Understanding weather and the weather forecast

Week 33
Climate Change

Terry Hart

“Greenhouse Effect” - Some early history

1824: Joseph Fourier (France) calculated that the earth should have been colder. He proposed that the atmosphere could modify the earth’s climate by allowing sunshine in, but impeding the escape of heat back to space.

1827 and 1838: Claude Pouillet (France) developed Fourier’s work and speculated that water vapour and carbon dioxide might trap infrared radiation in the atmosphere, warming the earth enough to support plant and animal life.

1856: Eunice Foote (USA) reported experiments on the contribution of carbon dioxide and water vapour to heating under sunlight. She described her findings in a paper, *"Circumstances Affecting the Heat of the Sun's Rays"*, that she submitted for the tenth annual meeting of the American Association for the Advancement of Science (AAAS) meeting, held on August 23, 1856, in Albany, New York.

ART. XXXI.—*Circumstances affecting the Heat of the Sun's Rays;* by EUNICE FOOTE.

(Read before the American Association, August 23d, 1856.)

MY investigations have had for their object to determine the different circumstances that affect the thermal action of the rays of light that proceed from the sun.

Several results have been obtained.

First. The action increases with the density of the air, and is diminished as it becomes more rarified.

The experiments were made with an air-pump and two cylindrical receivers of the same size, about four inches in diameter and thirty in length. In each were placed two thermometers, and the air was exhausted from one and condensed in the other. After both had acquired the same temperature they were placed in the sun, side by side, and while the action of the sun's rays rose to 110° in the condensed tube, it attained only 88° in the other. I had no means at hand of measuring the degree of condensation or rarefaction.

The observations taken once in two or three minutes, were as follows:

Exhausted Tube		Condensed Tube.	
In shade.	In sun.	In shade.	In sun.
75	80	75	80
76	82	78	95
80	82	80	100
83	86	82	105
84	88	85	110

This circumstance must affect the power of the sun's rays in different places, and contribute to produce their feeble action on the summits of lofty mountains.

Secondly. The action of the sun's rays was found to be greater in moist than in dry air.

In one of the receivers the air was saturated with moisture—in the other it was dried by the use of chlorid of calcium.

Both were placed in the sun as before and the result was as follows:

Dry Air.		Damp Air.	
In shade.	In sun.	In shade.	In sun.
75	75	75	75
78	88	78	90
82	102	82	106
82	104	82	110
82	105	82	114
88	108	92	120

The high temperature of moist air has frequently been observed. Who has not experienced the burning heat of the sun that precedes a summer's shower? The isothermal lines will, I think, be found to be much affected by the different degrees of moisture in different places.

Thirdly. The highest effect of the sun's rays I have found to be in carbonic acid gas.

One of the receivers was filled with it, the other with common air, and the result was as follows:

In Common Air.		In Carbonic Acid Gas.	
In shade.	In sun.	In shade.	In sun.
80	90	80	90
81	94	84	100
80	99	84	110
81	100	85	120

The receiver containing the gas became itself much heated—very sensibly more so than the other—and on being removed, it was many times as long in cooling.

An atmosphere of that gas would give to our earth a high temperature; and if as some suppose, at one period of its history the air had mixed with it a larger proportion than at present, an increased temperature from its own action as well as from increased weight must have necessarily resulted.

On comparing the sun's heat in different gases, I found it to be in hydrogen gas, 104°; in common air, 106°; in oxygen gas, 108°; and in carbonic acid gas, 125°.

ART. XXXII.—*Review of a portion of the Geological Map of the United States and British Provinces by Jules Marcou;** by WILLIAM P. BLAKE.

GEOLOGICAL maps of the United States published in Europe and widely circulated among European geologists, are necessarily regarded by us with no small degree of attention and curiosity. This is more especially true, when such maps embrace regions of which the geography has only recently been made known and the geology has never before been laid down on a map with any approach to accuracy.

The recent geological map and profile by M. J. Marcou, which has appeared in the Annales des Mines and in the Bulletin of

* Carte Géologique des Etats-Unis et des Provinces Anglaises de l'Amérique du Nord par Jules Marcou. *Annales des Mines,* 5e Série, T. vii, p. 329. Published also with the following:

Résumé explicatif d'une carte géologique des Etats-Unis et des provinces anglaises de l'Amérique du Nord, avec un profil géologique allant de la vallée du Mississippi aux côtes du Pacifique, et une planche de fossiles, par M. Jules Marcou *Bulletin de la Société Géologique de France.* Mai, 1855, p. 813.

1856 edition of the *American Journal of Science and Arts*

Eunice Foote's experiments

- used two glass cylinders (diameter 4 " and length 30")
- In each were two mercury-in-glass thermometers

In the first experiment, one cylinder had compressed air and the other was partly evacuated.
Once both thermometers read the same temperature, she placed them in the sun and then in the shade. When they were in the sun she noticed that they reached different temperatures.

Exhausted Tube		Condensed Tube.	
In shade.	In sun.	In shade.	In sun.
75	80	75	80
76	82	78	95
80	82	80	100
83	86	82	105
84	88	85	110

This showed that the more air in the tube, the greater the heating effect.

Secondly, she tried moist and dry air.

Dry Air.		Damp Air.	
In shade.	In sun.	In shade.	In sun.
75	75	75	75
78	88	78	90
82	102	82	106
82	104	82	110
82	105	82	114
88	108	92	120

Then she tried carbonic acid gas (carbon dioxide)

In Common Air.		In Carbonic Acid Gas.	
In shade.	In sun.	In shade.	In sun.
80	90	80	90
81	94	84	100
80	99	84	110
81	100	85	120

She also tried hydrogen gas and oxygen.

Her overall results were:

> On comparing the sun's heat in different gases, I found it to be in hydrogen gas, 104°; in common air, 106°; in oxygen gas, 108°; and in carbonic acid gas, 125°.

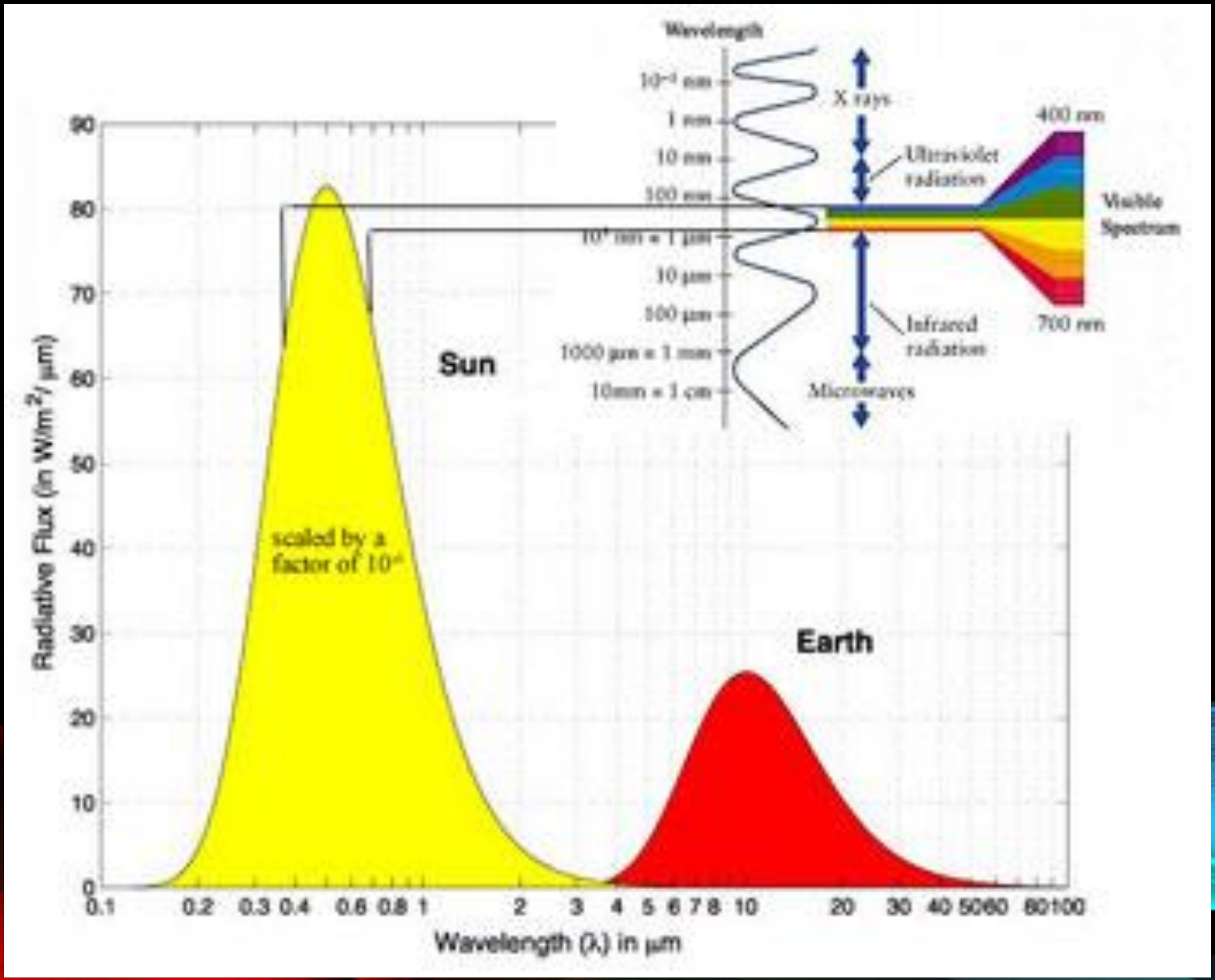
She then proposed:

> An atmosphere of that gas would give to our earth a high temperature; and if as some suppose, at one period of its history the air had mixed with it a larger proportion than at present, an increased temperature from its own action as well as from increased weight must have necessarily resulted.

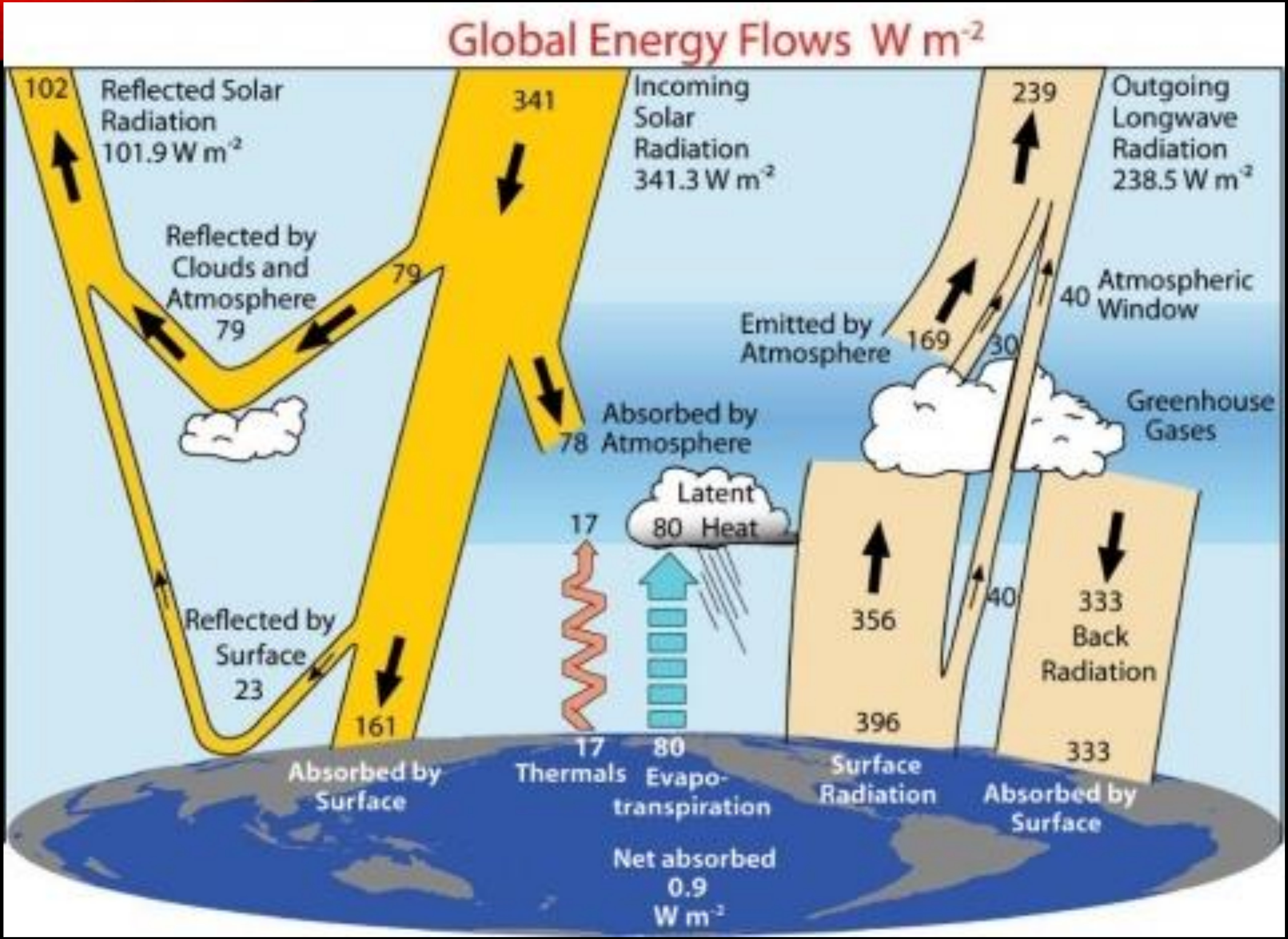
This was a clear proposal that increased levels of carbon dioxide in the atmosphere could cause warming.

The famous English scientist John Tyndall made more detailed experiments in 1859 and proposed a similar theory. He did not acknowledge the work of Eunice Foote and may not have known of them.

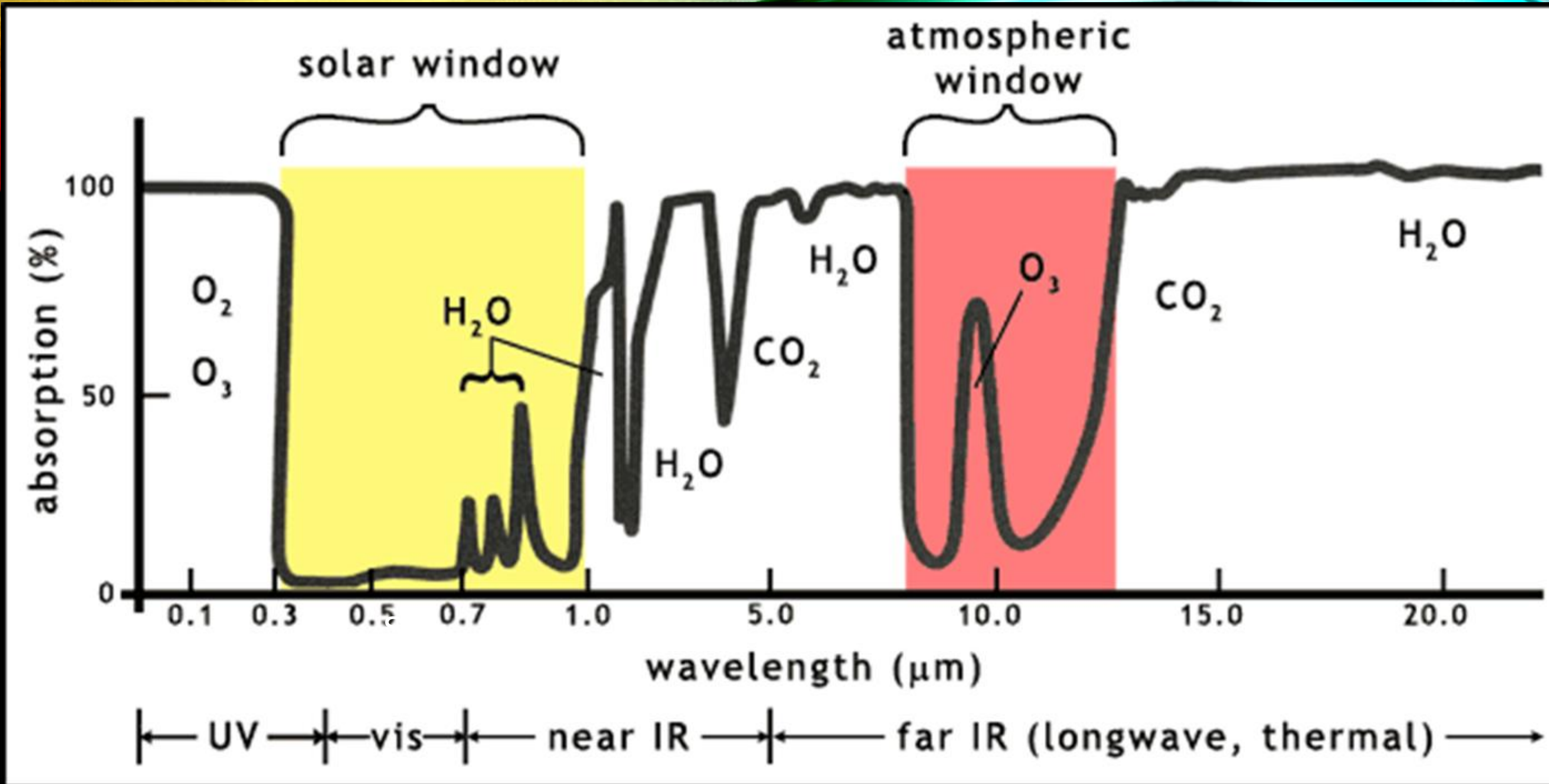
Incoming solar radiation and outgoing thermal radiation from the Earth



