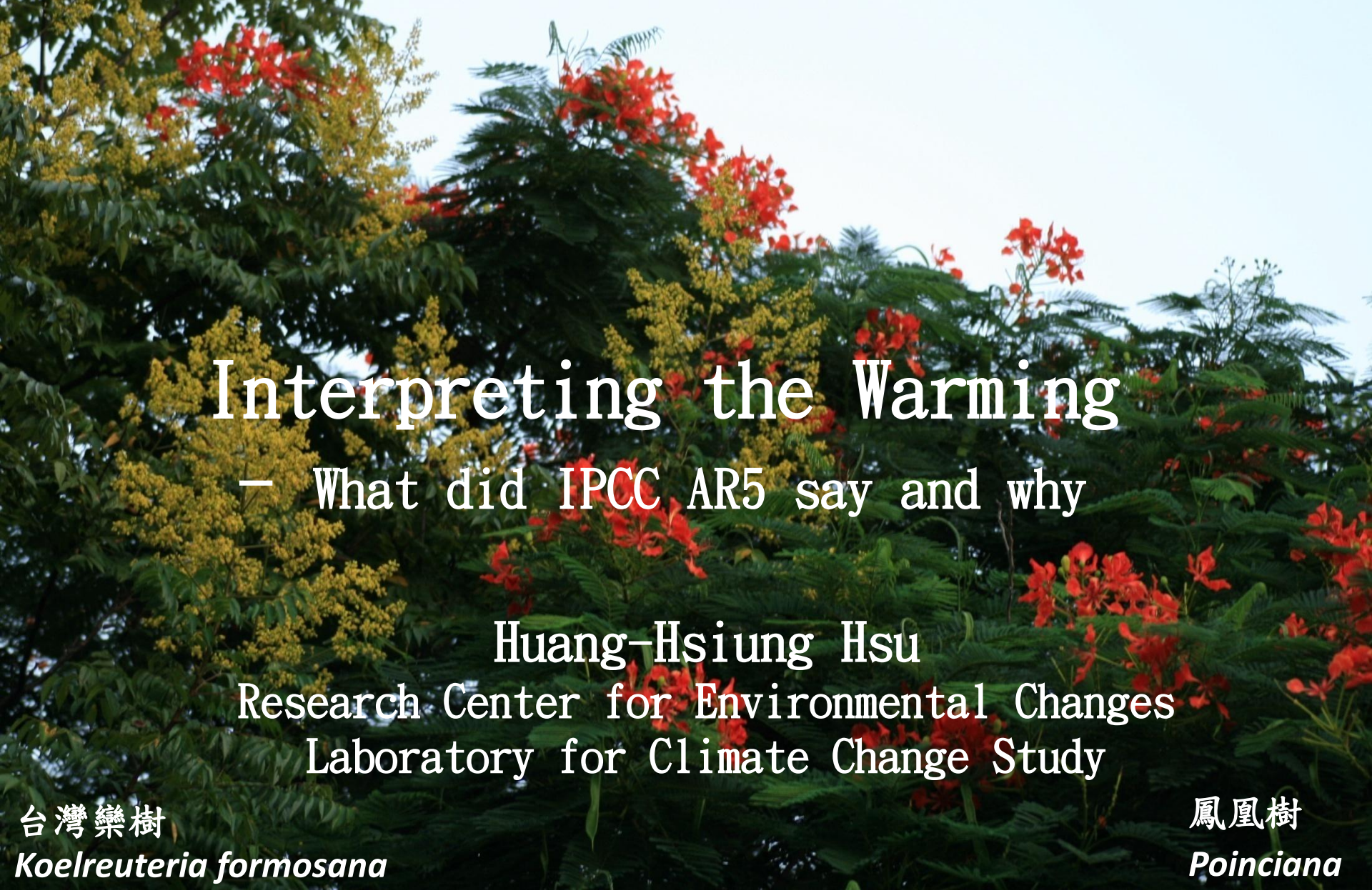


Interpreting the Warming

– What did IPCC AR5 say and why

Huang-Hsiung Hsu
Research Center for Environmental Changes
Laboratory for Climate Change Study

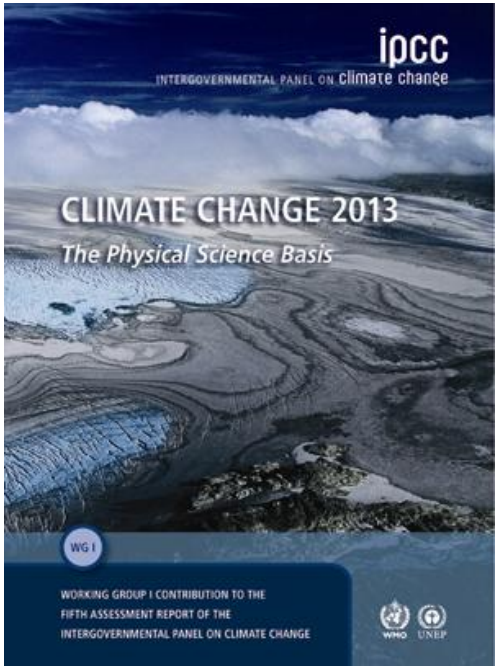
台灣欒樹
Koelreuteria formosana

鳳凰樹
Poinciana

ASIAA/CCMS/IAMS/LeCosPA/NTU-Phys Joint Colloquia
1 October 2013

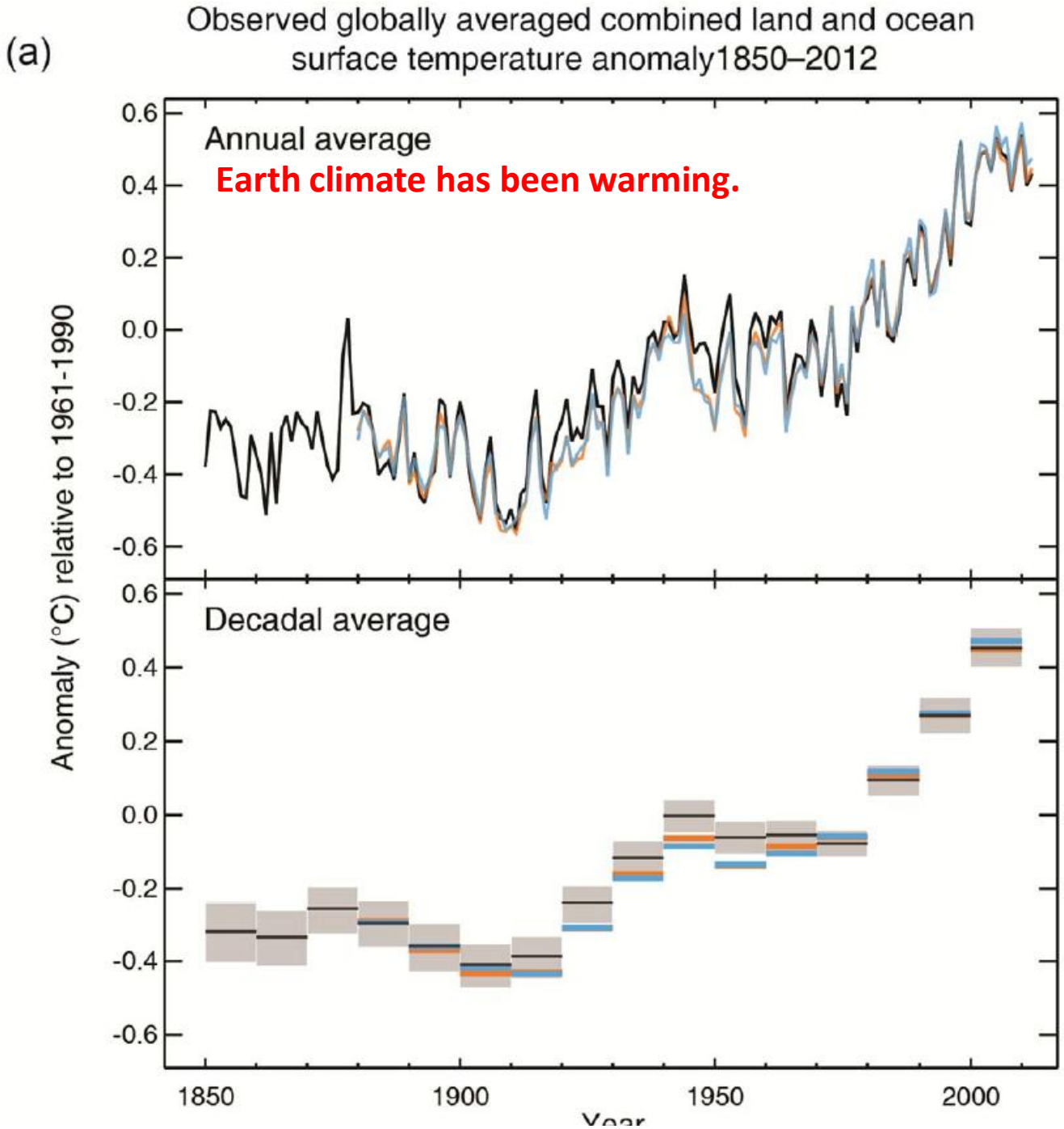
Evidence and confidence on the human influence on the recent warming have been growing from IPCC FAR (SAR, AR3, AR4) to the Fifth Assessment Report (AR5).

http://www.scidacreview.org/0902/html/esg.html

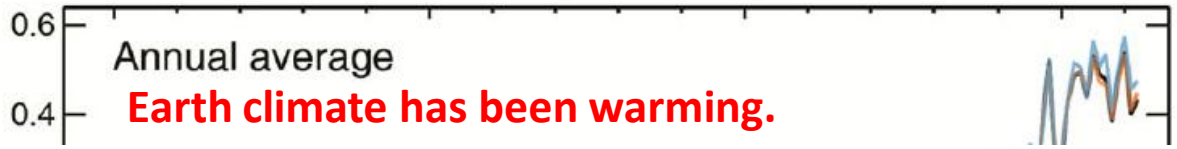


IPCC: Intergovernmental Panel for Climate Change
AR5 (released on 27 and 30 September 2013):
Fifth IPCC summary of literature published before March 2013 (209 authors, >9200 papers cited, 54677 comments, …)

It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.

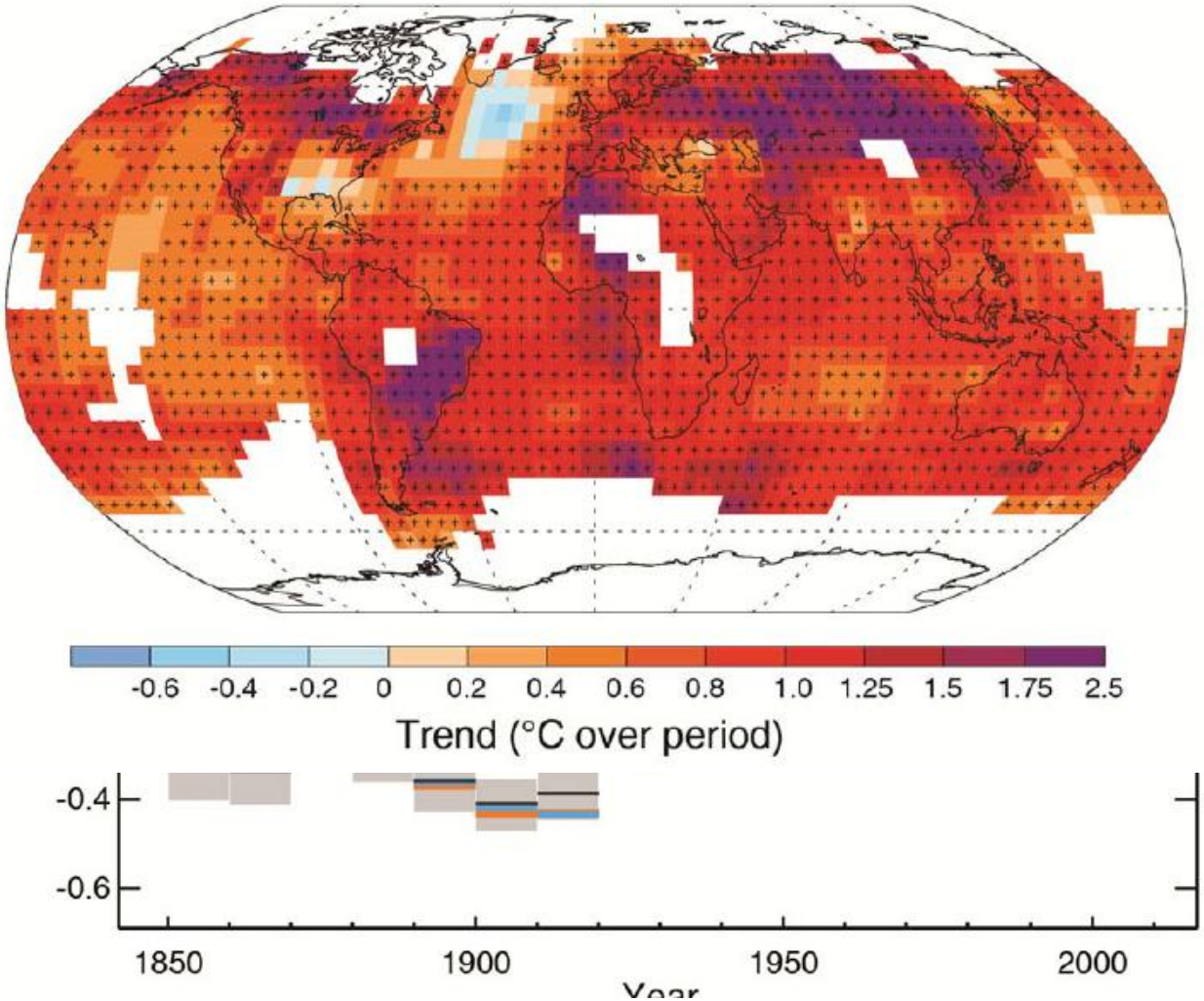

(a)
Observed globally averaged combined land and ocean surface temperature anomaly1850–2012
Annual average
Earth climate has been warming.
Decadal average
Anomaly (°C) relative to 1961-1990
0.6
0.4
0.2
0.0
-0.2
-0.4
-0.6
1850
1900
1950
2000
Year

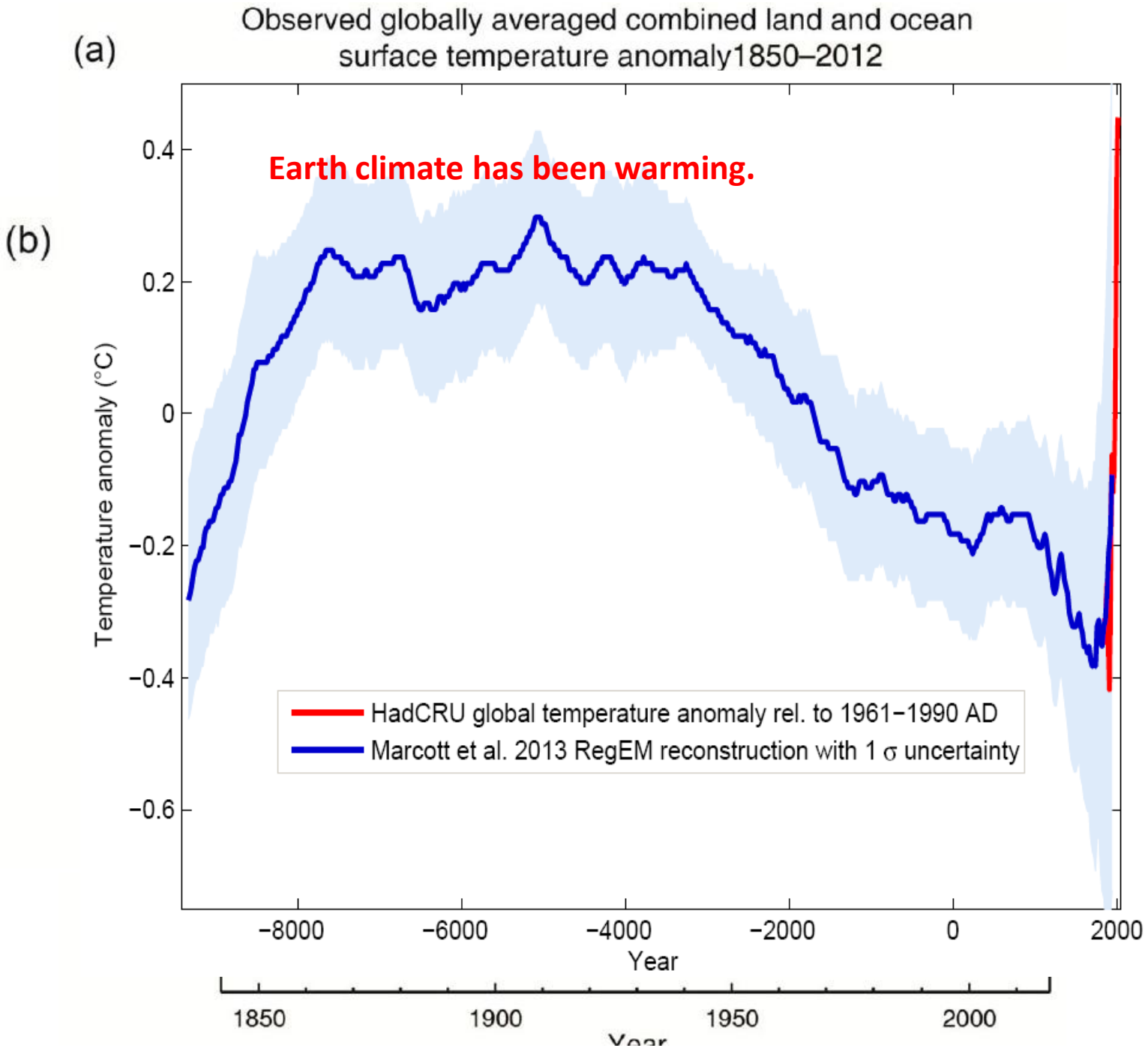
(a) Observed globally averaged combined land and ocean surface temperature anomaly1850–2012

