Climate Changes: Past & Future (Ch 16)

"**Climate change**" – change in any statistical property of earth-atmosphere climate system

– in response to alteration of an "external boundary condition"

– or as an "internal" fluctuation

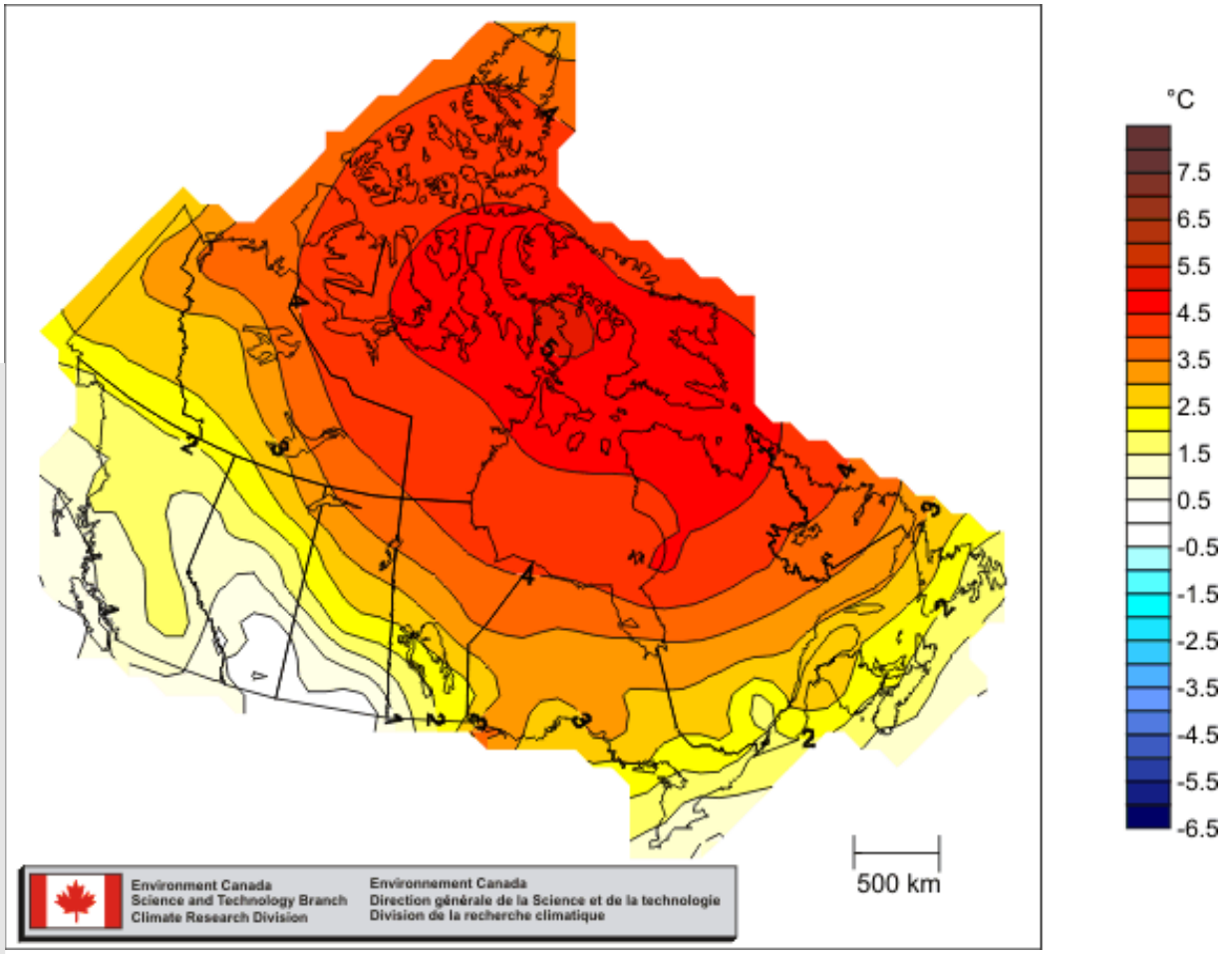
- climate change relative to what "normal" ?
- is "climate warming" happening? – refining the question
- if so, is it ***plausible*** that it is anthropogenic (man-induced)?

Is anthropogenically-driven climate change plausible? – factors to consider

If climate change is happening (on a time scale of concern to us), then is it ***plausible*** that it is anthropogenic (man-induced)?

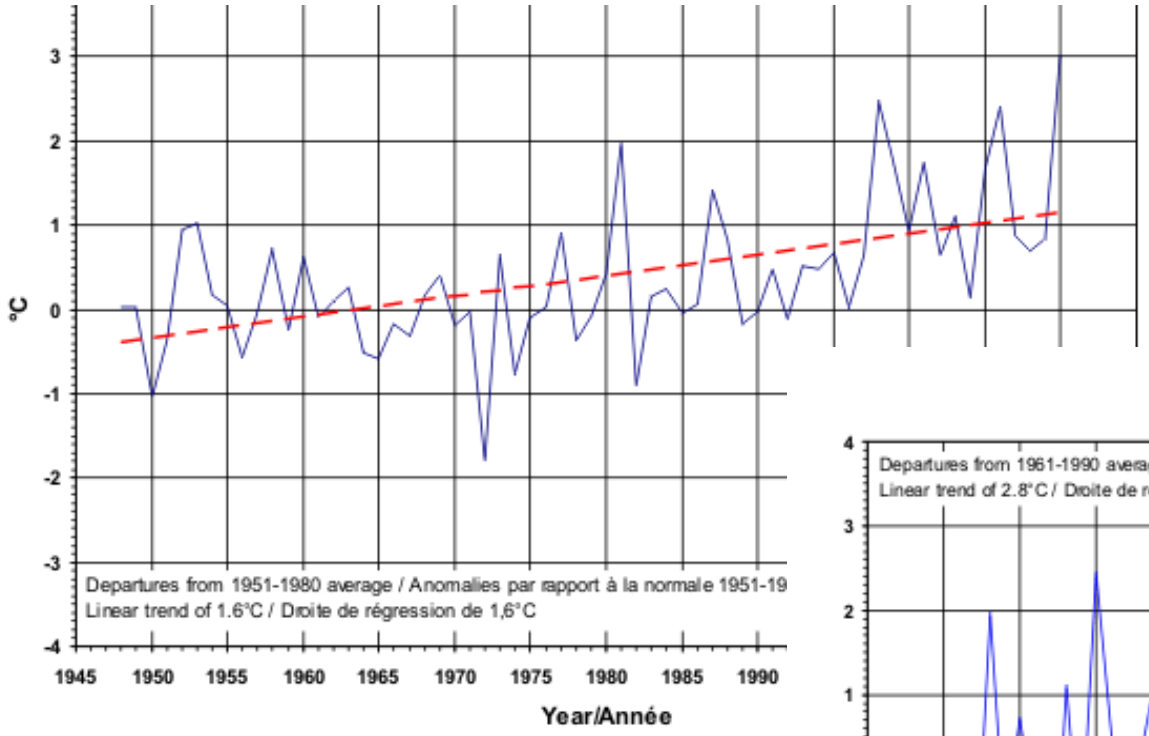
- Atmosphere is exceedingly thin, and contacts earth over huge surface area
- Do we modify the earth's surface?
- Without greenhouse gases, earth's equilib temperature would be much cooler

Climate Trends and Variations Bulletin - Annual 2010. The national average temperature for the year 2010 was 3.0°C above normal, based on preliminary data, which makes this the warmest year on record since nationwide records began in 1948. The previous warmest year was 1998, 2.5°C above normal.

