Past and Future Climate – Present Weather

Week 6

The Story in Ice Cores (Part 2)

Terry Hart

Dates

Term 2

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**

Australia's weather forecasts are suddenly identical each day

ABC meteorologist Tom Saunders

Weather Forecasts

8h ago

A stationary "blocking high" in the Tasman Sea is behind the stagnant weather pattern. *(Supplied: Tracey Frazer)*

‘The stagnant pattern is due to a stationary "blocking high" in the Tasman Sea.’

https://www.abc.net.au/news/2026-04-25/australia-weather-forecasts-suddenly-identical-each-day/106603146

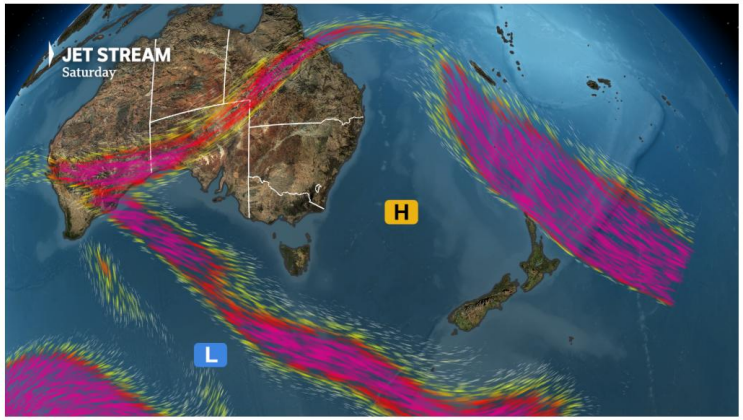
And the stubborn high has completely jammed up Australia's weather chart, both deflecting cold fronts and lows well south of eastern states, while also ensuring winds are blowing in the same direction at a similar speed every day.

Blocking high to control eastern Australia's weather next week.

While most blocks only last a few days, the current stagnation may last up to a fortnight, removing the standard day-to-day variability typically experienced in mid-latitude climates.

The subtropical jet stream typically sits at a latitude of about 25 to 30 south, stretching from about WA's Central West to south-east Queensland.

But the jet is currently bending well north over Queensland, reaching a tropical latitude in the Coral Sea equal to Cairns.

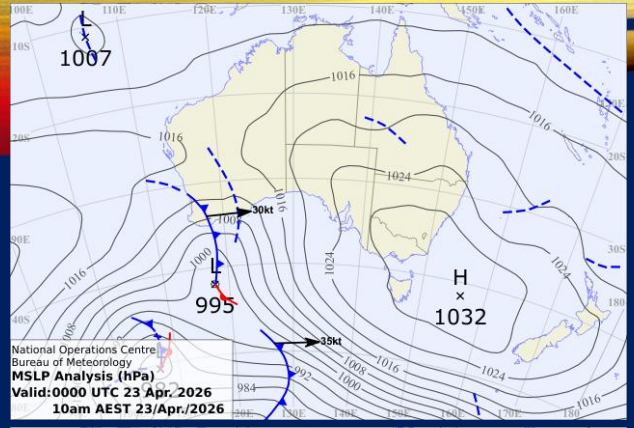


A split in the polar and sub-tropical jet streams over eastern Australia is cradling a stationary high-pressure system. *(ABC News)*

In the meantime, the polar jet is diving south below New Zealand, and that has opened up a broad region of calm winds, the perfect environment for the cradling of a strong high in the Tasman Sea.

However, the relationship between highs and jets is complex.

Once a strong high has stalled, it helps to divert the very jet stream that split to cause the high's formation. With both systems now reinforcing each other, blocks have the potential to last for a week or more.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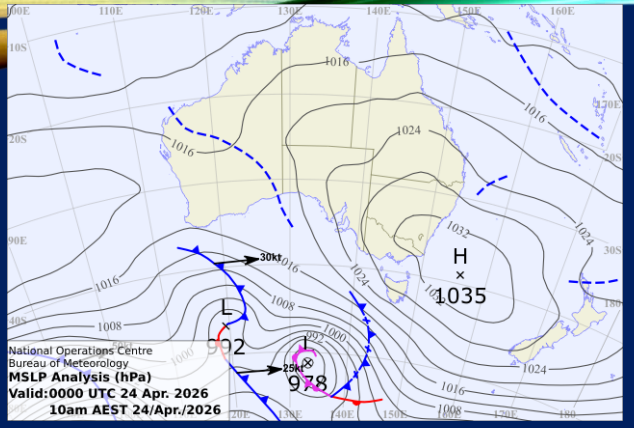
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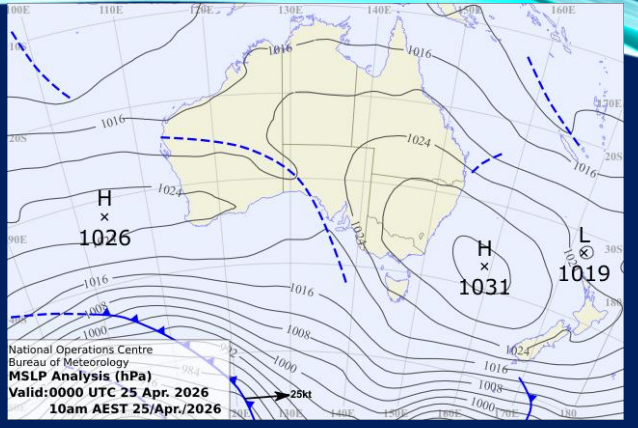
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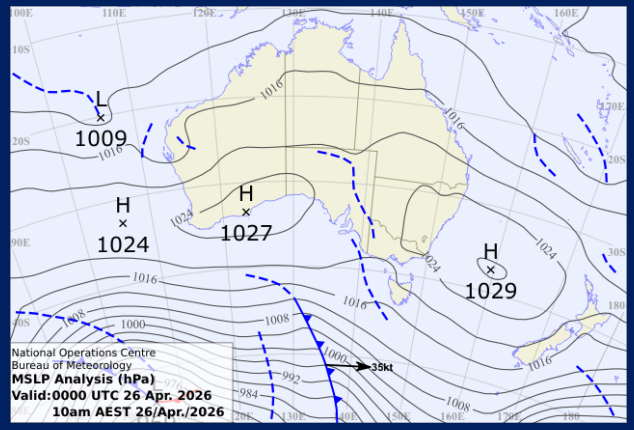
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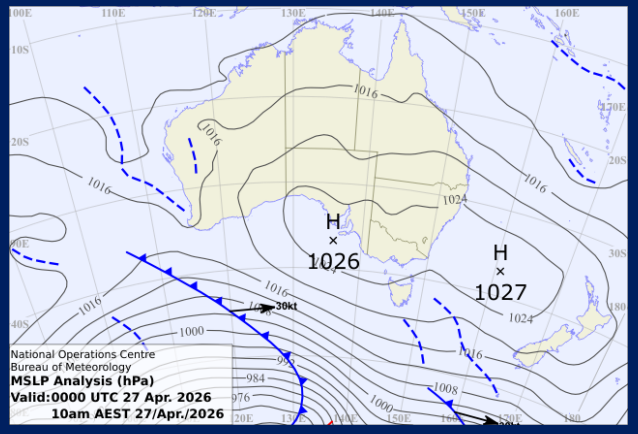
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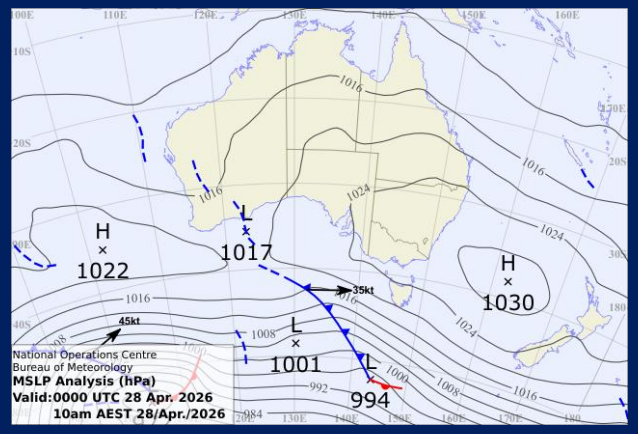
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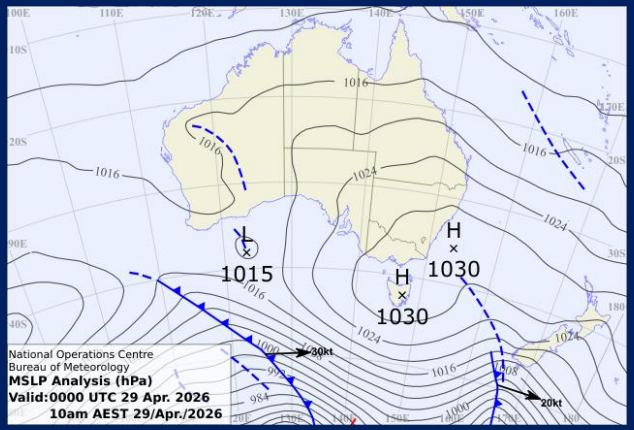
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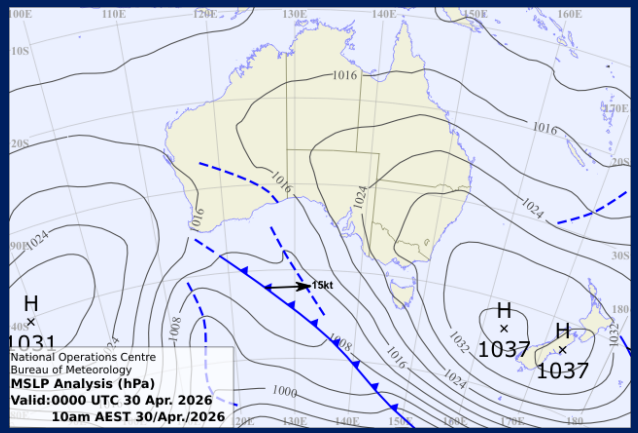
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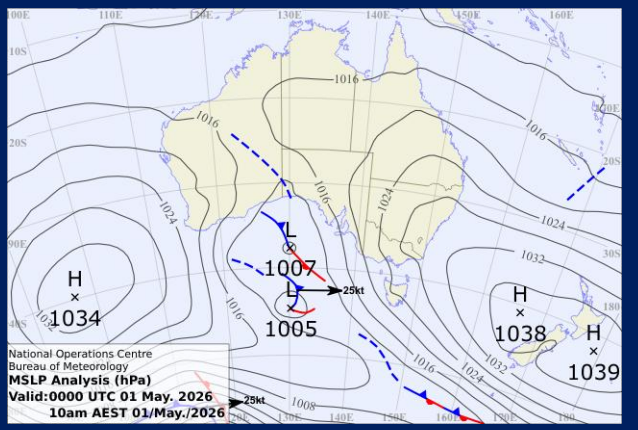
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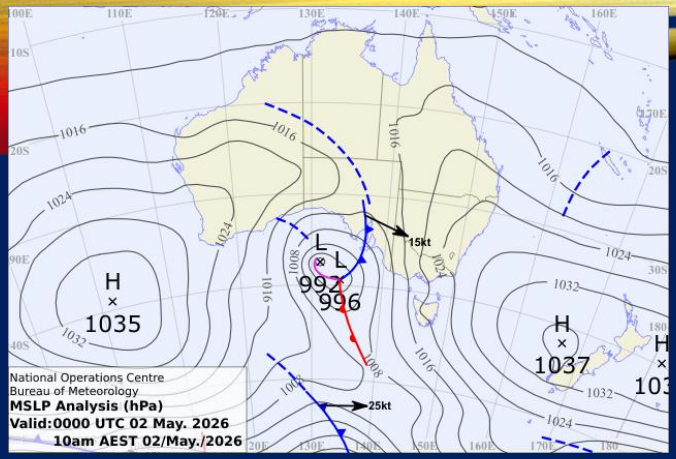
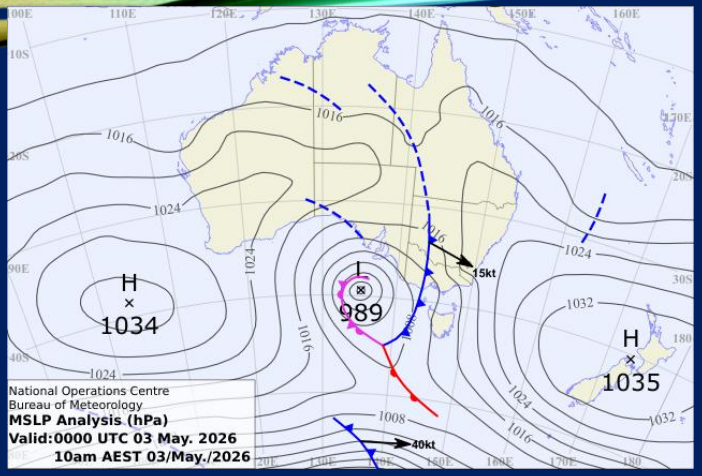
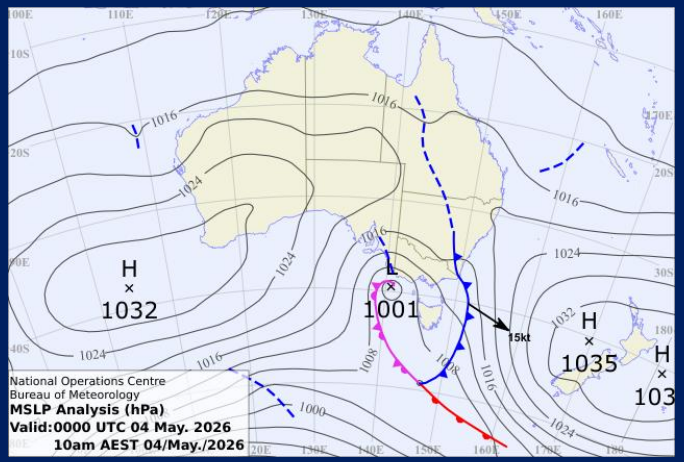
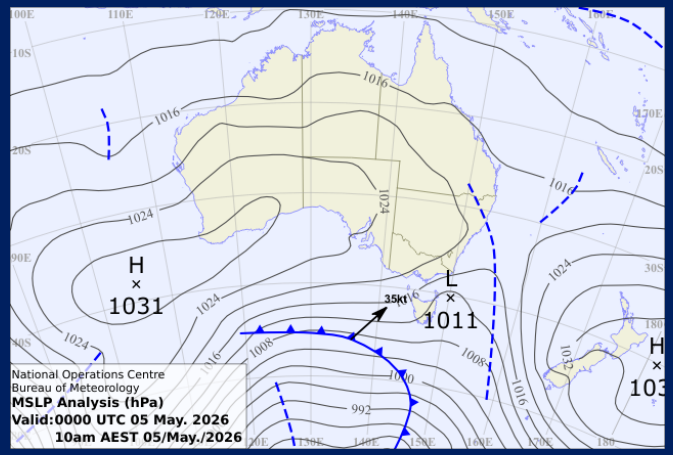
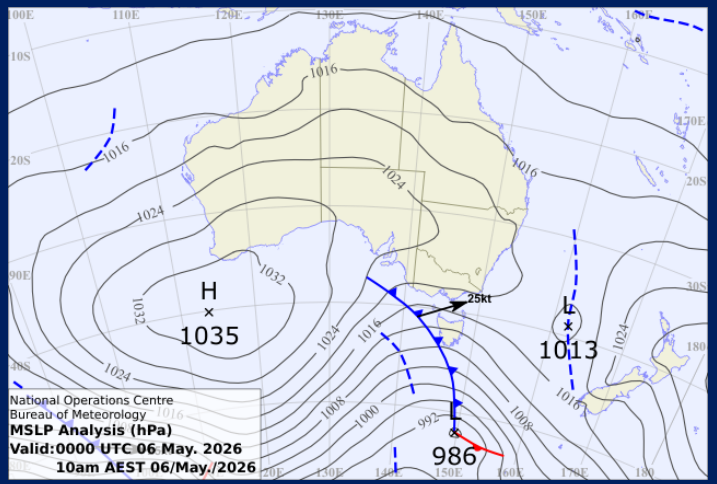
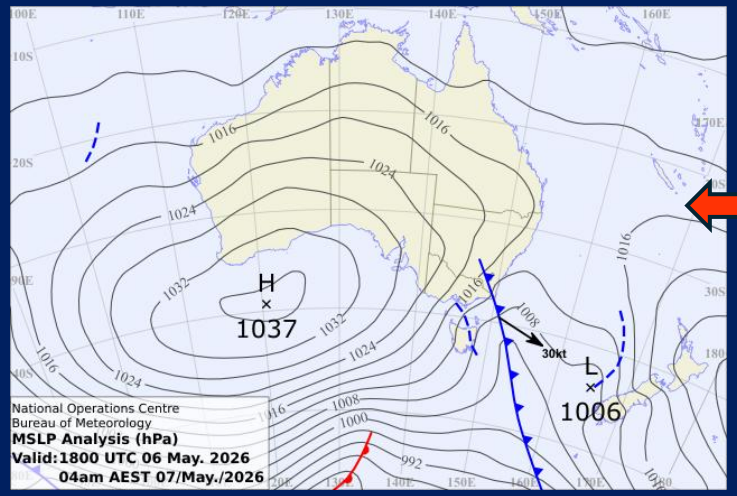




