Past and Future Climate – Present Weather

Week 2

What was the early atmosphere like?
Where did the Oxygen come from?

Terry Hart

- Dates for Term 1
  - February 12 and 26
  - March 12 and 26

From the Course Administrator (Elsie Mutton):

- Car Parking (see newsletter for nearby options)

- Respect for Desk Reception and other staff
  - Code of Conduct

The Adams Event, or Laschamp excursion – magnetic field reversal 42,000 years ago.

Tony Heyes videos:
Paleopocalypse! - Narrated by Stephen Fry.
https://www.youtube.com/watch?v=Qs1dLe3GsQY

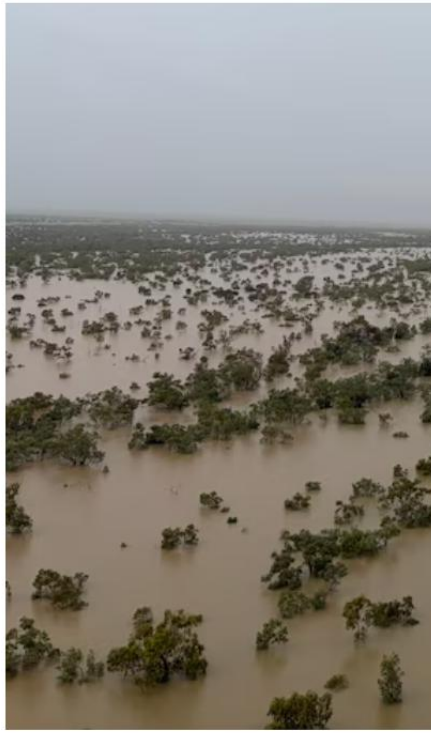
https://www.youtube.com/watch?v=NSig4MyLQ0o

Heavy rain soaks the Barkly and Central Australia, closing roads and inundating cattle stations

By Sam Parry, Charles Geary, Elsie Lange and Will Regan

Floods

1h ago



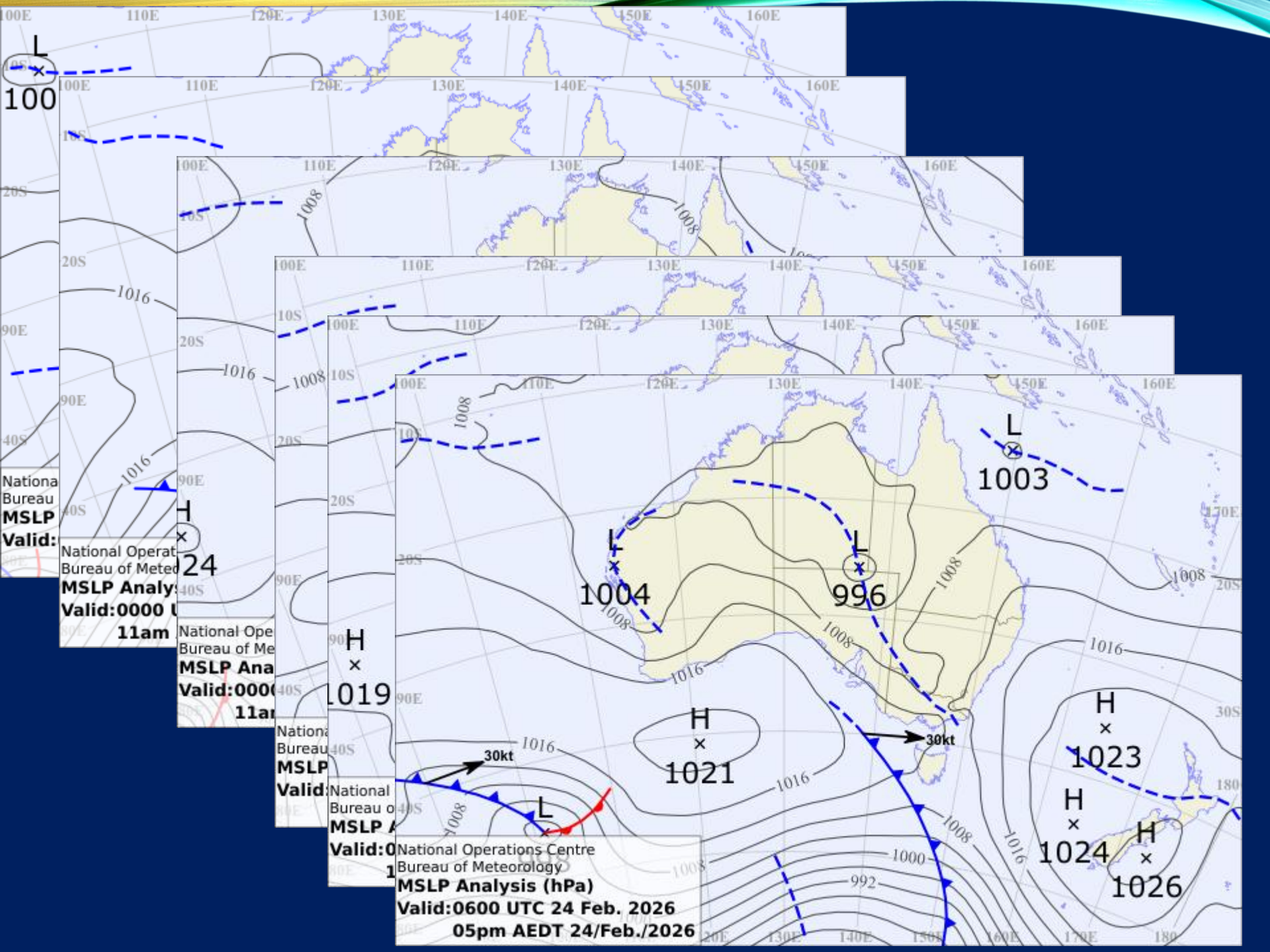
Flooding on Sunday at Lake Nash Cattle Statio

East West rail corridor cut by flooding amid heavy rain in northern SA

By Stacey Pestrin | By Daniel Keane | By Briana Fiore | By Anita Ward | Weather

20h ago

Water covers a road during outback downpours, which have also forced the closure of the East West rail corridor. *(Supplied: Ben Hennessy)*


National Operations Centre
Bureau of Meteorology
MSLP Analysis (hPa)
Valid:0600 UTC 24 Feb. 2026
05pm AEDT 24/Feb./2026
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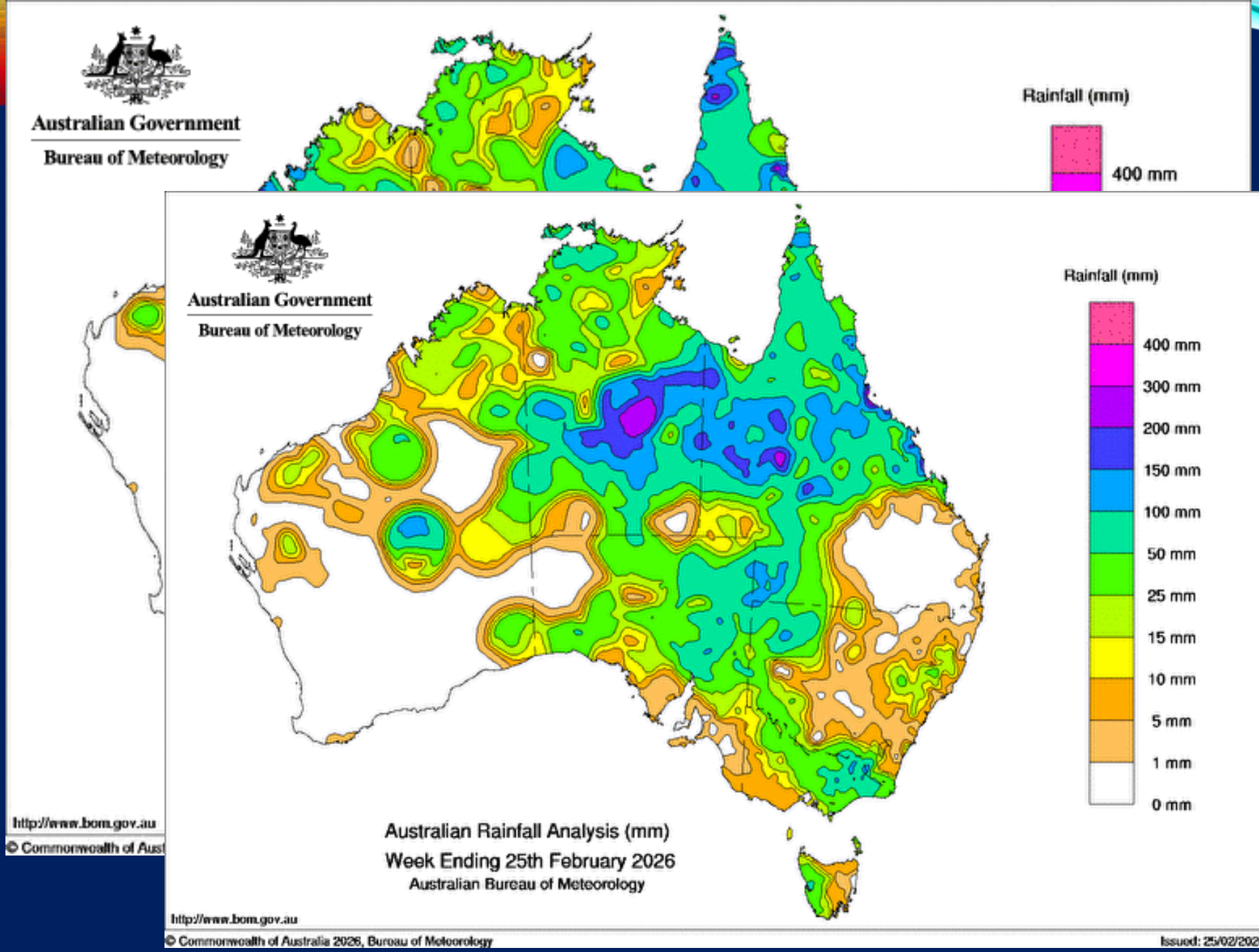
Australian Government
Bureau of Meteorology
Rainfall (mm)
400 mm
Australian Government
Bureau of Meteorology
Rainfall (mm)
400 mm
300 mm
200 mm
150 mm
100 mm
50 mm
25 mm
15 mm
10 mm
5 mm
1 mm
0 mm
Australian Rainfall Analysis (mm)
Week Ending 25th February 2026
Australian Bureau of Meteorology
http://www.bom.gov.au
© Commonwealth of Australia 2026, Bureau of Meteorology
Issued: 25/02/2026
http://www.bom.gov.au
© Commonwealth of Aust

MELBOURNE AREA

	Date/Time EDT	Temp °C	App Temp °C	Dew Point °C	Rel Hum %	Delta-T °C	Wind					Press MSL hPa	Rain since 9am mm	Low Temp °C time	High Temp °C time	Highest Wind Gust		
							Dir	Spd km/h	Gust km/h	Spd kts	Gust kts					Dir	km/h time	kts time
Melbourne (Olympic Park)	24/06:30pm	21.1	21.5	16.3	74	2.9	SSW	9	15	5	8	1012.7	15.2	20.7 06:19pm	23.8 01:03pm	WNW	28 02:42pm	15 02:42pm
Melbourne Airport	24/06:30pm	20.3	18.3	15.5	74	2.9	SSW	20	28	11	15	1012.7	21.4	20.2 06:26pm	27.1 12:55pm	WSW	33 02:14pm	18 02:14pm
Avalon	24/06:30pm	19.9	18.0	14.3	70	3.2	SSE	17	20	9	11	1013.3	2.8	19.8 06:09pm	25.3 01:16pm	SSE	24 05:52pm	13 05:52pm
Cerberus	24/06:30pm	18.7	19.3	15.2	80	2.1	SE	6	7	3	4	1012.9	3.2	18.2 06:12pm	24.9 02:10pm	WSW	35 03:08pm	19 03:08pm
Coldstream	24/06:30pm	20.9	21.8	16.5	76	2.7	S	7	13	4	7	1011.9	11.8	20.9 06:30pm	28.5 01:02pm	W	54 03:09pm	29 03:09pm
Essendon Airport	24/06:30pm	20.7	19.3	16.5	77	2.5	SSW	19	22	10	12	1012.4	11.8	20.5 06:28pm	26.6 01:00pm	NW	43 02:29pm	23 02:29pm
Fawkner Beacon	24/06:30pm	-	-	-	-	-	E	20	24	11	13	-	-	-	-	W	43 02:44pm	23 02:44pm
Ferny Creek	24/06:30pm	16.2	16.8	15.2	94	0.6	ESE	6	7	3	4	1012.4	18.8	16.1 06:30pm	27.1 12:07pm	ESE	26 05:16pm	14 05:16pm
Frankston (Ballam Park)	24/06:30pm	19.6	20.4	17.4	87	1.3	SE	9	17	5	9	1012.4	3.6	19.1 06:00pm	25.3 12:08pm	W	32 03:00pm	17 03:00pm
Frankston Beach	24/06:30pm	-	-	-	-	-	SE	9	17	5	9	-	-	-	-	WSW	56 03:02pm	30 03:02pm
Geelong Racecourse	24/06:30pm	19.7	18.7	15.6	77	2.4	S	15	19	8	10	1013.3	2.2	19.4 06:28pm	23.7 01:29pm	S	26 03:10pm	14 03:10pm
Laverton	24/06:30pm	20.5	19.5	16.5	78	2.4	SE	17	20	9	11	1012.8	2.8	20.5 06:30pm	25.4 12:25pm	SE	24 05:02pm	13 05:02pm
Moorabbin Airport	24/06:30pm	20.2	18.1	14.8	71	3.2	SE	19	24	10	13	1012.8	3.6	20.1 06:26pm	23.5 12:33pm	WNW	39 02:53pm	21 02:53pm
Point Cook	24/06:30pm	20.2	20.2	16.2	78	2.4	SSE	11	17	6	9	1012.7	3.6	20.1 06:30pm	23.1 01:17pm	SW	32 02:57pm	17 02:57pm
Point Wilson	24/06:30pm	-	-	-	-	-	SSE	13	17	7	9	-	-	-	-	S	26 03:41pm	14 03:41pm
Rhyll	24/06:30pm	18.4	18.2	15.8	85	1.5	ESE	11	13	6	7	1013.1	2.6	17.8 06:07pm	25.0 02:16pm	S	28 05:15pm	15 05:15pm
Scoresby	24/06:30pm	19.6	19.9	16.1	80	2.1	SSE	9	17	5	9	-	9.4	19.6 06:30pm	28.7 11:59am	WNW	44 03:01pm	24 03:01pm
She Oaks	24/06:30pm	20.3	19.0	13.7	66	3.8	ESE	13	17	7	9	1012.9	2.8	20.2 06:29pm	26.1 01:20pm	W	43 01:46pm	23 01:46pm
South Channel Island	*24/04:00pm*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
St Kilda Harbour RMYS	24/06:30pm	-	-	-	-	-	SSE	26	30	14	16	-	-	-	-	WNW	41 02:42pm	22 02:42pm
Viewbank	24/06:30pm	20.6	21.8	16.8	79	2.3	S	6	11	3	6	1012.4	15.6	20.6 06:30pm	26.6 11:53am	WNW	46 02:44pm	25 02:44pm
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Melbourne Rainfall

