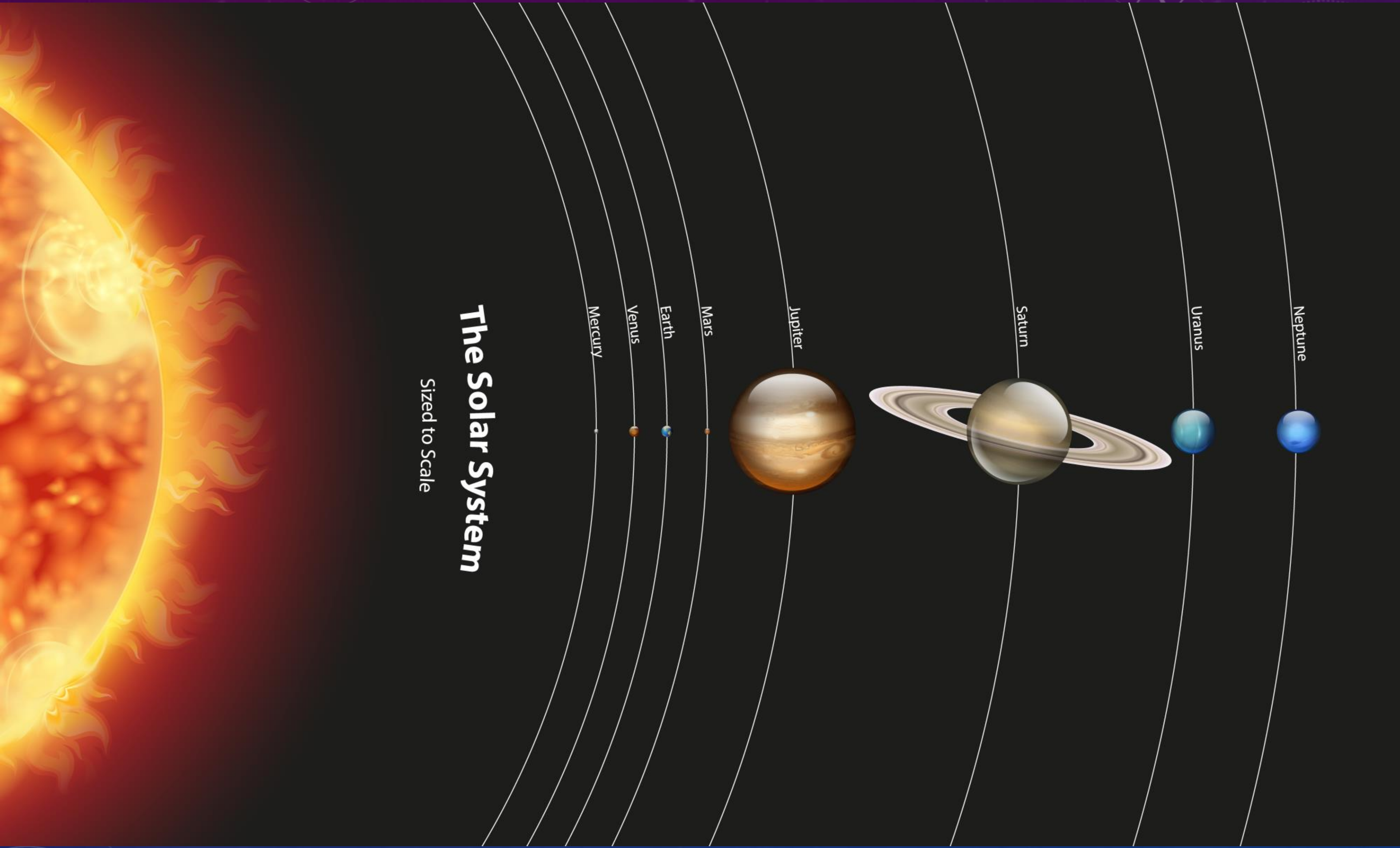
Weather, Climate and Geology

WHY DO WE HAVE WEATHER AND CLIMATE, AND WHAT DOES GEOLOGY HAVE TO DO WITH IT?

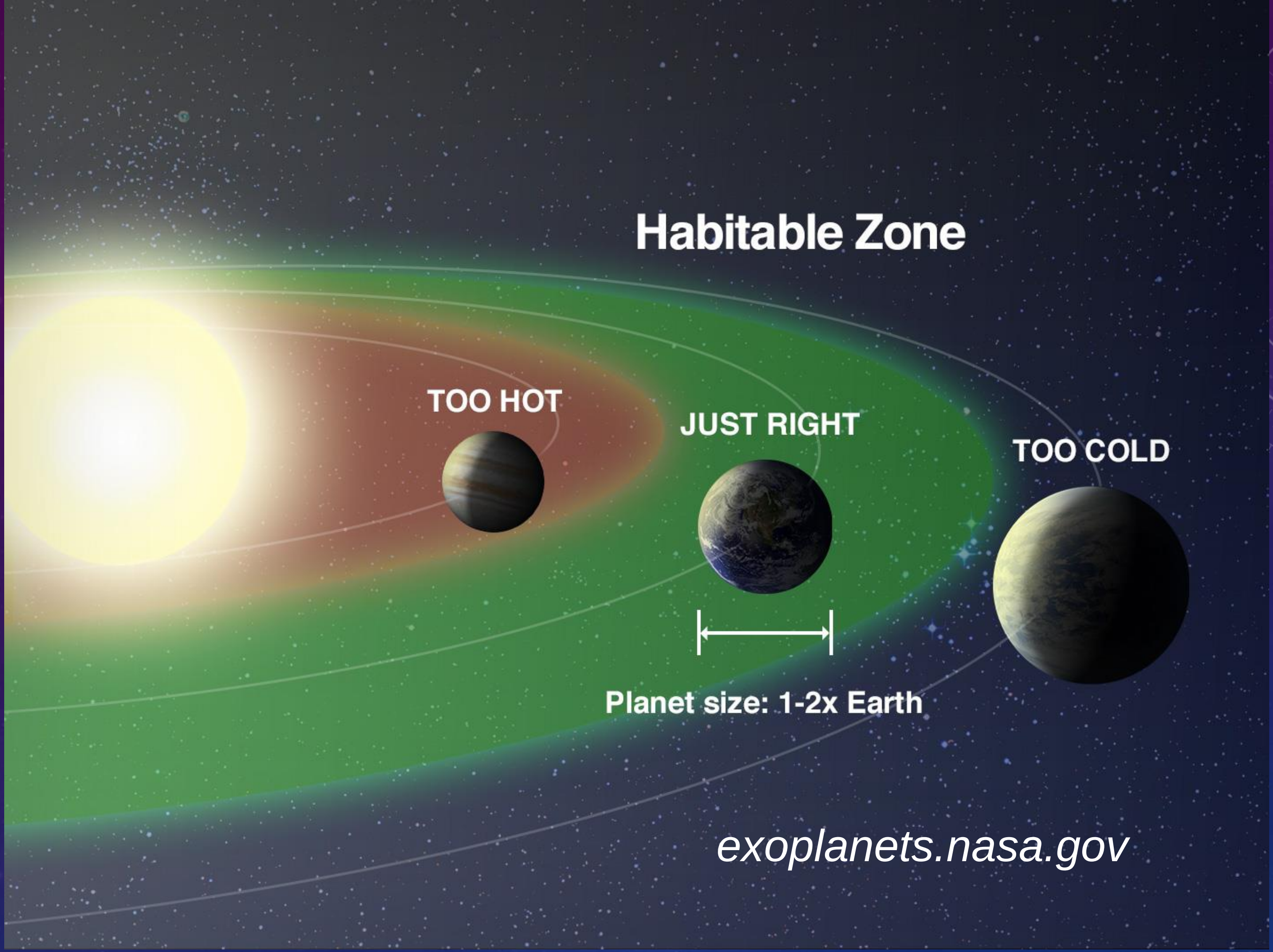
Field Naturalists Club Victoria
27 November 2024

TERRY HART


WHY DOES EARTH
HAVE WEATHER?



The Solar System

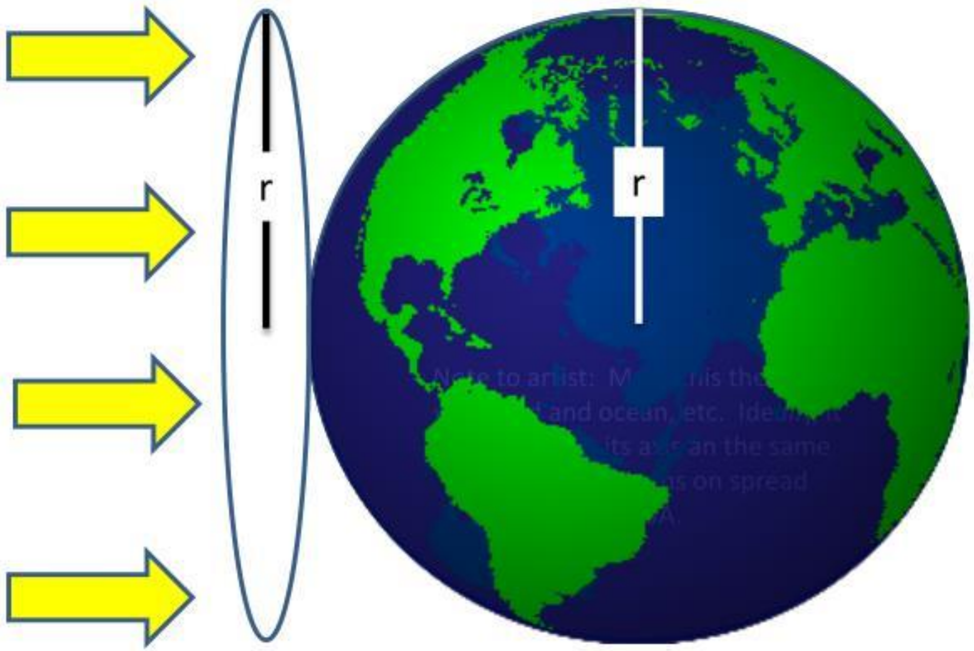


The **“habitable zone”** - where liquid water could exist on an orbiting planets’ surface.
These “Goldilocks zones” are where conditions might be just right – neither too hot nor too cold – for life.

The earth receives energy from the sun - as **sunlight**.

2. This energy falls over a circular area of (πr^2) square meters, where r is the radius of the earth, to give $1366\pi r^2$ total Watts of energy.

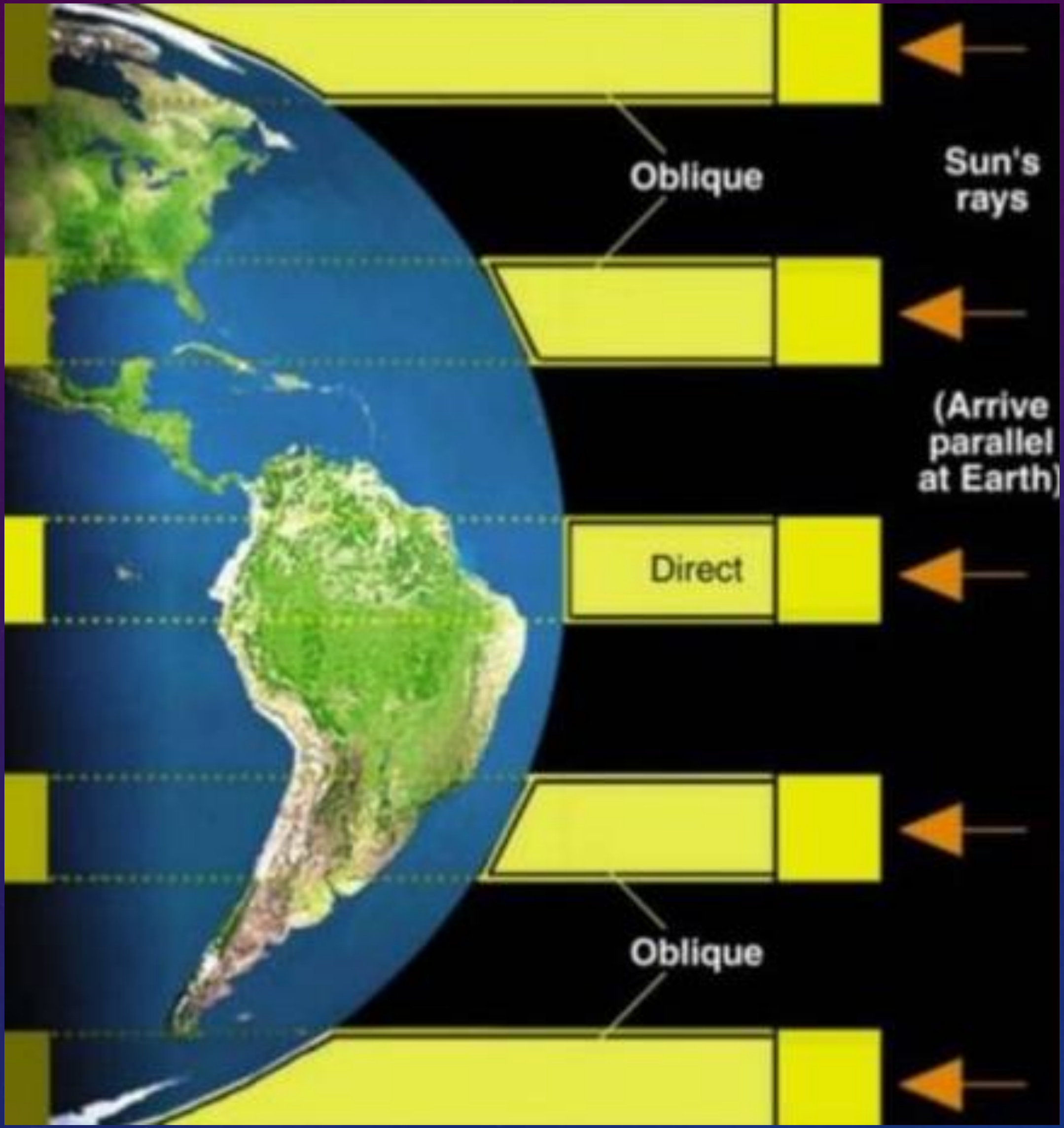
1. **1366** W m^{-2} is radiated on a plane tangent to the Earth at all times – the "Solar Constant." This amounts to only about one two-billionth of the power emitted from the Sun!



1366 watts per square meter

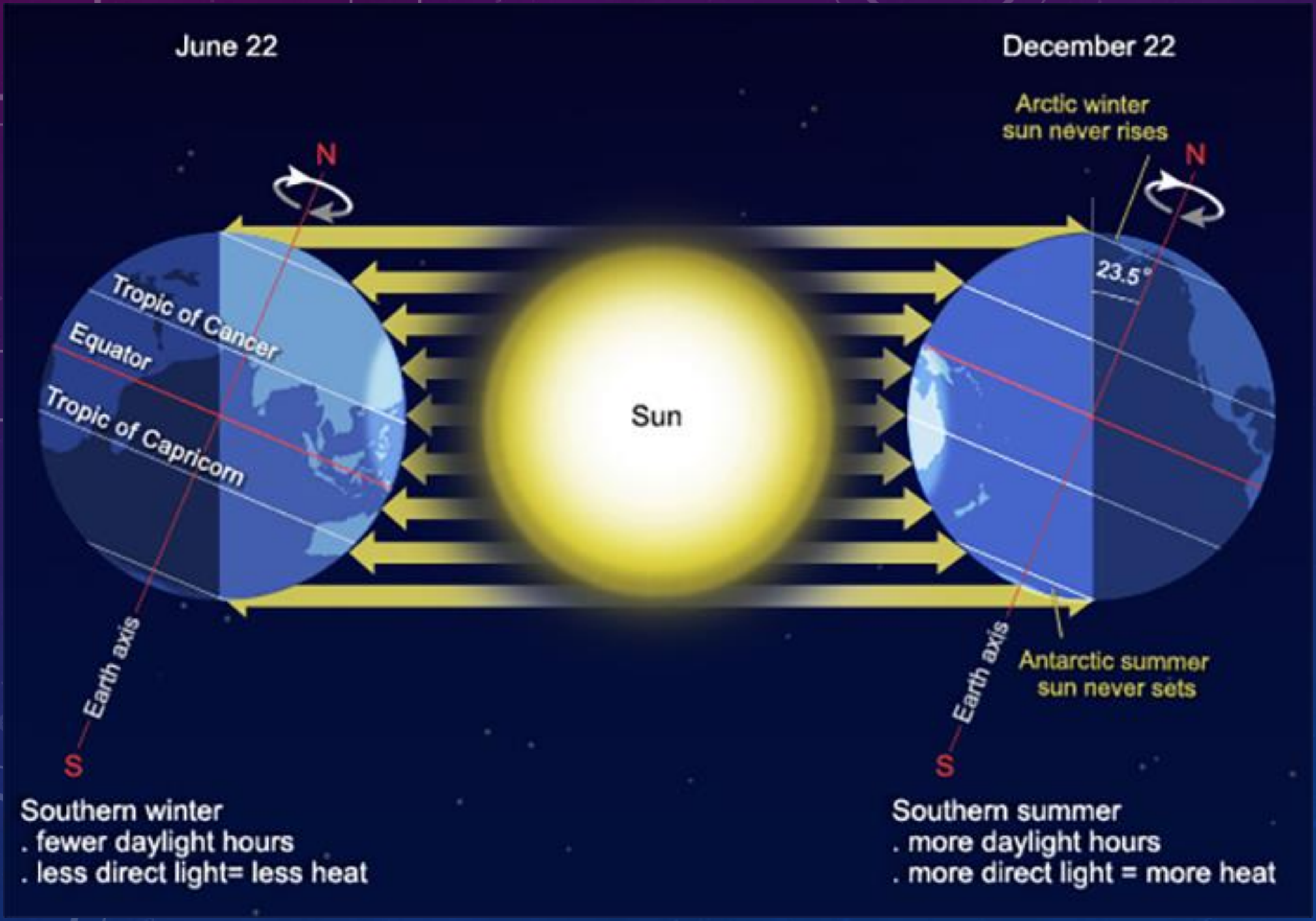
3. But these $1366\ \pi r^2$ Watts fall over the entire surface area of Earth. The surface area of any sphere is $4\pi r^2$, so $1366\pi r^2$ W / $4\pi r^2$ square meters, or **342** W m^{-2}.

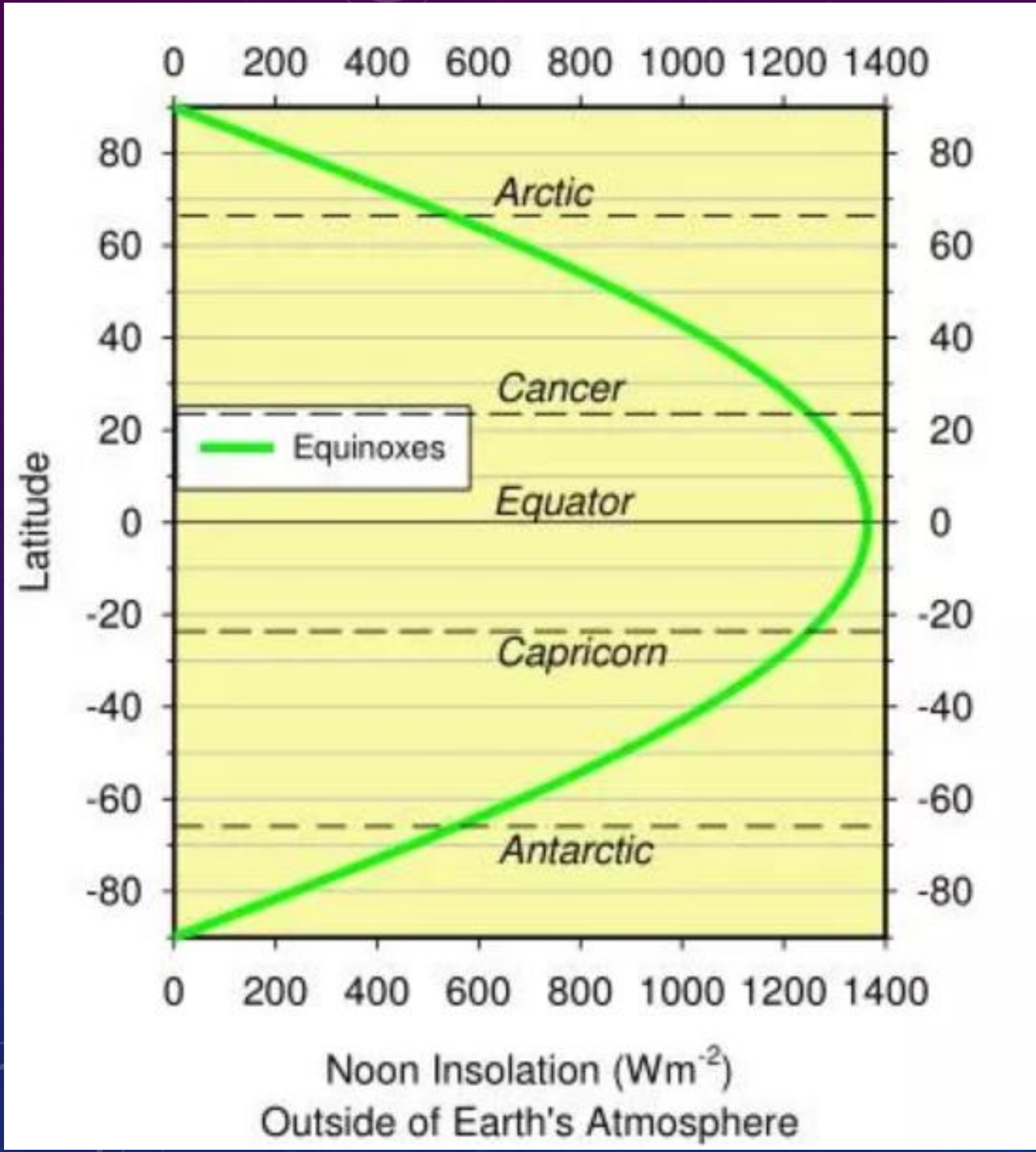
Average over all the earth: **342 watts per square meter**



The **main driver for the earth's weather** is the difference in energy from the sun received in the Tropics, compared with higher latitudes (the poles).

