

# Climate Change 2013: The Physical Science Basis

Working Group I contribution to the IPCC Fifth Assessment Report

## Competing Narratives of Global Climate Change

*Basics of climate change science and recent findings (AR5),  
with examples of misrepresentation and dismissal.*

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Ethics and Ecological Economics Study Group

September 8, 2014

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<http://denverclimatestudygroup.com/>

**A report on AR5 with details of the 20-point  
NAS/Royal Society report along with the  
Headlines of the 19-point Summary for  
Policy Makers (SPM)  
In the “extras” slides**

# OUTLINE

- IPCC History/Overview
- Physical Science Summary – Vol 1 (1552 pp.)
  - 2 approaches:
    - “Headlines” of Working Group
    - 20 points by Royal Soc./Nat. Academy of Sciences
  - Interspersed with supportive slides
  - Interspersed with where things get misrepresentations/dismissals by misinformation campaign groups
- Ideological drivers, ridicule and alarmism
- Conclusions and recommendations

# Disclaimer

Any views expressed here are the result of my study, education and research and not those of associated affiliated societies or organizations.

# Intergovernmental Panel on Climate change(IPCC); aka: Fifth Assessment Report (AR5) - 3 volumes

<http://www.ipcc.ch/report/ar5/>:



**September 2013**  
**Physical Science**

**March 2014**  
**Impacts, Adaptation  
& Vulnerability**

**April 2014**  
**Mitigation**

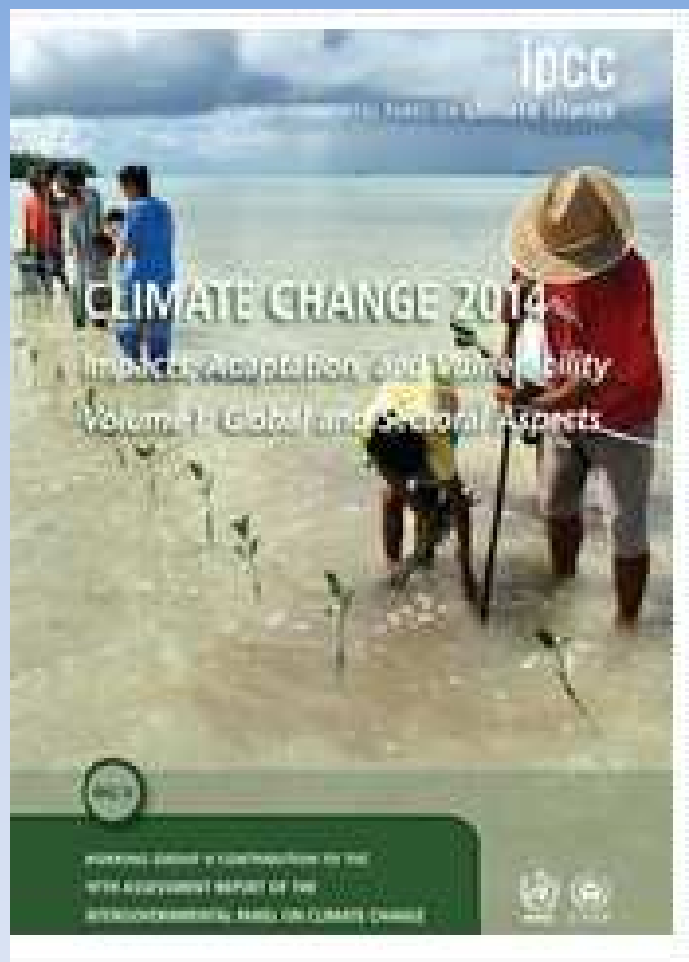
# WG I – The Physical Basis



## Chapters

- 1. Introduction [4.5MB](#) -
- 2. Observations: Atmosphere and Surface [38.3MB](#) -
  - [Supplementary Material](#) [1.5MB](#)
- 3. Observations: Ocean [48.3MB](#) -
- 4. Observations: Cryosphere [12.8MB](#) -
  - [Supplementary Material](#) [0.4MB](#)
- 5. Information from Paleoclimate Archives [10.7MB](#) -
- 6. Carbon and Other Biogeochemical Cycles [23.8MB](#) -
  - [Supplementary Material](#) [4MB](#)
- 7. Clouds and Aerosols [19.2MB](#) -
  - [Supplementary Material](#) [0.1MB](#)
- 8. Anthropogenic and Natural Radiative Forcing [18.9MB](#) -
  - [Supplementary Material](#) [15.9MB](#)
- 9. Evaluation of Climate Models [24.6MB](#) -
- 10. Detection and Attribution of Climate Change: from Global to Regional [10.4MB](#) -
  - [Supplementary Material](#) [1.3MB](#)
- 11. Near-term Climate Change: Projections and Predictability [14.1MB](#) -
- 12. Long-term Climate Change: Projections, Commitments and Irreversibility [36.3MB](#) -
- 13. Sea Level Change [32.9MB](#) -
  - [Supplementary Material](#) [0.1MB](#)
- 14. Climate Phenomena and their Relevance for Future Regional Climate Change [10.6MB](#) -
  - [Supplementary Material](#) [1.9MB](#)

# WG II – Impacts, Adaptation, Vulnerability

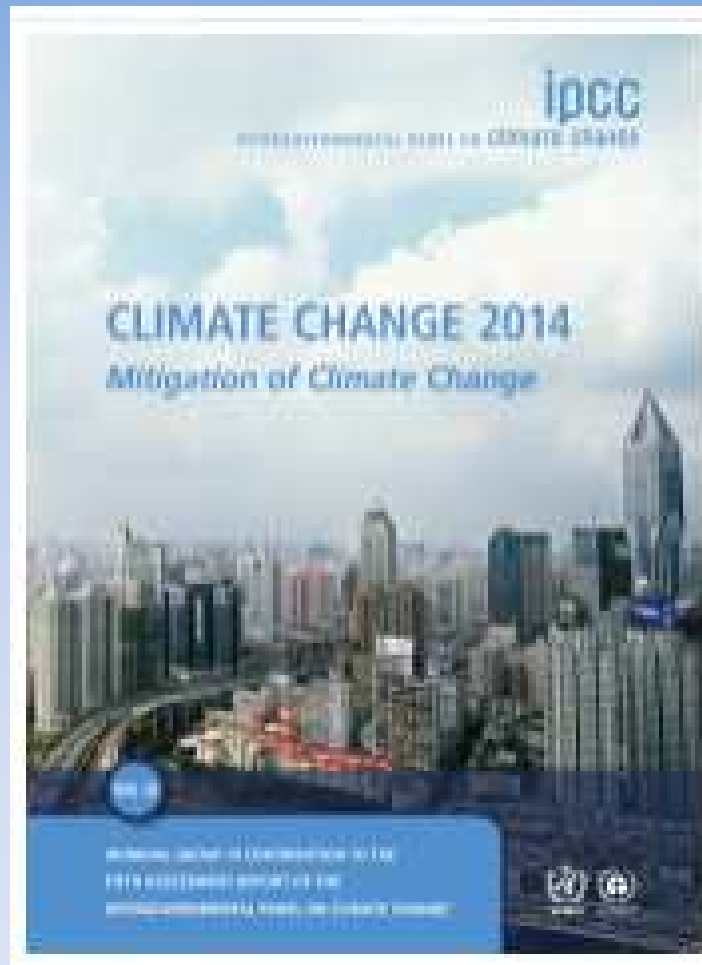


## Volume I: Global and Sectoral Aspects

- 1. Point of departure 0.95 MB -
- 2. Foundations for decisionmaking 1.31 MB -
- 3. Freshwater resources 2.50 MB -
- 4. Terrestrial and inland water systems 2.80 MB -
- 5. Coastal systems and low-lying areas 1.42 MB -
- 6. Ocean systems 9.07 MB -
- 7. Food security and food production systems 1.64 MB -
- 8. Urban Areas 3.76 MB -
- 9. Rural Areas 0.83 MB -
- 10. Key economic sectors and services 0.82 MB -
- 11. Human health: impacts, adaptation, and co-benefits 1.13 MB -
- 12. Human security 0.88 MB -
- 13. Livelihoods and poverty 2.13 MB -
- 14. Adaptation needs and options 0.44 MB -
- 15. Adaptation planning and implementation 0.46 MB -
- 16. Adaptation opportunities, constraints, and limits 1.56 MB -
- 17. Economics of adaptation 0.64 MB -
- 18. Detection and attribution of observed impacts 1.33 MB -
- 19. Emergent risks and key vulnerabilities 1.23 MB -
- 20. Climate-resilient pathways: adaptation, mitigation, and sustainable development 0.36 MB -



# WG III – Mitigation of Climate Change



## Chapters

- 1. Introductory Chapter [4.7MB](#) -
- 2. Integrated Risk and Uncertainty Assessment of Climate Change Response Policies [1.8MB](#) -
- 3. Social, Economic and Ethical Concepts and Methods [1.7MB](#) -
- 4. Sustainable Development and Equity [1.4MB](#) -
- 5. Drivers, Trends and Mitigation [7.1MB](#) -
- 6. Assessing Transformation Pathways [14.2MB](#) -
- 7. Energy Systems [7.9MB](#) -
- 8. Transport [4.7MB](#) -
- 9. Buildings [7.4MB](#) -
- 10. Industry [5.2MB](#) -
- 11. Agriculture, Forestry and Other Land Use (AFOLU) [8.1MB](#) -
- 12. Human Settlements, Infrastructure and Spatial Planning [7.8MB](#) -
- 13. International Cooperation: Agreements and Instruments [2.0MB](#) -
- 14. Regional Development and Cooperation [5.2MB](#) -
- 15. National and Sub-national Policies and Institutions [1.5MB](#) -
- 16. Cross-cutting Investment and Finance Issues [1.5MB](#) -



# CLIMATE CHANGE 2013

## *The Physical Science Basis*

WG I

WORKING GROUP I CONTRIBUTION TO THE  
FIFTH ASSESSMENT REPORT OF THE  
INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE



### Key SPM Messages

## 19 Headlines

on less than 2 Pages

Summary for Policymakers  
ca. 14,000 Words

14 Chapters  
Atlas of Regional Projections

54,677 Review Comments  
by 1089 Experts

2010: 259 Authors Selected

2009: WGI Outline Approved



# CLIMATE CHANGE 2013

## *The Physical Science Basis*

WG I

WORKING GROUP I CONTRIBUTION TO THE  
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INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

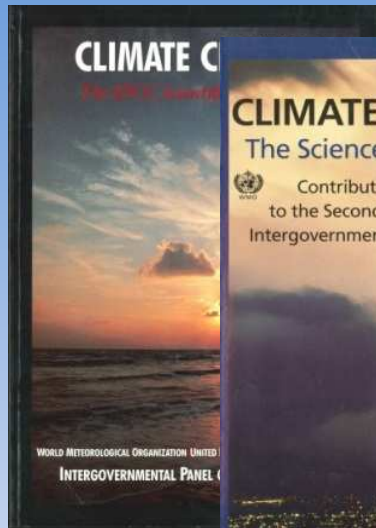


# Physical Basis: Communicating the main points

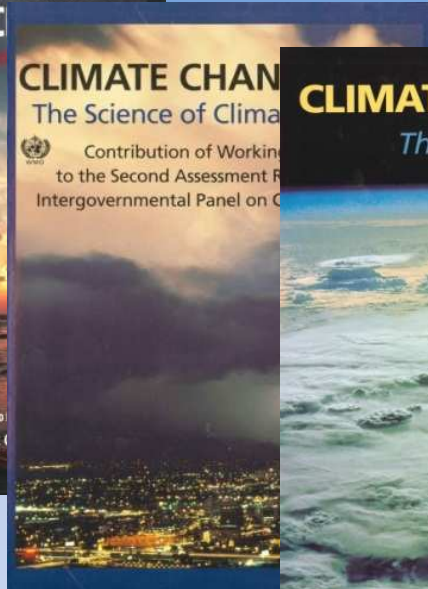
## Quick Links

- [Summary for Policymakers \(SPM\)](#)
- [Video](#)
- [Presentation](#)
- [Graphics](#)
- [SPM Errata - Brochure \[11.11.2013\]](#)
- [Full Report \(375MB\)](#)
- [WGI Report Website](#)

## IPCC Assessment Reports since 1990: WGI Contribution



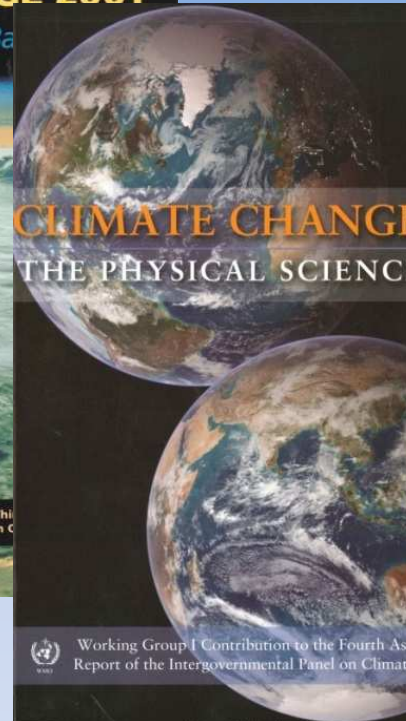
1990



1995



2001



2007



2013



# 2 SUMMARY APPROACHES

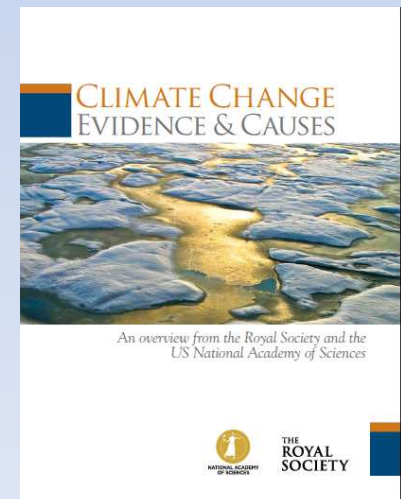
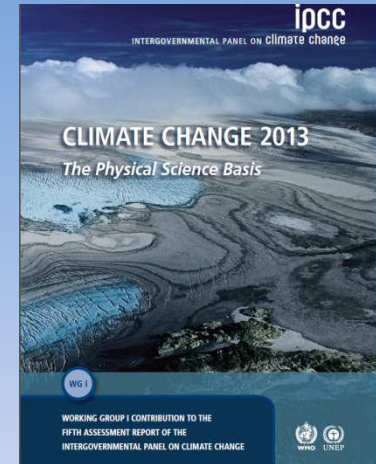
## Summary for Policy Makers (SPM)

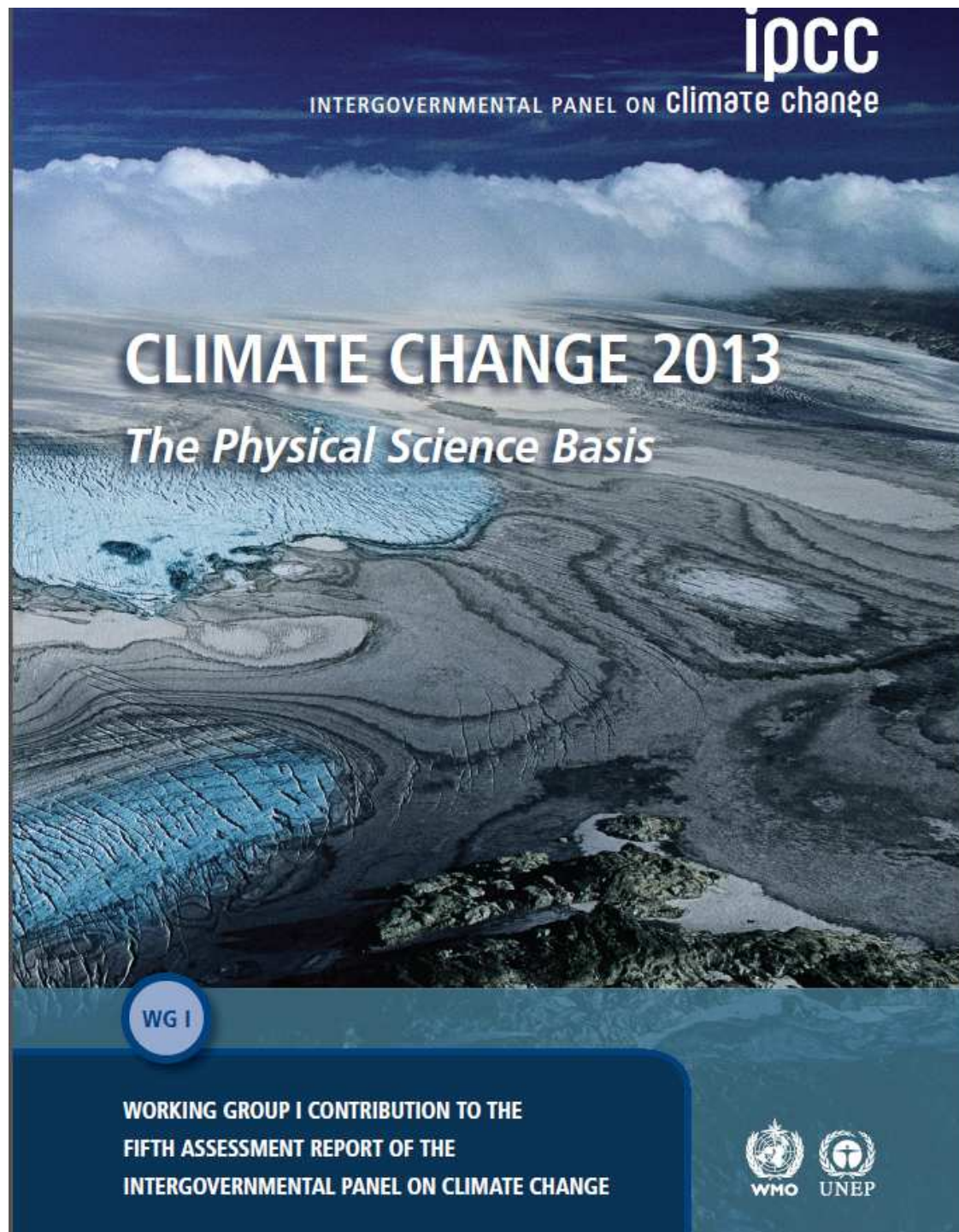
- 19 “HEADLINES”
- Majority: Temperature focused
- Causes, Modeling, Effects

VS.

## Royal Society & US National Academy of Sciences (RS/NAS)

- Public oriented queries
- More comprehensive summary of the science





# Approach # 1

19  
“Headlines”

# 19 “Headlines” / 6 slides







# CLIMATE CHANGE EVIDENCE & CAUSES



*An overview from the Royal Society and the  
US National Academy of Sciences*

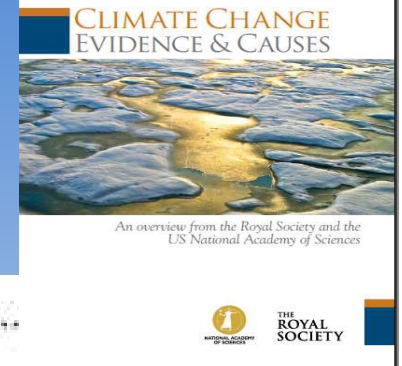


THE  
ROYAL  
SOCIETY

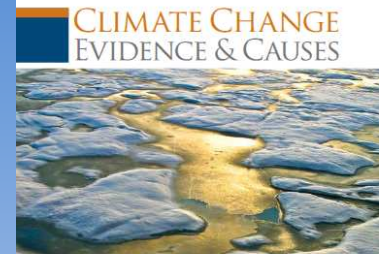


## Approach # 2

20  
Q/As  
to follow this  
slide



- 1 Is the climate warming? .....
- 2 How do scientists know that recent climate change is largely caused by human activities? .....
- 3 CO<sub>2</sub> is already in the atmosphere naturally, so why are emissions from human activity significant? .....
- 4 What role has the Sun played in climate change in recent decades? .....
- 5 What do changes in the vertical structure of atmospheric temperature—from the surface up to the stratosphere—tell us about the causes of recent climate change? .....
- 6 Climate is always changing. Why is climate change of concern now? .....
- 7 Is the current level of atmospheric CO<sub>2</sub> concentration unprecedented in Earth's history? .....
- 8 Is there a point at which adding more CO<sub>2</sub> will not cause further warming? ..... 1
- 9 Does the rate of warming vary from one decade to another? .....
- 10 Does the recent slowdown of warming mean that climate change is no longer happening? .....



An overview from the Royal Society and the  
US National Academy of Sciences

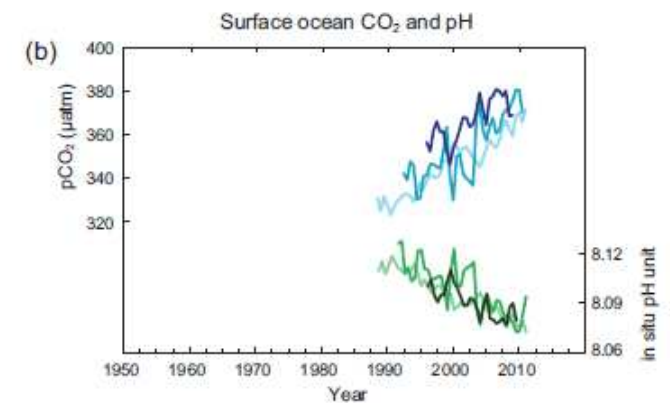
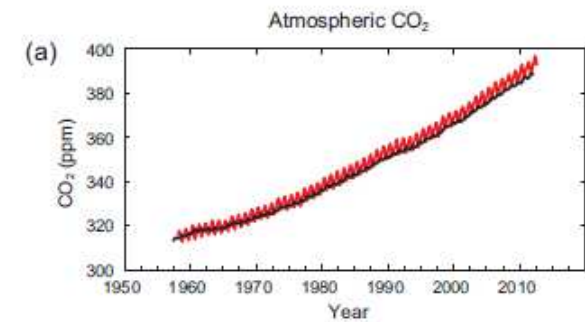
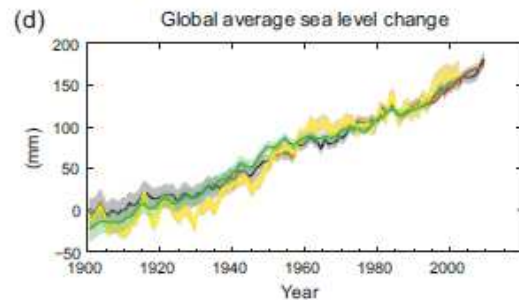
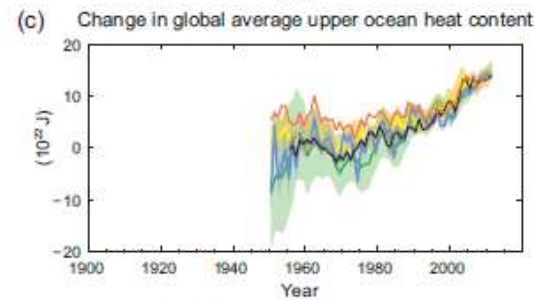
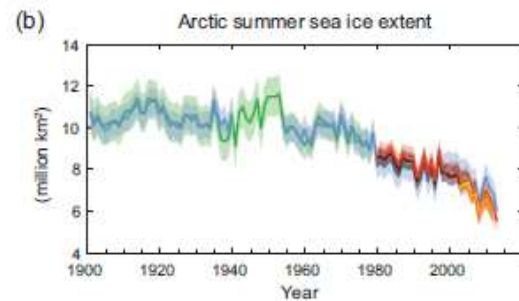
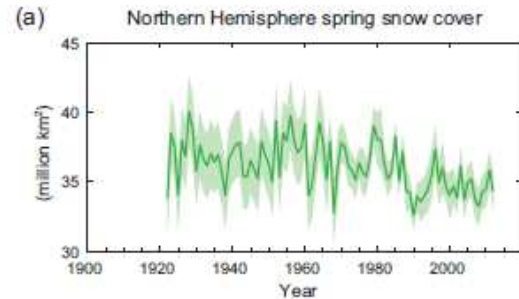
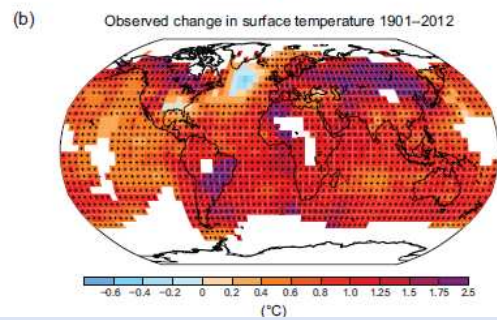
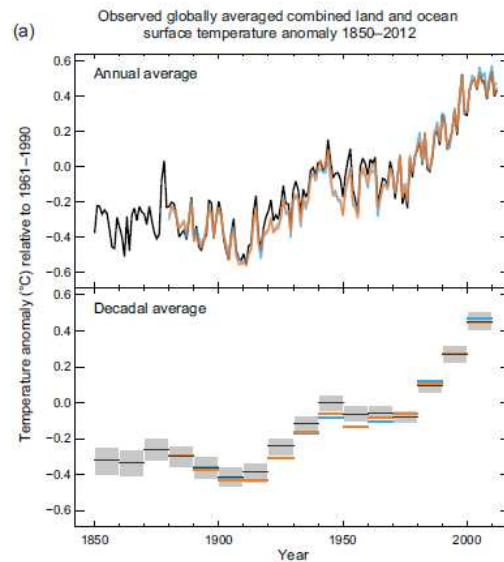


- 11 If the world is warming, why are some winters and summers still very cold?
- 12 Why is Arctic sea ice decreasing while Antarctic sea ice is not? .....
- 13 How does climate change affect the strength and frequency  
of floods, droughts, hurricanes, and tornadoes? .....
- 14 How fast is sea level rising? .....
- 15 What is ocean acidification and why does it matter? .....
- 16 How confident are scientists that Earth will warm further over the coming century? .....
- 17 Are climate changes of a few degrees a cause for concern? .....
- 18 What are scientists doing to address key uncertainties  
in our understanding of the climate system? .....
- 19 Are disaster scenarios about tipping points like 'turning off the Gulf Stream'  
and release of methane from the Arctic a cause for concern? .....
- 20 If emissions of greenhouse gases were stopped, would the climate return  
to the conditions of 200 years ago? .....

