Climate change science and policy

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American Institute of Aeronautics and Astronautics

ANTCI, 2005

Climate vs. weather

<u>Weather</u>
Shorter-term fluctuations

Current atmospheric conditions (e.g., temp, press, ws, wdir, rainfall, etc.)

Hours, Days, Weeks
Specific location for specific time

<u>Climate</u>
Longer-Term Changes

Broad composite of average (or mean) condition of a region (e.g., temp, rain, snowfall, ice cover, winds, ocean temperature)

Years (and longer), Typically 30 yr ave.
Mean state of a specific region
(e.g., continent, ocean, or entire planet)

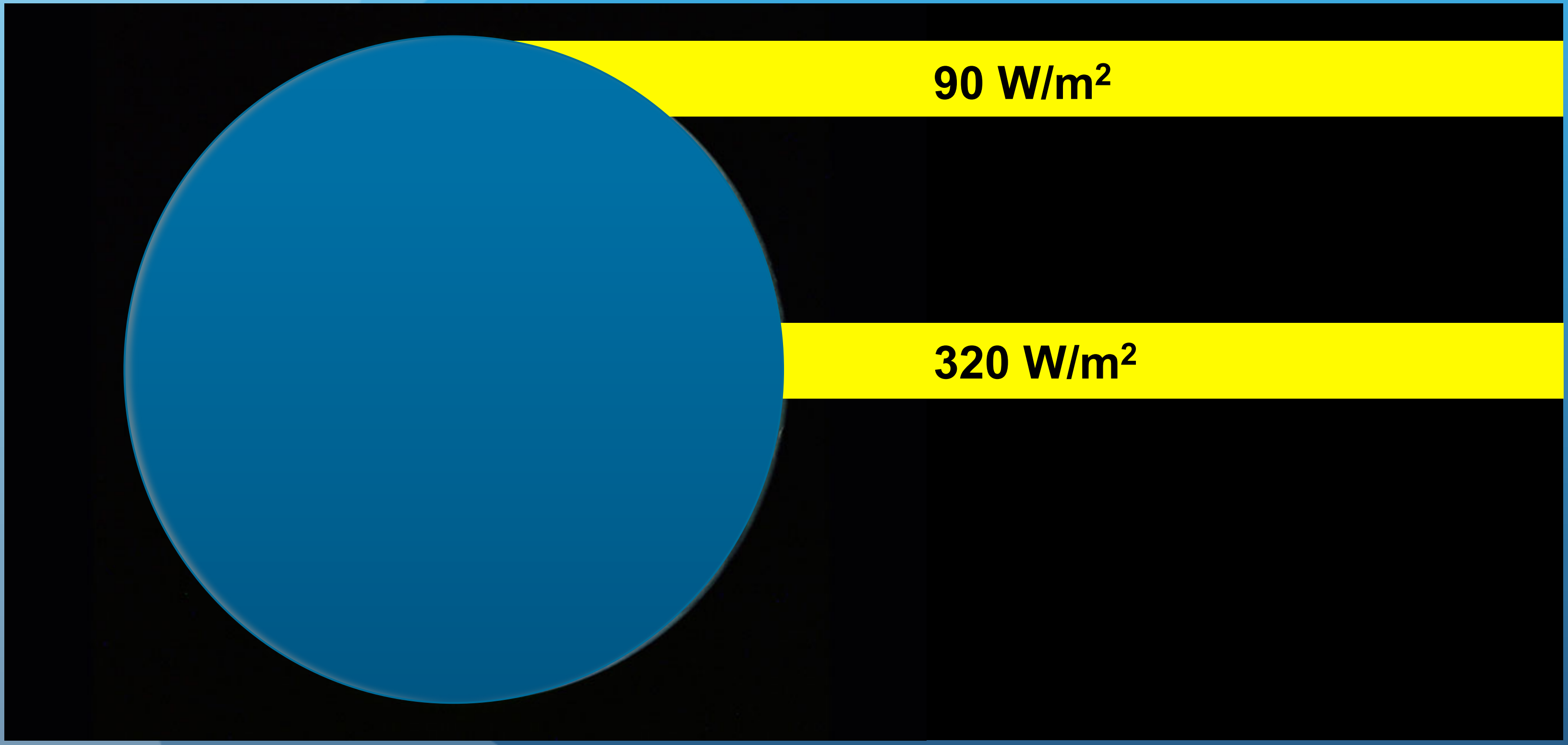
How does Earth's climate change?

Energy Input (E_{in}) ≠ Energy Output (E_{out})

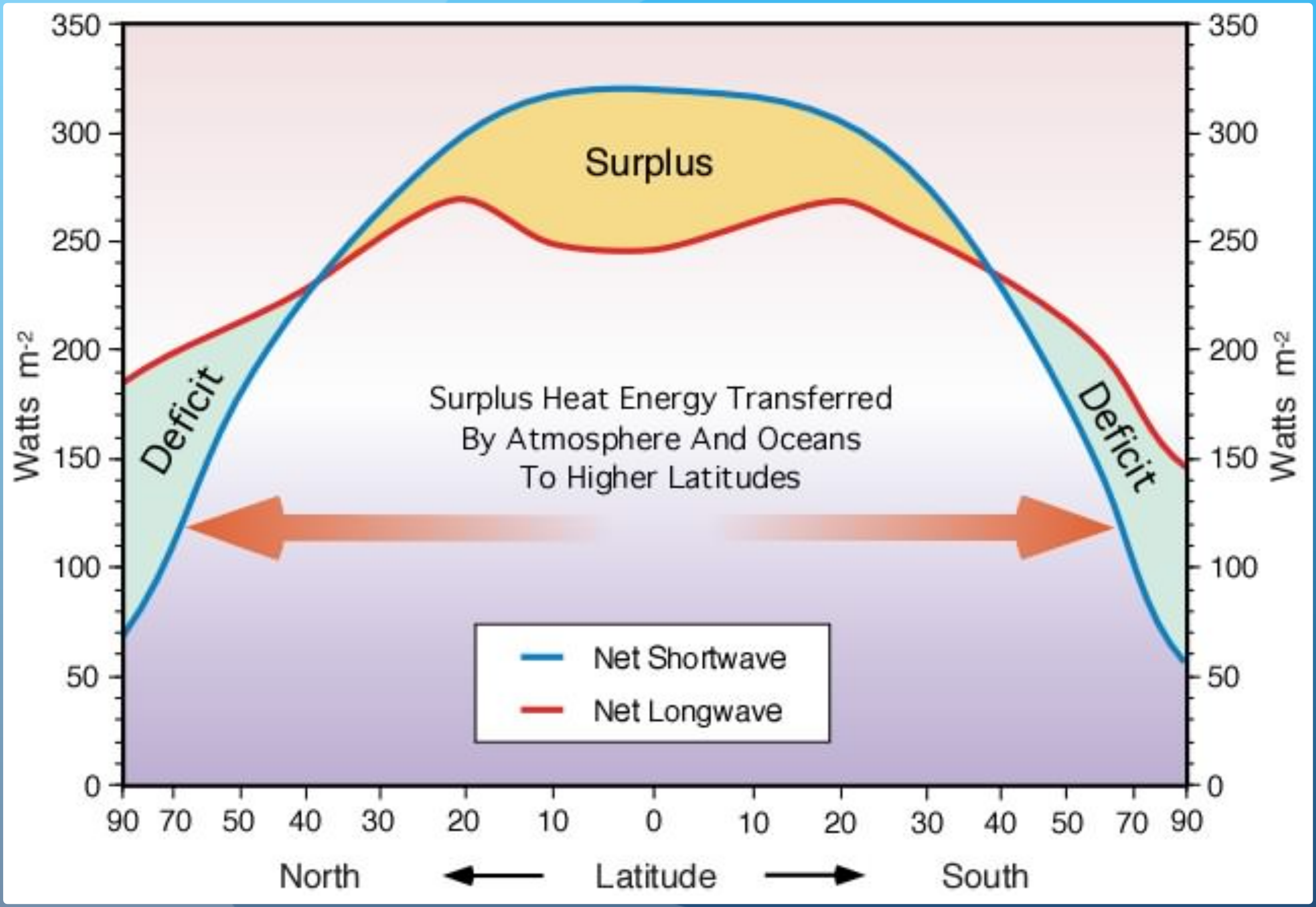
ΔE_{in}:
- Sun
- Earth's Orbit
- Albedo
- Clouds
- Particles

ΔE_{out}:
- CO_2
- CH_4
- N_2O
- Clouds
- Particles

So the Earth absorbs an average of 238 W/m^2 from the Sun, but that does not mean that every square meter absorbs this amount. Where is it absorbing less? Where is it absorbing more?



Energy Spatial Imbalance

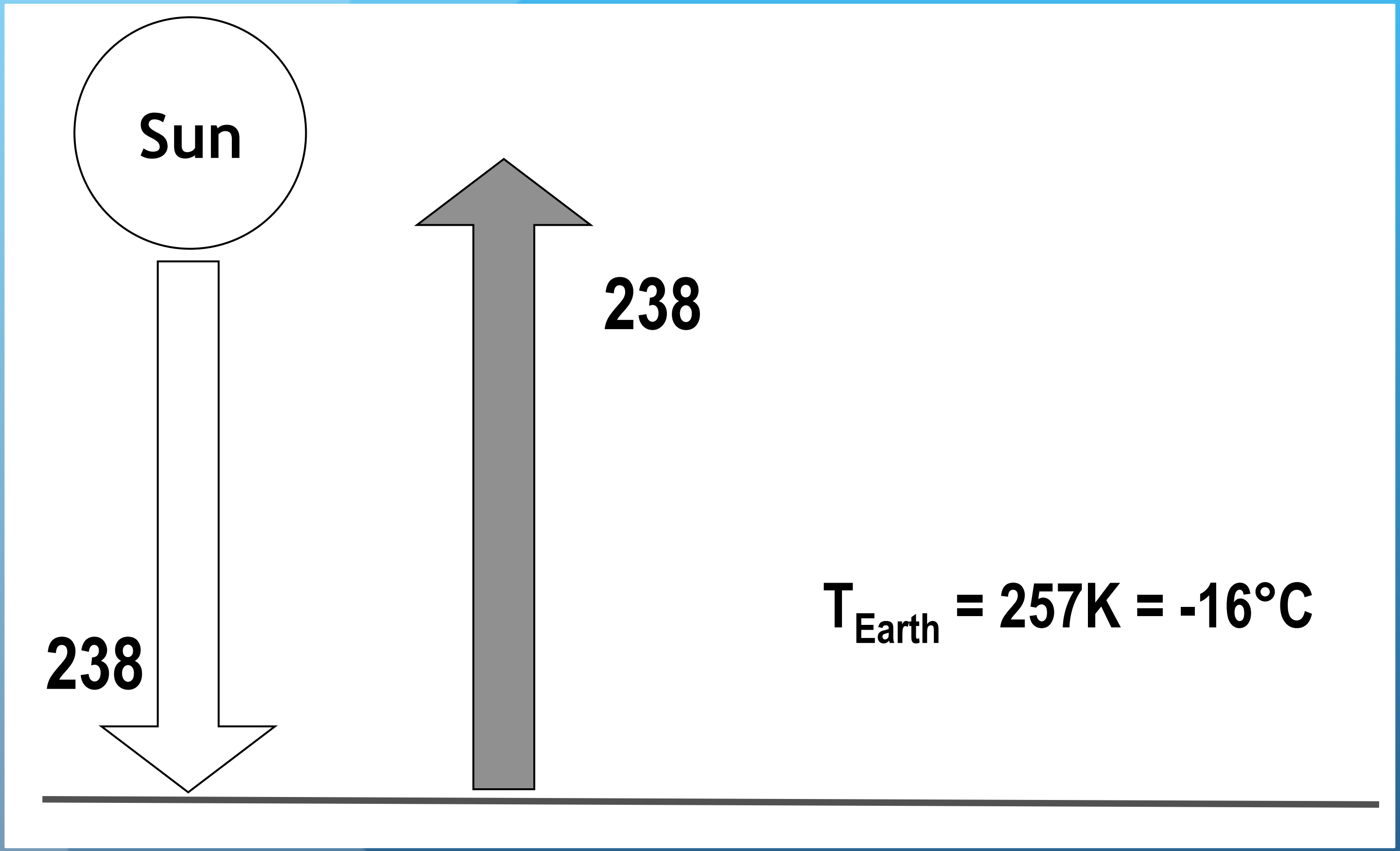


www.physicalgeography.net

Also Tilt of Earth (~23.5 deg)

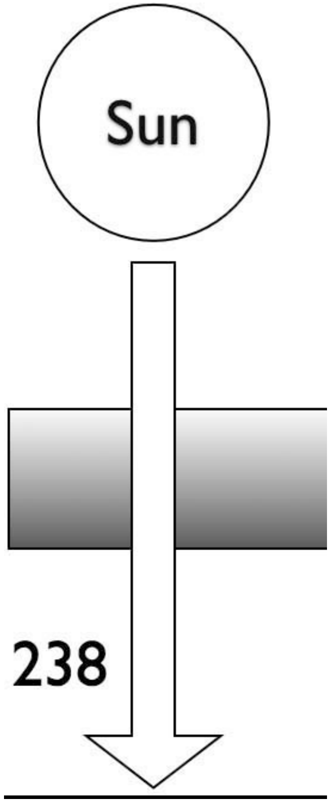
NASA Apollo 17 (12/7/1972)

Earth's Energy Budget – No GHG



Dessler, 2012

Earth's Energy Budget – with atmos



Dessler, 2012

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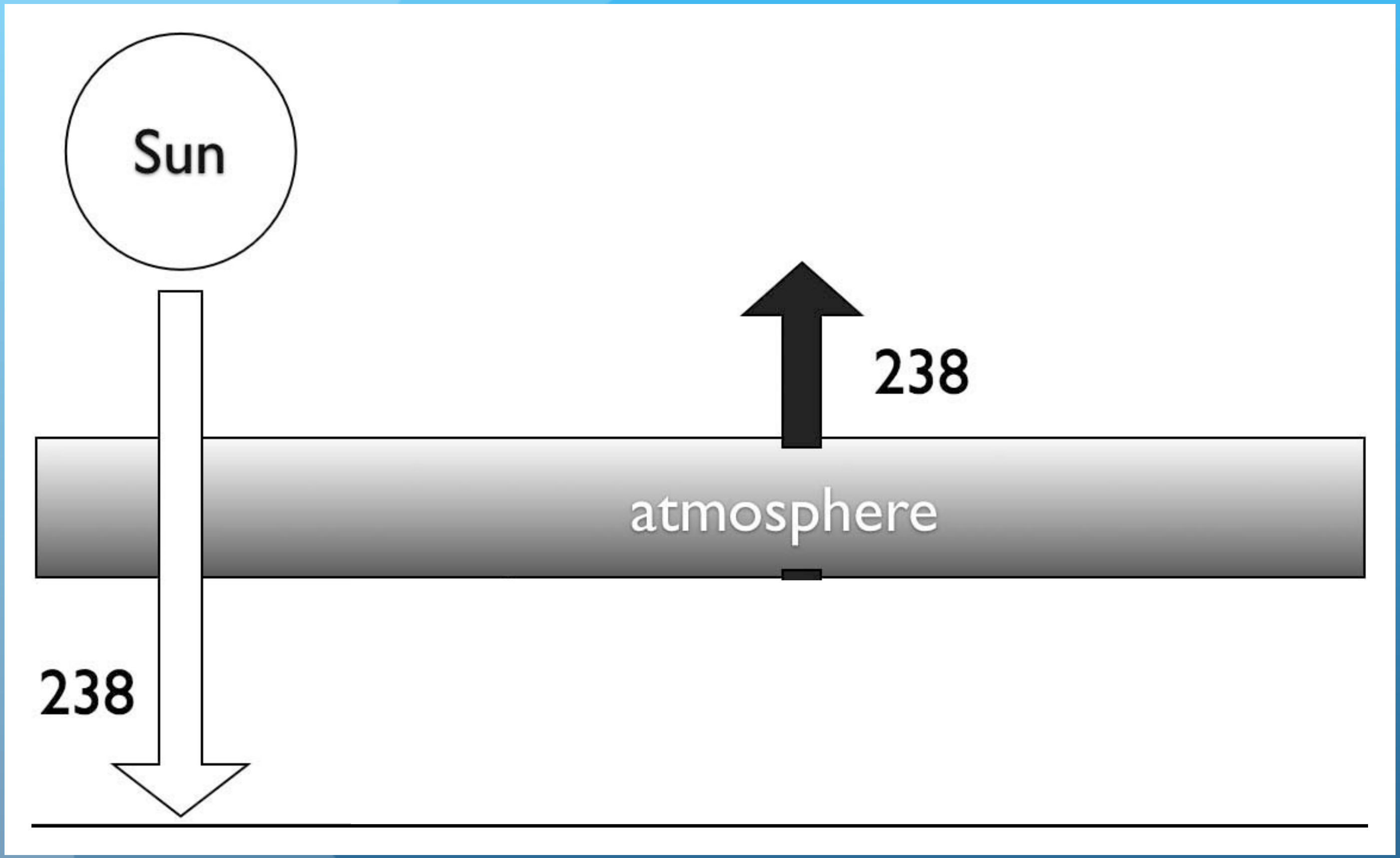

Dessler, 2012

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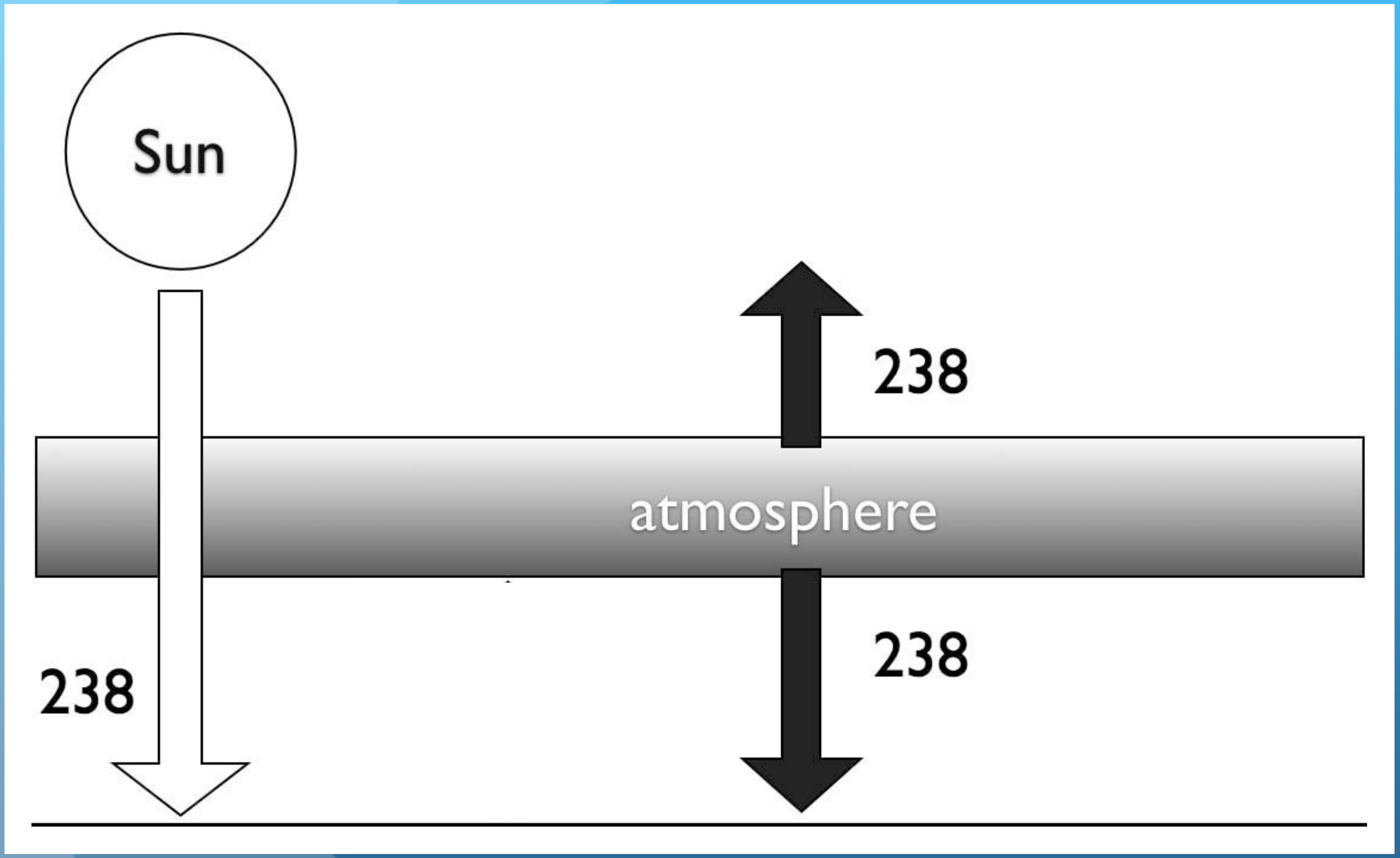
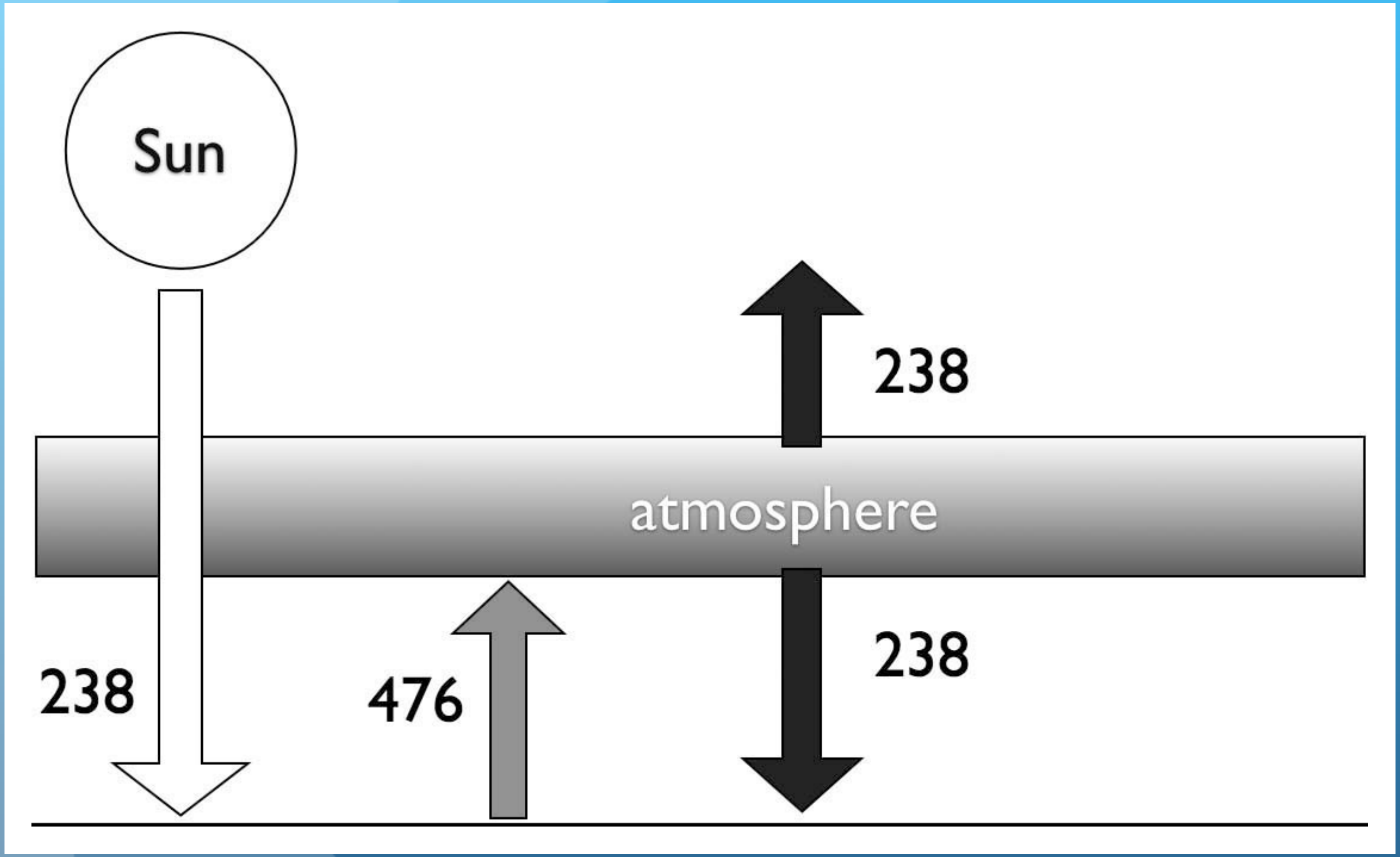