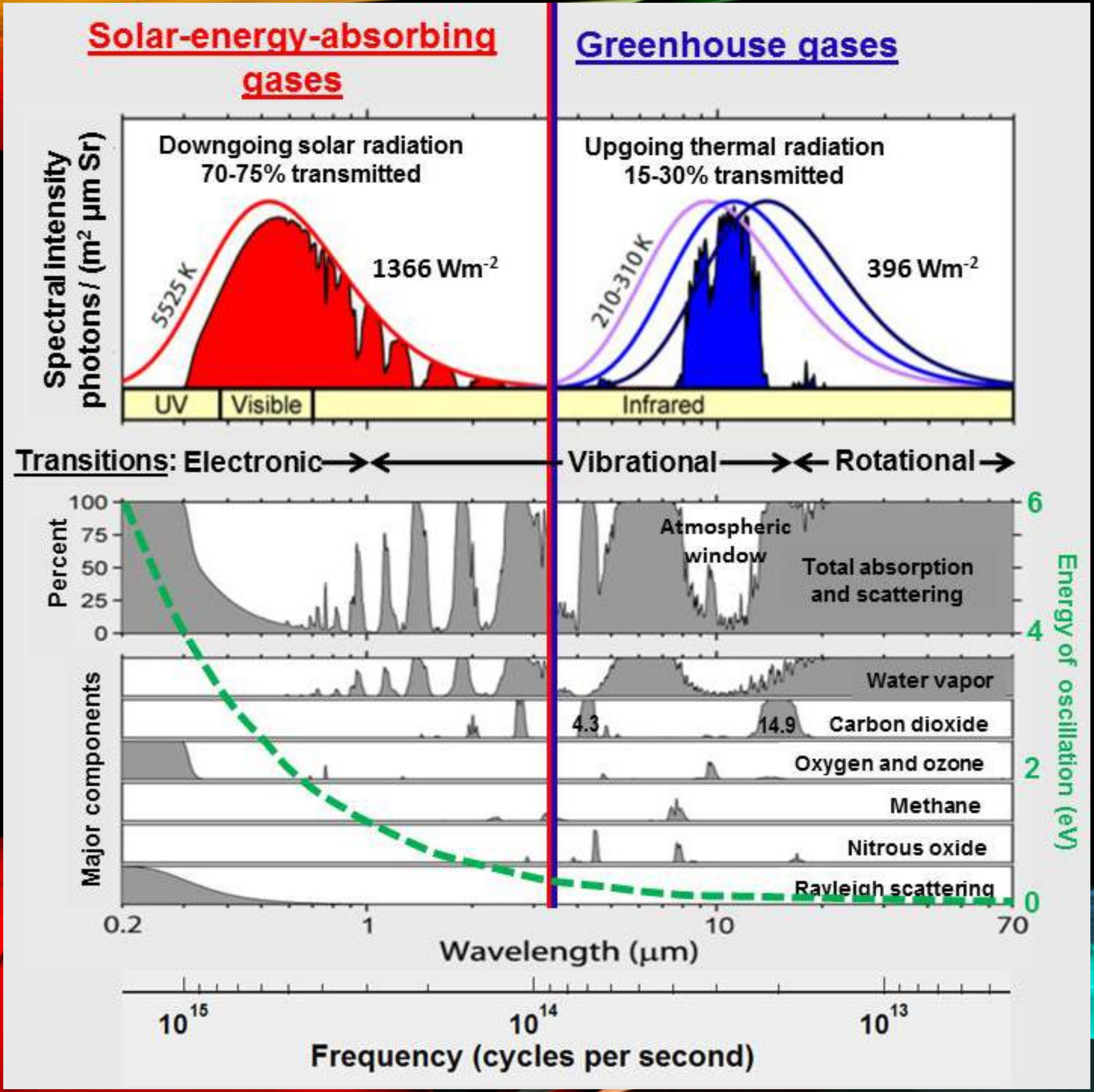
Schematic of radiation balance for Earth



Kiehl and Trenberth 1997 , updated 2009.



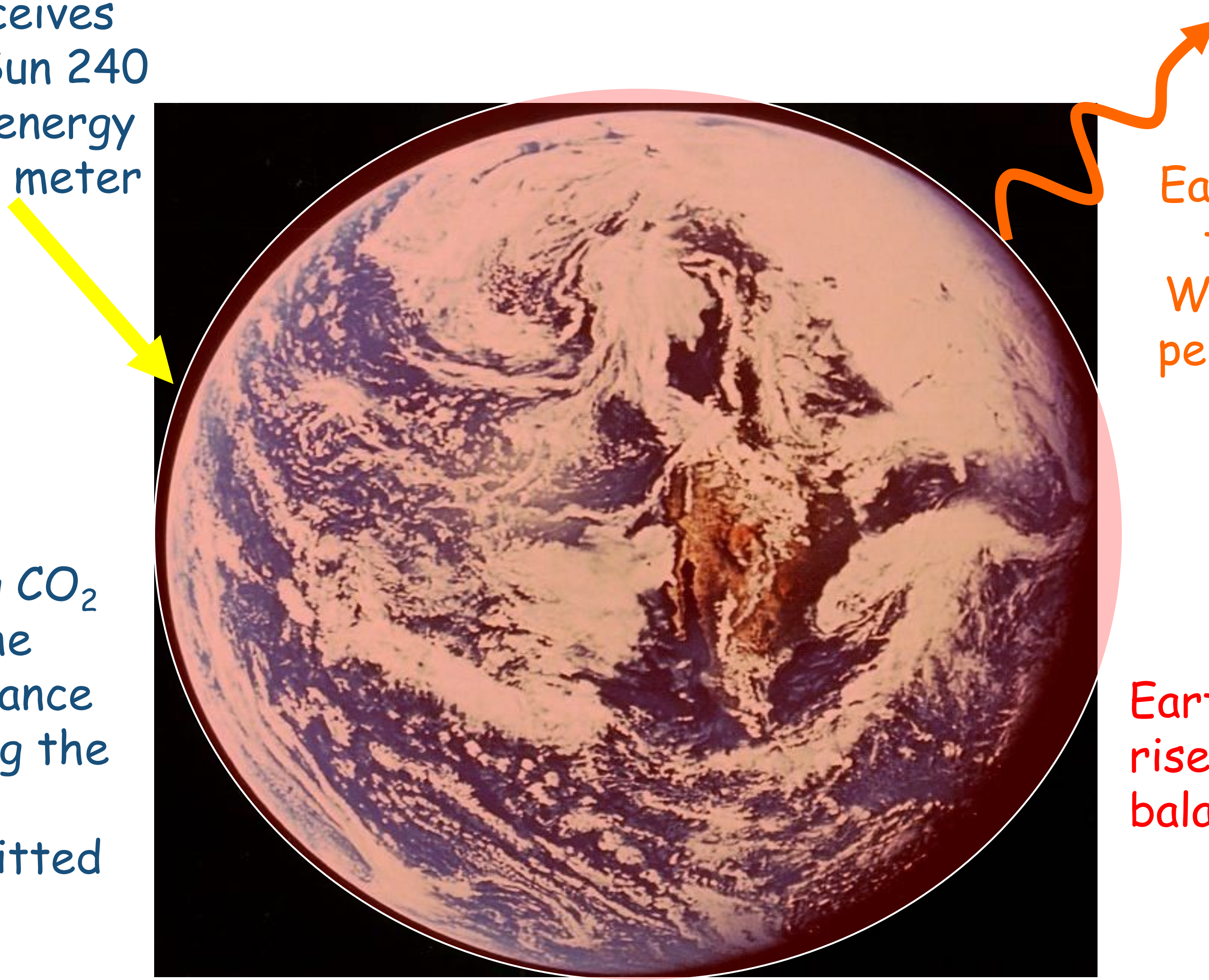
Most visible light is able to reach the earth's surface, but the thermal (infrared) radiation from the surface has to make its way through absorbing gases, except in the "atmospheric window". It does not mean that radiation at those wavelengths is blocked from leaving – rather radiation will be emitted from higher in the atmosphere and so at a lower temperature.



Methane, nitrous oxide and other fluoro and hydrocarbons are more powerful greenhouse gases than carbon dioxide but their concentration is much less and their life-time is shorter

EARTH'S ENERGY BALANCE

Earth receives from the Sun 240 Watts of energy per square meter

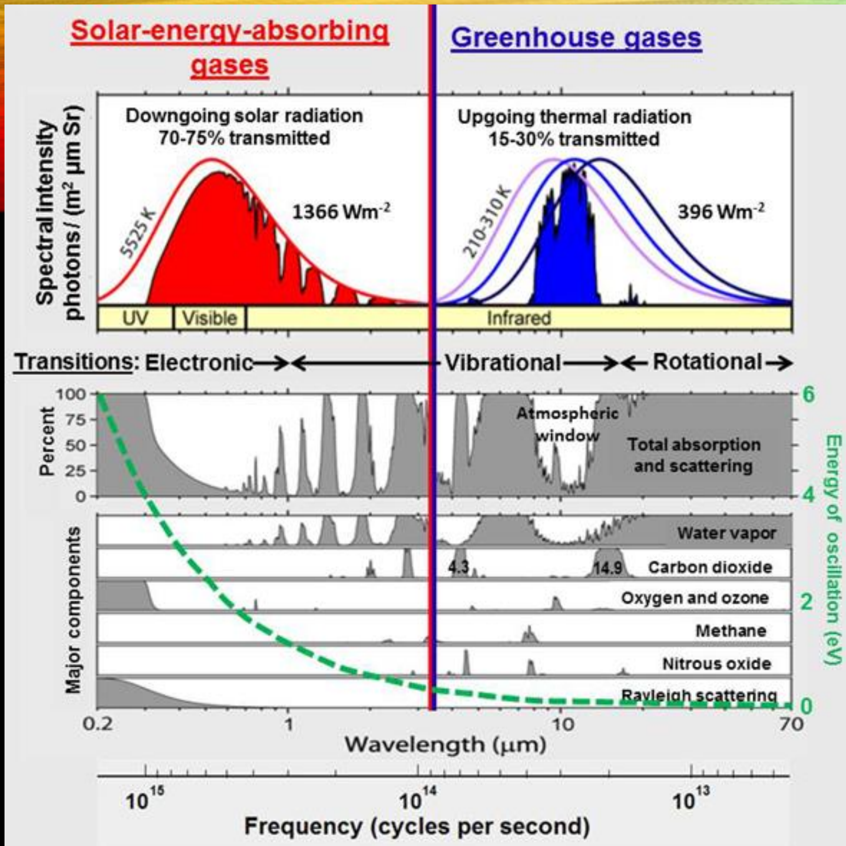


Earth emits back to space 240 Watts of energy per square meter

Increasing CO_2 changes the energy balance by reducing the amount of energy emitted to space

Earth's temperature rises to restore the balance

Graphic from Anthony J. Broccoli, Rutgers University

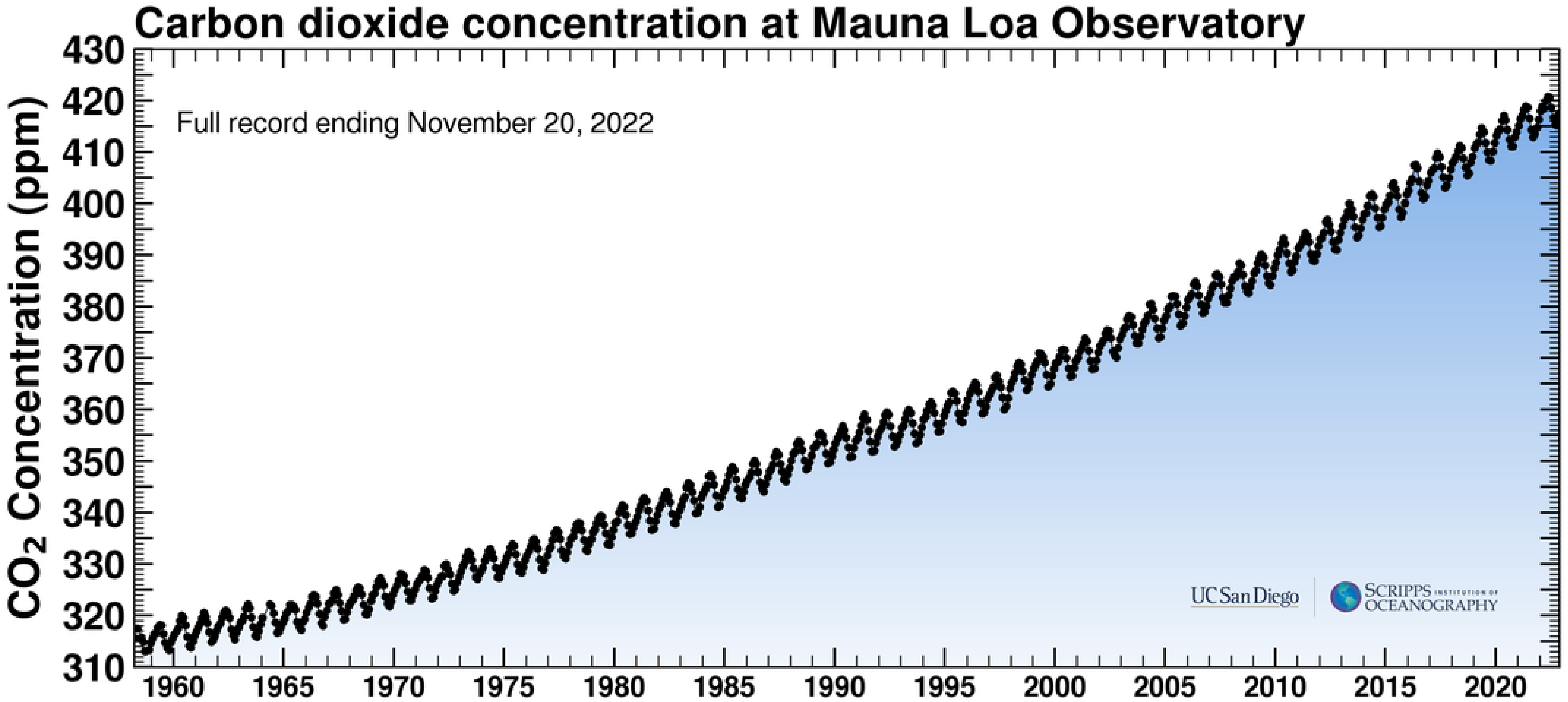


Long wave – thermal radiation

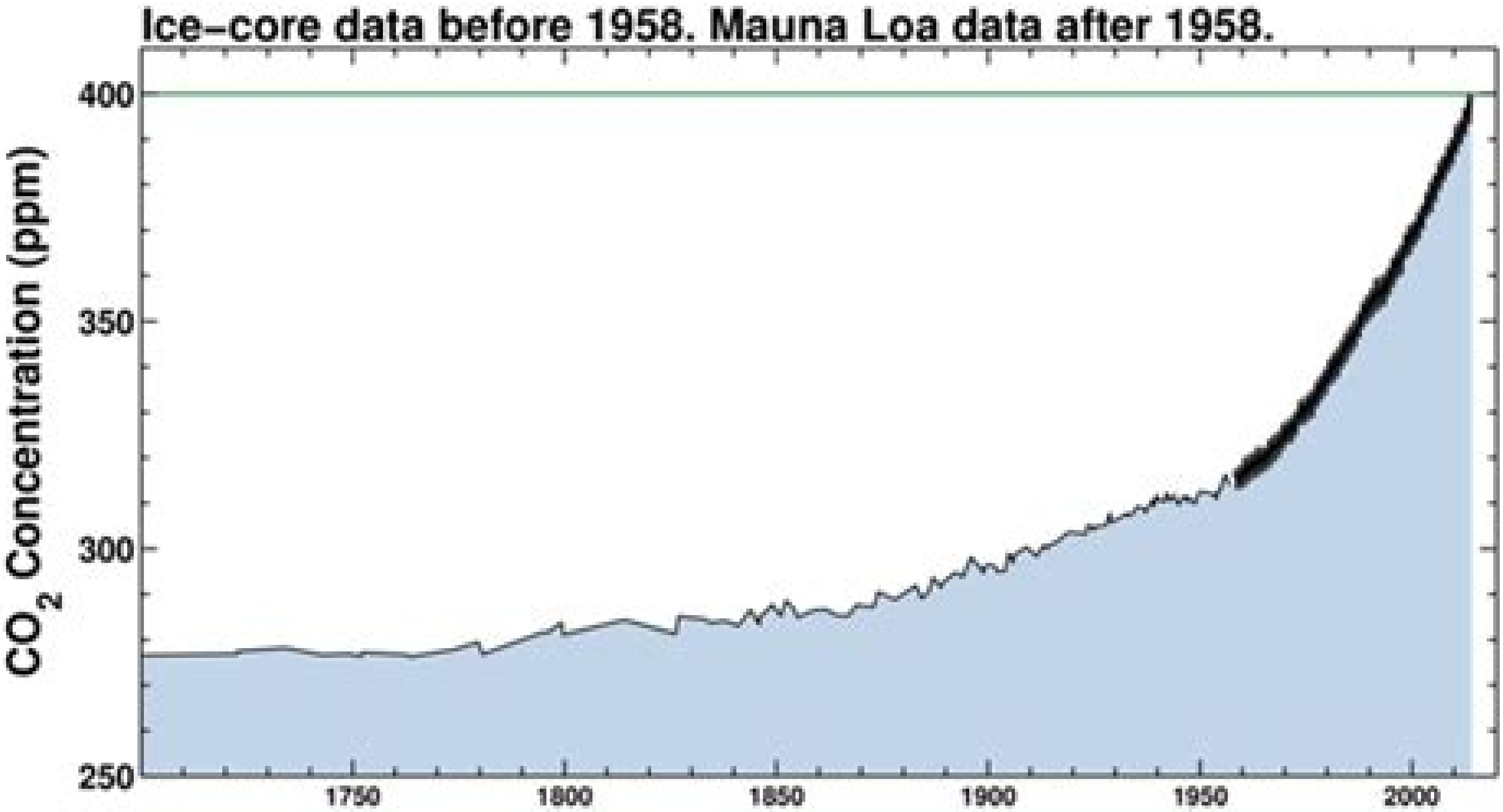
The energy is absorbed and then re-transmitted at the temperature of the layer of the atmosphere.

