



Past and Future Climate – Present Weather

Week 13

Computer Modelling of Climate

Terry Hart

Dates

Term 4

15 October

Computer modelling of the Climate

29 October

Where are we now? The current and future state of the Climate.

<https://journals.ametsoc.org/view/journals/bams/107/8/2026BAMSStateoftheClimate.1.xml?rskey=5cRb3y&result=1>

12 November

**Royal Institution Christmas Lecture 2020 -
Engine Earth**

December 21, 2023



March 19, 2024



June 20, 2024



September 22, 2024

Images from the NOAA Deep Space Climate Observatory – in an orbit between the Sun and Earth roughly 1.6 million kilometres from Earth.

The images show Earth on the December and June solstices and the March and September equinoxes, illustrating how the tilt of Earth's axis shifts the continent's apparent positions through the year.

Tony Heyes and ChatGPT – holiday reading.

Hunger Stones: Messages from the River - Ancient Warnings Written in Stone

Throughout Europe, particularly along the River Elbe in what is now the Czech Republic and Germany, there are remarkable monuments known as **Hunger Stones**.

- large boulders in rivers that become visible only when water levels fall to exceptionally low levels.
- natural warning markers. When they emerge from the water, they signal that the river has fallen to a dangerously low level.
- their appearance has long been associated with famine, failed harvests, interrupted river transport, and economic suffering.

The best-known Hunger Stone - River Elbe at Děčín in the Czech Republic.

Among its inscriptions is the haunting German phrase:

"Wenn du mich siehst, dann weine." ("If you see me, then weep.")



Some of the recorded drought years include:

1417

1473

1616

1707

1746

1790

1842

1868

1892

1904

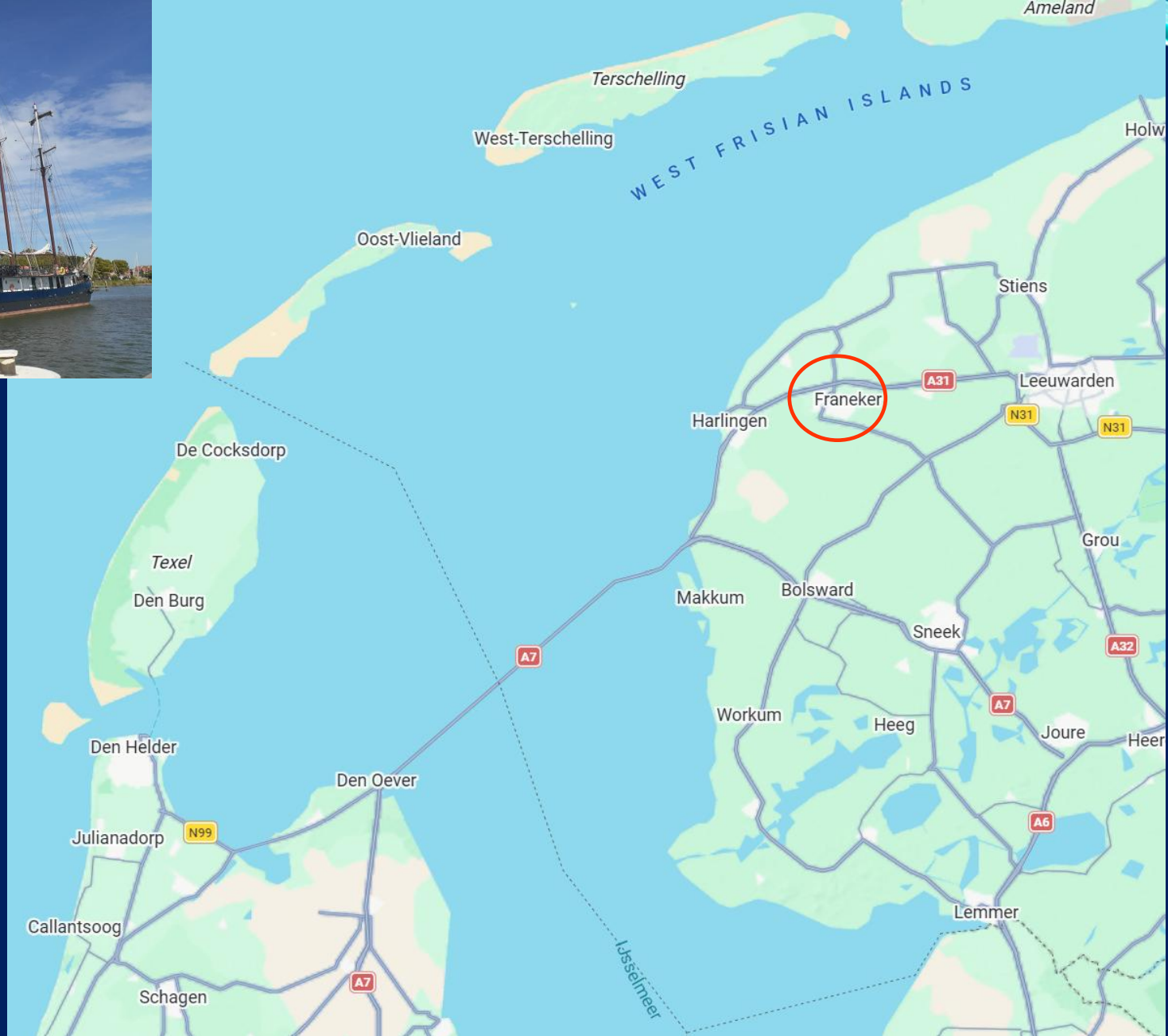
1911

1921

...

By Dr. Bernd Gross - Self-photographed,
<https://commons.wikimedia.org/w/index.php?curid=72106027>

The dates on the stones can be compared with historical records, tree-ring data and other climate records – as a way of cross-checking all these sources.





Eise Eisinga Planetarium, Franeker



The **Oort Cloud (or Öpik-Oort) Cloud** is a theorized spherical shell of icy bodies surrounding our solar system, located far beyond Pluto. It is believed to play a crucial role in supplying long-period comets that enter the inner solar system.

ifountains.nl

Jean-Michel Othoniel
De Oortwolk

NL

De Oortwolk

De fontein is een ode aan de wereldberoemde, yn Franeke geborene astronoom Jan Hendrik Oort. Zijn aanname dat zich rondom ons zonnestelsel een 'wolk' van miljarden komeetachtige objecten beweegt, betekende een doorbraak in de astronomie. De fontein is ontworpen als een reeks watervallen die vanuit een schaal langs een verticale ketting van nachtkleurige parels in het bassin stromen. Een van de parels is zilverkleurig, als de kleur van de maan, een ander is verguld, de kleur van de zon. 'De Oortwolk' zelf is een nevel van fijne druppeltjes die vanuit een goudkleurig gaaswerk in de schaal vallen.

krallen van RVS met zwart,
goud en zilver coating, gaaswerk
3,5 m hoog; schaal 1,5 m doorsnee;
bassin 3,8 m doorsnee

FRL

De Oortwolk

De fontein is in oade oan 'e wrâldberneamde, yn Frylantsjer berne, astronoom Jan Hendrik Oort. Syn ûnderstelling dat der om ús sinnestelsel hinne in 'wolk' fan miljarden komeetefrige objekten him beweecht, betsjutte in trochbraak yn 'e astronomy. De fontein is ûntwurpen as in rige wetterfallen dy't út in skaal by in fertikale ketting fan nachtkleurige pearls del yn it bassin streame. Ien fan dy pearls is sulverkleurich, lykas de kleur fan 'e moanne, in oar is fergulde, de kleur fan 'e sinne. 'De Oortwolk' sels is in dize fan fine driplets dy't út in goudkleurich gaaswurk yn 'e skaal falle.

krallen fan rustfrij stiel mei swart,
goud en silber coating, gaaswurk
3,5 m heech; skaal 1,5 m trochsnied;
wetterbassin 3,8 m trochsnied

EN

The Oort Cloud

The fountain is an ode to the world-famous astronomer Jan Hendrik Oort, who was born in Franeker. His assumption that a 'cloud' of billions of comet-like objects is moving around our solar system was a breakthrough in astronomy. The fountain is designed as a series of waterfalls that flow into the water basin from a bowl, along a vertical chain of night-coloured pearls. One of the pearls is silver-coloured, like the colour of the moon, another is gilded, the colour of the sun. 'The Oort Cloud' fountain itself is a mist of fine droplets falling from a gold-coloured mesh into the bowl.

