Past and Future Climate – Present Weather

Week 5

The Story in Ice Cores

Terry Hart

Dates

Term 2

23 April	**Climate – The Story in Ice Cores**
30 April	Geology
7 May	**Climate – The Story in Ice Cores (2)**
14 May	Geology
21 May	**Climate – Climate and Human Evolution**
28 May	Geology
4 June	**Climate – The Holocene (“Recent” Past)**
11 June	Geology
18 June	**Climate – El Niño/La Niña**

https://sonicpathfinder.org/U3A/Weather/Weather_index.html

Understanding Weather

by **Terry Hart**

Nunawading U3A

In 2026 Terry prosemted a course of lectures on Unferstading Climate

(A short tutorial - just in case you did not know!
You can look for a specific text string on this (or any other) web page. To find out how, go to How to jump to a text string)

A collection of links to pdf versions of Terry Hart's Power Point presentations.
(Links are

Introduction

Visiting th

Embedded a

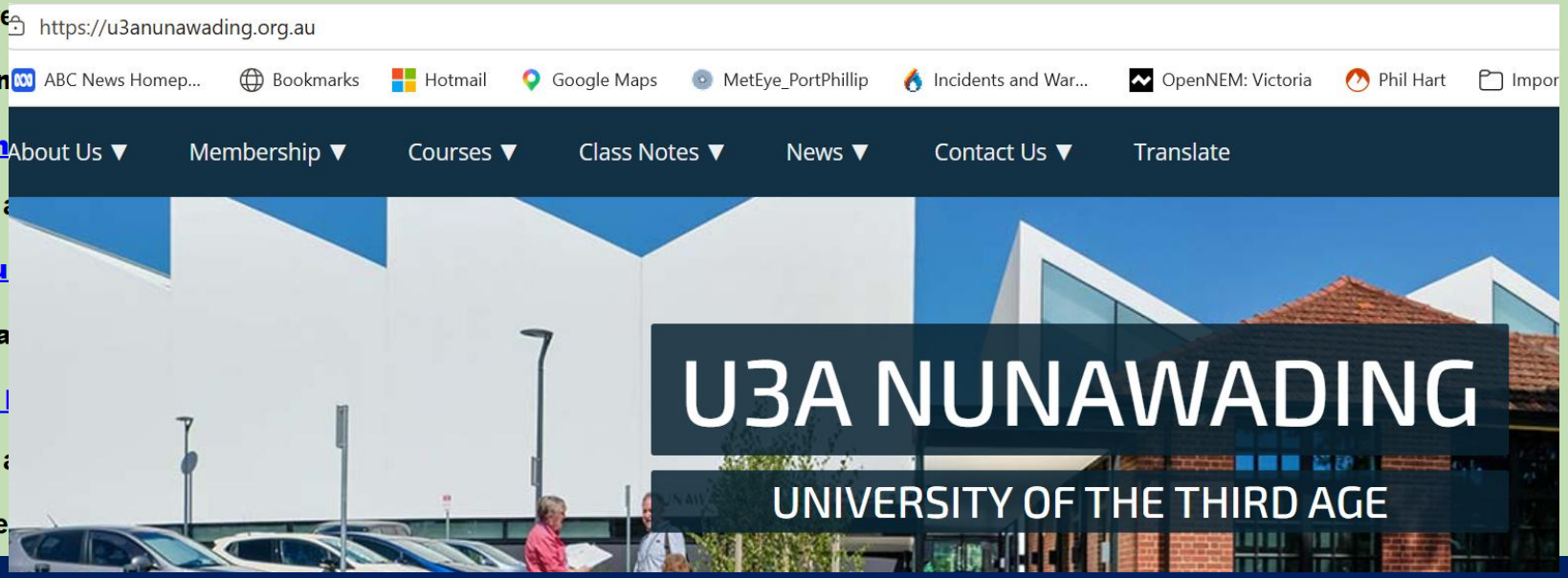
Bureau

What is Wea

Lightning

Embedded a

Youtube



https://u3anunawading.org.au/weather-and-climate-class-notes/

https://www.bom.gov.au/news-and-media/severe-tropical-cyclone-narelles-journey-across-northern-australia

TC *Narelle* is the second system, after Severe Tropical Cyclone *Ingrid* in 2005, to make landfall as a **severe tropical cyclone** (category 3 or stronger) in Queensland, the Northern Territory, and Western Australia since reliable intensity records began in 1980-81.

Latest Weather Observations for Learmonth

IDW60801

Issued at 9:23 am WST Friday 27 March 2026 (issued every 10 minutes, with the page automatically refreshed every 10 minutes)

About weather observations | Map of weather stations | Latest weather observations for WA | Other Formats

Station Details ID: 005007 Name: LEARMONTH AIRPORT Lat: -22.24 Lon: 114.10 Height: 5.0 m

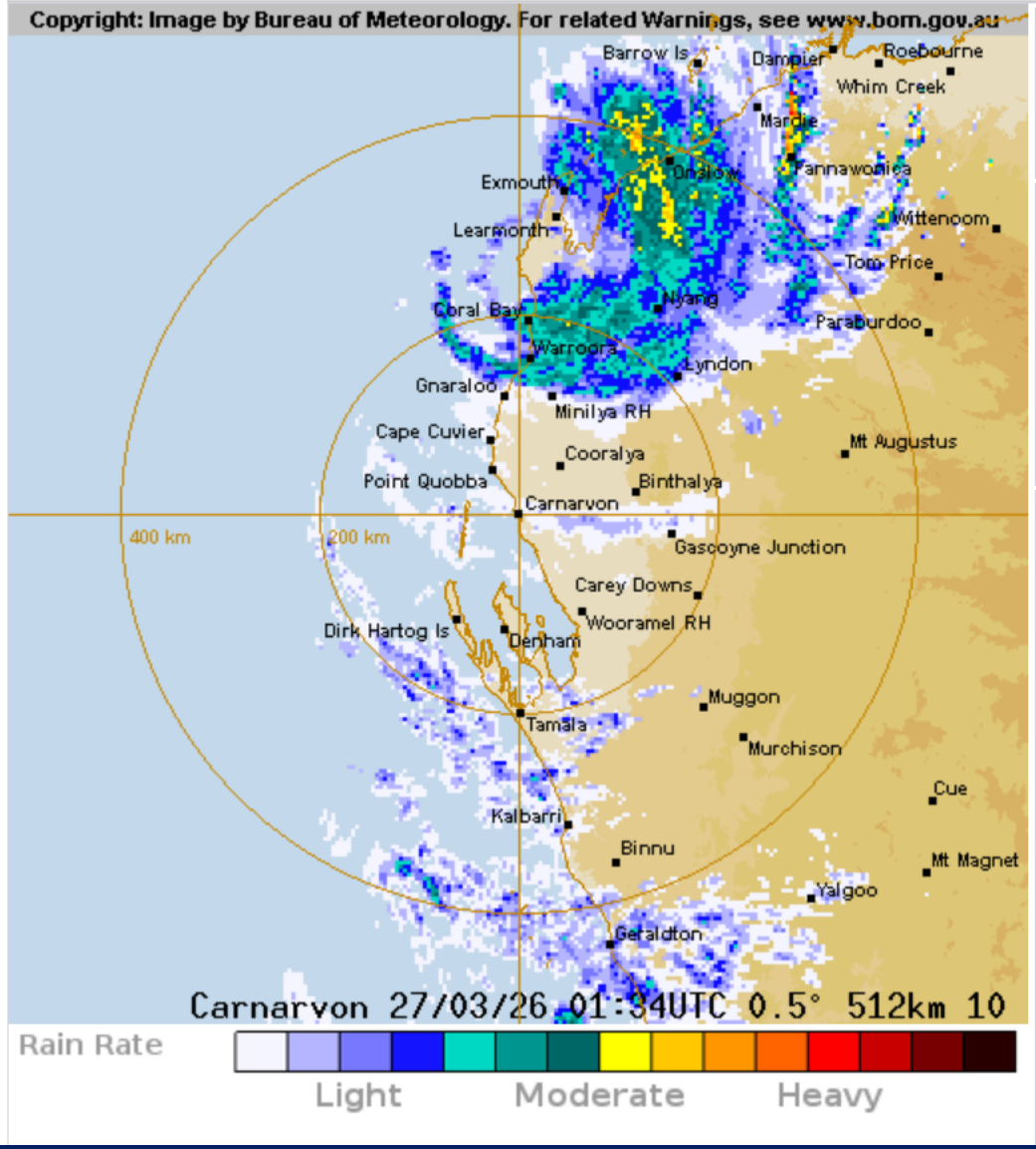
Data from the previous 72 hours. | See also: Recent months at Learmonth

Date/Time WST	Temp °C	App Temp °C	Dew Point °C	Rel Hum %	Delta-T °C	Wind					Press QNH hPa	Press MSL hPa	Rain since 9am mm
						Dir	Spd km/h	Gust km/h	Spd kts	Gust kts			
27/09:07am	24.7	4.8	24.4	98	0.2	N	137	167	74	90	972.5	972.5	7.6
27/09:00am	24.7	4.8	24.4	98	0.2	N	137	178	74	96	971.4	971.4	231.4
27/08:53am	24.8	4.5	24.5	98	0.2	N	139	178	75	96	970.4	970.4	225.4
27/08:30am	24.8	4.5	24.5	98	0.2	N	139	170	75	92	968.0	968.0	209.0
27/08:00am	25.1	5.0	24.8	98	0.2	NNE	139	176	75	95	965.9	965.9	202.8
27/07:30am	25.1	5.0	24.8	98	0.2	NE	139	180	75	97	965.2	965.2	171.2
27/07:00am	25.3	7.1	25.0	98	0.2	NE	130	163	70	88	966.9	966.9	139.4
27/06:30am	25.2	5.2	24.9	98	0.2	ENE	139	191	75	103	966.2	966.2	109.8
27/06:22am	25.2	5.9	24.9	98	0.2	ENE	135	176	73	95	966.9	966.9	106.4
27/06:00am	25.4	6.8	25.1	98	0.2	ENE	132	193	71	104	969.1	969.1	100.2
27/05:30am	24.8	5.3	24.5	98	0.2	E	135	183	73	99	970.5	970.5	90.2
27/05:18am	24.6	4.6	24.3	98	0.2	E	137	180	74	97	970.7	970.7	84.4
27/05:00am	24.5	4.1	24.2	98	0.2	E	139	187	75	101	973.1	973.1	74.2
27/04:52am	24.5	4.8	24.2	98	0.2	E	135	187	73	101	973.5	973.5	69.2
27/04:46am	24.5	5.4	24.2	98	0.2	E	132	169	71	91	974.0	974.0	66.4
27/04:30am	24.5	6.1	24.2	98	0.2	E	128	169	69	91	976.1	976.1	58.8
27/04:14am	24.4	7.1	24.1	98	0.2	ESE	122	154	66	83	977.0	977.0	54.0
27/04:00am	24.4	8.8	24.1	98	0.2	ESE	113	152	61	82	979.2	979.2	46.0
27/03:47am	24.4	9.6	24.1	98	0.2	ESE	109	139	59	75	980.8	980.8	41.6
27/03:30am	24.3	10.7	23.8	97	0.3	ESE	102	148	55	80	982.4	982.4	35.4
27/03:29am	24.3	11.0	23.8	97	0.3	ESE	100	148	54	80	982.7	982.7	34.8
27/03:28am	24.3	11.4	23.8	97	0.3	ESE	98	130	53	70	983.1	983.1	34.4
27/03:12am	24.4	11.8	23.7	96	0.5	ESE	96	135	52	73	985.2	985.1	31.0
27/03:00am	24.5	12.7	24.0	97	0.3	ESE	93	132	50	71	986.1	986.0	29.4
27/02:58am	24.4	13.0	24.1	98	0.2	ESE	91	132	49	71	986.2	986.1	29.2
27/02:53am	24.6	14.1	24.3	98	0.2	ESE	87	120	47	65	986.8	986.7	28.4
27/02:37am	24.5	13.9	24.2	98	0.2	ESE	87	130	47	70	987.5	987.4	25.6
27/02:30am	24.2	14.4	23.9	98	0.2	SE	82	124	44	67	987.8	987.7	24.4
27/02:15am	24.3	13.2	24.0	98	0.2	SE	89	119	48	64	989.0	988.9	19.4
27/02:05am	24.2	14.1	23.7	97	0.3	SE	83	113	45	61	988.9	988.8	17.4
27/02:01am	24.2	13.3	23.7	97	0.3	SE	87	113	47	61	989.5	989.4	16.2
27/02:00am	24.2	13.3	23.7	97	0.3	SE	87	113	47	61	989.5	989.4	16.2
27/01:51am	24.1	13.9	23.6	97	0.3	SE	83	111	45	60	989.7	989.6	15.0
27/01:46am	24.2	14.1	23.7	97	0.3	SE	83	117	45	63	990.0	989.9	13.4

512 km composite Carnarvon Radar Loop

View the current warnings for Western Australia

Loops	Single images	Radar Site Information	Othe
Radar	64 km	128 km	256 km	**512 km con**