View the current warnings for Victoria

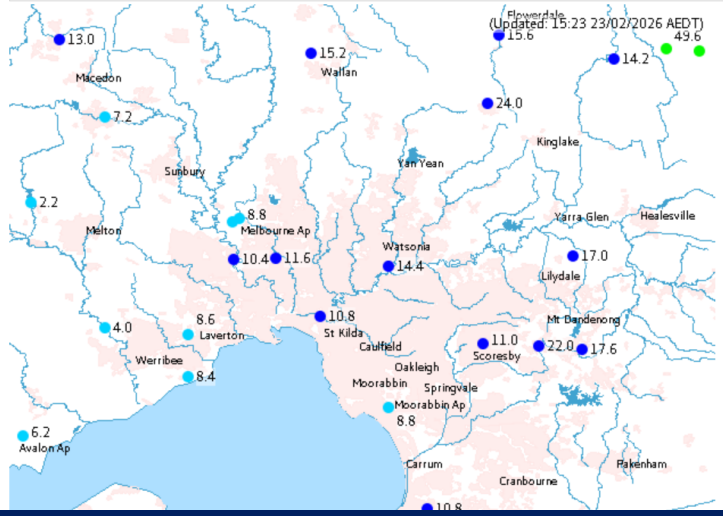
Display on map

- 24 Hour Rainfalls
- Last hour
- -3 hours
- -5 hours
- Rainfall since 9 am
- -2 hours
- -4 hours
- -6 hours

About Map

Note: Map contains unchecked data from automatic equipment.
Please remember to refresh page so the data is up to date.

Move mouse over station for more data.



Latest Observations:

- Melbourne Radar

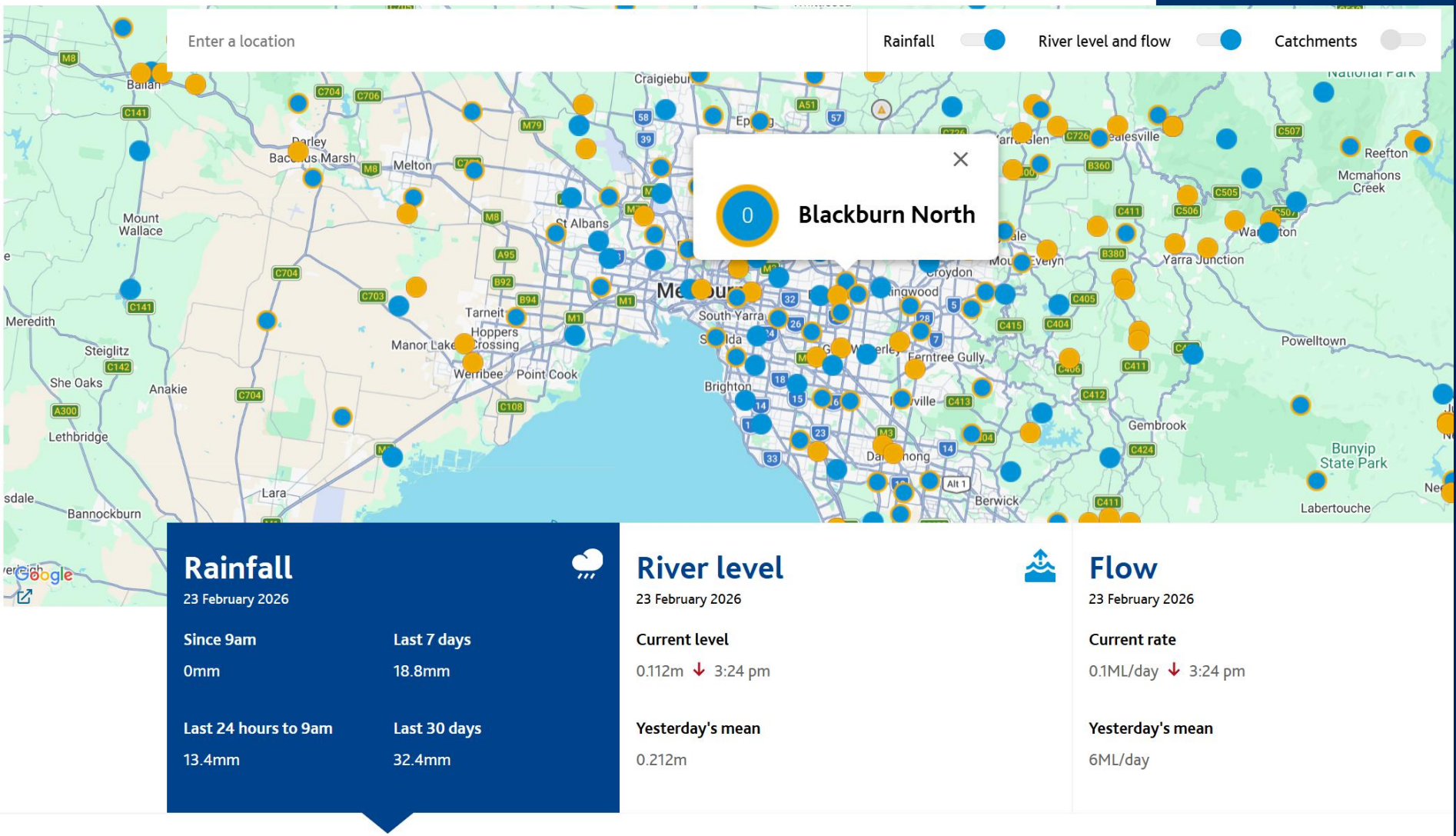
Zoom out to:

- Victoria
- Australia

External Links:

- Melbourne Water Rainfall and River data

The Bureau and Melbourne Water are working together to include rainfall and river level information for Greater Melbourne on the Bureau's website by mid 2026. Melbourne Water rainfall and river level data is currently available from https://www.melbournewater.com.au/water-and-environment/water-management/rainfall-and-river-levels.



https://www.melbournewater.com.au/water-and-environment/water-management/rainfall-and-river-levels#/

FRANCE - WEATHER

Record flooding across France as storms fall on saturated ground

Storms have left large parts of France underwater, with record levels of flooding after heavy rain fell on already saturated soil. In Paris, the Seine is four metres above its normal level, forcing the closure of the riverside motorway and some commuter rail stations.

The overflowing Garonne river flooding a residential area in Tonneins, south-western France, 13 February 2026, after Storm Nils swept across France. © Christophe Archambault/AFP

euronews.

Western France floods deepen after 3

Alexis Caraco
Fri 20 February 2026 at 6:37 pm AEDT
1 min read

Western France floods deepen after 35 days of rain

"France has marked a record-breaking streak of more than 35 consecutive days of rain.

"National weather service Meteo-France said the country was experiencing its longest series of rainy days since measurements began in 1959, breaking the 2023 record."

Double-digit snow totals have been reported across New York, New Jersey and Connecticut as a major nor'easter continues to hit the area.

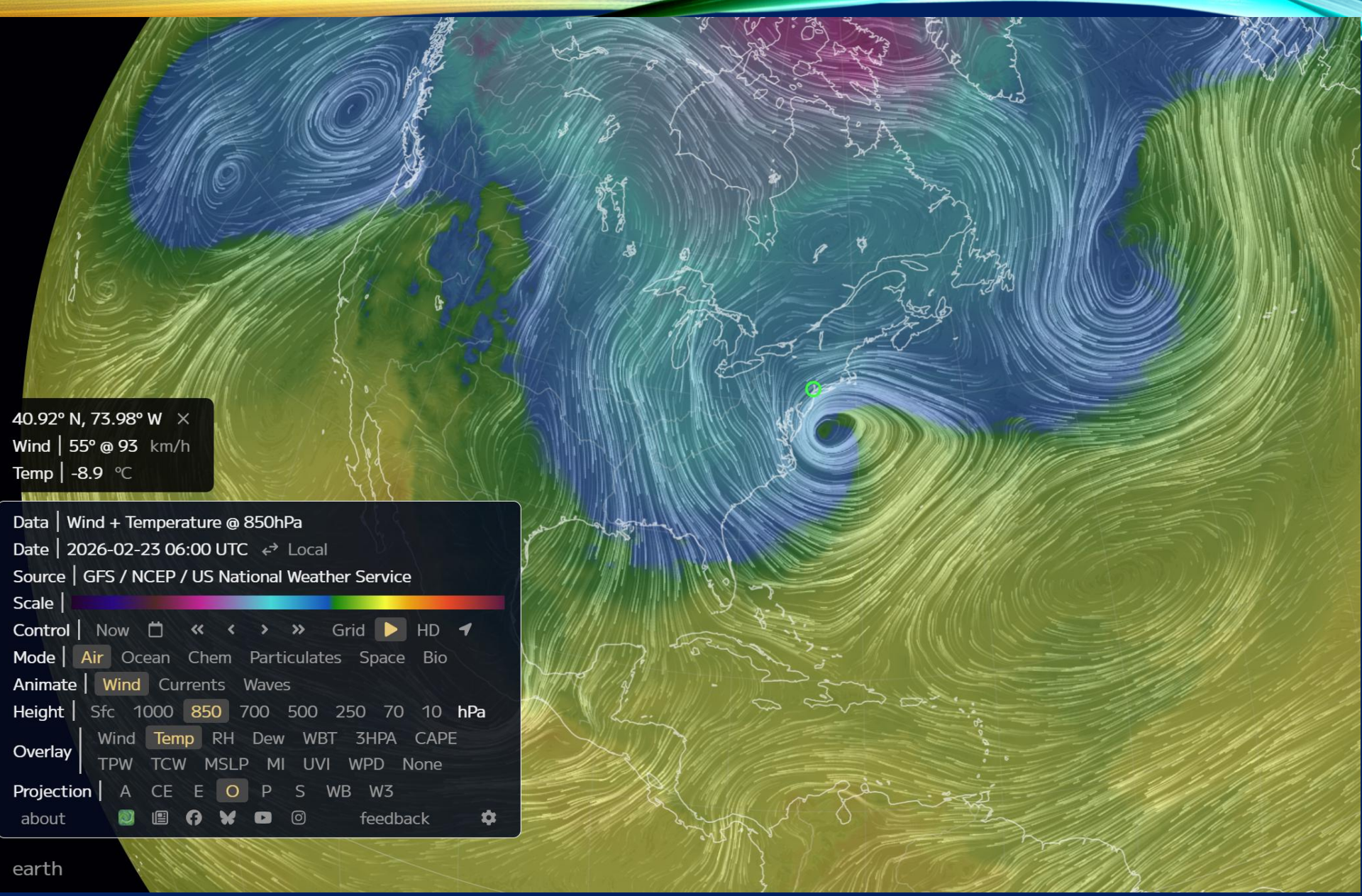
The largest storm in years continued to deliver some serious snow on Monday, before beginning to wind down in the afternoon. Some areas of Long Island and New Jersey received more than 2 feet.

CBS News New York

The storm is now the ninth biggest in New York City history, dating to 1869. As of 2:30 p.m., 19.7 inches have fallen in Central Park, which is just 0.1 inches less than what fell on Feb. 16-17, 2003, and just 0.3 inches less the seventh-place storm, from Dec. 26-27, 2010.

