Earth's Climate from Space

Richard Allan
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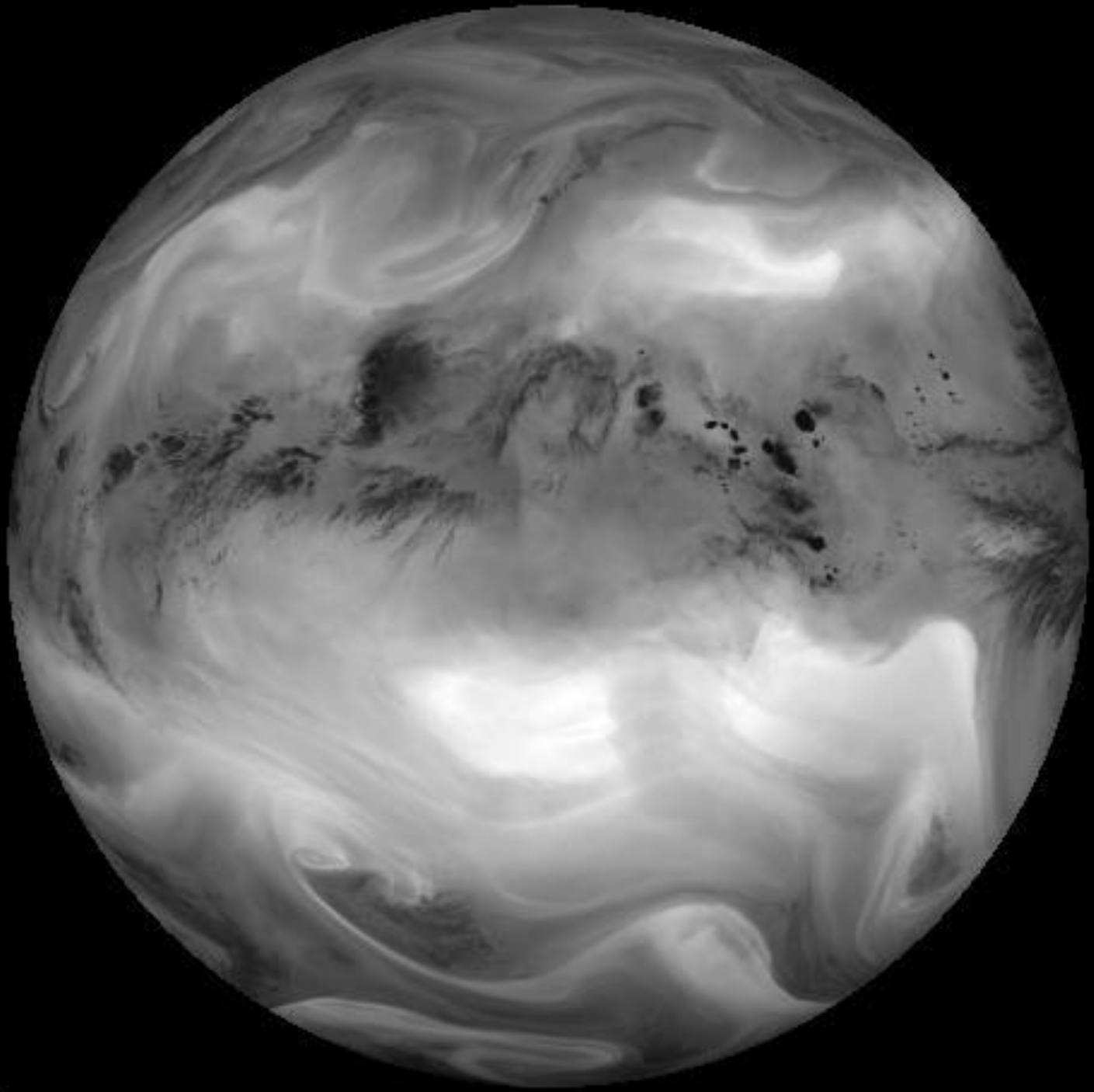
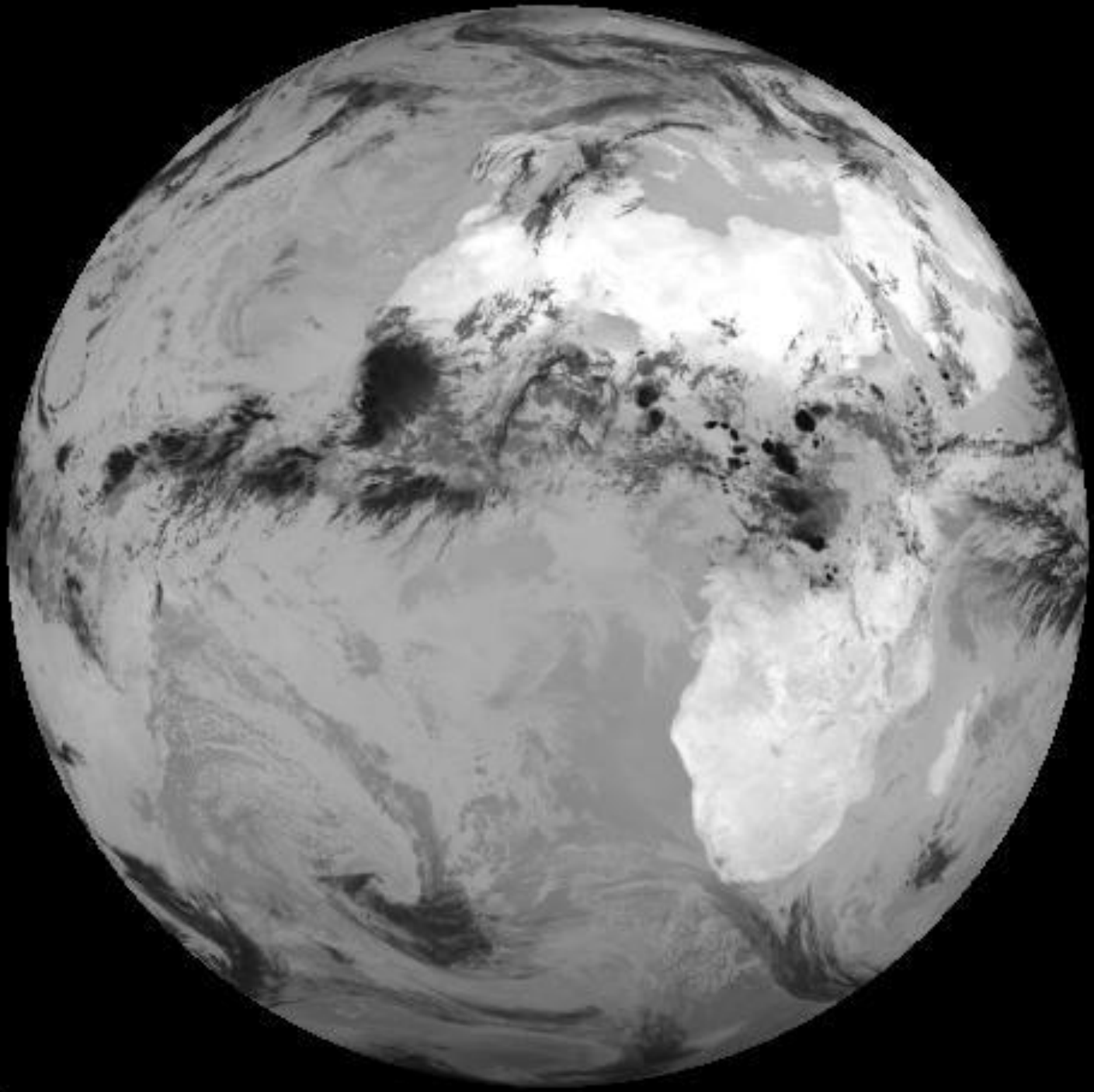
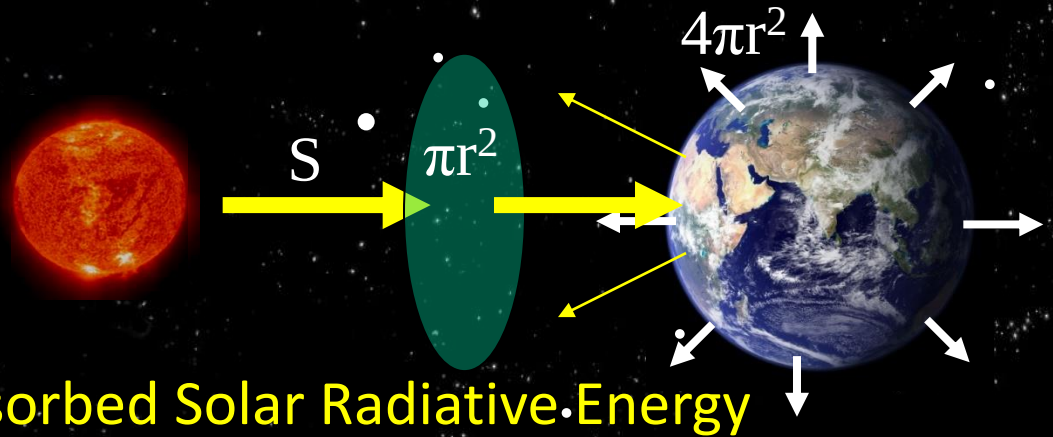




Earth's energy balance in space

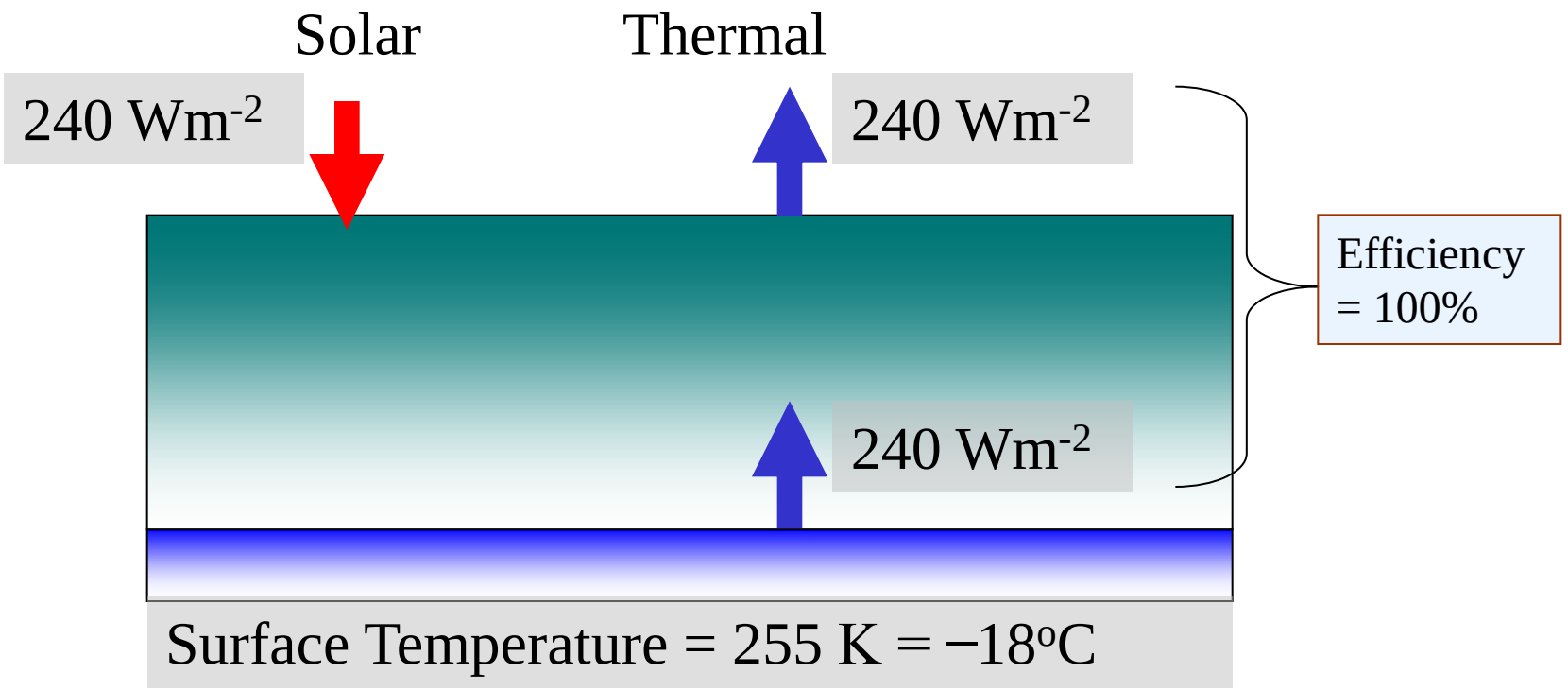


$$S/4\,(1-\alpha) = F$$

- There is a balance between the absorbed sunlight and the thermal radiative cooling of the planet
- Without the greenhouse effect, this balance would occur at a frigid global temperature of –18°C

Fourier (1824); Tyndall (1858); Arhenius (1896); Lacis et al. (2011)

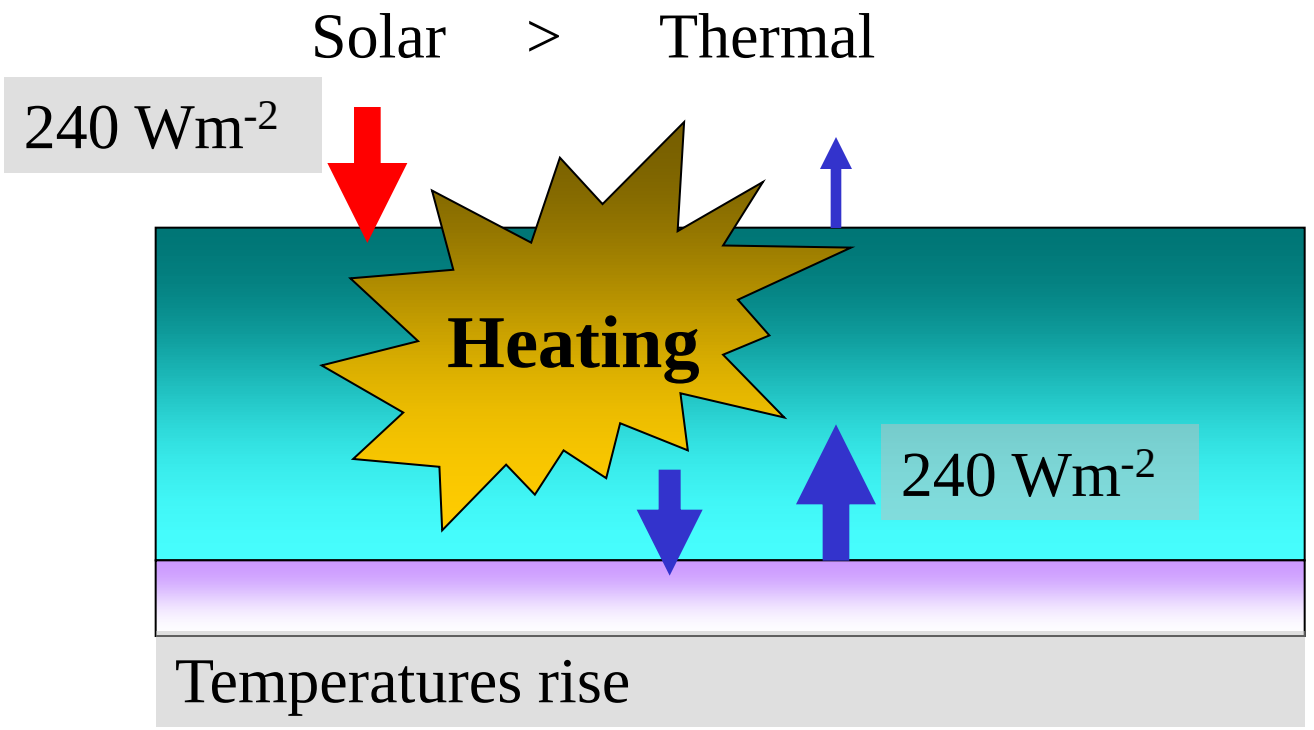
Earth's global average energy balance: no atmosphere



$$S/4\,(1-\alpha) = F \sim \varepsilon\sigma T_s^{\,4}$$

S≈1361 Wm^{-2} α~0.3 $\varepsilon = 1$ $\sigma = 5.67 \times 10^{-8}\, Wm^{-2}K^{-4}$

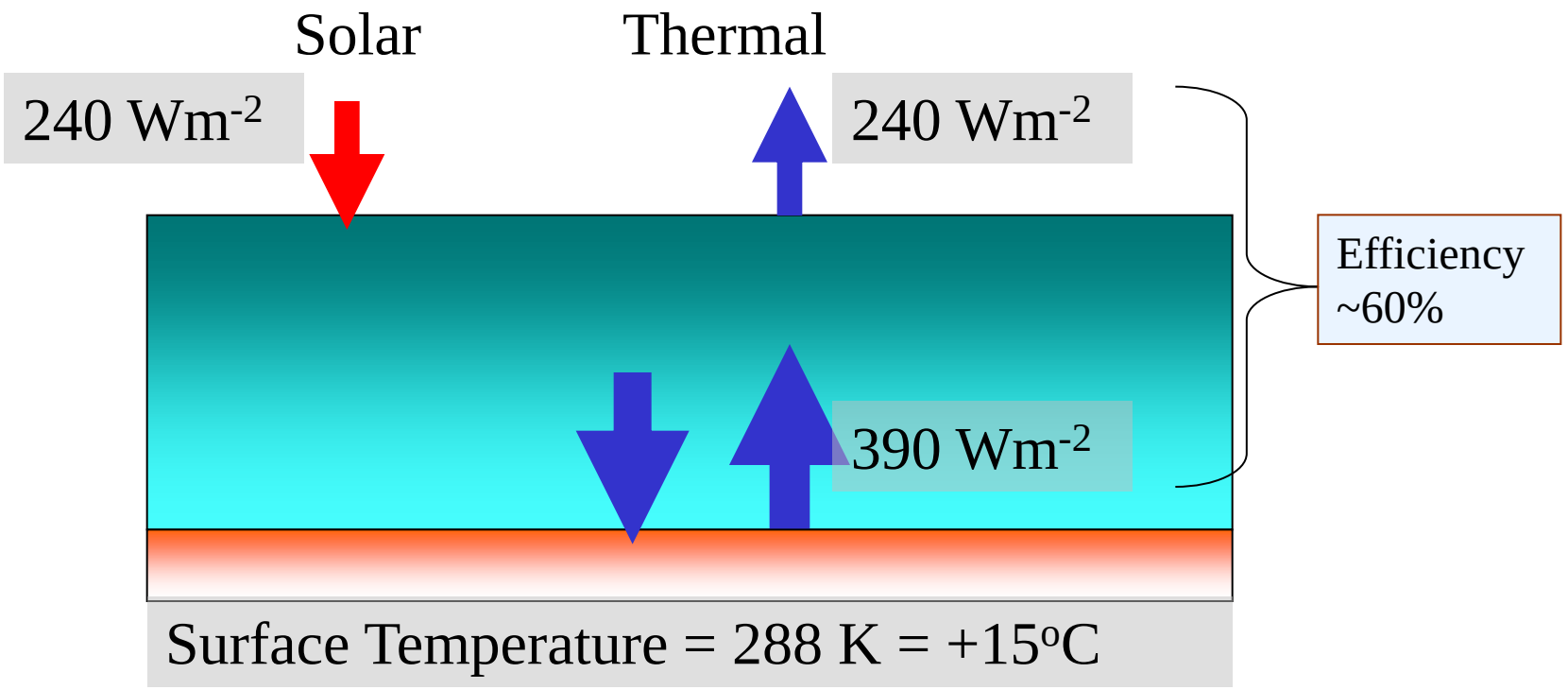
Earth's global average energy balance: add atmosphere



$$S/4\,(1-\alpha) = F \sim \varepsilon\sigma T_s^{\,4}$$

S≈1361 Wm^{-2} α~0.3 $\varepsilon < 1$ $\sigma = 5.67 \times 10^{-8}\, W m^{-2} K^{-4}$

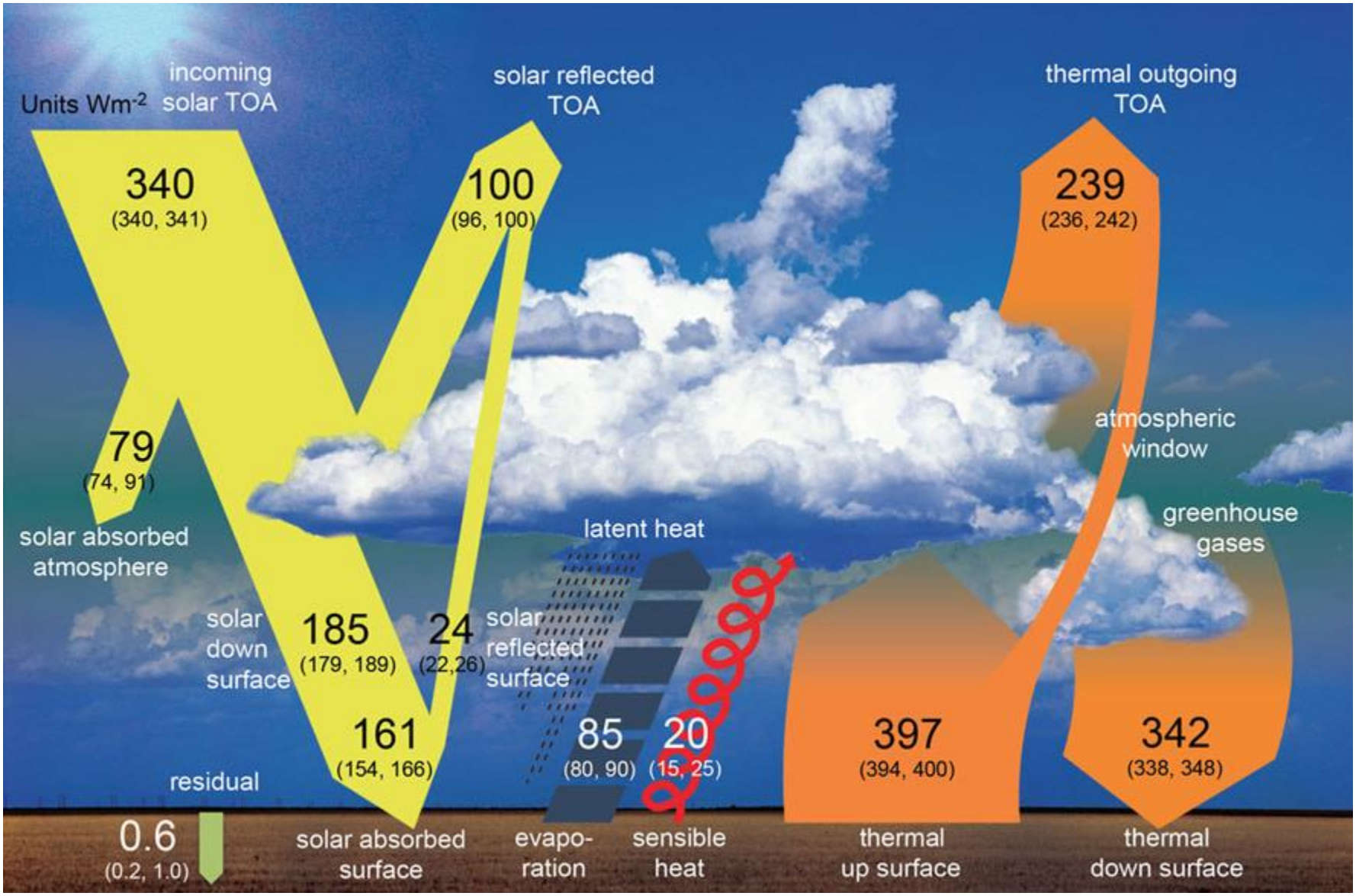
Earth's global average energy balance: present day