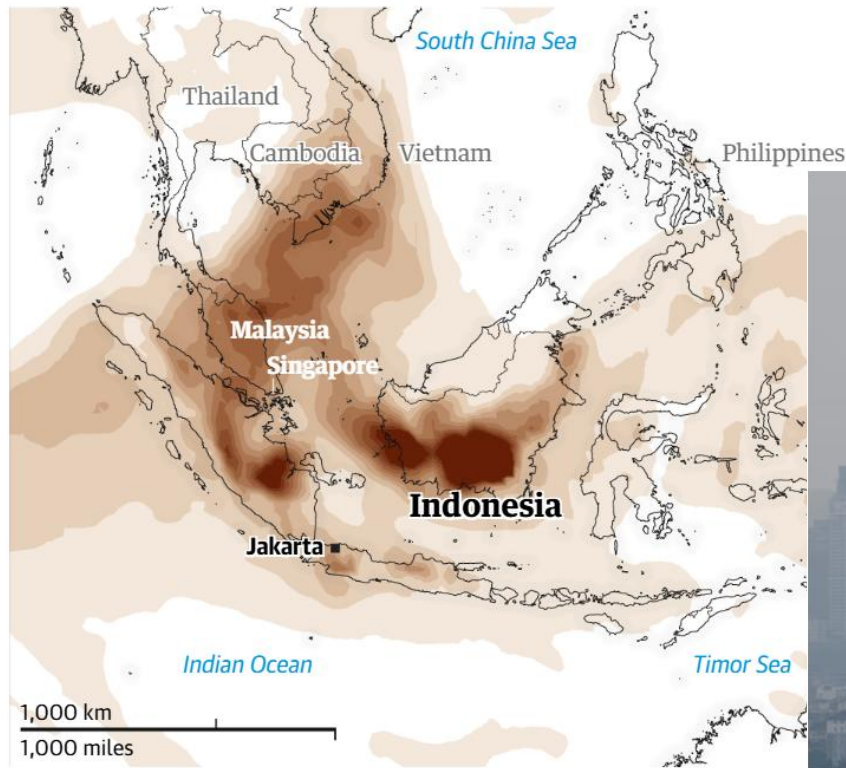
stainless steel beads with black,
gold and silver coating, wire mesh
3,5 m high; scale 1,5 m diameter;
water basin 3,8 m diameter

Indonesian wildfires spurred by super El Niño choke South-East Asia

Wildfire smoke forecast at 3pm on 15 September

Sunlight blocked by particles of smoke

Less  More

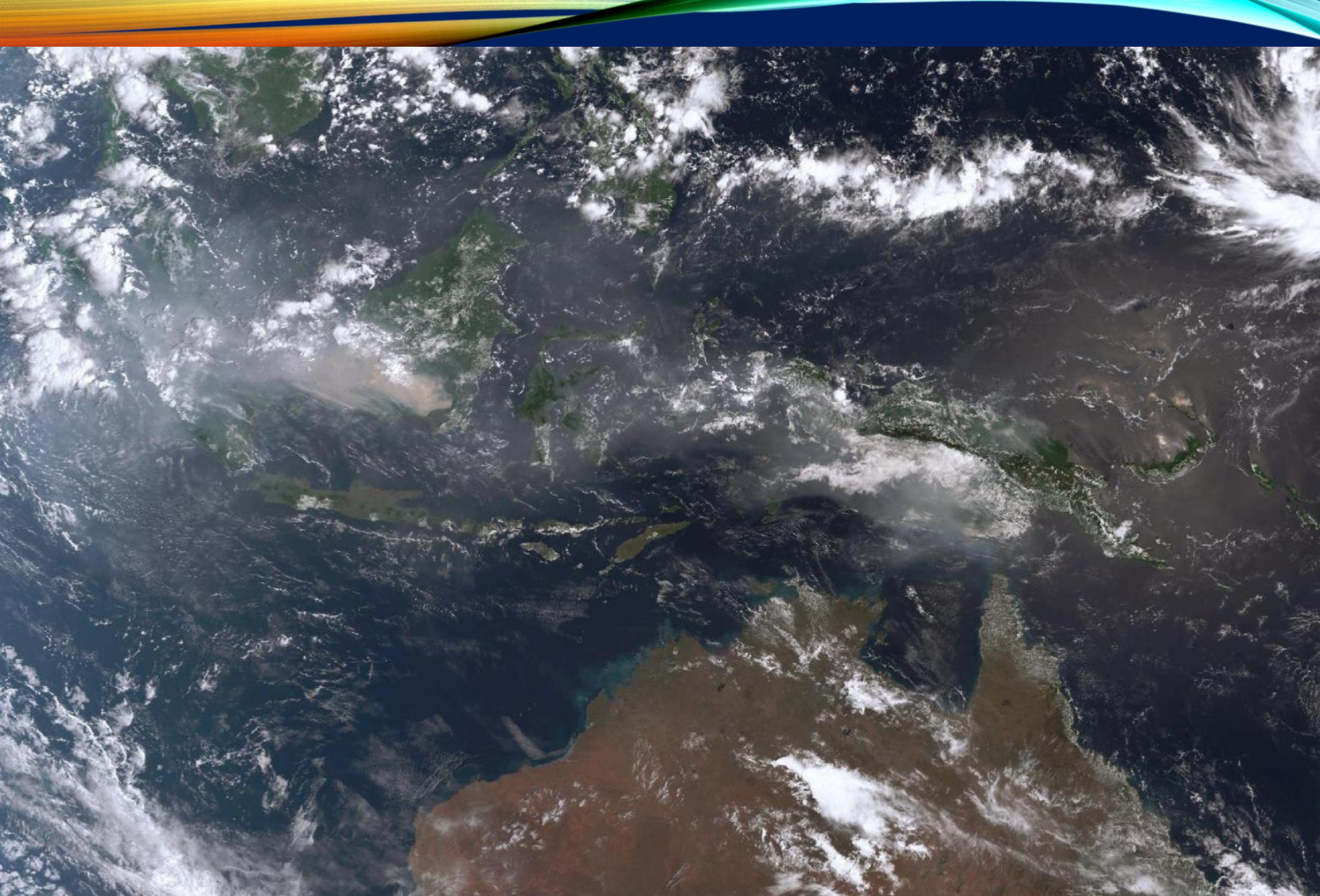


<https://www.theguardian.com/world/2026/sep/21/>

<https://www.abc.net.au/news/2026-09-07>



The distinctive Petronas Towers in Kuala Lumpur are barely visible behind the thick smog caused by Indonesia's fires.



Wednesday, 14 October 2026 12:00 pm AEDT

Slower — ◀ ▶ ⏸ + Faster

Frosty and dry conditions from El Niño create localised food shortages in PNG



By Alice Lolohea

By Natasha Emeck

El Niño

Posted 16 Sep 2026 at 5:36am



Locals say freezing nights followed by intense sunshine have destroyed crops. (*Mountain Mangii Photography*)

<https://www.abc.net.au/news/2026-09-16/frost-freezes-crops-in-png-as-el-nino-takes-hold>

Brings back memories of the good old days when a young Neville Nichols became interested in El Niño and an associated drought in PNG.

(Bruce Neal)



BUREAU OF METEOROLOGY
DEPARTMENT OF SCIENCE

WORKING PAPER 161

DROUGHT IN THE PAPUA NEW GUINEA HIGHLANDS
DURING THE PERIOD JUNE TO SEPTEMBER 1972

Staff Members, Synoptic Research Branch

DECEMBER 1972

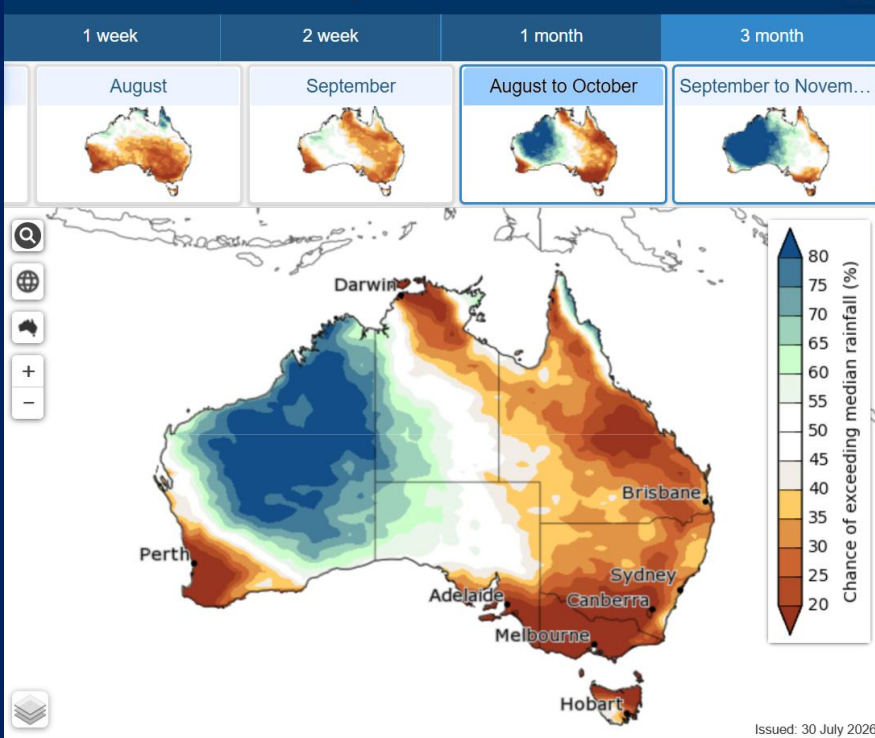
I presumably would have had a very different career if I hadn't been posted to Synoptic Research just before the 1972 PNG drought started, and the Bureau was instructed to investigate it. I was the youngest member of that group that included Henry Philpot, Peter Price, and Bruce Neal.

The drought was the catalyst for my interest in El Nino, of course.