Nearby radars

Radar controls

Frame: 7
09:36 WST
27/3/2026

Pointer data

Pointer

440 km West
62 km North
444 km Away
278 Degrees

Map Coordinates

23 deg 2 min S
110 deg 29 min E

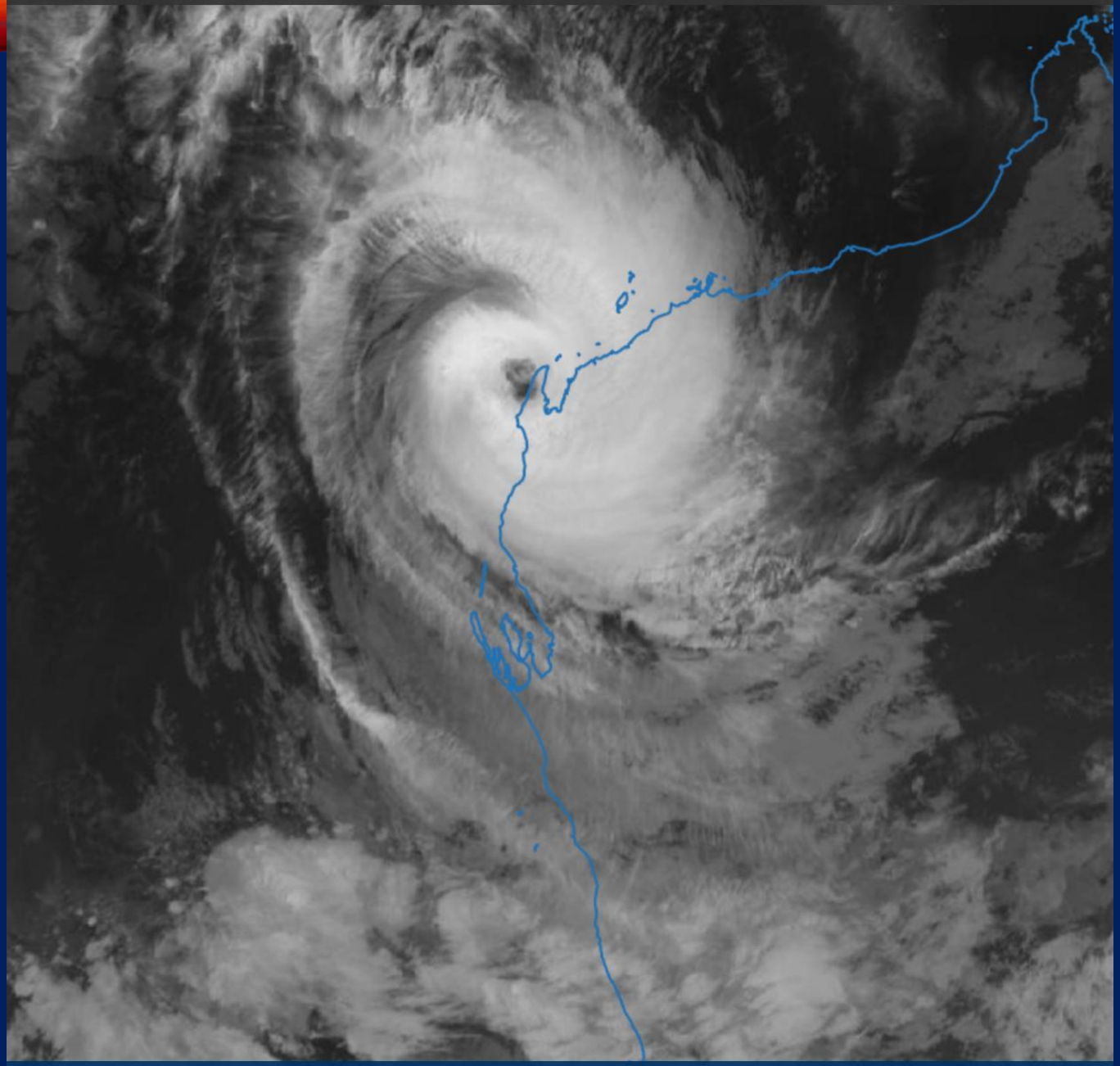
(•) Degrees & Minutes
( ) Decimal Degrees

Origin

114 km East
144 km North Rst.

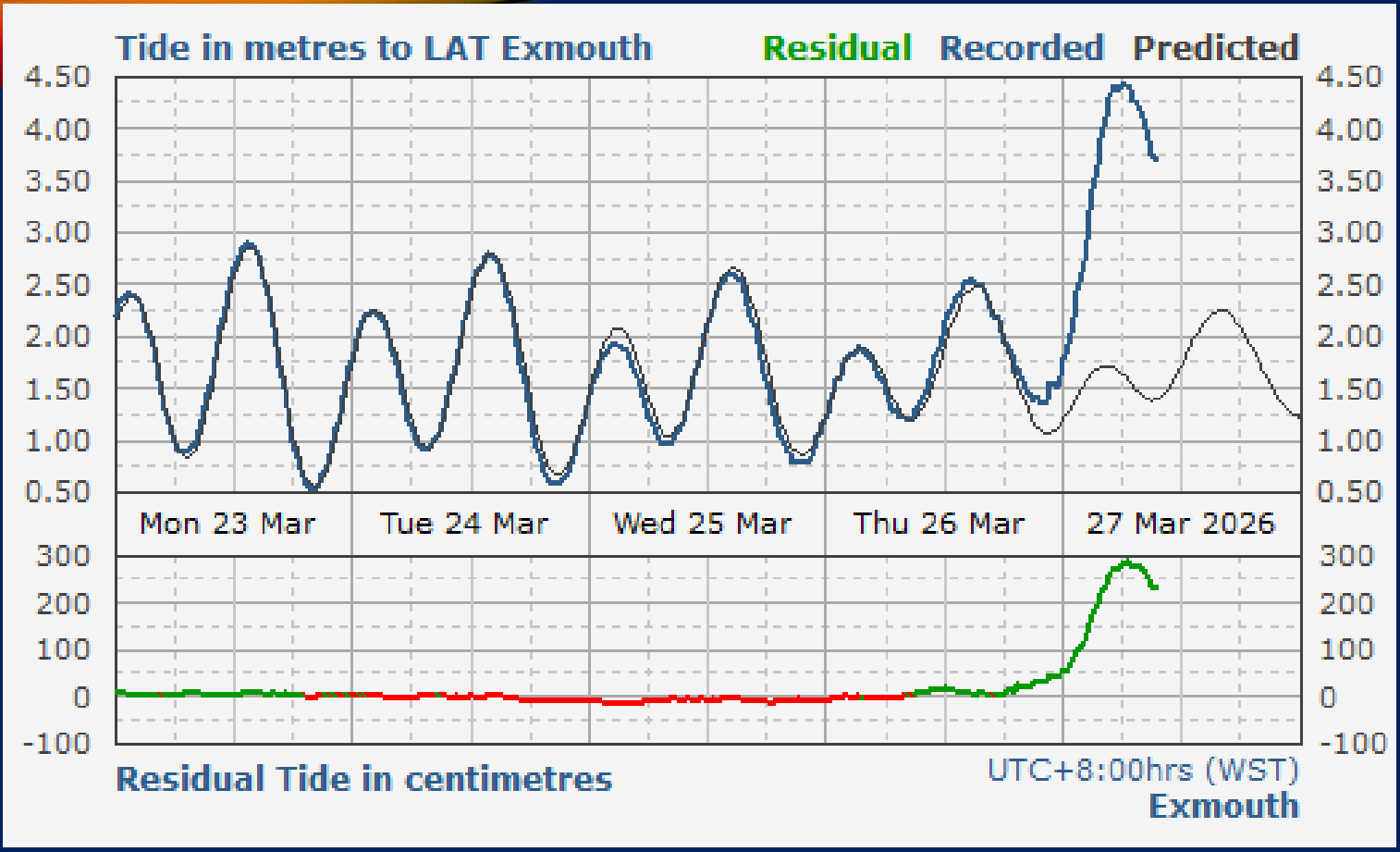
Pointer data is relative to

Day + Night



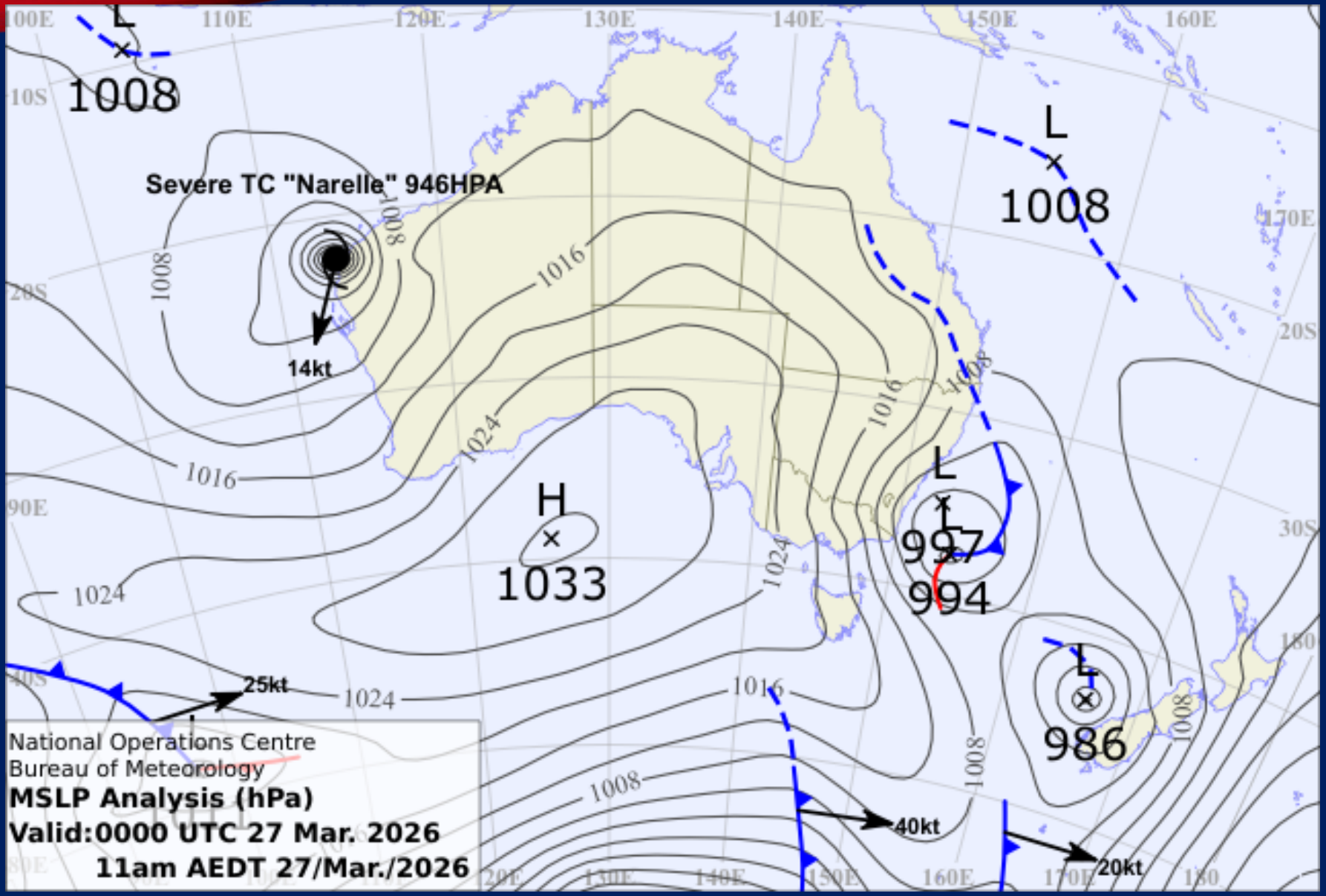
Friday, 27 March 2026 09:10 am AEDT

Slower



https://www.transport.wa.gov.au/marine/charts-warnings-current-conditions/coastal-data-charts/tide-data/exmouth

The top graph shows the recorded height and the astronomical tide prediction. The bottom graph just shows this difference, the **storm surge**, which peaked about 3 metres. The peak occurred around the time of a (not very) high tide.


L
1008
Severe TC "Narelle" 946HPA
14kt
L
1008
H
1033
L
997
994
L
986
25kt
40kt
20kt
National Operations Centre
Bureau of Meteorology
MSLP Analysis (hPa)
Valid:0000 UTC 27 Mar. 2026
11am AEDT 27/Mar./2026

Cyclone Vaianu Whakatāne evacuations praised as 'well-founded' after storm

NEWS NATIONAL

Kaitlyn Morrell, Tue, 14 Apr 2026, 3:09pm

The Storbecks, Coco Storbeck, 15 (from left), Quinn Storbeck, 9, Paia Storbeck, 11, Taimi Storbeck, 13, and r Storbeck, begin the clean-up in front of their Ōhope beachfront home on Monday after Cyclone Vaianu. Photo

Evacuation orders issued in the Whakatāne District ahead of ex-tropical cyclone Vaianu have been described as “well-founded” after extreme winds, large seas and high tide combined to create serious coastal inundation risks across the eastern Bay of Plenty.

Cyclone *Vaianu* developed near Fiji and intensified into a category 3 tropical cyclone before transitioning into an extratropical cyclone as it moved south. *Vaianu*'s gradual weakening meant that New Zealand was going to be hit a category 1 cyclone.