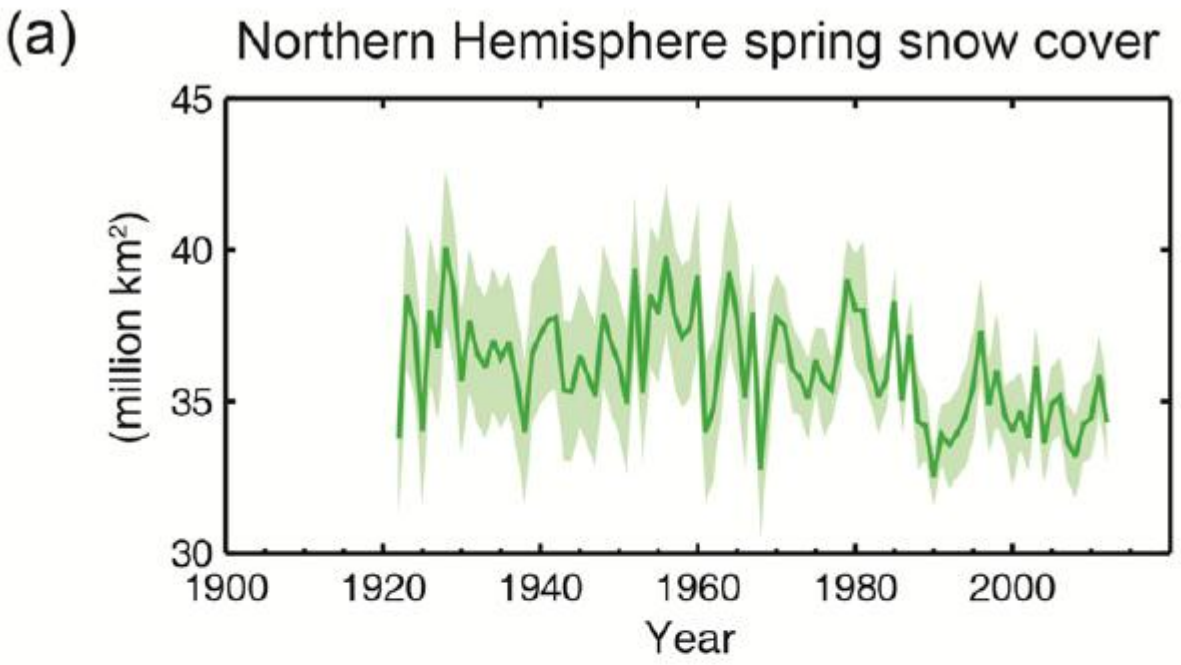


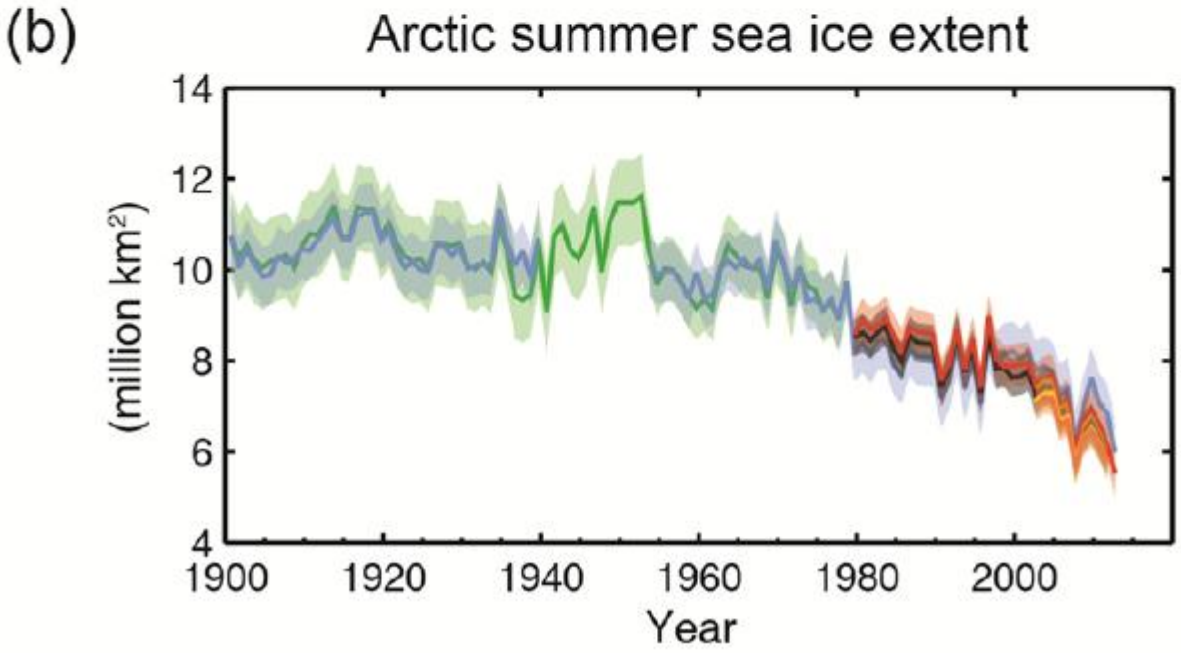
Earth climate has been warming.

(b) Observed change in average surface temperature 1901–2012




(a)
Observed globally averaged combined land and ocean surface temperature anomaly1850–2012
(b)
Earth climate has been warming.
Temperature anomaly (°C)
0.4
0.2
0
−0.2
−0.4
−0.6
HadCRU global temperature anomaly rel. to 1961−1990 AD
Marcott et al. 2013 RegEM reconstruction with 1 σ uncertainty
−8000
−6000
−4000
−2000
0
2000
Year
1850
1900
1950
2000
Year

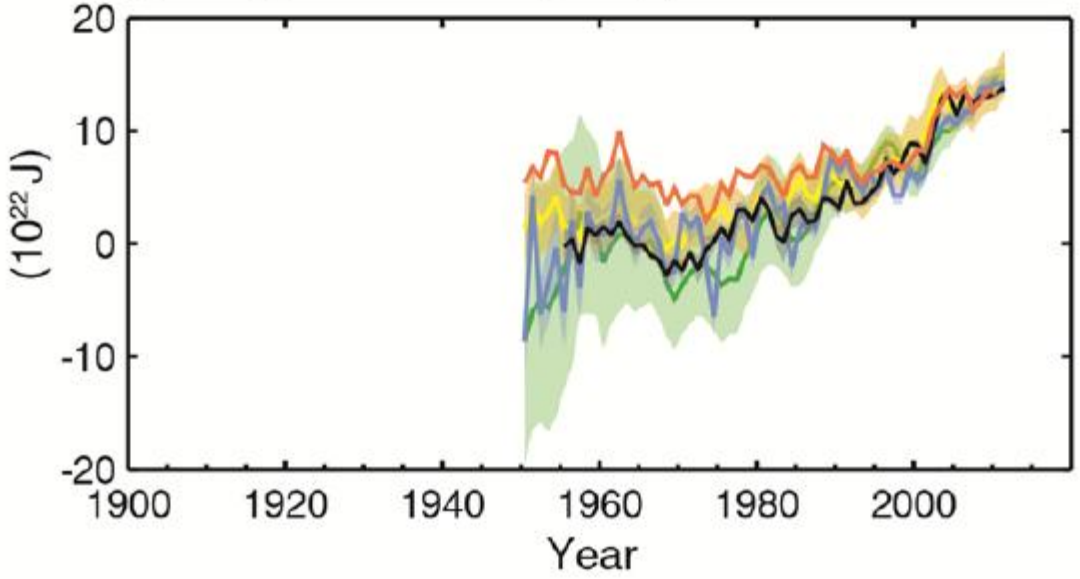




Also in sensitive variables that feedback positively to temperature change

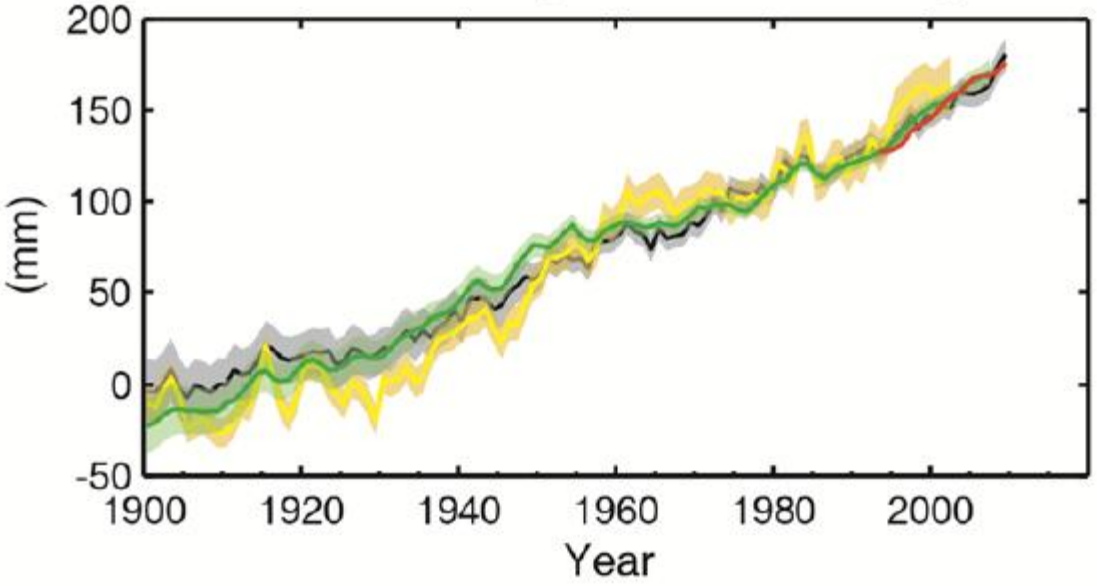
- **ice-albedo feedback**
- **heat release from ice-free ocean surface**
- **shorter winter, longer summer**
- **CO2, CH4 release from ice-free water and thawing land surface**
- **more human activities: shipping, mining, …**
- **…**

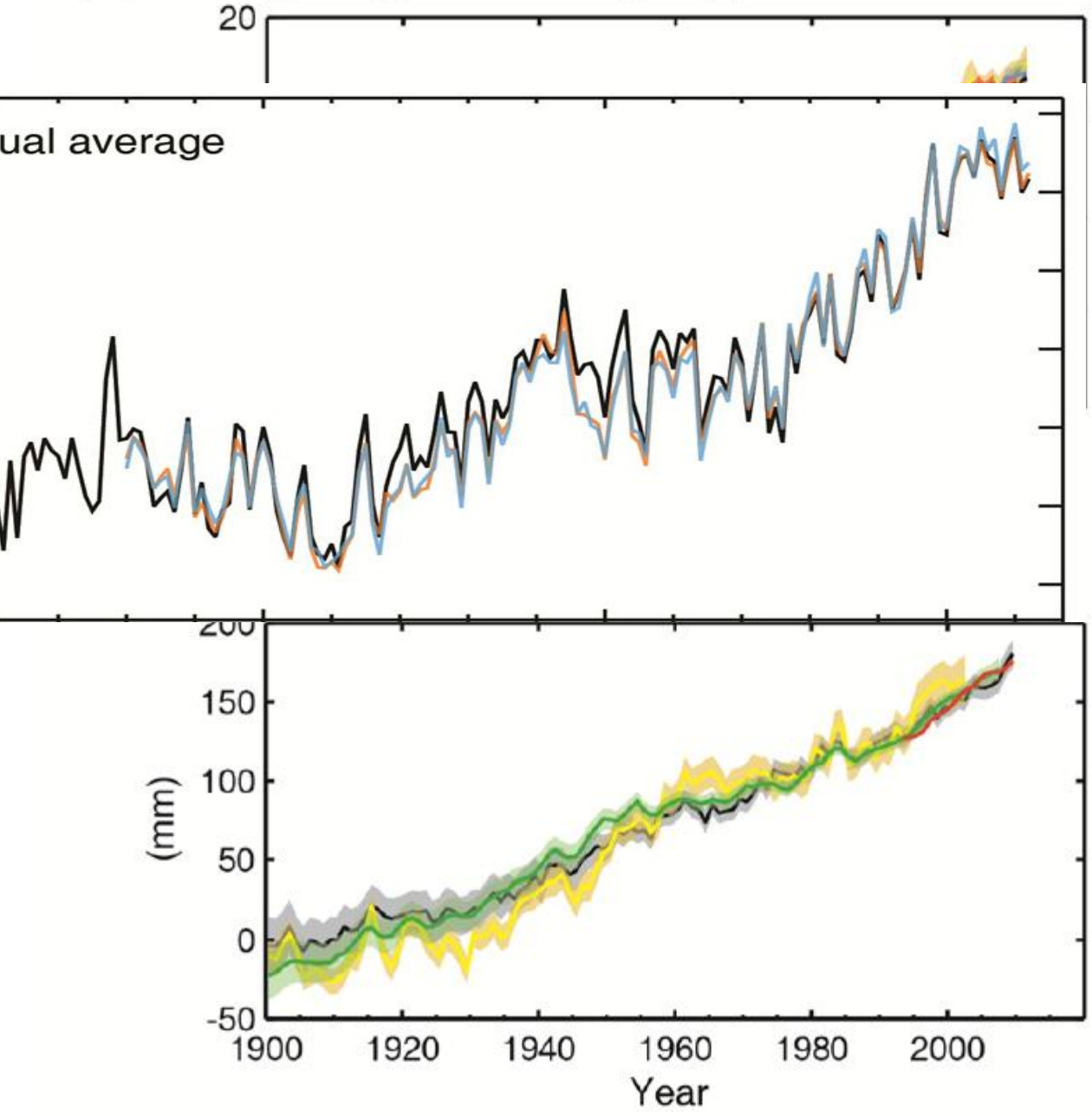
(c) Change in global average upper ocean heat content



Better variables preserving warming signal in ocean
- monotonically warming trend
- huge heat bank

(d) Global average sea level change





Better variables preserving warming signal in ocean

- monotonically warming trend

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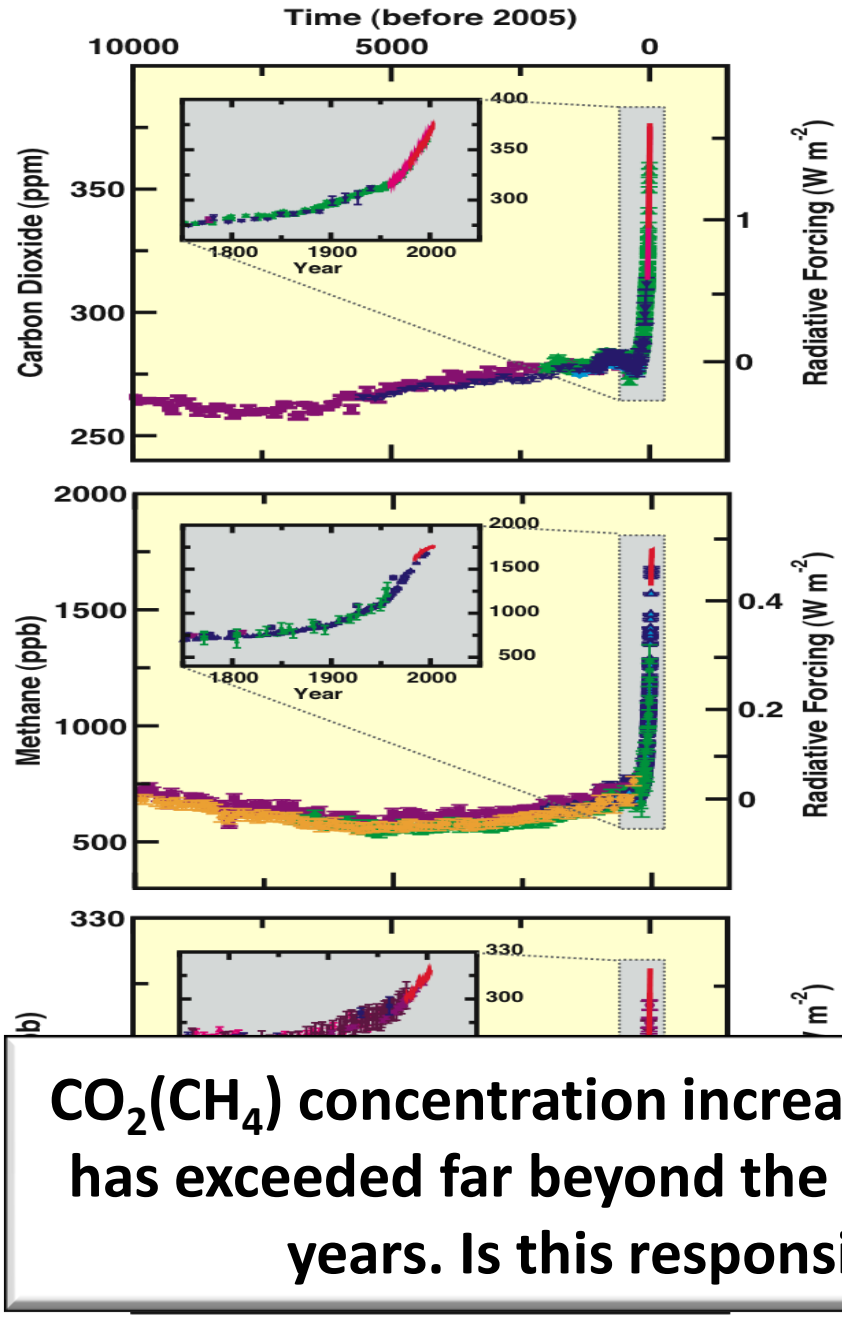
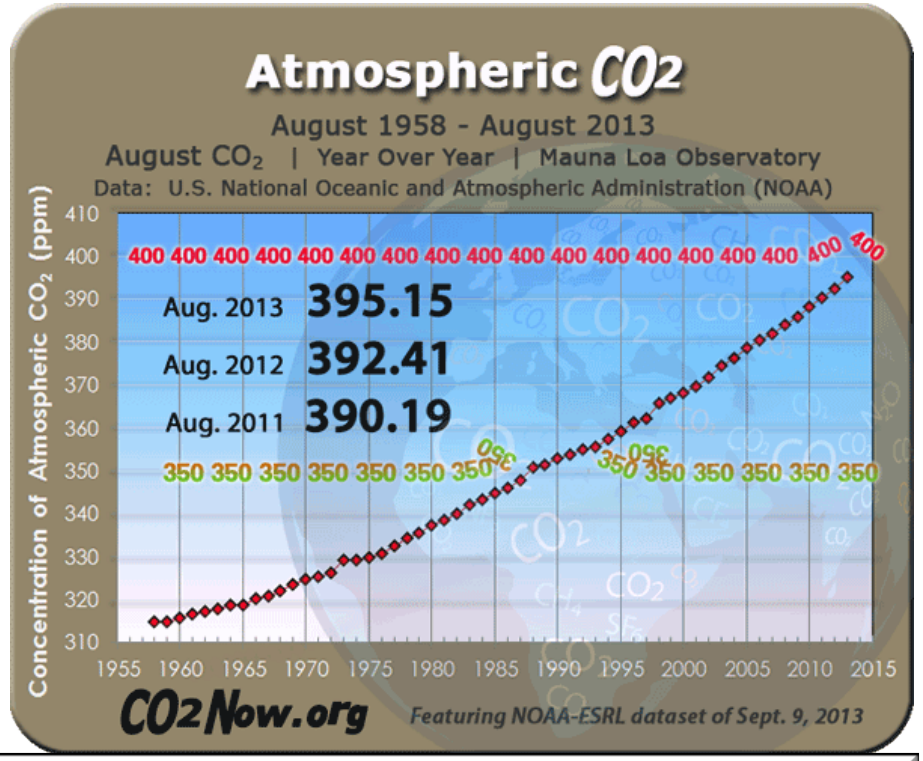
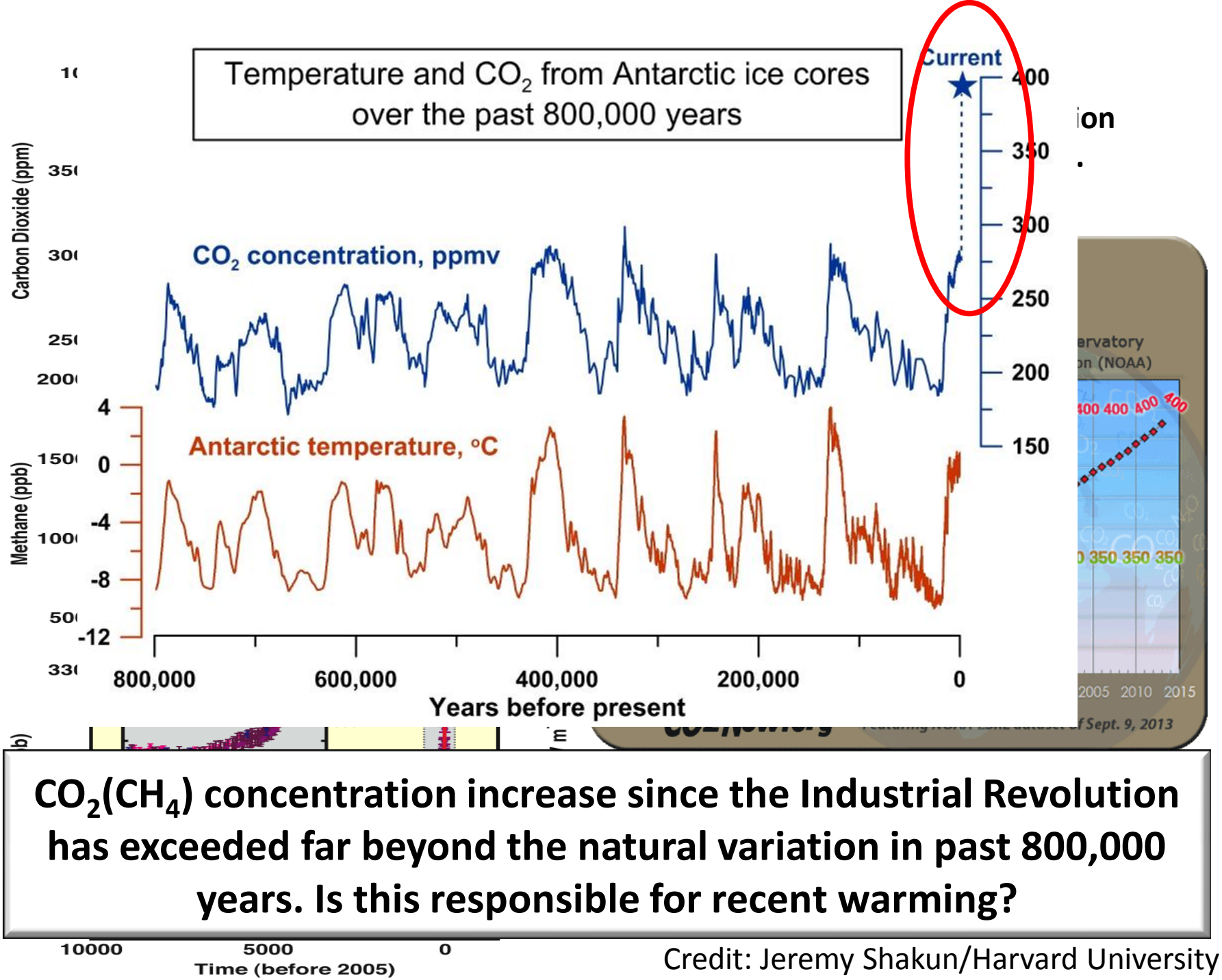