A second driver is how that difference between the tropics and the poles changes during the year, giving us **seasons**.





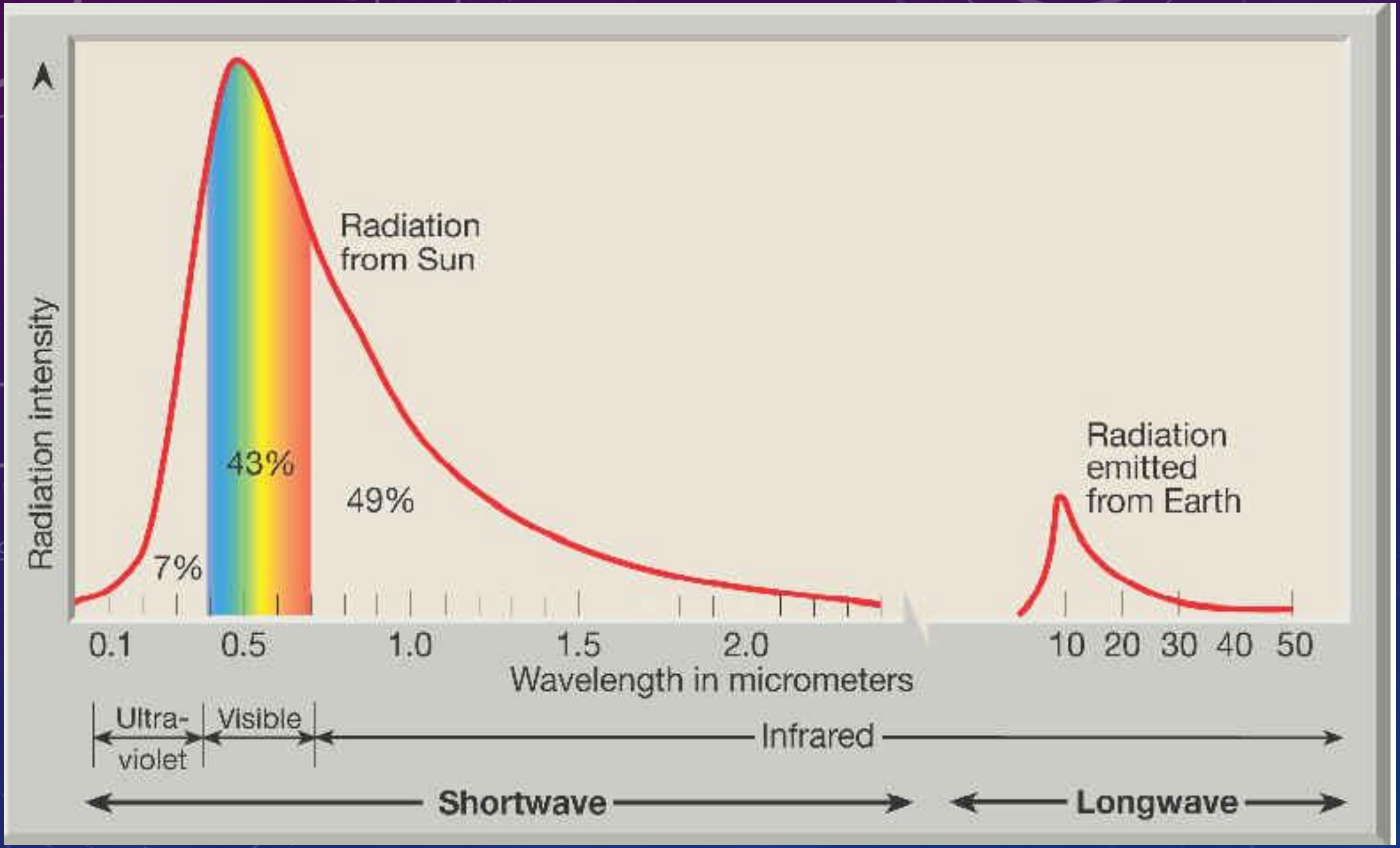
There is an unequal distribution of the sun's incoming energy across the earth.

The incoming solar energy is absorbed and heats up the air, land and ocean, which re-emit energy back to space as **infrared radiation.**

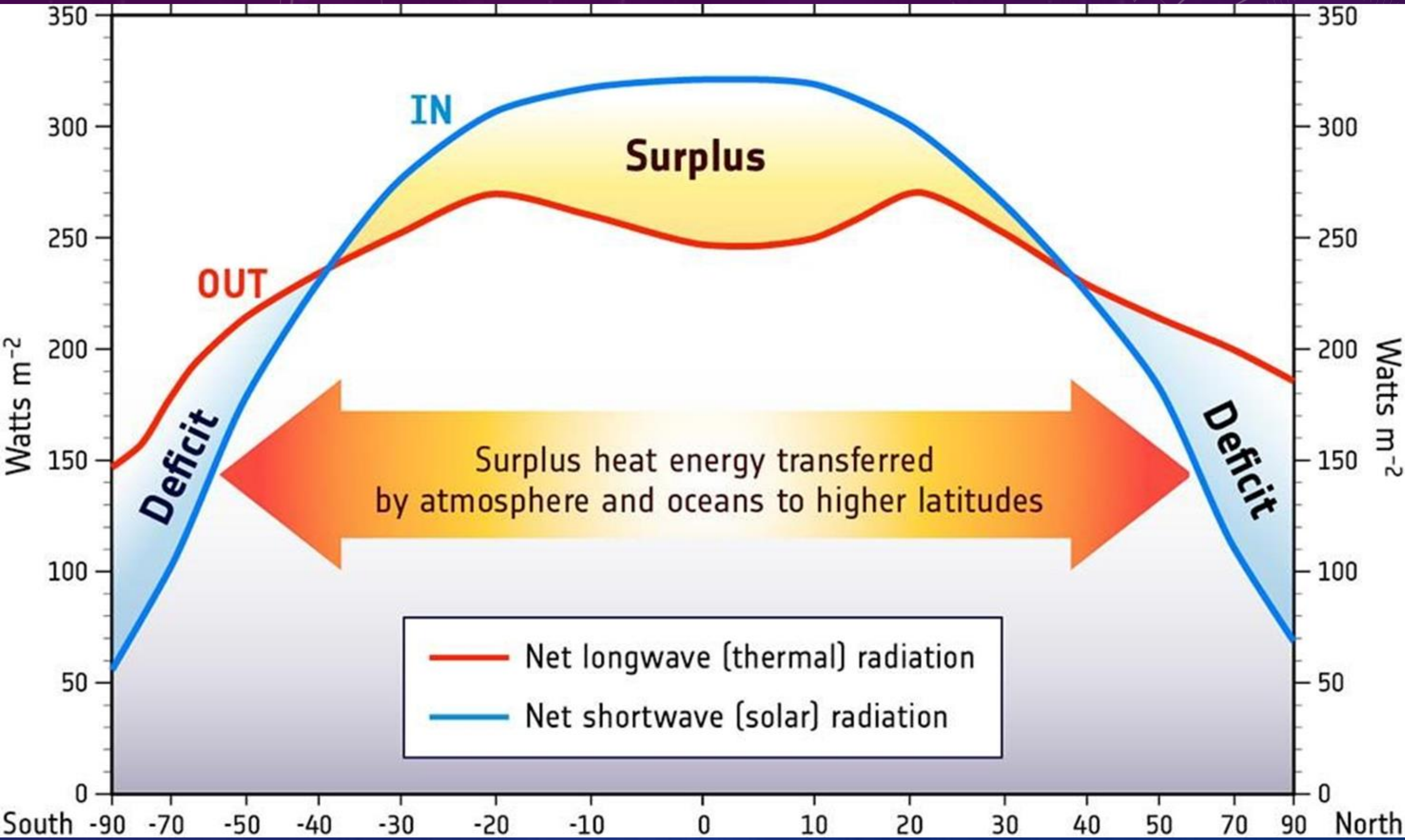
If there were no atmosphere or ocean each point on the earth's surface would have to come to an energy balance – as happens on the moon.

At the equator: 120°C at noon, -130°C at night.

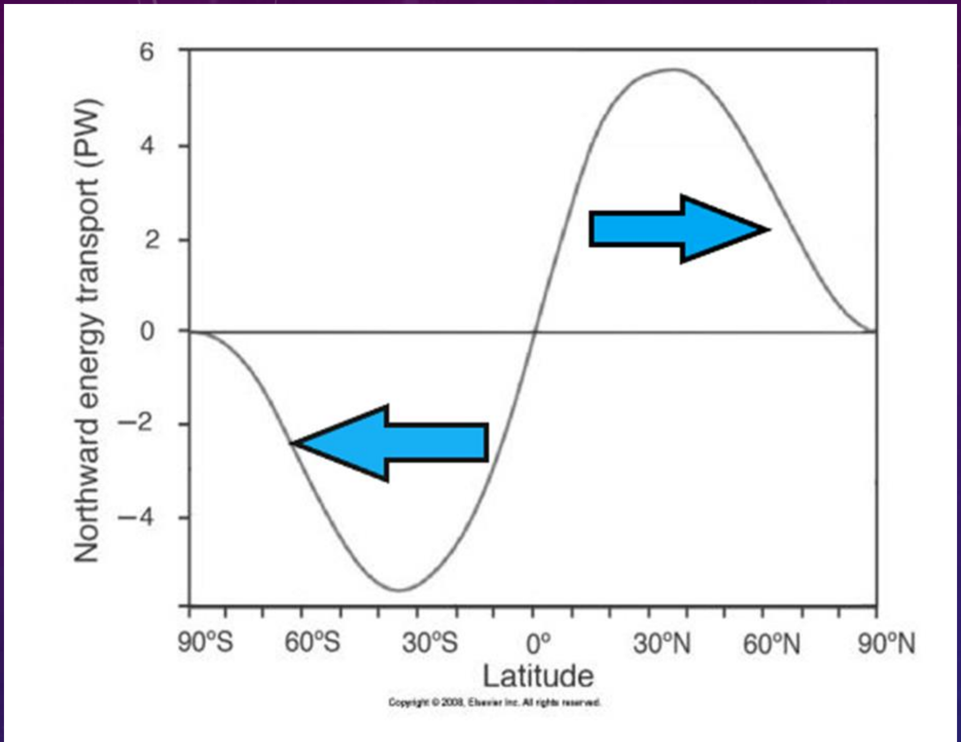
A very important point: the **incoming energy** from the sun and the **outgoing heat** from the earth are at very different wavelengths and behave very differently.



If there is an imbalance between the incoming and outgoing energy the earth will cool down or heat up.

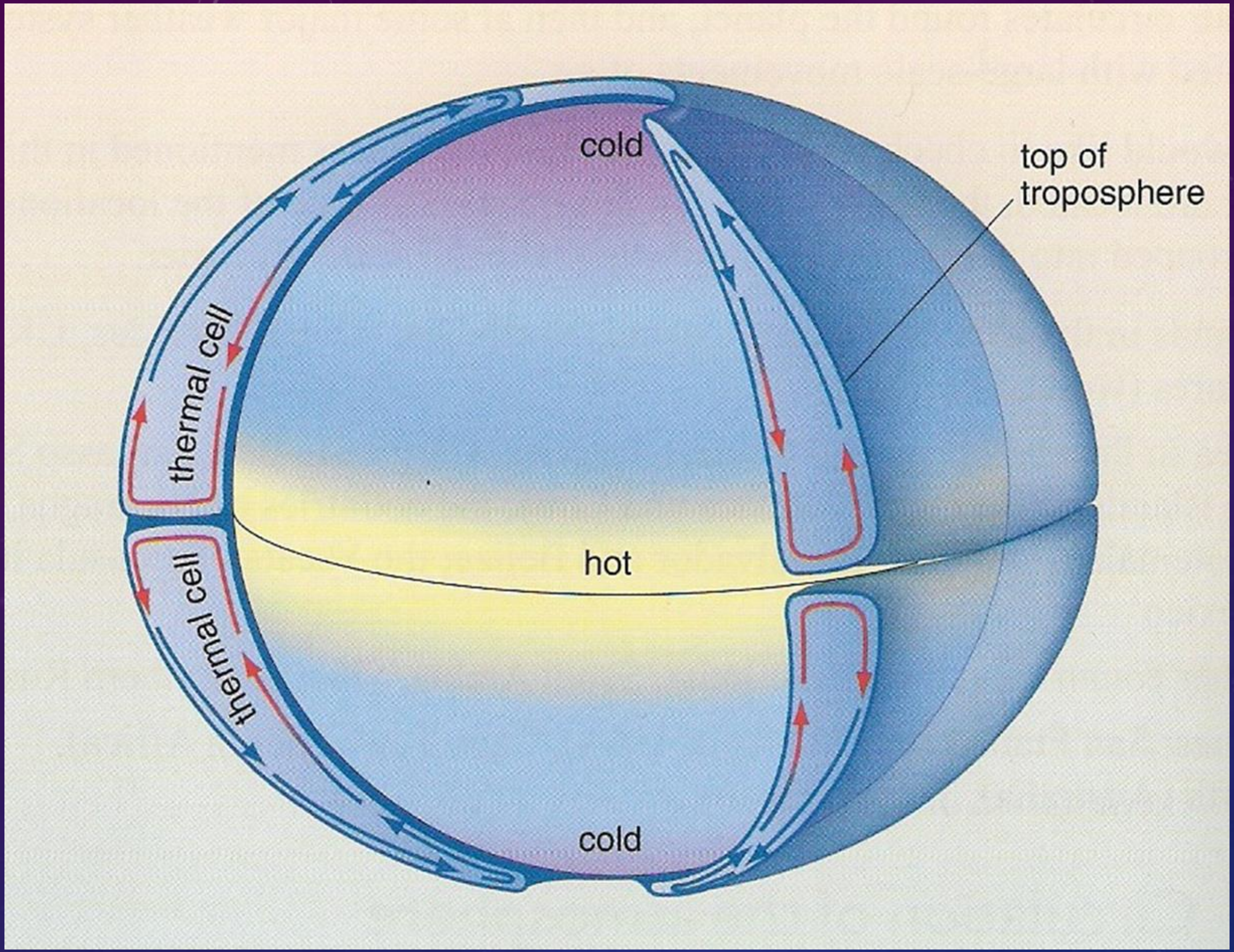


However, there is not a local energy balance. The atmosphere and ocean try to even out the incoming energy difference between the tropics and the high latitudes – and this is the fundamental reason for weather and climate.



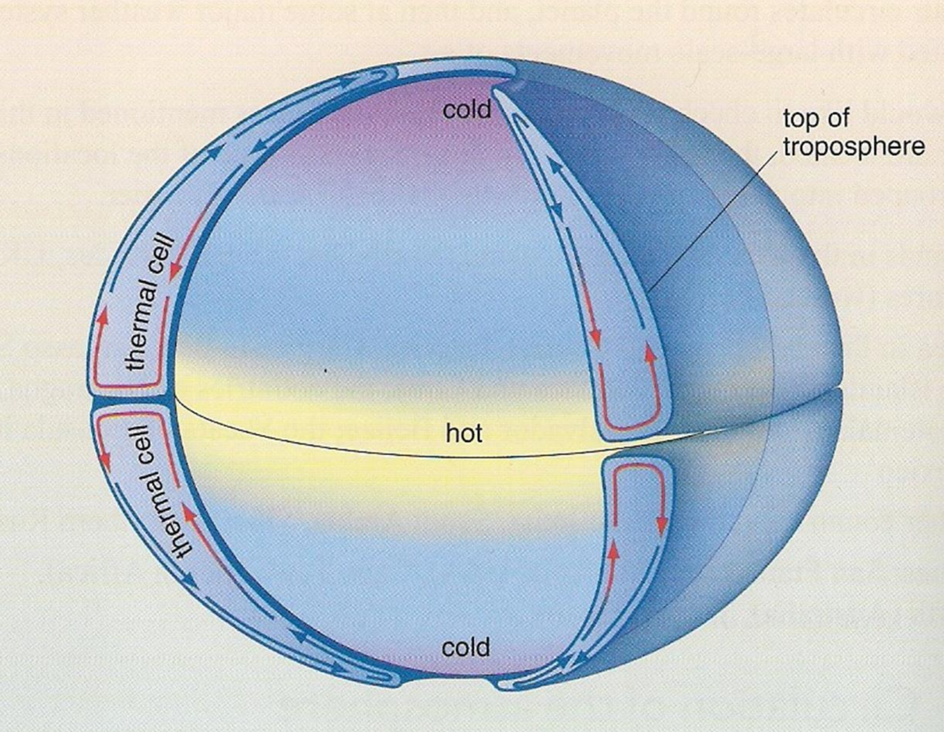
Energy transport from the tropics toward the poles.

- Heat is transported from the tropics to the polar areas by the atmosphere **and** the ocean.
- The poleward energy flow is highest in the middle latitudes – where we live! (e.g. hot northerly winds and cold southerly winds are part of that heat exchange)
- Some of the energy in the atmosphere is transported as *latent heat* by water vapour – energy is used to evaporate water in the tropics, transported to higher latitudes, then released in rain. (a bit like carrying energy from one place to another such as in coal, oil and gas).



Atmospheric circulation

In 1735 George Hadley described an idea of how the atmosphere worked - heated air rises in the Tropics, flows polewards, then sinks as it cools. Air would then be drawn in from the middle latitudes to replace the tropical air that had risen and moved polewards.



Atmospheric circulation

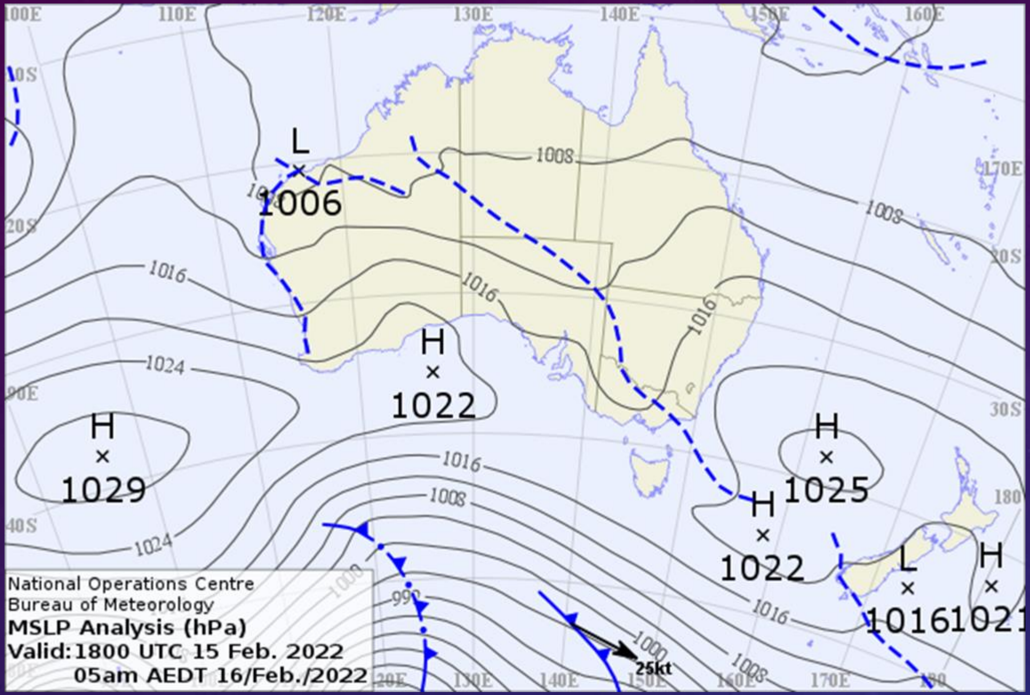
Importantly, he recognised the role of the **rotation of the earth**.

As air moves from more polar latitudes towards the Equator, the rotational speed of the Earth is higher, so the air appears to be deflected to the west as it moves towards the Equator. This is an explanation for the **easterly trade winds** in tropical regions.

Conversely, although it was not known at the time, as the upper air moves away from the Equator toward the poles, it leads to **westerly winds** at upper levels (including the jet streams).

This circulation was named the **"Hadley cell"** after him.

Second element - temporary diversion



The weather map shows lines of equal Pressure at Mean Sea Level (MSLP).

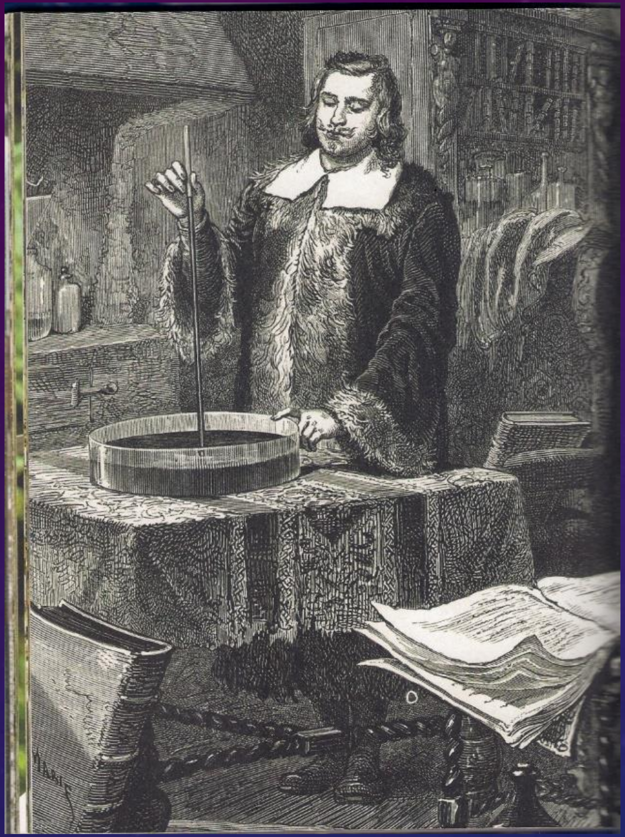
Why is pressure so important?

Barometers measure the pressure where they are, which is generally at some altitude. This pressure is called the **station level pressure.**

However, to be able to focus solely on the effect of weather systems the station level pressures need to be adjusted to a standard level.