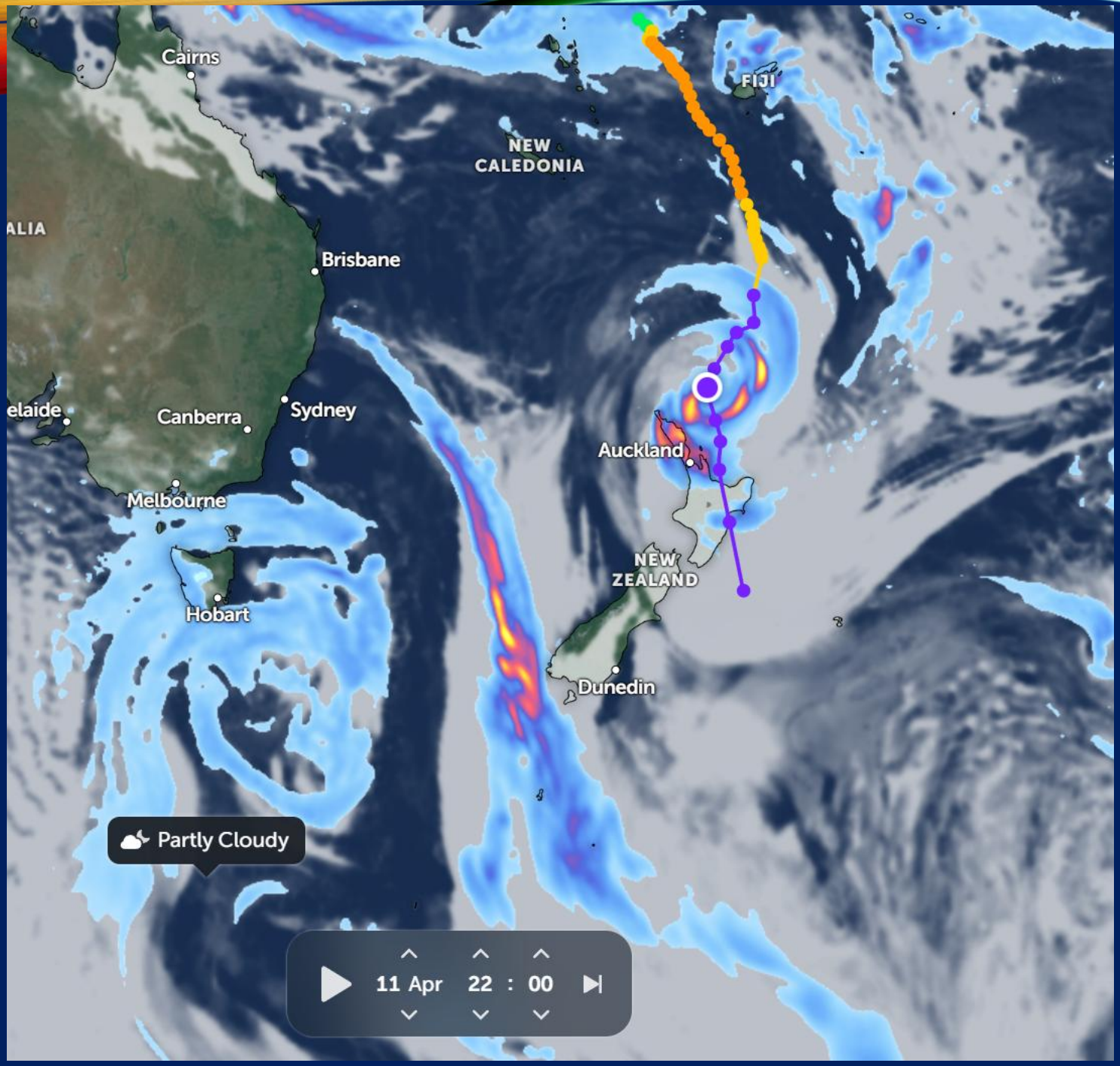
On Saturday 11th, impacts of Vaianu started to be observed over New Zealand's North Island, with up to 100mm of rainfall observed locally in elevated areas of Northland, Coromandel and Eastland.

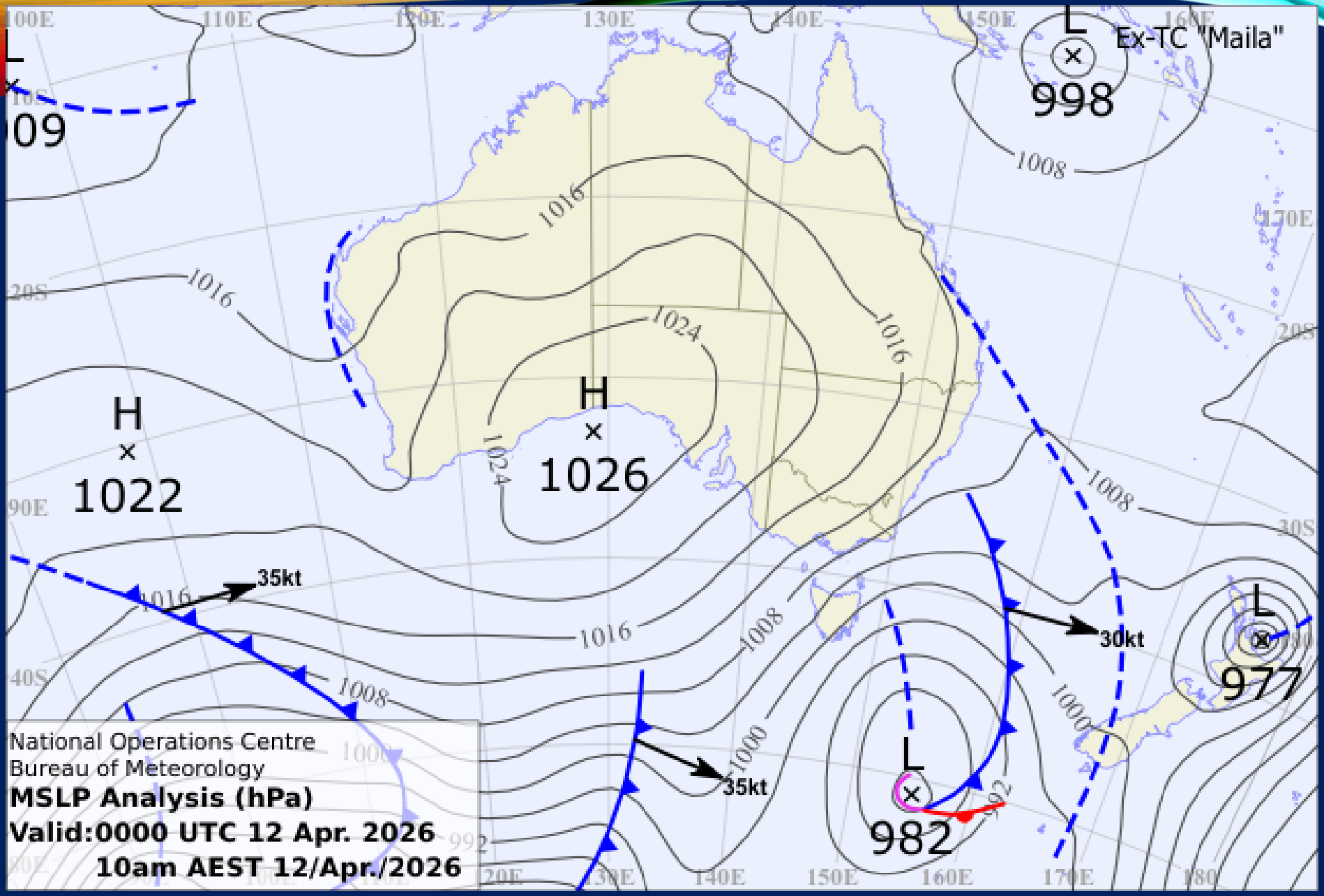
Floods, damage to New Zealand's North Island as Cyclone Vaianu makes landfall

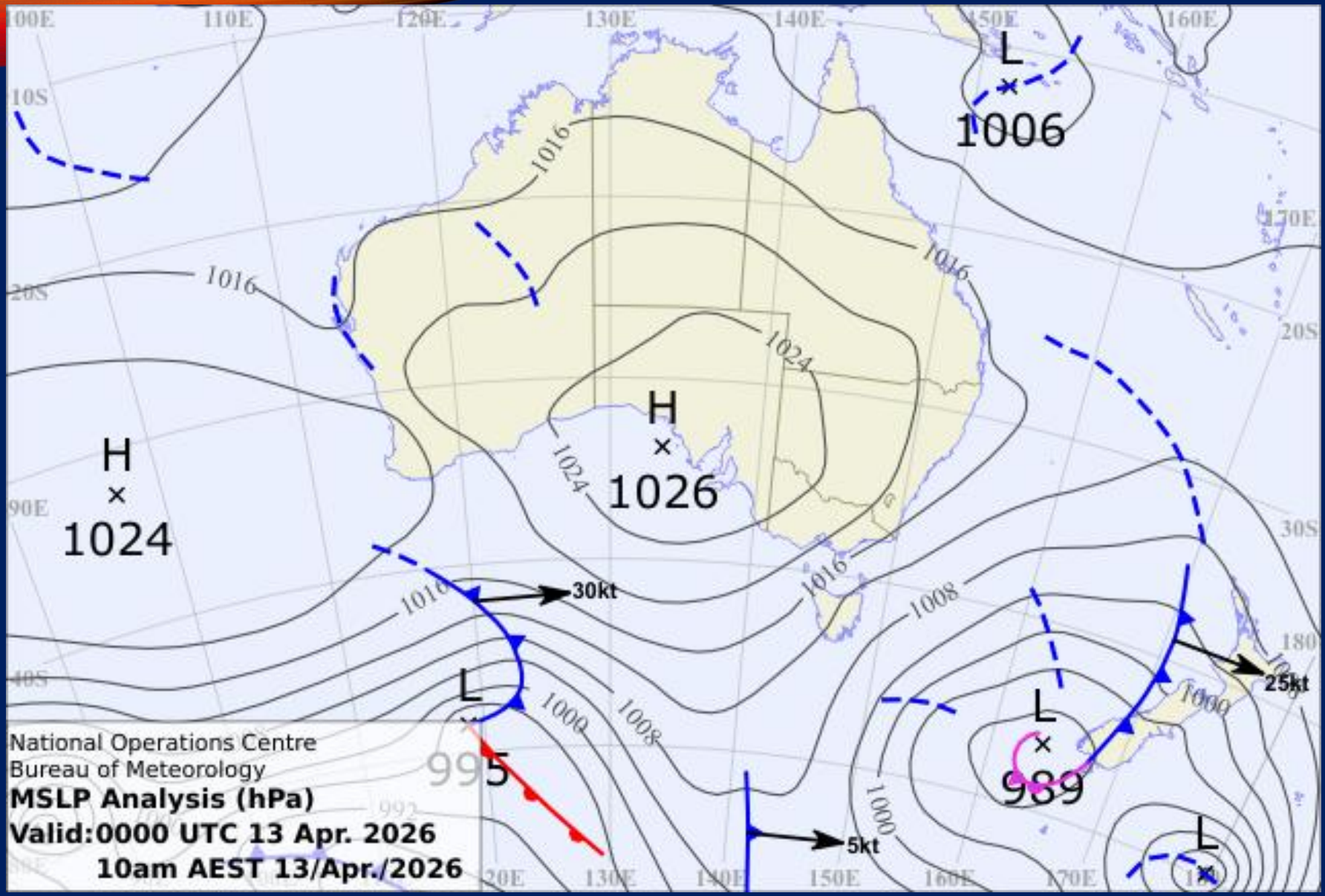
Cyclones

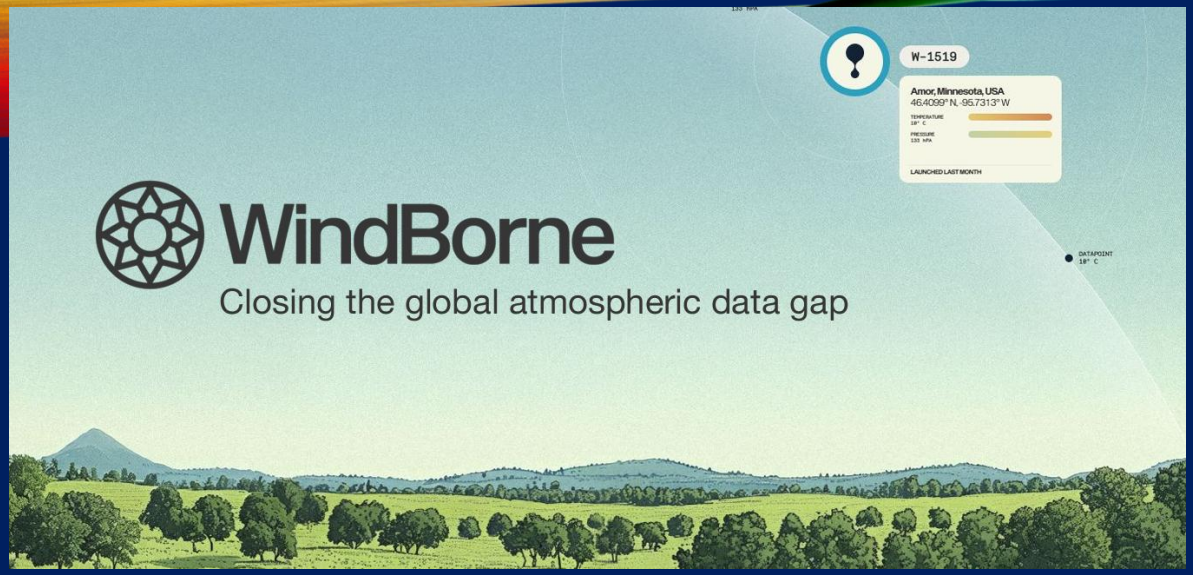
Sun 12 Apr

The cyclone has caused flooding around Whitianga, a town on the Coromandel Peninsula, North Island. *(Radio New Zealand: Marika Khabazi)*

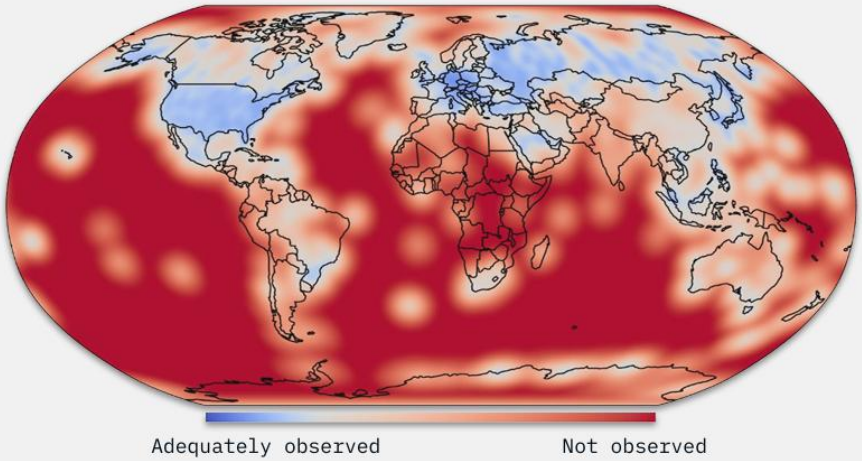

Cairns
FIJI
NEW CALEDONIA
ALIA
Brisbane
elaide
Canberra
Sydney
Auckland
Melbourne
NEW ZEALAND
Hobart
Dunedin
Partly Cloudy
11 Apr
22 : 00


Ex-TC "Maila"
998
1008
1016
1024
H
1022
H
1026
35kt
35kt
30kt
977
982
National Operations Centre
Bureau of Meteorology
MSLP Analysis (hPa)
Valid:0000 UTC 12 Apr. 2026
10am AEST 12/Apr./2026


L
1006
H
1026
H
1024
1016
1024
1016
1016
1008
1000
30kt
25kt
5kt
L
995
L
989
L
National Operations Centre
Bureau of Meteorology
MSLP Analysis (hPa)
Valid:0000 UTC 13 Apr. 2026
10am AEST 13/Apr./2026