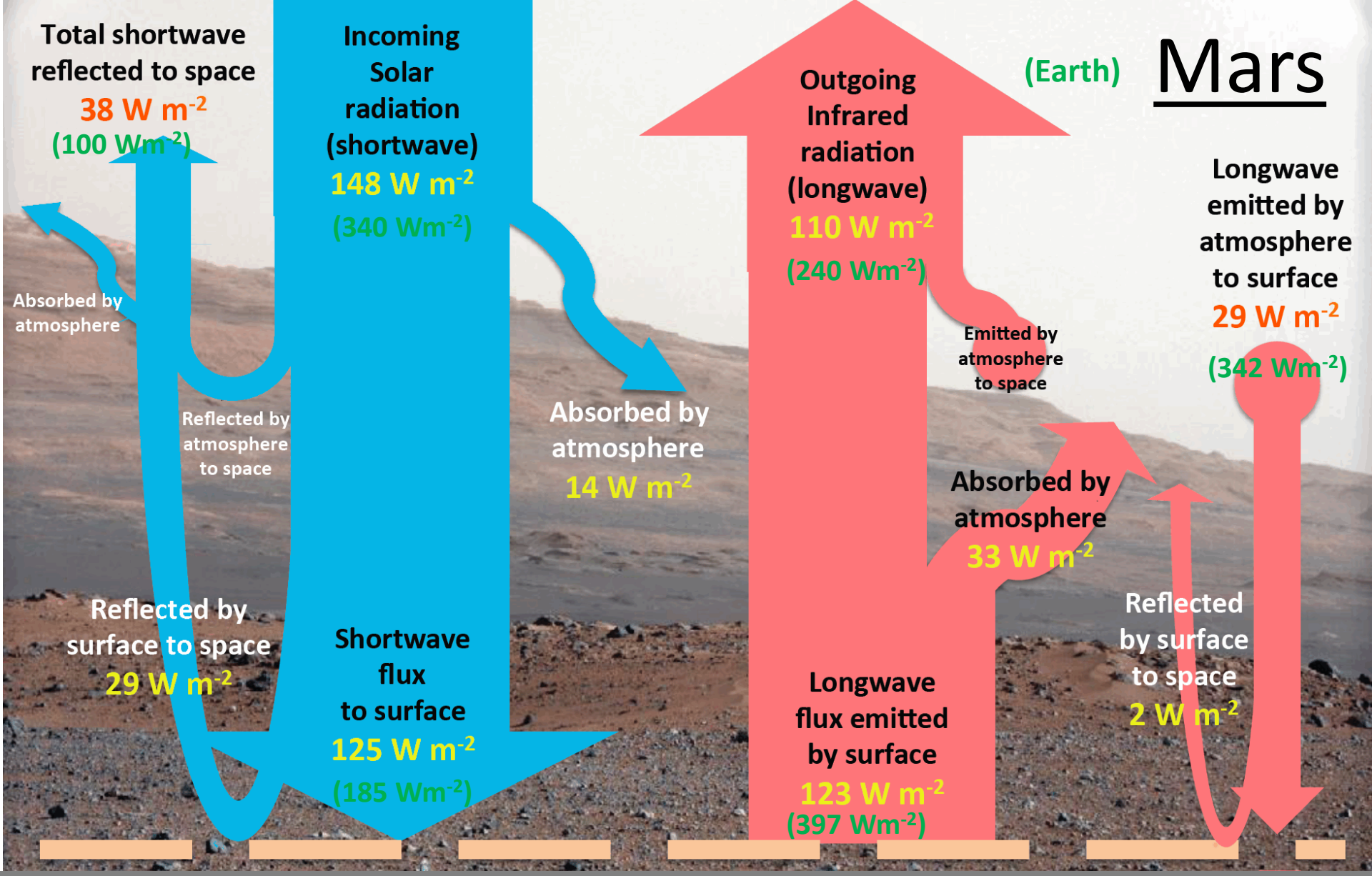
$$S/4\,(1-\alpha) = F \sim \varepsilon\sigma T_s^{\,4}$$

S≈1361 Wm^{-2} $\alpha \sim 0.3$ $\varepsilon \sim 0.6$ $\sigma = 5.67 \times 10^{-8}\, W m^{-2} K^{-4}$

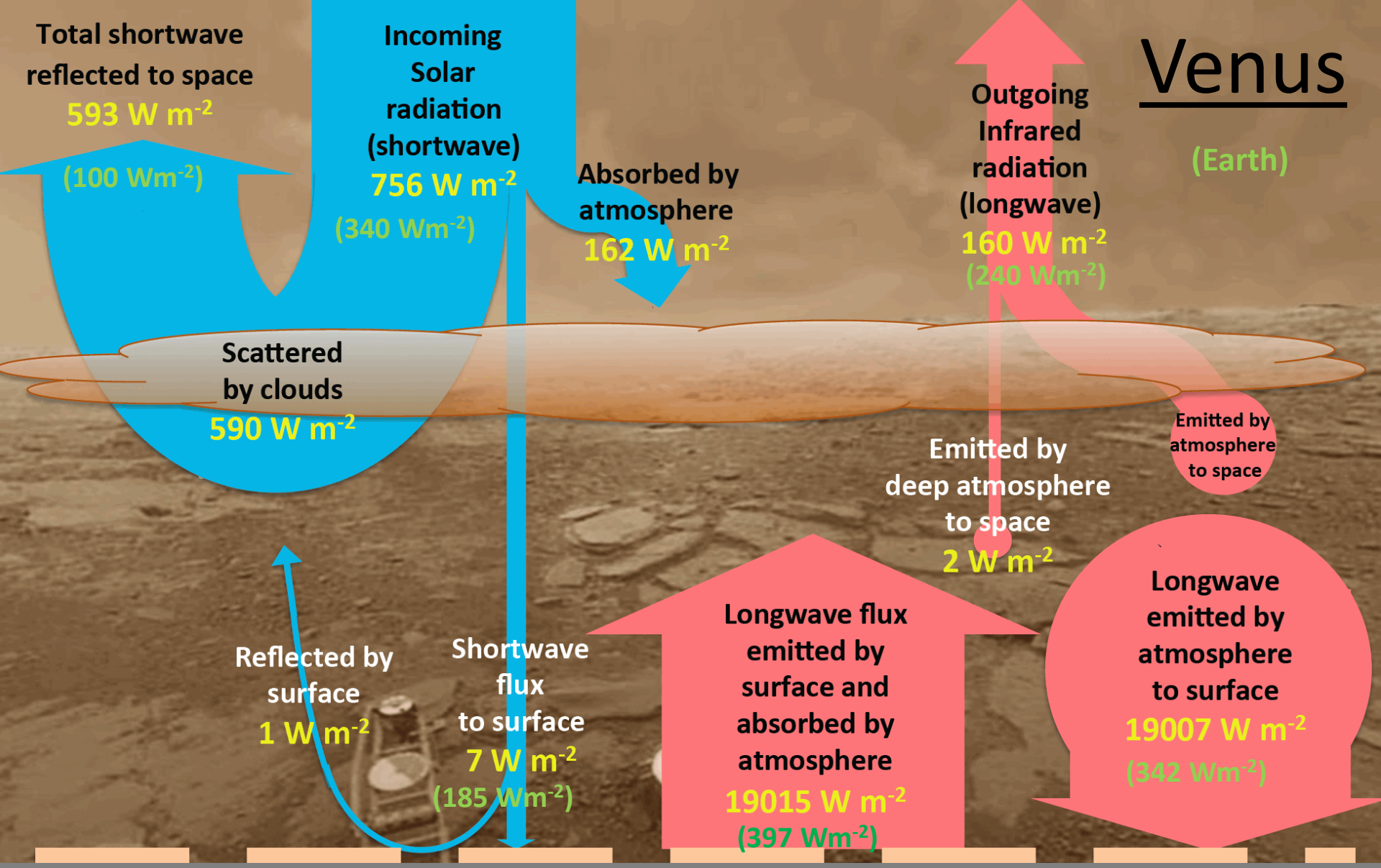
Earth's Global Annual Average Energy Balance



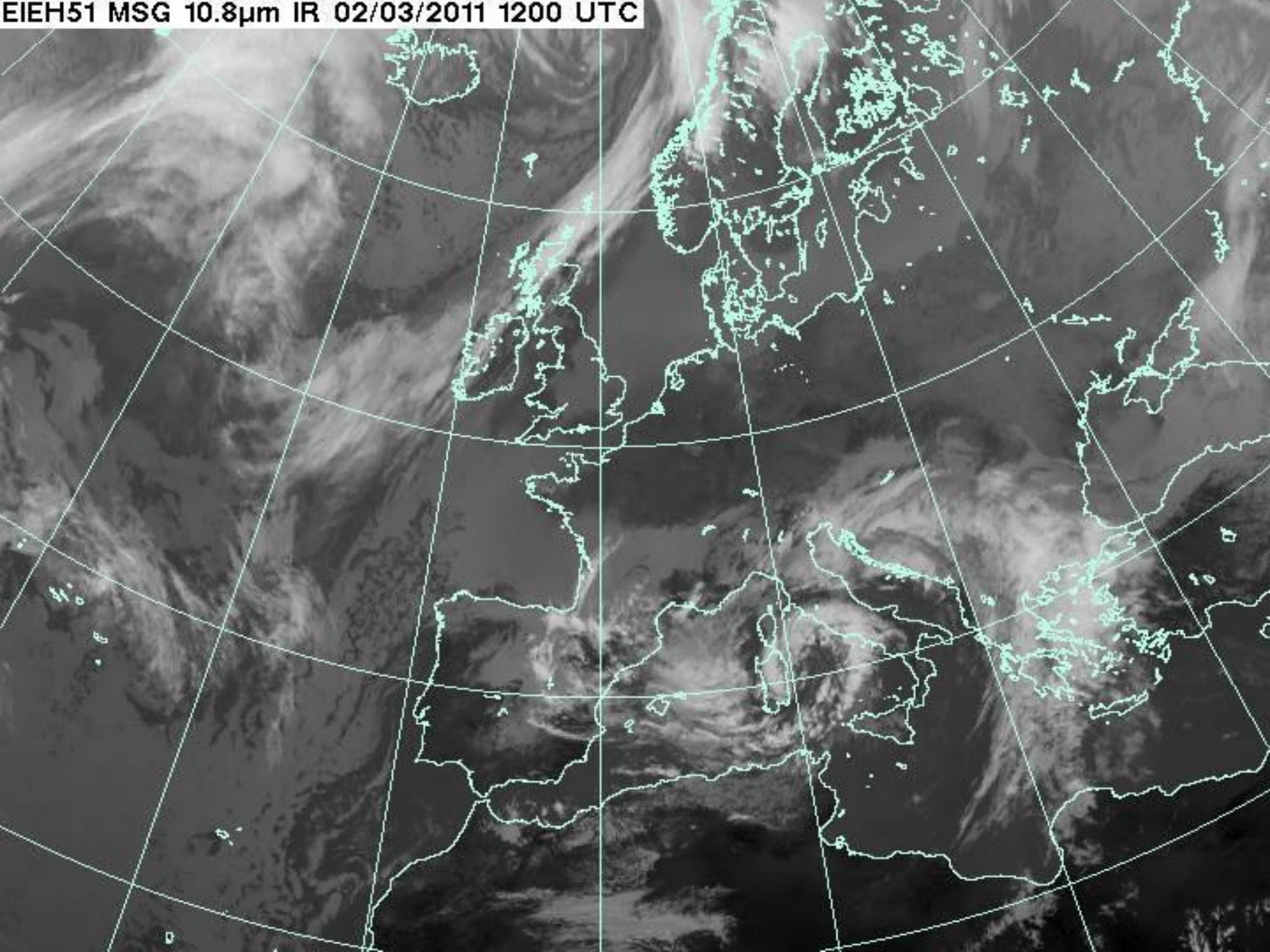
Wild et al. (2012) Clim. Dynamics. See also: Trenberth et al. (2009) BAMS

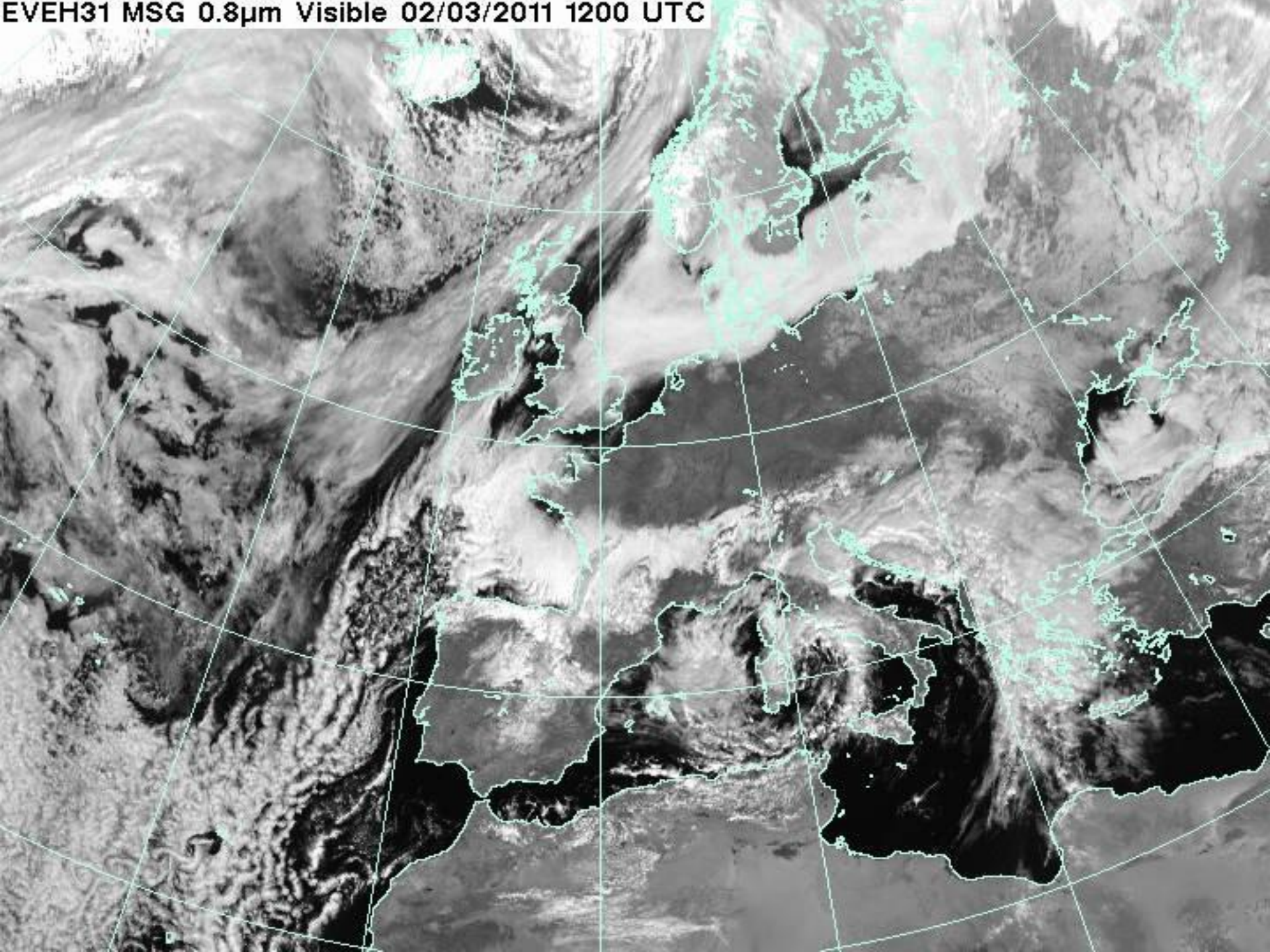


P. L. Read (Univ Oxford) after Angelats i Col et al. (2005)



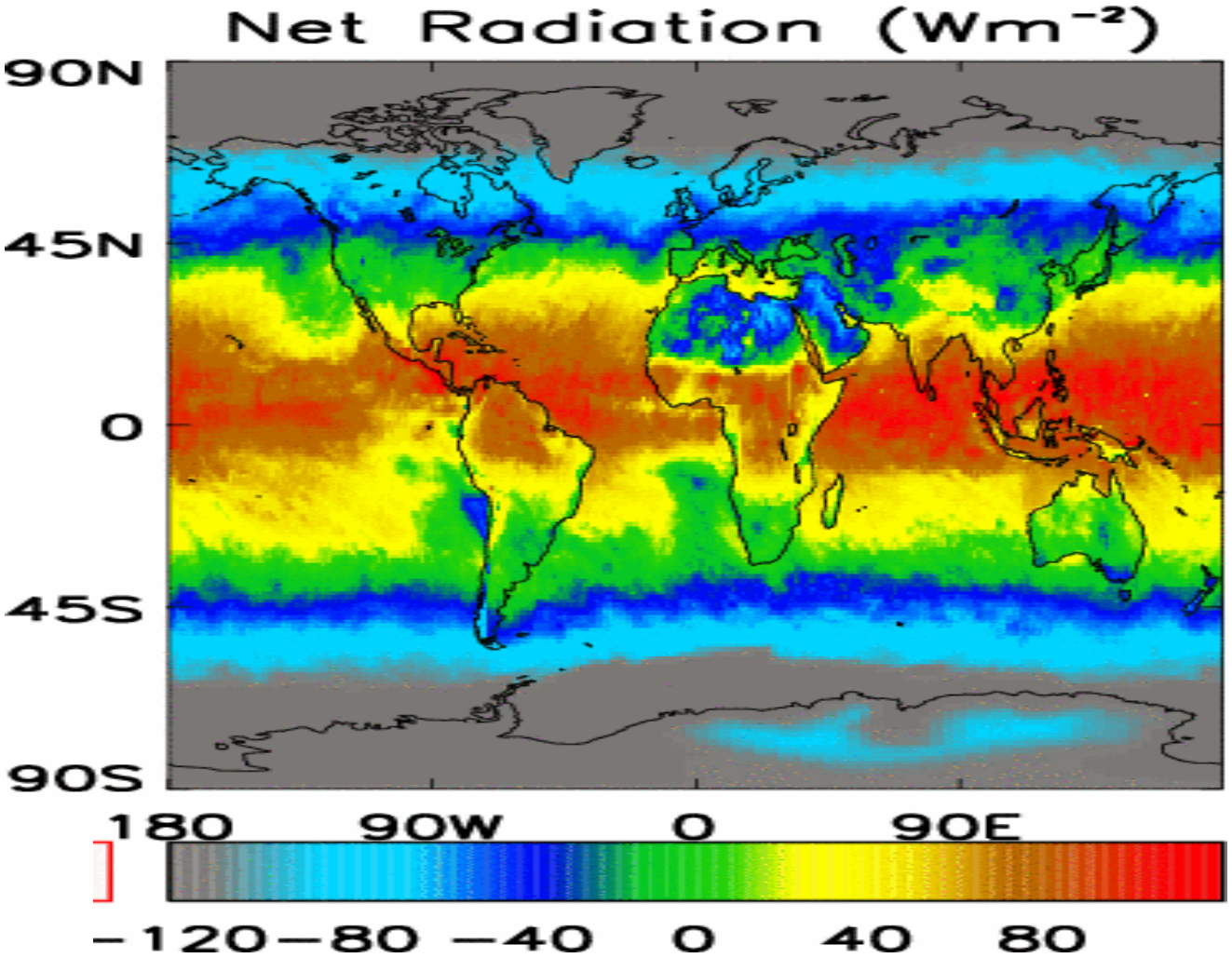
P. L. Read (Univ Oxford) after Mendonca (2013)


EIEH51 MSG 10.8µm IR 02/03/2011 1200 UTC


EVEH31 MSG 0.8µm Visible 02/03/2011 1200 UTC

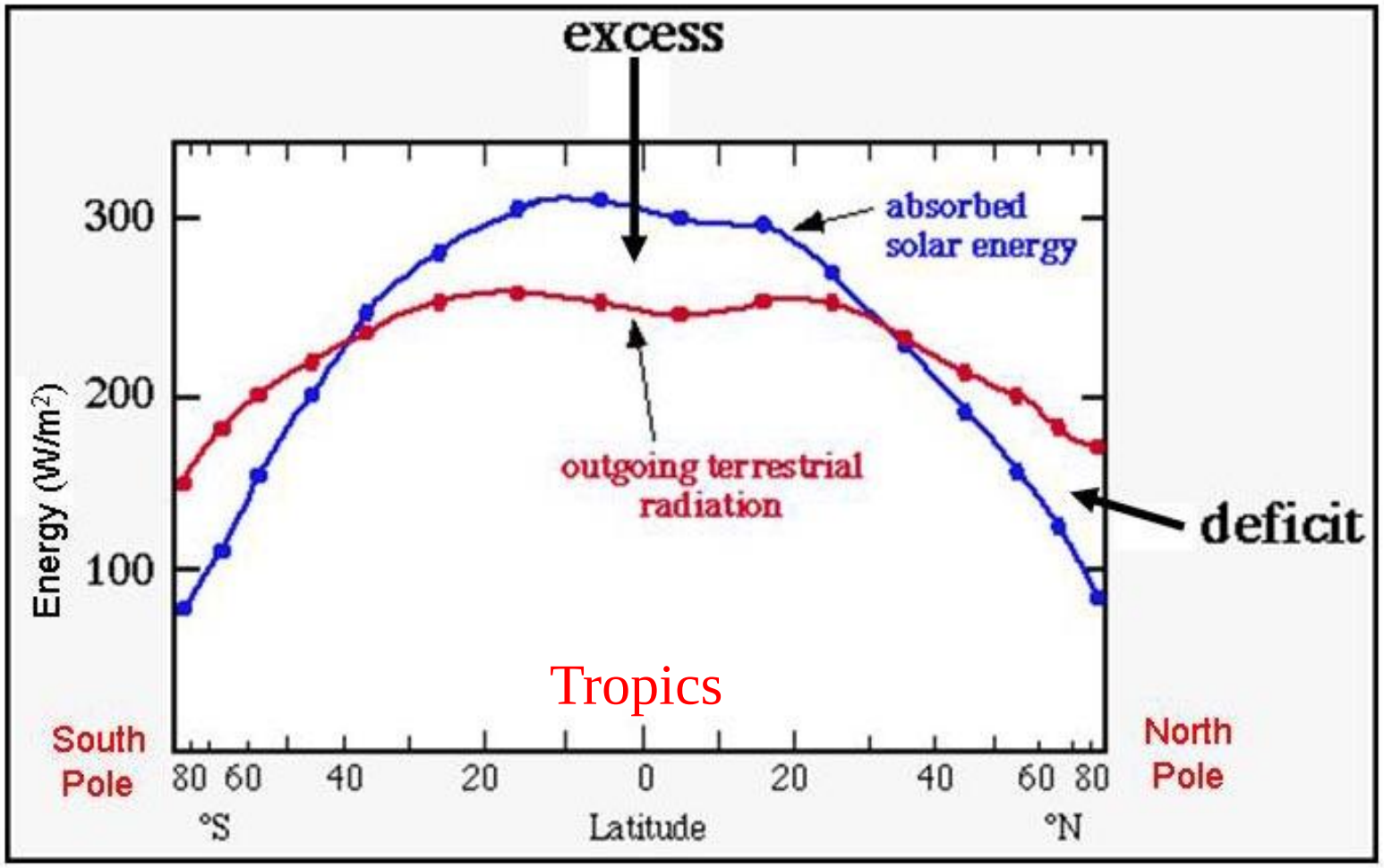
Top of Atmosphere Radiative Energy Fluxes

CERES/TERRA, September 2004



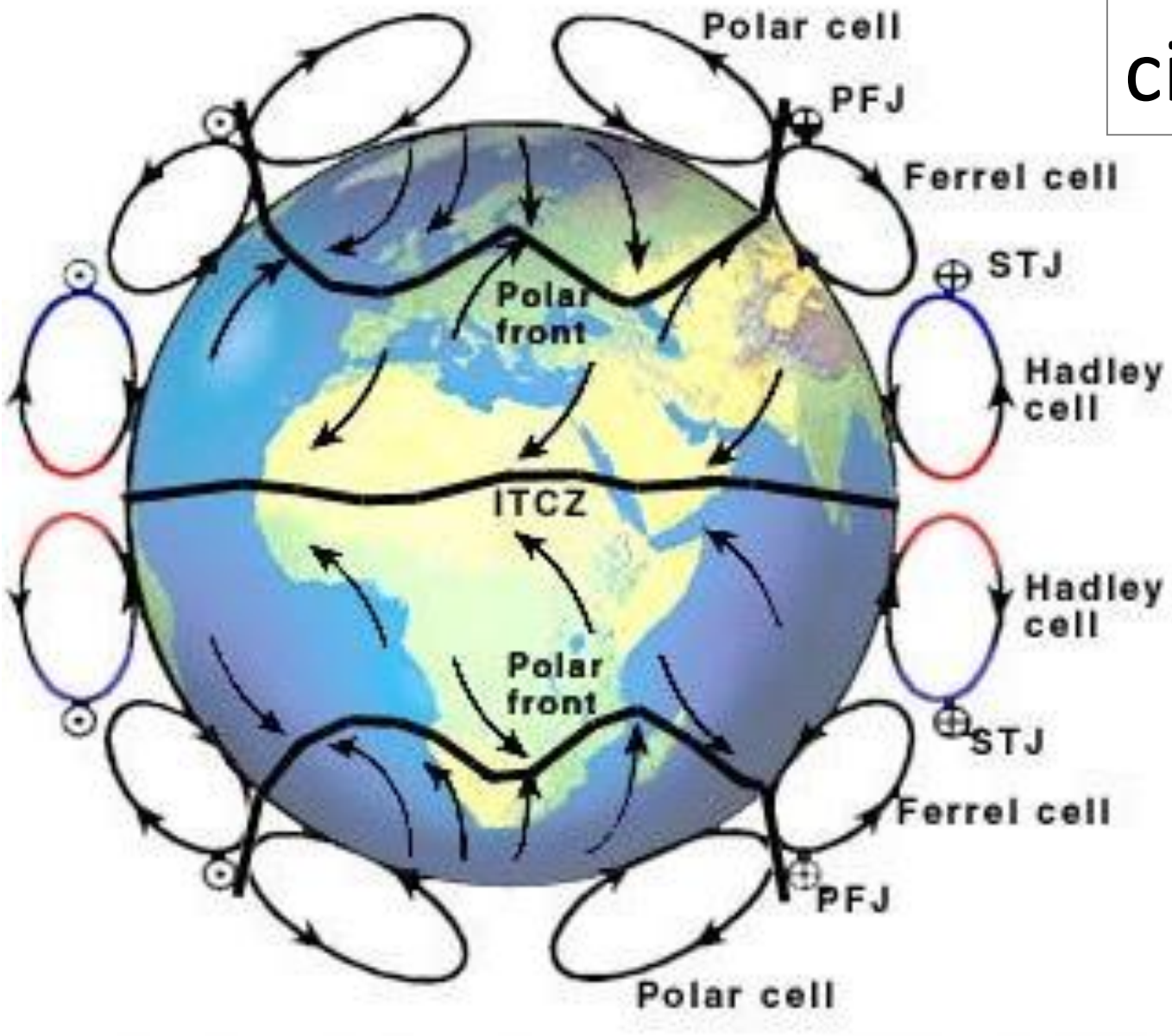
The Net Radiation Balance

Why don't the tropics get warmer and warmer and the poles colder and colder?



