

The Science of Climate Change

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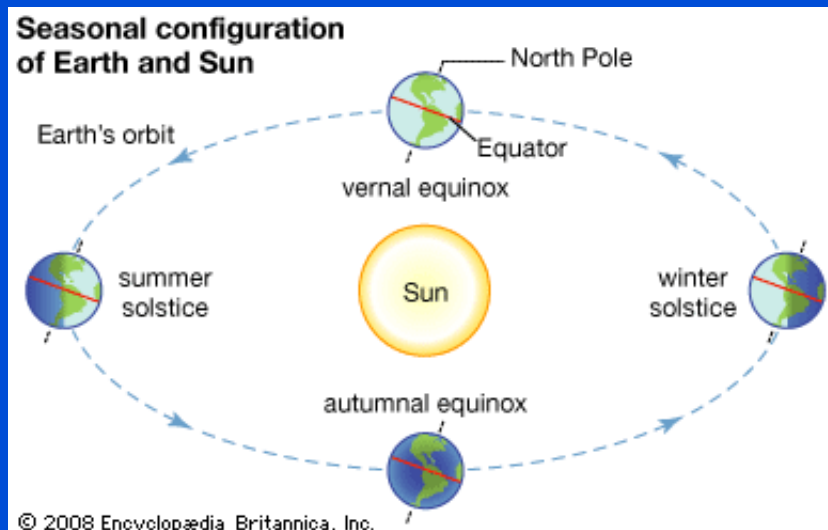
Background and Observations

Distinguishing Climate from Weather

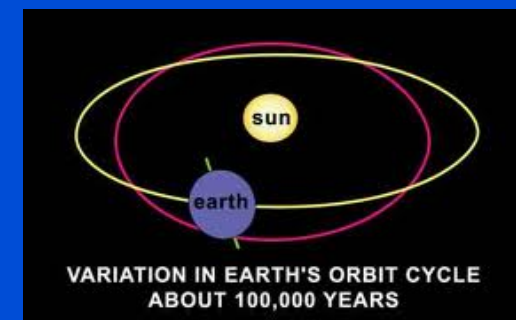
- ★ Both are measured by temperature, precipitation, humidity, atmospheric pressure, wind speeds, etc
- ★ Weather occurs at a specific time (day, hour, minute) and is spatially localised
- ★ Weather forecasts can be made fairly accurately for several days ahead at best
- ★ Beyond that, weather becomes chaotic and science cannot forecast the weather accurately several weeks or more ahead
- ★ Climate involves averages of weather over long periods of time (decades)
- ★ Some aspects of climate, eg global average temperatures, can be predicted quite well decades ahead, given data on human activities

What determines Climate?

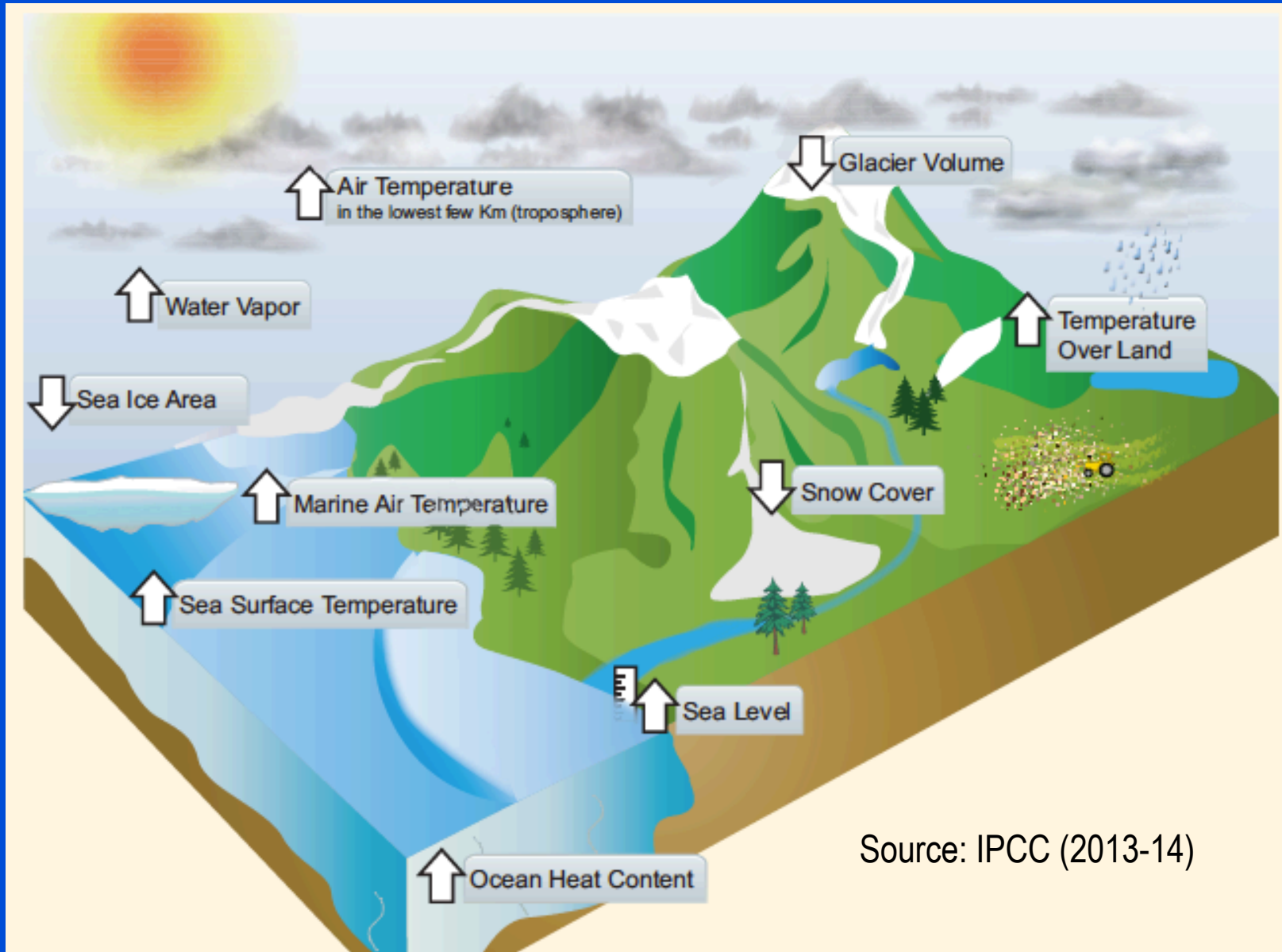
- ★ Global climate determined by solar energy input, **composition of the atmosphere**, geographic distribution of land & oceans, Earth's rotation, **density & types of vegetation**, quantity & location of ice & snow
- ★ Solar energy input is determined by activity of the Sun, Earth's orbit around the Sun and tilt of Earth's rotation on its axis
- ★ Climate in localised regions is affected by latitude, terrain, altitude, nearby water bodies and their currents, **vegetation**.



Yellow items are influenced by human activities



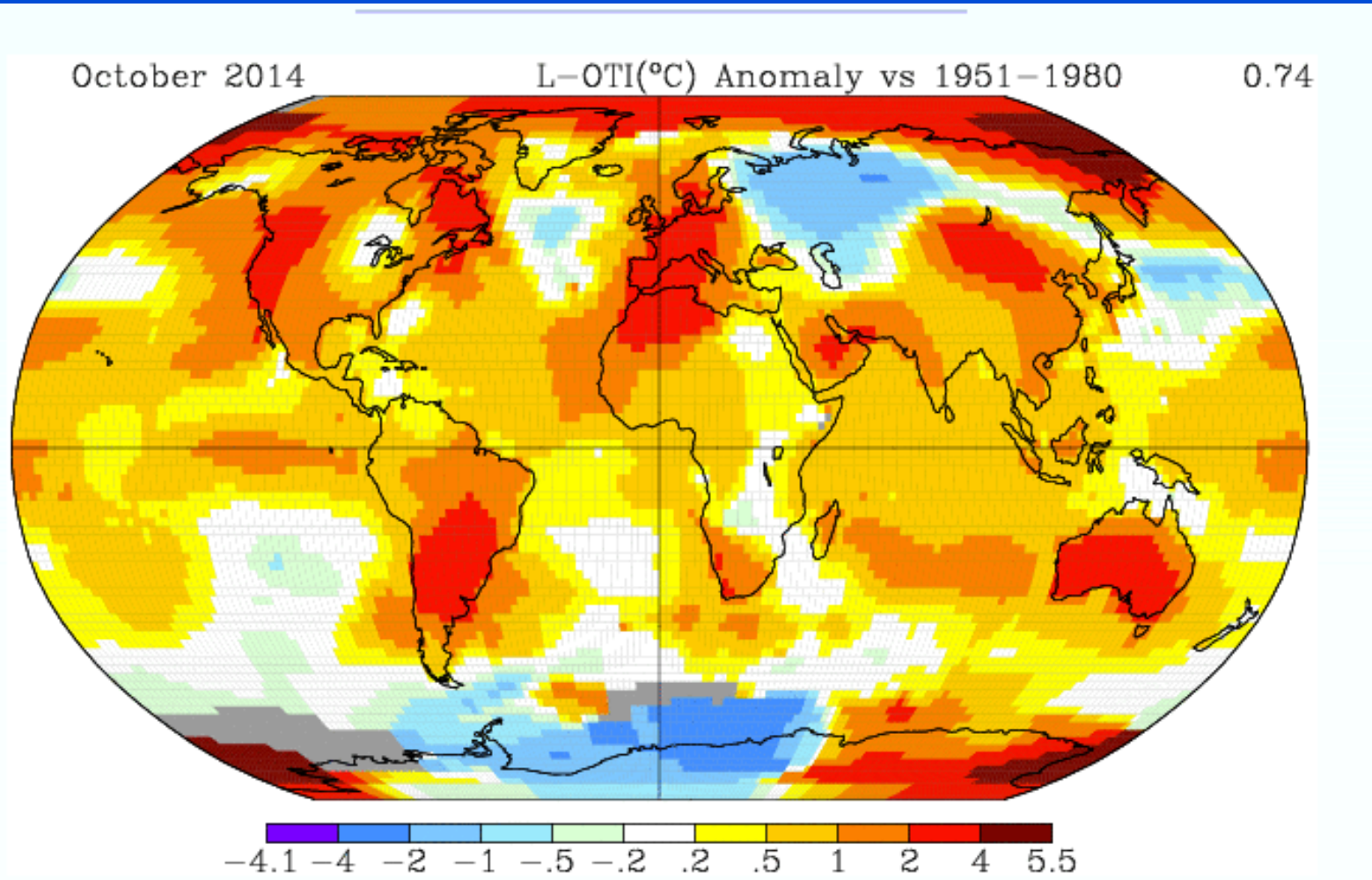
Multiple Evidences of Global Warming



Source: IPCC (2013-14)

Global Mean Surface Temperature Increase °C

Source: NASA GISS



Note: Gray areas signify missing data.