Dessler, 2012

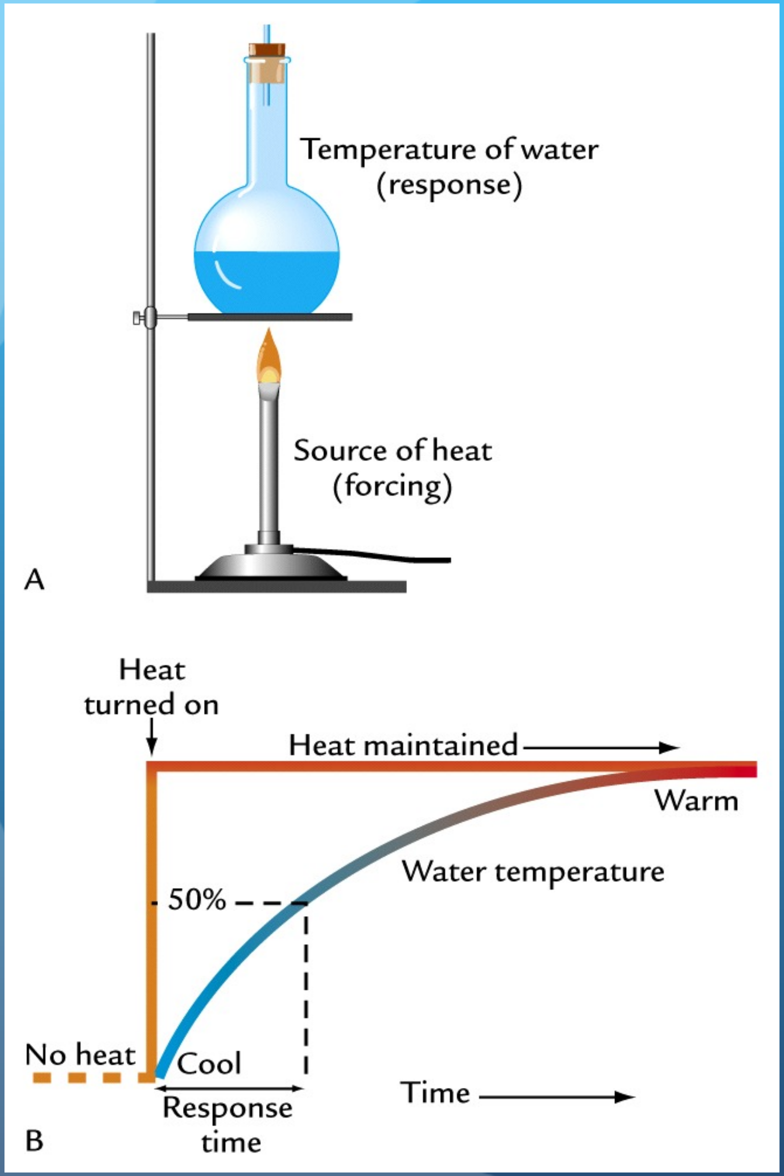
Earth's Energy Budget – with atmos



2015 T_{Earth} = 289K = 16°C

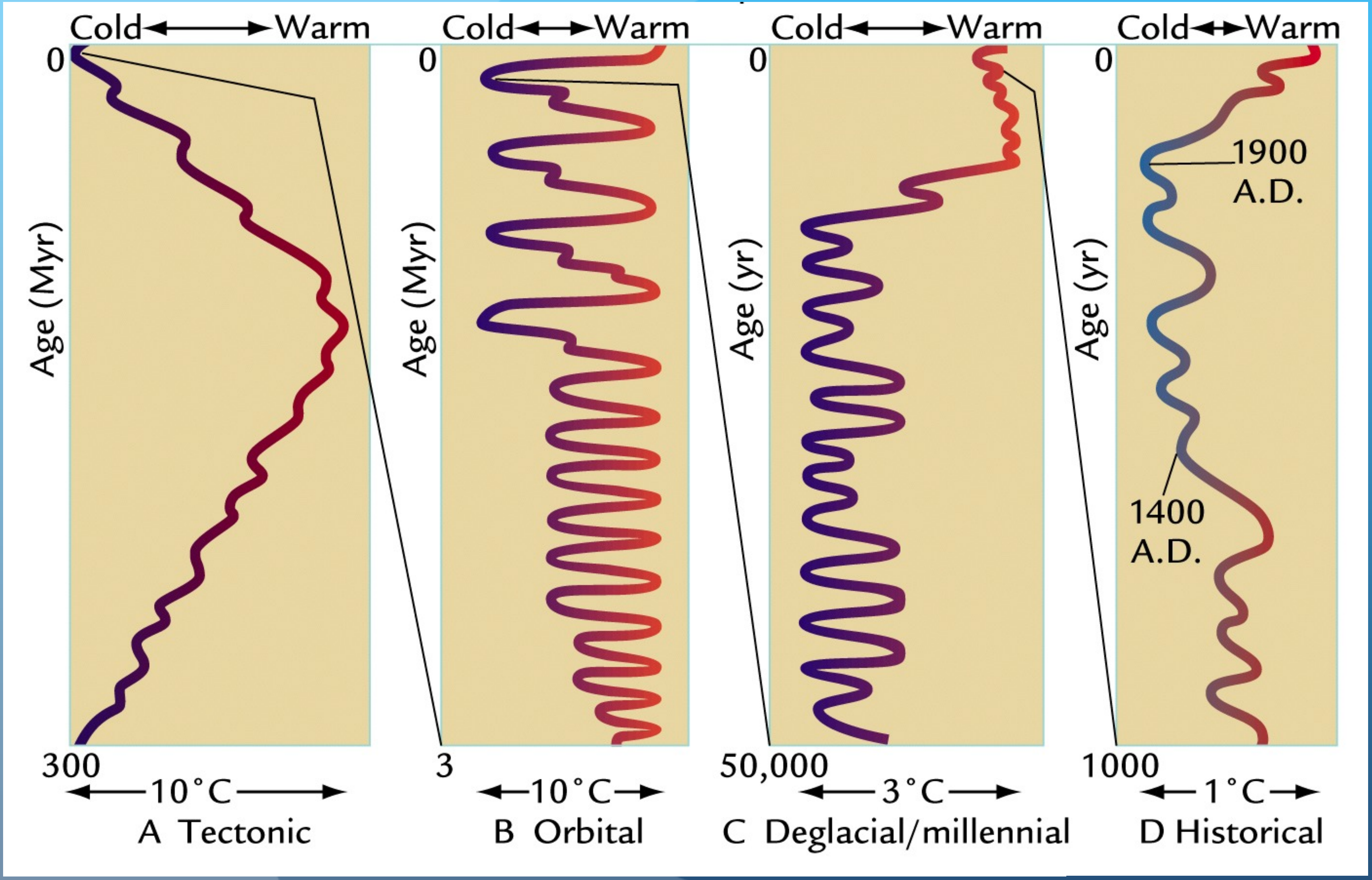
Dessler, 2012

Climate system response



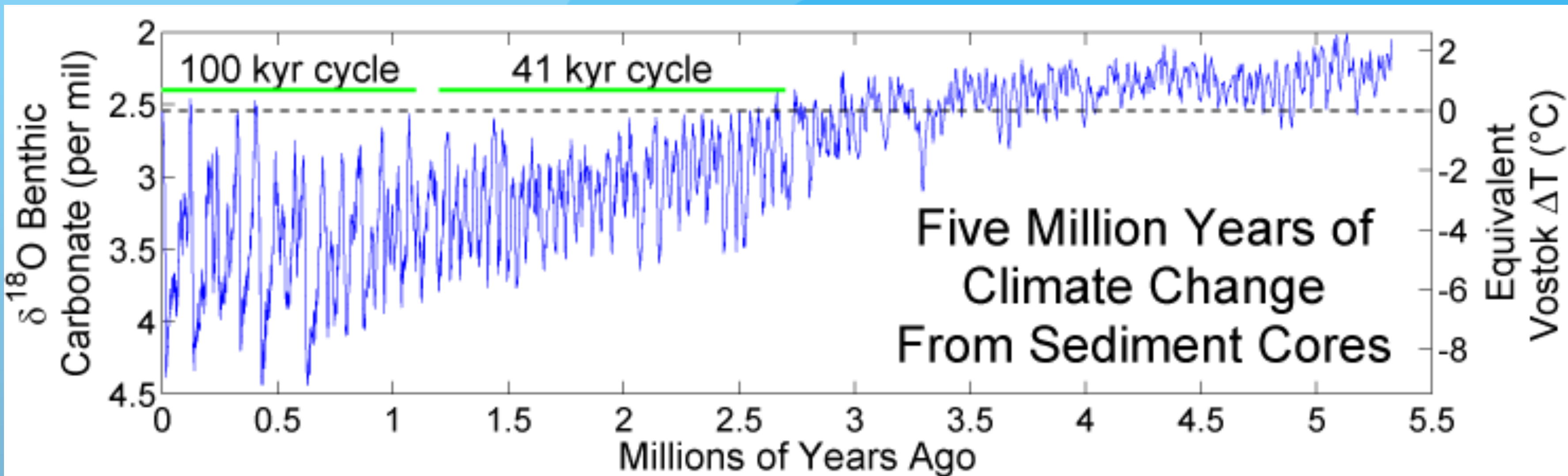
Ruddiman, 2008

Time scales of climate change



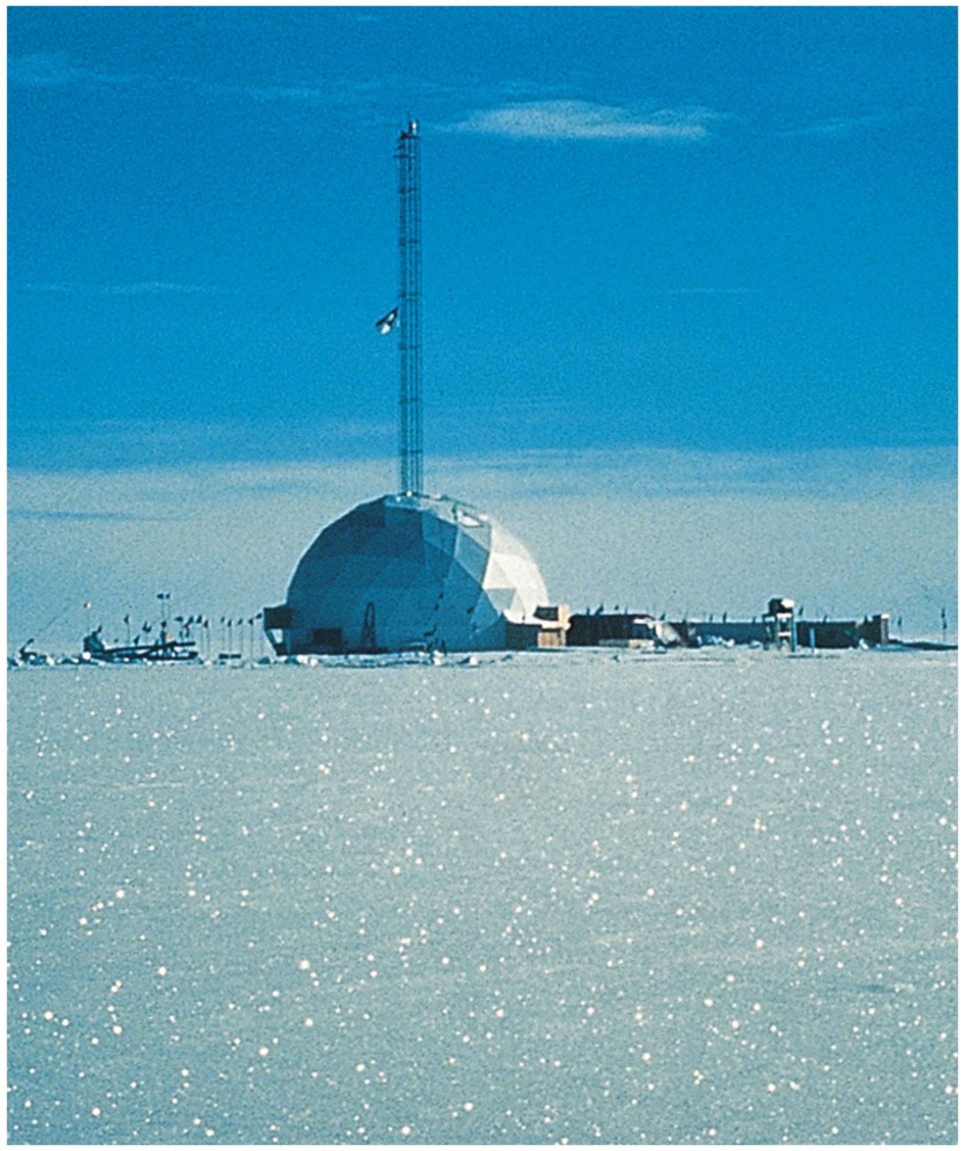
Ruddiman, 2008

Ocean sediment core record



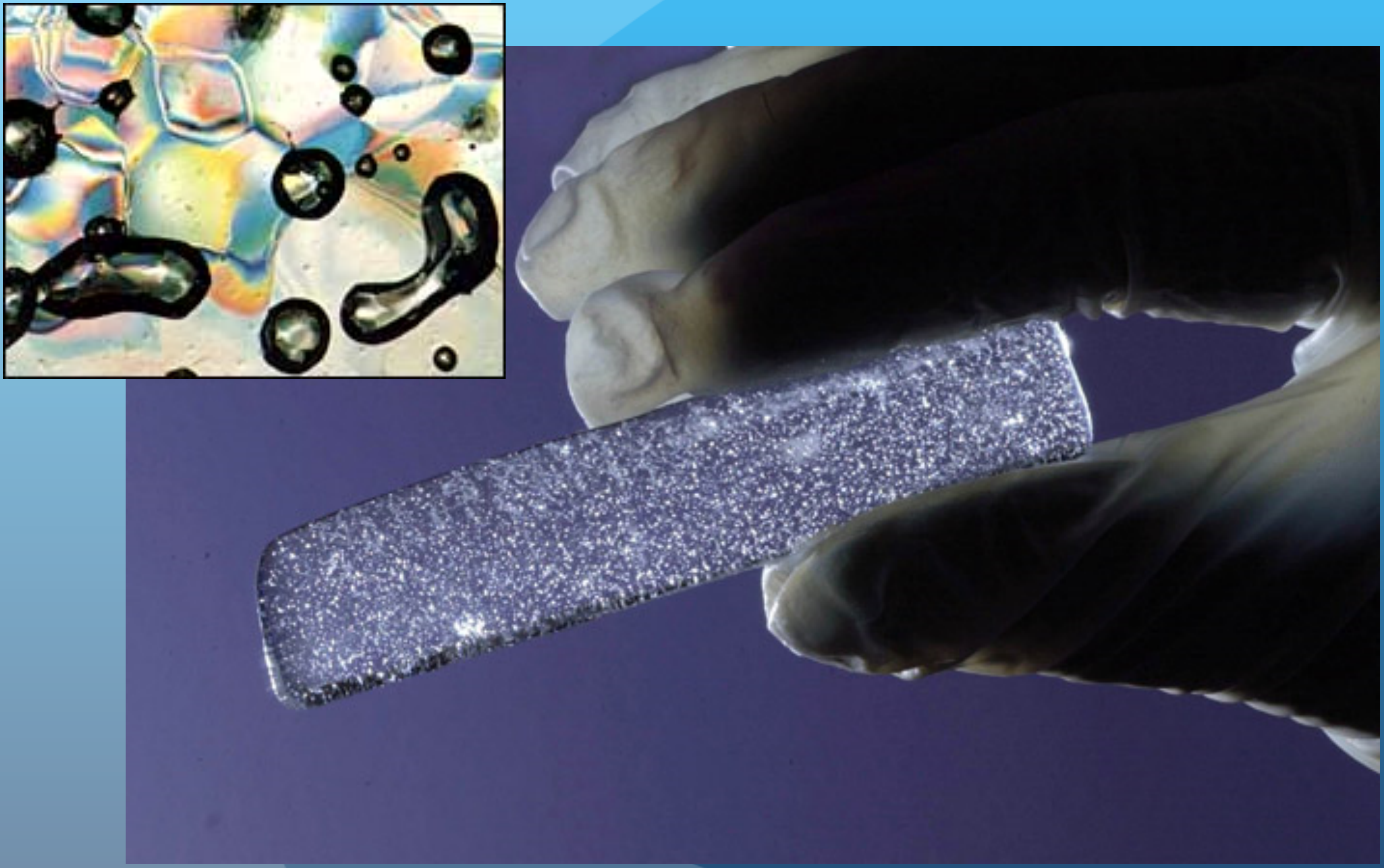
GlobalWarming Art (t), Ruddiman, 2008 (b)

Coring Earth’s ice sheets



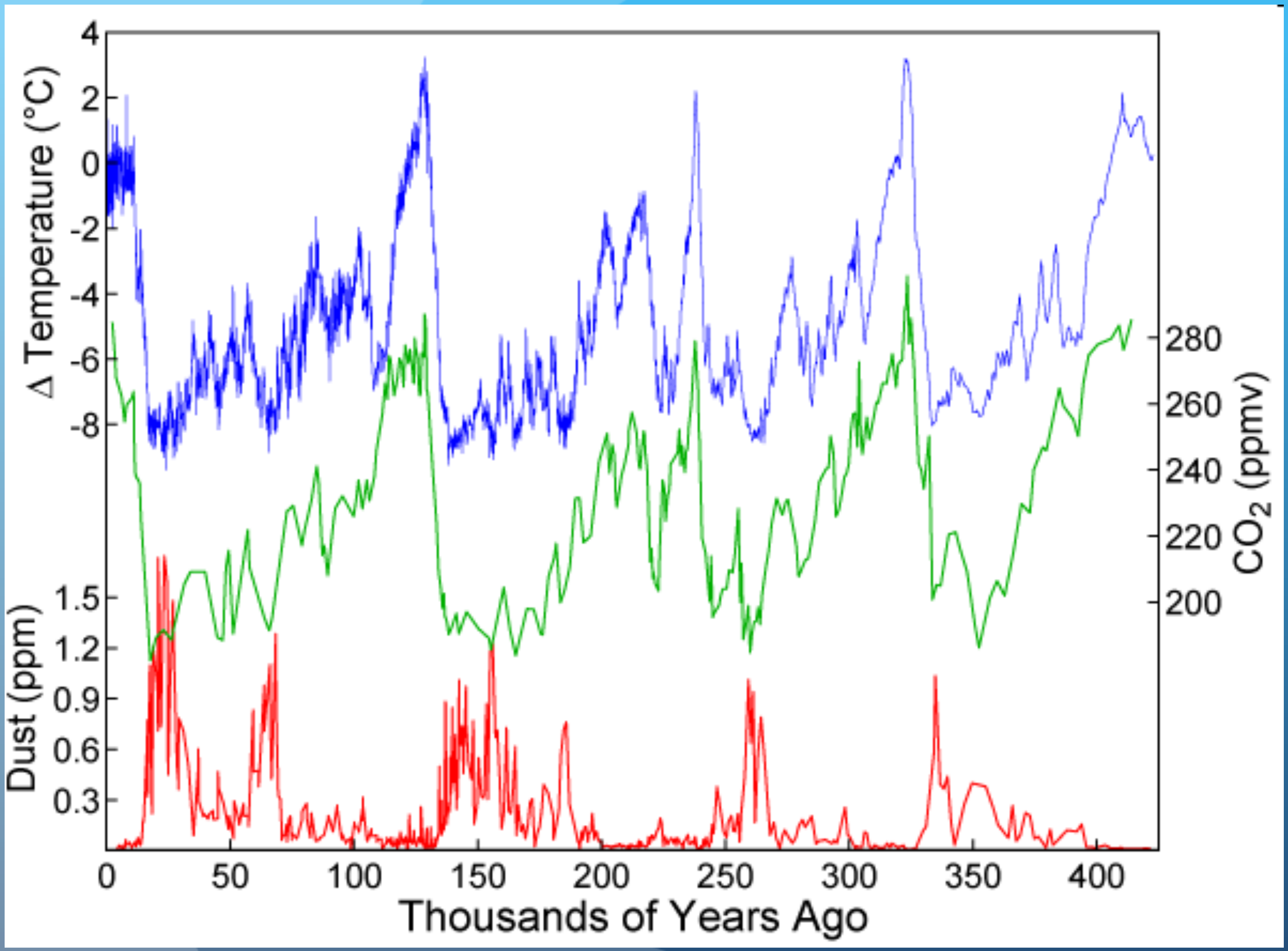
Twickler – GISP2 SMO (1994)