*Neville Nicholls
Emeritus Professor
School of Earth, Atmosphere & Environment
Monash University*

Long-range forecast – back in July

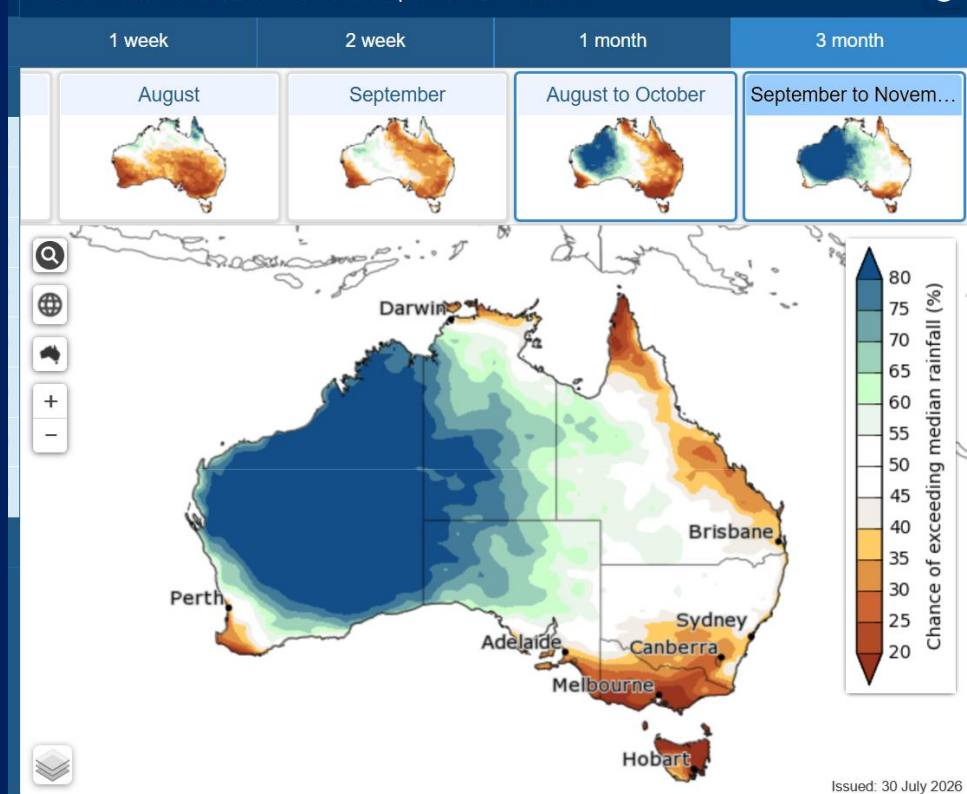
Rainfall – Chance of above median for August to October



**Rainfall – Chance of above median
September to November**

**Rainfall – Chance of above median
August to October**

Rainfall – Chance of above median for September to November



El Niño declared by BOM and it could become the strongest on record

By ABC meteorologist Tom Saunders

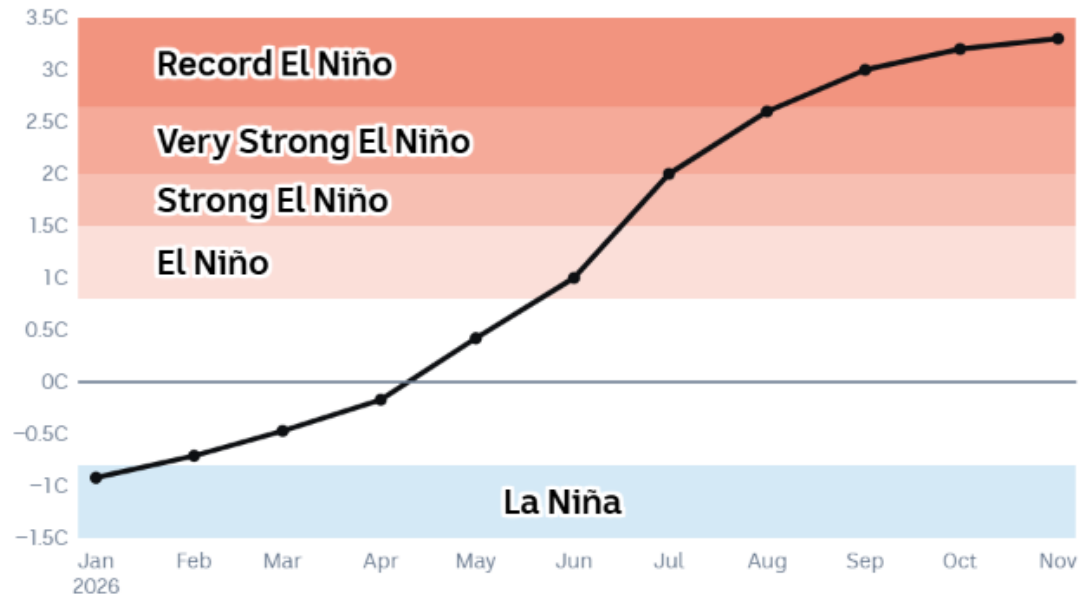
Weather Forecasts

4h ago

The BOM's seasonal model, called ACCESS-S, is tipping an all-time record later in the year with a peak warming in excess of 3C above normal, comfortably above the previous post-1900 high of 2.65C from November 1902.

NINO3.4 Analysis and Forecast

Analysis to June, ACCESS-S model from July



Forecast mean of 99 member ensemble

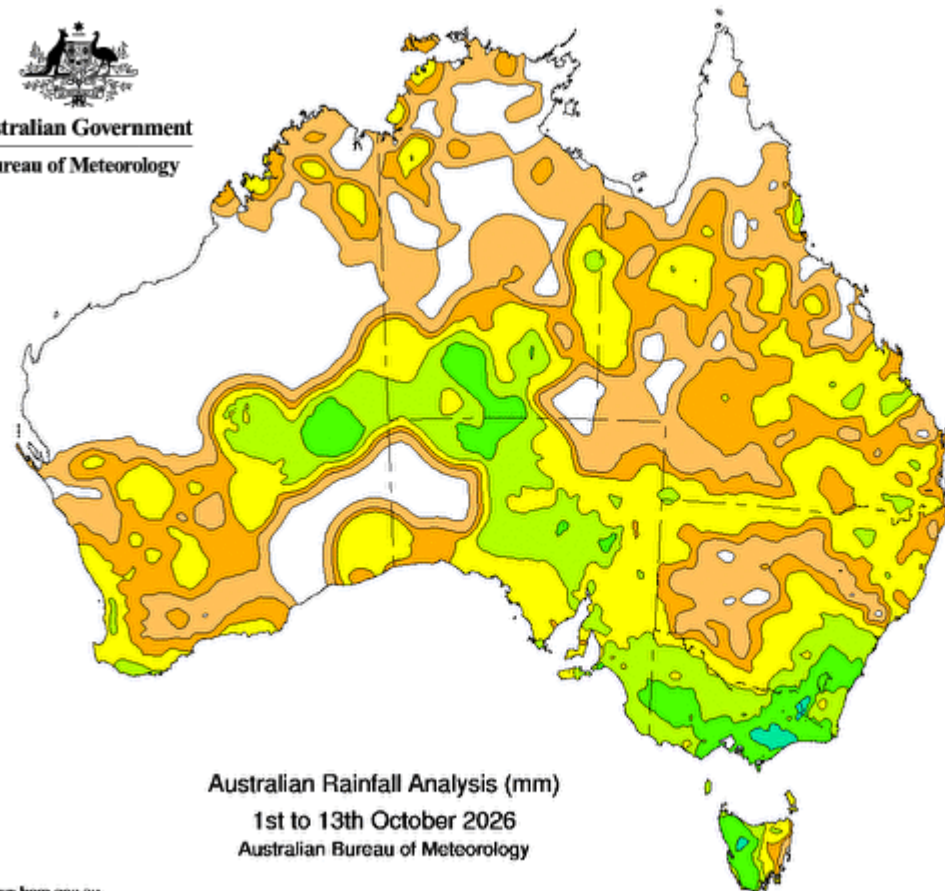
Source: BOM

Thankfully though for Australia, there is only a very weak relationship between the strength of the Pacific warm signal and the local impacts, so a record event does not mean a record drought.