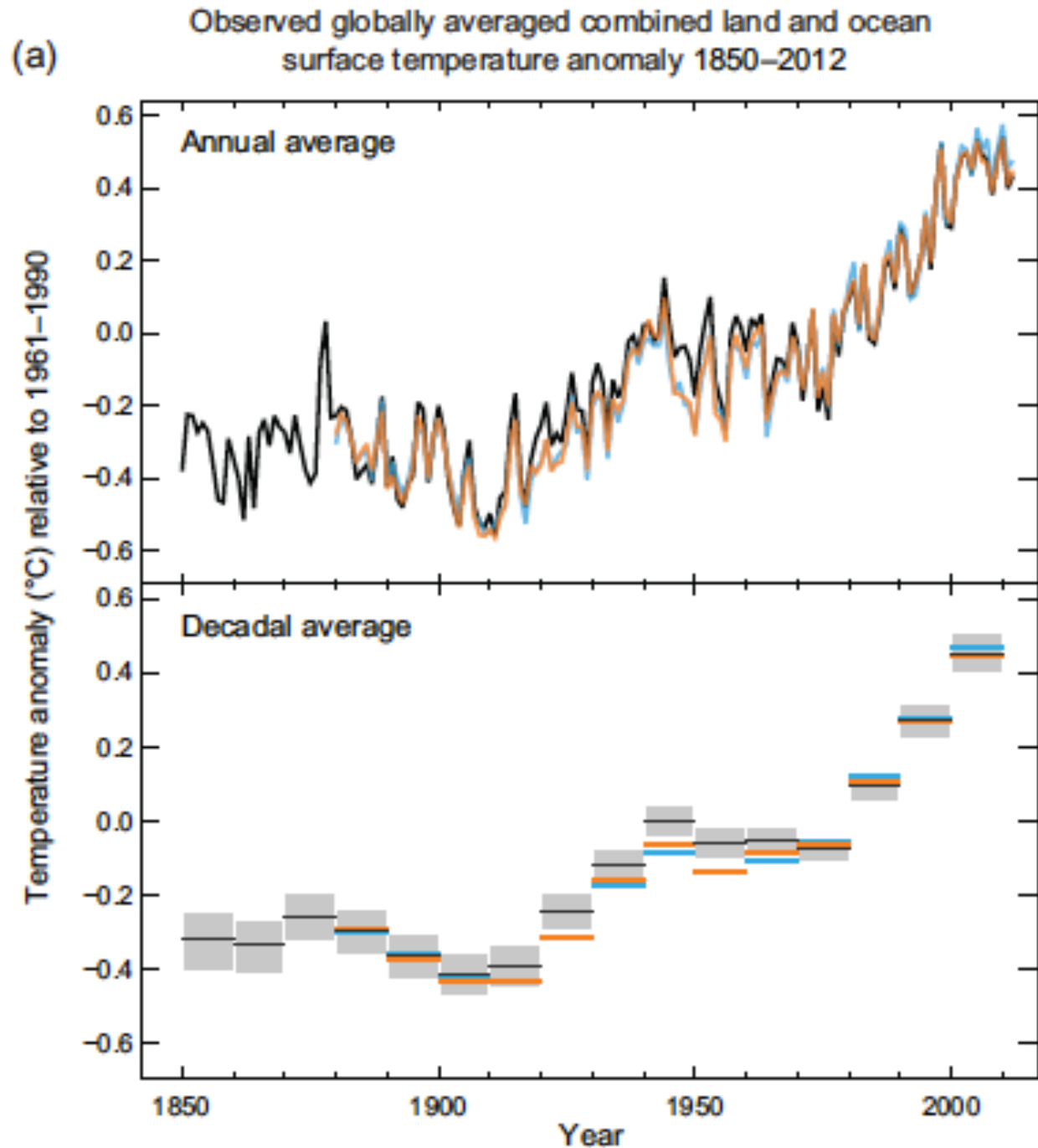
Note: Ocean data are not used over land nor within 100km of a reporting land station.

Trend in Annual and 10-Year Average Temperatures 1850–2012

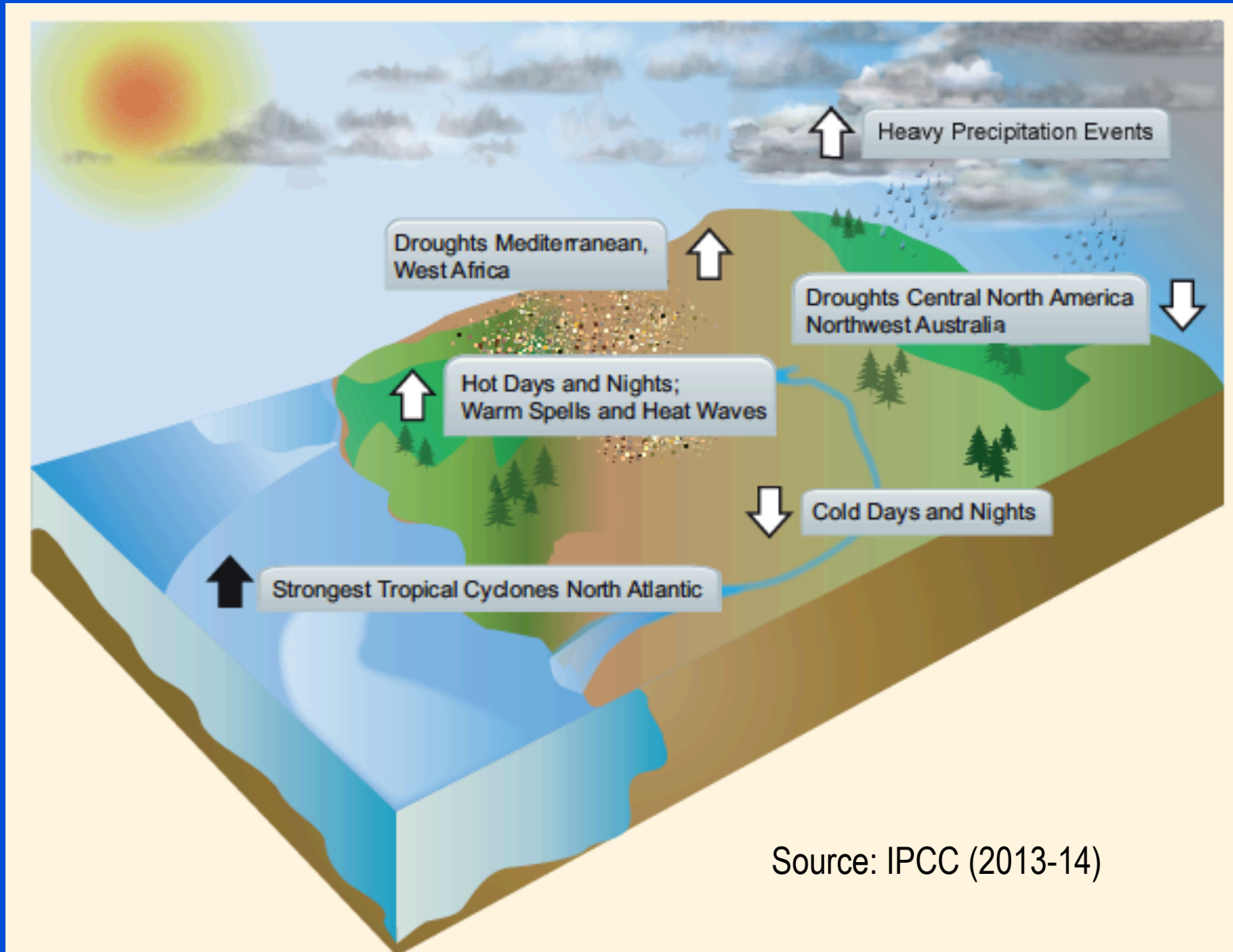
Combined land & ocean surface data averaged over globe.

Source: IPCC (2013-14)

There is no pause in decadal averages!