BUSINESS INSIDER

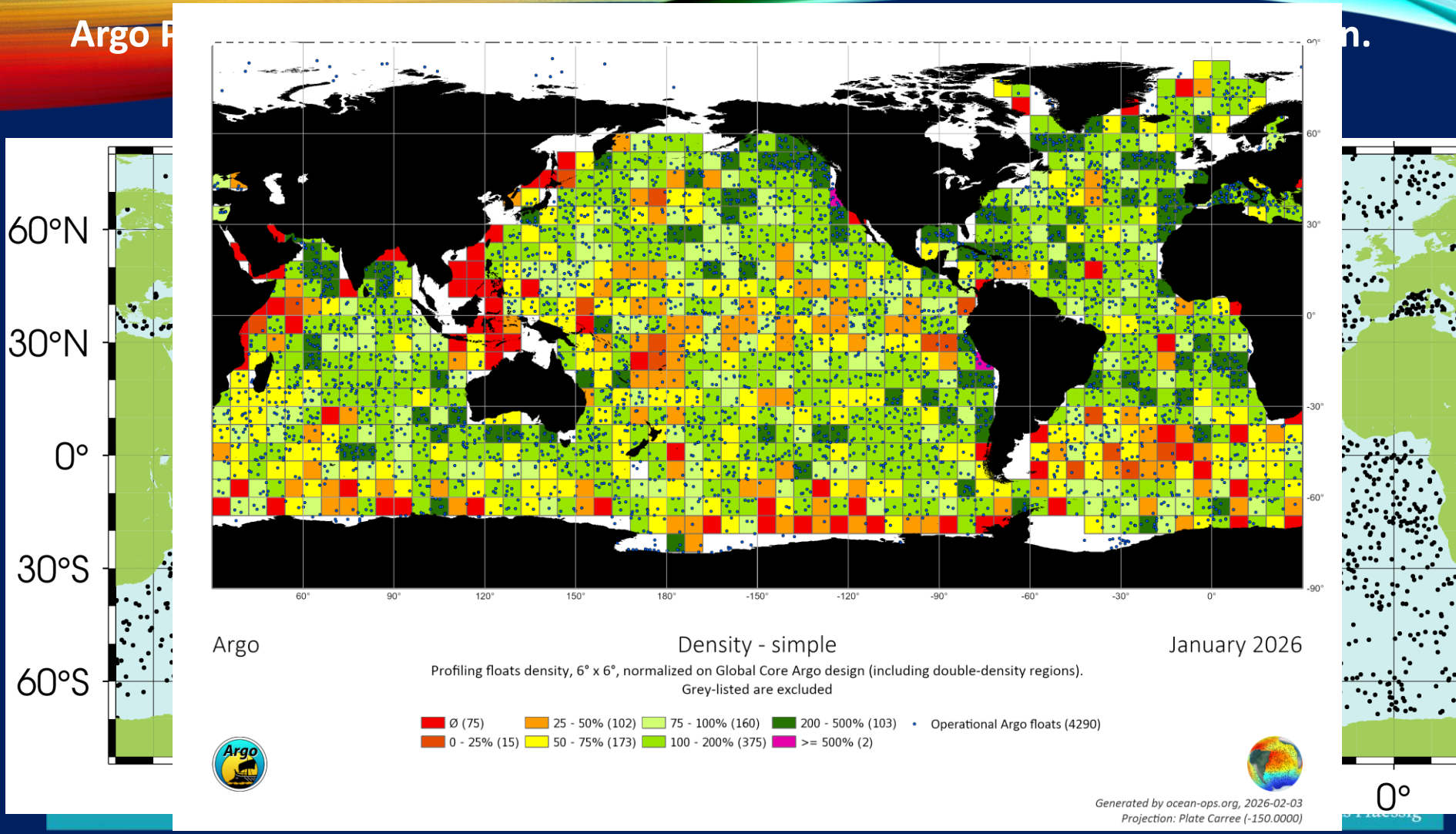
Blizzard updates: 9,000 flights canceled and thousands left without power as winter storm pummels the Northeast



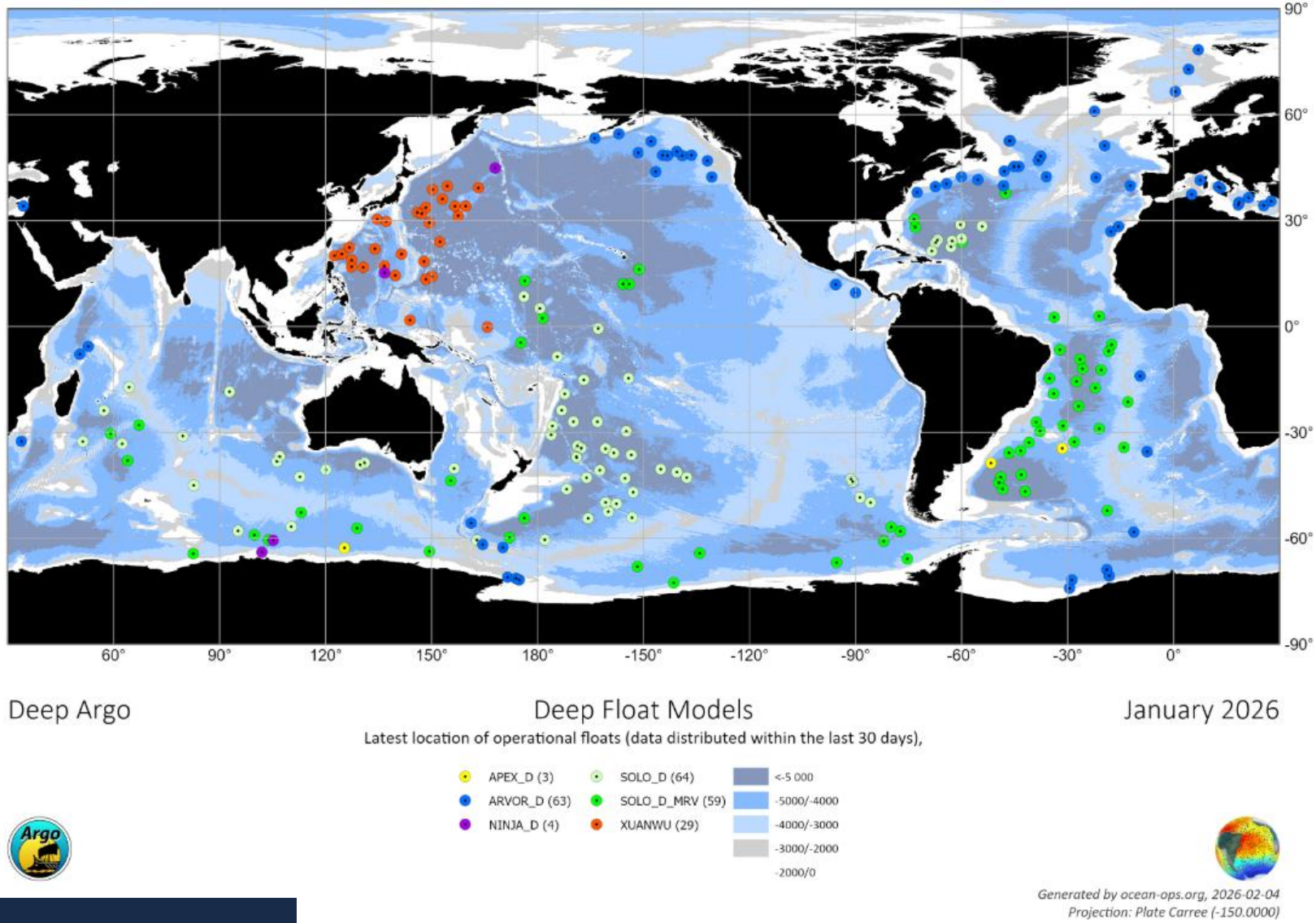
https://earth.nullschool.net/

Tuesday 17 February 2026

Time	Ballroom 1 (Plenary)	Ballroom 2	Ballroom 3	Harbourview 1	
8:15	Registration (opens 8:15 AM)				
8:30					
8:45	Welcoming Ceremony - Sarah Perkins-Kirkpatrick (AMOS President) and Danielle Udy (AMOS 2026 Convenor)				
9:00					
9:10	PLENARY: Jaci Brown (NESP) & Leanne Haupt (DCCEEW) - AMOS sciences informing Australia's future (Sponsored by NESP Climate Systems Hub)				
9:30					
9:45					
10:00	RH CLARKE LECTURE: Annie Foppert (IMAS) - Antarctic Bottom Water: Present understanding, new insights, and future priorities				
10:15					
10:30	Morning Tea				
10:45					
	History	4. Compound climate, weather and ocean events	12. Climate change risk assessments and adaptation I	11. Innovations, communication and co-design approaches in weather and ocean forecasting and warning services	
11:00	**49 Voice** - Southern Sailors' Encounters with Weather in the Age of Exploration	**44 Pepler** - Impactful wet/windy extremes in Australia	**137 Narsey** - Beyond conventional projections: exploring uncharted climate futures	**101 Whelan** - A Collaborative, User-Centered Approach to Development and Deployment of Blended Forecast Products at the Bureau of Meteorology	
11:15	**194 Hart** - Antarctic and Southern Ocean synoptic analysis from first explorers to World Meteorological Centre Melbourne	**23 Wang** - Projected changes in Compound Extremes in Australia: Insights from NARClim2.0	**318 Round** - Framing the Future: making climate projections tangible through familiar frames	**34 Young** - Climate Suita-what? How to talk about and show future climate suitability.	
	3. Weather Systems: Processes and impacts across scales I				
11:30	**78 Ma** - The contribution of atmospheric features to precipitation across Australia	**184 Anand** - Contribution of anomalously warm sea surface temperatures during the Ningaloo Niño of March 2011 to temperature extremes over land in Southwest WA	**160 Morrissey** - The Australian Climate Service Risk Evaluation of Climate Extremes (RECE): A scenario-based approach to measuring risk in a changing climate	**116 Heinrich** - Enhancing weather services in Australia, how to people receive, understand and respond to warnings and risk communications?	
11:45	**223 Henderson** - Heatwaves and heavy rainfall in the summer of southeastern Australia, and their link to anticyclonic Rossby wave breaking.	**339 Vogel** - The effect of spatially compounding climate extremes on production and trade of major food crops	**159 Oke** - Using hazard data to identify current and future climate risk for the natural environment and primary industries	**360 Saunders** - Data-driven recommendations for enhancing real-time natural hazard warnings	
12:00	**366 Spengler** - A weather feature perspective on jet dynamics	**89 Talmale** - How well do CMIP6 models represent temperature–precipitation variability and associated concurrent compound events?	**209 Henry** - Australia's Climate Risk Needs Assessment	**182 Ramchurn** - "Fluctuations in long term forecasts with reduced lead times - Investigating potential causes and assessing the outcomes".	
12:15	**326 Jiang** - Weak Polar Vortex Events and QBO Modulation: Pathways Linking Stratospheric Variability to Australian Heat and Fire Risk	**80 Laura** - What triggers compound heat and wildfires events in southeast Australia?	**216 Maguire** - Assessing our hazard projections capability to inform climate risk assessments and resilience decisions	**192 Hayman** - Imperfect seasonal forecasts, imperfectly communicated to imperfect decision makers in the Australian grains industry.	
12:30	**153 Parker** - A review of global climatologies of fronts, with case studies of front-associated extreme weather	**LLS: 315 Dutta** - Heavy precipitation clusters in Australia; **365 Rogers** - Humid-heat trends across Australia	**340 Hawton** - Unpacking Tasmania's Risk Assessment for Climate Change 2024	**351 Grey** - The Break suite of climate communication products, 19 years of climate extension in Victoria. Results of binenial readership surveys	



Since the start of the Argo program in 2000, these **autonomous profiling floats** have been limited to the top half of the sea (0-2000 m), and the accuracy of sensors was similarly limited to upper ocean levels of temperature and salinity. A new generation of floats, called **Deep Argo,** will sample the full ocean volume, capable of reaching **6000 m**.



Deep Argo Mission

Poster ID#: 304, Poster Session 2, 32nd AMOS, 16–20 February 2026, Hobart, Australia

MILLION YEAR ICE CORE PROJECT

DOME C NORTH

Joel Pedro[1,2], Daniel Baggenstos[1,2], Mark Curran[1,2], Andrew Moy[1,2], Andy Mackintosh[1,2], Meredith Nation[1,2], Chris Plummer[1,2], Jason Roberts[1,2], Lemeke Jong[1,2], Amanda Pepper[1], Derryn Harvie[1], David Etheridge[1,2], Andrew M. Smith[1], Ailsa Chung[1], Robert Mulvaney[3], Frédéric Parrenin[3], Tas van Ommen[1].

OBJECTIVE

The Million Year Ice Core (MYIC) Project is an Australian Antarctic Program initiative to recover a continuous ice core spanning the mid-Pleistocene Transition (MPT: 700–1,250kyr; *Fig 1*). During the MPT global ice volume increases and the pacing of glacial cycles changes from 41-kyr, phase-locked with obliquity, to quasi-periodic 100-kyr cycles. The climate and carbon-cycle dynamics involved in this transition are poorly understood. MYIC gas and climate records will be used to test hypotheses on the MPT, providing new data to evaluate climate models and improve understanding of long-term climate stability.

SITE AND AGE MODELLING

The MYIC Dome C North (DCN) drill site is located at 75.0422S, 123.6312E, ice thickness 3064 m.

Site selection was informed by 1D ice modelling, constrained by ice penetrating radar (*Fig 2*) and isochrones traced back to the EPICA Dome C ice core (which lies 9km to the NW).

The age-depth model predicts 1.5 Ma ice ~100 m above the bed at resolution better than 10 ka per m and no basal melt; see depth-age comparison to the Beyond EPICA and Dome C records in *Fig 3*. MYIC offers great potential to extend the continuous ice core record will into the '41-kyr world'.

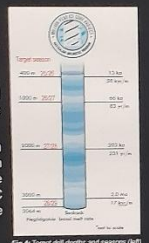


Fig 4: Target drill depths and seasons (left) and modelled age and resolution (right).

DRILLING

2024-25 Season: The MYIC camp was established at DCN, drill shelter built, incline trench excavated and pilot drilling and reaming completed to 150 m using an Eclipse drill.