Mean Sea Level (MSL) is the most common standard level and the pressure is called the **Mean Sea Level Pressure** (MSLP)

Atmospheric Pressure



Evangelista Torricelli
(1608 -1647)

Torricelli was trying to explain why there was a limit to a free-standing column of liquid. He concluded:

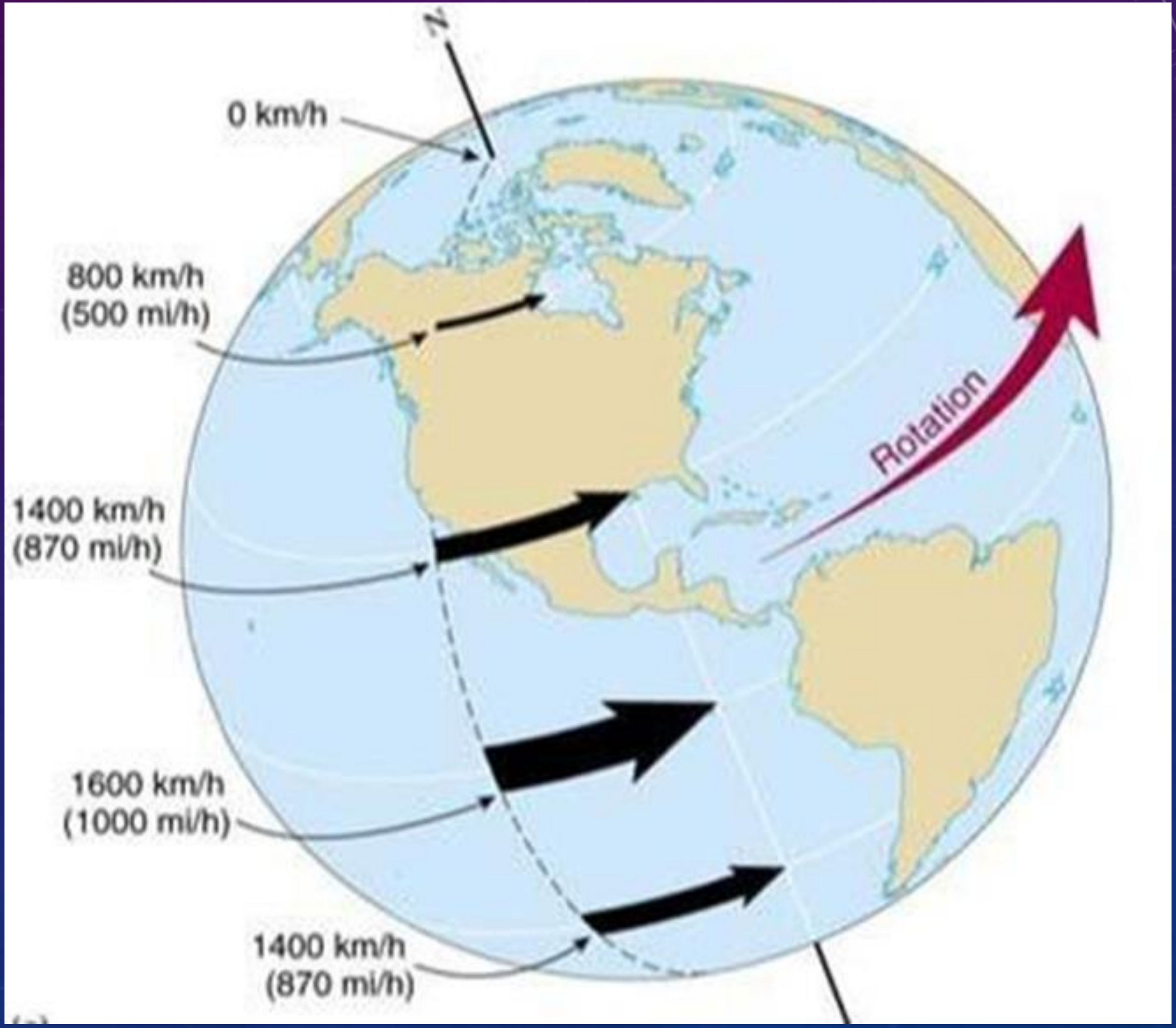
"We live immersed at the bottom of a sea of elemental air, which by experiment undoubtedly has weight,……"

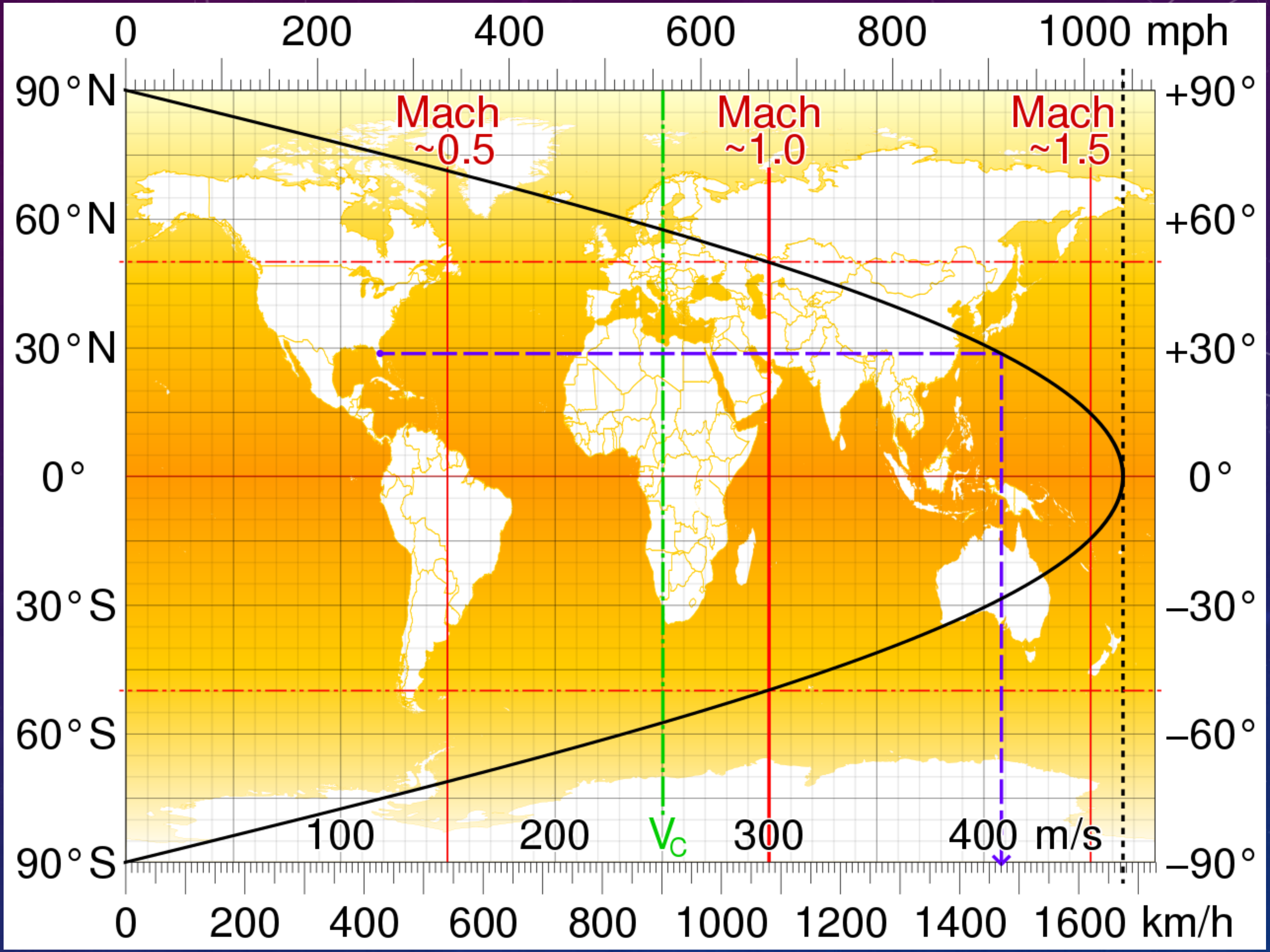
Torricelli also observed that the mercury level changed from day to day and he noticed a link between pressure and weather.

"Winds are produced by differences of air temperature , and hence density, between two regions of the earth."

With this concept Torricelli laid the foundation for meteorology.

It seems logical that if there is a pressure difference, air should move from areas of high pressure to areas of low pressure. If not, why not?





Rotational speed of the earth at different latitudes

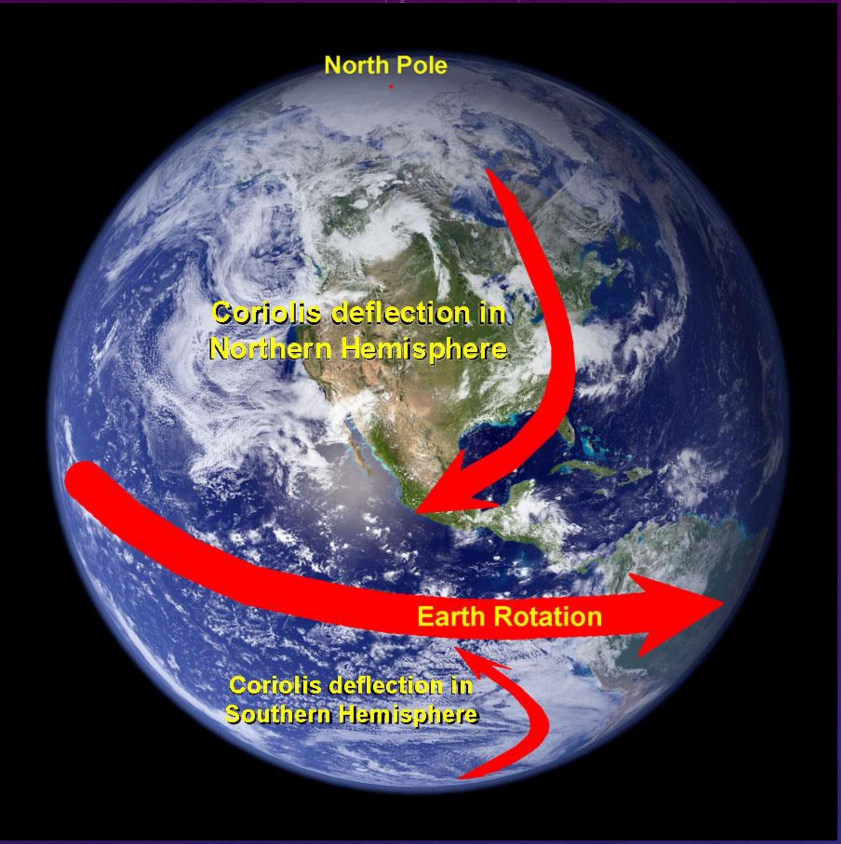
Diagram from Wikipedia

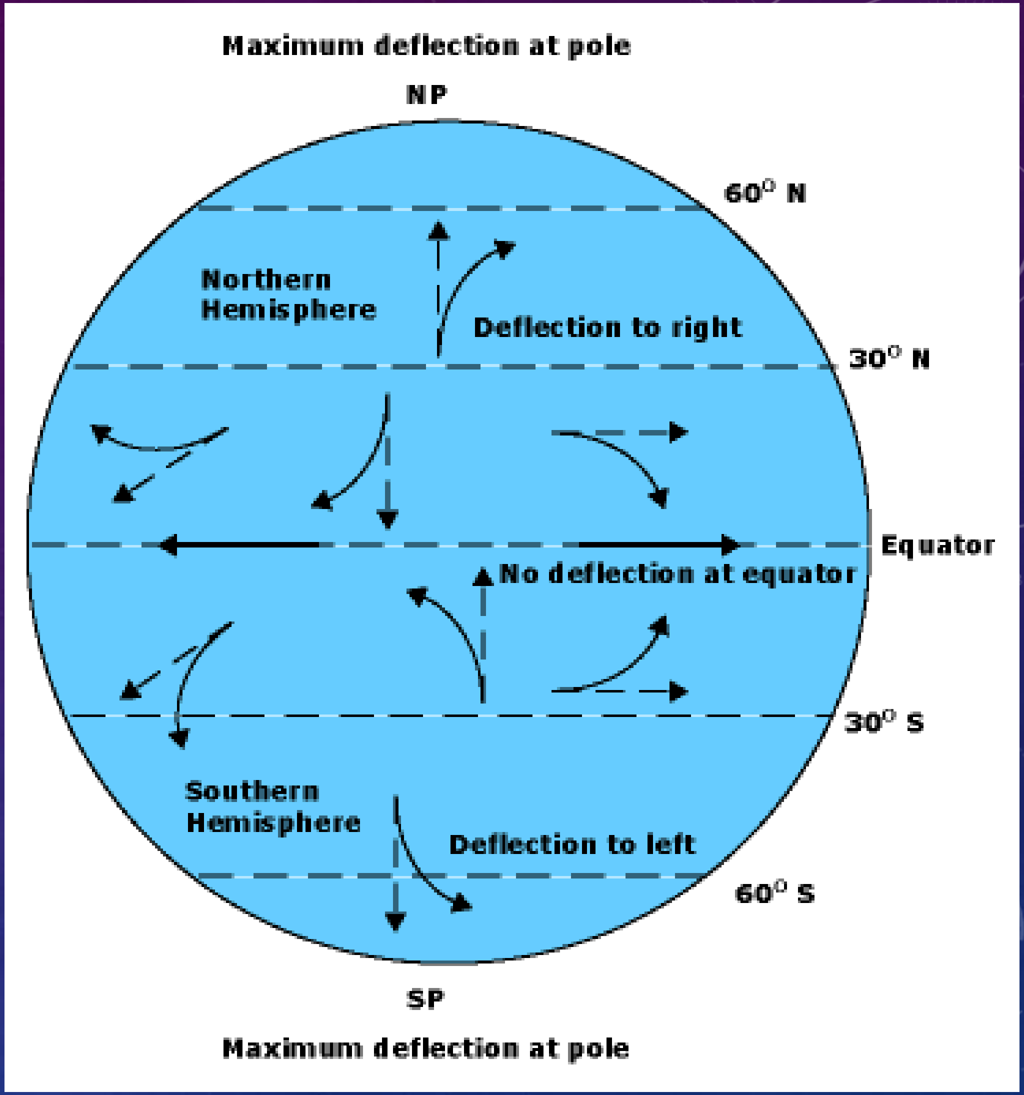
Green dashed line the typical passenger jet cruising speed

Coming back to air pressure - What happens if air starts to move from an area of high pressure to an area of lower pressure?

- To help, think about what happens when something (e.g. a long distance arrow) is fired northwards from Melbourne - **but viewed on our rotating, spherical planet.**
- **Its path would appear straight if viewed from outer space!**
- Both “north/south” or “east/west” directions are affected.

This turns out to be the reason why the winds flow around lows and highs on earth – the wind tries to even out the pressure, but as air moves from areas of higher to lower pressure, it is turned by the “Coriolis Effect” and ends up flowing parallel to the pressure gradient. (at least as viewed on earth).

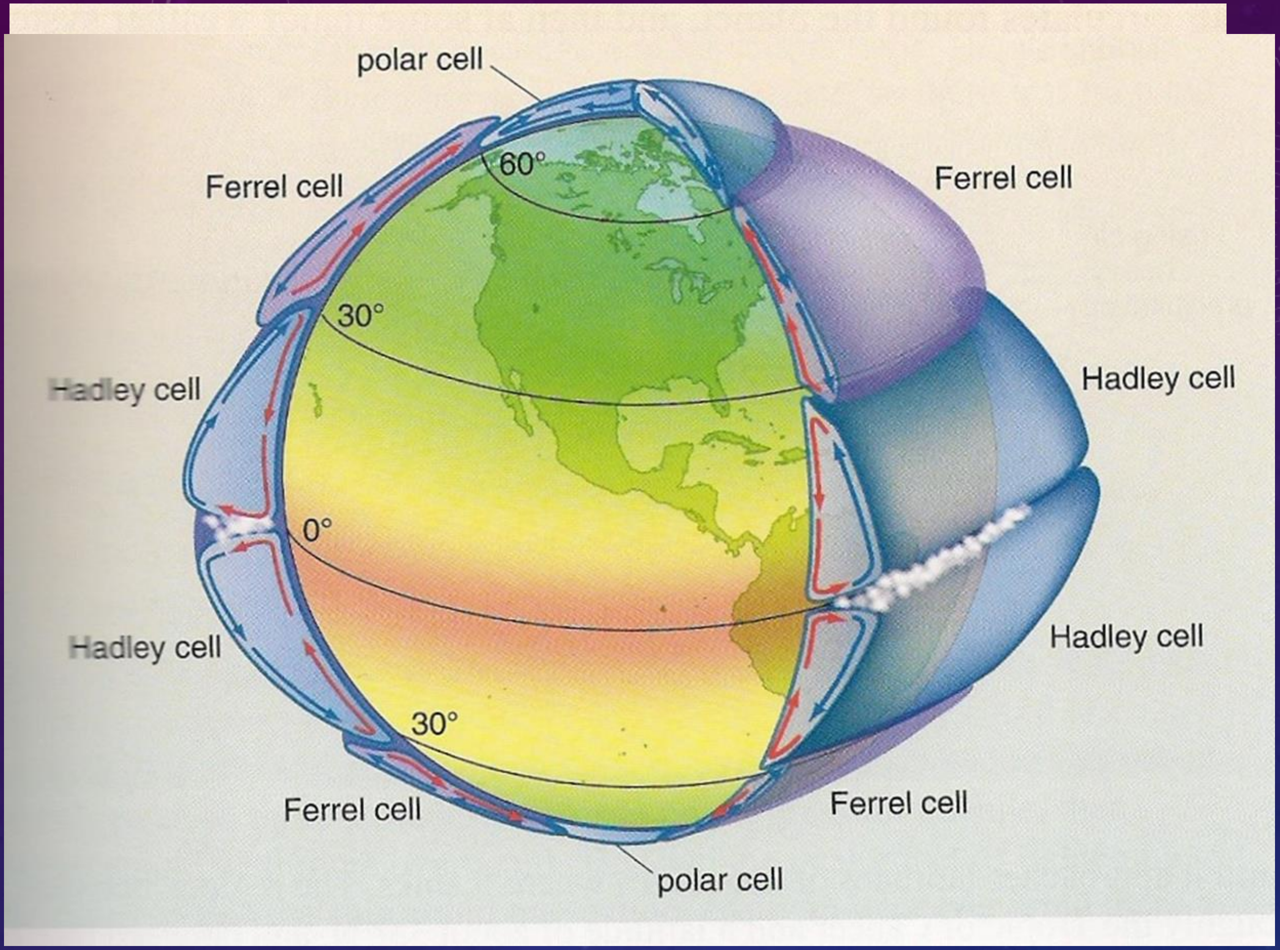




Coriolis Effect (Force)

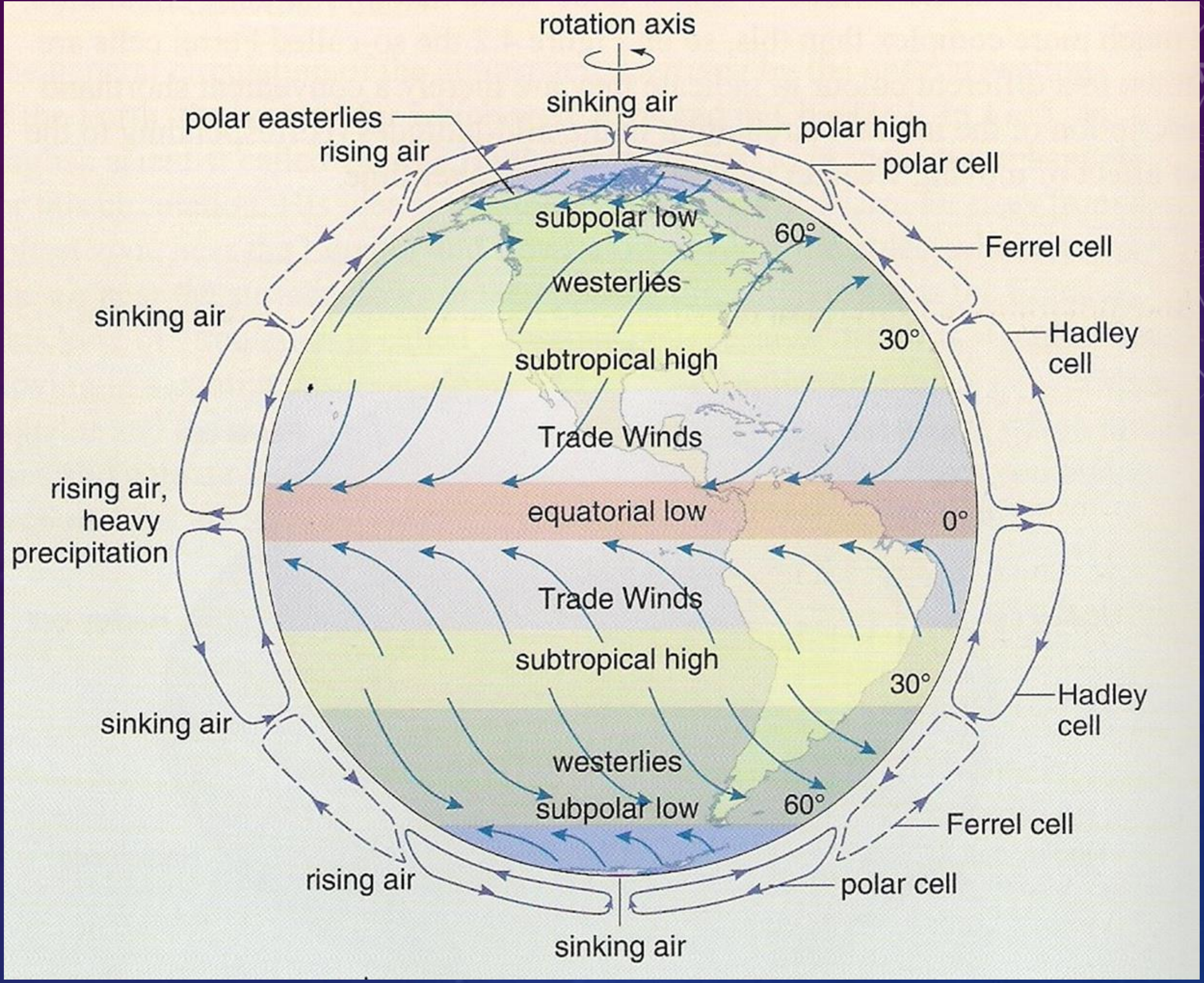
Gustave Coriolis (1792-1843) developed the mathematics of why anything that moves across the earth without being attached to it (including a long-range artillery shell) follows a curved path.