Extreme Events are more Frequent

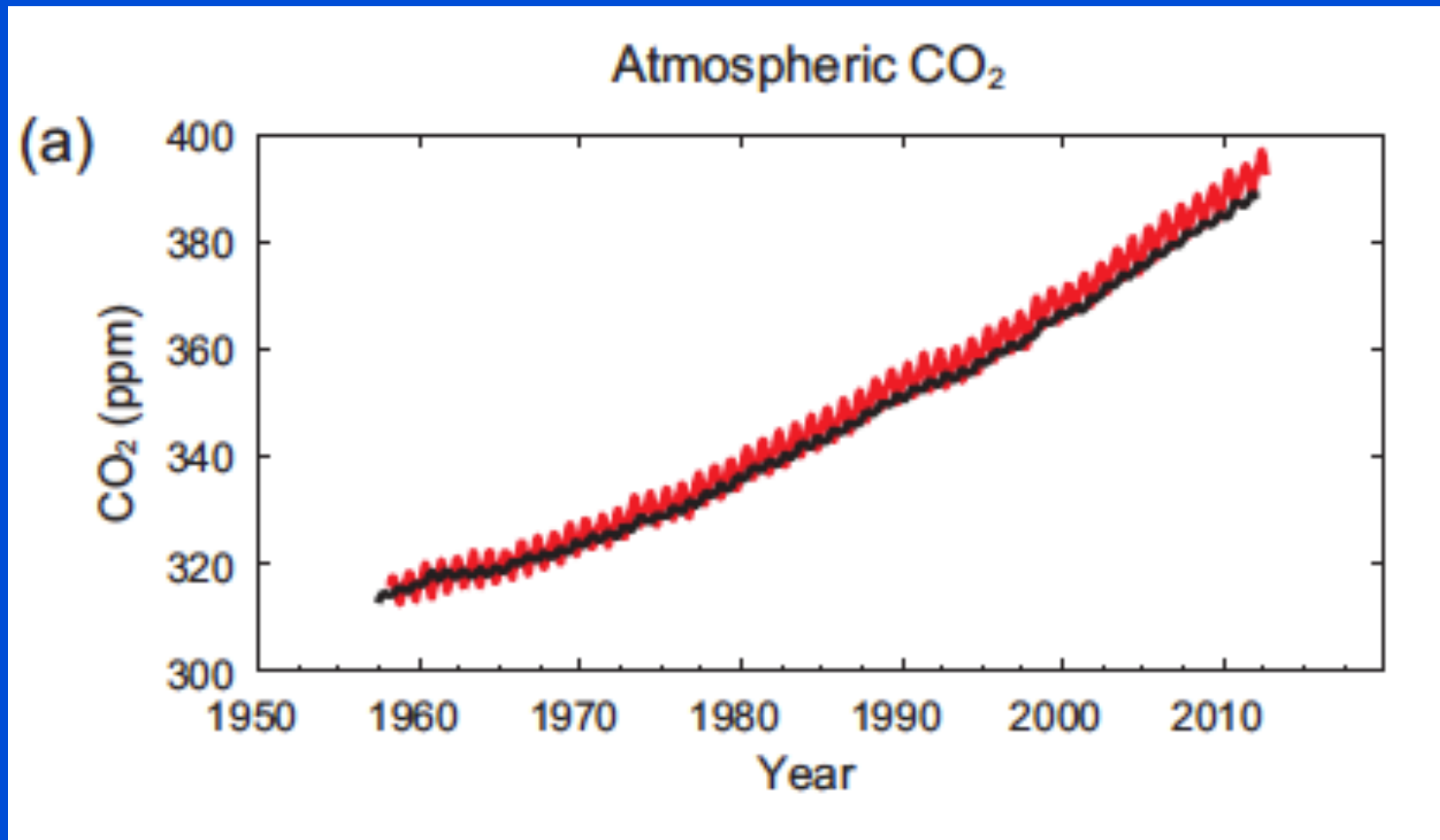


Source: IPCC (2013-14)

Extreme Events are more Frequent in some Regions – Details

- ★ Warm days & nights increased; cold days & nights decreased for most regions of globe
- ★ Heat waves increased since mid 20th century over most of globe
- ★ Extreme precipitation events increased in frequency & intensity in recent decades in some regions (North & Central America and Europe)
- ★ Storms increased in N. Atlantic since 1970s; so far inconclusive in other regions
- ★ Drought increasing in Mediterranean & W. Africa, but decreasing in Central N. America & N-W Australia

Trend in Atmospheric CO₂ Concentration



Source: IPCC (2013); red: Hawaii, black: south pole

Concentrations of Greenhouse Gases over past 20,000 yrs: CO₂, Methane & Nitrous Oxide

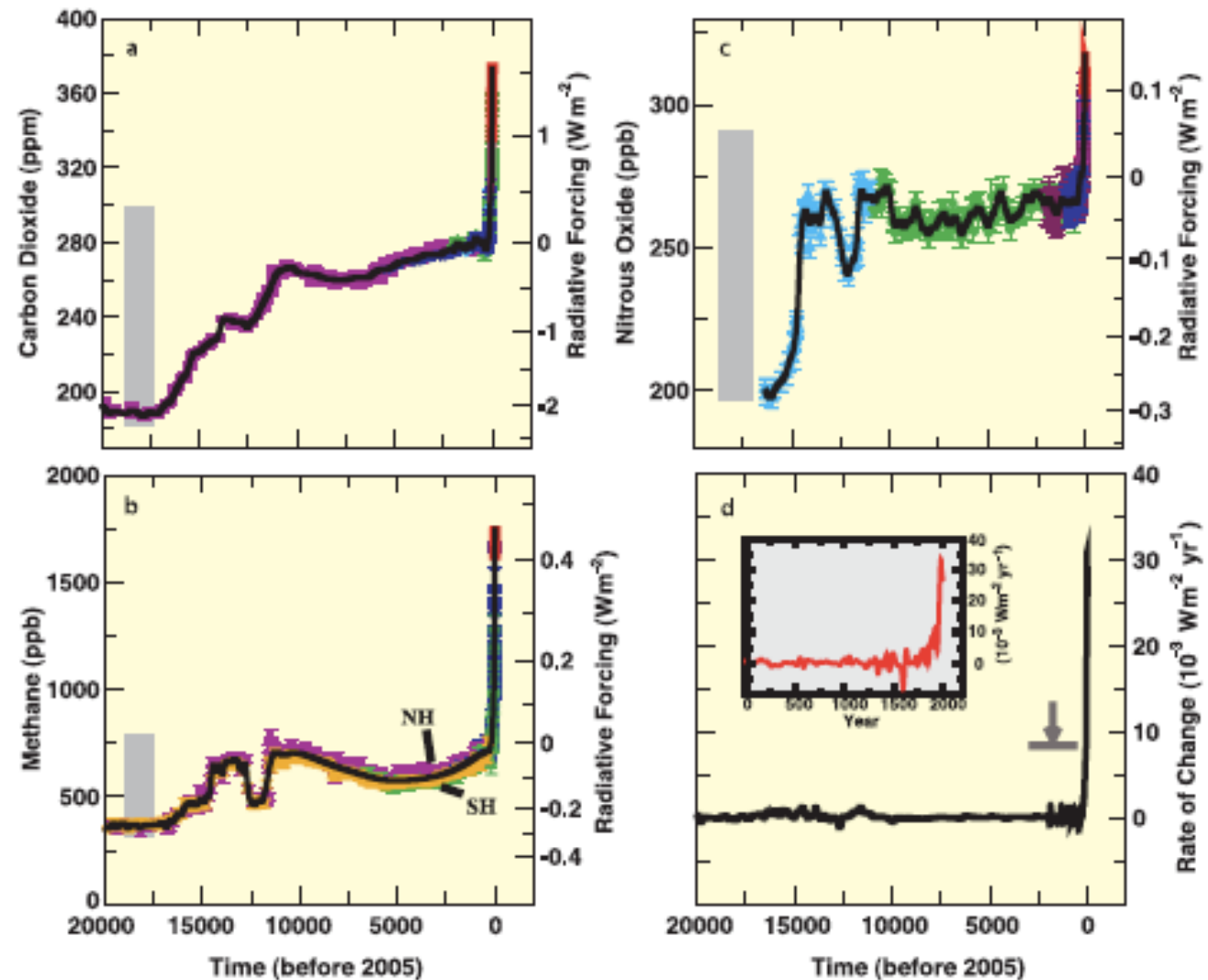
Source: IPCC (2007)

Grey bars: range of natural variation over past 650,000 yrs.

Bottom right: combined forcing

Each of the 3 gases now has its highest concentration in the past 800,000 years.

CHANGES IN GREENHOUSE GASES FROM ICE CORE AND MODERN DATA



Consequences of Observed Temperature Increases in Lower Atmosphere & Upper Oceans

- ★ Glaciers are melting
- ★ Arctic ice-cap is melting
- ★ Greenland and West Antarctic ice-caps are melting
- ★ Sea-level is rising, 19 cm since 1901, and accelerating
- ★ Permafrost is melting
- ★ Precipitation patterns are changing
- ★ Impacts on biodiversity & ecosystems are observed
- ★ Extreme events – heat-waves, droughts, firestorms and floods – are increasing in frequency and severity in some regions

Melting of Himalayan Glaciers



Rongbuk Glacier, Himalayas

1968



2007



Rongbuk glacier in 1968 (top) and 2007. The largest glacier on Mount Everest's northern slopes feeds Rongbuk River.