# 1: THE CLIMATE IS WARMING

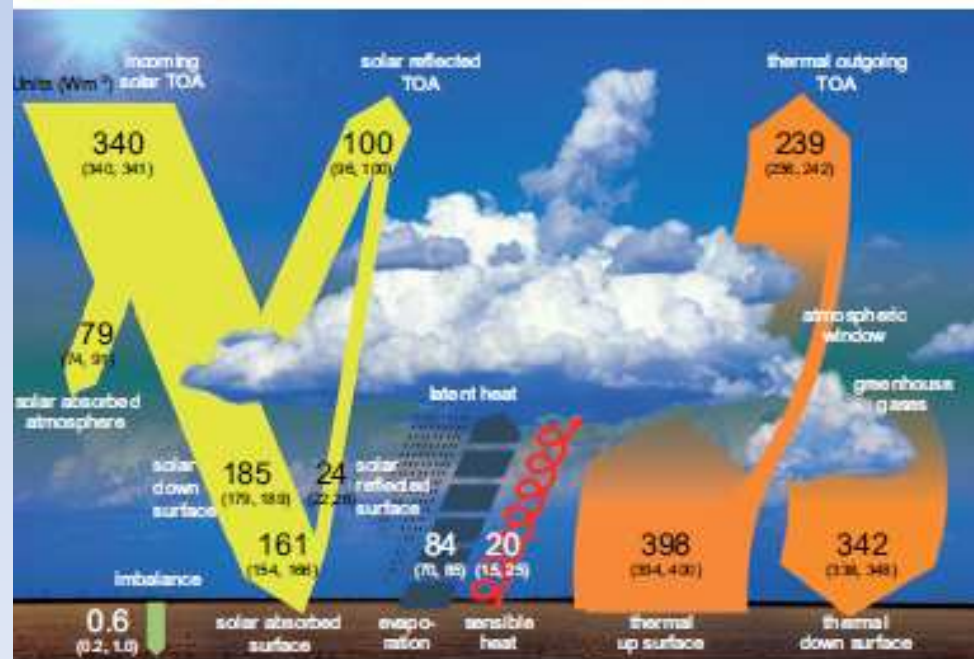
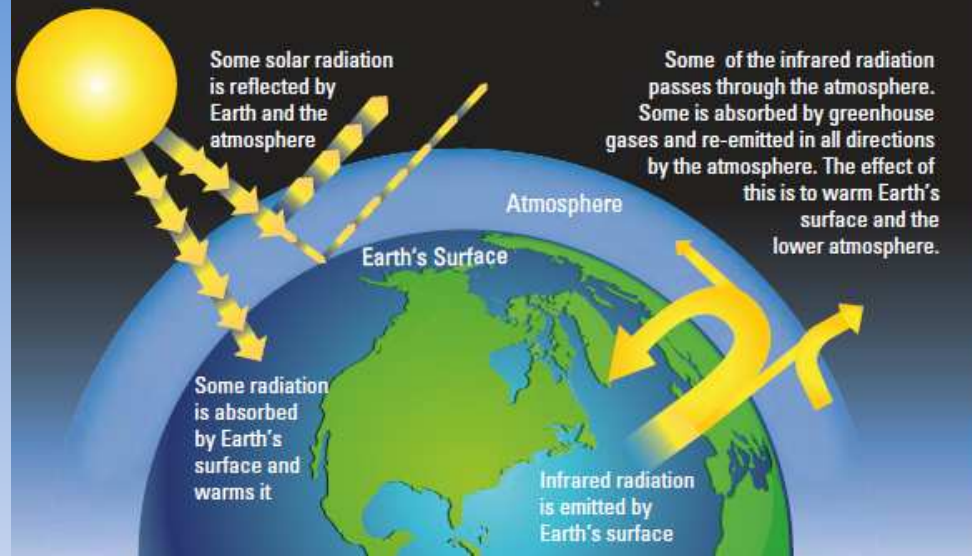
- The evidence:
  - Atmosphere
  - Oceans
  - Cryosphere
  - Sea Level
  - Carbon and Other Biogeochemical Cycles

# 1 – Resulting in:





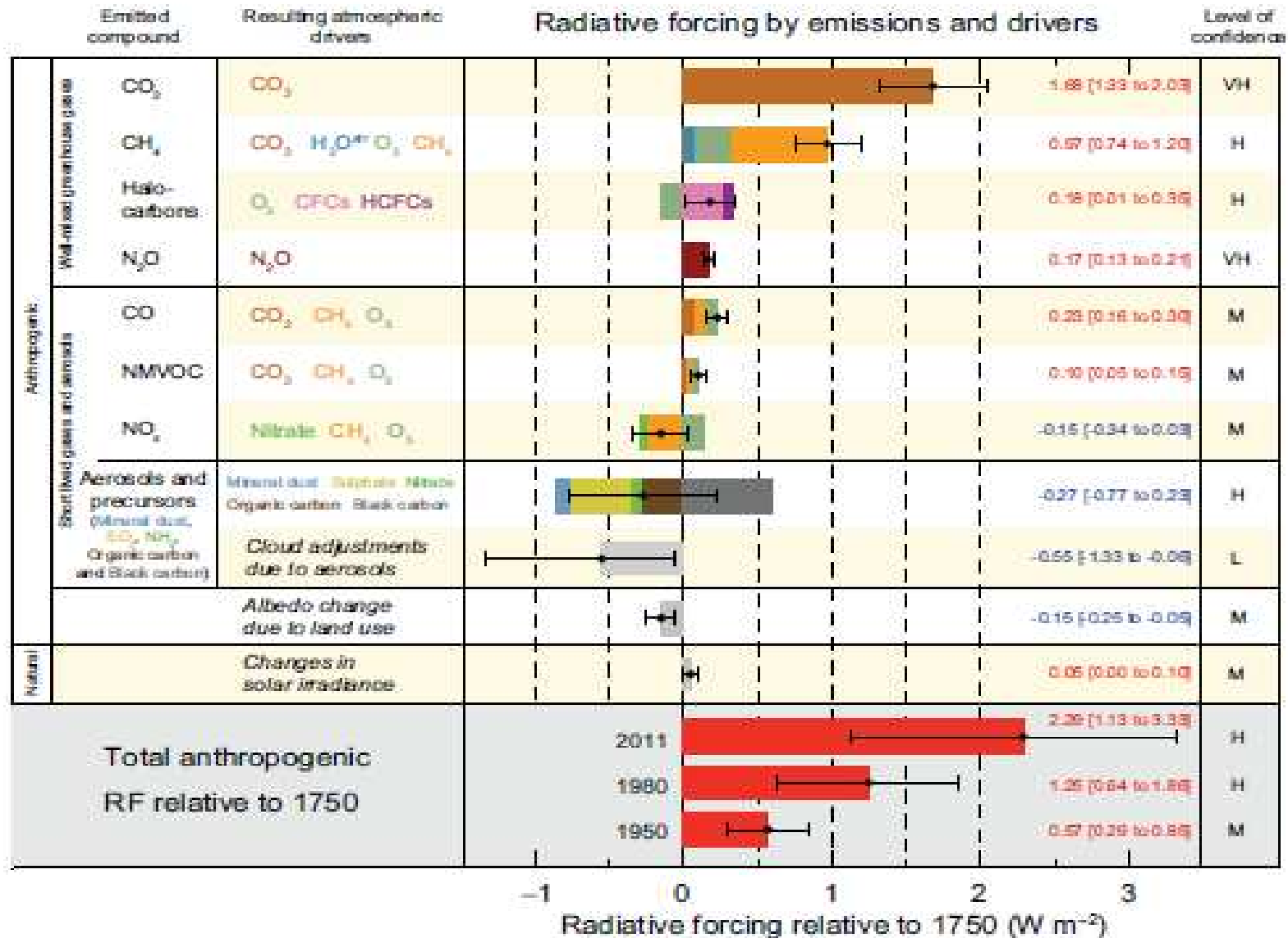
# THE GREENHOUSE EFFECT





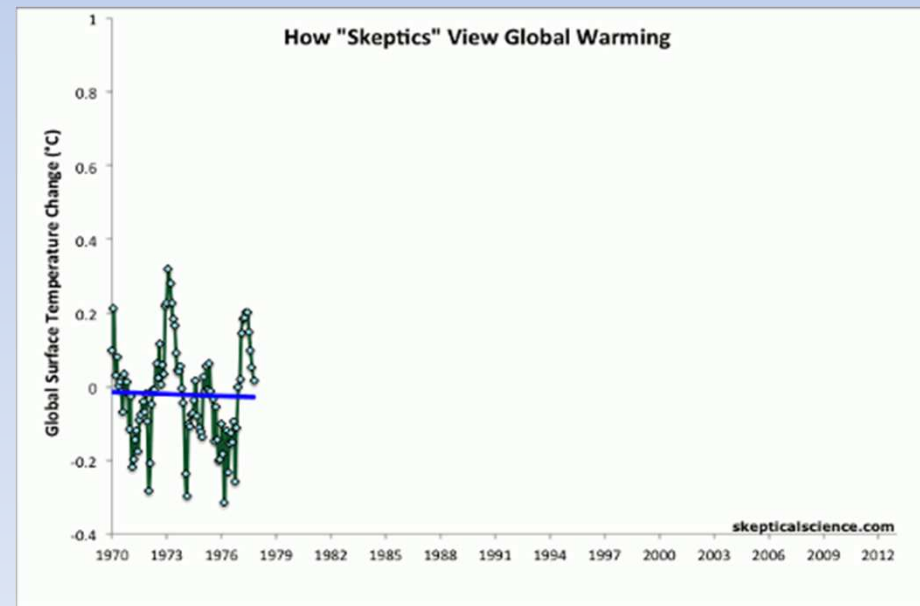
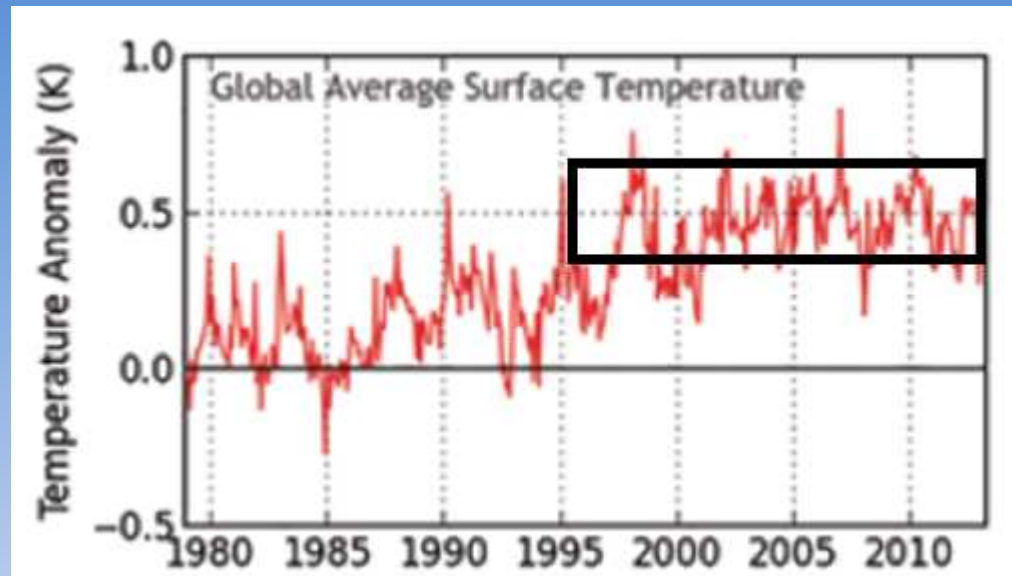
# 1: THE CLIMATE IS WARMING

- Drivers; aka forcings, i.e. causes

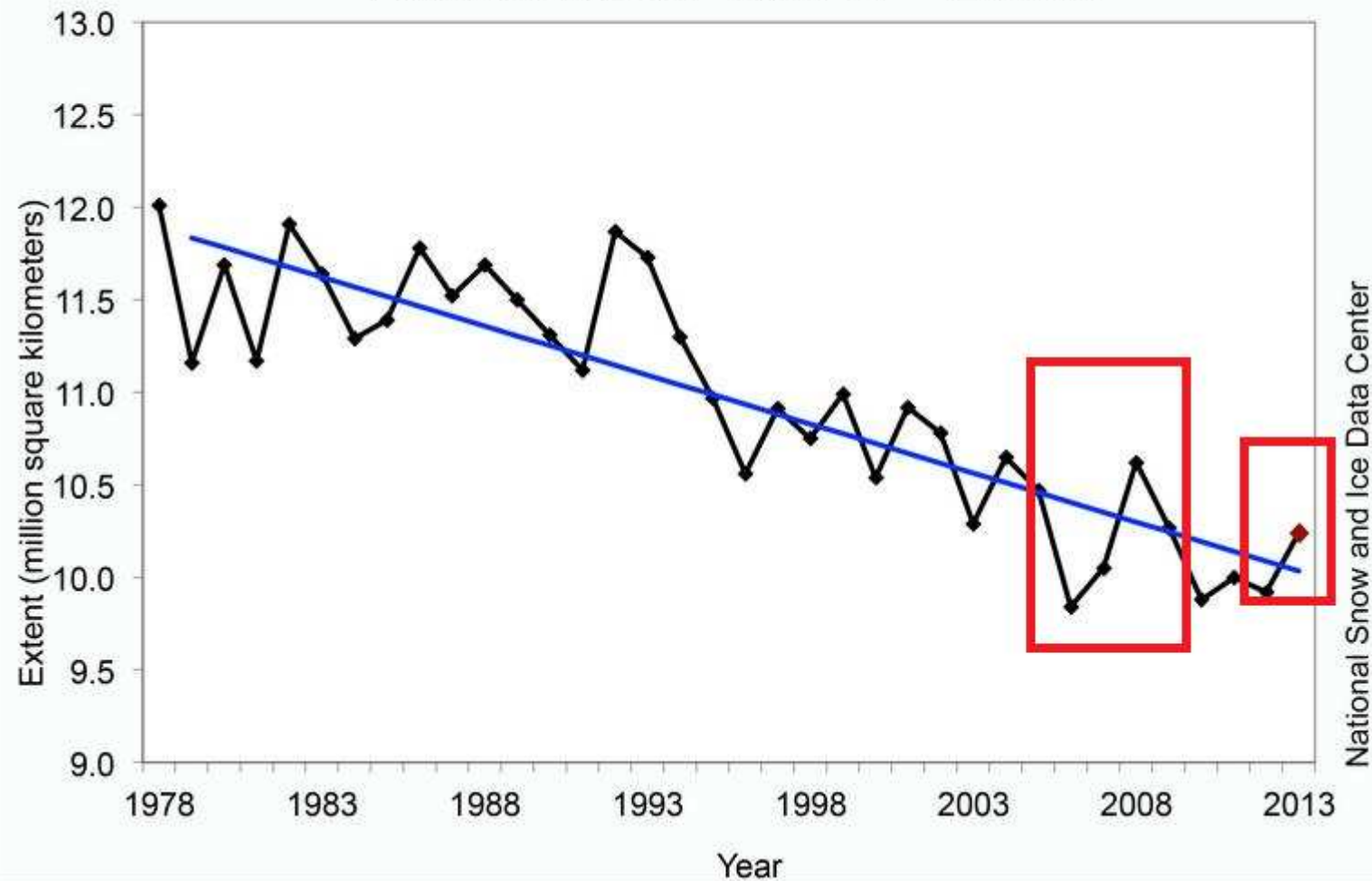


# Disinformation campaign (see next 5 slides)

- Will focus on last 15-17 years and claim global warming isn't happening – all part of natural variability
- Or, Arctic Sea Ice recovering
- Or focus on select glaciers growing
- Or Antarctic sea ice growing
- Mostly ignore ocean acidification

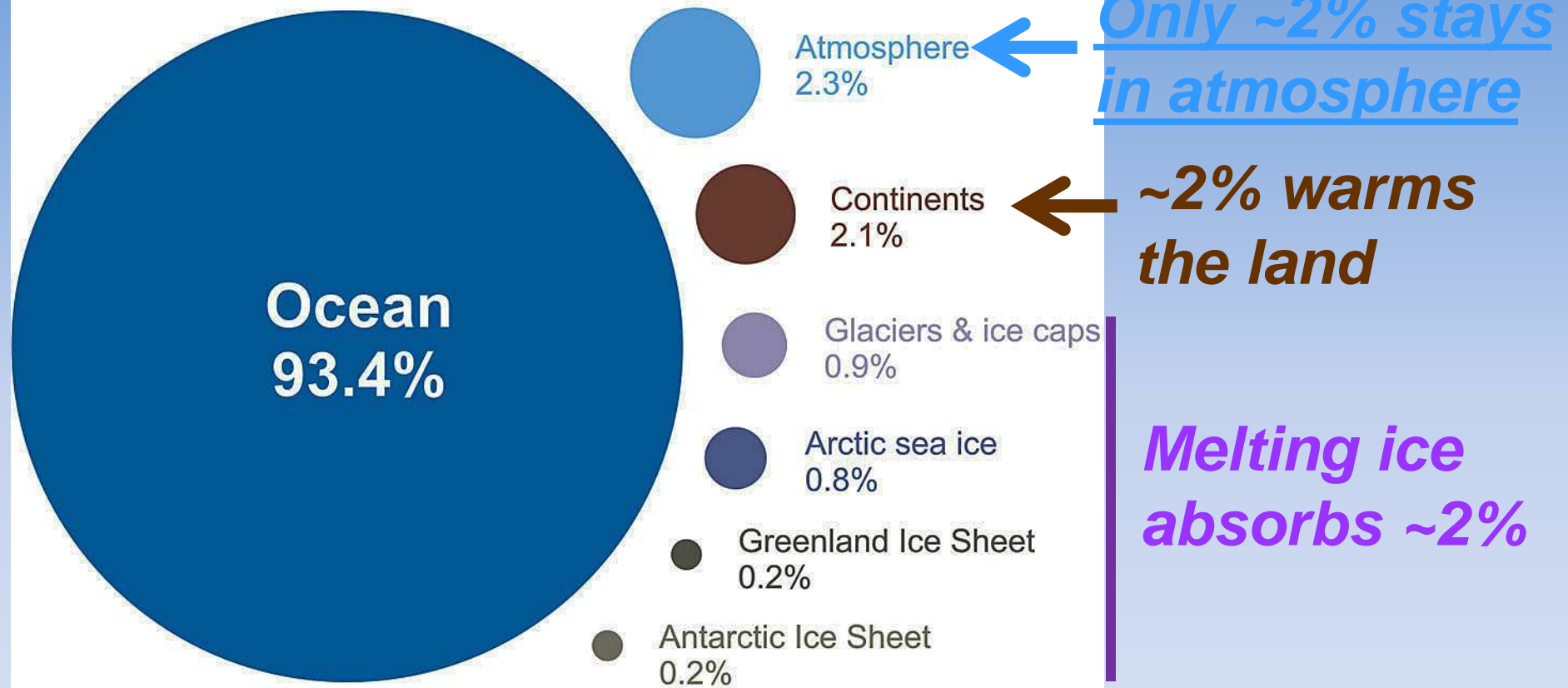


## Average Monthly Arctic Sea Ice Extent November 1978 - 2013



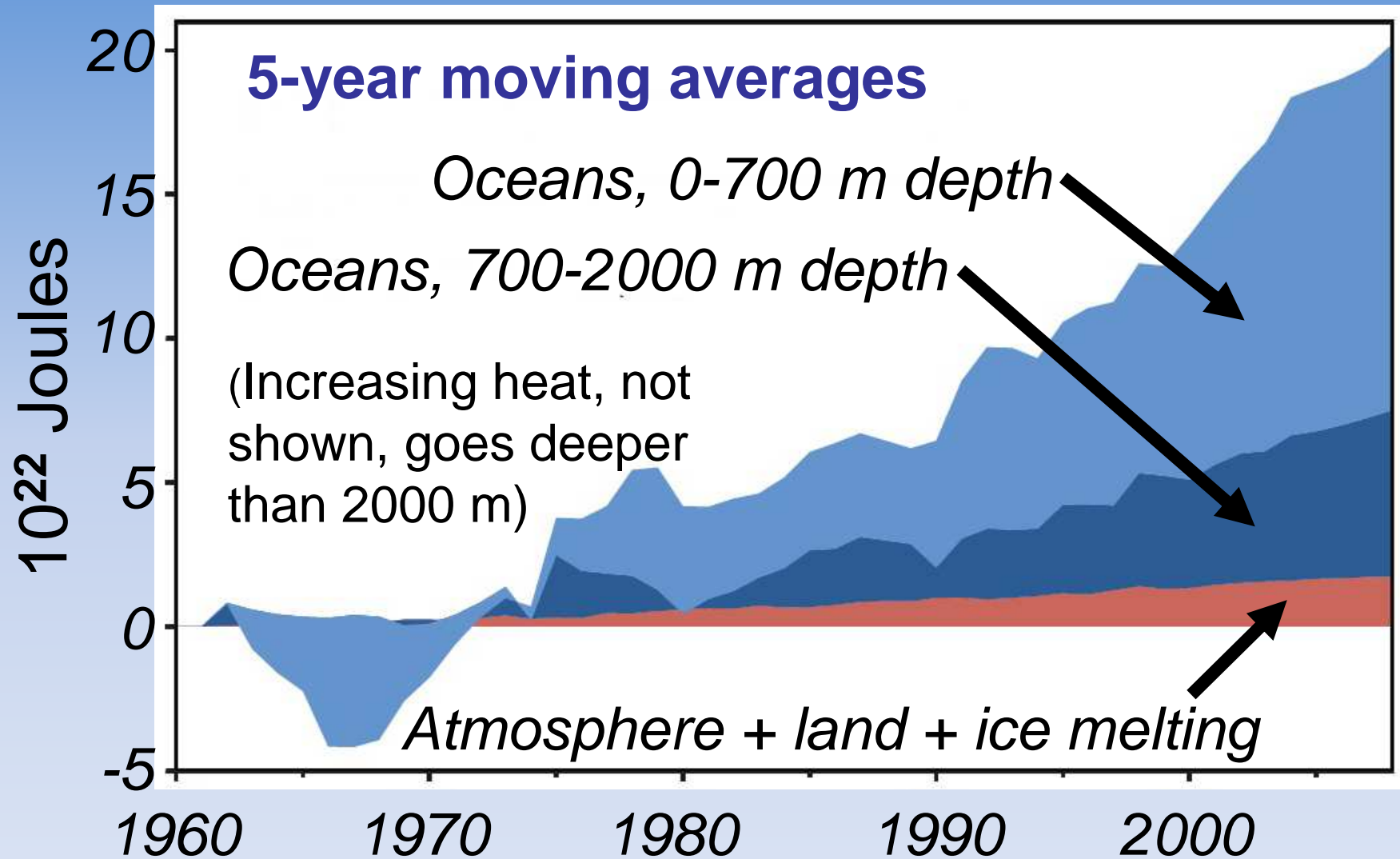
For more see: <http://www.skepticalscience.com/melting-ice-global-warming.htm>

# Where is global warming going?



*John Cook, from IGPP 2007 data; ~93% to oceans continues (NOAA/NODC, 2012)*

# Change in heat content, 1958-2011



(NOAA 2012 data, Nuccitelli et al. 2012 plot)



## **2: LARGELY CAUSED BY HUMAN ACTIVITIES**

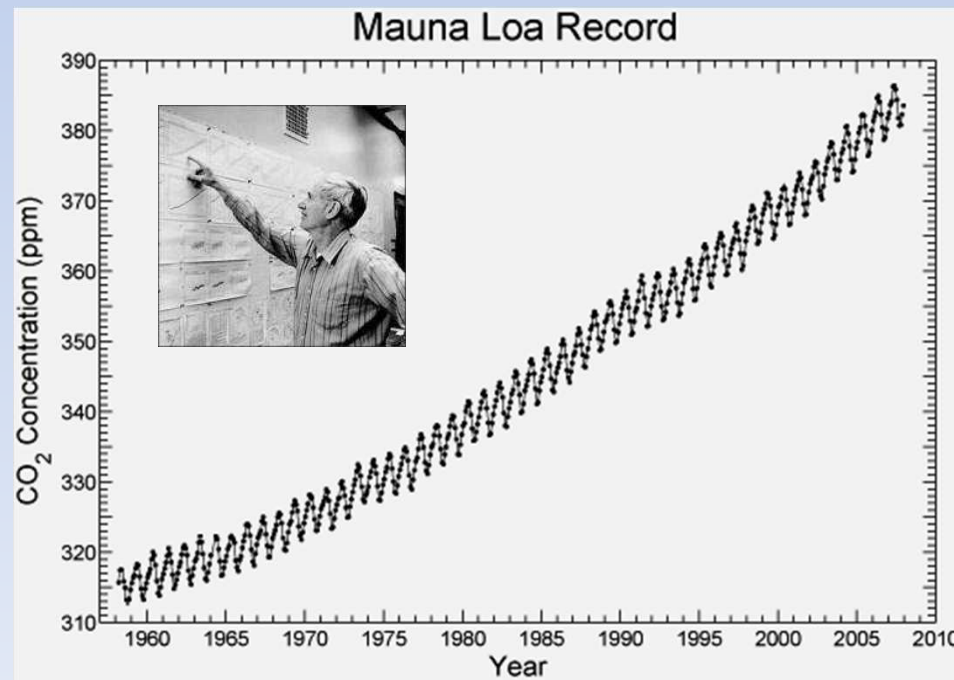


# Disinformation campaign

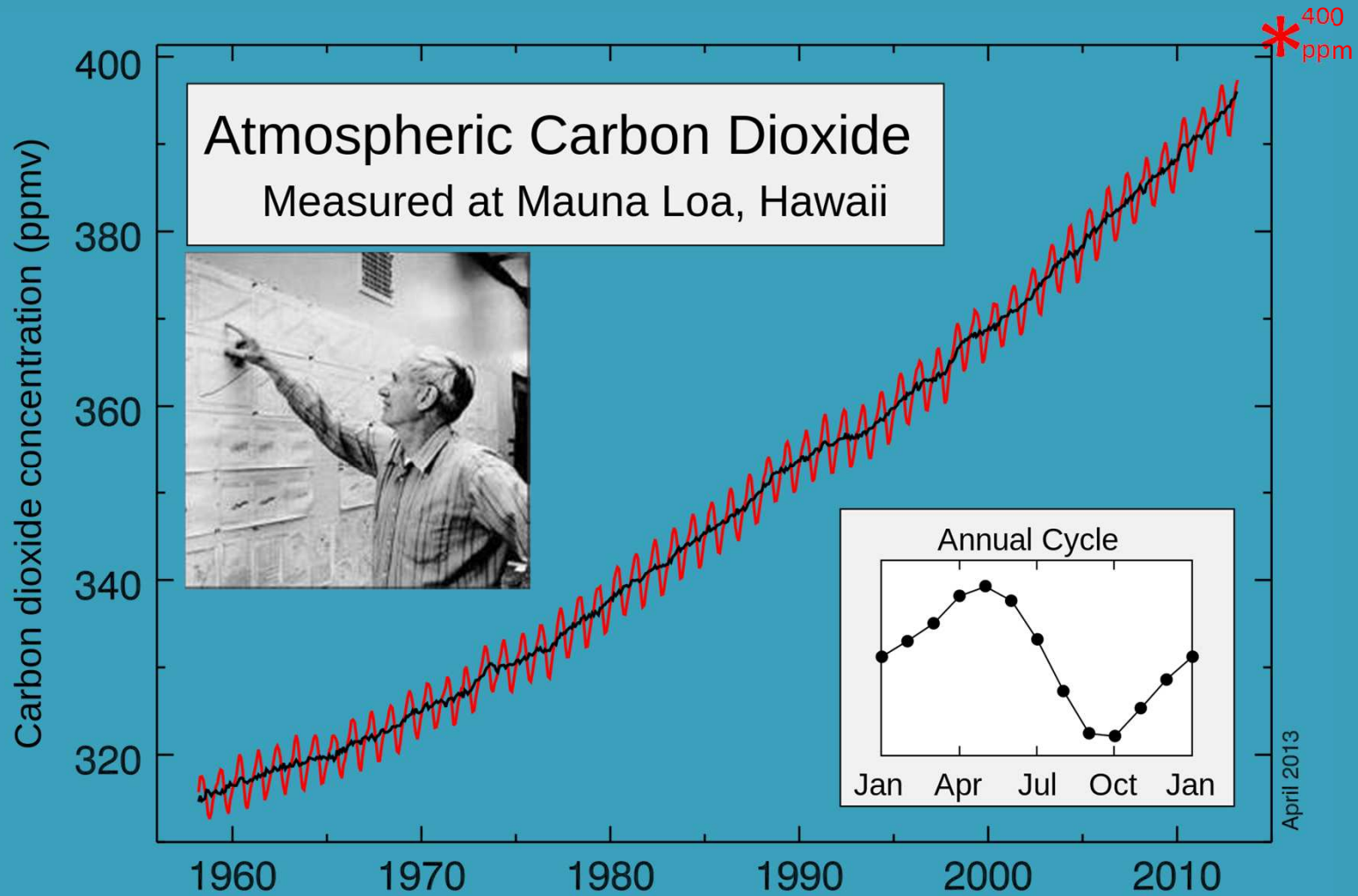
- Might argue the economics of change and pollution of generating metals for batteries
- ....not that there aren't environmental concerns for new technology
- For more, see:  
<http://www.skepticalscience.com/its-not-us.htm>