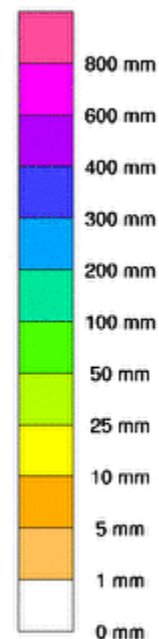
<https://www.abc.net.au/news/2026-06-16/nsw-bureau-of-meteorology-declares-el-nino-weather/106776598>



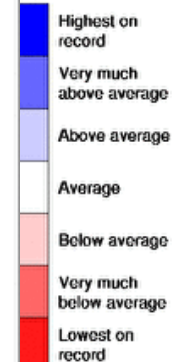
Australian Government
Bureau of Meteorology



Rainfall (mm)



Decile ranges



Australian Rainfall Analysis (mm)
1st to 13th October 2026
Australian Bureau of Meteorology

<http://www.bom.gov.au>

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Issued: 13/10/2026

Australian rainfall deciles
September 2026
Australian Gridded Climate Data

Base period: 1900—Sep 2026

© Commonwealth of Australia 2026, Bureau of Meteorology

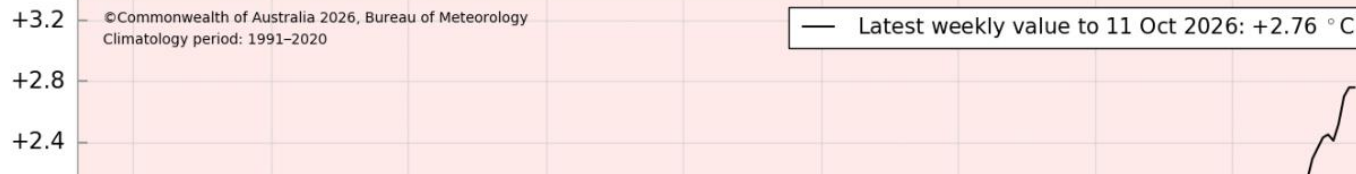
Dataset: AGCD v2

Issued: 30/09/2026

Base period: 1900—Sep 2026

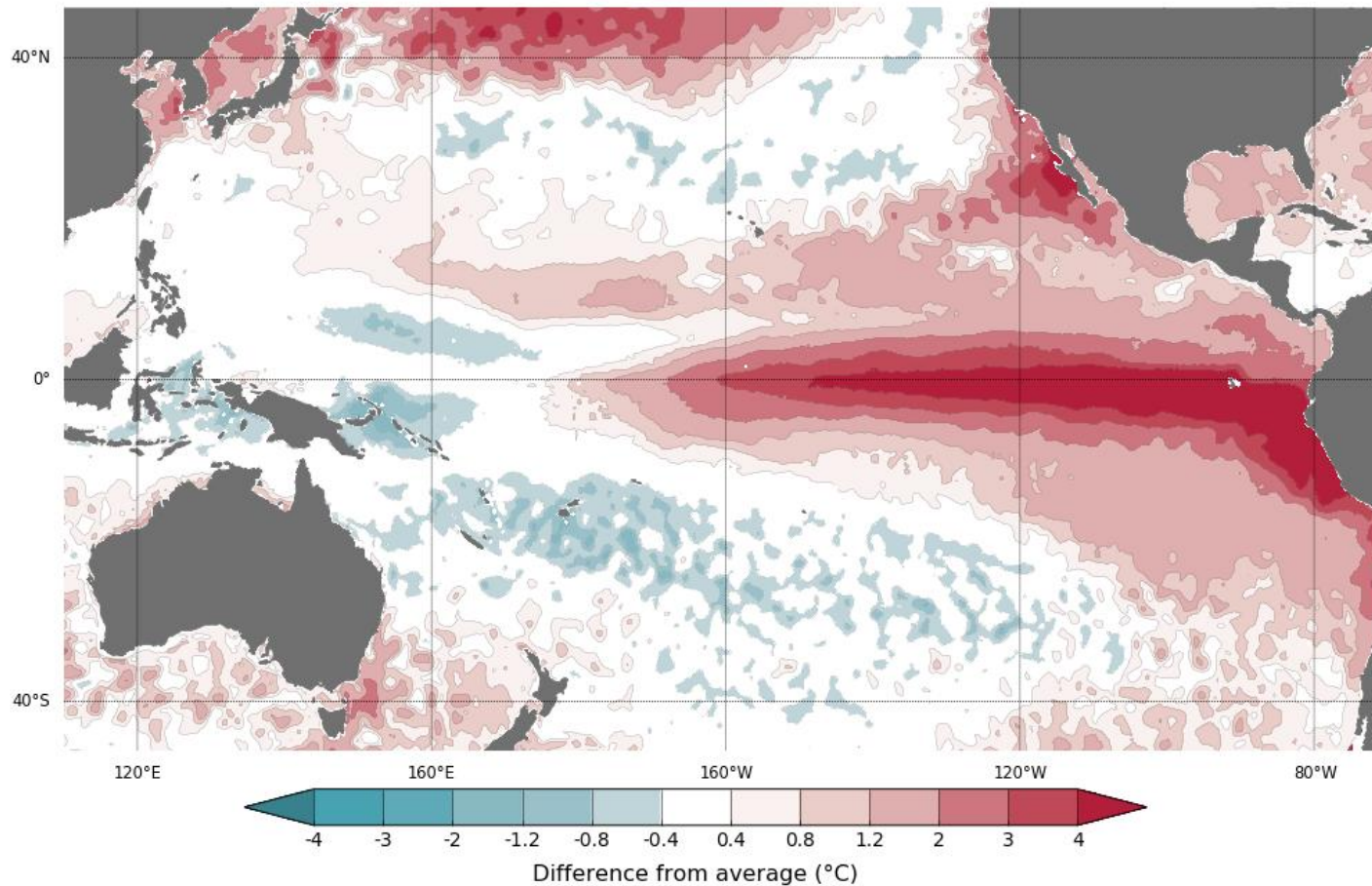
© Commonwealth of Australia 2026

Relative Niño3.4 index



Difference from average sea surface temperature observations
September 2026

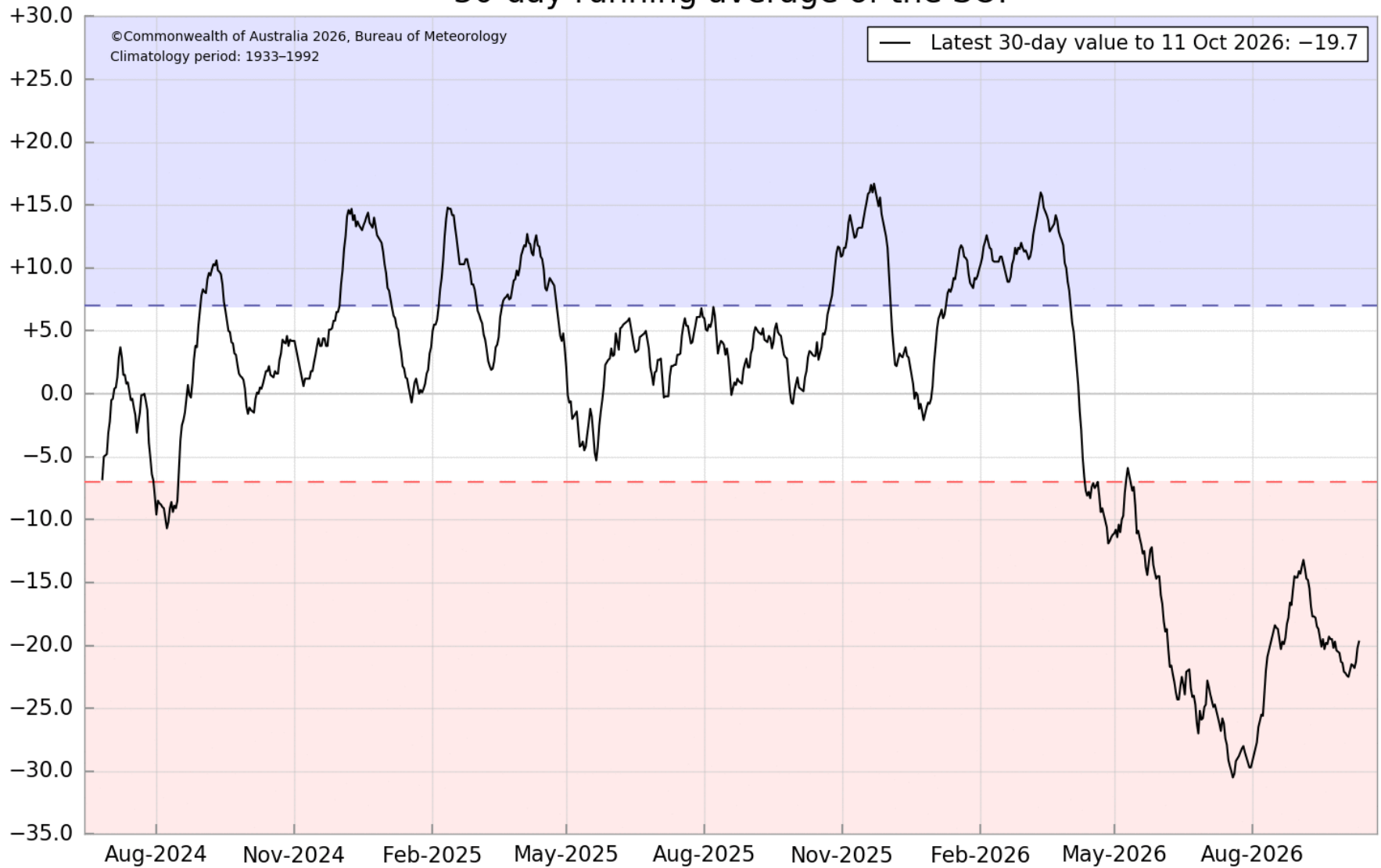
Relative Niño3.4 index (°C)



Data: GAMSSA SST
Climatology baseline: 1991 to 2020
© Commonwealth of Australia 2026, Australian Bureau of Meteorology