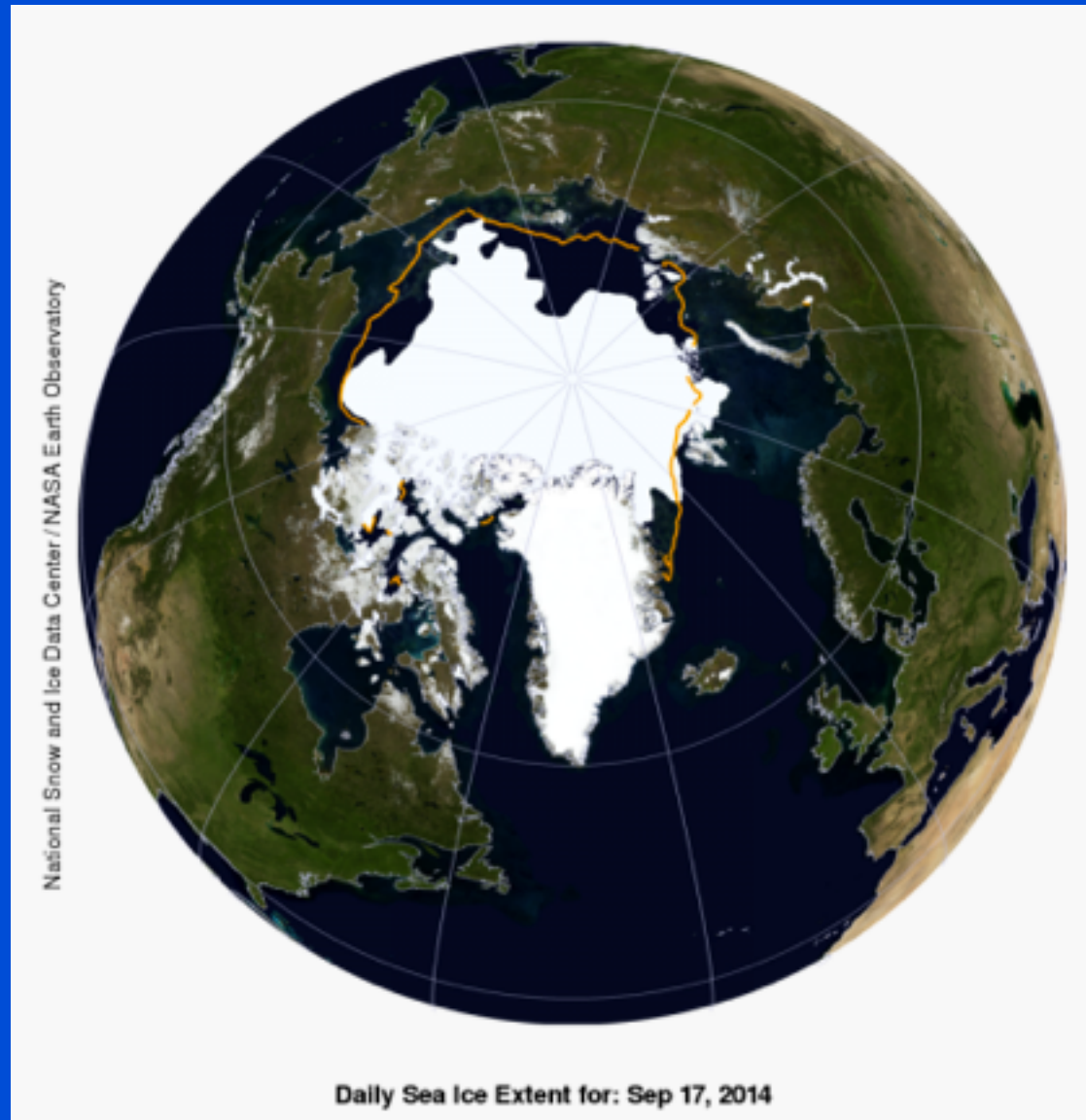
The Snows of Kilimanjaro



Arctic Ice Cap is Melting

Source: NASA,
published: <http://nsidc.org>

Orange line shows the 1981 to
2010 average extent for that
day, 17-9-2014



Area of Arctic Ice-Cap in Summer Minimum, September, 1980-2012

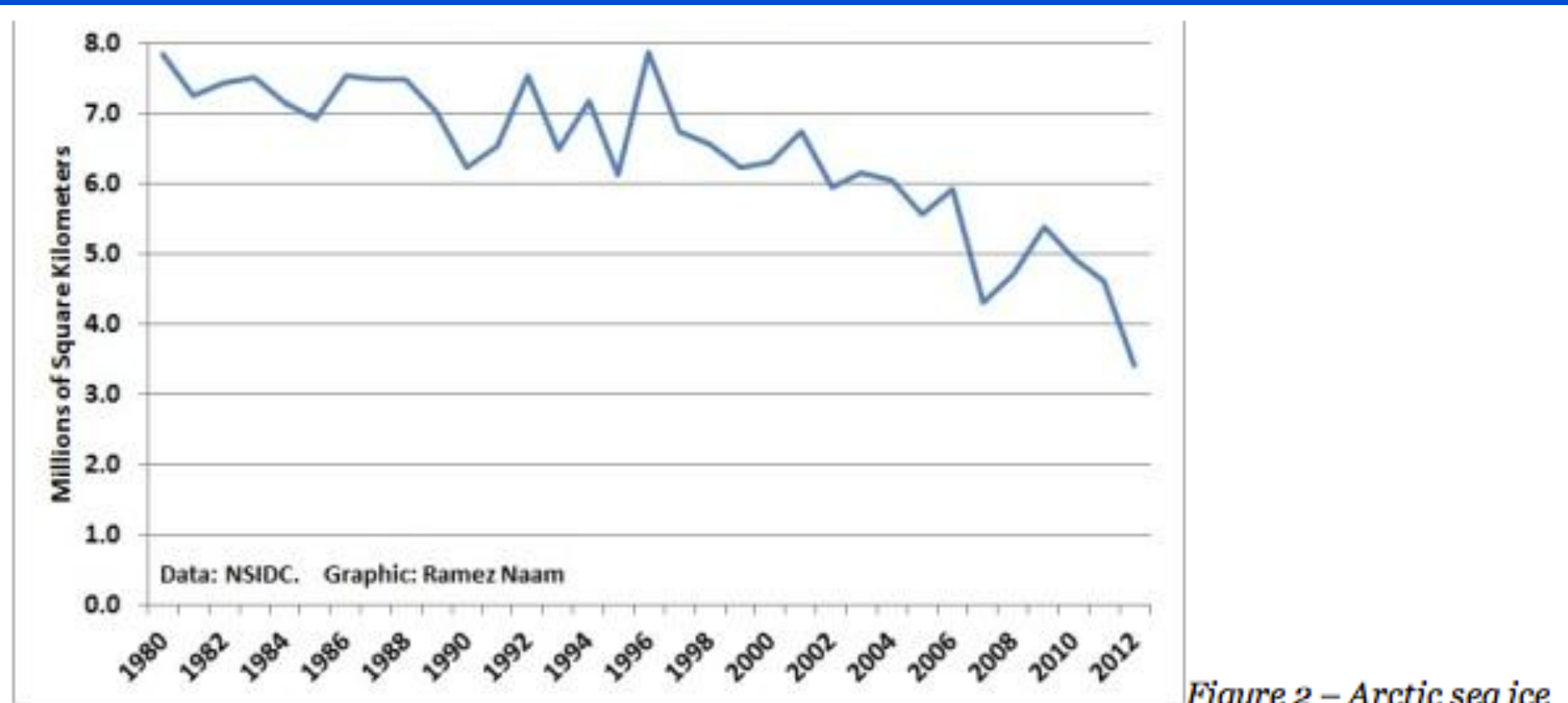
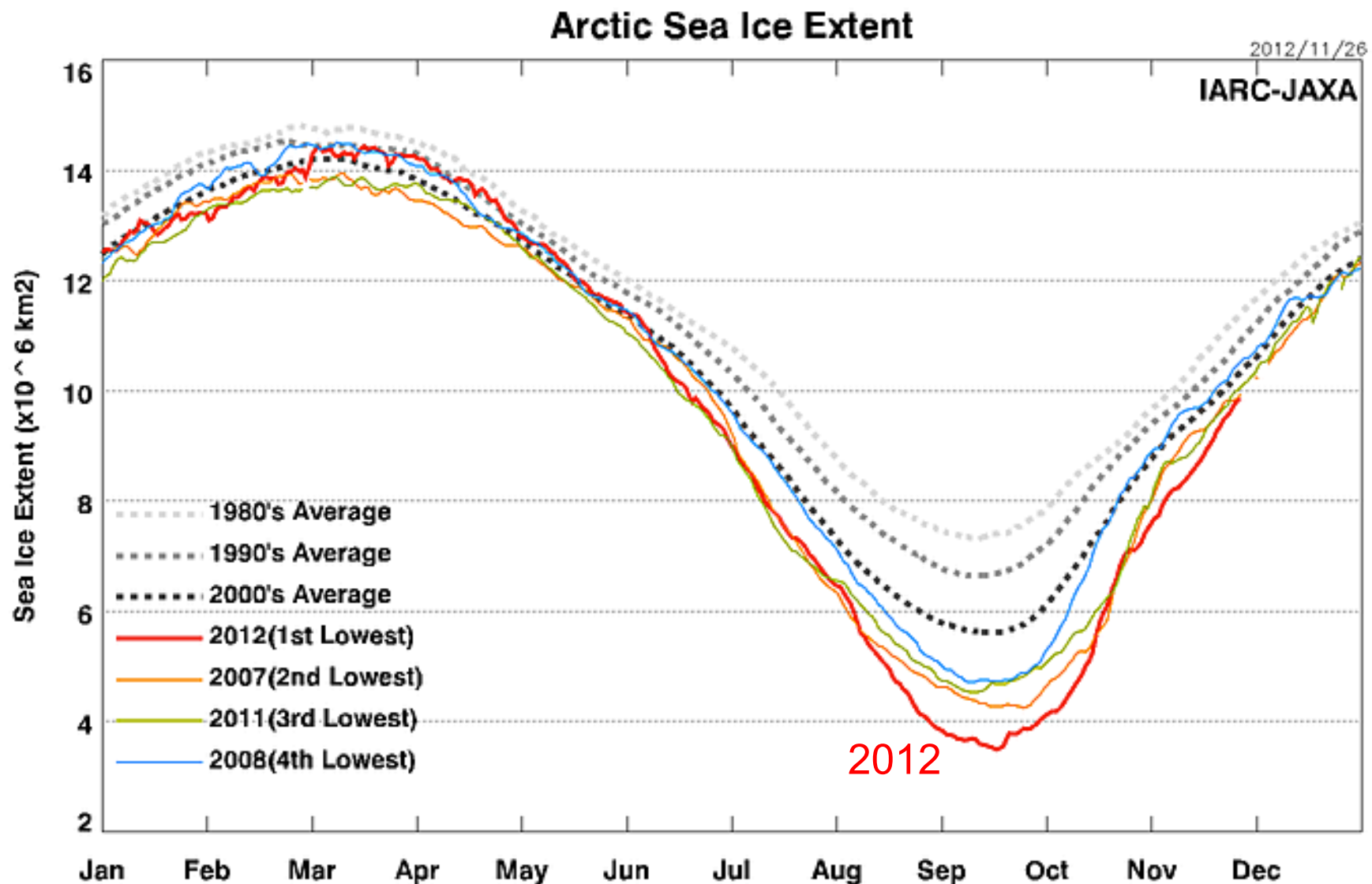
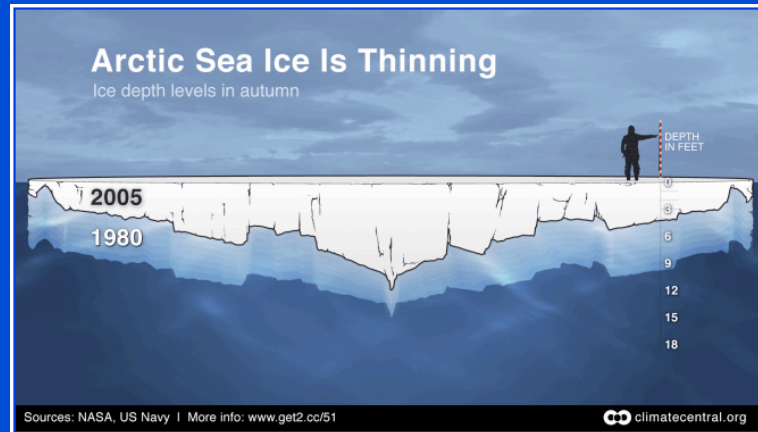