2025-26 Season: Bore casing was installed, AAD deep drill commissioned and drilling completed through to the 400 m target (ca. 13,000 y BP), see *Fig 5*.

Drilling to bedrock is scheduled for completion in 2028-29; *Fig 4* timeline.

SCAN ME for short video of 25/26 drilling season.

MYIC MEASUREMENTS

ICE CHEMISTRY: The Holocene section of the MYIC record is scheduled for Continuous Flow Analysis (CFA) this year, including for conductivity, dust, Na^+ and Ca^{2+} ions, along with collection of discrete fractions for ion chromatography and cosmogenic ^{10}Be analysis. CFA of water isotopes and CH_4 gas are in development.

GAS: MYIC gas analysis commences this year using a small-sample sublimation extraction system, Quantum Cascade Laser spectrometer and dual inlet isotope ratio mass spectrometry for measurement of CO_2, $\delta^{13}C$-CO_2, CH_4, and N_2O as well as the main air isotopes. Refer *Fig 6*.

Fig 6 Antarctic Ice Core Analytics Labs capabilities developed for MYIC. Top: CFA chemistry lab. Bottom: gas lab. The labs are operated as a partnership between the AAD and the University of Tasmania. [photos J. Pedro]

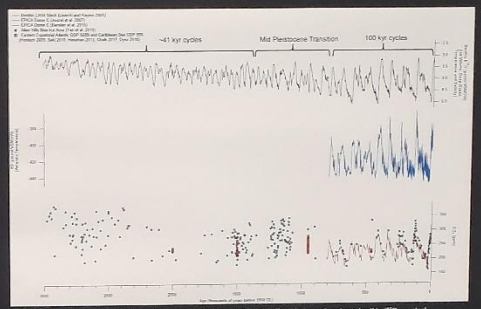


*Fig 1: Extending the continuous ice core record across the Mid-Pleistocene Transition. **Top:** Marine sediment core benthic $\delta^{18}O_{benthic}$ stack, proxy for global ice volume and ocean temperature. **Middle:** Antarctic ice core EPICA Dome C $\delta^{18}O_{ice}$ record, proxy for Antarctic temperature. **Bottom:** Continuous atmospheric CO_2 from a composite of Antarctic ice cores spanning the past 800 kyr (brown), along with discrete CO_2 measurements from Allan Hills blue ice (mid) and proxy-CO_2 from marine sediment core boron isotope-based reconstructions (light blue). Data sources in legend [figure credit: A. Mersking].*

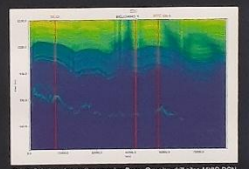


Fig 2: Polaris radar section covering Dome C region drill sites MYIC DCN (Aus), EPICA Dome C (EDC) and Beyond EPICA Oldest Ice (BE-OI) flown Jan 2024 (data credit: ICECAP, DTU, ESA, AAD).

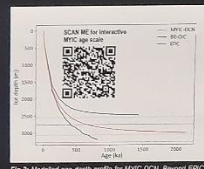


Fig 3: Modelled age-depth profile for MYIC DCN, Beyond EPICA and the observed age-depth profile at EPICA Dome C. [credit: A. Chung].

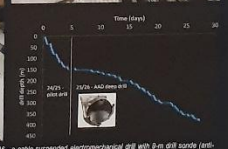


*Fig 5: **Left:** The AAD deep drill system commissioned in the field 2025/26—a cable-suspended electromechanical drill with 9-m drill sonde (anti-torque, motor, transmission, chip chamber and core barrel core barrel). capable of drilling 3-m ice cores to ice depth exceeding 3 km. In this image the drill is tilted vertically in the drill tower for descent /recovery from the borehole and drilling. Note the 4-tonne winch (rear) and drill control cabin. **Top right:** extracting the drill core barrel for transfer of the core to the ice core processing line. **Right bottom:** Drill penetration versus drilling days for the 24/25 and 25/26 seasons. [photos J. Pedro]*

AFFILIATIONS
[1]Australian Antarctic Division (AAD), Kingston, Australia, [2]Australian Antarctic Program Partnership (AAPP), Institute for Marine and Antarctic Studies (IMAS), University of Tasmania, Hobart, Australia, [3]Centre for Australian Weather and Climate Research, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Hobart, Australia, [4]Australian Nuclear Science and Technology Organisation (ANSTO), Lucas Heights, Australia, [5]Université Grenoble Alpes, CNRS, INRAE, IRD, Grenoble INP, IGE, 38000 Grenoble, France, [6]British Antarctic Survey, Cambridge, UK, [7]Institute for Marine and Antarctic Studies (IMAS), University of Tasmania, Hobart, Australia.

Australian Government | AUSTRALIAN ANTARCTIC PROGRAM | UNIVERSITY of TASMANIA | British Antarctic Survey | ANSTO | CSIRO | UGA Université Grenoble Alpes

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Fig 6 Antarctic Ice Core Analytics Labs capabilities developed for MYIC. Top: CFA chemistry lab. Bottom: gas lab. The labs are operated as a partnership between the AAD and the University of Tasmania. [photos J. Pedro].

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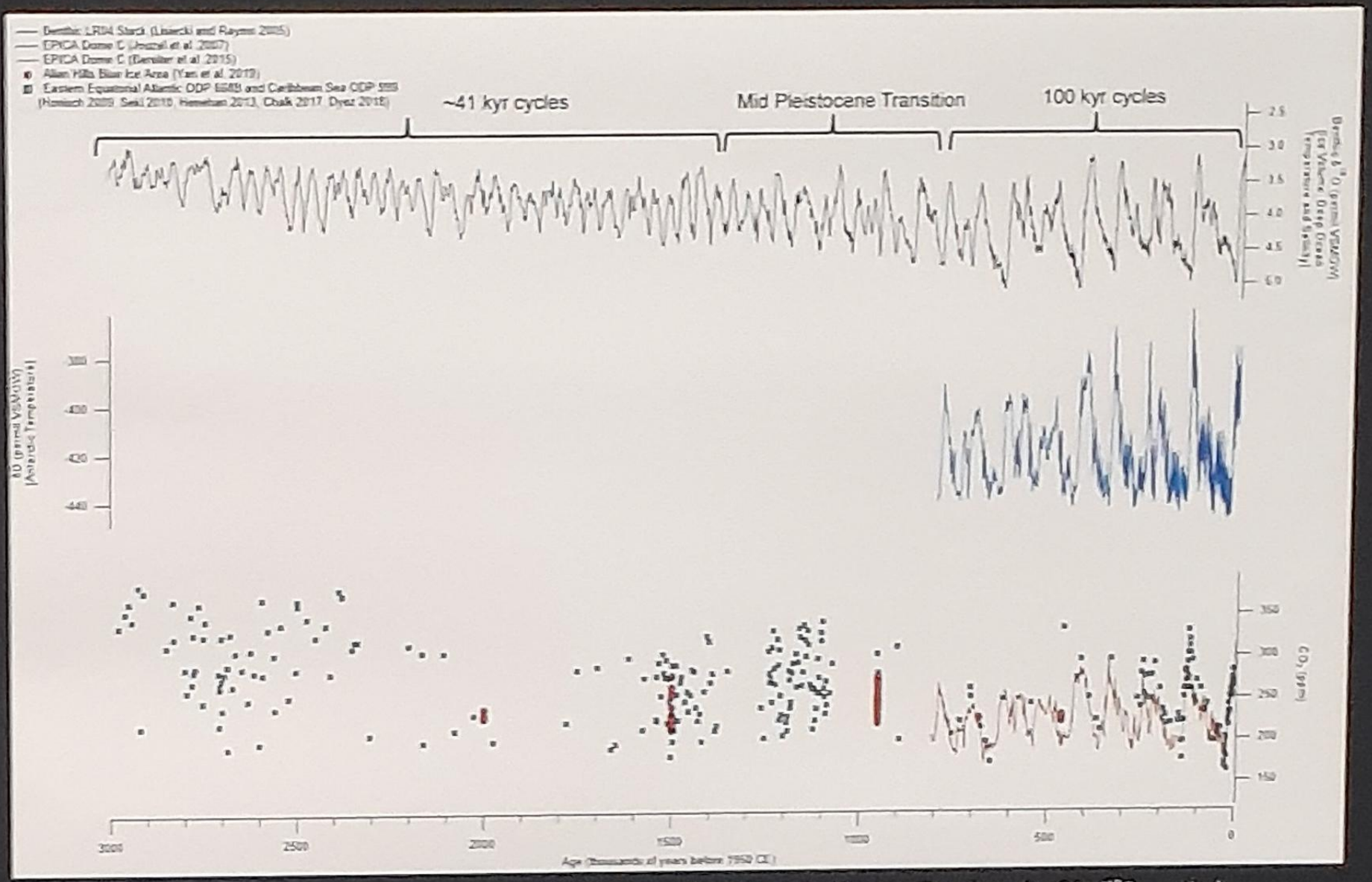


Fig 1: *Extending the continuous ice core record across the Mid-Pleistocene Transition.* ***Top:*** *Marine sediment core benthic* $\delta^{18}O_{calcite}$ *stack, proxy for global ice volume and ocean temperature.* ***Middle:*** *Antarctic ice core EPICA Dome C* $\delta^{18}O_{water}$ *record, proxy for Antarctic temperature.* ***Bottom:*** *Continuous atmospheric* CO_2 *from a composite of Antarctic ice cores spanning the past 800 kyr (brown), along with discrete* CO_2 *measurements from Allan Hills blue ice (red) and proxy-*CO_2 *from marine sediment core boron isotope-based reconstructions (light blue). Data sources in legend [figure credit: A. Menking].*

What was the earliest earth atmosphere like?

Where did oxygen come from?

Why does it stay fairly constant these days?

The Great Oxidation Event – how cyanobacteria changed life

A mass extinction caused by oxygen.

Early Earth and its Atmosphere

Earth formed about 4.6 billion years ago from a swirling disk of dust and gas orbiting the young Sun.

It was too hot to hold onto any gases. What little atmosphere it might have had—primarily hydrogen and helium - would have been swept away by the solar wind.

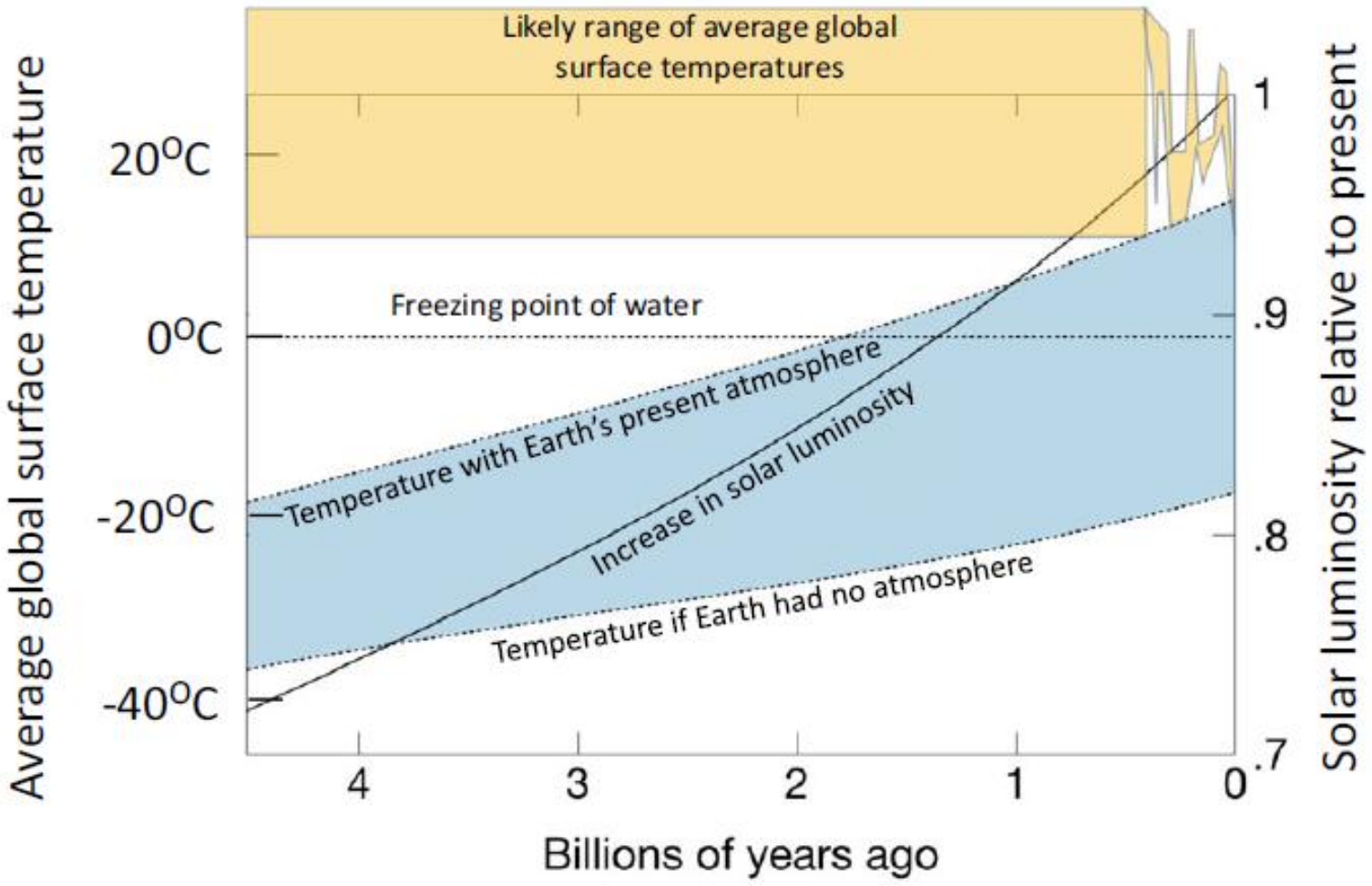
Bombardment from space kept the surface hot and vaporised any moisture but brought minerals and ammonia (nitrogen).