Bubbles trapped in ice core



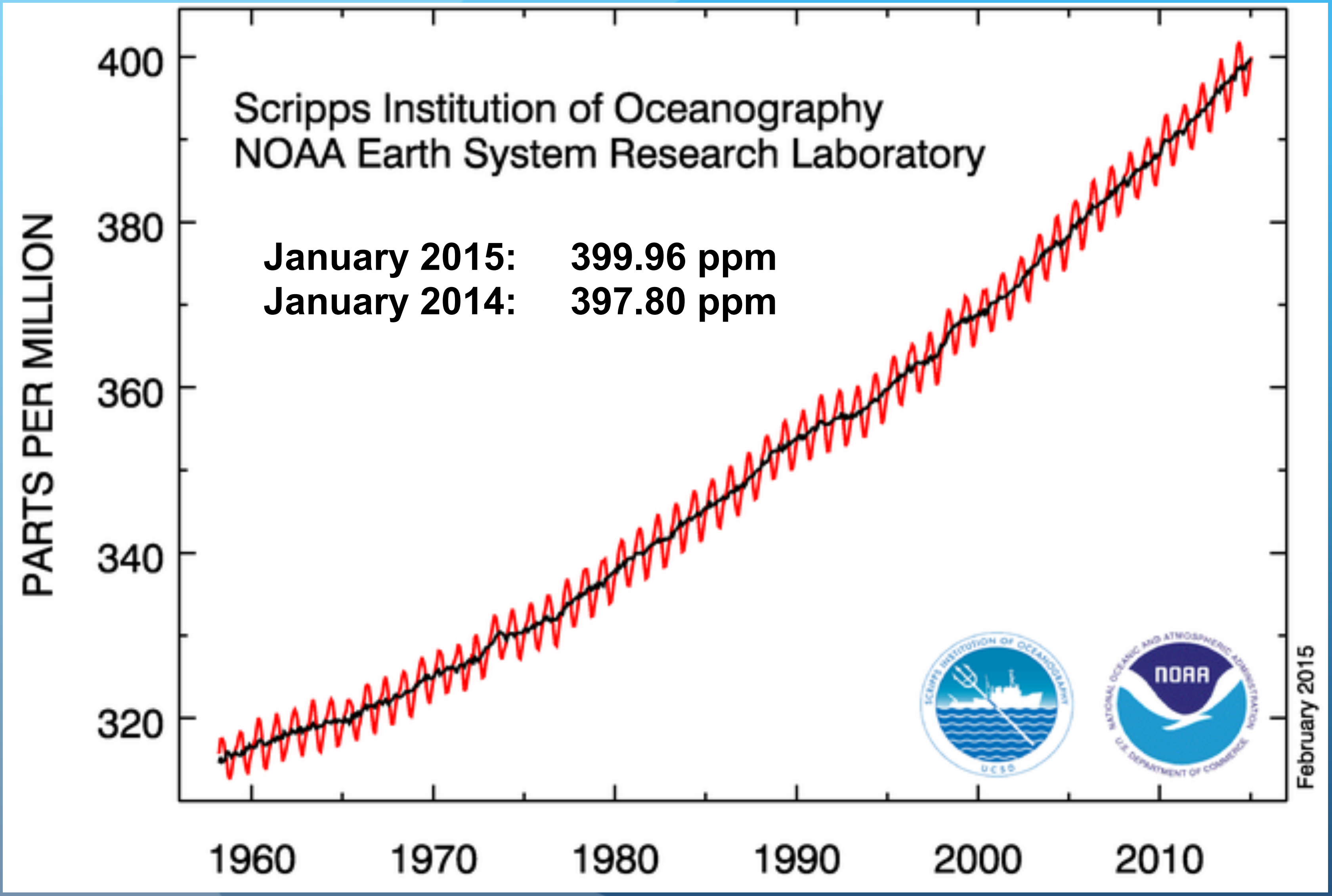
EPICA (2004)

Ice core proxy T, CO_2, dust record



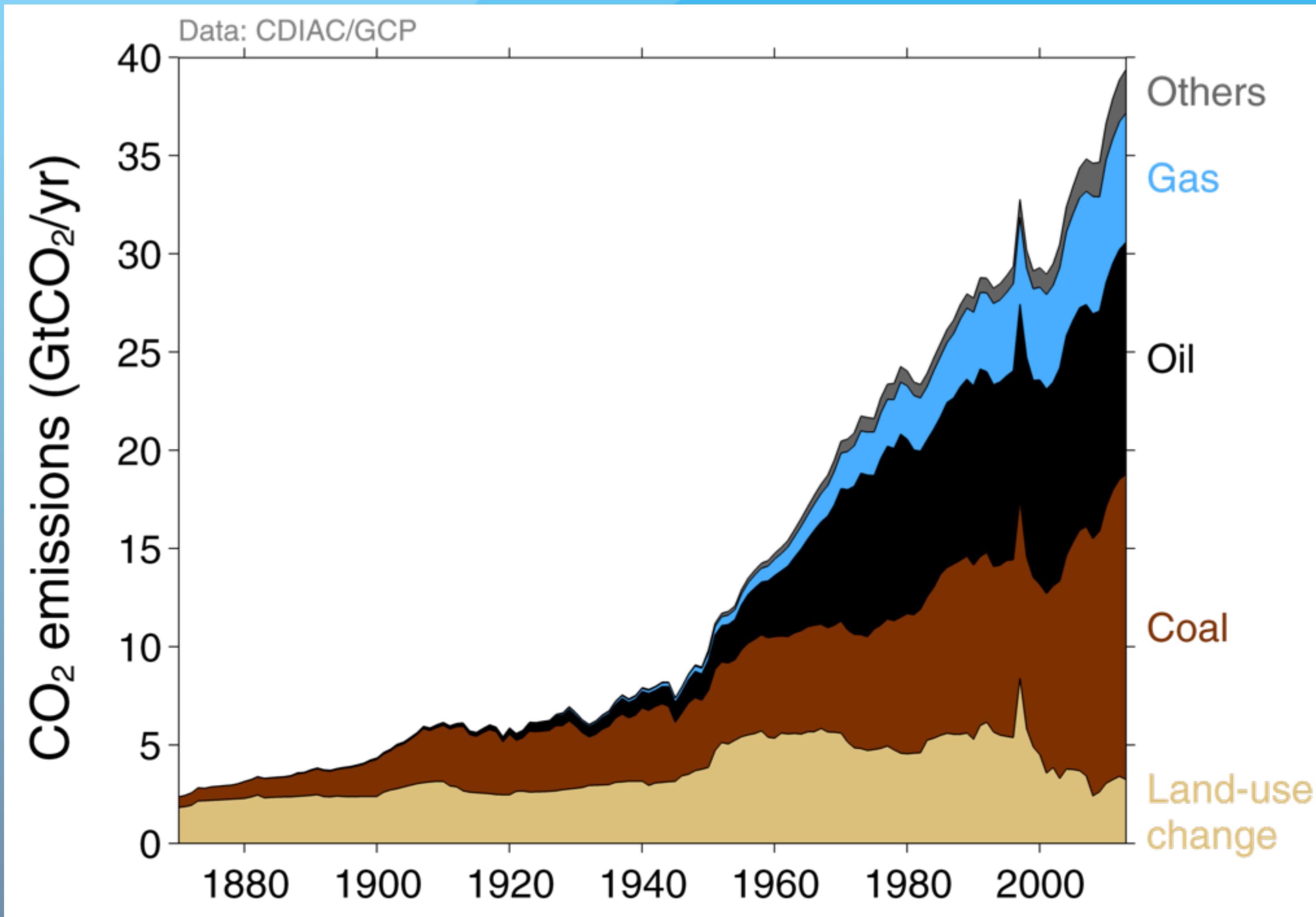
GlobalWarmingArt.com

CO_2 measurement record



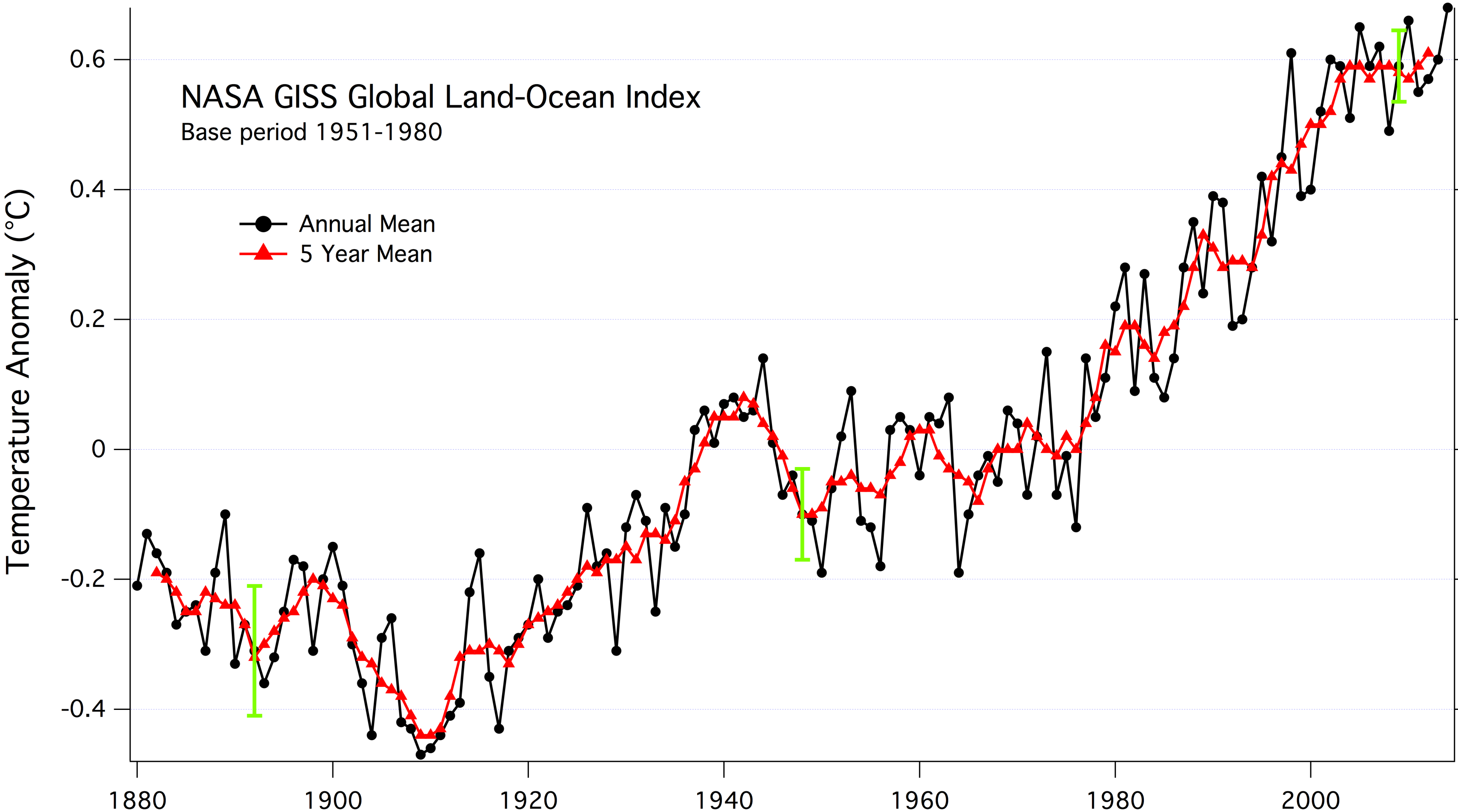
NOAA (2015)

CO_2 Emissons (1870 – 2013)



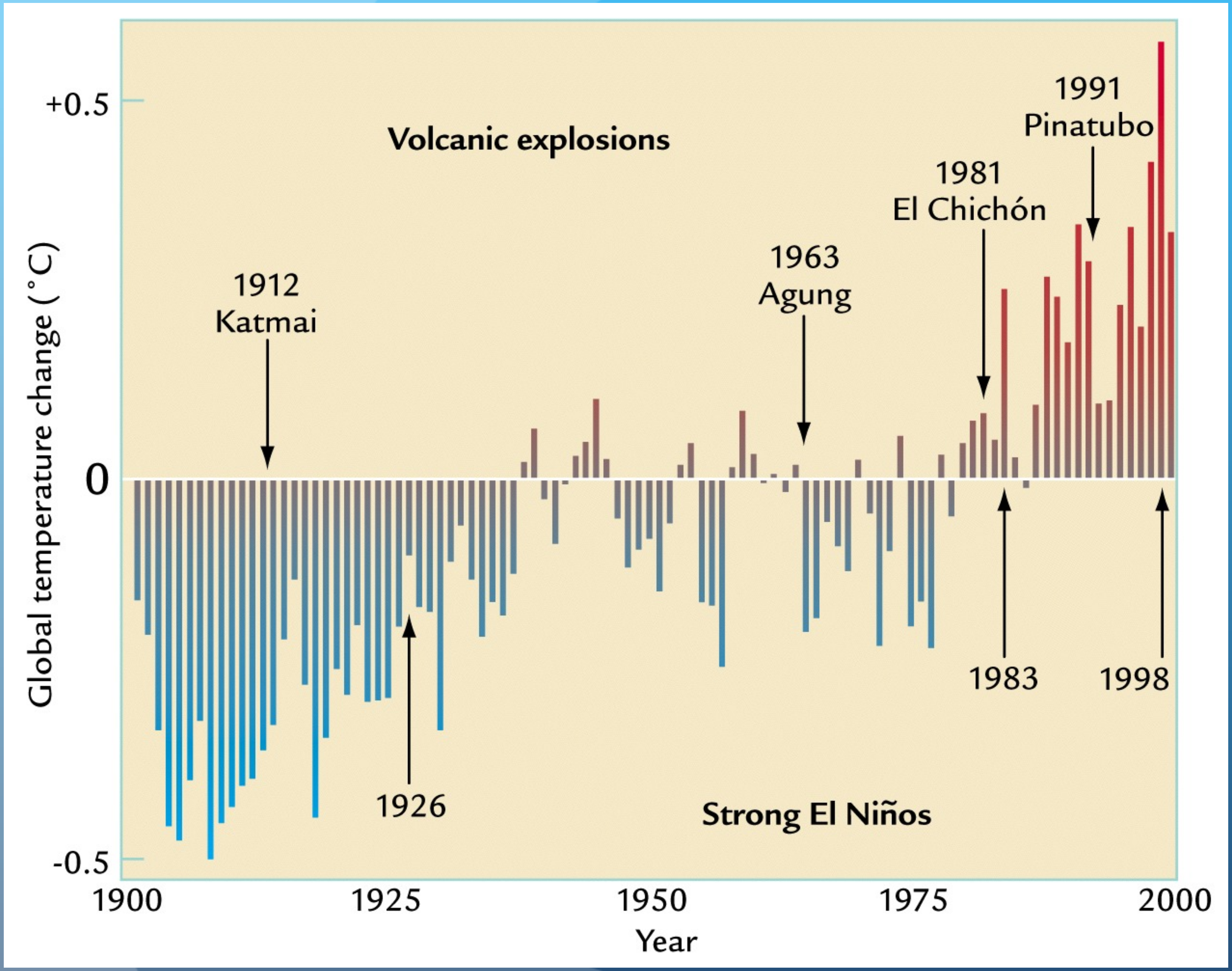
CDIAC/Global Climate Project

Global Annual Surface Temperature



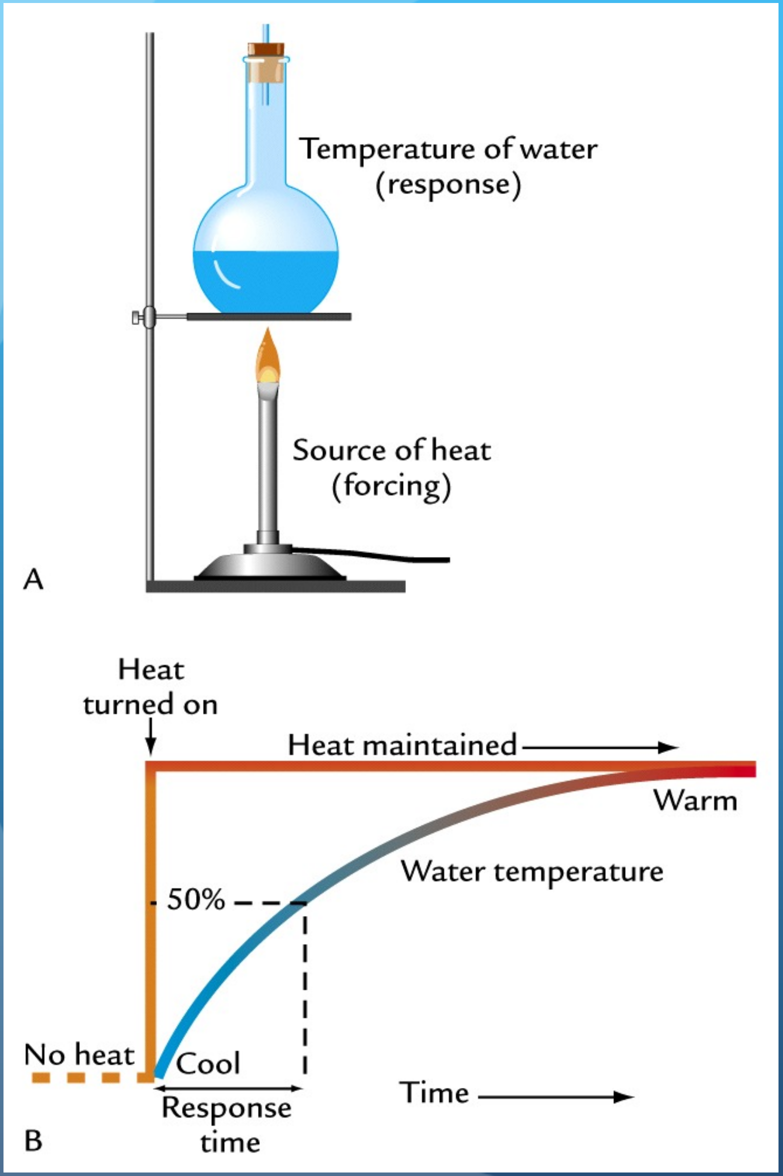
NASA GISS (2015)

Volcanic cooling and El Niño warming



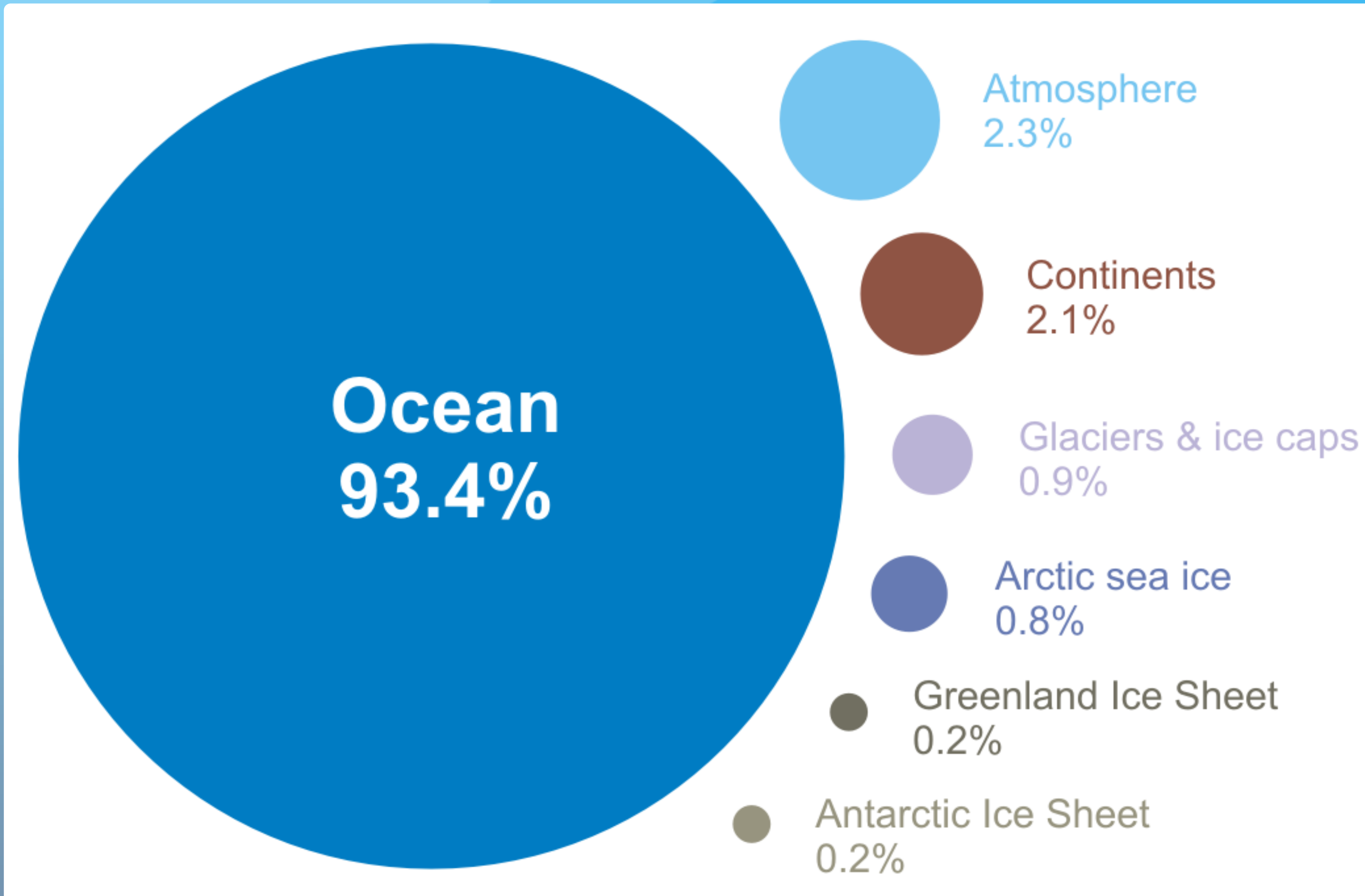
Ruddiman, 2001

Climate system response



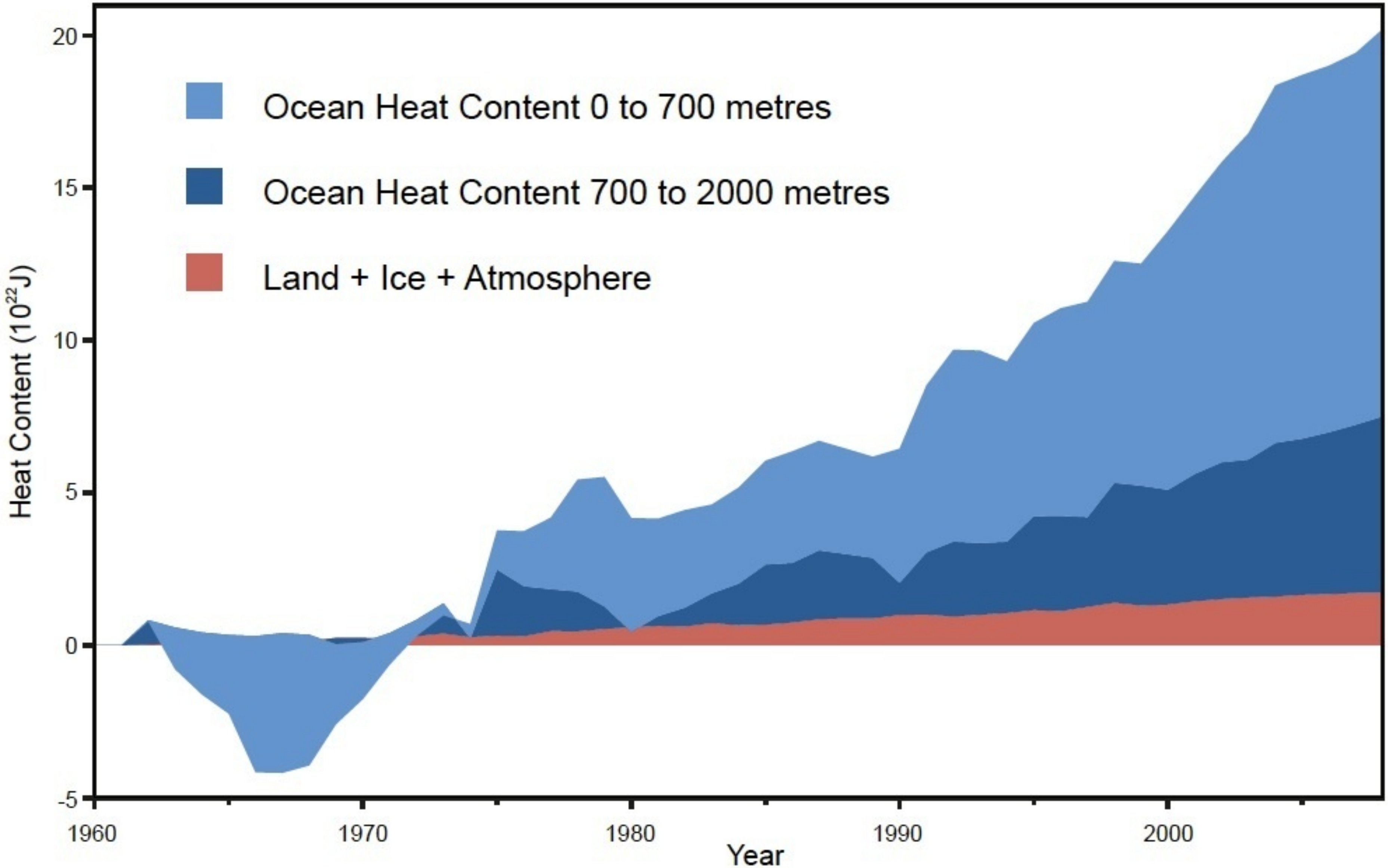
Ruddiman, 2008

Where is the trapped heat being stored?