Figure 2 – Arctic sea ice coverage in September has dropped in half since 1980, and the drop appears to be accelerating.

Area of Arctic Ice-Cap by Month & Year

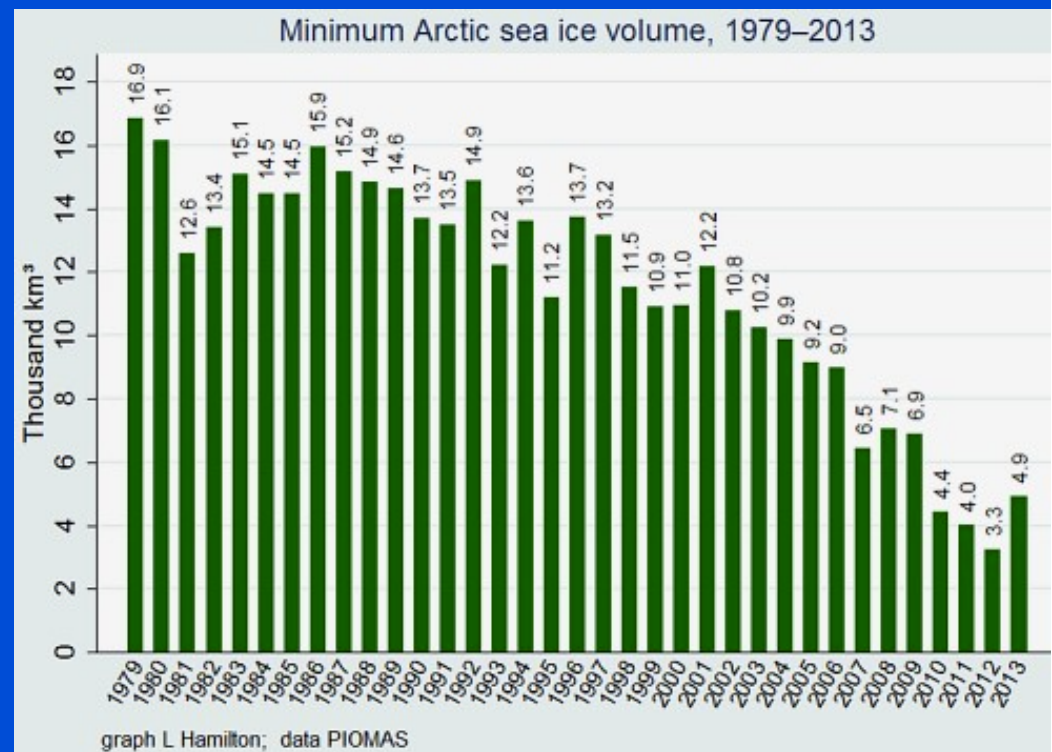


Arctic Ice-Cap: Thickness



Symbolic diagram: Different scales for thickness and width.

Actual volume



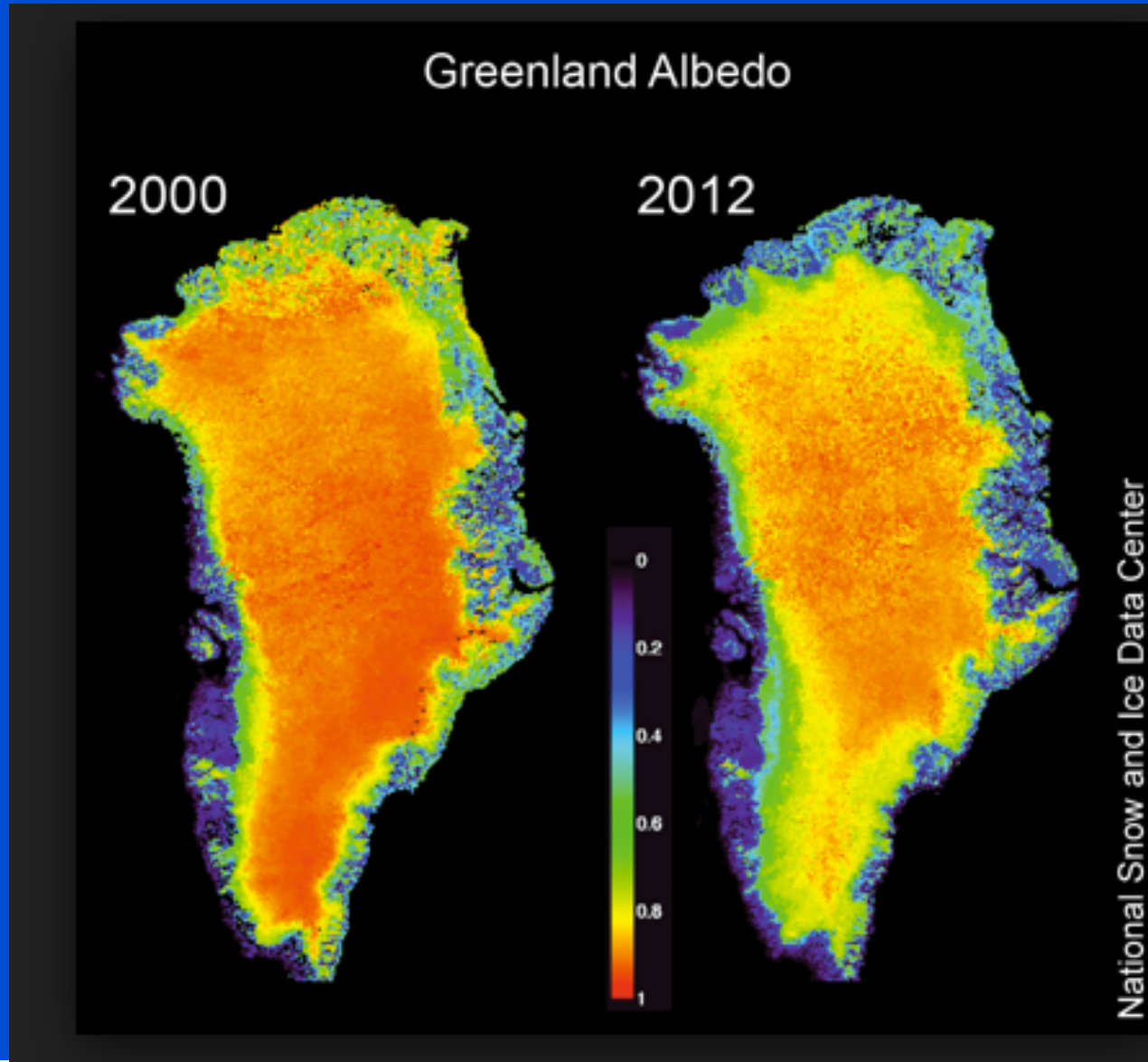
Melting of Greenland Ice-Cap

Melt descending into a moulin, a vertical shaft carrying water to ice sheet base.



