Past and Future Climate – Present Weather

Week 12

Carbon Dioxide and Climate

Terry Hart

Dates

Term 3

20 August	**Carbon dioxide and climate**
3 September	Away
17 September	Away

Term 4

15 October	**Computer modelling of the Climate**
29 October	**Where are we now? The current and future state of the Climate.**
19 November	**Royal Institution Christmas Lecture 2020 - Engine Earth**

A composite image shows the progression of a total solar eclipse over San Millán de los Caballeros, Spain, on August 12, 2026.

https://science.nasa.gov/earth/earth-observatory/a-sunflowers-view-of-totality/

00:27 AEST

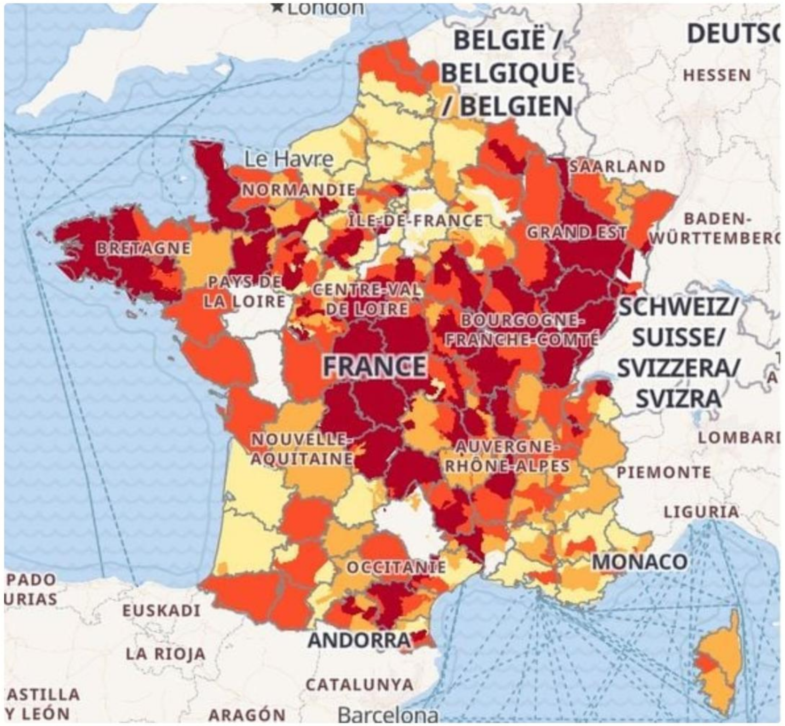
Belgian firefighters push to encircle 'largest wildfire in a century'

Firefighters were locked in a potentially decisive push Tuesday to encircle Belgium's largest wildfire in a century, despite rainclouds hampering air support operations over the High Fens nature reserve, AFP reported.

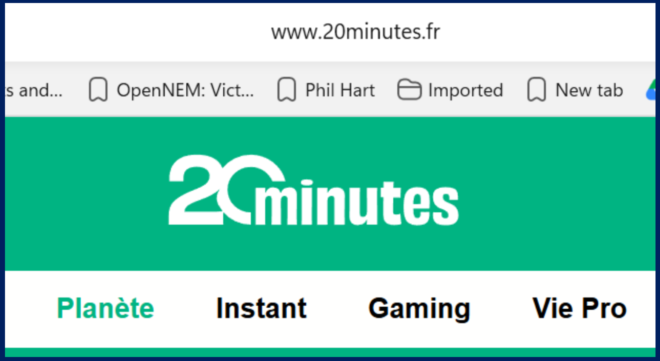
A Belgian firefighter in a field affected by a wildfire in Waimes, in the High Fens (Hautes Fagnes) region, Belgium. Photograph: Yves Herman/Reuters

The blaze charring the expanse of peatland, pine trees and hiking trails grew over the weekend to half the size of Manhattan - **3,000 hectares (7,500 acres)** - with **hundreds of firefighters working night and day to wrestle it**

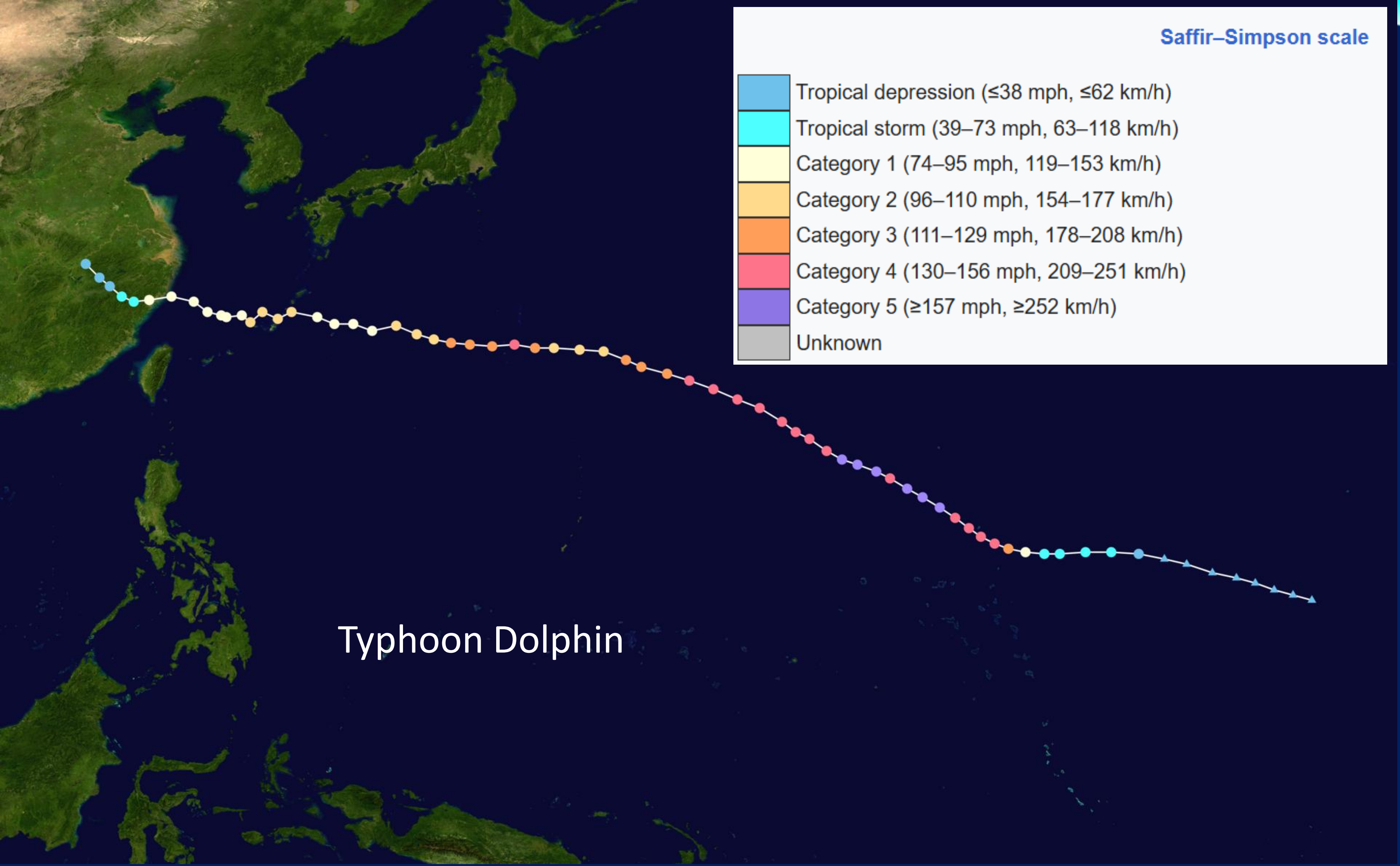
Guardian
19 August



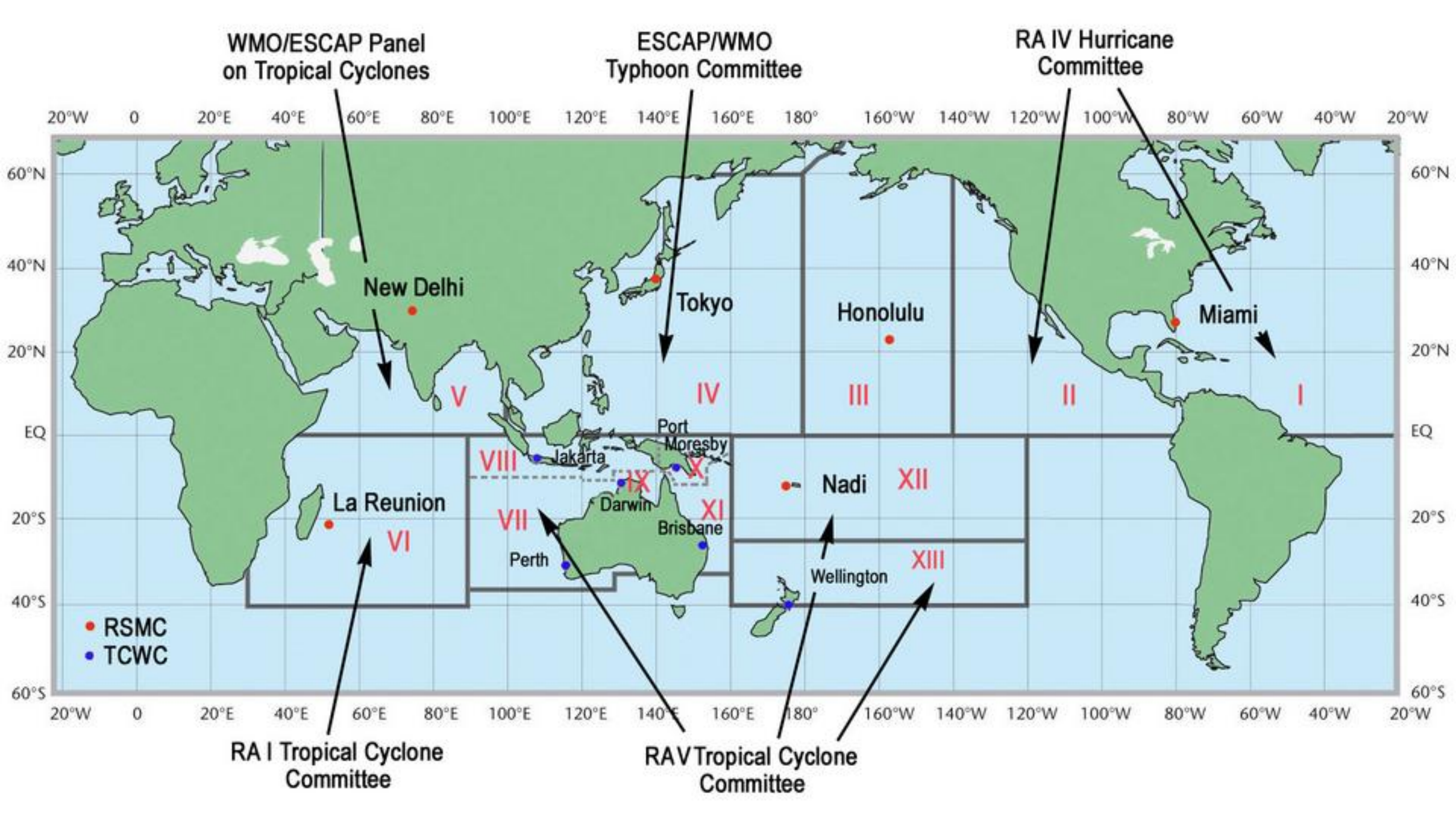
En rouge vif, la carte Vigieau montre les restrictions d'eau dans les zones en situations de crise. *- Capture d'écran/Vigieau*