### 3: EMISSIONS FROM HUMAN ACTIVITIES LARGELY TO BLAME

- 40% increase in  $\text{CO}_2$
- Dead carbon altering atmospheric  $\text{C}^{14}$
- That Carbon is more negative/enriched in  $\text{C}^{12}$



# Lest we forget: CO<sub>2</sub> is still going up



# Disinformation campaign

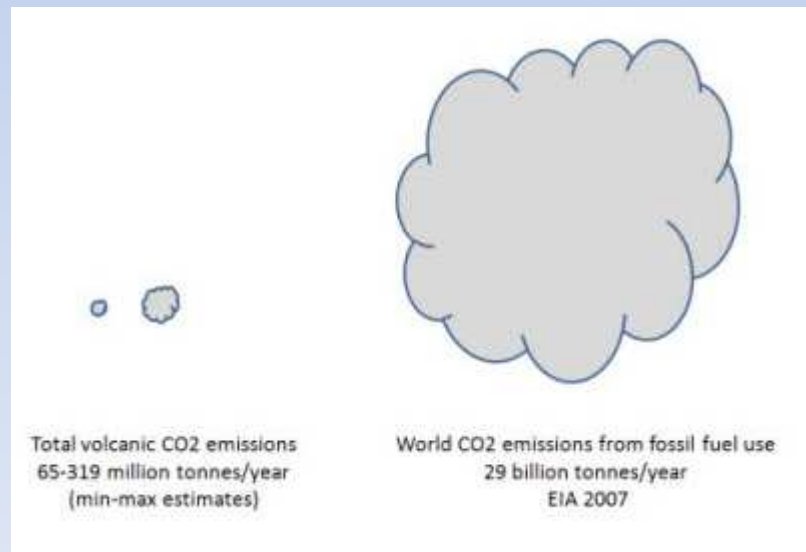
- Plimer (and others):
- <http://www.skepticalscience.com/volcanoes-and-global-warming.htm>

Volcanoes emit more CO2 than humans

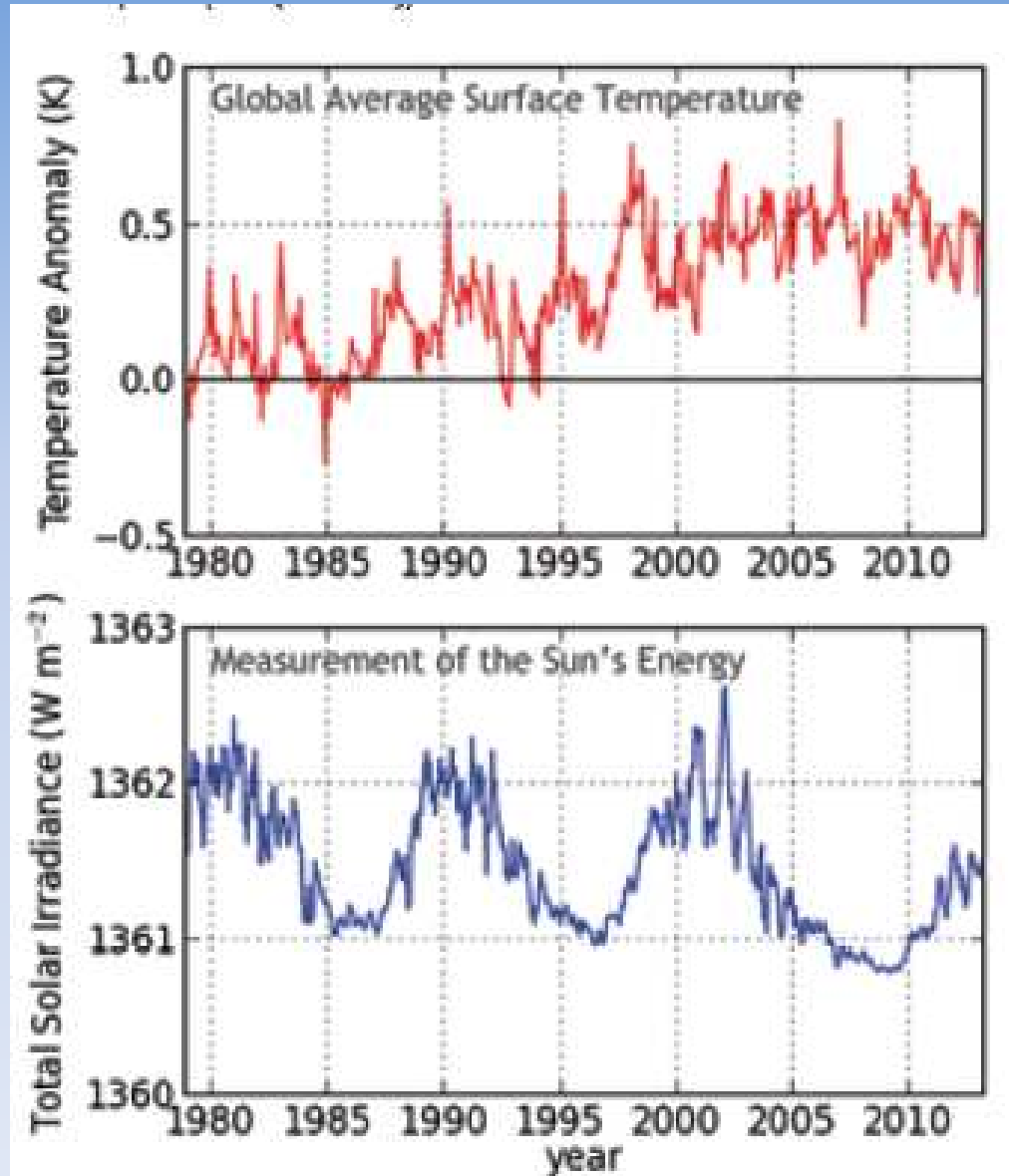
"Human additions of CO2 to the atmosphere must be taken into perspective.

Over the past 250 years, humans have added just one part of CO2 in 10,000 to the atmosphere. One volcanic cough can do this in a day." (Ian Plimer)

– Versus - <1 % (I have the references)



## 4: THE SUN'S ROLE IS MINIMIZING

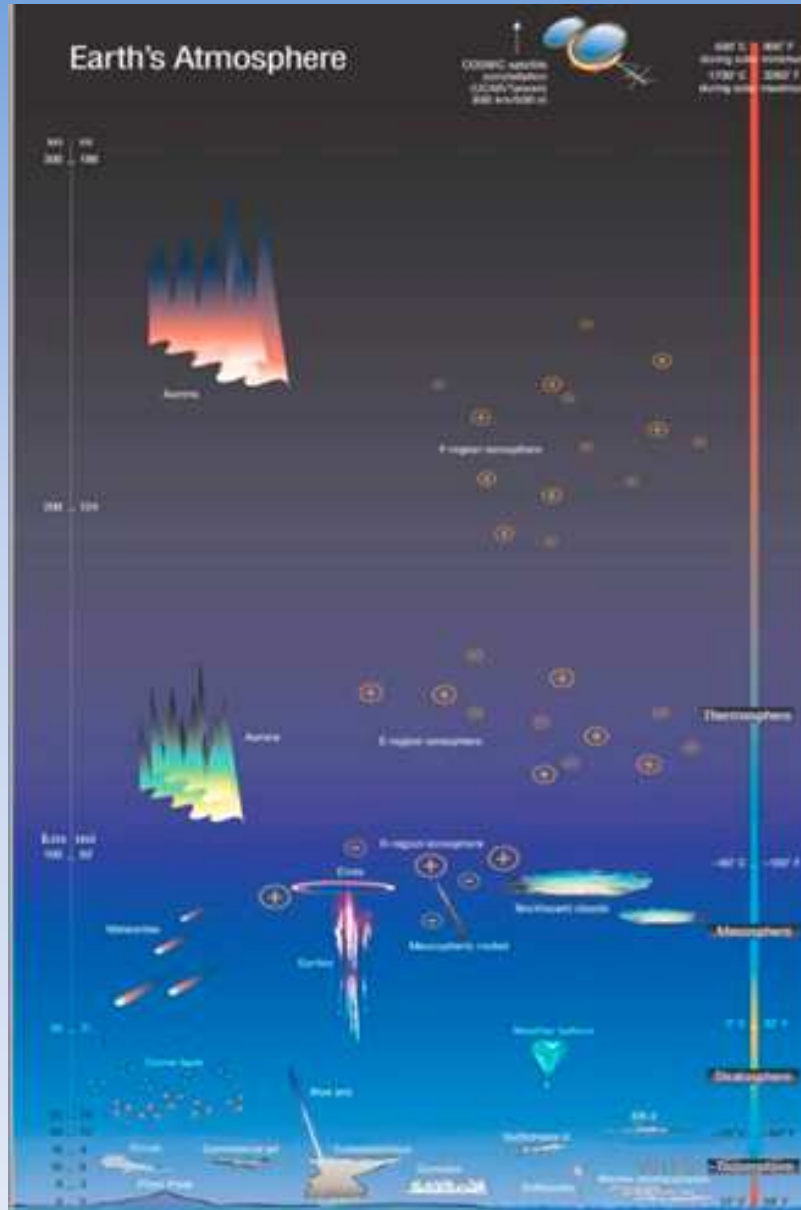




# Disinformation campaign

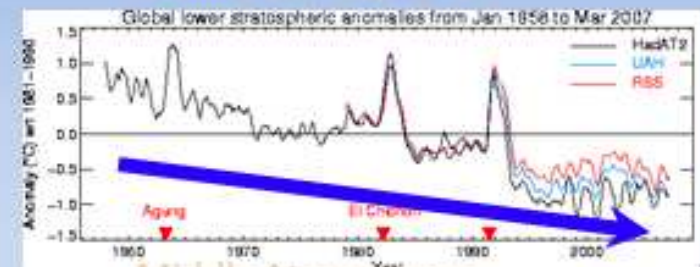
- Predict long cold period coming, citing Russian studies that predict entering another “Little Ice Age”
- Predicted last solar cycle wasn’t going to happen – go dormant / that didn’t occur!

# 5: SURFACE TO STRATOSPHERE CHANGES

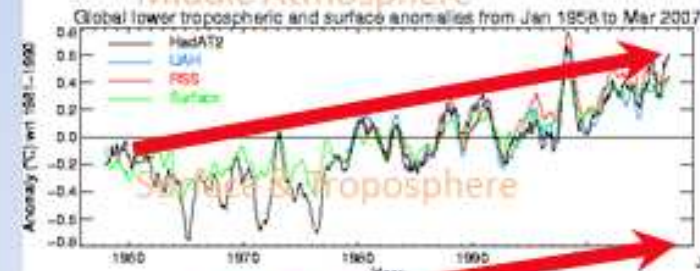


## Greenhouse Fingerprint

Middle Atmosphere



Middle Atmosphere



Subsurface (Land/Ocean)

Earth's Climate System

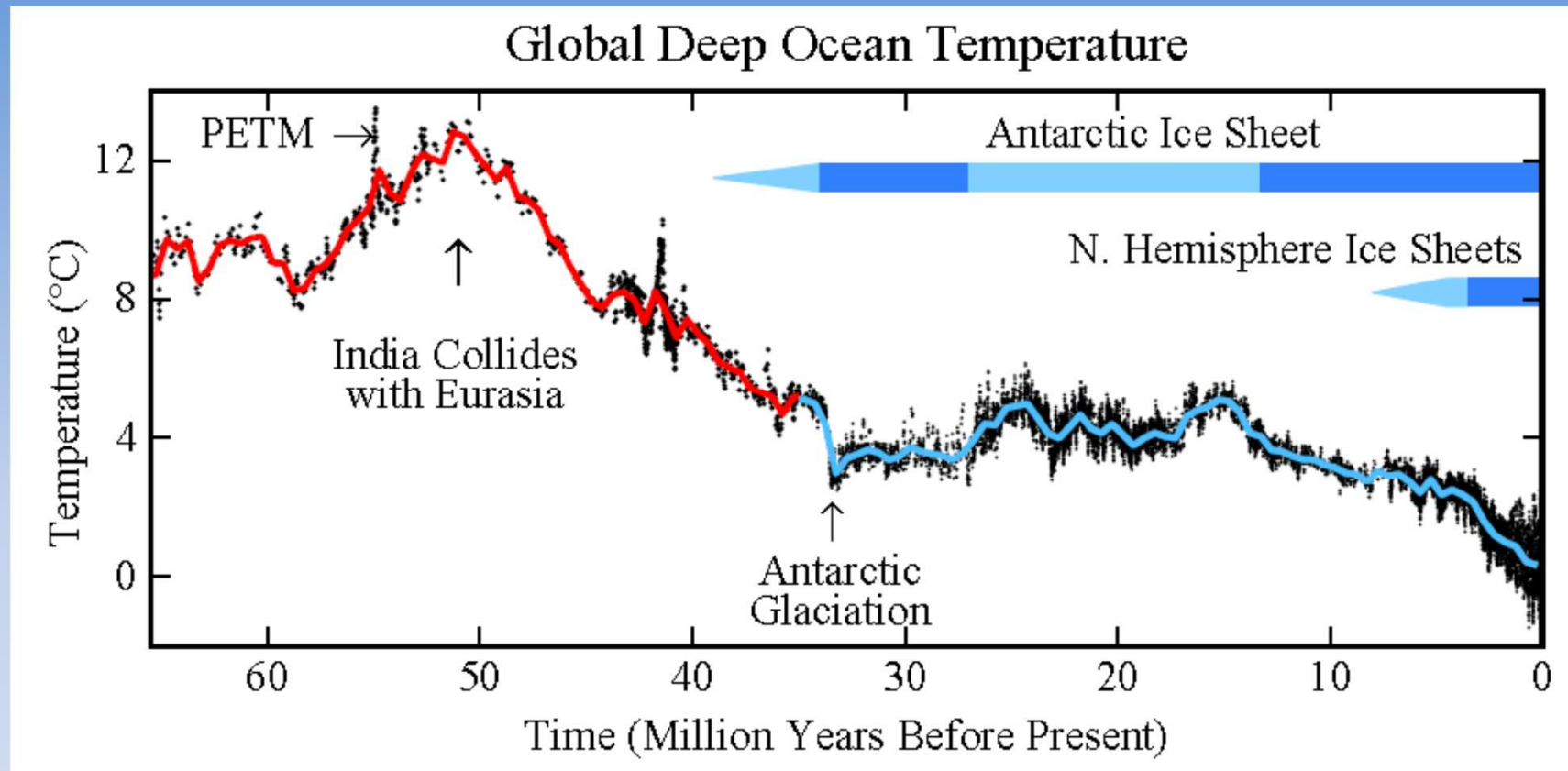
January 14, 08

# Disinformation campaign

- Spencer and Christie will focus on cooling of Tropopause and mislead people
- Etc....
- For more see:  
<http://www.skepticalscience.com/satellite-measurements-warming-troposphere.htm>

## **6: CLIMATE IS ALWAYS CHANGING – SO WHAT?**

- It's not about whether the Earth will survive – it will!
- It's about sustainability with expected consequences
  - Refugees
  - Economies
  - Etc., etc.



**50 million years ago (50 MYA) Earth was ice-free.**

**Atmospheric CO<sub>2</sub> amount was of the order of 1000 ppm 50 MYA.**

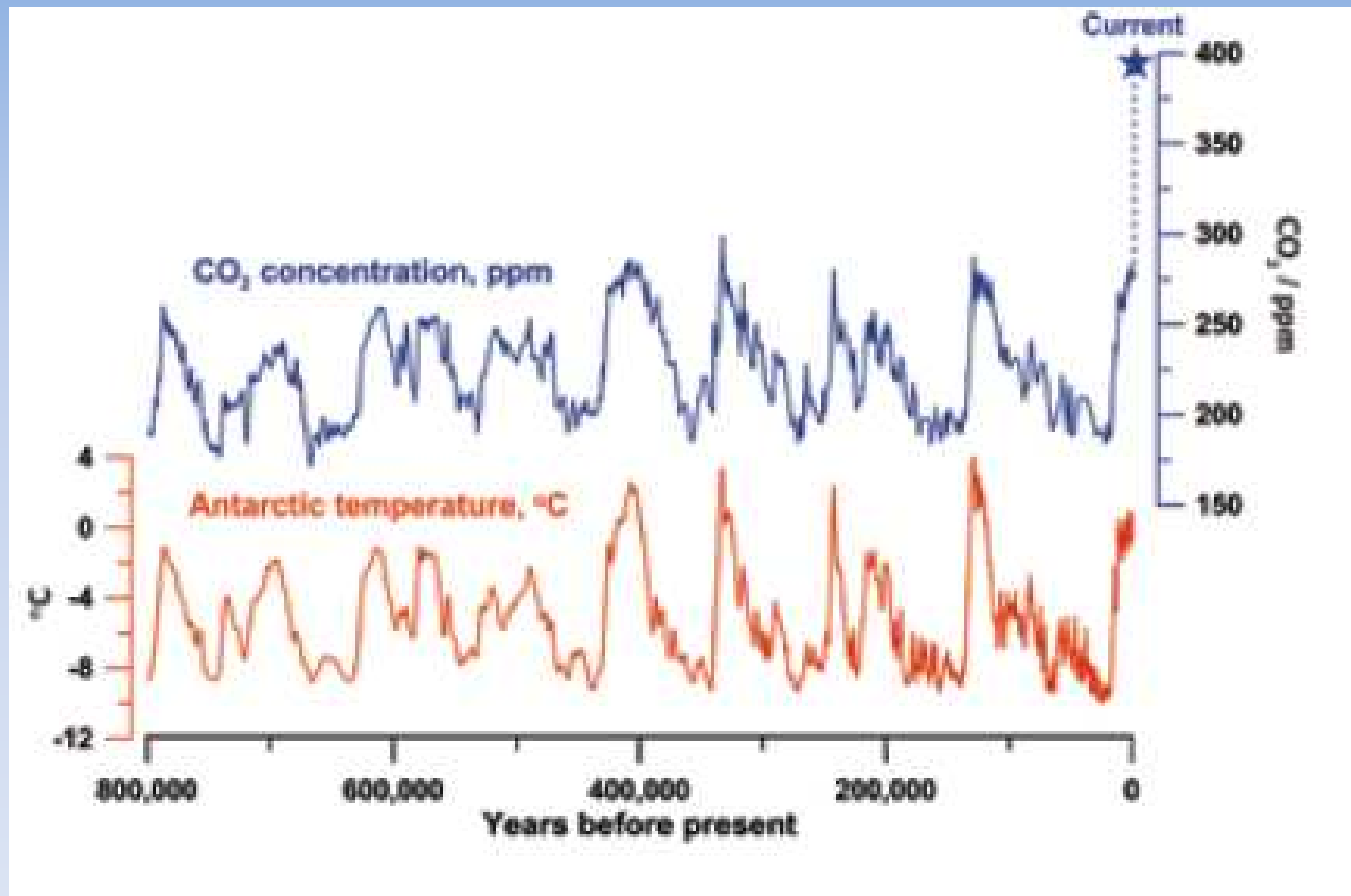
**Atmospheric CO<sub>2</sub> imbalance due to plate tectonics  $\sim 10^{-4}$  ppm per year.**

# Disinformation campaign

- Fish analogy:
  - Some meteorologists who don't buy climate change: in bottom of fish tank looking at the sand grains.
  - Some geologists who don't buy climate change: in outer space looking at the fish tank.
  - BOTH not seeing the pyranahs swirling in the fish tank : It's about sustainability!
- For more see:  
<http://www.skepticalscience.com/climate-change-little-ice-age-medieval-warm-period.htm>



## 7: HISTORICALLY UNPRECEDENTED CO<sub>2</sub> CONCENTRATIONS



**8: WILL ADDING MORE CO<sub>2</sub> EVENTUALLY STOP  
CAUSING WARMING?**

**NO**

# Disinformation campaign

- Say CO<sub>2</sub> saturated
- Water vapor as more abundant and more important green house gas (GHG) – ignoring feedback increase cause by warming caused by increases in CO<sub>2</sub>
- PETM shows that CO<sub>2</sub> spikes do continue to influence climate

See next 3 slides

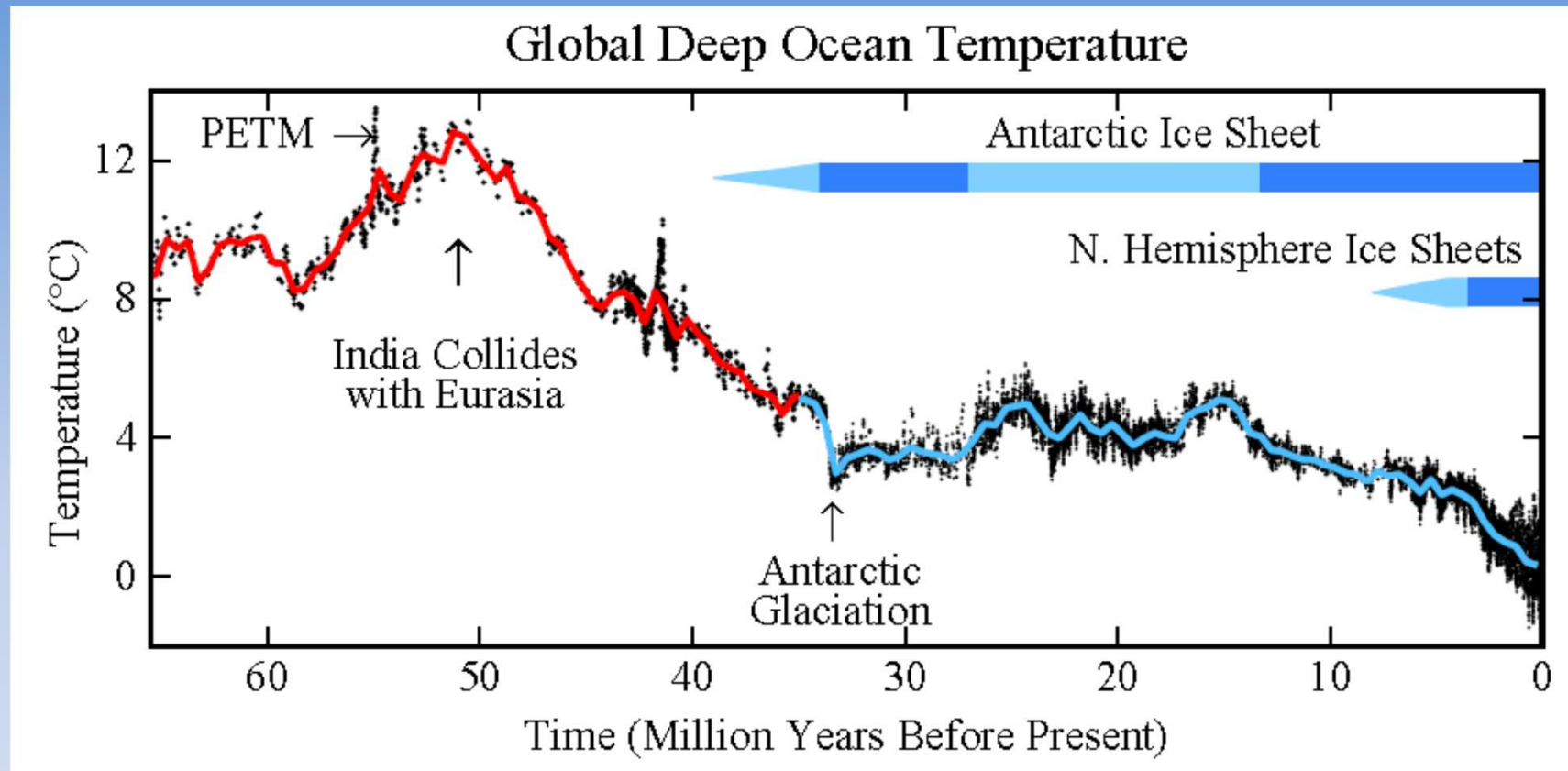
The  $\text{CO}_2$  greenhouse gas effect is concentrated  
The most potent greenhouse gas is  $\text{H}_2\text{O}$  - vapor  
in the polar regions !!!



Particularly in the  
Arctic!