CLAUS movie

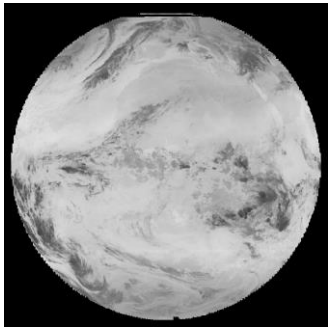
The global circulation



no rotation: no coriolis effect

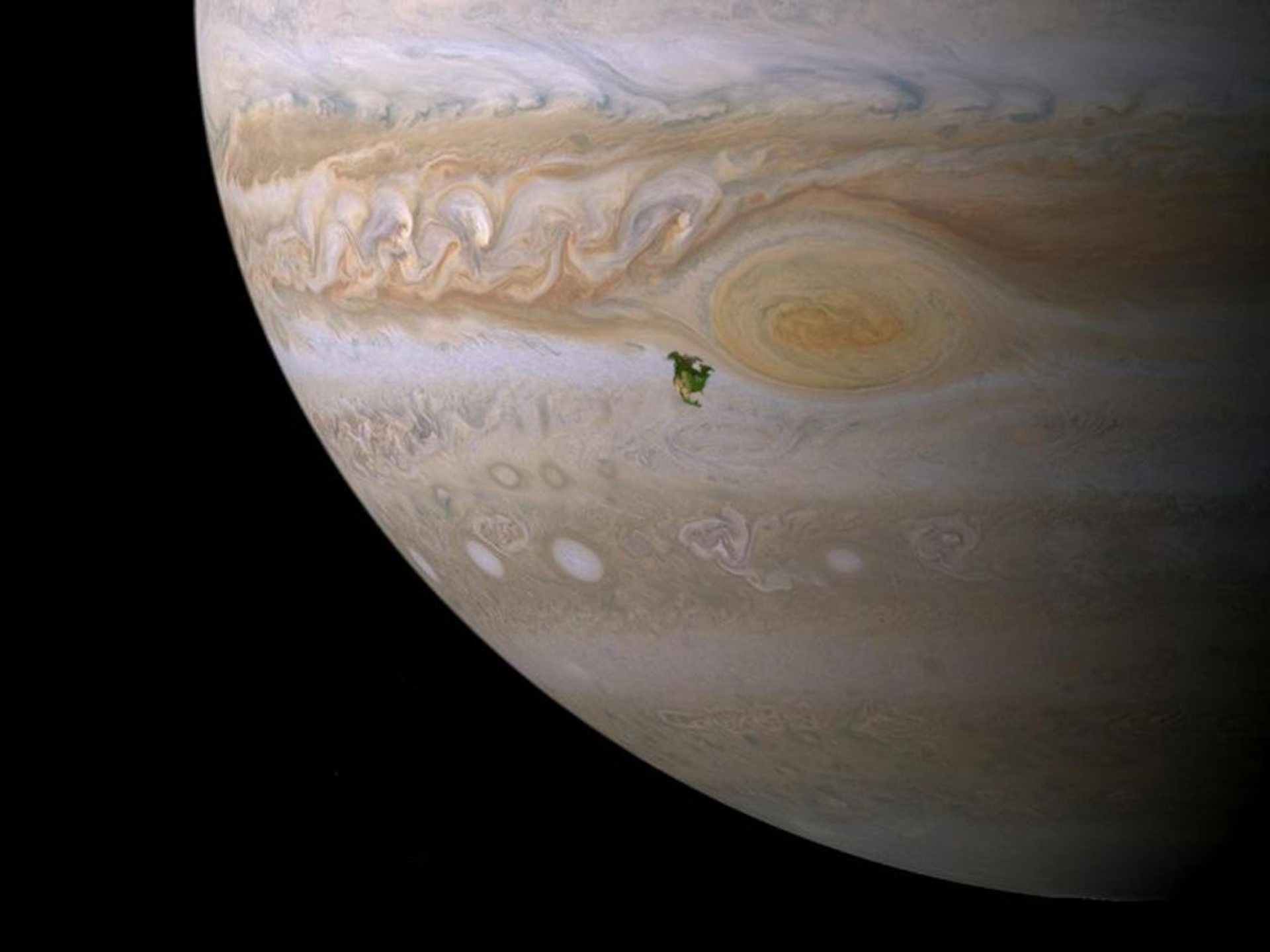
Comparing the planets

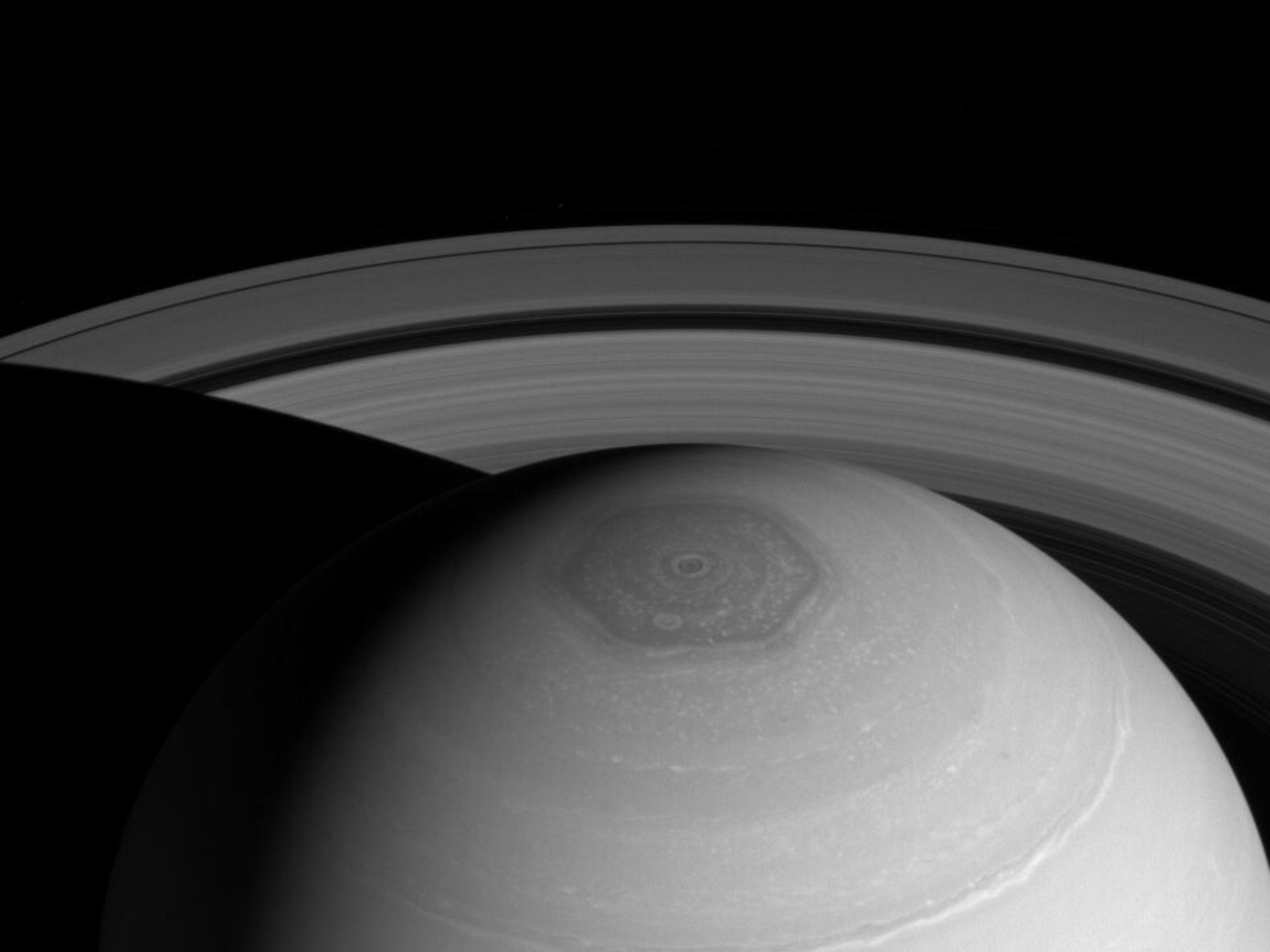
…thanks to Wikipedea



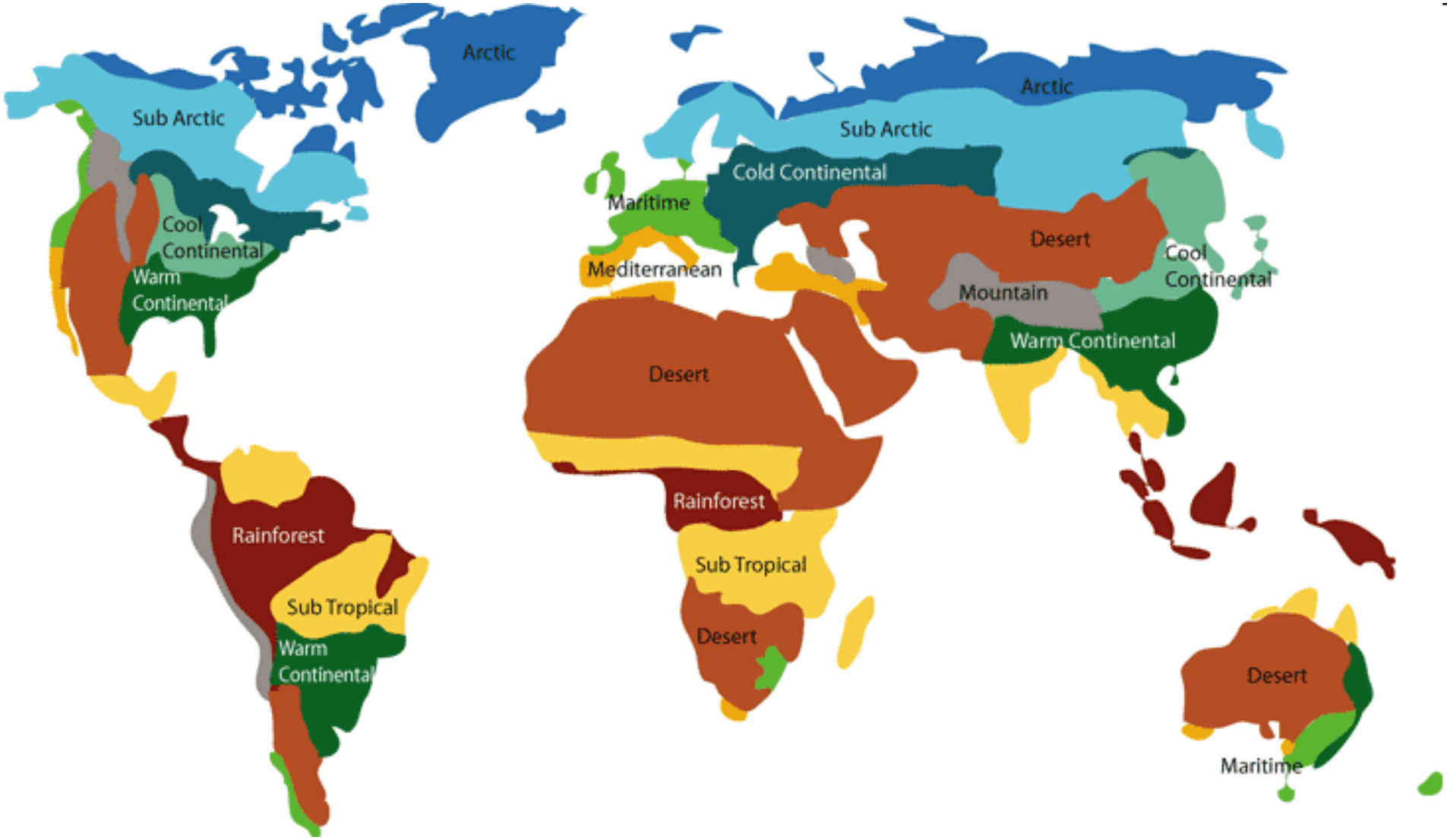
Planet	Surface Temp.	Surface pressure	Diameter (Earth's)	Rotation (hrs)	Coriolis Effect
Mercury	80-700 K	~0	0.38	~0	None
Venus	737 K	200 kPa	0.95	slow	Weak
Earth	184-330 K	101 kPa	1	24	Moderate
Mars	130-308 K	0.6 kPa	0.53	24.5	^Small
Jupiter	*165 K	20-200 kPa	11.2	9.8	STRONG
Saturn	*134 K	1000 kPa	9.4	10.5	STRONG
Uranus	*76 K	10,000 kPa?	4.0	17	#Strong
Neptune	*72 K	MASSIVE	3.9	16	Strong

*Temperature at 100 kPa level #Uranus has a weird tilt ^dust stoms affected

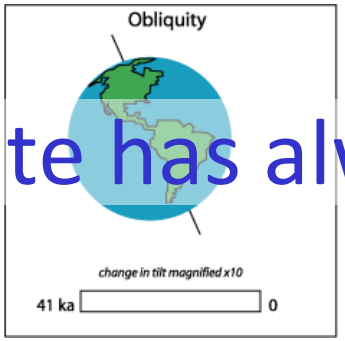


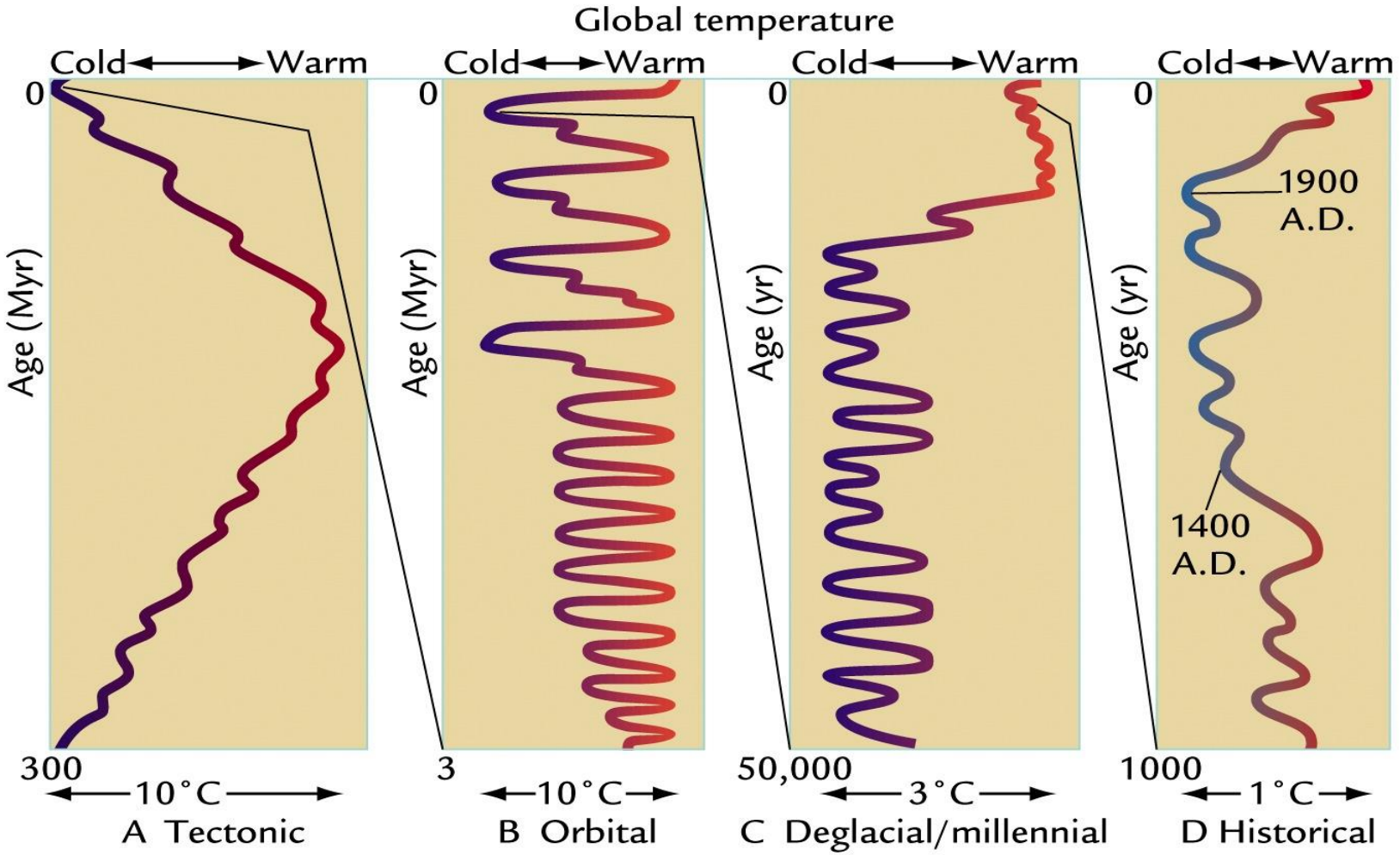


Earth's Current Climate Zones

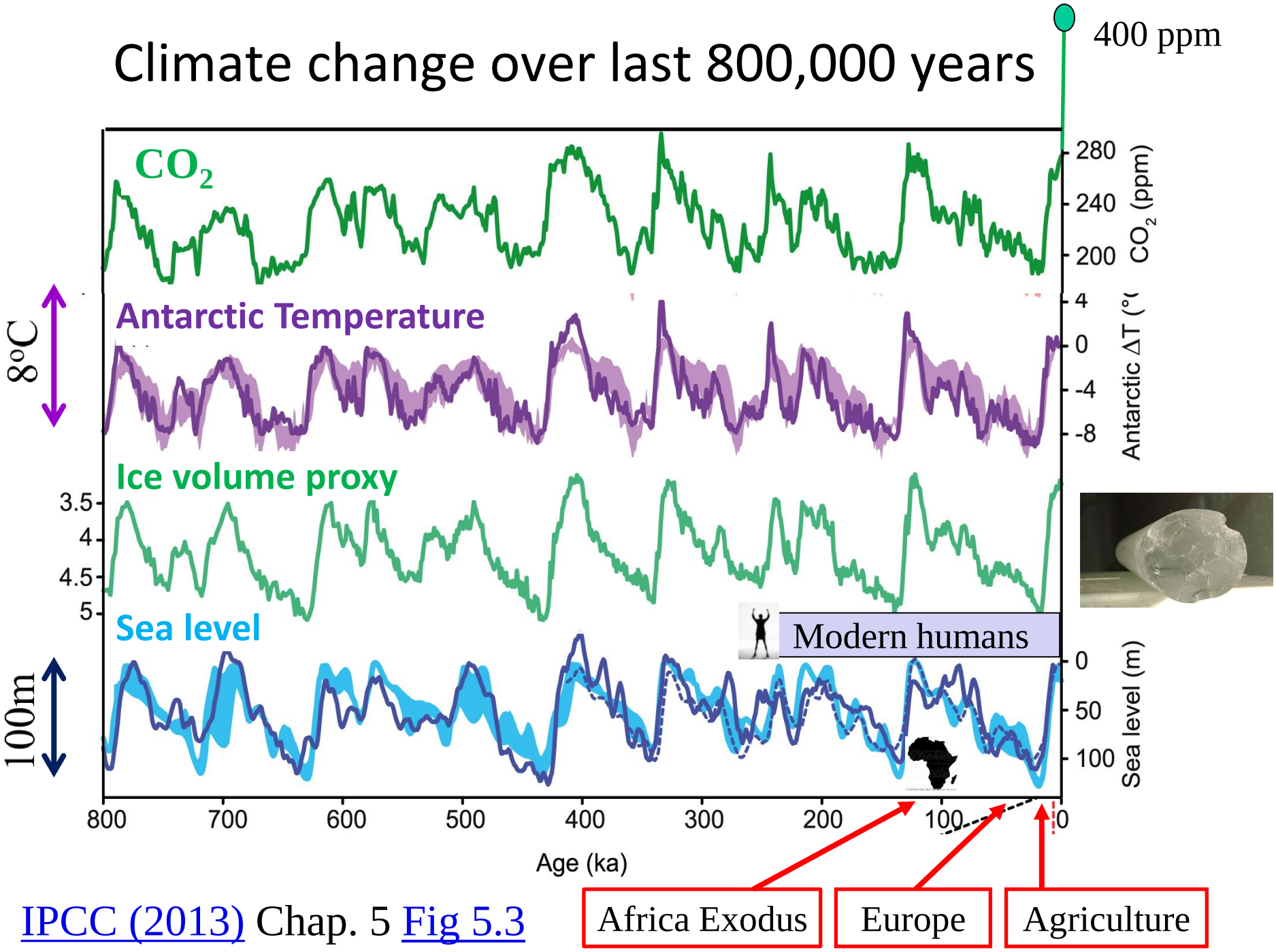


Earth's Climate has always been changing





Climate change over last 800,000 years



IPCC (2013) Chap. 5 Fig 5.3

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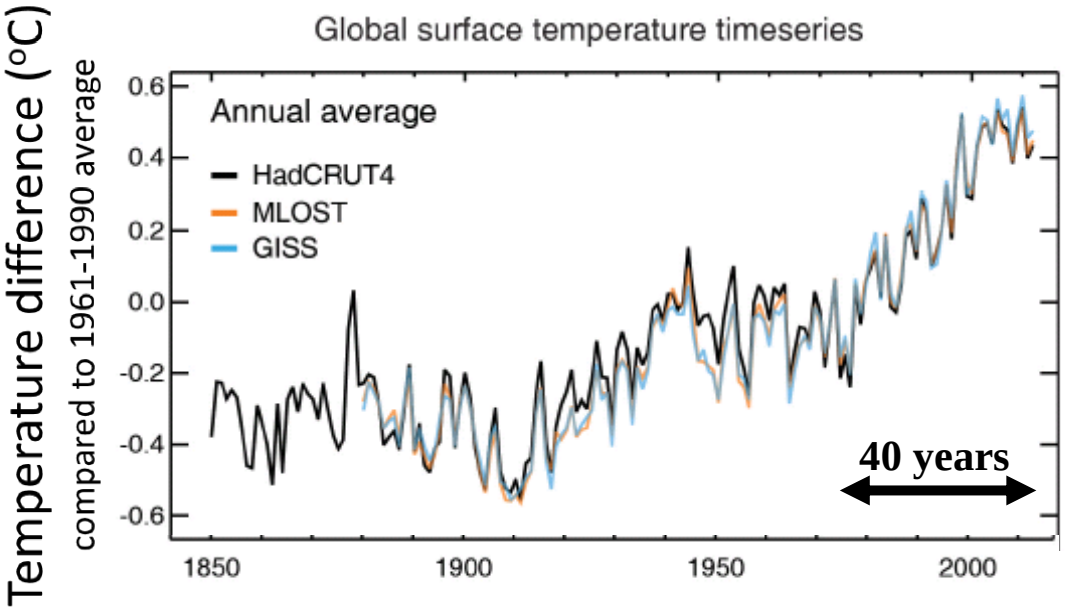
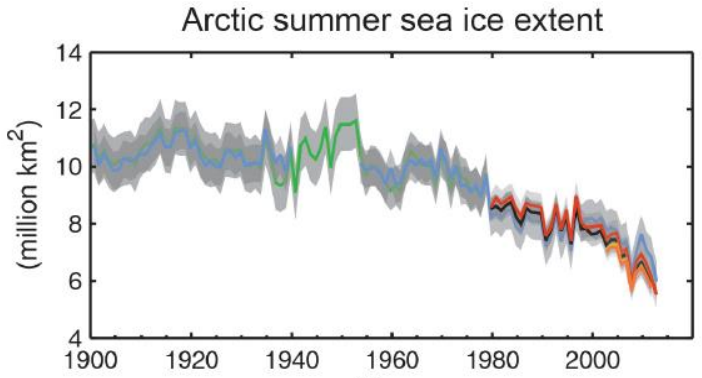
1) Is climate changing now?