Mission: Close the In-Atmosphere Data Gap



- Only 15% of the globe adequately observed with in-atmosphere sensors
- Weather is a global phenomenon, and global data is required for accurate forecasting
- Presents significant challenges to weather forecasting, natural disaster planning and mitigation, and climate adaptation

Source: WMO

Our platform (GSB)

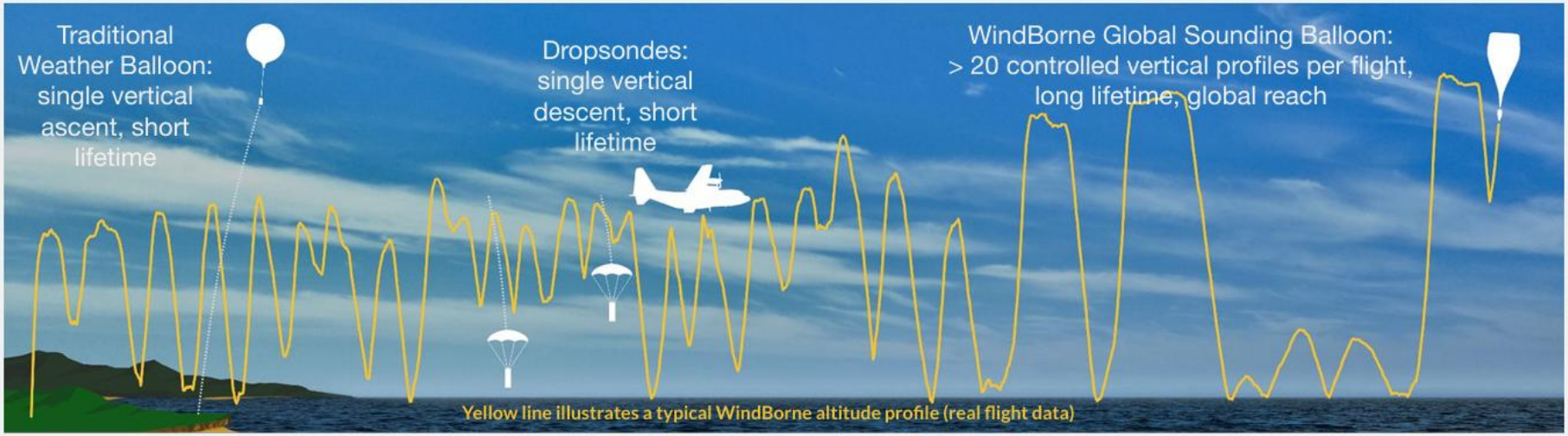
Global Sounding Balloon

The GSB is a highly cost-effective platform that can reach data -sparse and -void regions, supplementing existing collection methods and **closing the existing in-situ data gap**.

- **In situ observations** from **surface to stratosphere**
- **Long duration:** average of 6-12 days (Winter/Summer), current record: 250+
- **Long range:** able to circumnavigate the globe
- Can **target areas of interest** using wind
- Observations available within **10 minutes**
- **AI-powered** autonomous flight control
- **Small & lightweight** (under 1.2 kg)

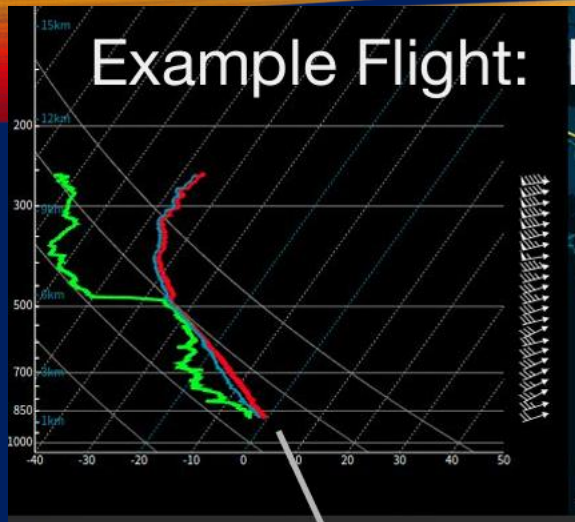
“Argo of the sky”

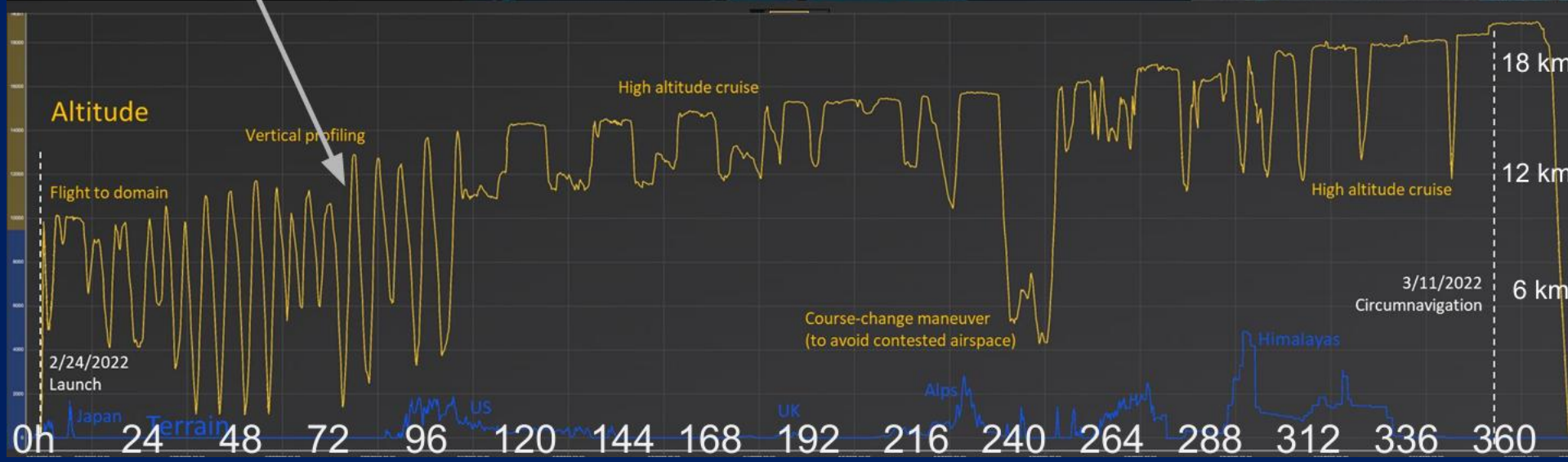
Repeated Vertical Profiles



- Unlike any other in-situ data collection platform, the GSB can make **repeated vertical profiles from ground level to lower stratosphere,** creating repeated "soundings," or vertical ascents and descents that are 3 to 20 km in depth.
- GSBs shift altitude autonomously to change directions and maintain navigation settings while making **repeated planetary boundary layer (PBL) observations**. We can configure altitudinal boundaries for each GSB to pinpoint specific atmospheric layers for observation.

Example Flight: Path and Data Collection






Active launch site
Planned launch site
WindBorne has launched over 6500 balloons from 31 launch sites worldwide – each yellow line is the path of a real balloon (Aug 2025). Currently we have 14 permanent launch sites operational, and two in progress

Network on 31 March 2026

Minimizing environmental impact

With our commitment to continued development, WindBorne is continually reducing waste while progressively collecting more data and decreasing costs.

	12+ mo. ago	Now	12 mo.	24 mo.	Long-term
Envelope (grams)	700	250	150	150	Recovery & reuse
Payload (grams)	480	350	150	150	~30 grams
Soundings per flight	18	15-25	40	80	Hundreds

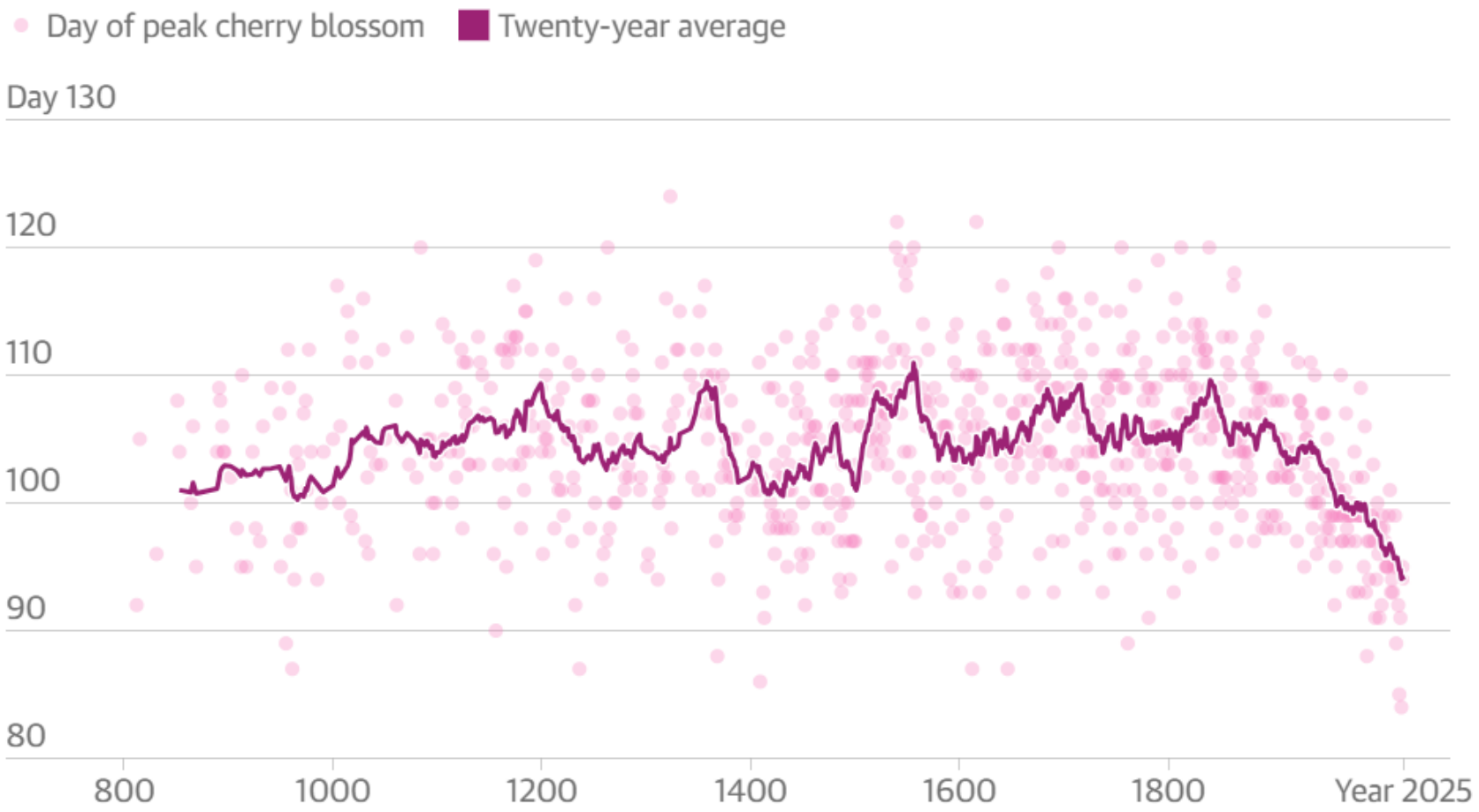
- We currently purchase plastic offsets representing 2x the waste we produce, and we collect magnitudes more data per flight than other similar in-situ observation methods.
- Since 2024, WindBorne balloon mass has been reduced by more than half, from 2.8 kg to 1.2 kg.
- As GSB flight durations continue to lengthen, we will develop a targeted landing and collection method, aiming to collect 80% of our balloons.

Impact:

- Small but positive impact on computer forecasts
- Promising results on forecasts for the tracks of tropical cyclones.

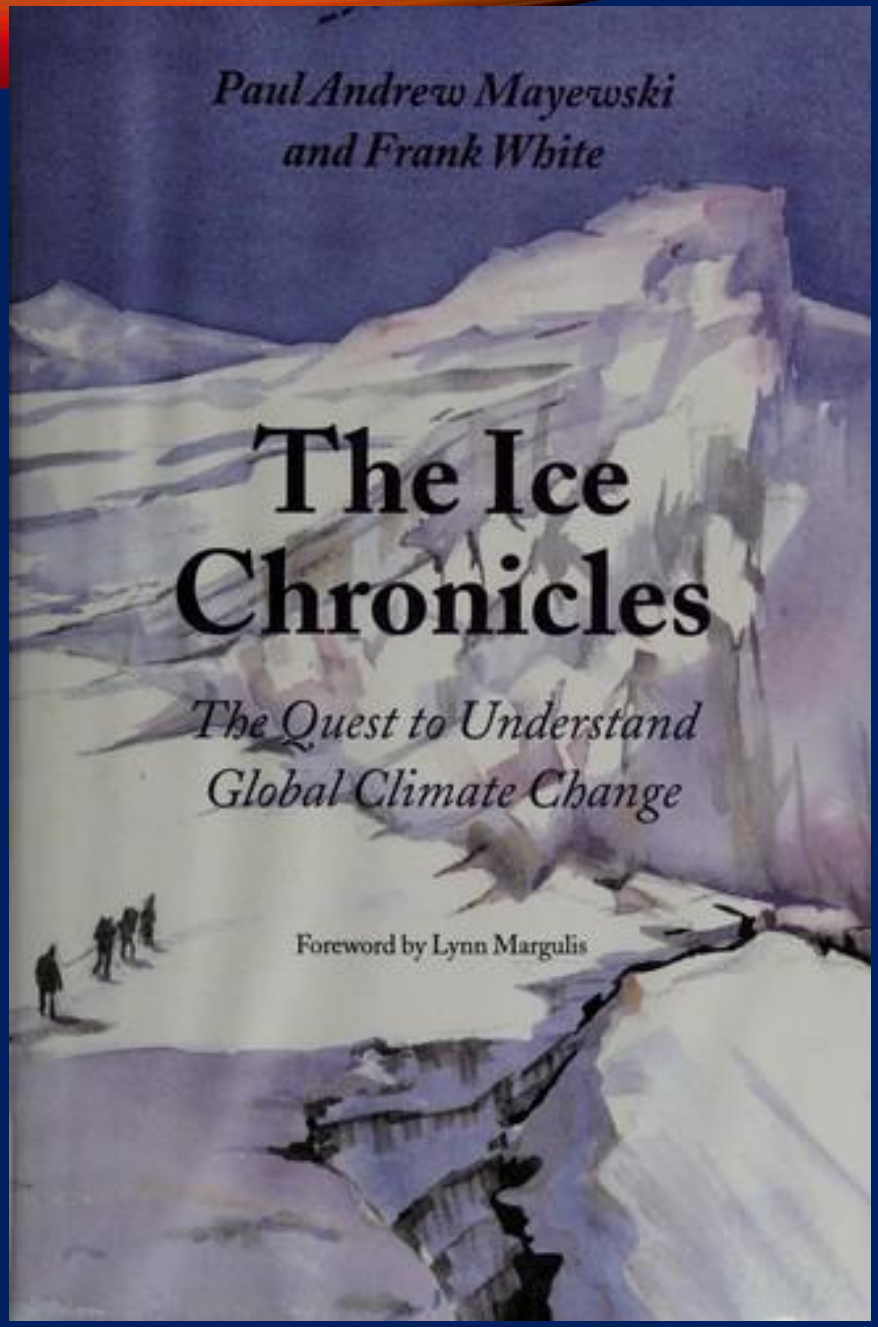
Peak blossom day is earlier in the year due to higher temperatures