The large  $\text{H}_2\text{O}$  greenhouse effect  
is controlled by  
temperature –  
 $\text{H}_2\text{O}$  saturation doubles  
with every  
 $10^\circ\text{C}$  increase  
 $\text{CO}_2$  is evenly  
distributed throughout  
the atmosphere

As a result It is  
concentrated in  
the lower atmosphere  
of the tropics

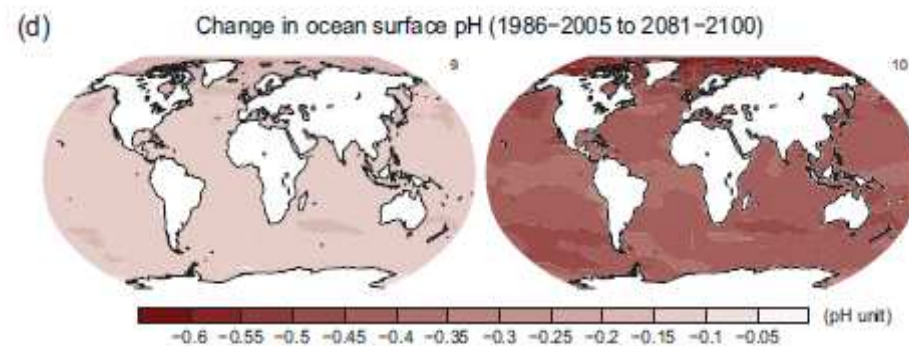
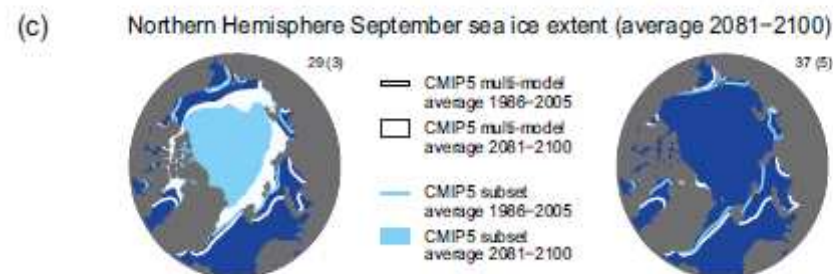
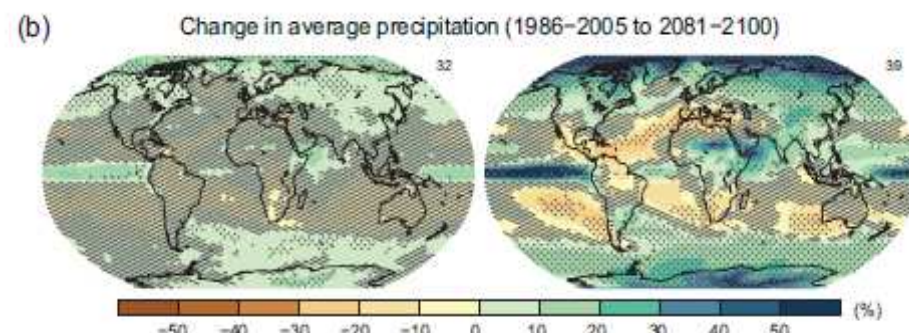
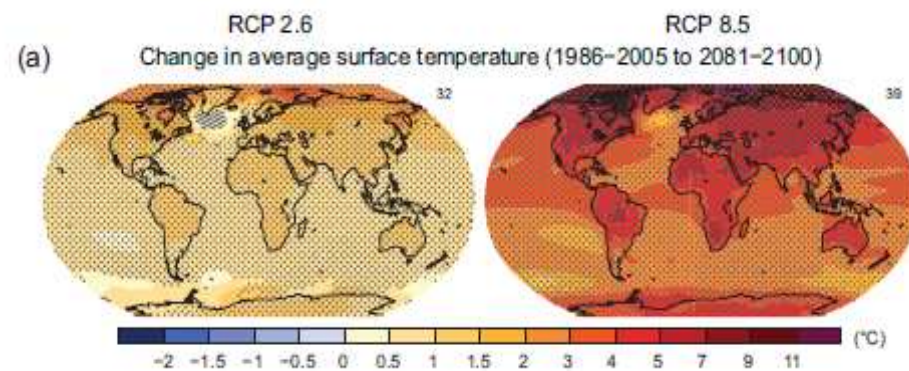
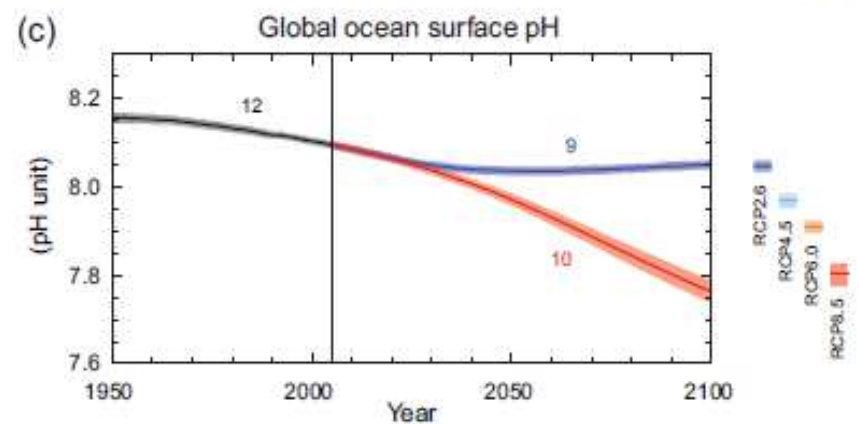
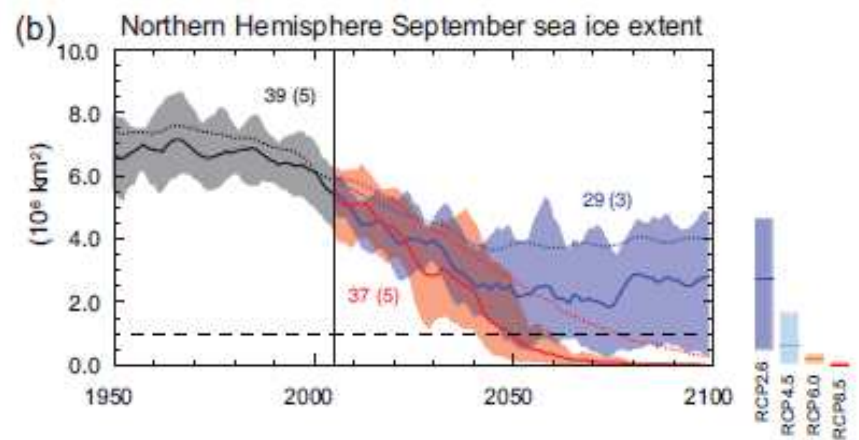
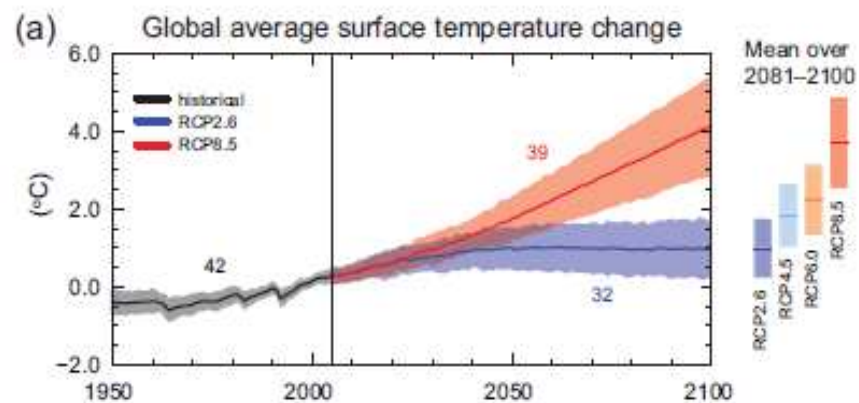


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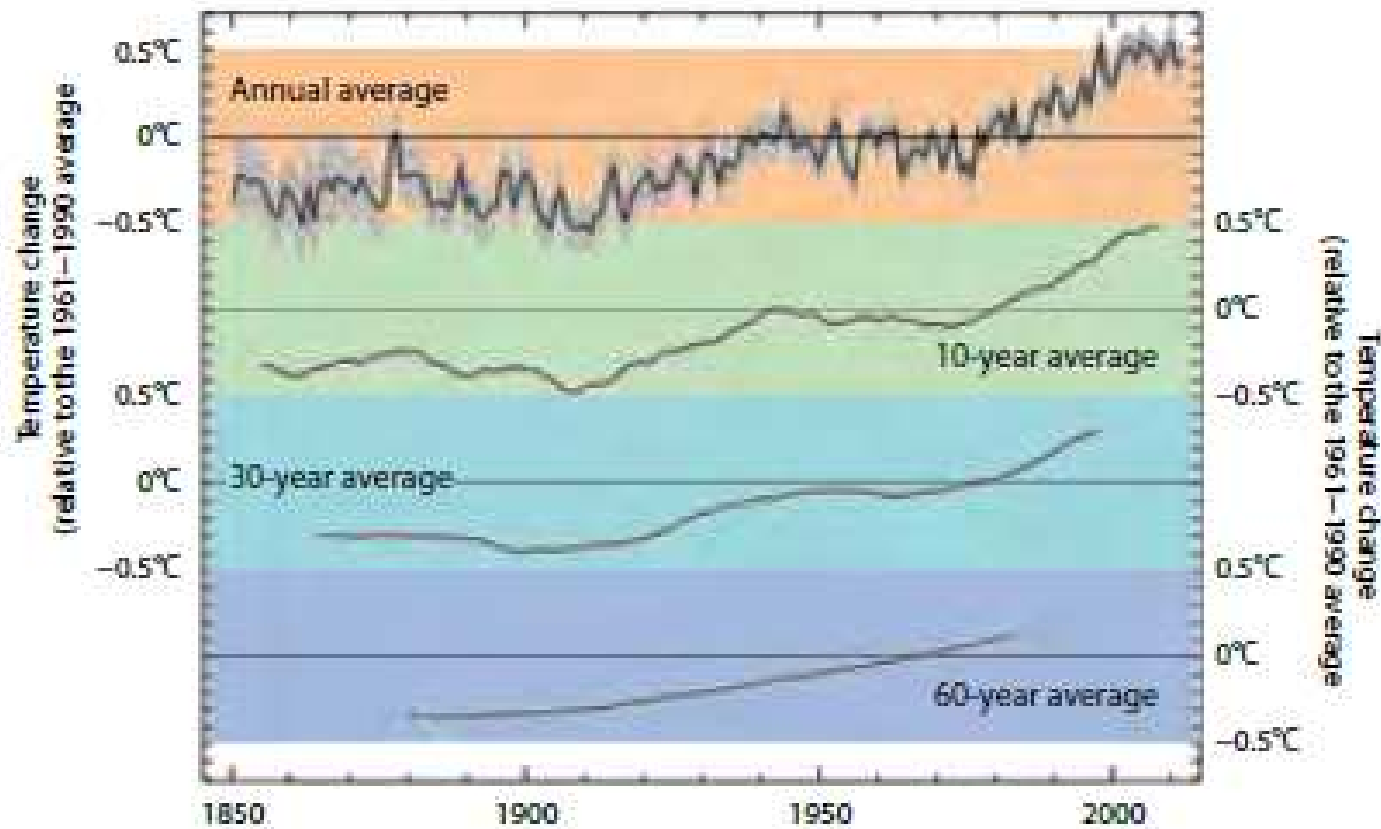
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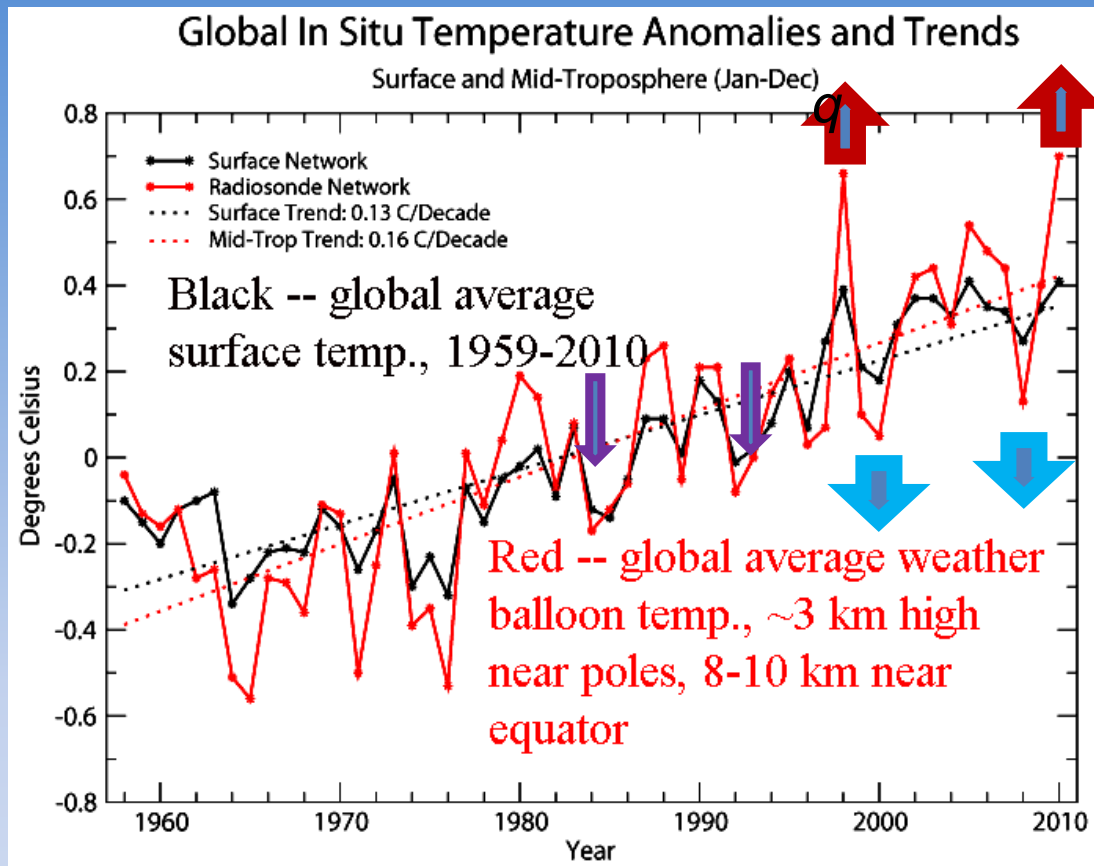




## 9: DOES RATE OF WARMING CHANGE BY DECADE TO DECADE?



**YES**



↑↑ El Niño

Major volcanic eruption ↓

↓↓ La Niña

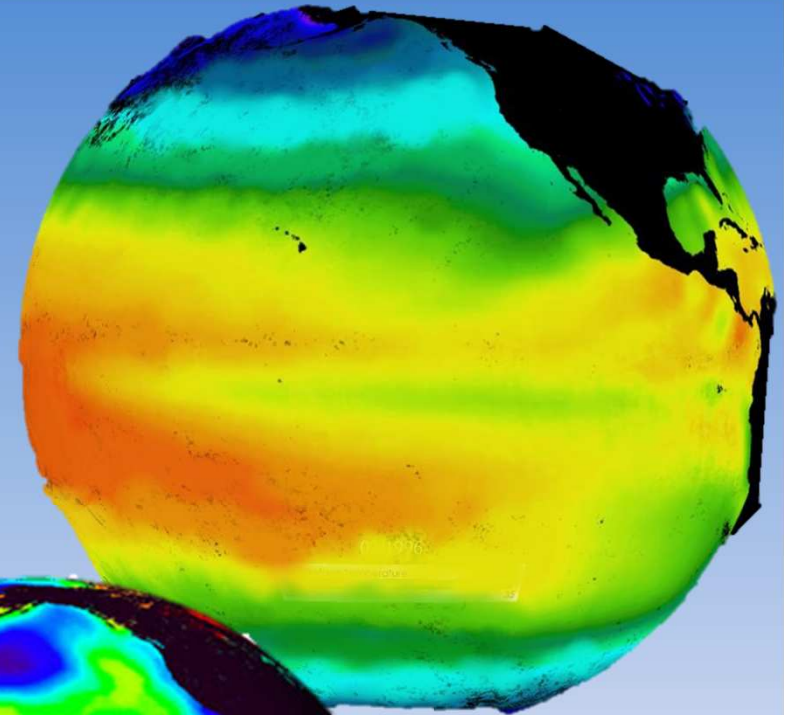
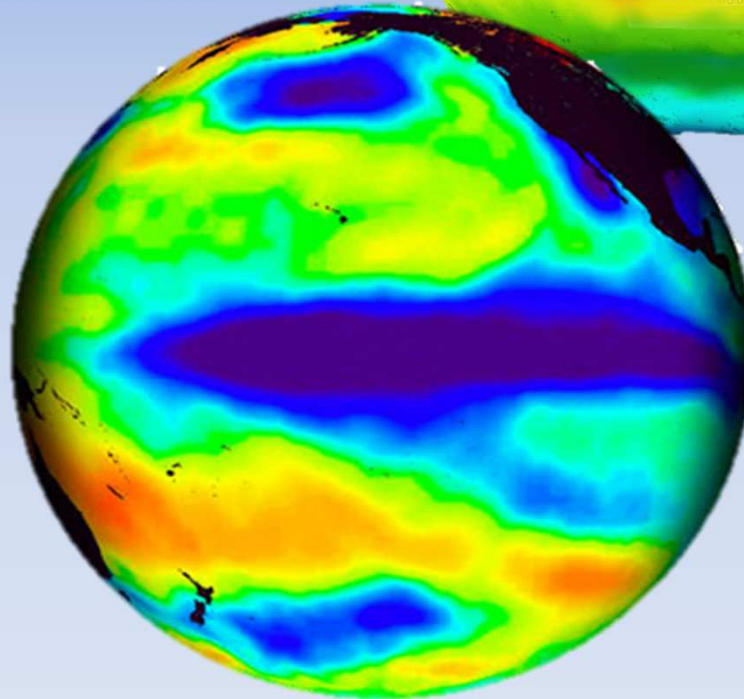
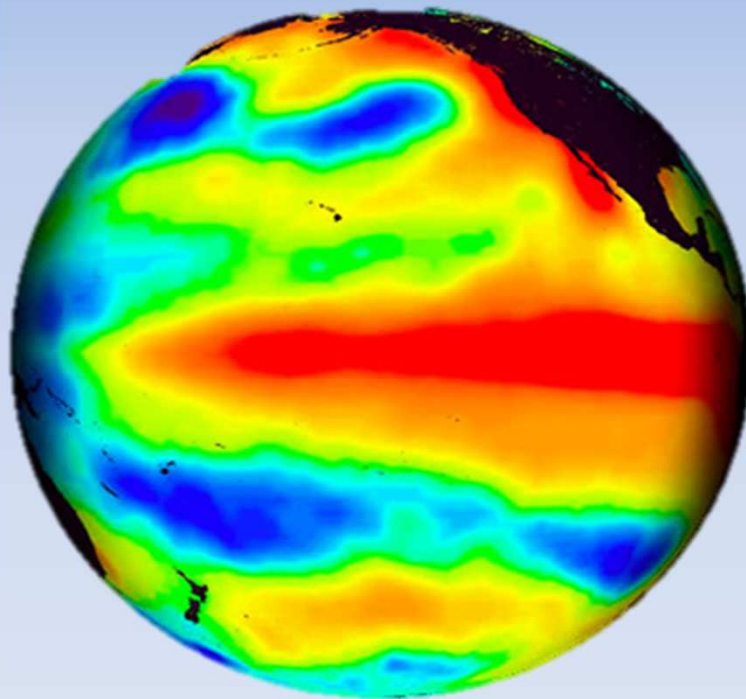
*Warm El Niño tropical Pacific releases ocean heat to air*

*Cool La Niña is less cloudy, so water absorbs more solar heat and atmosphere gets less*

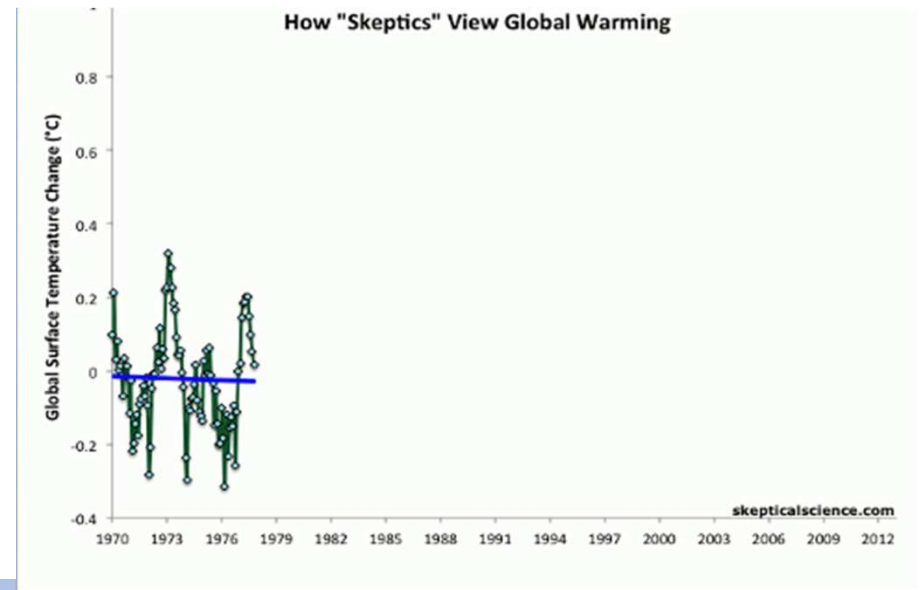
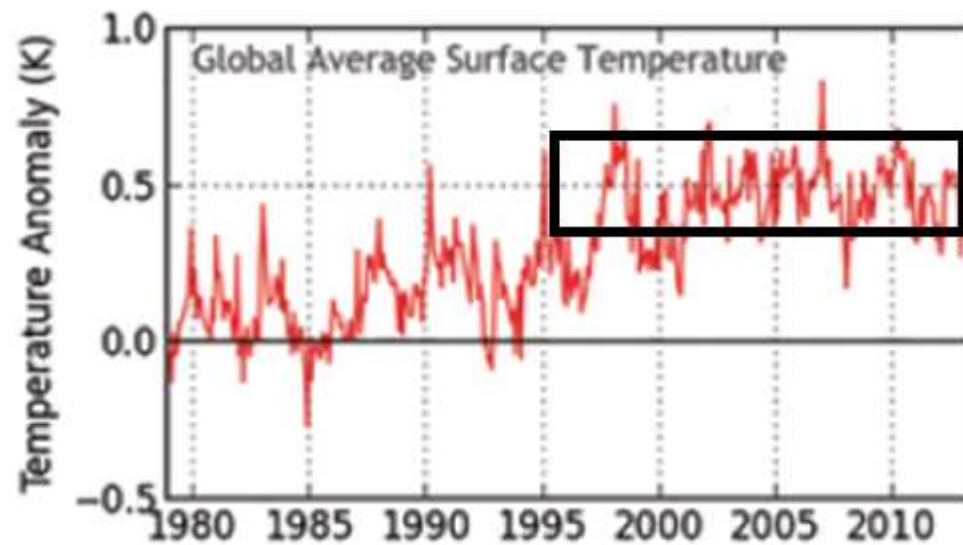
The Pacific –  
'normal condition'

El Niño

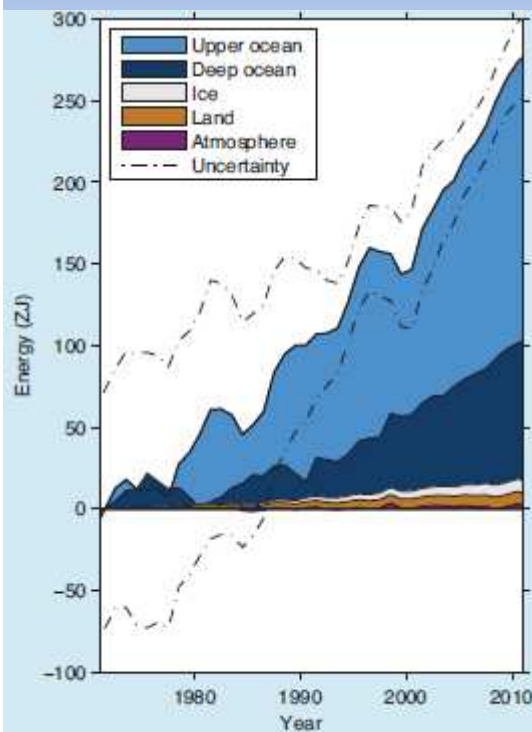
La Niña



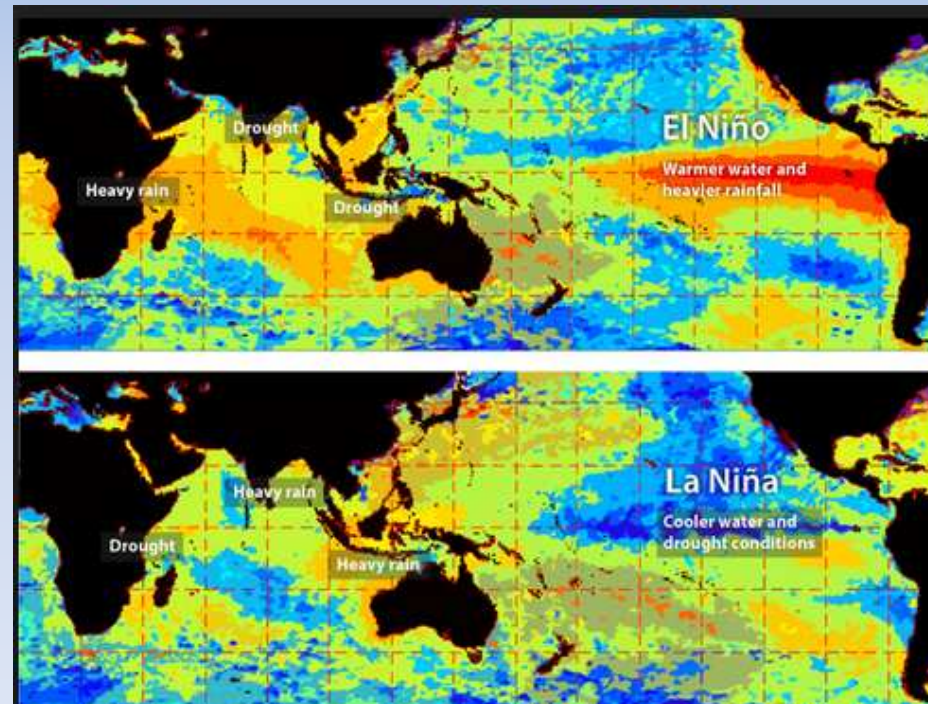
Temperature  
Anomaly °C



<http://www.skepticalscience.com/graphics.php?g=47>



Box 3.1, Figure 1 | Plot of energy accumulation in ZJ ( $1 \text{ ZJ} = 10^{21} \text{ J}$ ) with



**10: DOES CURRENT WARMING SLOWDOWN  
MEAN WARMING IS NO LONGER HAPPENING?**

**NO**



# Disinformation campaign

- Harp on climate-gate
- Harp on hockey stick curve by Mann, subsequently addressed by NAS – i.e. in support of the curve, albeit proxy data has large error bars

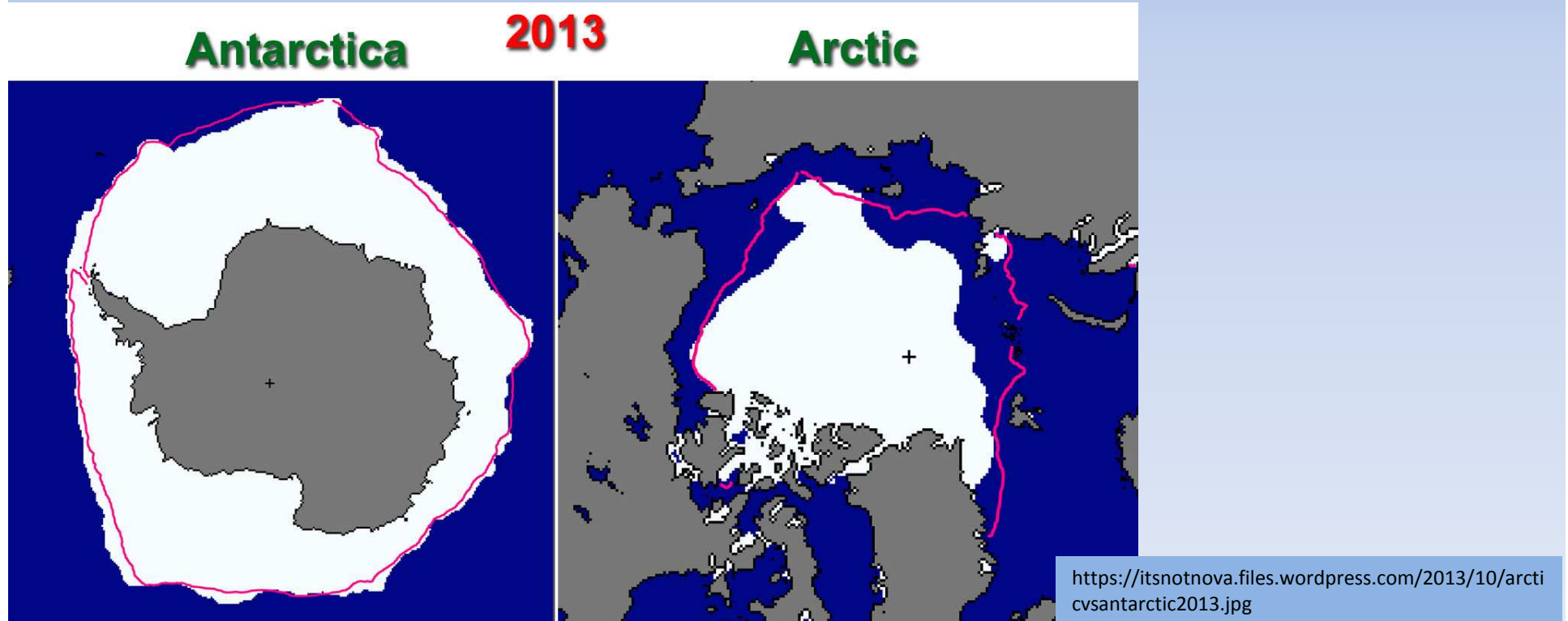
# **11: WHY ARE SOME WINTERS STILL VERY COLD?**

# Disinformation campaign

- A favorite one whereby they point out the anomalies of winter weather to deny global warming – ignoring the GLOBAL PICTURE

## 12. ARCTIC ICE vs. ANTARCTIC SEA ICE

- Ans. More moisture in air around Antarctica (AA) to nucleate sea ice
- Despite  $>$  AA is does not compensate for Arctic loss

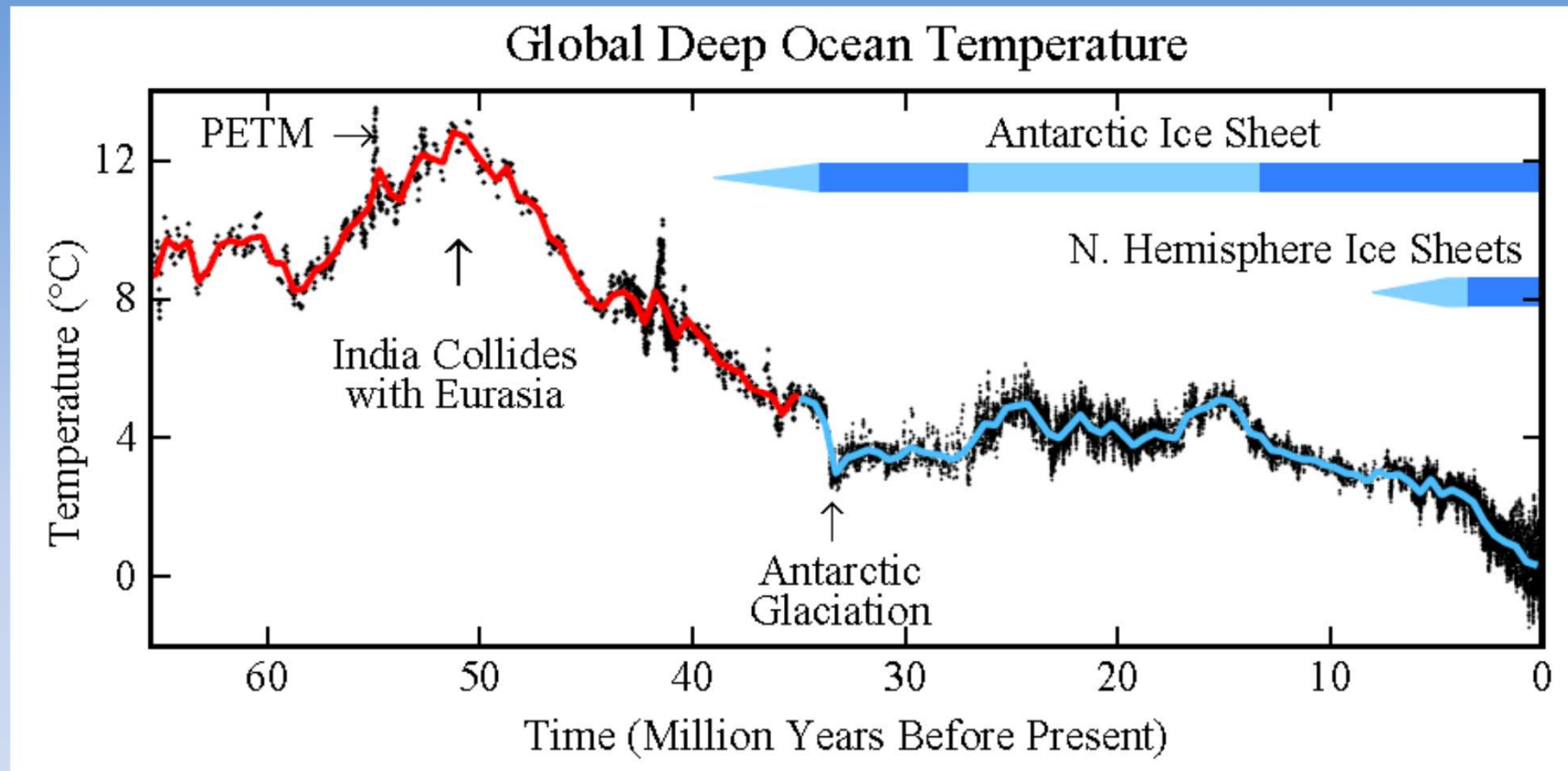


# **13: HOW DOES CLIMATE CHANGE AFFECT THE STRENGTH AND FREQUENCY OF FLOODS, DROUGHTS, HURRICANES AND TORNADOES?**



# First: the Disinformation campaign

- Another favorite one with some validity IN THAT NOT YET STATISTICALLY RELEVANT: Judith Curry, Roger Pielke, Jr.
- So my answer: they do not have the geologic perspective (see next 3 slides) and thus I ask: should we wait until it is statistically relevant?