It is proportional to speed and depends on latitude – it is weakest in the tropics and increases as you go to the poles.

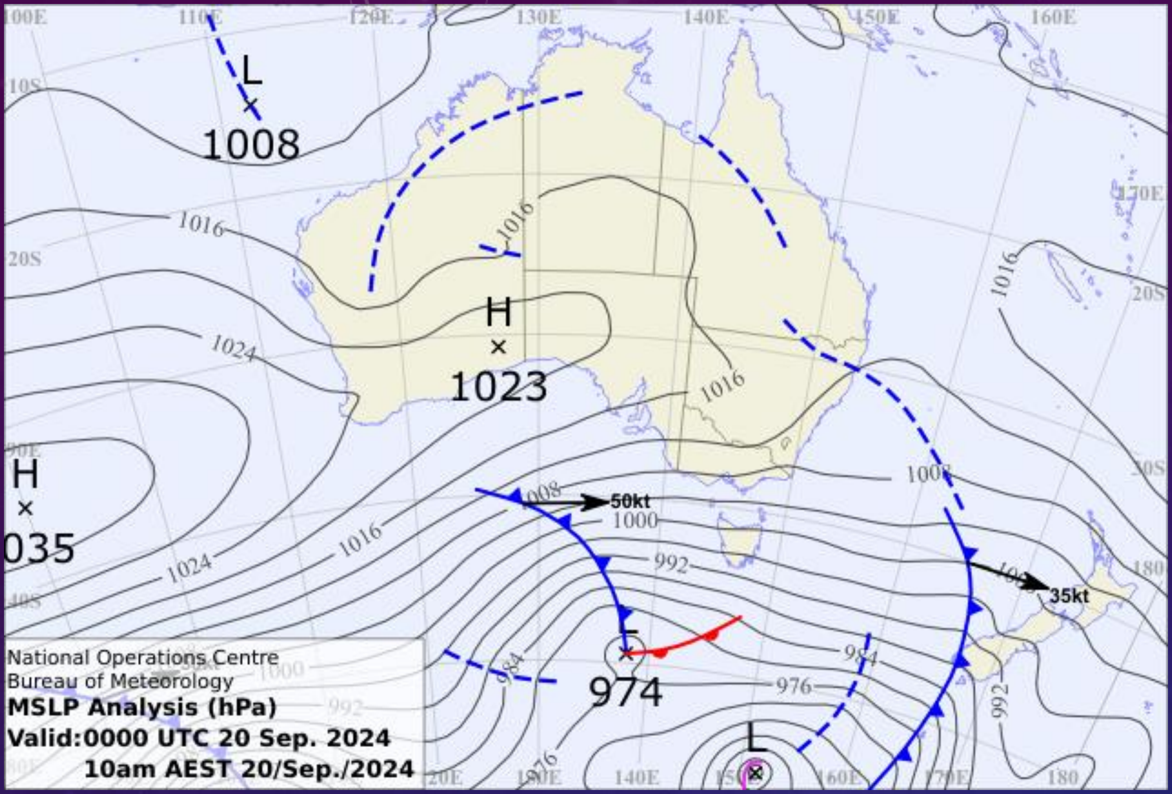


Coming back to Hadley's concept of the atmosphere - It turns out to be a bit more complex due to instabilities in the wind patterns that develop out of the Coriolis force.

In fact, there are three main cells in each hemisphere.
The "Ferrel cell" is the average effect of all the highs, lows and fronts that we experience in the middle latitudes.



The average picture over-simplifies the real world but it captures some basic principles. Naturally, it is hard to see this pattern in the day-to-day weather.



Weather Map

Basic rules for reading weather maps:

- The wind blows clockwise around lows, and anticlockwise around highs (the opposite way in the Northern Hemisphere)
- the closer the isobars (lines of equal pressure), the stronger the wind
- rain and thunderstorms are generally associated with lows or occur in the low pressure zone between highs.

Because:

- We live on a spherical planet where the incoming energy from the sun is greater in the tropics than in the polar areas
- We have an atmosphere and ocean which try to even out the energy imbalance
- We live on a rotating sphere that complicates the work of the atmosphere and ocean by deflecting winds (and currents) that develop. (Coriolis Force)
- The air has water that changes phase (vapour, liquid, ice) depending on temperature. As well as effects like rain, the **water cycle** is an important part of the **energy cycle** as it transports **heat.**
- Land and ocean, mountain ranges and different types of surface add their own effects. This is where geology and geomorphology come in!

No wonder the earth's weather (climate) is so complex!

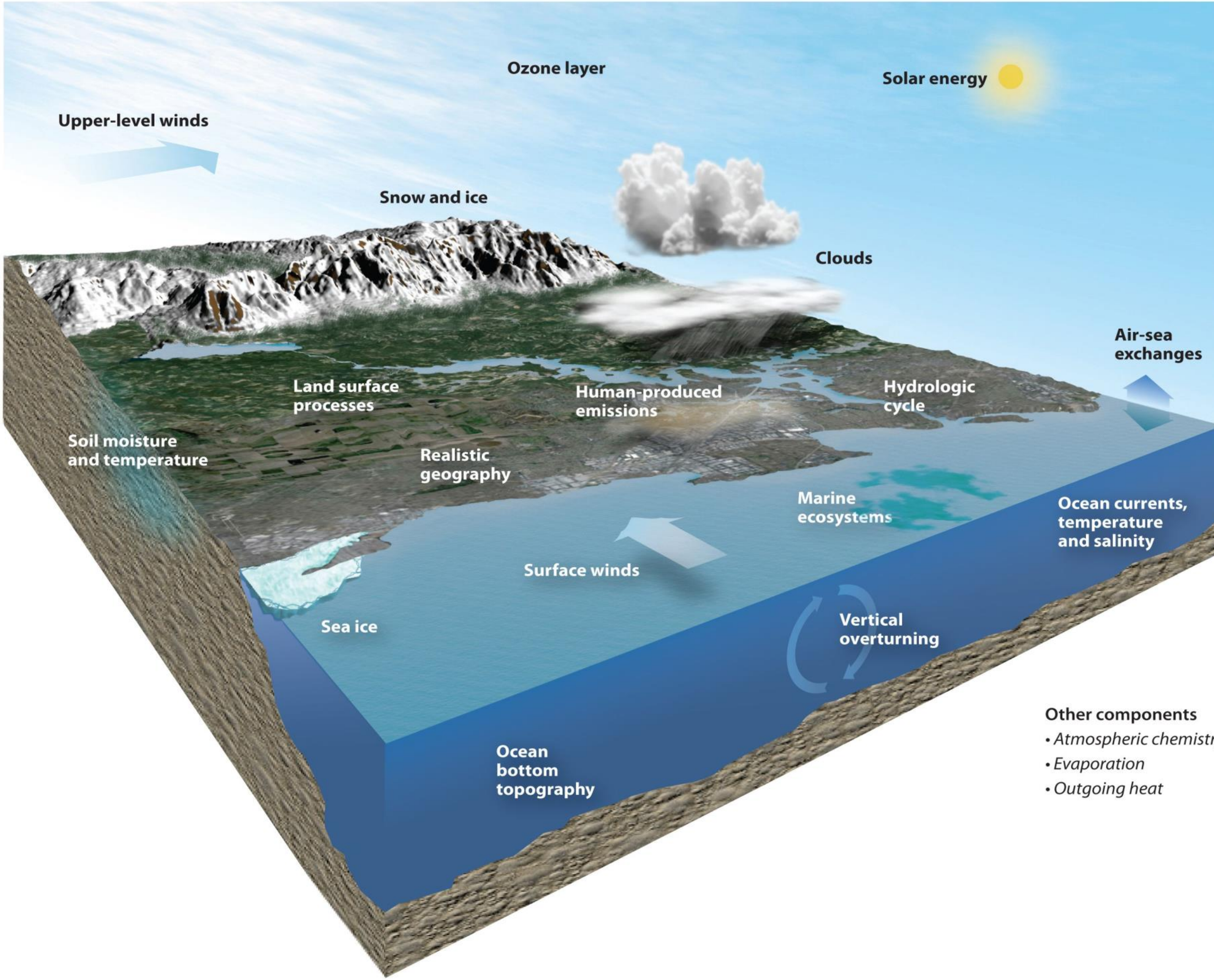
Weather differences related to Land and Sea

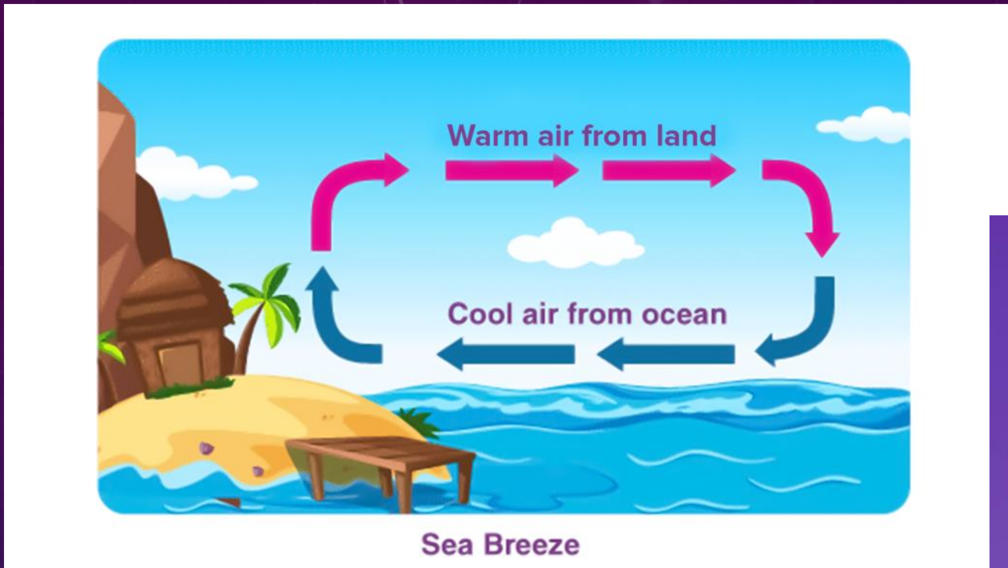
Land

- Temperature changes at the surface are shallow and local, leading to big changes in temperature
- Limited and variable moisture content
- Terrain can be rough (e.g. trees) – high friction
- Moderately dark but the reflectivity can be changed by snow and ice
- Elevation varies (mountains).

Sea

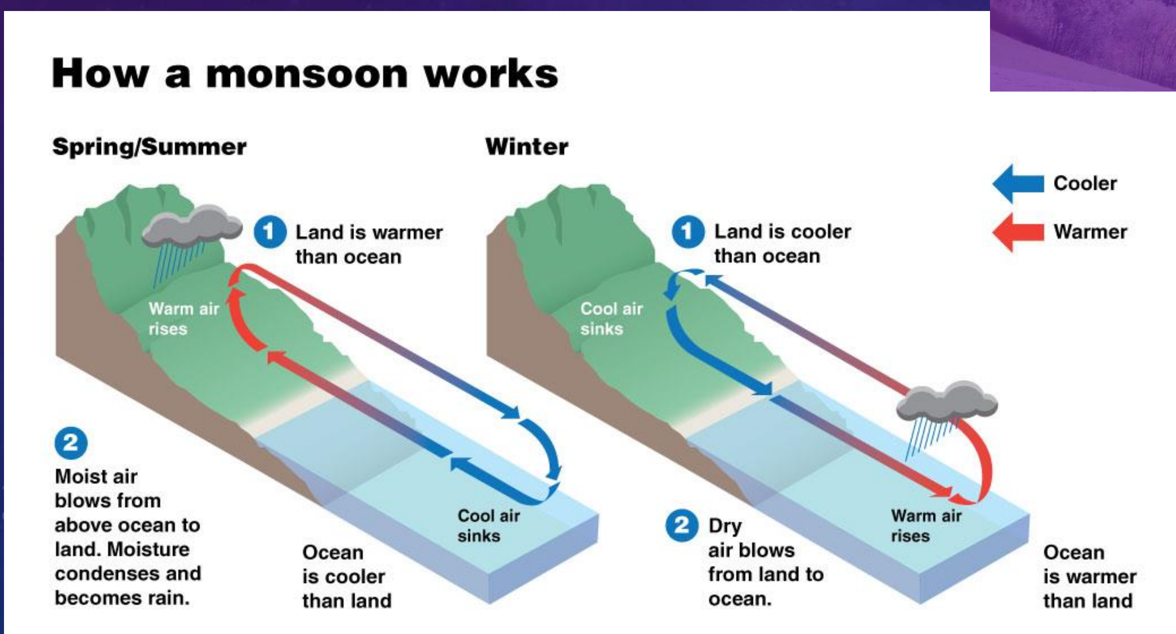
- Fairly homogeneous
- Energy can be transported over long distances and mixed to great depths
- Fairly smooth – although can be roughened by wind
- High heat capacity – temperature is slow to change
- Dark – but can be frozen to sea ice. (reflects; isolates ocean from winds)


Ozone layer
Solar energy
Upper-level winds
Snow and ice
Clouds
Air-sea exchanges
Land surface processes
Human-produced emissions
Hydrologic cycle
Soil moisture and temperature
Realistic geography
Marine ecosystems
Ocean currents, temperature and salinity
Surface winds
Vertical overturning
Sea ice
Ocean bottom topography
Other components
• Atmospheric chemistry
• Evaporation
• Outgoing heat



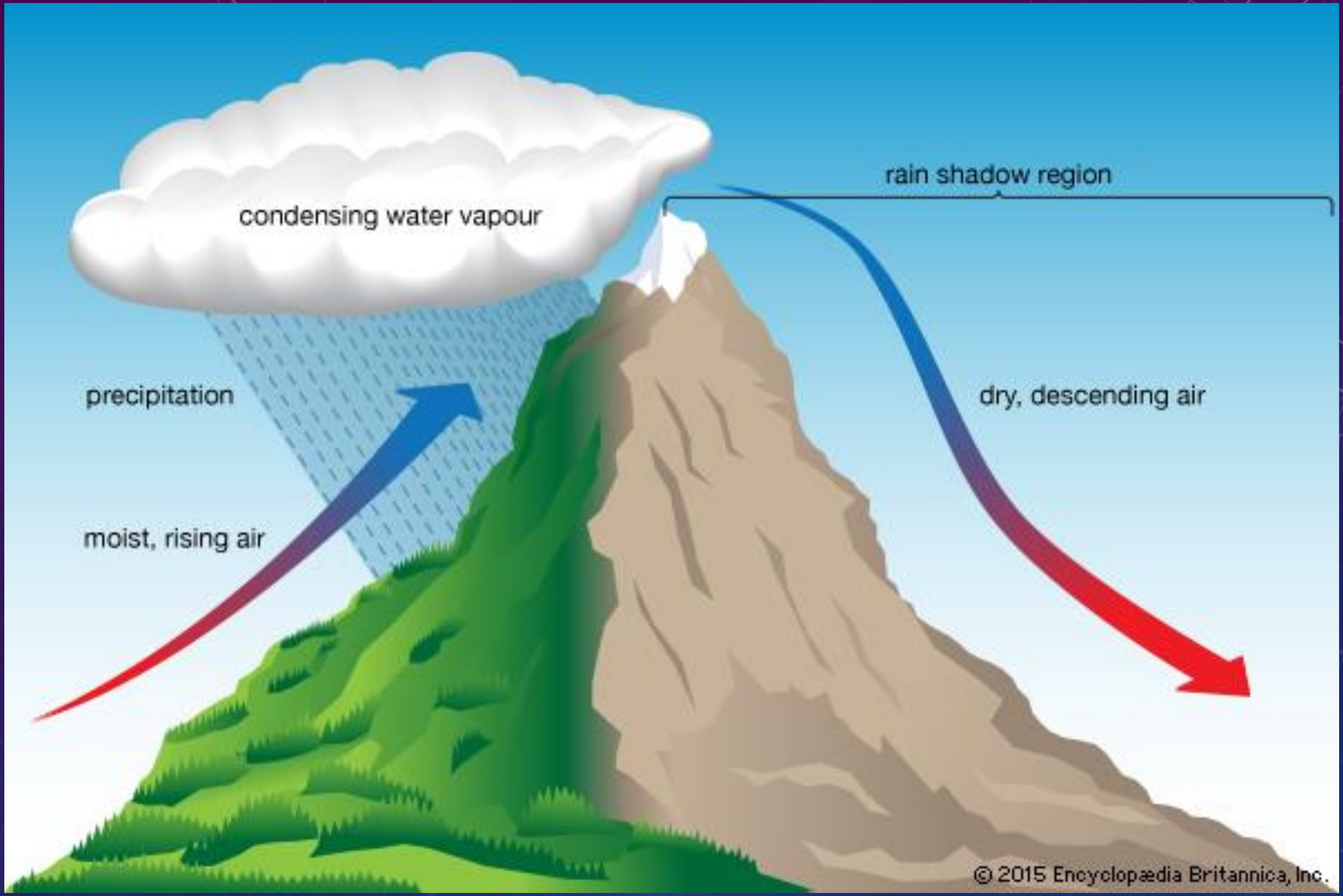
Sea Breeze

Frost



Some examples of local effects arising from land/sea differences

Monsoon



Wind over a mountain range – enhanced rainfall on the windward side, with a rain shadow and warmer air on the leeward side.

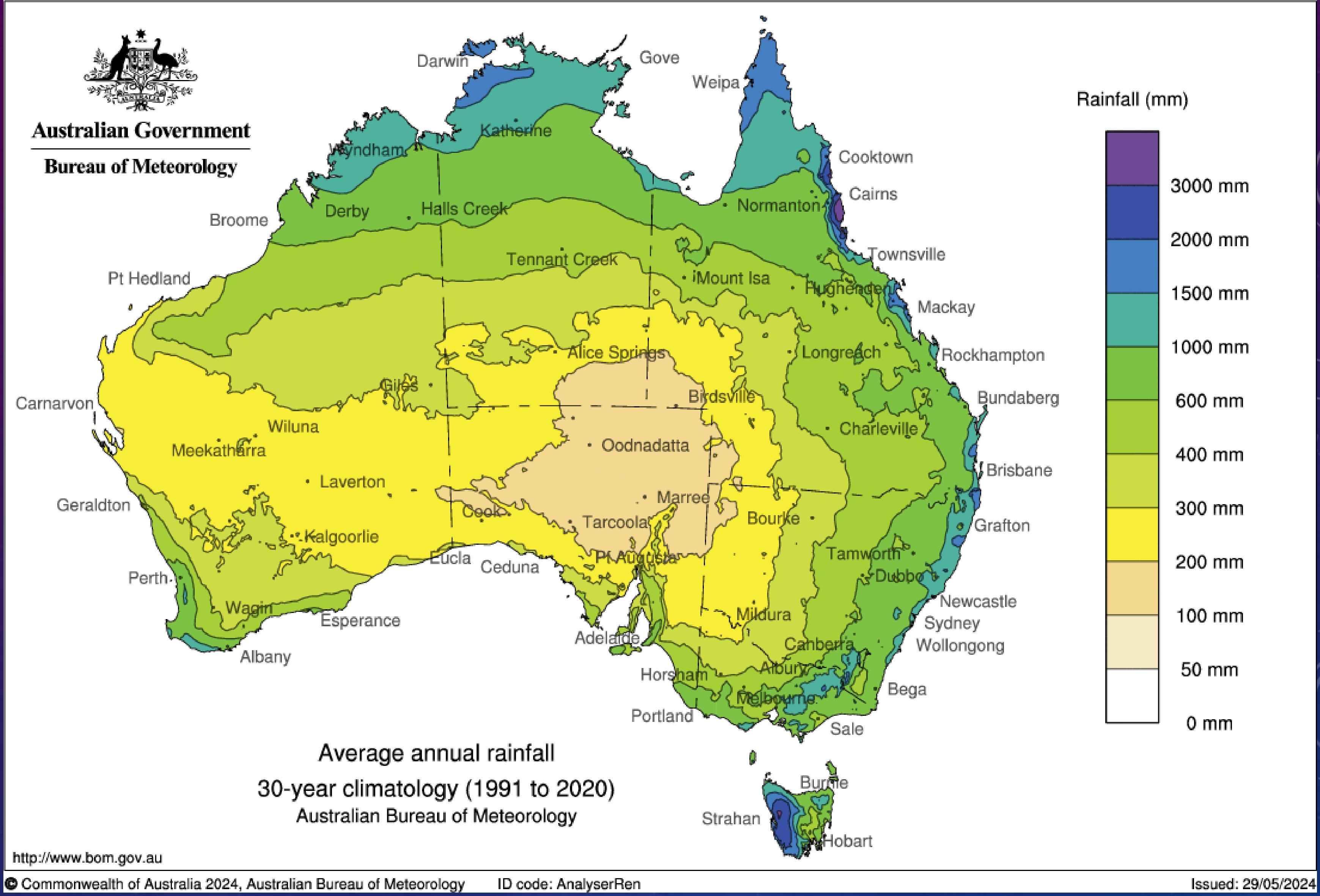
Also effects on the wind itself – turbulence; mountain waves and lee winds (such as Bora, Mistral, Chinook and Föhn).

Large-scale effects in the land/sea distribution that affect weather and climate

- Disposition of continents – northern hemisphere compared with the southern

- Mountain ranges
  - moisture barrier; enhanced rainfall windward
  - blockage and channelling of wind flow (e.g. tornado belt USA)

The effects can be seen in maps of averages – such as rainfall, temperature, and pressure.