Source: Roger Braithwaite, University of Manchester (UK)

Surface melting on Greenland is expanding



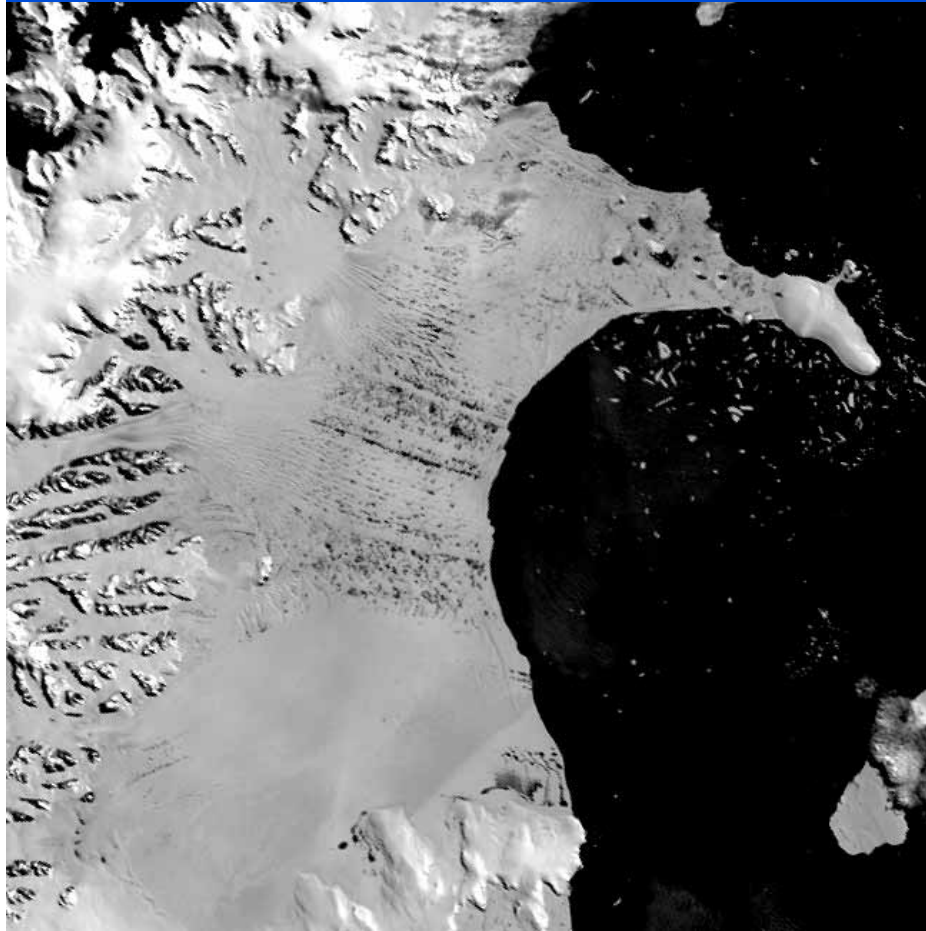
Jakobshavn Ice Stream in Greenland

Discharge from major Greenland ice streams is accelerating markedly.

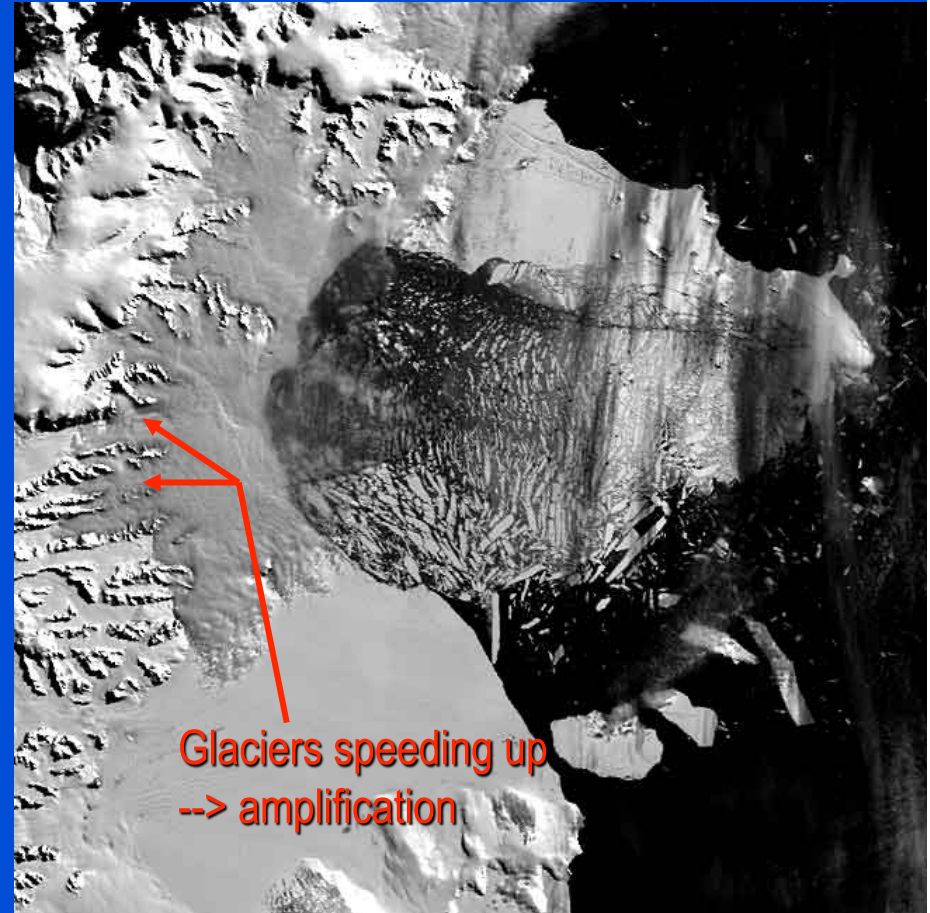
Source: Konrad Steffen,
Univ. of Colorado