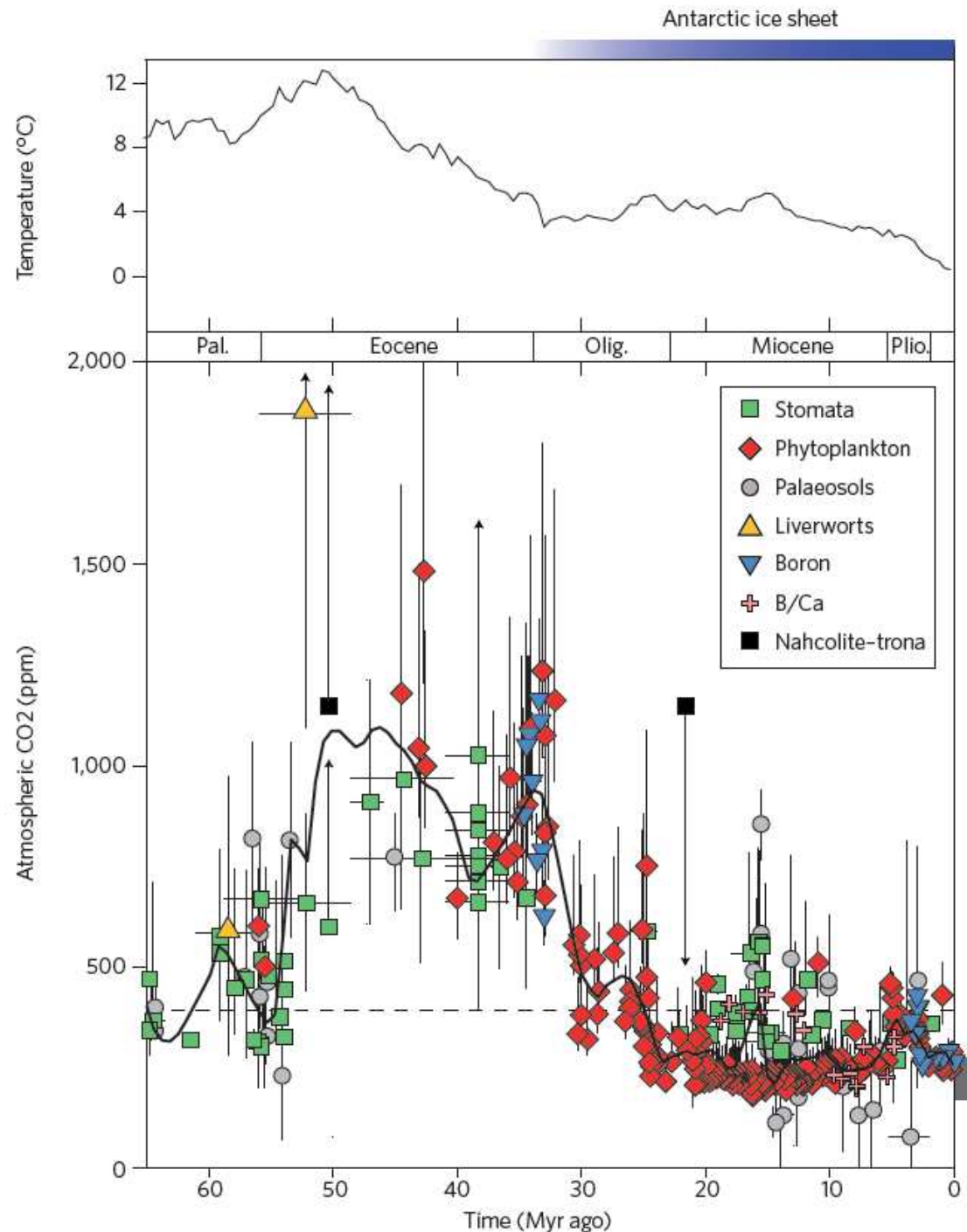
**50 million years ago (50 MYA) Earth was ice-free.**

**Atmospheric CO<sub>2</sub> amount was of the order of 1000 ppm 50 MYA.**

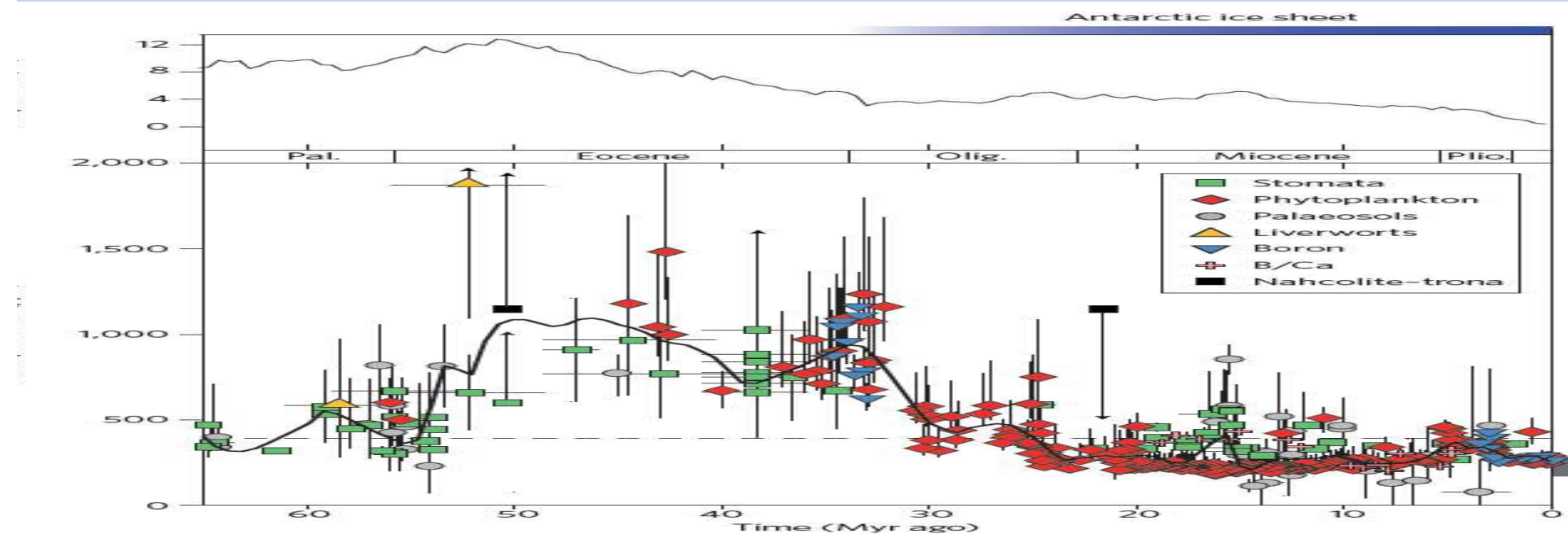
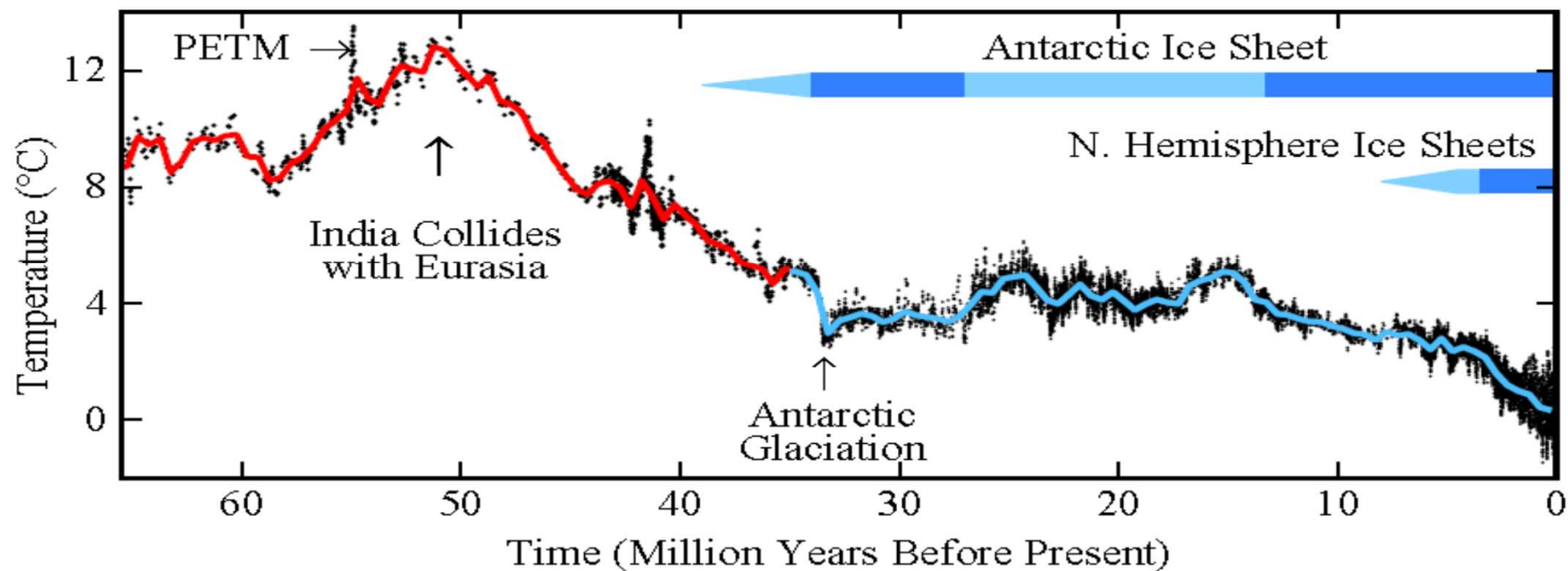
**Atmospheric CO<sub>2</sub> imbalance due to plate tectonics  $\sim 10^{-4}$  ppm per year.**

# Correlation of CO<sub>2</sub> and temperature over last 65 million years

Beerling and Royer, Nature 2011



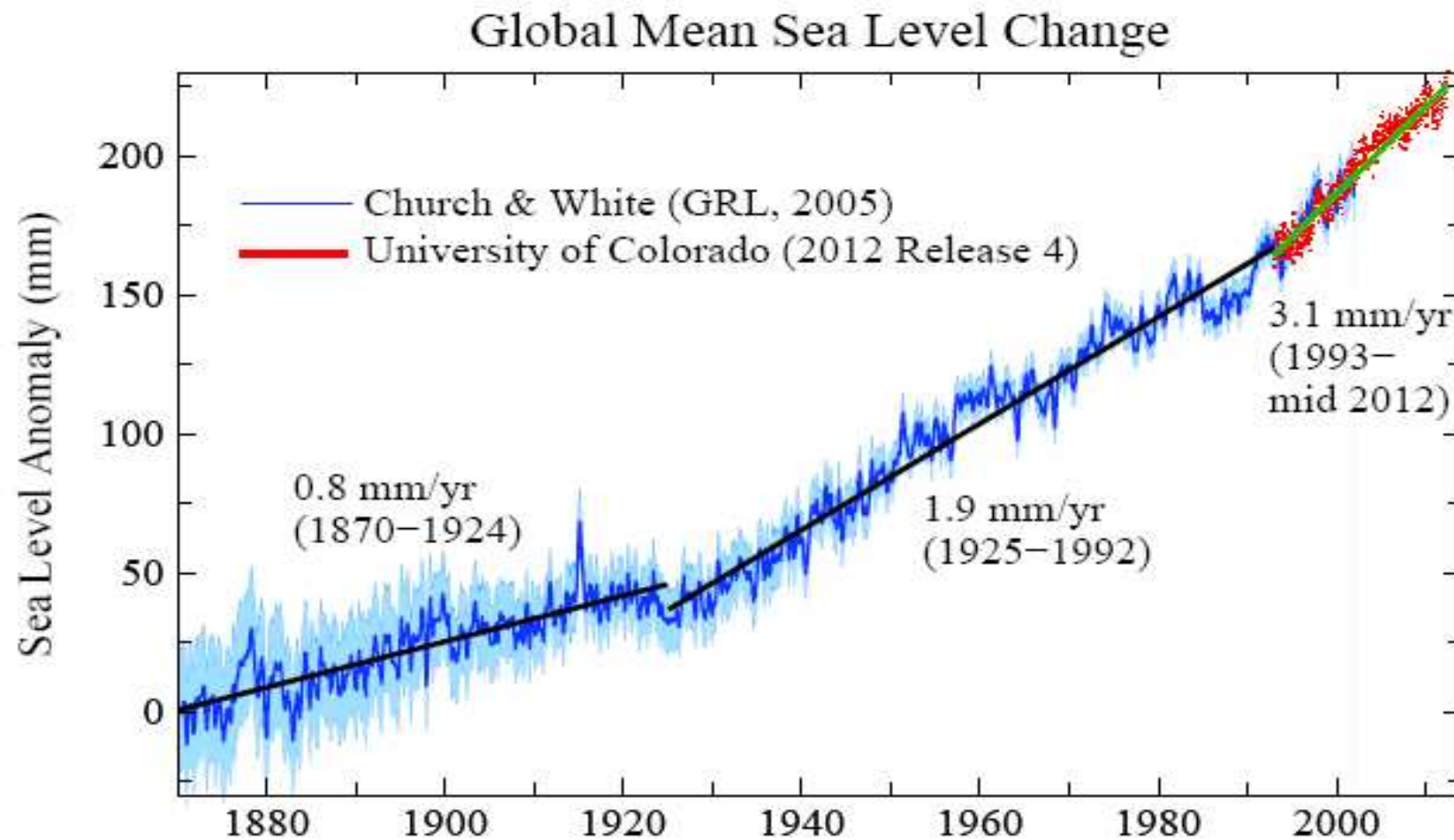
## Global Deep Ocean Temperature



## **14: HOW FAST IS SEA LEVEL RISING?**

**...let the next slide answer  
that**

## 14: HOW FAST IS SEA LEVEL RISING?

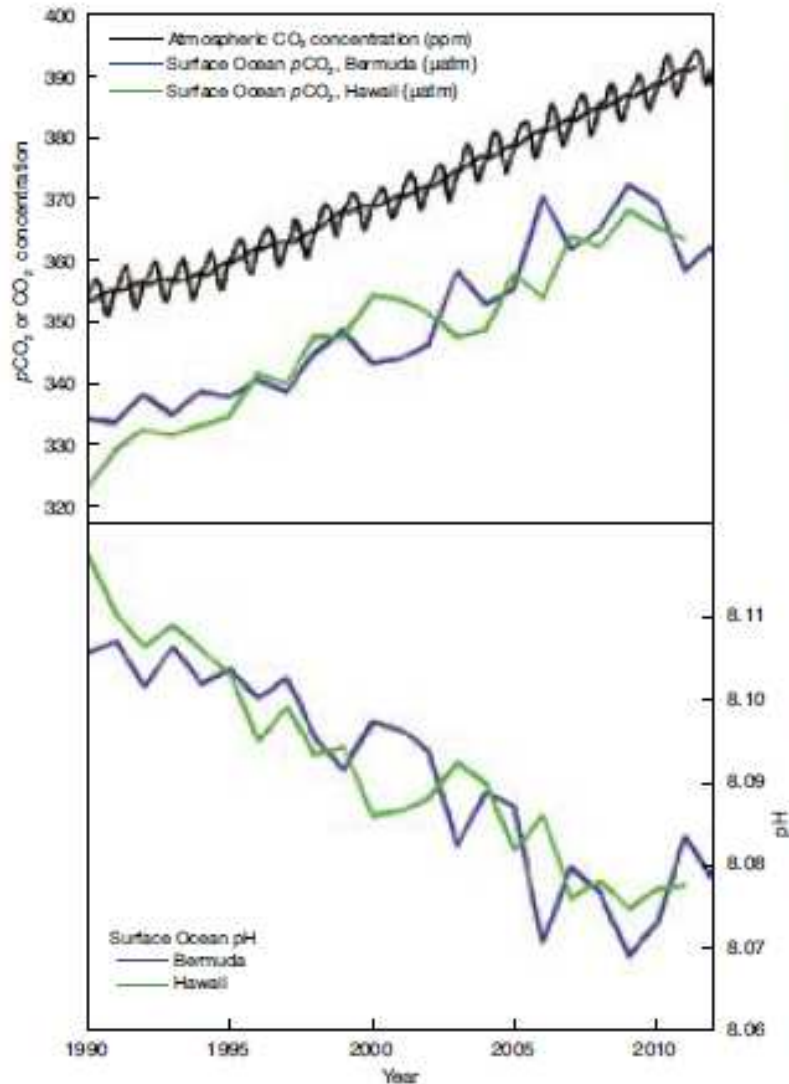


Blue: Sea level change from tide-gauge data (*Church J.A. and White N.J., Geophys. Res. Lett. 2006; 33: L01602*)

Red: Univ. Colorado sea level analyses in satellite era (<http://www.columbia.edu/~mhs119/SeaLevel/>).



# 15: OCEAN ACIDIFICATION



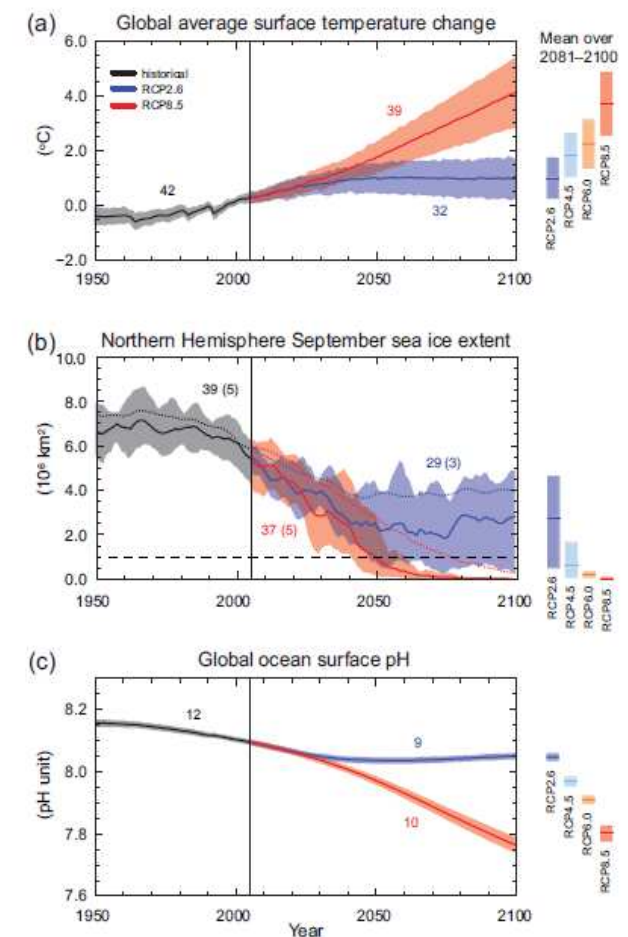
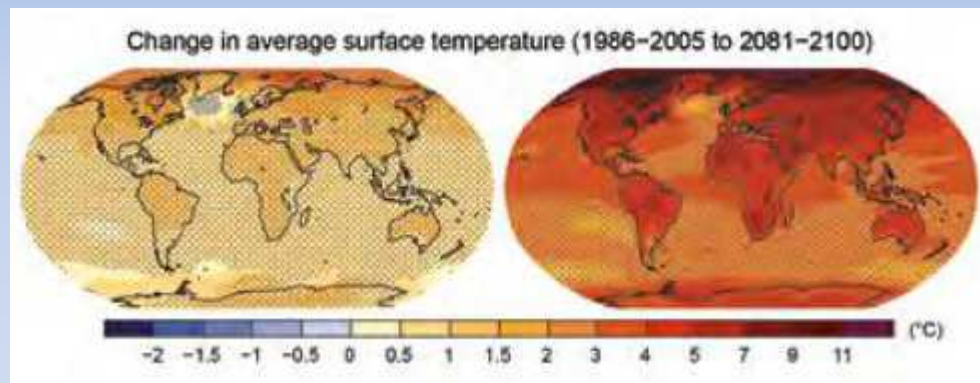
- Makes aragonite harder to be deposited
- Growth rates slow down
- Favors calcite secreting organisms
- Complex with feedbacks

# Disinformation campaign

- Will cite coral bleaching recovery cases, the few there are – and that's true
- Natural cycles of not? Time will tell.
- Temperatures rises are also a factor in coral bleaching and subsequent temporary cooling of affected areas can result it recovery

# 16: HOW CONFIDENT ARE CLIMATE SCIENTISTS ABOUT FUTURE WARMING?

- Quite confident – the basis of AR5



# Disinformation campaign

- Will cite overstated claims that didn't happen
  - e.g. Himalayas glaciers to melt by 2030, a AR4 mistake/retraction
  - Various quotes that don't happen in the time frame specified by the quote
  - Then ridicule them
  - Lesson to be learned – be cautious about what you say

# Disinformation campaign

- Will cite coral bleaching recovery cases, the few there are – and that's true
- Natural cycles of not? Time will tell.
- Temperatures rises are also a factor in coral bleaching and subsequent temporary cooling of affected areas can result it recovery

# **17: SO WHAT'S A FEW DEGREES?**

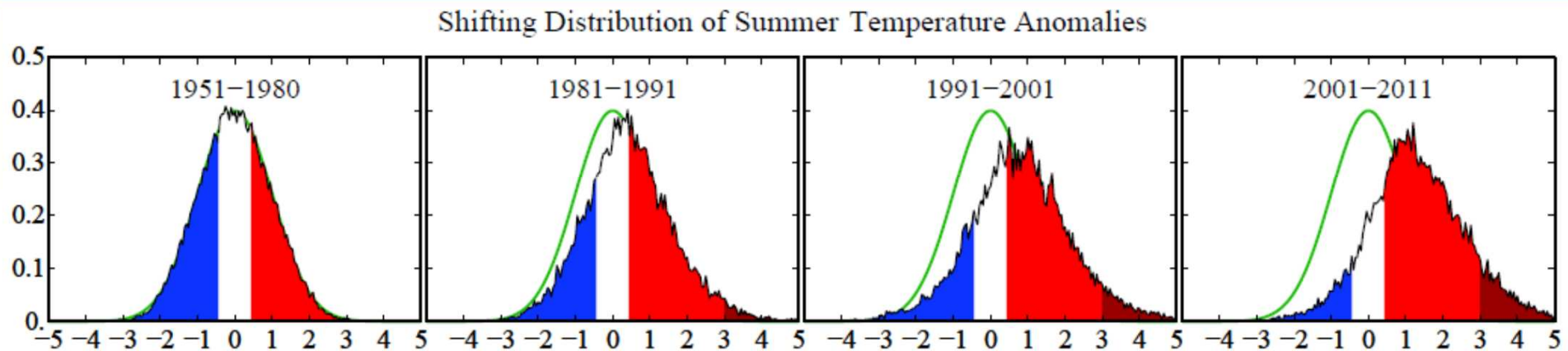
- Let the next slide address this



**Loaded Climate Dice: global warming is increasing extreme weather events.**

**Extreme summer heat anomalies now cover about 10% of land area, up from 0.2%.**

**This is based on observations, not models.**



Frequency of occurrence (vertical axis) of local June-July-August temperature anomalies (relative to 1951-1980 mean) for Northern Hemisphere land in units of local standard deviation (horizontal axis). Temperature anomalies in the period 1951-1980 match closely the normal distribution ("bell curve", shown in green), which is used to define cool (blue), typical (white) and hot (red) seasons, each with probability 33.3%. The distribution of anomalies has shifted to the right as a consequence of the global warming of the past three decades such that cool summers now cover only half of one side of a six-sided die, white covers one side, red covers four sides, and an extremely hot (red-brown) anomaly covers half of one side.