Day of the year with peak cherry tree blossom in Kyoto, Japan



Guardian graphic. Source: Yasuyuki Aono (2021, 2025). Our World in Data. Note: the 20-year average is calculated when there are at least five years with data in the 20-year window

https://www.theguardian.com/world/2026/apr/15/cherry-blossom-1200-years-japan-climate-scientist-yasuyuki-aono

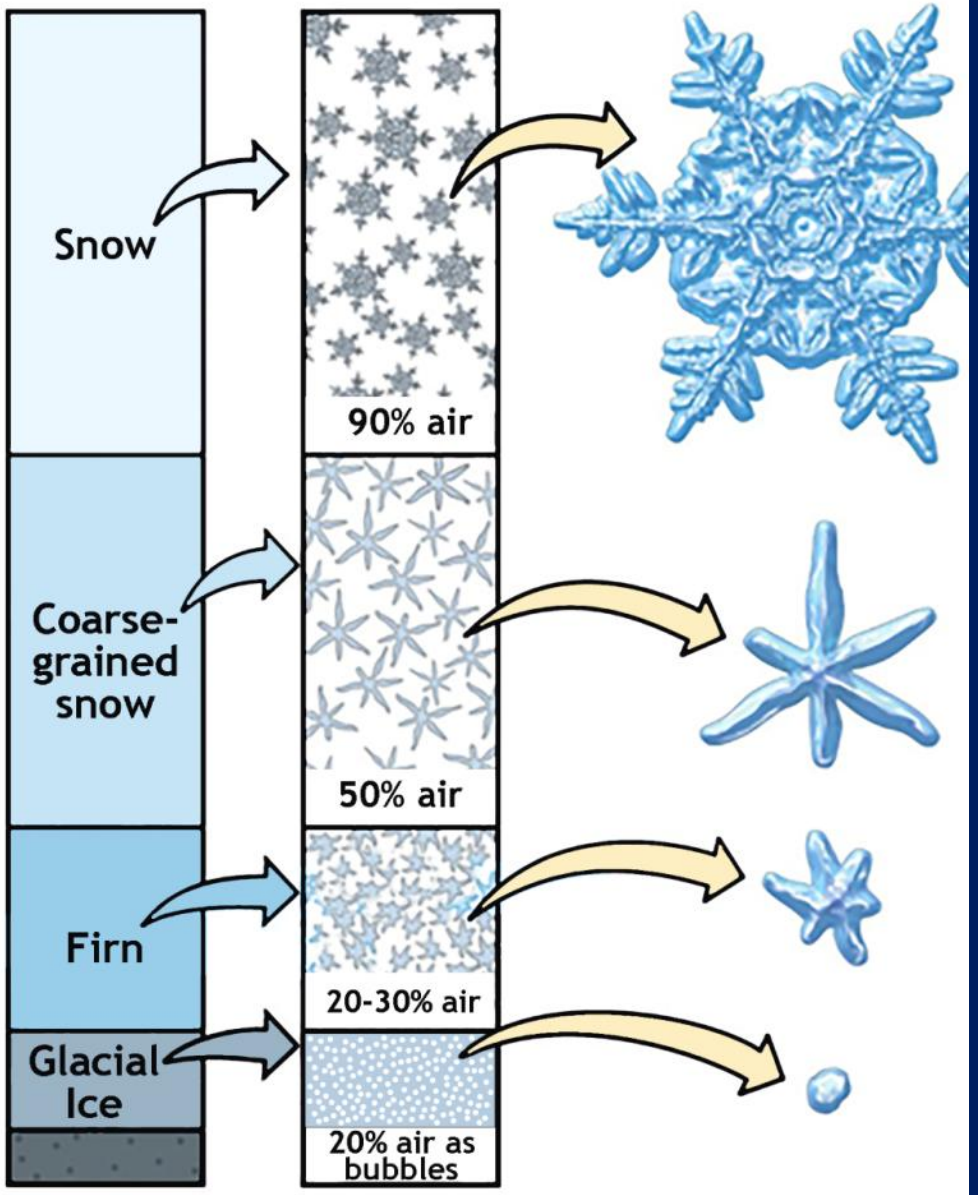


Ice Cores in Greenland

Paul Mayewski was the leader of the US National Science Foundation's Greenland Ice Sheet Project Two (GISP2)

The drilling reached bedrock on 1 July 1993.

At that stage it was the longest environmental record – and the ***longest possible*** in the northern hemisphere.

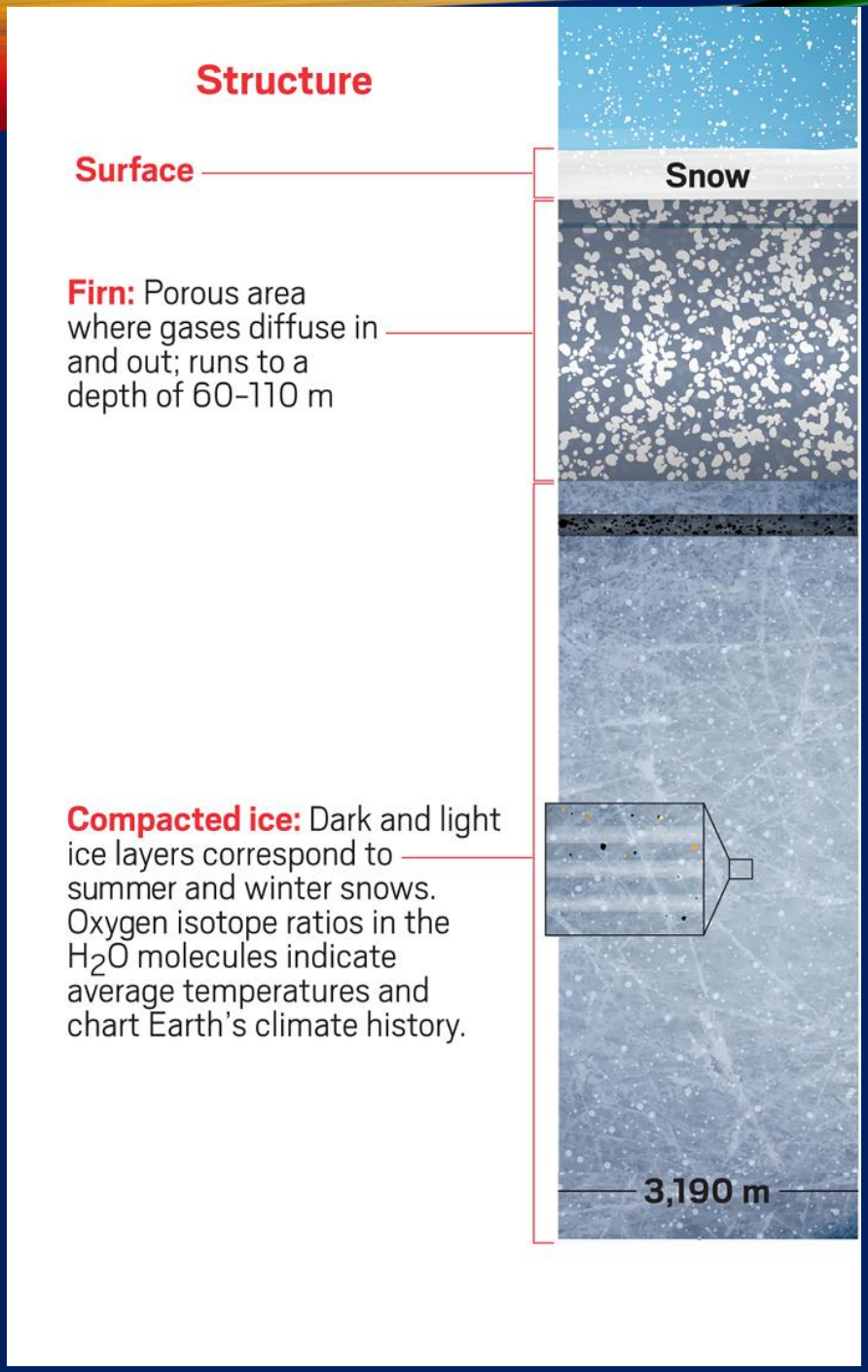


If **snow** lasts through the year it begins to transform. The weight of new snow on top compacts it, slowly squeezing air out and changing the shape of the snowflakes into pointy grains of snow.

Under enough pressure, these pointy snow grains are forced into closer and closer contact, forming a mesh of grains with an uneven but connected air space, known as **firn**.

Firn may exist for 100-300 years before being transformed into **glacial ice**, but in some very cold and dry regions of Antarctica, firn can exist for up to 2000 years before transforming into glacial ice.

https://www.antarcticglaciers.org/glacier-processes/mass-balance/firn-and-firn-aquifers/



The ice layer is **isolated** from the air above.

Any bubbles trapped in the ice date back to the time when the ice formed.

Can count the layers – annual cycles, or any layers of dust.

Where annual snowfall is lower the layers are narrower, but a given length column covers a greater time interval.

Problems with Ice Cores

- Remoteness
- Logistics
- Storing and transporting the ice cores
- Counting the layers and dating
  - some automation using electrical conductivity variations.
  - distortion and possible folding where ice moves over underlying rocks – especially near the bottom of the hole.
- Adjustment for when the snow was finally closed off from atmosphere.
  - Could be a few hundred to a thousand years offset between the gas bubble and the temperature when it fell.
- What is under the ice?
- Vostok – identified a lake below the ice so they stopped 100 m from bottom to prevent contamination of the lake with contemporary bacteria, etc.

There is a lot of interest in the deep ice cores that go hundred of thousands of years back in time. However, areas where snowfall is greater and the cores are shallower are also useful for studying more recent times.

Video from Dr Nerilie Abram – at that time with the British Antarctic Survey but now is Chief Scientist at the Australian Antarctic Division.
What do Antarctic ice cores tell us about climate change?
https://www.youtube.com/watch?v=VjTsj-fi-p0

Three types of information from ice cores:

1. Solid and dissolved impurities in the snow.

   - Aerosols - traces of dust, salts from the ocean, and from human activities, volcanoes and forest fires.
   - used to detect major environmental changes as well as variations in the chemistry and circulation of the atmosphere.

2. Bubbles of air trapped in glacier ice.

   - time-capsules of the atmosphere when they were trapped.

3. Information comes from the frozen water itself – such as isotopes of hydrogen and oxygen.

   - to infer temperatures when the snow originally fell
   - thickness of layers gives information on precipitation (snowfalls)
   - Beryllium-10 concentration relates to cosmic rays, and solar activity.

https://www.antarctica.gov.au/about-antarctica/weather-and-climate/climate-change/ice-cores/
https://scied.ucar.edu/learning-zone/how-climate-works/ice-cores-tell-story-climate

Some history

- Drilling into the ice dates back to Greenland expeditions in the 1930s
- Greater focus in the International Geophysical Year (1956-7) in both Greenland and Antarctica.
- The “Camp Century” story – Cold War tunnels in Greenland
- Push for deep drilling Greenland and Antarctic ice sheets from late 1960s
- Initially cores were extracted where bases were – later more strategic focusing on deepest parts of ice sheets.

Greenland

- 1986 – mid 1990s Teams from US and Europe –drilling holes 30 km apart near the summit of the ice cap.

- Independent double-checking – to make sure that any features were real and not just distortions from natural flow of the ice sheet.
  - US - Greenland Ice Sheet Project Two (GISP2)
  - Europe – Greenland Ice Core Project (GRIP)

- Each core 3km long dating back 110,000 years.

Coordinates	77.1667°N 61.1333°W
	Site history
In use	1959–1967

Camp Century is an abandoned Arctic United States military scientific research base in Greenland. When built, it was publicized as a demonstration of affordable ice-cap military outposts and a base for scientific research.

According to documents declassified in 1996, Camp Century was a preliminary camp for *Project Iceworm*, whose goal was to install a network of nuclear missile launch sites that could survive a first strike. Missiles were never deployed at the facility, and the Danish Government was never approached for its consent.

The camp operated from 1959 until 1967 - 21 tunnels, total length of 3.0 km, powered by a nuclear reactor.

Project Iceworm was aborted after realization that the ice sheet was not as stable as originally thought, and so the missile basing concept would not be feasible. The reactor was removed and Camp Century later was abandoned. However, hazardous waste remains buried under the ice and has become an environmental concern. *(Wikipedia)*

So, US interest in Greenland does go way back!