Greenhouse gase concentration has been and continue rising.



CO_2(CH_4) concentration increase since the Industrial Revolution has exceeded far beyond the natural variation in past 800,000 years. Is this responsible for recent warming?

Credit: Jeremy Shakun/Harvard University



CO_2(CH_4) concentration increase since the Industrial Revolution has exceeded far beyond the natural variation in past 800,000 years. Is this responsible for recent warming?

Credit: Jeremy Shakun/Harvard University

Anthropogenic or natural effect?

Back-to-the-past (future) virtual reality simulation
Climate model: atmos., ocean, land, vegetation, biogeochemical cycle, ……

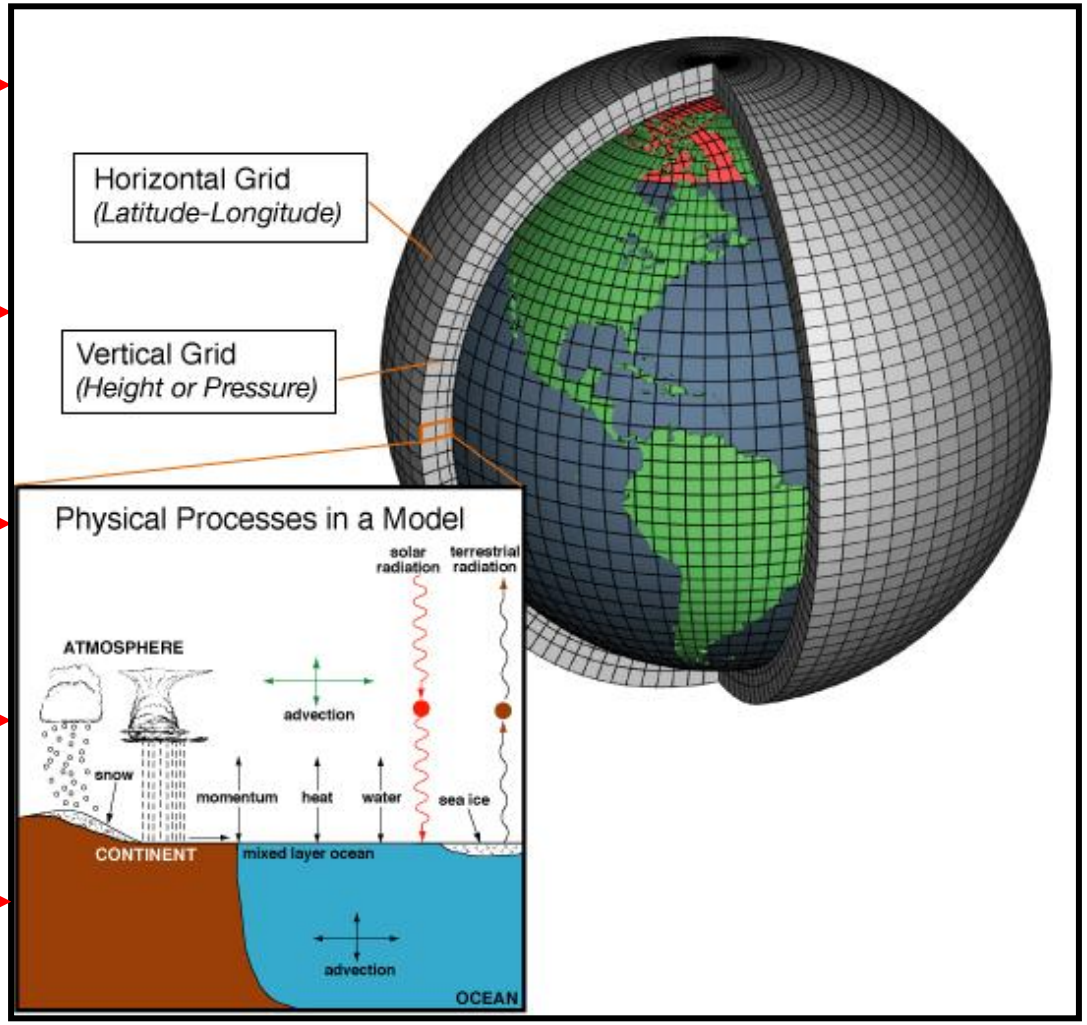
greenhouse gases

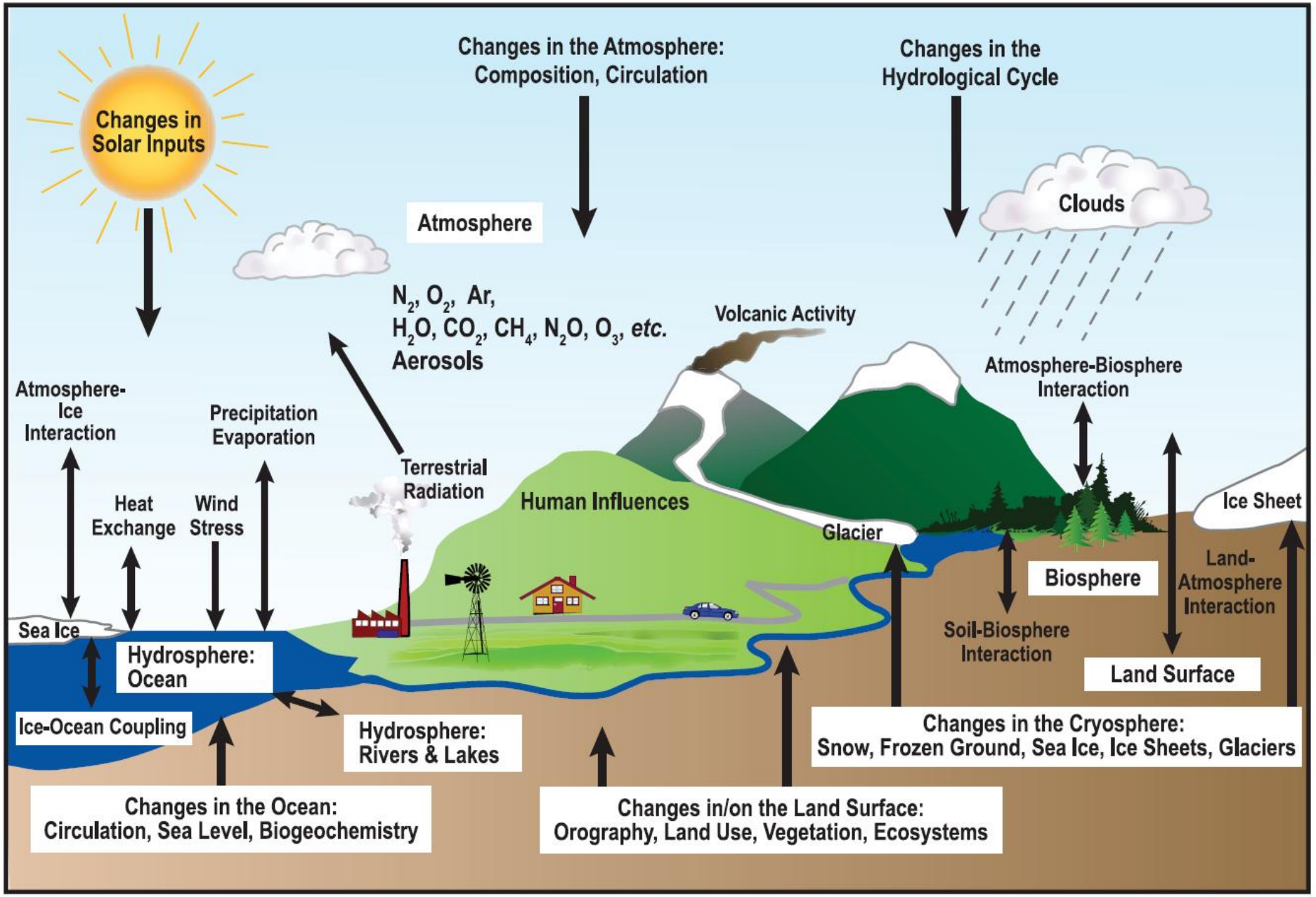
aerosol

volcanic ash

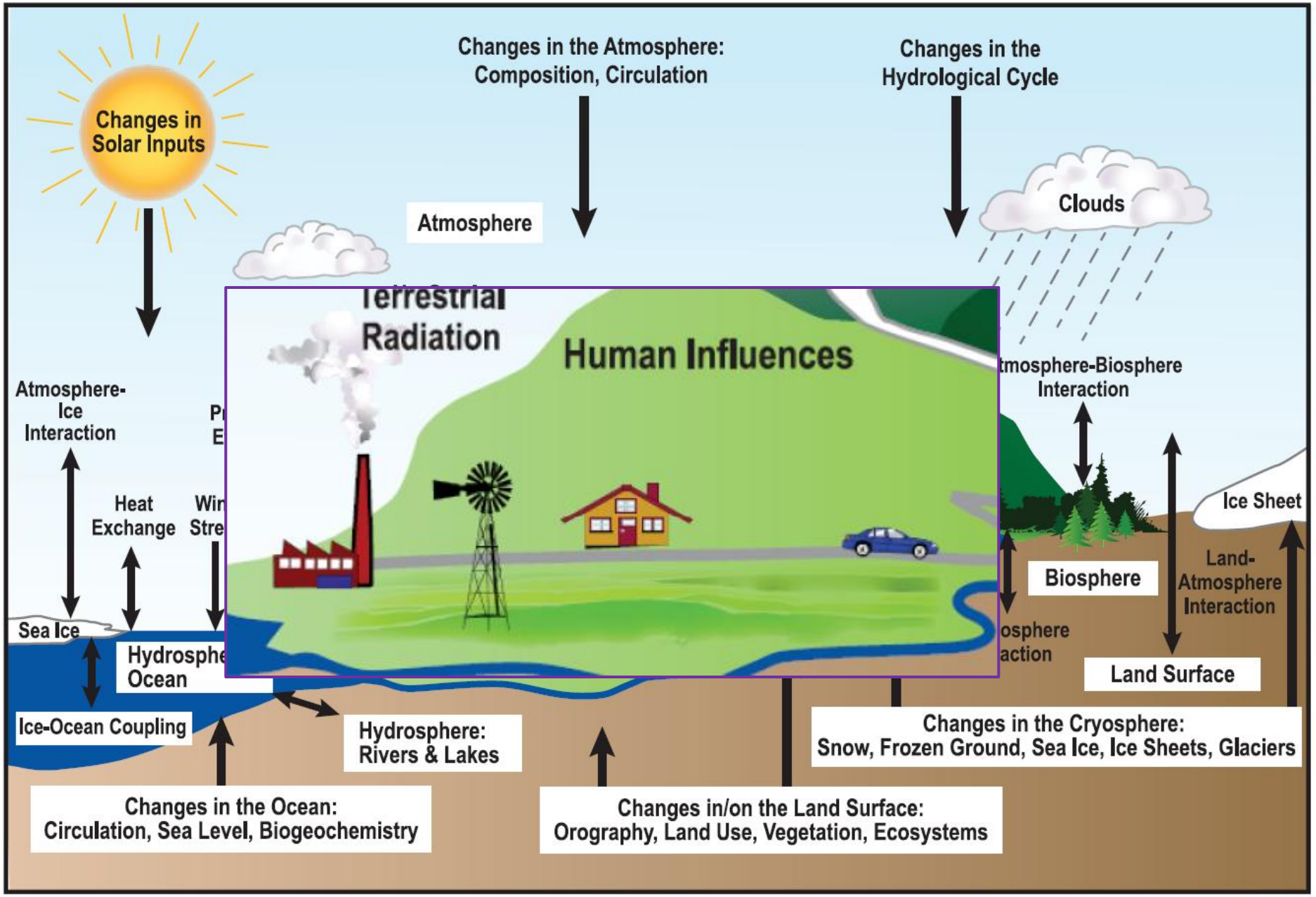
solar radiation

land use change





FAQ 1.2, Figure 1. *Schematic view of the components of the climate system, their processes and interactions.*

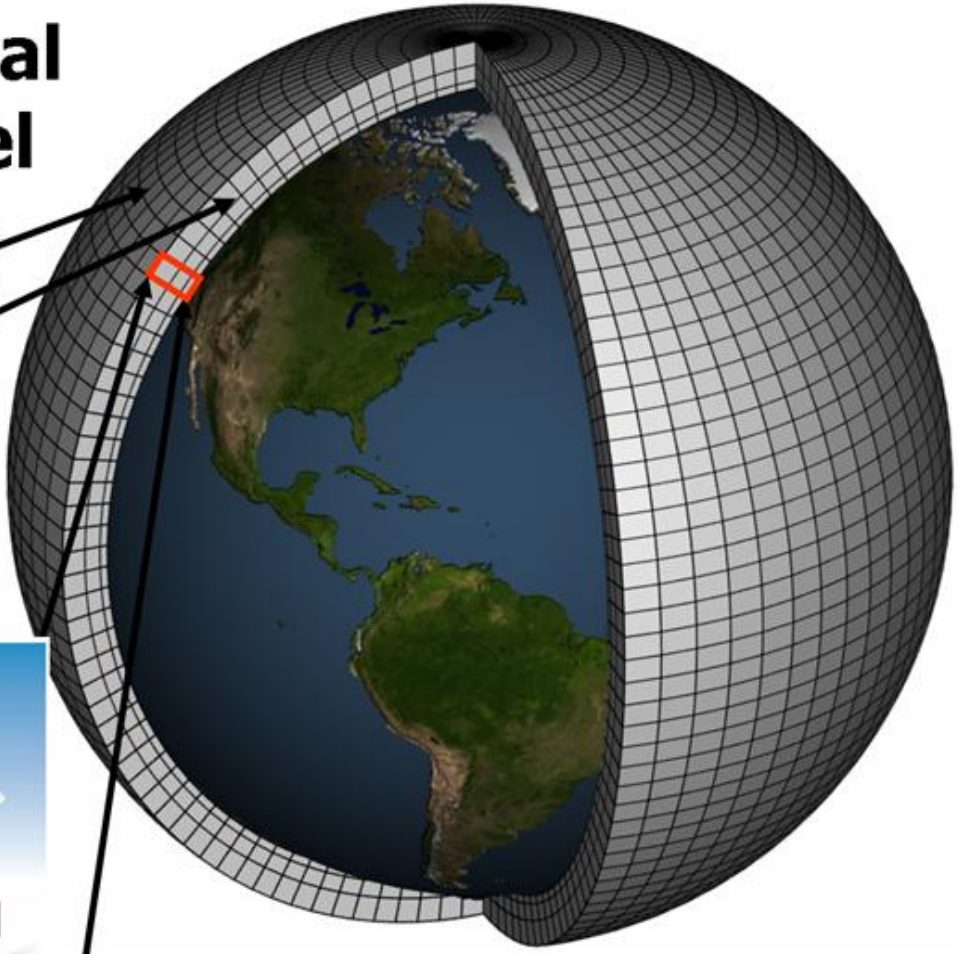


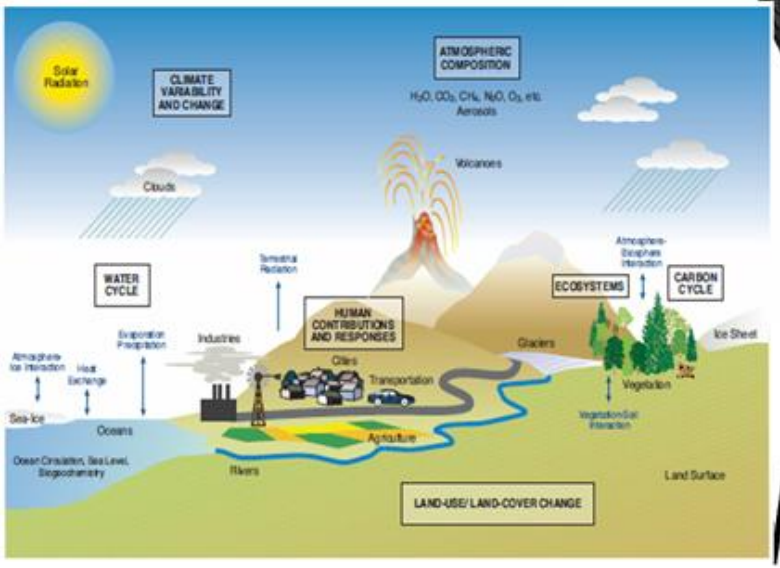
FAQ 1.2, Figure 1. *Schematic view of the components of the climate system, their processes and interactions.*