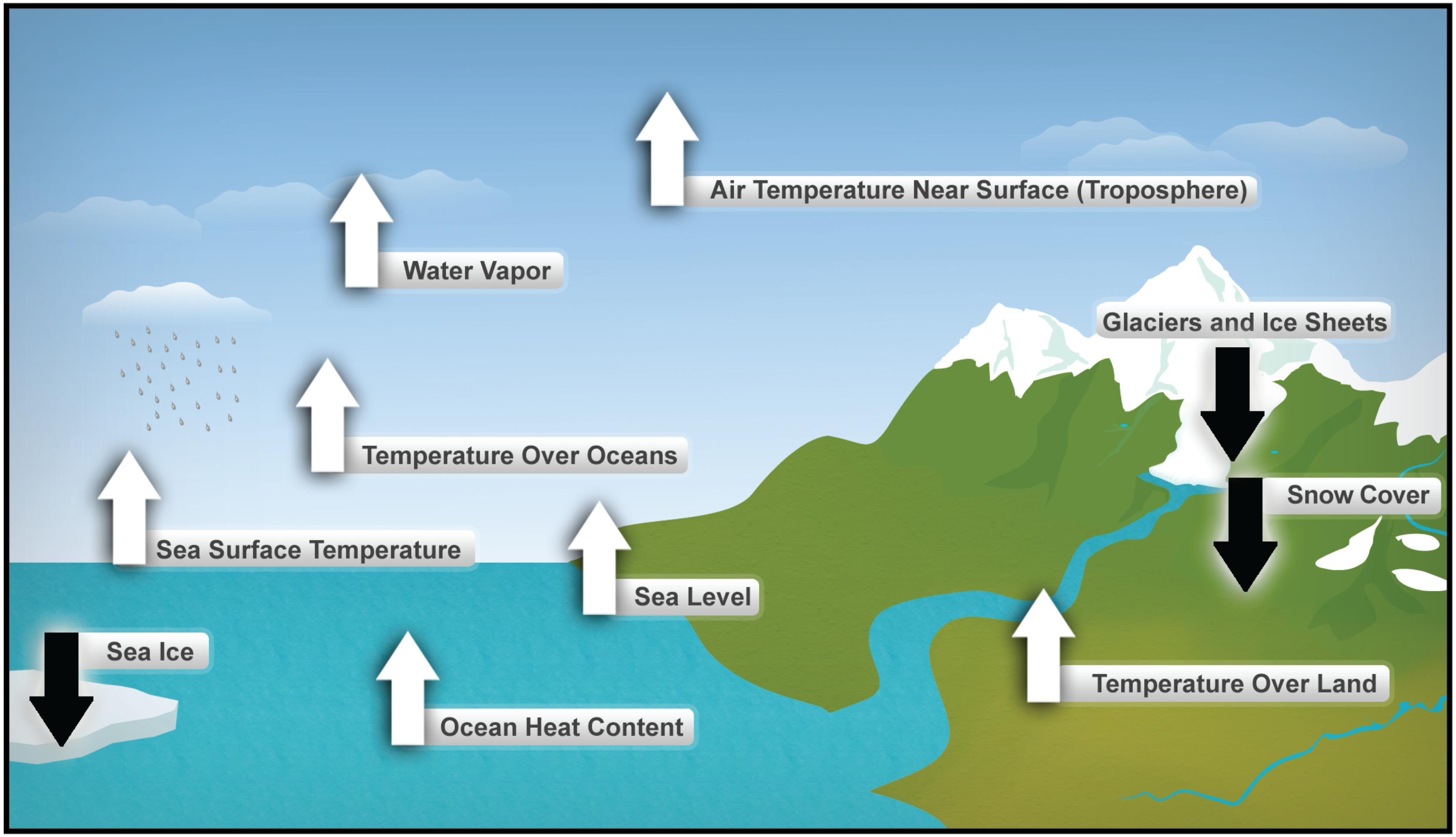
NOAA NESDIS (2014)

Total Heat Content



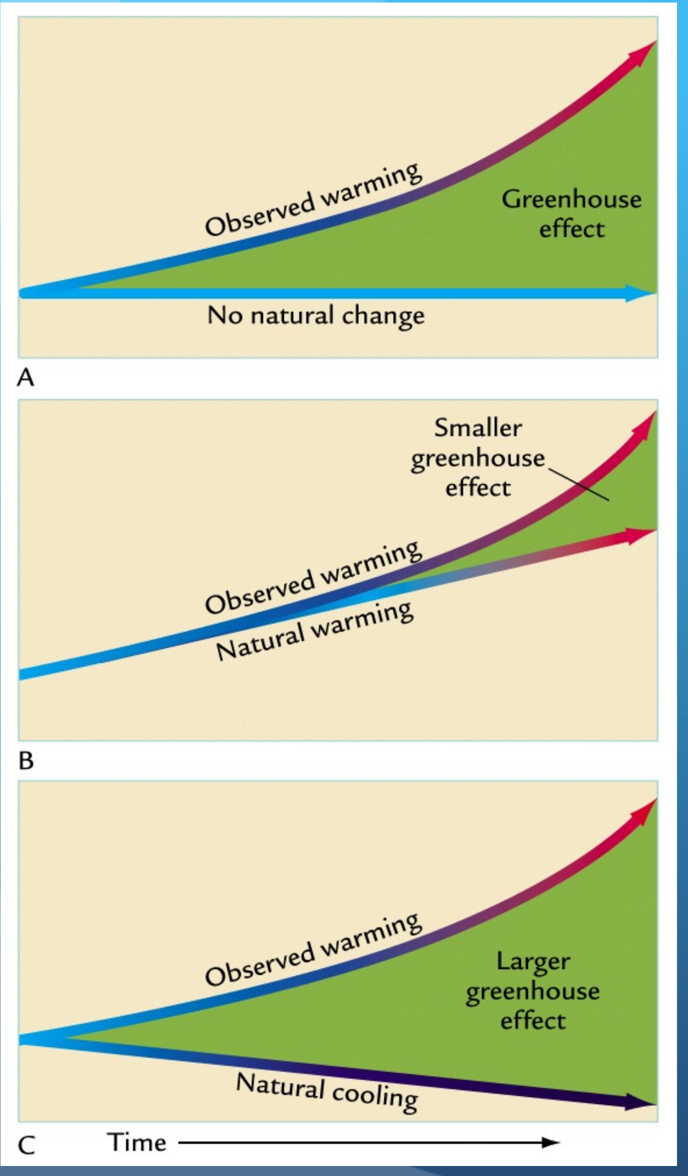
Church et al. (2011), Nuccitelli et al, (2012)

Ten Indicators of Warming



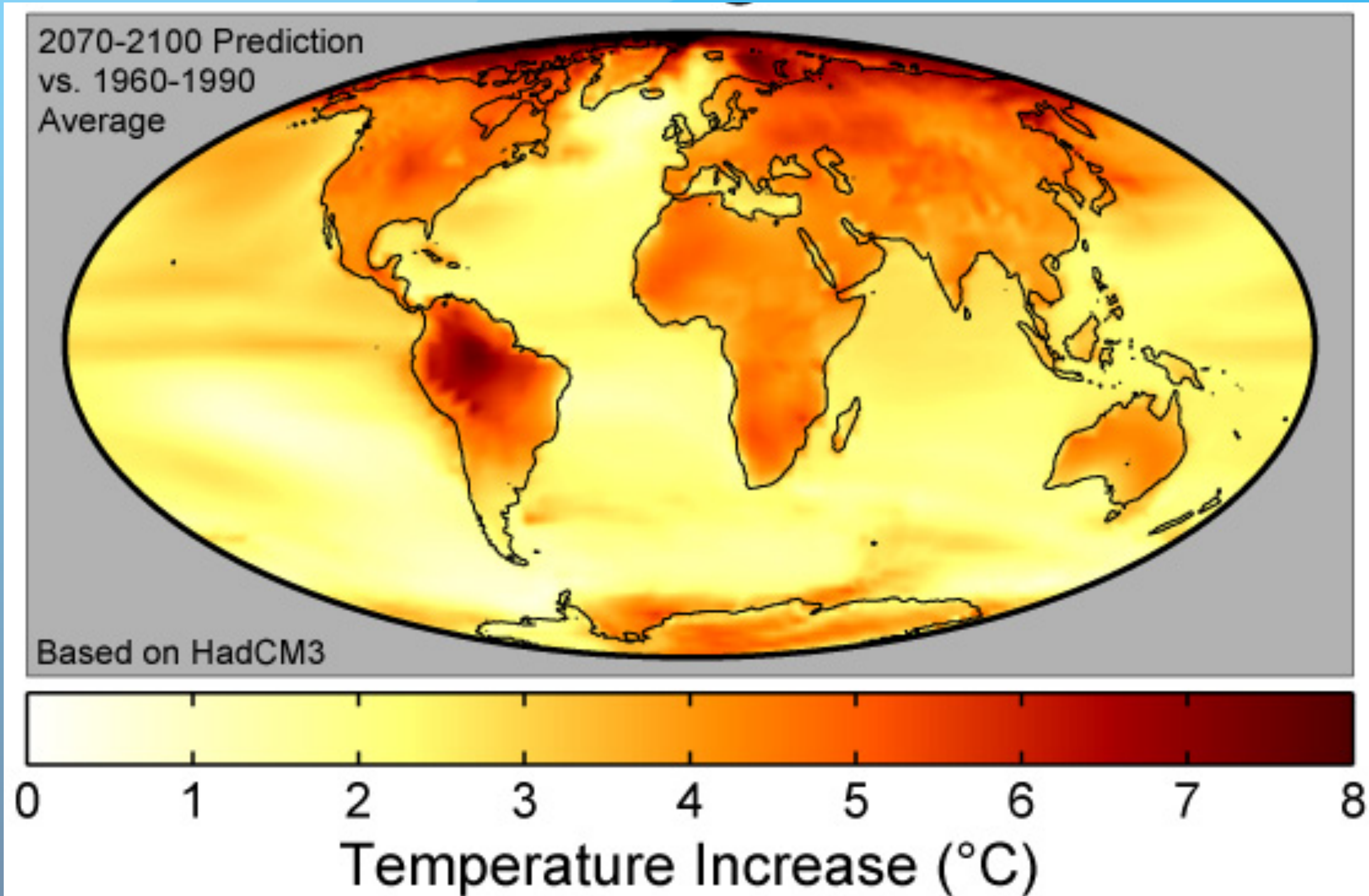
National Climate Assessment, 2014

Natural warming and greenhouse effects



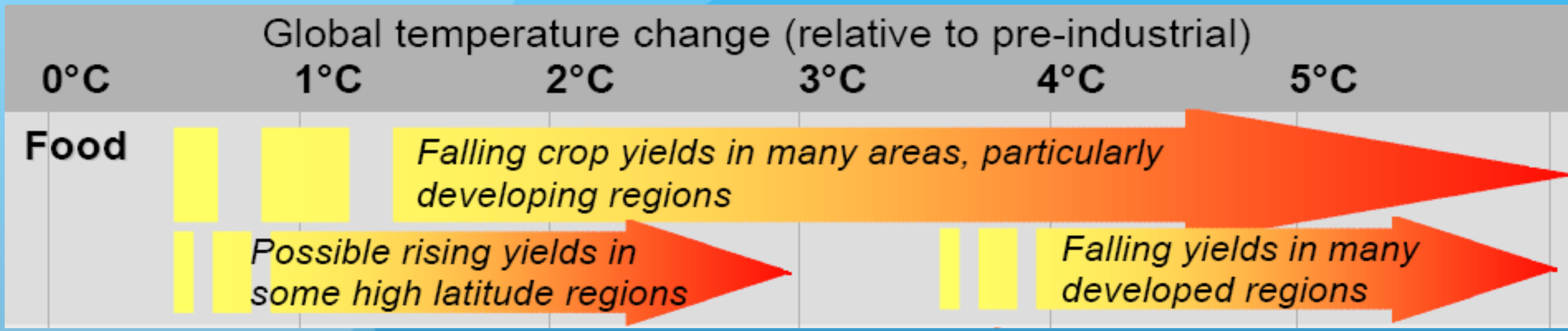
Ruddiman, 2008

Another future global temperature forecast



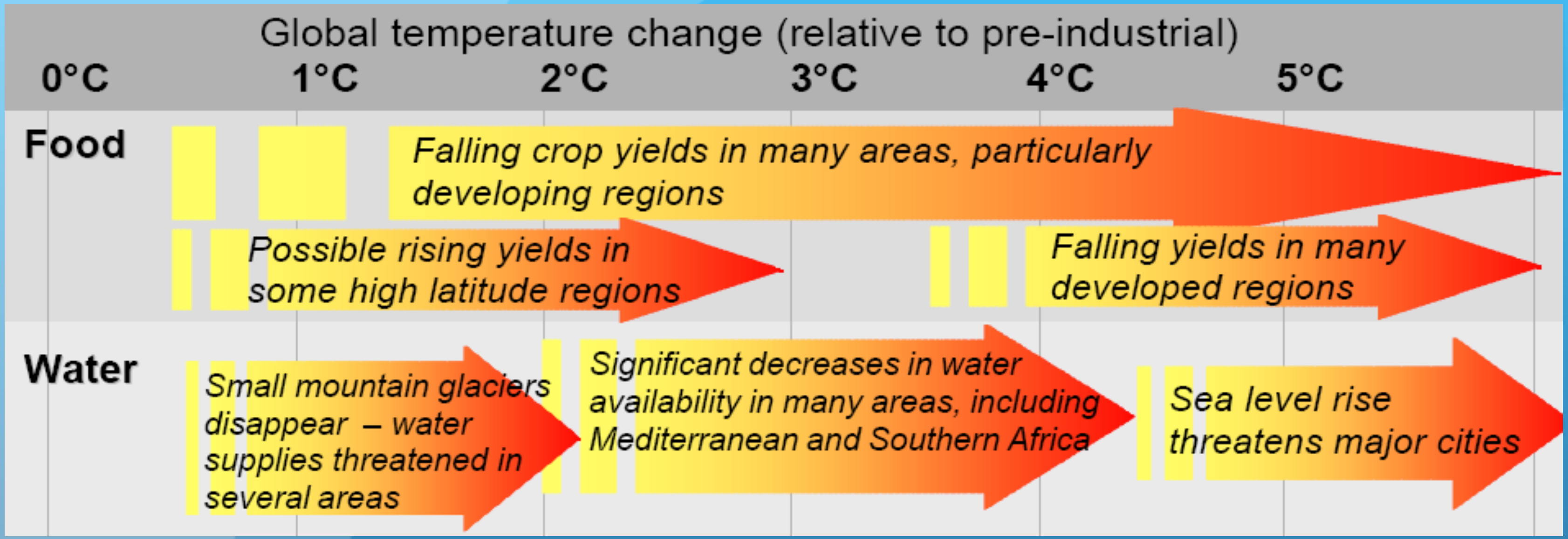
http://www.globalwarmingart.com/

Projected impacts of climate change



IPCC, 2007

Projected impacts of climate change



IPCC, 2007

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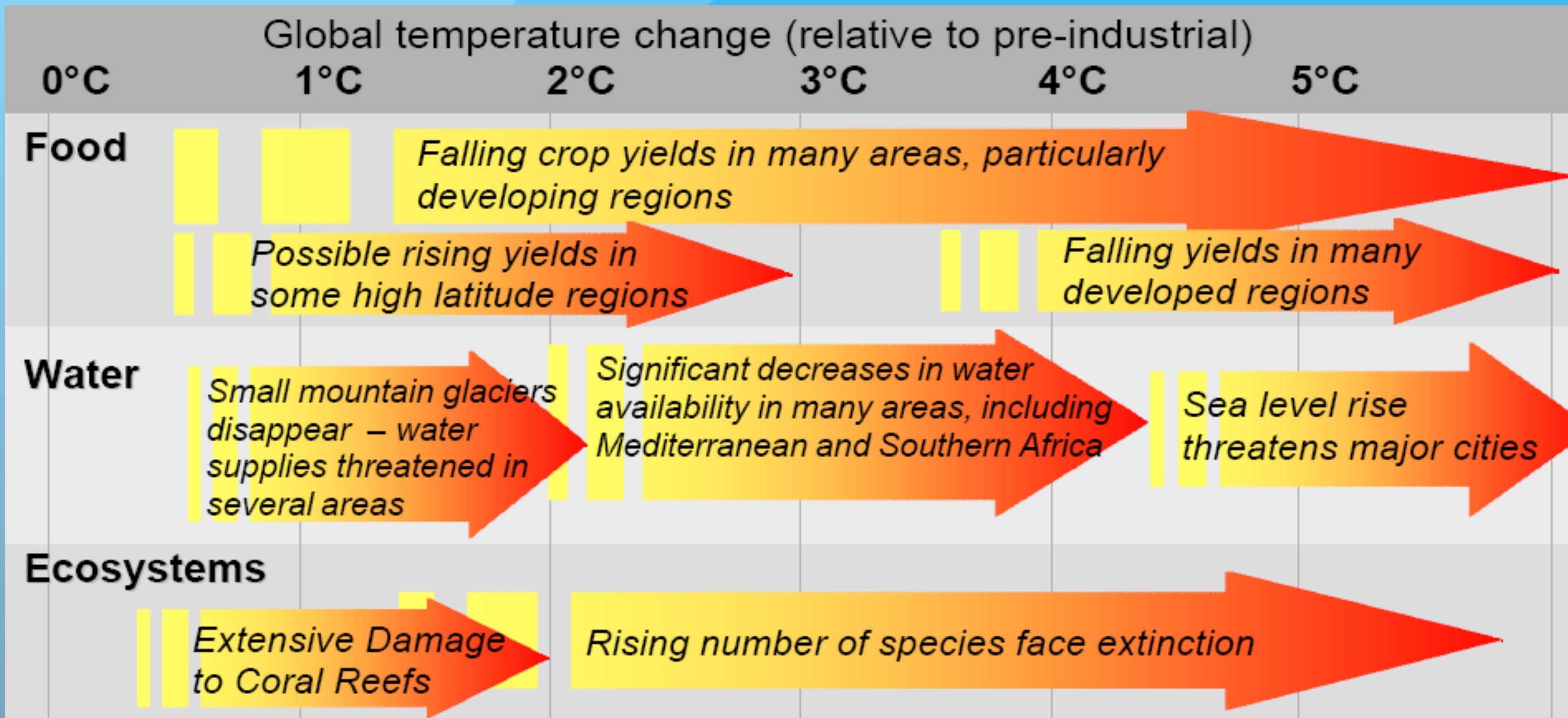
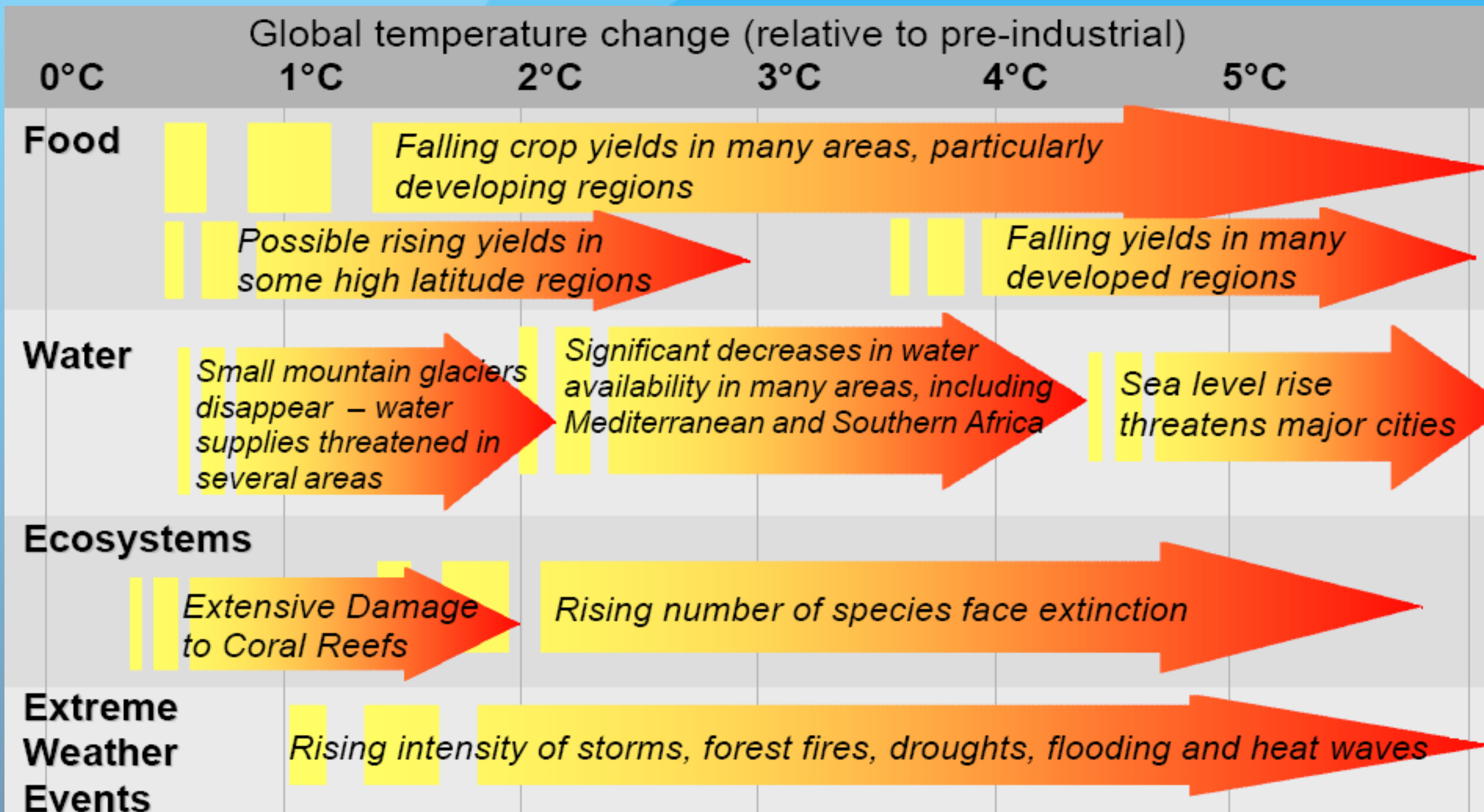


IPCC, 2007

Projected impacts of climate change



IPCC, 2007

Climate Change Summary

- We have explored the fundamental physics of climate change, and you all have seen greenhouse gases trap heat and warm the Earth's surface and oceans.