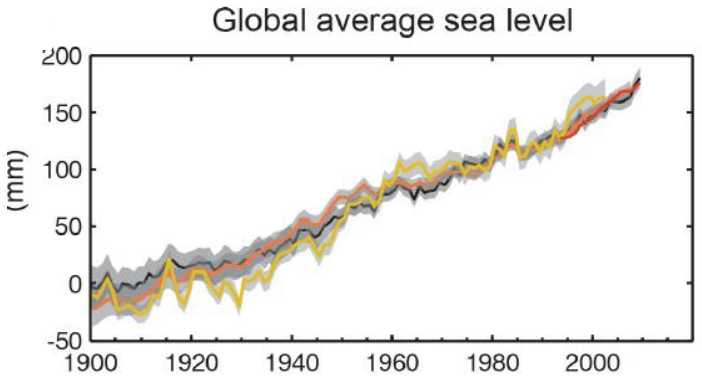
Evidence for current climate change

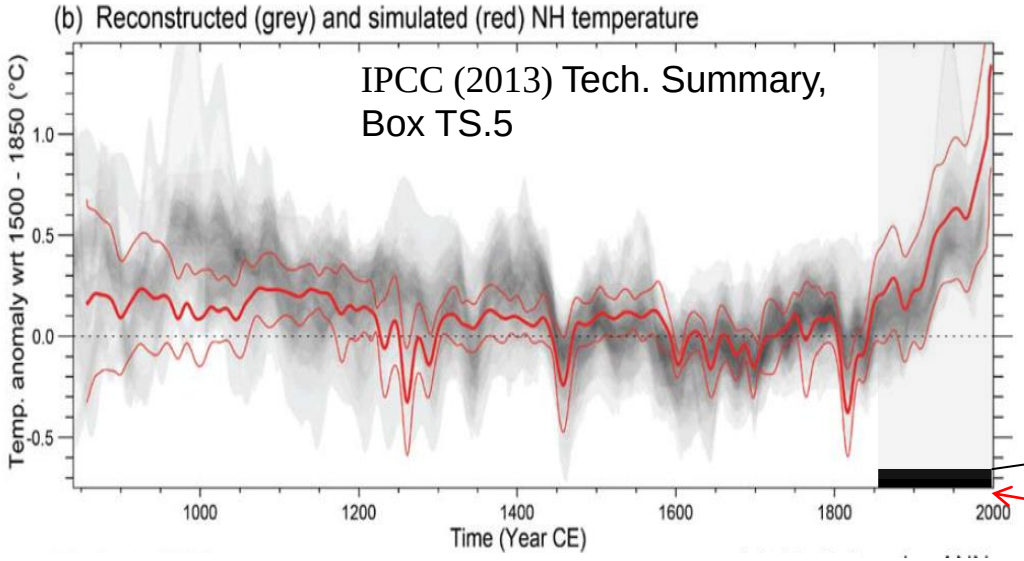
"Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased." IPCC (2013)

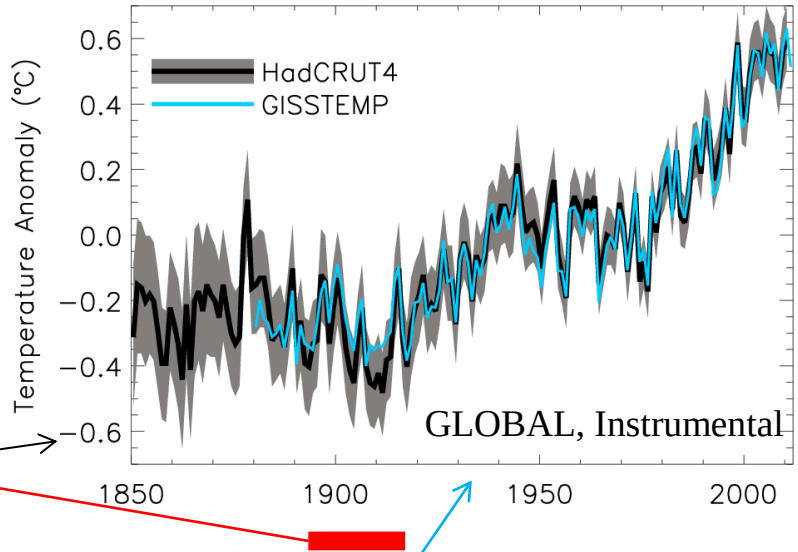


Top: Differences in global average surface temperature compared to the 1961-1990 average
Middle: Changes in the July-September average summer Arctic sea ice extent
Bottom: Changes in global average sea level compared with 1900-1905 average
Source: IPCC WGI (2013) SPM

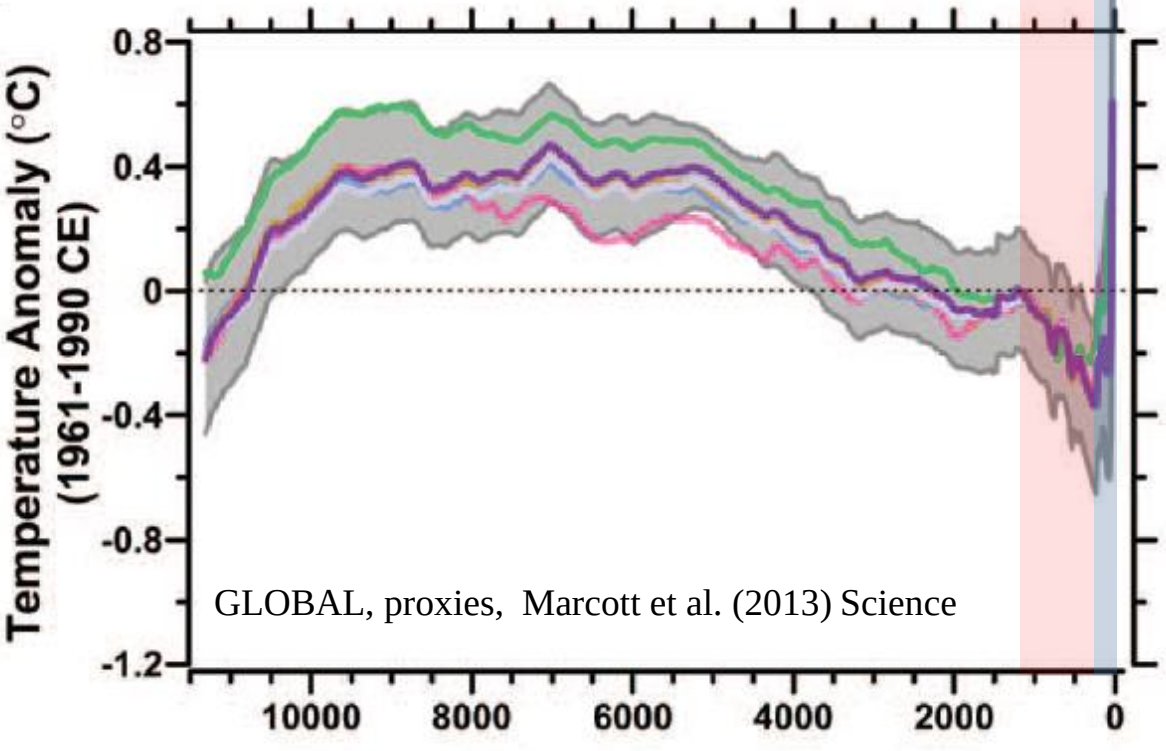








Northern hemisphere proxies



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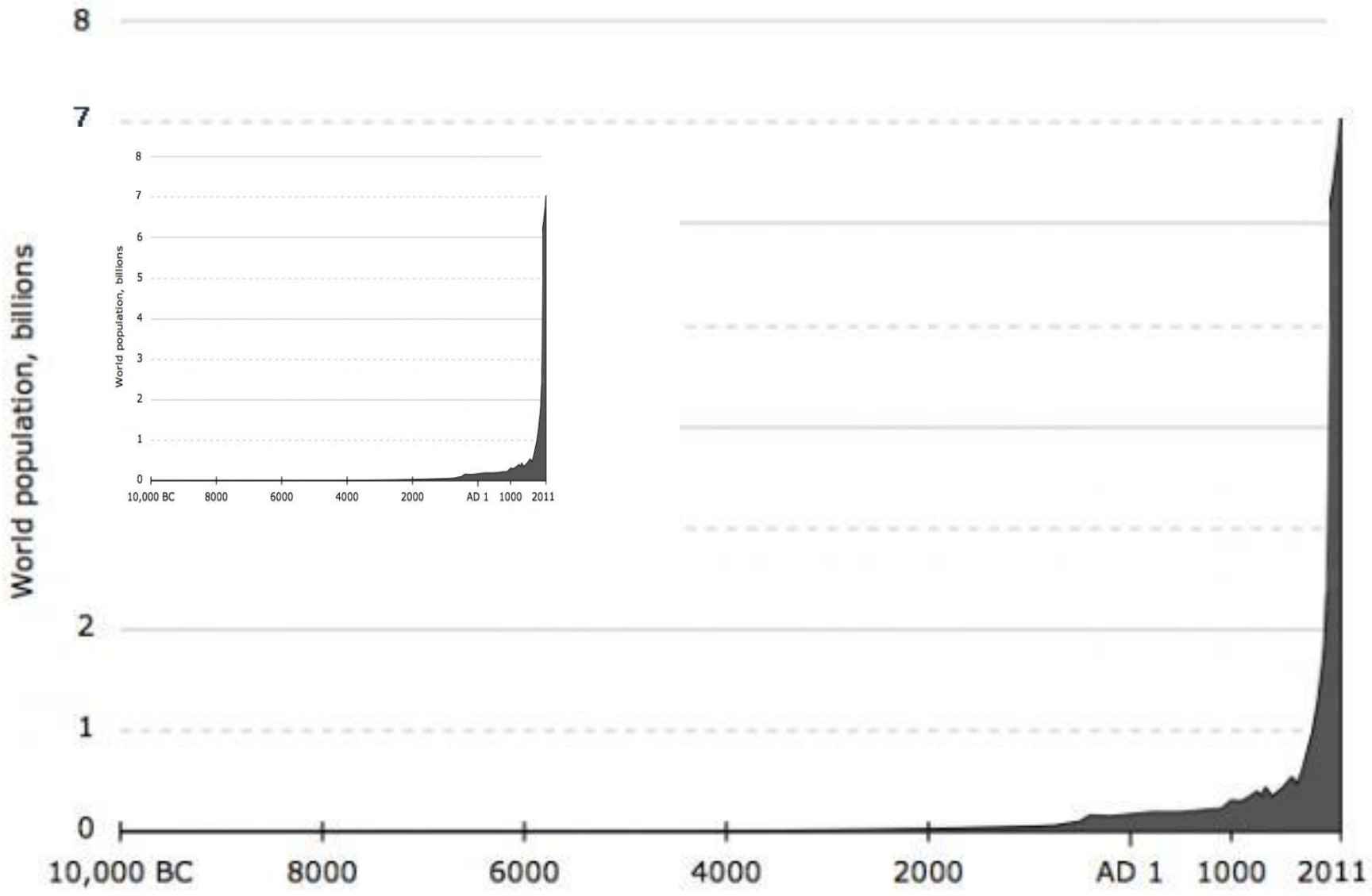
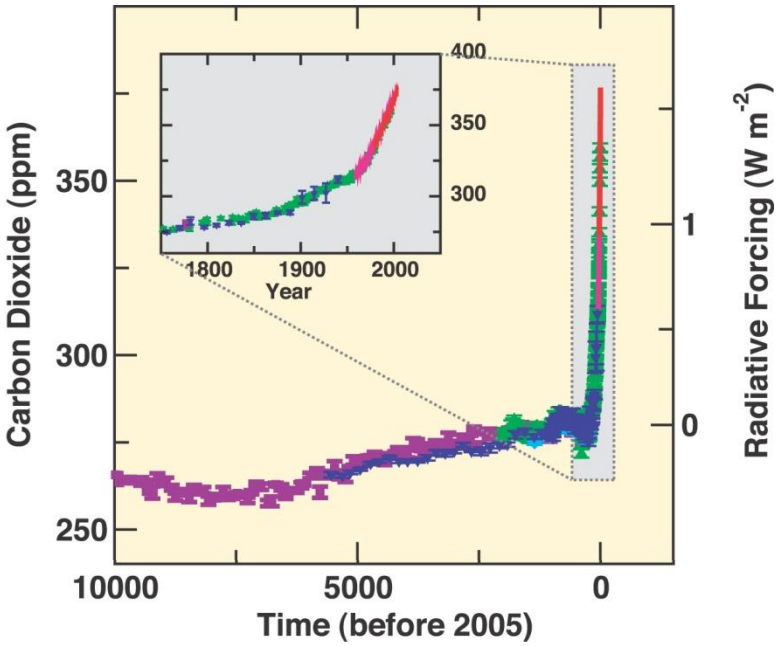
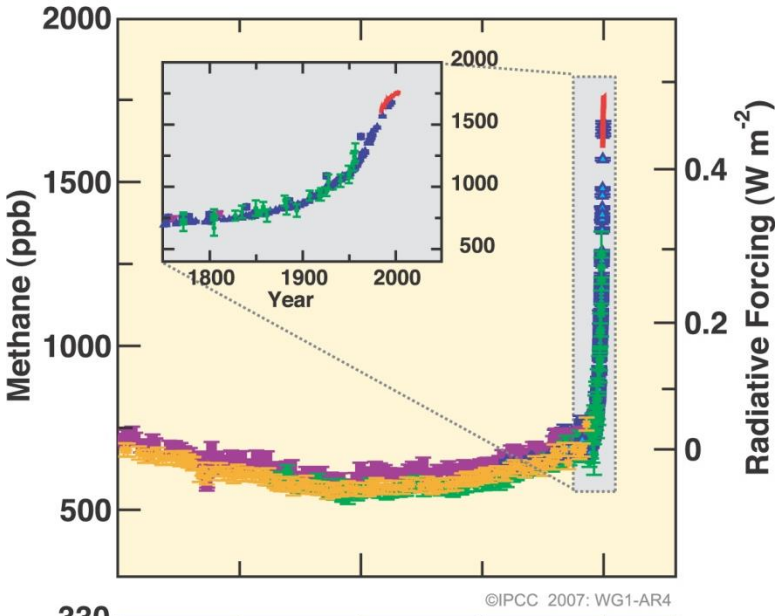
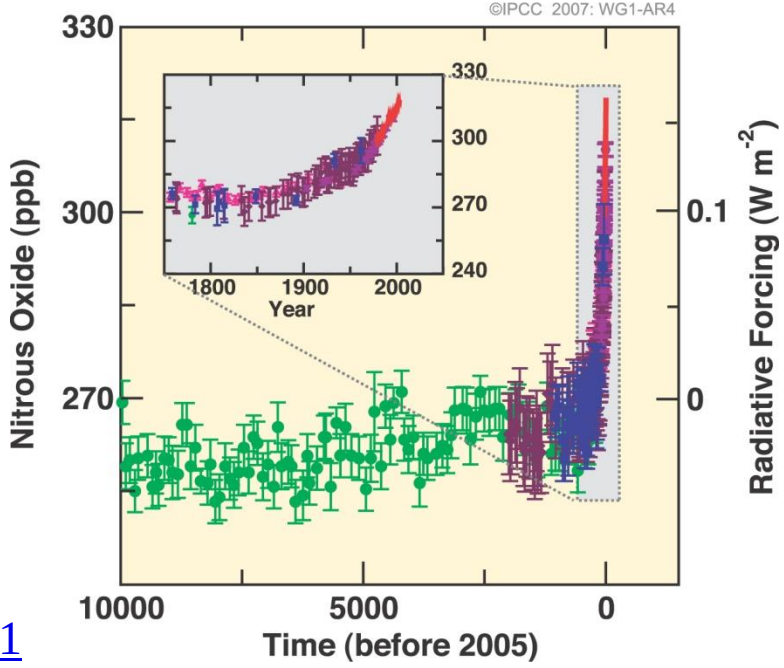
2) Why is Earth warming?


World population, billions
8
7
2
1
0
10,000 BC
8000
6000
4000
2000
AD 1
1000
2011
World population, billions
8
7
6
5
4
3
2
1
0
10,000 BC
8000
6000
4000
2000
AD 1
1000
2011

Changes in greenhouse gases from ice core and modern data



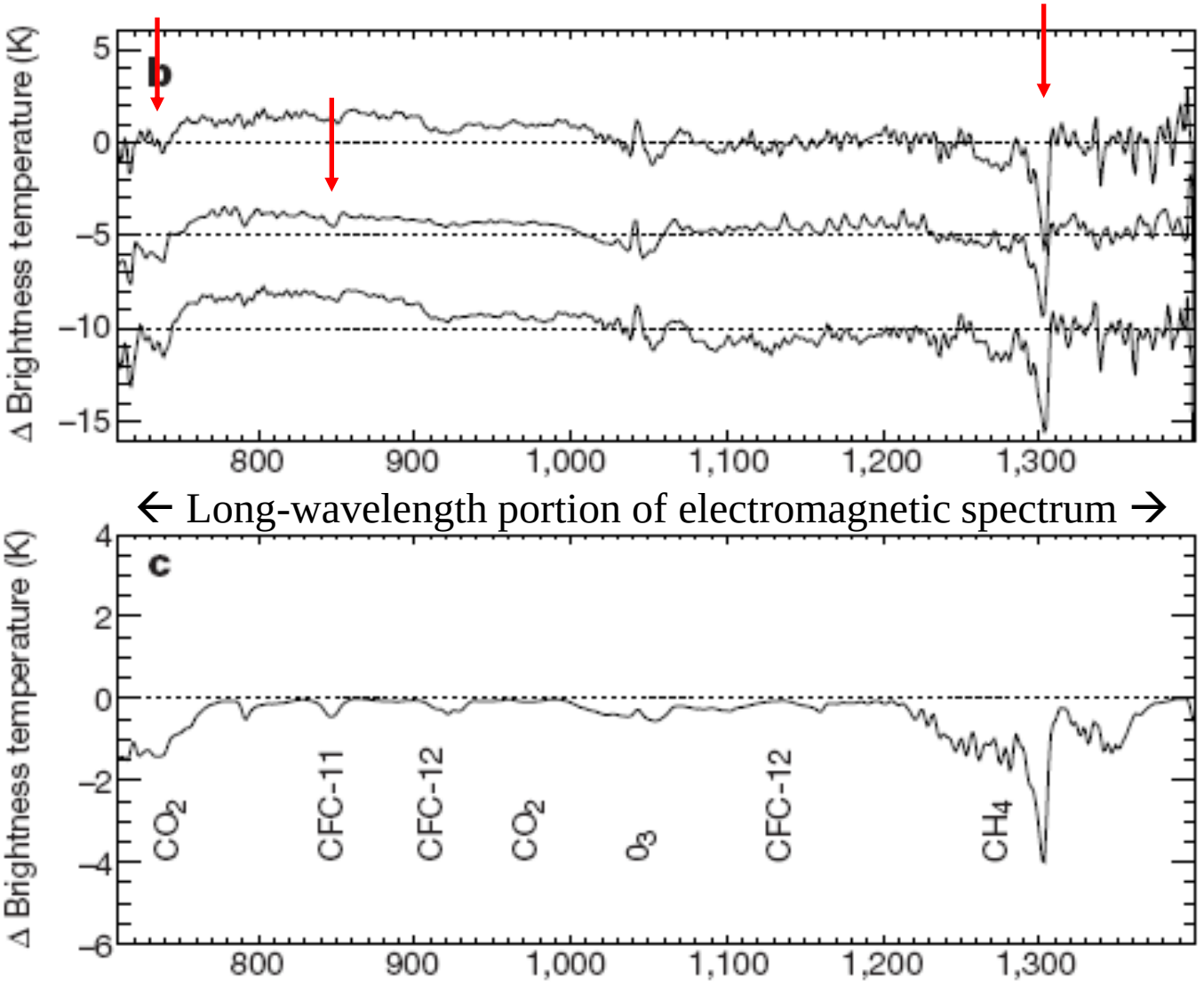




Carbon dioxide, **methane** and **nitrous oxide**

IPCC (2007) Summary for Policy Makers Fig. SPM.1

Satellite observations detect enhanced greenhouse effect: 1997-1970 Harries et al. 2001, Nature

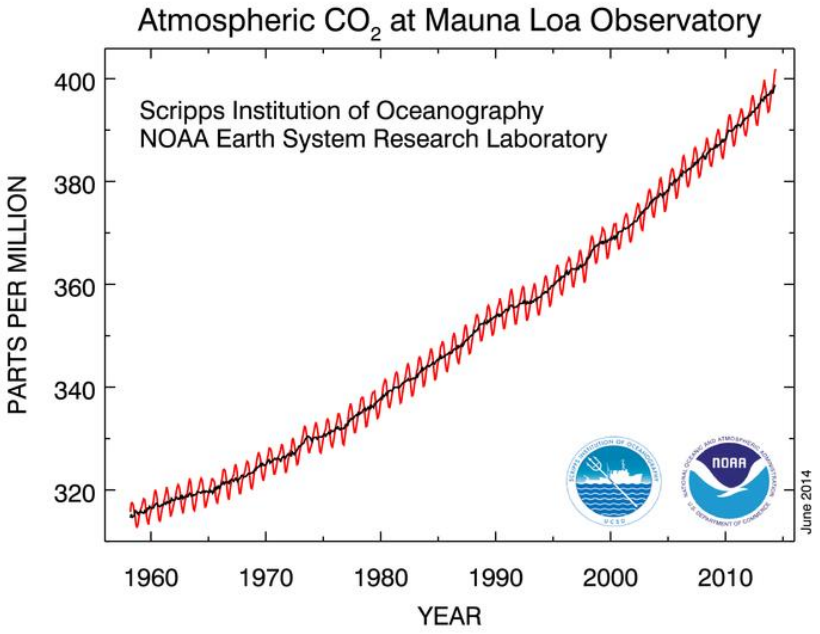


These results showed for the first time experimental confirmation of the significant increase in the greenhouse effect from trace gases such as carbon dioxide and methane

“Radiative forcing” of climate

- Increases in greenhouse gases heat the planet by reducing how easily Earth can cool to space through infra-red emission
- More small pollutant “aerosol” particles cool the planet by reflecting sunlight
- If more energy is arriving than leaving, Earth should heat up…

Currently energy is accumulating at rate equivalent to 300 billion electric heaters (1 kilo Watt) spread over the globe