Schematic for Global Atmospheric Model

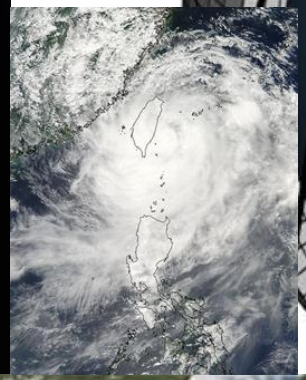
Horizontal Grid (Latitude-Longitude)

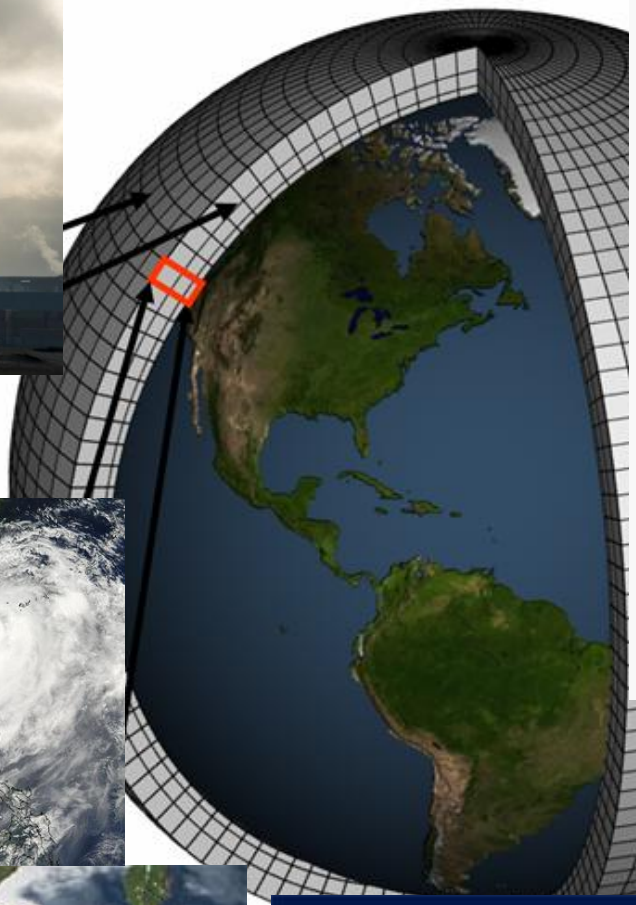
Vertical Grid (Height or Pressure)

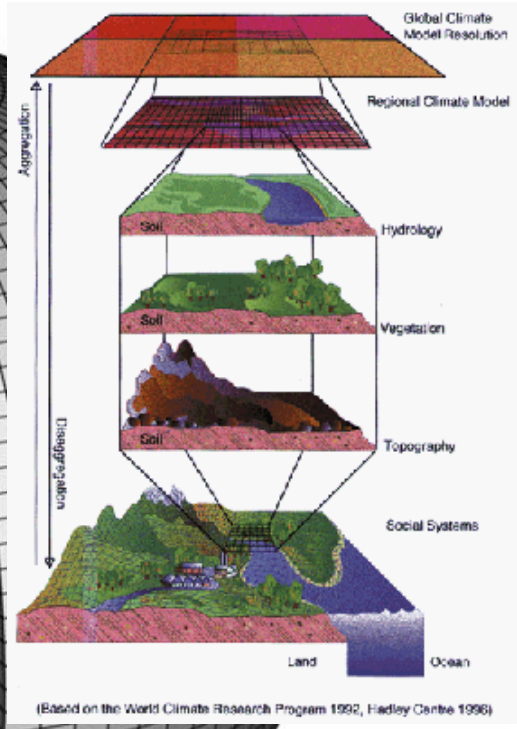


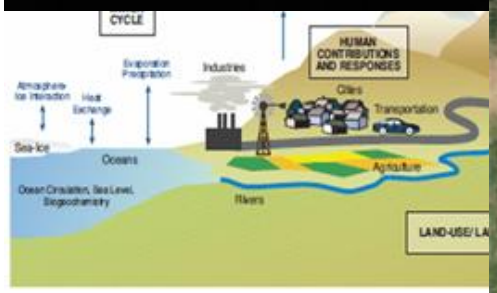


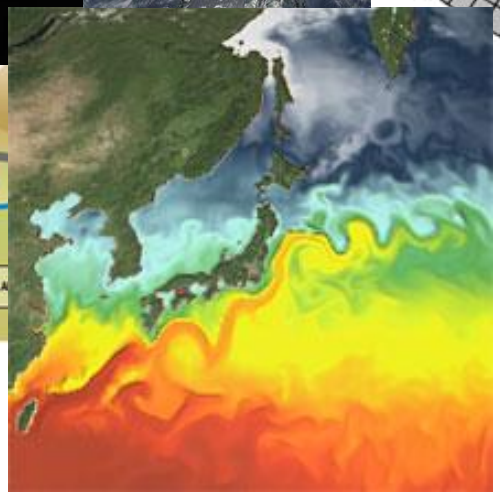
Sch
At











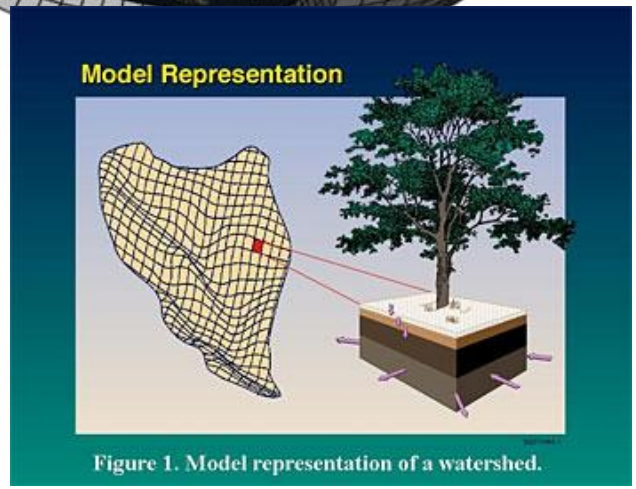
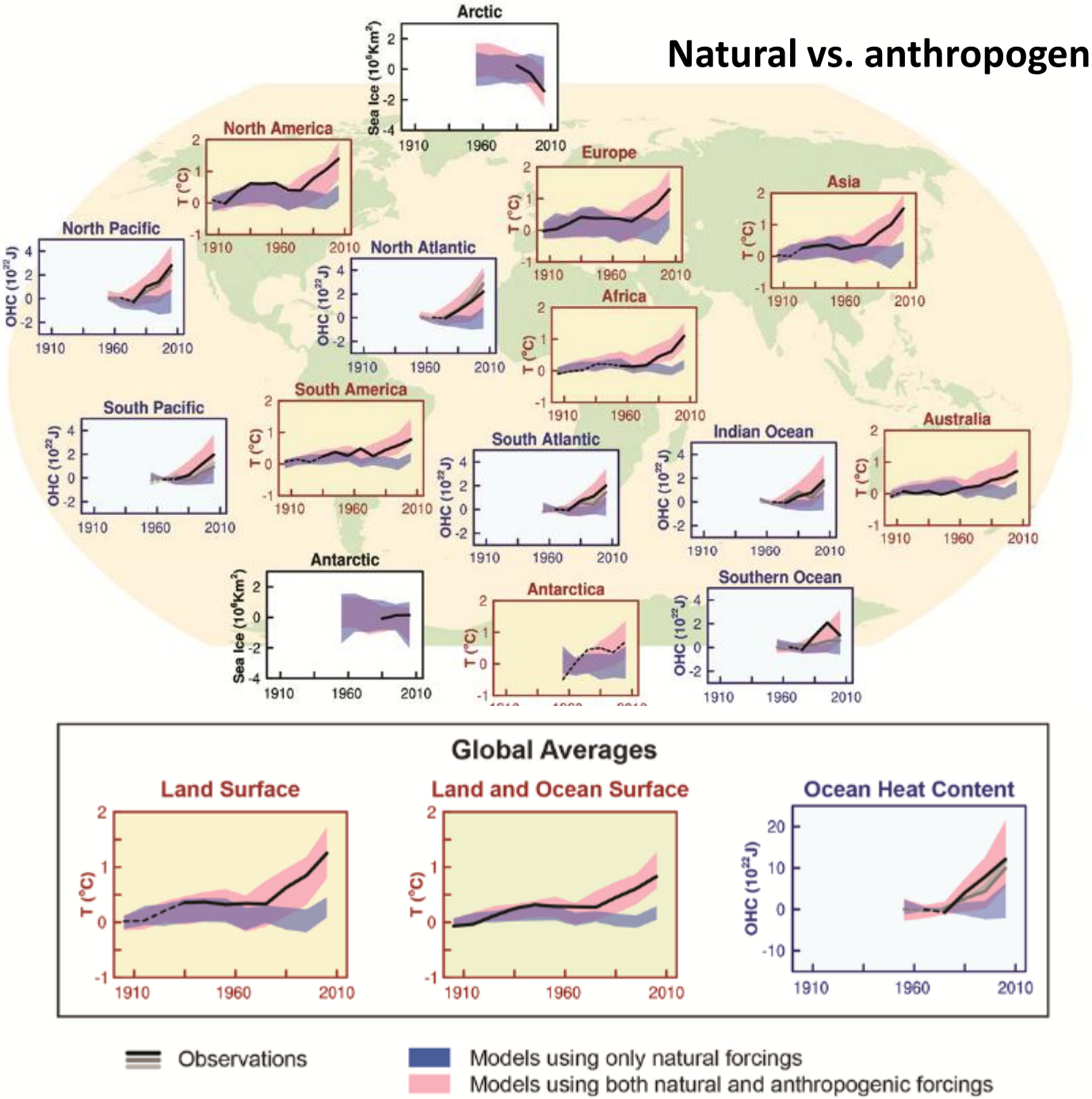
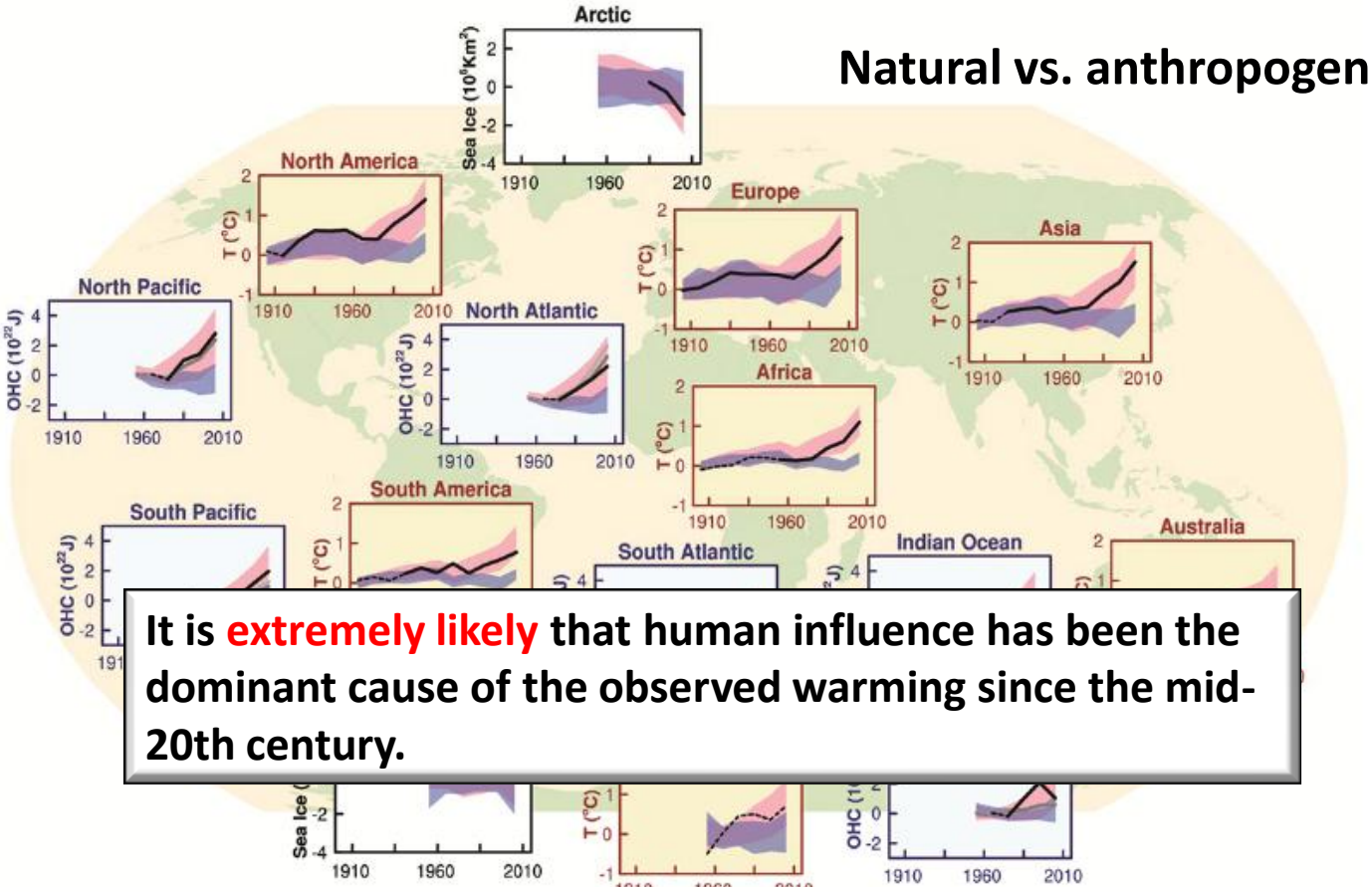


Figure 1. Model representation of a watershed.

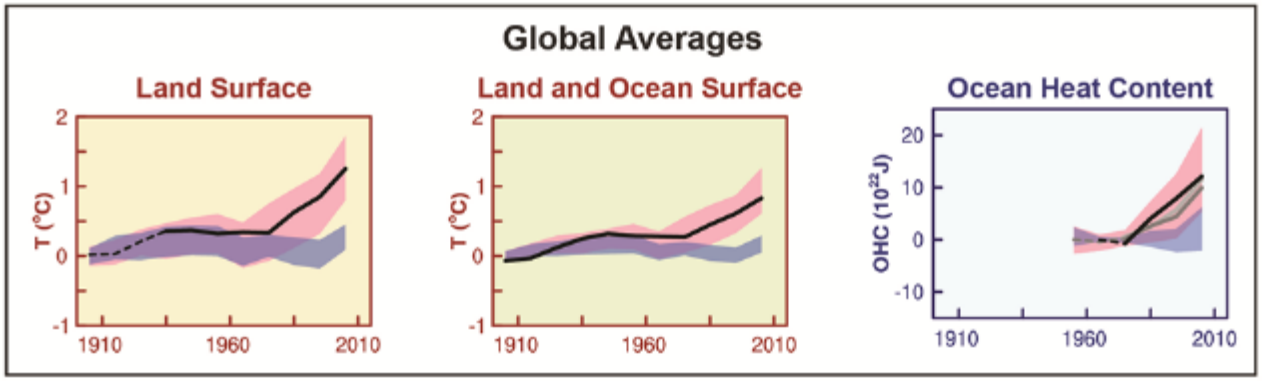
Natural vs. anthropogenic forcings



Natural vs. anthropogenic forcings



It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.