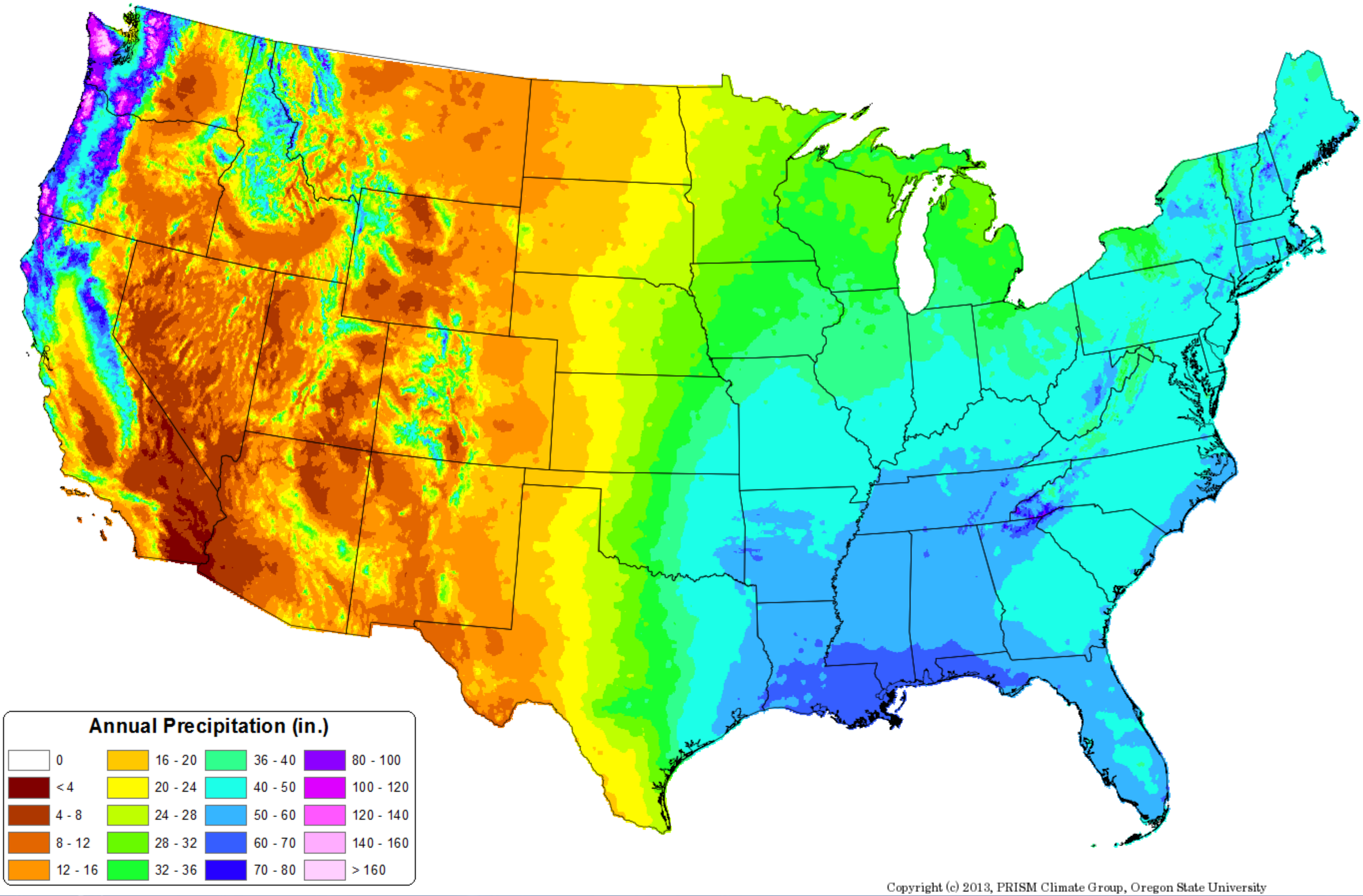


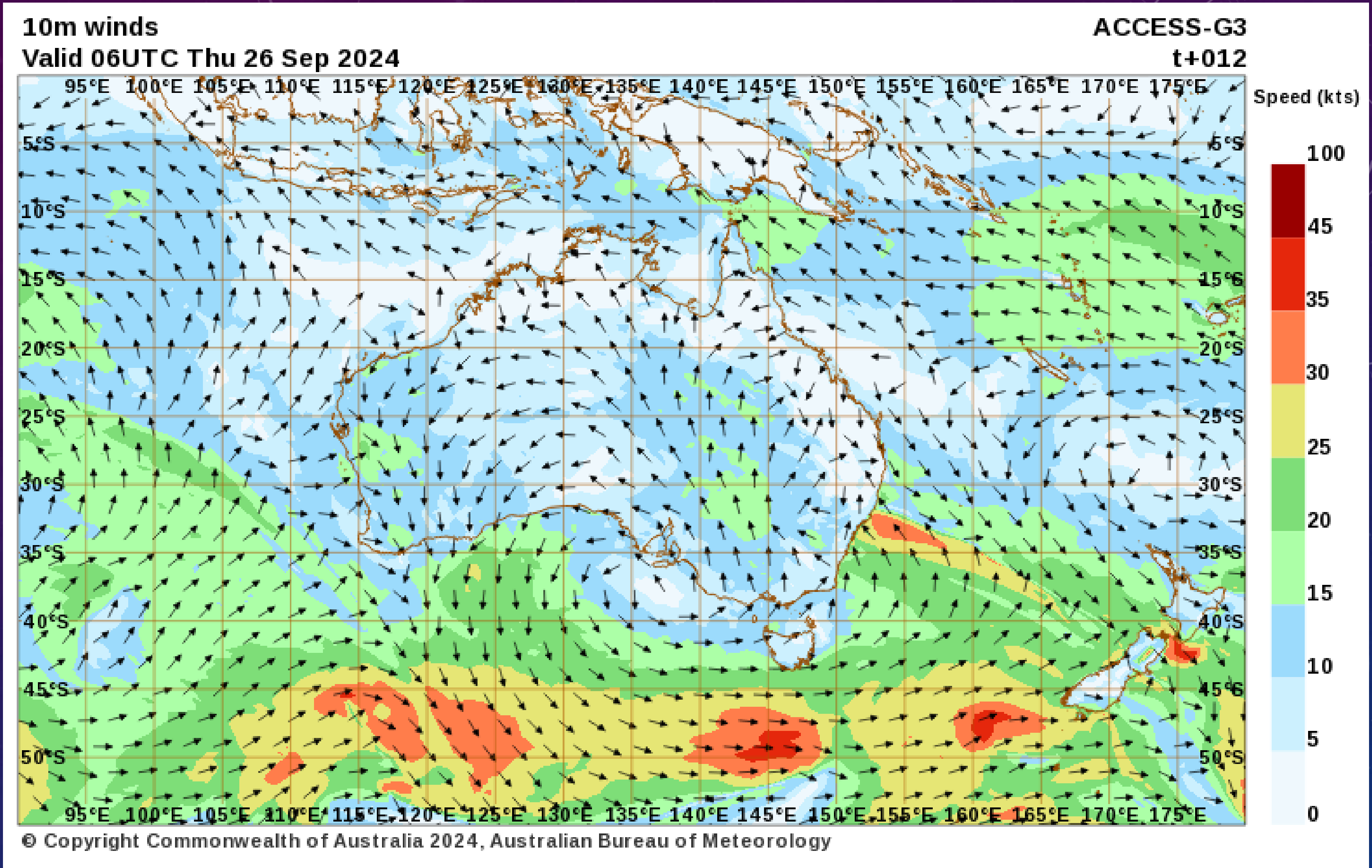
Some of these factors at work in average rainfall patterns:

- Distance from coast and from the tropics (with higher moisture content)
- Mountain ranges – rain on the windward side/ rain shadow leeward side

30-yr Normal Precipitation: Annual

Period: 1981-2010





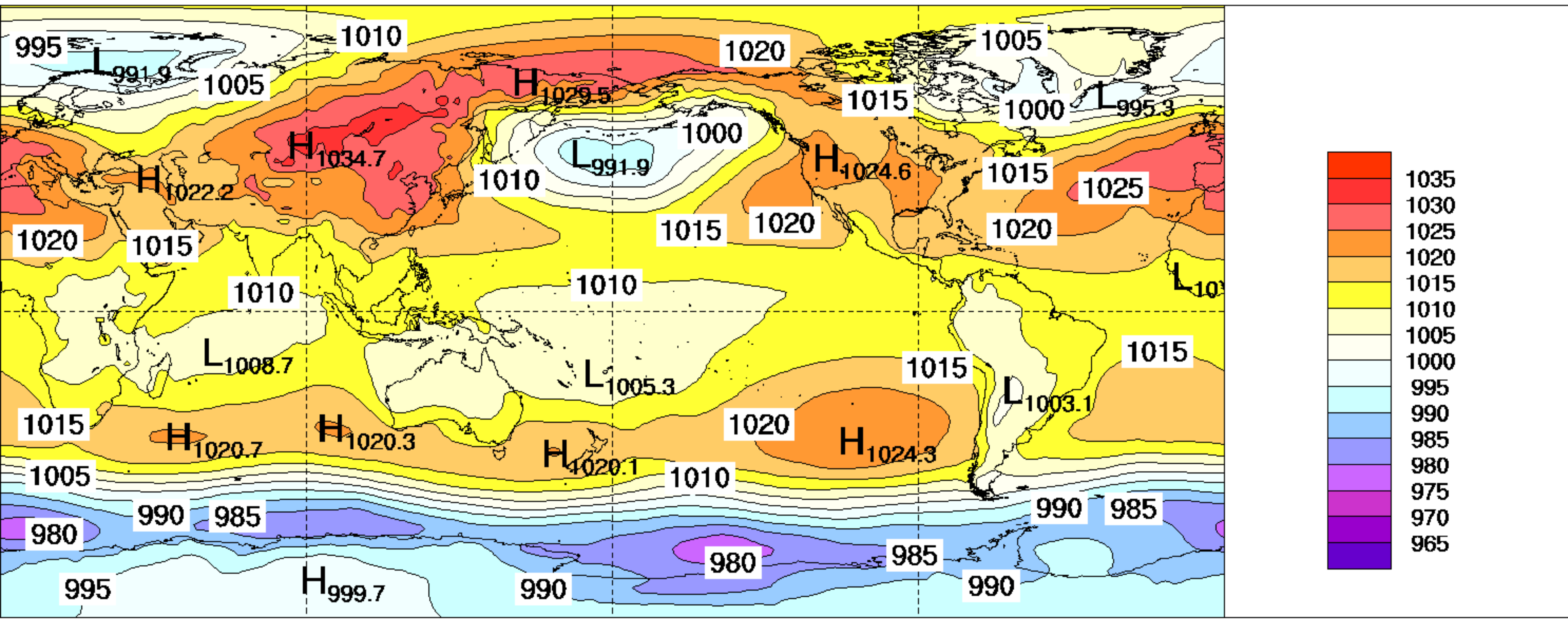
Wind speed – generally higher over the sea due to lower friction.

Australian Government
Bureau of Meteorology

Bureau Home > Climate > Climate Maps > Climate Monthly Bulletin - Atmospheric Circulation

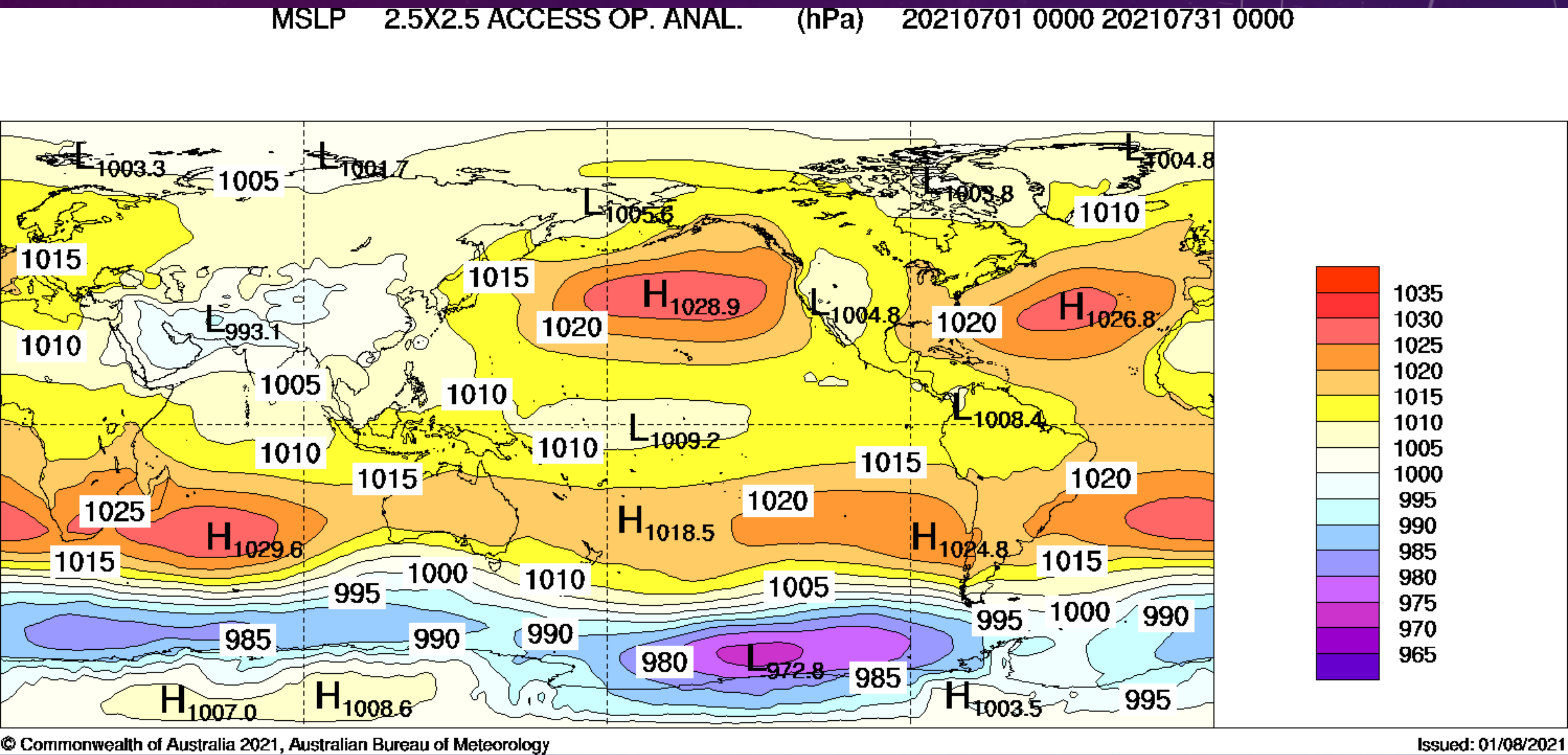
Monthly mean MSLP - Global

MSLP 2.5X2.5 ACCESS OP. ANAL. (hPa) 20220101 0000 20220131 0000

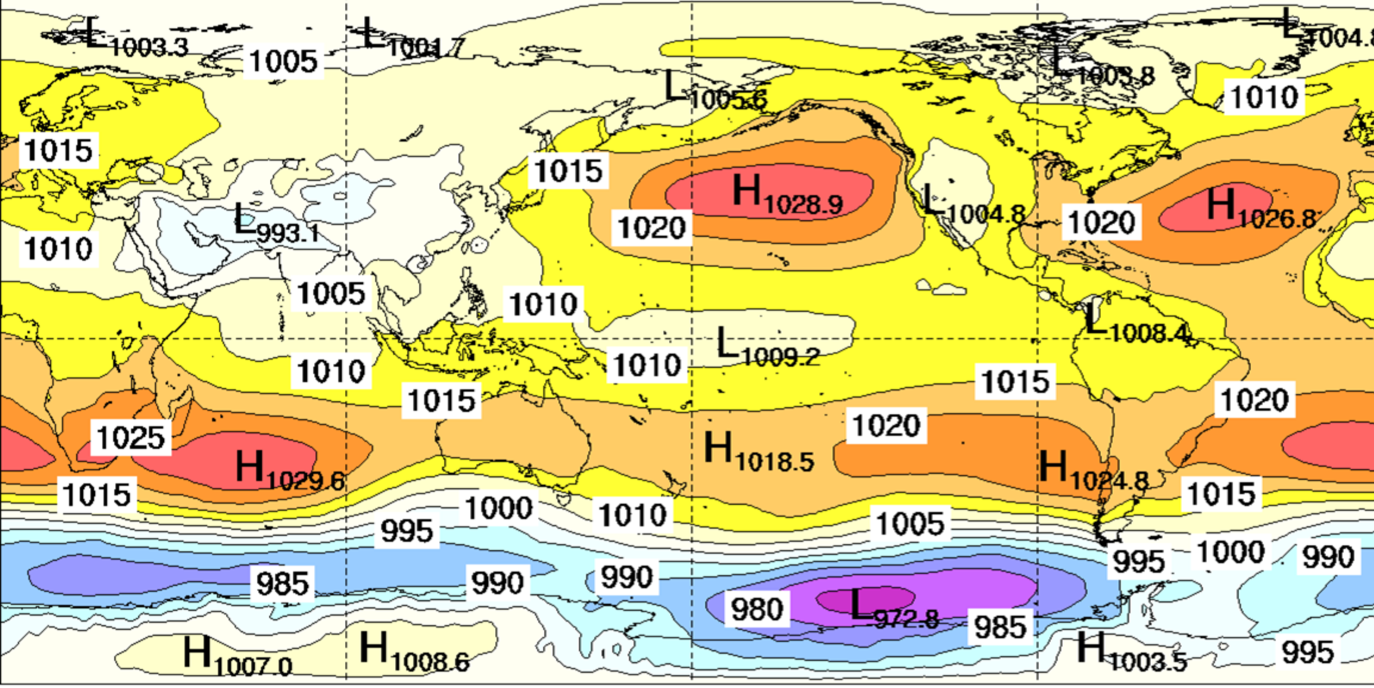


Issued: 01/02/2022

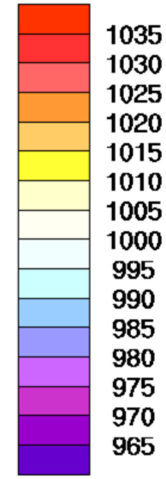
Monthly average Mean Sea Level Pressure (MSLP)
January 2022



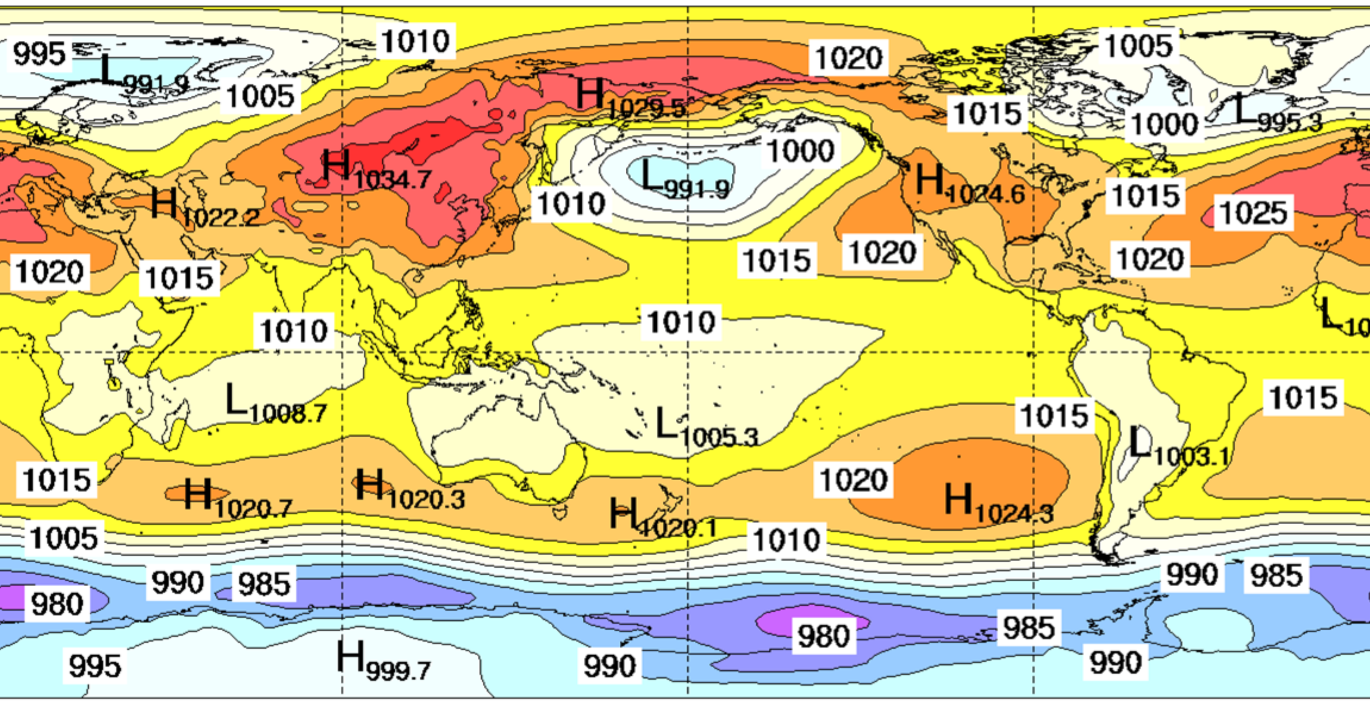
Monthly average Mean Sea Level Pressure (MSLP)
July 2021



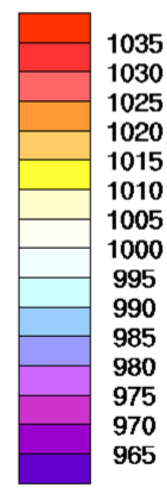
July 2021



Issued: 01/08/2021



January 2022



A few things to note including effects that flow from the different geomorphology of the two hemispheres:

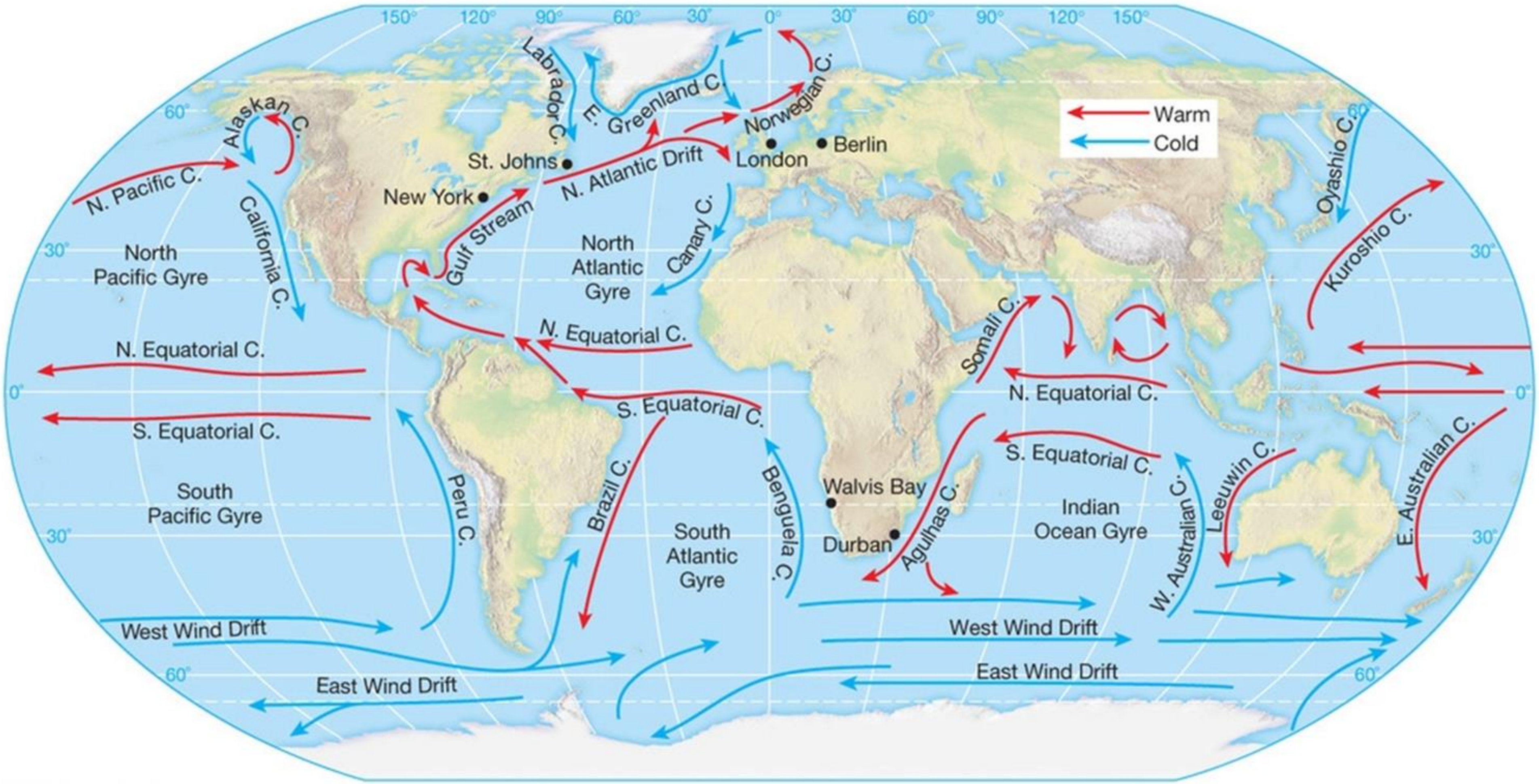
- The pressure pattern "follows the sun" north and south between winter and summer as expected,

- But, there are big differences in the pattern between the northern and southern hemispheres,

- The pattern in the northern hemisphere changes much more between summer and winter than the south,

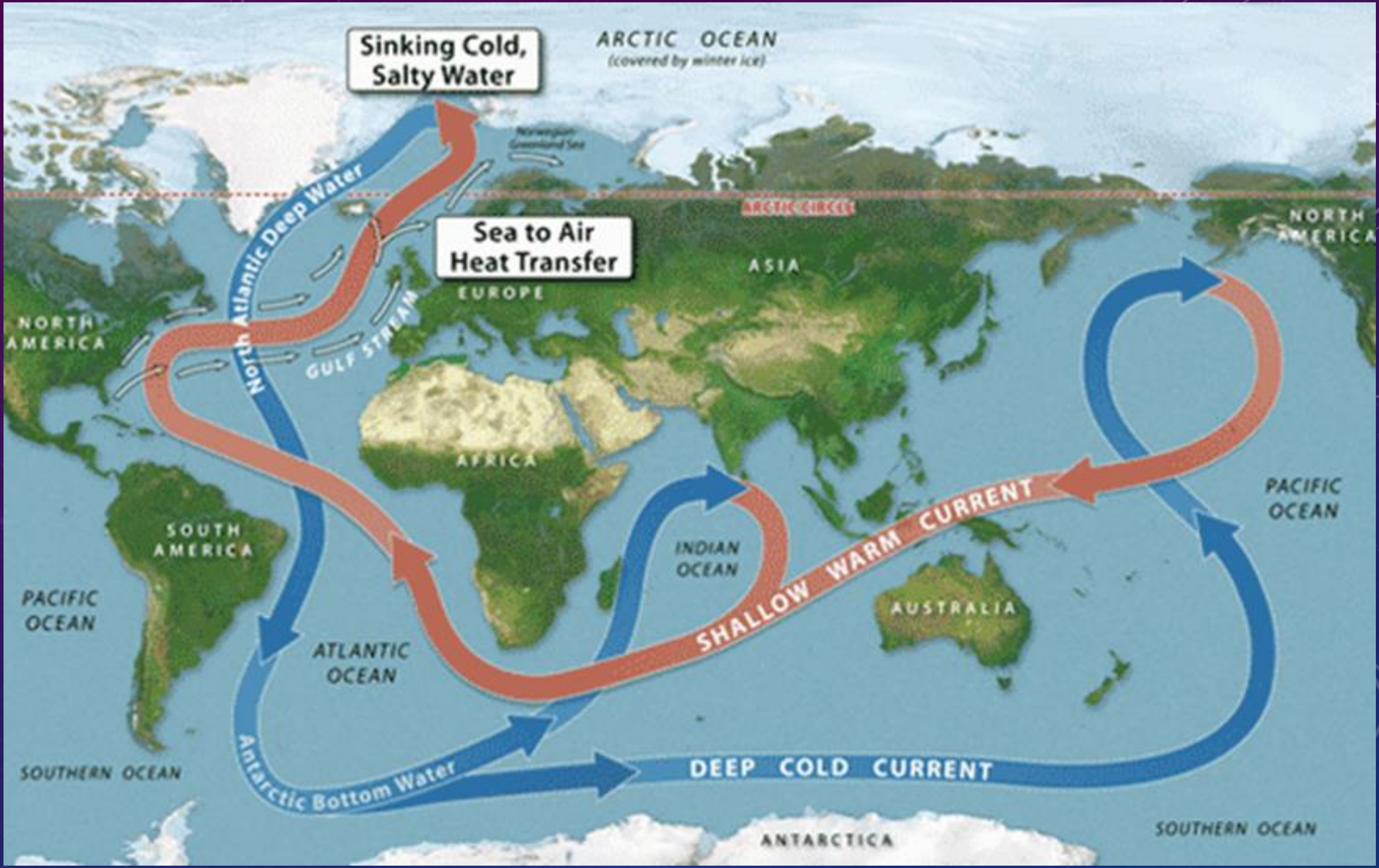
- In the southern hemisphere the band of westerly winds ("roaring forties") is present in both summer and winter.

- Why?
- More land and mountain ranges in the north
- More ocean in the south and relatively little land
- Large, high and cold continent over the south pole
- Stronger temperature difference on average between pole and equator in the southern hemisphere.



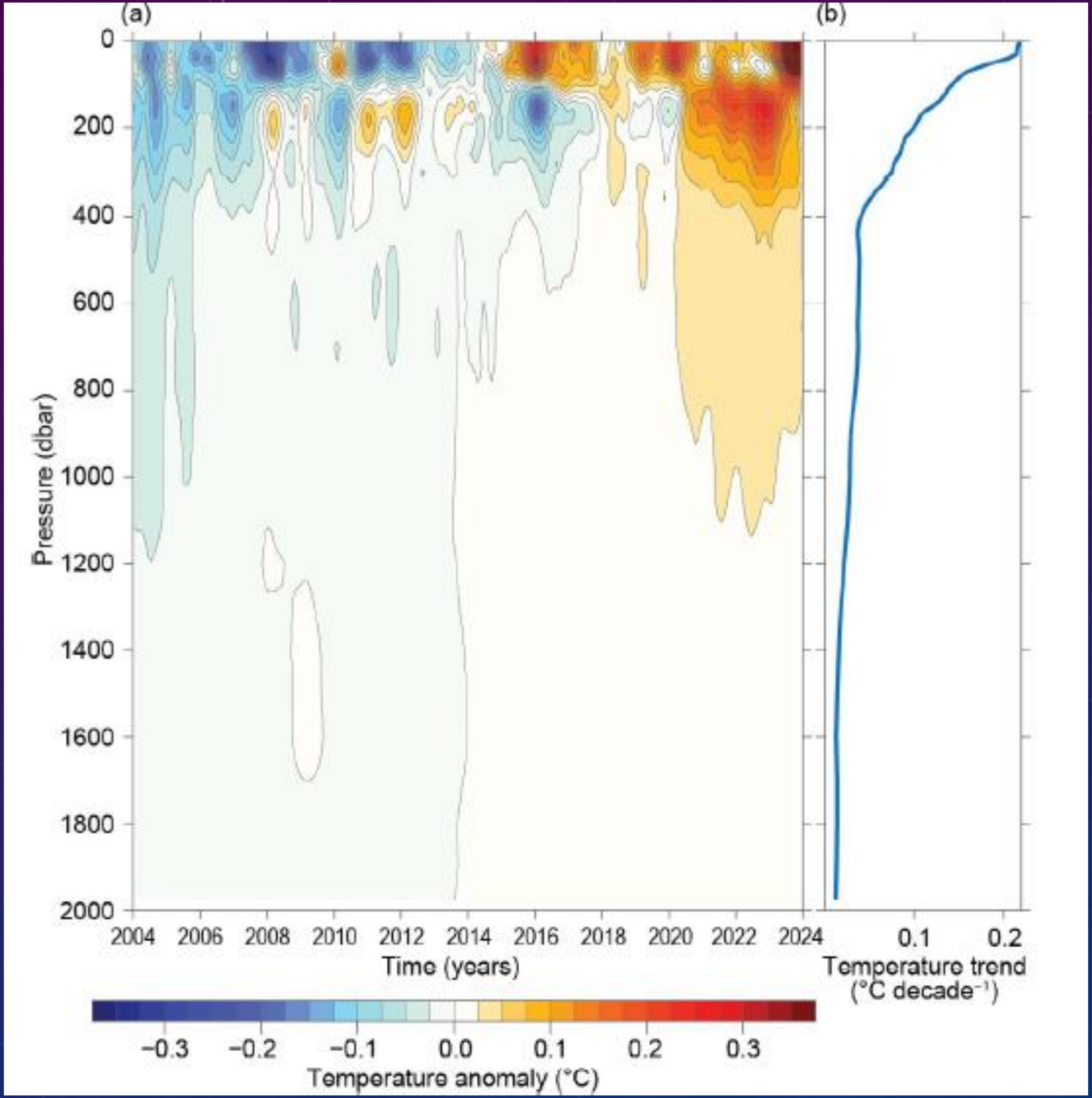
The differences in the ocean are also important as currents in the ocean also transport heat. This diagram shows the currents in the ocean surface layer driven by the wind.

Note the differences between the northern and southern hemispheres and especially the strong circumpolar current flowing west to east near Antarctica.



There are also currents in the deeper ocean that result from differences in heat and salinity. Salty water is denser than fresh and so will sink below fresher water if the temperatures are the same.

Note again the differences between the north and southern oceans.



This diagram shows the difference from the long-term average ocean temperature down to 2000 metres over the period 2004-2021, since a network of robotic deep ocean sensors (ARGO floats) was deployed.

There is a lot of ocean if you want to change its temperature!

What does the General Circulation look like in reality?

Satellites have played a major role in increasing understanding of the weather as the video showed.

There is still a lot to learn.

physicsworld

ATMOSPHERE RESEARCH UPDATE

Mountaintop observations of gamma-ray glow could shed light on origins of lightning

16 Oct 2024

Mountain high The cosmic-ray observatory on Armenia's Mount Aragats. (Courtesy: Vahram Mekhitarian/CC BY-SA 4.0)

Research done at a mountaintop cosmic-ray observatory in Armenia has shed new light on how thunderstorms can create flashes of gamma rays by accelerating electrons. Further study of the phenomenon could answer important questions about the origins of lightning.

*"Research done at a mountaintop cosmic-ray observatory in Armenia has shed new light on how thunderstorms can create flashes of **gamma rays** by accelerating electrons. Further study of the phenomenon could answer important questions about the origins of lightning."*

16 October 2024

Climate is the *collective effect of weather events*. It deals in statistics such as averages, extremes and typical weather.

It can deal with topics such as:

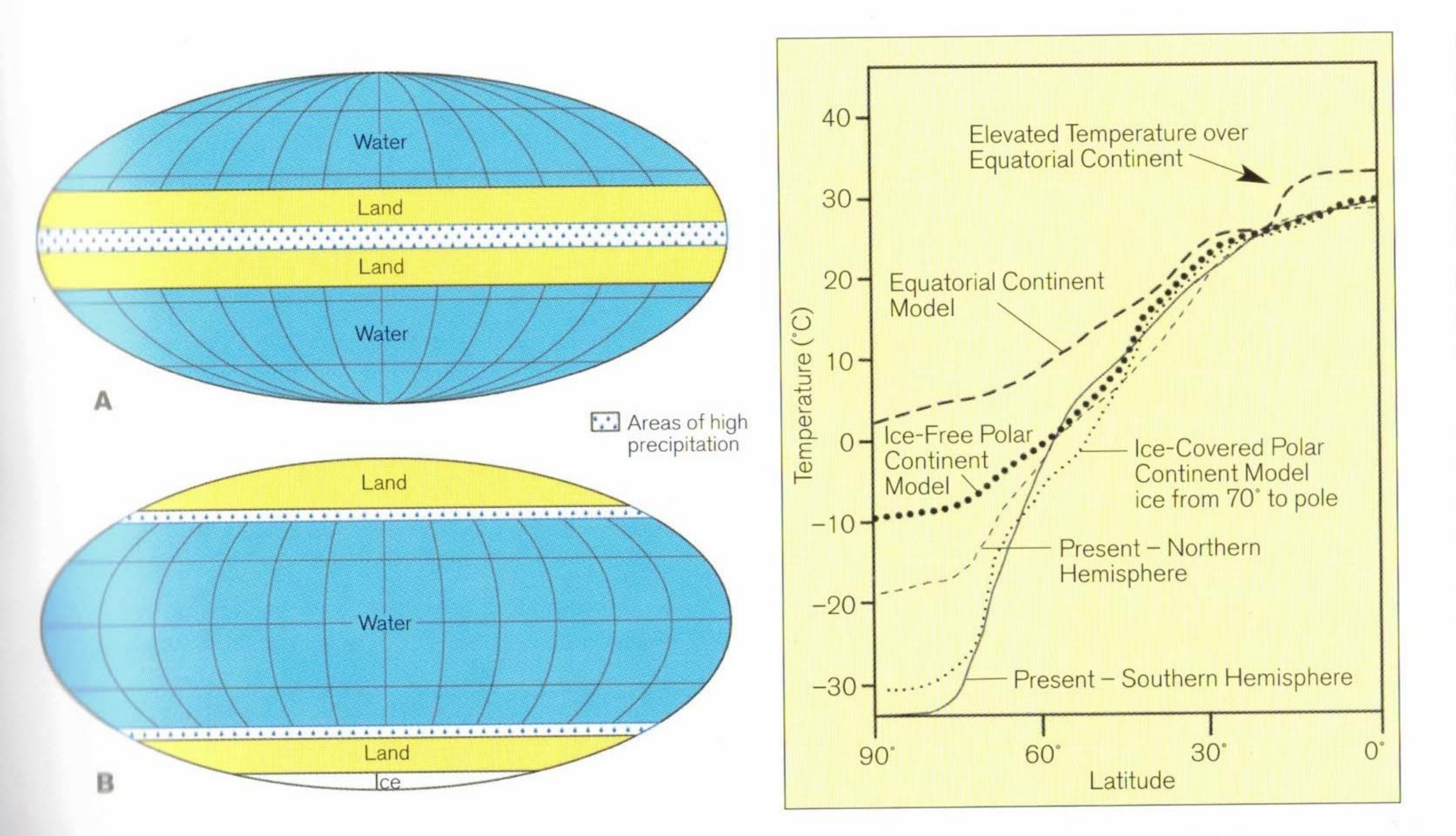
- Temperature
- Rainfall
- Wind
- Number of days of phenomena such as frost, thunderstorms,…
- Sea temperatures
- Atmospheric drivers – such as El Niño, La Niña, …
- Mean Sea Level Pressure (MSLP)
- Atmospheric wind patterns such as monsoons, “roaring forties”,..

Note: Climate is concerned with upper temperatures not just the surface

What could cause the climate to change?

- Variations in the sun's output
- Earth's orientation to sun – Croll/Milankovich theory
- Volcanoes
- Plate tectonics – positions of continents, changing ocean currents
- Mountain building – silicate weathering
- Changes in composition of the atmosphere
- Snow/ice changes – changing the reflectivity of the earth.
- Life – role of oxygen
- Land use changes (such as land clearing)

Items in green where geology may play a role.



Location of continents

Mark Maslin in "*The Complete Ice Age – how climate change shaped the World*" edited by Brian Fagan (2009)

To create an ice age – one criterion is to have continents near the poles.

The temperature difference between the Equator and the poles can be greater if the continents are at the poles. The diagram on the right shows modern day temperature differences and several model simulations.

Changes in the positions of continents can have a significant effect on the winds and ocean currents.

9 November 2021

Plate tectonics as a driver for cooling around Antarctica during global climate transition from greenhouse to icehouse

High-resolution simulations of ocean circulations 34 million years ago are shedding a new light on the 50-year-old question about how and why the Antarctic ice sheets formed. The simulations show that the tectonic opening of Southern Ocean seaways caused a fundamental reorganisation of ocean currents, heat transport and initiated a strong Antarctic surface water cooling of 5 °C. The new study conducted by an international team of researchers has been published in the November 9th issue of *Nature Communications*.

https://www.uu.nl/en/news/plate-tectonics-cooling-antarctica

Major impacts on the Southern Oceans that persists today:

- Opening up of the ocean between Tasmania and Antarctica (35 Million years ago) and of the Drake Passage (30 Million years ago)

Antarctica became isolated from the ocean gyres that brought heat southwards. Antarctica became colder, enhancing the temperature gradient between the tropics and the poles and hence speeding up the westerly winds and ocean currents.

- Closing of the Panama Isthmus (4.5 – 2 Mya) that separated the tropical Pacific and Atlantic Oceans.

Pacific Ocean water was fresher than the Caribbean and cutting it off made the Caribbean saltier. This denser water transported in the Gulf Stream could have sped up the deep water formation and the conveyor belt in the Atlantic, transporting more heat northwards, but also more moisture that is needed for ice formation.

The separation from the Atlantic Ocean may have set up the conditions that allowed El Nino/La Nina events across the Pacific Ocean….

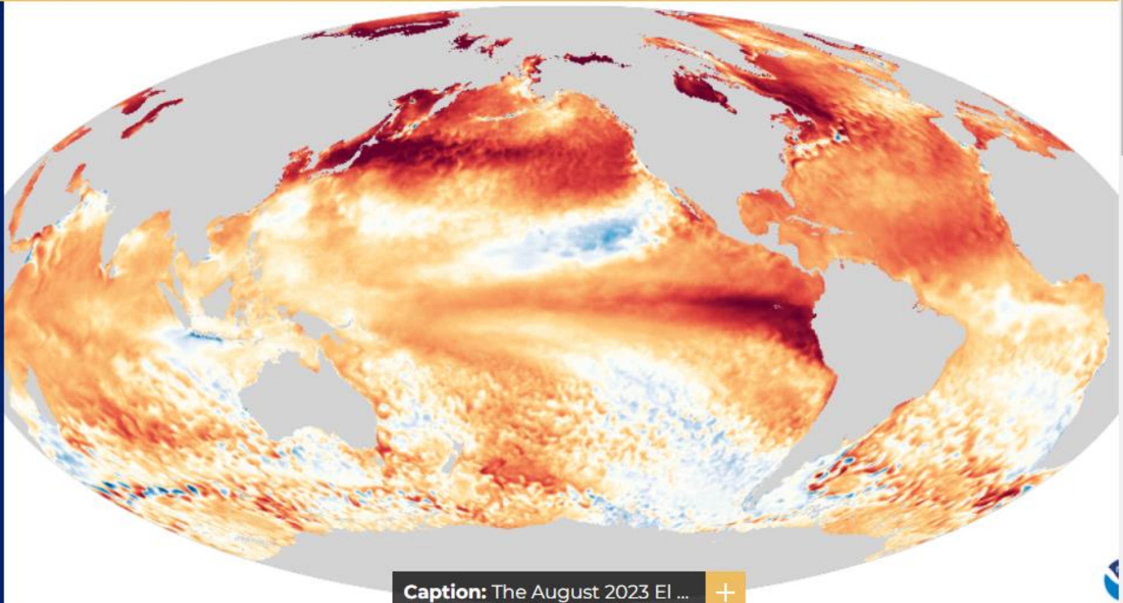
… or perhaps not?

Duke TODAY

Sections Trending Watch

Weather-Changing El Niño Oscillation Is at Least 250 Million Years Old

Modeling experiments show Pacific warm and cold patches persisted even when continents were in different places



Caption: The August 2023 El ...