- The data leads us to confidently conclude that humans are changing the Earth's climate.

- The continuing addition of greenhouse gases to the atmosphere will bring significant changes to our climate over the next century and beyond.

Dessler, 2012

Climate Change Summary

- We are not certain how bad this climate change will be, but the upper end of the range (global warming of 5° C or more by the end of the century) includes warming large enough for the experts to consider its impacts to be potentially catastrophic.

- The lower end of the range (~2 ◦C) will be challenging for the world's poor as well as our most vulnerable ecosystems.

- Possible responses to this risk, including mitigation, adaptation, and geoengineering.

Dessler, 2012

Should we reduce emissions?

- This decision must be made with incomplete knowledge because we do not know the answers to all of these key questions:

    1) **How much warming will we experience if we do nothing?**

    2) **How bad will that much warming be?**

    3) **How expensive will it be to reduce emissions?**

    4) **How much warming can we avoid?**

Dessler, 2012

What is the Urgency?

- Why must we make a decision now on whether to reduce emissions or not.

  Because of lags in the climate system and in our economy, we must begin efforts to reduce emissions now in order to significantly reduce warming in the second half of the 21st century.

  While we have a reduced capacity to affect the trajectory of temperatures over the next decade, our decision will determine the climate for 2050 and beyond.

Dessler, 2012

Decisions under uncertainty

- This is not an unusual situation.

- Many important policy decisions must be made in the face of uncertainty.

- This includes important defense and economic decisions:

  Should we aid the Syrian rebels?
  Should we help the Ukraine?
  Should we lower corporate taxes?
  What to do about illegal immigrants?
  Should federal government legalize marijuana?

Dessler, 2012

Values

- These decisions contain implicit value judgments about the choices. Consider the following two arguments:

1) Because the worst-case scenario of climate change is so serious, we must take action now to reduce emissions, even though we don't know exactly how bad climate change will be.

2) Because of the high cost of reducing emissions, we must be certain that climate change is serious before we take action.

Both statements argue that we must err on the side of caution in order to avoid a bad outcome. However, the bad outcome is different in these two arguments.

Dessler, 2012

Which potential error is worse?

Must we be certain beyond a reasonable doubt that climate change is a serious threat to mankind before taking action to reduce emissions?

Which error is worse:

Reducing emissions unnecessarily because climate change turns out to be a minor threat…

Or

Not reducing emissions and climate change turns out to be a serious threat?

Dessler, 2012

Advantages?

Energy security by reducing imports of oil from politically hostile countries AND reductions in air pollution.

Costs would be spread over the next several decades, at least some of the cost can be avoided by scaling back future efforts once we learn they are unnecessary.

Would a person in Year 2100 be upset that we reduced the use of fossil fuels in favor of other energy sources?

Dessler, 2012

Reducing emissions is reversible

- If an action you take is irreversible, then you have to be more certain that it's the right action than if a decision is easily reversible.

- If we decide later that climate change is not that serious, then we can always change our policies and increase emissions of carbon dioxide.

- But the converse is not true: If we continue emitting carbon dioxide, and then find out that climate change is a more serious problem, there is no practical way to remove carbon dioxide from the atmosphere.

Dessler, 2012

Costs of reductions

- We know that putting a price on carbon will likely spur development of new technologies by providing a financial incentive to reduce emissions that does not exist in today's economy.

- The resulting estimated costs of reducing emissions cover a wide range; some analyses conclude it will be quite inexpensive whereas others conclude it will be ruinously expensive.

Costs of Climate Change

- Estimating the costs of the impacts of climate change – and therefore the benefits of avoiding it – is even more difficult.

- Converting estimated changes in climate into a dollar figure can be difficult and arbitrary.

Timing is an issue

- Another problem in estimating the costs of climate change comes from the timing of climate impacts.
- If 1 ton of carbon is emitted into the atmosphere today, it will warm the planet for centuries to come and will cause impacts over that entire time.
- However, the cost of not emitting that ton must be paid today.

Dessler, 2012

Costs/Impacts not equally distributed

Many of the hardest-hit regions are also the poorest regions, and those that have contributed little to climate change.

The worst-case scenarios might include catastrophic outcomes such as abrupt climate changes and starvation.

For some people, uncertainty in how bad things can get trumps a quantitative cost–benefit analysis.

And the possibility of a true catastrophe in the next century compels aggressive action.

Dessler, 2012

Less than 2°C of warming

A simpler way to select a long-term goal is to simply pick a limit for temperature or atmospheric carbon dioxide above which you judge the climate impacts to be unacceptable.

The limit should be low enough that it gives us a good chance to avoid serious climate impacts, but high enough that it is politically and economically acceptable.

Over the past several years a consensus has grown up around a target of 2°C of warming above pre-industrial temperatures.

Dessler, 2012

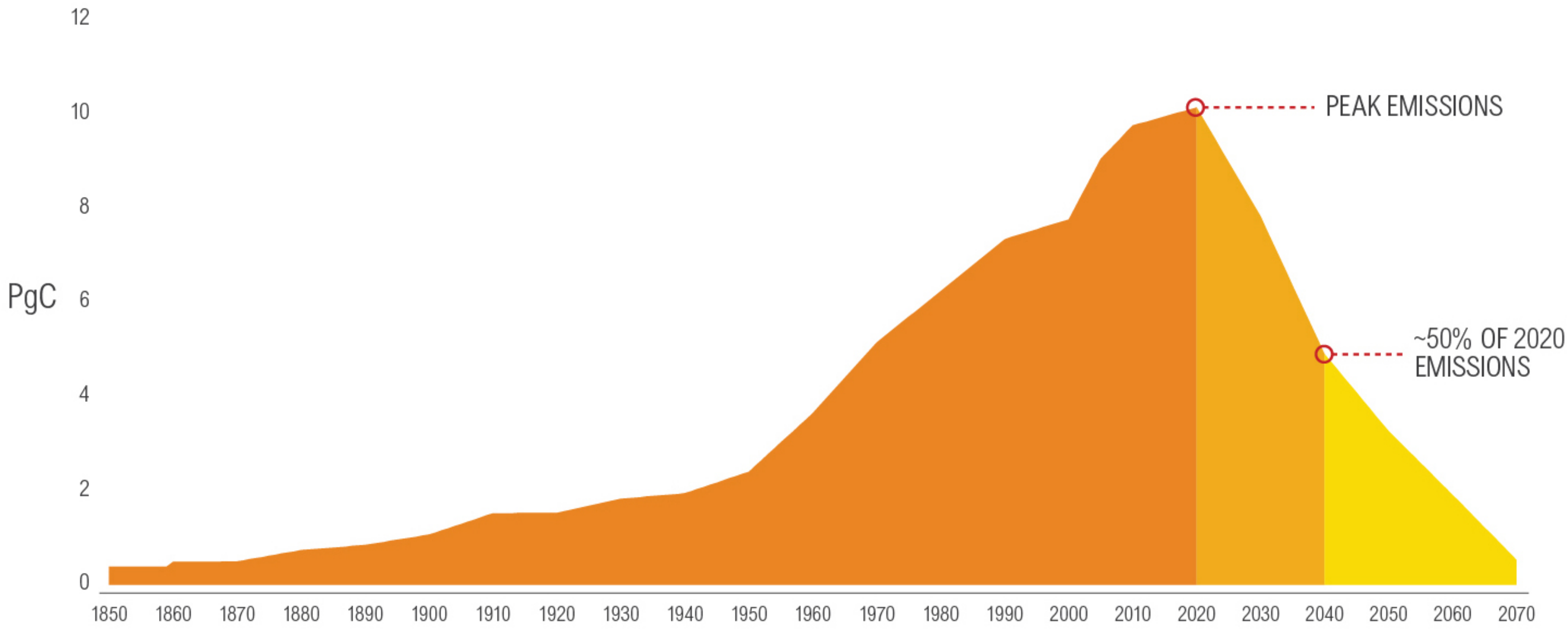
How to get there?

- Cut emissions by 50–80% in 35 years, so we would need to reduce emissions by, on average, 1–2% per year.

Dessler, 2012

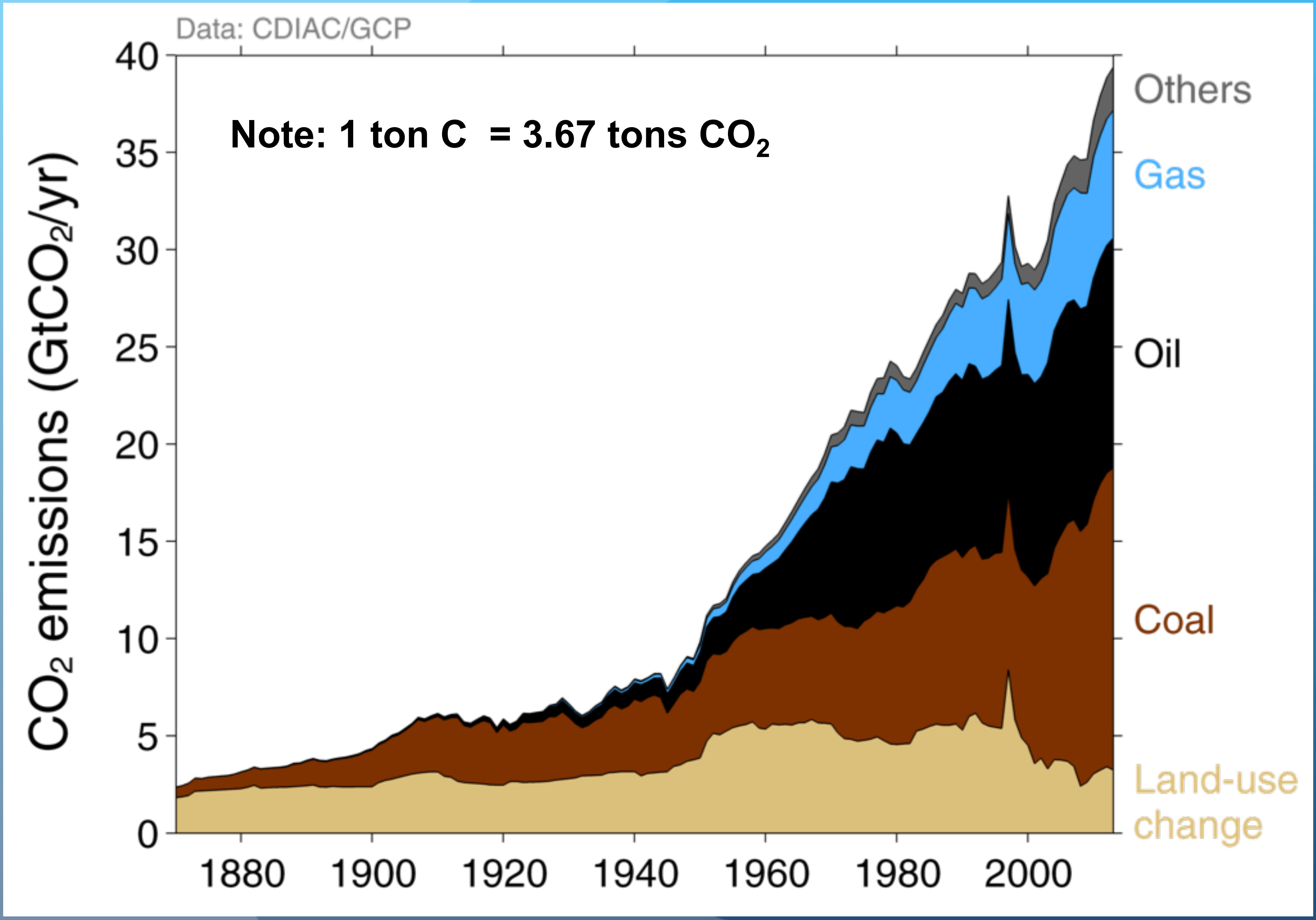
The challenge

To best ensure we are able to limit warming to 2°C it is essential that annual global emissions peak by the year 2020, and are reduced steeply thereafter.



IPCC, 2007

Global CO_2 Emissions



CDIAC/GCP, 2014

What factors control emissions of GHG? (PAT)

Emissions trends reflect a combination of economic factors:

P = Population
A = Affluence = per capita output (GDP/population)
T = Technology = Energy Intensity and Carbon Intensity

Energy Intensity (EI) = energy use per dollar of GDP
Carbon Intensity (CI) = CO_2 emissions per unit of energy

Dessler, 2012

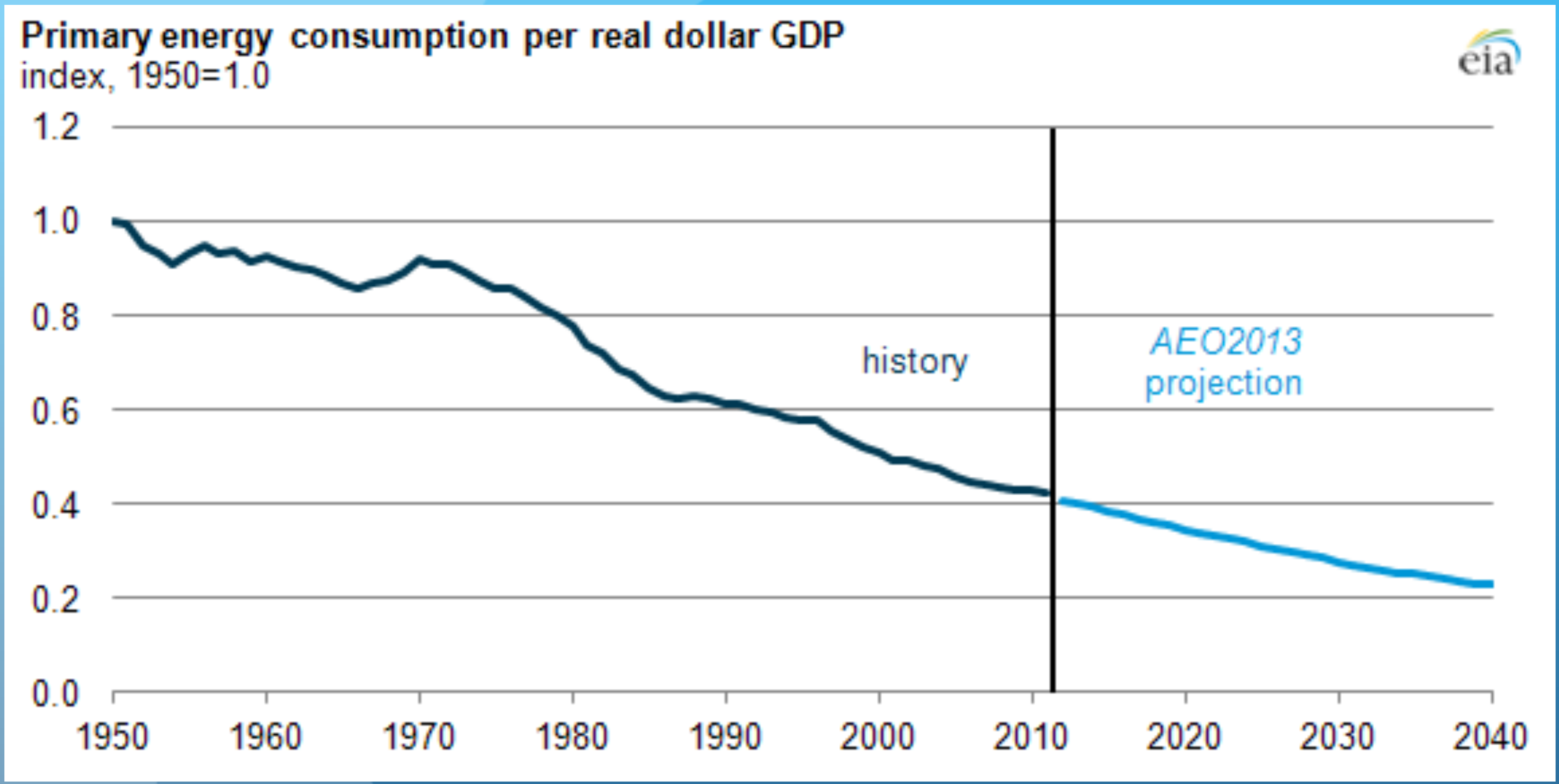
Is it possible to cut GHG emissions 50%

Both the population and affluence of the world will increase by 2050. Estimates are that population growth over the next 50 years would be,1% per year, and affluence will grow at 2–3% per year.

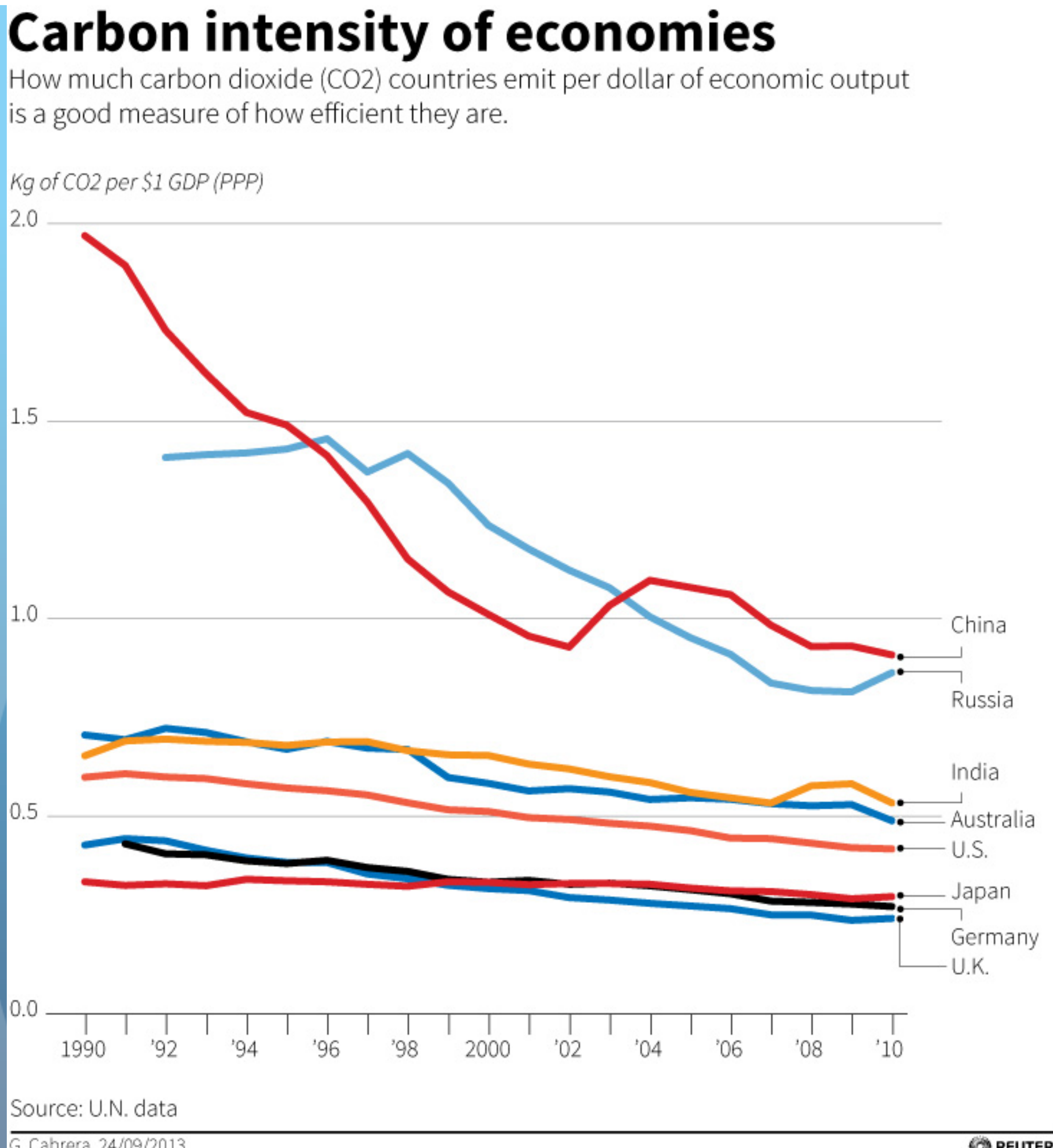
In order for emissions to decrease at 1–2% per year while population and affluence are growing, we would need to reduce the greenhouse-gas intensity by 4–6% per year.