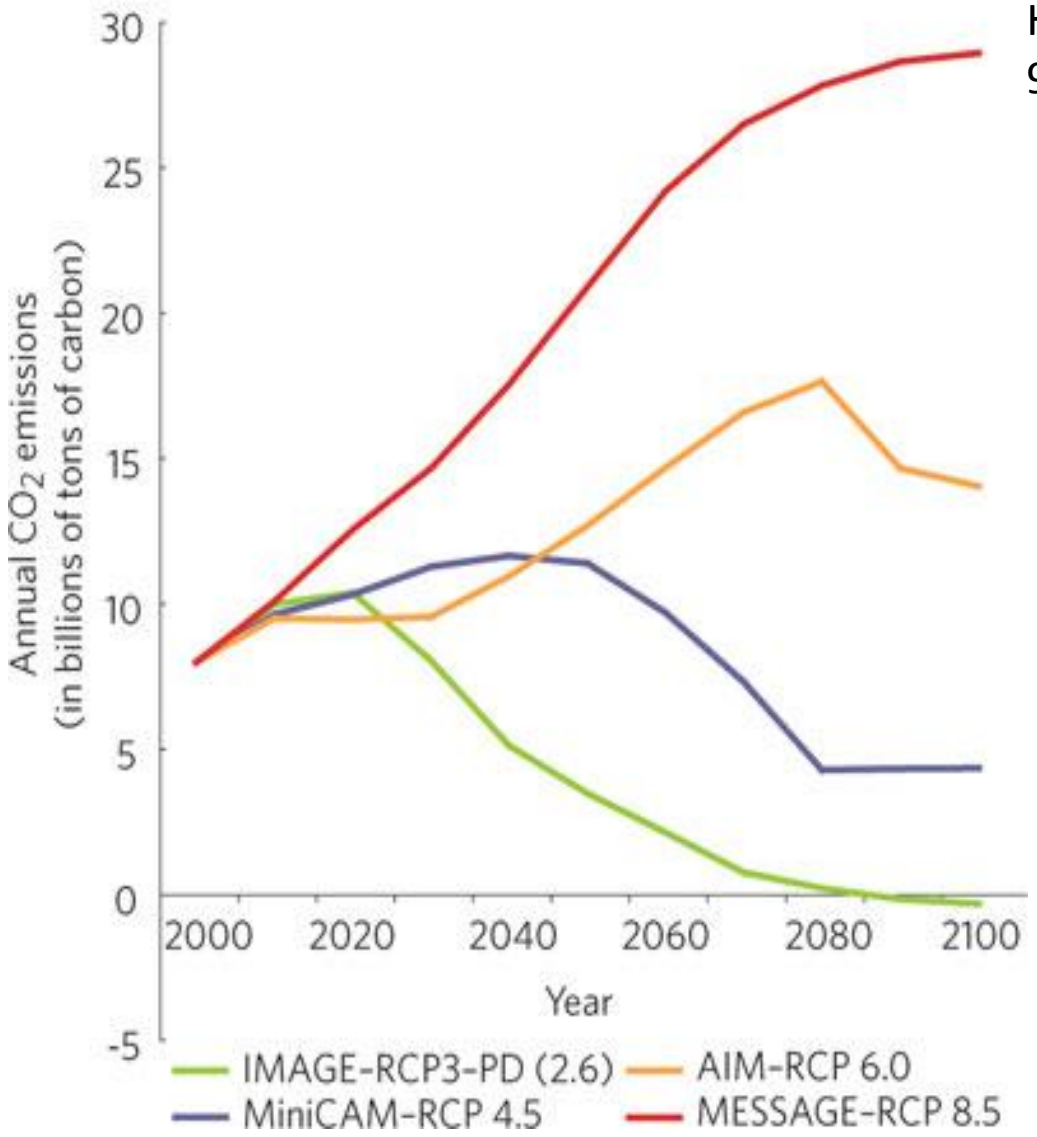


Observations

Models using only natural forcings

Models using both natural and anthropogenic forcings

How to project the future?
Carbon Dioxide Emission Scenario (RCP, AR5)



High emission Pathway
936 ppm

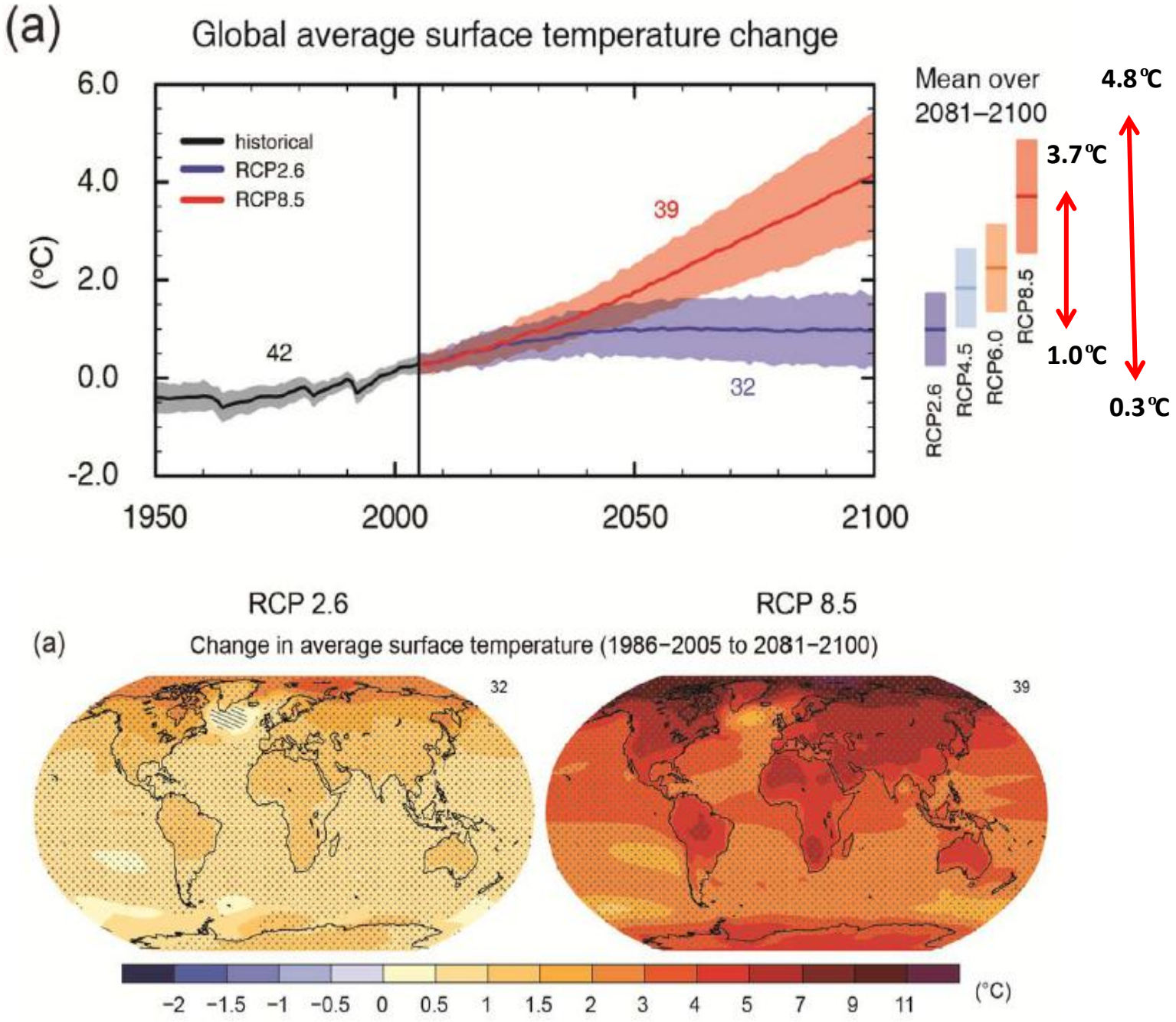
Stabilization Pathway
670 ppm

Stabilization Pathway
538 ppm

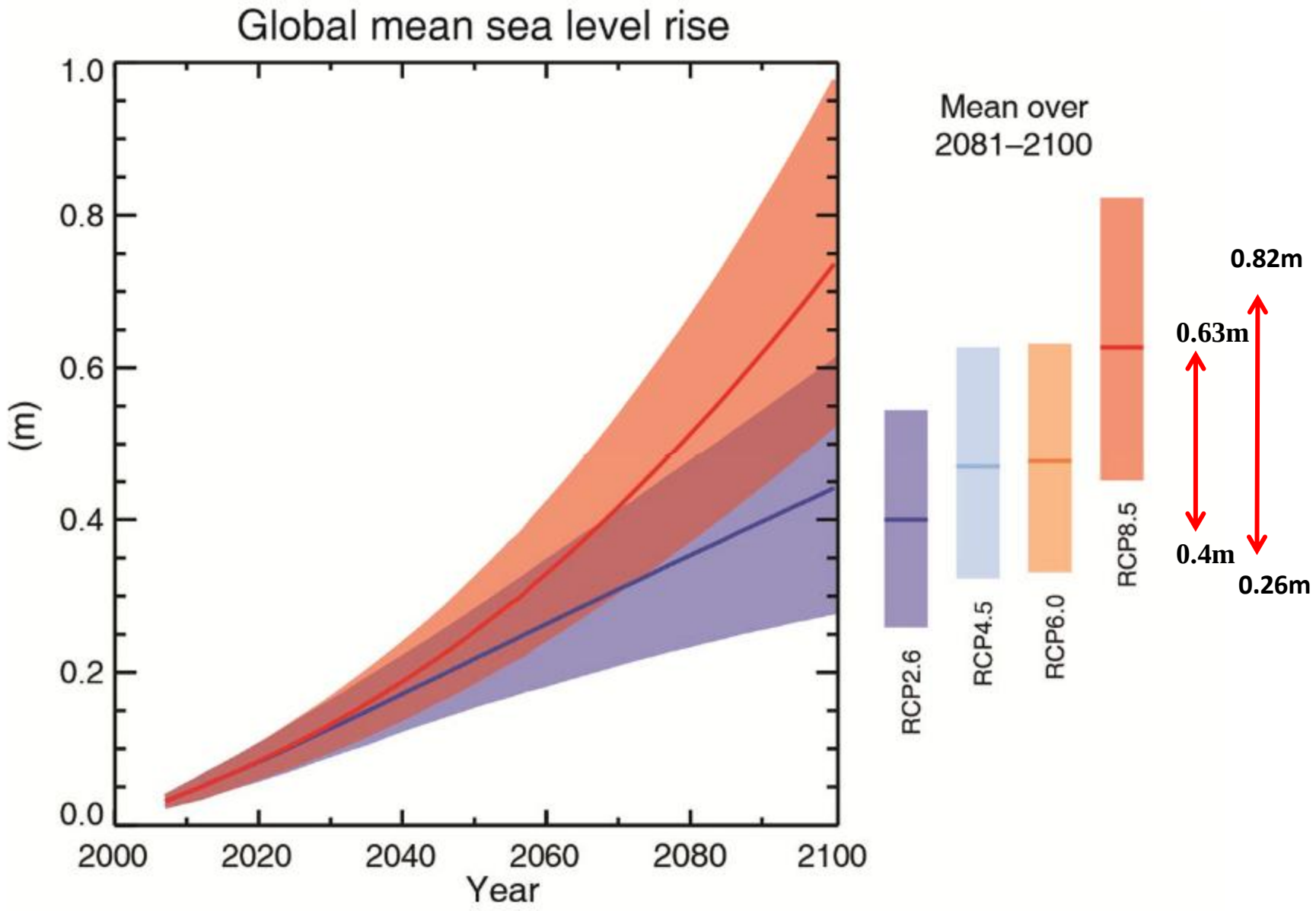
Mitigation Pathway
421 ppm

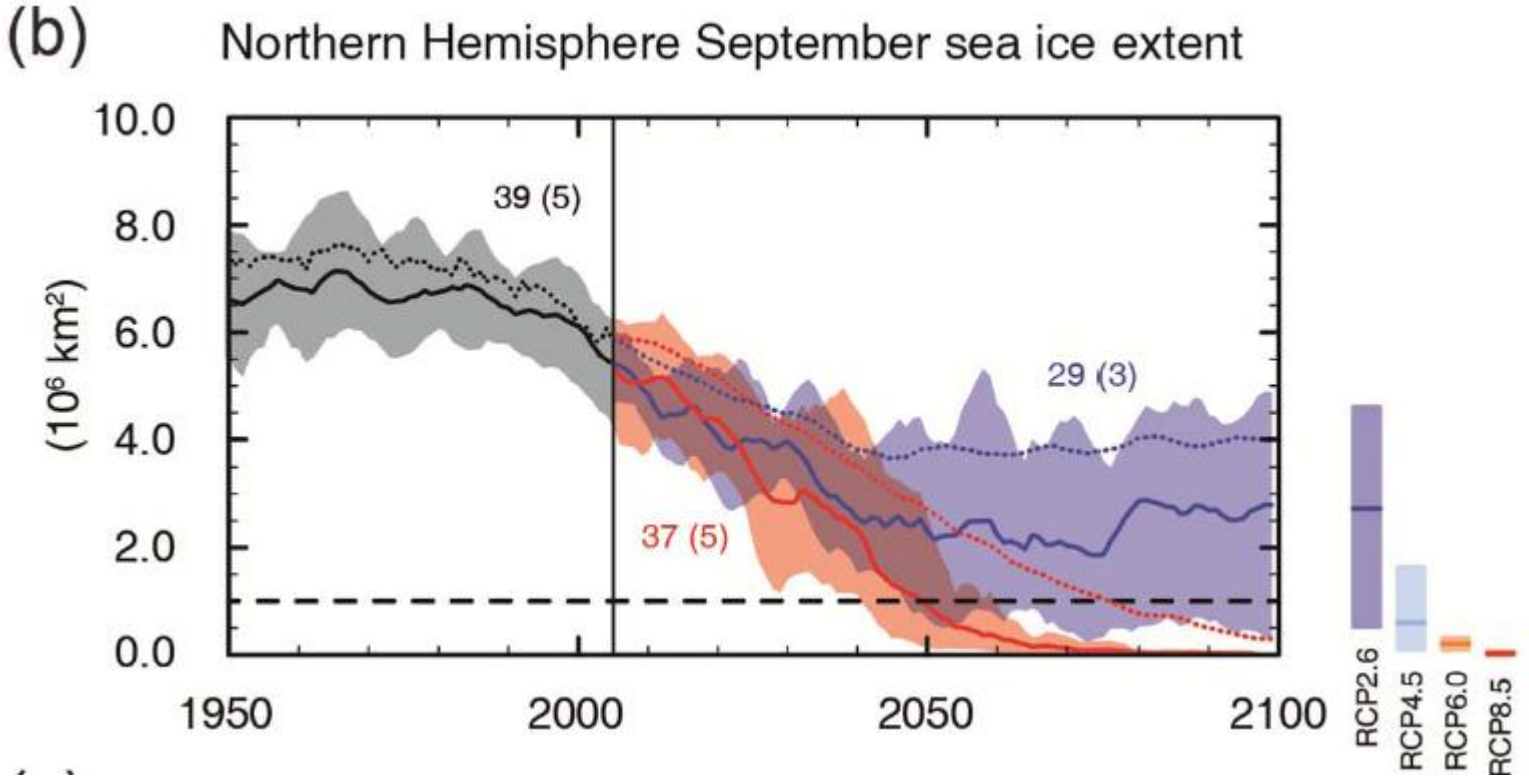
Present: 395 ppm

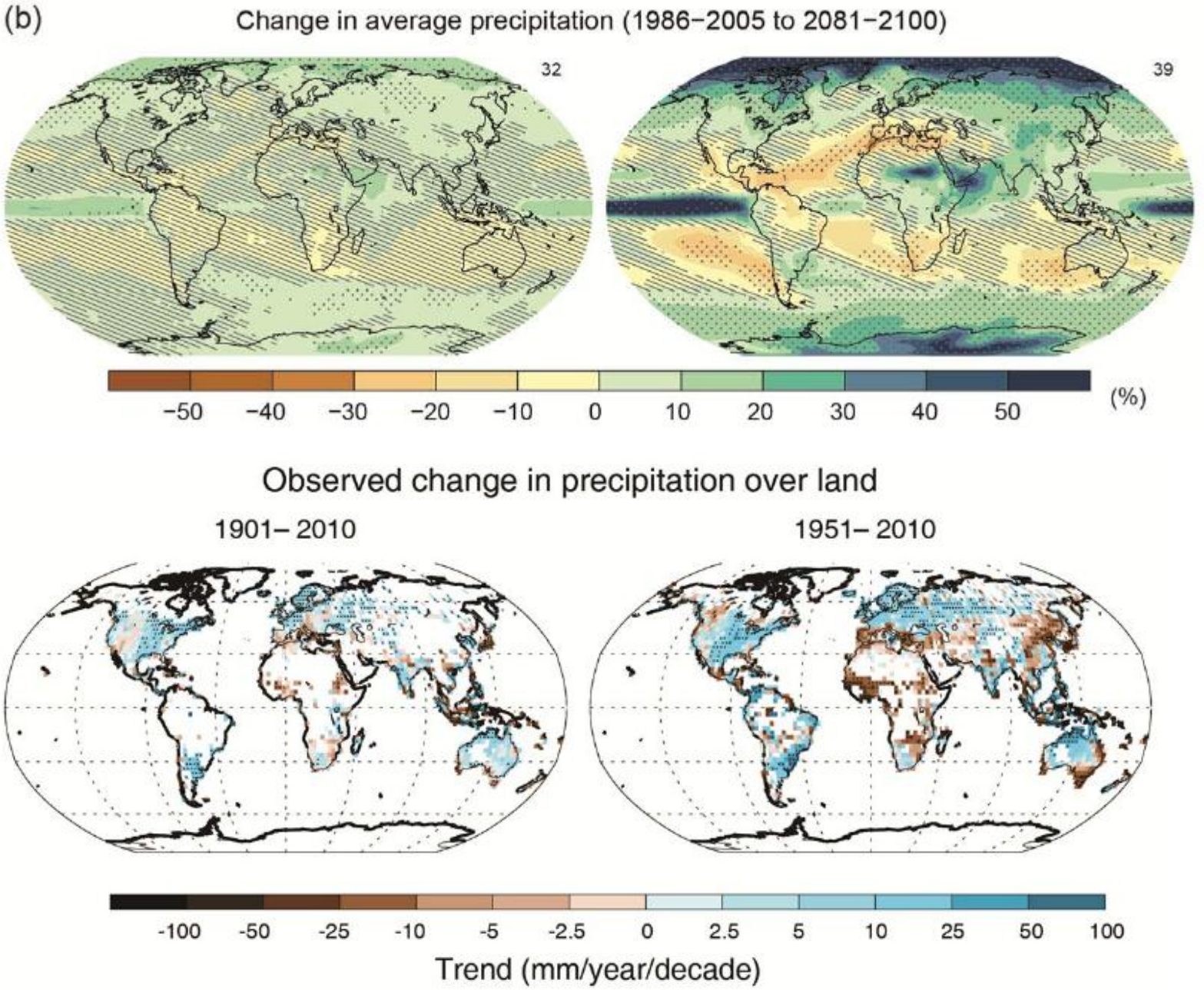
IPCC AR5


(a)
Global average surface temperature change
6.0
4.0
2.0
0.0
-2.0
(°C)
historical
RCP2.6
RCP8.5
42
39
32
1950
2000
2050
2100
Mean over
2081–2100
4.8℃
3.7℃
1.0℃
0.3℃
RCP2.6
RCP4.5
RCP6.0
RCP8.5
RCP 2.6
RCP 8.5
(a)
Change in average surface temperature (1986–2005 to 2081–2100)
32
39
−2
−1.5
−1
−0.5
0
0.5
1
1.5
2
3
4
5
7
9
11
(°C)