*Source: Hansen, J., Sato, M., and Ruedy, R., Proc. Natl. Acad. Sci., 2012.*

# 18: WHAT ARE SCIENTISTS DOING TO ADDRESS KEY UNCERTAINTIES?

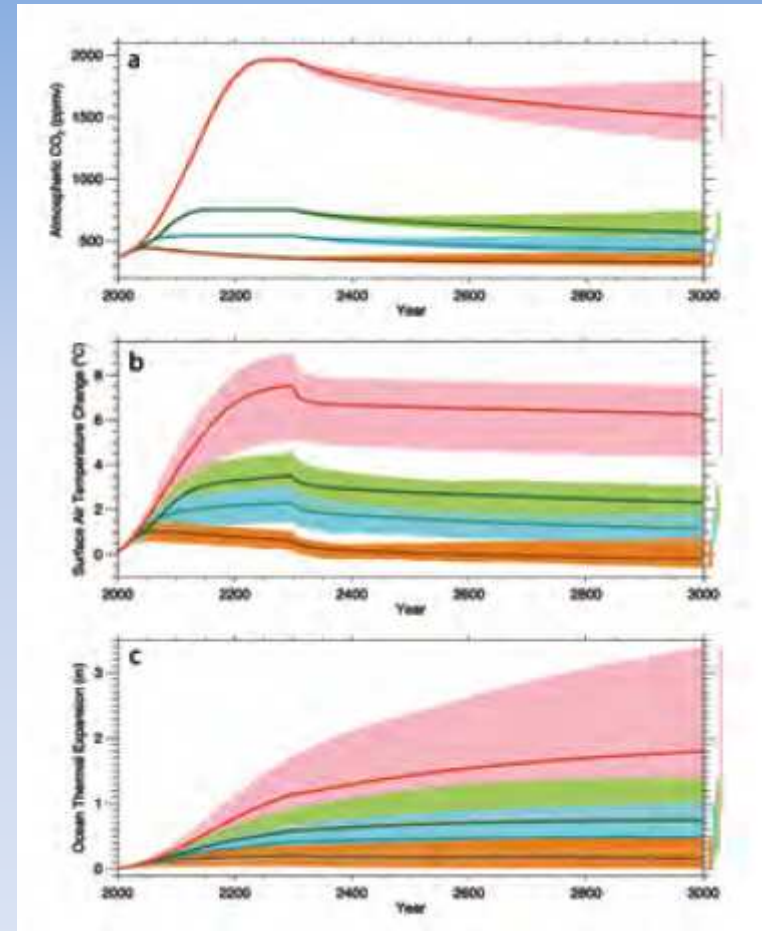
- 100s/1000s continuing to study:
  - To gather data
  - Better understand
  - Refine models
  - Etc., etc....

## 19: ARE TIPPING POINTS OF CONCERN?

- AR5 mostly dismissive of tipping points causing catastrophe as often carried out in alarmism statements
- Beware of what you say and how you say it!

## 20: IF WE STOPPED OR CONTINUED EMISSIONS, WHAT WOULD HAPPEN?

- It's in the bank, without Geoengineering options:
  - Solar Radiation Management (SRM)
  - Carbon Dioxide Removal (CDR) – for which Biochar gets lumped into this latter category



# So is there hope?

- YES
- SRM has some serious unintended consequences, and if ever stopped huge subsequent corrections
- CDR: BECCS and/or Biochar have the greatest promise – cost and effectiveness will be key!
  - My personal favorite is Biochar: for more see [http://denverclimatestudygroup.com/?page\\_id=28](http://denverclimatestudygroup.com/?page_id=28) (Denver climate study group page – under page drop-down and click on Biochar)
    - See Promise for the future regarding agriculture and sequestering Carbon (with a potential claim of 100 ppm in 30 years) [Cool Planet](#) and associated [YouTube](#).

# Conclusions/Recommendations

- Don't let ideologies blind oneself to the data and science
- Be careful what and how you say, or how a person says or makes claims; it comes back to haunt one.
- Ridicule accomplishes nothing
- Study and discuss; weigh the factors of choices:
  - Do nothing
  - Mitigate
  - Save for the future
  - Or various combinations of the above based on economics and consequences



# Three books to consider:

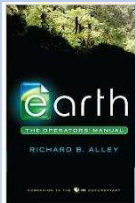
- Simple succinct Summary:

- [What We Know About Climate Change \(Boston Review Books\)](#) by Kerry Emanuel (Nov 30, 2012)



- Intermediate Level Book:

- [Earth: The Operators' Manual](#) by [Richard B. Alley](#) (Apr 18, 2011)



- 

<http://earththeoperatorsmanual.com/>

- More comprehensive book:

[Experimenting on a Small Planet: A Scholarly Entertainment](#) by [William W. Hay](#) (Dec 14, 2011)



# Websites to consider:

- <http://www.skepticalscience.com/>
- <http://www.realclimate.org/>
- <http://www.climatecentral.org/>
- <http://www.noaa.gov/> , particularly  
<http://www.noaa.gov/climate.html>
- ...etc.....

# THANK YOU

- QUESTIONS?

**Ethics and Ecological Economics Study Group**  
**September 8, 2014**

[pebelanger@glassdesignresources.com](mailto:pebelanger@glassdesignresources.com)

<http://denverclimatestudygroup.com/>

EXTRAS

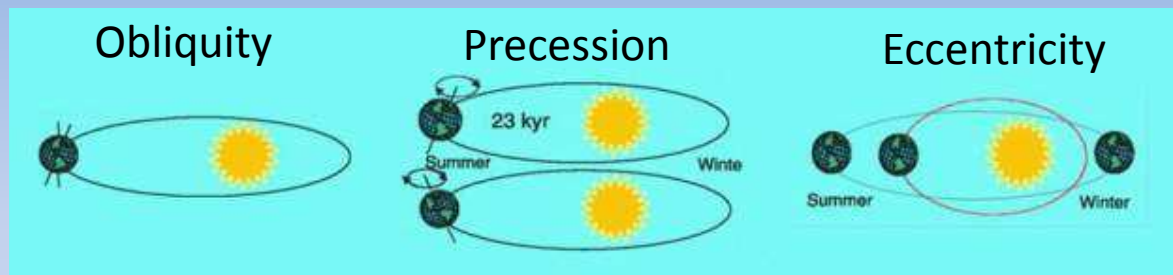
# LONGER TIME-FRAME CONTROLS ON CLIMATE

- NEXT 2 SLIDES

## INTRODUCTION: Definitions:

### •First order Forcings: EXTERNAL Influences (3):

#### SOLAR input:



#### Atmospheric Opacity

(gases that absorb radiation in or out)



#### Albedo (30-85%)

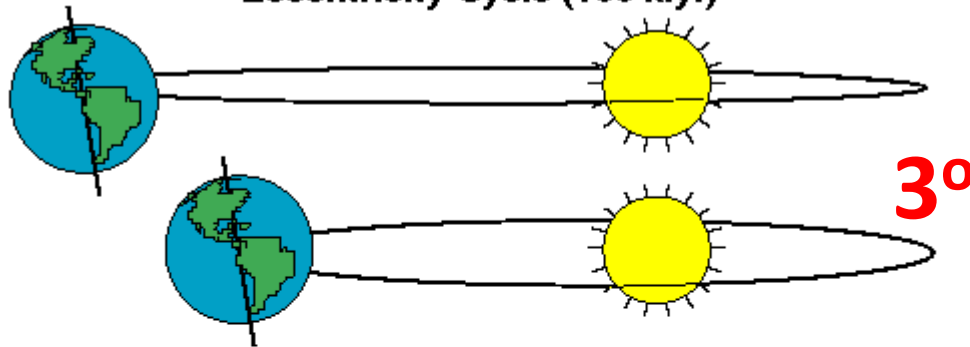


### •Feedbacks: INTERNAL dynamics and responses

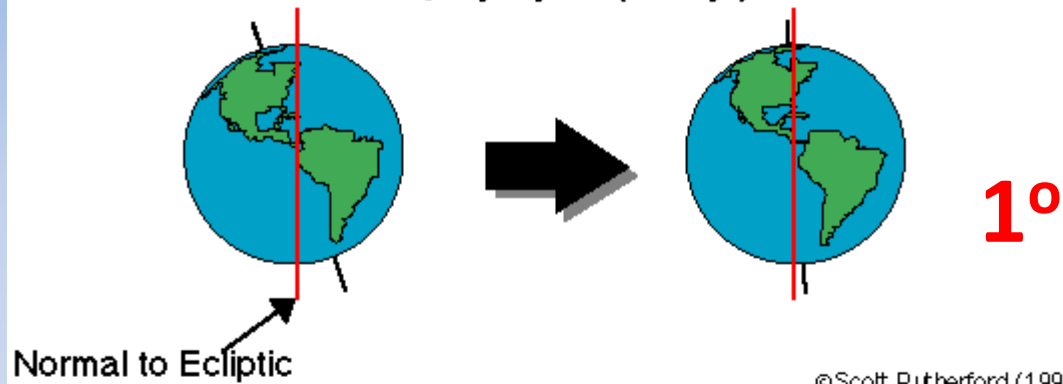
- e.g. higher water vapor in atm. due to heating of atm



### Eccentricity Cycle (100 k.y.)

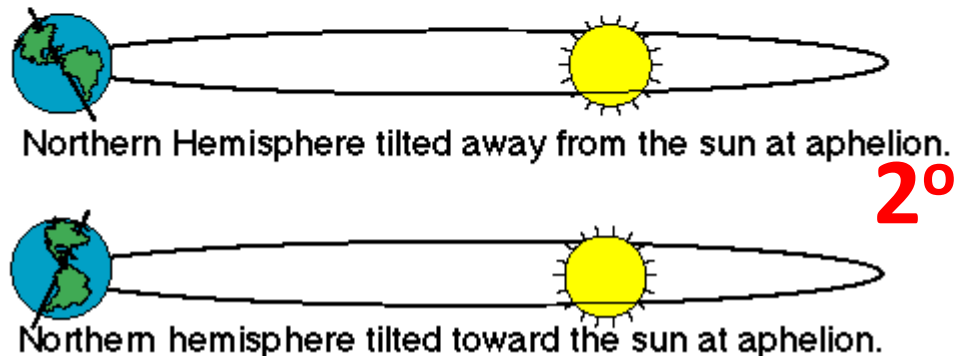


### Obliquity Cycle (41 k.y.)



©Scott Rutherford (1997)

### Precession of the Equinoxes (19 and 23 k.y.)



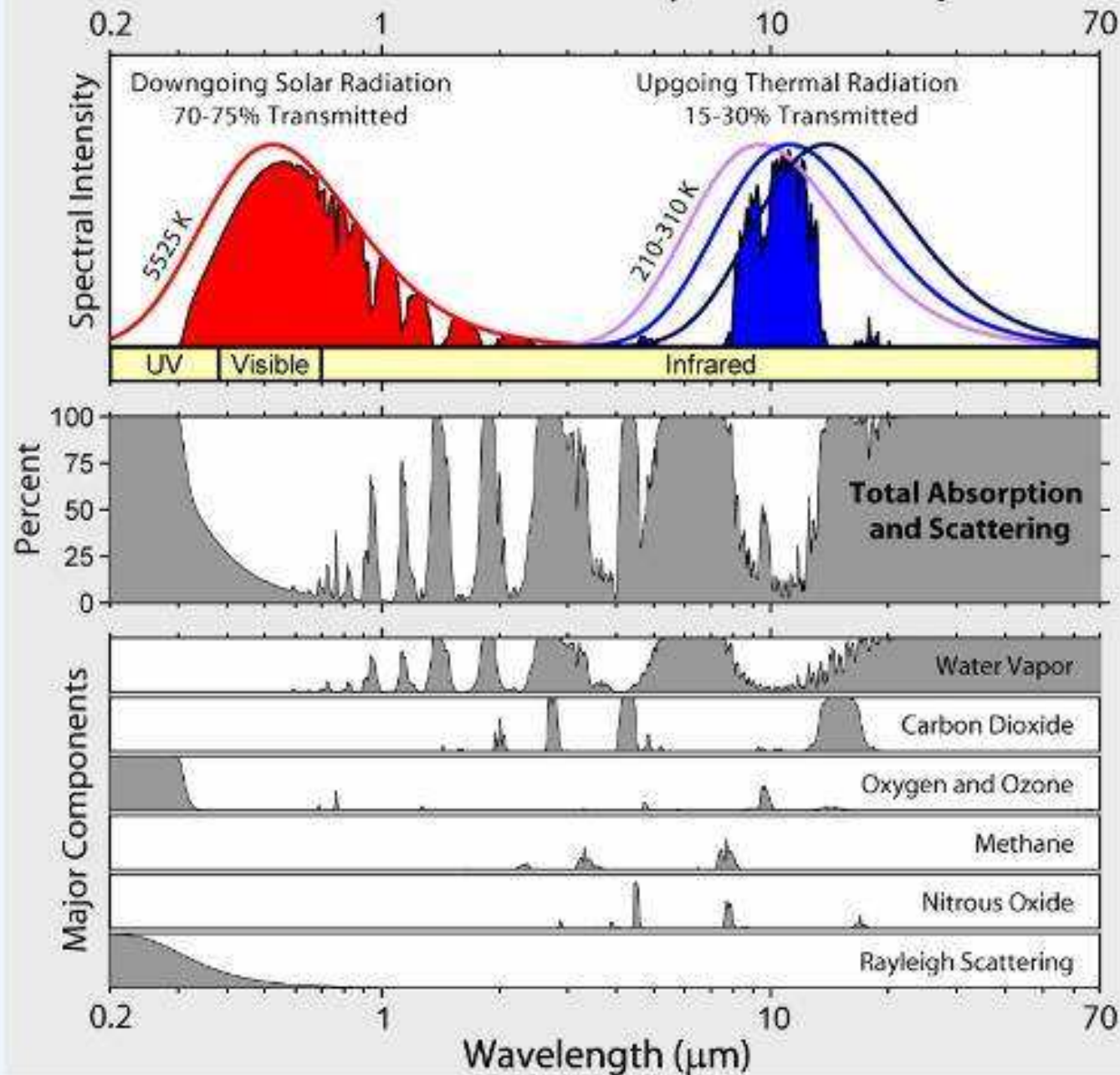
## Milankovitch Cycles

(in order of greatest Influence @65°)

# The physics of spectral absorption

- NEXT SLIDE

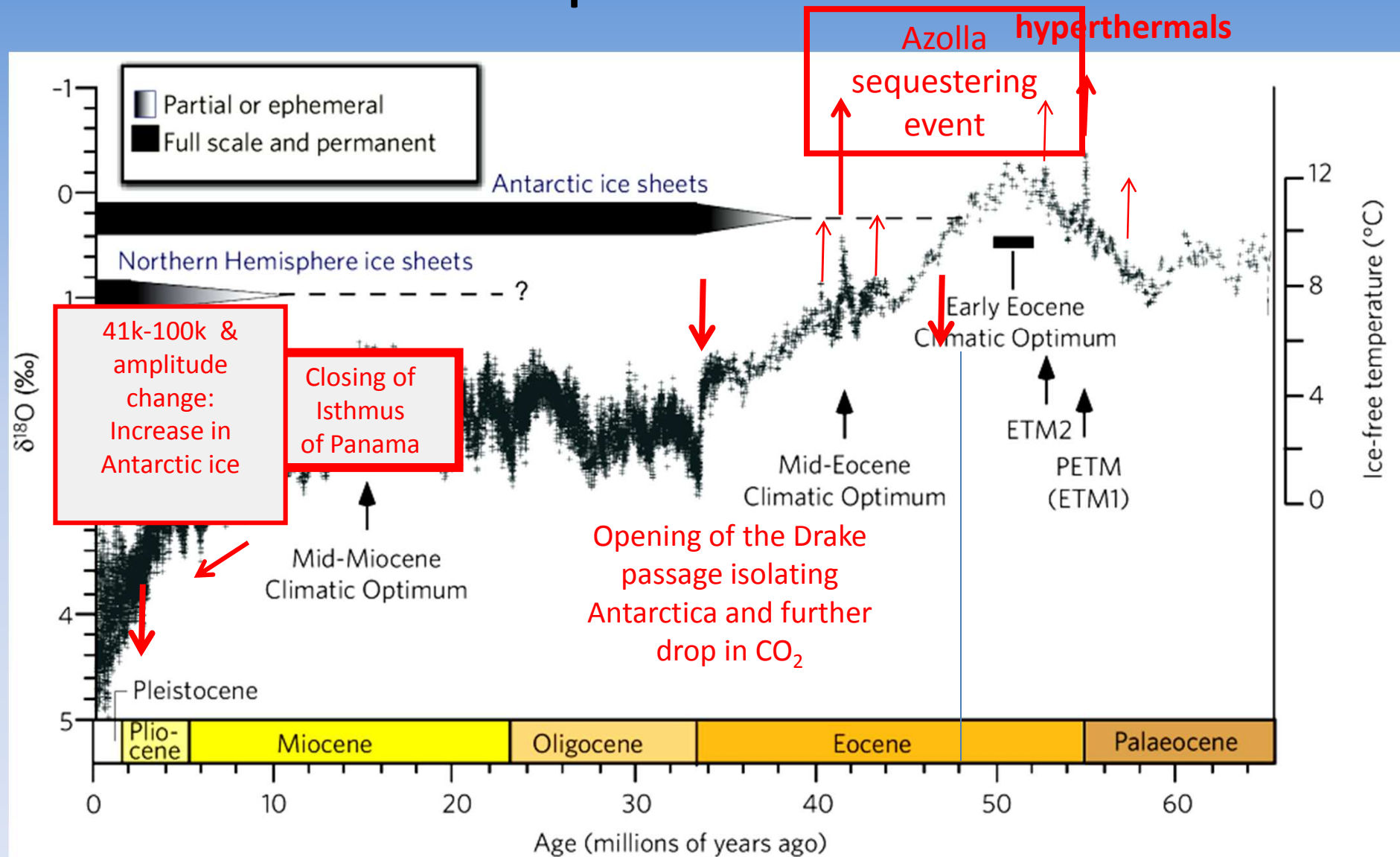
# Radiation Transmitted by the Atmosphere

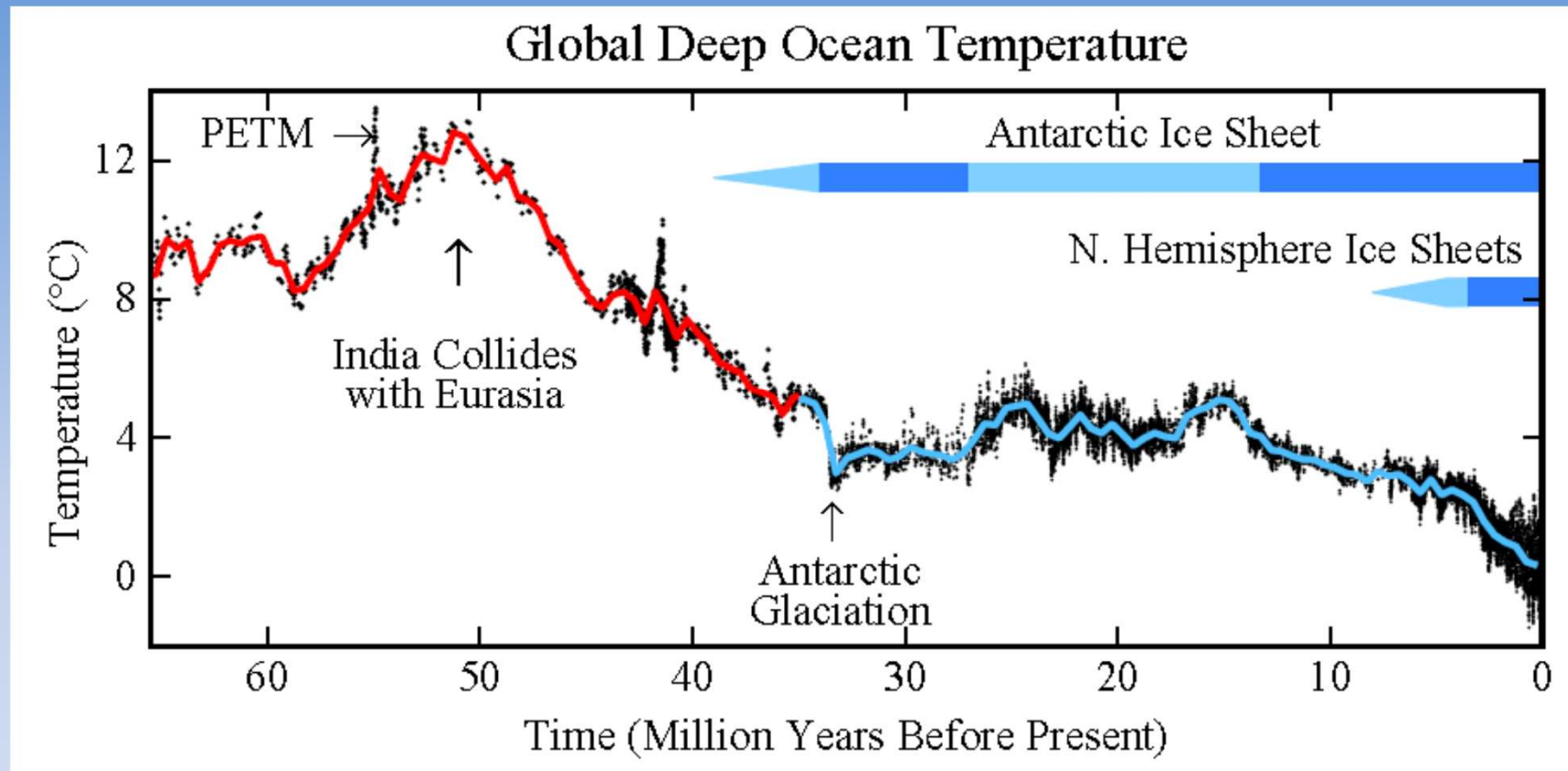


# Details of the past 65 Ma

- NEXT SLIDE

# Cenozoic Deep Sea Climate Record





**50 million years ago (50 MYA) Earth was ice-free.**

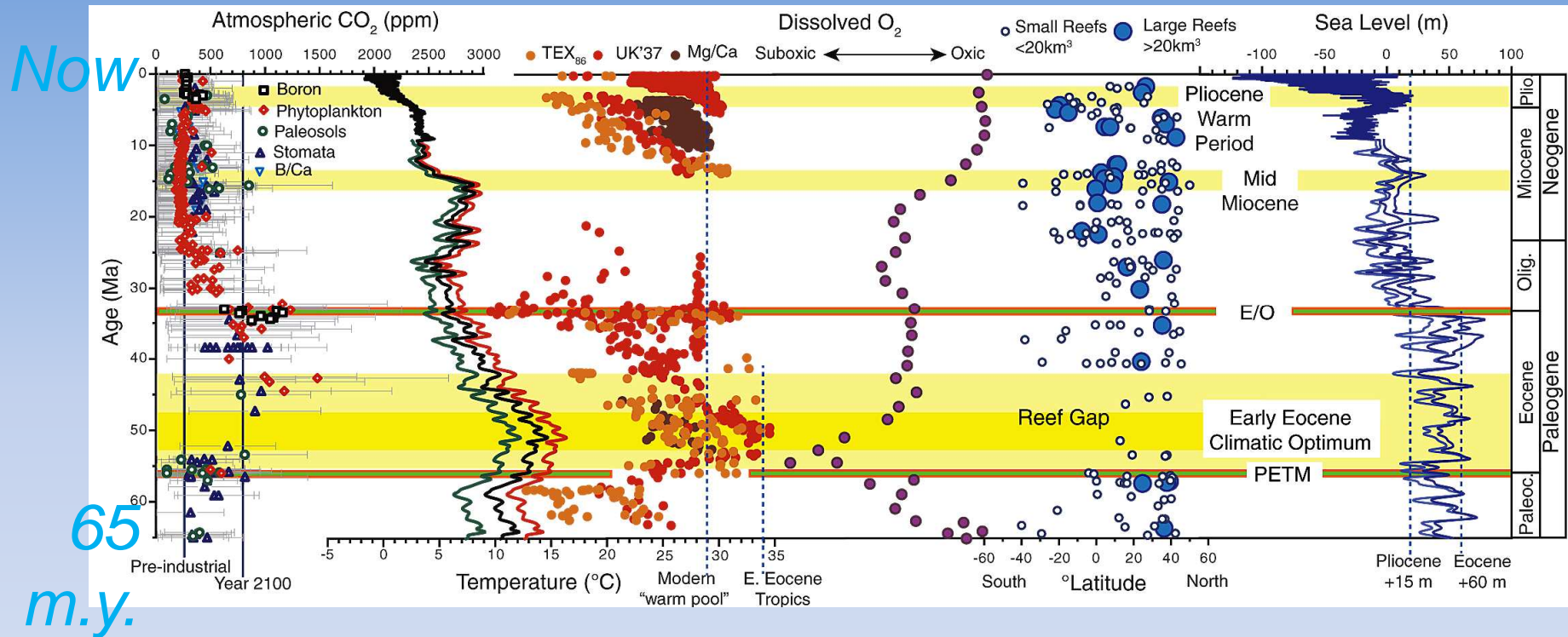
**Atmospheric CO<sub>2</sub> amount was of the order of 1000 ppm 50 MYA.**

**Atmospheric CO<sub>2</sub> imbalance due to plate tectonics  $\sim 10^{-4}$  ppm per year.**

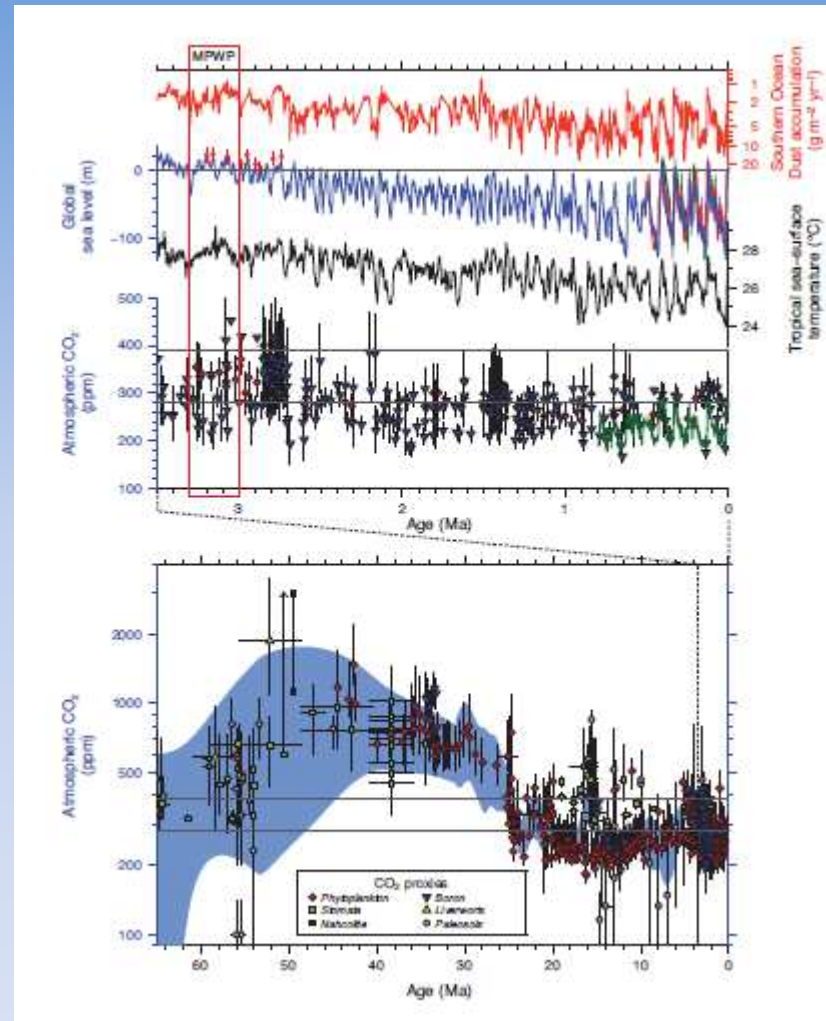


# History of oceans for last 65 m.y.

We know a great deal about past CO<sub>2</sub>, temp., etc.