PUBLISHED
October 21, 2024

CREDITS
Karl Leif Bates, Duke Research

SCHOOLS

The El Niño event, a huge blob of warm ocean water in the tropical Pacific Ocean that can change rainfall patterns around the globe, isn't just a modern phenomenon.

A new modeling study from a pair of Duke University researchers and their colleagues shows that the oscillation between El Niño and its cold counterpart, La Niña, was present at least 250 million years in the past, and was often of greater magnitude than the oscillations we see today.

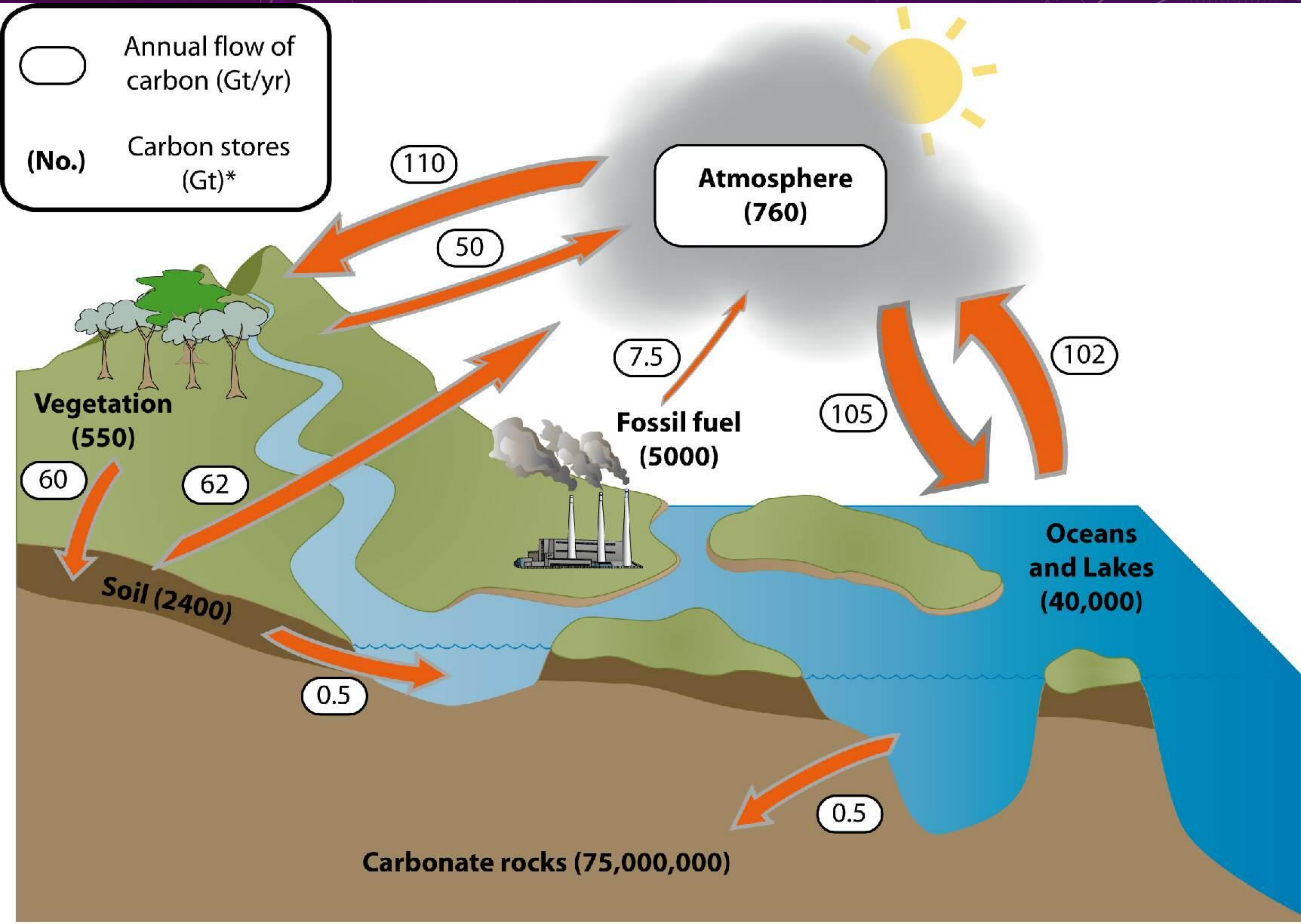
Changes in the composition of the atmosphere

Geological processes can change the composition of the atmosphere (e.g. prolonged and massive volcanic eruptions) and major mass extinctions were linked to what happened in the atmosphere and ocean.

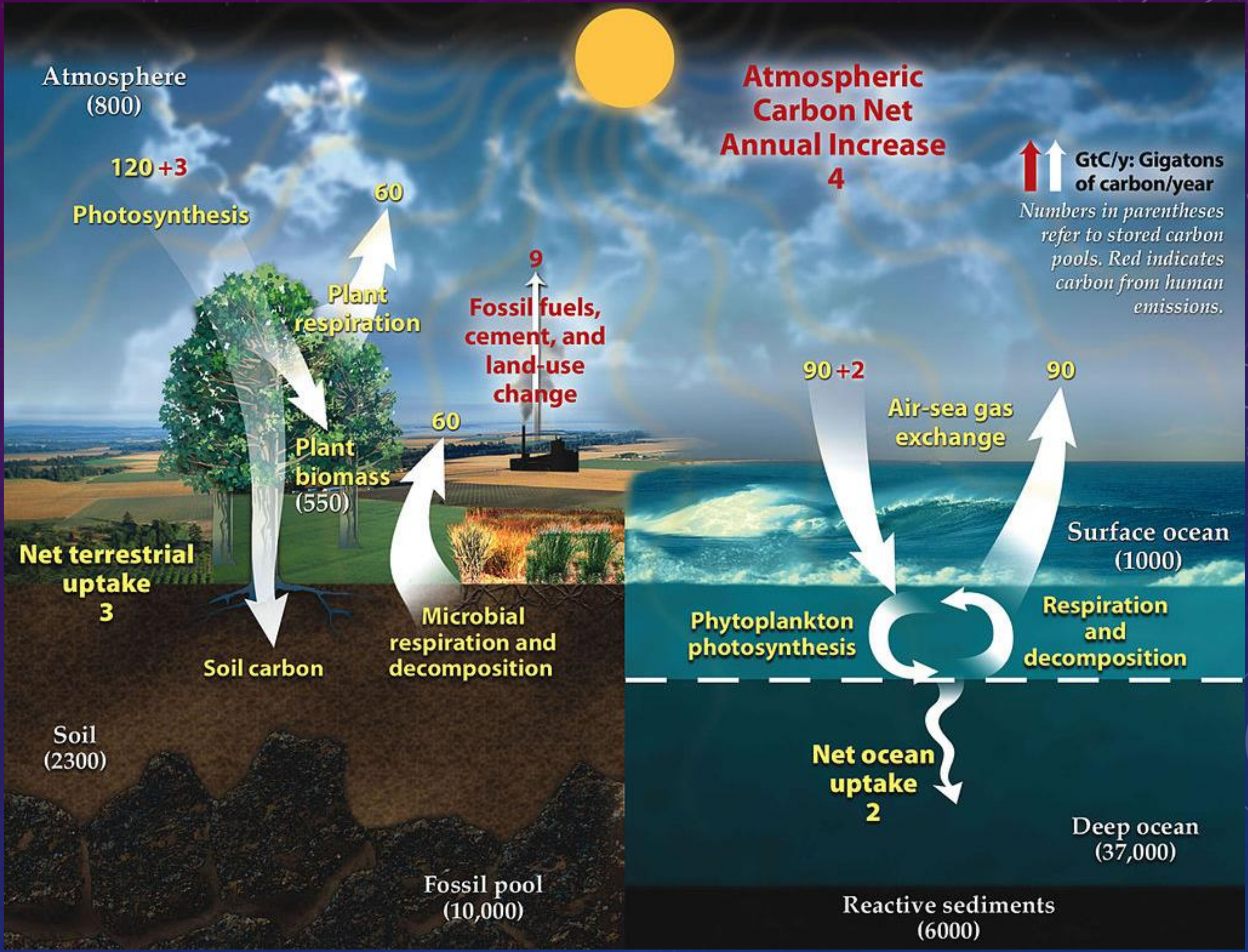
The greenhouse gases (carbon dioxide, methane, etc.) have been crucial.

The carbon cycle operates over several time scales:

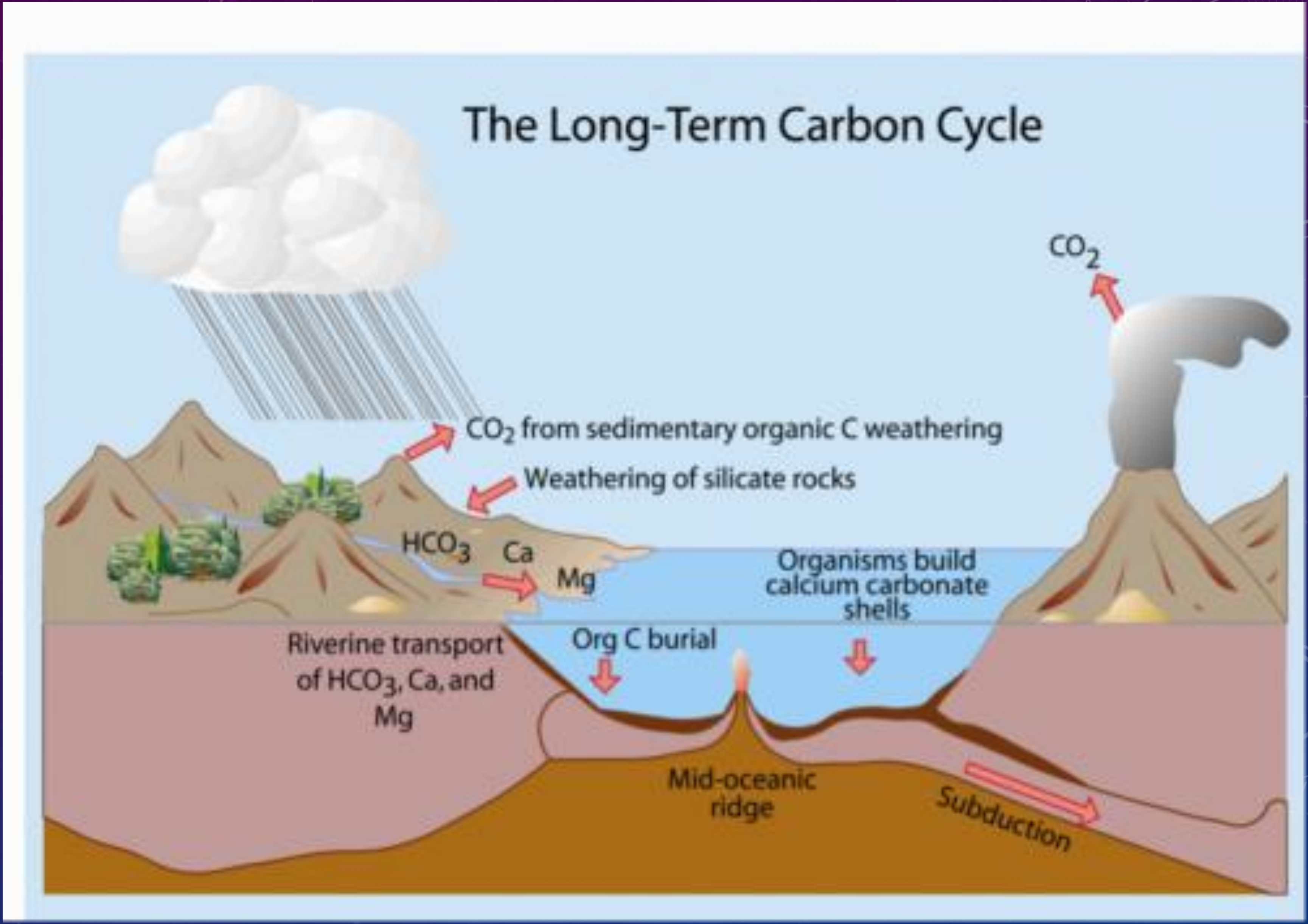
- a **(relatively) short term (fast) cycle (**up to thousands of years) – involving vegetation, storages in soil and oceans - **biological**
- A **slow cycle** that operates over geological time scales and involves **geological** processes.



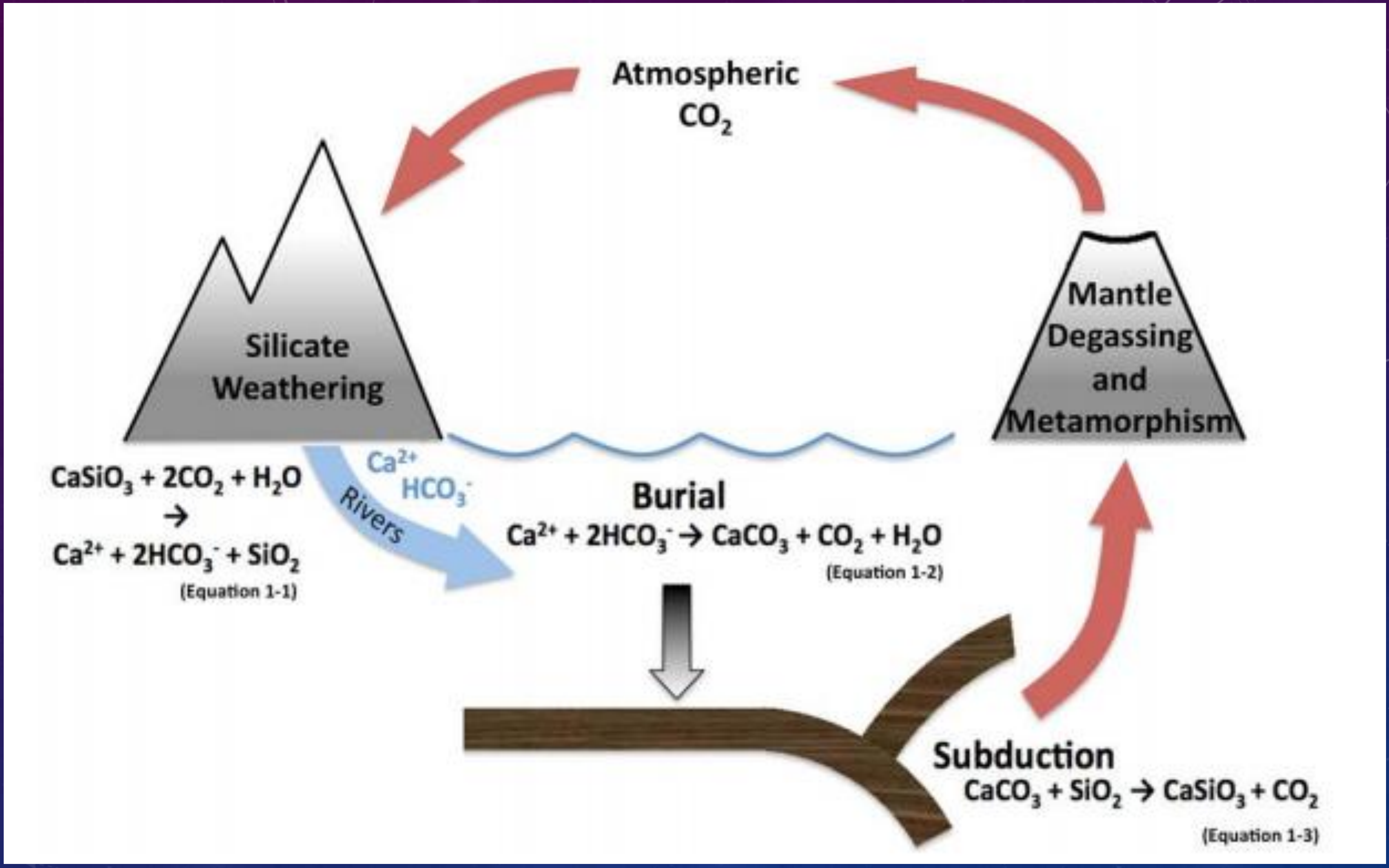
* 1 Gt = 1 Gigatonne = 1 billion metric tonnes

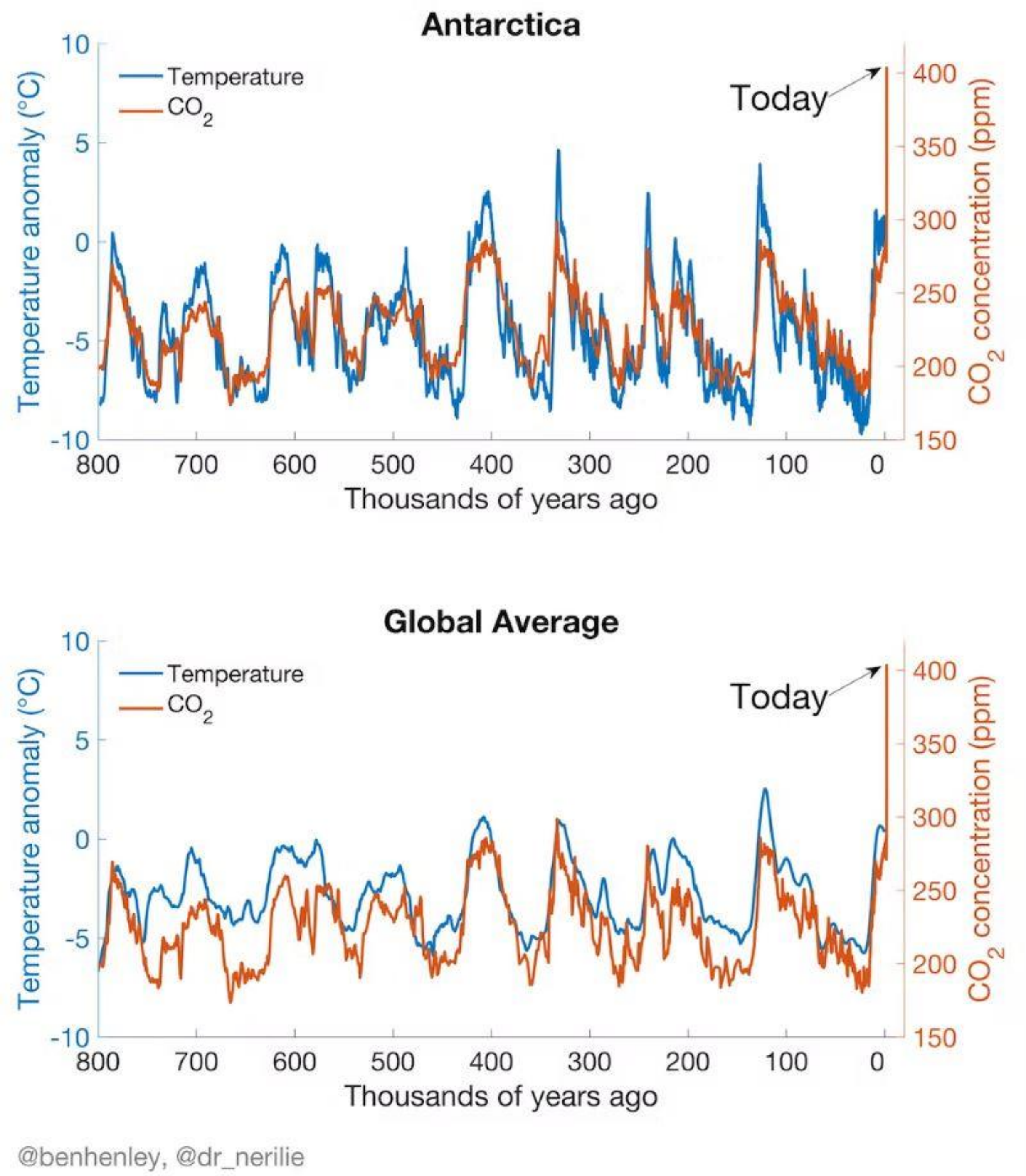


The **fast carbon cycle** showing the movement of carbon between land, atmosphere, and oceans. Yellow numbers are natural fluxes, and red are human contributions in gigatonnes of carbon per year. White numbers indicate stored carbon. (Wikipedia)



The Slow Carbon Cycle is driven by geological processes, although Biology also plays a role through the deposition of carbonates from the shells and skeletons of organisms in the ocean.


Atmospheric
CO_2
Silicate
Weathering
Mantle
Degassing
and
Metamorphism
$CaSiO_3 + 2CO_2 + H_2O$
→
$Ca^{2+} + 2HCO_3^- + SiO_2$
(Equation 1-1)
Ca^{2+}
HCO_3^-
Rivers
Burial
$Ca^{2+} + 2HCO_3^- \rightarrow CaCO_3 + CO_2 + H_2O$
(Equation 1-2)
Subduction
$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$
(Equation 1-3)



Over geological time-scales there is a close connection between carbon dioxide concentration and global temperatures.