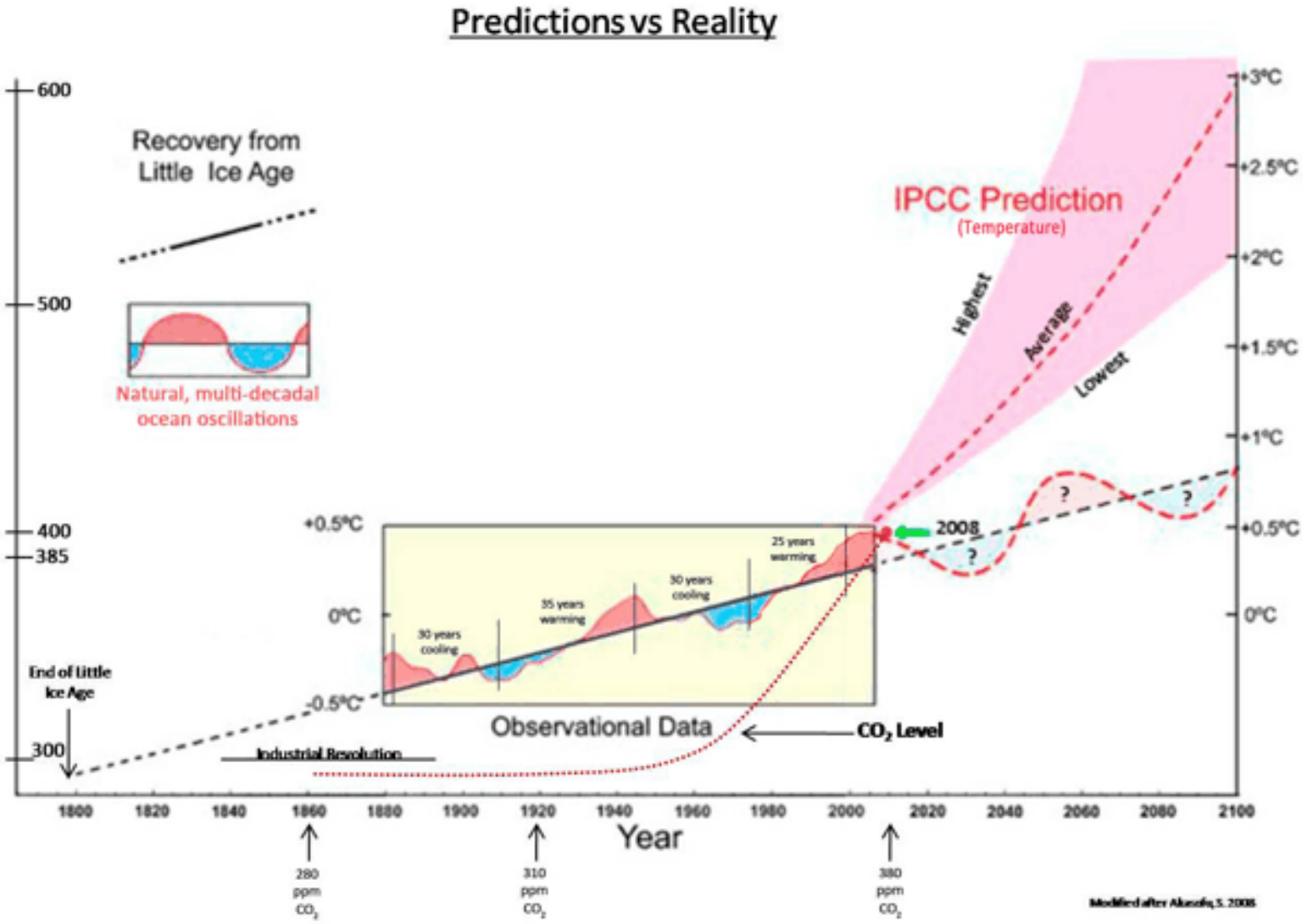
IPCC AR5


Global mean sea level rise
1.0
0.8
0.6
0.4
0.2
0.0
(m)
2000
2020
2040
2060
2080
2100
Year
Mean over
2081–2100
RCP2.6
RCP4.5
RCP6.0
RCP8.5
0.82m
0.63m
0.4m
0.26m

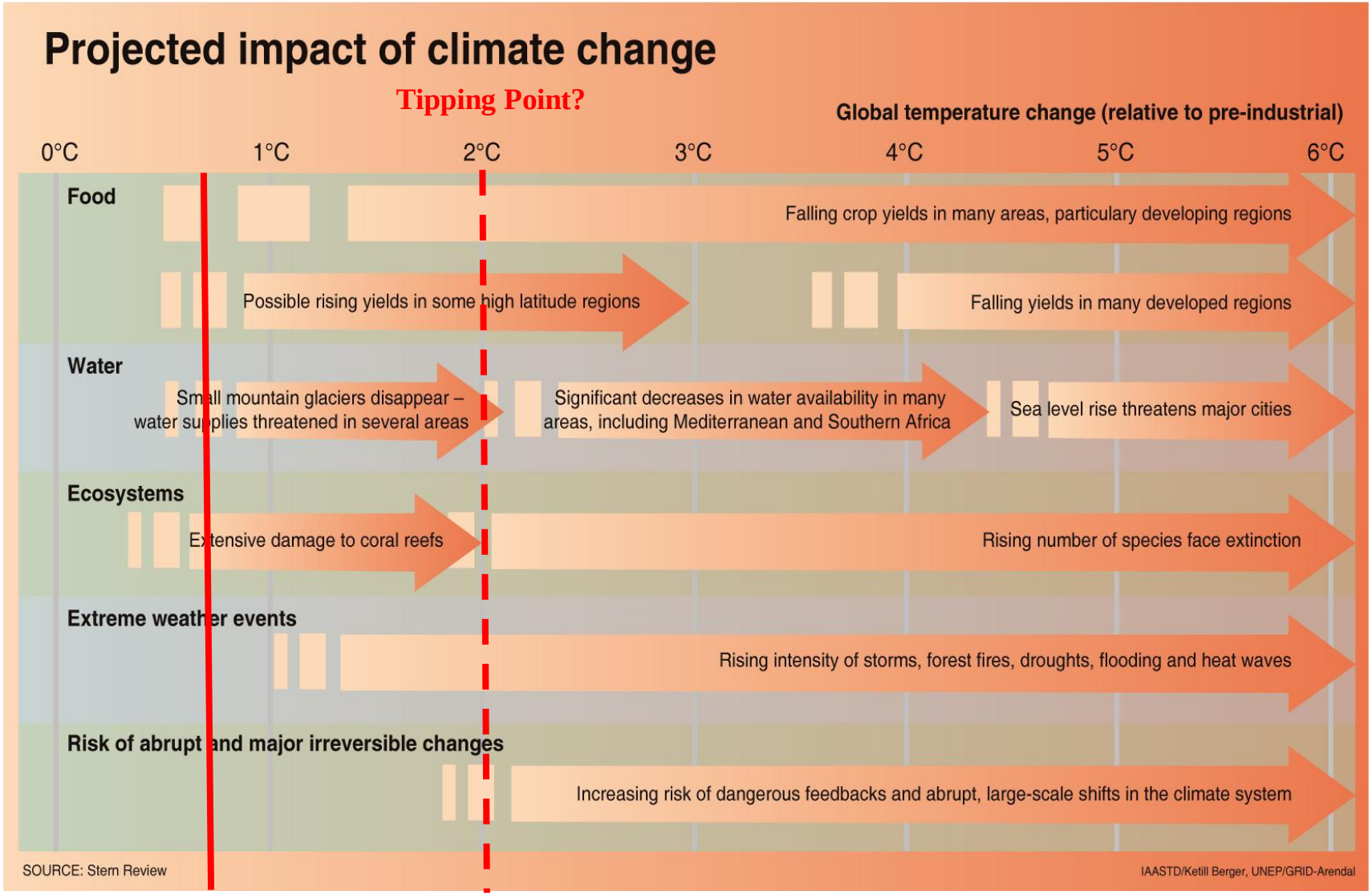

(b)
Northern Hemisphere September sea ice extent
10.0
8.0
6.0
4.0
2.0
0.0
(10⁶ km²)
39 (5)
29 (3)
37 (5)
1950
2000
2050
2100
RCP2.6
RCP4.5
RCP6.0
RCP8.5


(b)
Change in average precipitation (1986–2005 to 2081–2100)
32
39
−50 −40 −30 −20 −10 0 10 20 30 40 50
(%)
Observed change in precipitation over land
1901– 2010
1951– 2010
-100 -50 -25 -10 -5 -2.5 0 2.5 5 10 25 50 100
Trend (mm/year/decade)

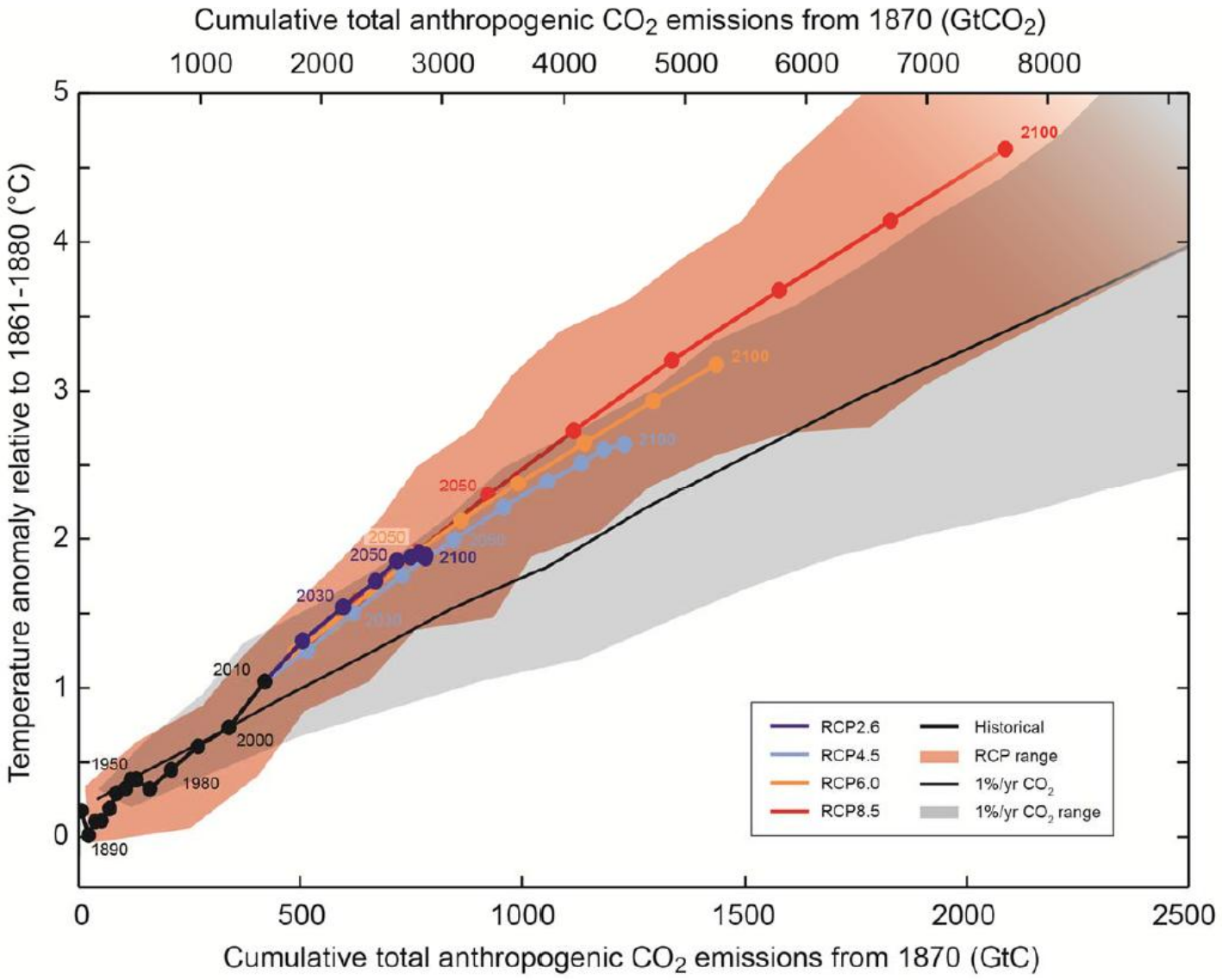
Natural variation？Anthropogenic effect？



How good is our chance to avoid 2℃ warming?



Cumulative emissions of CO2 largely determine global mean surface warming by the late 21st century and beyond.



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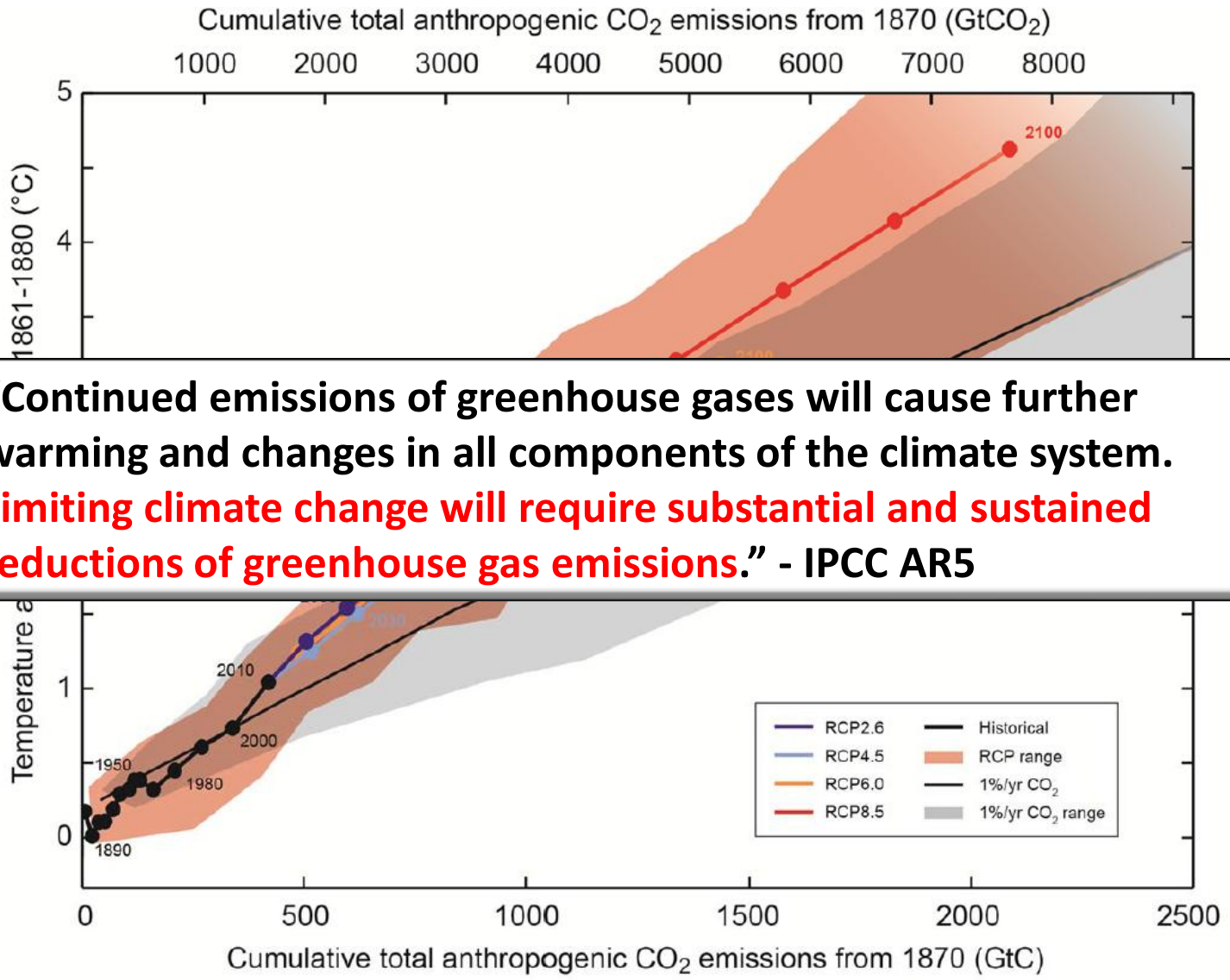


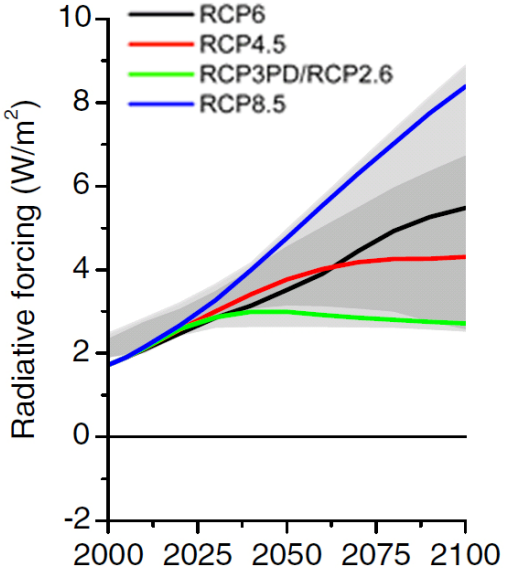
"Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions." - IPCC AR5

Different scenarios yield different projection. We have a choice.

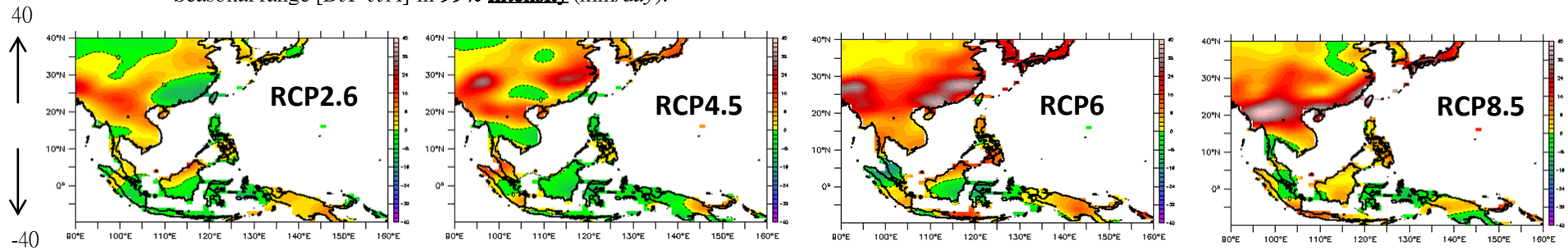
End of 21st Century, Asia

RCP8.5: stronger extreme rainfall, no-rain day frequency increase

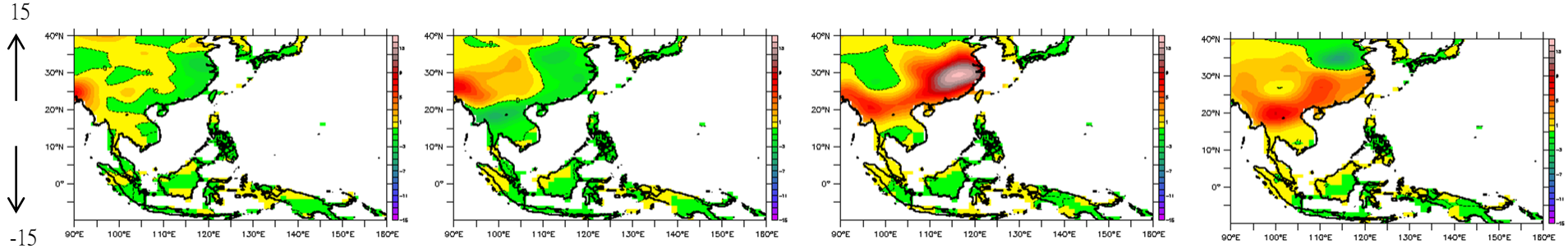
RCP2.6: weaker extreme rainfall, no-rain day frequency decrease



Seasonal range [DJF-JJA] in 99% intensity (*mm/day*).