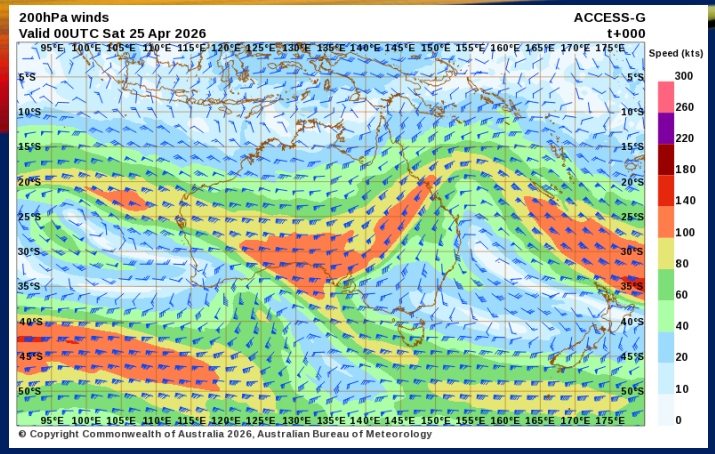








4 am
Thursday 7
May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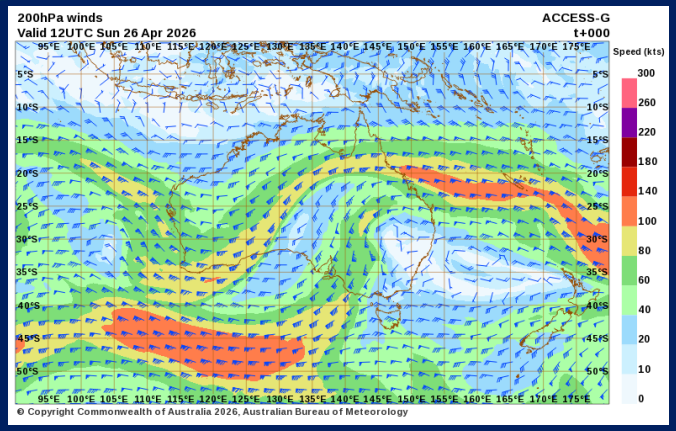
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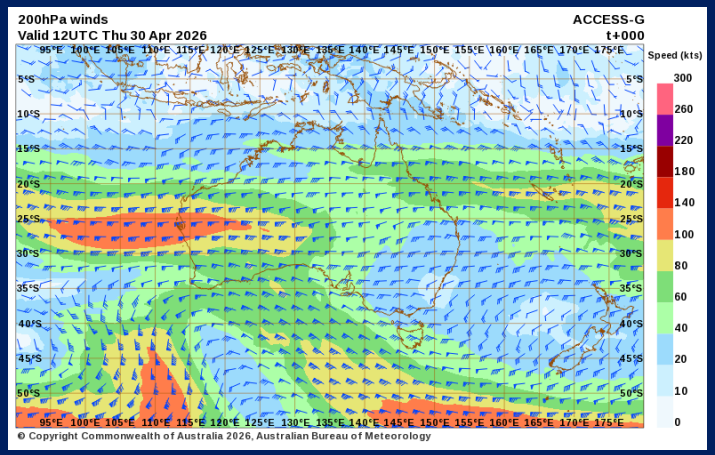
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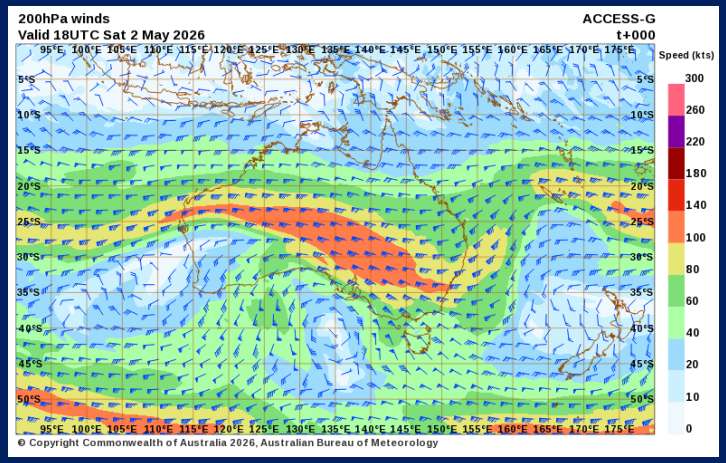
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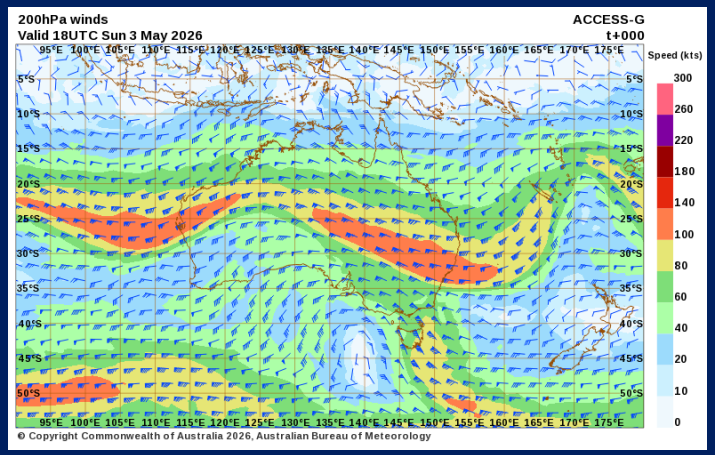
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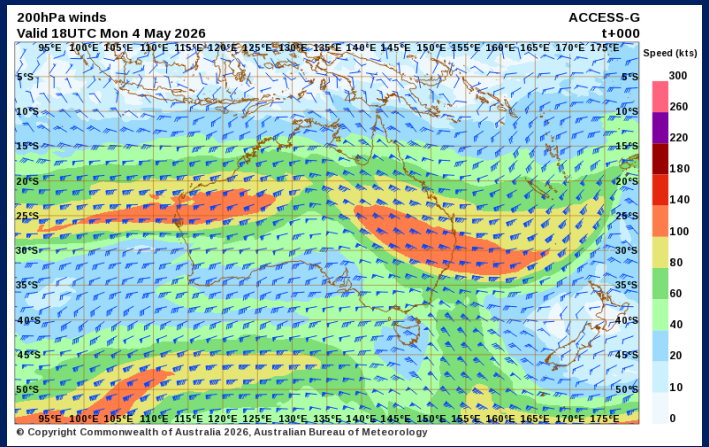
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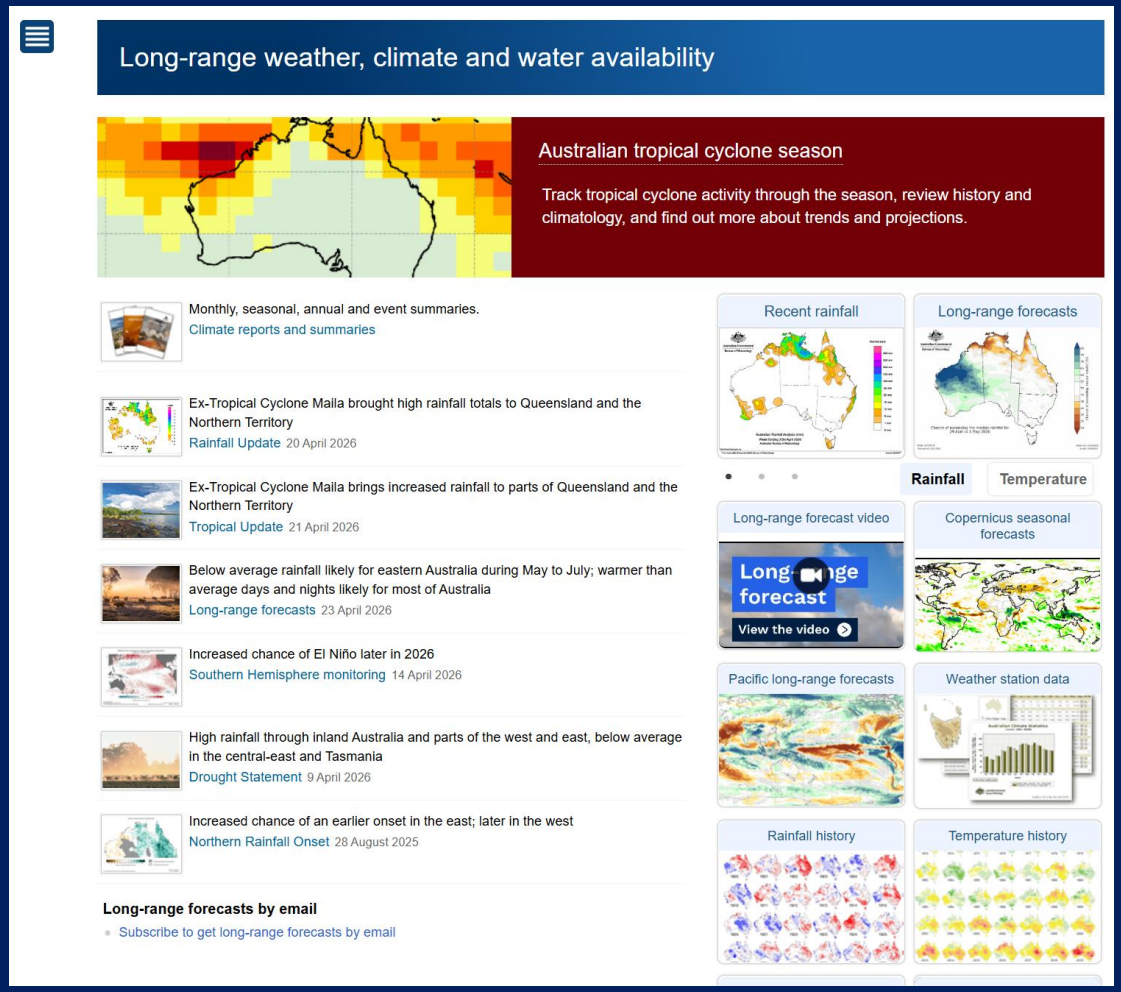
Finding Past Weather Data on the BoM web-site

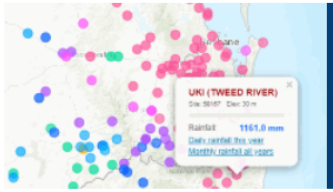


https://reg.bom.gov.au/climate/

https://www.bom.gov.au/weather-and-climate/past-weather-and-climate

Climate

Forecasts & monitoring
News & reports
Station data
Recent observations index
Latest rainfall
Daily rainfall
Recent observations
Monthly statistics
Major cities
Water Data Online
Hydrologic Reference Stations
Long-term temperature data
Maps – history to now
Maps – averages
Climate change
Extremes and records
Data services



Latest rainfall totals, daily and monthly data

Quickly find the latest totals. Station dots link to the rainfall tables.
For more stations, including historical stations, search below.

Climate Data Online

About Climate Data Online | How to get data - FAQs | Technical help

Additional data available
Data services requests
Service announcements
Quality control updates

Use either the Text search OR the Map search to find local weather stations.

You can get daily and monthly statistics, historical weather observations, rainfall, temperature and solar tables, graphs and data.

Related information

- For additional data types, or specifc dates and localities go to: Weather Station Directory
- For weather station lists: Filter and download station lists

Text search

Select your data type, your location, then select from the list of stations.
If you prefer to see the station locations, use the map search instead.

Help

1: Selected: Daily rainfall

Data about: Rainfall

Type of data: Observations (Daily / Monthly) | Statistics (Daily / Monthly)

Daily rainfall data and graphs for a selected year. Data download for one or all years.

2: Select a weather station in the area of interest

Enter a location | Find

OR - search by Position

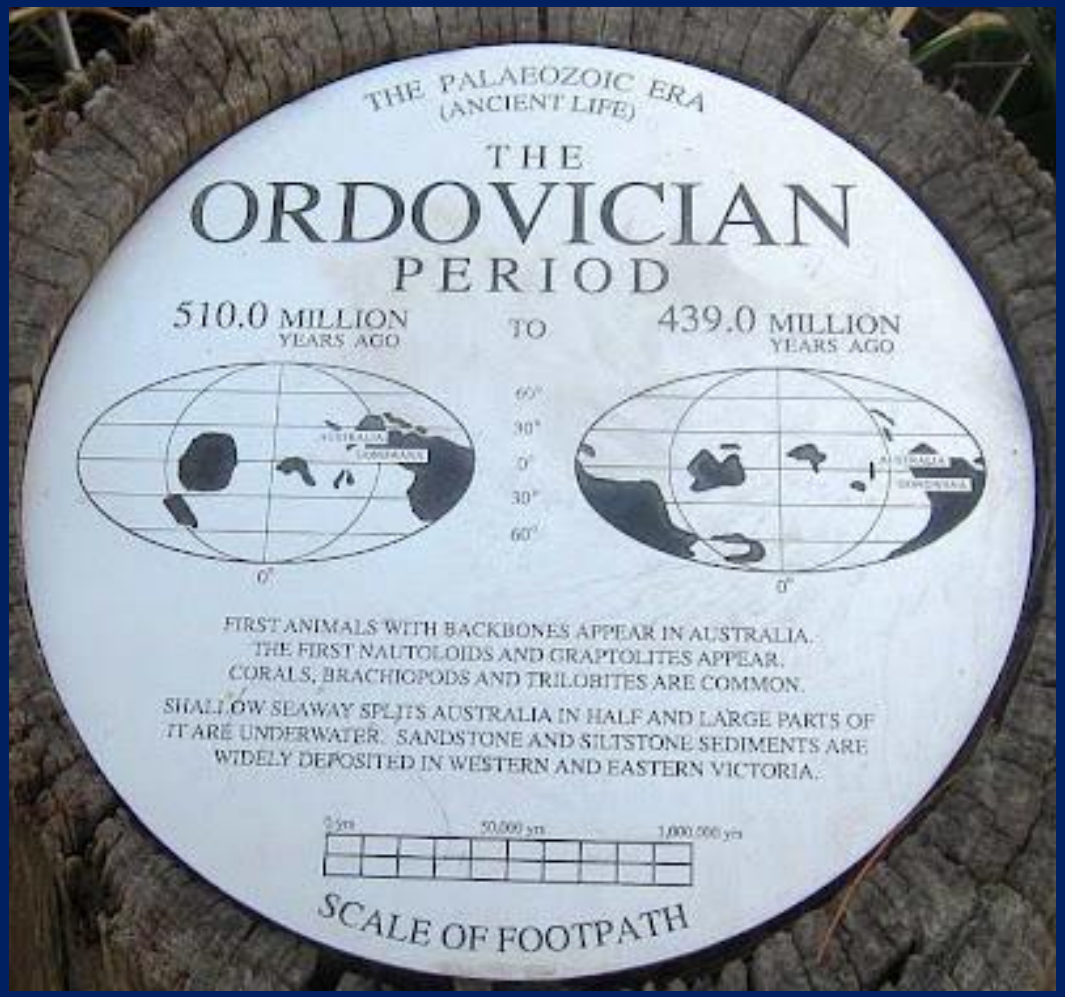
3: Get the data

If you already know the station number you may enter it below instead of using the search above.