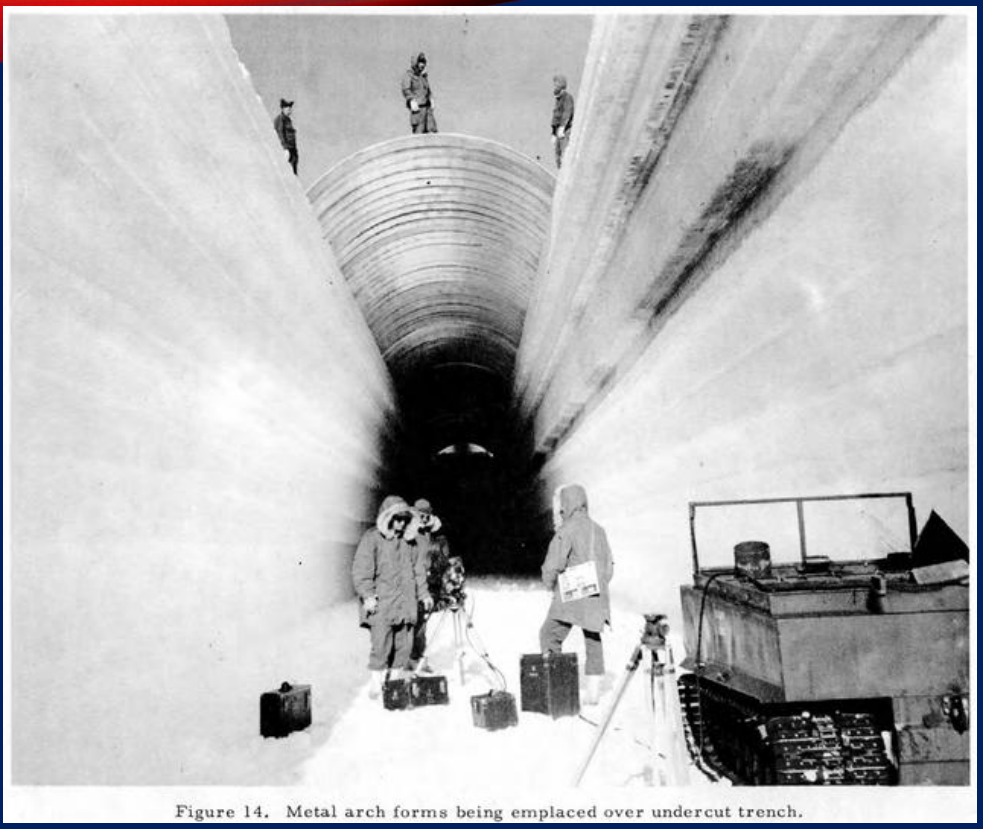
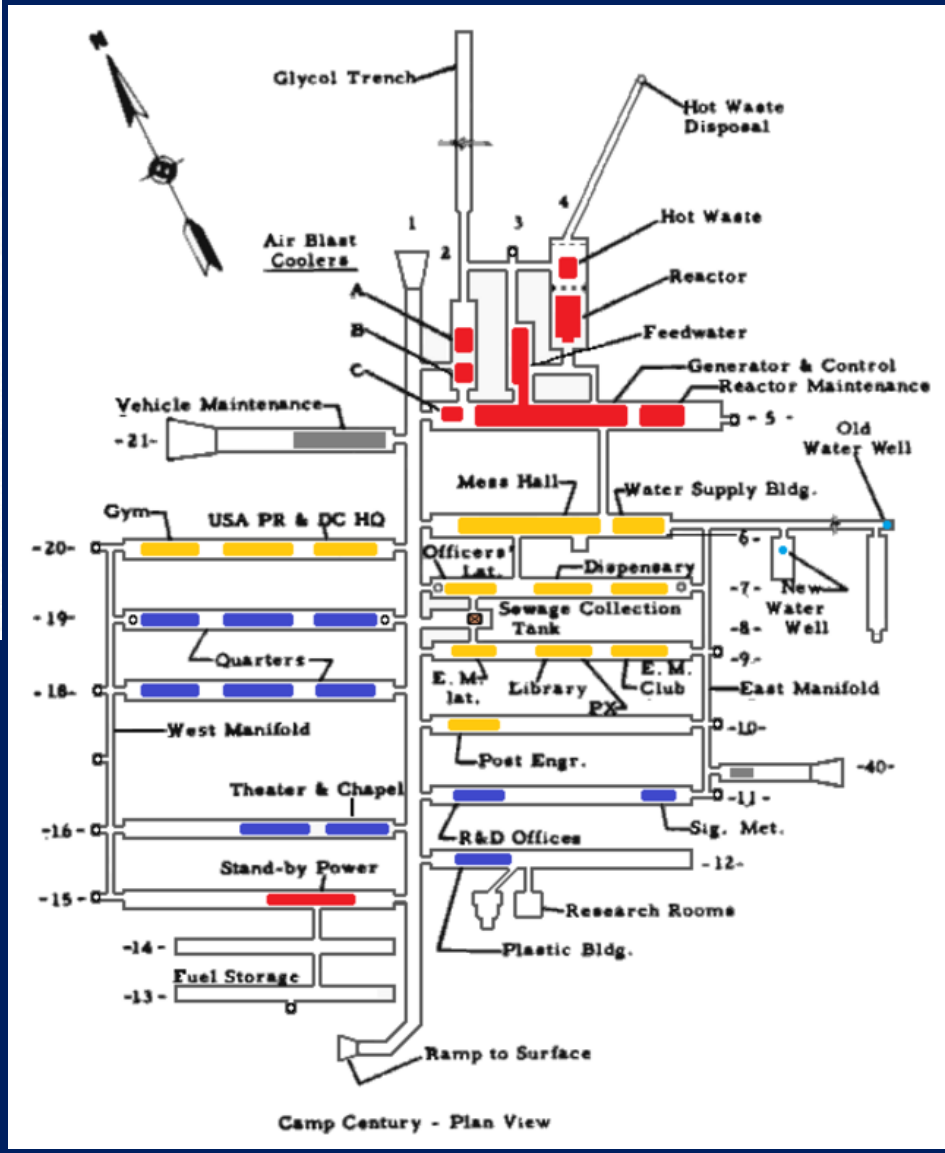


Figure 14. Metal arch forms being emplaced over undercut trench.

Metal arches being placed over a trench to form a tunnel.

(Wikimedia Commons)

Camp Century Layout



However, a 1.4 km core of ice was drilled over five years. Drilling reached the bed of the ice sheet and also recovered a 3.4 metre-long core of subglacial sediment.

Figure 2: Historic photos of ice coring at Camp Century (a) Recovery of an ice core at Camp Century [Credit: USACE]. (b) B. Lyle Hansen (left) and Chester C. Langway (right) examine the subglacial sediment from the Camp Century ice core [Credit: David Atwood, U.S. Army-ERDC-CRREL, courtesy AIP Emilio Segrè Visual Archives].

The Camp Century ice core stimulated ice core science. Analysis of oxygen isotopes generated an unprecedented record of Earth's temperature over the last 100,000 years.

17 metres of debris-rich basal ice and the 3 metres of subglacial sediment – were not completely studied although finding that sediment meant that northwestern Greenland was ice-free at some point in the "Ice Age".

https://blogs.egu.eu/divisions/cr/2022/01/28/camp-century-bottom-ice/

- In the early 1990s the core was sent to the University of Copenhagen, where the samples remained frozen but forgotten.
- 2017 – Rediscovered and analysed with modern techniques.

"To our surprise, the sediment was filled with delicate twigs, leaf tips, and woody material .. the presence of plant fossils meant that this sector of northwestern Greenland was ice-free and vegetated in the past. But when was the ice gone and what ecosystem emerged?

We determined that … the ice sheet was absent, within the last million years. The lower-most sediment is much older, possibly buried since 3 million years ago."

The sediments are significant as the ice cores only go back 130,000 years.

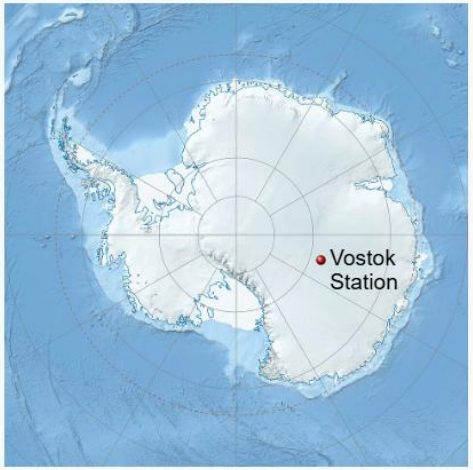
Figure 4: Left: Leah Williamson (left) and Andrew Christ (right) excitedly picking fossil twigs from the Camp Century sediment. Right: microscope photos of some of the moss leaf tips, twigs, and stems found in the sediment [Credit: Paul Bierman, Andrew Christ, & Dorothy Peteet].

Antarctica

Drilling in many locations but the deepest cores come from the Plateau.

Vostok

- lower snowfall than Greenland
- Russian base but US and France joined in drilling
- 1970s drilled to about 1 km depth with further drilling from 1980s to 1996
- 3.6km depth covering 420,000 years.



Location of Vostok Station in Antarctica

Coordinates: 78°27′52″S 106°50′14″E

Country	Russia
Location	Princess Elizabeth Land Antarctica
Administered by	Arctic and Antarctic Research Institute
Established	16 December 1957

European Project for Ice Coring in Antarctica (EPICA)

- Concordia Station on **dome C** from 1996-2005
- Drilling completed in December 2004, reaching a depth of 3270.2 m, 5 m above bedrock.
- Dates back 800,000 years
- Present-day annual average air temperature is −54.5 °C and snow accumulation 25 mm/yr.

Ice cores from Mountain Glaciers

- late 1970s onwards pioneered by Lonnie Thompson Ohio State Uni.
- generally shorter period of record but important for studying impact of climate events up to about 25,000 years ago
- Records from tropical glaciers may be short (e.g. 1500 years) but can give information on impacts on societies (e.g. Central and South American civilisations) on wet periods and dry periods, volcanoes.
- Record altitude – 1997 in Tibet 7,200 m above sea level.
- Provide global coverage.

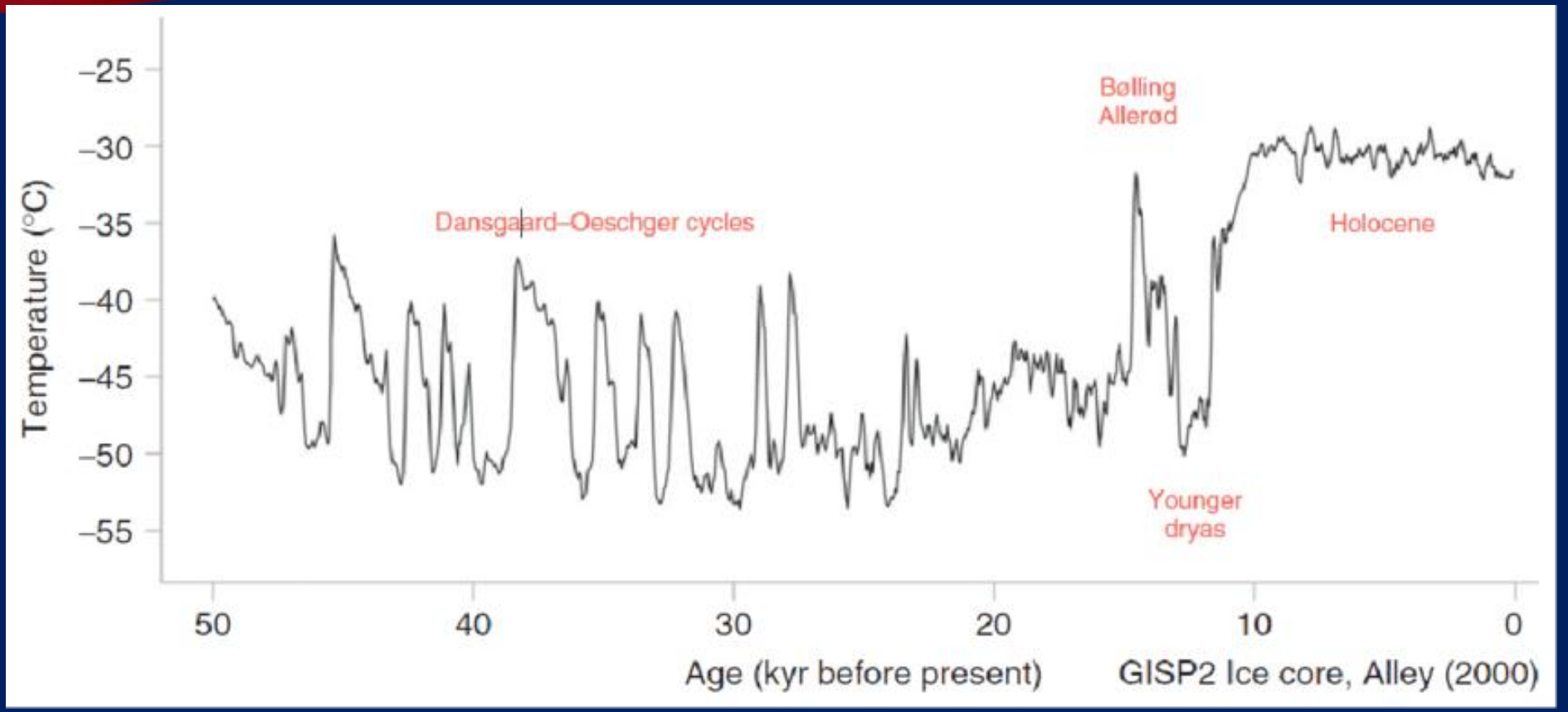
A 1,200-year-old birch distaff found near the shrinking Lendbreen ice patch in Norway.

Ice preserves all information from the time when it was deposited.