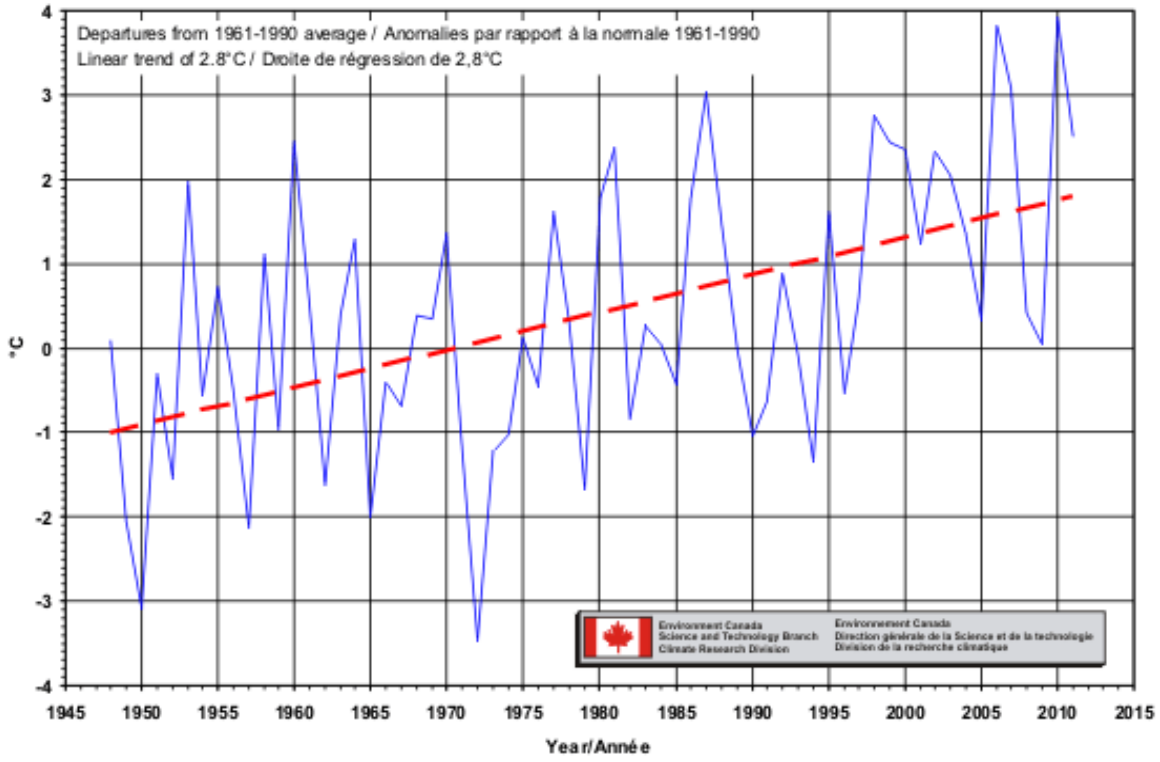


Canada's annual mean surface temperature (departure from 1951-1980 average)

The temperature trend graph below shows that **annual** temperatures have been above normal since 1993. The red dashed linear trend line indicates annual temperatures have warmed over the last 63 years by 1.6°C.



Winter National Temperature departures and long-term trend, 1948 - 2011

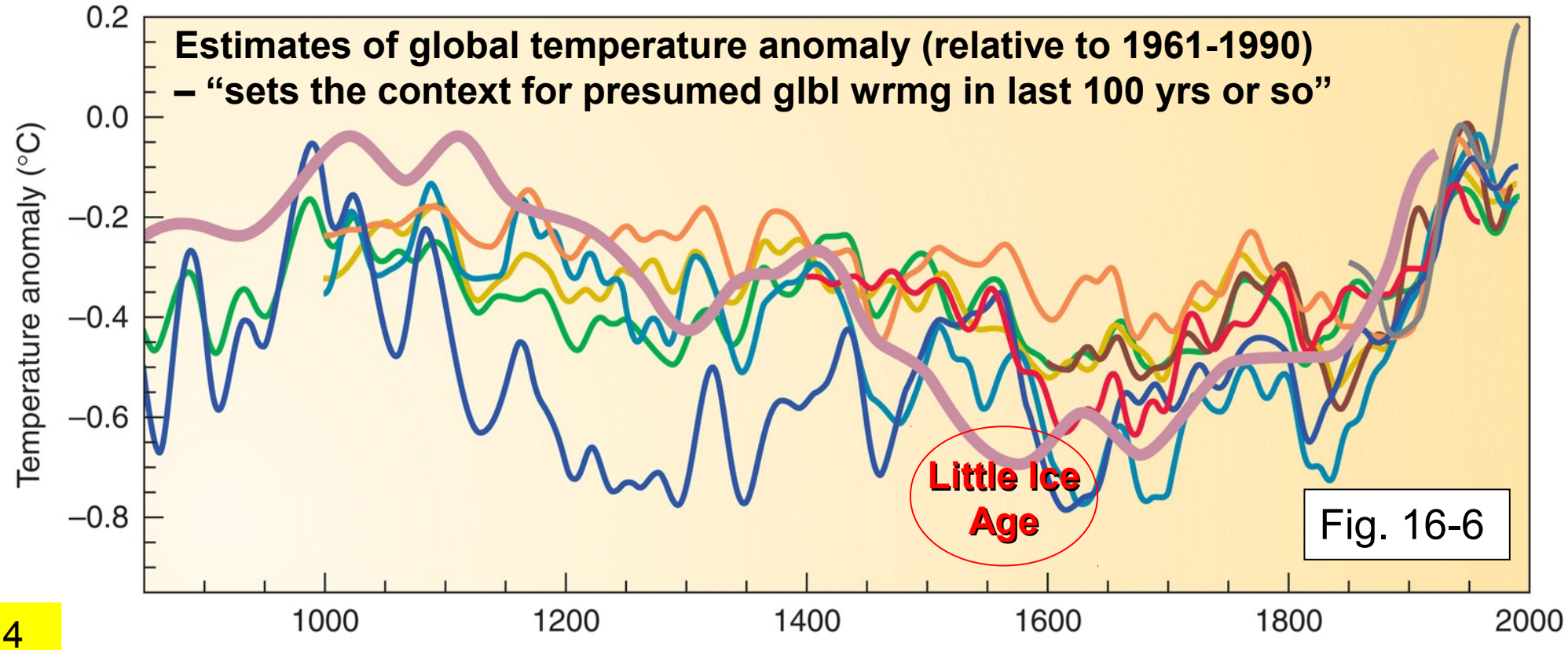


Climate Change – "boundary conditions," i.e. external factors

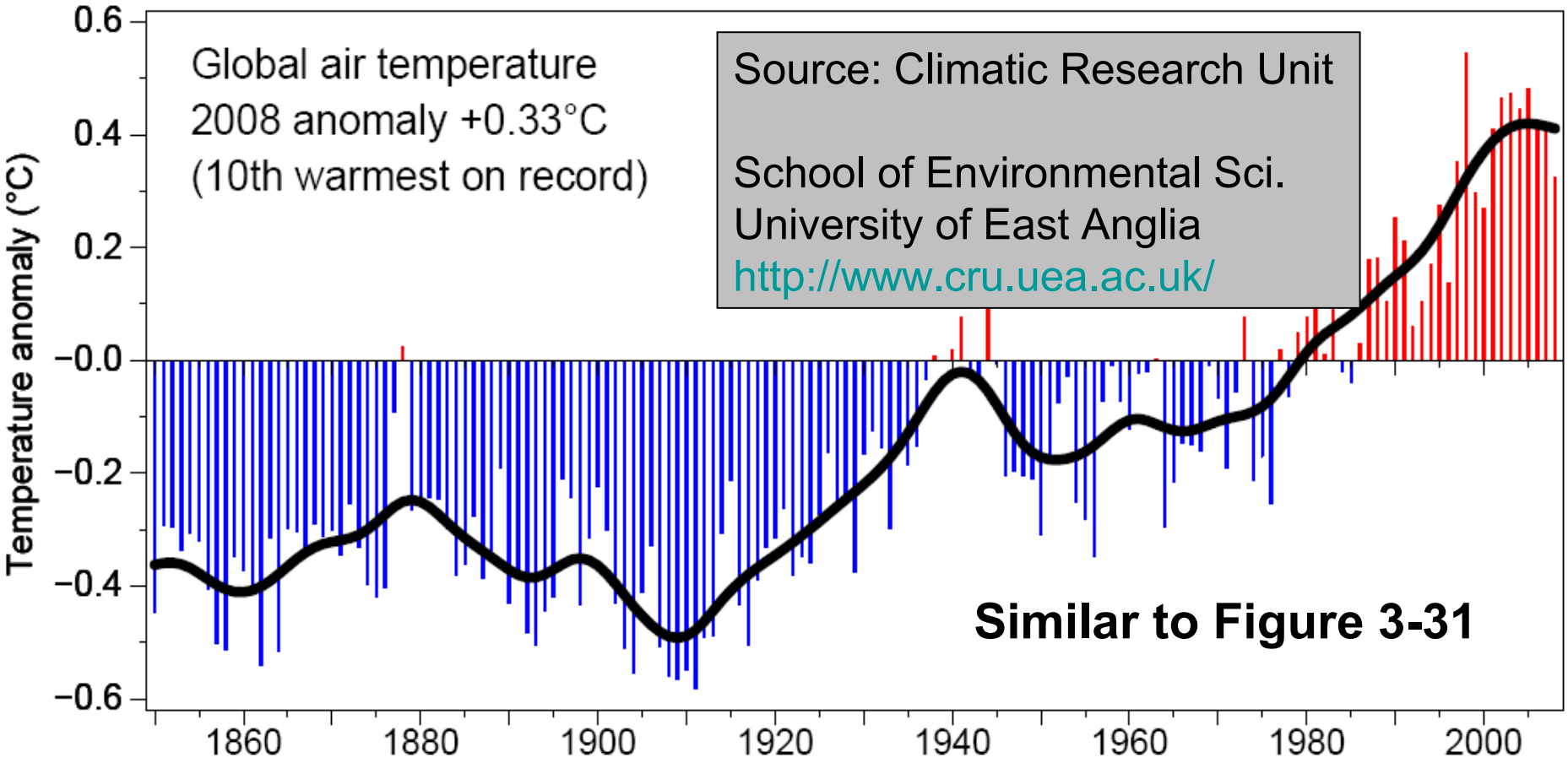
Logical to consider earth's climate to be a function of these "external factors" (the text calls them "boundary conditions"):

- intensity of sunlight (solar output, sun-earth geometry)
- arrangement of continents and oceans
- composition of the atmosphere

- what about *organisms*/*life*?