Deutsche Welle 15 August



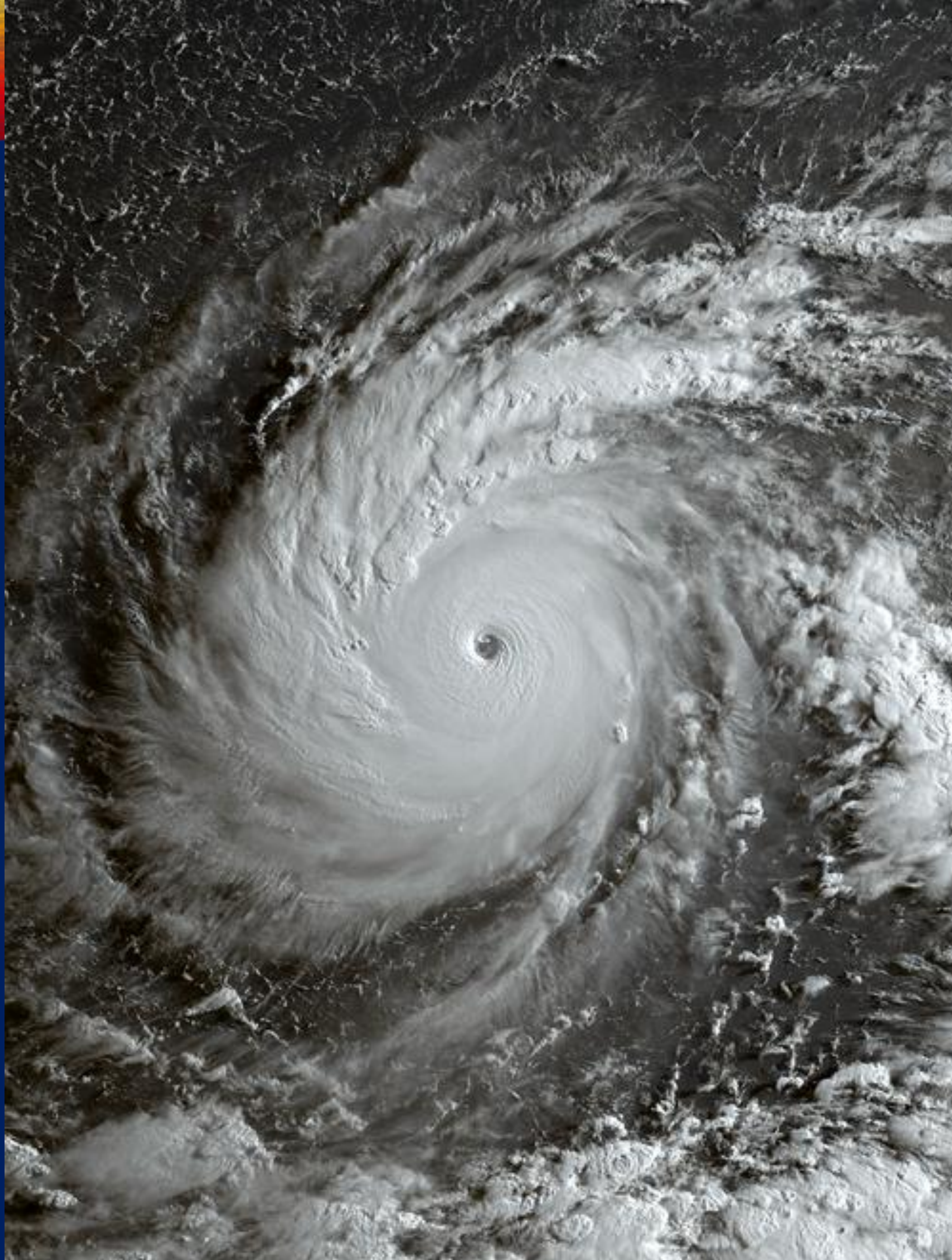
It formed in the area of responsibility of the Central Pacific Hurricane Center (CPHC) of the United States National Weather Service in Honolulu - the official body responsible for tracking and issuing tropical cyclone warnings for the Central Pacific region: from the equator northward, 140°W–180°W.



Areas of responsibility for Tropical Cyclone warnings under the World Meteorological Organisation (WMO).

The Joint Typhoon Warning Center (JTWC) based in Pearl Harbor, Hawaii, is responsible for the issuing of tropical cyclone warnings for defence and other U.S. government agencies – but its products are used widely by national meteorological services and the public.

Dolphin at its peak on July 29



Dolphin at its peak intensity on July 29

Meteorological history	
Formed	July 26, 2026
Dissipated	August 13, 2026
Violent typhoon	
10-minute sustained (JMA)	
Highest winds	205 km/h (125 mph)
Lowest pressure	910 hPa (mbar); 26.87 inHg
Category 5-equivalent super typhoon	
1-minute sustained (SSHWS/JTWC)	
Highest winds	280 km/h (175 mph)
Lowest pressure	909 hPa (mbar); 26.84 inHg
Overall effects	
Fatalities	6 indirect
Injuries	14 (7 direct, 7 indirect)
Damage	Unknown
Areas affected	Marshall Islands, Japan (particularly Minamitorishima, Bonin Islands, Daitō Islands, Ryukyu Islands), Taiwan, East China, Philippines

Part of the **2026 Pacific typhoon season**

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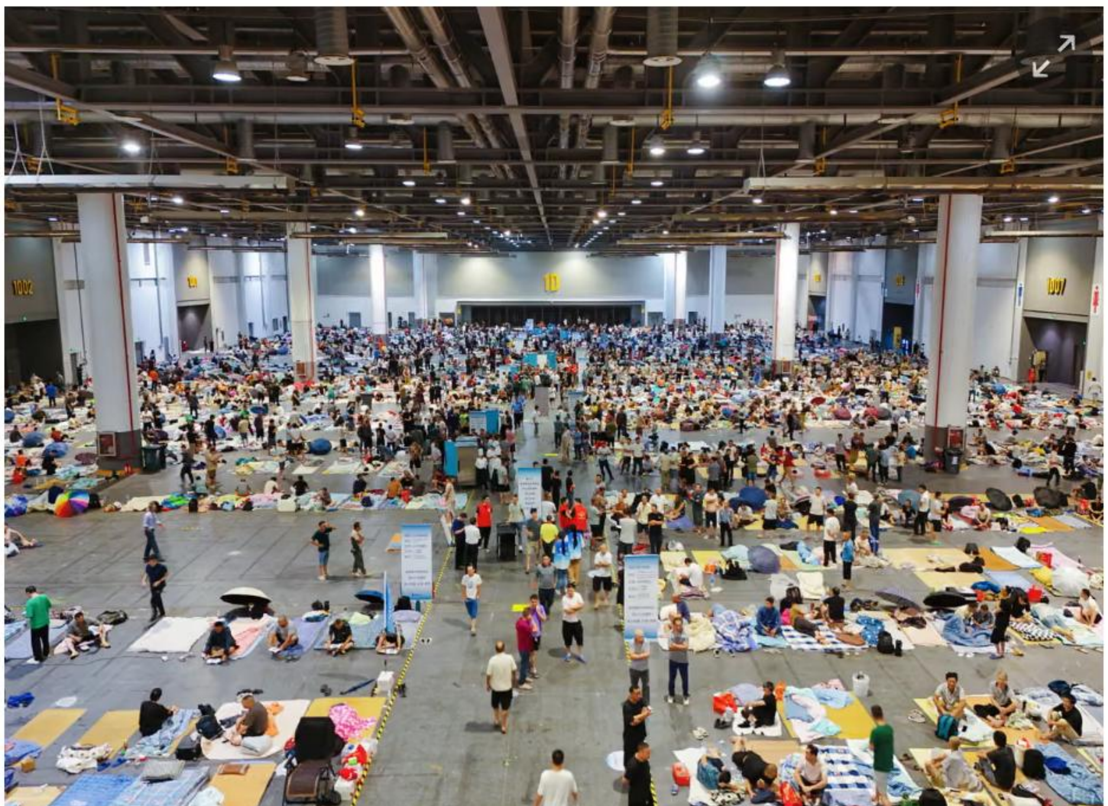
Climate > News

Typhoon Dolphin: More than a million evacuated as China's most powerful storm of the year makes landfall

Authorities reported no casualties but several state media outlets said a nine-year-old boy was missing after being swept into the sea

Stuti Mishra
Monday 10 August 2026 06:23 BST

2 Comme



A temporary shelter in Hangzhou, where thousands of people were evacuated because of Typhoon Dolphin. Photograph: VCG/Getty Images

Typhoon Dolphin hits Beijing as city braces for one-third of annual rainfall over 24 hours

Flooding already reported in some districts of Chinese capital and rains are expected to get worse overnight

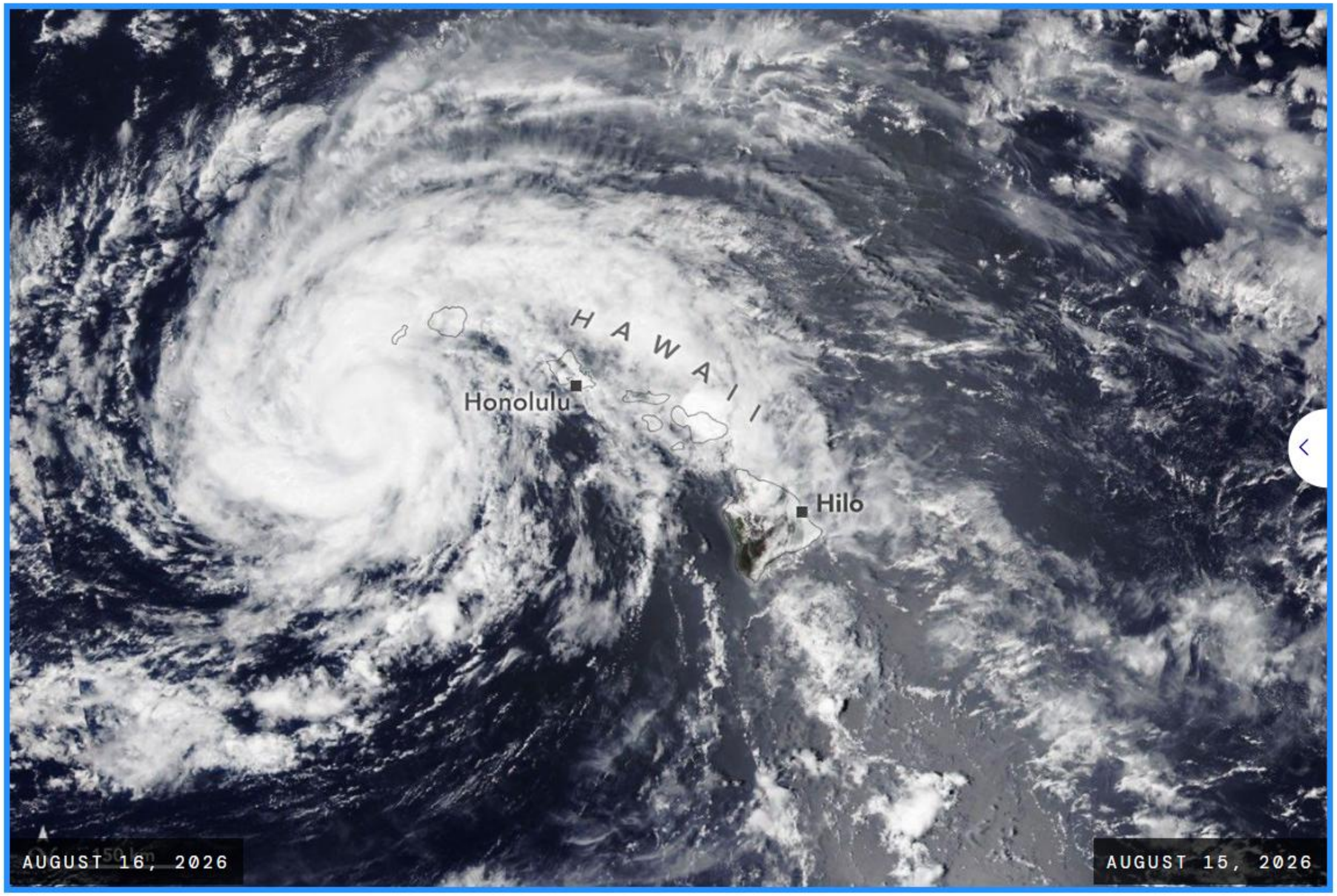
Beijing on Tuesday. Some parts of the city are on the highest level of emergency flood response. Photograph: Wu Hao/EPA

A drone view of huge waves crashing on the coast of Huangqi, as Typhoon Dolphin approaches, in Huangqi town of Lianjiang, Fuzhou, Fujian province, China August 8, 2026.