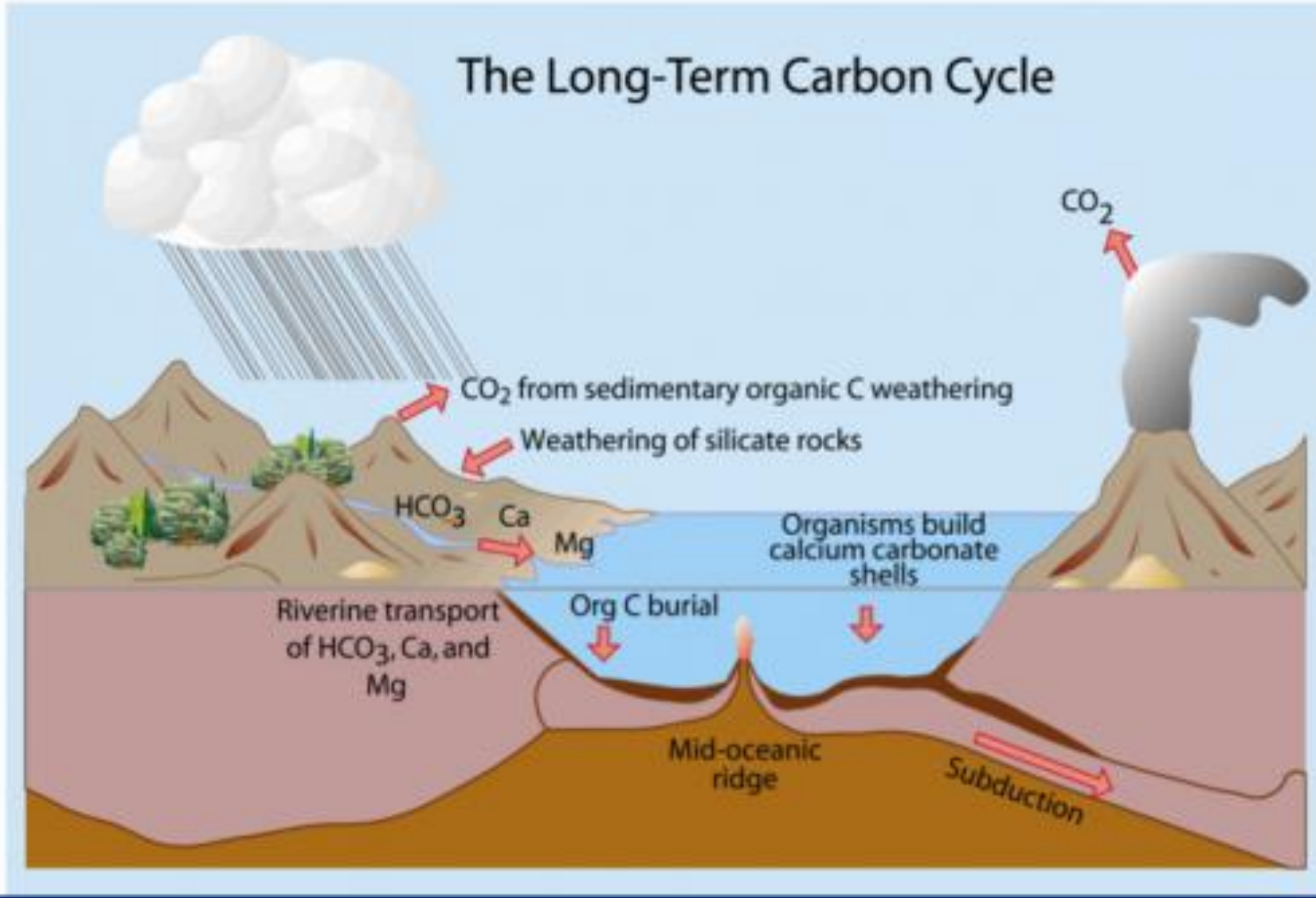
Station number | Get Data (Opens in new window)

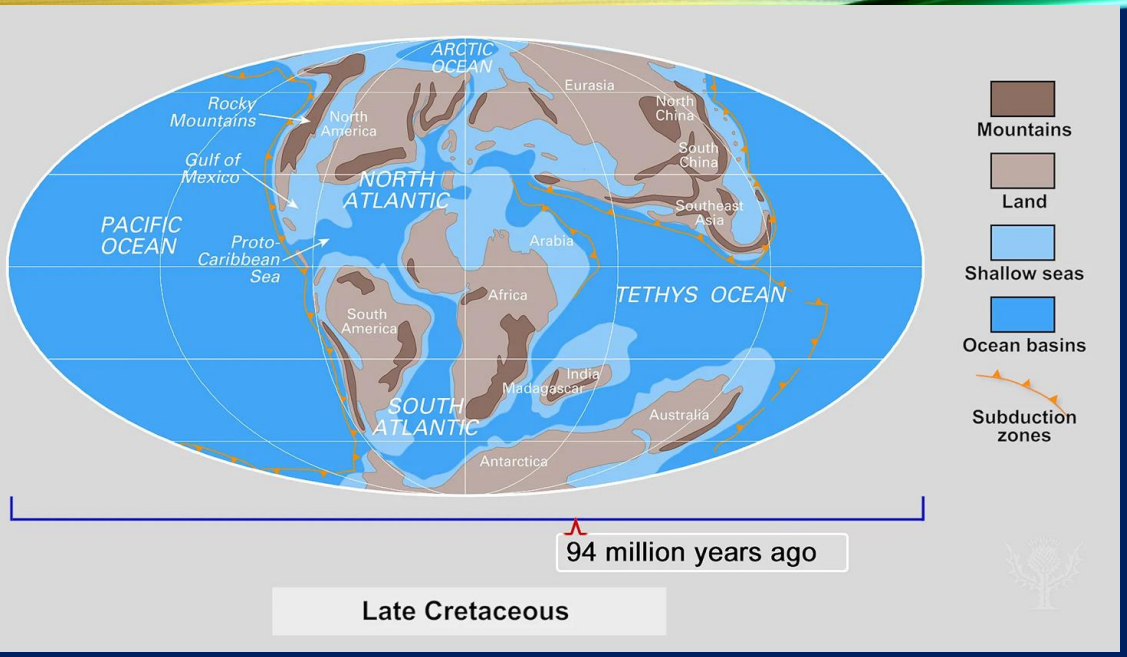
Save | Clear

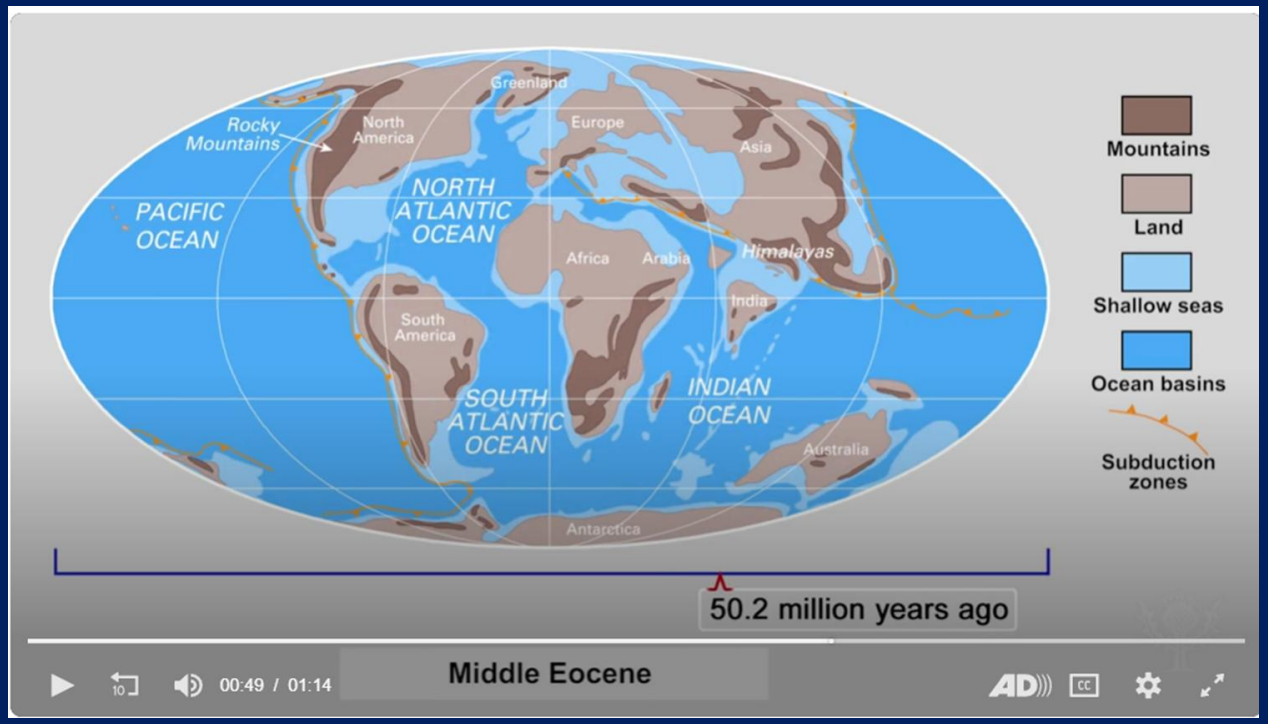
Gardiner's Creek Trail, Burwood.



Gardiners Creek, Burwood


The Long-Term Carbon Cycle
CO_2
CO_2 from sedimentary organic C weathering
Weathering of silicate rocks
HCO_3
Ca
Mg
Organisms build calcium carbonate shells
Riverine transport of HCO_3, Ca, and Mg
Org C burial
Mid-oceanic ridge
Subduction


ARCTIC OCEAN
Eurasia
North China
South China
Southeast Asia
Rocky Mountains
North America
Gulf of Mexico
NORTH ATLANTIC
PACIFIC OCEAN
Proto-Caribbean Sea
Arabia
Africa
TETHYS OCEAN
South America
India
Madagascar
SOUTH ATLANTIC
Australia
Antarctica
Mountains
Land
Shallow seas
Ocean basins
Subduction zones
94 million years ago
Late Cretaceous


Greenland
Rocky Mountains
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Subduction zones
50.2 million years ago
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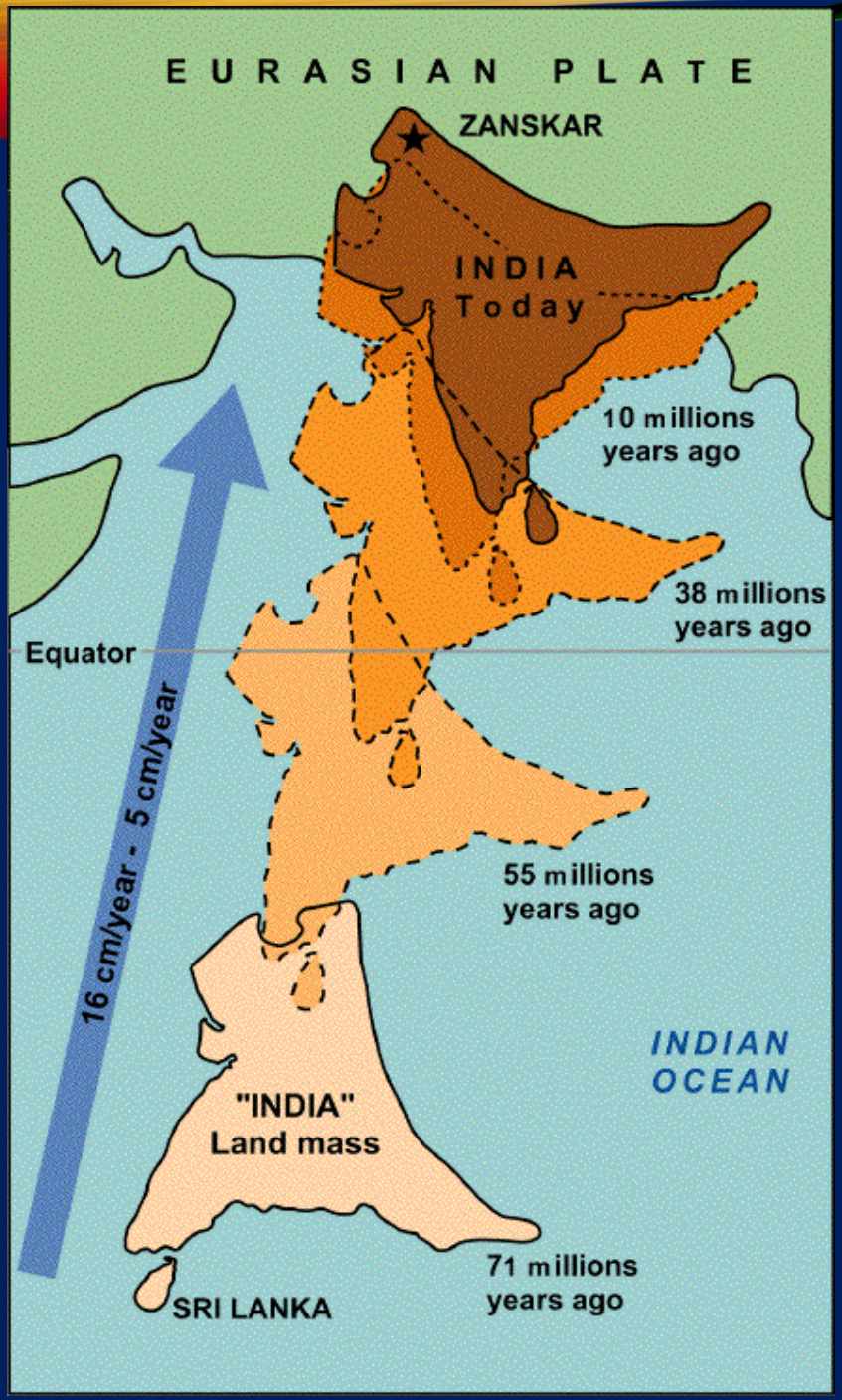
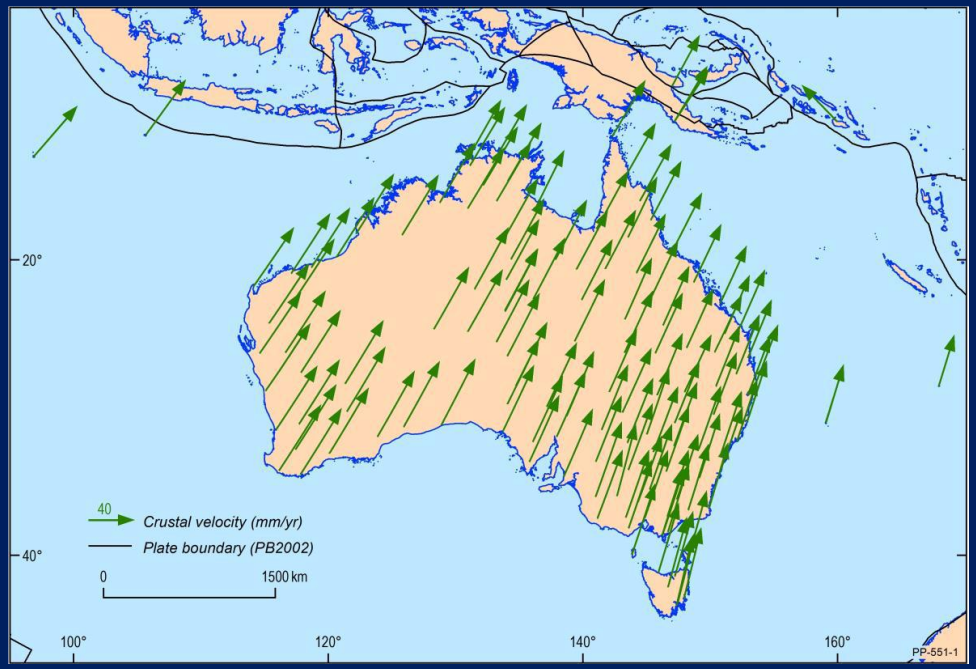
Middle Eocene



How fast did India move?