Monthly average: September 2026
Created: 12/10/2026
<http://www.bom.gov.au/climate>

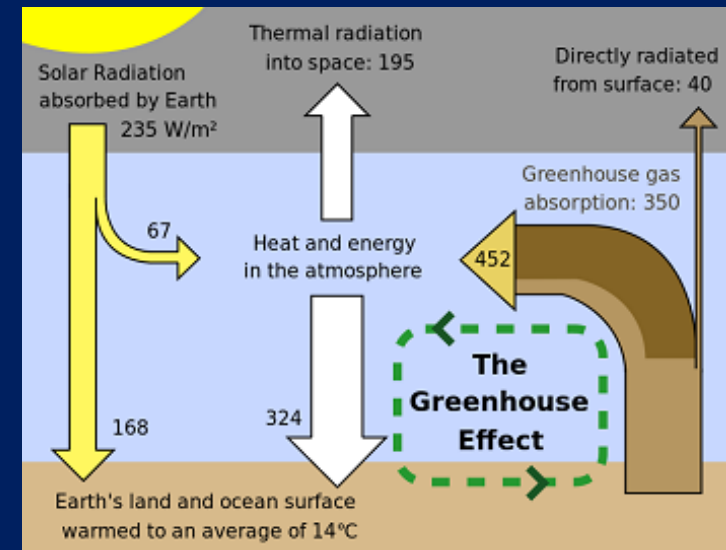
30-day running average of the SOI



The first mathematical model of the climate

Swedish chemist, **Svante Arrhenius**, wanted to understand if changes in carbon dioxide were factors in triggering glacial and interglacial periods. He invented a tool that is now widely used – a **mathematical model of the climate**.

- based on the energy budget of the atmosphere (energy coming in from the sun, and the energy emitted from the earth and atmosphere back to space).

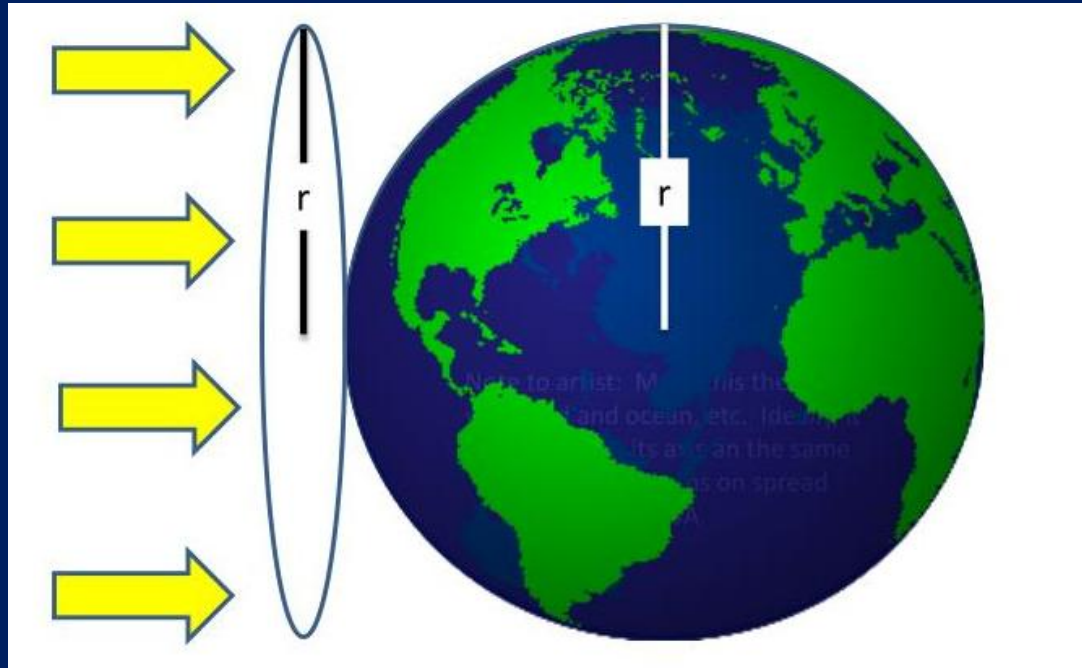


Despite a lack of knowledge about the properties of carbon dioxide in the atmosphere, Arrhenius's pioneering work was groundbreaking, and his concepts were used in the more advanced models that were developed from the 1960s.



The **very simplest** Climate Model – based on the Energy Budget.

- The earth receives energy from the sun - what we call **sunlight** – at a rate of 1366 Watts per square metre (averaged over the year).
- This is called the Solar Constant (S)



- The total energy coming into a disc (of radius r) is: $\pi r^2 \times S$
- However, about 30% of the sunlight is reflected back to space (the earth's *albedo*), so the energy coming in from the sun is actually: $\pi r^2 \times 0.7 \times S$

- The energy coming in from the sun heats up the earth – land, ocean and atmosphere – and that heat is re-radiated back to space as infrared energy.
- Assume that the earth is just a solid mass and that the energy from the sun is spread evenly over the surface.
- In pioneering work at the end of the 19th century the Stefan-Boltzmann law for the energy emitted per square metre by an object like the earth is in proportion to the 4th power of its absolute temperature (Kelvin scale, not Celsius).
- So, the energy emitted by the earth is: $4 \pi r^2 \sigma T^4$
(T is the temperature of the earth and σ is known as the Stefan-Boltzmann constant with the value $\sigma = 5.67 \times 10^{-8}$ Watts per square metre per Kelvin⁴).
- The outgoing and incoming energy have to be in balance (or close to it) – otherwise there would be big temperature changes – so we end up with the equation: $\pi r^2 \times 0.7 \times S = 4 \pi r^2 \sigma T^4$
- This can be simplified to: $0.7 \times S = 4 \times \sigma \times T^4$

- Putting in the numbers our simple model gives a value for the temperature of the earth as : **254.8 K or -18.3°C**
- The **actual** surface temperature of the earth is **15°C or 288 K**.
- So this suggests that there is a problem somewhere in the model:
 - Unlikely to be in the incoming energy from the sun
 - It is more likely that the **effective temperature** for the earth's radiation to space is less than the surface temperature.
 - This implies that some of the heat from the earth's surface is being blocked by the atmosphere.



Told you so!!

Messrs Fourier and Pouillet
(1820 – 1830s)

The simple model has some uses:

- Gives an idea of the overall effect of the atmosphere
- Can be used to conduct sensitivity tests:
 - Impact of changes in the incoming sunlight (e.g. volcanoes)
 - Expected temperature change if the effect of the atmosphere were different.

The model can also be extended:

- Divide Earth into latitude bands to represent how solar energy varies between equator and poles.
 - Ice-albedo feedback can be included
 - It can show how heat is moved from warm equatorial regions to cold polar areas through atmospheric winds and ocean currents.
- Represent the earth by a single column but with many atmospheric layers (*Radiative convective models*). They can calculate temperature and humidity at various atmospheric layers and explore the effect of greenhouse gases.

These have all been important, but the most common tools now are General Circulation Models (GCMs) that are simulations of the whole atmosphere-earth-ocean system.

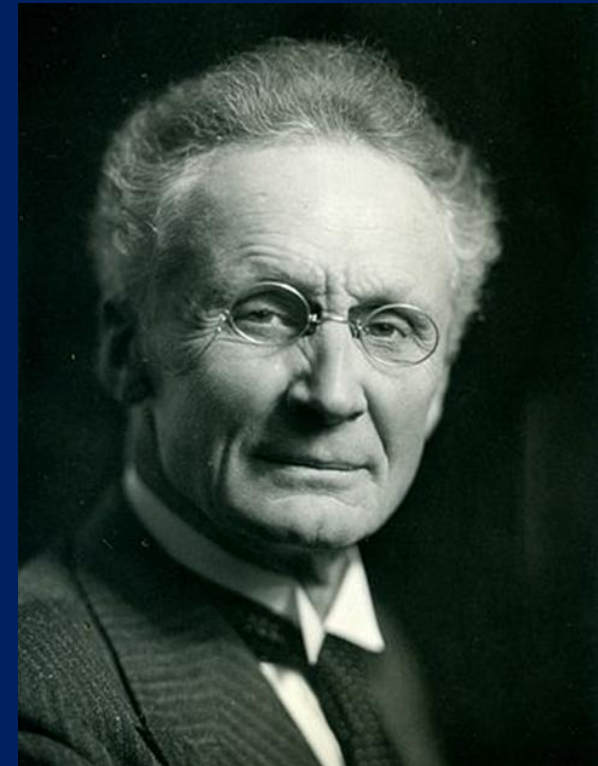
The foundation for these GCMs came from Weather Forecasting.

Some major developments for meteorology in the 1800s:

- Formulation of mathematical equations that describe the flow of fluids, called the *Navier-Stokes equations*, and also Thermodynamics.
- The invention and deployment of the telegraph allowed real-time exchange of weather data internationally.
- A major organisation studying weather was the Bergen School of Meteorology in Norway, founded by Vilhelm Bjerknes (1862-1951). His son Jacob (1897-1975) was part of the team.
- Very influential in establishing the modern practice of weather forecasting.