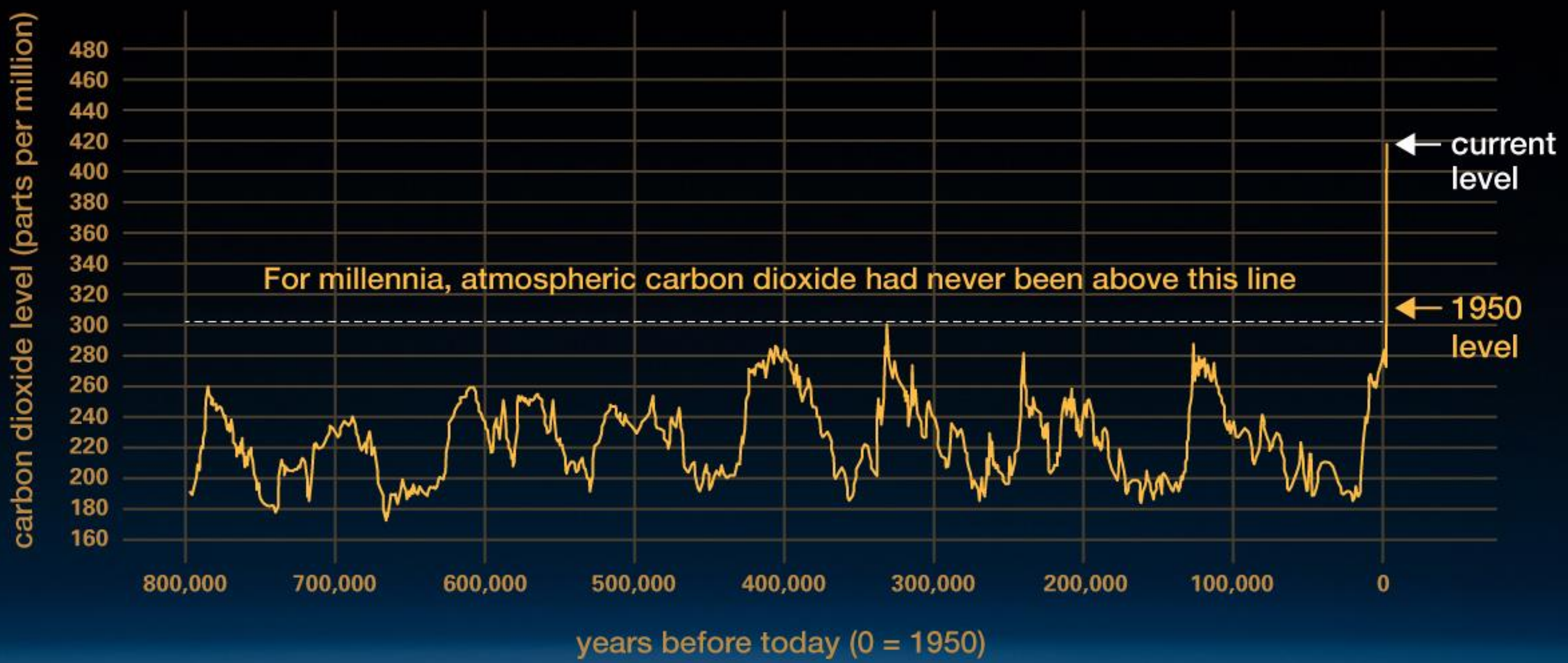
So, a basic statement of the "greenhouse effect":

An increase of gases such as CO_2 makes the atmosphere more opaque at infrared wavelengths. As a consequence, the earth's heat radiation to space comes from higher, colder levels in the atmosphere, thus reducing emission of heat energy to space. The temporary imbalance between the energy absorbed from the Sun and heat emission to space, causes the planet to warm until planetary energy balance is restored.

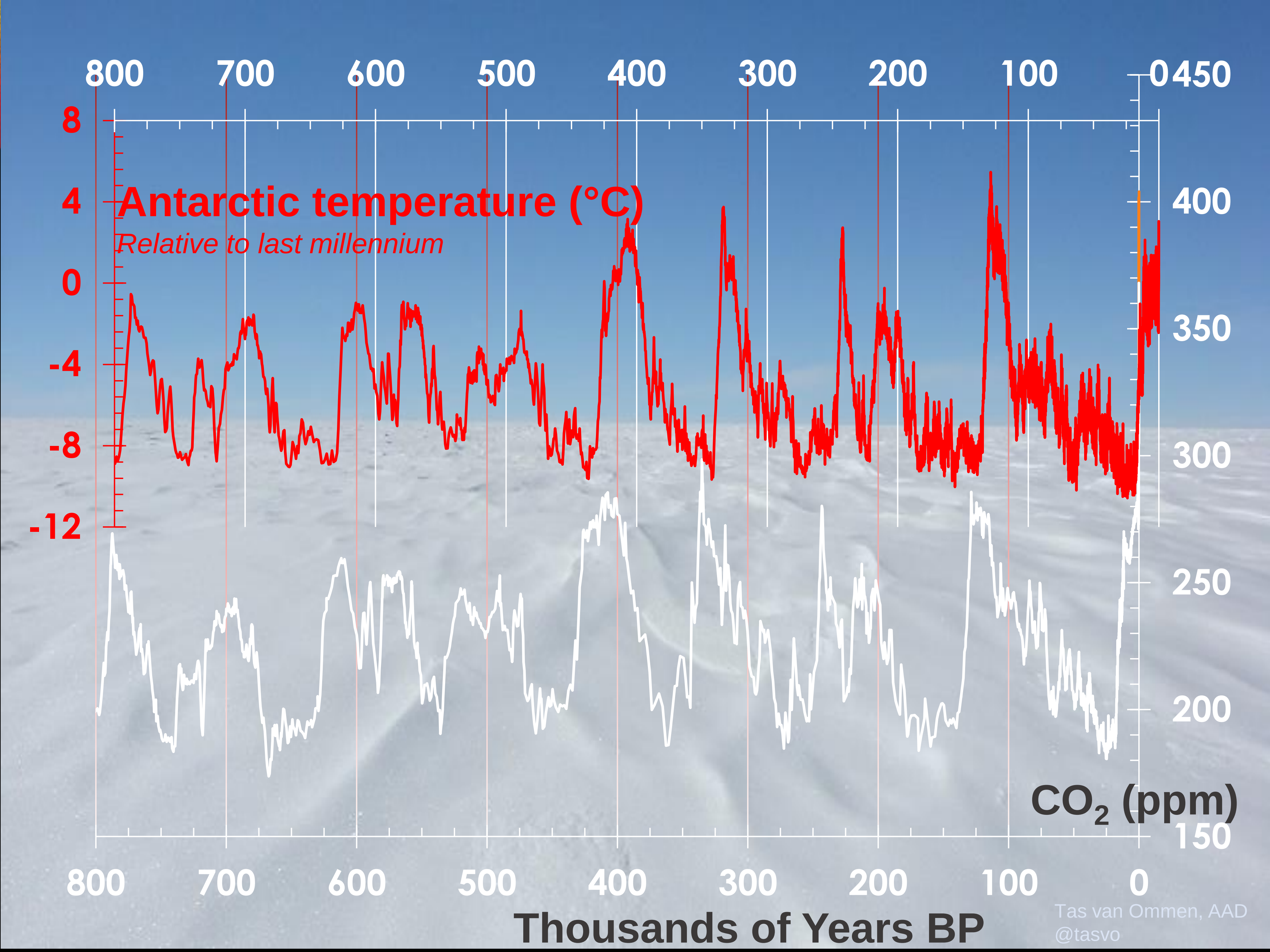


https://keelingcurve.ucsd.edu/

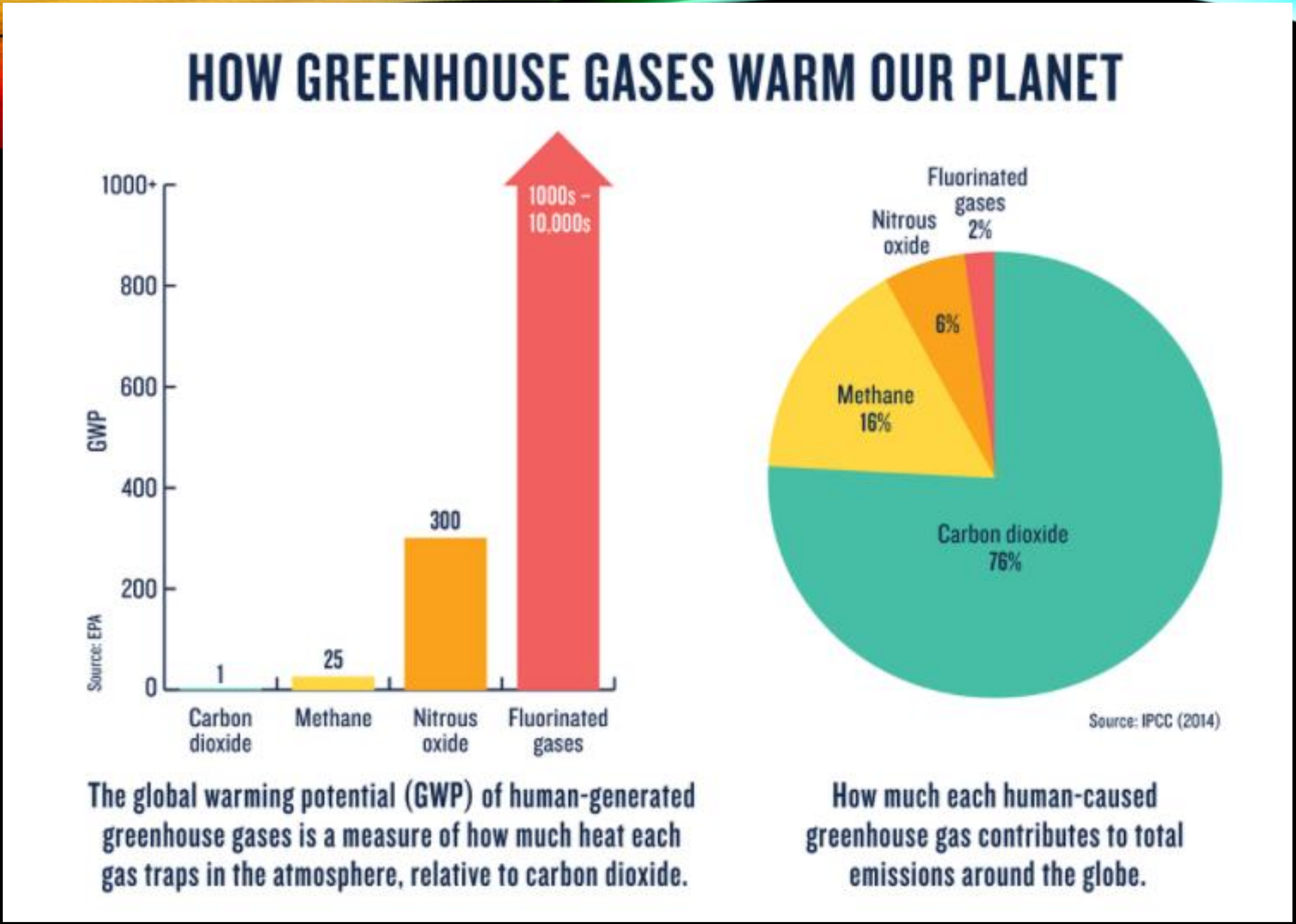

Ice–core data before 1958. Mauna Loa data after 1958.
CO_2 Concentration (ppm)
400
350
300
250
1750
1800
1850
1900
1950
2000



climate.nasa.gov



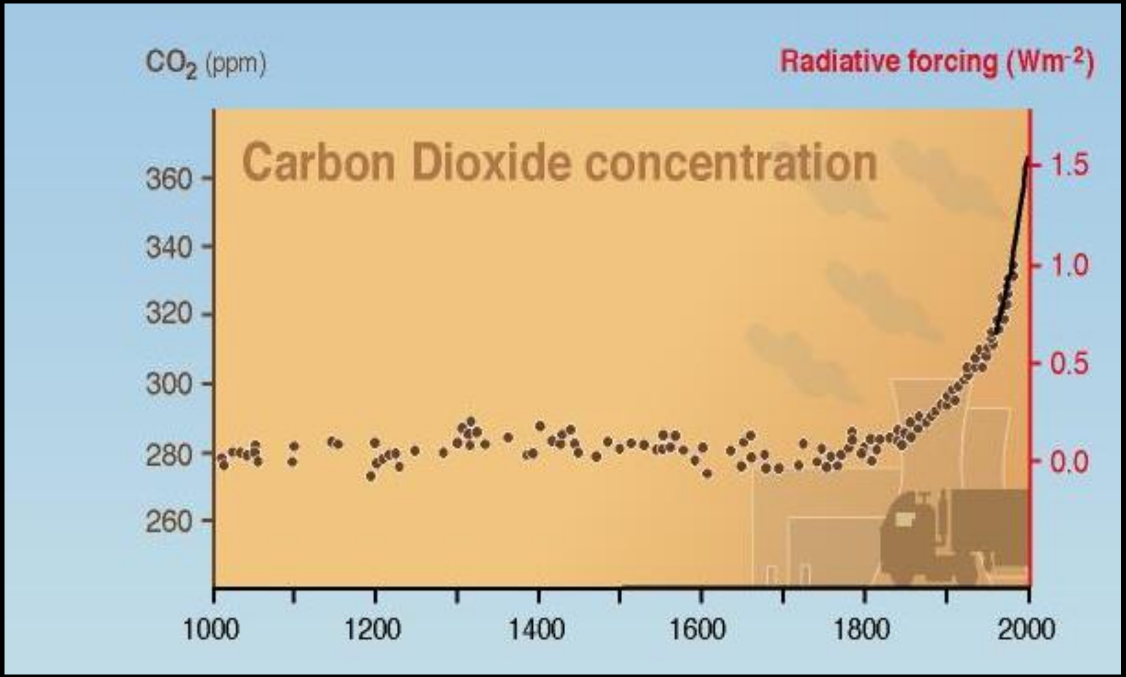
800
700
600
500
400
300
200
100
0
450
8
4
0
-4
-8
-12
Antarctic temperature (°C)
Relative to last millennium
400
350
300
250
200
150
CO2 (ppm)
Thousands of Years BP
Tas van Ommen, AAD
@tasvo



https://www.abc.net.au/news/rural/2021-09-28/zero-emission-agriculture-global-warming/100496270

IPCC DEFINES RADIATIVE FORCING OVER THE INDUSTRIAL PERIOD:

- IPCC uses the concept *radiative forcing* of changes from pre-industrial times (around 1800) to the present.



The estimate is a few W/m^2 of net extra positive forcing over the industrial period. Currently it has reached about 3 W/m^2.

The impact

- The earth has warmed up and so its emission of heat to space has increased, in response to the greenhouse gas forcing. Around 1 W/m^2
- There is net energy flow into the earth-ocean system (especially ocean temperatures) Around 1 W/m^2
- Since industrialisation, global warming is less than what might be expected from increased greenhouse gas concentrations, if this had been the only change. There has been an offsetting effect from aerosols + aerosol effects on clouds (1 – 1.5 W/m^2) due to:

– Large volcanic eruptions (e.g. Krakatoa in 1883 or Mt Pinatubo in 1991) that cause short-lived but quite large negative forcing, -3 to -4 W/m^2

– air pollution from industry, traffic, and large scale burning of forests.(However, the air pollution is being cleaned up!)

- About 90% of the extra energy at the surface is going into heating the ocean, rather than the land and atmosphere. It takes a lot of energy to heat the ocean!

