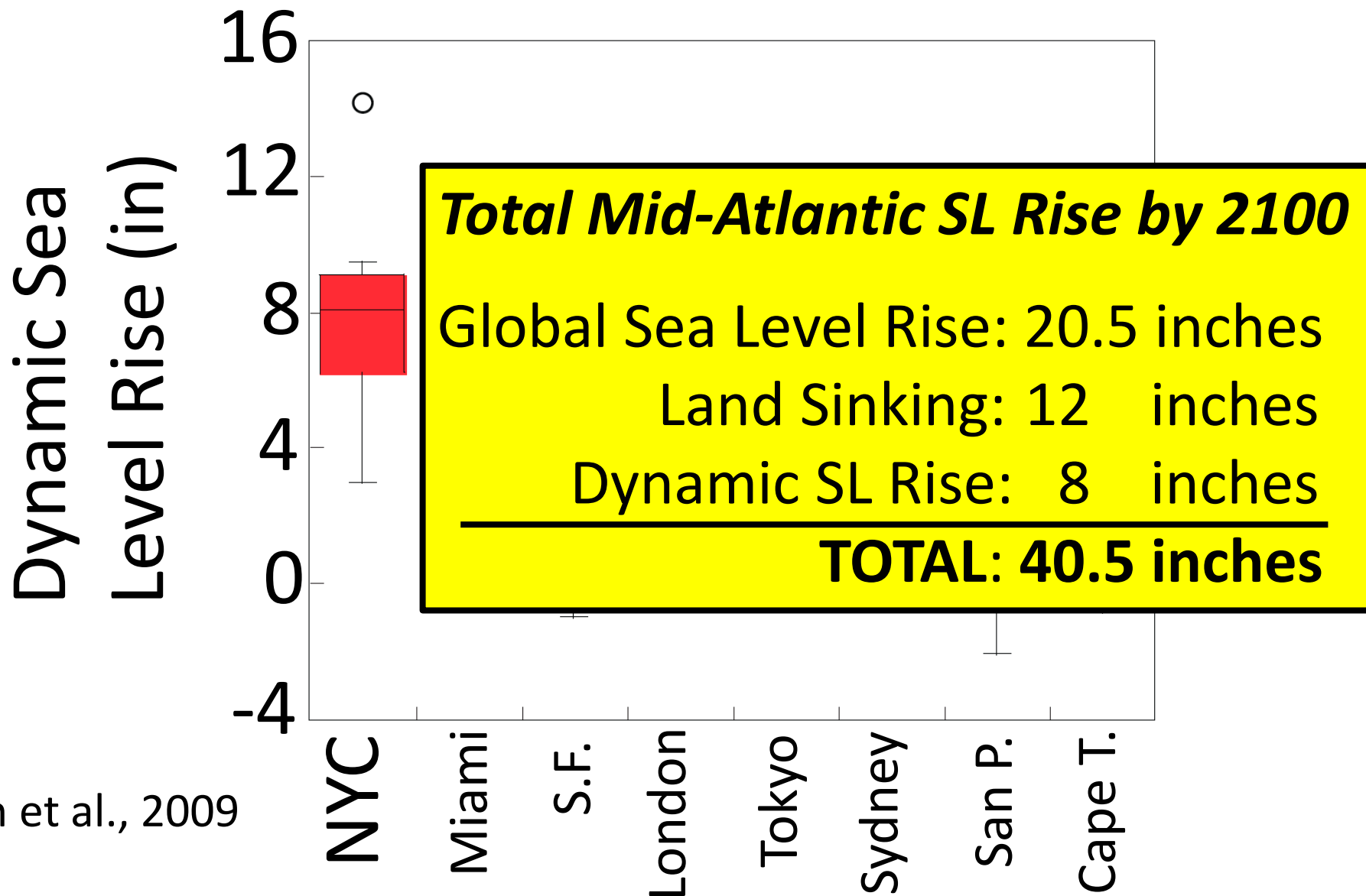
1. Ice Age Response: 4 inches/100 years
2. Groundwater Removal: 8 inches/100 years