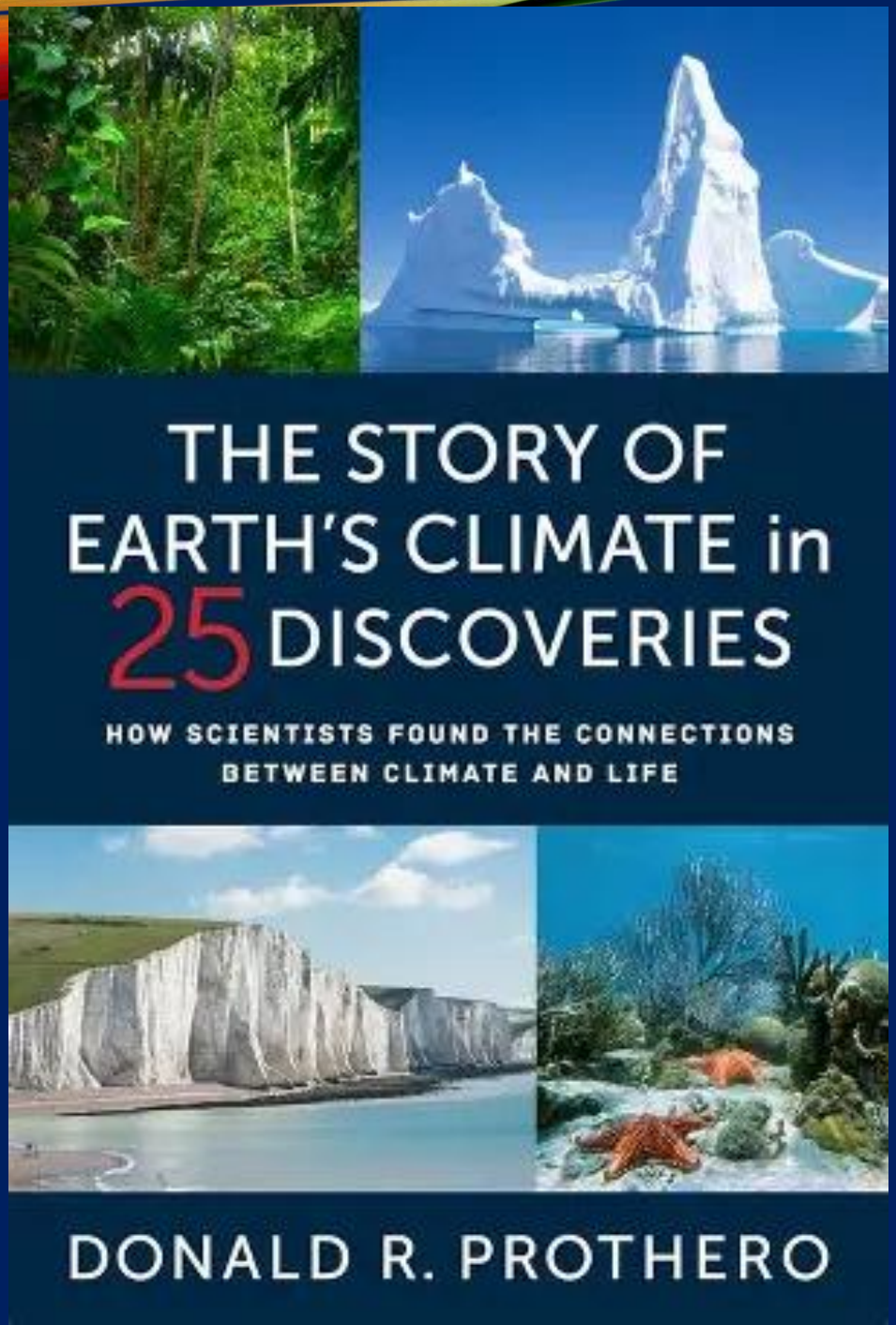
https://www.earthdate.org/episodes/fast-moving-india

And Australia now?

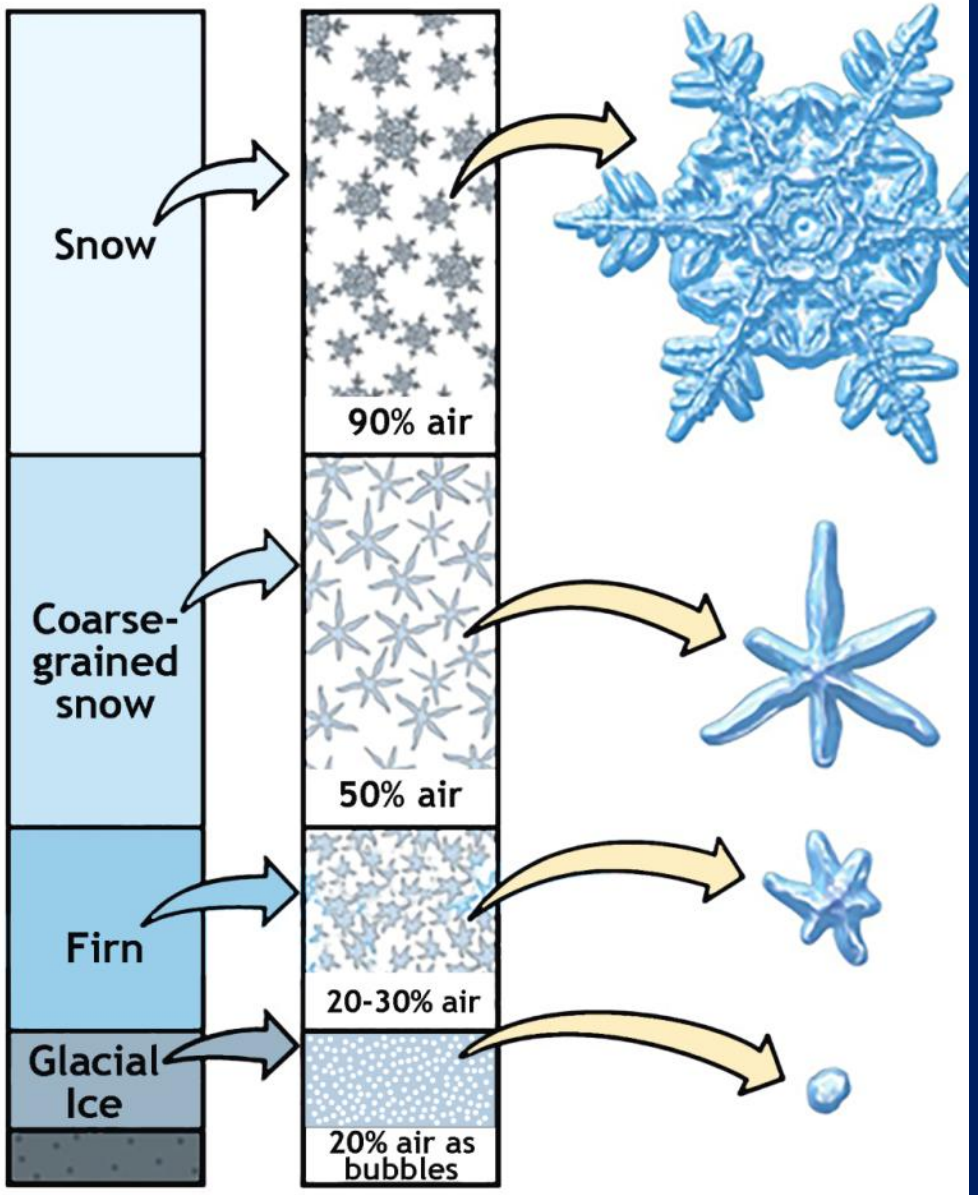


Typically, about 7 cm per year

https://seasia.co/2024/02/14/tectonic-tango-australias-journey-toward-indonesia-7-centimeters-closer-each-year



Columbia University Press (2024)

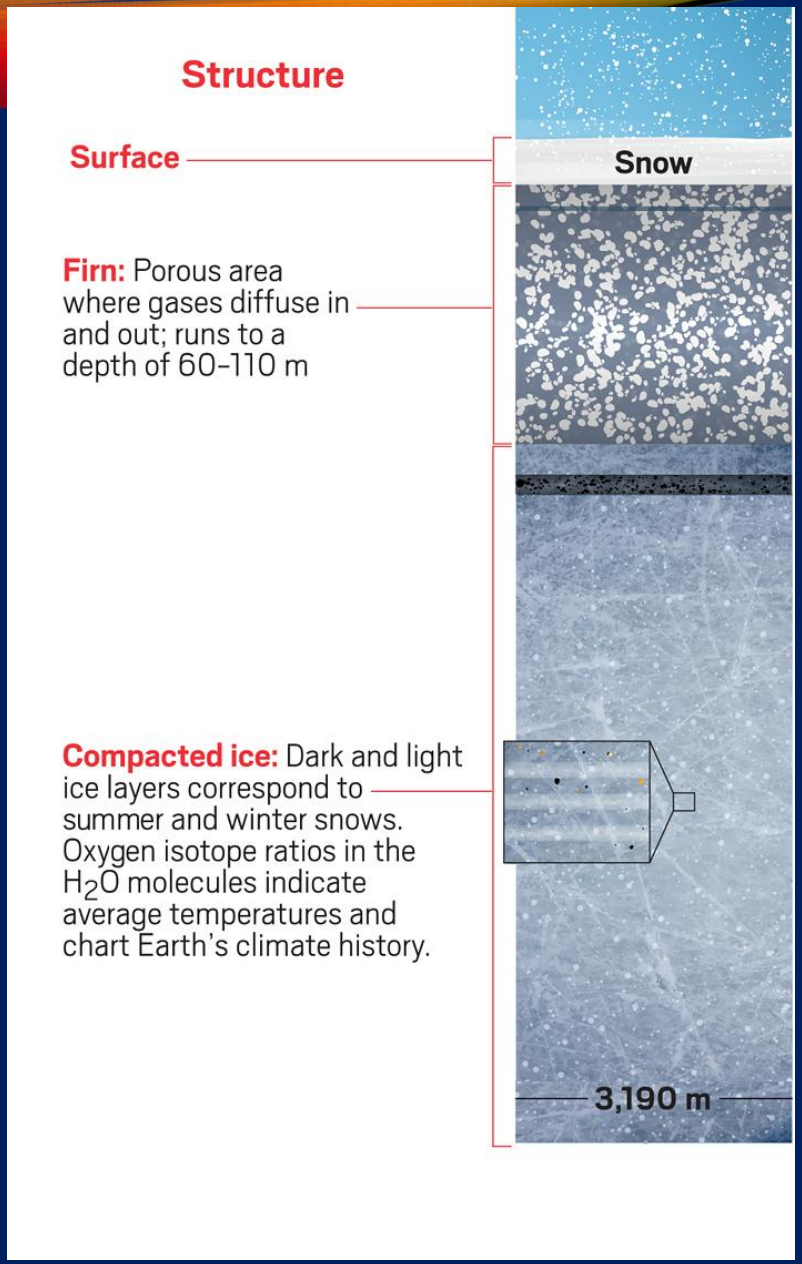


If **snow** lasts through the year it begins to transform. The weight of new snow on top compacts it, slowly squeezing air out and changing the shape of the snowflakes.

These pointy snow grains are forced into close 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.**

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.

The layers show annual cycles, or any layers of dust.

Ice flows – even on the ice caps.

e.g. Antarctica has had ice cover for the past 34 million years, but the oldest ice found so far is about 1 million years old. The current Australian Antarctic Division project hopes to find a core dating back 2 million years.

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.

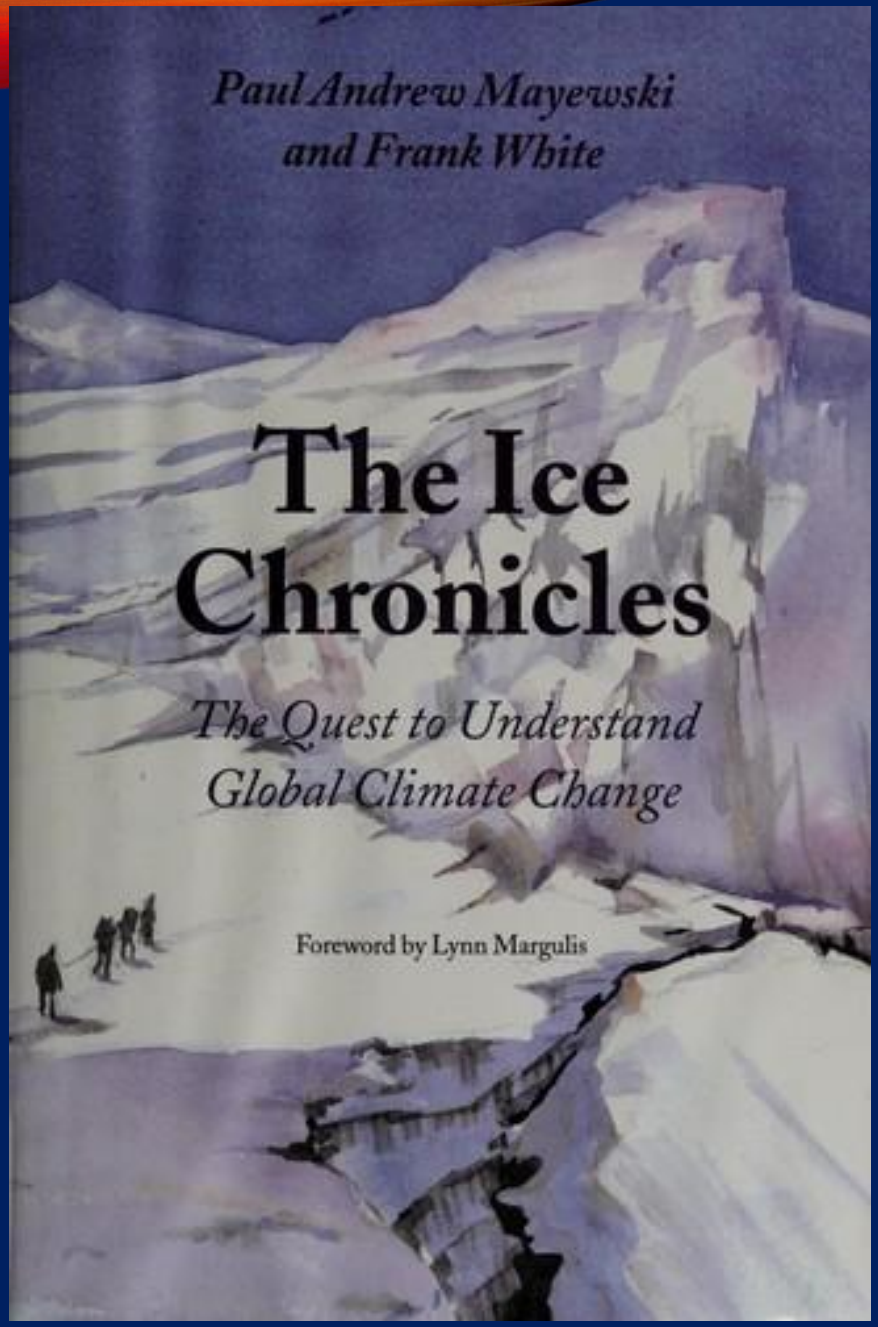
2. Bubbles of air trapped in glacier ice.