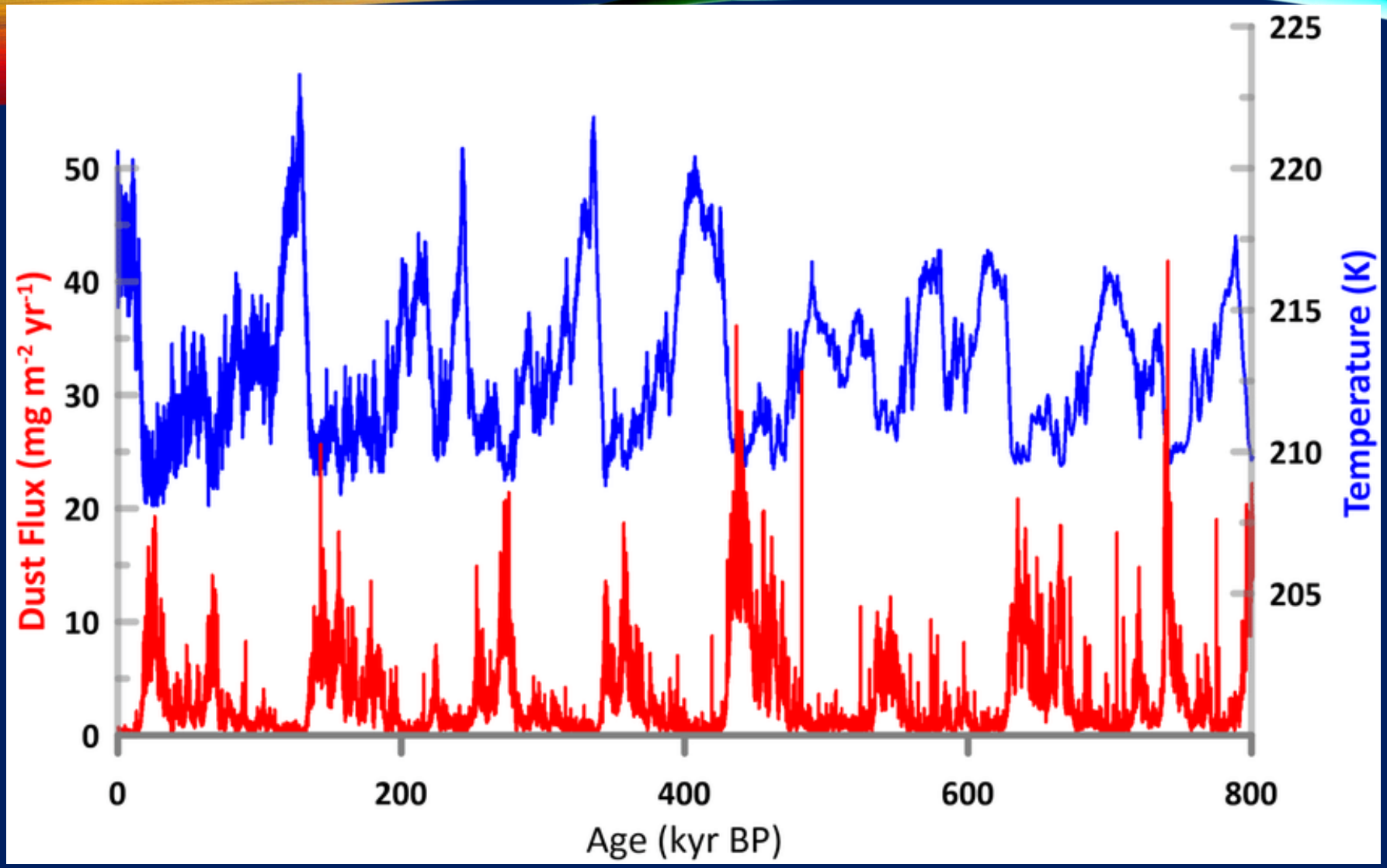
- A spike in lead pollution during the Roman Empire
- A drop in pollen due to collapse of farming during the Black Death
- radioactive cesium from Chernobyl
- Black carbon and the sugars from burned cellulose from forest fires.

https://e360.yale.edu/features/glacier-melt-ice-cores-artifacts-meteorites

The Race to Save Glacial Ice Records Before They Melt Away



Temperature record from the GISP2 ice core in Greenland

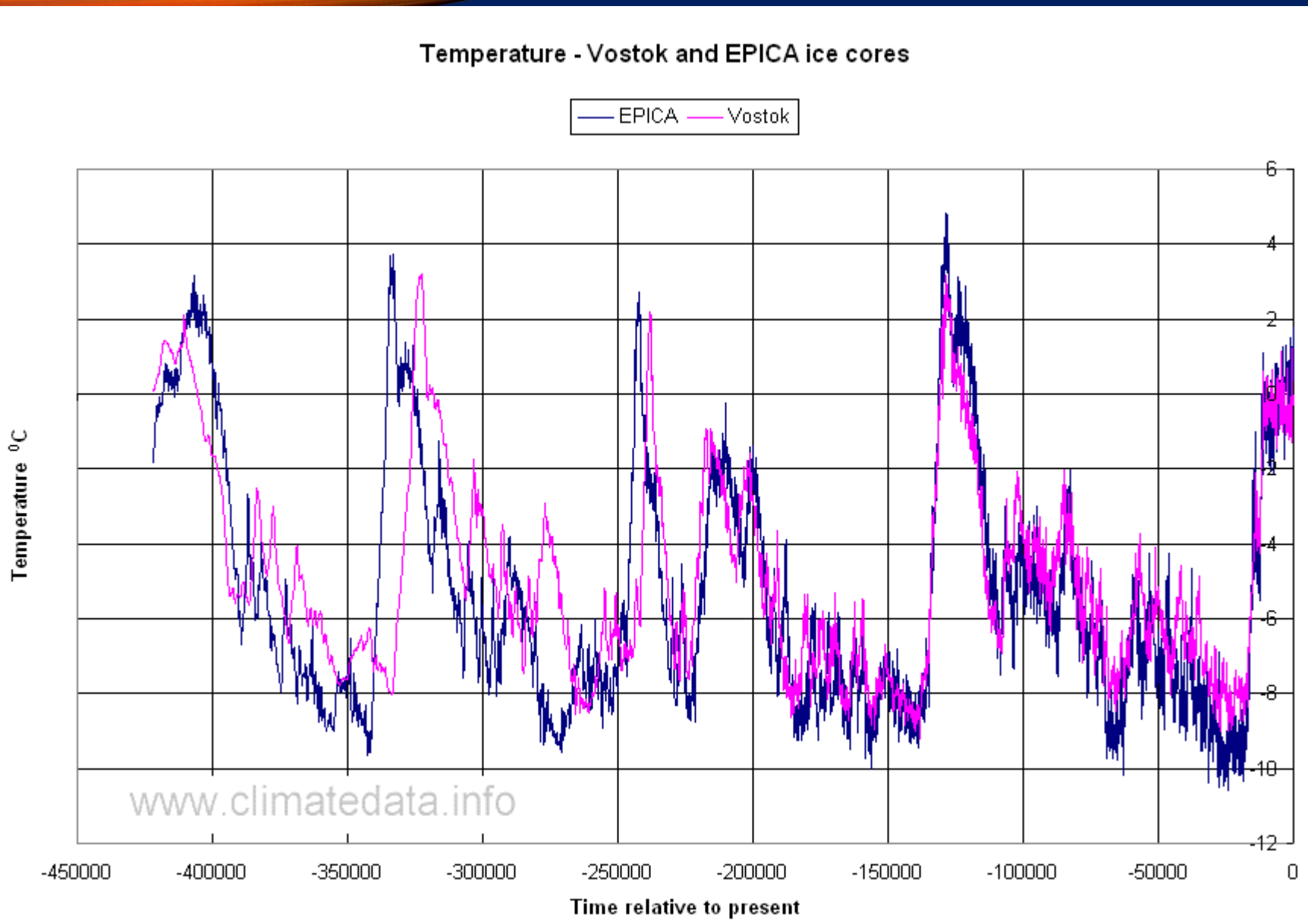


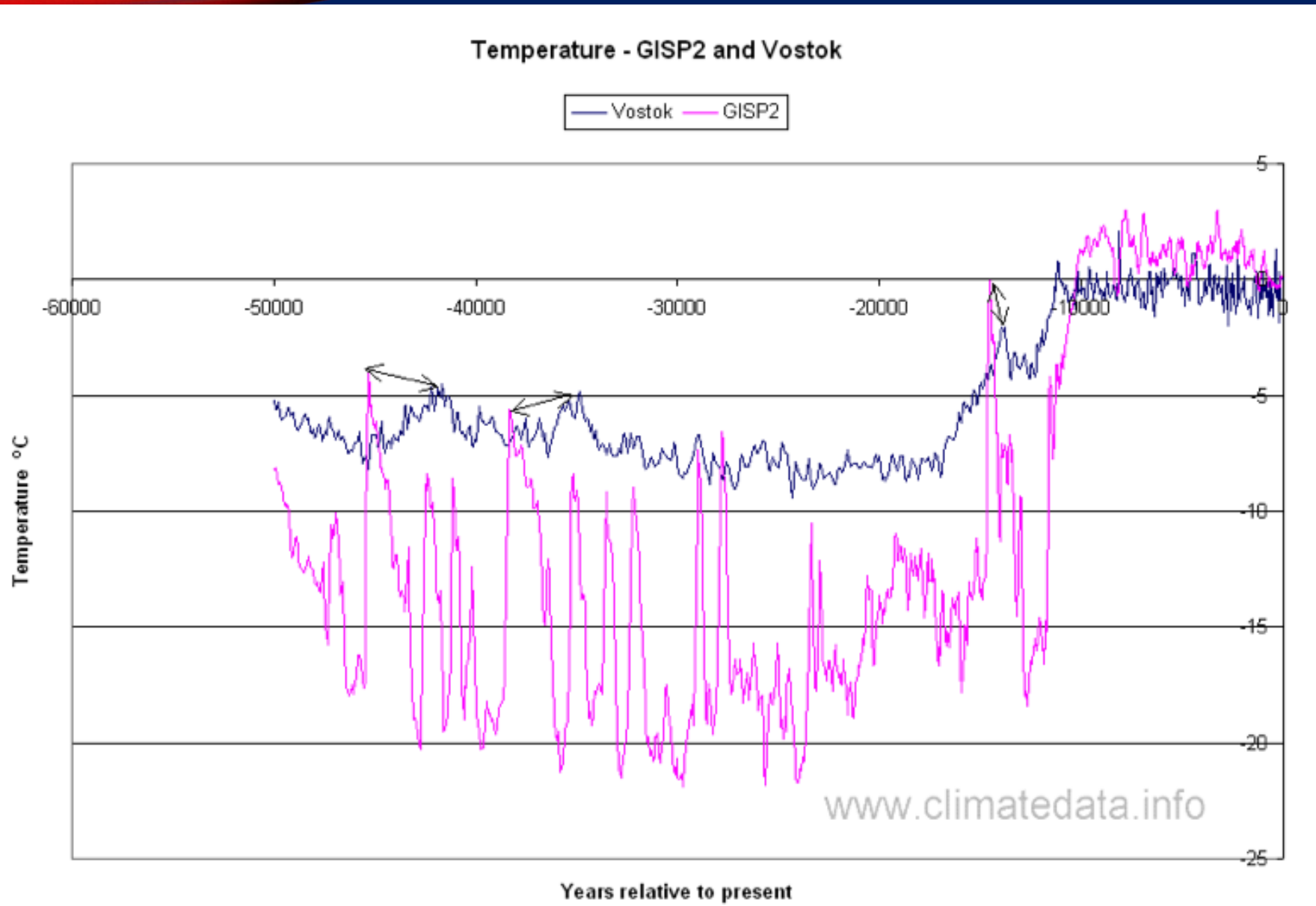
Temperature (blue) and dust flux (red) from the EPICA Dome C ice core

Lovejoy, Shaun & Lambert, Fabrice. (2019). Spiky Fluctuations and Scaling in High-Resolution EPICA Ice Core Dust Fluxes. Climate of the Past Discussions. 1-33. 10.5194/cp-2018-171.

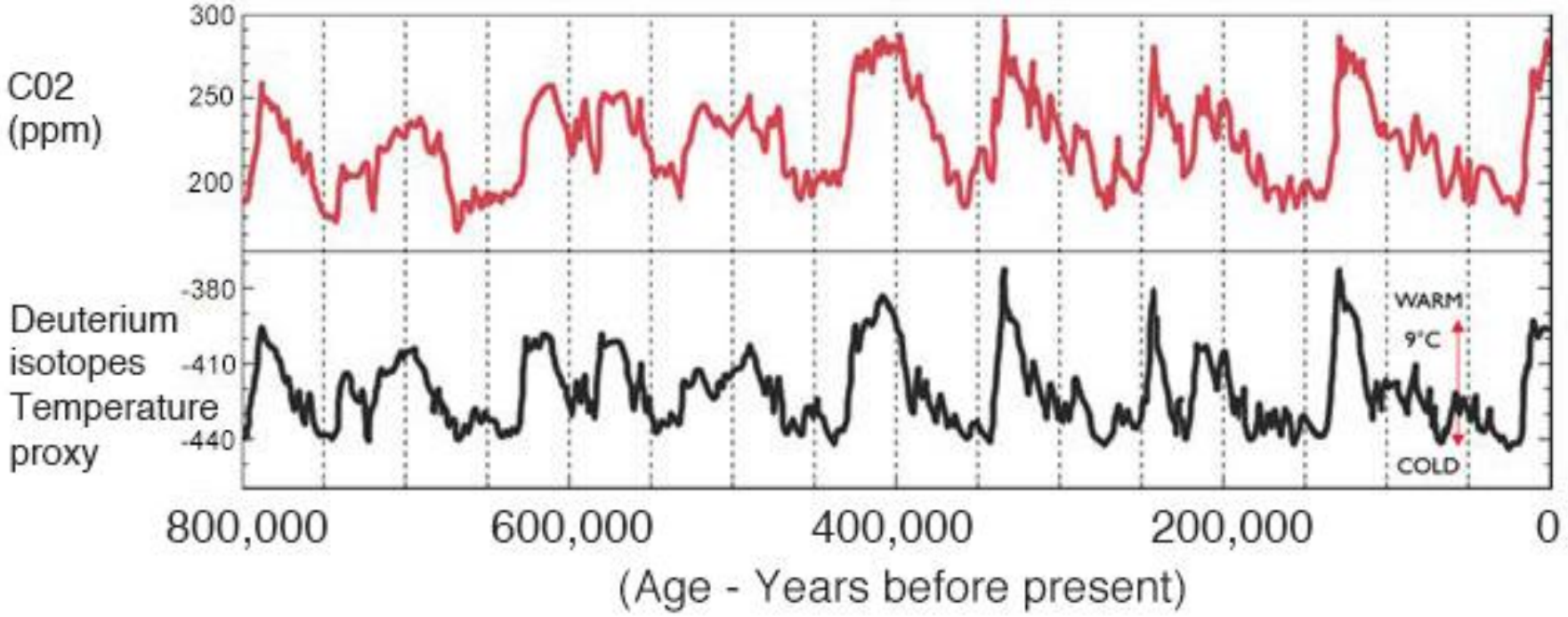
What have they found?