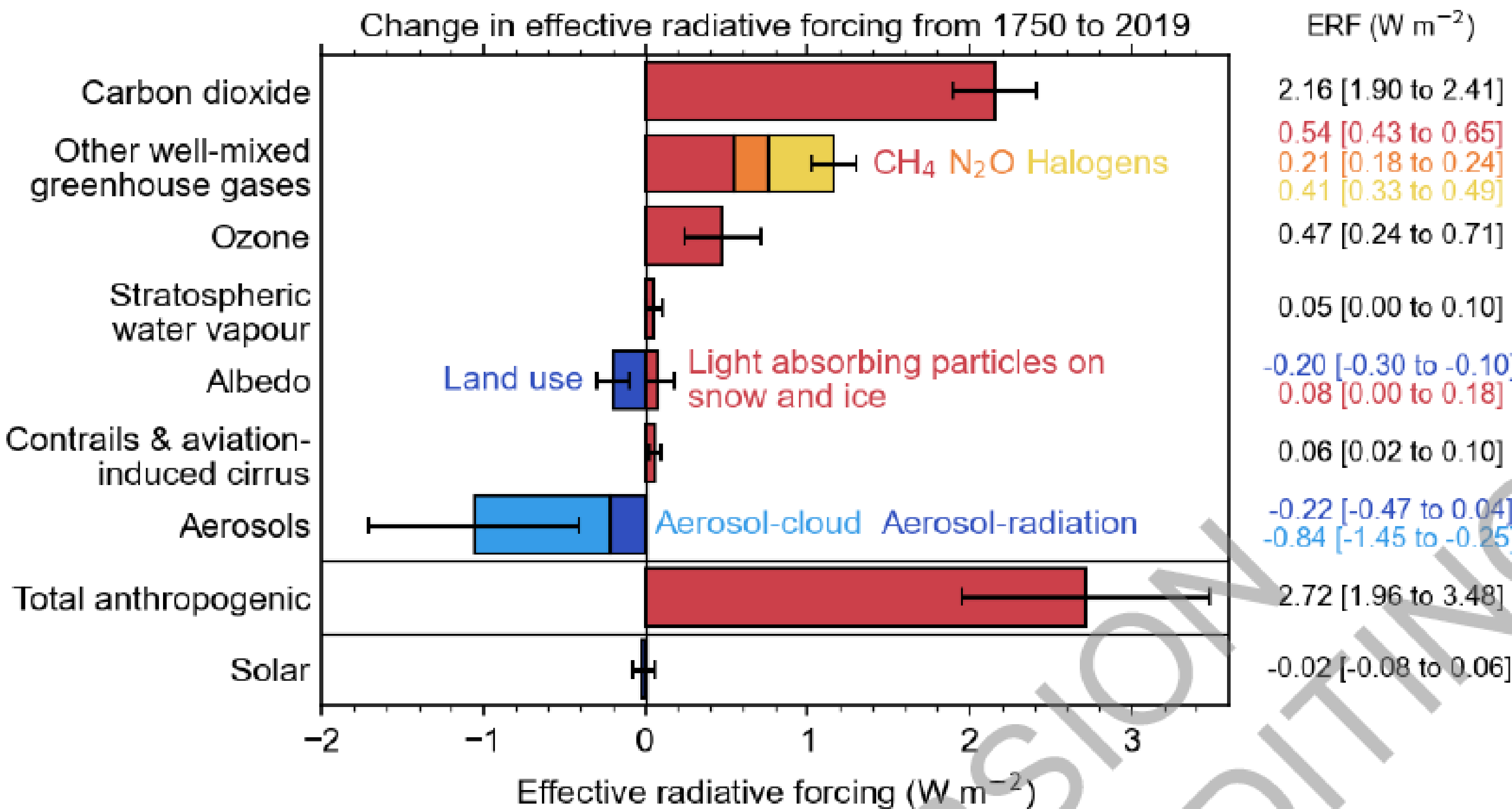
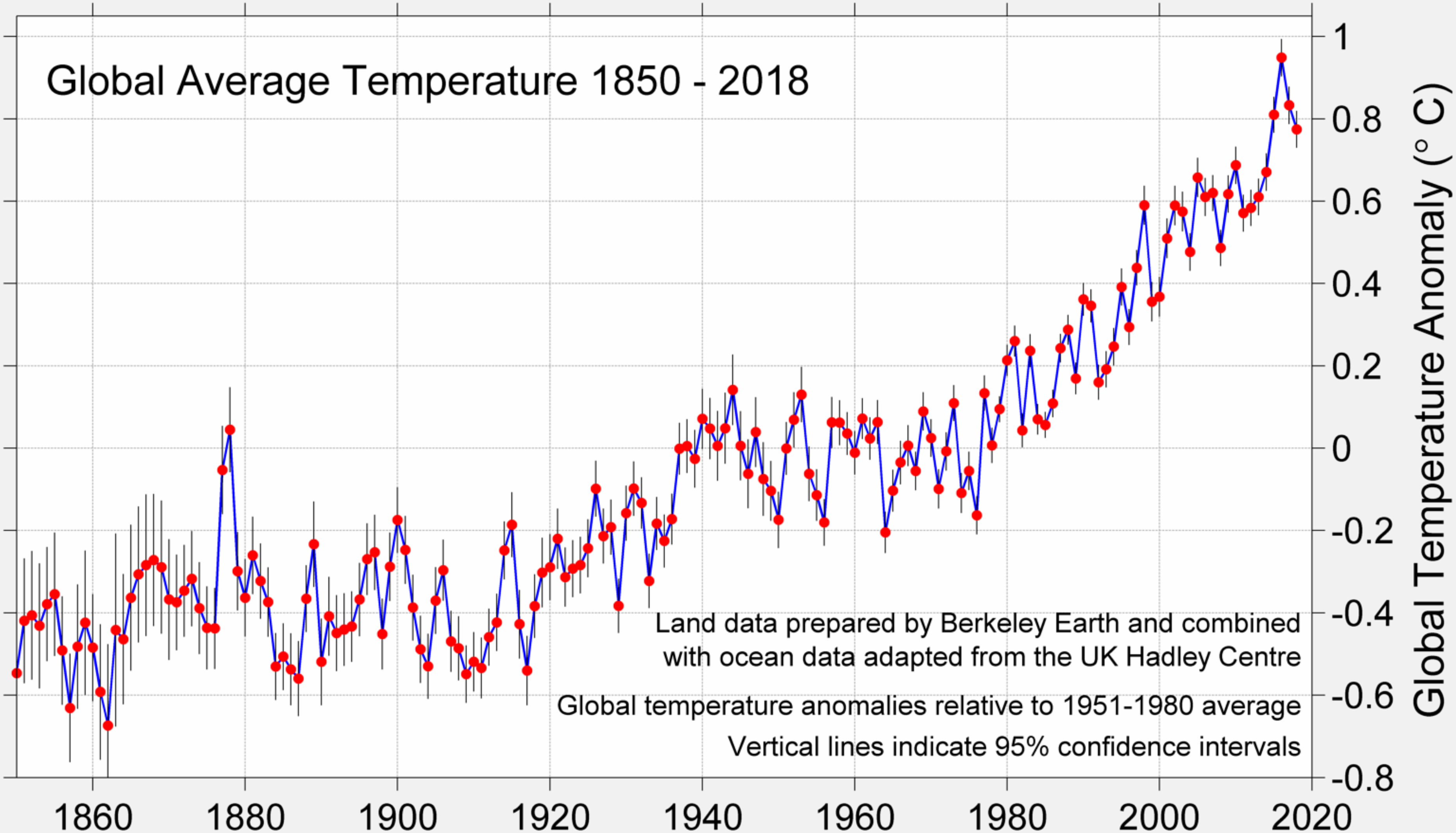
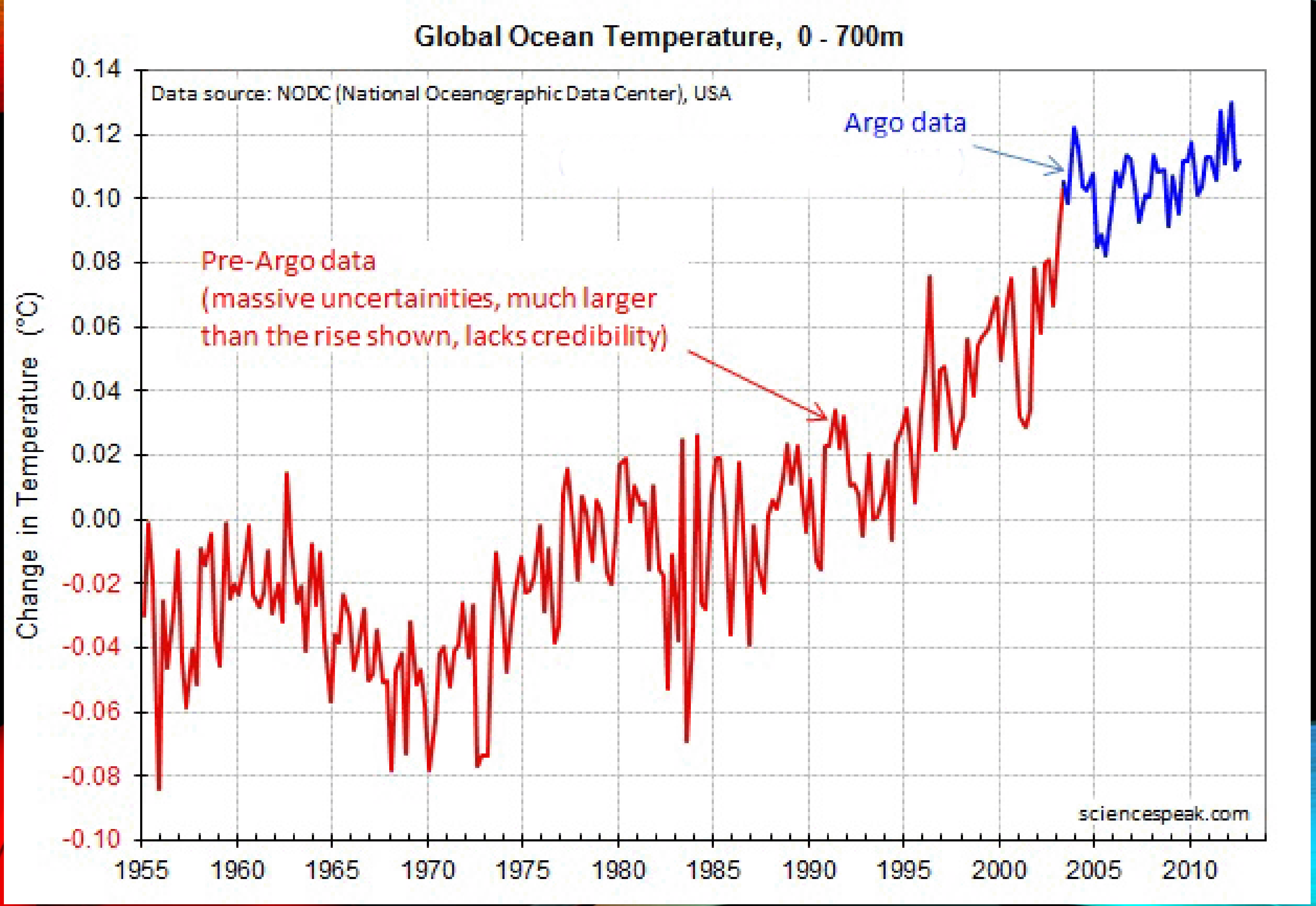


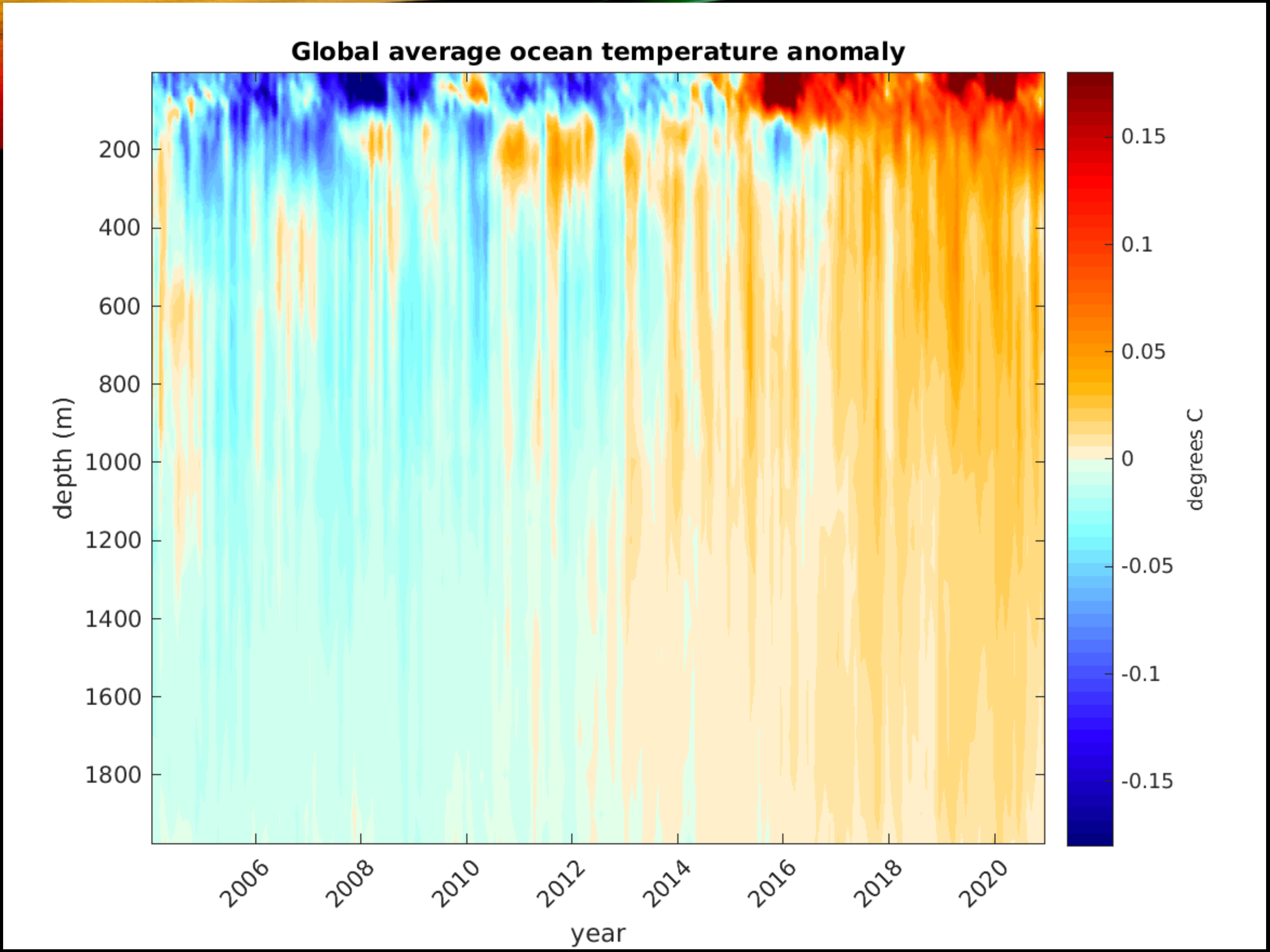
Figure 7.6: **Change in effective radiative forcing from 1750 to 2019 by contributing forcing agents (carbon dioxide, other well-mixed greenhouse gases (WMGHGs), ozone, stratospheric water vapour,**

IPCC Working Group 1 report – August 2021

Observational evidence




Global Ocean Temperature, 0 - 700m
Data source: NODC (National Oceanographic Data Center), USA
Argo data
Pre-Argo data
(massive uncertainities, much larger than the rise shown, lacks credibility)
Change in Temperature (°C)
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
sciencespeak.com



There is a lot of ocean to warm up!

Trevor McDougall wins $250,000 science prize for researching ‘thermal flywheel’ of climate system

Oceanographer takes top honours in prime minister's prizes for science after researching ocean's role in regulating climate

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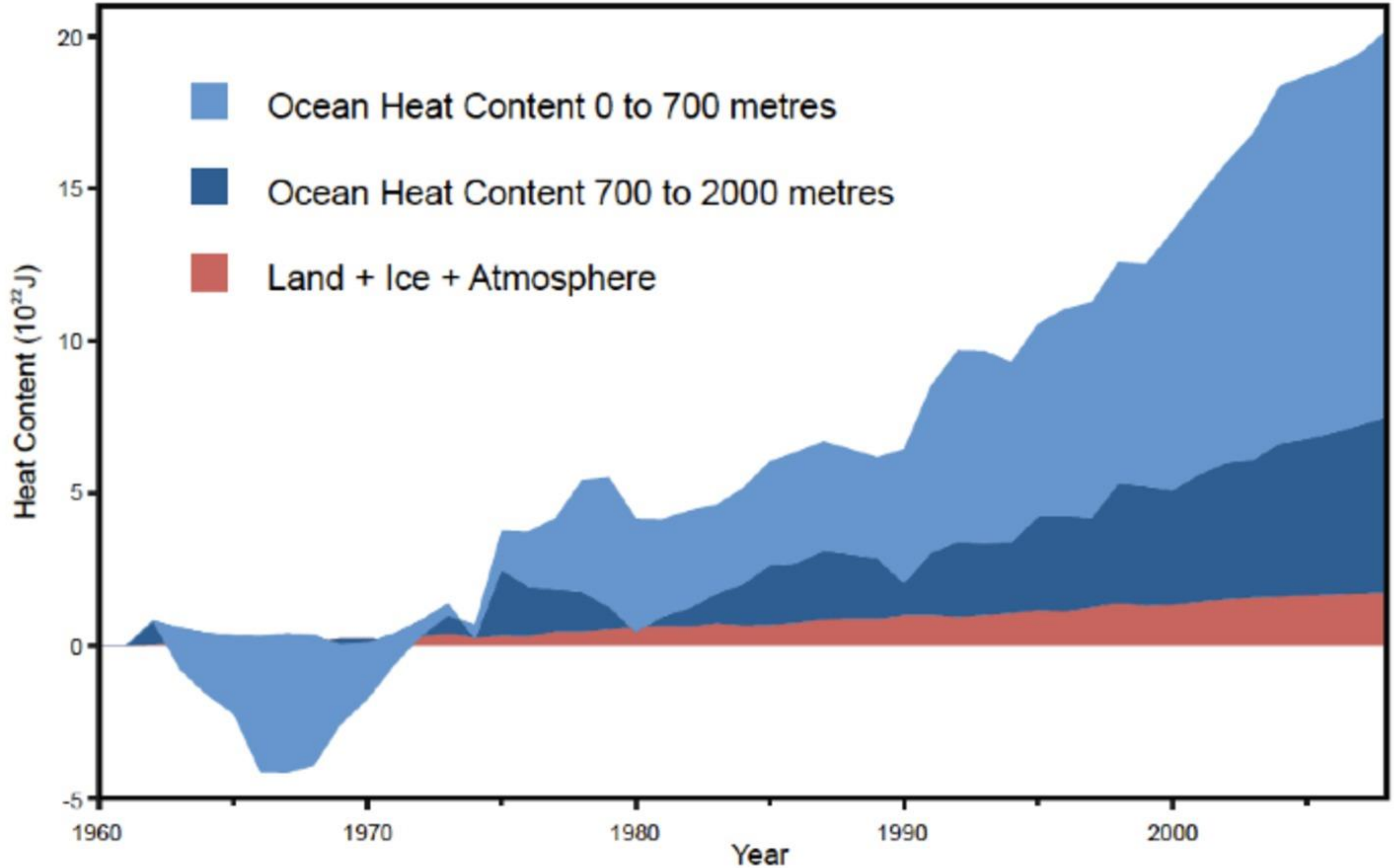
Oceanographer Trevor McDougall says the idea for one of his greatest breakthroughs came while swimming in a freshwater pond