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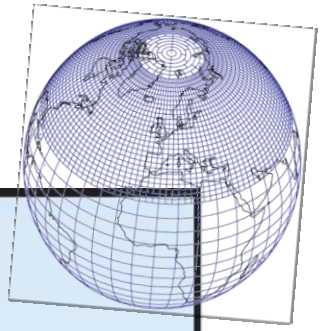
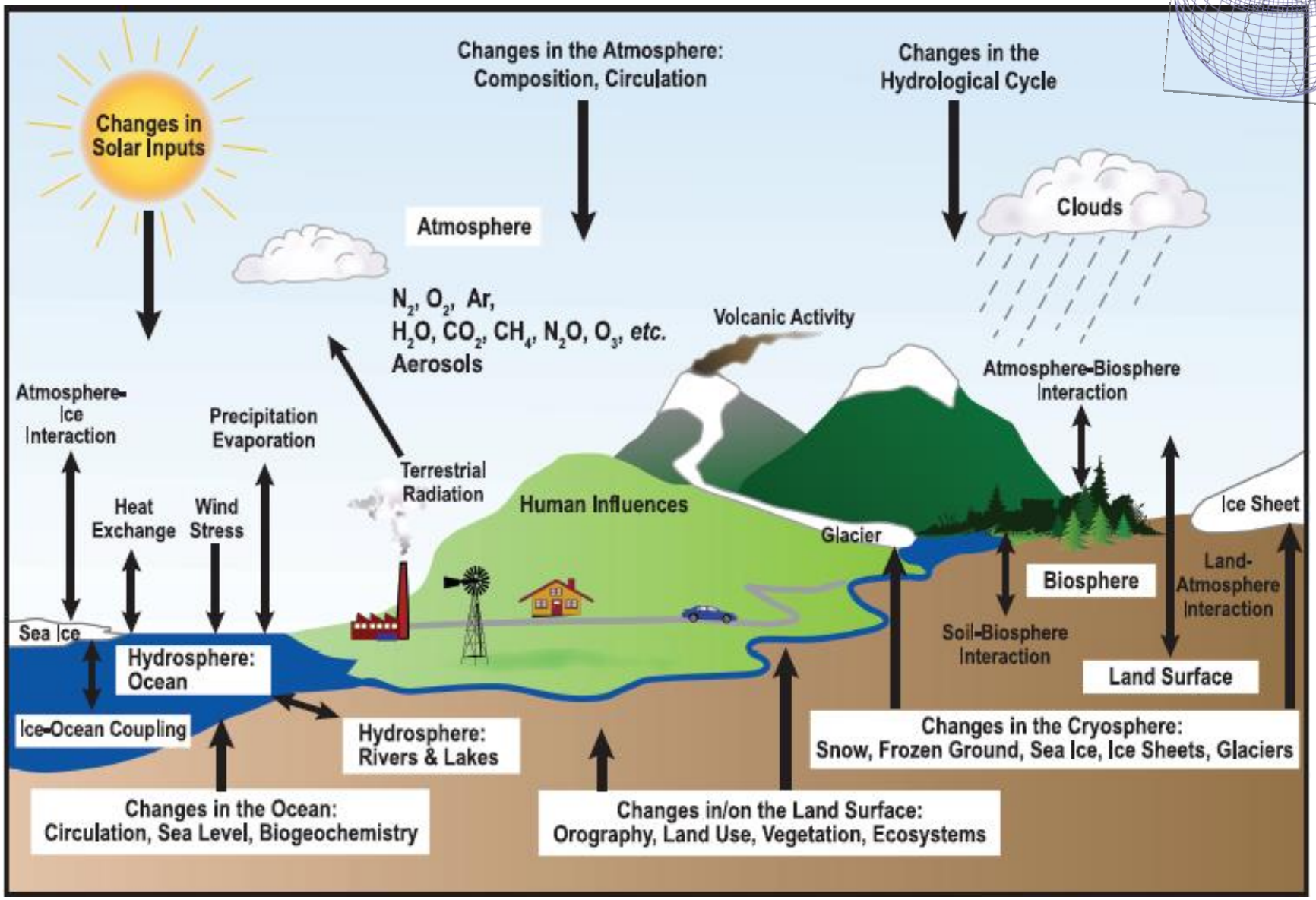
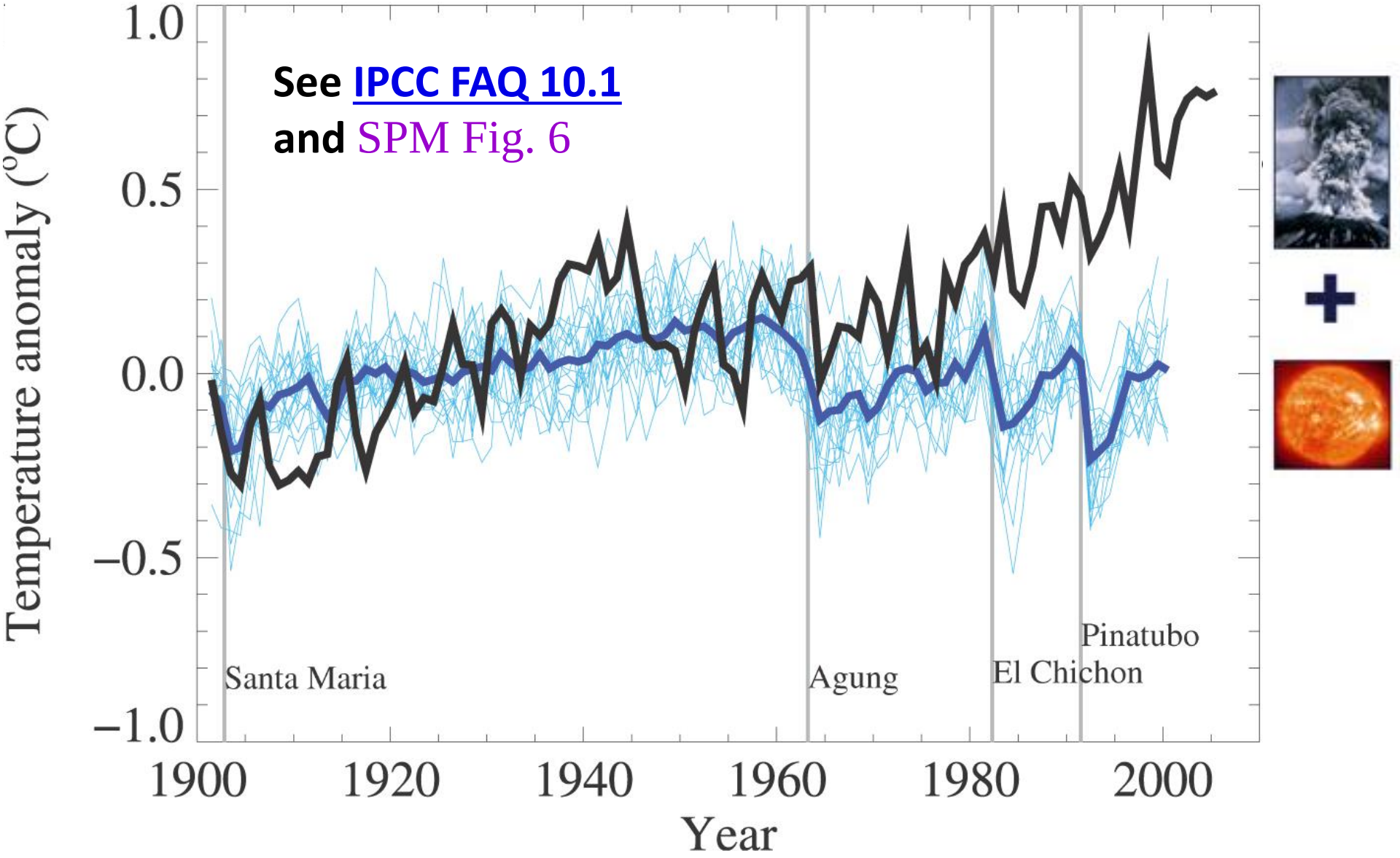
3) Can we explain recent warming?

Comprehensive climate simulations…

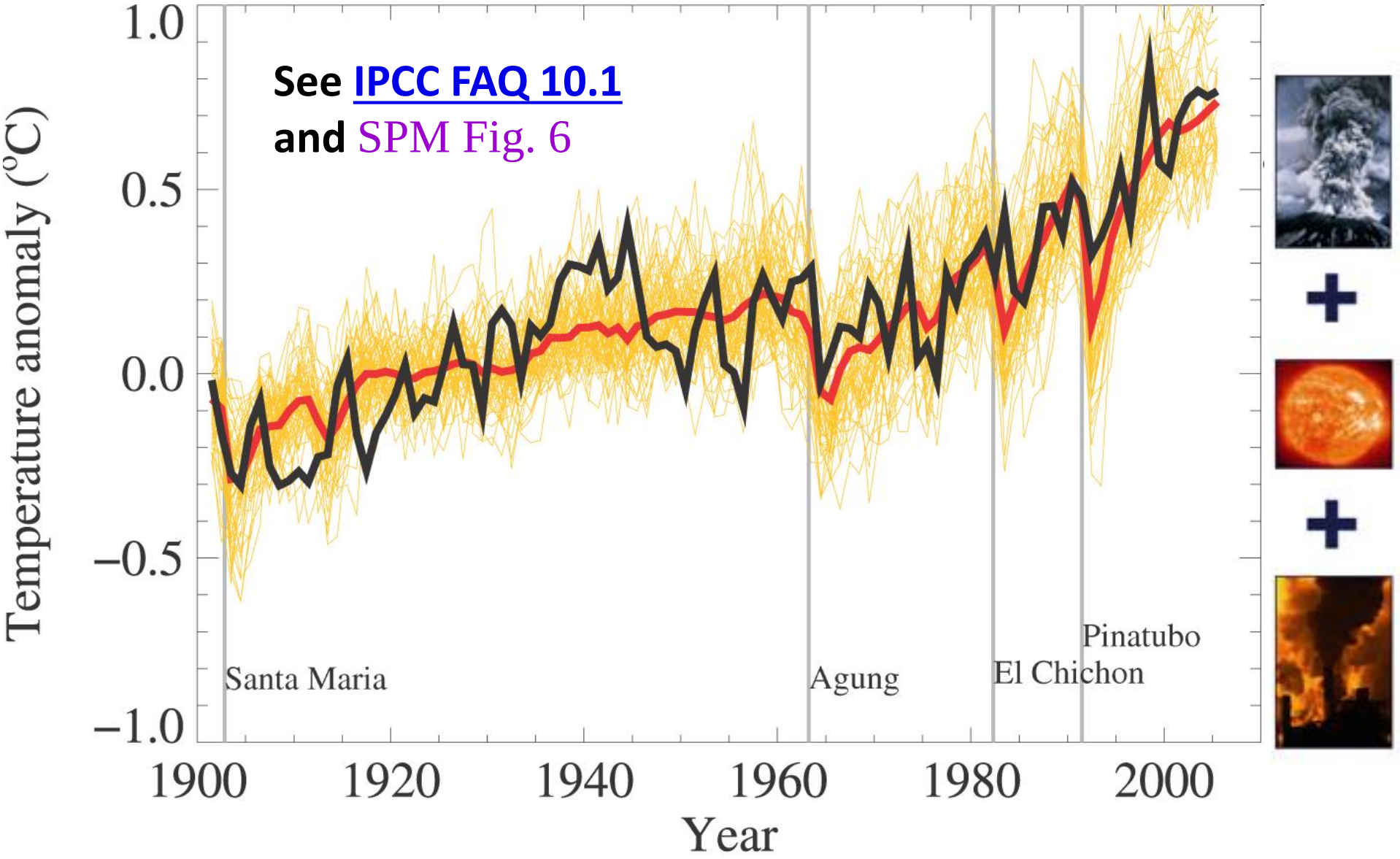




Natural factors cannot explain recent warming



Recent warming can be simulated when man-made factors are included



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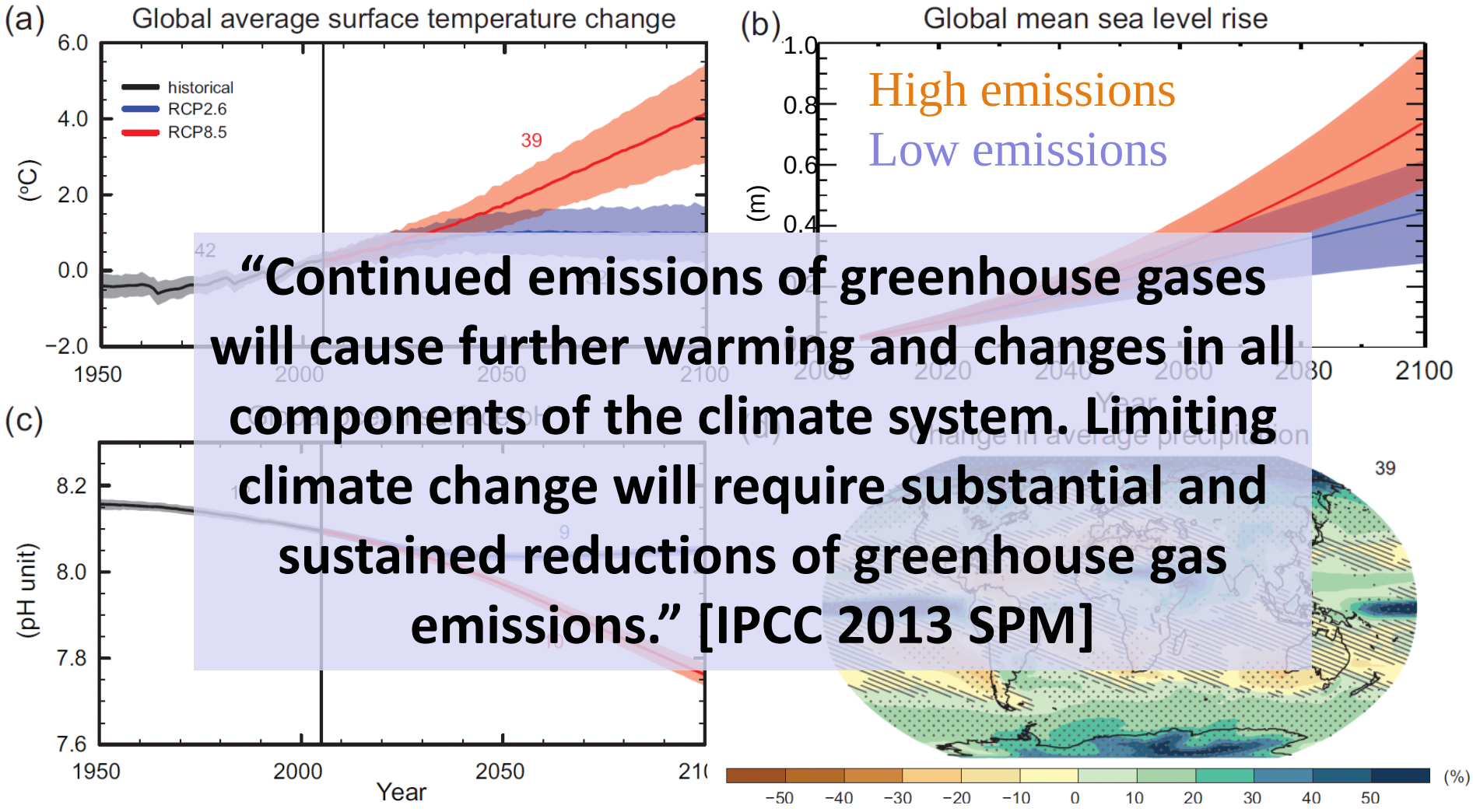
4) What are the predictions?

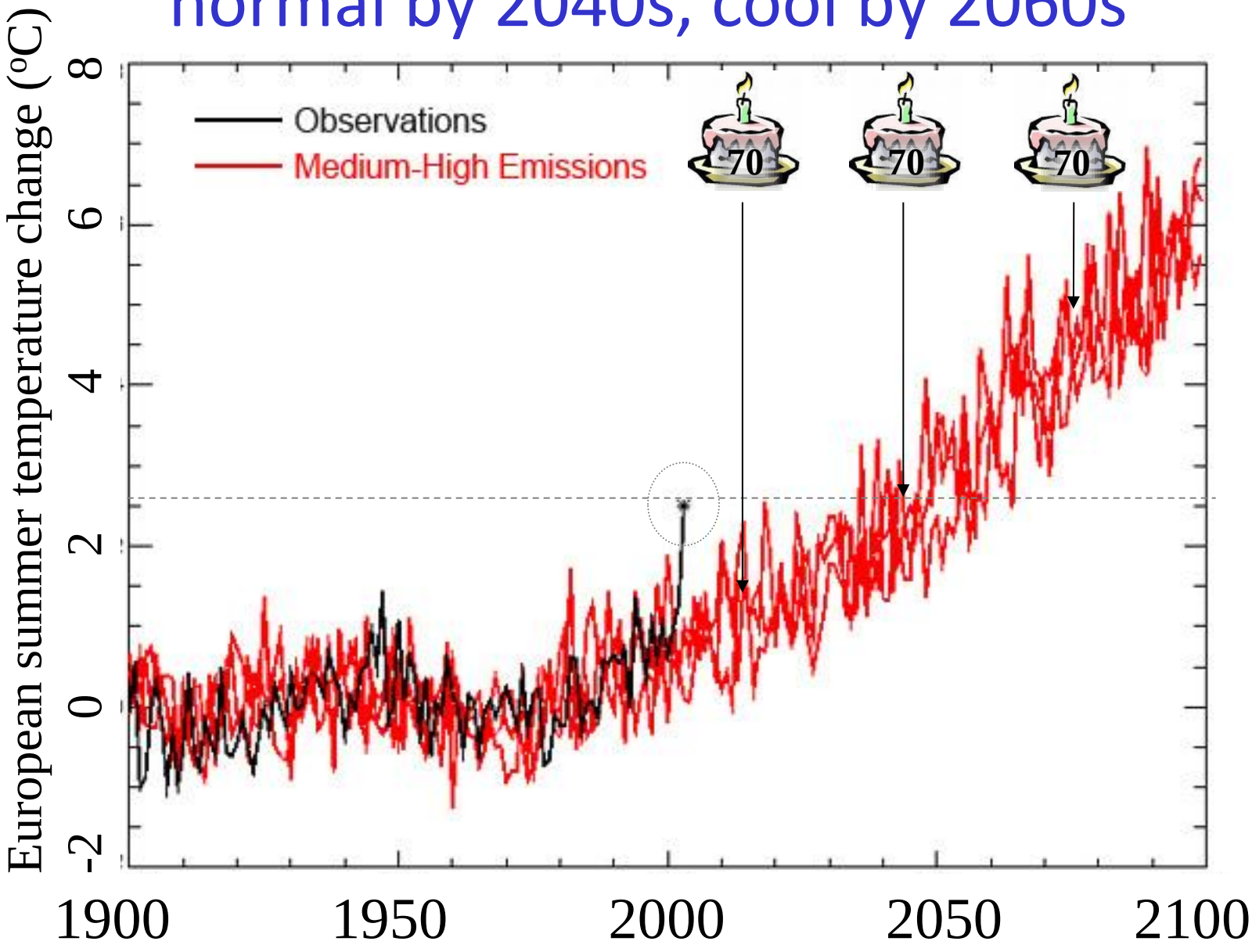
Future projections to 2100 from climate models



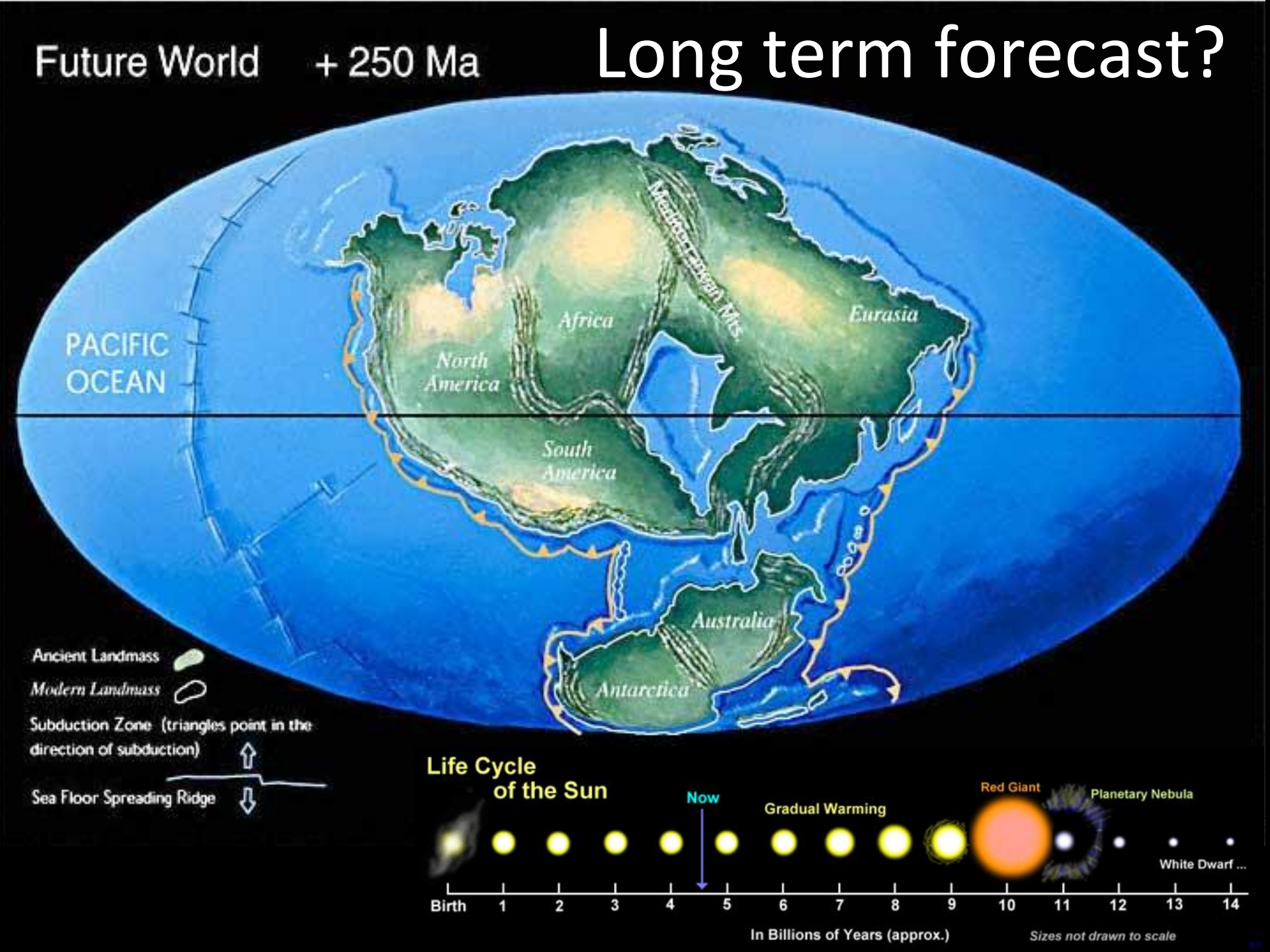
"Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions." [IPCC 2013 SPM]

IPCC (2014) [WG1 Summary for Policy Makers]

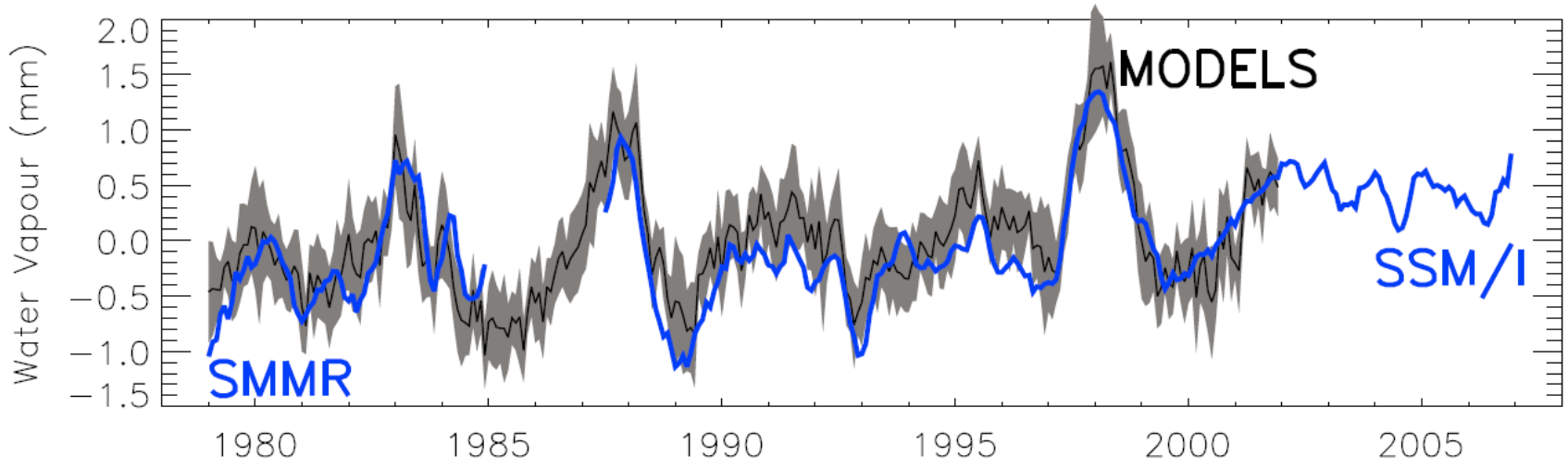
European 2003 summer temperatures could be normal by 2040s, cool by 2060s

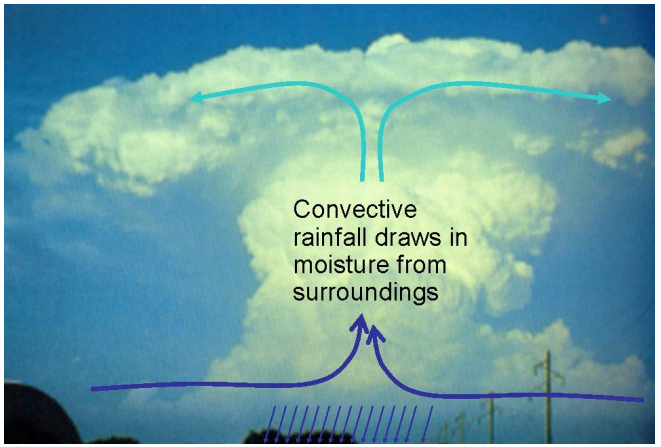


Long term forecast?