   - 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

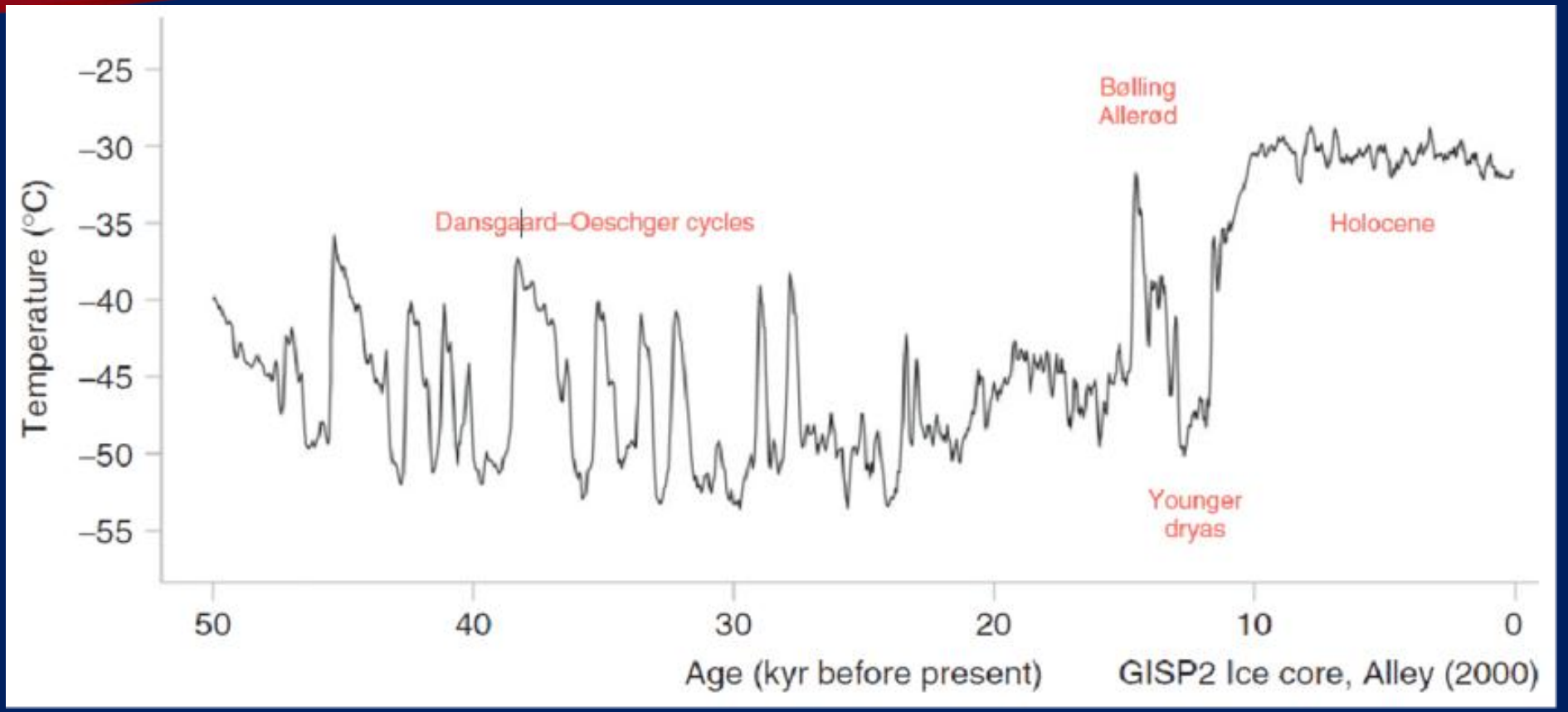


Ice Cores in Greenland

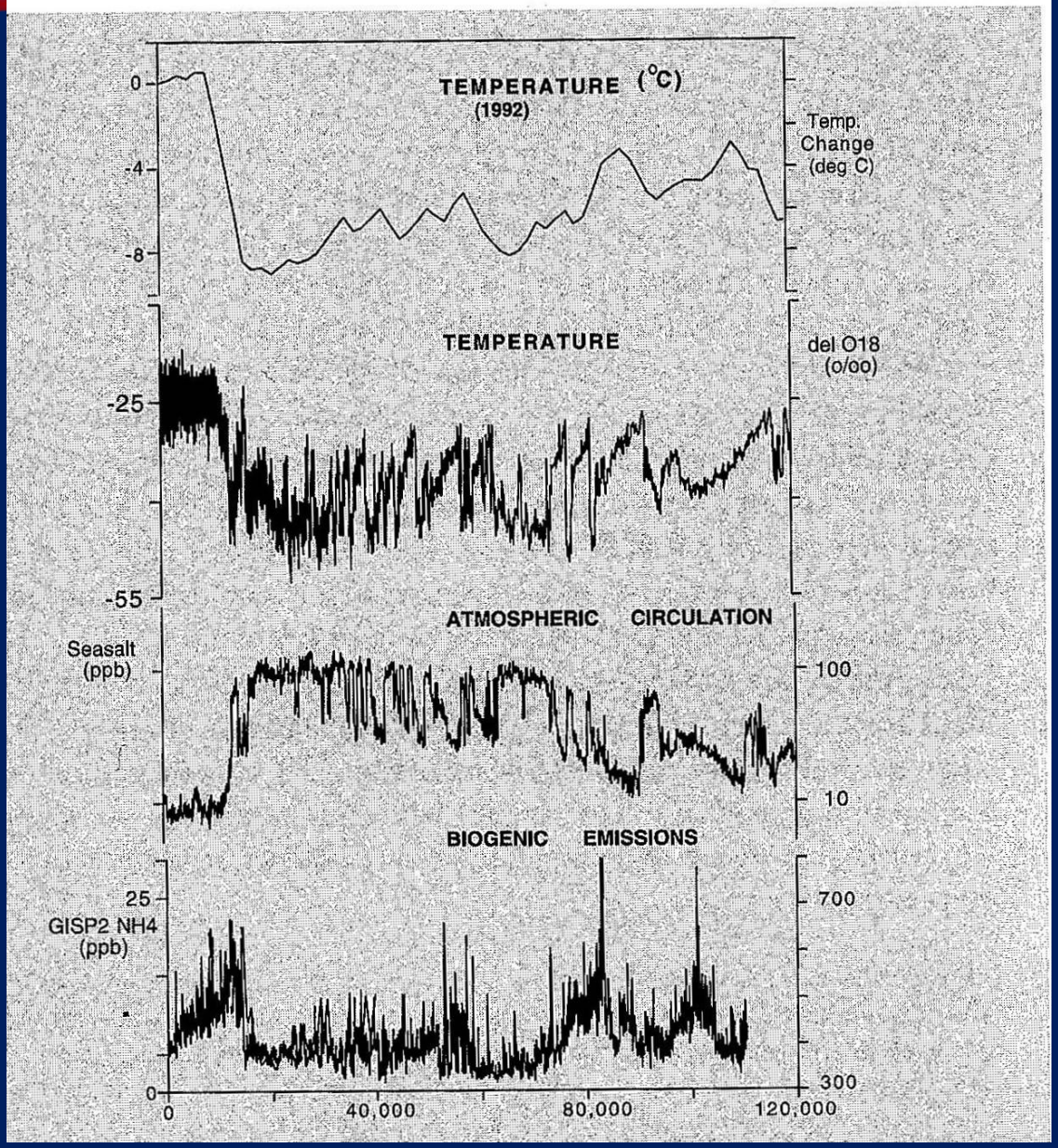
Paul Mayewski was the leader of the US National Science Foundation's Greenland Ice Sheet Project Two (GISP2)

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.



Temperature record from the GISP2 ice core in Greenland



"How the Greenland ice cores transformed our view of climate change."

Top: typical view in 1992 of temperature change based on analysis of sediment cores from lakes and the ocean.

Upper middle: Greenland ice core data based on Oxygen-18

Lower middle: Sea salt concentration indicating windiness over oceans.

Bottom: Ammonium levels indicating biomass. Extreme spikes indicate burning events. *Ice Chronicles* Fig. 3.2

Some History

Early 19th century – some researchers interpreted features in the Alps as evidence that the earth's climate must have been much colder some time in the past and that ice had covered much of the northern hemisphere.

e.g. "Erratic boulders" in Alpine regions; scratch marks on rocks; glacier debris.

The name most commonly associated with making the idea widespread was **Louis Agassiz** (1801-1873).

Many questions – **when, why, more than one?**

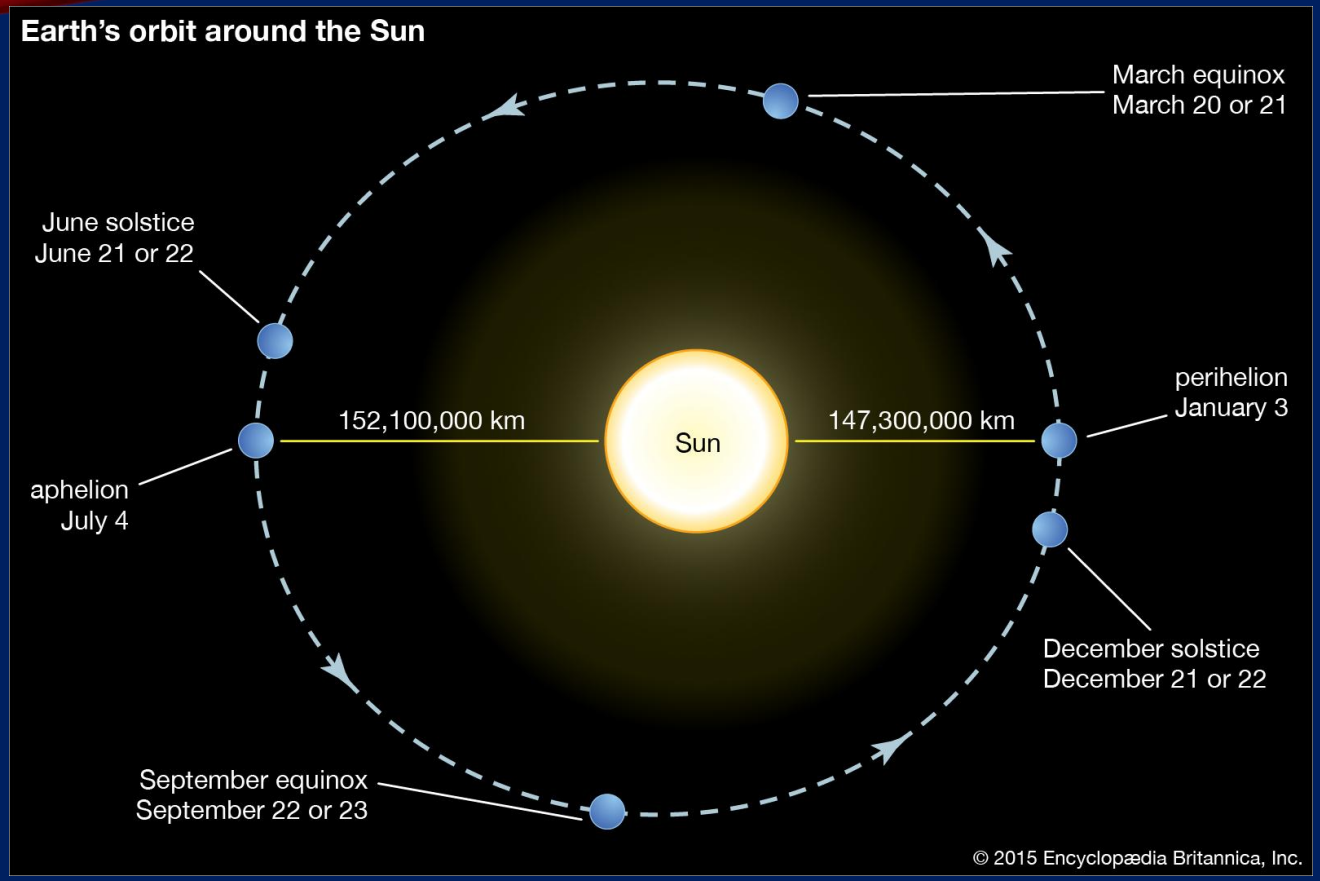
Suggested causes:

- Earth cooling from its original hot origin
- A shift in the earth's axis
- The earth had passed through hotter and colder regions of space
- Rearrangement of land masses.

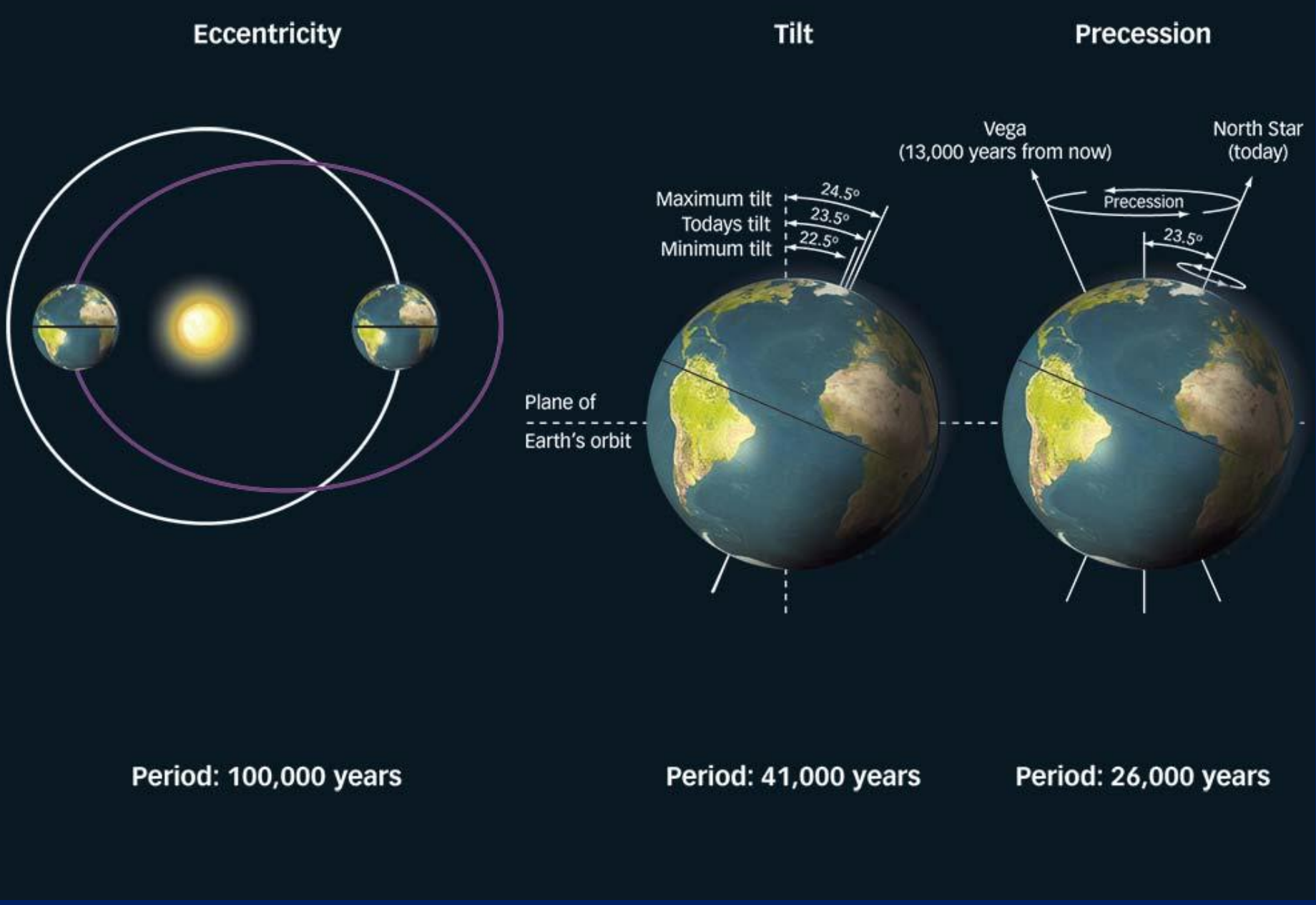
Around the same time, variations of the earth's orbit, some of them known since Ancient Greek times, were being studied – primarily for improved navigation.