PHOTO: cnsphoto via Reuters

People stand next to huge waves crashing on a waterfront as Typhoon Dolphin approaches, in Sanmen County, Taizhou, Zhejiang Province, China, August 8, 2026. PHOTO: cnsphoto via Reuters

Lala Batters Hawaii



https://science.nasa.gov/earth/earth-observatory/lala-batters-hawaii/

Tropical Storm Lala

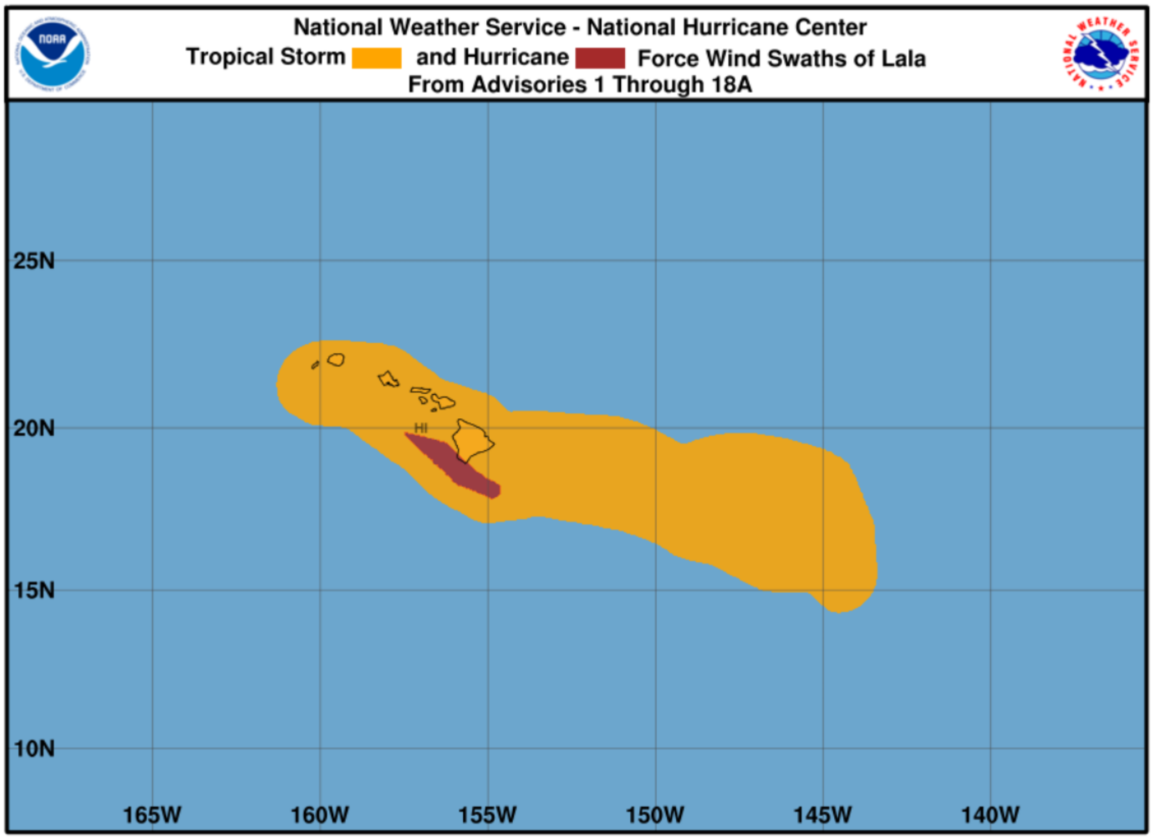
Select Advisories & Forecasts +

Select Maps & Graphics +

Cumulative Wind History

Advisory Number: 18A

200 PM HST Sun Aug 16 2026



The storm made its closest approach to the Big Island late on August 15 as a Category 1 hurricane.

Lala's eyewall brushed the south side of the Big Island. Had Lala made landfall, it would have been the first hurricane landfall on the Big Island since at least 1871.

Lala has become only the fifth hurricane since 1957 to pass within 70 miles of the Big Island, according to NOAA's historical database, joining 2024's Hone, 2020's Douglas, 2014's Iselle and 1957's Kanoa.

Weather Underground

More than 200,000 customers are still without power across the islands, and nearly 70% of the Big Island is without power. Hurricane-force wind gusts were reported in Hawaii, Honolulu and Maui counties, with the mountainous island terrain amplifying winds at higher elevations.

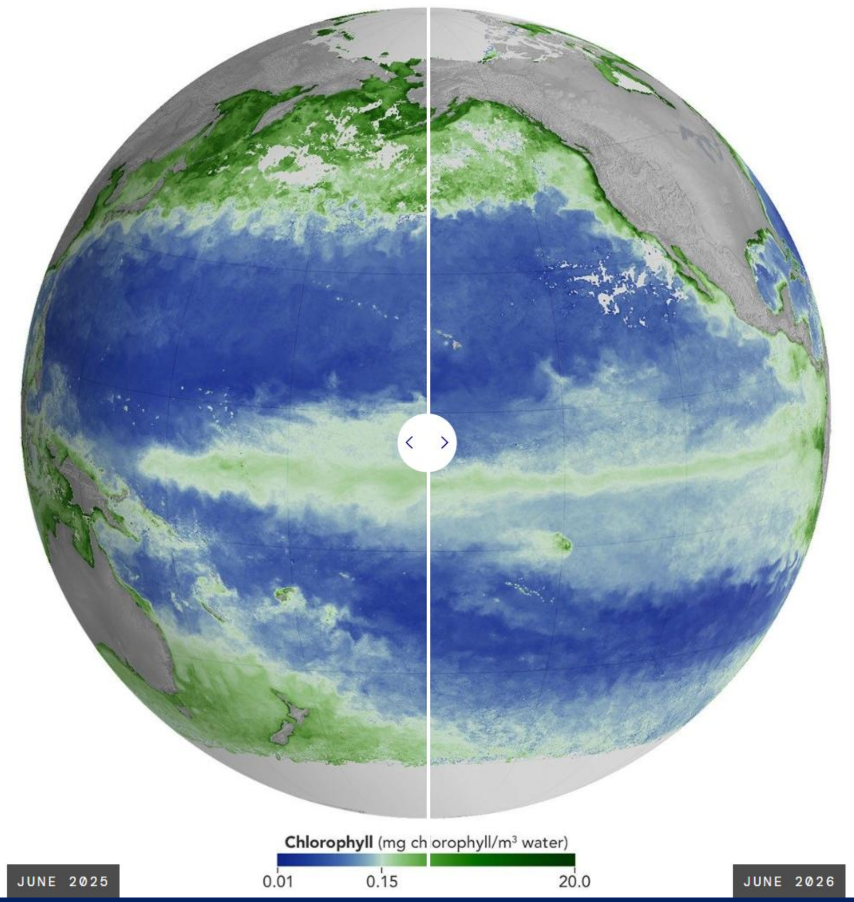
At least 100 homes were damaged and lost in the storm, Hawaii Gov. Josh Green said during a Sunday news conference.

"Tropical storms approaching Hawaii typically hit cooler ocean temperatures before reaching the islands, but Lala remained over warmer waters due to an ongoing marine heat wave extending to California and a developing Super El Niño.

"El Niño is helping fuel increased storm potential in the central Pacific this year with warmer ocean temperatures and weaker winds in the upper atmosphere, which can normally break up storms. The National Oceanic and Atmospheric Administration has forecast an above-average central Pacific season, with five to 13 cyclones expected."

https://edition.cnn.com/2026/08/16/weather/tropical-storm-lala-hawaii-damage-climate

El Niño Alters Marine Life in the Pacific



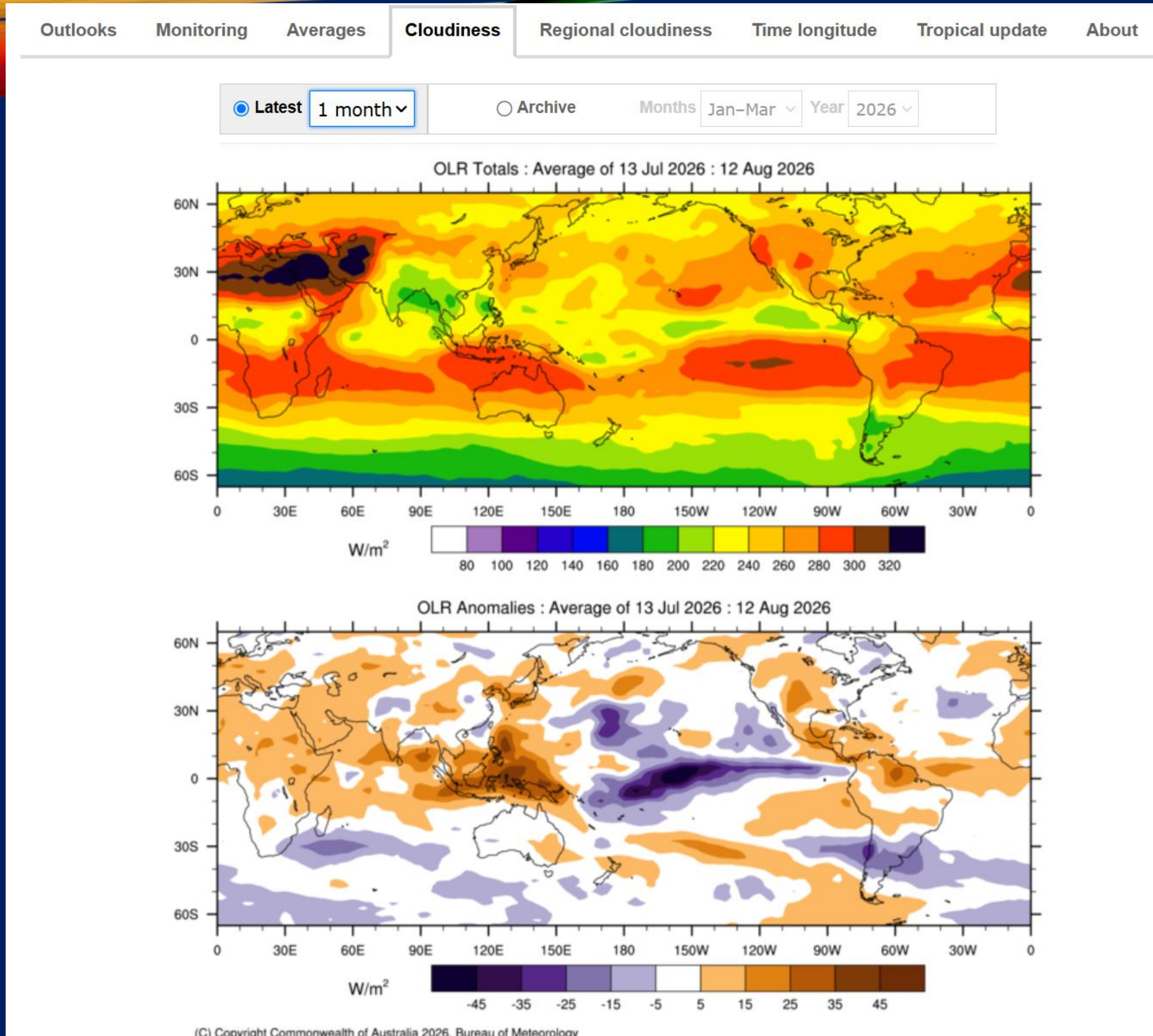
"Among the first ecological downstream effects are changes to the marine food web. The maps show chlorophyll-a concentrations—the pigment present in most phytoplankton—as observed by the OCI (Ocean Color Instrument) on NASA's PACE (Plankton, Aerosol, Cloud, ocean Ecosystem) satellite.