Extra slides



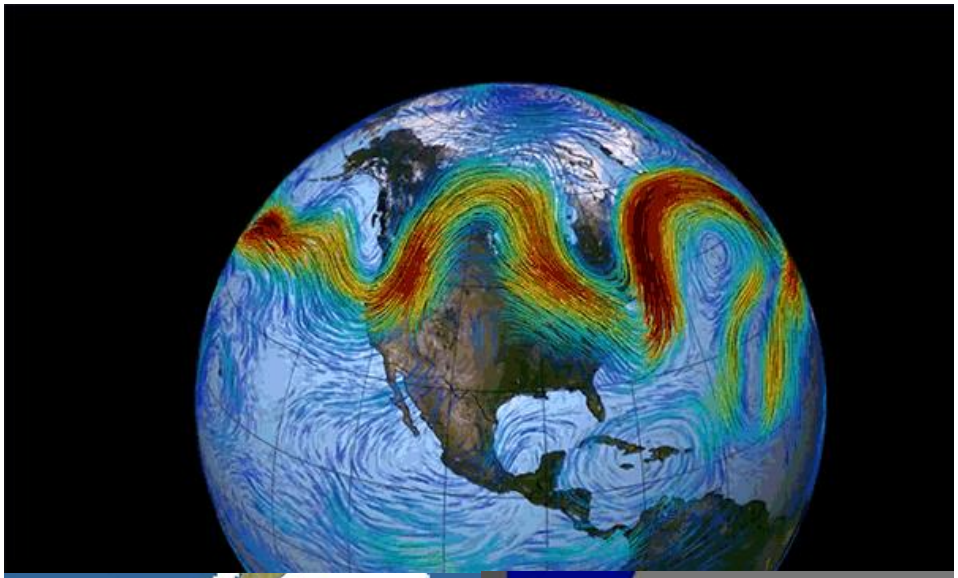


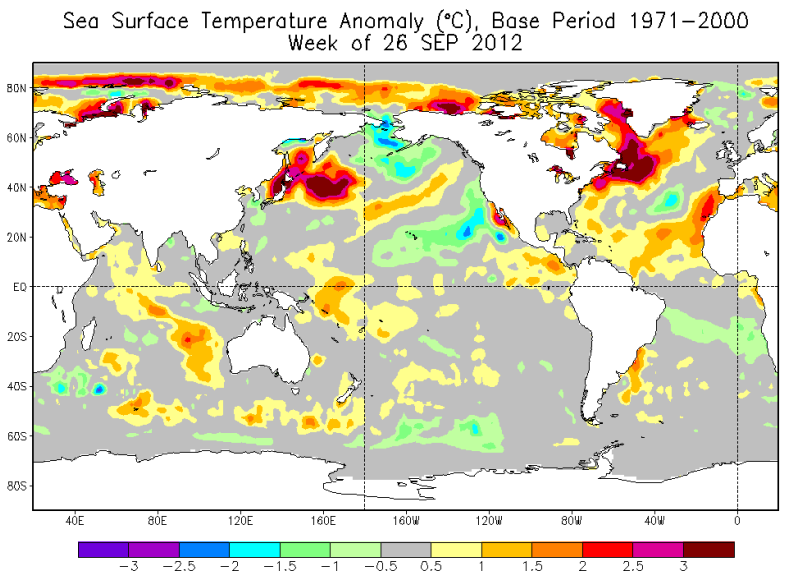
- Atmospheric moisture increases with warming in computer simulations and as detected by conventional and satellite observations

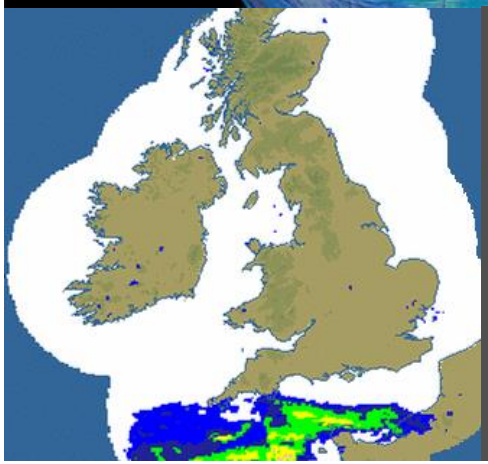
- The enhanced greenhouse effect amplifies climate change (+ve “feedback”)

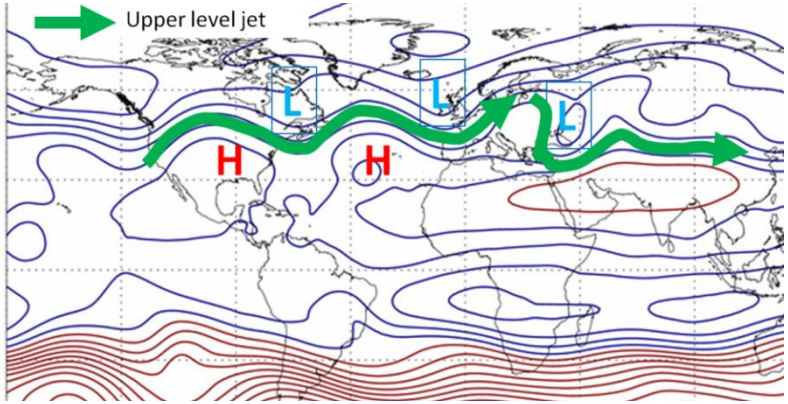
- Additional moisture also fuels a greater intensity of rainfall

But how will climate change regionally?

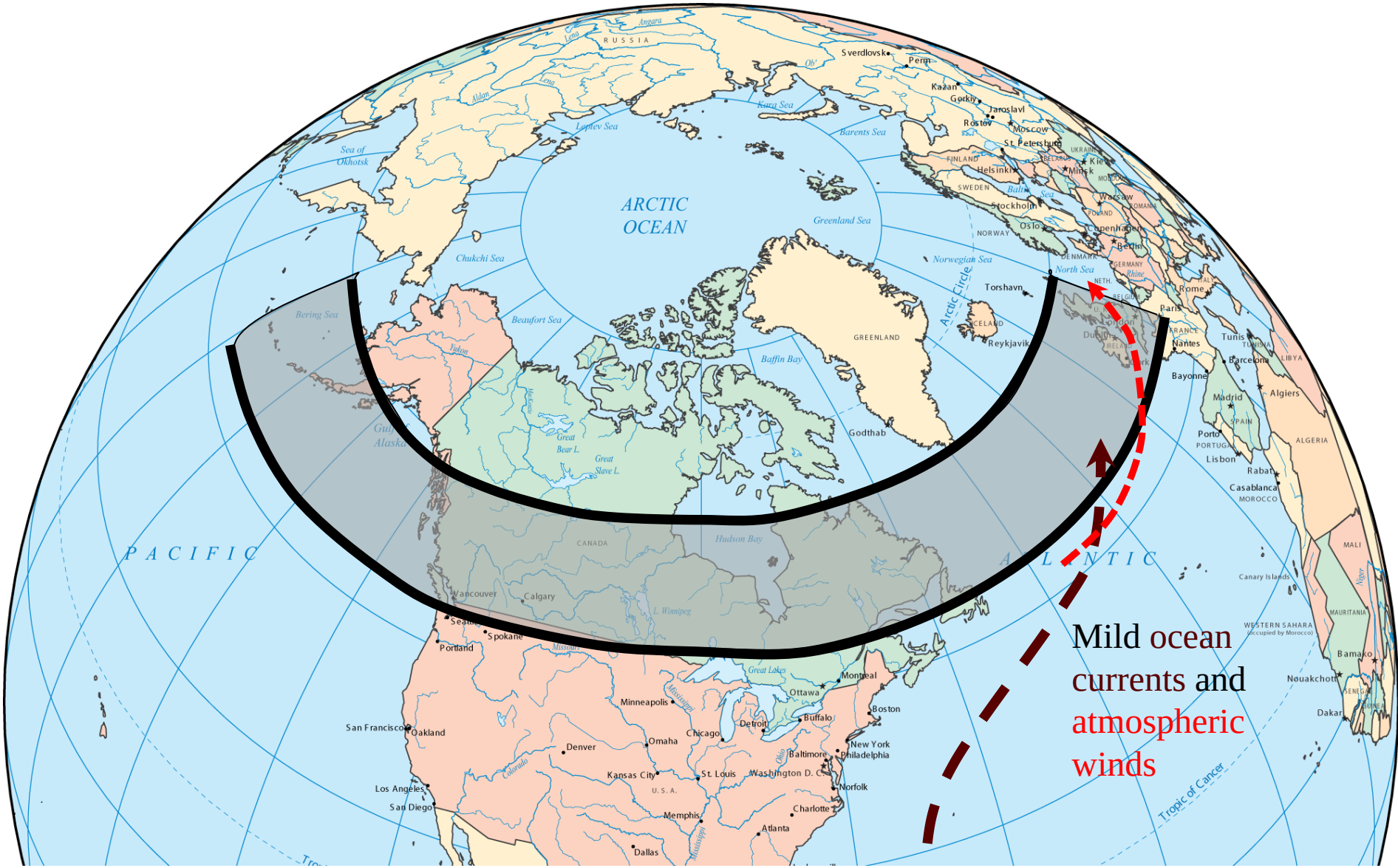




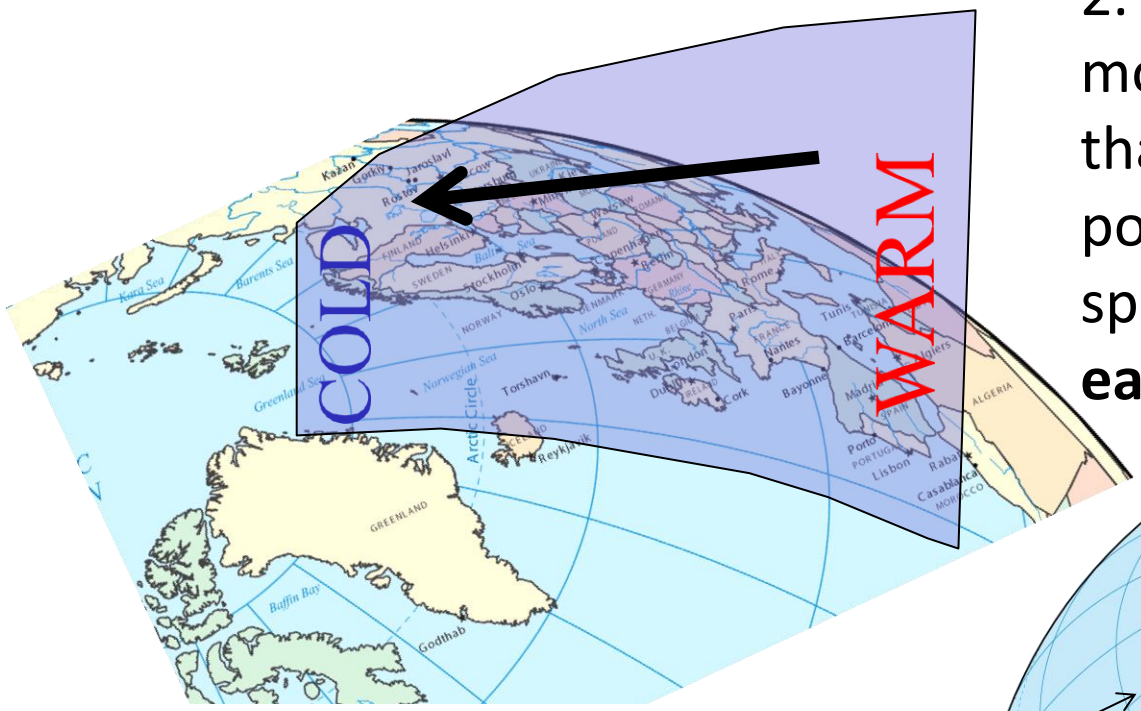




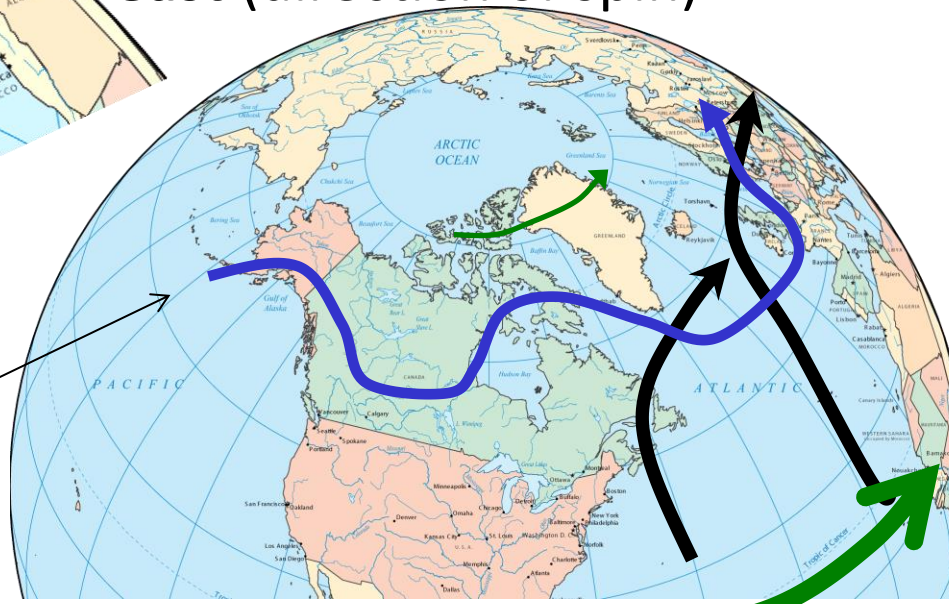
What explains the mild climate in the UK and its variations from year to year?



1. Air is warmer closer to the tropics (air expands) than at the poles (air contracts). This generates a **poleward flow of air** high up in the atmosphere

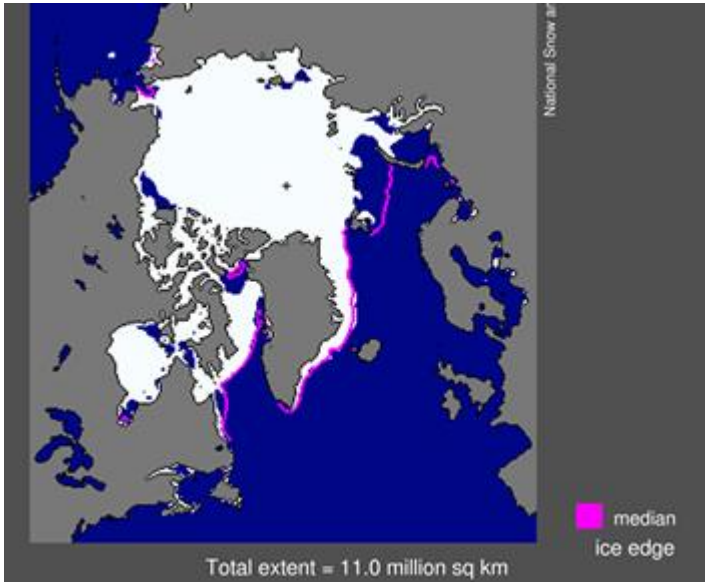


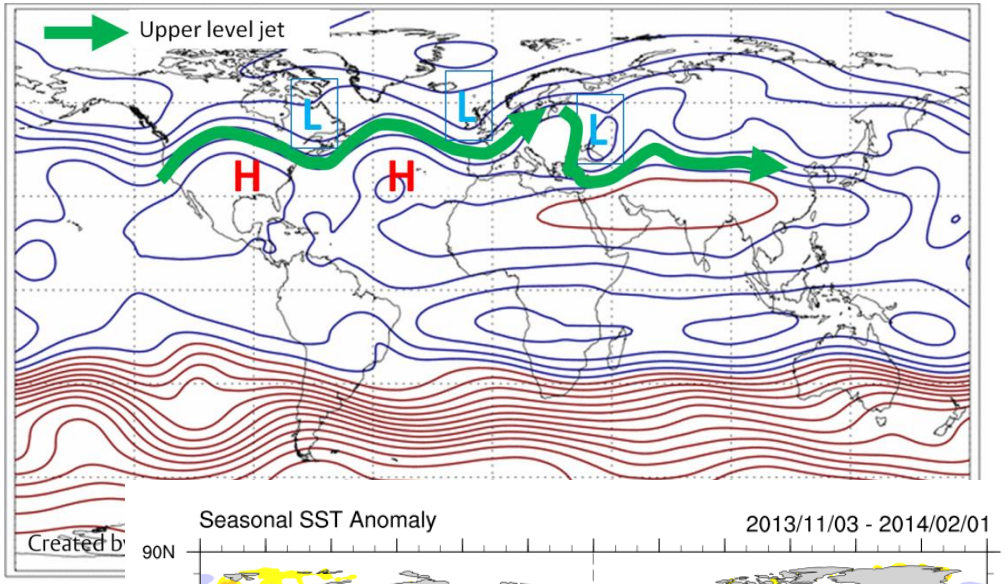
2. The Earth spins: the surface moves quicker near the equator than at higher latitudes. So poleward-flowing air retains this speed and is deflected to the **east** (direction of spin)

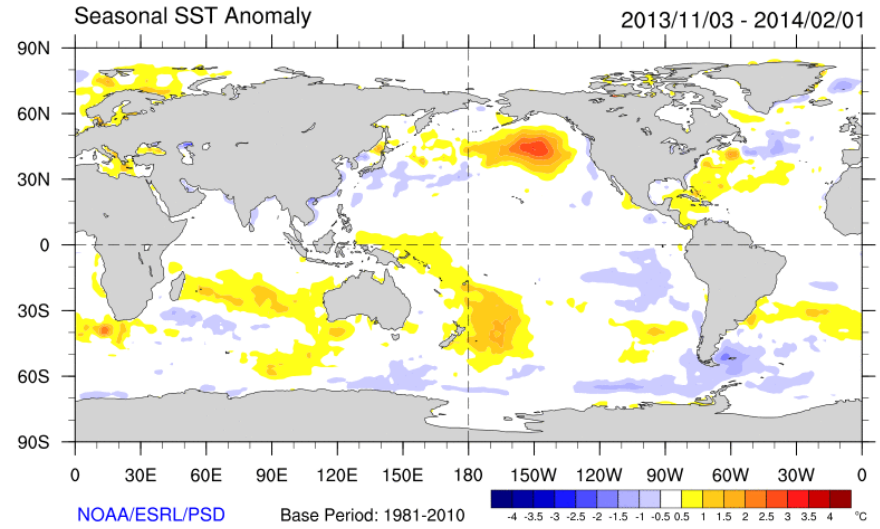


3. This high altitude (5-7km) fast moving ribbon of air is called the jet stream. It steers weather systems over or away from the UK.