Around 4.3 billion years ago earth started to cool, and the deluge of space rocks eased up. As Earth cooled, it is thought that volcanoes burst through the crust, pouring out lava and belching gases similar to what comes out of volcanoes today – nitrogen, hydrogen sulphide, carbon dioxide, sulfur dioxide, water vapour and traces of methane and ammonia. There was no oxygen yet and no ozone layer to block ultraviolet rays.

https://www.sciencenewstoday.org/exploring-the-history-of-earths-atmosphere

But the Sun back then was only about 70% as bright as it is today - the "***faint young Sun paradox***":

- how could Earth stay warm enough to support liquid water if the Sun was so dim?



Climate Change – Geoscience Perspective page 309

The answer lies in the “greenhouse gases”: Carbon dioxide, water vapour and, especially, methane block heat leaving earth. Without them Earth might have been an icy desert.

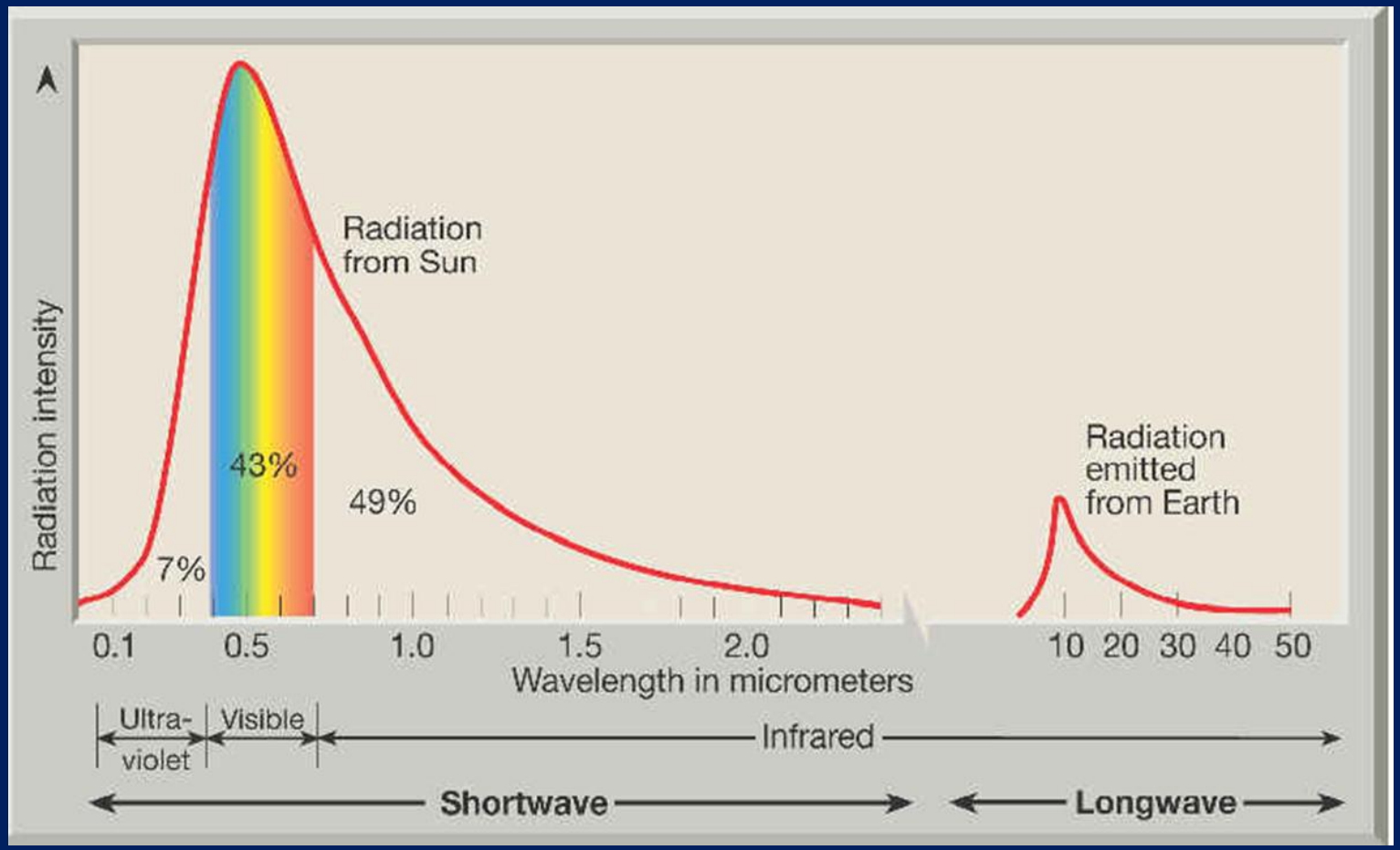
Water vapour, another powerful greenhouse gas, began to condense as the planet cooled. Rains fell for centuries, possibly for thousands of years, leading to oceans. This hydrosphere, originating from volcanoes, was the first great transformation on Earth’s surface.

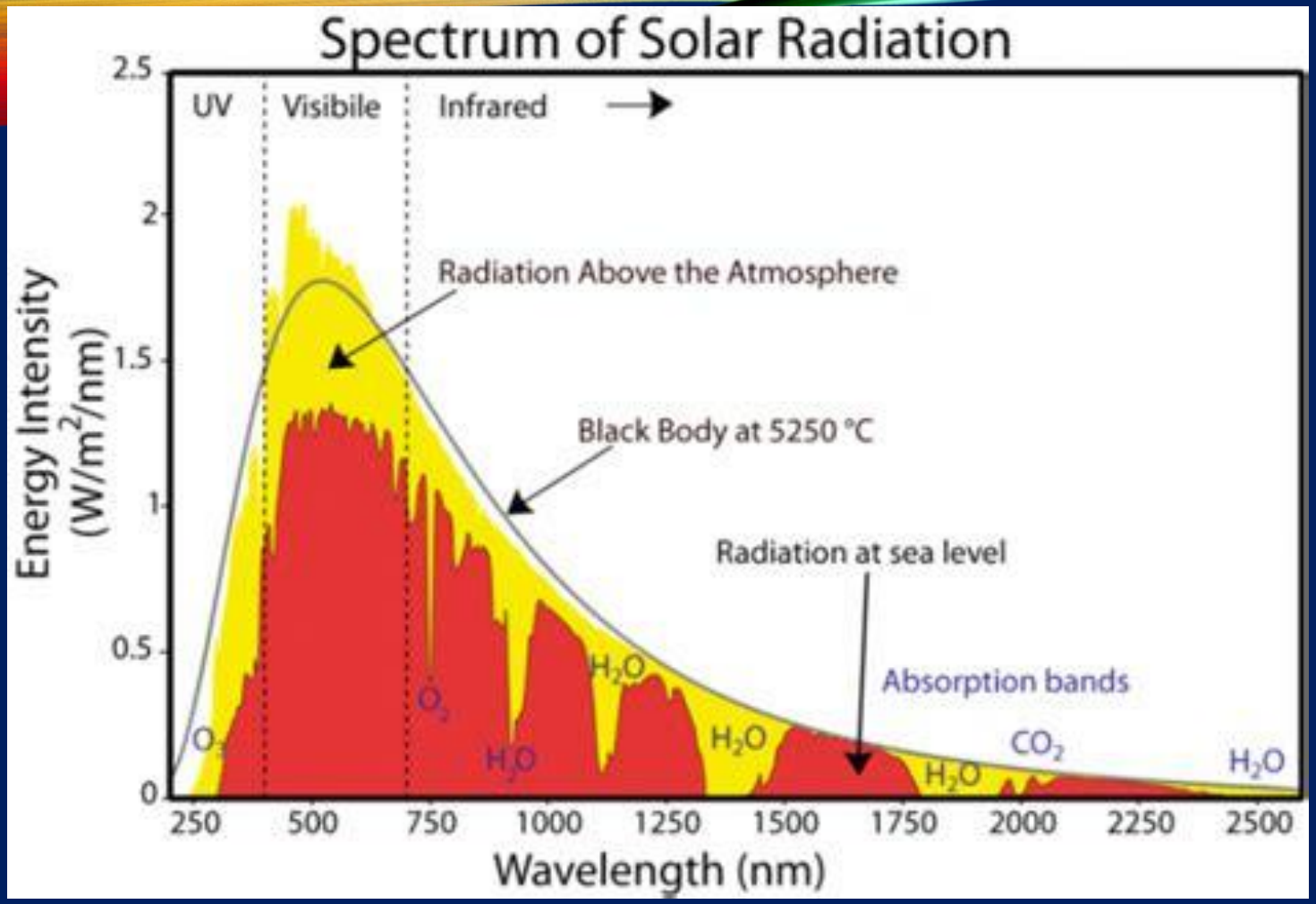
There were possibly occasional 'whiffs' of oxygen puffing up from volcanic activity or from sunlight breaking apart water vapour, but it wouldn’t take long for it to react with the other gases, leaving the planet largely oxygen free (less than 0.001%) for its first billion years or so.

Slight diversion: What are “greenhouse gases”?

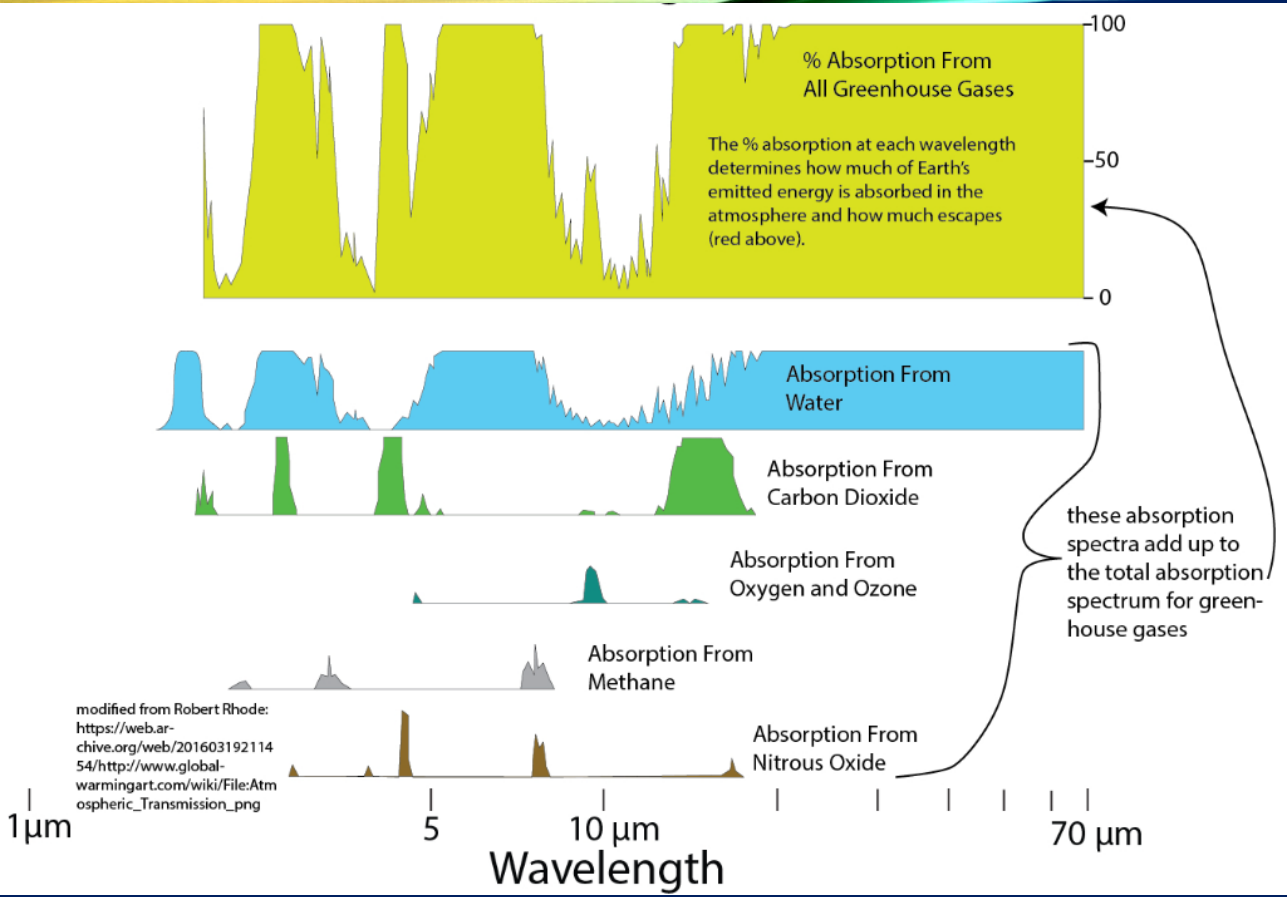
The Earth is warmed by the incoming sunlight and then sends (radiates) heat (infrared energy) back to space. If there is an imbalance the Earth will either warm up or cool down. However, measurements show that it is very close to balanced.

A very important point – sunlight has a very different spectrum from the heat that the Earth sends back to space.





The air is almost (but not completely) transparent to sunlight. About 30% is reflected back to space (mainly from clouds and the earth's surface) but 70% is absorbed by, and heats up, the land, ocean and air.