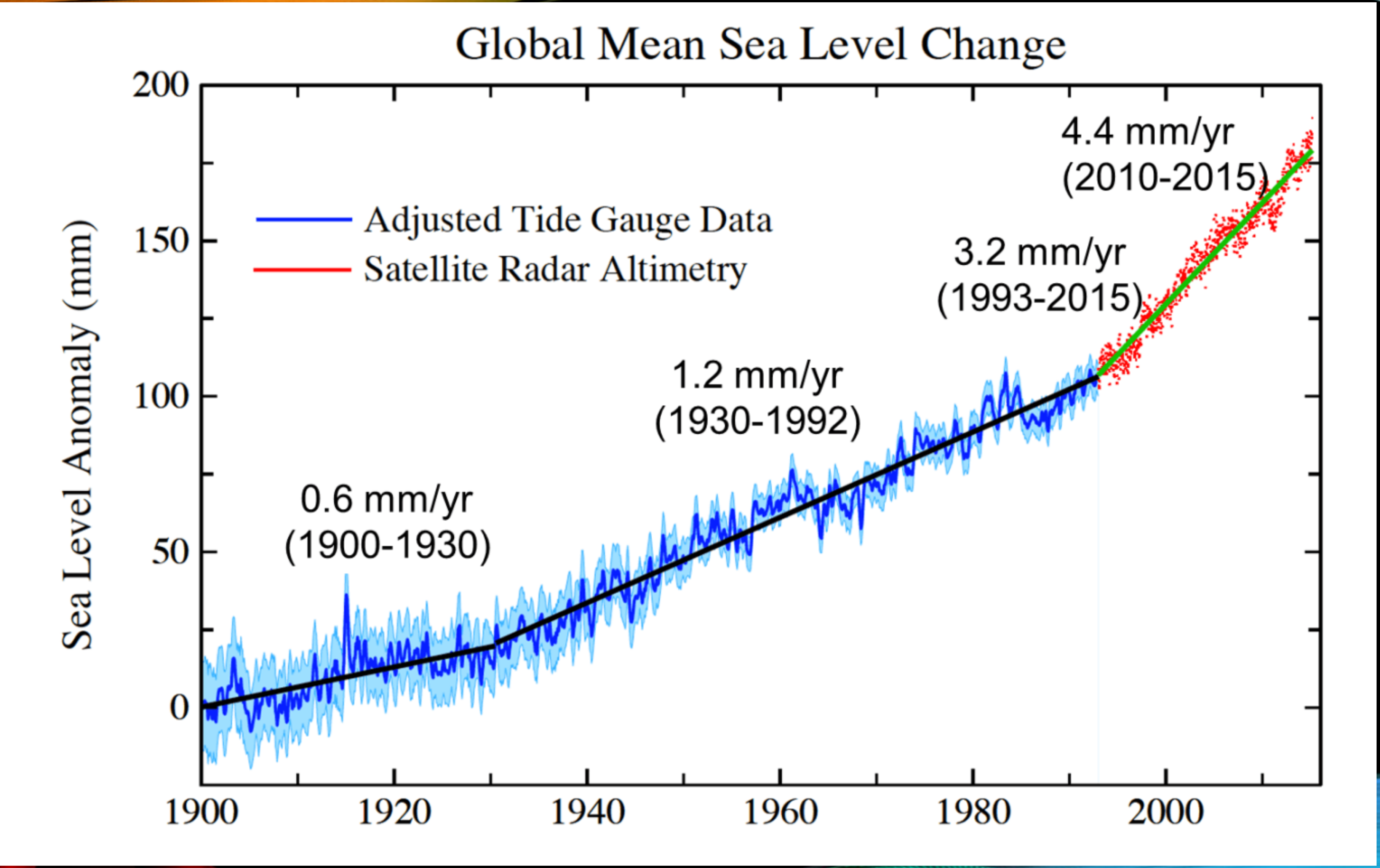
When Trevor McDougall began studying the ocean in the 1970s he had no idea that his field would become a crucial part of climate science.

Guardian.com

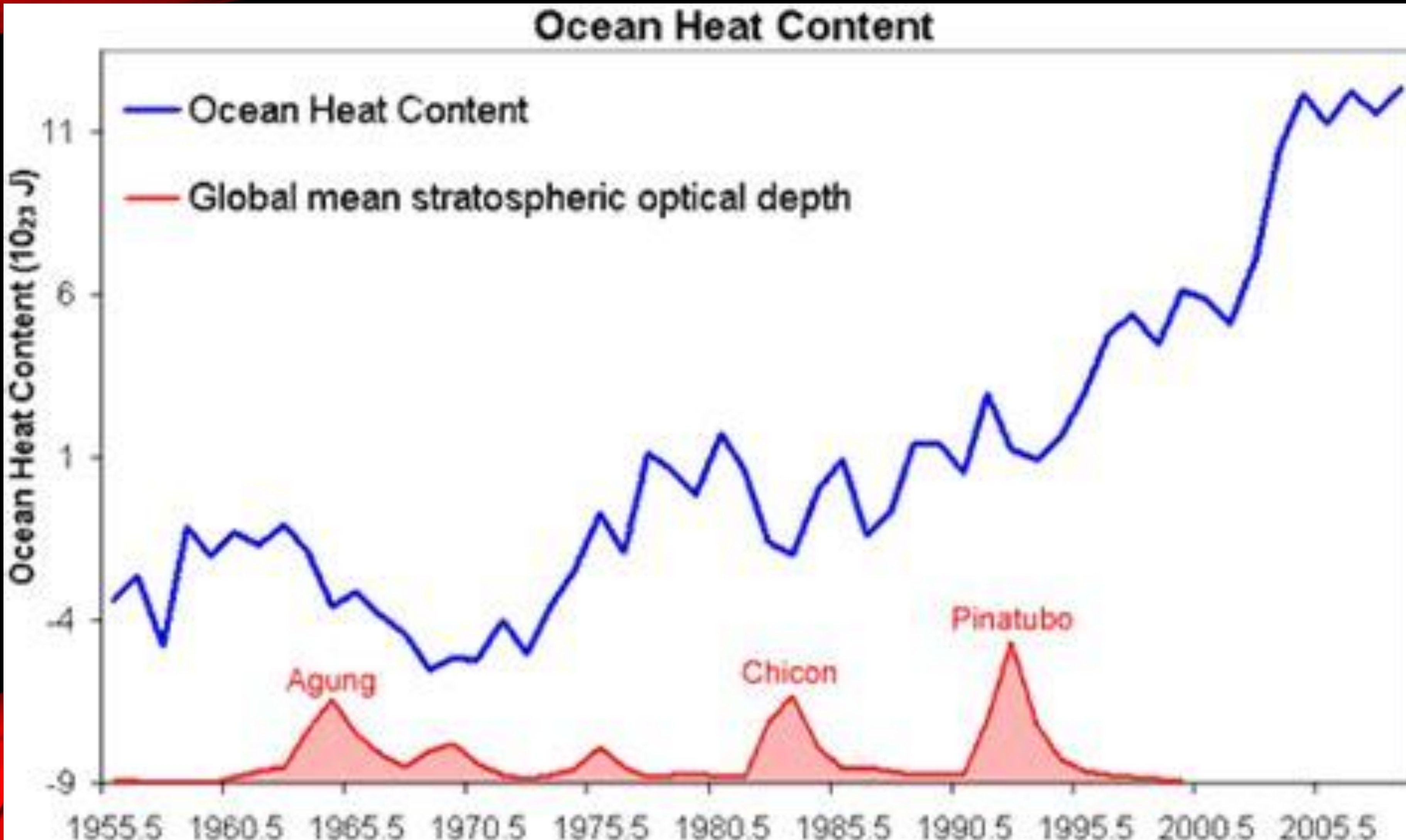
https://www.industry.gov.au/publications/prime-ministers-prizes-science-2022/2022-prime-ministers-prize-science

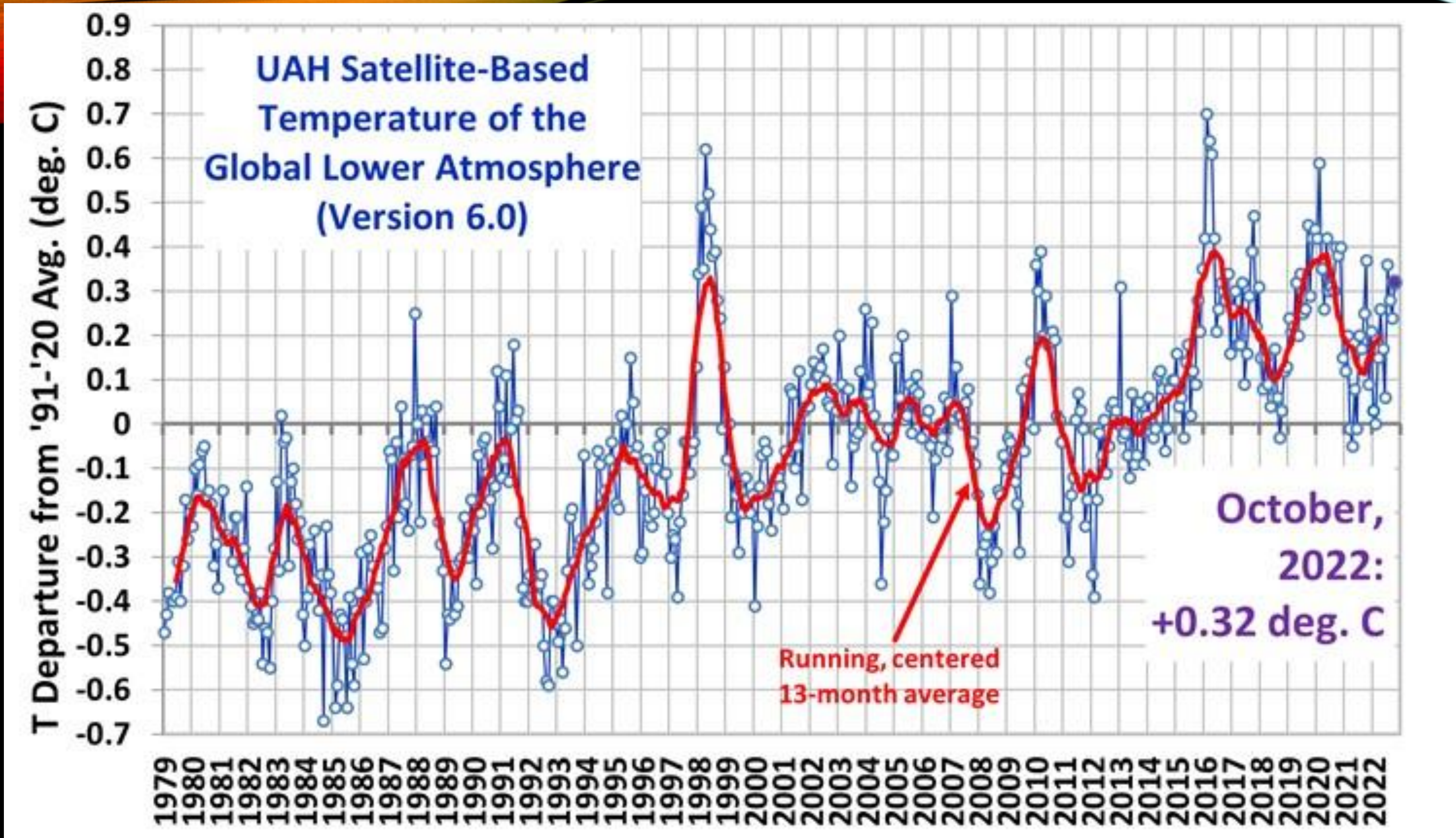


Ocean Heat Content 0 to 700 metres
Ocean Heat Content 700 to 2000 metres
Land + Ice + Atmosphere
Heat Content (10^{22} J)
20
15
10
5
0
-5
1960
1970
1980
1990
2000
Year



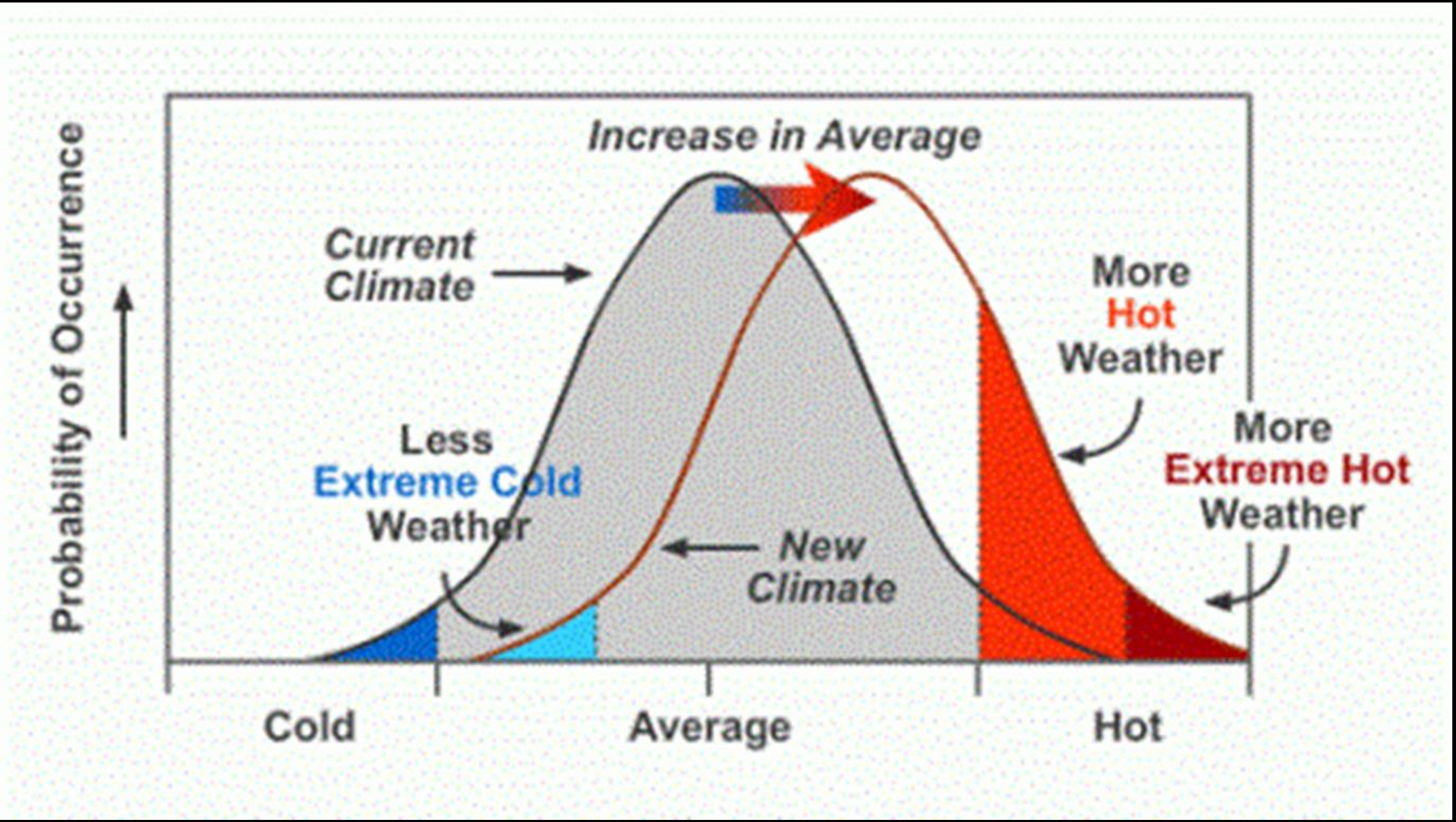
Climatefeedback.org


Ocean Heat Content
Ocean Heat Content
Global mean stratospheric optical depth
Ocean Heat Content (10^{23} J)
11
6
1
-4
-9
Agung
Chicon
Pinatubo
1955.5
1960.5
1965.5
1970.5
1975.5
1980.5
1985.5
1990.5
1995.5
2000.5
2005.5