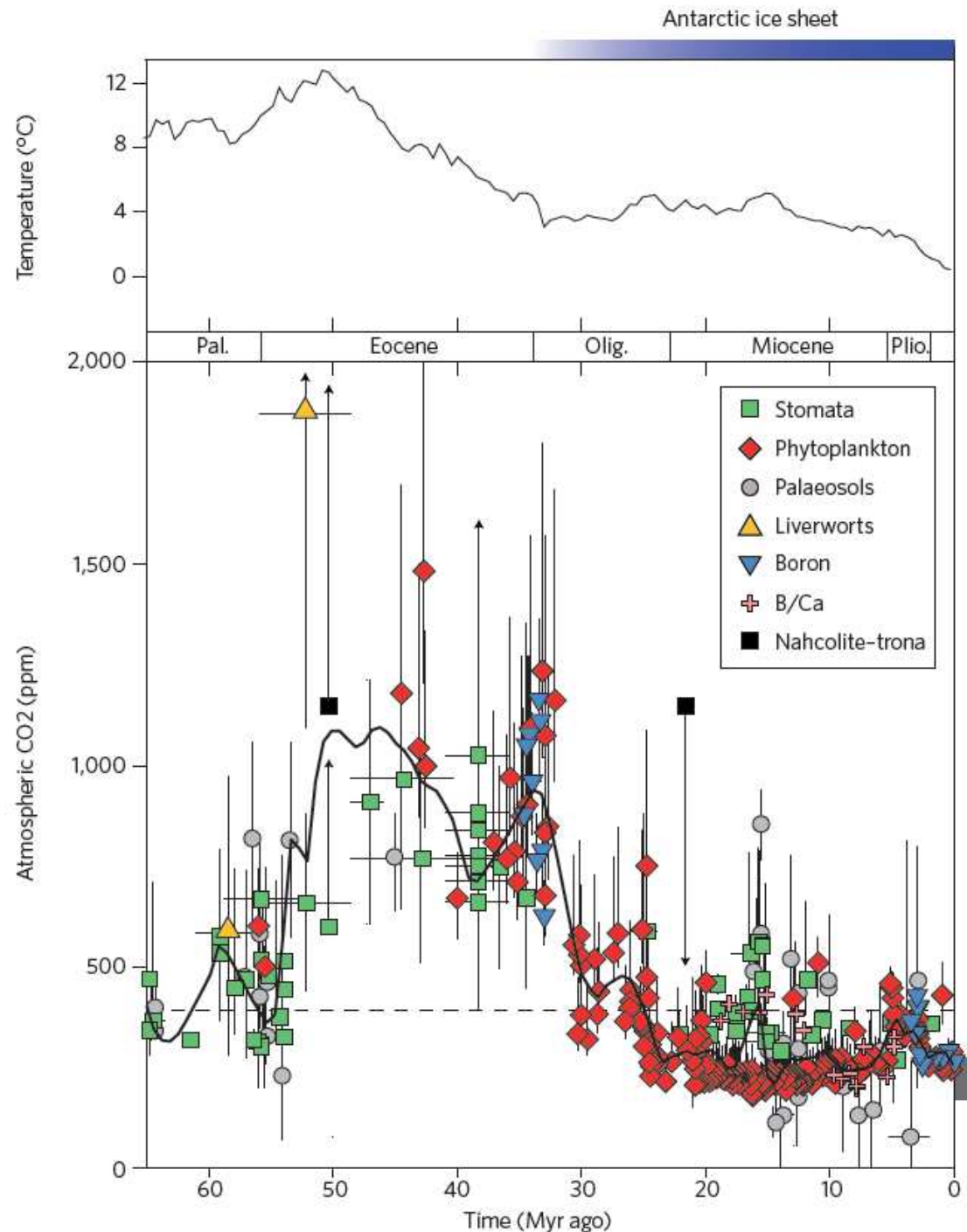


*R. Norris et al., Science, 2013*

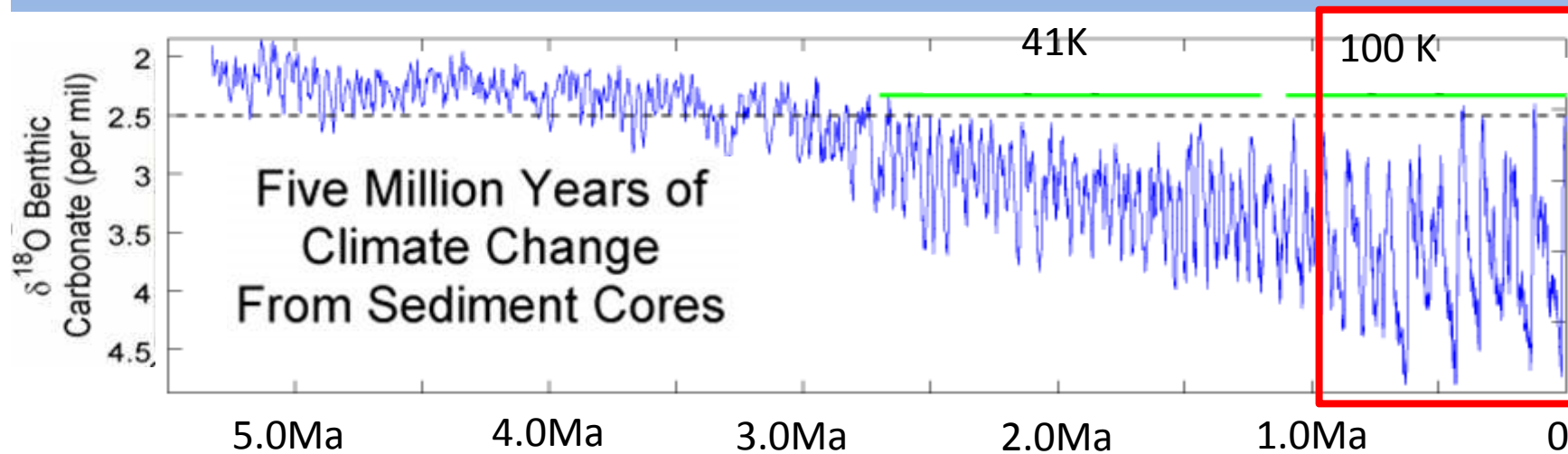


# Correlation of CO<sub>2</sub> and temperature over last 65 million years

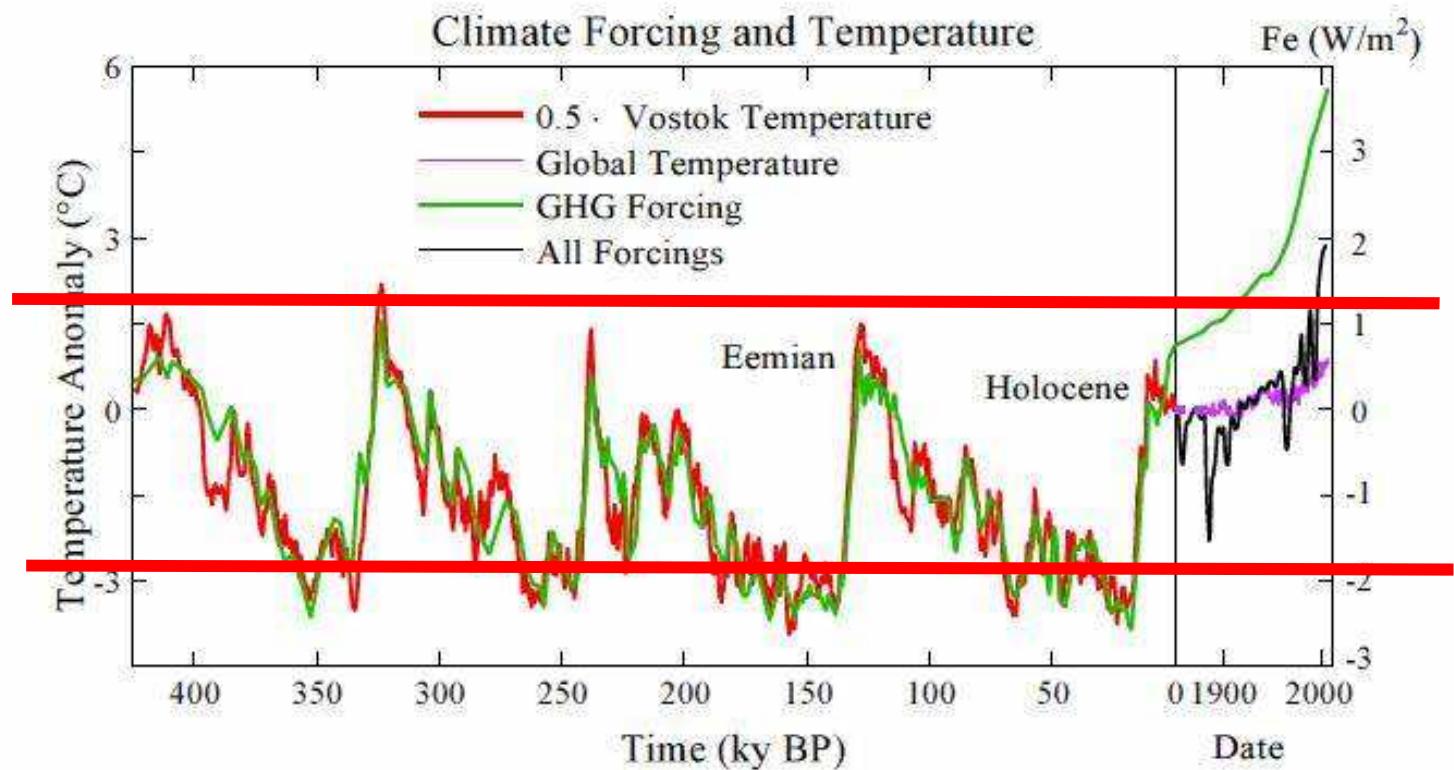
Beerling and Royer, Nature 2011



# Climate Changes from Ocean Sediment Cores, since 5 Ma. Milankovitch Cycles



When CO<sub>2</sub> levels get below ~400-600 ppm Orbital parameters become more important than CO<sub>2</sub>



★ 400 ppm  
(2014)

# Water vapor trends with temperature

- NEXT 2 slides



Table 1 Specific humidity of a kilogram of air (at average sea level pressure)

Temp. (°C)	Temp. (°F)	Grams of water vapor per kg of air (g/kg)
-40	-40	0.1
-35	-31	0.2
-30	-22	0.3
-25	-13	0.51
-20	-4	0.75
-10	14	1.8
0	32	3.8
5	41	5
10	50	7.8
15	59	10
20	68	15
25	77	20
30	86	27.7
35	95	35
40	104	49.8

**What is the volume of 1 kg of air?**

Answer: 0.8562 m<sup>3</sup>

(95 cm x 95 cm x 95 cm)



# Amount of water vapor, if condensed in 1 kg air (`1 cubic meter)

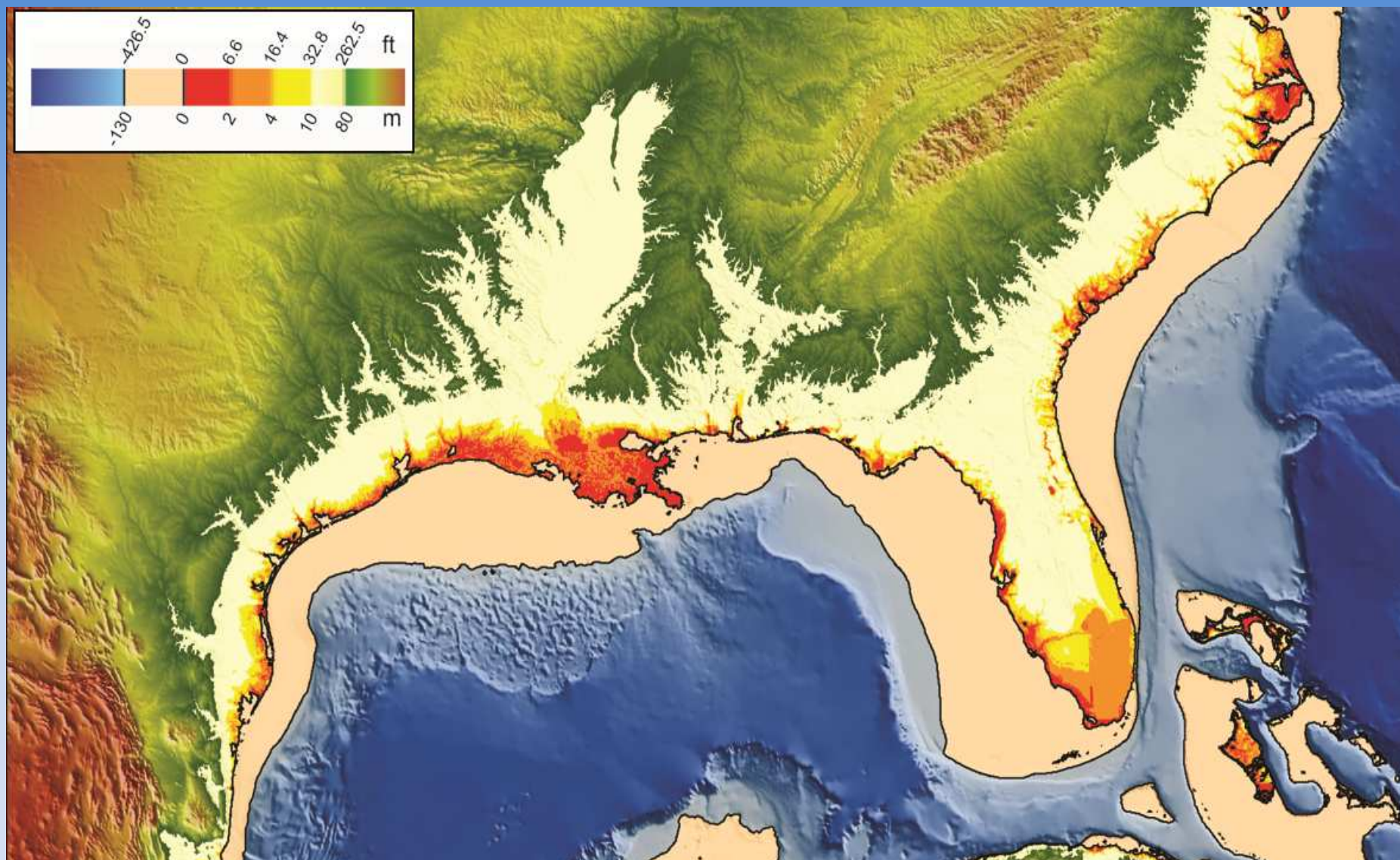


10°C =  
(50°F)  
7.8 cc

20°C =  
(68°F)  
15 cc

30°C =  
(86°F)  
27.7 cc

40°C =  
(104°F)  
49.8 cc



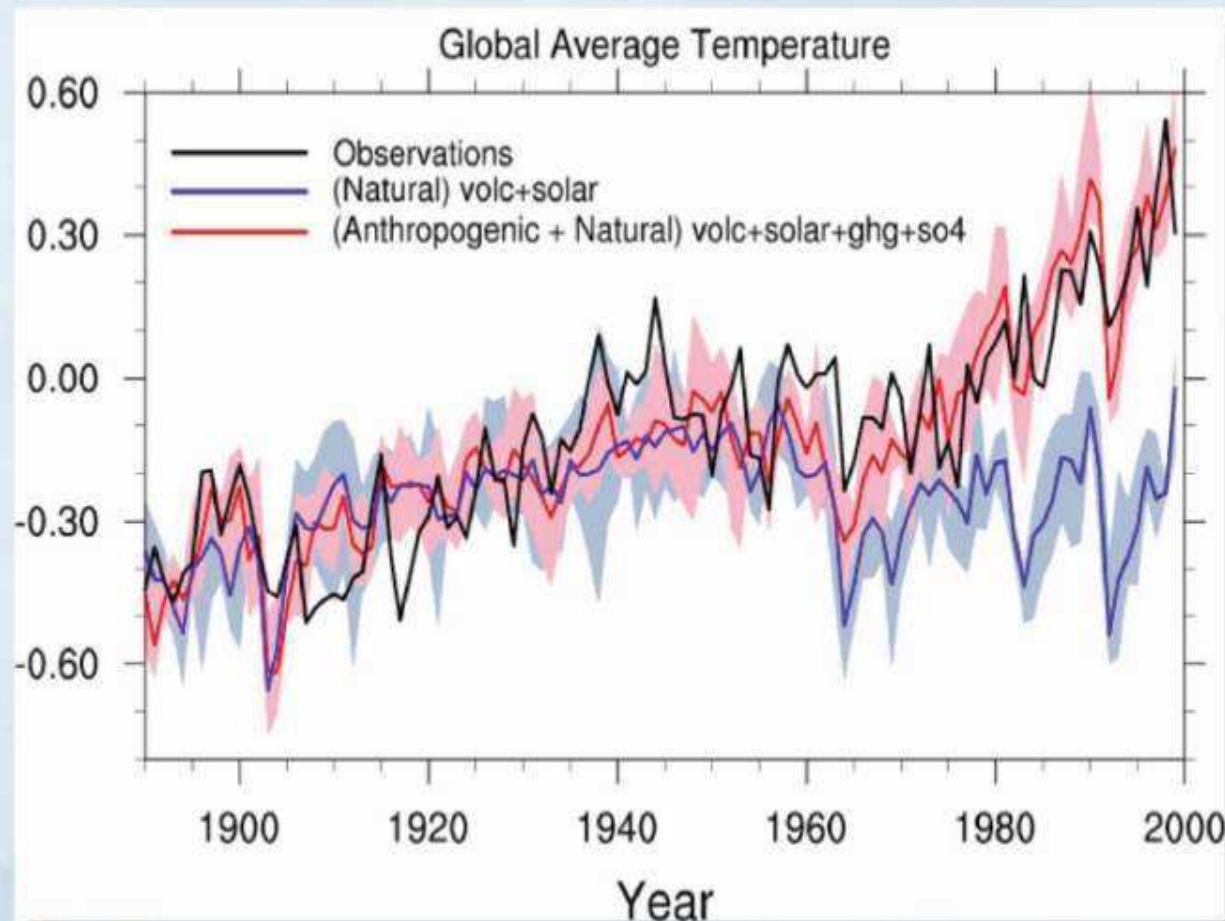
The effects of sea-level rise. Tan = - 130 m – Last Glacial Maximum (24,000 BP)  
Red = +2 m – possible by 2100. Orange = +4 m (2200) Yellow = Greenland ice gone.  
The white area shows the transgression if all ice (Greenland + Antarctica) were to melt.



# Simulations of the 20th century: Time



NCAR



All  
forcings

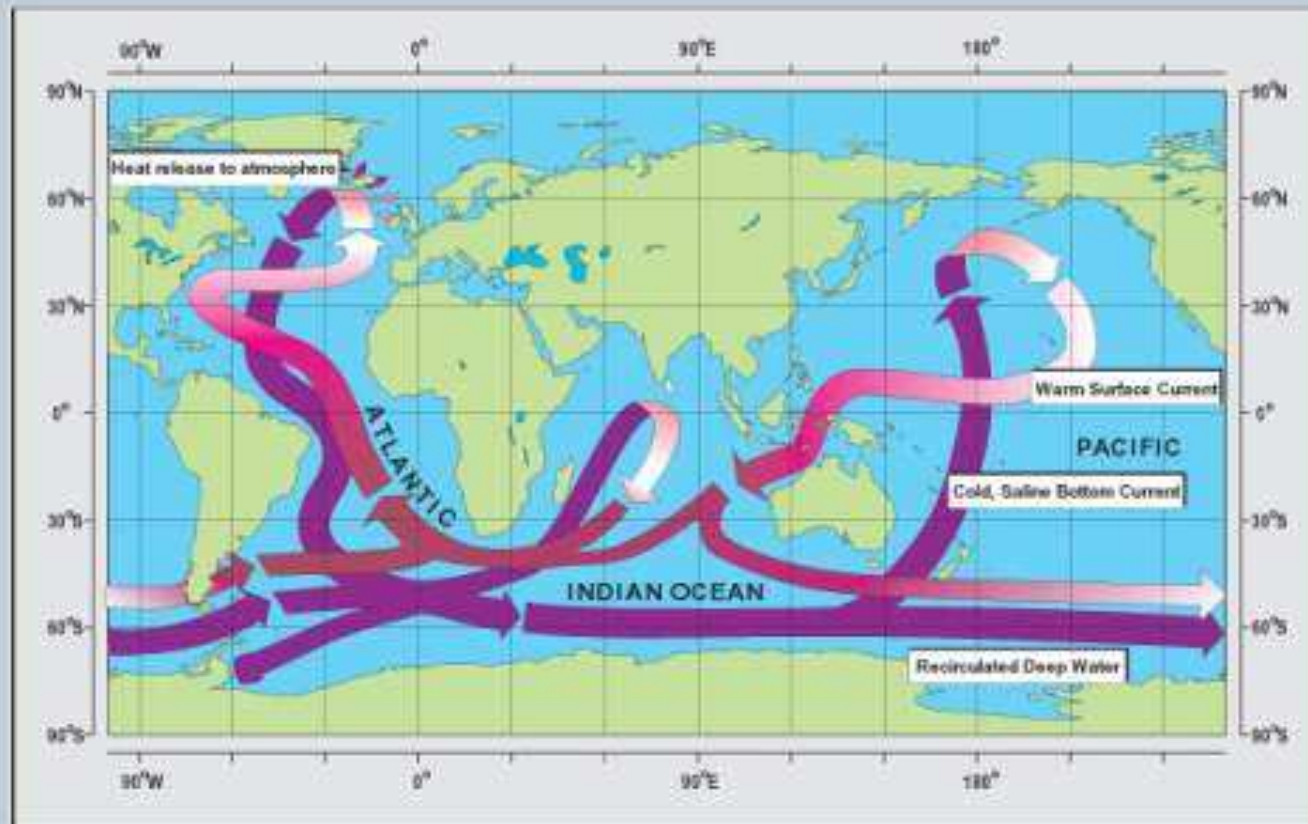
Natural  
only

Meehl et al. 2004



# The Atlantic Thermohaline Circulation

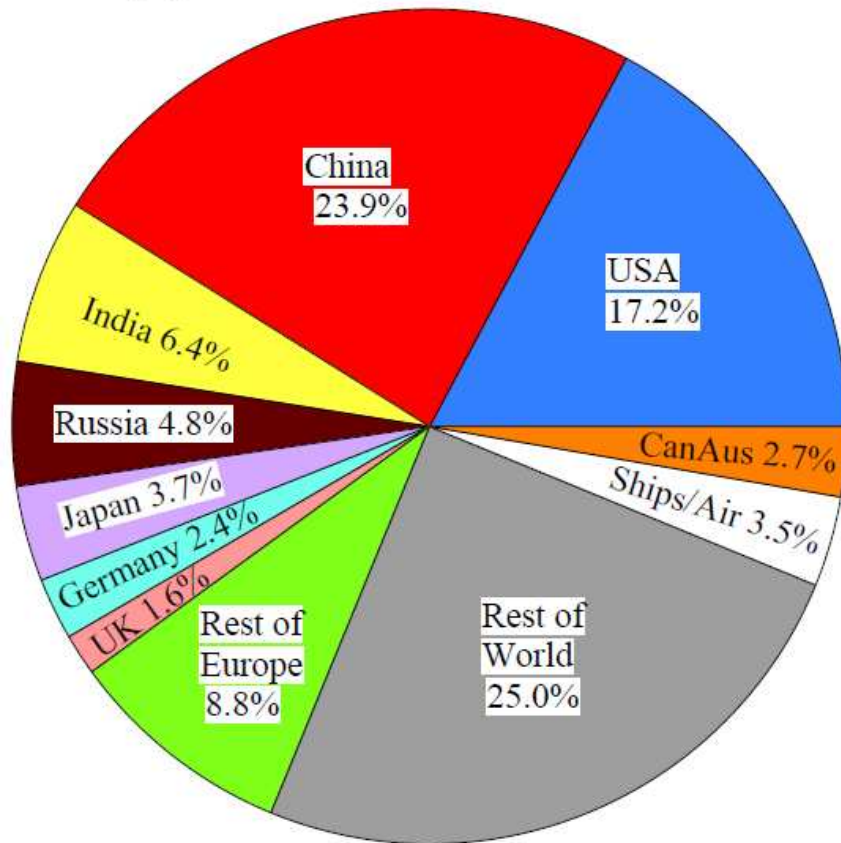
- A key Element of the Global Oceanic Circulation -



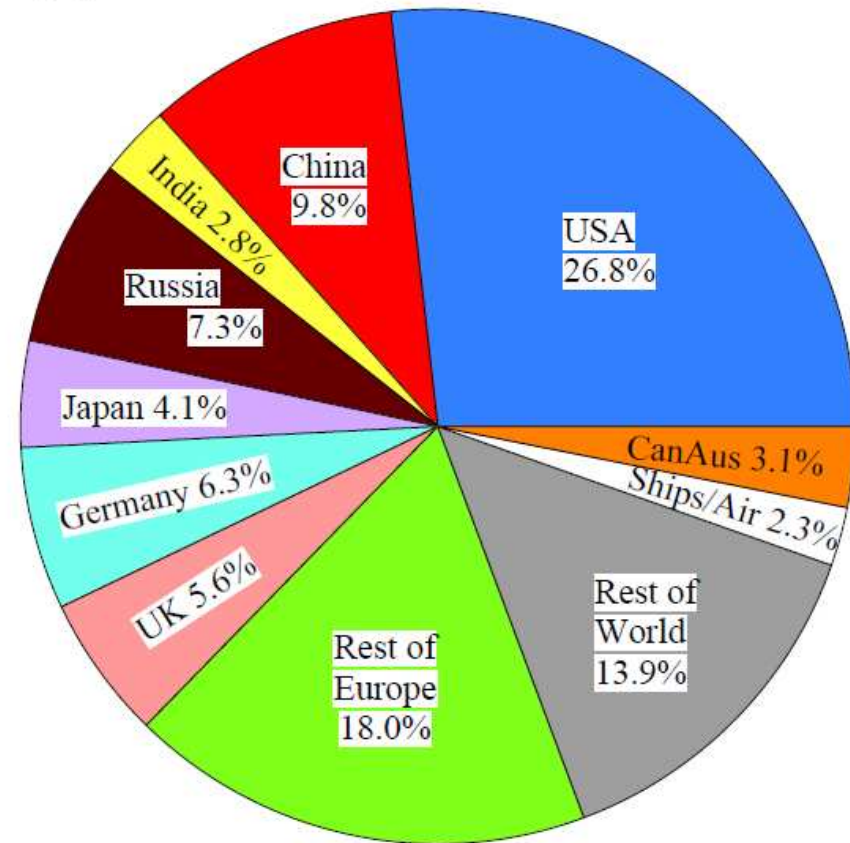
Schematic diagram of the global ocean circulation pathways, the 'conveyor' belt (after W. Broecker, modified by E. Maier-Reimer).