They aimed:

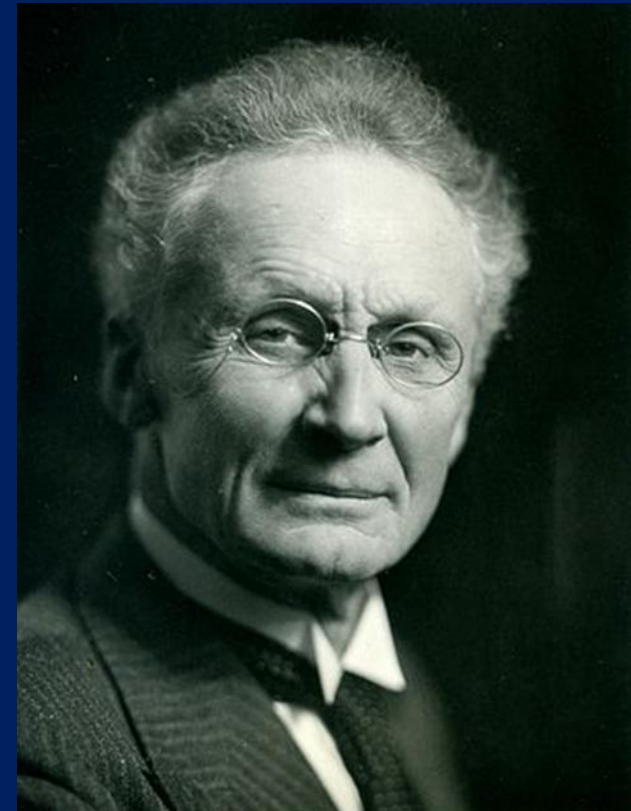
- to develop the mathematical equations that apply to the atmosphere using **fluid dynamics** and **thermodynamics**
- use these equations to make mathematical predictions of the weather based on systematic data analysis.



Bjerknes established the equations that are now used in computer weather prediction but due to their complexity he had no way of applying these equations except qualitatively and conceptually.

They did work out that rain and thunderstorms tended to form in lines and introduced the concept of the “front”. (during World War 1)

Remember – there were no satellite images, or radar, so their work was based solely on weather maps using weather reports transmitted by telegraph.



Equations of the atmosphere:

1. How the wind will change as a result of all the forces acting on it such as:

- Pressure differences
- Coriolis force
- Gravity
- Friction. *(Basically, Newton's Second Law on a sphere)*

2. How the local temperature will change due to effects such as:

- Incoming wind bringing air with different temperature
- Cooling of air by expansion or compression
- Effects of incoming sunlight or outgoing infrared energy
- Condensation/evaporation, conduction.

3. How temperature, pressure and density are connected.

(Ideal Gas Law)

4. The total amount of air has to stay constant (“continuity equation” or conservation of mass)

5. Water vapour budget - rainfall, evaporation and changes in water vapour amount.

$$\frac{du}{dt} - \left(f + u \frac{\tan \phi}{a} \right) v = -\frac{1}{a \cos \phi} \frac{1}{\rho} \frac{\partial p}{\partial \lambda} + F_\lambda$$

$$\frac{dv}{dt} + \left(f + u \frac{\tan \phi}{a} \right) u = -\frac{1}{\rho a} \frac{\partial p}{\partial \phi} + F_\phi$$

momentum

$$g = -\frac{1}{\rho} \frac{\partial p}{\partial z}$$

$$\frac{\partial \rho}{\partial t} = -\frac{1}{a \cos \phi} \left[\frac{\partial}{\partial \lambda} (\rho u) + \frac{\partial}{\partial \phi} (\rho v \cos \phi) \right] - \frac{\partial}{\partial z} (\rho w)$$

mass

$$C_p \frac{dT}{dt} - \frac{1}{\rho} \frac{dp}{dt} = Q$$

energy

$$p = \rho R T$$

equation of state

u – east-west component of wind
 v – north-south component of wind
 p – pressure
 T – temperature
 λ – longitude
 φ – latitude

These terms show how the
 property will evolve with time
 – if you know the starting
 point (initial value).

Lewis Fry Richardson (1881 – 1953)

Pioneer of Numerical Weather Prediction

- 1913 - in charge of the UK Met Office's Eskdalemuir observatory, Scotland
- started developing ideas on weather forecasting using mathematical methods
- a Quaker and pacifist, he was a conscientious objector during World War I
- 1916 - joined the Friends' Ambulance Unit driving ambulances in Ypres
- attempted the first-ever numerical forecast - a past case for Central Europe, using published weather data, such as temperature, pressure and wind speed
- the calculations took him more than six weeks to produce a six-hour forecast for just one location ...
- ... and it was very inaccurate predicting a pressure change of 145 hPa (actual change about 1 hPa)
- After the war he continued to develop his theories and rejoined the Met Office but resigned again when the Met Office became part of the Air Ministry.
- In 1922, published his now famous book, *Weather Prediction by Numerical Process*.
- (During the war, a draft of his book was sent away from the frontline for safe keeping but was lost until rediscovered months later under a heap of coal.)



Perhaps some day in the dim future it
will be possible to advance the
computations faster than the weather
advances and at a cost less than the
saving to mankind due to the
information gained. But that is a dream.

— Lewis Fry Richardson —

AZ QUOTES

There had been big advances in the development of computers during WW2. The first successful numerical prediction was performed using the ENIAC digital computer in 1950 by a team led by American meteorologist Jule Charney and mathematician John von Neumann.

These first calculations for a 24-hour forecast **still took ENIAC nearly 24 hours to produce.**

1950 –Richardson received news of this weather forecast by the first modern computer – *“an enormous scientific advance”*.

Weather Prediction by Numerical Process

Second Edition

Lewis Fry Richardson

Cambridge Mathematical Library

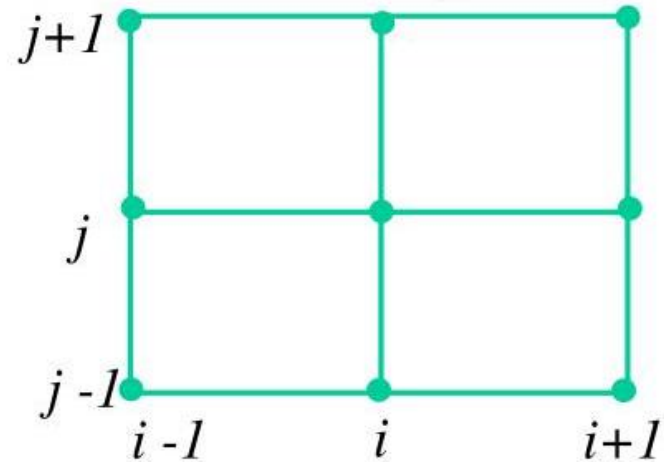
Finite Difference Method – Example

- Consider Poisson's equation.

$$\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + g = 0$$

- Discretise

$$\frac{u_{i+1,j} - 2u_{i,j} + u_{i-1,j}}{\Delta x^2} + \frac{u_{i,j+1} - 2u_{i,j} + u_{i,j-1}}{\Delta y^2} + g = 0$$



- The atmosphere is broken up into boxes, and the results are an average over the box
- This involves some smoothing
- As computing power increases, the boxes can be made smaller and the numerical model made more complex.



Figure 1. A schematic showing grid points, both horizontal and vertical, at which calculations are made in a numerical prediction model of the atmosphere. (Source: Bureau of Meteorology)

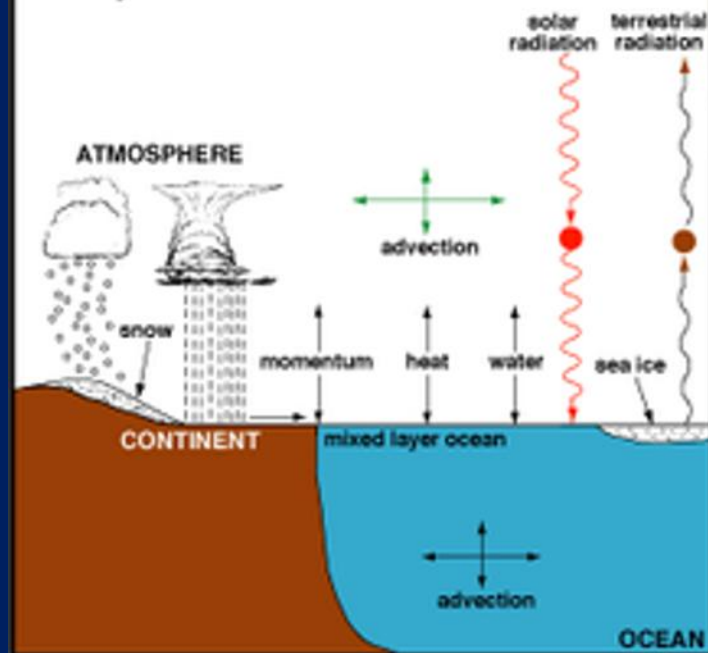
As computing power has increased the density of grid points and the number of levels in the vertical can be increased.

Note: in the vertical the models have to account for mountains.