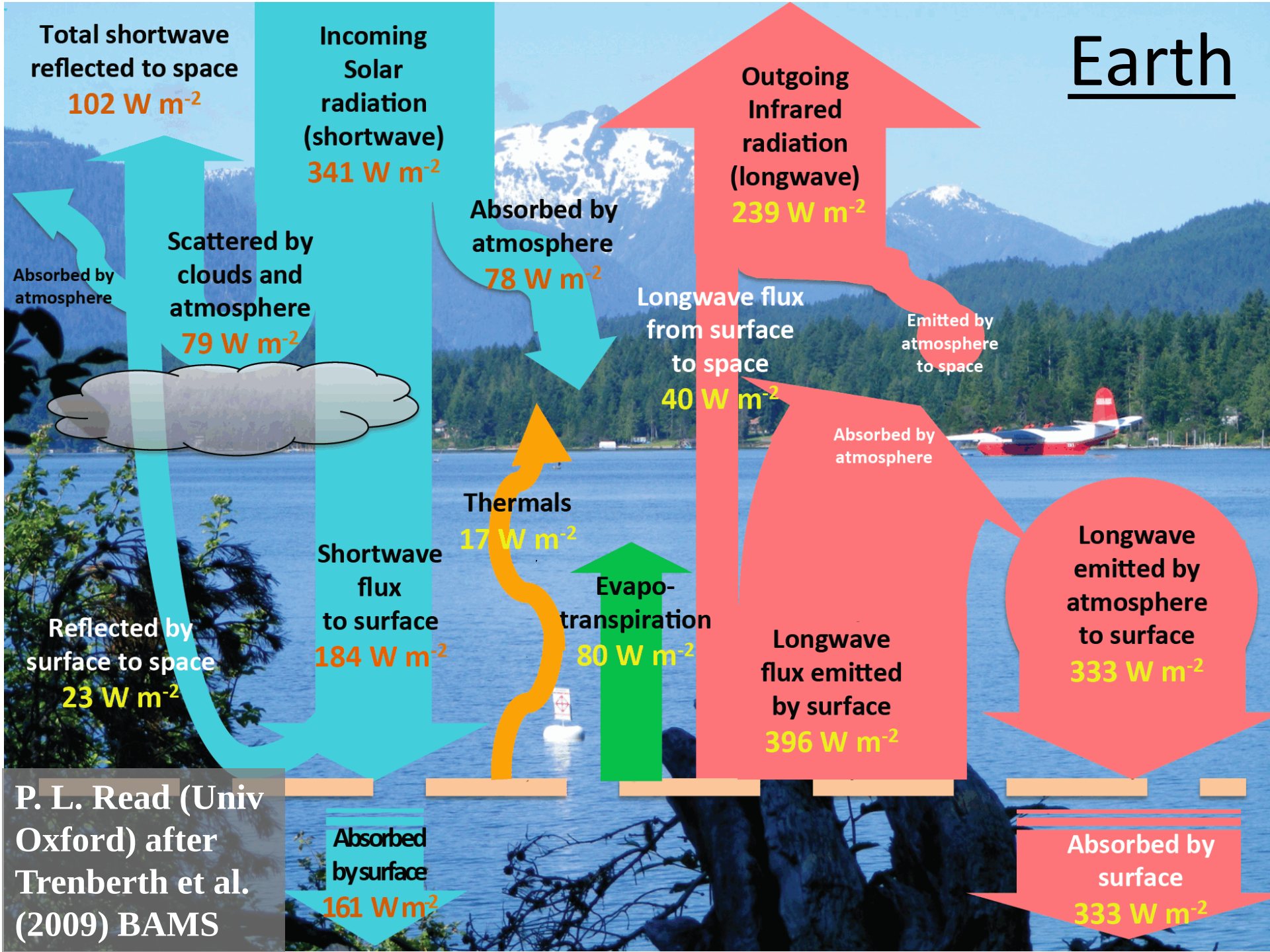
Remote influences on the jet stream

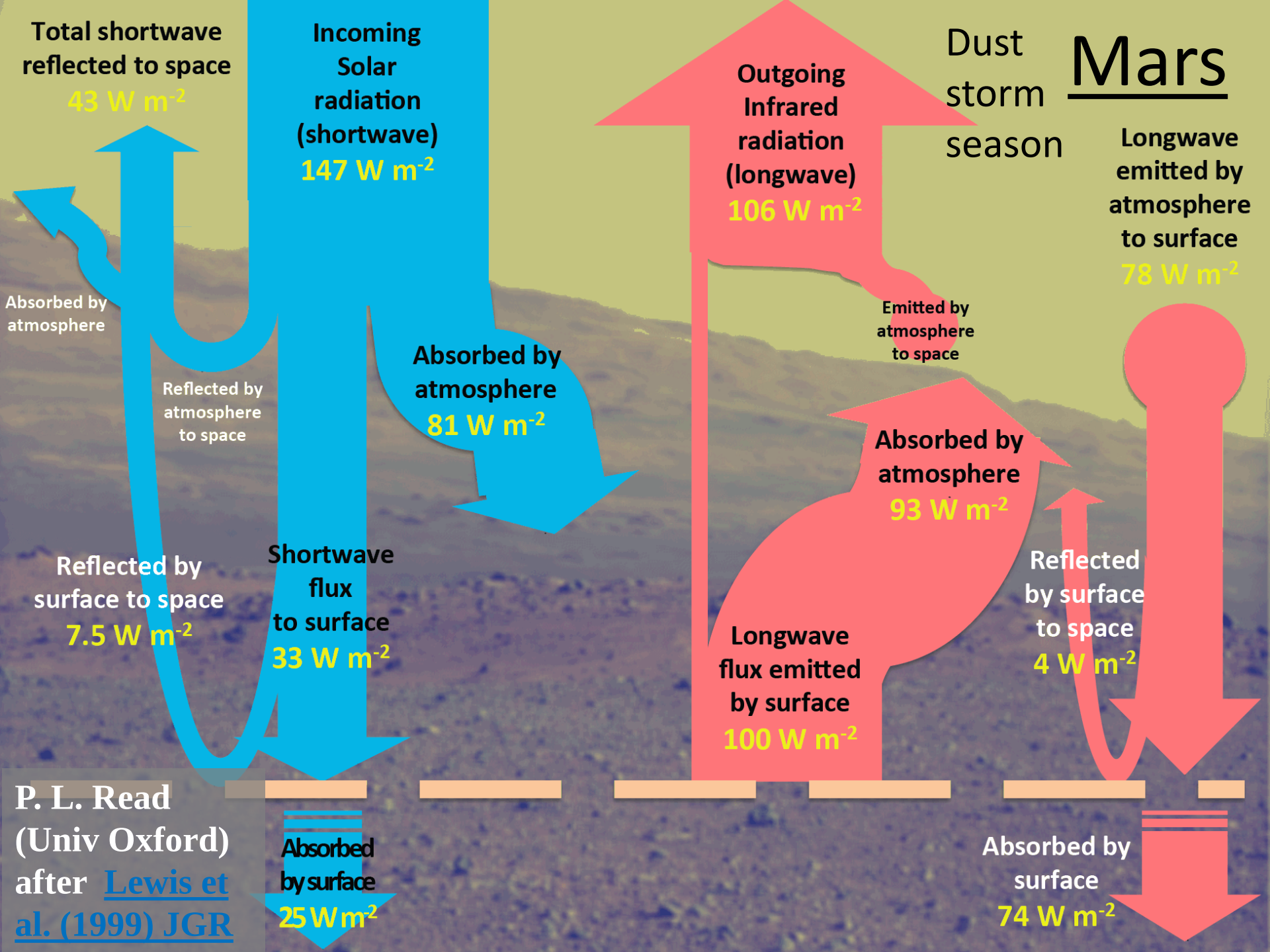






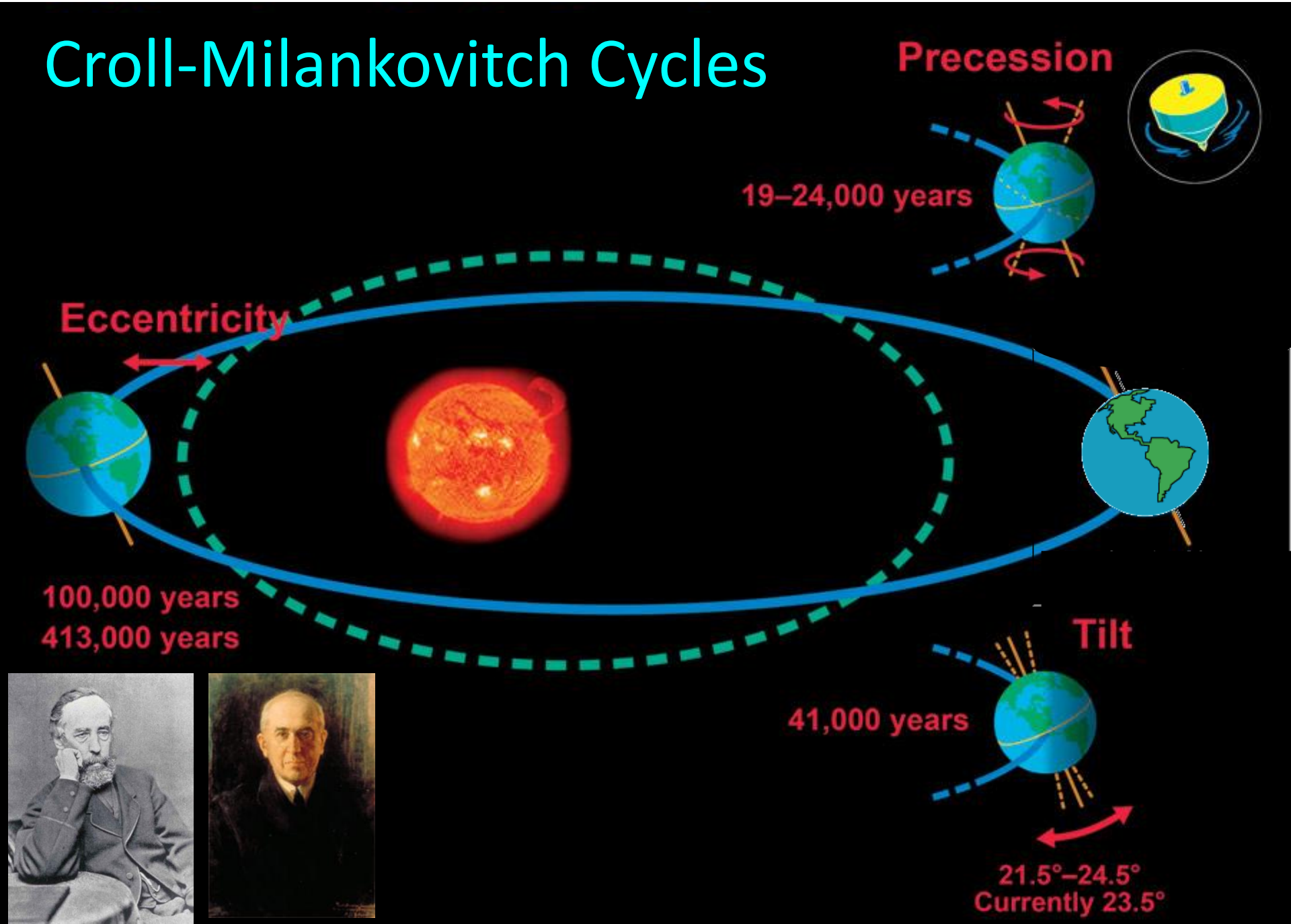
4. Changes in this temperature difference between equator and pole can alter the position and strength of the jet stream. This and other **natural** and **human-caused** effects influence our weather patterns and extremes.

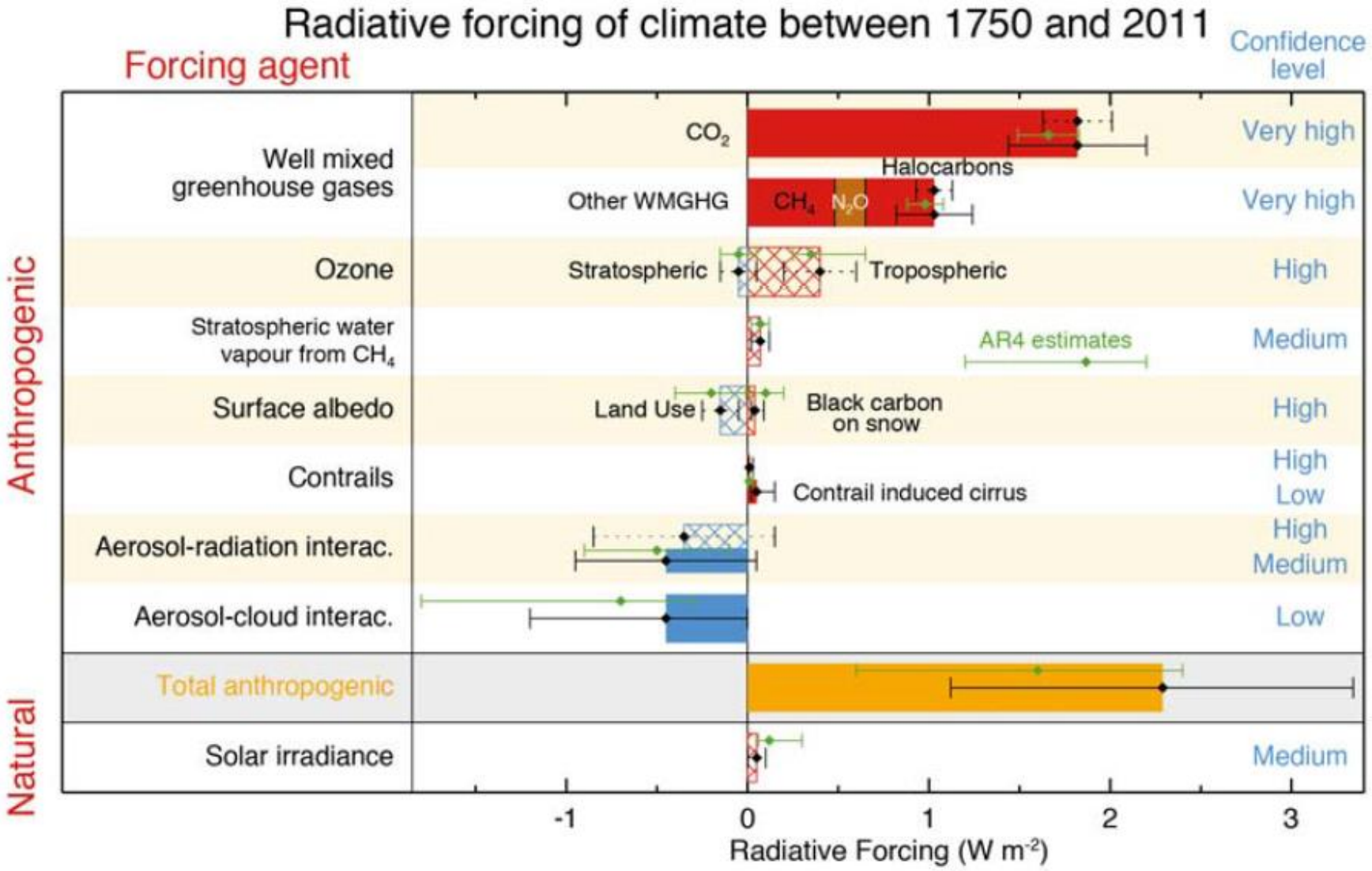

Earth
Total shortwave reflected to space
102 W m-2
Incoming Solar radiation (shortwave)
341 W m-2
Outgoing Infrared radiation (longwave)
239 W m-2
Absorbed by atmosphere
78 W m-2
Absorbed by atmosphere
Scattered by clouds and atmosphere
79 W m-2
Longwave flux from surface to space
40 W m-2
Emitted by atmosphere to space
Absorbed by atmosphere
Thermals
17 W m-2
Shortwave flux to surface
184 W m-2
Evapo-transpiration
80 W m-2
Longwave emitted by atmosphere to surface
333 W m-2
Reflected by surface to space
23 W m-2
Longwave flux emitted by surface
396 W m-2
Absorbed by surface
161 W m-2
Absorbed by surface
333 W m-2
P. L. Read (Univ Oxford) after Trenberth et al. (2009) BAMS



P. L. Read (Univ Oxford) after Lewis et al. (1999) JGR

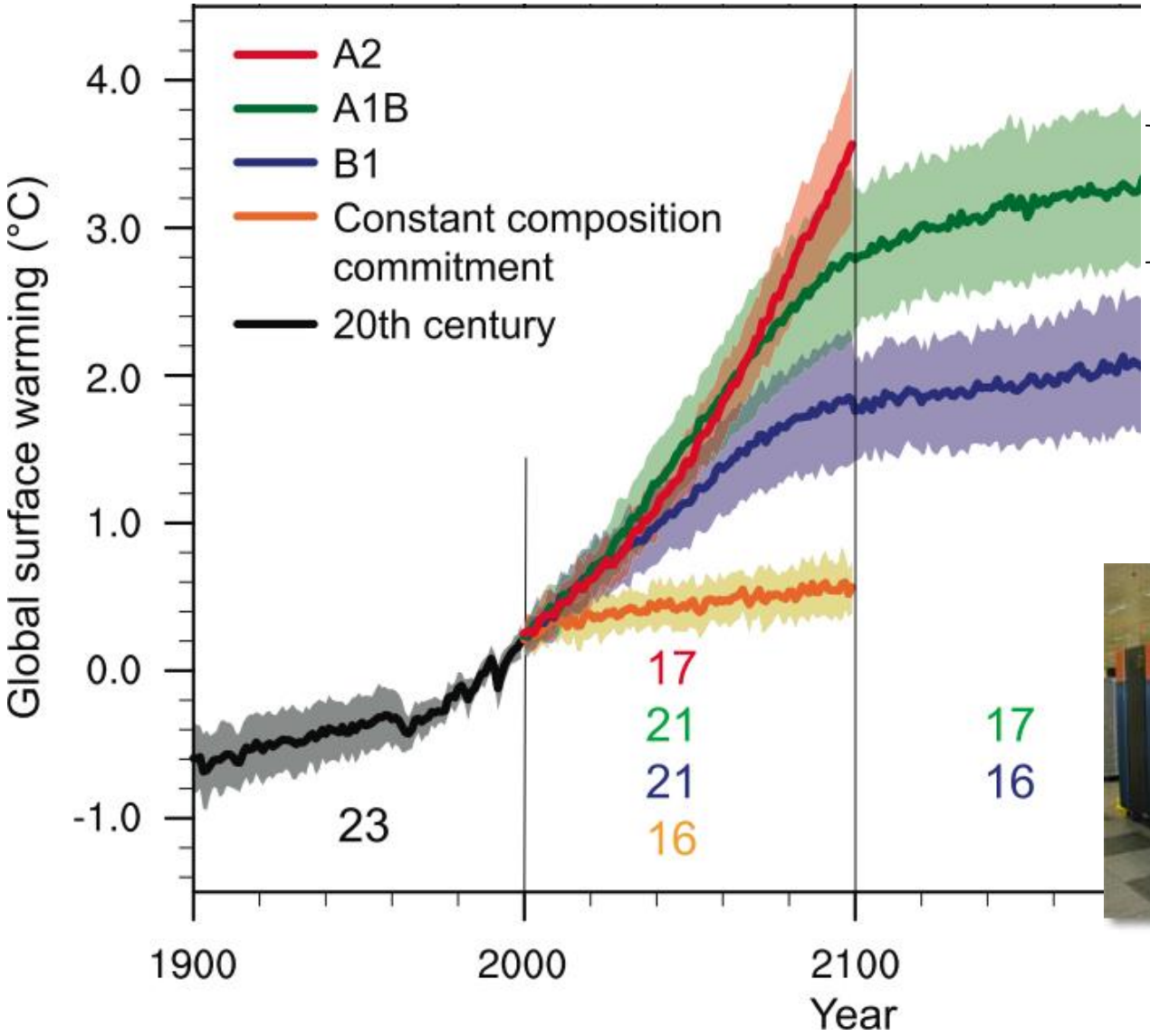
Croll-Milankovitch Cycles





See also [IPCC (2013) Summary for Policy Makers](#) (Figure SPM.4)

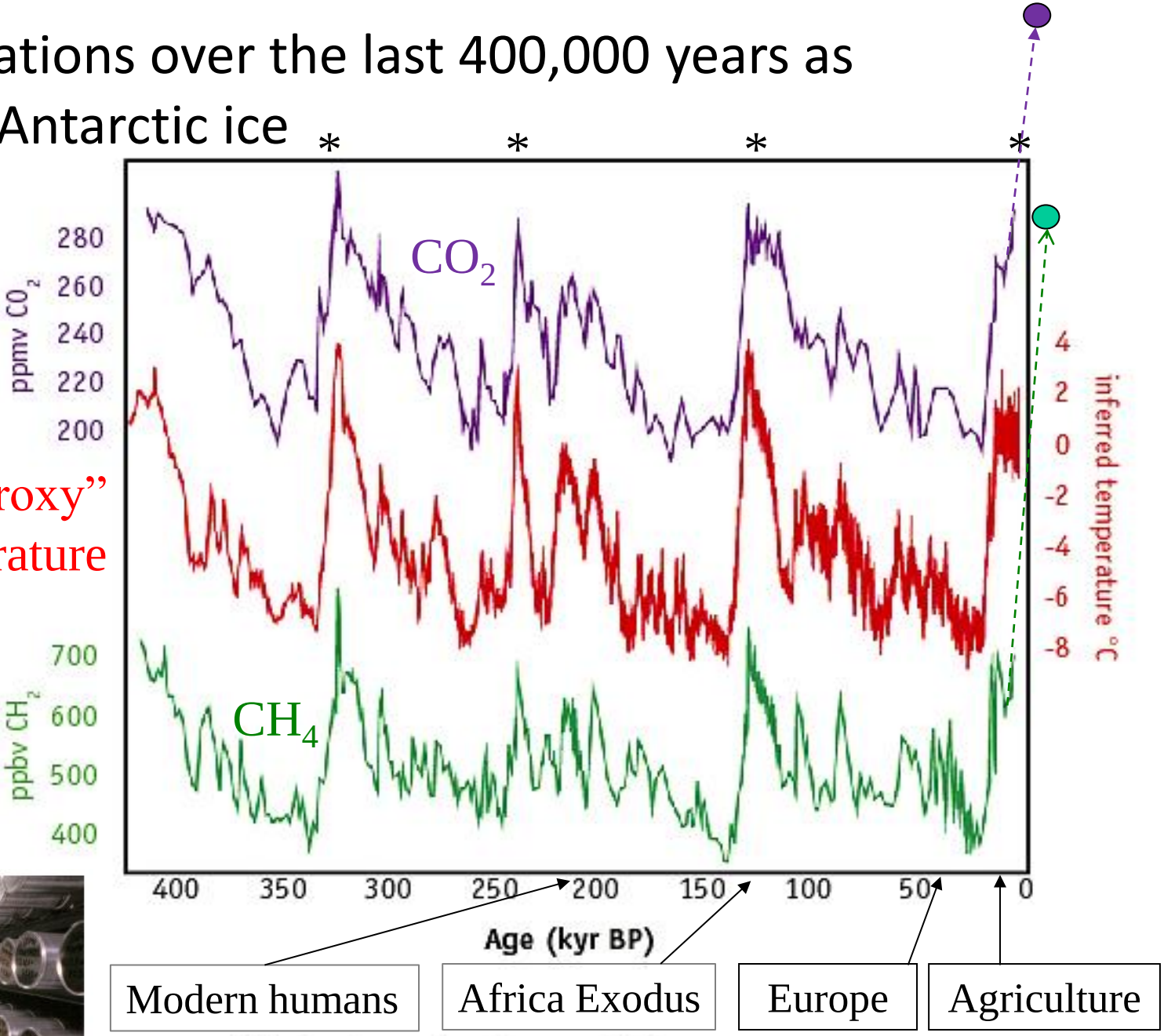
Clouds and why global warming predictions are uncertain?



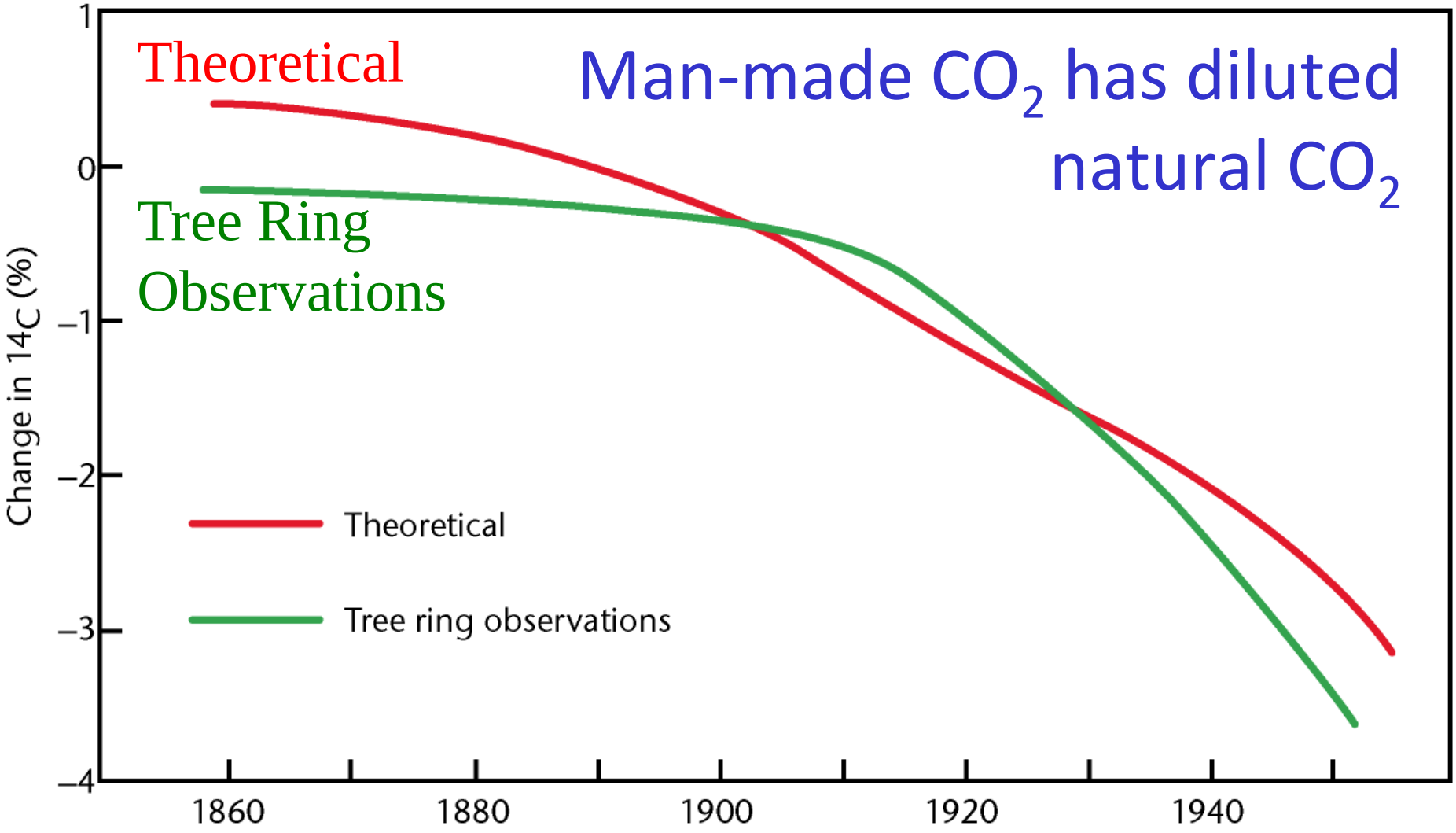
Climate variations over the last 400,000 years as recorded in Antarctic ice

* - indicates interglacial period

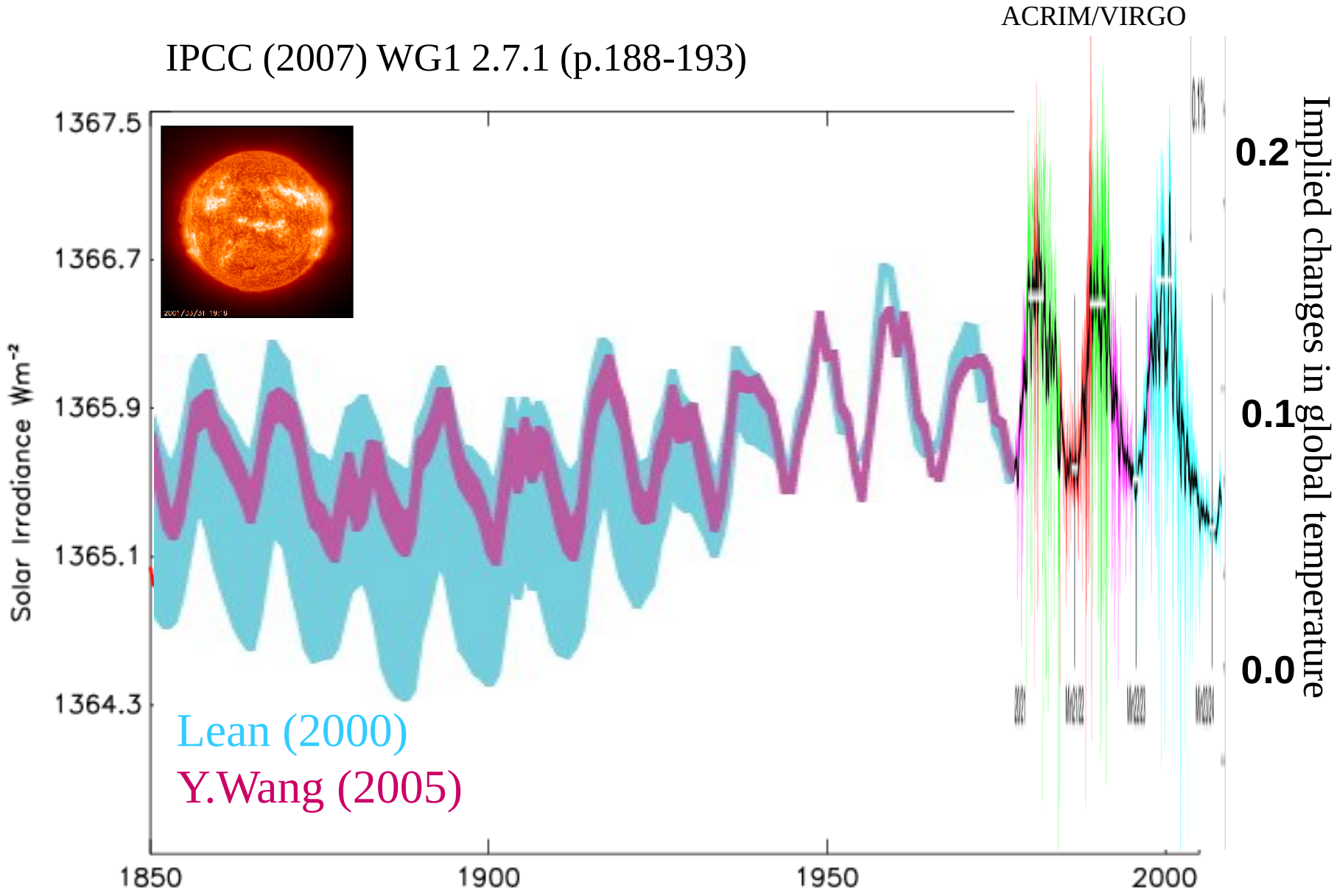
Inferred "proxy" Temperature



J.R. Petit et al., *Nature*, **399**, 429–36, 1999.