AV/D3/99-2

(a) 2010 Annual Emissions



(b) 1751–2010 Cumulative Emissions



**China has the largest fossil fuel emissions today.  
However, climate change is driven by cumulative emissions, so  
developed nations, especially the U.S., have greatest responsibility.**

# 1: THE CLIMATE IS WARMING

- The evidence:
  - Atmosphere
  - Oceans
  - Cryosphere
  - Sea Level
  - Carbon and Other Biogeochemical Cycles

## Headline #1

Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased (see Figures SPM.1, SPM.2, SPM.3 and SPM.4). (2.2, 2.4, 3.2, 3.7, 4.2–4.7, 5.2, 5.3, 5.5–5.6, 6.2, 13.2)

# 1: THE CLIMATE IS WARMING

- The evidence:
  - Atmosphere
  - Oceans
  - Cryosphere
  - Sea Level
  - Carbon and Other Biogeochemical Cycles

## Headline #2

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850 (see Figure SPM.1). In the Northern Hemisphere, 1983–2012 was *likely* the warmest 30-year period of the last 1400 years (*medium confidence*). (2.4, 5.3)



# 1: THE CLIMATE IS WARMING

- The evidence:
  - Atmosphere
  - Oceans

## Headline #3

Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010 (*high confidence*). It is *virtually certain* that the upper ocean (0–700 m) warmed from 1971 to 2010 (see Figure SPM.3), and it *likely* warmed between the 1870s and 1971. (3.2, Box 3.1)

# 1: THE CLIMATE IS WARMING

- The evidence:
  - Atmosphere
  - Oceans
  - Cryosphere

## Headline #4

Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and Arctic sea ice and Northern Hemisphere spring snow cover have continued to decrease in extent (*high confidence*) (see Figure SPM.3). (4.2–4.7)

# 1: THE CLIMATE IS WARMING

- The evidence:
  - Atmosphere
  - Oceans
  - Cryosphere
  - Sea Level

## Headline #5

The rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia (*high confidence*). Over the period 1901 to 2010, global mean sea level rose by 0.19 [0.17 to 0.21] m (see Figure SPM.3). (3.7, 5.6, 13.2)

# 1: THE CLIMATE IS WARMING

- The evidence:
  - Atmosphere
  - Oceans
  - Cryosphere
  - Sea Level
  - Carbon and Other Biogeochemical Cycles

## Headline #6

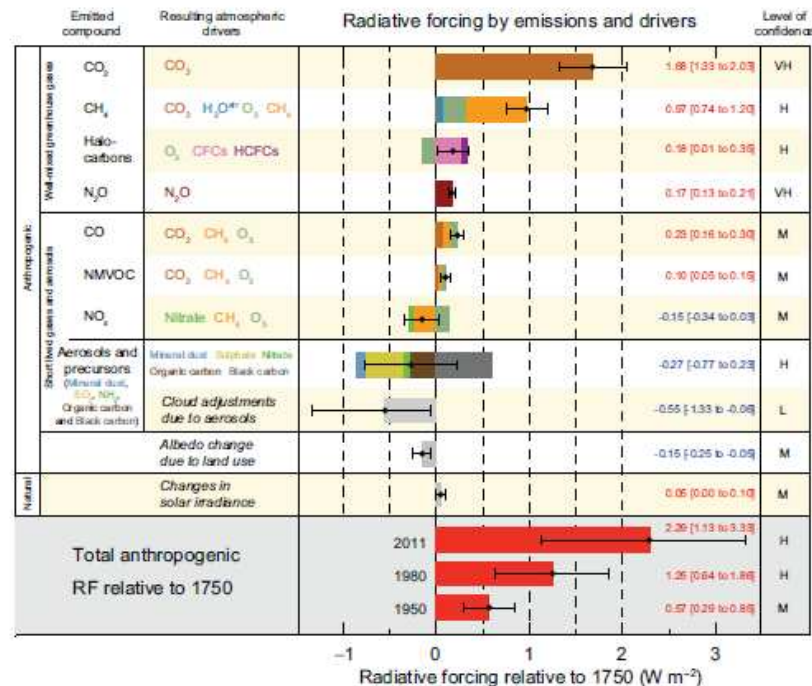
The atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years. Carbon dioxide concentrations have increased by 40% since pre-industrial times, primarily from fossil fuel emissions and secondarily from net land use change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification (see Figure SPM.4). (2.2, 3.8, 5.2, 6.2, 6.3)

# 1: THE CLIMATE IS WARMING

- Drivers; aka forcings, i.e. causes

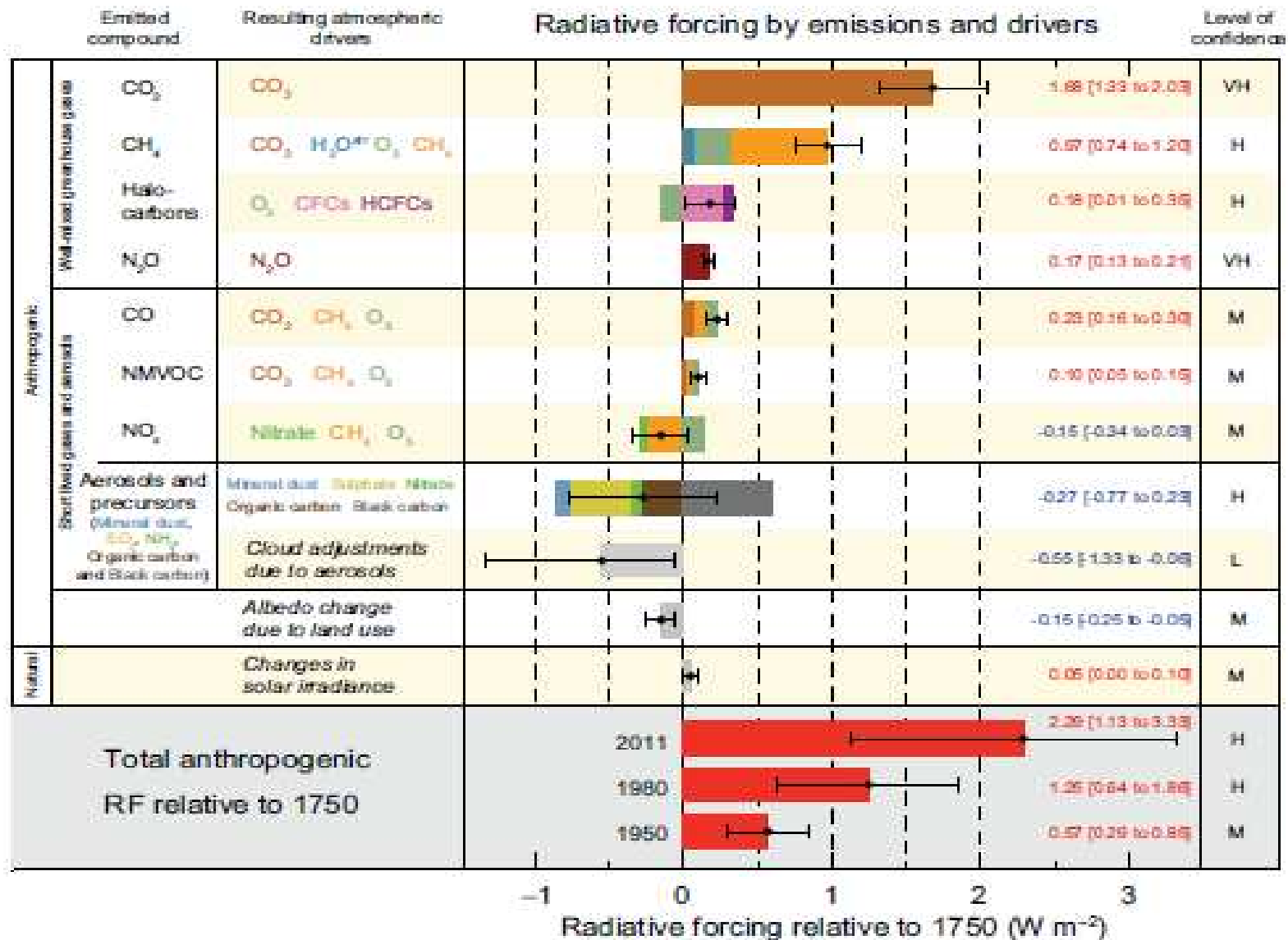
## Headline #7

Total radiative forcing is positive, and has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO<sub>2</sub> since 1750 (see Figure SPM.5). (3.2, Box 3.1, 8.3, 8.5)

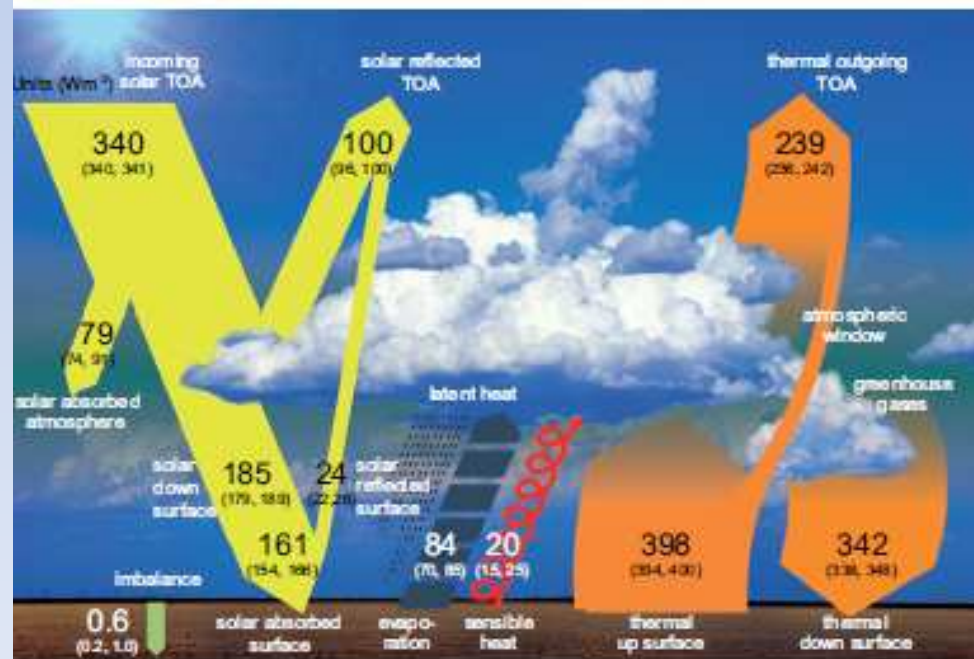
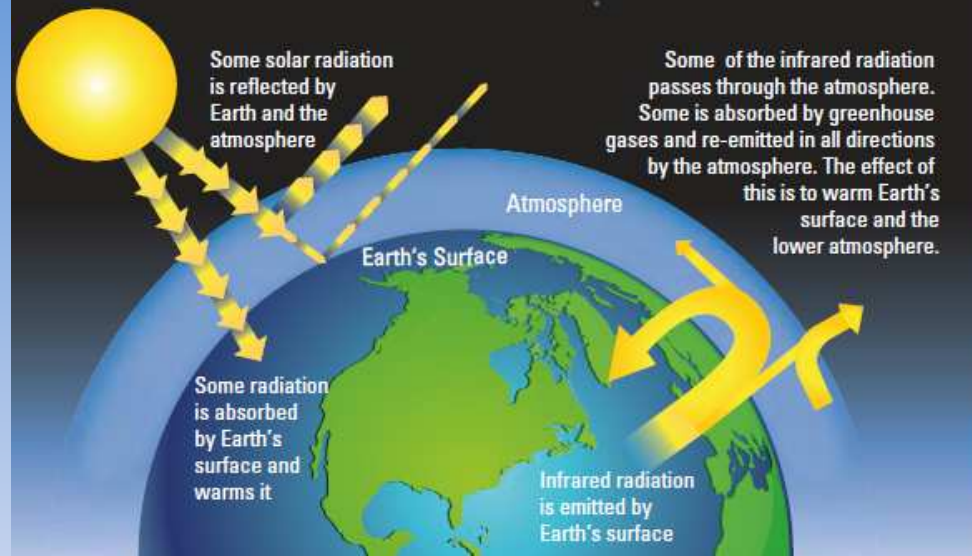


# 1: THE CLIMATE IS WARMING

- Drivers; aka forcings, i.e. causes

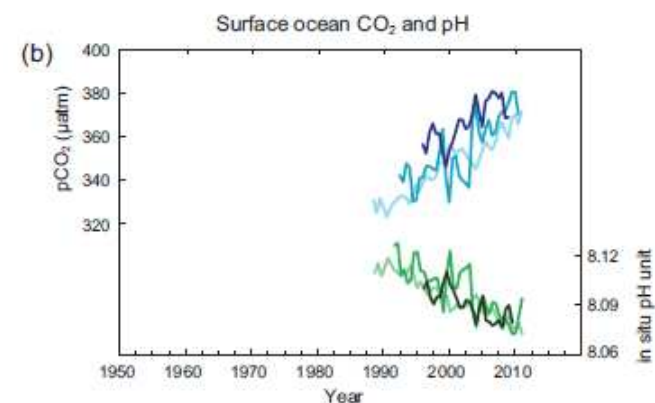
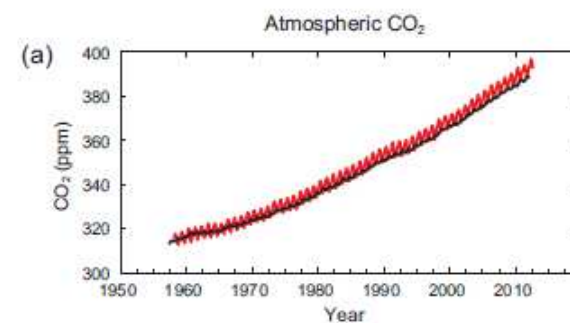
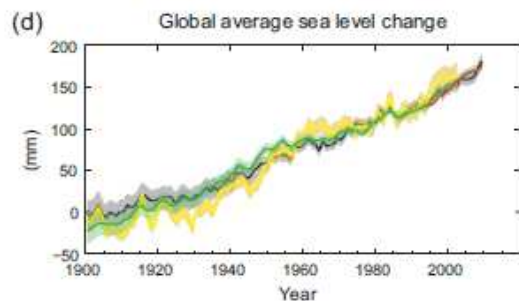
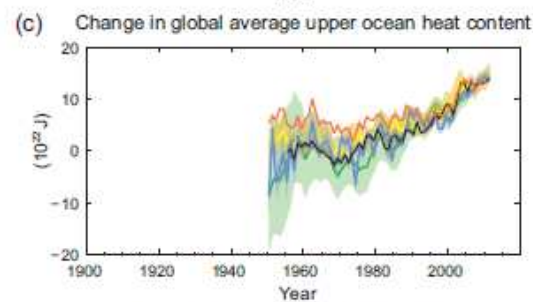
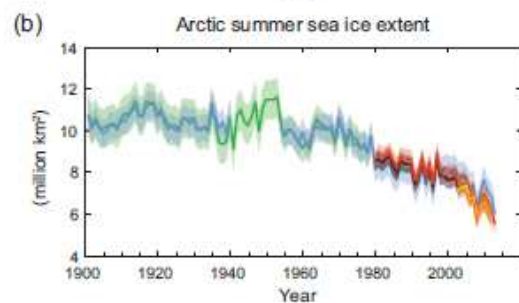
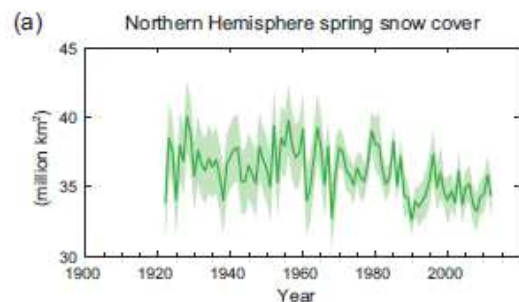
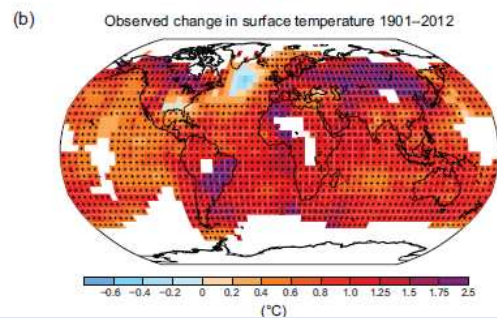
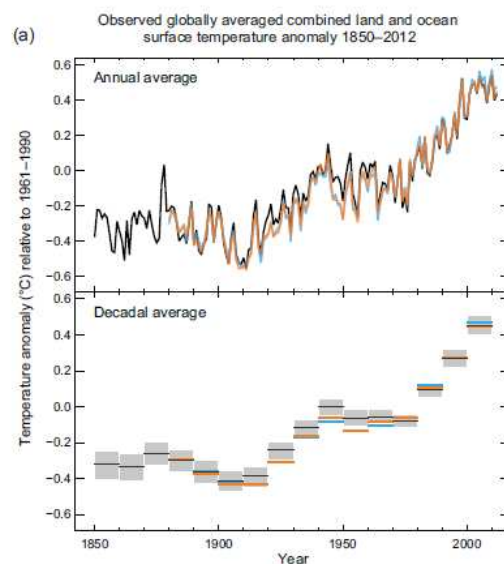


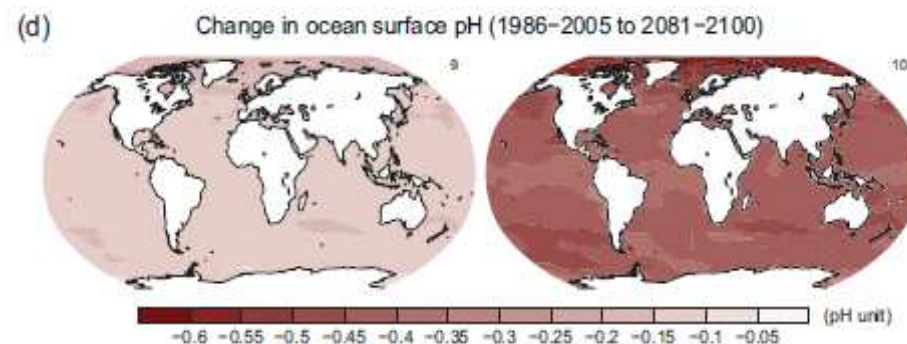
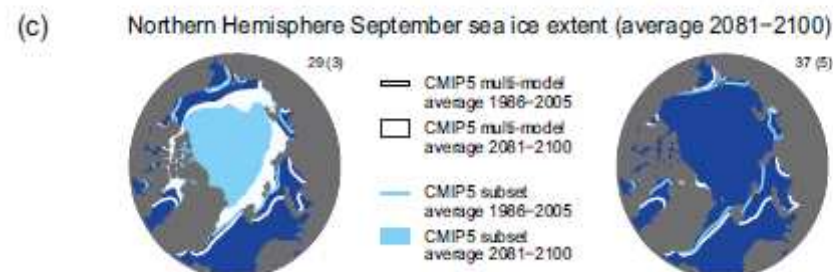
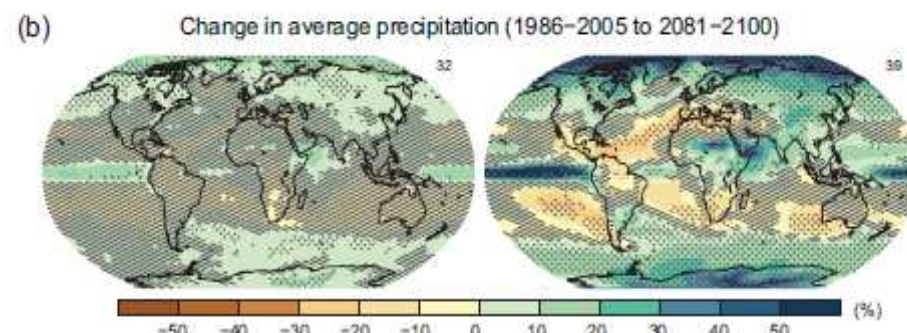
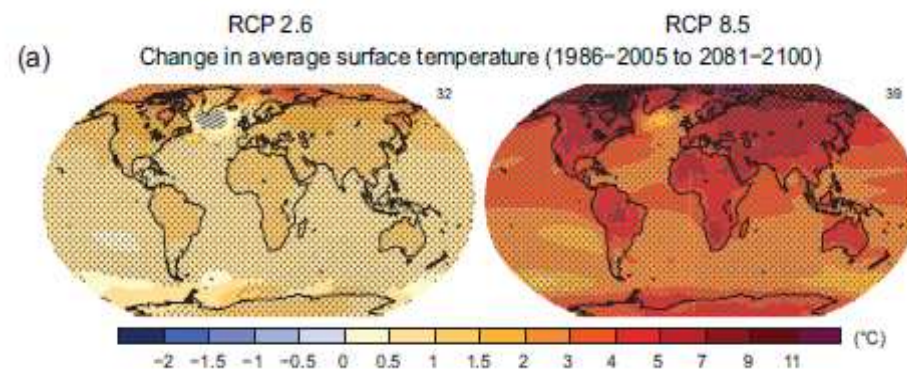
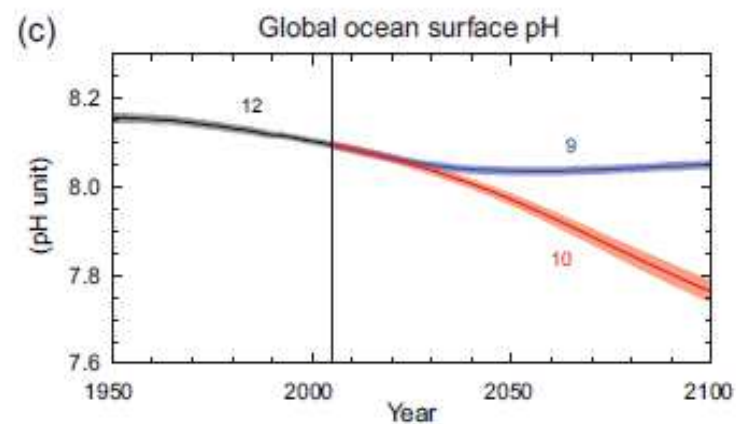
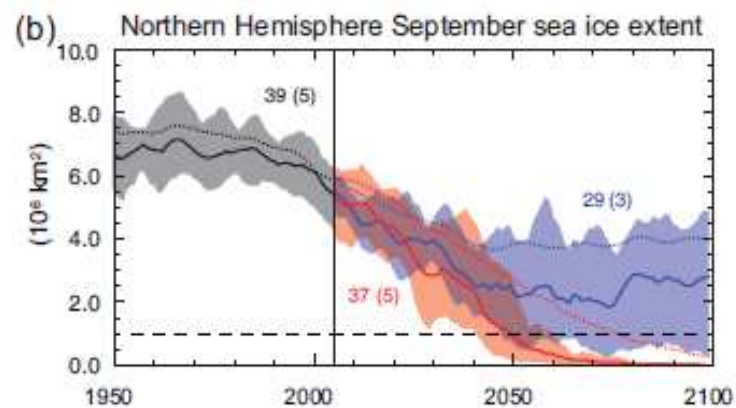
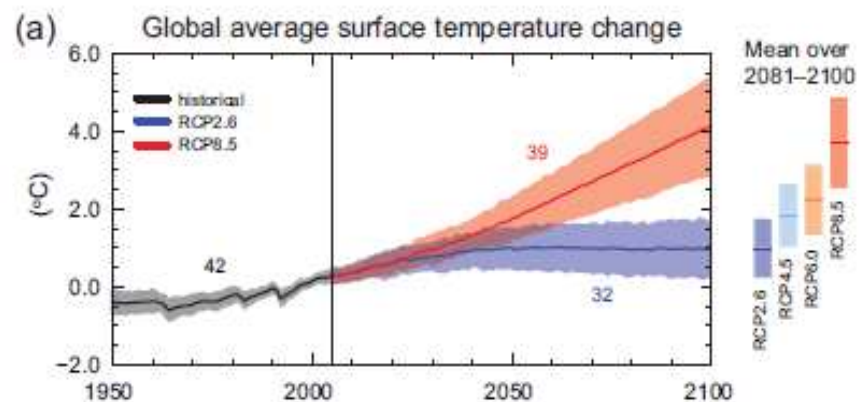
# THE GREENHOUSE EFFECT





# 1 – Resulting in:





## 2: LARGELY CAUSED BY HUMAN ACTIVITIES

### Headline #8

Human influence on the climate system is clear. This is evident from the increasing greenhouse gas concentrations in the atmosphere, positive radiative forcing, observed warming, and understanding of the climate system. (2-14)





# Modeling

## Headline # 9

Climate models have improved since the AR4. Models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling immediately following large volcanic eruptions (*very high confidence*). {9.4, 9.6, 9.8}

		2046–2065		2081–2100	
	Scenario	Mean	<i>Likely range<sup>c</sup></i>	Mean	<i>Likely range<sup>c</sup></i>
Global Mean Surface Temperature Change (°C) <sup>a</sup>	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
	Scenario	Mean	<i>Likely range<sup>d</sup></i>	Mean	<i>Likely range<sup>d</sup></i>
Global Mean Sea Level Rise (m) <sup>b</sup>	RCP2.6	0.24	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

Notes:

## Headline # 10

Observational and model studies of temperature change, climate feedbacks and changes in the Earth's energy budget together provide confidence in the magnitude of global warming in response to past and future forcing. {Box 12.2, Box 13.1}

## 2: Causes and Effects

### Headline # 11

#### D.3 Detection and Attribution of Climate Change

Human influence has been detected in warming of the atmosphere and the ocean, in changes in the global water cycle, in reductions in snow and ice, in global mean sea level rise, and in changes in some climate extremes (see Figure SPM.6 and Table SPM.1). This evidence for human influence has grown since AR4. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-20th century. (10.3–10.6, 10.9)

### Headline # 12

Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions. (6, 11–14)

## 2: Effects: Temperature rise

### Headline # 13

#### E.1 Atmosphere: Temperature

Global surface temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850 to 1900 for all RCP scenarios except RCP2.6. It is *likely* to exceed 2°C for RCP6.0 and RCP8.5, and *more likely than not* to exceed 2°C for RCP4.5. Warming will continue beyond 2100 under all RCP scenarios except RCP2.6. Warming will continue to exhibit interannual-to-decadal variability and will not be regionally uniform (see Figures SPM.7 and SPM.8). (11.3, 12.3, 12.4, 14.8)

# Effects: Hydrologic and Ocean responses

## Headline # 14

### E.2 Atmosphere: Water Cycle

Changes in the global water cycle in response to the warming over the 21st century will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase, although there may be regional exceptions (see Figure SPM.8).

{12.4, 14.3}

## Headline # 15

### E.4 Ocean

The global ocean will continue to warm during the 21st century. Heat will penetrate from the surface to the deep ocean and affect ocean circulation. {11.3, 12.4}



# Effects: Snow & Ice/Sea level responses

## Headline # 16

### E.5 Cryosphere

It is *very likely* that the Arctic sea ice cover will continue to shrink and thin and that Northern Hemisphere spring snow cover will decrease during the 21st century as global mean surface temperature rises. Global glacier volume will further decrease. (12.4, 13.4)

## Headline # 17

### E.6 Sea Level

Global mean sea level will continue to rise during the 21st century (see Figure SPM.9). Under all RCP scenarios, the rate of sea level rise will *very likely* exceed that observed during 1971 to 2010 due to increased ocean warming and increased loss of mass from glaciers and ice sheets. (13.3–13.5)

# Effects: Ocean Acidification/other consequences

## Headline # 18

### Carbon and Other Biogeochemical Cycles

Climate change will affect carbon cycle processes in a way that will exacerbate the increase of CO<sub>2</sub> in the atmosphere (*high confidence*). Further uptake of carbon by the ocean will increase ocean acidification. (6.4)

## Headline # 19

### Climate Stabilization, Climate Change Commitment and Irreversibility

Cumulative emissions of CO<sub>2</sub> largely determine global mean surface warming by the late 21st century and beyond (see Figure SPM.10). Most aspects of climate change will persist for many centuries even if emissions of CO<sub>2</sub> are stopped. This represents a substantial multi-century climate change commitment created by past, present and future emissions of CO<sub>2</sub>. (12.5)