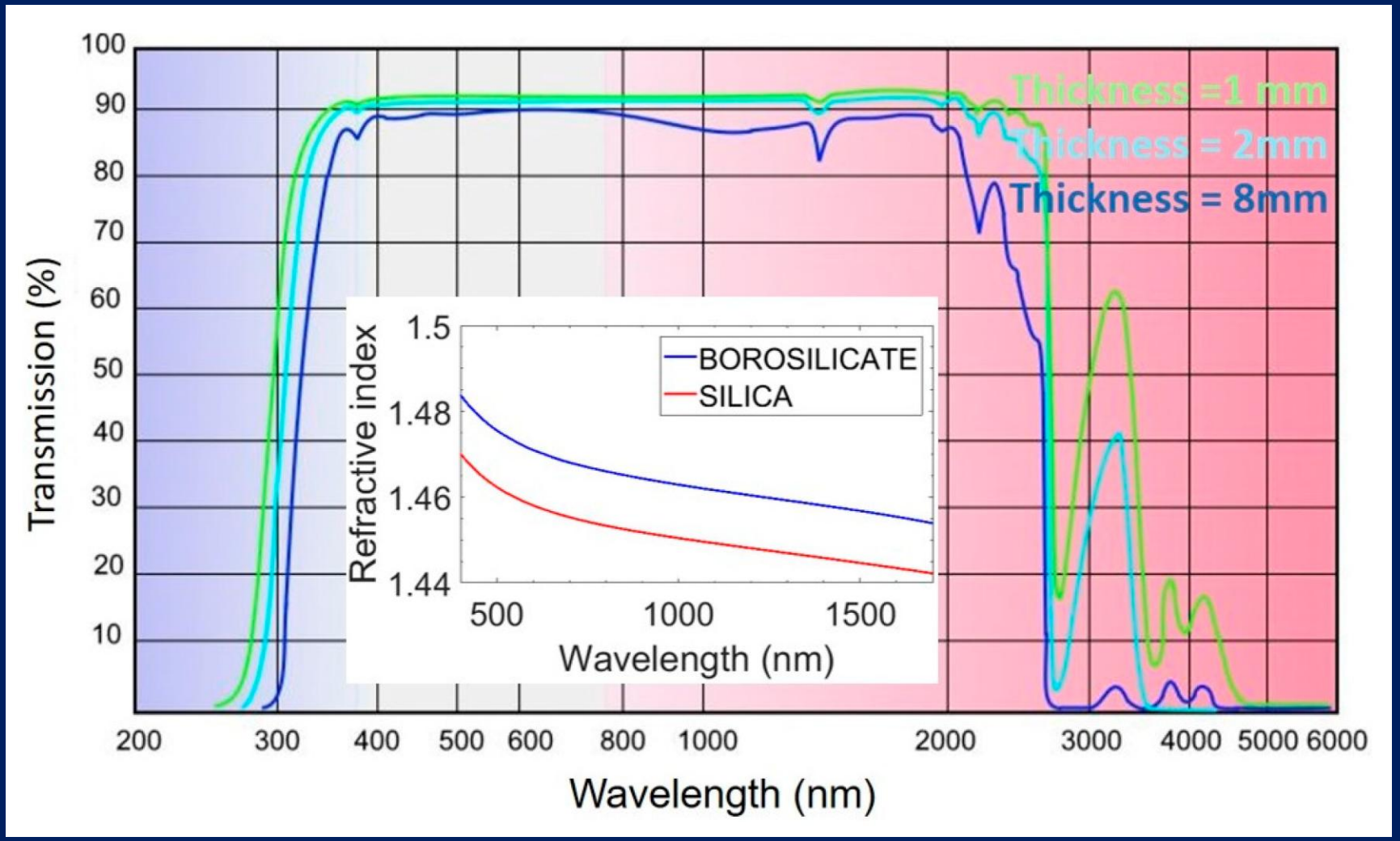
On the other hand, there are gases in the air that are very effective in absorbing infrared radiation. They then emit the infrared energy at the colder top of the atmosphere. The net effect is to trap the heat in the atmosphere. These are called "greenhouse gases".

The diagram shows the absorption spectra for some of these gases and their comparative effect in today's world. In the early Earth there would have been much more methane and so its effect would have been much greater.

https://courses.ems.psu.edu/earth103/node/1006

You can feel how effective this mechanism is when you leave your car out in the sun!

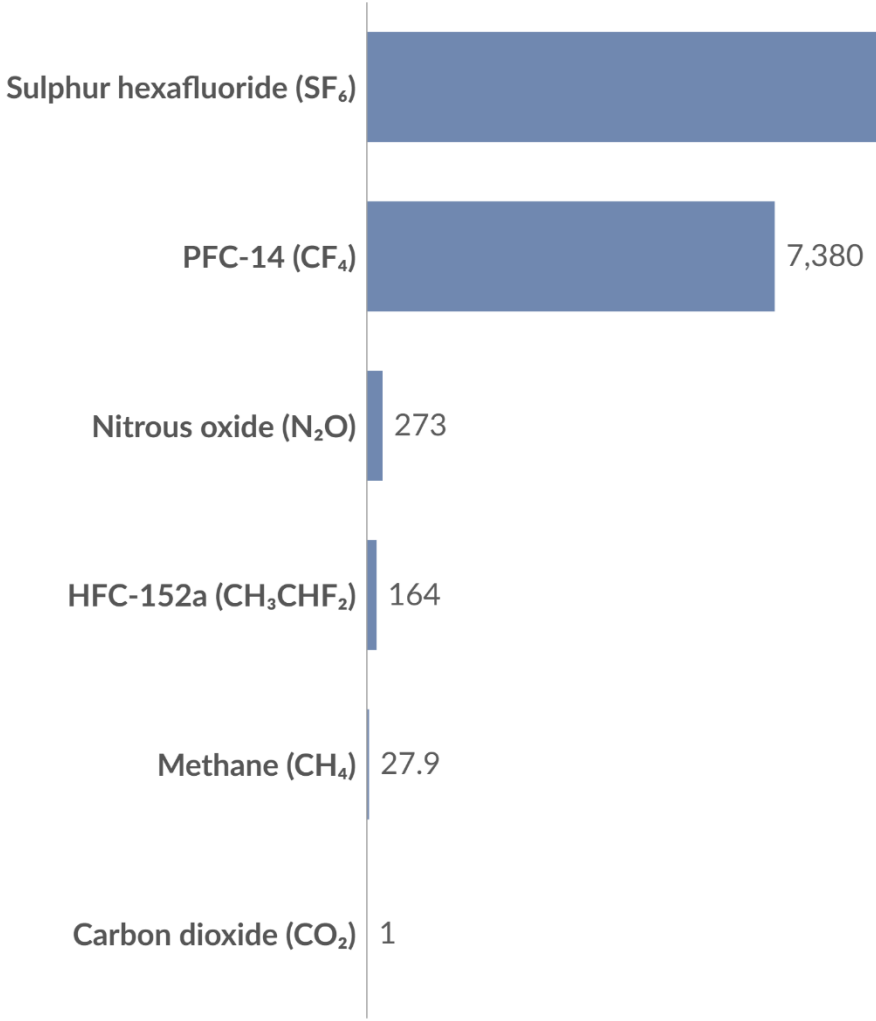
Glass is transparent but blocks infrared radiation – its transmission drops off rapidly from the visible range to the infrared.

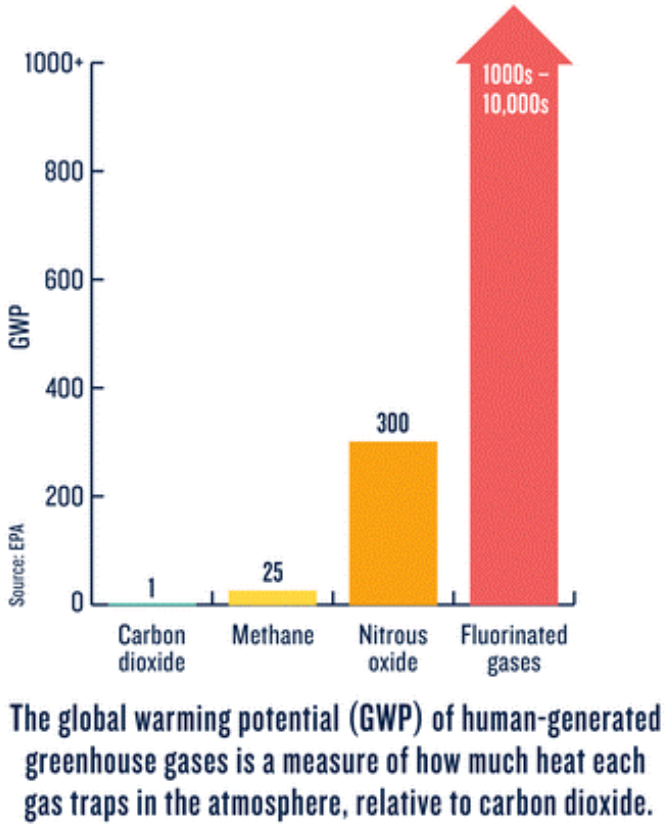


Global warming potential of greenhouse gases relative to CO2

Our World in Data

Global warming potential measures the relative warming impact of one unit mass of a greenhouse gas relative to carbon dioxide over a 100-year timescale.



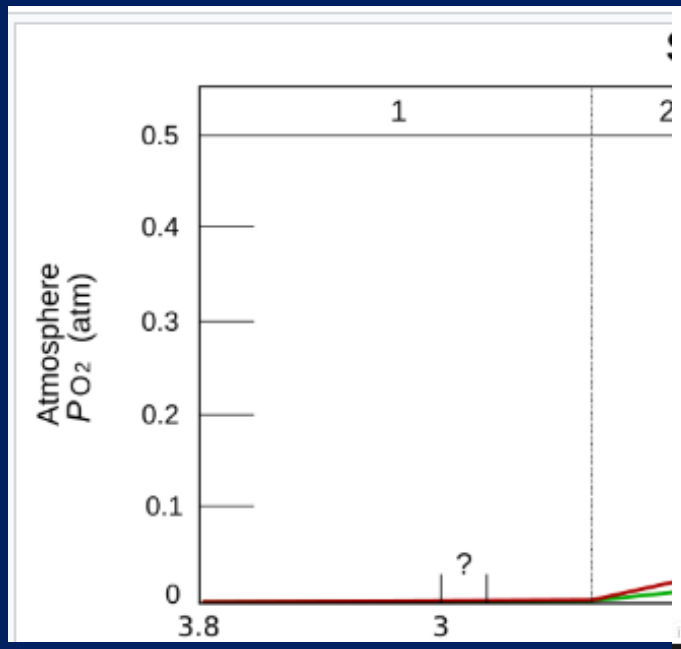


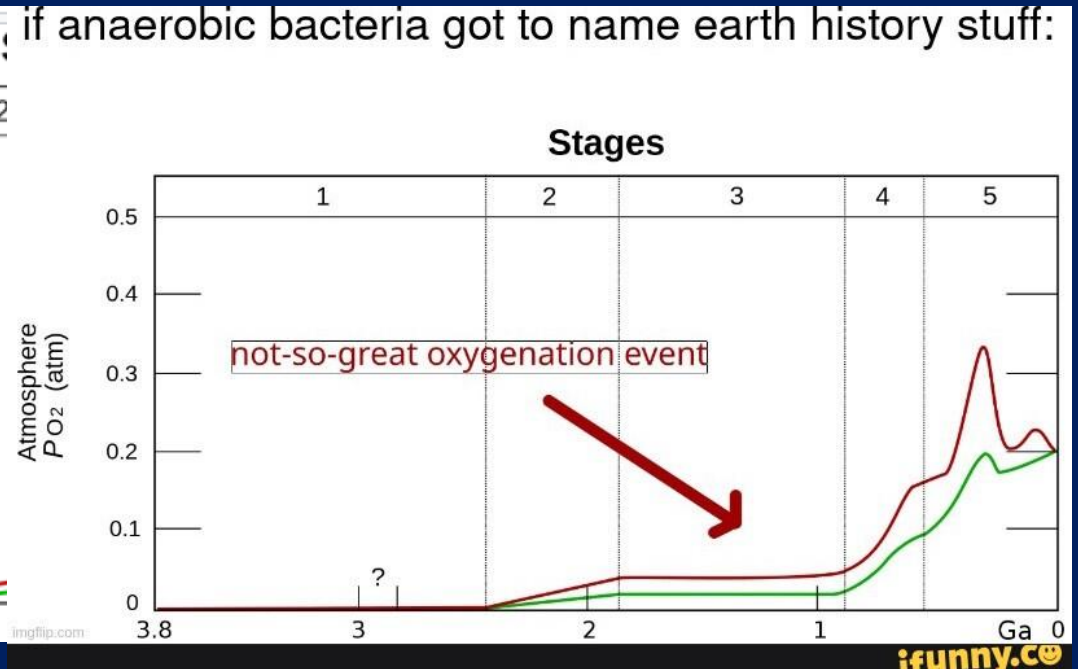
Data source: IPCC (2021)

Early Earth and its Atmosphere (continued)

- Bodies of water formed and sunlight provided energy for various *geochemical* reactions - and possibly *precursors to biochemistry* – to take place.
- Around 3.8 billion years ago the earliest organisms formed - single-celled microbes clinging to hydrothermal vents or floating in shallow seas. They were anaerobic and for them, oxygen was toxic.
- Perhaps within a few hundreds of millions of years of Earth's formation, a form of *photosynthesis* had developed – but not the oxygen producing type – e.g. purple bacteria and green sulphur bacteria.
- Around 2.7 billion years ago that 'oxygenic' variety of photosynthesis originated in ancestors of cyanobacteria (blue-green algae).
- In oxygenic photosynthesis energy from sunlight is captured and used to convert carbon dioxide and water into organic compounds (mostly sugars) – food to provide energy for the organism.
- However, in doing so, they released a by-product oxygen.