In June 2025 (left)   conditions were neutral
June 2026 (right)   El Niño was strengthening.

In the central Pacific chlorophyll concentrations, an indication of phytoplankton abundance, are substantially lower in 2026

… during an El Niño, easterly equatorial trade winds weaken, the warm surface layer of the ocean extends deeper, and the upwelling of cool, nutrient-rich water that typically fuels phytoplankton growth is suppressed. "

https://science.nasa.gov/earth/earth-observatory/el-nino-alters-marine-life-in-the-pacific/



Maps of total and anomaly outgoing longwave radiation (OLR)

https://www.bom.gov.au/climate/mjo/#tabs=Cloudiness

Indonesia wildfires threaten orangutans rescued from animal traffickers

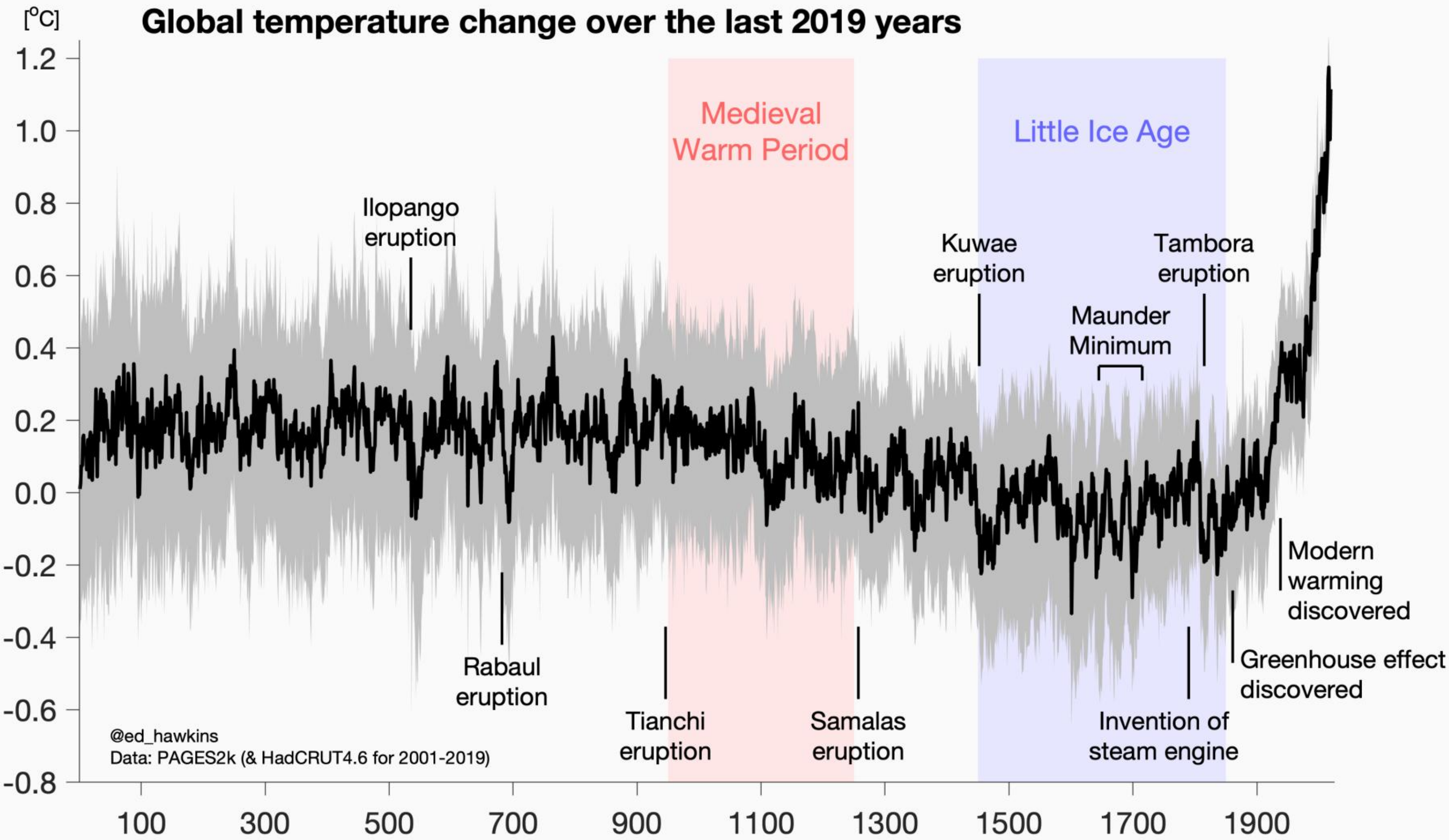
Blaze fuelled by hot, dry and windy conditions comes within metres of West Kalimantan rehabilitation centre

Firefighters and staff from the centre battle to contain the approaching wildfire. Photograph: Yiari

"In the first 13 days of August, Indonesia registered more than three times more forest fire hotspots than in the whole of the same month last year. This followed a record number of blazes between January and July.
West Kalimantan has been at the epicentre. After 40 days without rain, there have been dozens of severe outbreaks of fire in the region."

Orangutans at the Yiari rehabilitation centre. Photograph: Yiari

https://www.theguardian.com/world/2026/aug/14/indonesia-wildfires-threaten-orangutans-rescued-from-animal-traffickers



Reconstruction of **global temperature** going back to the year 1 CE thanks to the work of the PAGES2k team from a wide variety of proxy records such as tree rings, cave deposits, corals, etc.

> https://web.archive.org/web/20200202220240/https://www.climate-lab-book.ac.uk/2020/2019-years/

Carbon dioxide and climate

What is the connection?

Jean-Baptiste Joseph Fourier (1768 – 1830)

Joseph Fourier (France) 1824, 1827.

- leading scientist on heat – "Newton of Heat" but also a famous mathematician
- pointed out that infrared radiation is the only way a planet loses energy to space
- calculated that an object the size of the Earth, and at its distance from the Sun, should be considerably colder (by about 30 degrees) than it actually is
- considered the possibility that the Earth's atmosphere might act as an insulator of some kind by allowing sunshine in but impeding the escape of heat back to space.

Claude Pouillet (France) 1827, 1838.

- 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.

Why CO_2?

The question of CO_2 has a long history.

The first experiments on the effect of gases on trapping infrared radiation were made in 1856 by Eunice Foote (USA), a pioneer who was long forgotten.

In a simple but elegant experiment she used glass cylinders, with mercury-in-glass thermometers inside and varied the gas inside the cylinder.

She placed them in the sun and then in the shade. When they were in the sun, she noticed that they reached different temperatures depending on the gas inside the cylinder. Her results:

> 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°.

From this simple experiment she made the stunning insight about CO_2:

> 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.

In May 1859, the Irish physicist John Tyndall made more detailed investigations. He came to similar conclusions as Eunice Foote, although he did not acknowledge her work - he may not have known of them.

He tested many gases including carbon dioxide, nitrous oxide and water vapour, although ethylene was the strongest. He realised that it was the complex compounds that had much greater effect than simple elements such as oxygen and hydrogen. Of the components of air, water vapour had the strongest effect. He was astounded by the results:

"Those who like myself have been taught to regard transparent gases as almost perfectly diathermanous (i.e. transmit radiant heat) will probably share the astonishment with which I witnessed the foregoing effects. I was indeed slow to believe it possible that a body so constituted, and ***so transparent to light*** *as olefiant gas (ethylene), could be* ***so densely opake*** *to any kind of calorific rays; and to secure myself against error, I made several hundred experiments with this single substance."*

He also saw a link to the climate from any changes in these gases.
"Such changes may in fact have produced all the mutations of climate which the researches of geologists reveal".

However, neither Eunice Foote nor John Tyndall were the first to propose that past changes in the level of carbon dioxide in the air could have changed the climate.

That honour goes to Jacques Joseph Ébelmen (1814-1852):

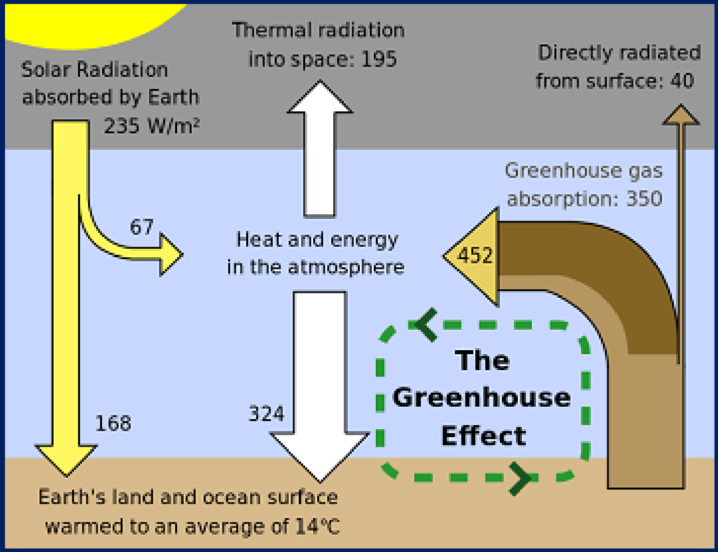
- Mining engineer but made many improvements in ceramics at the Royal Porcelain Works in Sèvres
- a pioneer in the study of the chemical weathering of silicate minerals and basaltic rocks
- proposed the existence of a deep carbon cycle in which the carbon dioxide buried in organic remains and carbonate rocks are returned in volcanic gases to the atmosphere and ocean
- noted that a close balance between weathering and volcanic emissions was needed to keep the level of carbon dioxide constant.

"many circumstances … tend to prove that in ancient geologic epochs the atmosphere was denser and richer in carbonic acid, and perhaps oxygen, than at present. To a greater weight of the gaseous envelope should correspond a stronger condensation of solar heat and some atmospheric phenomena of a greater intensity." (1845)

This work was largely forgotten until rediscovered by Robert Berner of Yale University in 1996. The Ébelmen Award in Geochemistry of the International Association of Geochemistry, is named in his honour.