Dessler, 2012

Trend in US Energy Intensity (EI)

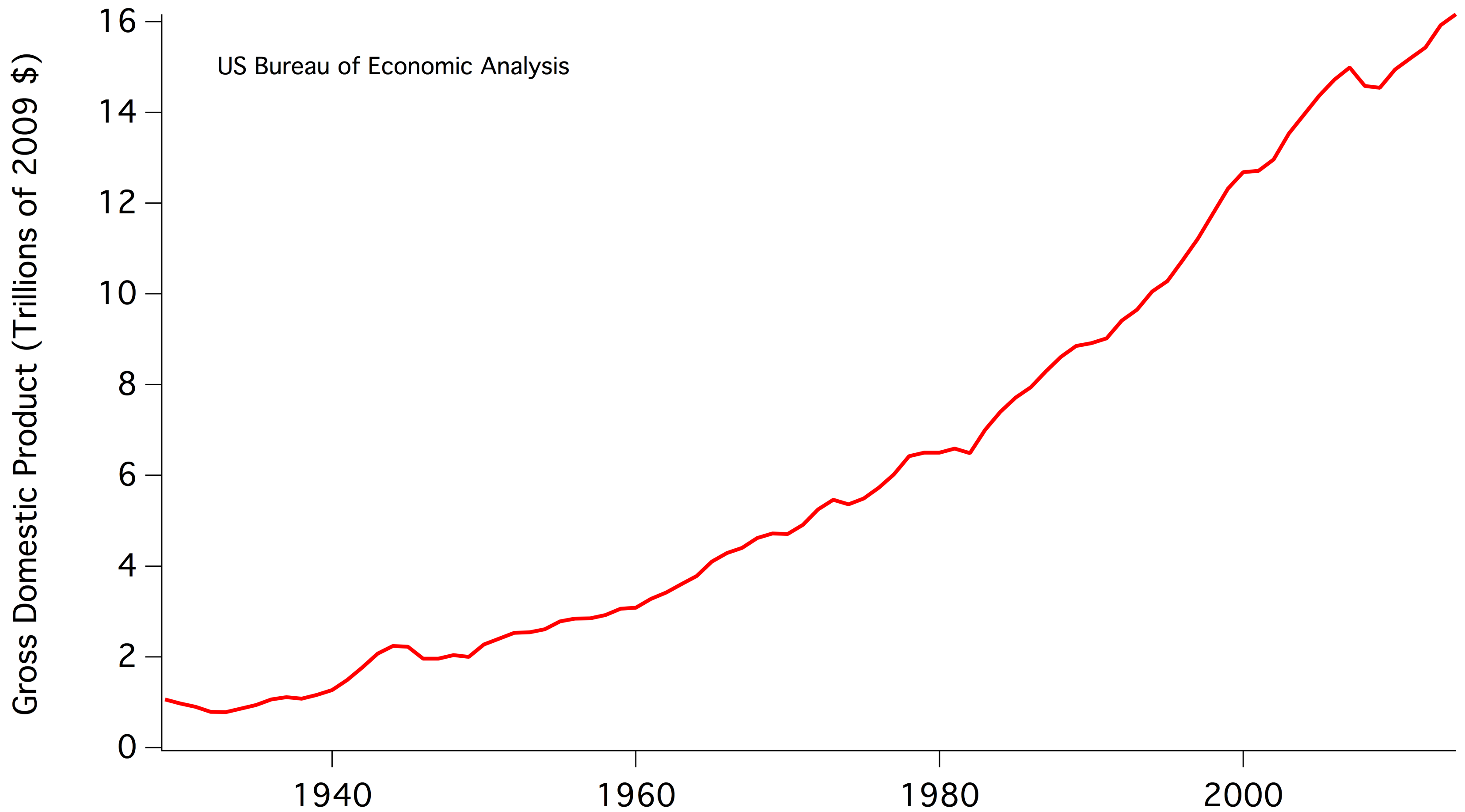


EIA, 2013



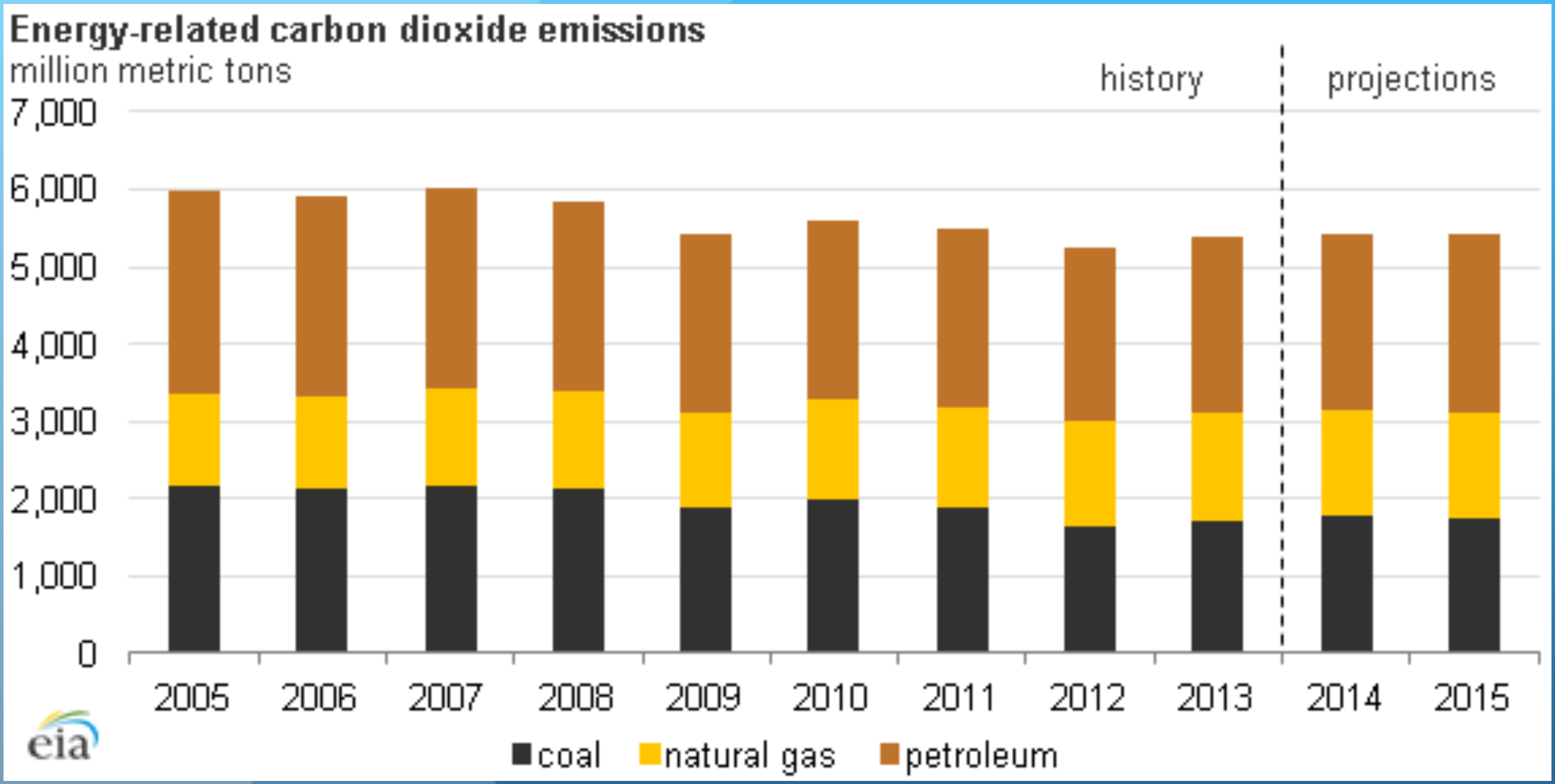
Reuters, 2012

Trend in U.S. Real GDP



USBEA, 2014

Recent Trend in U.S. CO_2 emissions



EIA, 2014

How to get there?

- Rapidly switch to energy sources that release less (and/or do not release any) greenhouse gases.

- By “rapidly”, would need to construct approximately 1 billion watts (1 GW) of carbon-free power <u>every day</u> between 2015 and 2050 to meet this target.

- A typical coal or nuclear power plant generates roughly 10 GW. This is not an impossible challenge, but difficult. (e.g. China).

Dessler, 2012

Six steps towards a solution

1) Put a price on emissions of carbon dioxide and other greenhouse gases.

2) Efficiency standards and incentives to encourage careful energy use.

3) Fund the research and development of new technologies.

4) Prepare to adapt to climate change.

5) Research the geoengineering options.

6) Review and amend policies as new information (re: science and technology) arises.

Dessler, 2012

Costs unknown

The climate change challenge is not unique; we almost never know in advance how much it will cost to comply with environmental regulations.

Before regulations to ozone depletion were passed in the 1980s, some advocates were predicting that the regulations would cause severe economic hardship, with people in the developed world having to get rid of their air conditioners and millions dying because of a lack of food refrigeration.

It turned out that the cost of complying with ozone layer protection regulations was inexpensive.

Dessler, 2012

Mid-course corrections allowed

Whether this will happen or not in this case is impossible to know until we put a price on carbon.

If it turns out that reducing emissions is too much of a hardship economically, then the policies can be reversed and we can return to consuming fossil fuels without regard for the climate.

But if reducing emissions turns out to have an acceptable cost, then we will be on the road to heading off a potentially severe climate impacts.

Dessler, 2012

Climate change common ground

Climate scientists agree that:

1) Earth's total heat content has increased over the past 50 years, a conclusion based on direct measurements.

2) Concentrations of CO_2, CH_4, N_2O, and other greenhouse gases have built up in the atmosphere over the last 100 years due to human activities.

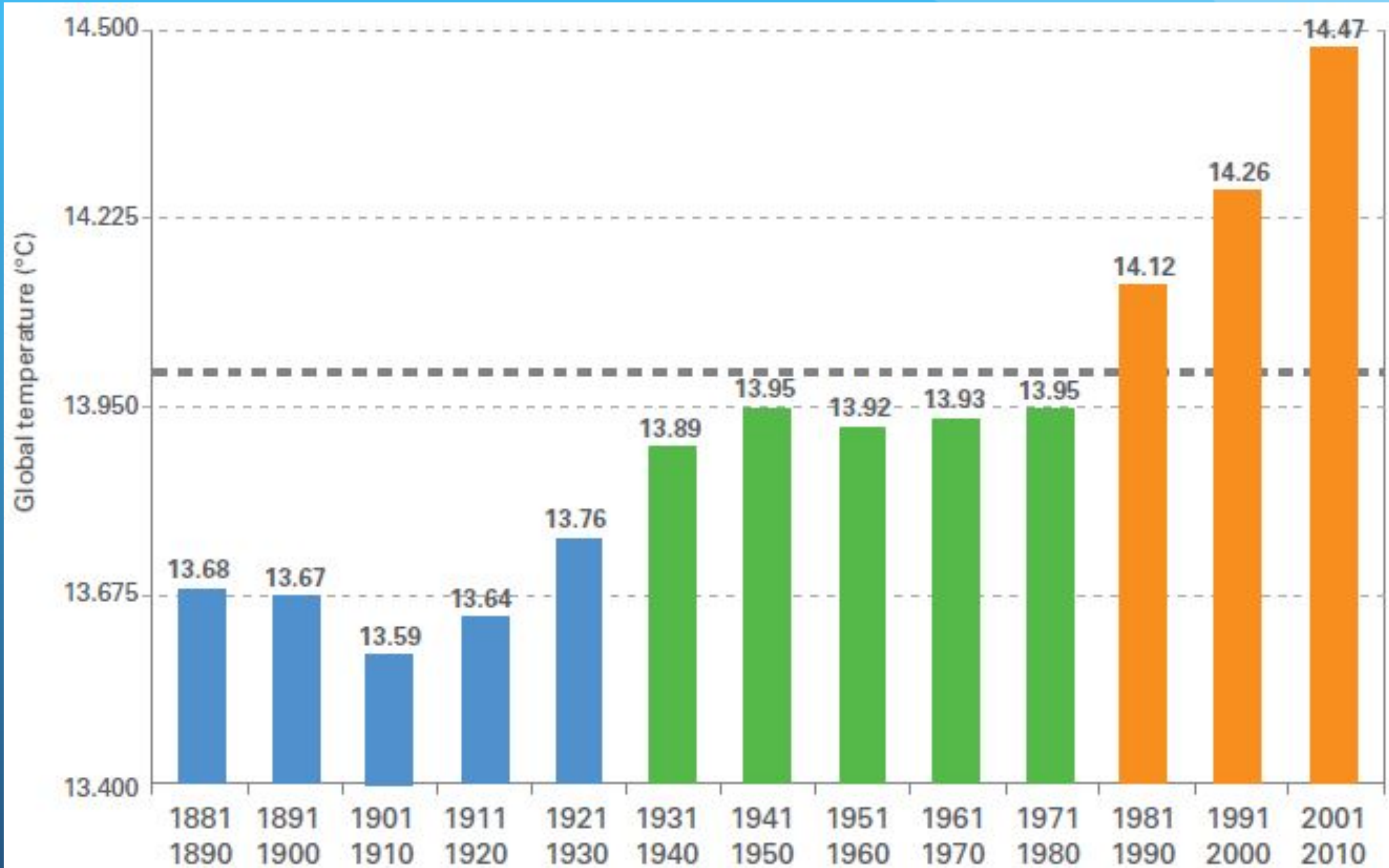
3) Climate change will result in significant (negative) impacts to our environment and society.

4) World should act now to invest in both adaptation and mitigation efforts to reduce impacts of climate change to society.

Questions?

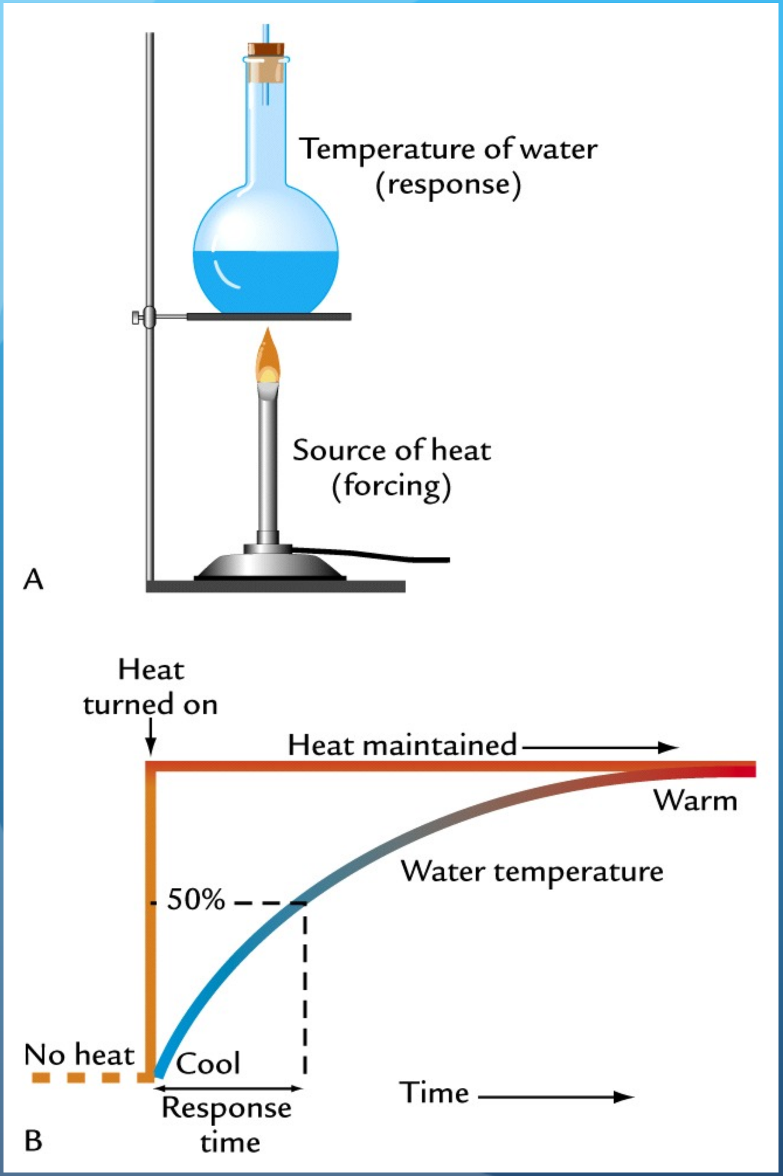
Dessler, 2012

Decadal global surface temperature



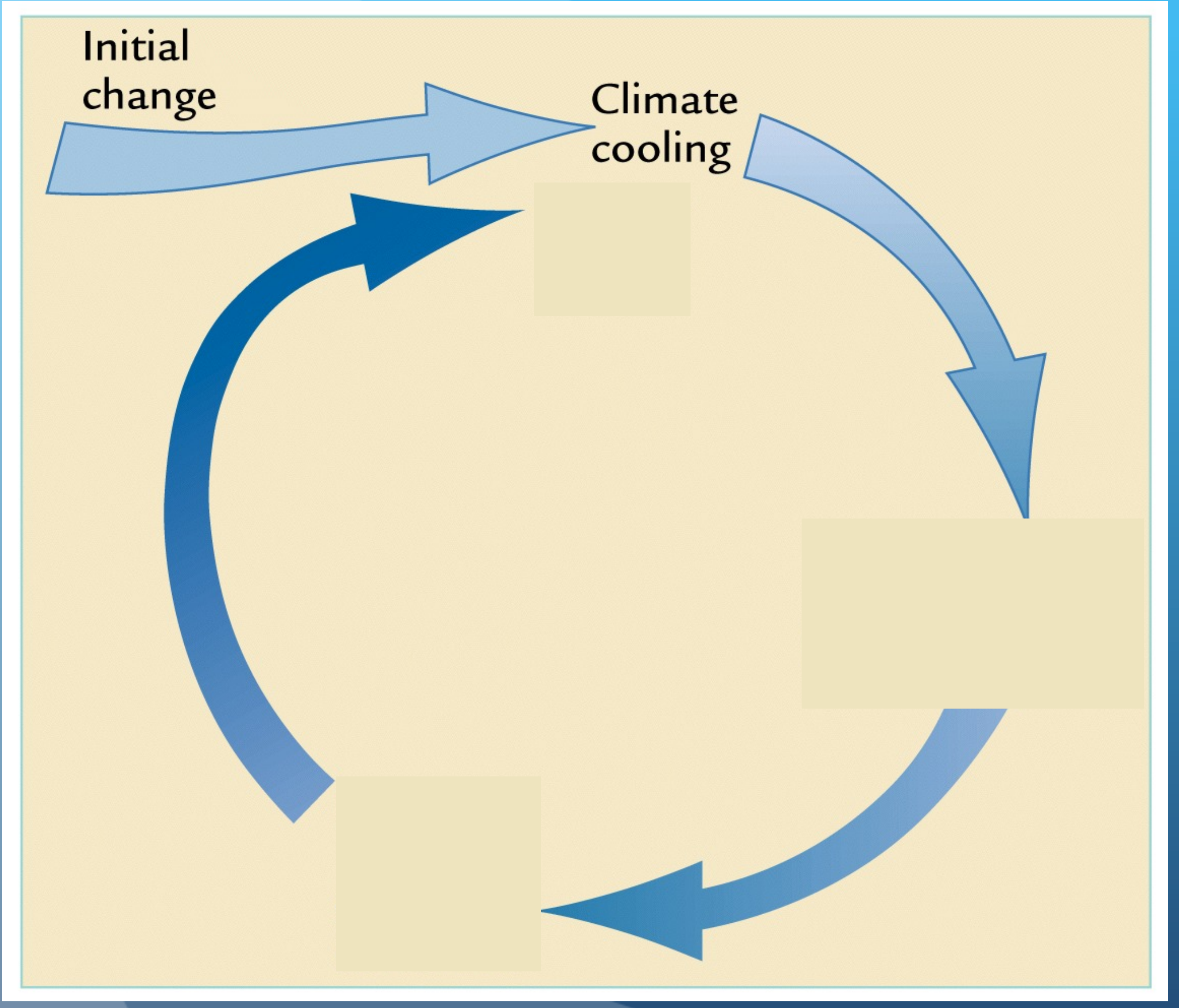
WMO, 2014

Climate system response



Ruddiman, 2008

Albedo-temperature feedback



Ruddiman, 2008

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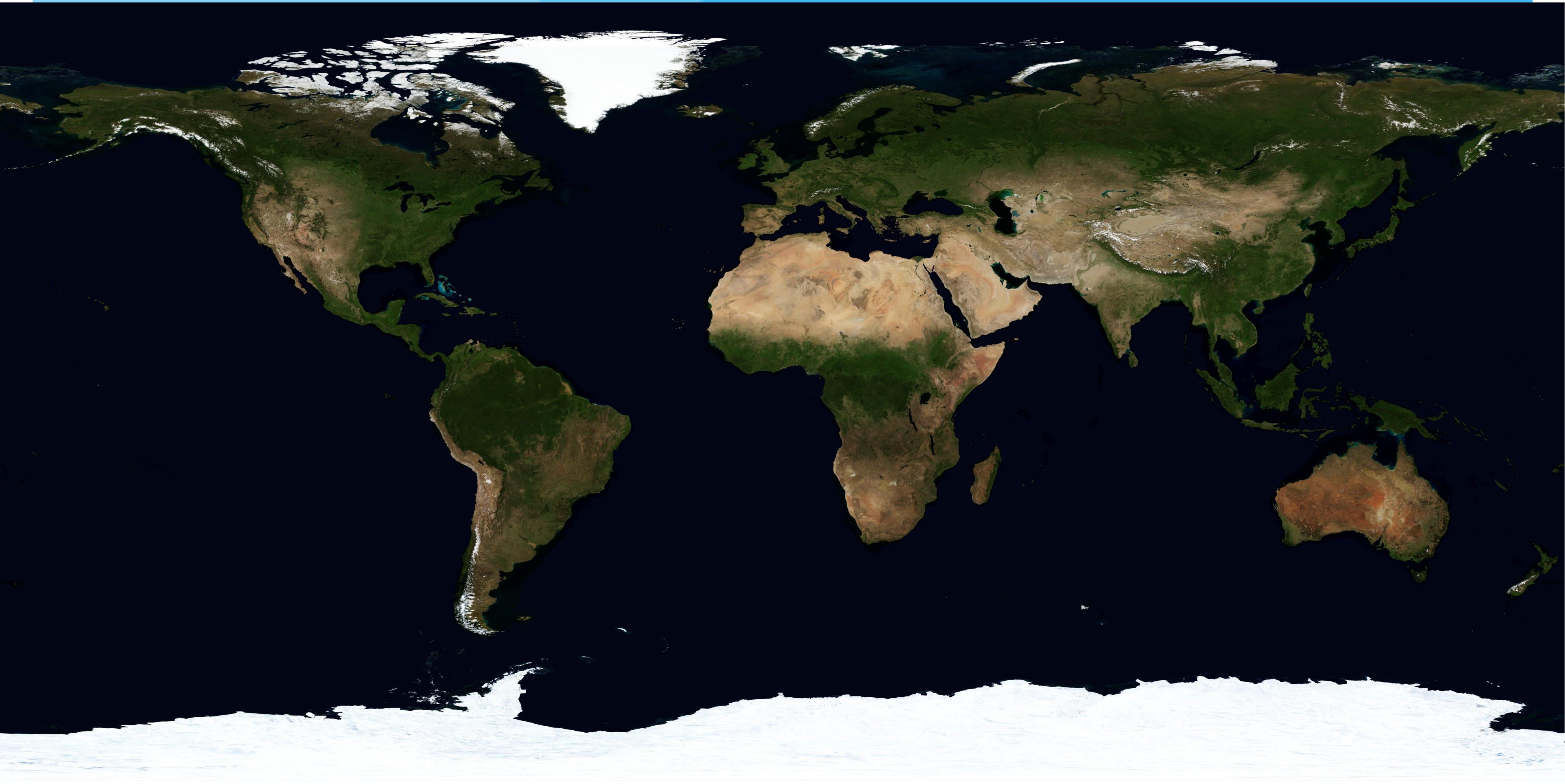
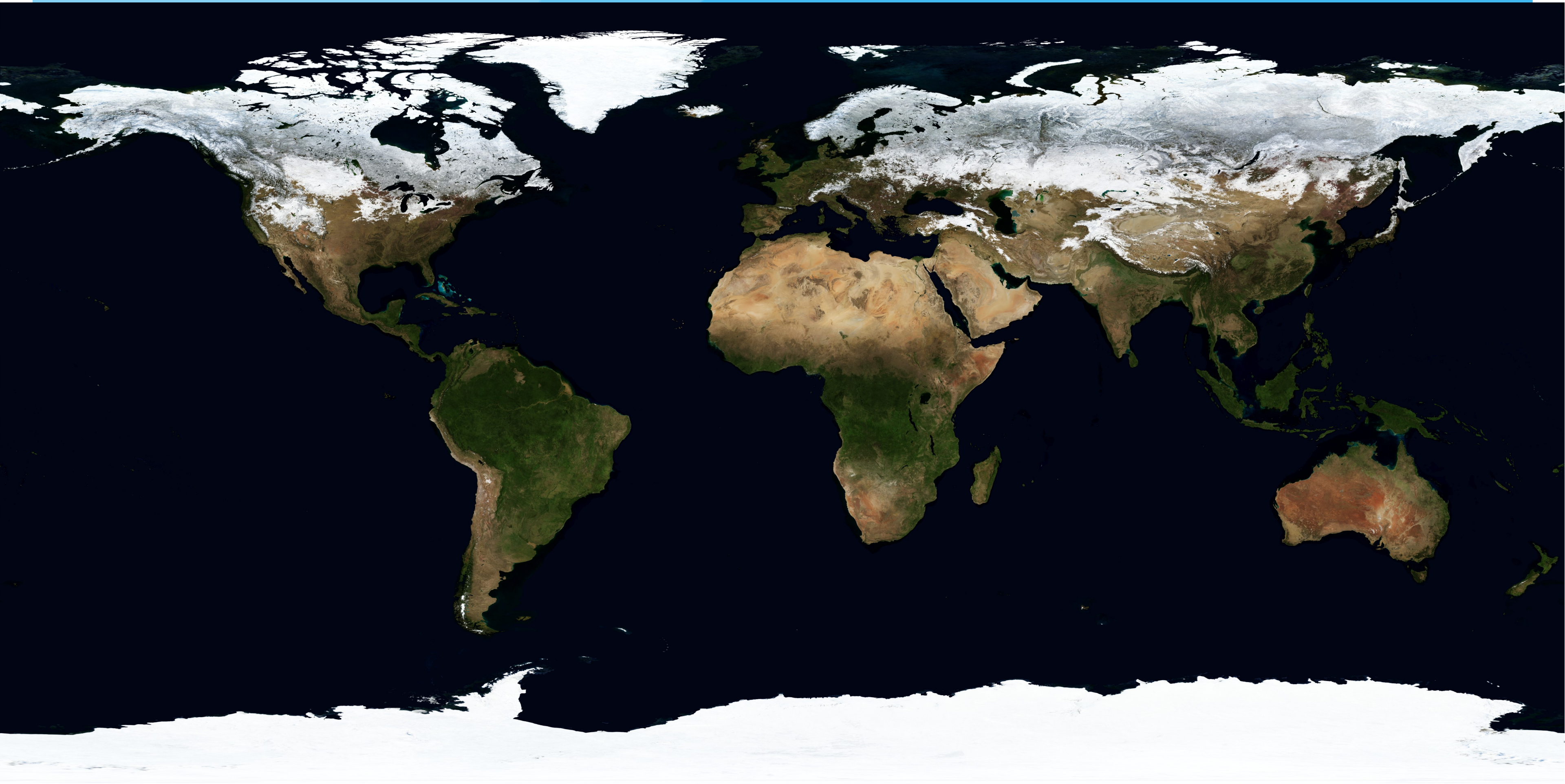