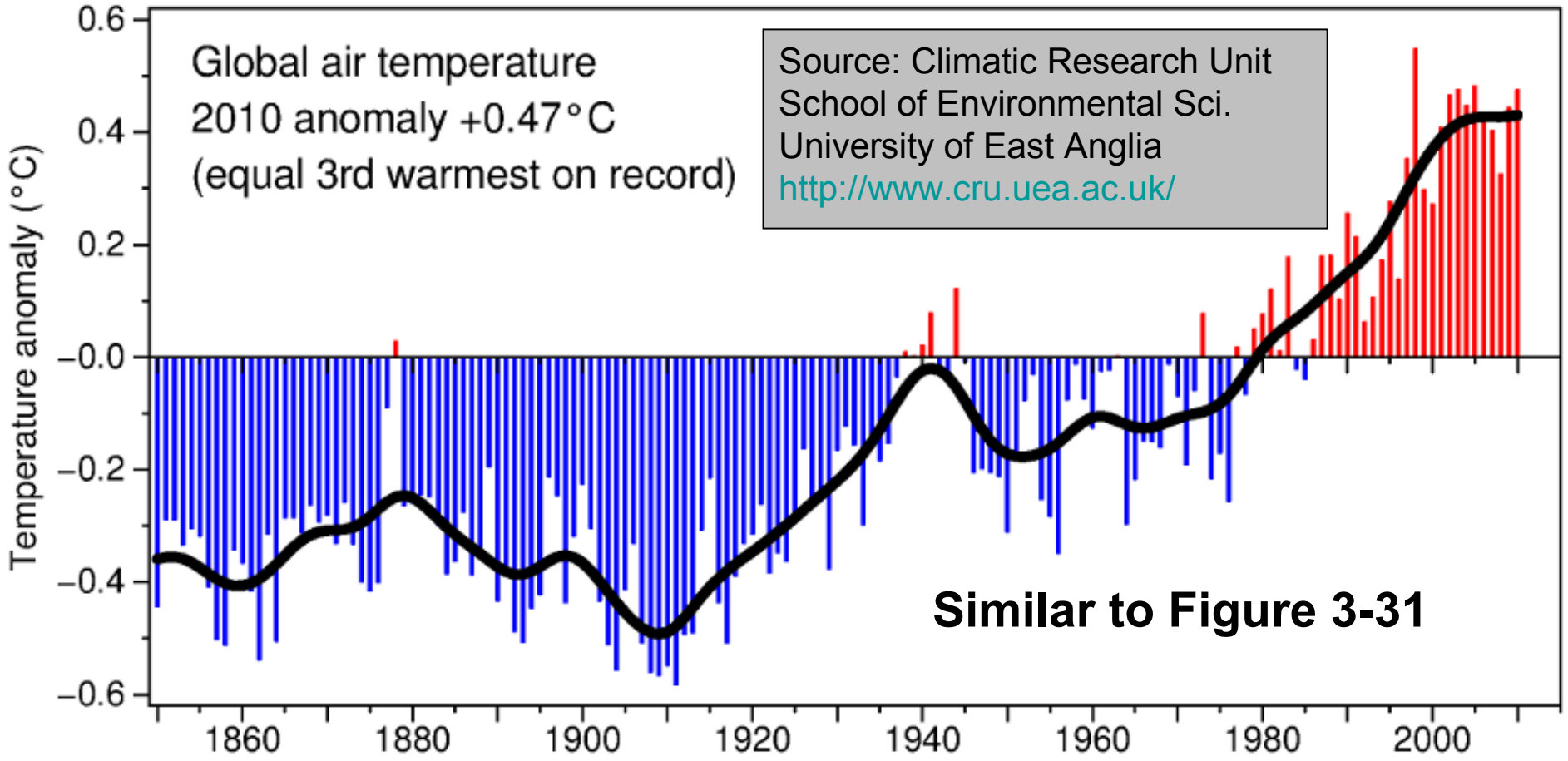


Climate Change – climate uniqueness?



"Climate change can be defined as the response of the Earth-atmosphere system to changes in the boundary conditions" (p498). But this is an acceptable definition only if climate statistics are defined over an averaging interval much longer than all possible internal oscillations – which is why the textbook broadens def'n to embrace (also) Δclimate caused by internal oscillations

Climate Change – climate uniqueness?



Does earth have a unique climate for fixed values of the "boundary conditions" ? Probably not. It would be surprising if it did – that would have to mean the "external factors" control earth's climate processes down to a surprising level of detail, including (eg). evolution/adaptation of plants – and humans

Climate Change – the long term perspective

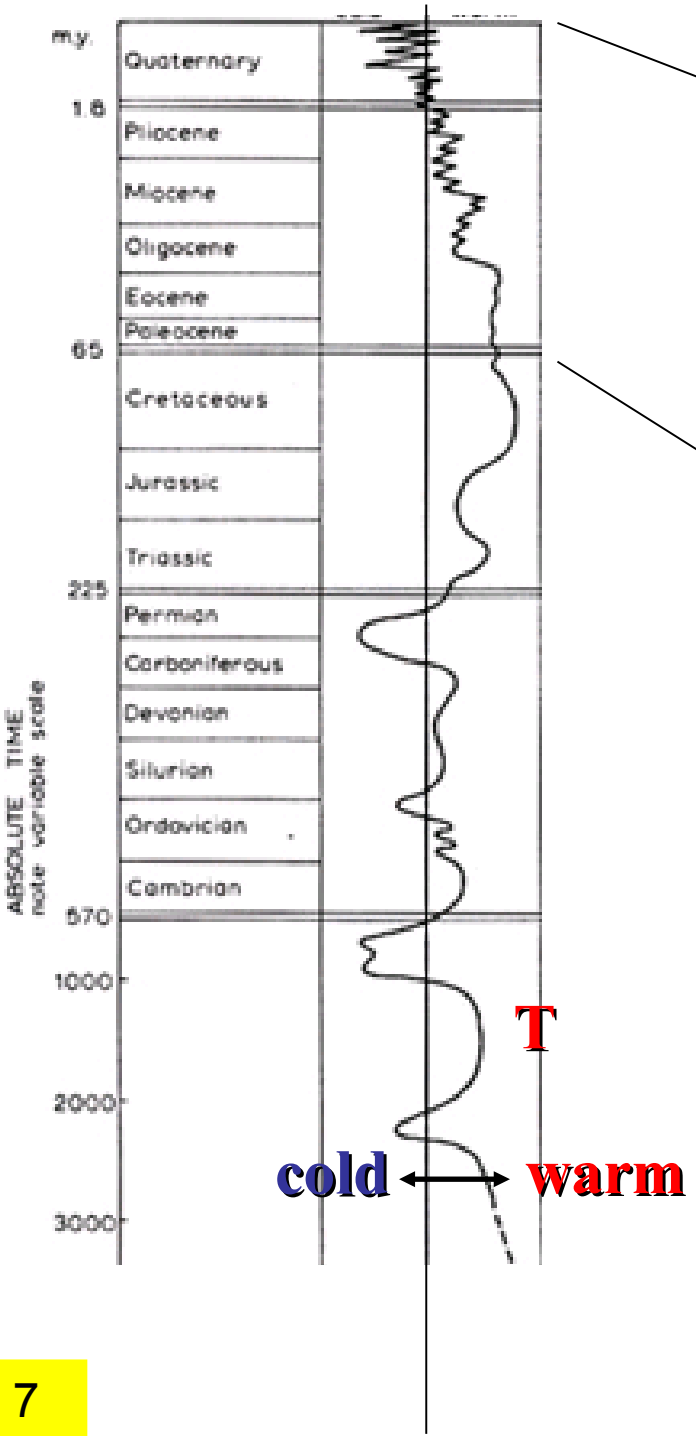
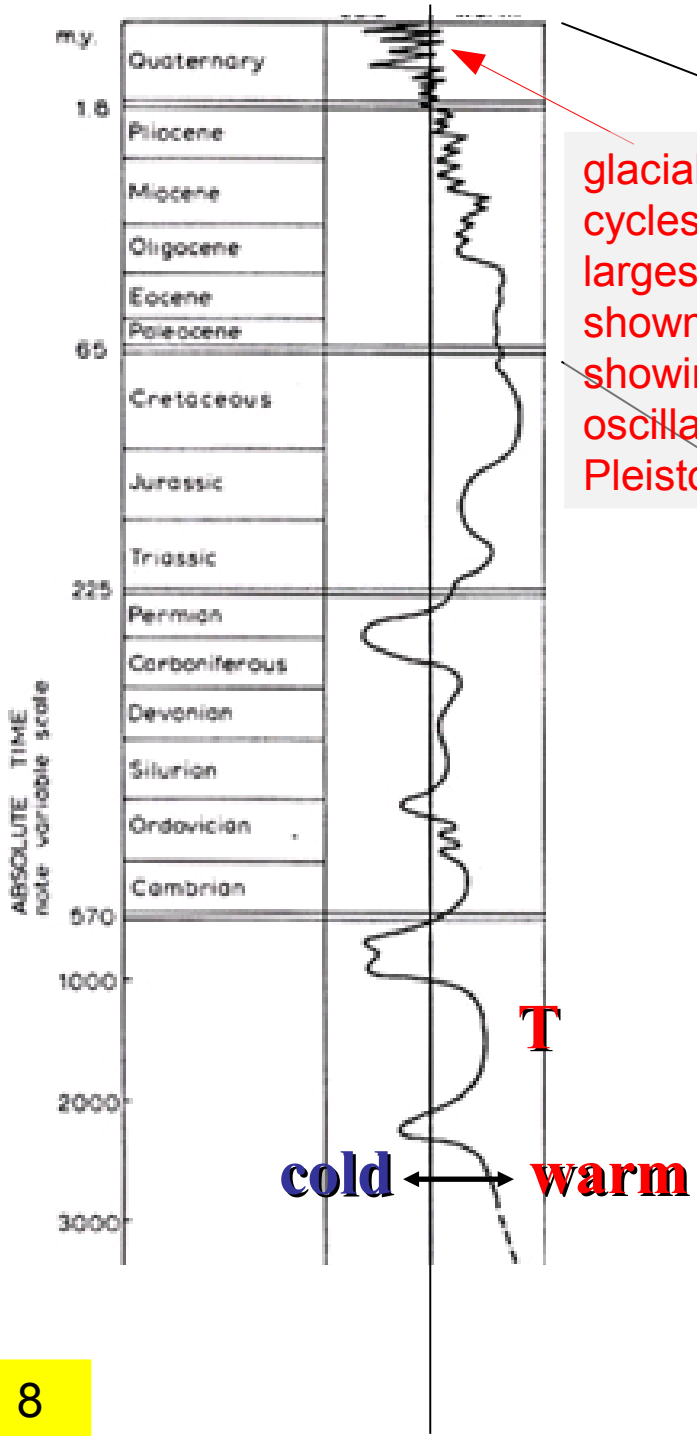