Responses to the findings of Foote and Tyndall

The next step was taken by a Swedish chemist, Svante Arrhenius. He wanted to understand if changes in carbon dioxide were factors in triggering glacial and interglacial periods. He invented what are now widely used – mathematical models of the climate:



- Based on the energy budget of the atmosphere (energy coming in from the sun, and the energy emitted from the earth and atmosphere back to space)
- Took into account the increase of water vapour in the air as the temperature increased, and the change in reflection from the earth as snow and ice melts
- Used a single layer for the atmosphere
- Assumed cloud cover and energy transport by winds and ocean were unchanged.

Despite a lack of knowledge about the properties of carbon dioxide in the atmosphere, Arrhenius's pioneering work was ground-breaking, and his concepts were used in the more advanced models that were developed from the 1960s.

A Geologist takes up the problem - Inspired by the work of Arrhenius

Thomas Chrowder Chamberlin (1843 – 1928) (USA)

- His geological mapping work in southeastern Wisconsin led him to recognize multiple episodes of glaciation during the Pleistocene

- In 1899 Chamberlin wrote, *"An Attempt to Frame a Working Hypothesis of the Cause of Glacial Periods on an Atmospheric Basis"* based on the idea that changes in climate could result from changes in the concentration of atmospheric carbon dioxide

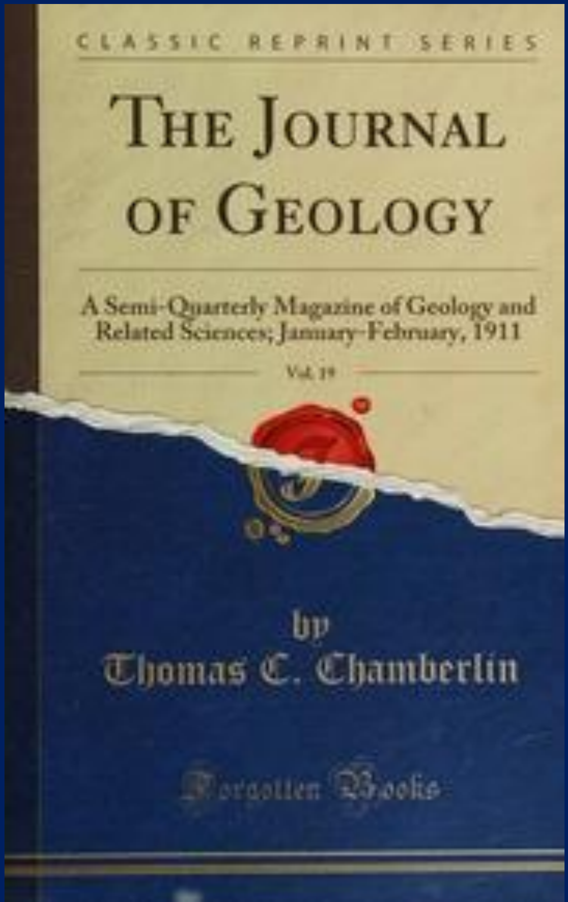
- Redeveloped the ideas of Ébelmen on the long carbon cycle.

- He was the first to propose the role of the ocean in controlling the amount of CO_2 in the air:

"the ocean, during a glacial episode instead of resupplying the atmosphere … would withhold its carbon dioxide to a certain extent … and when the temperature is rising after a glacial episode … the ocean gives forth its carbon dioxide at an increased rate and thereby assists in the amelioration of climate."

- He applied his theory to the Ice Age during the past 2 million years
- He thought that the patterns would be influenced and modified, but not controlled, by the orbital variations proposed by Croll.

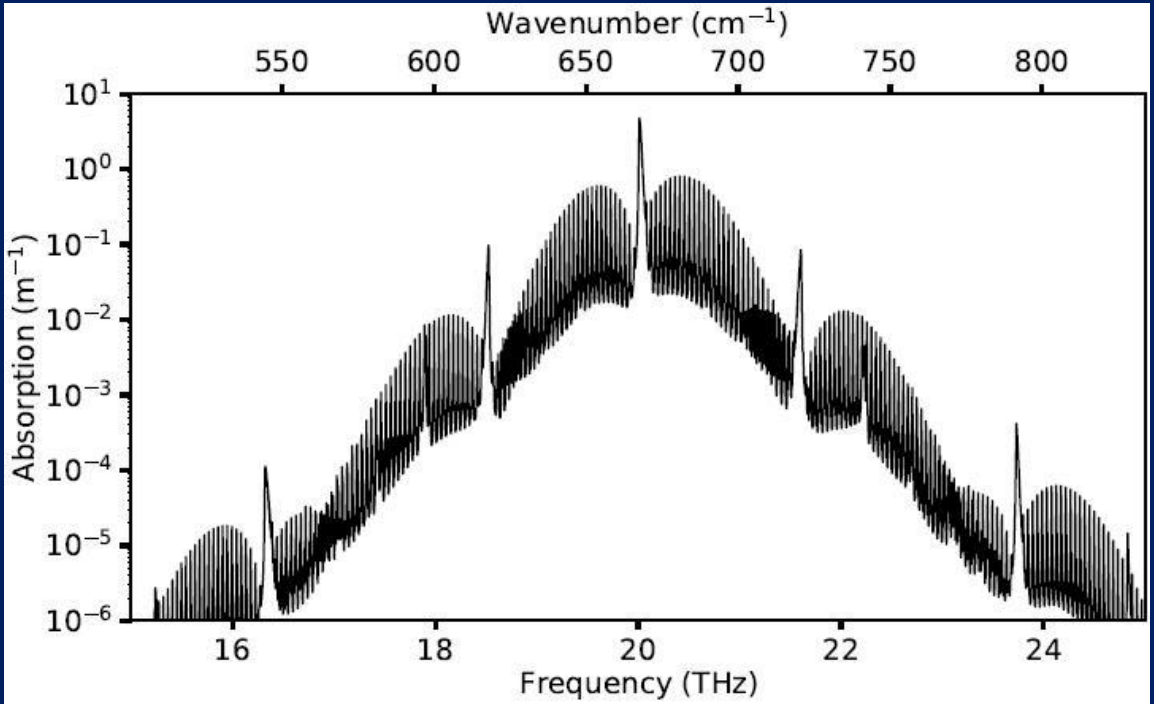
- His work was also largely forgotten, although as a recent historian (James Fleming) noted his was essentially the modern understanding of multiple glaciations and the role of the ocean.
- ".. A surprisingly modern voice from the past."



In 1893 he founded the Journal of Geology, of which he was editor for many years.

Finding out more about the effect of carbon dioxide on infrared radiation.

- It was known that CO_2 absorbed infrared radiation – but not much about how that varied with wavelength.
- Military need – to know what wavelengths to use to be able to detect the exhaust of aircraft or missiles.
- 1950 - US Office of Naval Research funded the building of high-resolution spectrometers to work out the spectrum.
- Early data were published in 1952, but the full report not declassified until 1961.



At atmospheric pressure, collisions between molecules broaden each line, so viewed with a spectrometer of lower resolution—or averaged over Earth's outgoing infrared spectrum—the individual lines merge into a broad feature centered at 15 µm.

Roger Revelle (1909 – 1991)

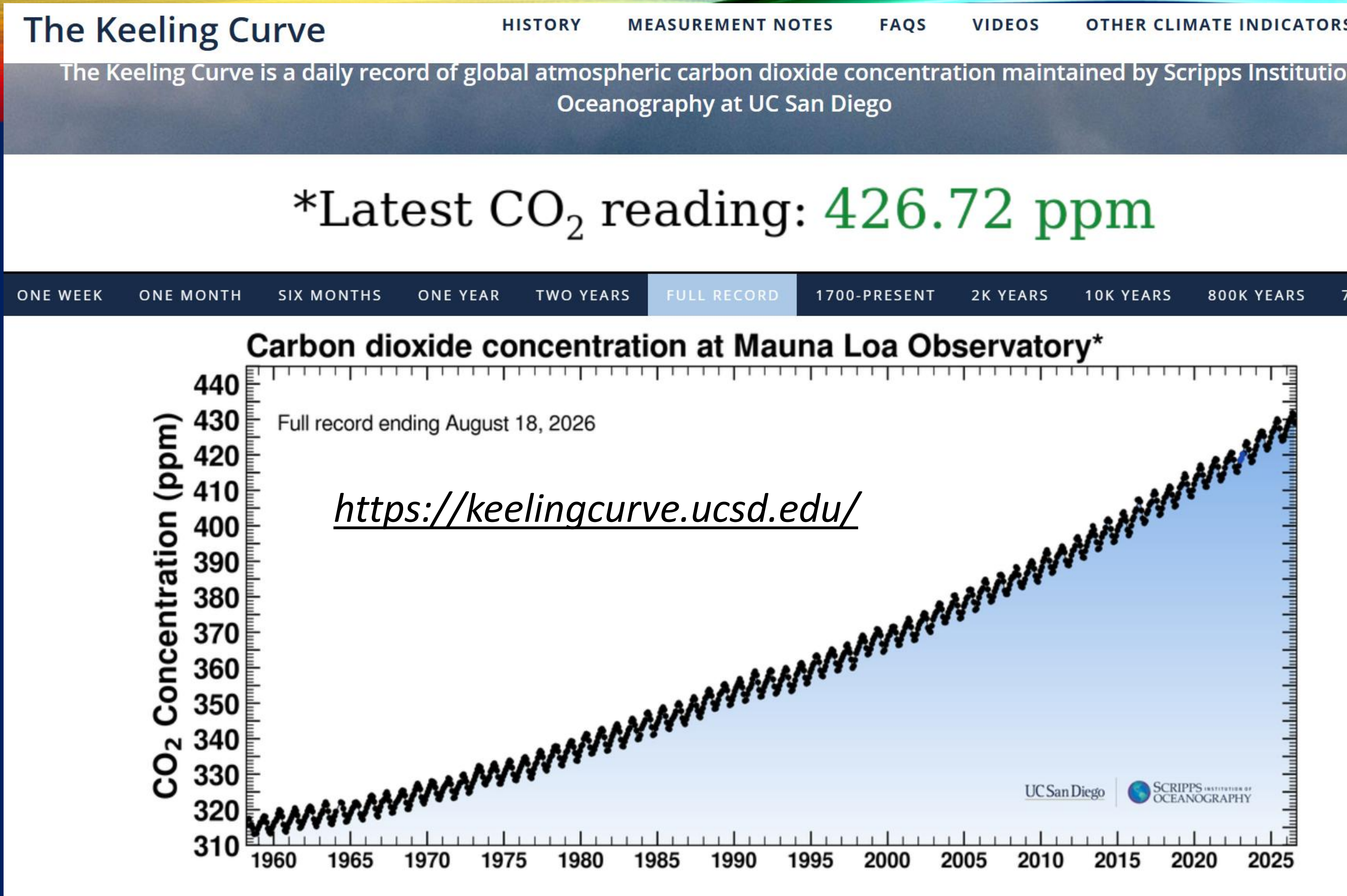
- Studied as a geologist but in 1931 turned to oceanography, a young science at that time
- Studied carbonate sediments in the ocean, and then how carbon dioxide and carbonates (e.g. from skeletons of marine life) interact to control the acidity of the ocean.

- Became concerned at the rate of fossil fuel emissions of CO_2 - much greater than the long-term rate from volcanoes
- Realised that greater understanding of the carbon cycle was needed.

"It therefore becomes of prime importance to attempt to determine the way in which carbon dioxide is partitioned between the atmosphere, the oceans, the biosphere and the lithosphere."