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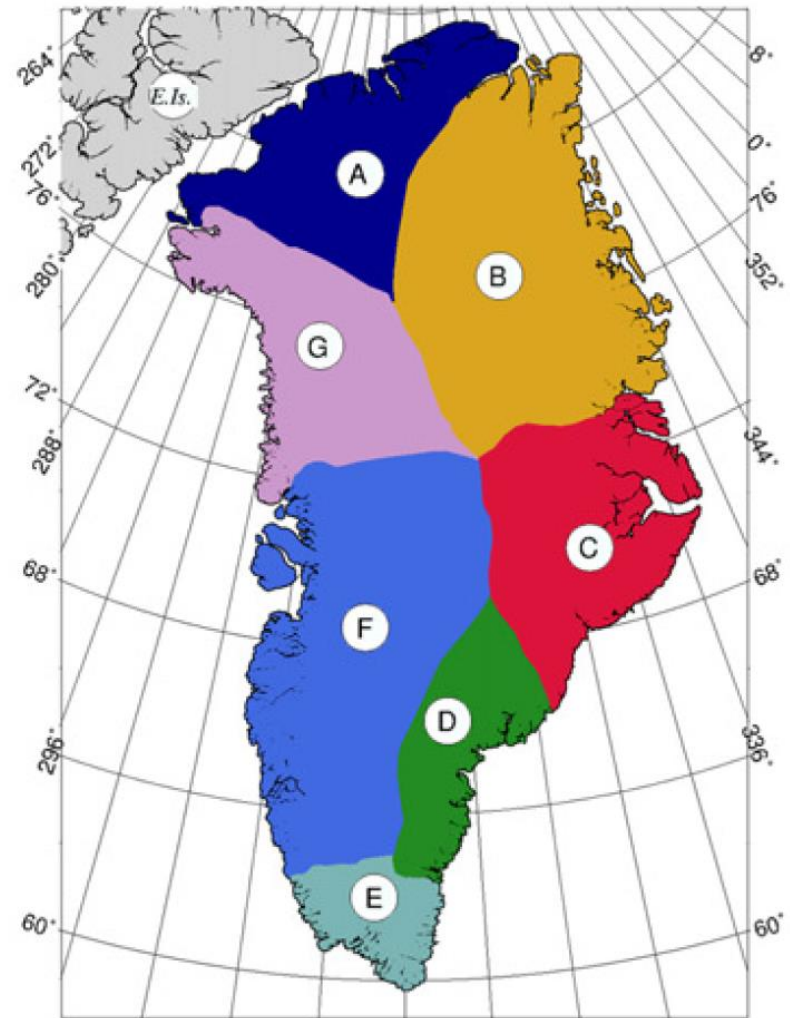
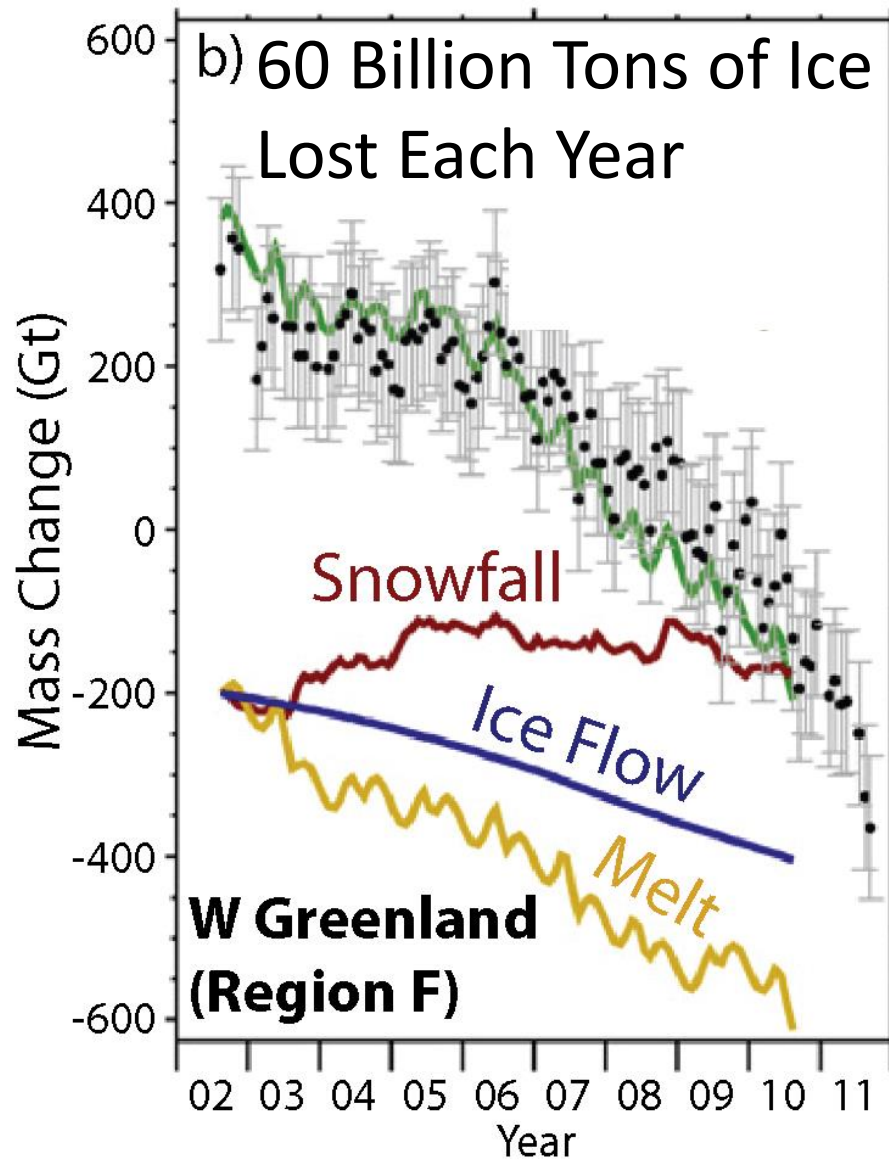
**Total: 12 inches/100 years**



# Sea Level Rise by 2100 Just from Ocean Currents



# Greenland Melting is Speeding Up



Sasgen et al., 2012