Horizontal Grid
(Latitude-Longitude)

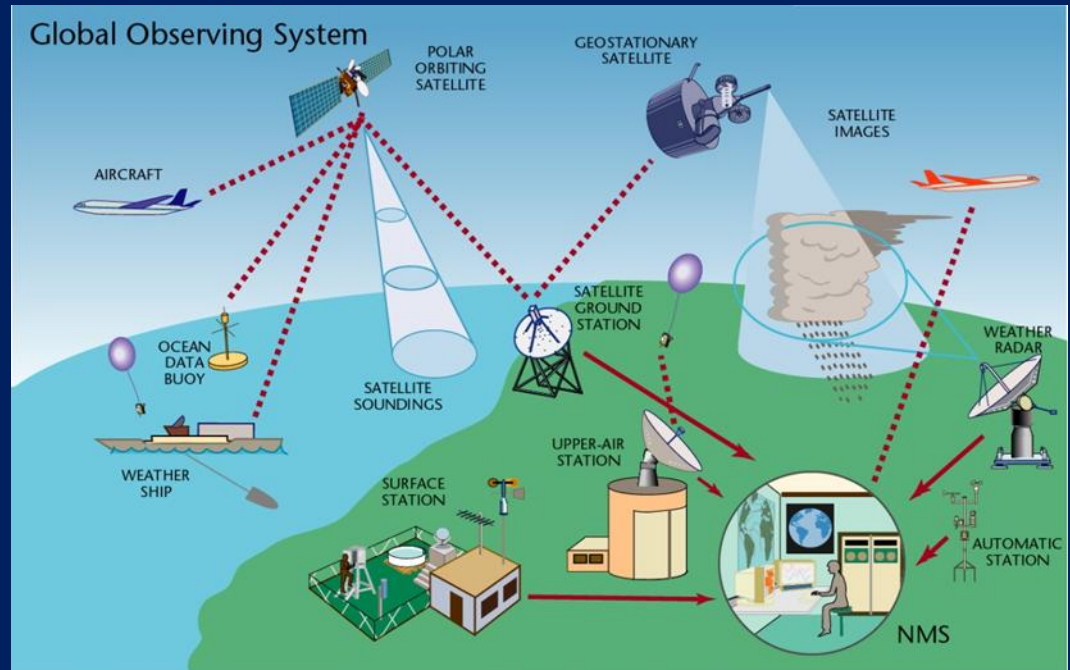
Vertical Grid
(Height or Pressure)

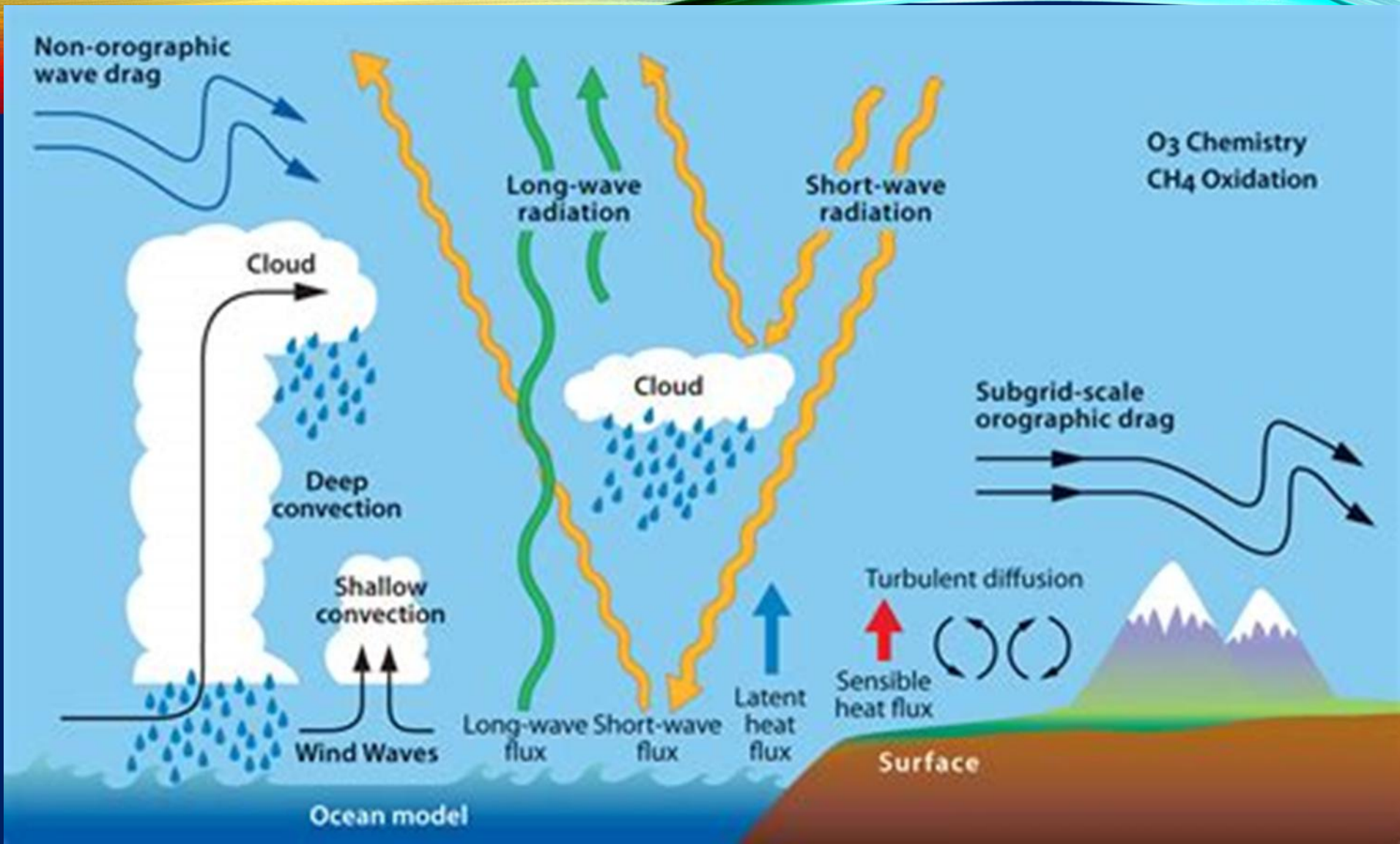
Physical Processes in a Model



Computer Weather Prediction (or Numerical Weather Prediction)

- We have equations that tell how things will change in the atmosphere (e.g. Vilhelm Bjerknes), **but we need to know what the atmosphere looks like to start with.**
- Importance of weather observations and analysis
- Like seeing a doctor – analysis before prognosis and treatment





Typical atmospheric processes modelled in a computer weather prediction model

As weather prediction models became established, especially in the northern hemisphere, during the 1950s and 1960s, attention turned to using these tools for climate modelling also.

What is the difference between weather and climate models?

At their core they both have the same set of equations describing fluid dynamics, physical processes, etc.

Weather prediction models are used to underpin weather forecasts and warnings and focus on the shorter-term outlooks.

Climate models need more detail on aspects that will affect the long term – such as more details on the ocean. They are long term averages and so do not rely so much on the starting point.

The focus of Climate models:

- Longer term
- Ask “what if” questions or scenarios
- Can be used to explore the past also.

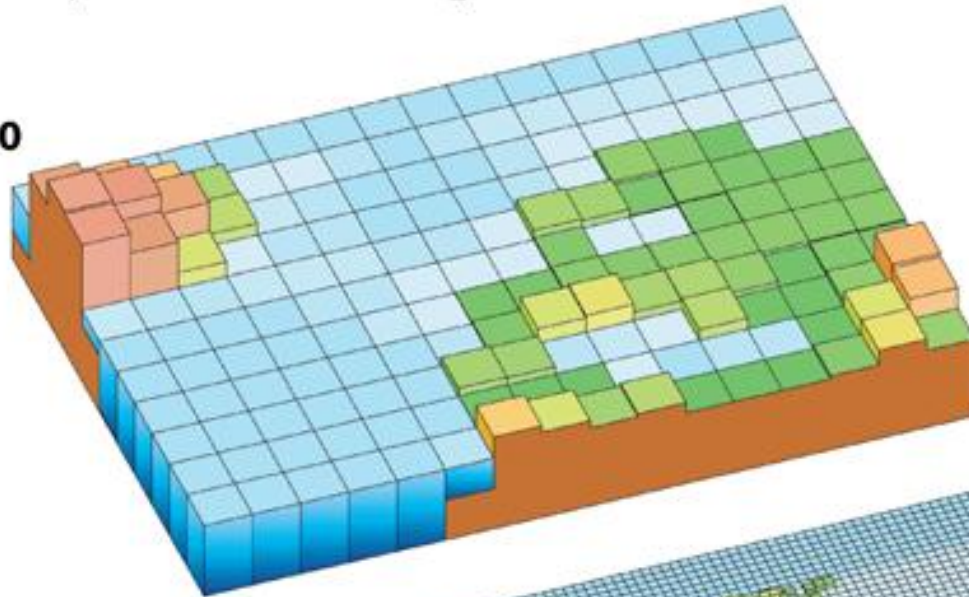
Major differences between weather and climate models.