Fig. 16-2

Erathem Era	System Period	Series Epoch	Duration in Millions of Years	Millions of Years Ago
CENOZOIC	Neogene	Holocene	0.0115	0.0115
		Pleistocene	1.8	1.8
		Pliocene	3.5	5.3
		Miocene	17.7	23.0
	Paleogene	Oligocene	10.9	33.9 ±0.1
		Eocene	21.9	55.8 ±0.2
		Paleocene	9.7	65.5 ±0.3

- present climate unusual - earth mostly has been “considerably warmer” than now (p499)
- most of its 4.5B yr life, earth free of permanent ice (p500)

Climate Change – the long term perspective



glacial/inter-glacial cycles; only the largest/slowest shown; see Fig. 16-3 showing many more oscillations through Pleistocene

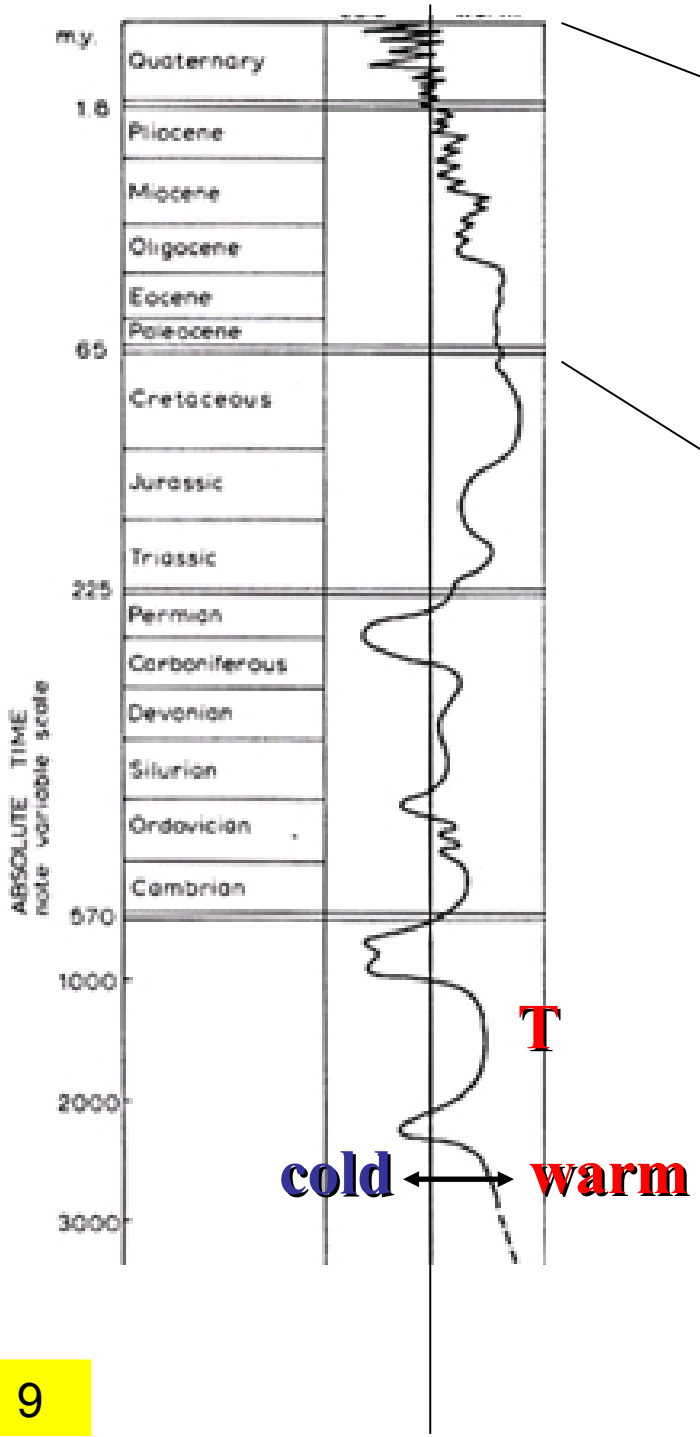
Fig. 16-2

Erathem Era	System Period	Series Epoch	Duration in Millions of Years	Millions of Years Ago
CENOZOIC	Neogene	Holocene	0.0115	0.0115
		Pleistocene	1.8	1.8
		Pliocene	3.5	5.3
		Miocene	17.7	23.0
	Paleogene	Oligocene	10.9	33.9 ±0.1
		Eocene	21.9	55.8 ±0.2
		Paleocene	9.7	65.5 ±0.3

- "warm planet" (perhaps 5 to 15°C warmer global mean) punctuated by about seven brief ice ages (of which first about 2.3 ByrBP)... p500

- last 1.8 million years cover period of humans and recognizable ancestors; entire period an ice age, numerous oscillations in global *T* & ice cover. A handful of interglacial phases as warm as our present one; the "last interglacial" 125 KyrBP

Climate Change – the long term perspective



Erathem Era	System Period	Series Epoch	Duration in Millions of Years	Millions of Years Ago
CENOZOIC	Neogene	Holocene	0.0115	0.0115
		Pleistocene	1.8	1.8
		Pliocene	3.5	5.3
		Miocene	17.7	23.0
	Paleogene	Oligocene	10.9	33.9 ±0.1
		Eocene	21.9	55.8 ±0.2
		Paleocene	9.7	65.5 ±0.3

- climate change occurs on many time scales
- rapid (and growing) climate oscillations during the Quaternary (=Pleistocene + Holocene), see Fig. 16-3
- we are in interglacial phase of an ice age

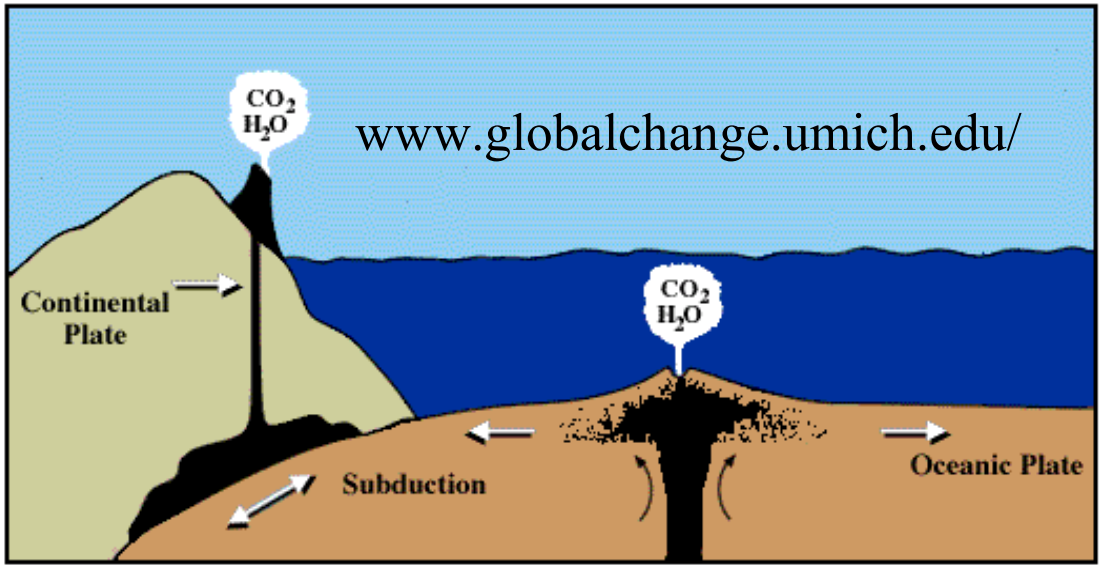
Long-Term Changes

The long term (100's million years) paleoclimate record is characterized by relatively few, isolated glacial outbreaks - the great Ice Ages.