Le Verrier (1811-1877) worked on the various cycles in earth's orbit – in eccentricity, obliquity and precession - and published tables in 1861.

The Earth's orbit around the Sun - now



- Earth's orbit is not a perfect circle (Kepler).
- The changing Earth-Sun distance results in about 7% more in total solar energy reaching the Earth at perihelion (January) compared with aphelion.
- Currently, the Earth's orbit is close to circular, with about 5 million km difference between the perihelion and aphelion distances. At its most elliptical, that difference is about 15 million km.


Eccentricity
Tilt
Precession
Vega
(13,000 years from now)
North Star
(today)
Maximum tilt
Todays tilt
Minimum tilt
24.5°
23.5°
22.5°
Precession
23.5°
Plane of
Earth's orbit
Period: 100,000 years
Period: 41,000 years
Period: 26,000 years

Two separate topics were being discussed in the nineteenth century:

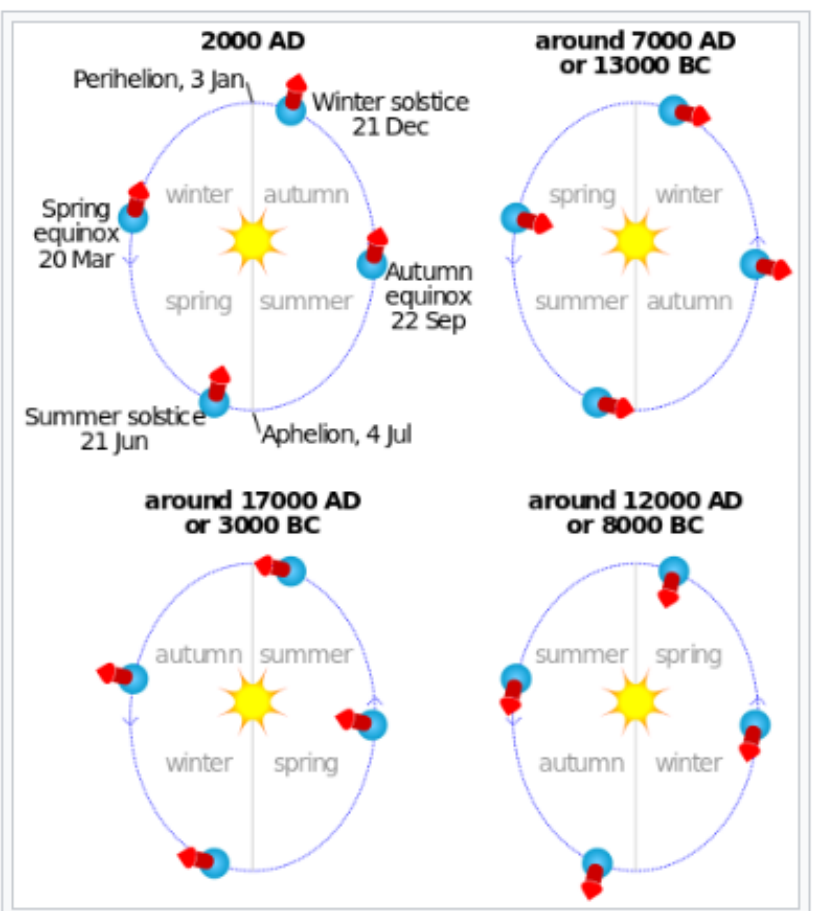
- Variations in the Earth's orbit
- Ice Ages

A few started putting the two together.

1842 Joseph Alphonse Adhémar (France) proposed that glaciation occurs when northern winters are anomalously long, which happens when they coincide with aphelion (the point of Earth's orbit that is farthest from the Sun) as part of the 22,000-year precession of the equinoxes.

1864 James Croll (Scotland) published an article *"On the physical cause of the change of climate during geological epochs".*
From the calculations on the earth's orbit, he computed the expected changes in incoming energy from the sun over 5 million years.

He predicted that one hemisphere or the other would experience an ice age when the winter solstice occurred far from the sun when the orbit was at its most elongated.



https://en.wikipedia.org/wiki/Axial_precession

James Croll looked at the combination of precession and ellipticity.

If the earth's orbit were truly circular there would be no effect from the precession – the amount of energy from the sun would just show the seasonal variation.

If the earth's axis precesses, the season when the earth is at aphelion (i.e. further from the sun) or at perihelion (closest to the sun) can change.

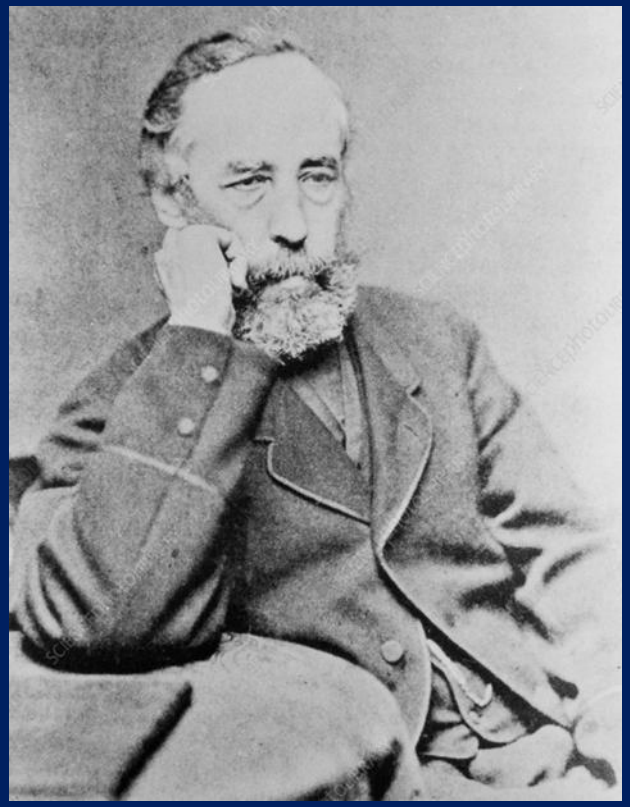
One example from Croll – if:

- northern hemisphere winter occurred when the earth was furthest from the sun. (sunlight is weaker)
- and the orbit was at its most elliptical (winter is longer)

then there could be a **runaway effect** – winter snow may not completely melt during summer and so could build up from year to year.

Croll's basic theory:

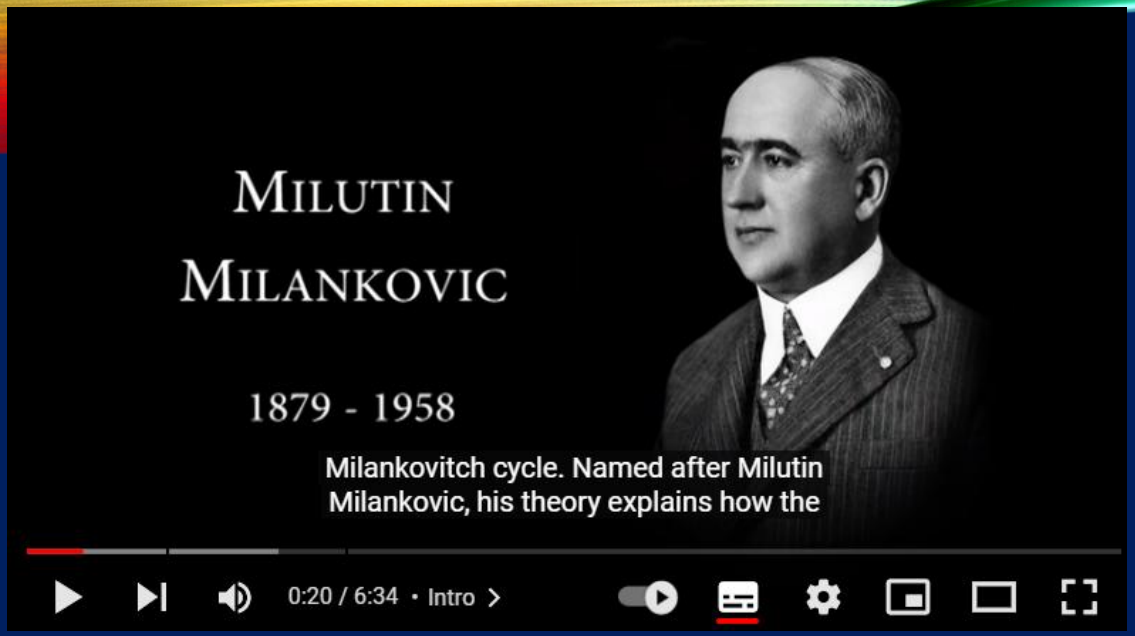
- decreases in winter sunlight would favour snow accumulation.
- need for feedback mechanisms to amplify the solar changes
  - Ice-albedo feedback
  - Changes in sea level, winds and currents such as the Gulf Stream.
- there would be multiple ice ages alternating between southern and northern hemispheres, lasting approximately 10,000 years each
- the last ice ages should have ended about 80,000 years ago.



Very influential – including on Charles Darwin and Charles Lyell (who revised his book to recognize changes in the earth's orbit as a factor in climate change).

Emerging geological evidence conflicted with his theory and by the end of the nineteenth century his ideas were discredited.

However, his theory had been a bold pioneering attempt to combine two different fields of work – and would be revived.



https://www.youtube.com/watch?v=iA788usYNWA

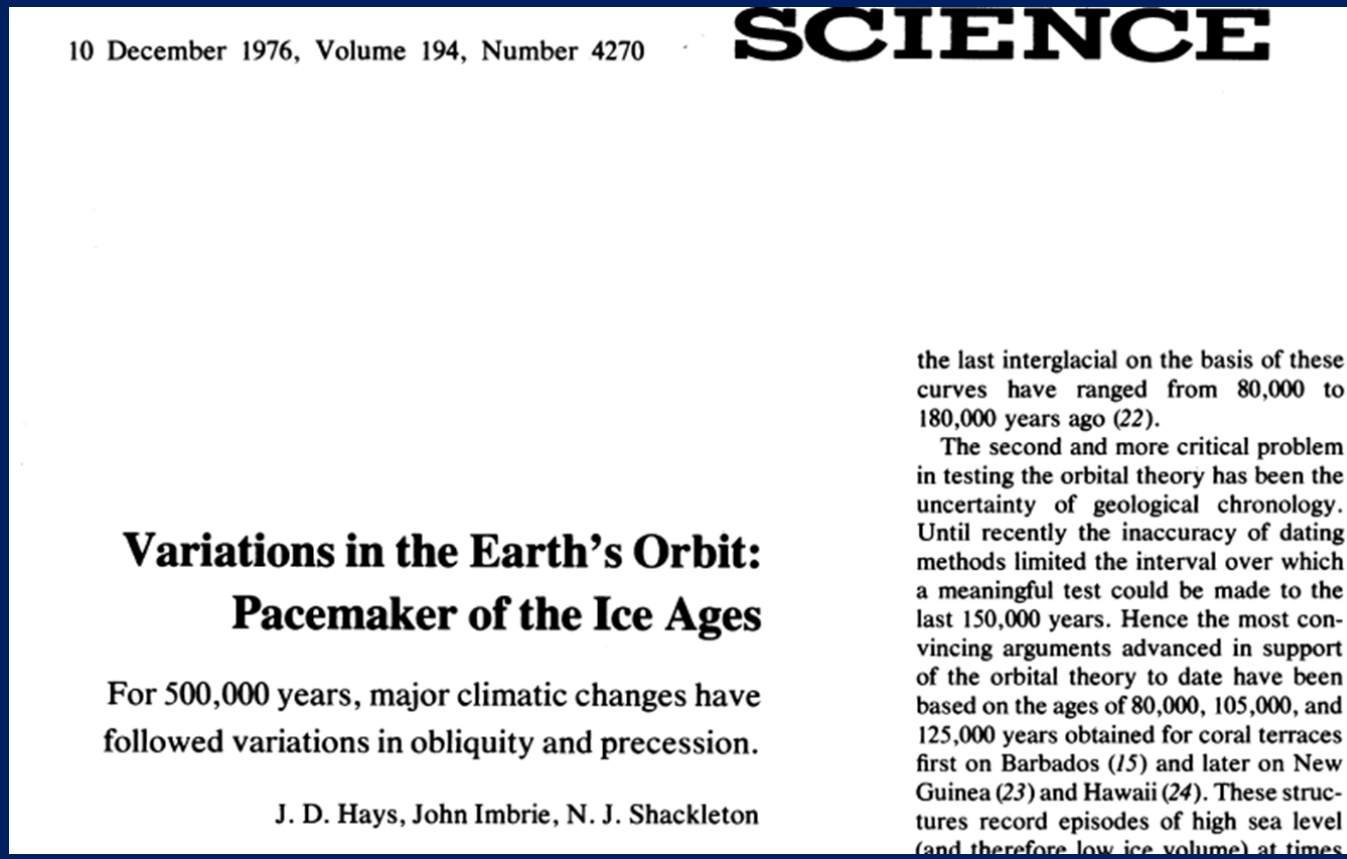
- Became fascinated with the causes of the ice ages
- As a Serbian he was detained during World War 1 but was given sympathetic treatment and allowed to keep working on astronomical problems.
- 1941 –*"Canon of Insolation of the Earth and Its Application to the Problem of the Ice Ages."* (In German)
- 1969, ten years after his death, his book was translated into English by the Israel Program for Scientific Translations.

He suggested that the extent of snow and ice cover in the Northern Hemisphere during Summer was a crucial factor in global climate. If the ice and snow cover did not melt in the summer, it could build up from year to year and lead to the onset of an ice age.

Project CLIMAP (Climate: Long Range Investigation, Mapping and Production) finally provided evidence for the theory of astronomical cycles based on analysed temperatures over the past 700,000 years from deep-sea sediment cores .

A crucial paper was published in 1976 that in the past 500,000 years, the climate has changed depending on the shape of the Earth's orbit, its axis of rotation and its precession.

Like Croll, it agreed that the changes in orbit are not enough alone and there has to be some feedback mechanism. However, the concept of the Croll-Milankovitch cycle as **a pacemaker** has continued to be a key concept.