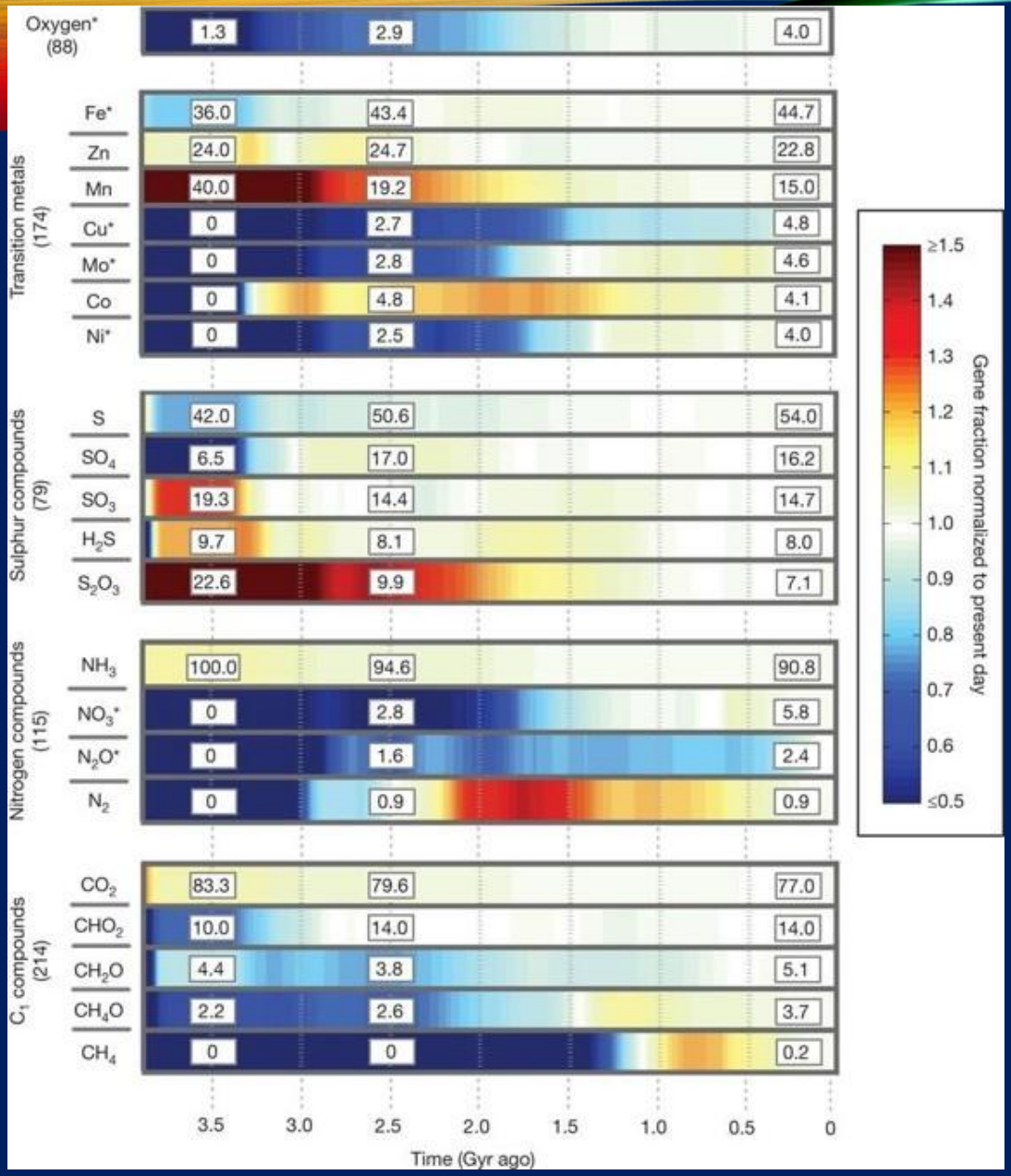
- The early cyanobacteria may have poisoned themselves with their waste product (oxygen) until they evolved the capacity to live in an oxygen rich environment.
- For millions of years, this oxygen bubbled quietly into the oceans, reacting with iron, sulphur and other elements.
- Eventually, the rate of release of volcanic gases slowed, reactive sinks were used up, and **oxygen began to accumulate in the air**, rising up from the sea.
- Around 2.3-2.4 billion years ago the trickle of oxygen gas finally produced significant levels of oxygen in the atmosphere, the ***Great Oxidation Event*****.**





How do we know all that when it happened so long ago?

- The oldest rocks include some minerals that would be changed in the presence of even small amounts of oxygen: pyrite, siderite, uraninite and molybdenum compounds.
- Continental red beds (*banded iron formations*) – ferric iron (magnetite and haematite) began to appear in the geological record.
- Isotopic composition of sulphur – "mass independent fractionation" reactions equally affecting *all* sulphur isotopes (^{32}S, ^{33}S, ^{34}S, ^{36}S) – presumably from UV light on volcanic SO_2 emissions, that could only have occurred if there were no ozone layer. The ozone layer was formed from oxygen.
- Some very old fossils are depleted in ^{13}C isotope – indicating organic life forms although not necessarily from oxygen-based life. Atmospheric oxygen concentration of about 2% is needed for the formation of compounds such as collagens used by all multicellular animals to provide connective tissue in complex organ systems.
- DNA evidence recording different metabolic types through Earth's history (Cranfield, Chapter 2; Plate 5). There was a diverse biosphere before oxygen, driven by chemical compounds associated with vulcanism.



David, L. and Alm, E. **Rapid evolutionary innovation during an Archaean genetic expansion.** *Nature 469*, 93–96 (2011). https://doi.org/10.1038/nature09649

Investigating the chemical processes in microbial organisms *independent of the geological evidence* – all organisms record their evolutionary development in their DNA (in a complicated way!) – **including in their metabolism**.

The diagram shows fractions of enzymes with various elements compared with present day values:

White: today's ratio
Red/Brown: higher than today
Blue: less than today.

Red or white at the start shows that mechanism was present back then (e.g. Mn and Sulphates)

Blue at the start indicates later development (including oxygen).

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RESEARCH ARTICLES | 07 AUG 2025

The emergence of metabolisms through Earth history and implications for biospheric evolution

Special Collection: Royal Society journal articles by Fellows of the Royal Society

Edmund R. R. Moody; Tom A. Williams; Sandra Álvarez-Carretero; Gergely J. Szöllősi; Davide Pisani; Timothy M. Lenton; Philip C. J. Donoghue

+ Author & article information

Philos Trans R Soc Lond B Biol Sci (2025) 380 (1931): 20240097 .

https://doi.org/10.1098/rstb.2024.0097 **Article history**

Abstract

4(b) Fit to geochemical record

Where sedimentary geochemical evidence of metabolic activity exists, there is generally good agreement with our inferences ….. There is coherent evidence for oxygenic photosynthesis by 2.945 Ga and so our inference, that modern photosynthesis pathways rise from 25% completeness at 3 Ga to 50% complete at 2.5 Ga is consistent with this.

https://royalsocietypublishing.org/rstb/article/380/1931/20240097/234994/The-emergence-of-metabolisms-through-Earth-history

Consequences of the Great Oxidation Event

- To many of the organisms that had evolved in an oxygen-free world, it was a catastrophe. Oxygen attacked their cellular machinery, driving some species into extinction. But for others, oxygen enabled the rise of aerobic respiration, a far more efficient way to extract energy from food, leading to more complex life.

- Oxygen likely oxidized atmospheric methane (a strong greenhouse gas) to carbon dioxide (a weaker one) and water. This weakened the greenhouse effect of the Earth's atmosphere, causing planetary cooling, which may have been the trigger for a series of ice ages known as the Huronian glaciation (2.45–2.22 billion years ago).

- There was a new opportunity for biological diversification, as well as tremendous changes in the nature of chemical interactions between rocks, water and air. Life had remained energetically limited until the widespread availability of oxygen.

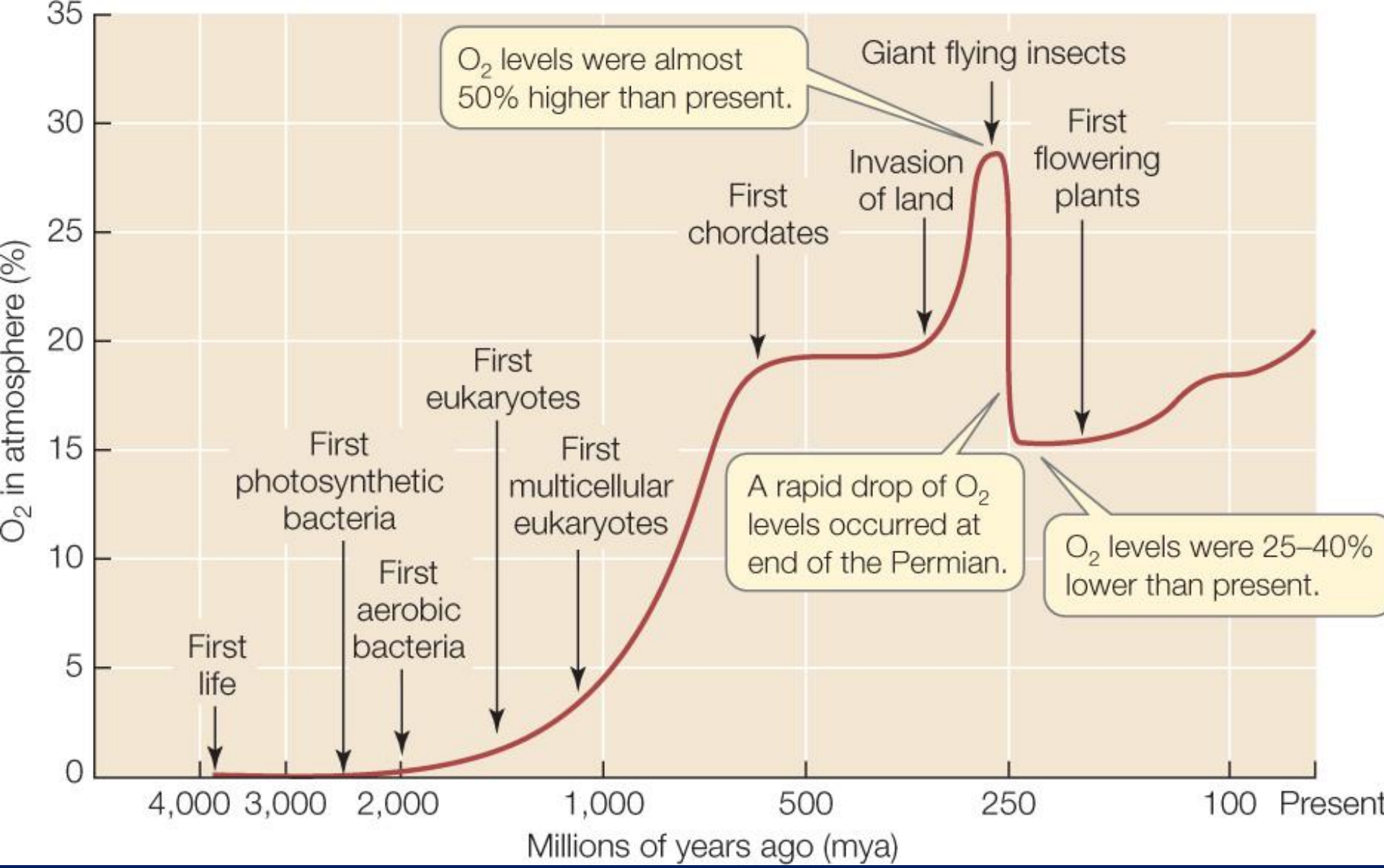
- Many new minerals, oxidized forms, appeared.

Around 540 million years ago, the atmosphere reached a tipping point. Oxygen levels rose to a threshold that could support larger, more complex life forms. The Ediacran era and the Cambrian Explosion saw a riot of new body plans—most of them powered by aerobic metabolism.

Animals colonized the shallows and later the land.

Over the next hundreds of millions of years, Earth's oxygen levels fluctuated, rising and falling with tectonic shifts, evolutionary booms, and extinction events. During the Carboniferous period, oxygen soared to nearly 35%, creating a world where dragonflies the size of seagulls soared through swampy forests. But high oxygen also brought volatility—fire, for example, became far easier to spark and far harder to contain.

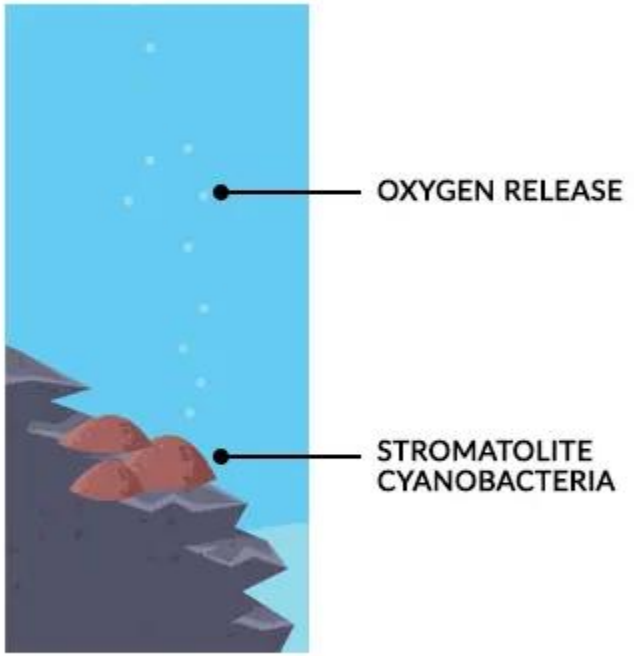
One major contributor to life is the ozone layer formed by the interaction of solar ultraviolet light with oxygen. It acts as a shield, protecting life from harmful UV radiation.