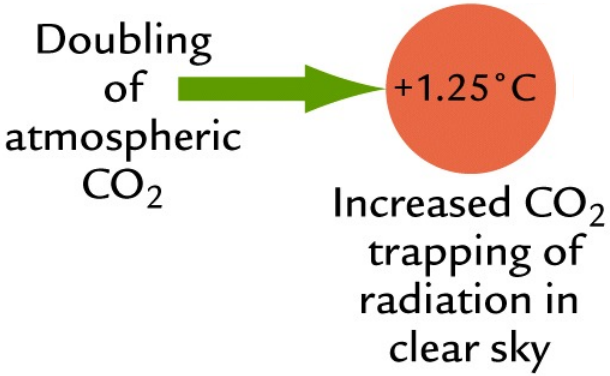
Source: NASA

Albedo-temperature feedback



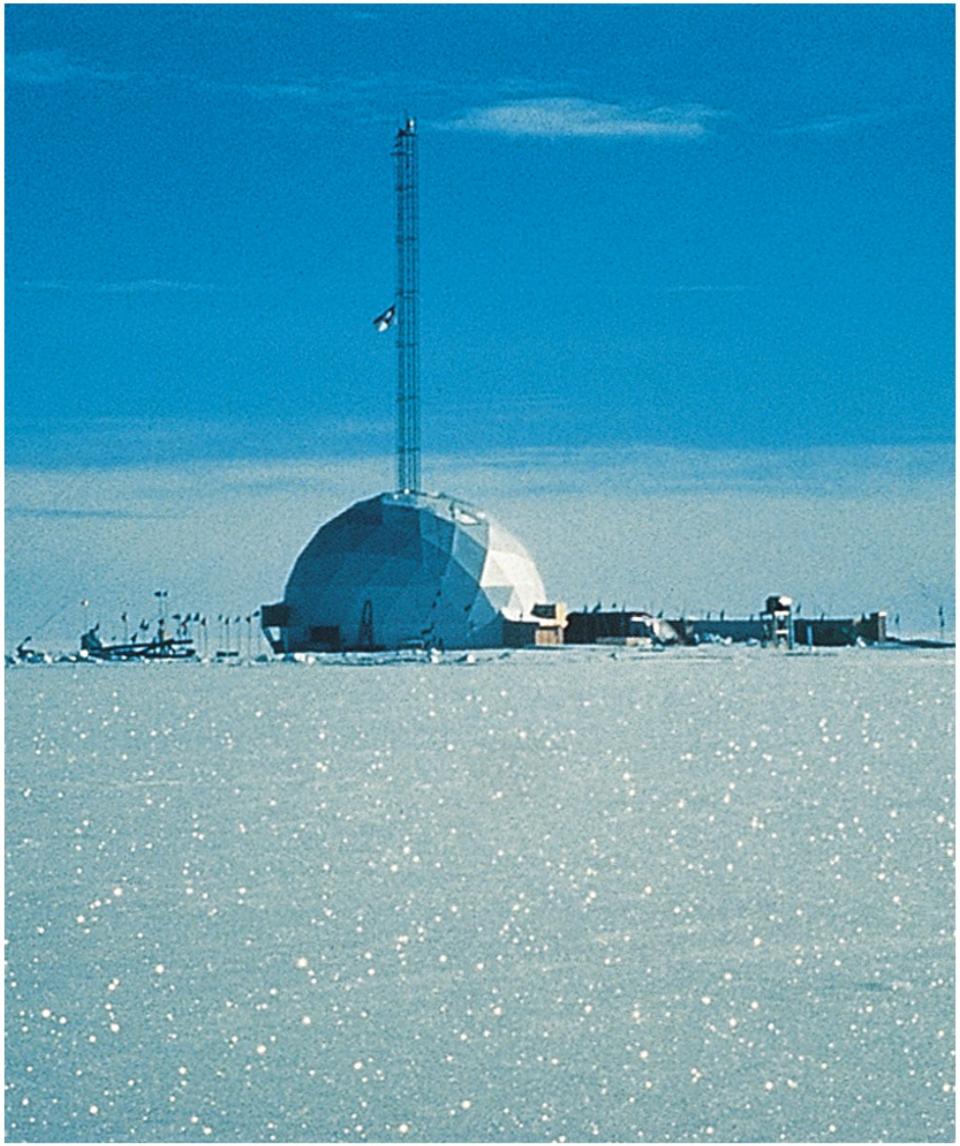
Source: NASA

Positive and negative feedbacks



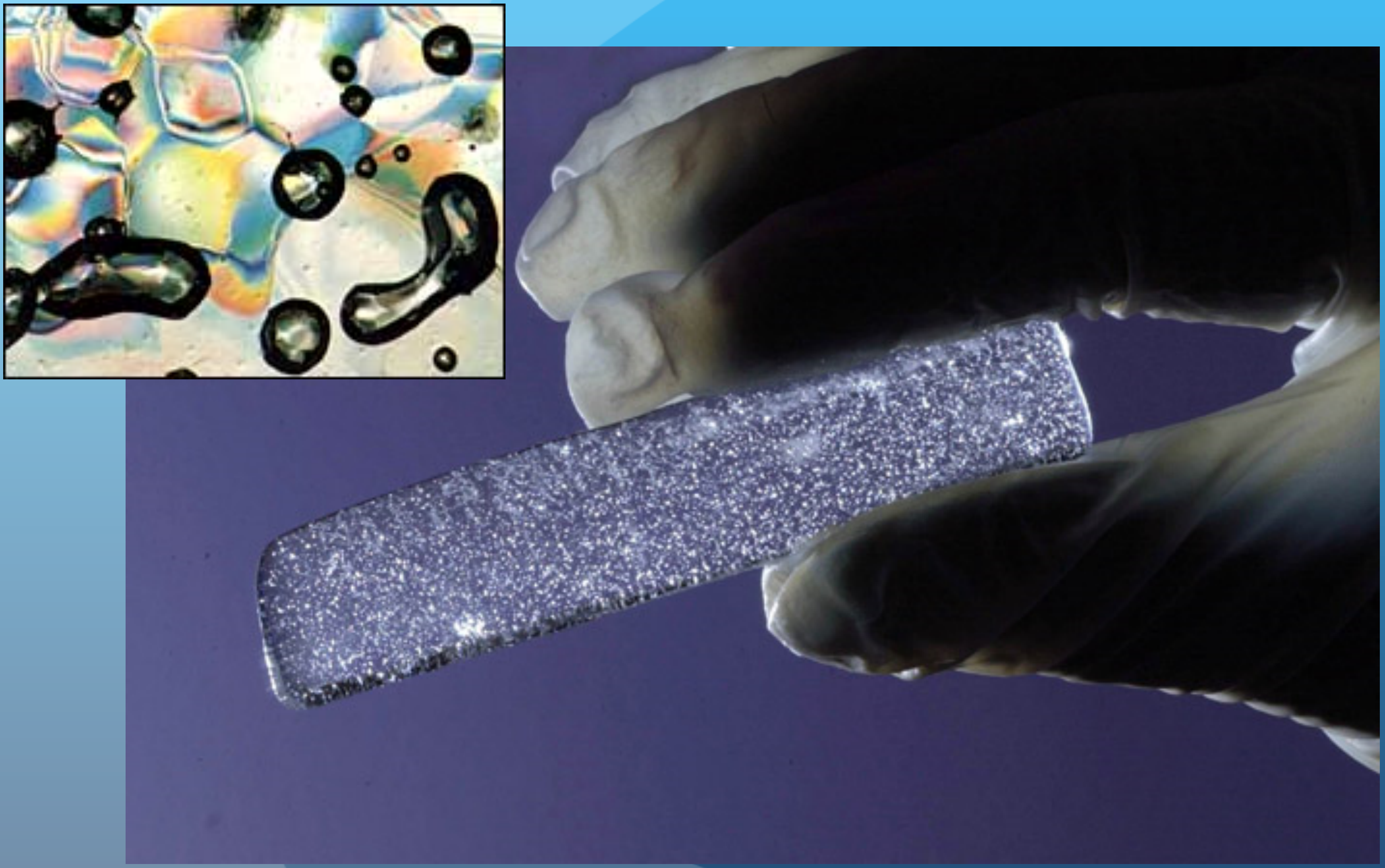
Ruddiman, 2008

Coring Earth's ice sheets



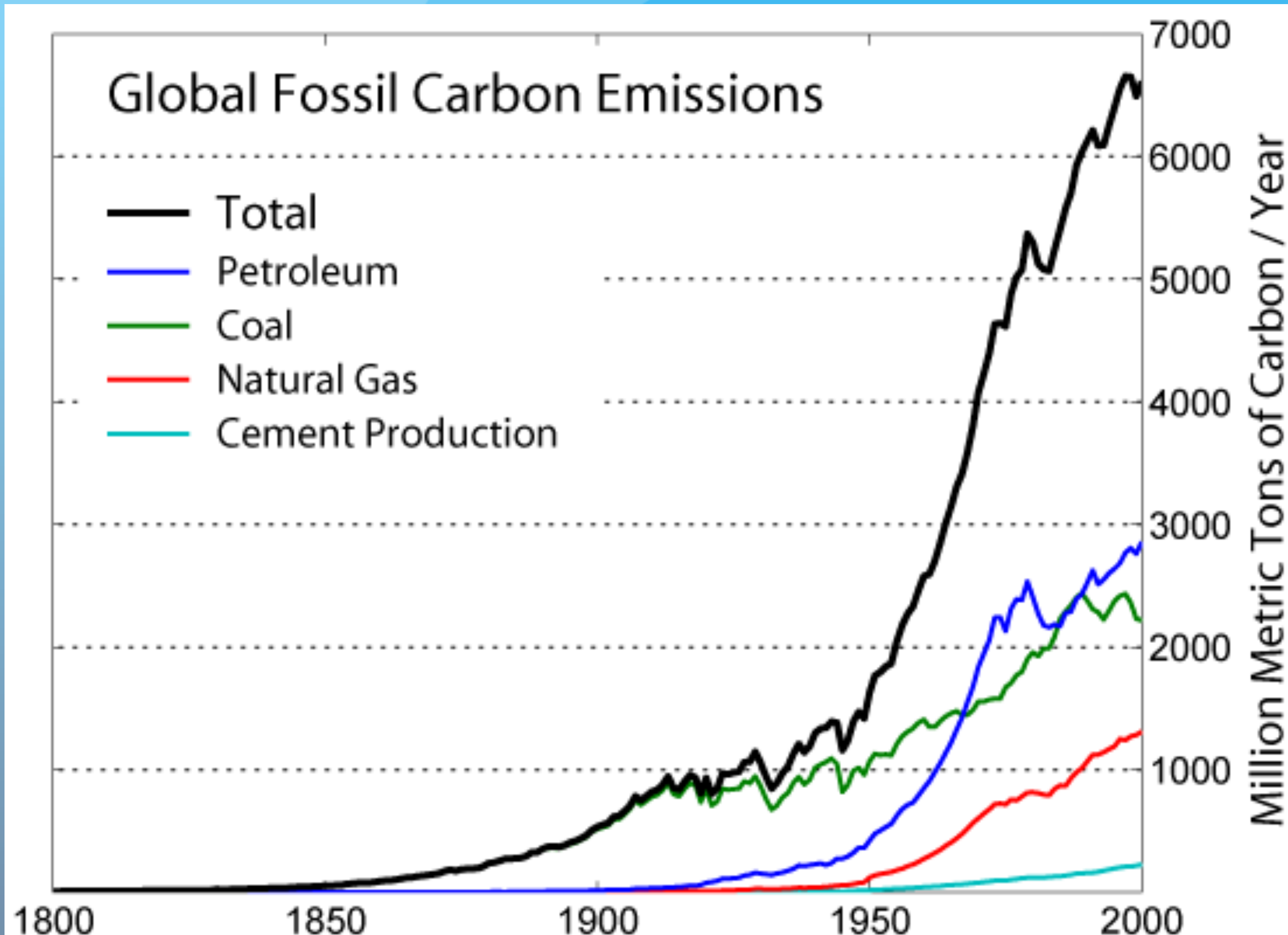
Twickler – GISP2 SMO (1994)

Bubbles trapped in ice core

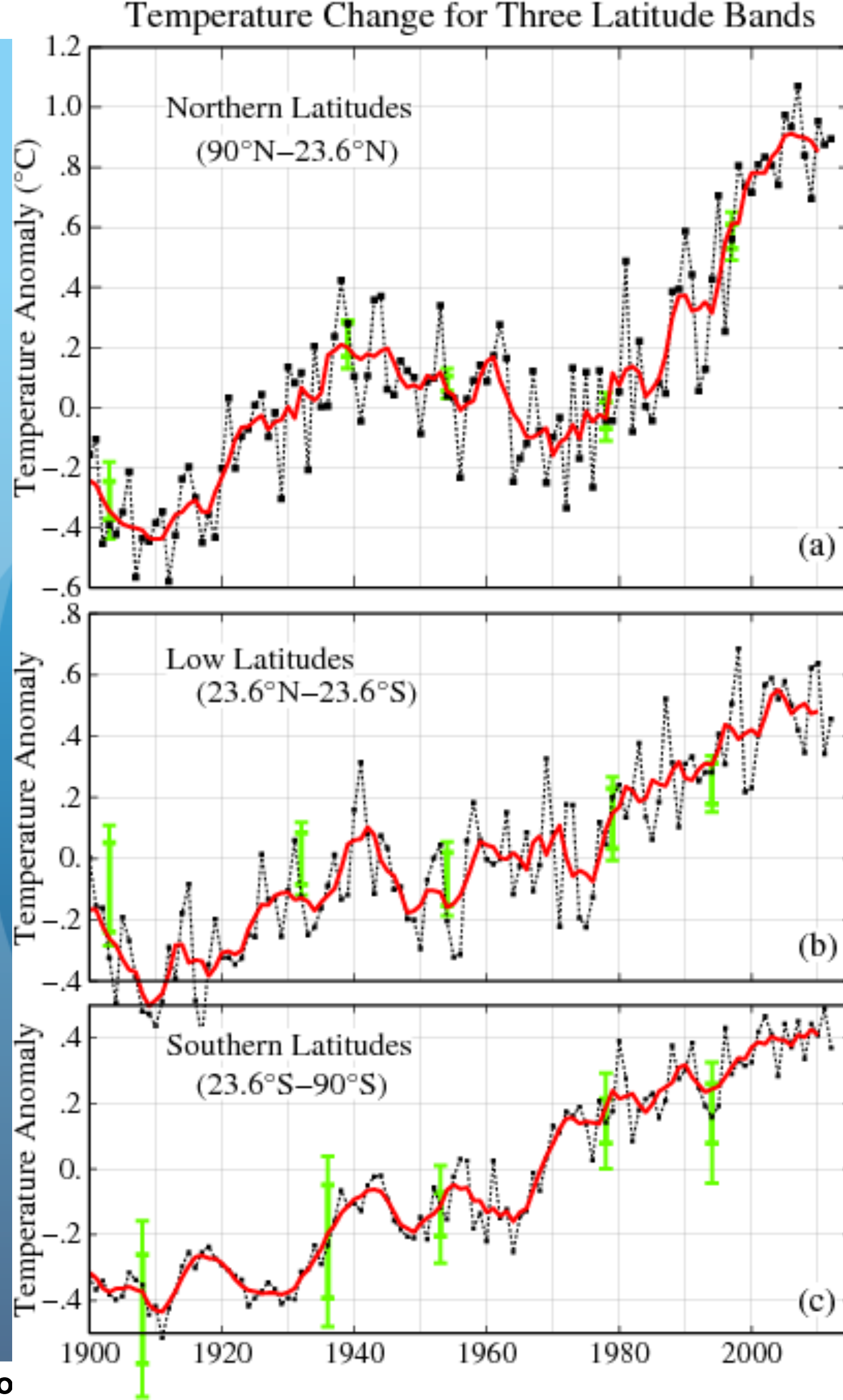


EPICA (2004)