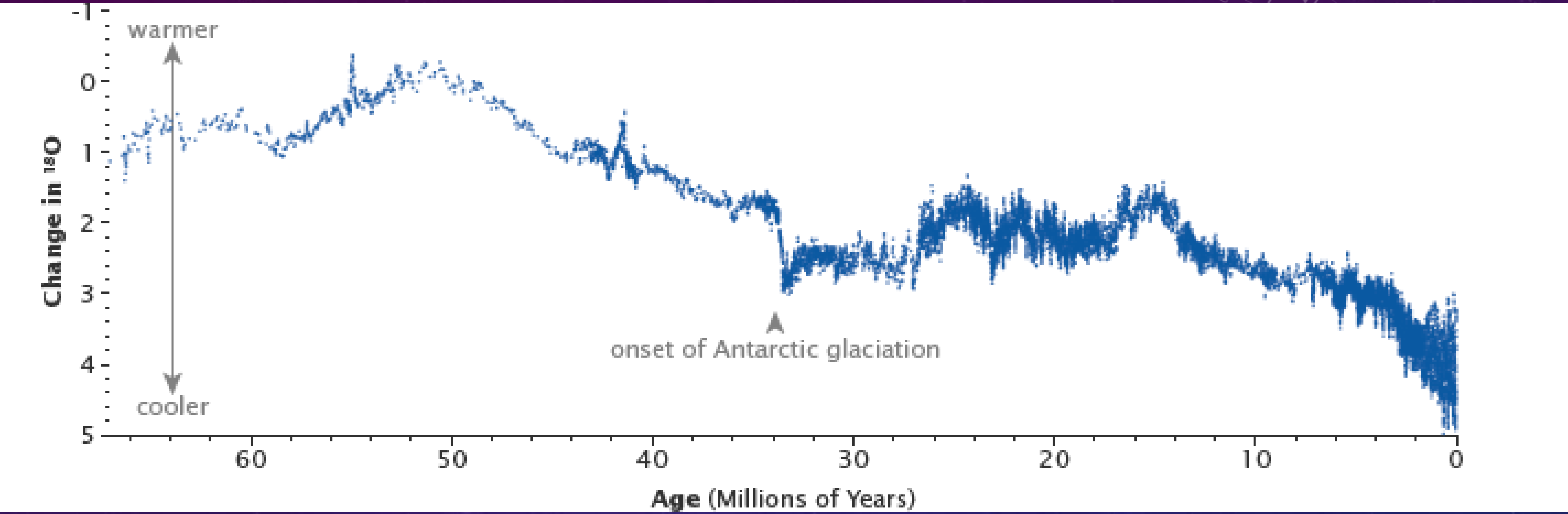
E.g. Antarctic and Greenland ice cores; deep sea sediment cores.

Role of Mountain Building in the Climate

- Altering wind and precipitation patterns and affecting both regional and global atmospheric circulation

- Weathering and erosion of uplifted silicate rocks (for example, granites) including by plants affects the carbon cycle over millions of years by slowly removing carbon dioxide, a greenhouse gas, from the atmosphere

- Because temperatures decrease with altitude, mountains affect the distribution of snow and ice cover and how water cycles through ecosystems.



The uplift of the Tibetan-Himalayan and Sierra-Coloradan plateaus, beginning 50 million years ago, reset Earth's thermostat by providing a large source of fresh rock to pull more carbon into the slow carbon cycle through chemical weathering. The resulting drop in temperatures and the formation of ice sheets changed the ratio between heavy and light oxygen in the deep ocean, as shown in this graph.

https://www.earthobservatory.nasa.gov/features/CarbonCycle

However, the temperatures vary a lot and there is much research into them as they can reveal information about our climate

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www.clim-past.net/10/887/2014/
doi:10.5194/cp-10-887-2014

Climate of the Past
Open Access

Temperature reconstruction from 10 to 120 kyr b2k from the NGRIP ice core

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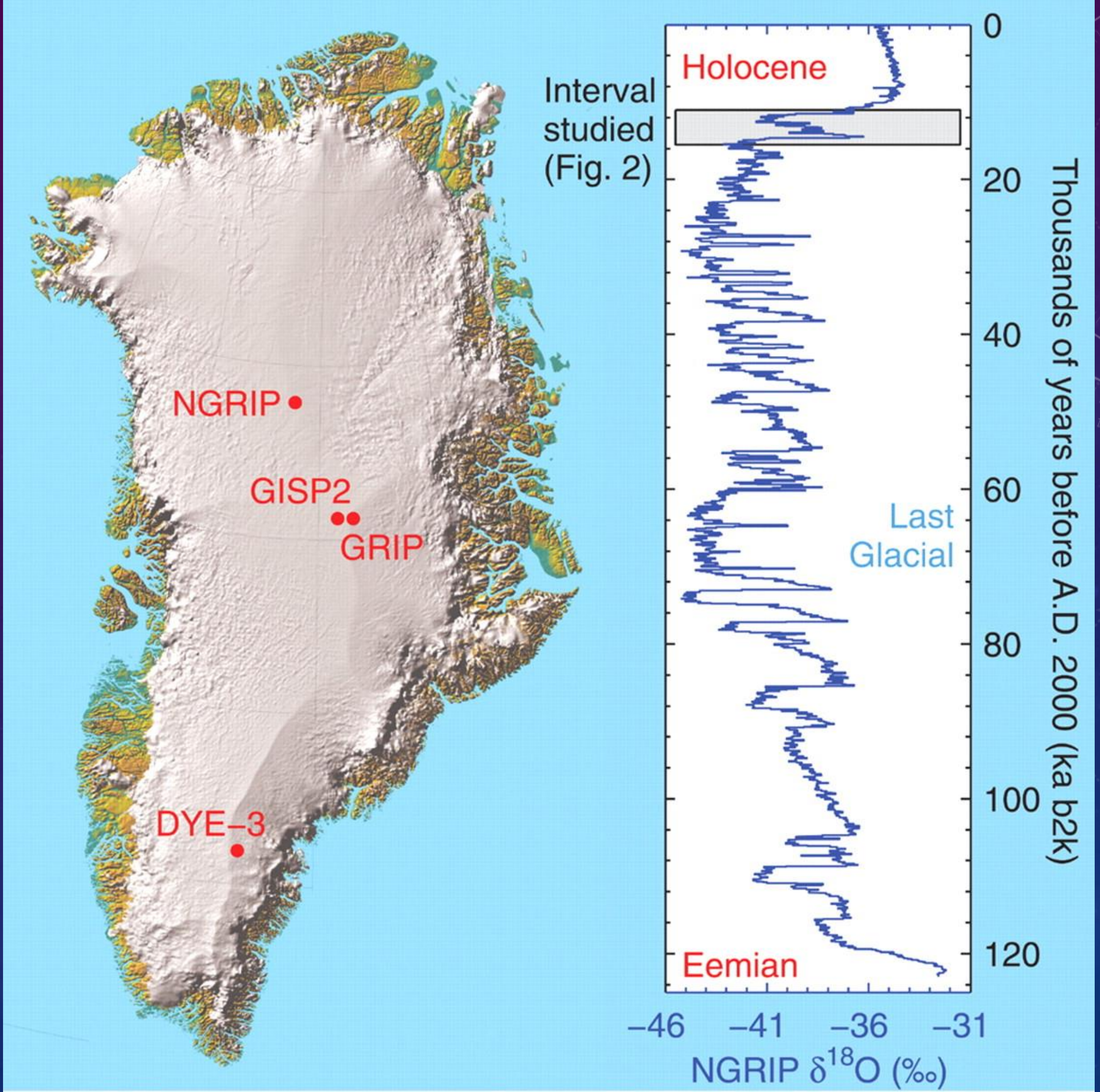
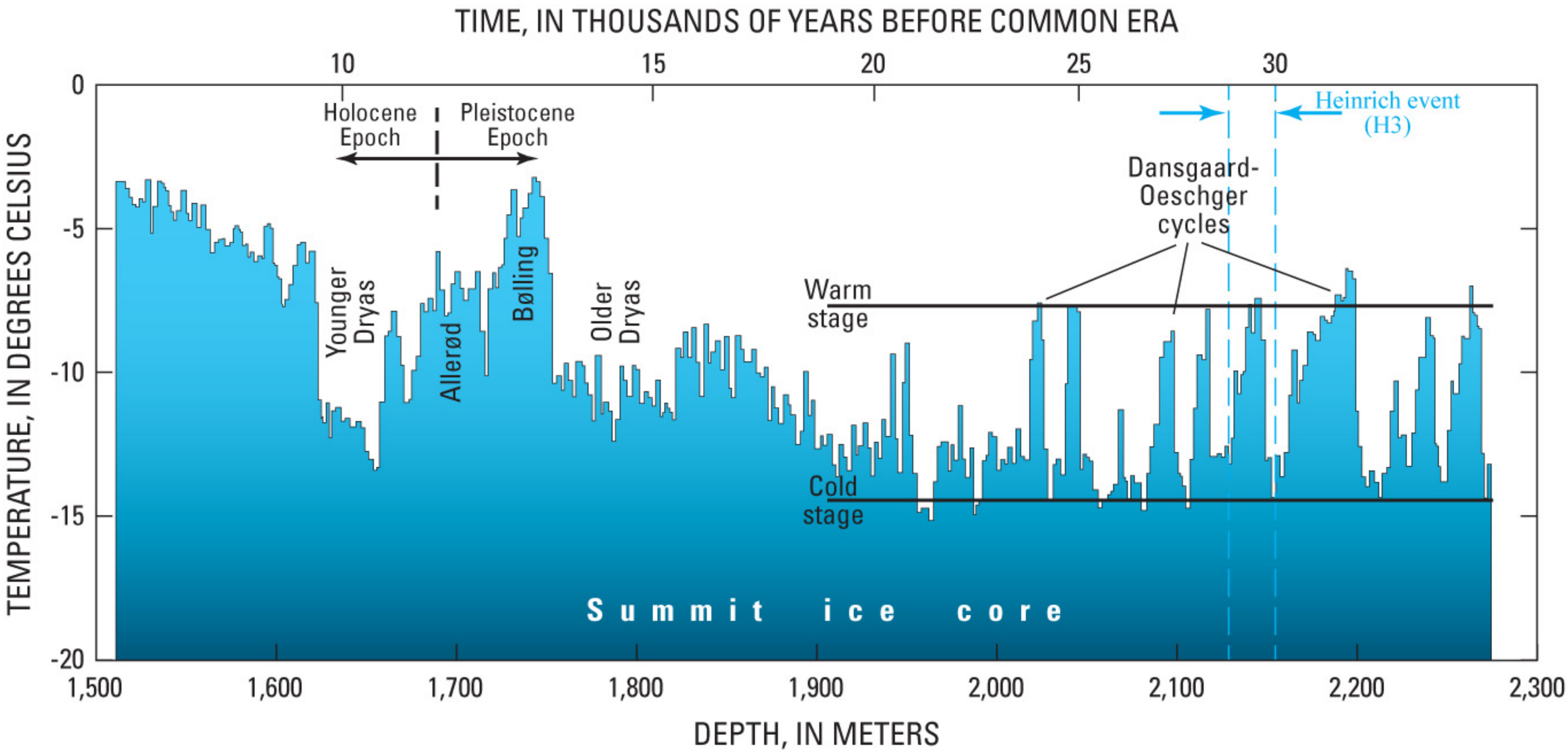
Temperature reconstructions from stable isotope measurements in the North Greenland Ice Core Project (NGRIP) have shown some **rapid temperature changes** over the last 120,000 years that are an active field of research as they seem to involve changes in the Atlantic Ocean circulations.


NGRIP
GISP2
GRIP
DYE–3
Interval
studied
(Fig. 2)
Holocene
Last
Glacial
Eemian
0
20
40
60
80
100
120
Thousands of years before A.D. 2000 (ka b2k)
–46
–41
–36
–31
NGRIP δ18O (‰)



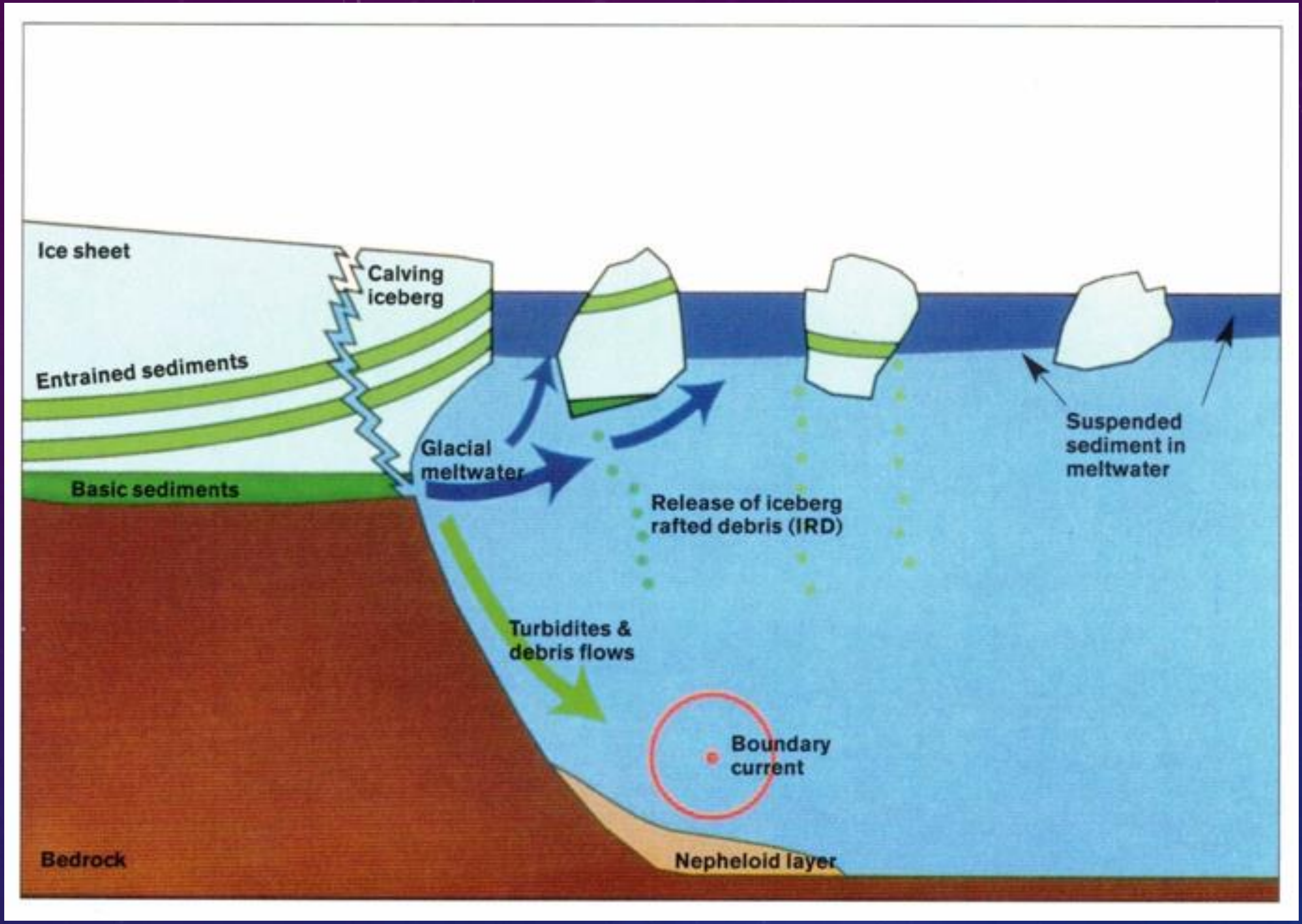
Note: Significant temperature variations even during the Holocene.

State of the Earth's Cryosphere at the Beginning of the 21st Century: Glaciers, Global Snow Cover, Floating Ice, and Permafrost and Periglacial Environments—

GLACIERS

By RICHARD S. WILLIAMS, JR., *and* JANE G. FERRIGNO

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1386–A–2



Heinrich Events

Complete Ice Age (2009)
(ed. Brian Fagan)

Named after a marine geologist Harmut Heinrich who in 1988 identified high proportions of rocks of continental origin in ocean sediment cores in the Atlantic. The larger size fractions could ot be transported by ocean currents and are interpreted as having been carried by icebergs or sea ice which broke off glaciers or ice shelves and dumped the debris as the icebergs melted. Attributed to massive collapses of the **North American Laurentide ice sheet.**

A **Dansgaard-Oeschger Cycle** is characterized by a sudden warming of Greenland by 10–15 °C within a few decades, followed by a gradual cooling lasting from 500 to over 2000 years. They are identifiable in the Greenland ice cores, other ice core climate proxies (e.g. dust and aerosol content) and in other types of climate proxies (such as ocean sediment cores).

Thus far, 25 events have been identified with an apparent 1500-year periodicity.

The rapid temperature variations are at least of northern hemispheric extent.

It is widely assumed that DO events are linked to reorganisations and/or variations in the strength of the Atlantic Meridional Overturning Circulation (AMOC) triggered by a strong flow of fresh water (melting ice?) .

Most of the DO events are present also in Antarctic ice core records but are not as pronounced and are out of phase. This asynchronous behaviour is in line with the concept of a “thermal bipolar seesaw” where the Southern Ocean is considered as a heat reservoir which delivers heat via the AMOC to the Northern oceans.

https://www.sciencedirect.com/topics/earth-and-planetary-sciences/dansgaard-oeschger-cycle

There seems to be a connection between DO events and Heinrich events.

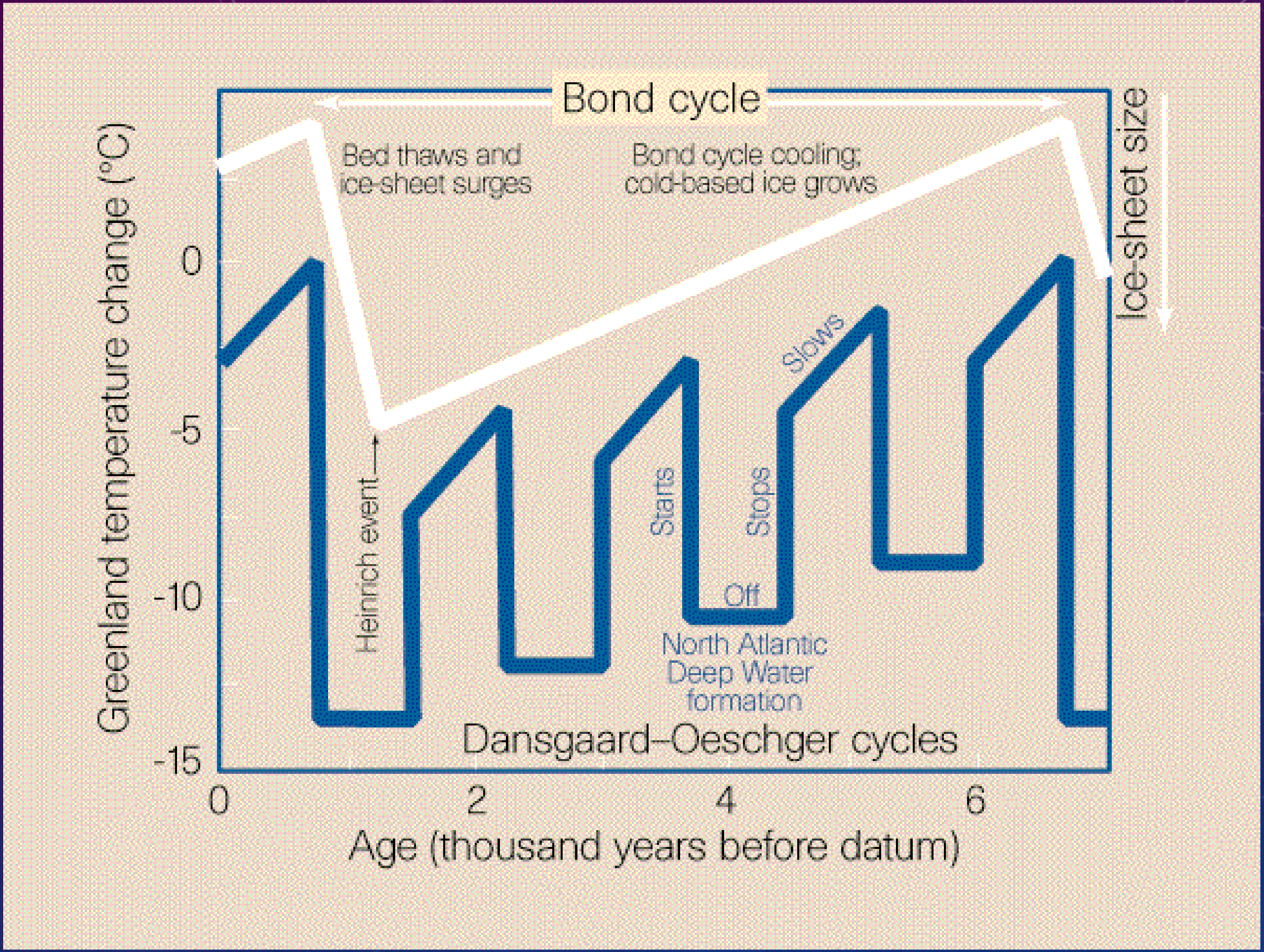
Dansgaard-Oeschger cycles identified in the Holocene are also termed “Bond events”.

Proposed Bond events include:

- Younger Dryas (11,000 ya)
- Late Antique Little Ice Age (600 CE)
- Little Ice Age (1500 CE)

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

They are all related to switching on/off of the Atlantic conveyor belt, which is a great topic of interest within current climate change research. Information from the past on the extent of variations and the global impact could be useful for understanding the present.



Heinrich Events and Dansgaard-Oeschger Cycles appear to be linked in Bond Cyles – but it is an active area of research.

nature communications

Article

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A mechanism for reconciling the synchronisation of Heinrich events and Dansgaard-Oeschger cycles

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Check for updates

Clemens Schannwell[1] ✉, Uwe Mikolajewicz[1], Marie-Luise Kapsch[1] & Florian Ziemen[2]

The evolution of the northern hemispheric climate during the last glacial period was beset by quasi-episodic iceberg discharge events from the Laurentide ice sheet, known as Heinrich events (HEs). The paleo record places most HEs into the cold stadial of the Dansgaard-Oeschger cycle. However, not every Dansgaard-Oeschger cycle is associated with a HE, revealing a complex interplay between the two modes of glacial variability. Here, using a coupled ice sheet-solid earth model, we introduce a mechanism that explains the synchronicity of HEs and Dansgaard-Oeschger cycles. Unlike earlier studies, our mechanism does not require a trigger during the stadial. Instead, the atmospheric warming signal during the interstadial of the Dansgaard-Oeschger cycle causes enhanced ice stream thickening that leads to the HE during the late interstadial. We demonstrate that this mechanism reproduces the key HE characteristics and provides an explanation for synchronous HEs from different regions of the Laurentide ice sheet.

- Geology and Geomorphology are important for the weather and climate of the atmosphere and the ocean.
- They have played a major role in changing the climate.
- New techniques for studying the climate (past and present) are being developed raising many questions.
- There is still a lot to learn about past climates and the causes on variations in the past.
- Need multi-disciplinary approach.
- These questions may be of interest to scientists but by better understanding our climate and its variations, we may also better understand what could happen by human interventions.