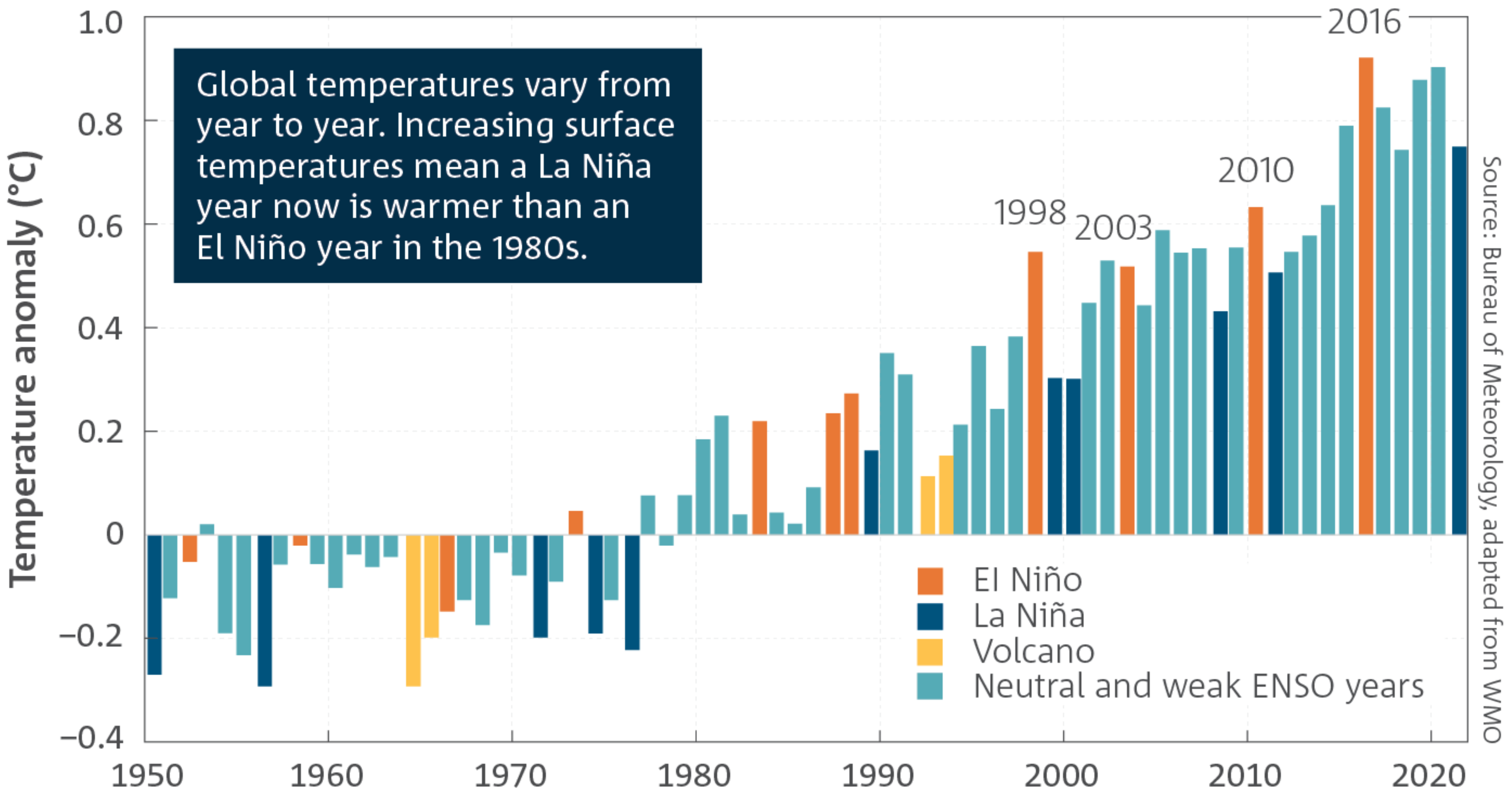
https://www.drroyspencer.com/latest-global-temperatures/

"**Attributing**" a particular event to climate change is difficult in most cases. The climatologists prefer to say "such an event is much more likely under climate change" as the average conditions change.

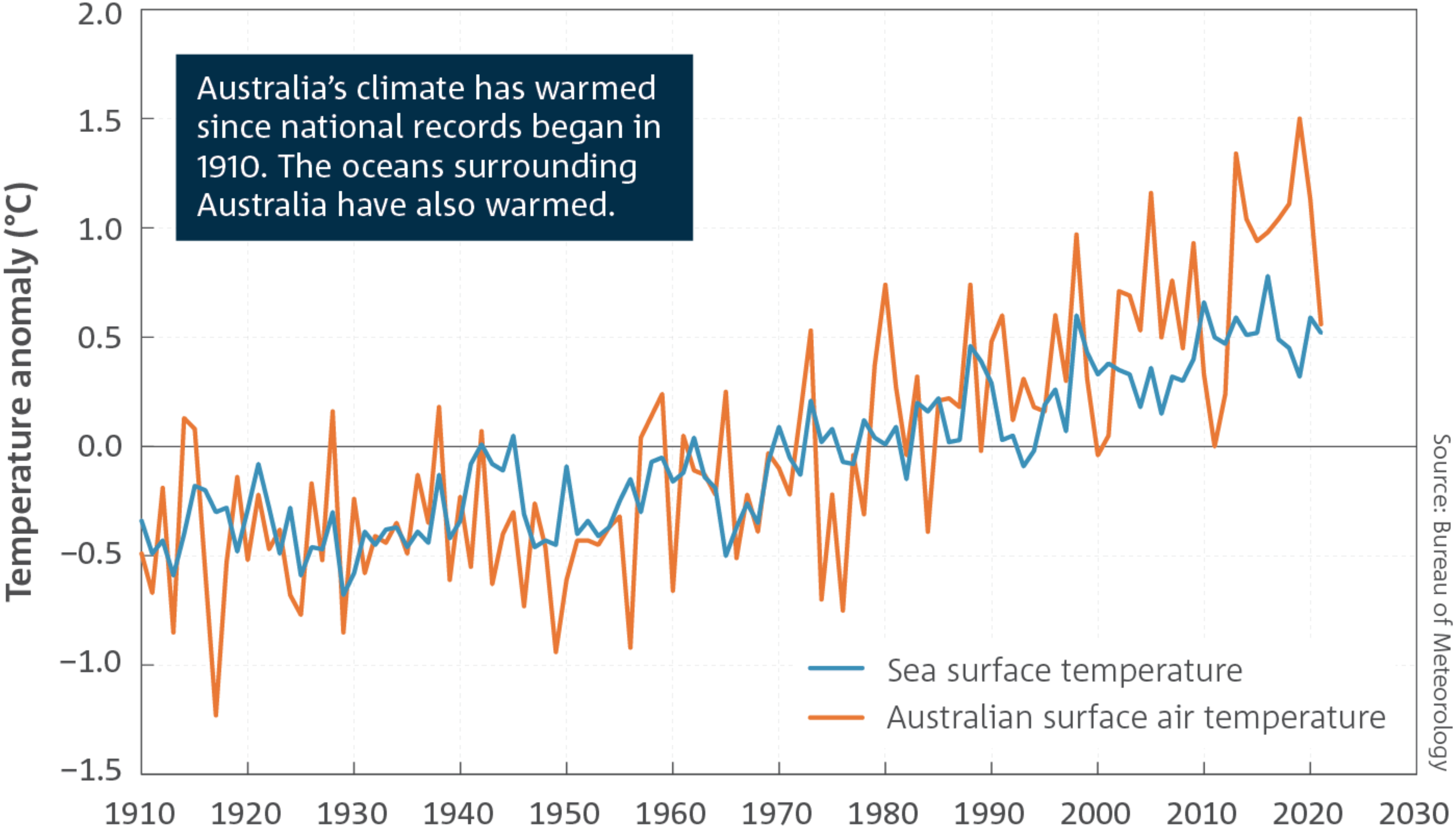


But spread could change – more extremes at either end – e.g. jet stream meanders northern hemisphere

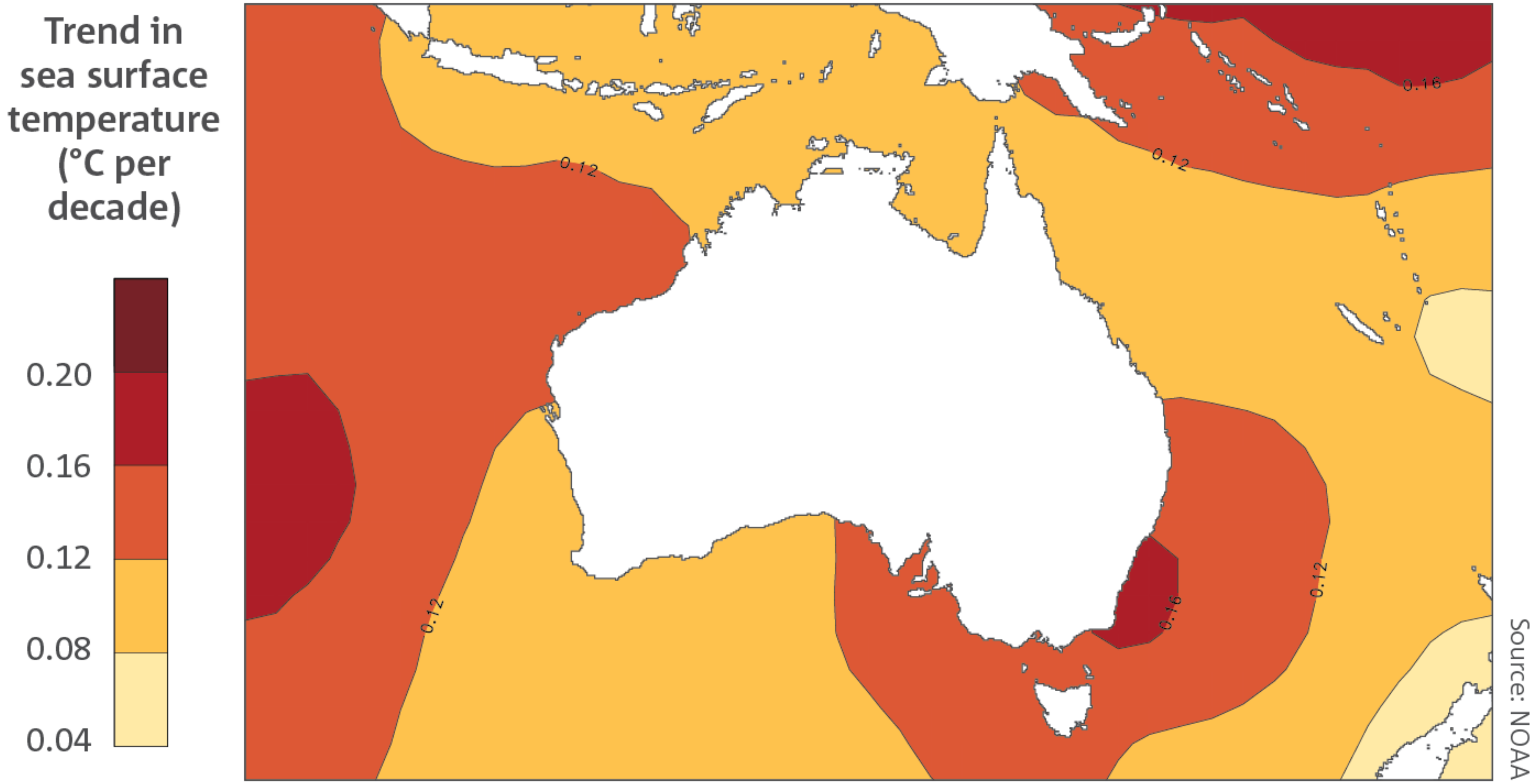
http://www.bom.gov.au/state-of-the-climate/

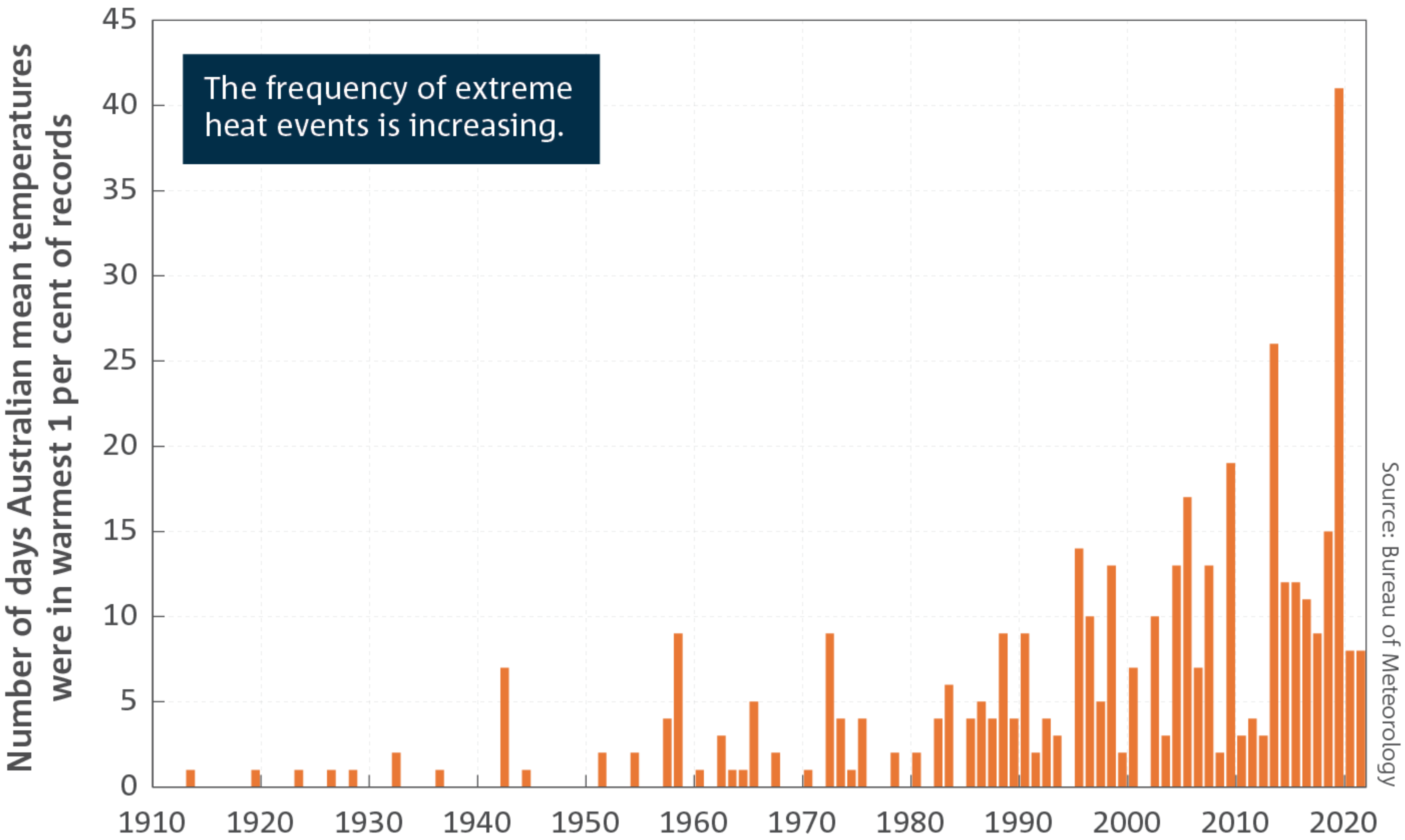


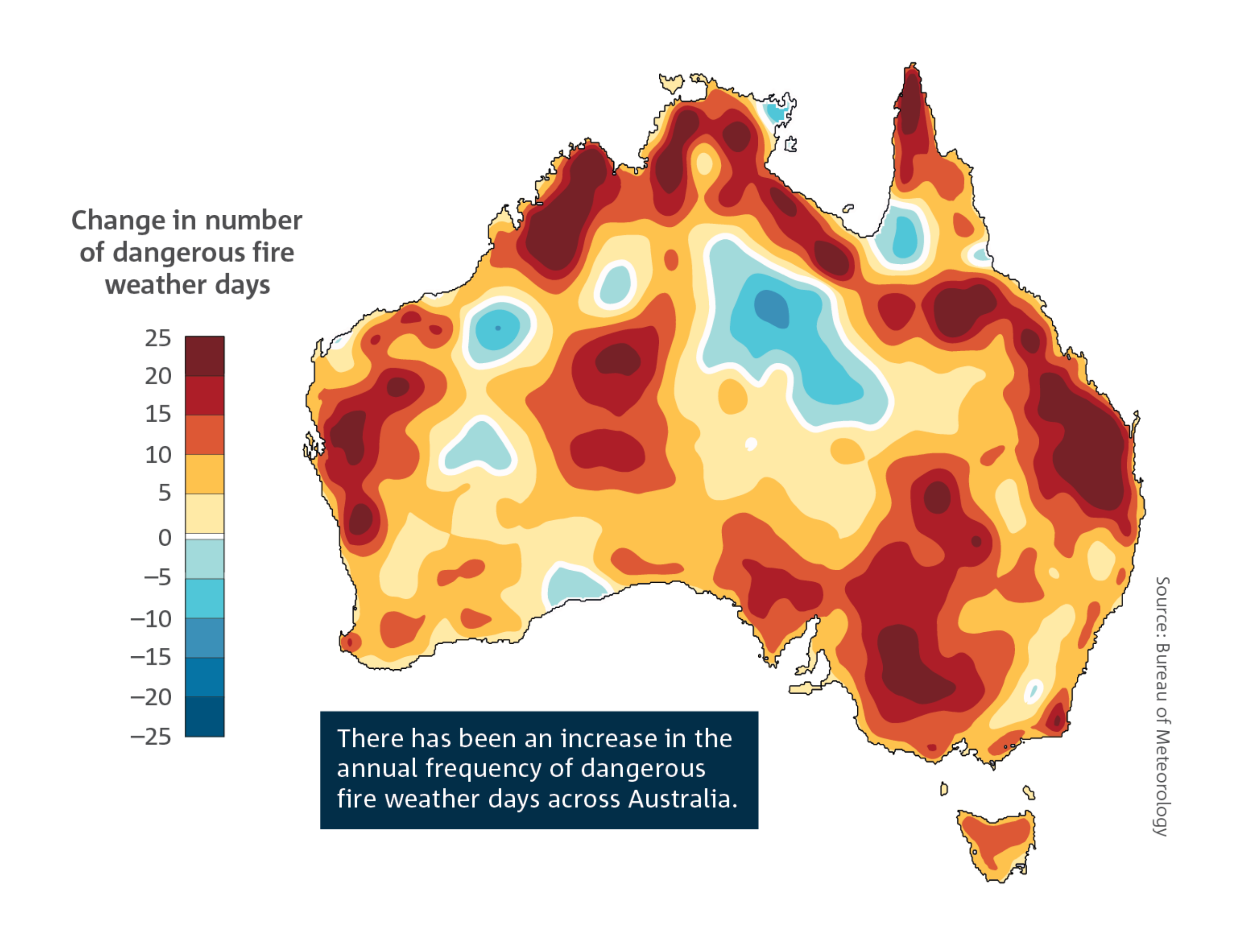
Global temperatures vary from year to year. Increasing surface temperatures mean a La Niña year now is warmer than an El Niño year in the 1980s.
Temperature anomaly (°C)
1.0
0.8
0.6
0.4
0.2
0
−0.2
−0.4
1950
1960
1970
1980
1990
2000
2010
2020
1998
2003
2010
2016
El Niño
La Niña
Volcano
Neutral and weak ENSO years
Source: Bureau of Meteorology, adapted from WMO