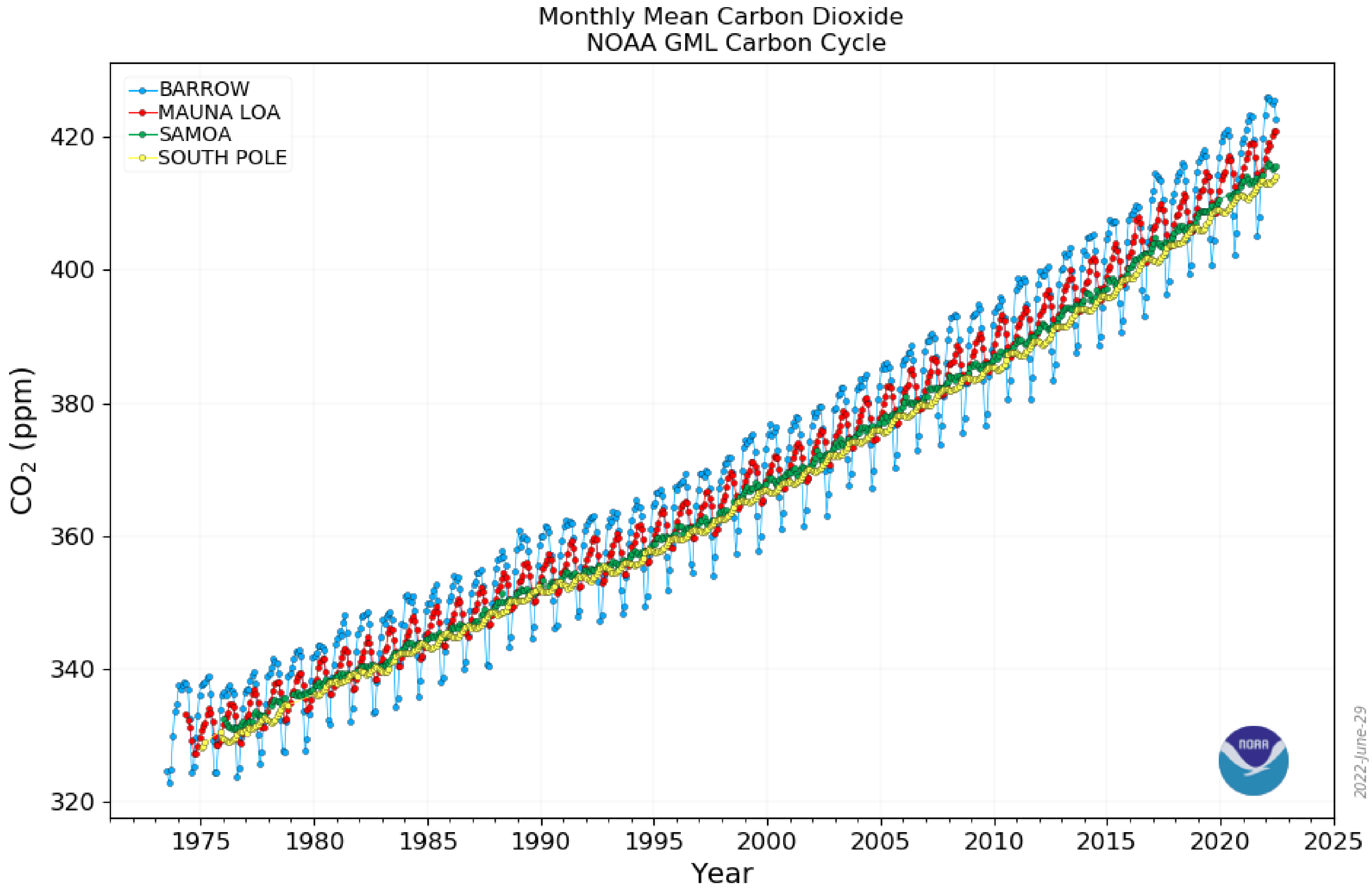
- Used funding available for the International Geophysical Year (1957-8) to employ Charles Keeling to set up a carbon dioxide observing site at an elevation of 3000 metres on Mauna Loa, Hawaii in 1958. Those measurements continue today.

- Other monitoring stations have been established since then, including at Kennaook/Cape Grim in NW Tasmania by CSIRO and the Bureau of Meteorology in 1985.



There are similar curves for other "greenhouse gases" such as methane, nitrous oxide, chlorofluorocarbons.

Note: how small the concentration of carbon dioxide is – now around **0.04%**

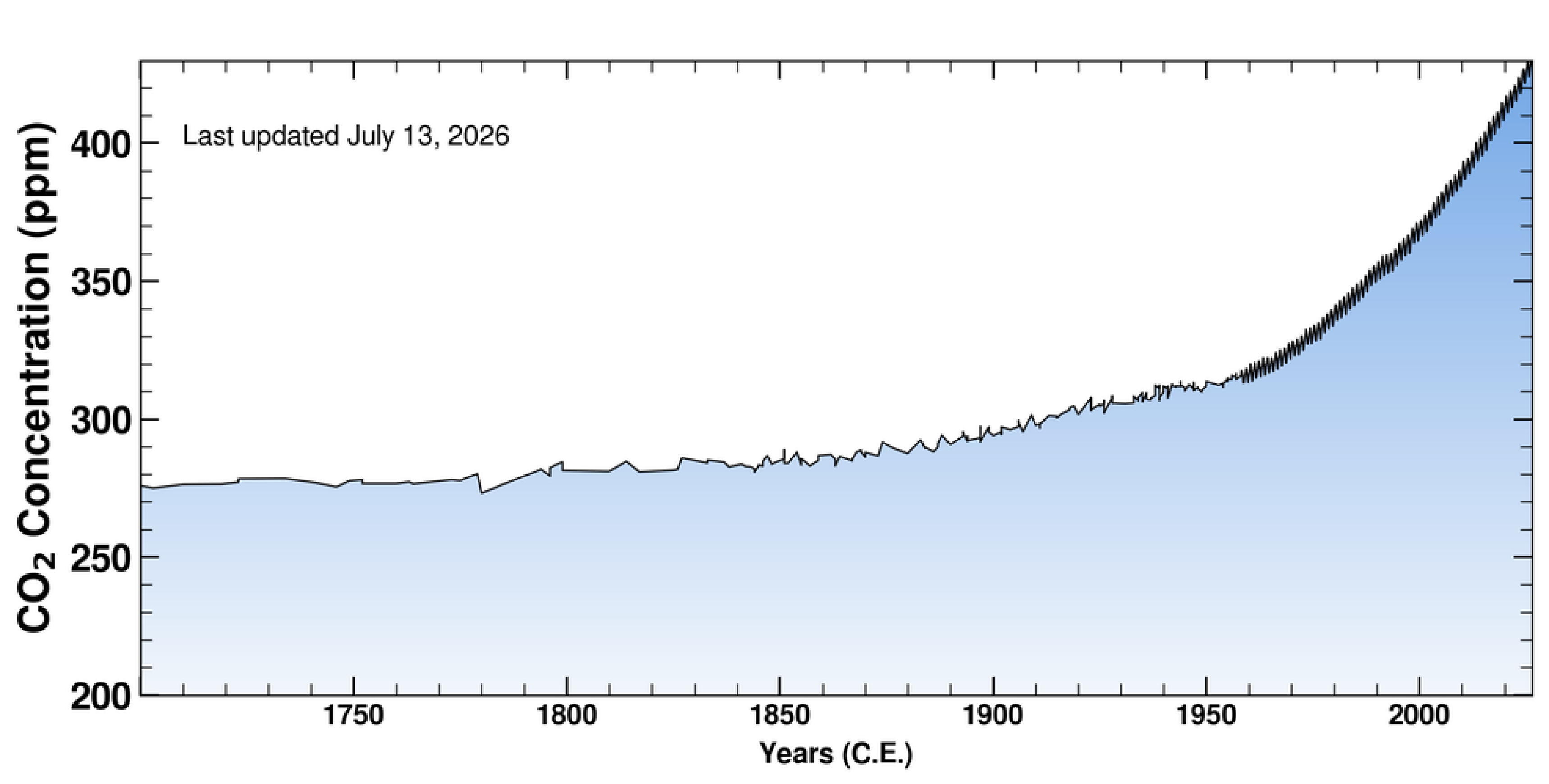


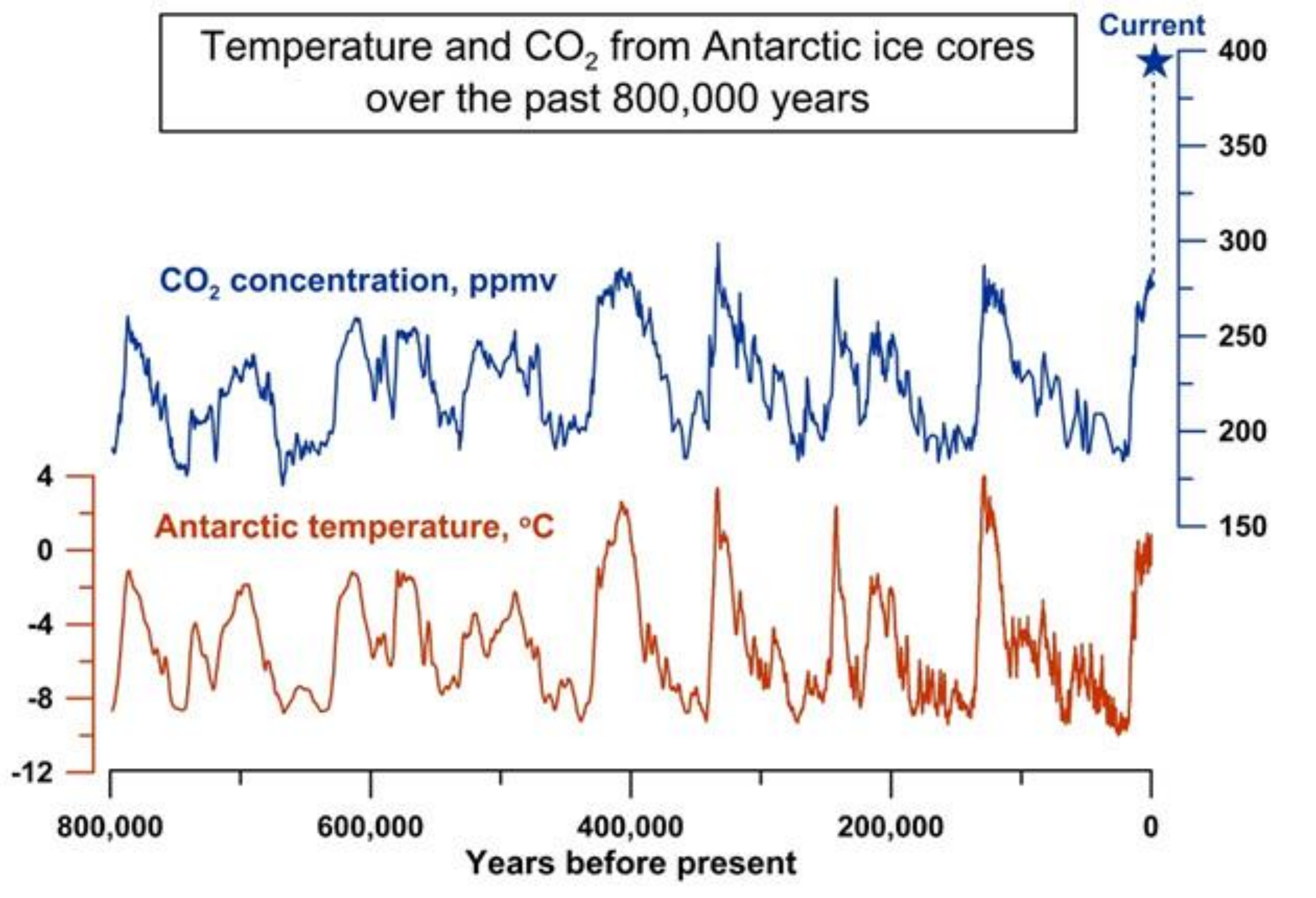
NOAA Global Monitoring Laboratory https://gml.noaa.gov/

CO_2 in the past – pre-industrial era

- Tree ring data - the difference between carbon-12 and carbon-13 depends on the carbon dioxide concentration in the air.
- Ice cores with trapped bubbles of air.