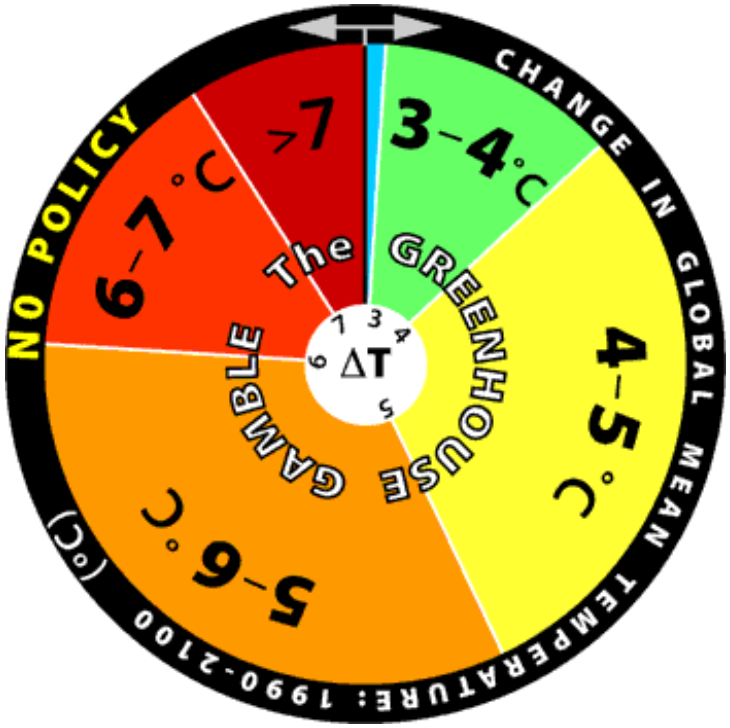
Seasonal range [DJF-JJA] in frequency and no rain days (*days/season*)



Nicolas Freychet

- **Global warming is a projection, not prediction, based on scenarios. If scenarios do not occur, the projection may not happen.**
- **Although projection tools are not perfect, they are the best tools in the human history.**
- **Global warming projection contains uncertainty. It is not a pure scientific issue. It is a matter of choice and a risk assessment and management issue.**
- **Key question: What should we do , in view of future warning, to minimize the potential impact of future global warming?**

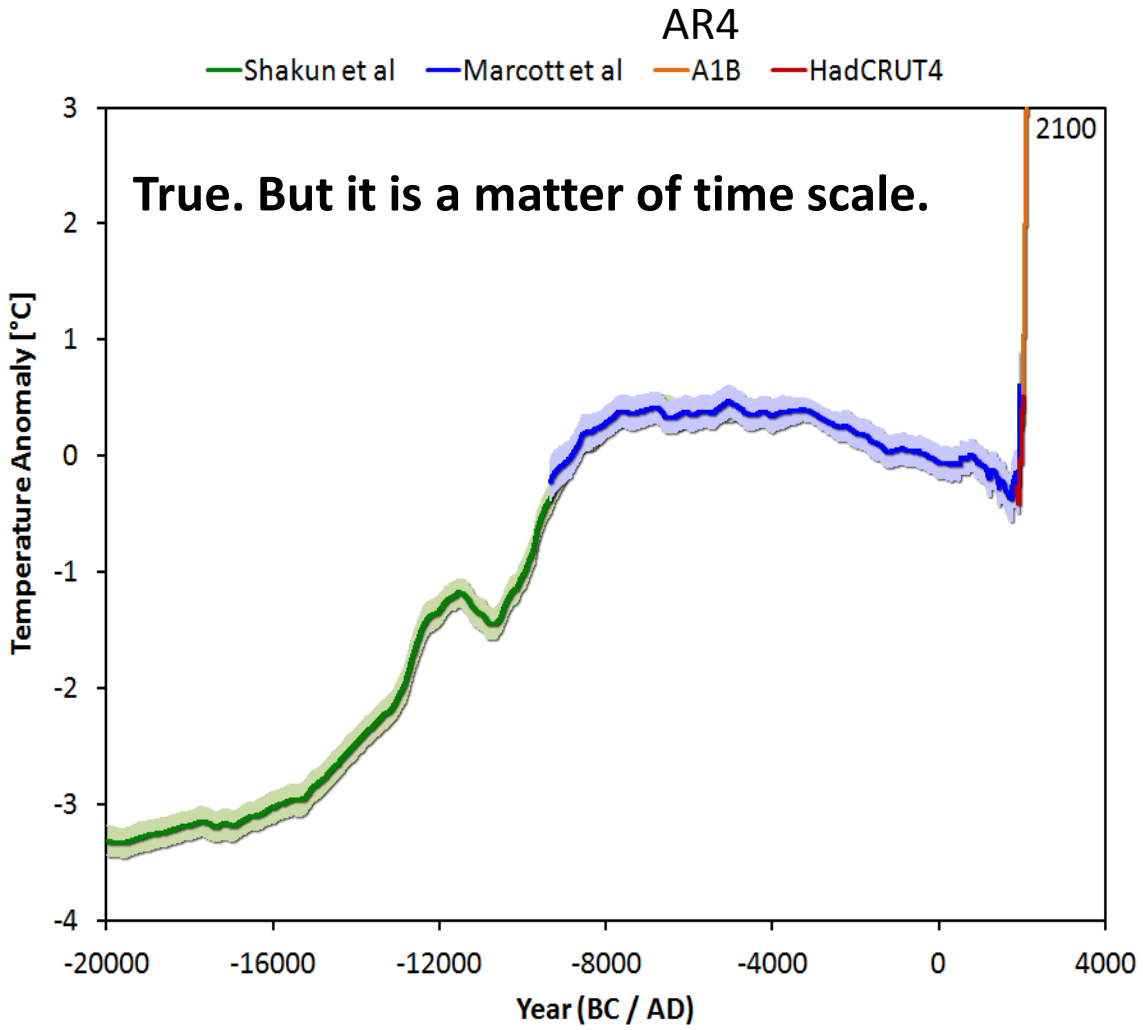
Future is in our hands.



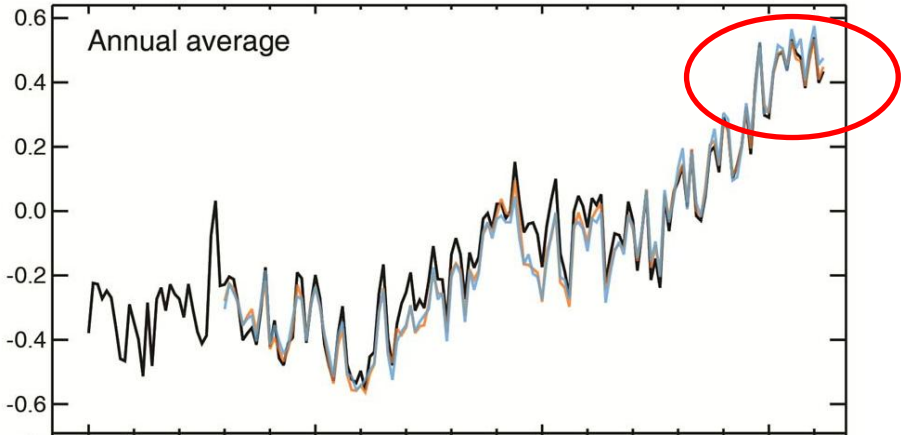
The Joint Program on the Science and Policy of Global Change, MIT
http://globalchange.mit.edu/index.html

Some counter arguments

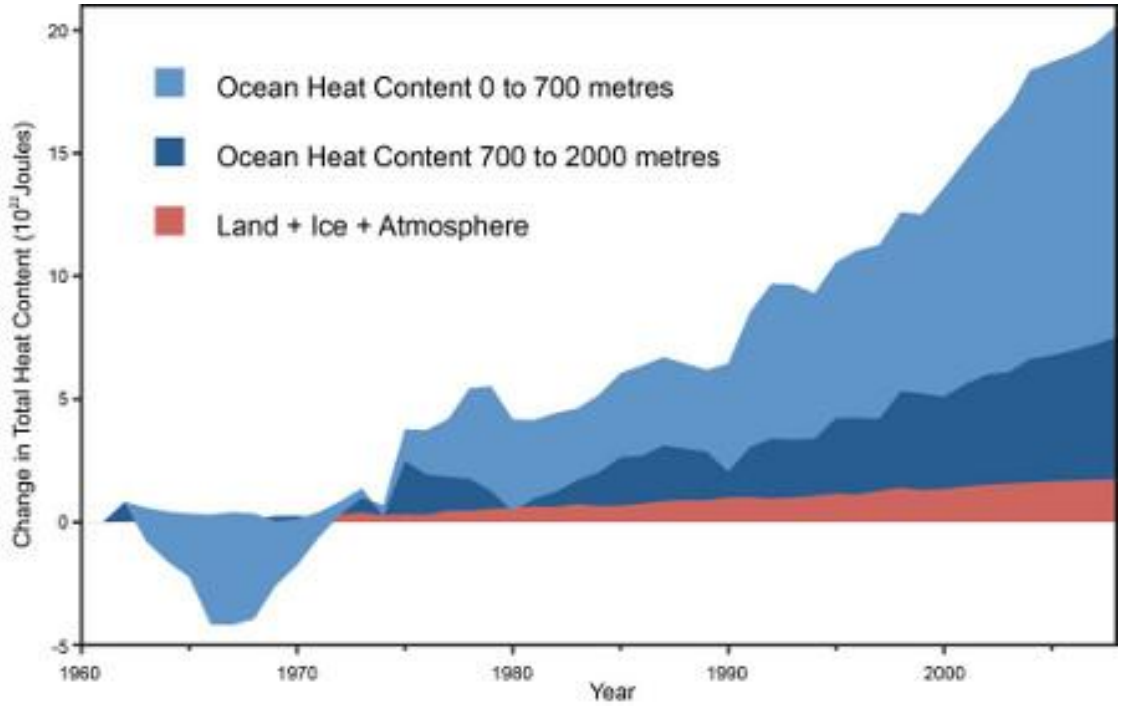
- **Earth climate had fluctuated in a much larger amplitude. 2-3℃ warming is nothing in the Earth history.**



- **Warming has been slowing down since 1998 and may stop.**



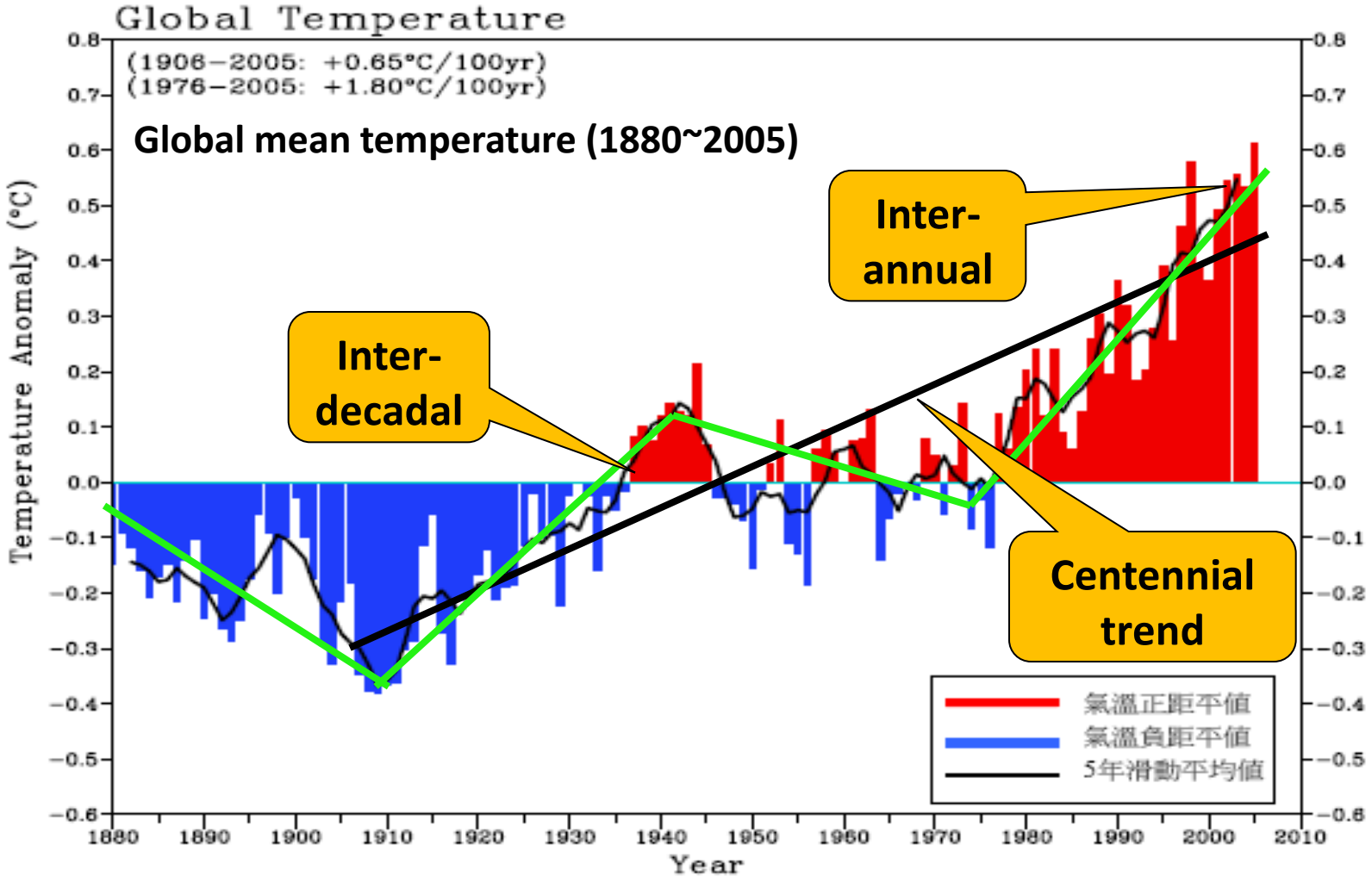
But ocean heat content (sea level) continues increasing.



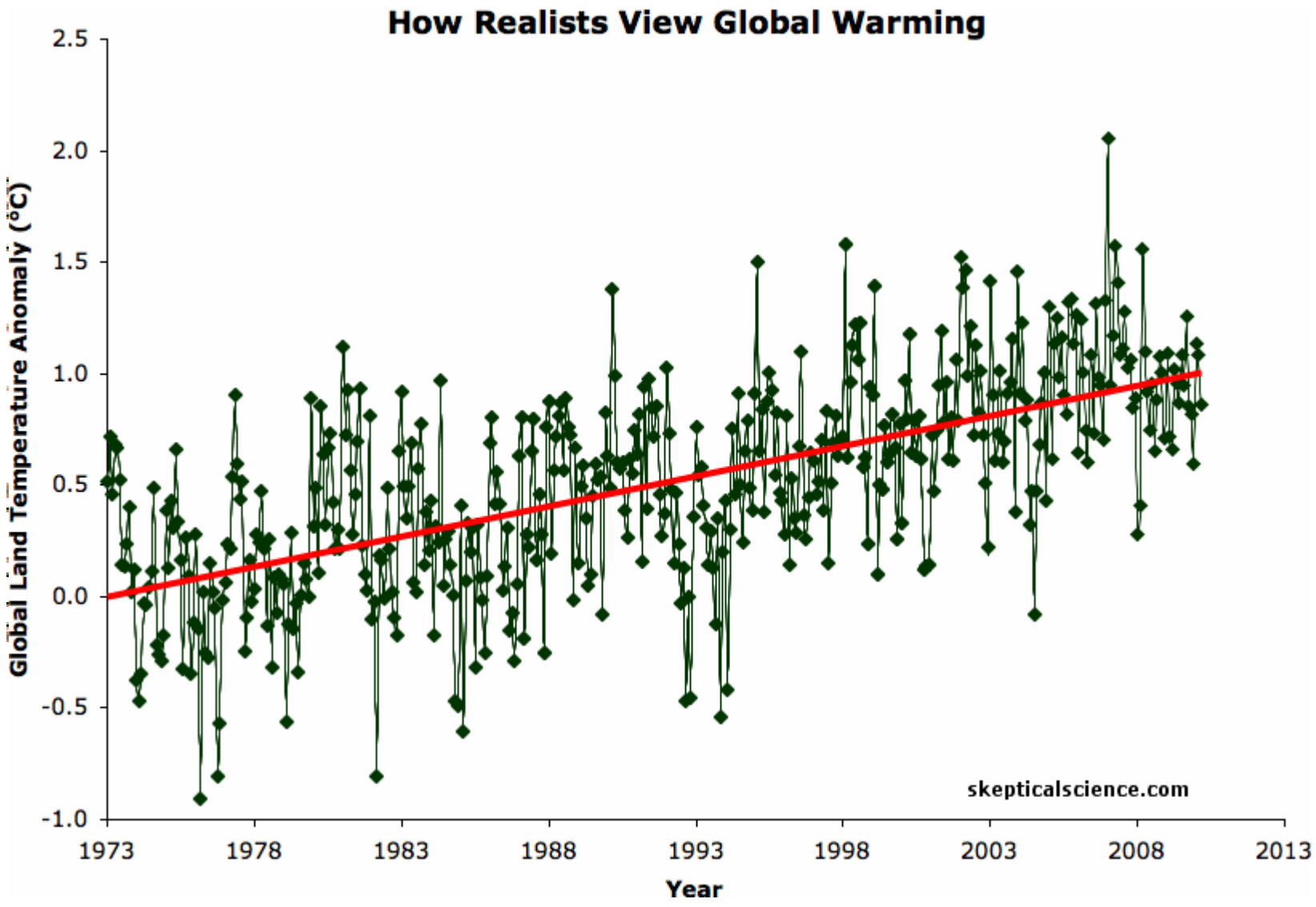
And, again, it is matter of time scale.