Theoretical
Man-made CO_2 has diluted natural CO_2
Tree Ring Observations
Change in ^{14}C (%)
1
0
−1
−2
−3
−4
1860
1880
1900
1920
1940
Theoretical
Tree ring observations

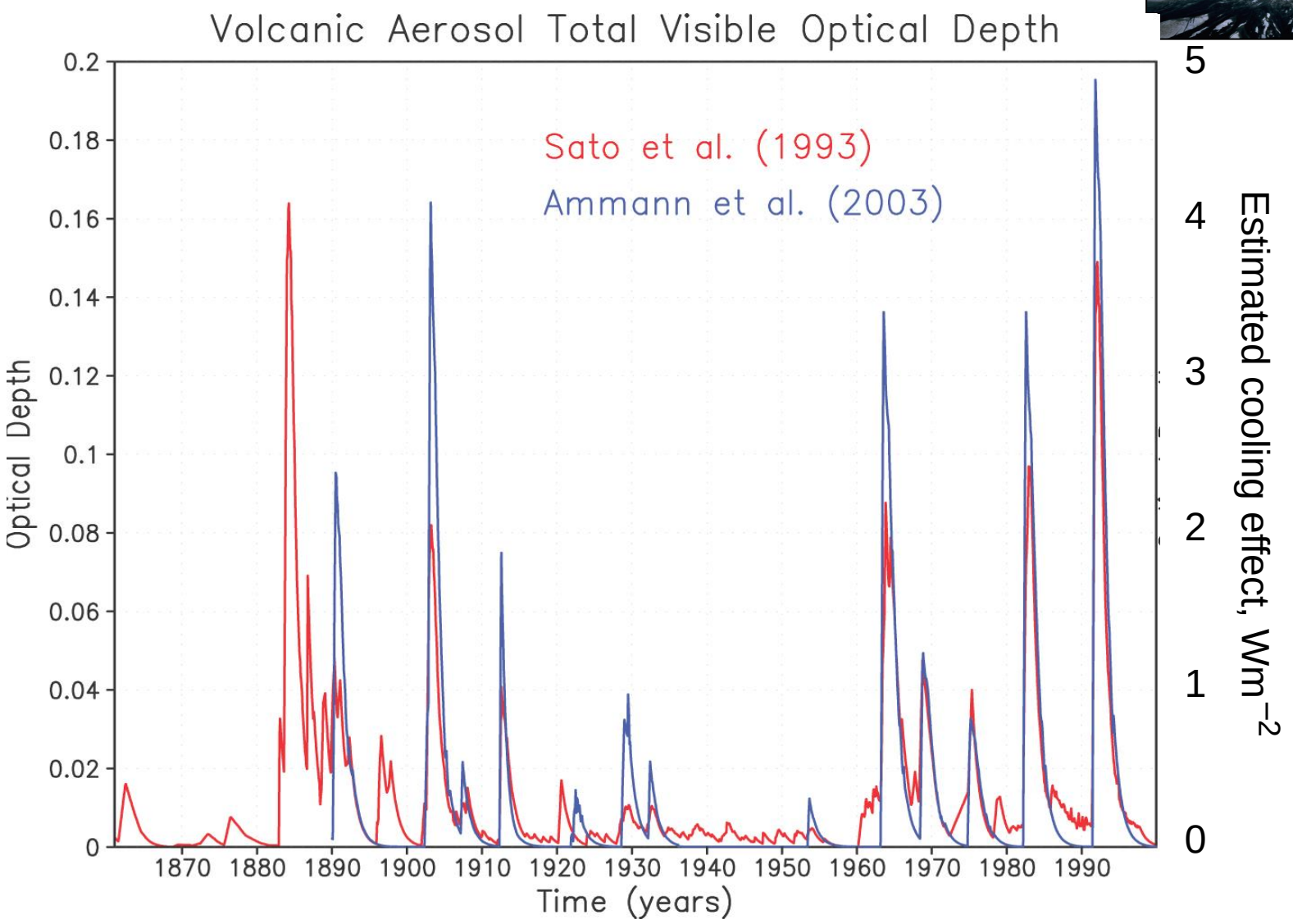
Energy from the Sun; stable over last 50 years



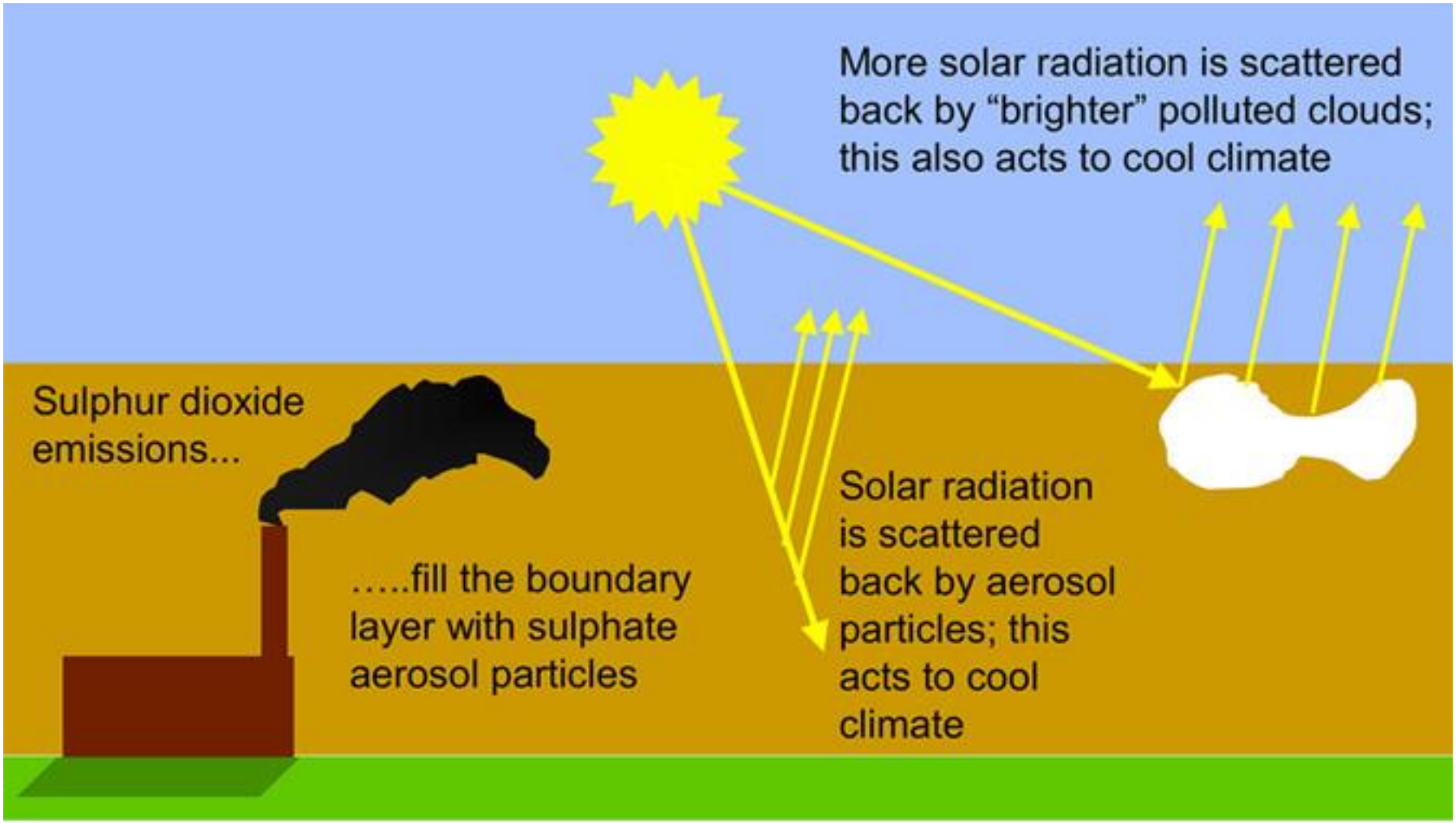
See also: http://www.pmodwrc.ch/pmod.php?topic=tsi/composite/SolarConstant

Changes in volcanic activity

IPCC (2007) WG1 2.7.2 (p.193-195)

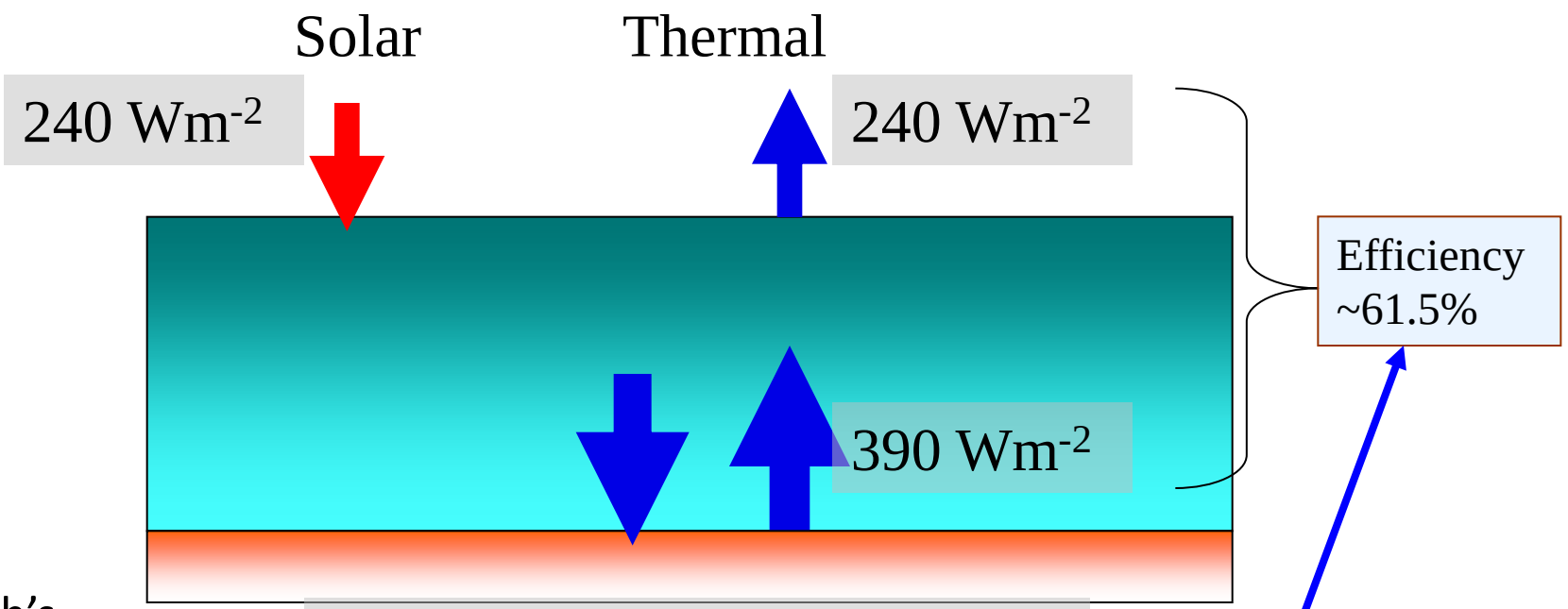


Sulphur aerosols cool climate directly and indirectly



Met Office Hadley Centre

What would happen if we enhance the greenhouse effect?



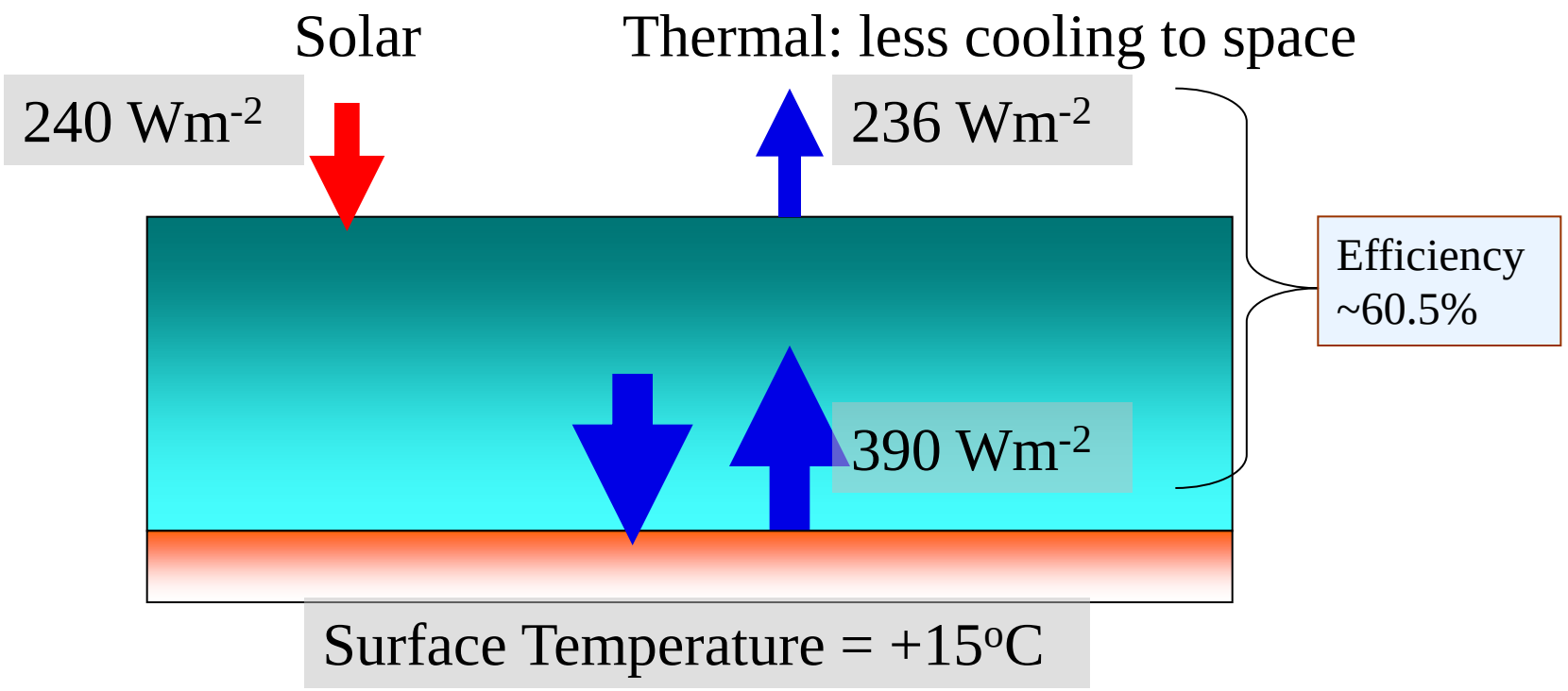
T_E is Earth's effective temperature as seen from space

$$(1- \alpha)S_o/4 = \sigma T_E^4$$

Radiating Efficiency, or the inverse of the Greenhouse Effect, is strongly determined by water vapour absorption across the electromagnetic spectrum

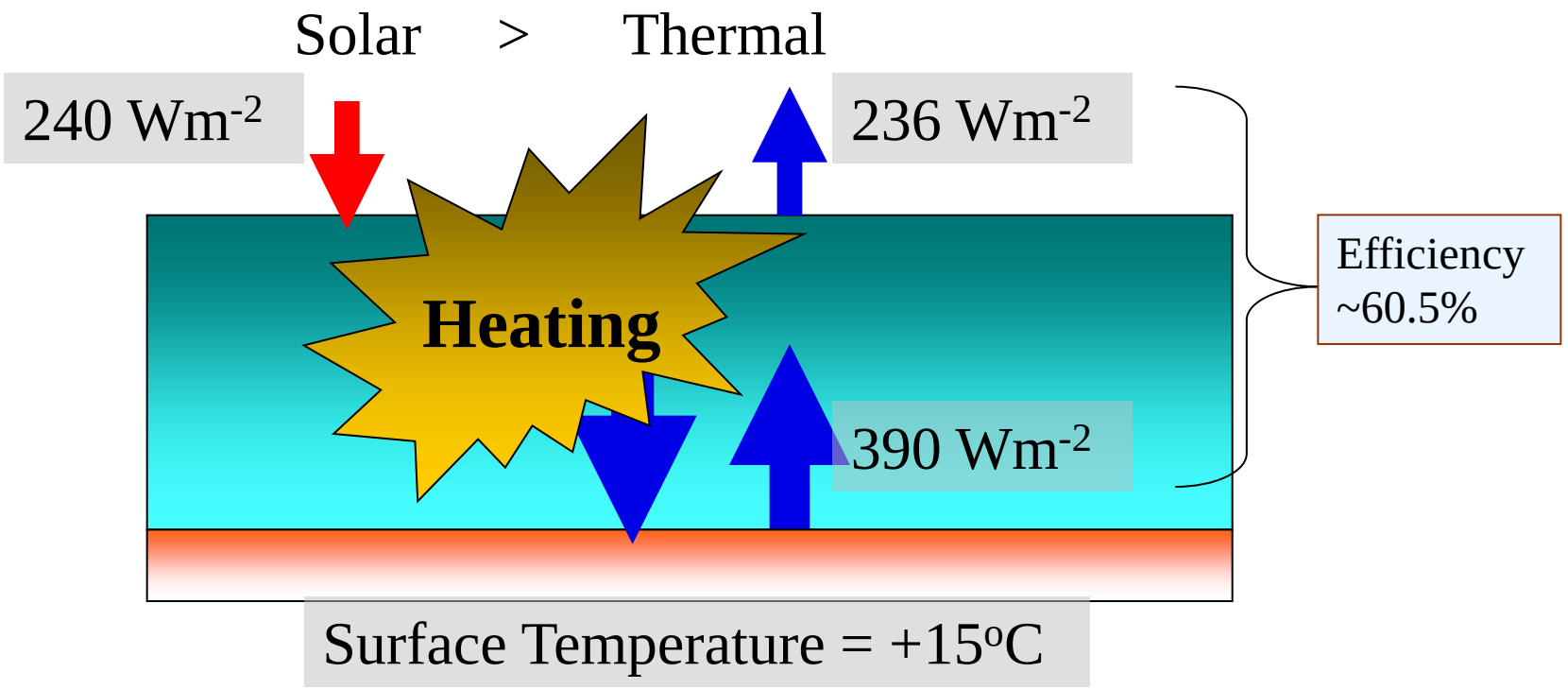
Introduce a radiative forcing (e.g. $2xCO_2$)

note: could equally choose to change solar

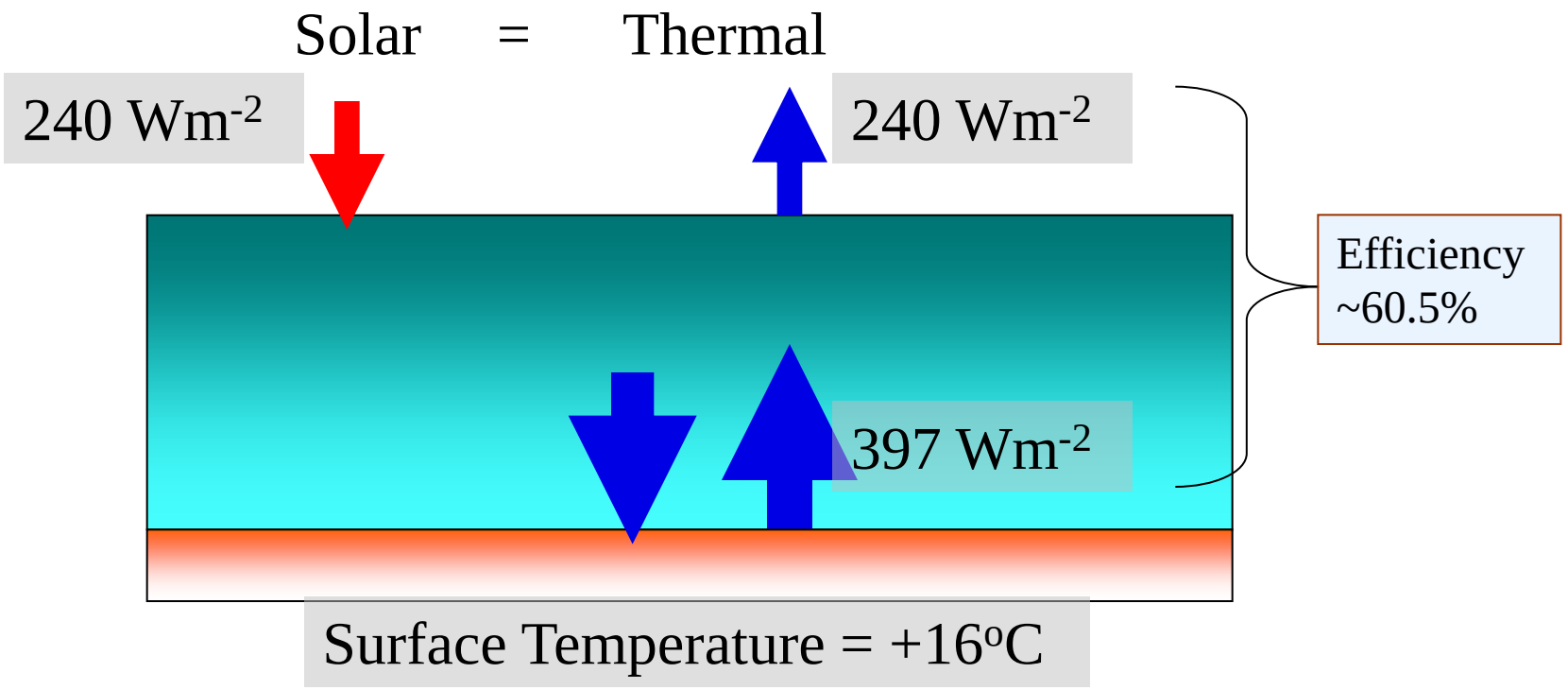


Radiative cooling to space through longwave emission drops by about 4 Wm^{-2} resulting in a radiative imbalance

The climate system responds by warming



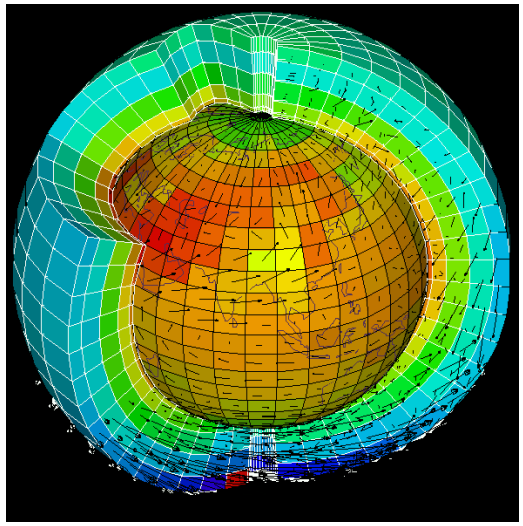
New global temperature

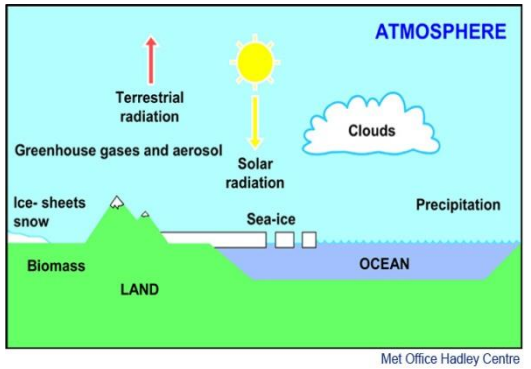


Doubling CO_2 concentrations increased temperature by about 1°C in this simple example. But this ignores feedback processes that may amplify or retard the response to the forcings.

Experiments with climate models

- How much of recent warming is explained by natural effects?
- To answer such questions, experiments can be performed with climate simulations
  - including just natural factors (ocean circulation, volcanic eruptions, changes in the sun, …)
  - including natural and anthropogenic factors (e.g. greenhouse gas emissions which cause heating + sulphate aerosol pollutant particles which cause cooling)





Met Office Hadley Centre