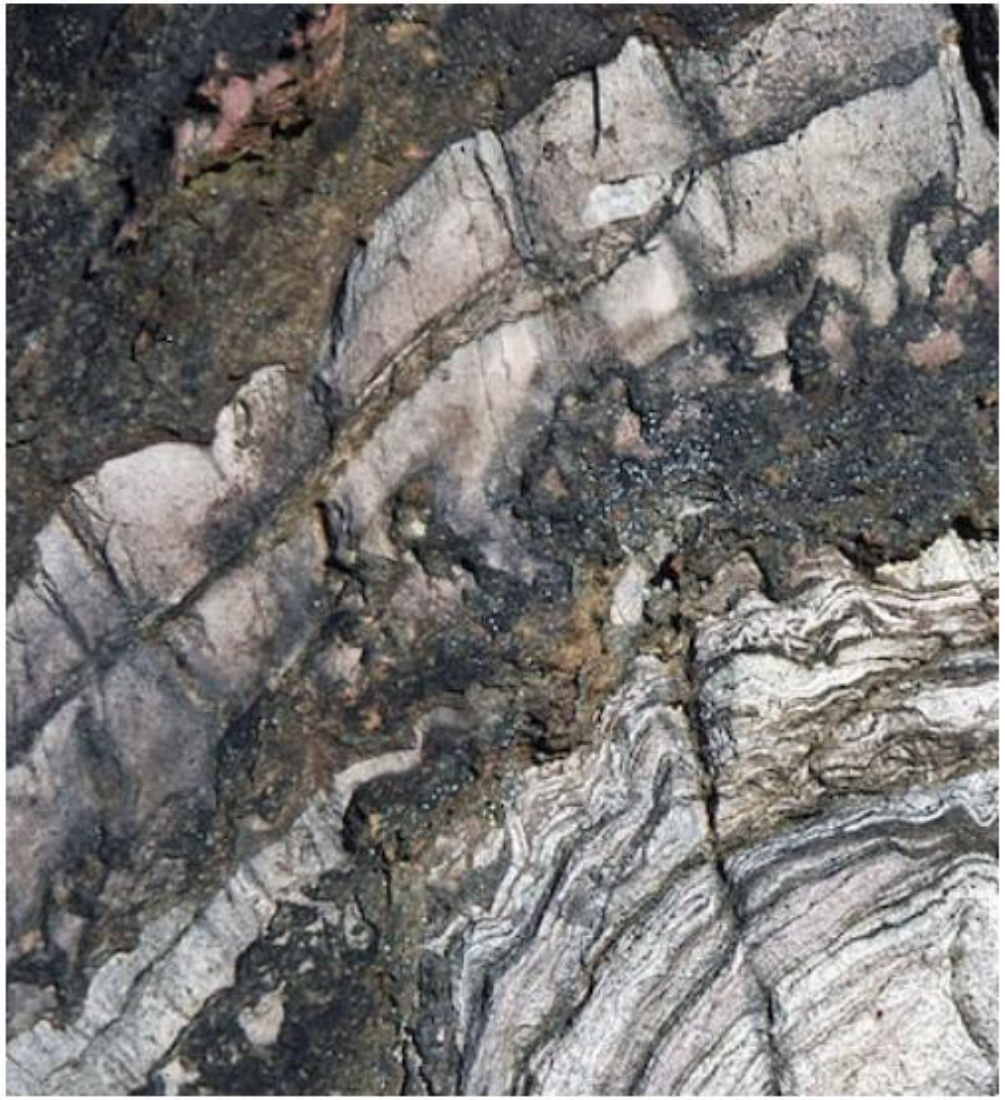


https://www.macmillanhighered.com/BrainHoney/Resource/6716/digital_first_content/trunk/test/hillis2e/asset/img_ch18/c18_fig07.jpg

How a single-celled organism almost wiped out life on Earth ...

https://youtu.be/dO2xx-aeZ4w





Stromatolites are large, layered structures built up by mats of cyanobacteria. Source: James St. John/flickr.com.

Clues to the Early Rise of Oxygen on Earth Found in Sedimentary Rock

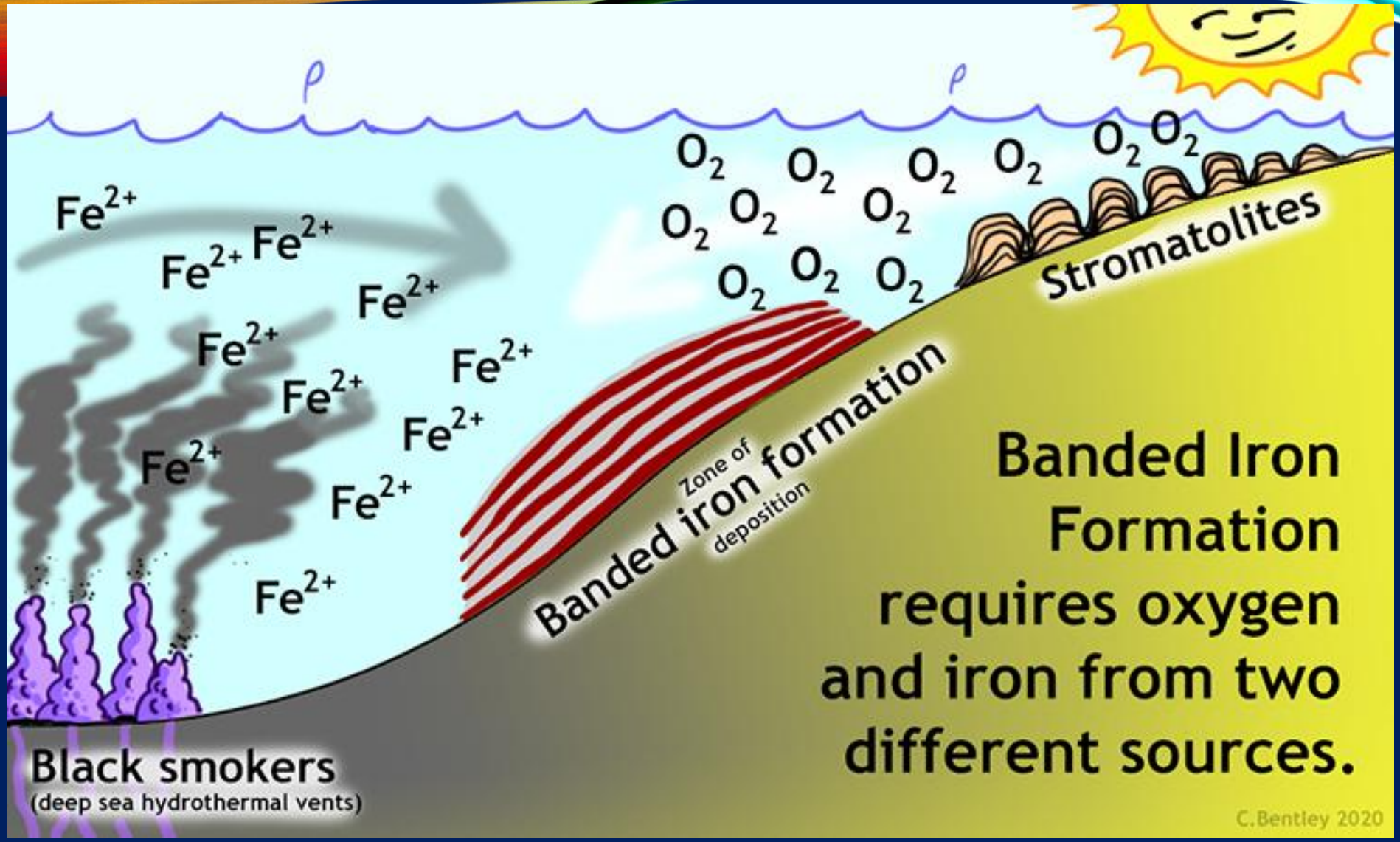
RESEARCH HIGHLIGHTS March 05, 2019 / Posted by: Miki Huynh

Photo of stromatolites in Shark Bay, Western Australia. Scientists have found evidence for ocean oxygenation happening at an earlier date than the Great Oxygenation Event in Mt. McRae Shale in Western Australia. Source: A. Anbar / ASU

https://astrobiology.nasa.gov/nai/articles/2019/3/5/clues-of-earths-early-rise-of-oxygen/index.html

Banded iron formation (BIFs) – the basis for the iron ore in the Pilbara!

- Banded iron formation can form only when dissolved ferrous iron is transported into shallow basins where oxygen can mix with the water and the ferric iron oxide is deposited out.
- Needs both a **deep ocean without oxygen** and **an oxidized shallow ocean** where the ferrous iron is oxidized to insoluble ferric iron.
- Deposition was episodic and there may have been significant intervals without oxygen.
- BIFs largely disappear from the geological record at 1.85 billion years ago, after peaking at about 2.5 billion years ago. The end of the deposition is interpreted as marking the oxygenation of the deep ocean.

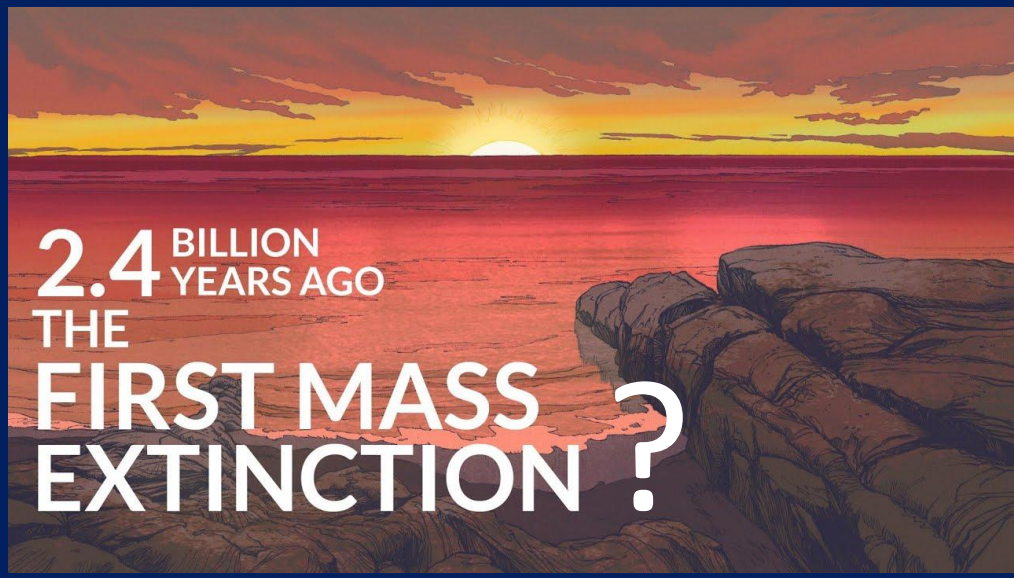


https://opengeology.org/historicalgeology/case-studies/greenstone-belts-primordial-tectonics/

Was there a mass extinction associated with the GOE?

Oxygen is very reactive element. We have specialized enzymes for dealing with the damage that free oxygen can cause our more delicate organic molecules, such as DNA. So, it's easy to imagine that without adaptations for coping with oxygen, early organisms would die off in huge numbers.

It's possible there was a catastrophic die-off of many existing anaerobic species, but it is difficult to tell and so it is not generally counted as a "*mass extinction*".



Oxygen levels in the air – sources and sinks

- Dissolved iron in oceans is one oxygen sink. This was important in the early stages of oxygen appearing in the atmosphere.
- The rate of photosynthesis is a major source. But if all the life forms decay there is no nett increase of oxygen.
- Burial of organic material and pyrites can allow oxygen to accumulate in the atmosphere.
    - When land plants spread over the continents in the Devonian (around 400 million years ago) more organic carbon was buried and likely allowed higher oxygen levels to occur.
    - The sulphide/sulphate cycle (driven by emission of hydrogen sulphide and sulphur dioxide from volcanoes) also operates on the geological time-scale and has been important at times in Earth's history.

Maintaining oxygen levels in the atmosphere

In the last few thousand years, the level of oxygen in the air has been maintained at around 21 %.

It seems that there is a balance between three short term processes:

- **Respiration**
- **Combustion/Decomposition**
- **Photosynthesis**

Essentially, it is life on Earth that is keeping the balance it needs.

Long term biological/geological processes (on the time-scale of millions of years): organic carbon and pyrite burial.

Oxygen in the Atmosphere – some references

https://www.sciencealert.com/where-did-earth-s-oxygen-come-from

https://www.sciencenewstoday.org/exploring-the-history-of-earths-atmosphere

Great Oxidation Event - Wikipedia
https://en.wikipedia.org/wiki/Great_Oxidation_Event

Oxygen – a Four Billion Year history. Donald Canfield. (Princeton University Press, 2014)

How a single-celled organism almost wiped out life on Earth ...

https://youtu.be/dO2xx-aeZ4w

The Time Oxygen Almost Killed Everything
Squarespace Video: https://youtu.be/qERdL8uHSgI