Australia's climate has warmed since national records began in 1910. The oceans surrounding Australia have also warmed.
Temperature anomaly (°C)
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
2030
Sea surface temperature
Australian surface air temperature
Source: Bureau of Meteorology

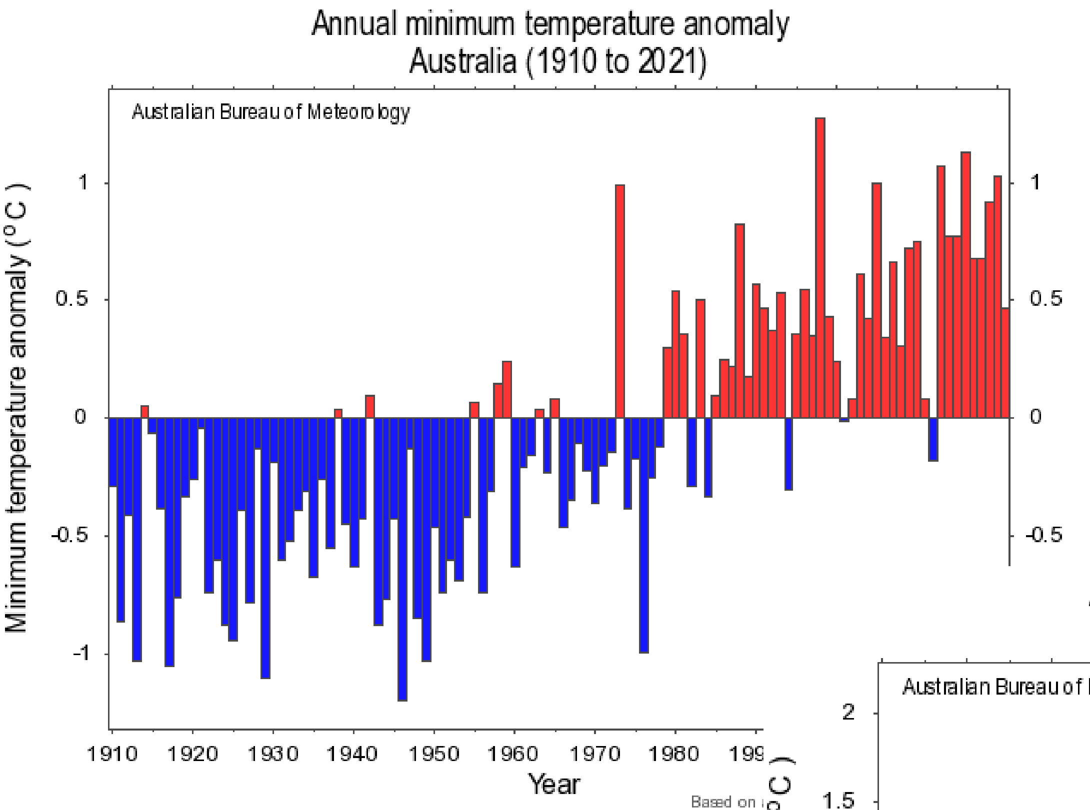
The ocean surface around Australia has warmed, with the greatest ocean warming occurring off south-east Australia and Tasmania.

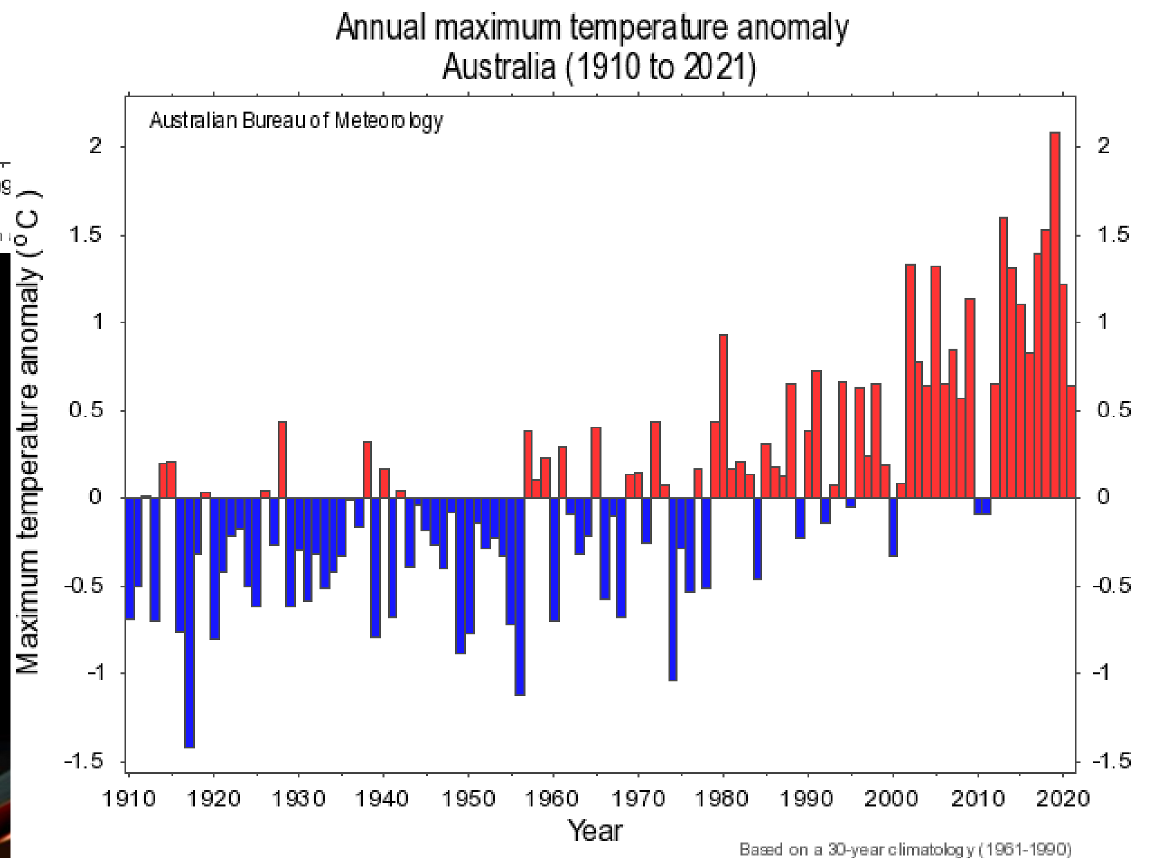


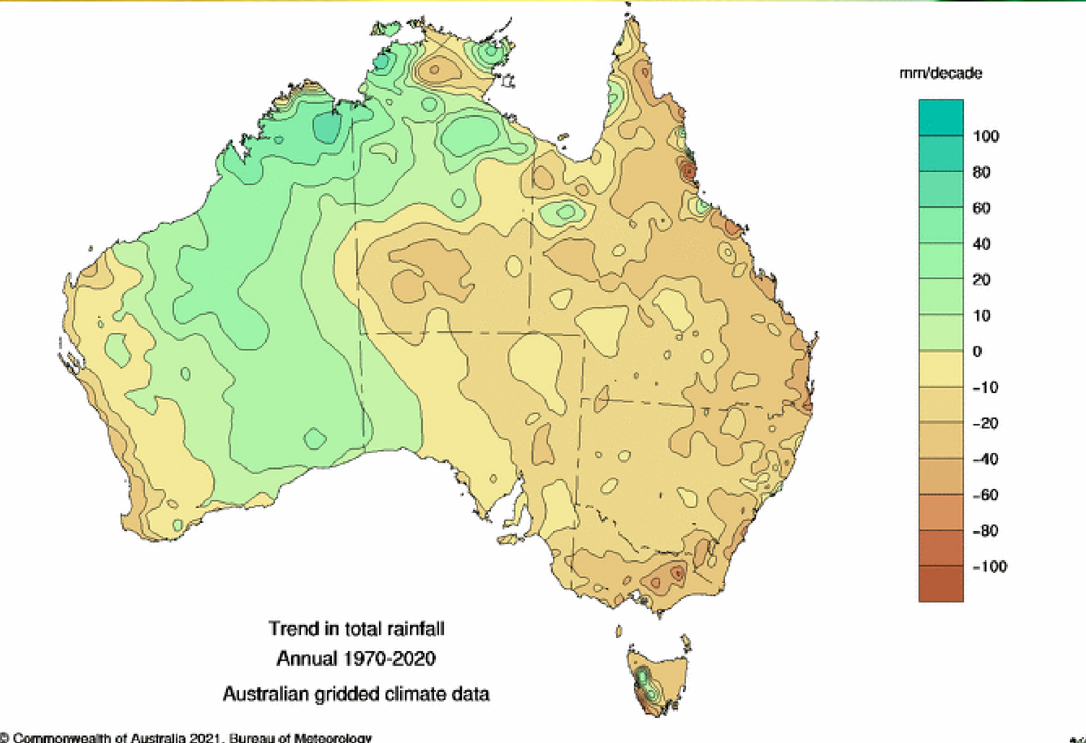

The frequency of extreme heat events is increasing.
Number of days Australian mean temperatures were in warmest 1 per cent of records
0
5
10
15
20
25
30
35
40
45
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Source: Bureau of Meteorology

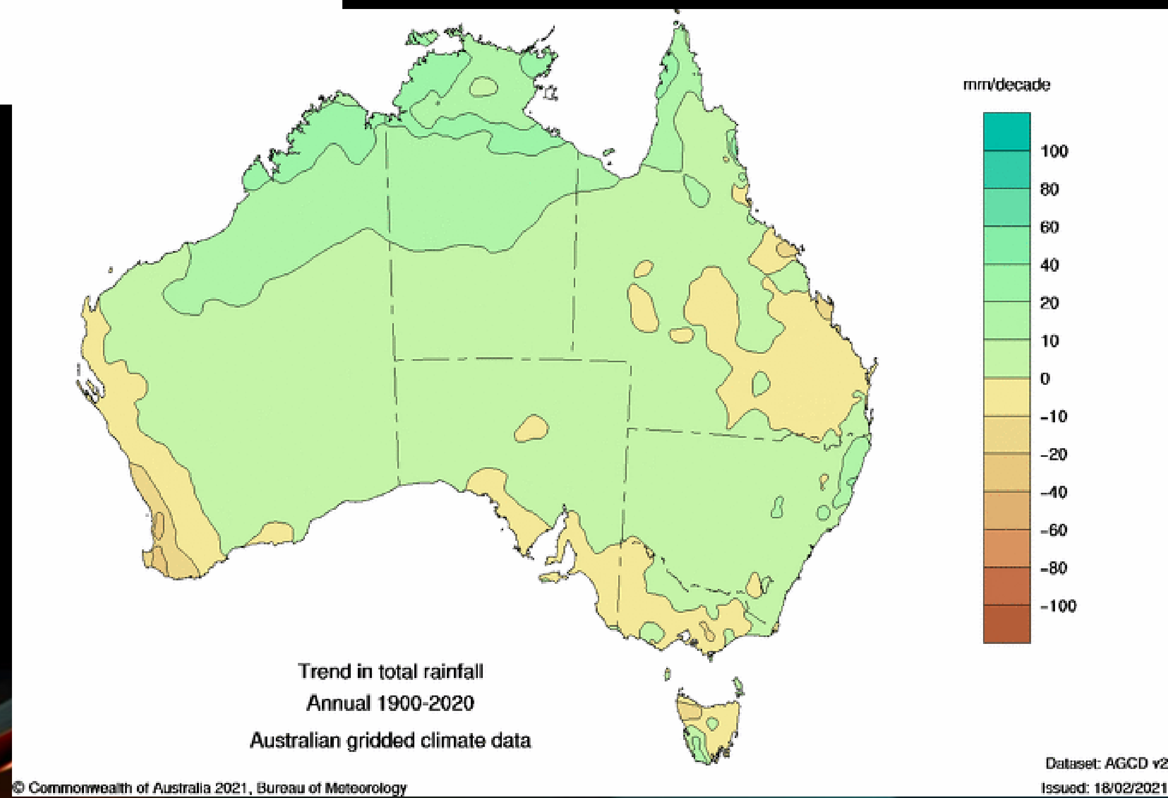


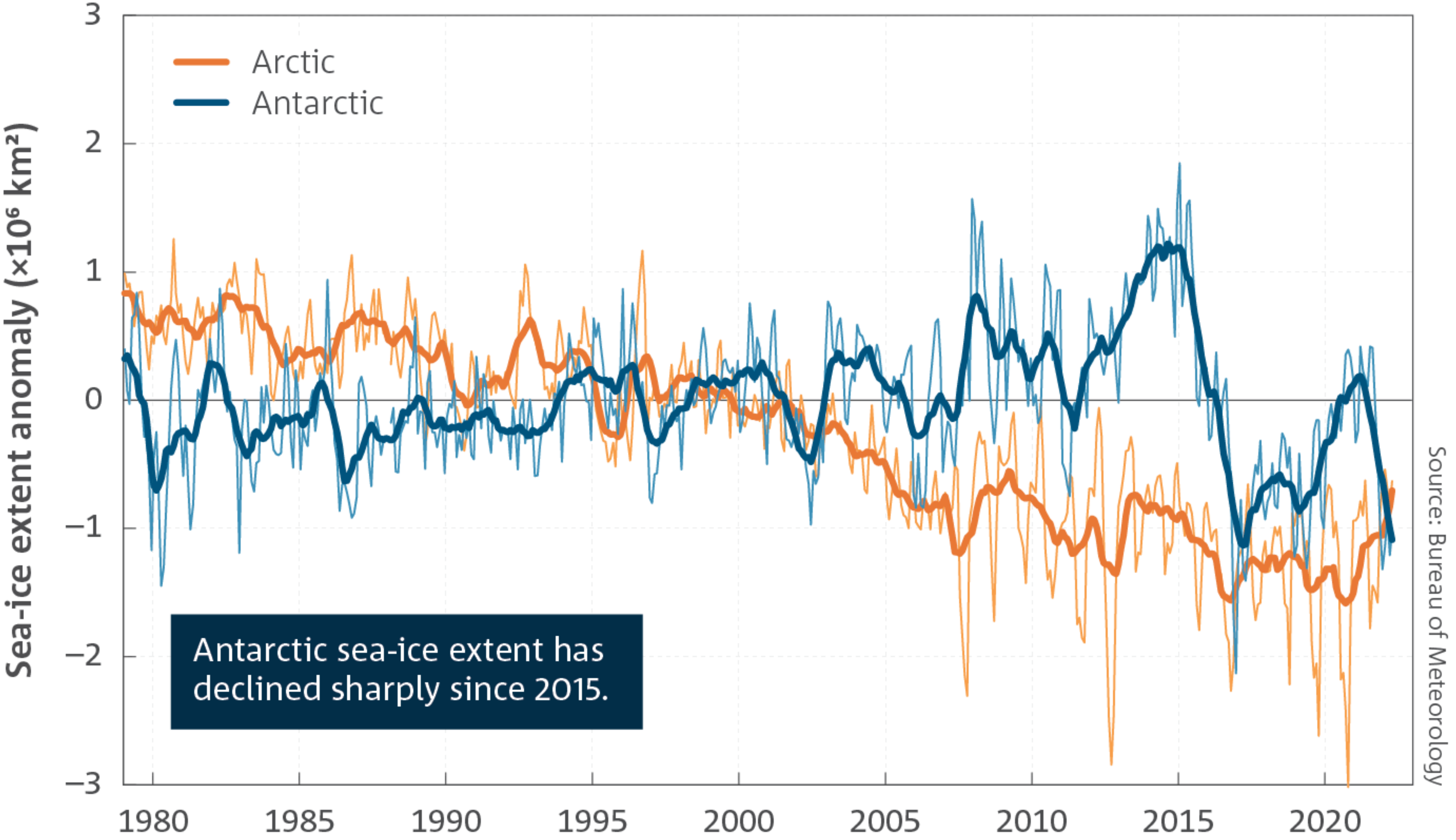
There has been an increase in the number of days with dangerous weather conditions for bushfires. The map shows the change in the annual (July to June) number of days that the FFDI exceeds its 90th percentile between the two periods: July 1950 to June 1986 and July 1986 to June 2022. The FFDI is an indicator of dangerous fire weather conditions for a given location.