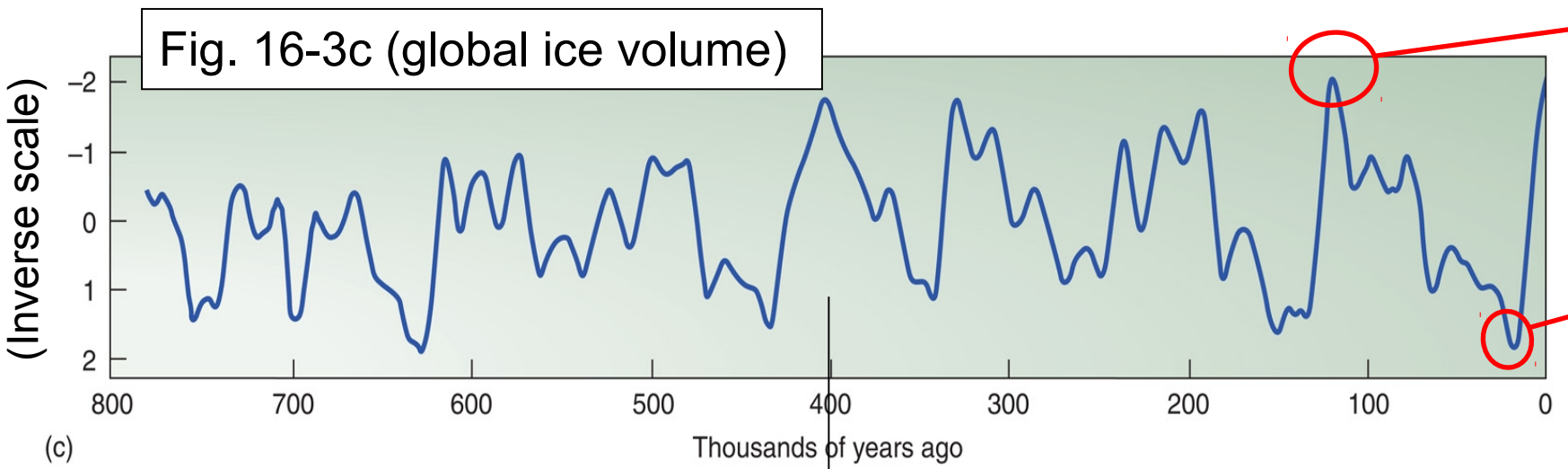
- the trend can't be explained by variations in solar output – sun was *less* radiant in the distant past (p511)

- can't be explained by orbital changes (which are too fast)

- it is considered plausible that the long term pattern reflects the influence of plate tectonics on volcanism and cycling of carbon in sedimentary rocks, processes influencing the concentration of atmospheric greenhouse gases



Glacial/interglacial cycles within "our" ice age (climate oscillations)

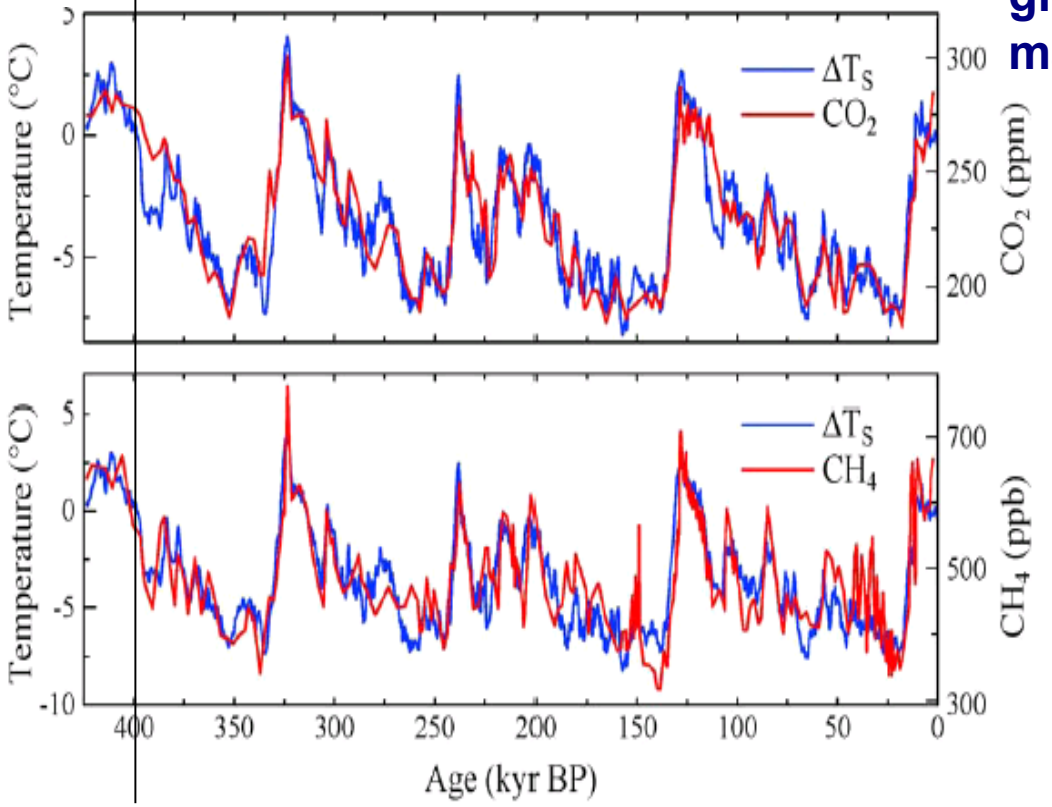


Last inter-glacial (125Kyr BP)

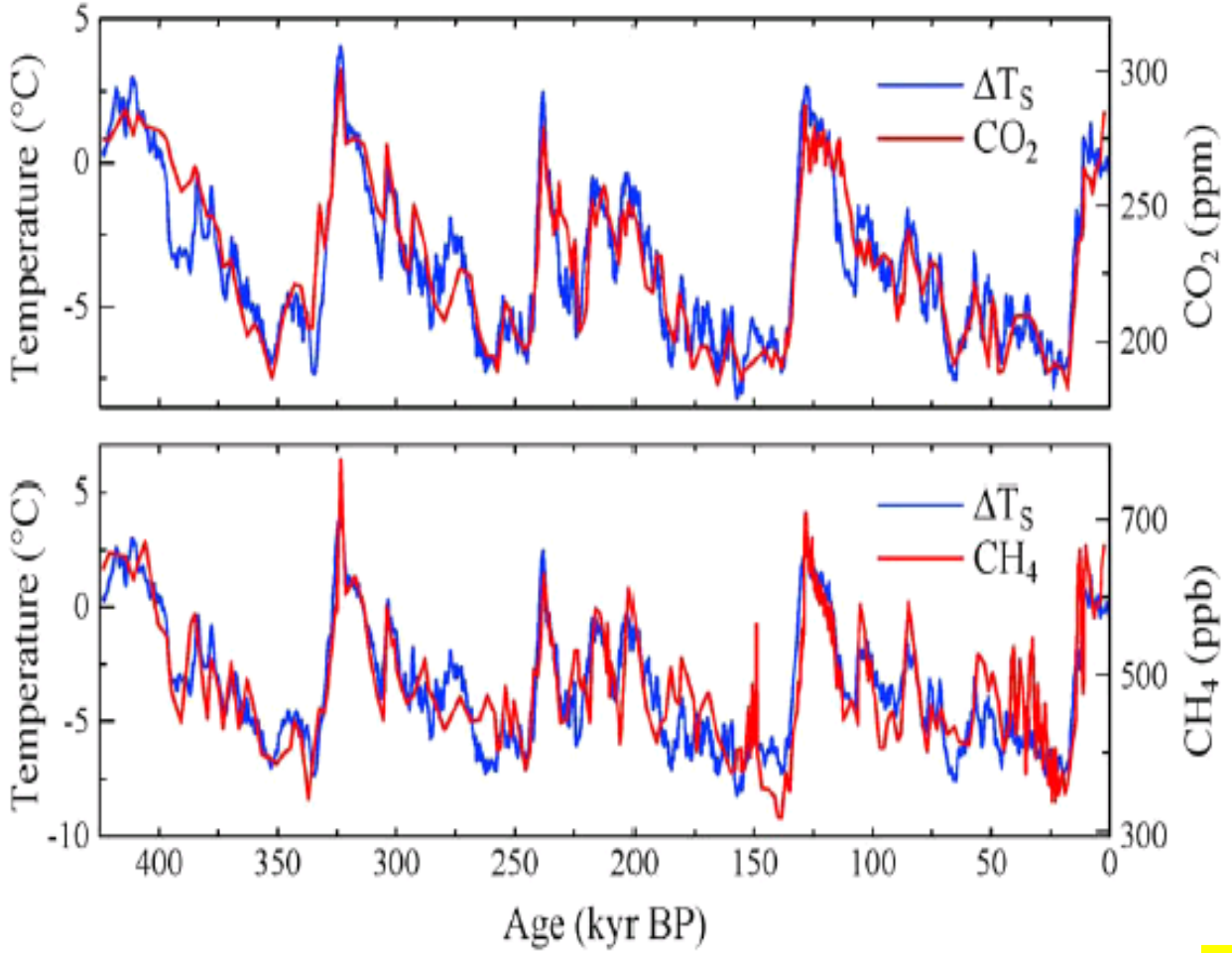
Later phase of last glacial max

- planet is now in a warm interglacial

From Antarctic (Vostok) ice core record…



“strong correlation between past temperatures and concentrations of carbon dioxide and methane. Past periods of high temperature coincide with high concentrations… Generally the changes in gas concentration lag behind the temperature changes by 800 to 1000 years” (p529)