Anthropogenic CO_2



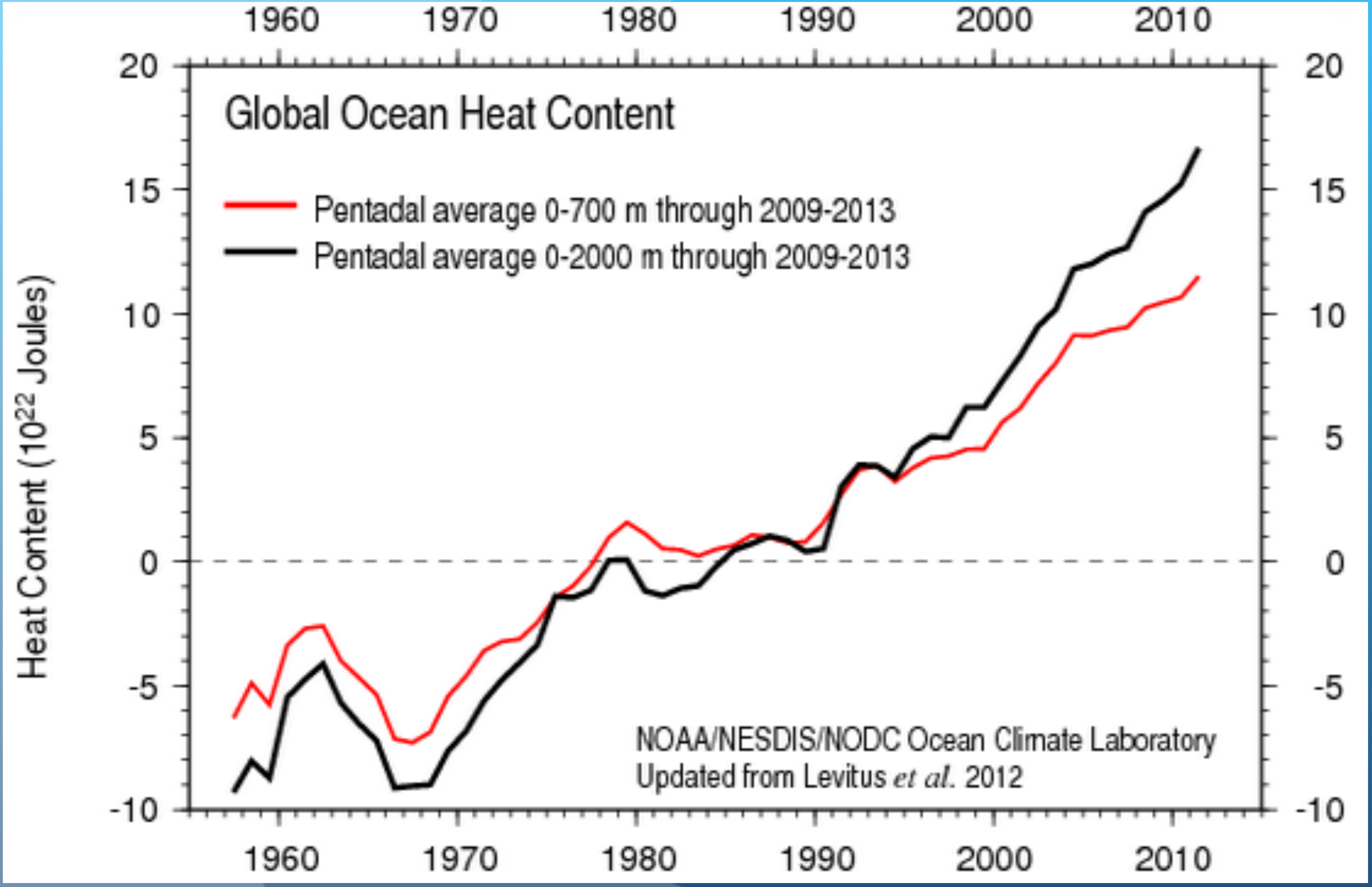
GlobalWarmingArt



Lefer 27 – iii. natural & anthro

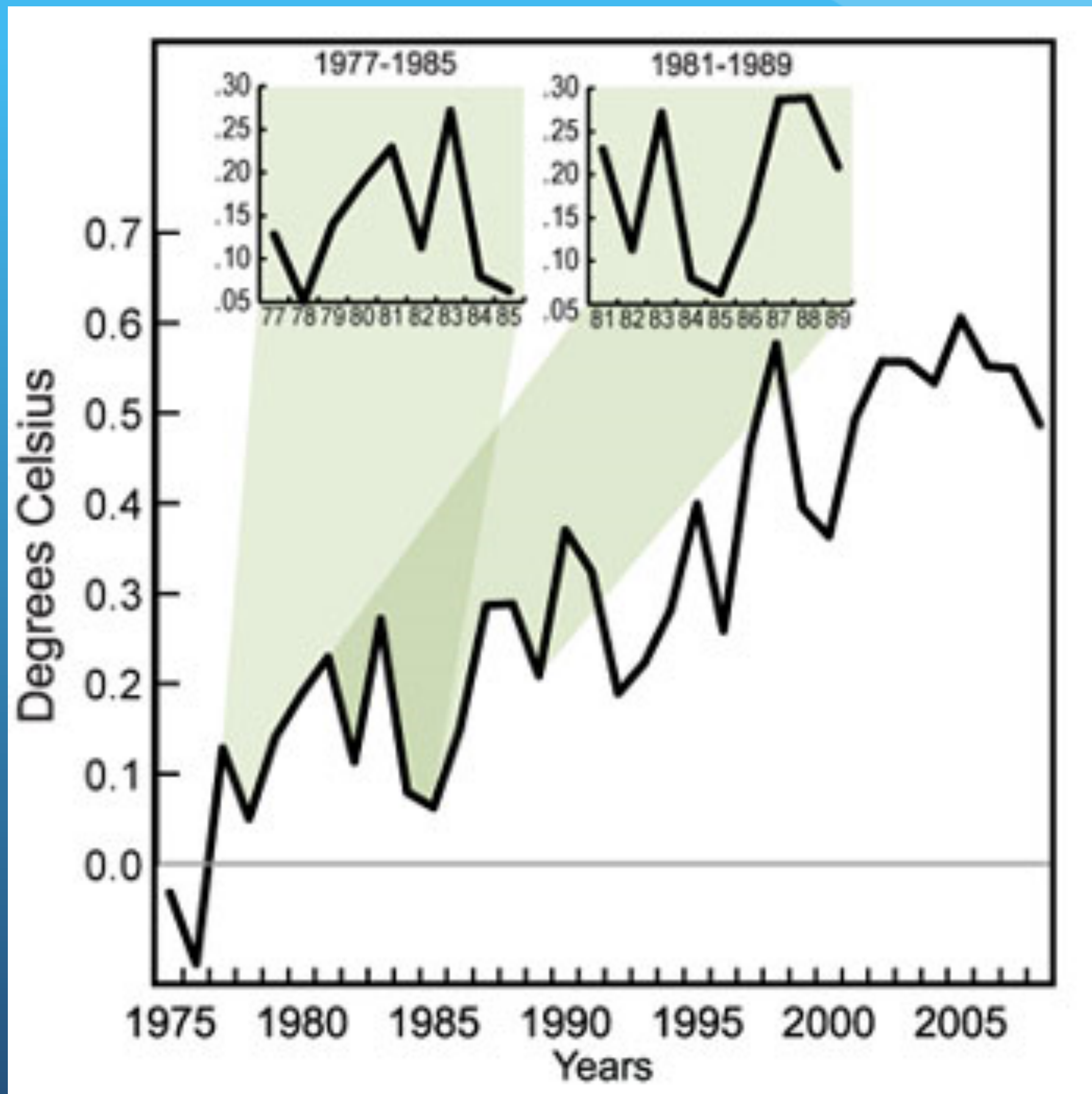
NASA GISS

Global Ocean Temperature



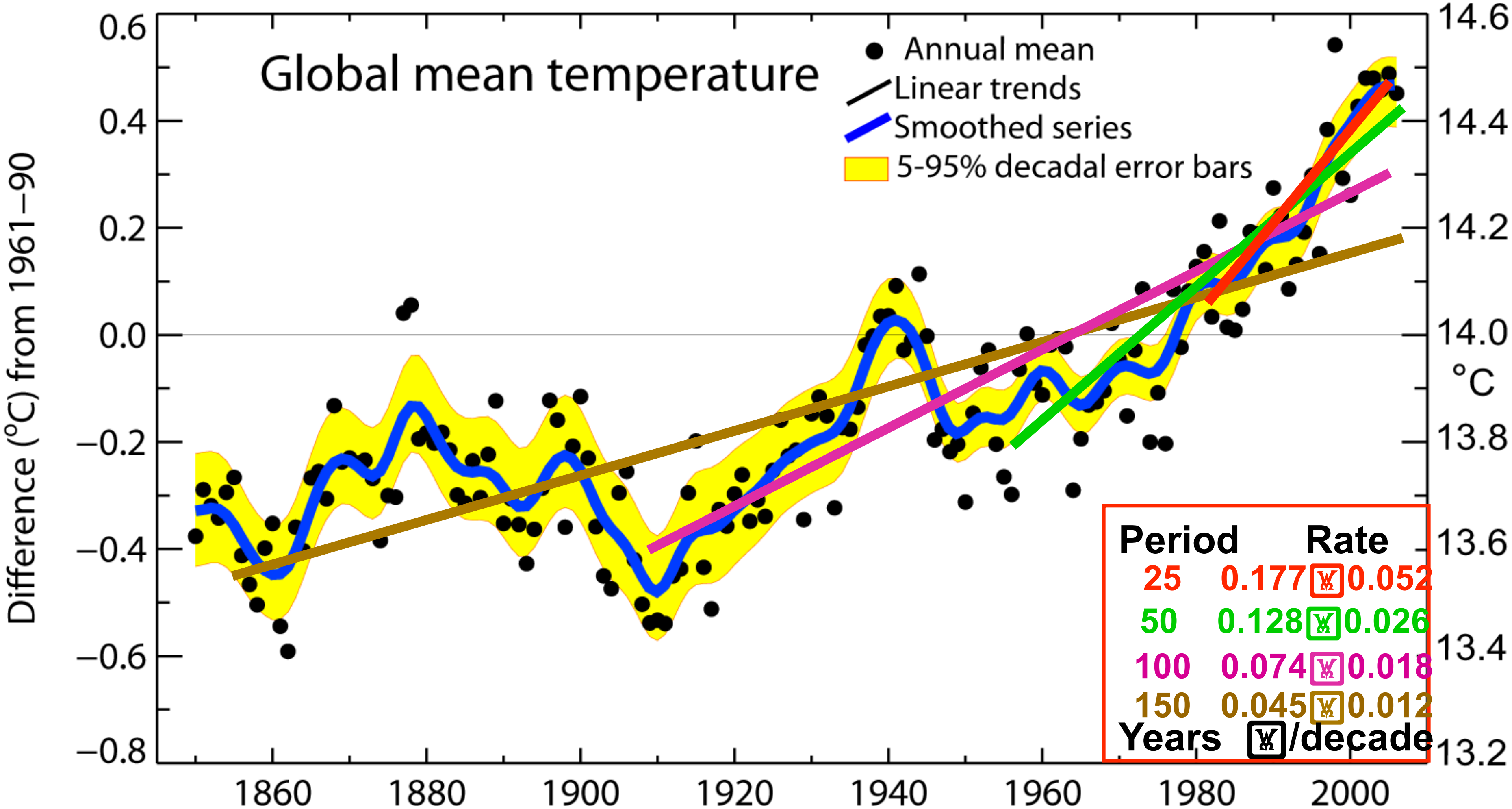
NASA GISS

Natural interannual variability

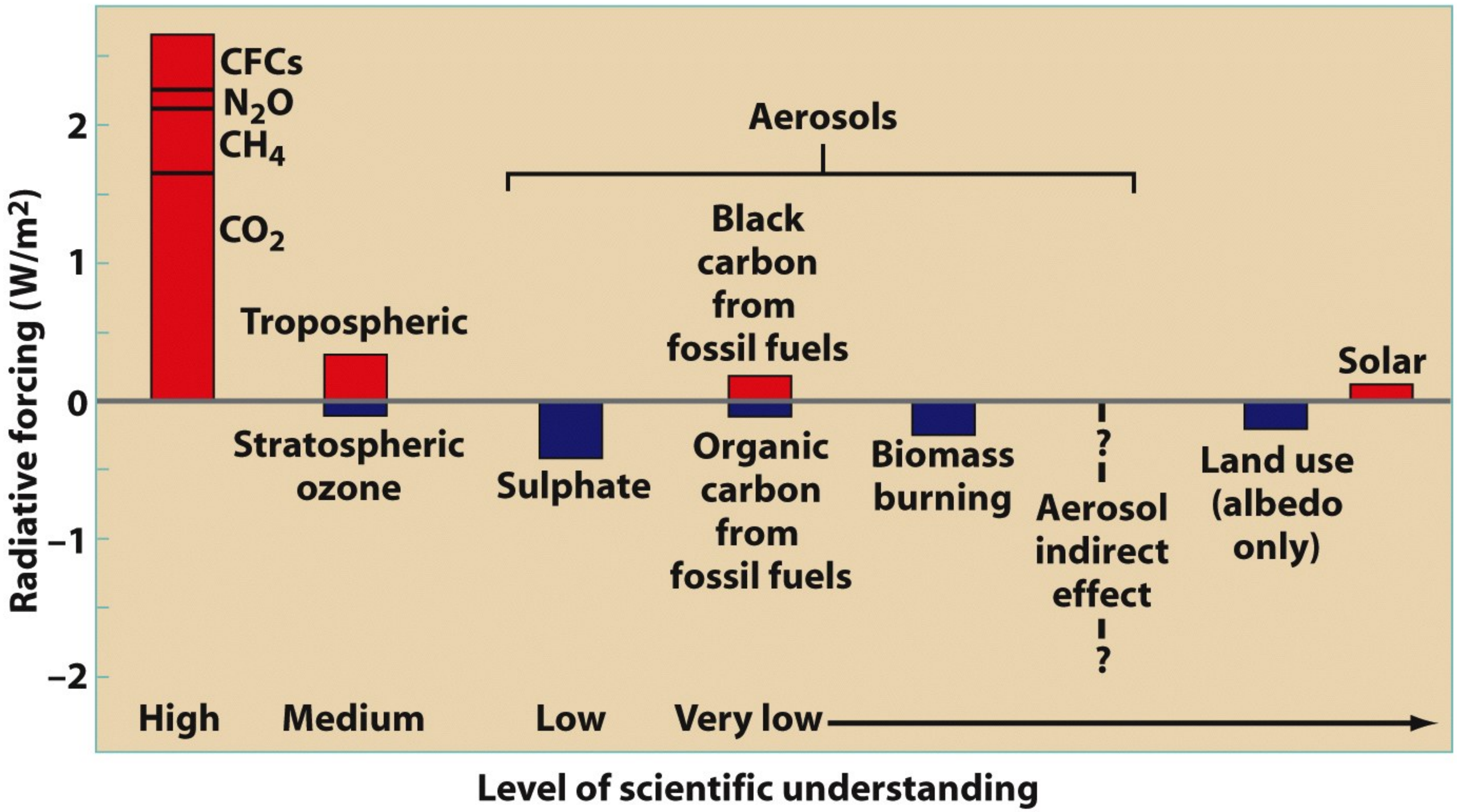


Science, 2010

Rate of global temperature rise



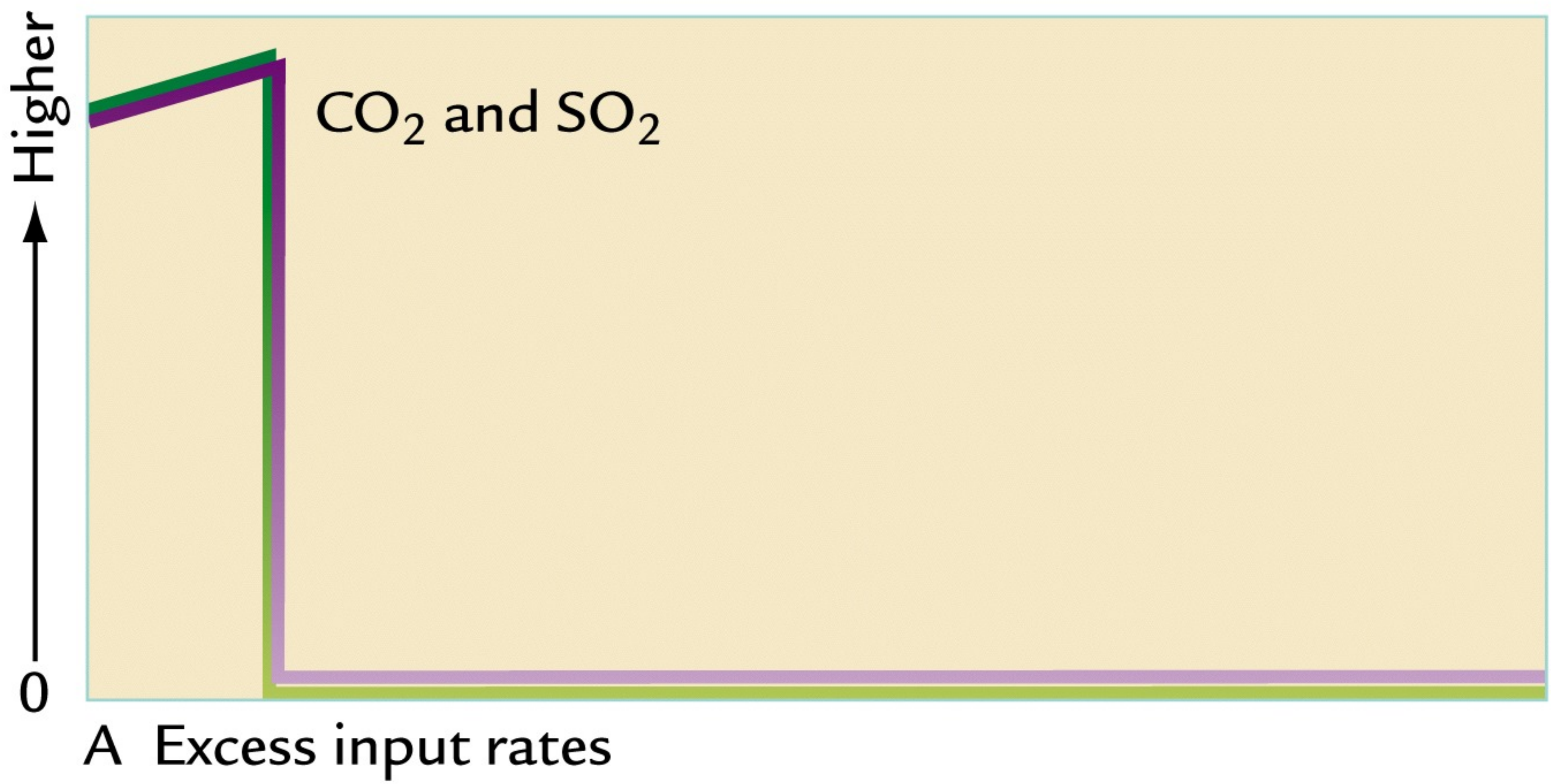
Radiative forcing of recent warming



Box 18-1b
Earth's Climate: Past and Future, Second Edition

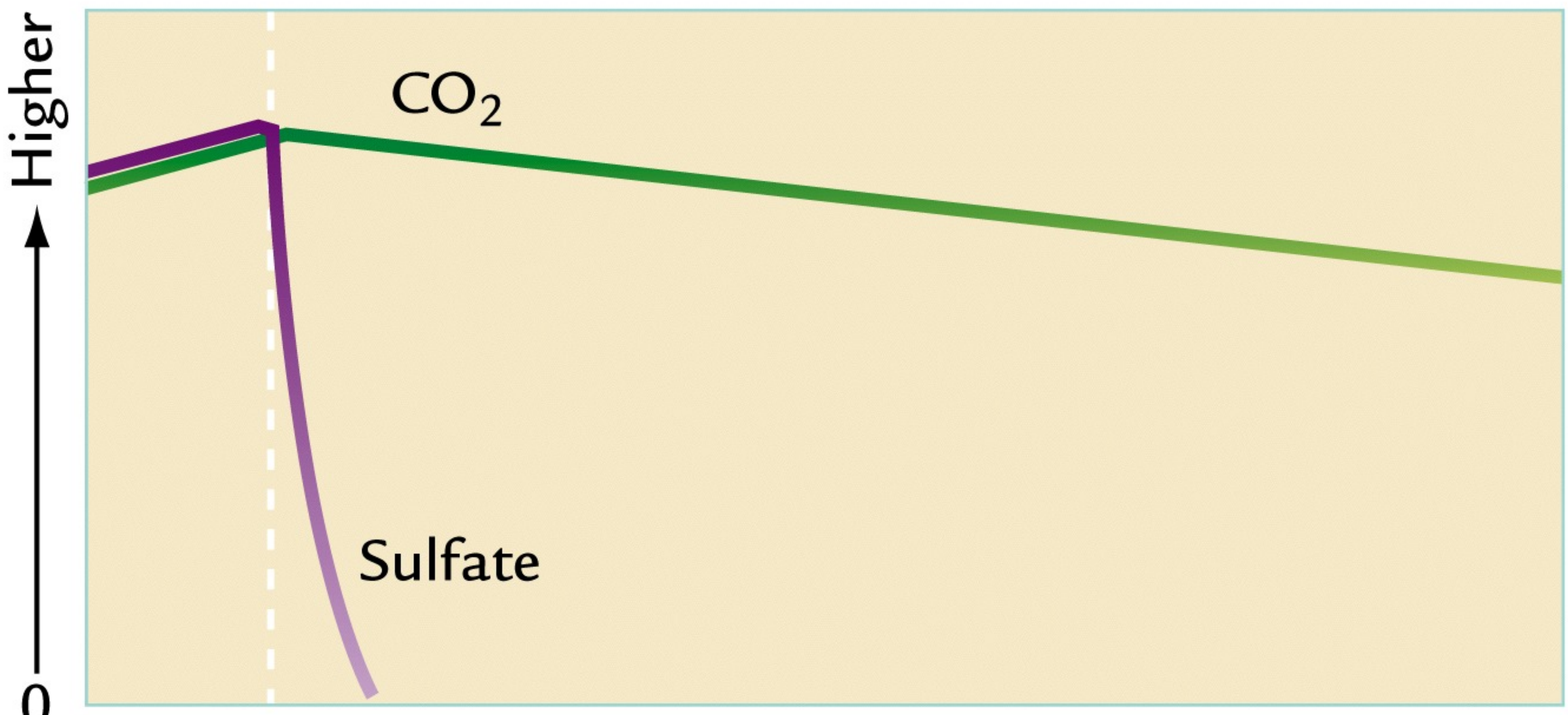
Ruddiman, 2008

Response to abrupt CO_2 and SO_2 emissions?



Ruddiman, 2008

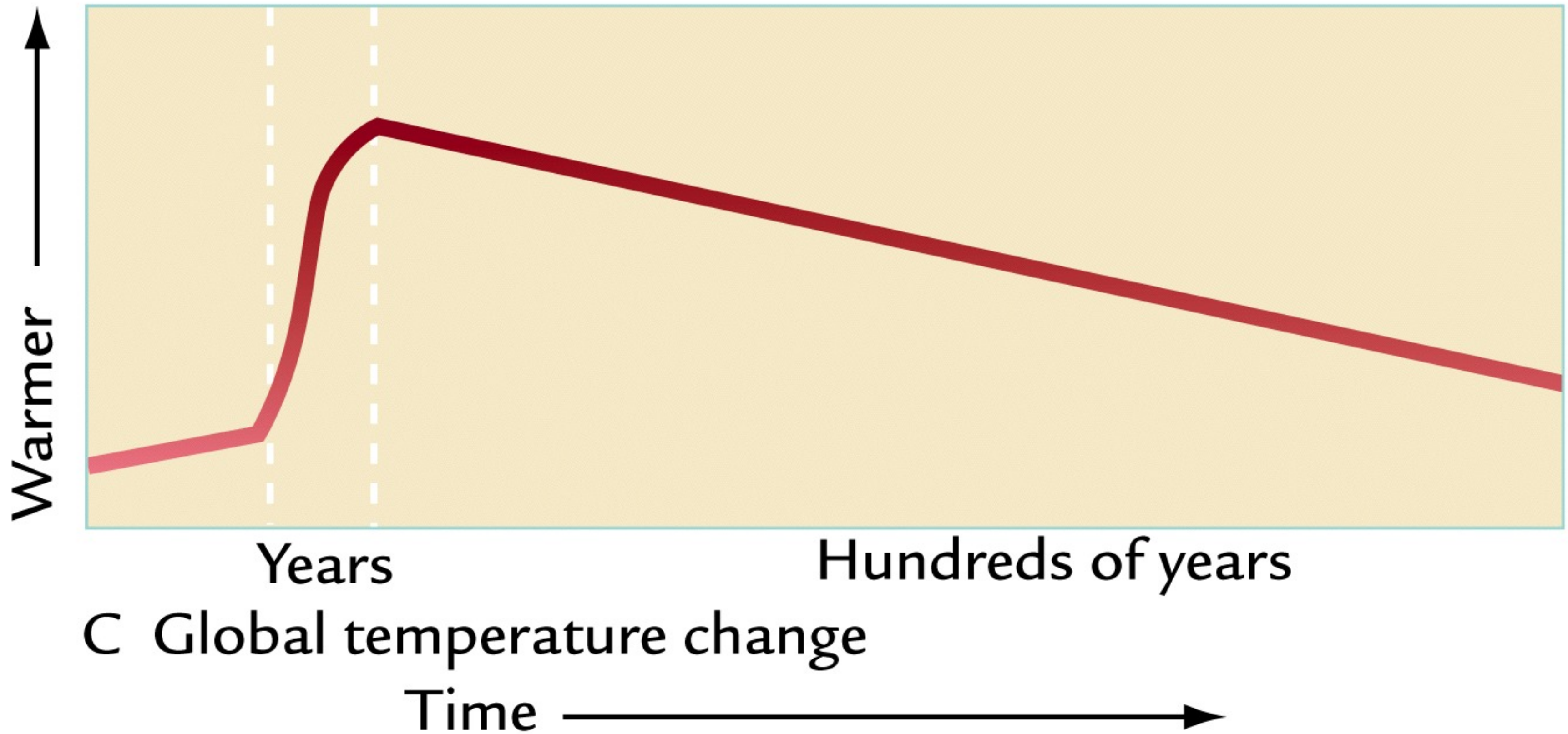
Response to abrupt CO$_2$ and SO$_2$ emissions?



B Excess concentrations in atmosphere

Ruddiman, 2008

Response to abrupt CO_2 and SO_2 emissions?



Ruddiman, 2008