A comparison of measurements available in 1983 showed that the pre-industrial era concentration of CO_2 was between 260 and 280 ppm.
Seem to have settled now on 280 ppm as bench-mark value.





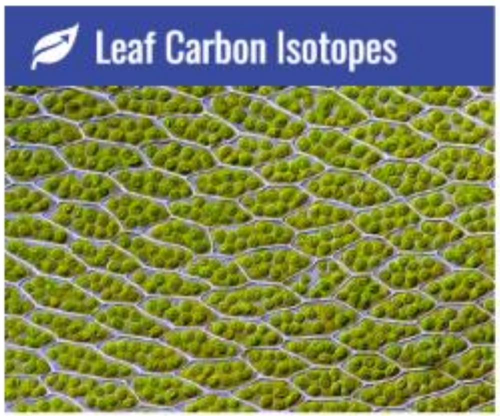
https://niwa.co.nz/file/32553

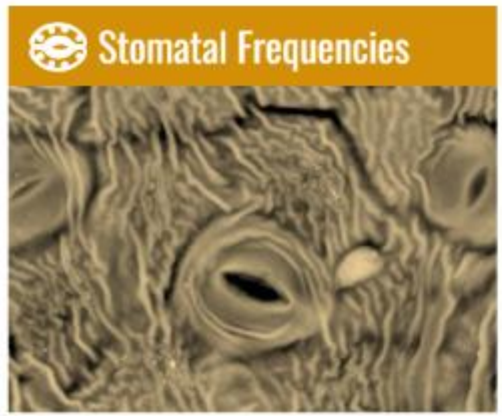
How to measure CO2 back past the time covered by ice cores?

The international consortium of the Cenozoic CO_2 Proxy Integration Project (CenCO_2PIP) has undertaken a 7-year effort to document, evaluate, and synthesize published paleo-CO_2 records from all available archives, spanning the past 66 million years.

They plan to extend the approach back to cover the past 500 million years

https://youtu.be/HNQFtNstp9g





Types of proxy data

paleo-CO_2

How exactly do paleo-CO_2 proxies work?

All have strengths and weaknesses, but lose sensitivity as atmospheric CO2 increases, meaning they provide more precise records at low than at high CO2 concentrations.

Terrestrial:

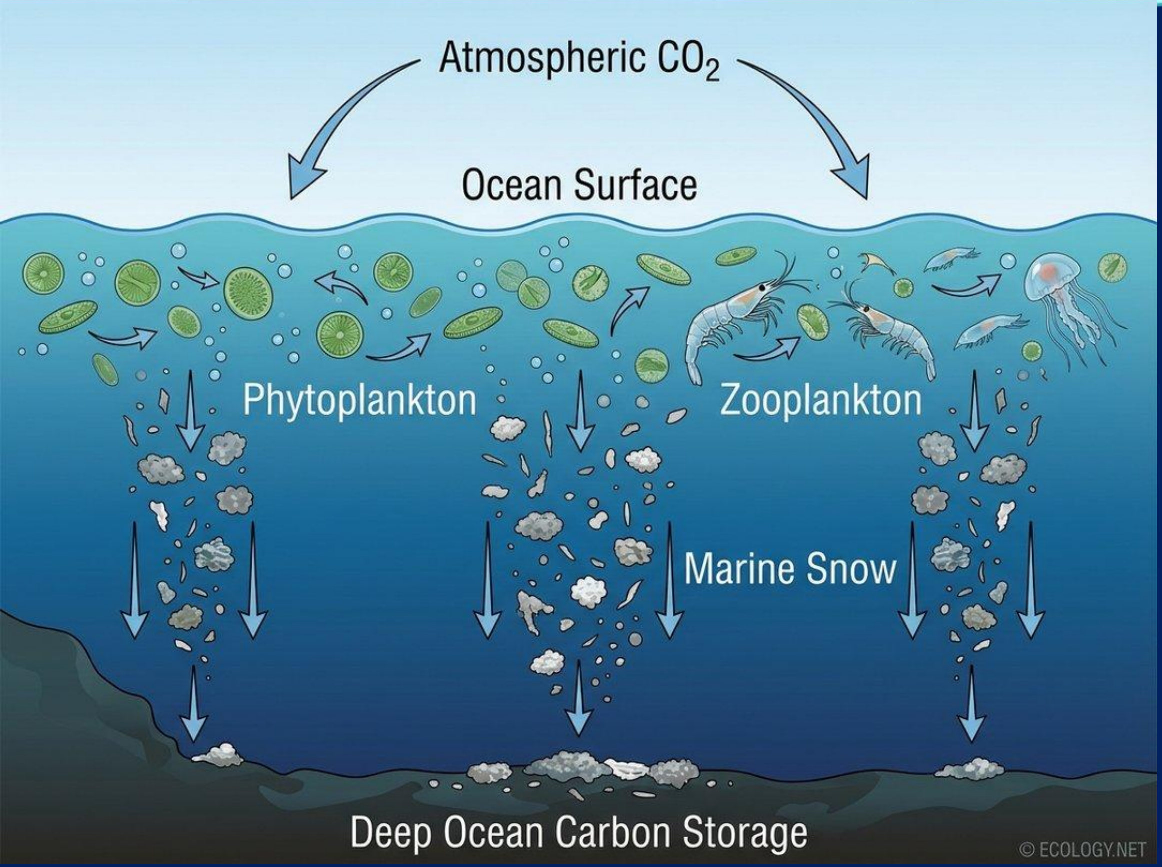
- 1. the density of stomata on fossil leaves
- 2. the carbon isotope composition of fossil plants such as liverworts
- 3. the carbon-13 in calcium carbonate minerals formed in fossil soils
- 4. the presence and absence of nahcolite and trona, two sodium bicarbonate minerals, that precipitate in evaporative lakes – which one is preferred depends on the CO_2 concentration.

Marine:

(4) the carbon-13 of algae biomolecules such as alkenones

(5) the boron isotope composition of planktonic foraminifera shells.

(6) Carbonate compensation depth (CCD).



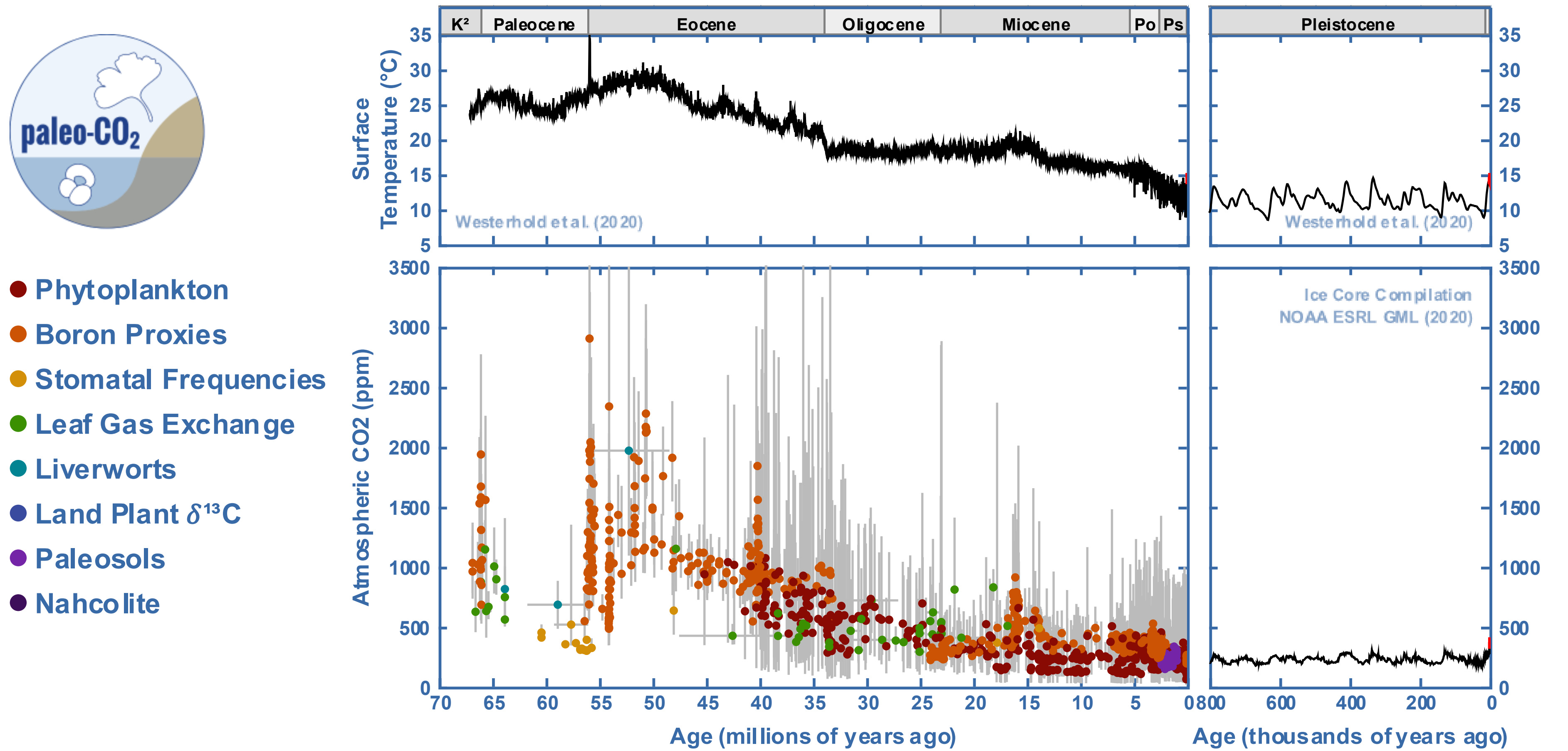
The ocean absorbs and releases CO_2 according to its concentration in the atmosphere.