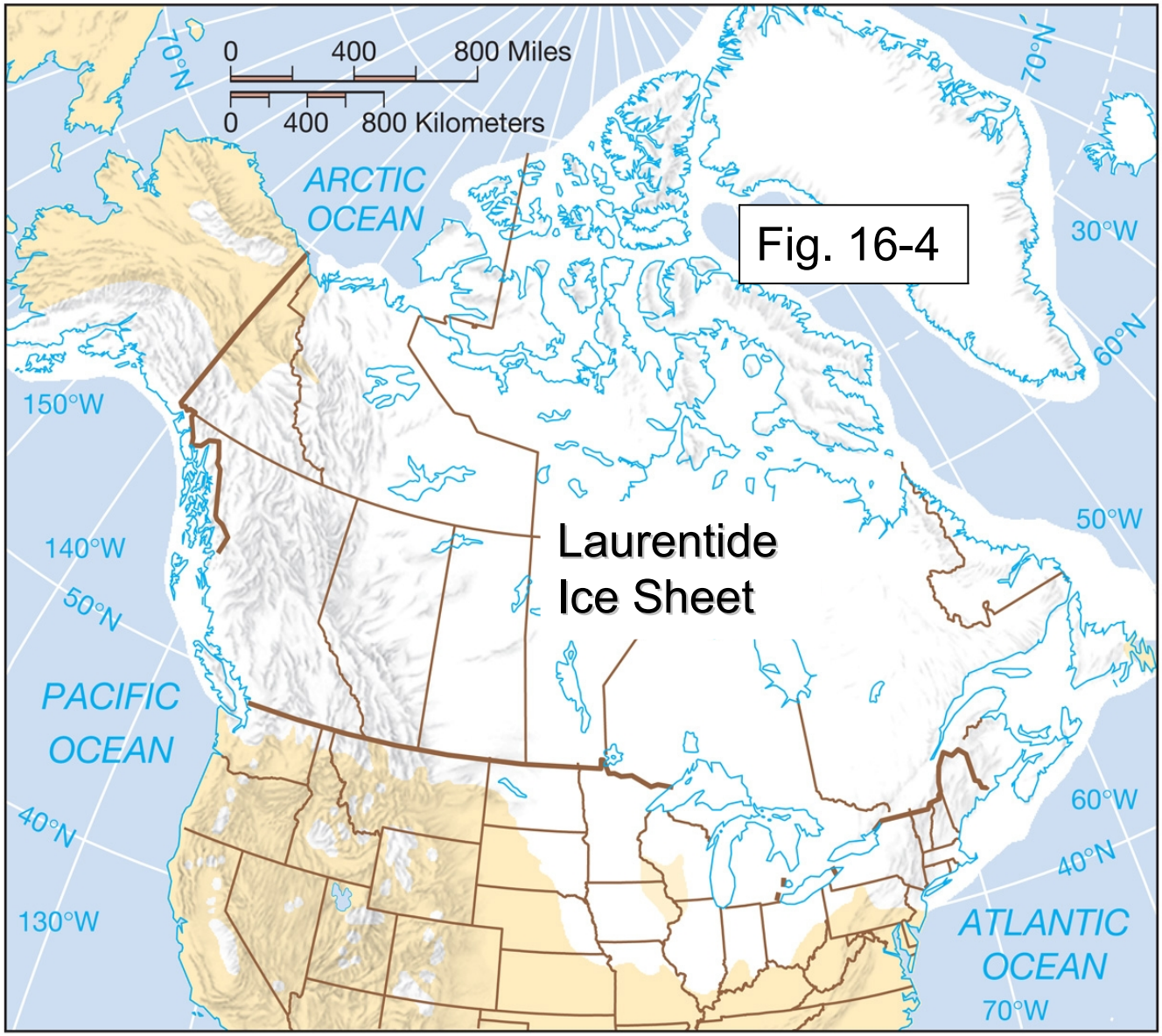
Glacial/interglacial cycles within “our” ice age (climate oscillations)

- smaller changes to Antarctic ice sheet than to Laurentide

- but timing of major cooling/warming cycles in step over past 150KY

- a 5-10 degree change in global mean temp suffices to cause *massive* environmental change!

Maximum extent of ice, last glaciation (about 20Kyr BP)

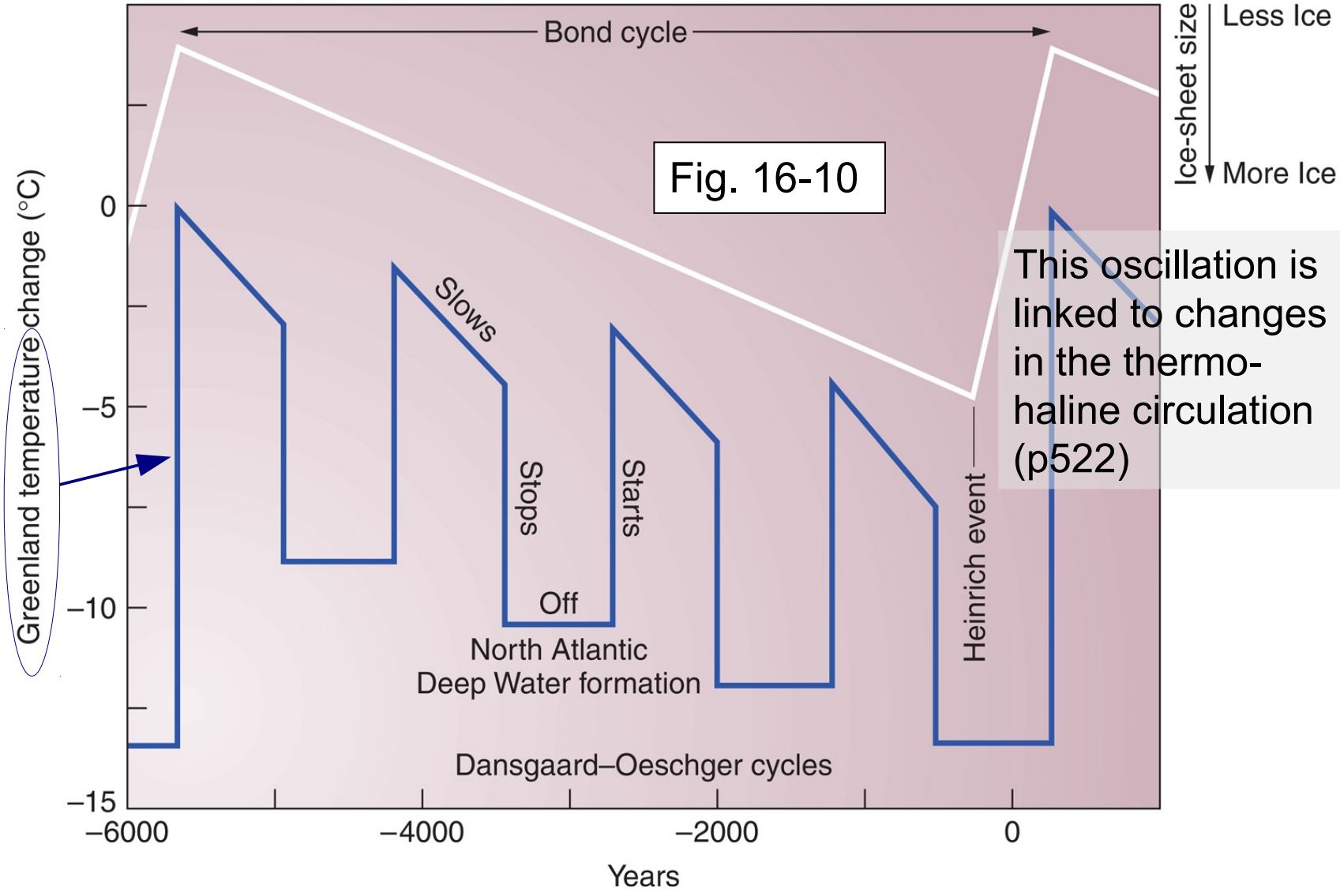


– consequence of a 5 to 10 degree change in global mean temp

Millennial scale oscillations – climate "flip/flop"

- two climate states ("modes") for given boundary conditions?