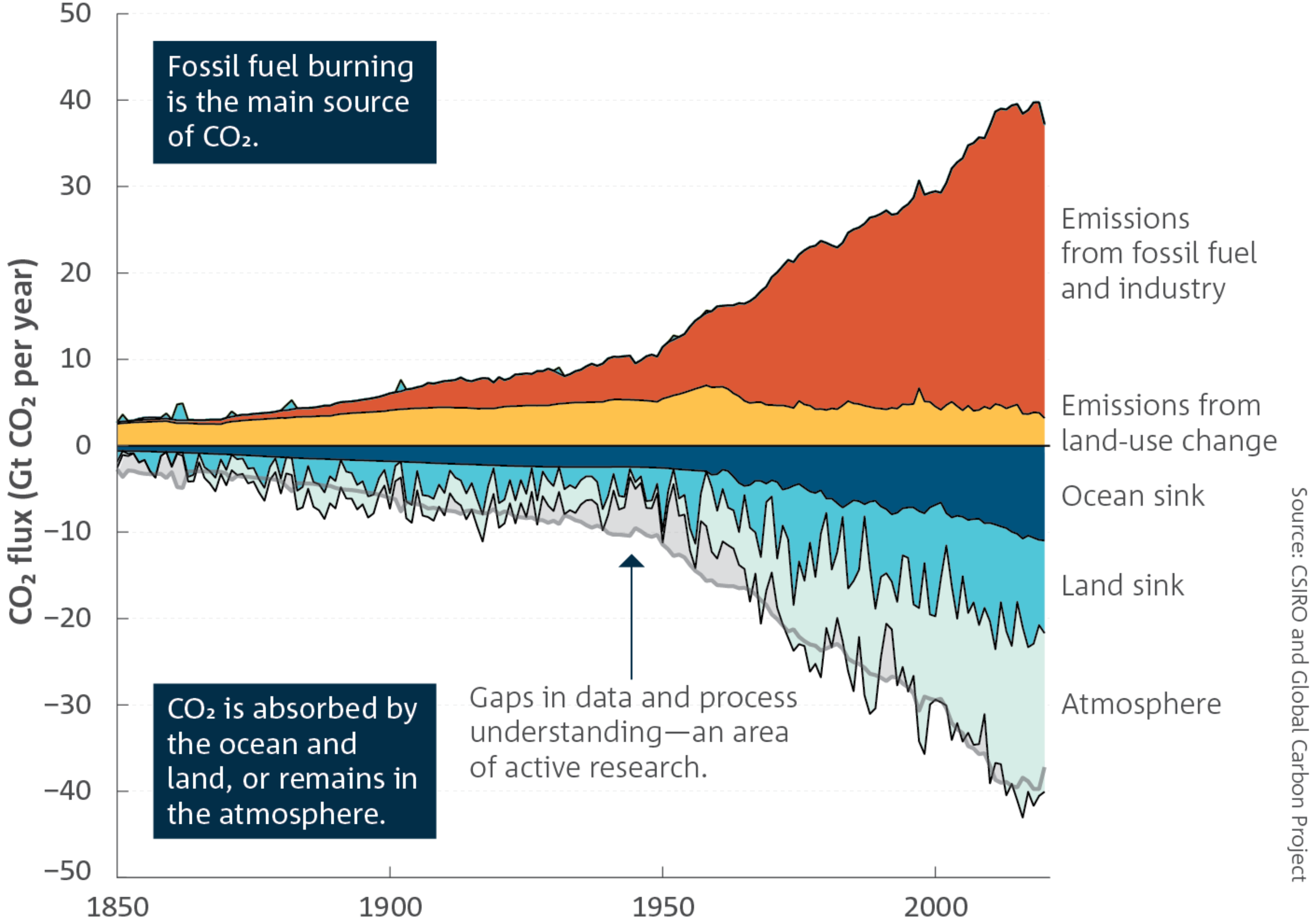

Annual minimum temperature anomaly
Australia (1910 to 2021)
Australian Bureau of Meteorology
Minimum temperature anomaly (°C)
1
0.5
0
-0.5
-1
1910
1920
1930
1940
1950
1960
1970
1980
Year


Annual maximum temperature anomaly
Australia (1910 to 2021)
Australian Bureau of Meteorology
Maximum temperature anomaly (°C)
2
1.5
1
0.5
0
-0.5
-1
-1.5
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year
Based on a 30-year climatology (1961-1990)

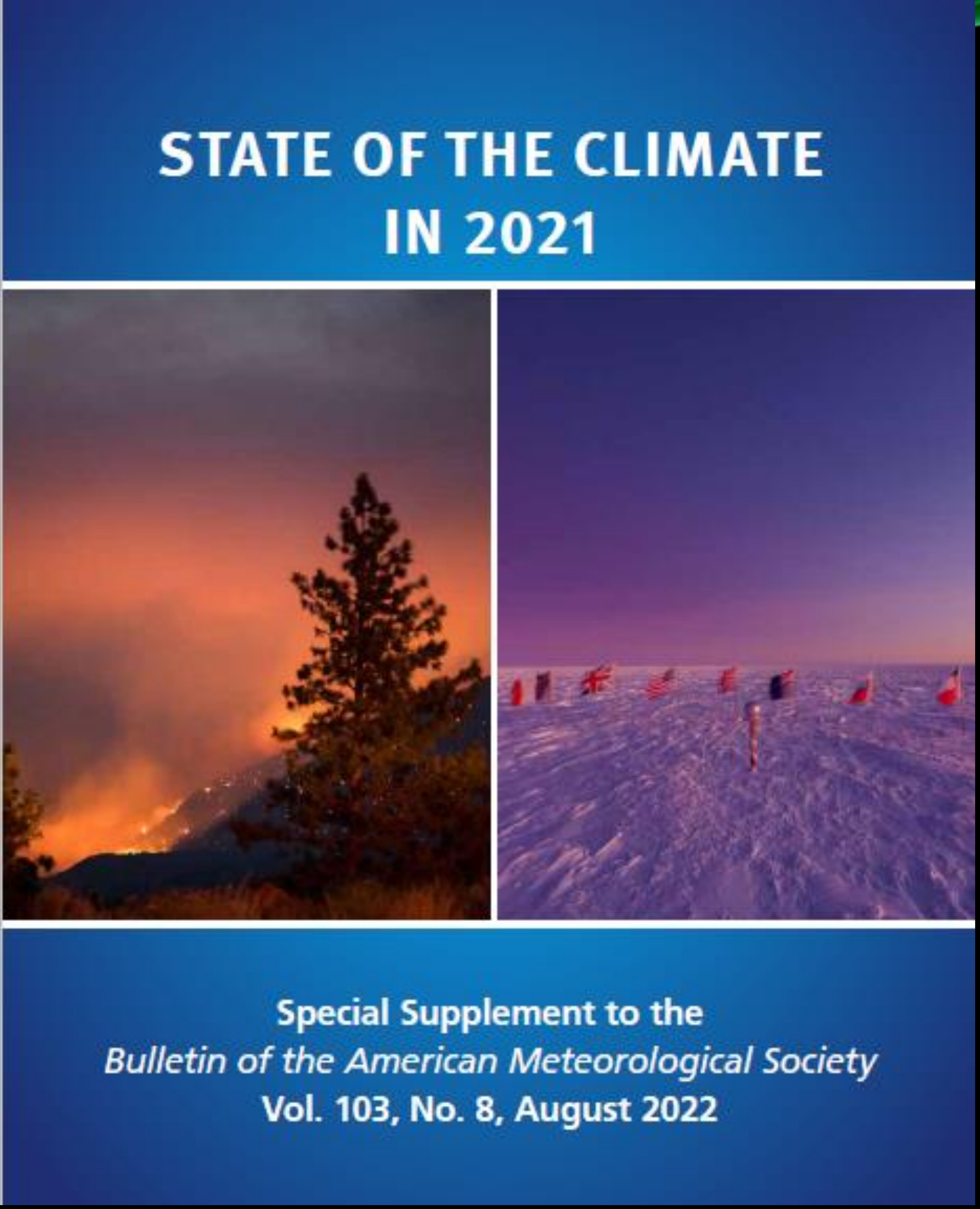

mm/decade
100
80
60
40
20
10
0
-10
-20
-40
-60
-80
-100
Trend in total rainfall
Annual 1970-2020
Australian gridded climate data
© Commonwealth of Australia 2021, Bureau of Meteorology


mm/decade
100
80
60
40
20
10
0
-10
-20
-40
-60
-80
-100
Trend in total rainfall
Annual 1900-2020
Australian gridded climate data
Dataset: AGCD v2
Issued: 18/02/2021
© Commonwealth of Australia 2021, Bureau of Meteorology

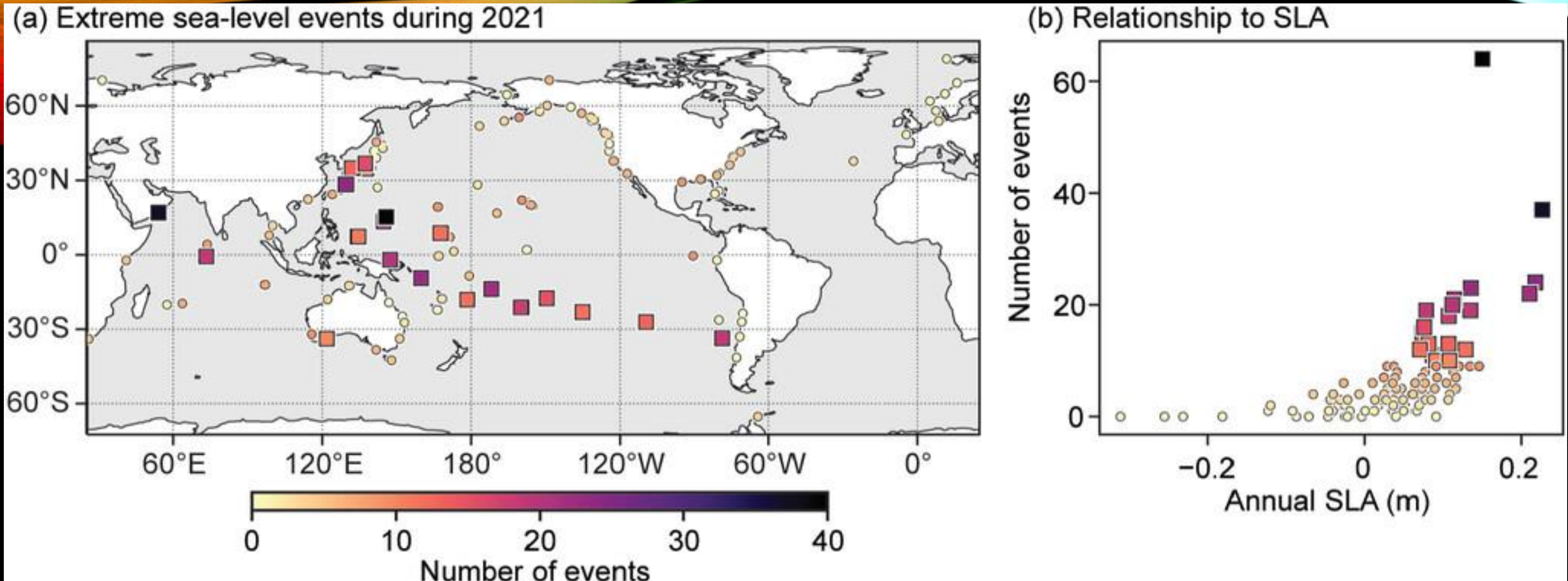

Arctic
Antarctic
Sea-ice extent anomaly (×10⁶ km²)
3
2
1
0
−1
−2
−3
1980
1985
1990
1995
2000
2005
2010
2015
2020
Antarctic sea-ice extent has declined sharply since 2015.
Source: Bureau of Meteorology



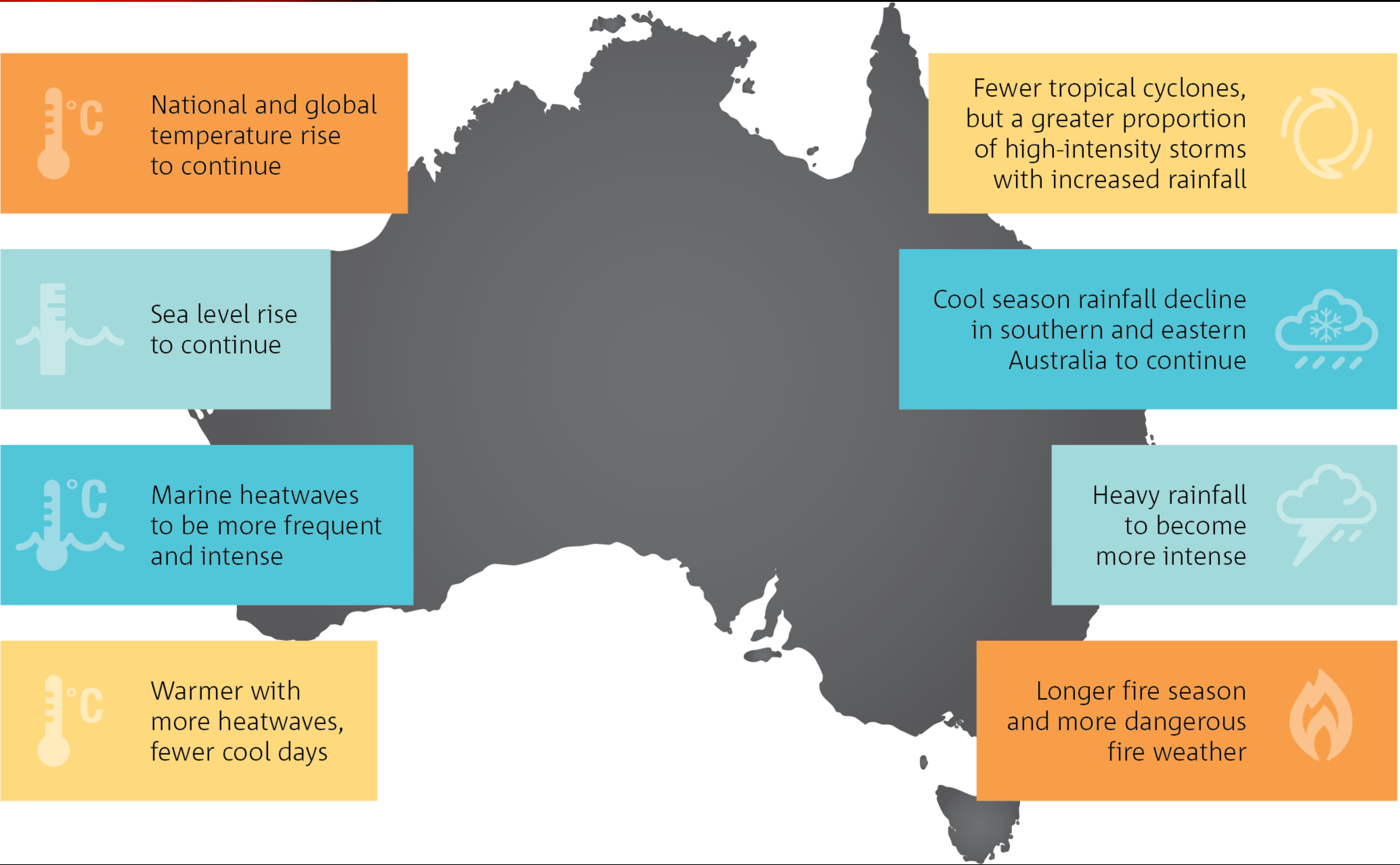
Fossil fuel burning is the main source of CO_2.
50
40
30
20
10
0
−10
−20
−30
−40
−50
CO_2 flux (Gt CO_2 per year)
1850
1900
1950
2000
Emissions from fossil fuel and industry
Emissions from land-use change
Ocean sink
Land sink
Atmosphere
Gaps in data and process understanding—an area of active research.
CO_2 is absorbed by the ocean and land, or remains in the atmosphere.
Source: CSIRO and Global Carbon Project



https://www.ametsoc.org/index.cfm/ams/publications/bulletin-of-the-american-meteorological-society-bams/state-of-the-climate/



The map on the left shows the number of extreme sea level events measured at 114 tide gauges during 2021. The graph on the right shows the relationship between the number of extreme events at each location and the annual sea level departure from average from that location. Twenty of the 114 locations experienced more than 10 extreme sea level events during 2021 (represented by squares), and were especially concentrated in the tropical western Pacific and in a diagonal region of the South Pacific near where annual sea levels were the highest compared to their long-term averages. Extreme sea level is defined as a daily sea level measurement in its highest 1% compared with all measurements for that particular location. Over time, the median number of extreme sea level events per year and location increased from one during 1993–97 to four during 2017–21. (Figs. 3.17a,b in State of the Climate in 2021; see discussion in section 3f.)



Source:Bureau of Meteorology and CSIRO

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Australian Academy of Science
https://www.science.org.au/education/immunisation-climate-change-genetic-modification/science-climate-change

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