10 December 1976, Volume 194, Number 4270 SCIENCE

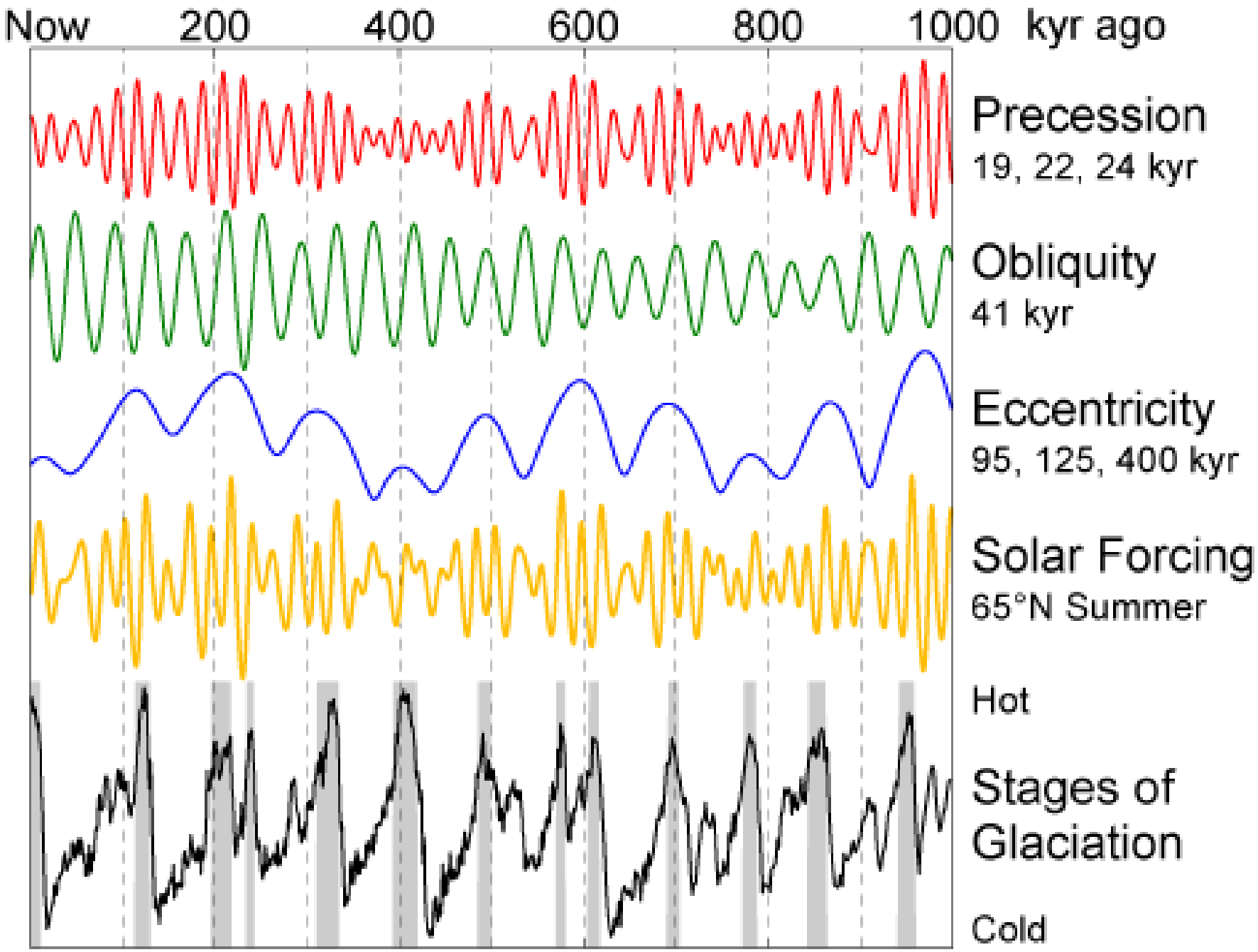
Variations in the Earth's Orbit: Pacemaker of the Ice Ages

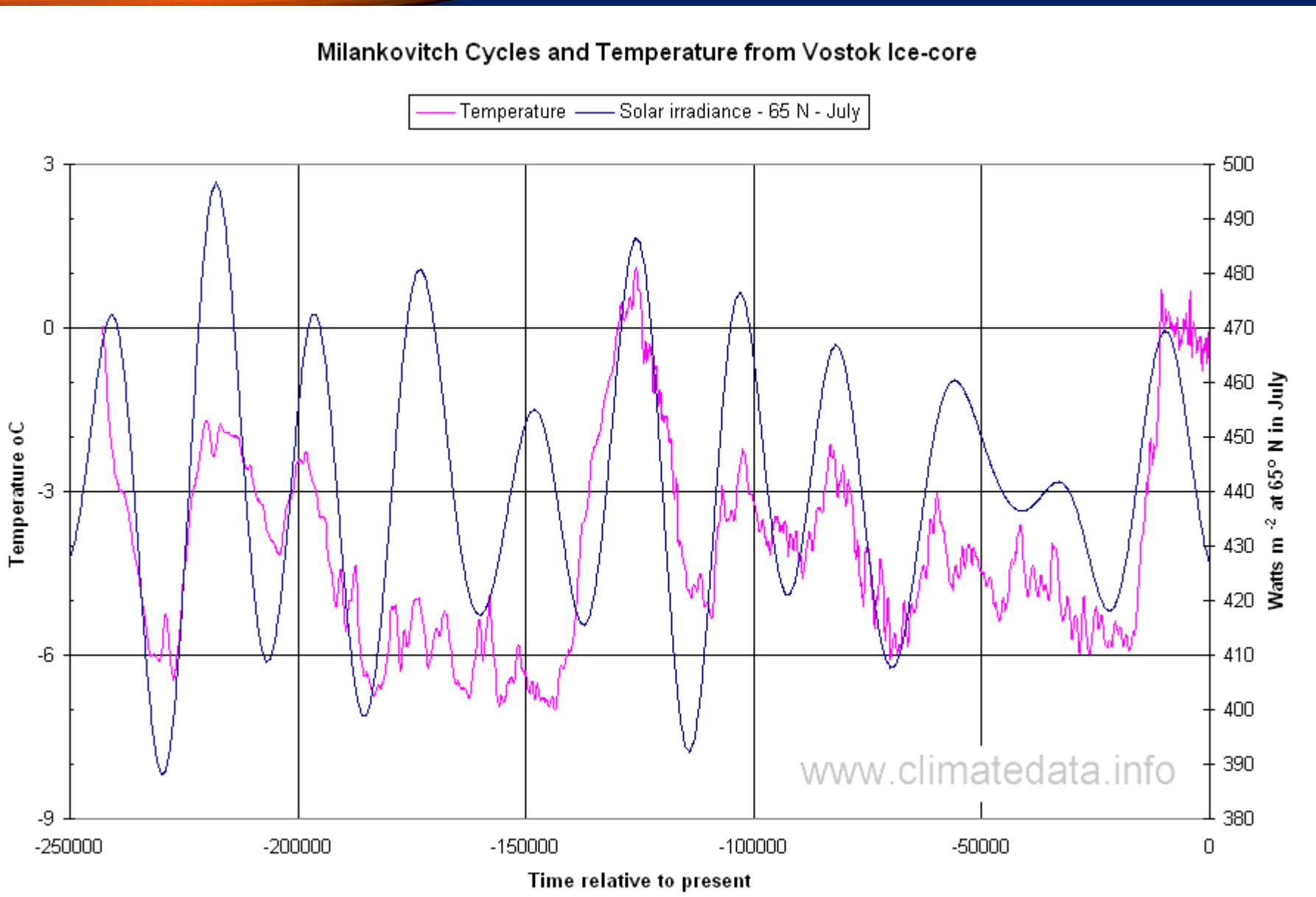
For 500,000 years, major climatic changes have followed variations in obliquity and precession.

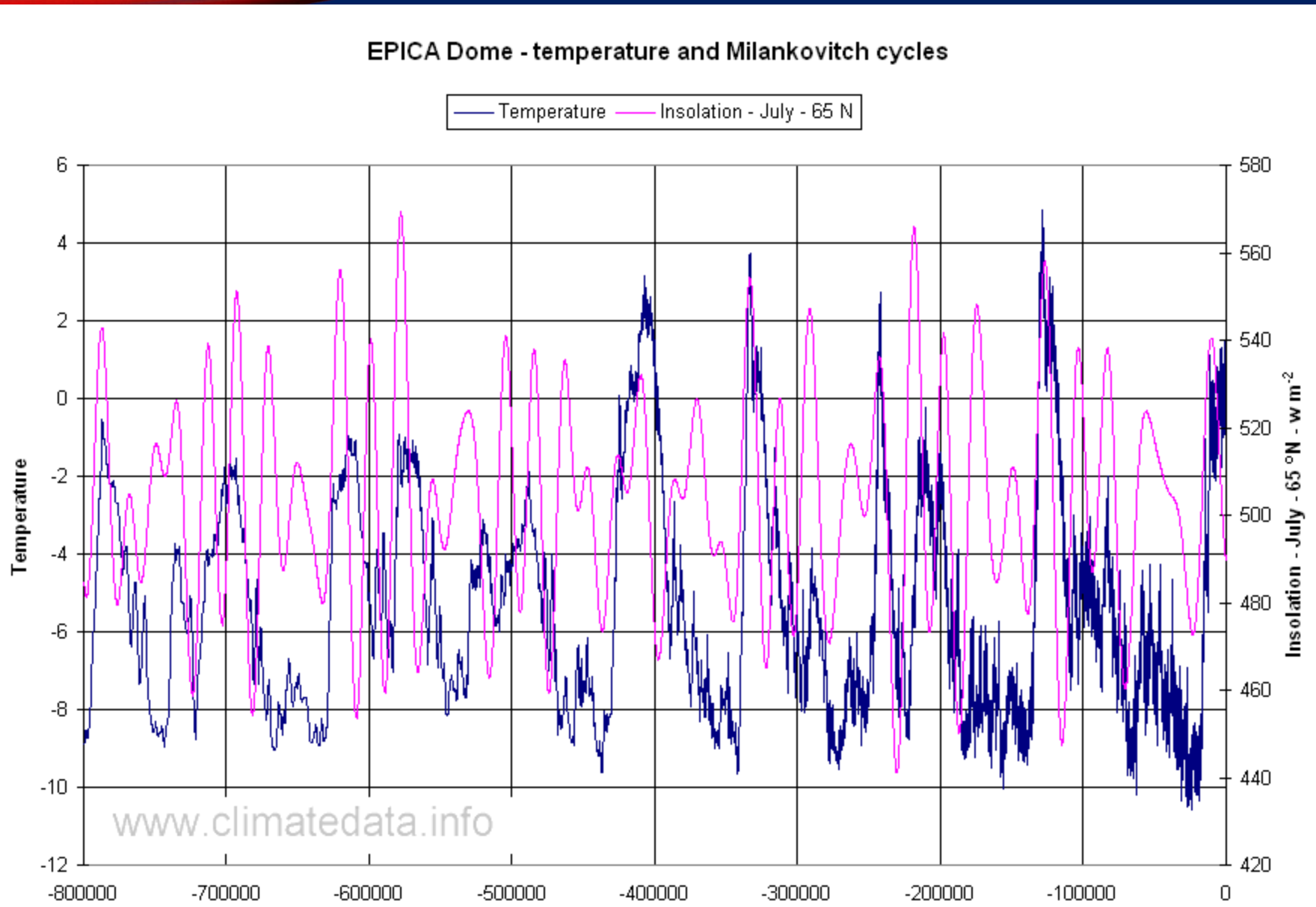
J. D. Hays, John Imbrie, N. J. Shackleton

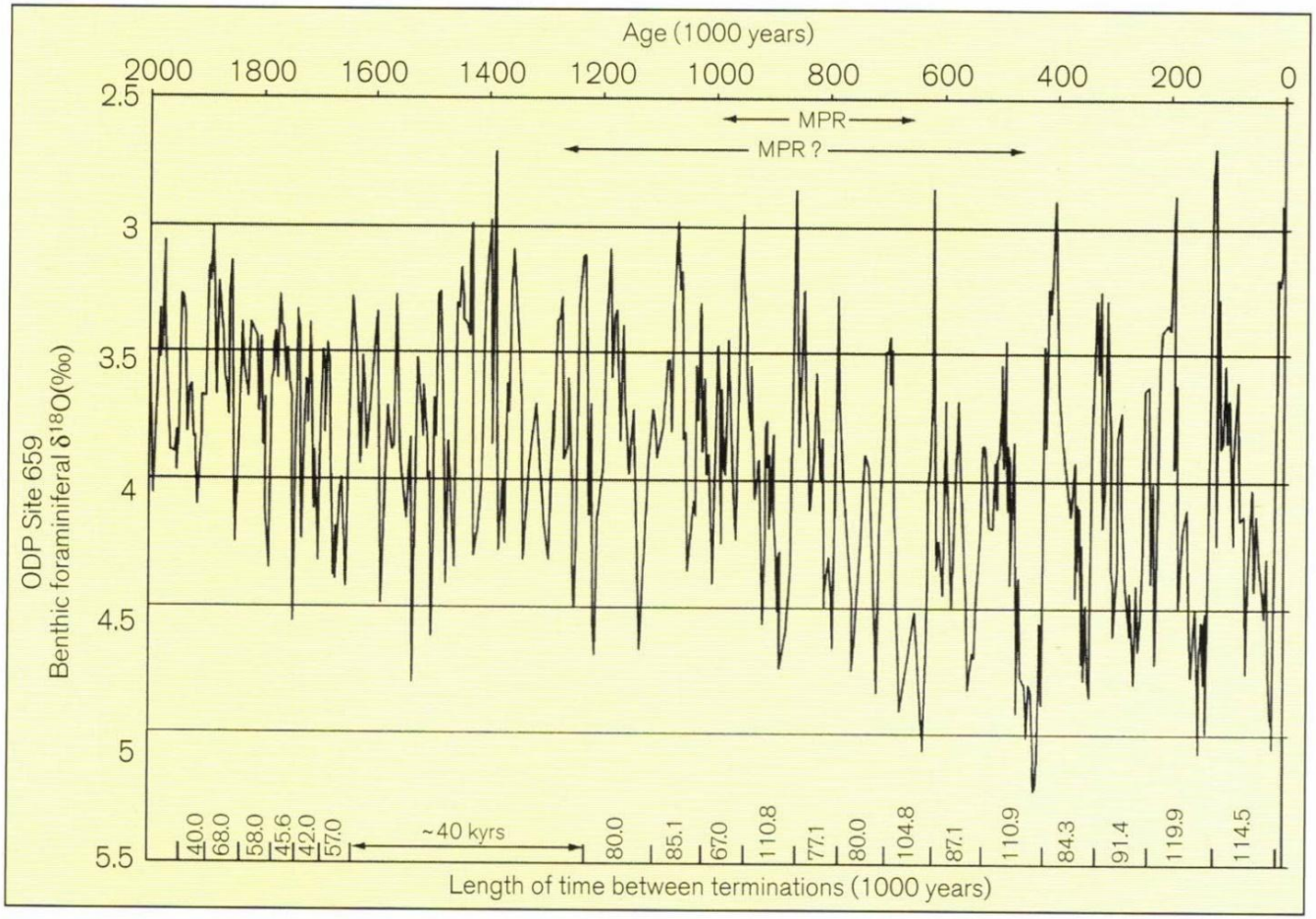
the last interglacial on the basis of these curves have ranged from 80,000 to 180,000 years ago (*22*).