Observed change

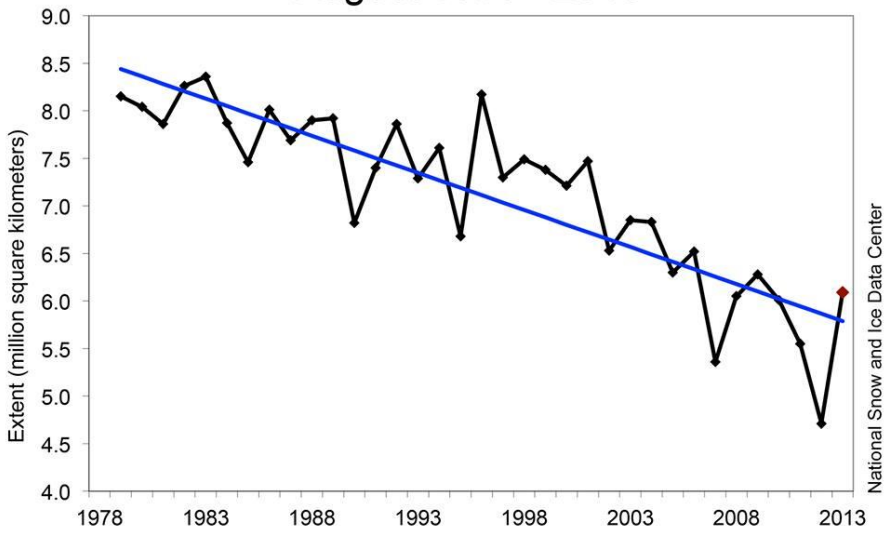
＝centennial＋interdecadal＋interannual

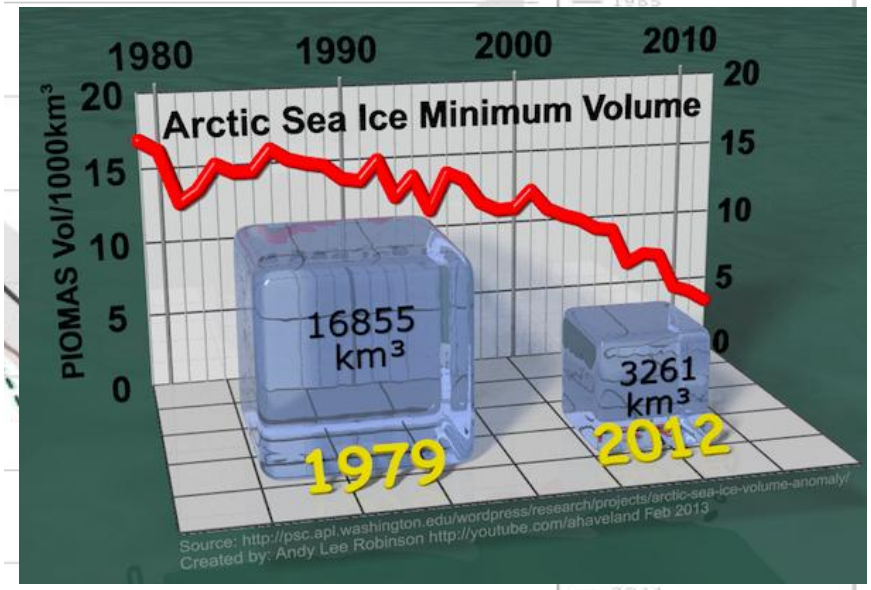


氣象局陳雲蘭提供


How Realists View Global Warming
Global Land Temperature Anomaly (°C)
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
1973
1978
1983
1988
1993
1998
2003
2008
2013
Year
skepticalscience.com

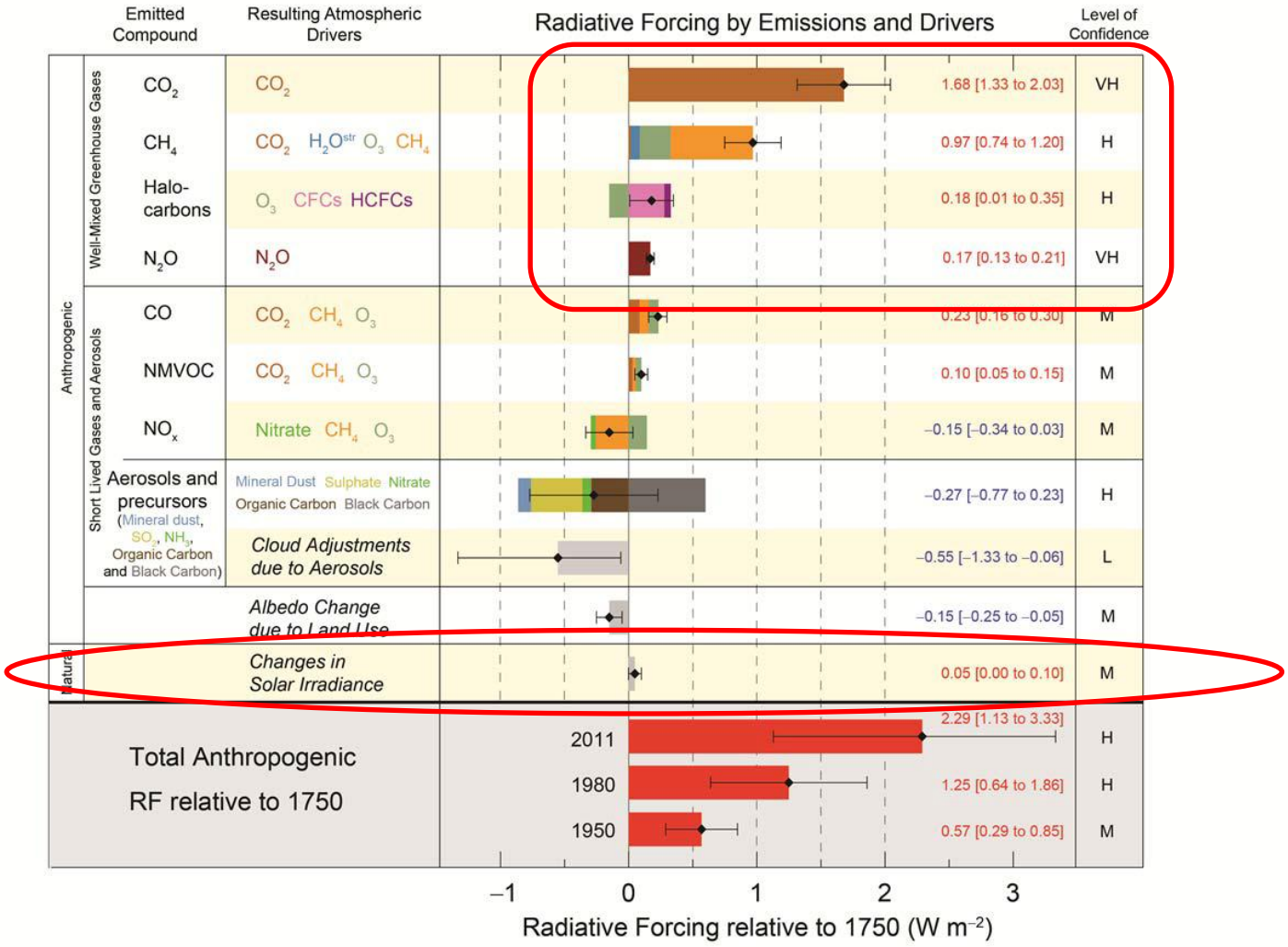
- **Arctic sea ice extent increased by 60% in 2013. Warming has stopped; instead, global cooling may start.**
  - **Matter of time scale, again!**
    2013 was the year with 6th smallest sea ice extent and still lying along the downward trend

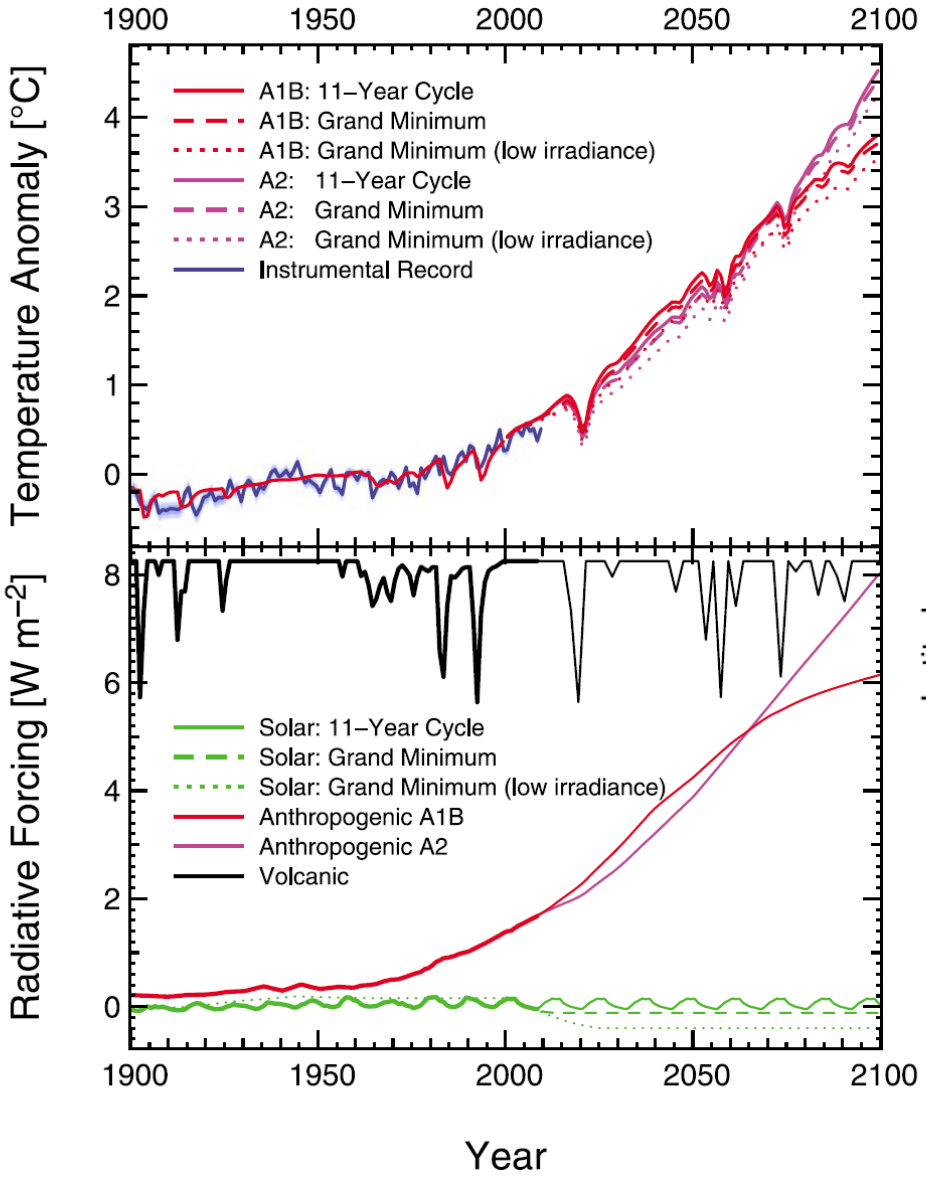




- **How about solar cycle?**

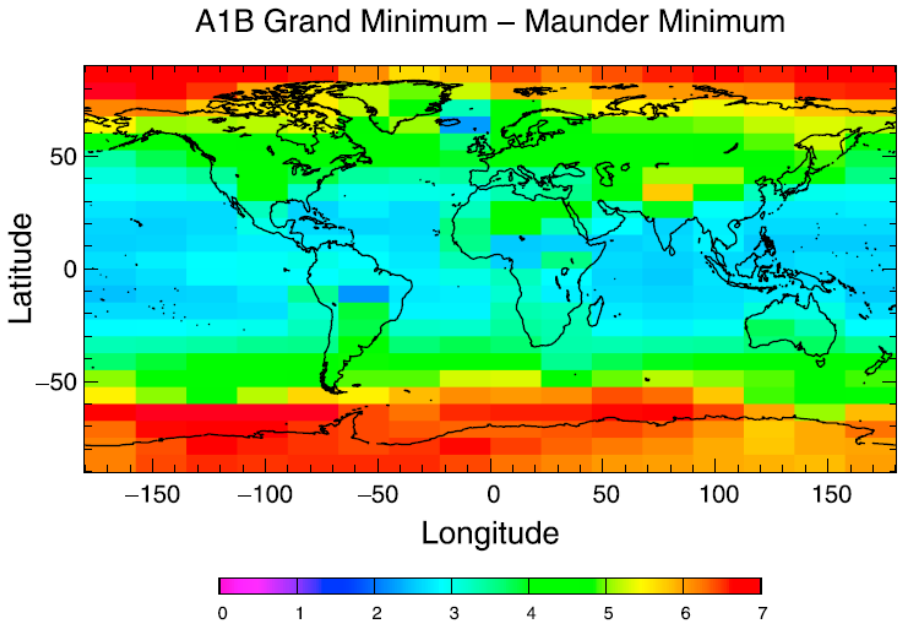
Changes in solar irradiance have been small (0.05Wm^{-2}) compared to other radiative forcings (GHG ~ 3Wm^{-2}).





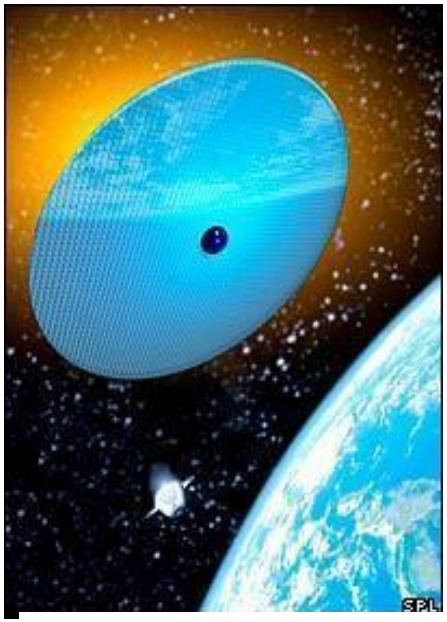
What will happen if "Maunder Minimum" occur again in the future?

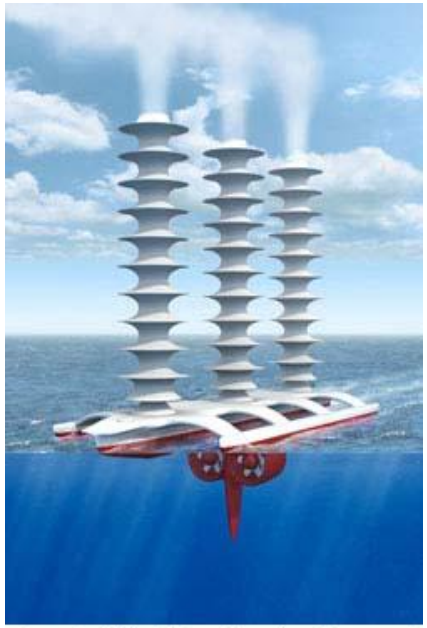
Temperature decrease due to "future grand minimum of solar activity" is much smaller than the warming expected from anthropogenic greenhouse gas emissions by the end of the century.



Feulner, G., and S. Rahmstorf (2010), On the effect of a new grand minimum of solar activity on the future climate on Earth, Geophys. Res. Lett., 37, L05707, doi:10.1029/2010GL042710.

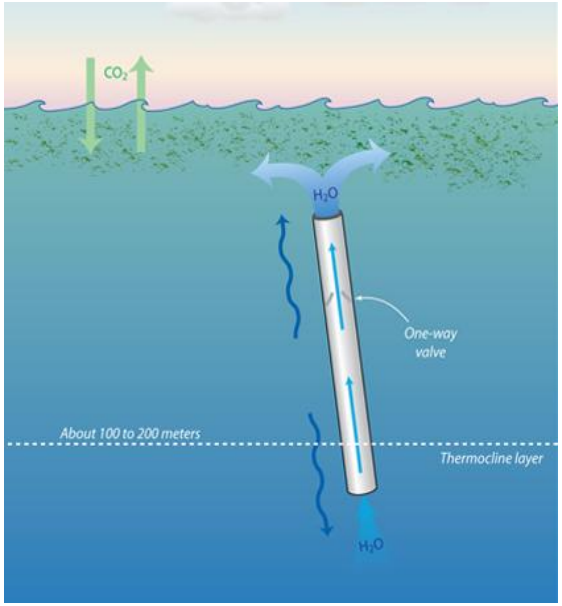
Geoengineering: Hopes for offsetting future warming?



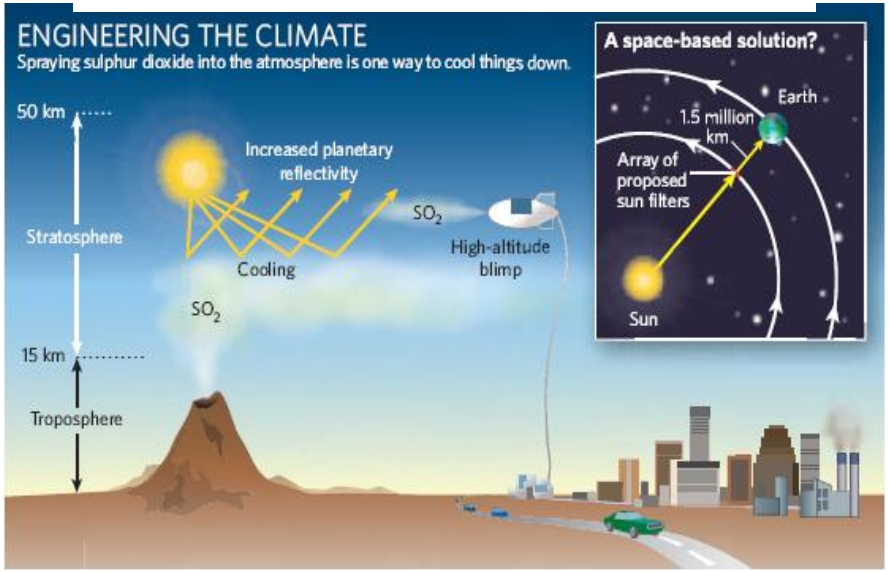


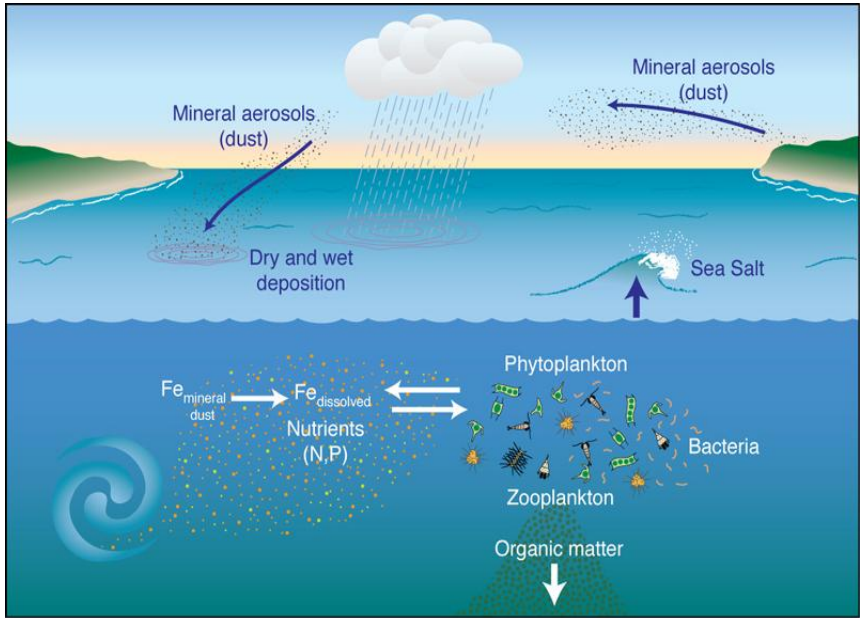
cloud-seeding vessel
John McNeill

Carbon Dioxide Removal (CDR)



Solar Radiation Management (SRM)





AR5 Assessment

- **CDR methods have biogeochemical and technological limitations to their potential on a global scale. There is insufficient knowledge to quantify how much CO2 emissions could be partially offset by CDR on a century timescale.**
- **Modelling indicates that SRM methods, if realizable, have the potential to substantially offset a global temperature rise, but they would also modify the global water cycle, and would not reduce ocean acidification.**
- **If SRM were terminated for any reason, there is *high confidence* that global surface temperatures would rise very rapidly to values consistent with the greenhouse gas forcing.**
- **CDR and SRM methods carry side effects and long-term consequences on a global scale.**