- Similar pattern to sediment cores but more detail
- Long period cycles – glacial/interglacial periods.
- Most of the time it is in the cold phase
- The warm phases are generally short
- Sharp transitions from cold to warm (Abrupt Climate Change Events)
  - Up to 6 degrees warming in a few years!
- Dust layers
  - Indicators of windiness and aridity
  - anti-correlated with temperature
  - most dust at the coldest times of glacial periods indicating a cold and arid climate (contributor to deep soil in eastern Australia?)
- Close correspondence between temperature and carbon dioxide concentrations.


Temperature - Vostok and EPICA ice cores
EPICA
Vostok
Temperature °C
6
4
2
0
-2
-4
-6
-8
-10
-12
-450000
-400000
-350000
-300000
-250000
-200000
-150000
-100000
-50000
0
Time relative to present
www.climatedata.info

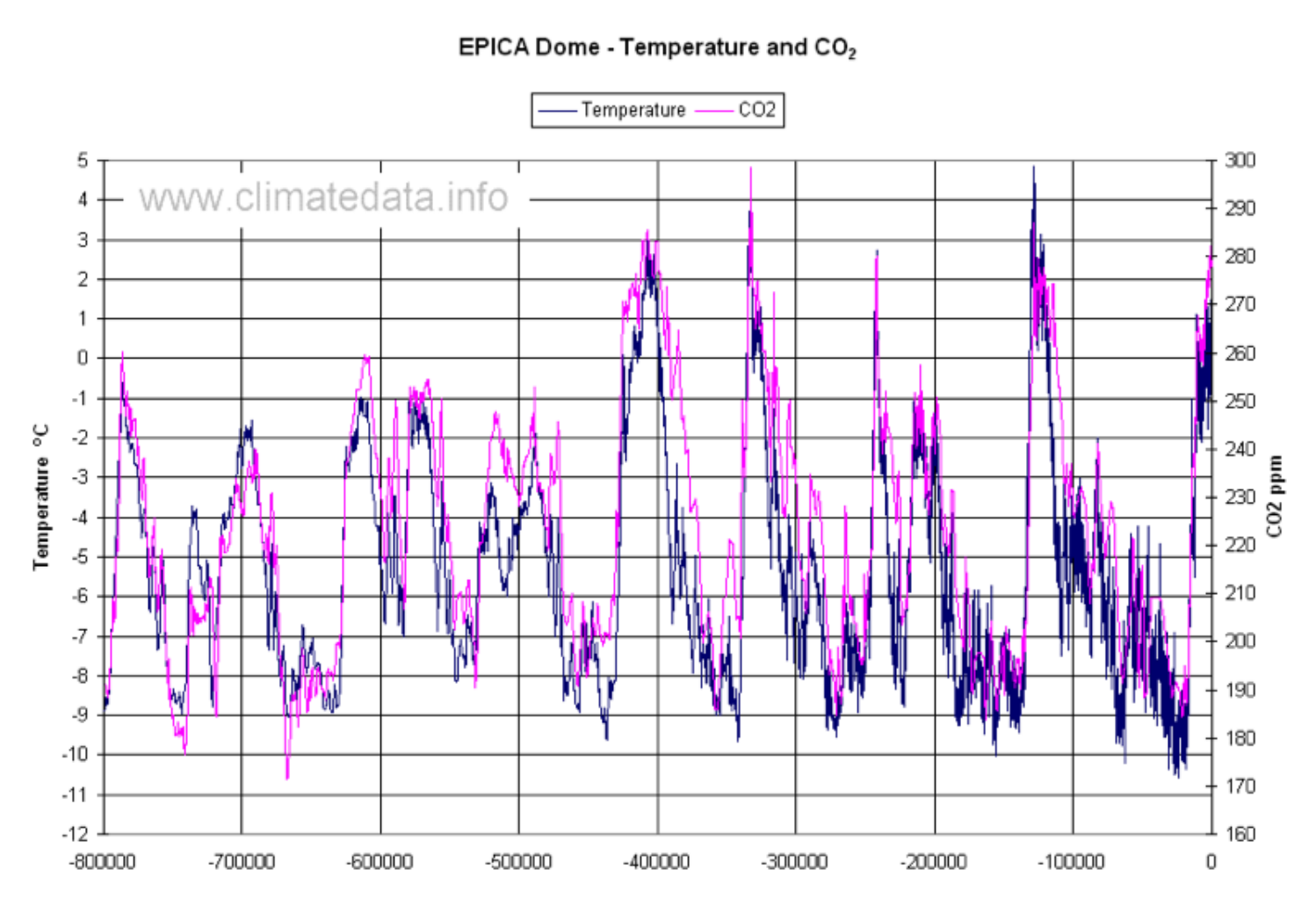

Temperature - GISP2 and Vostok
Vostok
GISP2
5
-5
-10
-15
-20
-25
-60000
-50000
-40000
-30000
-20000
-10000
0
Temperature °C
Years relative to present
www.climatedata.info

EPICA ice core records 100,000-year cycle in ice ages



Source: BAS/EPICA

BBC



Although it is not clear from this chart there is general agreement that temperature changes precede CO_2 changes during the rising phase and CO_2 lags temperature by a larger amount during the falling phase.

Australian Antarctic Division Million Year Ice Core Project.

Australian and a European team (Beyond EPICA Oldest Ice) are leading drilling operations, about 50 km apart at Dome C North and Little Dome C, respectively.

- independent ice cores for replication and verification of the data especially from the very oldest ice near the bedrock.

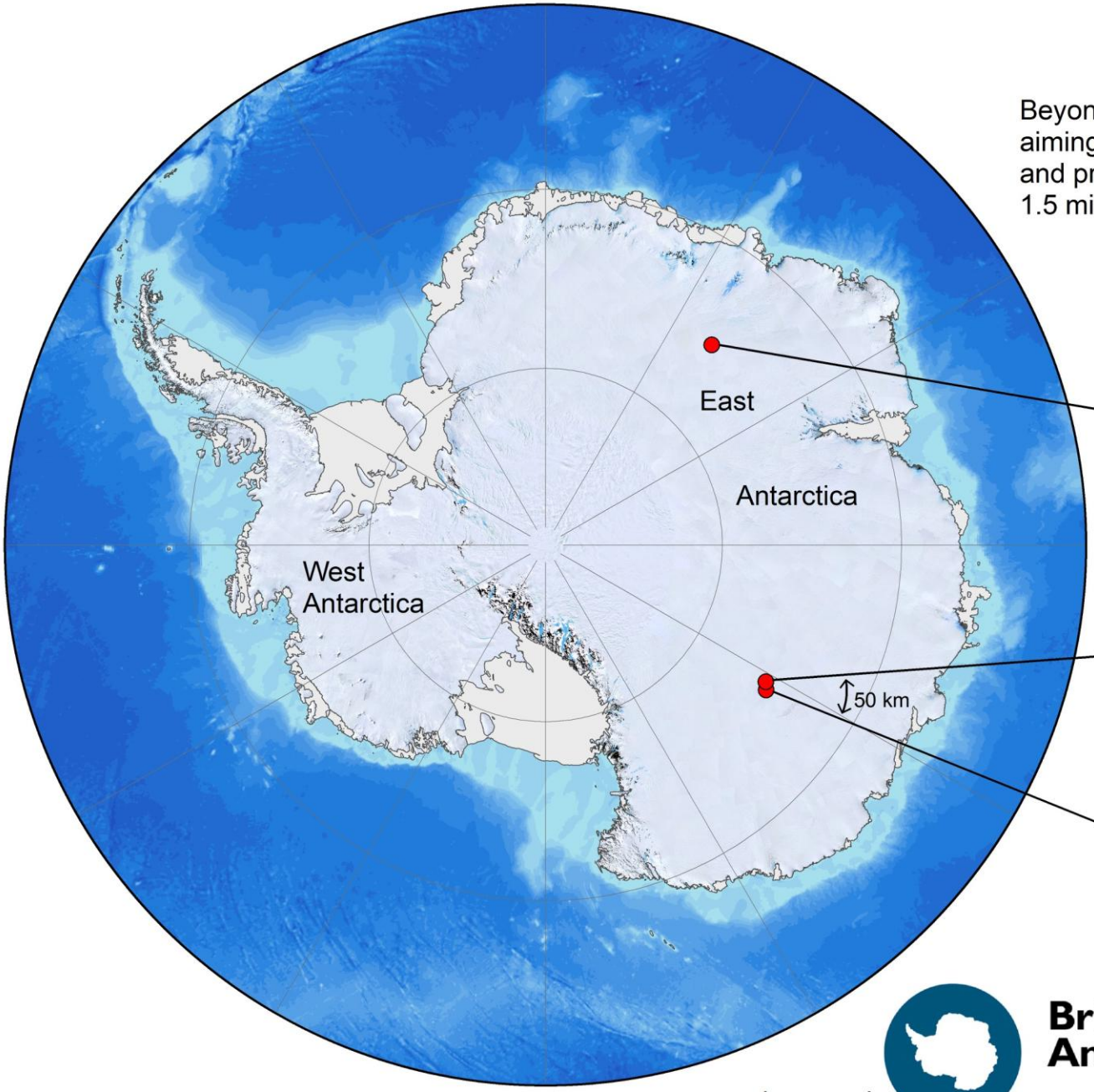
Key features of the Dome C North site:

- 3239 metres above sea level
- Ice thickness 3,100 metres above bedrock
- undisturbed layers, with a smooth and minimal ice flow path to the site
- a maximum modelled age of up to 2 million years, preserved at a time resolution of better than 20,000 years per metre.

Drilling commenced in in January 2025.
https://www.antarctica.gov.au/science/climate-processes-and-change/antarctic-palaeoclimate/million-year-ice-core/
(video in this article).

In 2025 the European team had extracted a 2.8 km core dating back 1.2 million years.
https://polarjournal.net/beyond-epica-oldest-ice-1-2-million-years-of-climate-history-unearthed-in-oldest-ice-core/

BEYOND EPICA - OLDEST ICE



Beyond EPICA is a new project aiming to drill the oldest ice core and provide past climate spanning 1.5 million years.

Dome F

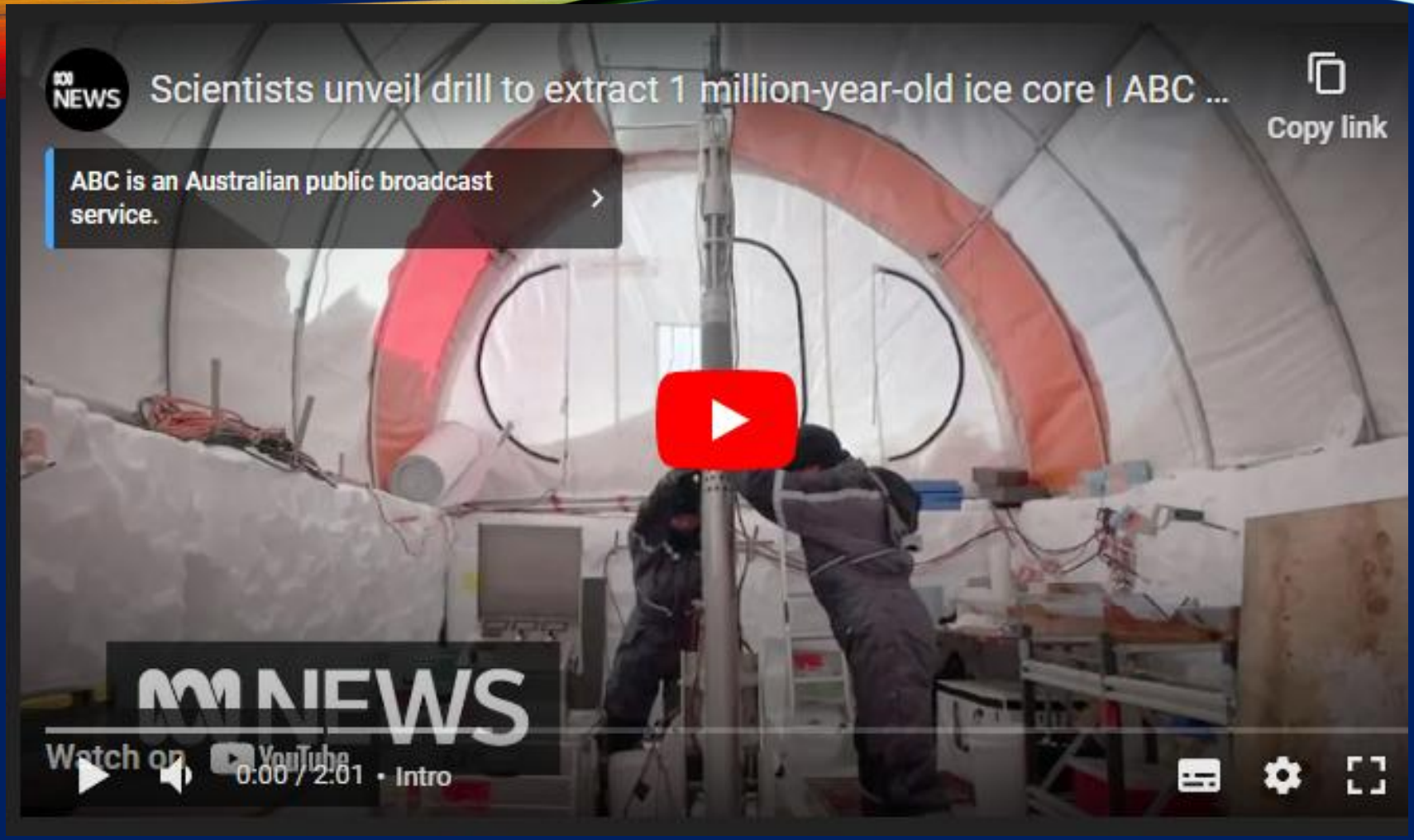
Little Dome C:
Site survey Nov/Dec 2016

Dome C:
Current oldest ice core site

www.bas.ac.uk

British Antarctic Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



https://youtu.be/cCwbWtgXJR4

https://www.antarctica.gov.au/science/climate-processes-and-change/antarctic-palaeoclimate/million-year-ice-core/