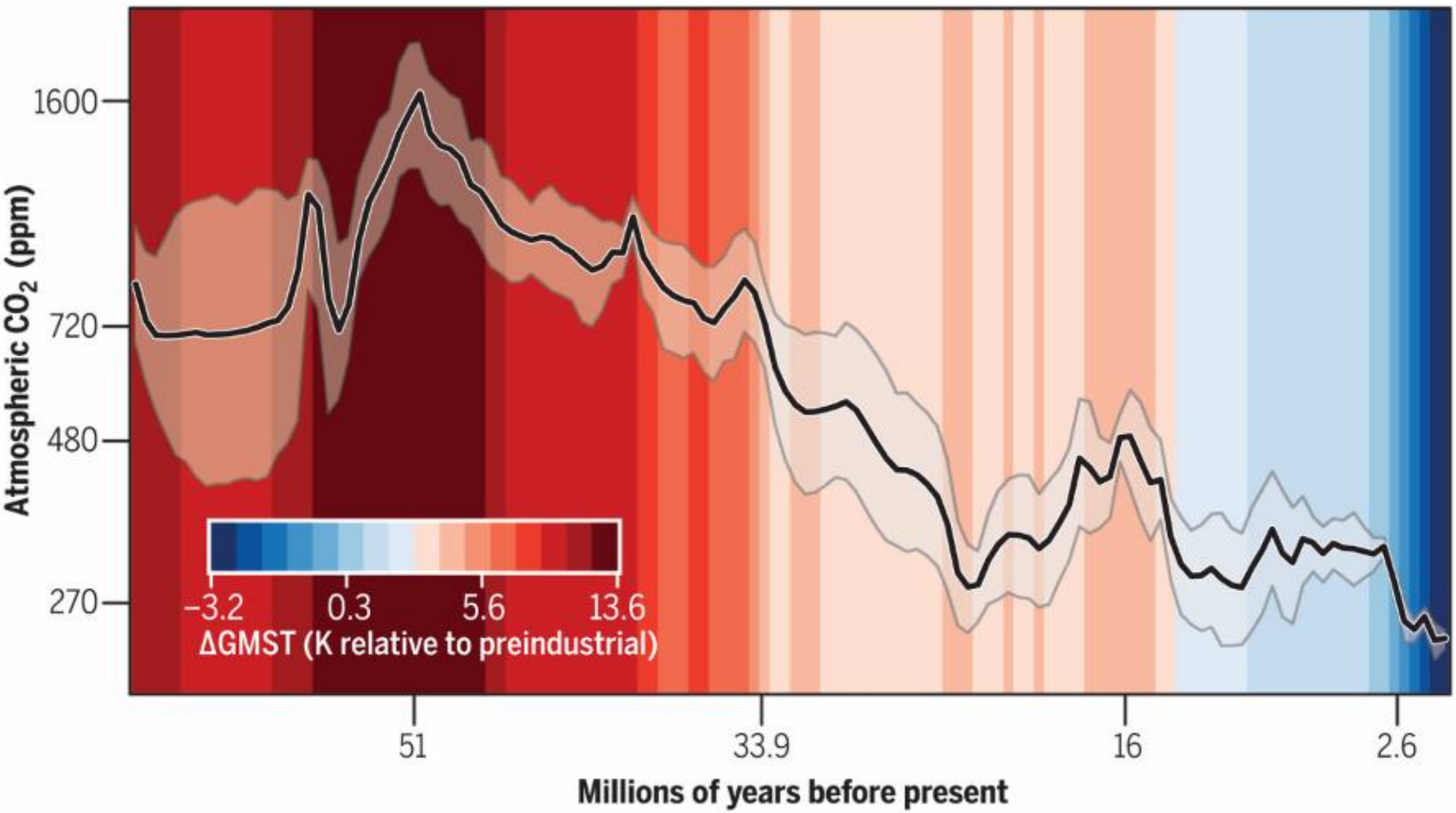
Some marine plankton store information on the chemical composition of seawater in their molecular and skeletal structures. When they die, their dead cells and skeletal structures fall to the seafloor.

As sediment settles on top, the chemical and isotopic information that the plankton once incorporated in the surface ocean becomes archived in seafloor sediments.

If the ocean is deep enough and the CO_2 concentration high enough, eventually all the carbonate will have been dissolved. That is called the carbonate compensation depth (CCD). That can be seen in the sediment if it exists.

What have they found?





Community-vetted quantitative CO_2 record.
Paleo-CO_2 (including 95% credible intervals) is superimposed on the GMST trend over the past 66 million years. Age and CO_2 labels highlight notable climate extrema and transitions as described in the text.

Global Mean Surface Temperature (GMST) in colour overlain on the time series of Atmospheric Carbon Dioxide concentration over the past 66 million years.

Selected large-scale climate indicators from the Cenozoic era to the recent past

	Atmosphere			Cryosphere	Biosphere	Ocean	
	CO_2 (ppm)	CO_2 rate of change (ppm/100 yr)	Temperature relative to 1850–1900 (°C)	Glacier extent relative to 1850–1900	Northern tree line relative to 1850–1900 (°lat)	Sea level relative to 1900 (m)	Sea level rate of change (mm/yr or m/1000 yr)
Younger — Recent past (1995–2014 CE)	360 → 397	192 to 198	0.66 to 1.00		0.5 to 1.0	0.15 to 0.25	2.9 to 3.6
Approximate pre-industrial (1850–1900 CE)	286 → 296	17 to 27	-0.15 to 0.11		0	−0.03 to 0.00	0.4 to 0.6
Last Millennium (850–1850 CE)	278 to 285	-7 ~ 5	-0.14 ~ 0.24		−1.5 to 1.5	−0.05 to 0.03	-1.1 ~ 0.7
Mid-Holocene (6.5–5.5 ka)	260 to 268		0.2 to 1.0		1 to 3	−3.5 to 0.5	
Last Deglacial Transition (18–11 ka)	193 → 271	10			−6 → 1	−120 → −50	24 to 44
Last Glacial Maximum (23–19 ka)	188 to 194		−5 to −7		−23 to −17	−134 to −125	
Last Interglacial (129–116 ka)	266 to 282		0.5 to 1.5		8 to 2	5 to 10	
Mid-Pliocene warm period (3.3–3.0 Ma)	360 to 420		2.5 to 4.0		4 to 10	5 to 25	
Early Eocene climate optimum (53–49 Ma)	1150 to 2500		10 to 18			70 to 76	
Older — Paleocene-Eocene thermal maximum (55.9–55.7 Ma)	900 → 2000	4 to 42	10 to 25				

X to Y: very likely range, unless otherwise stated in FAIR data table
X → Y: start to end of period, with no stated uncertainty
X ~ Y: lowest and highest values, with no stated uncertainty

Minimum — Pre-industrial Level — Maximum

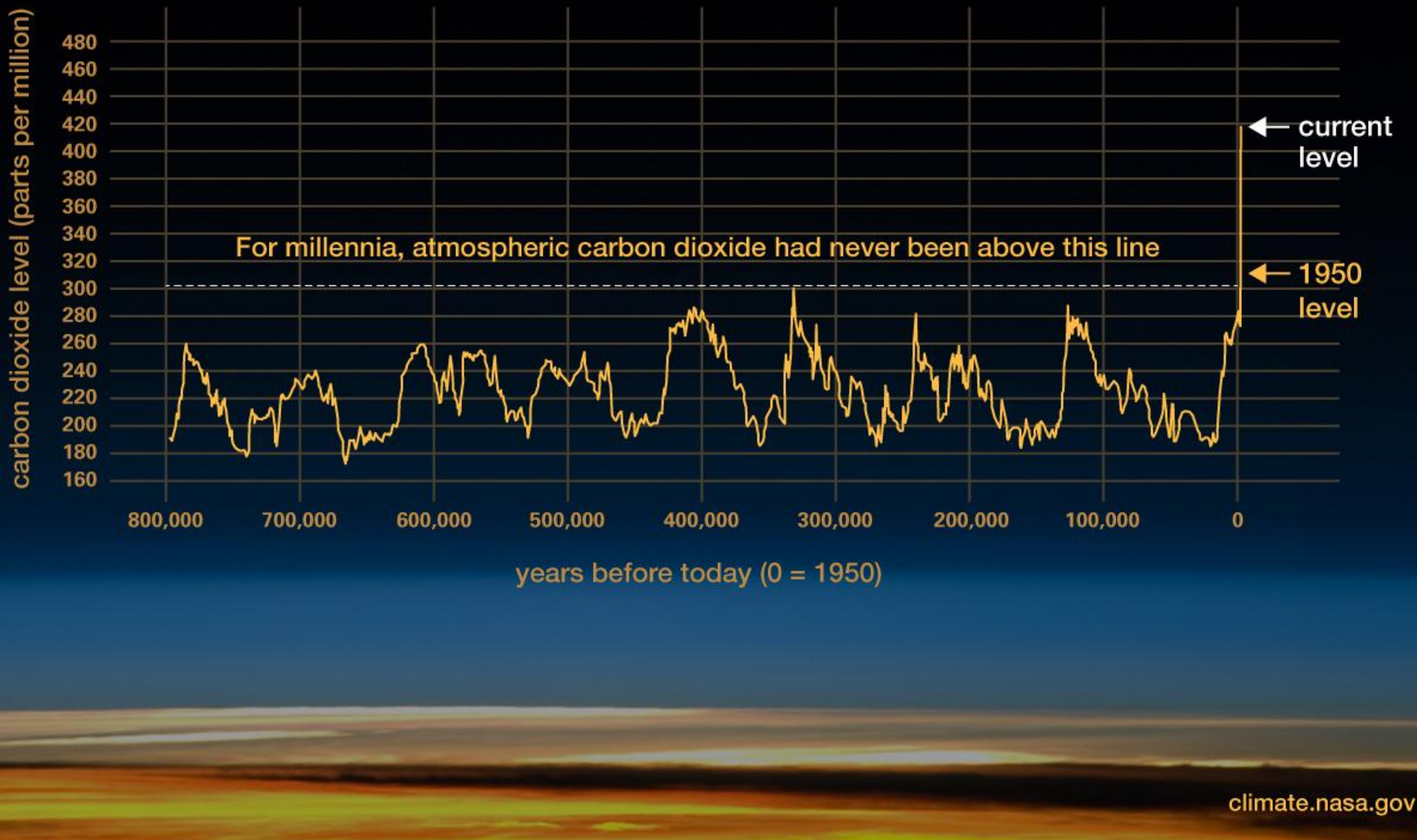
Colder / Lower sea level / More ice

Warmer / Higher sea level / Less ice

Insufficient data or not assessed

Figure 2.34 in IPCC, 2021: Chapter 2. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Where are we now?



Ice core data going back 800,000 years.

Climate science pioneer Claude Lorius, dies at 91

French glaciologist Claude Lorius was one of the first scientists to provide proof of human caused globa…

Leading glaciologist Claude Lorius, whose Antarctica discoveries in the 1980s helped prove humanity's role in global warming, has died at 91.

"The discovery of significant changes in climate forcing linked with the composition of the atmosphere has led to the idea that changes in the CO_2 and CH_4 content have played a significant part in the glacial-interglacial climate changes by amplifying, together with the growth and decay of the Northern Hemisphere ice sheets, the relatively weak orbital forcing and by constituting a link between the Northern and Southern Hemisphere climates."

https://phys.org/news/2023-03-climate-science-claude-lorius-dies.html

21 March 2023

Lorius, C., J. Jouzel, D. Raynaud, J. Hansen, and H. Le Treut, 1990: *The ice-core record: Climate sensitivity and future greenhouse warming. Nature*, **347**, 139-145.

The current understanding of the role of carbon dioxide in climate.

- The graphs of temperature and carbon dioxide show a close relationship. Sometimes the temperature leads the carbon dioxide so there has been an argument that carbon dioxide cannot be the cause of climate change.
- However, the current view is that the Croll—Milankovich variations in the incoming solar energy are a trigger to initiate a change in temperature or the melting of ice and snow.
- Once the temperature starts to increase, carbon dioxide becomes less soluble in the ocean and bubbles into the air. Similarly, higher temperatures mean that the air can hold more water vapour, which, in itself, has the major greenhouse effect. Also melting of permafrost leads to release of methane.
- Along with the reduced reflection of light as ice and snow melts, these are the feedback mechanisms that amplify the initial impetus.
- In other geological eras the carbon dioxide level can increase due to periods of very high volcanic activity or decrease if there is burial of masses of carbon (such as in the formation of coal during the early Carboniferous period.