Thought to be an "internal" (i.e. unforced) oscillation – tendency for regional climate of N. Atlantic to flip between warm and cold states – concern it could happen again



This oscillation is linked to changes in the thermo-haline circulation (p522)

– a coupled ocean-atmosphere phenomenom

Climate forcing factors/mechanisms

- varying solar output? Direct measurements are very recent. There is a correlation between solar output and the sunspot cycle (and we have historical era records of sunspots). Correlations between (best guess) solar output and climate have been found on *some* timescales (p510)

- changes in earth's orbit (Milankovitch cycles)… "widely accepted as driving glacial/interglacial cycles". Their periods (100, 41, 11) KY are short compared to the very long term record

- changing continent/ocean distribution

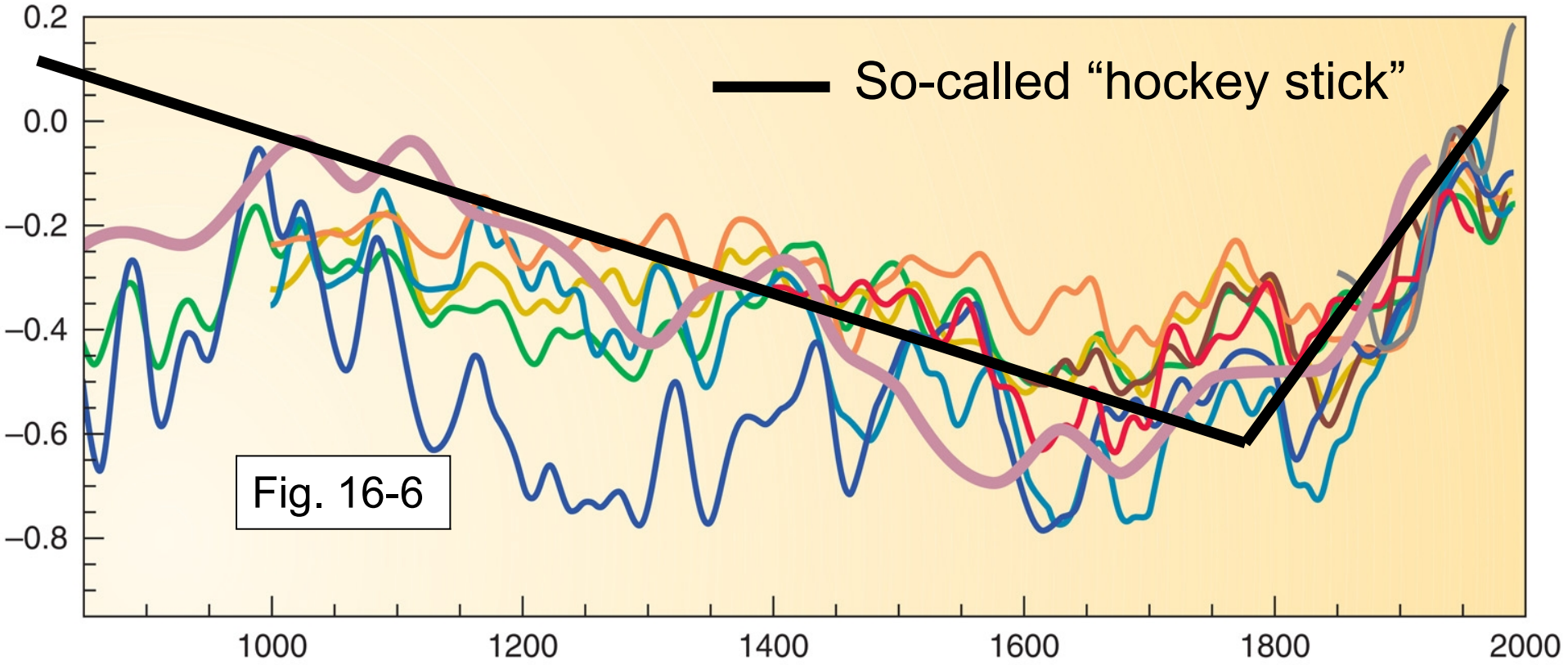
- atmospheric composition
    - tropospheric aerosols
    - stratospheric aerosols
    - CO2, methane,…

Climate change – CO2 buffering by the ocean (and its timescales)

- in the past 200 years oceans have absorbed approximately half of the CO_2 produced by fossil fuel burning and cement production
- oceans and the organisms they support contain about 95% of all the carbon that is in the oceans, atmosphere and terrestrial system
- only the near-surface waters (down to about 100 m on average) are well mixed and so in close contact with the atmosphere. Carbon dioxide in the atmosphere dissolves in the surface waters of the oceans and establishes a concentration in equilibrium with that of the atmosphere. Molecules of CO_2 exchange readily with the atmosphere and on average only remain in the surface waters for about 6 years. However mixing and advection (vertical motions, sinking and upwelling) with the intermediate and deep waters of the oceans (down to about 1000 m and 4000 m respectively) is much slower, and takes place on timescales of several hundred years or more. Over time this mixing will spread the increased atmospheric uptake of CO_2 to the deeper oceans (Royal Society 2005)

Is earth's (global mean) climate warming? – can one reasonably dispute the data?

- If so, is the cause anthropogenic?



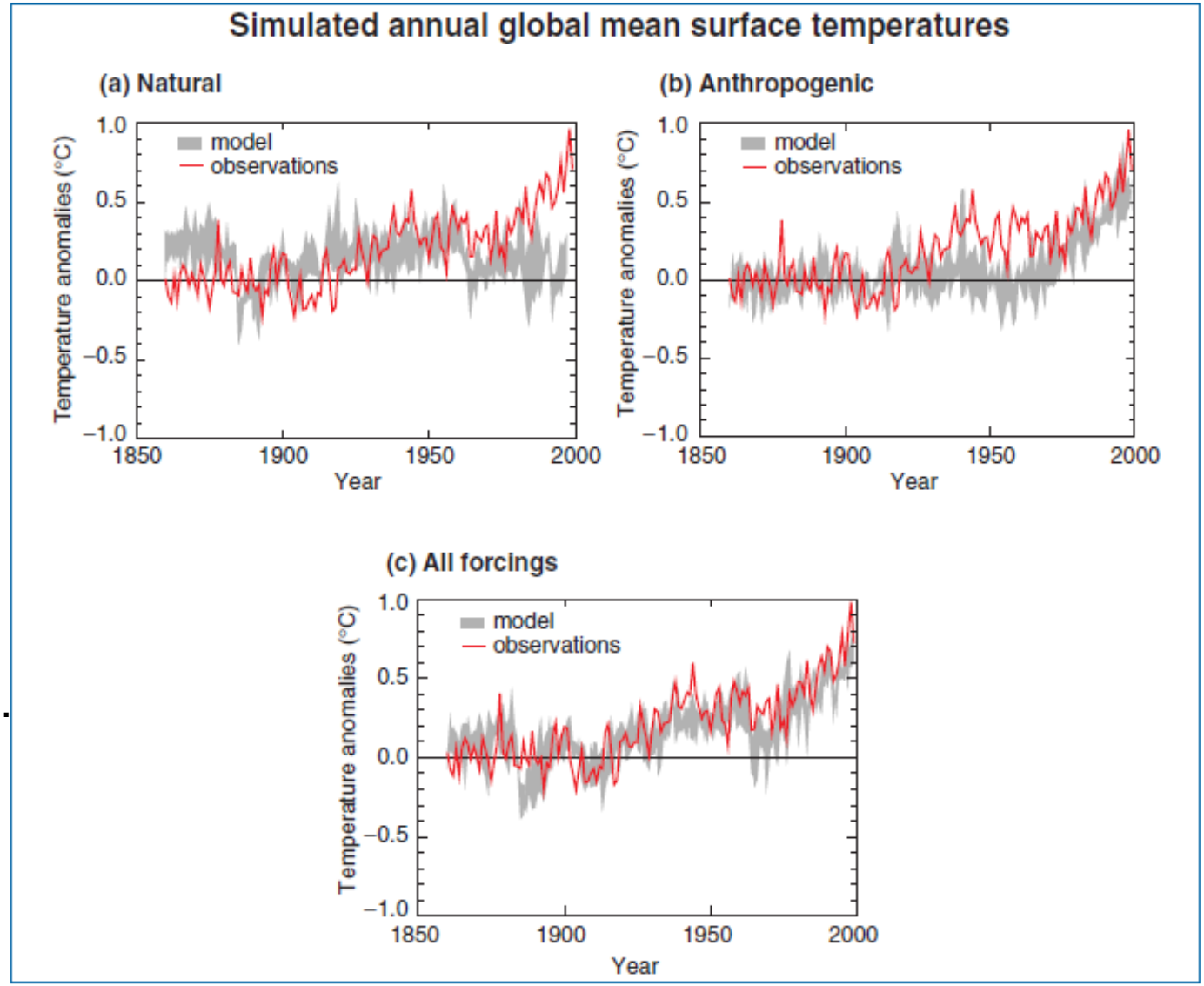
We've seen that climate has varied on many time scales. The upturn during the 20th century is not, in and of itself, incontrovertible proof of a climatic response to GHG – but we'll see that climate models *require* to be driven by GHG forcing in order to follow the observed climate trend in the industrial era