Antarctic: Break-up of Larsen B Ice Shelf



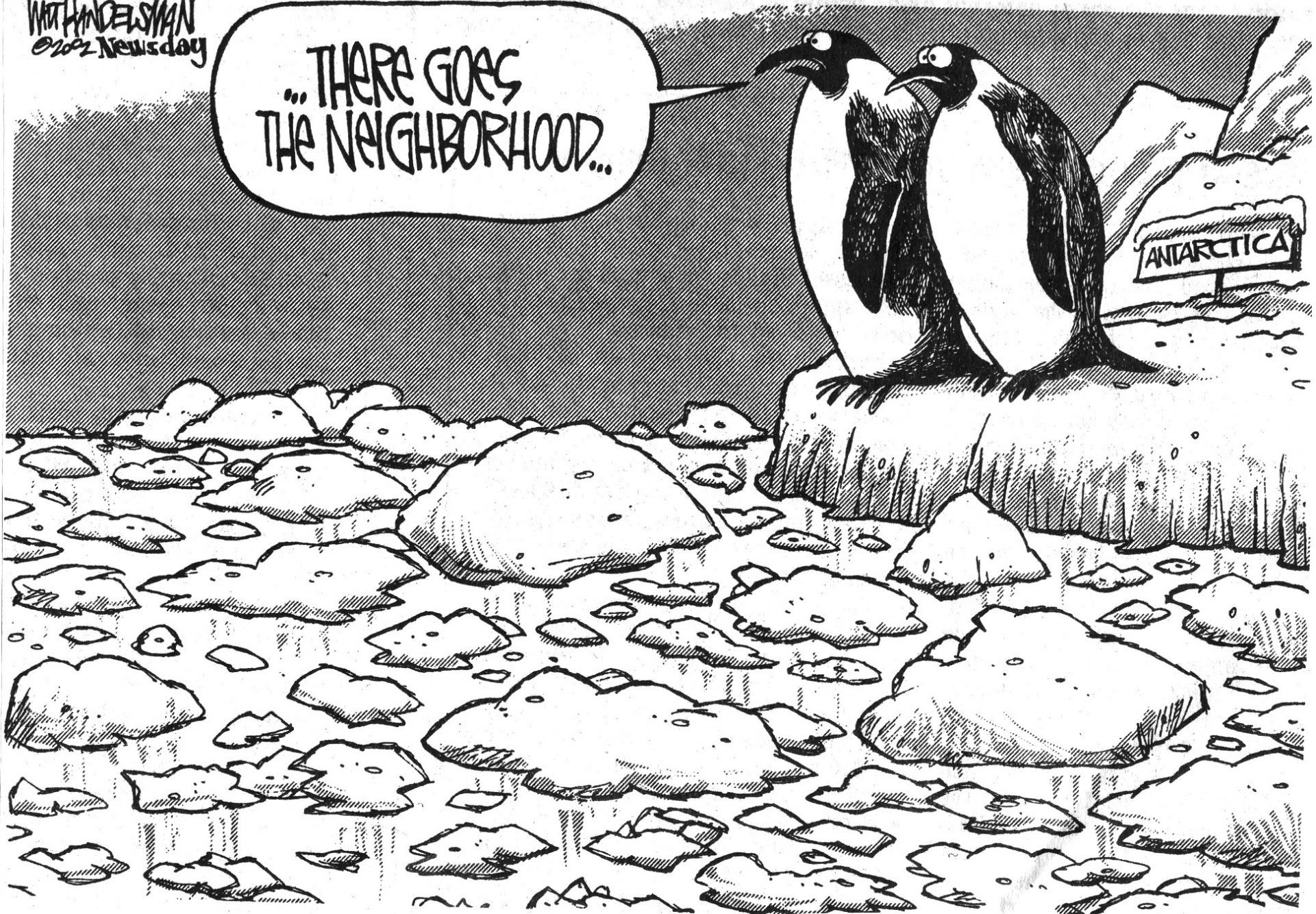
31 Jan 2002



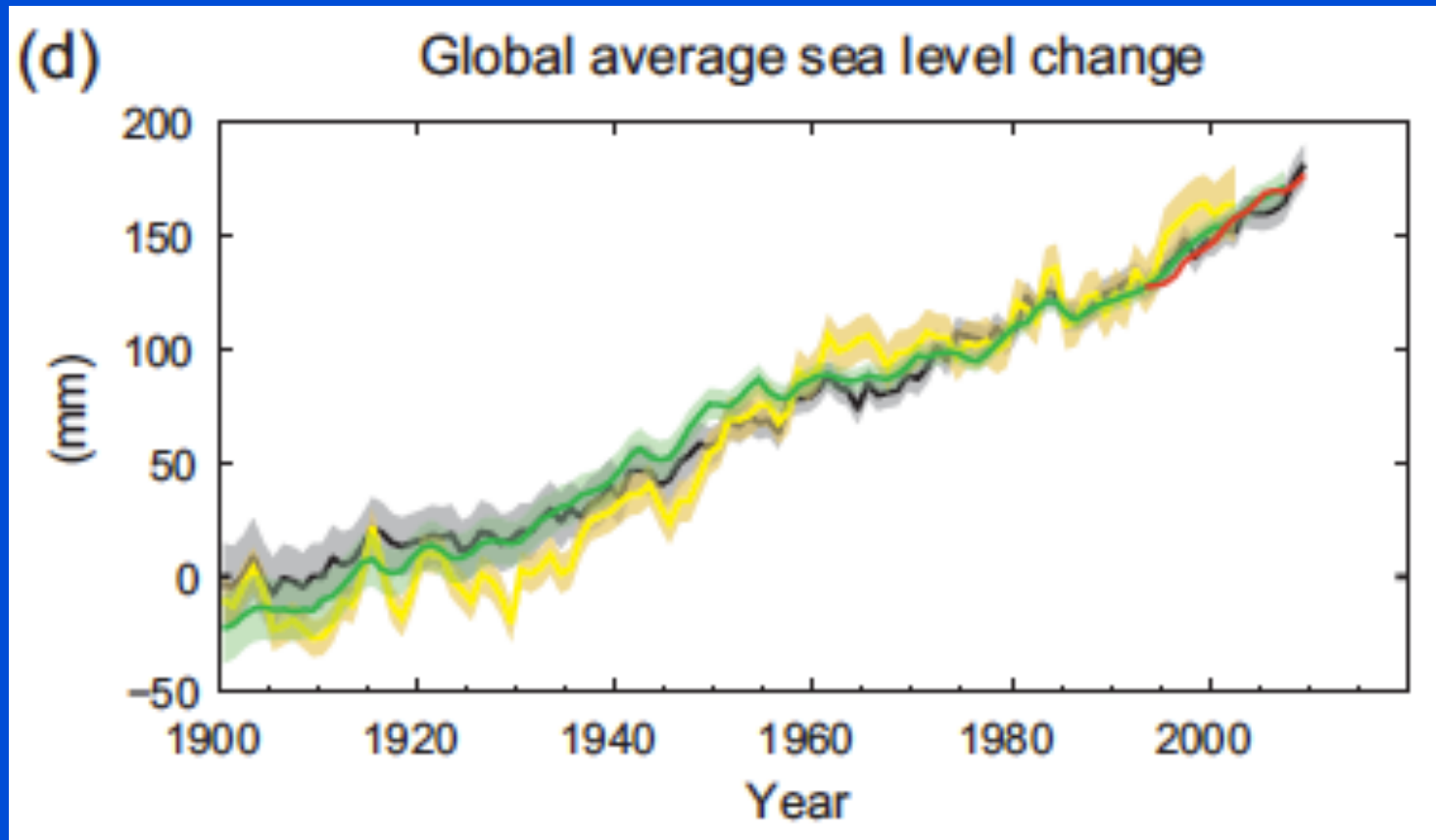
5 March 2002

WITH ANDELSMAN
©2002 Newsday

...THERE GOES
THE NEIGHBORHOOD...



Global Average Sea-Level Change



20th century sea-level rise 1901-2010 19 cm [17-21 cm]. Rate increased from 1.7 mm/year in 1901–2010 to 3.2 mm /year in 1993–2010.

Source: IPCC (2013)

Permafrost is melting: close-up



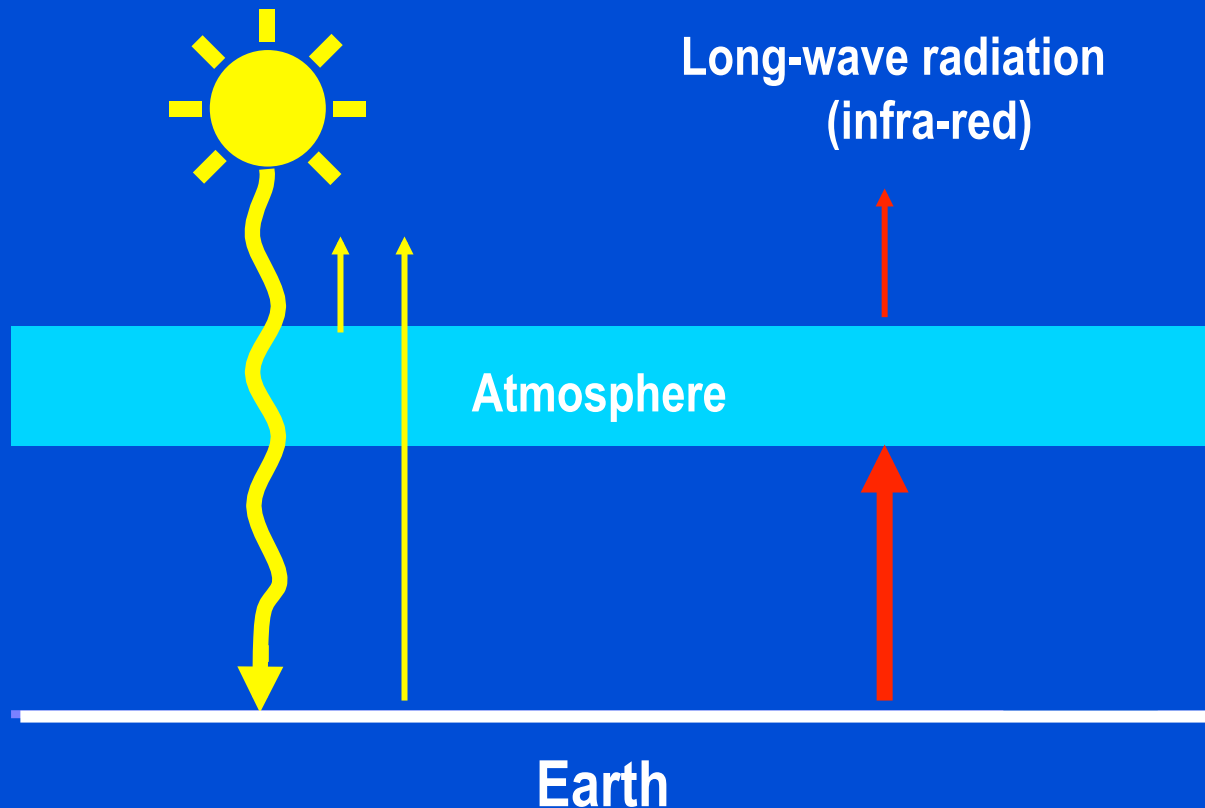
Figure 11 –

Once frozen solid, permafrost near the Arctic is melting, creating conditions for decomposition of organic matter and the release of carbon as CO₂ and methane. Image courtesy of NASA.

Interpretation of the Observations

The Greenhouse Effect

Solar radiation (mostly visible light)



3 physical effects:
reflection, absorption
&
re-emission

Increasing GHG in atmosphere reduce outward flow of infra-red (heat) radiation from Earth, which heats up

2 Types of Evidence that Human Activities are responsible for Global Climate Change

- ★ Global observations interpreted in framework of basic physics. Several independent observations → fingerprint of climate change (next slide)
- ★ Climate models agree well with temperature observations

Plus evidence on *sensitivity* of climate (eg temperature) to CO₂ increases

- ★ Paleoclimate: history & prehistory of Earth's climate

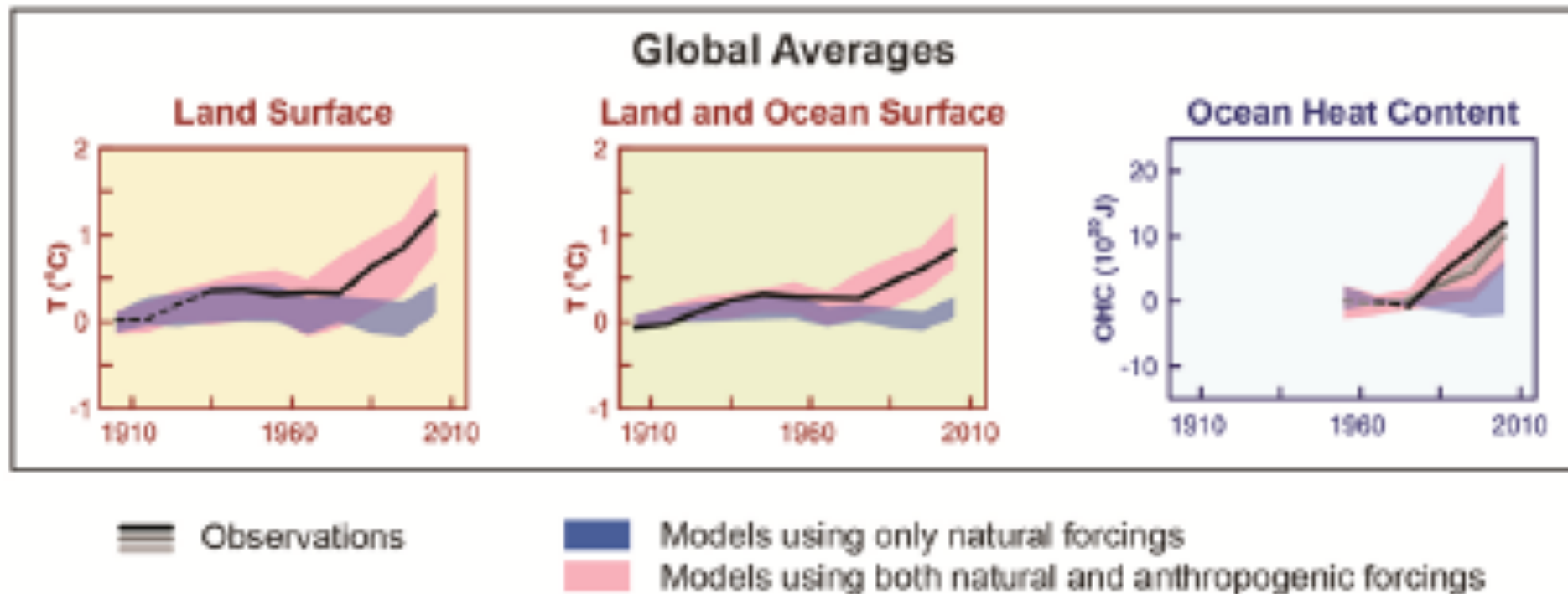
The Fingerprint of Climate Change is Human

- ★ Warming of Earth's surface and troposphere (lower atmosphere) coupled with cooling of stratosphere (upper atmosphere)
- ★ Night-time minimum temperatures are rising faster than day-time maxima
- ★ (Northern) winters are warming faster than (northern) summers
- ★ Solar radiation has been constant over past 50 years, apart from well-known 11-year solar cycle
- ★ Land surface is warming faster than ocean surface
- ★ High latitudes (eg Arctic, Antarctic) are warming faster than tropics

The fingerprint identifies the criminal. It's not the Sun, it's us... or, more precisely, mainly some of us.