The second and more critical problem in testing the orbital theory has been the uncertainty of geological chronology. Until recently the inaccuracy of dating methods limited the interval over which a meaningful test could be made to the last 150,000 years. Hence the most convincing arguments advanced in support of the orbital theory to date have been based on the ages of 80,000, 105,000, and 125,000 years obtained for coral terraces first on Barbados (*15*) and later on New Guinea (*23*) and Hawaii (*24*). These structures record episodes of high sea level (and therefore low ice volume) at times


Now
200
400
600
800
1000
kyr ago
Precession
19, 22, 24 kyr
Obliquity
41 kyr
Eccentricity
95, 125, 400 kyr
Solar Forcing
65°N Summer
Hot
Stages of Glaciation
Cold


Milankovitch Cycles and Temperature from Vostok Ice-core
Temperature
Solar irradiance - 65 N - July
3
0
-3
-6
-9
Temperature oC
500
490
480
470
460
450
440
430
420
410
400
390
380
Watts m -2 at 65° N in July
-250000
-200000
-150000
-100000
-50000
0
Time relative to present
www.climatedata.info

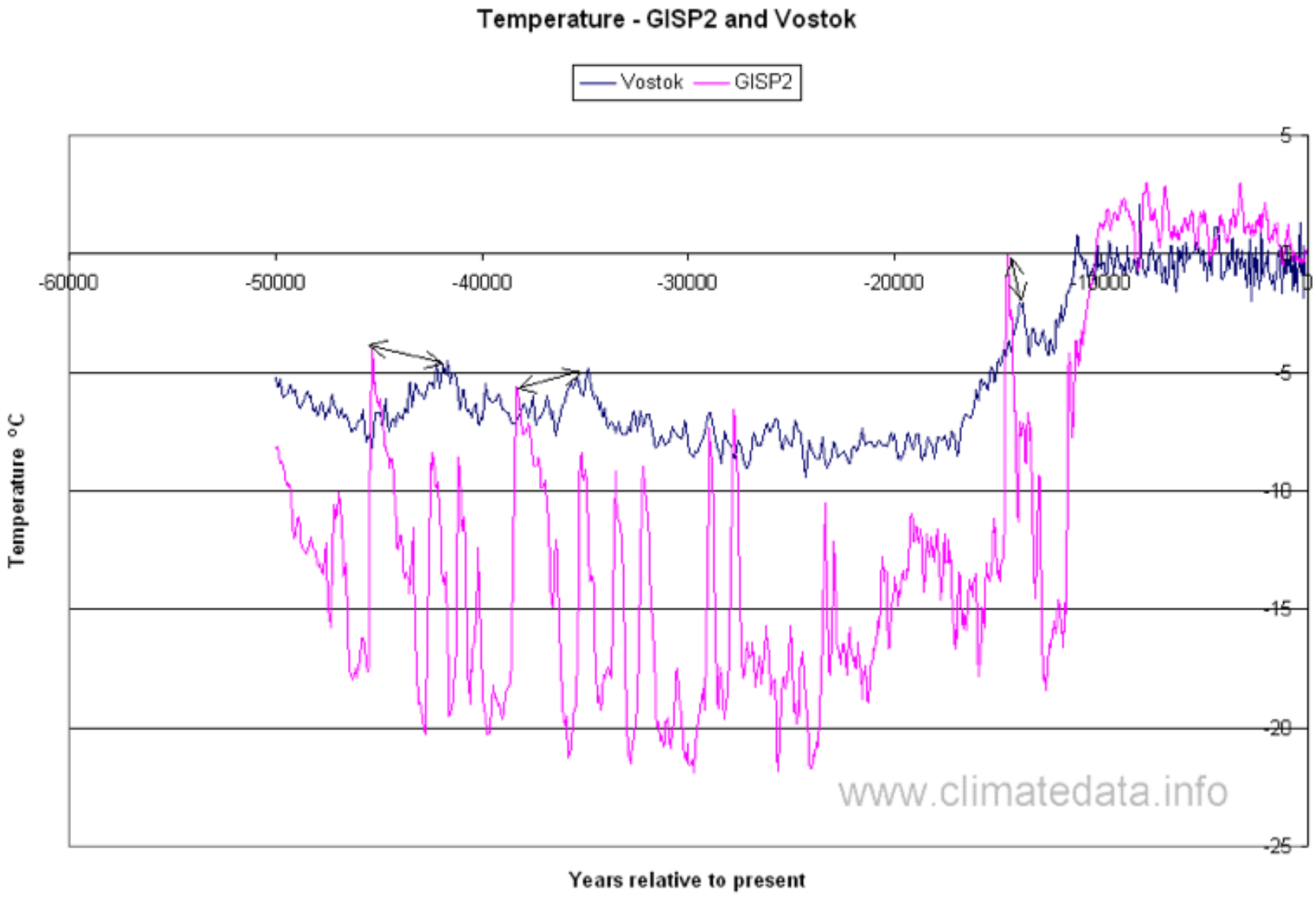

EPICA Dome - temperature and Milankovitch cycles
Temperature
Insolation - July - 65 N
Temperature
Insolation - July - 65 °N - w m-2
6
4
2
0
-2
-4
-6
-8
-10
-12
580
560
540
520
500
480
460
440
420
-800000
-700000
-600000
-500000
-400000
-300000
-200000
-100000
0
www.climatedata.info



This oxygen isotope record from the deep ocean, showing the changes in the amount of ice on earth, reveals the timing of the glaciations of the Ice Age. Before 1 million years ago these glaciations occurred approximately every 41,000 years, after which point they started to become longer. This climate transition is called the Mid-Pleistocene Revolution (MPR) but scientists are unsure how long this transition should continue for.

Complete Ice Age – How Climate Change Shaped the World.
Brian Fagan (ed.)

The earlier 40,000-year cycles were not as extreme as the later 100,000 year cycles.



Abrupt Climate Change Events – especially in Greenland

The cycles with rapid warming episodes seen in Greenland ice cores are named Dansgaard–Oeschger events after their discoverers.

- Temperatures in the North Atlantic region rose dramatically (often ~5–10 °C) within a decade (!) followed by gradual cooling back to colder “stadial” conditions.
- Occurred roughly every 1,000–3,000 years during the last ice age.

Heinrich events extreme cold disruptions tied to iceberg floods.

- Massive discharges of icebergs from the Laurentide Ice Sheet into the North Atlantic leaving a trail of rock fragments on the ocean floor, including fossils in the sediments.
- These icebergs melted and released large amounts of freshwater.
- The freshwater disrupted ocean circulation, especially the Atlantic Meridional Overturning Circulation (AMOC), which transports heat northwards.
- This amplifies the cooling in the North Atlantic region but allows heat to build up in the south *(“bipolar climate see-saw”).*

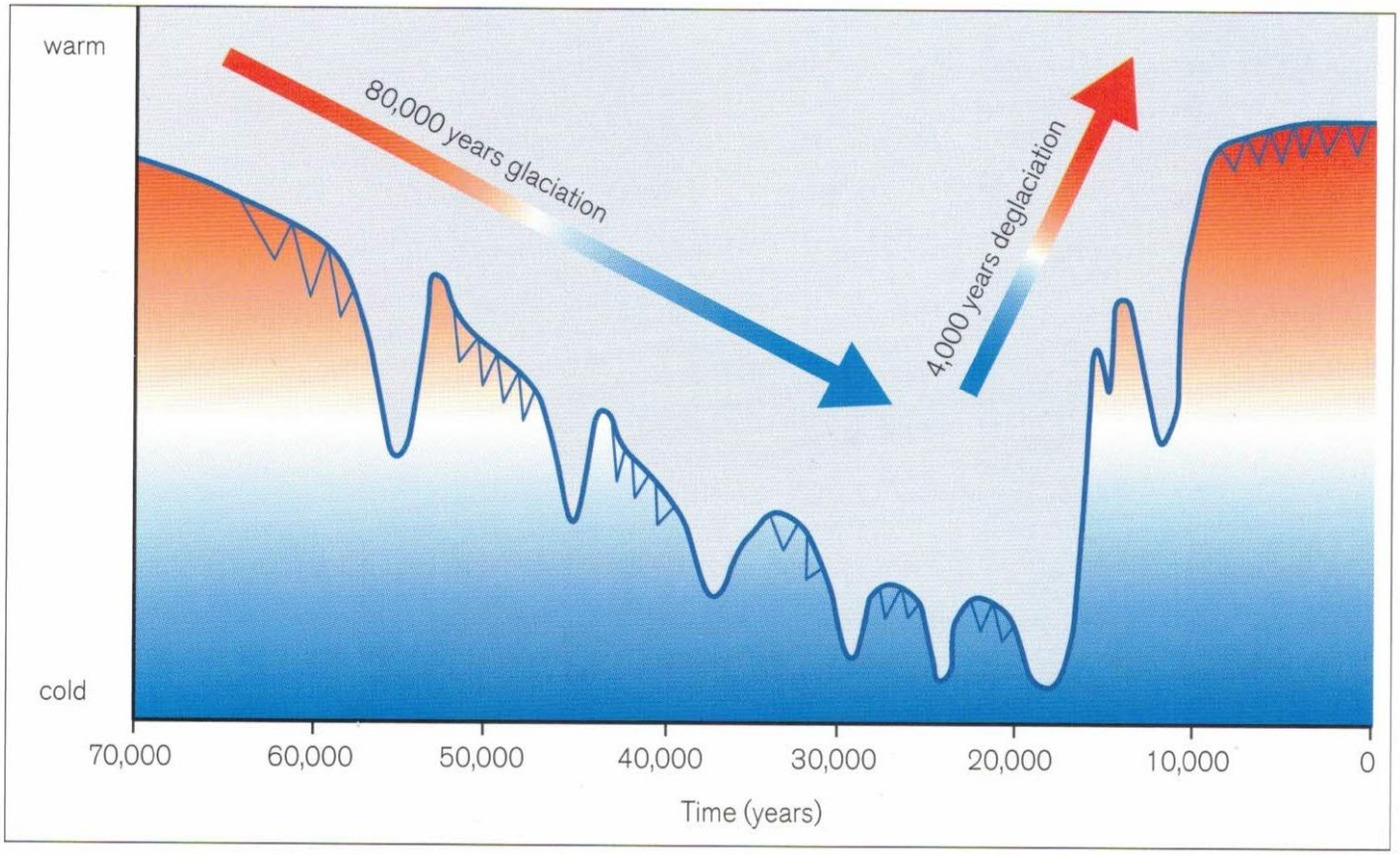
(ChatGPT)

The end of the Ice Age:

- triggered by the increase in solar energy from the Croll-Milankovic cycle – but there is a lot of ice to melt!
- rising sea level undercuts and melts the much colder ice sheets at the edge of the ocean
- removing a buttress that stops the glaciers flowing to the ocean
- the deglaciation is much more rapid than the glaciation.

Overall temperature cycle of a glacial period

- Heinrich events - large dips
- Dansgaard-Oeschger – smaller cycles.

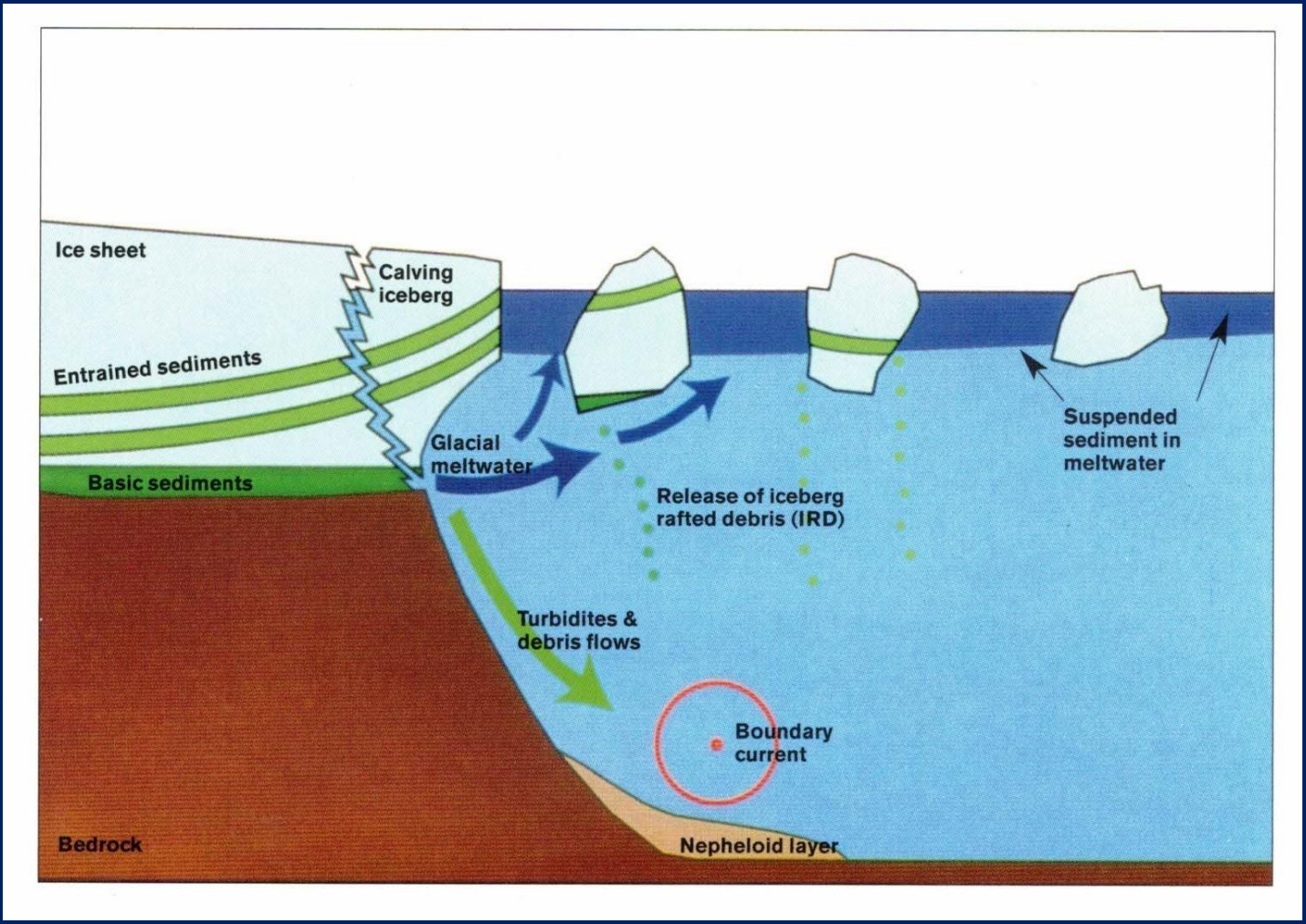


It takes a long time – about 80,000 years – for the climate to be pushed into a glacial period, but only about 4,000 years to bounce out of one. This is because of the unstable nature of ice sheets, which continually collapse even though the climate continues to get colder and colder. Each one of the large dips in temperature on the graph during the last glacial period represents a Heinrich event, while the small saw-toothed events that occur both during the glacials and interglacials represent the Dansgaard–Oeschger climate cycles.

The massive discharge of the icebergs could be due to:

- Instability of the ice sheet – too much ice on weak unconsolidated sediment
- Undercutting of the ice sheet by warmer water.

Evidence is ice-rafted debris on the floor of the Atlantic Ocean.



Complete Ice Age – How Climate Change Shaped the World. Brian Fagan (ed.)

Recovery from Heinrich events can trigger rapid warming

- After the freshwater input stops, the ocean circulation gradually recovers and the heat that has been retained in the south can now head northwards.
- This can lead to a rapid warming transition.

Summary:

- D-O events are the broader climate oscillations, while Heinrich events are extreme iceberg-outburst episodes that sometimes occur within them.
- Heinrich events push the climate system into extreme cold
- the recovery of ocean circulation often snaps it back into a rapid warming.
- These events appear to be related to a natural cycle of the ice sheets and the ocean circulation – not to astronomical cycles.
- The smaller D-O events can work in interglacial periods also and seems to have occurred during the past 12,000 years (Holocene).
- **Detection of these rapid changes was a big surprise (when first detected in the Greenland ice cores), and they are still being studied.**
- **Next class: Some of the implications for human evolution.**