Climate simulations – comparing modelled versus observed climate

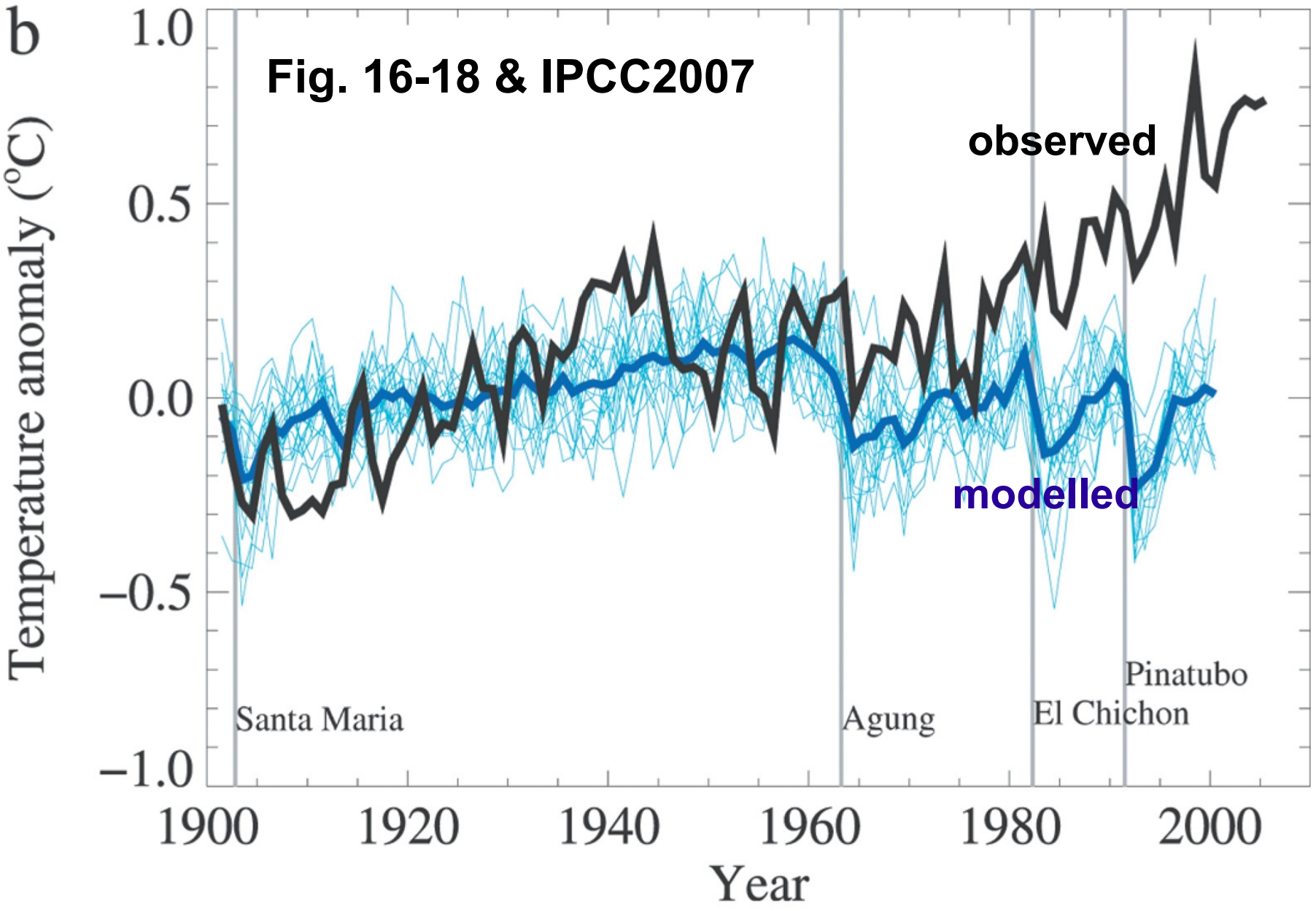
IPCC2007

Working Group 1 Summary for Policymakers

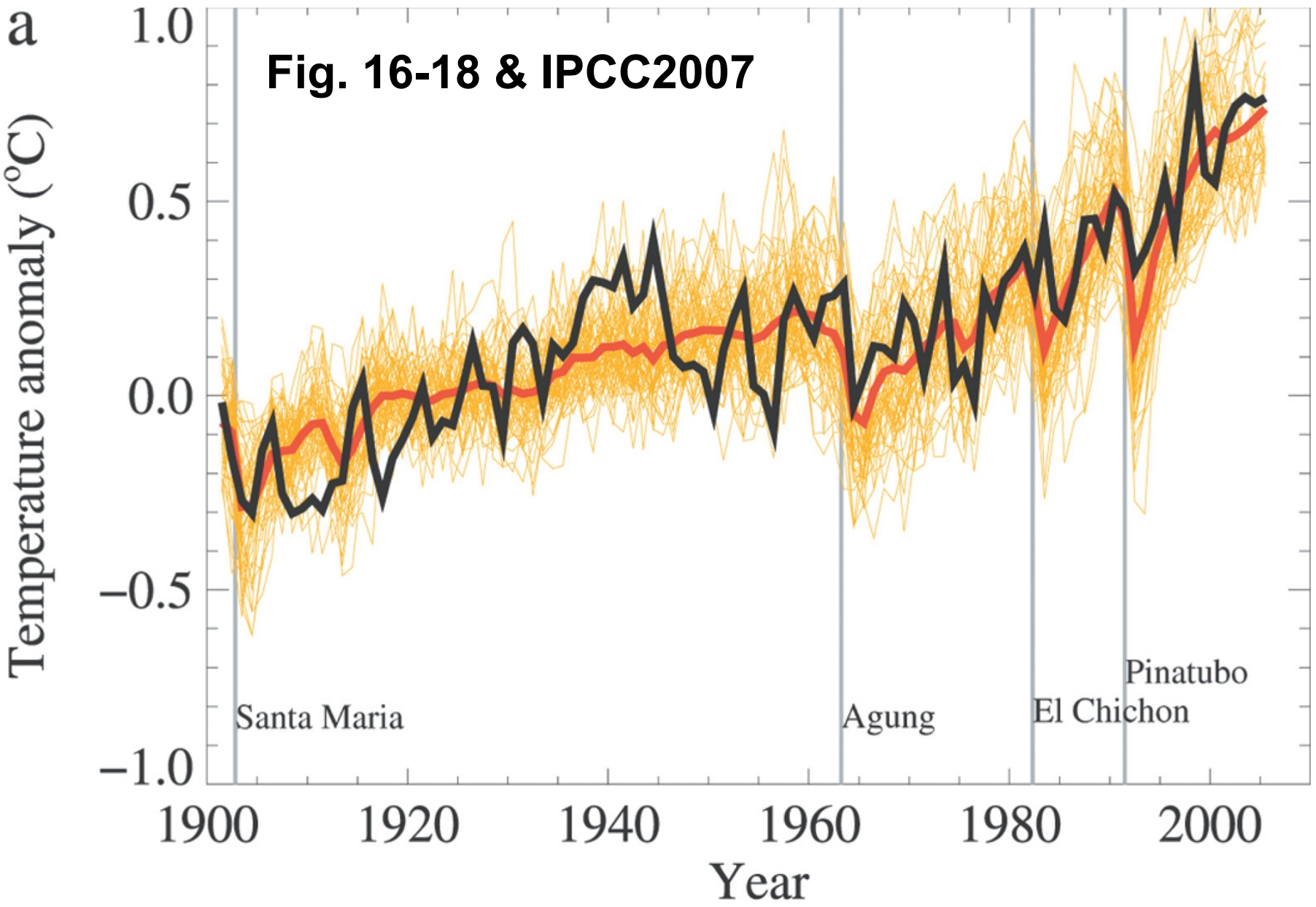
(Equivalent to Fig. 16-18)



Climate simulations with natural forcings only



Climate simulations with both anthropogenic and natural forcings



• Climate models require the anthropogenic forcing in addition to the natural forcing if they are to be able to reproduce the trend in global annual mean surface temperature observed in the instrumental era

• Since climate models, albeit imperfect, do anticipate warming due to rising CO_2, it is not illogical to suggest the 20th Century warming is a response

• In tandem with the strong suggestion from the ice cores that changes in GHG levels have systematically been associated with modest-looking changes in temperature that have (in fact) had radical consequences, there is reason to think ***we*** (i.e. human society collectively) are causing changes that will have a lot of impact