90 companies caused 2/3 of warming since industrialisation.

Modelling: Natural climate forcings can't explain temperature observations



Source: IPCC (2013)

'Extreme' or 'Dangerous' Climate Change (omitted from most climate models)

- ★ Positive feedbacks

 - Only water vapour feedback included in recent models

- ★ Irreversible events

 - e.g. Ice caps melt or slide into sea; ocean conveyor shuts down; more Amazon rainforest dies off

Positive Feedbacks are Accelerating Global Warming

- ★ Melting of Arctic ice reduces reflection of sunlight, amplifying warming
- ★ Melting of permafrost releases methane and CO₂, amplifying warming
- ★ Warming of Arctic Ocean releases methane, amplifying warming
- ★ Warming atmosphere holds more water vapour, a GHG, amplifying warming [The only positive feedback in climate models so far]
- ★ Warming soils release more CO₂, amplifying warming
- ★ Warming oceans absorb less CO₂, amplifying warming
- ★ Global warming increases prevalence and intensity of wild fires which release CO₂ amplifying warming

Negative Feedbacks that could Slow Global Warming

- ★ Increased CO₂ stimulates plant growth, absorbing CO₂, *provided* there are enough water & nutrients, and provided pests don't increase
- ★ An increase in *low* cloud, if it occurs, may cause some cooling, by reflecting sunlight. However, an increase in *high* cloud traps heat and increases global warming

Summary of Evidence

Summary: It is certain that:

- ★ Increasing atmospheric concentrations of greenhouse gases are caused primarily from burning fossil fuels and secondarily from changes in land use (deforestation and agriculture)
- ★ Current concentrations of CO₂ (400 ppm) far exceed those determined from ice-core measurements spanning the past 800,000 years (180–280 ppm).
- ★ These changes are increasing the Earth's average temperature & sea-level, changing rainfall patterns and increasing the frequency of some extreme climate events, especially heatwaves
- ★ Computer modelling gives a good description of global average temperature changes over the past century, when the effects of both anthropogenic greenhouse gases and natural effects are included. Natural effects are much smaller than anthropogenic.

More specifically

- ★ CO₂ concentration has increased by 40% since 1750, reaching 400 ppm in 2013, the highest in 800,000 yrs (from ice core data), likely highest in 20 million yrs
- ★ Earth's *average* temperature has increased by 0.78°C between averages 1850–1900 and 2003–2012
- ★ If emissions could somehow be cut to zero today, the temperature would continue to rise to at least 1.3°C; 2.4°C if air pollution stops too
- ★ Previous decade was warmest in recorded history. So global warming has not stopped; the *rate* of warming of Earth's surface has slowed recently; not surprising since most of extra heat is going into the oceans
- ★ Likely that 1983–2012 was warmest 30-yr period in Northern Hemisphere in past 1400 years

Deniers and their Arguments



CLIMATE SUMMIT

WHAT IF IT'S A BIG HOAX AND WE CREATE A BETTER WORLD FOR NOTHING?

- ENERGY INDEPENDENCE
- PRESERVE RAINFORESTS
- SUSTAINABILITY
- GREEN JOBS
- LIVABLE CITIES
- RENEWABLES
- CLEAN WATER, AIR
- HEALTHY CHILDREN
- etc. etc.



YOUNG PETER
12/19/04 USA TODAY

Comparing Genuine Sceptics and Climate Science Deniers



Leading climate scientist: the late Stephen Schneider



Climate denier: Christopher Monckton: no scientific education

- ★ Genuine sceptics question truth of common beliefs, seeking scientific evidence
- ★ Science considers all objections, but 'for every Galileo there are 1000 fossil fools'
- ★ Scientists are generally sceptical, but very few are climate deniers, because they accept the scientific evidence
- ★ Deniers ignore scientific evidence and are biased in their scepticism
- ★ Deniers repeat claims that have been refuted scientifically – this raises questions about their motives
- ★ Some deniers are funded by the fossil fuel industries
- ★ Very few deniers are climate scientists

Hypothesis: The Aim of Deniers

To sow doubt and create a large group of deniers and biased sceptics among decision-makers and the public, in order to undermine climate action by government and business.

The same strategy was used, sometimes by the same people, to undermine action to control the dangers of tobacco smoking and asbestos.

Tactics by Climate Change Deniers

1. Some deny that there is a warming trend. Some even claim the Earth is cooling, despite the empirical observations
2. Some accept the warming trend, but deny that human activities are responsible. But they have no alternative theory to explain the observations.
3. Some accept the warming trend and human cause, but deny it matters
4. Some claim that mitigation would be more expensive than adaptation
5. Some misrepresent scientific data, publish hacked private conversations and emails, and make personal attacks on climate scientists
6. Some use all of the above, even though they are inconsistent

Myth 1:
“Earth is cooling”

Deniers' Arguments for Myth 1 & Scientific Responses

- ★ Small non-typical bits of data, selected from a much larger data set, show cooling. **Response: Cherry-picking is bad science.**
- ★ The fact that cities are warmer than surrounding countryside is distorting global average temperatures. **Response: No, examined scientifically and found to be negligible.**
- ★ Satellite measurements of temperature contradict ground data? **Response: No, satellite & ground data are consistent.**
- ★ The Medieval Warm Period in 950–1100 was warmer than present. **Response: Not globally, it was a local event.**
- ★ Global warming ended in 1998. **Response: No, it's continuing. Only the *rate* of warming of Earth's surface has slowed; not surprising because most extra heat goes into oceans whose rate has not slowed**

Myth 1 is busted: Earth is NOT cooling; the spike in temperature in 1998 is irrelevant

- ★ A single year means nothing. However, for what it's worth 2012 was warmest in recorded history
- ★ 1998 had the warmest El Niño effect (naturally warm), giving a spike in temperature; subsequent years were either La Niña (naturally cool) or weak El Niño
- ★ The decade 2000s was the warmest in history of instrument recordings)
- ★ The decade 2000s was a period of quiet (cooler) Sun!

Myth 2:
“Human activities are not the cause of
global warming”

Deniers' Arguments for Myth 2 and Scientific Responses

- ★ Global warming is due to changes in cosmic rays reaching Earth.
Response: No evidence!
- ★ Global warming is due to an increase radiation from the Sun.
Response: Refuted by observation: the past decade, warmest in recorded history, had a slightly cooler Sun
- ★ Natural flows of CO₂ are much greater than human-made flows.
Response: True but irrelevant. The bathtub example.
<http://www.planetseed.com/node/15254>

2 Types of Evidence that Human Activities **are** responsible for Global Climate Change

- ★ Climate models agree with observations, especially on global average temperature
- ★ Global observations interpreted in framework of the basic physics of greenhouse gases
- ★ Global observations reveal a human 'fingerprint' (see next slide)

Plus evidence on sensitivity of climate to CO₂

- ★ Paleoclimate: history & prehistory of Earth's climate

The Fingerprint of Climate Change is Human

- ★ Warming of surface and troposphere coupled with cooling of stratosphere
- ★ Night-time minimum temperatures are rising faster than day-time maxima
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Myth 3:
“Human-induced global warming is occurring, but it’s too small to matter”

Deniers' Arguments for Myth 3 and Scientific Responses

- ★ Since water vapour is a more important greenhouse gas than CO₂, human emissions of CO₂ are unimportant.

Response: Water vapour is the principal cause of the *natural* greenhouse effect, but CO₂ is the principal cause of the additional *human-induced* effect

- ★ Natural climate variations on geological timescales (about every 100 million years) were much bigger than the current change

Response: True but irrelevant. Also, most natural variations were much slower

- ★ Natural flows of CO₂ are much greater than human-induced flows, so human-induced flows don't matter.

Response: First statement is true but conclusion is false. Bathtub analogy.

Myth 4: “Mitigation would be more expensive than adaptation”

Responses:

- ★ Stern Report finds that doing nothing (business-as-usual) is much more expensive than mitigation.
- ★ We cannot adapt cheaply by building dams on rivers and sea-walls; how can our agriculture adapt to worse droughts?
- ★ Sustainable energy, that is renewable energy + energy efficiency, has become much cheaper over the past decade. Nowadays wind and solar PV are affordable.

Video: ‘What’s the worst that can happen?’

<http://www.youtube.com/watch?v=zORv8wwiadQ>

Summary of Climate Myths Busted

| Myth or fallacy | Result |
|---|---|
| 1. Earth is cooling | Busted. The scientific data are irrefutable if taken as a whole. |
| 2. Earth is warming, but humans are not the cause | Busted. The fingerprint is human, not solar. |
| 3. Human activities are warming Earth, but the effect is negligible | Busted. Human activities are upsetting the natural balance and are already causing impacts. |
| 4. Mitigation would be more expensive than adaptation | Failing to mitigate could cost us human civilisation. |

More myth-busting: see www.skepticalscience.com .

ARGUMENTS AGAINST-



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