Weather models	Climate models
aims to predict in detail out to only about 10 days into the future	may want to simulate conditions hundreds of years ahead or go back in time and describe past climates.
try to predict details such as the <i>when</i> and <i>where</i> of a storm or front.	has weather systems, but the focus is on looking for average conditions.
e.g. a weather model aims to predict where a tropical cyclone is, and when/where it will impact land	Concerned more about the average number of hurricanes per year and not about the details of those storms.
as accurate a starting analysis as possible, using all available weather observations.	Research on making sure the computer model accurately describes the current climate
Runs at the highest spatial resolution possible with the computing resources that allow it to produce a forecast in time for it to be useful	Needs to run forward its forecast for many years so it may need to run at lower spatial resolution
To save computing time it may omit some physical processes that are not important on a short time scale (such as the deep ocean)	To improve their simulations are constantly adding more physical processes (ocean, atmospheric chemistry)

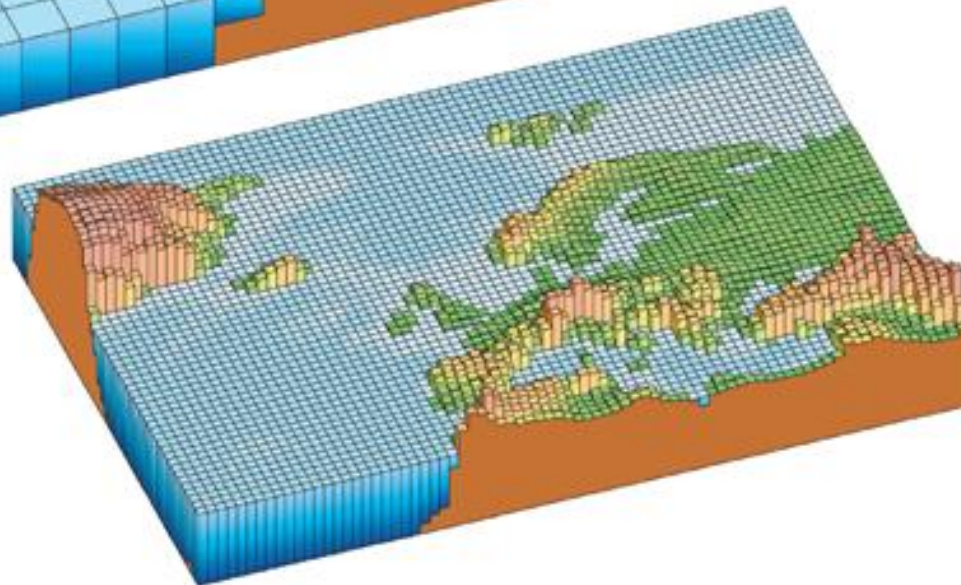
The Difference Resolution Makes

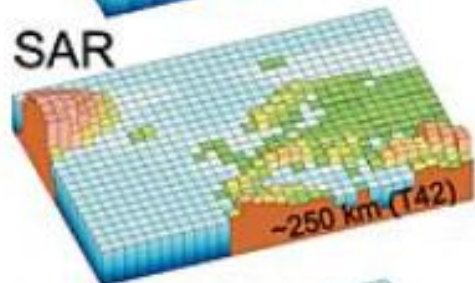
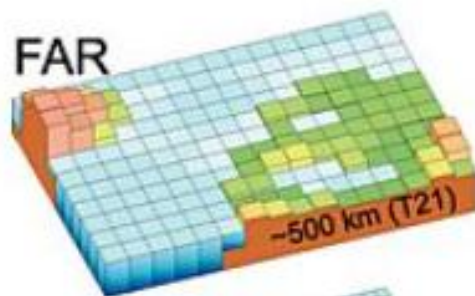
From the first Intergovernmental Panel on Climate Change (IPCC) report in 1990 to the fourth assessment in 2007, the resolution of climate modeling improved significantly, allowing scientists to get a more detailed picture of climate changes.

1990

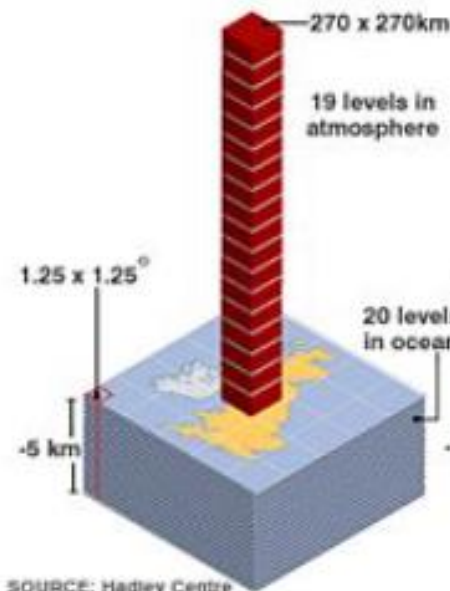


2007

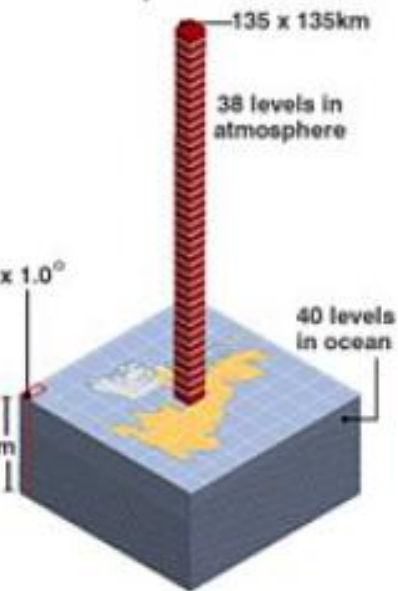




PROGRESSION OF CLIMATE MODELS
1990s



Present day



SOURCE: Hadley Centre

AR5: ~70km maximum horizontal resolution; up to 90 layers in the atmosphere and over 60 in the ocean.

The World in Global Climate Models

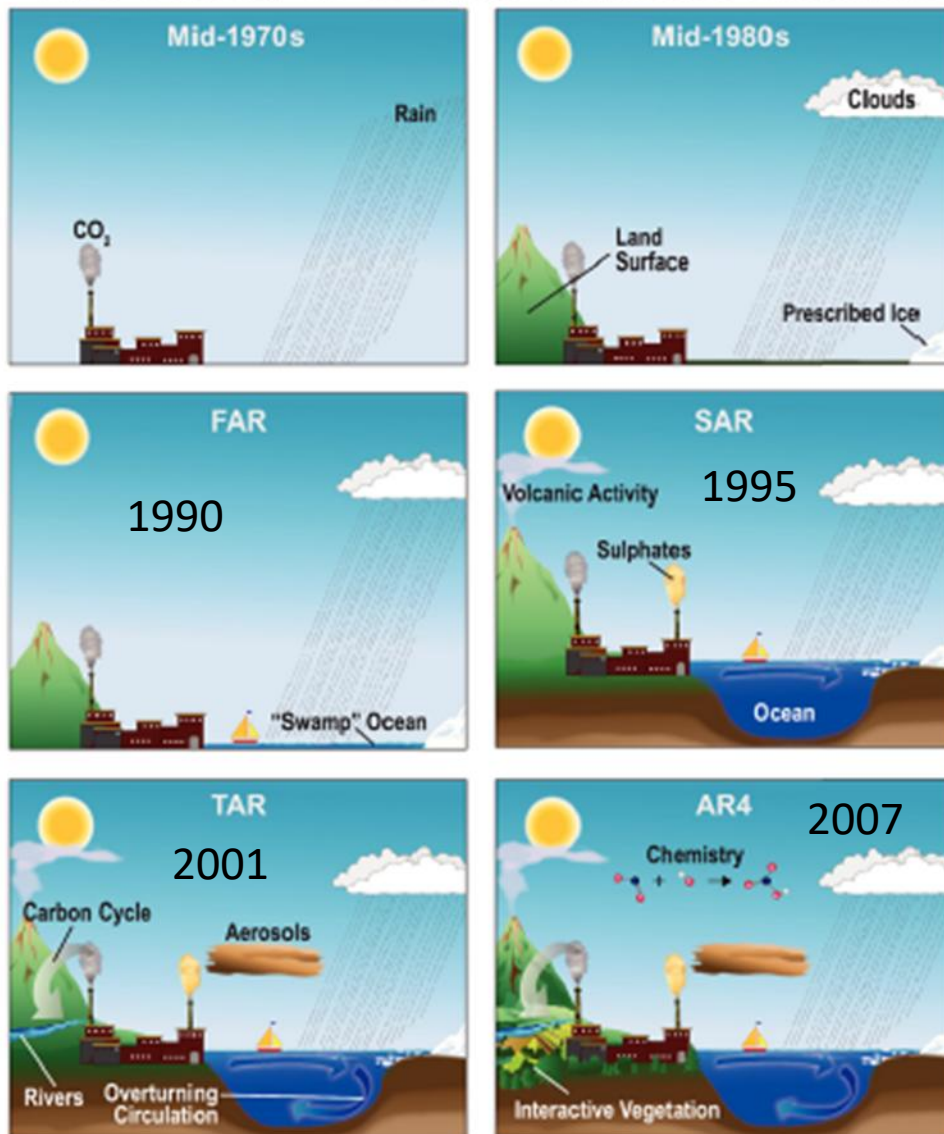


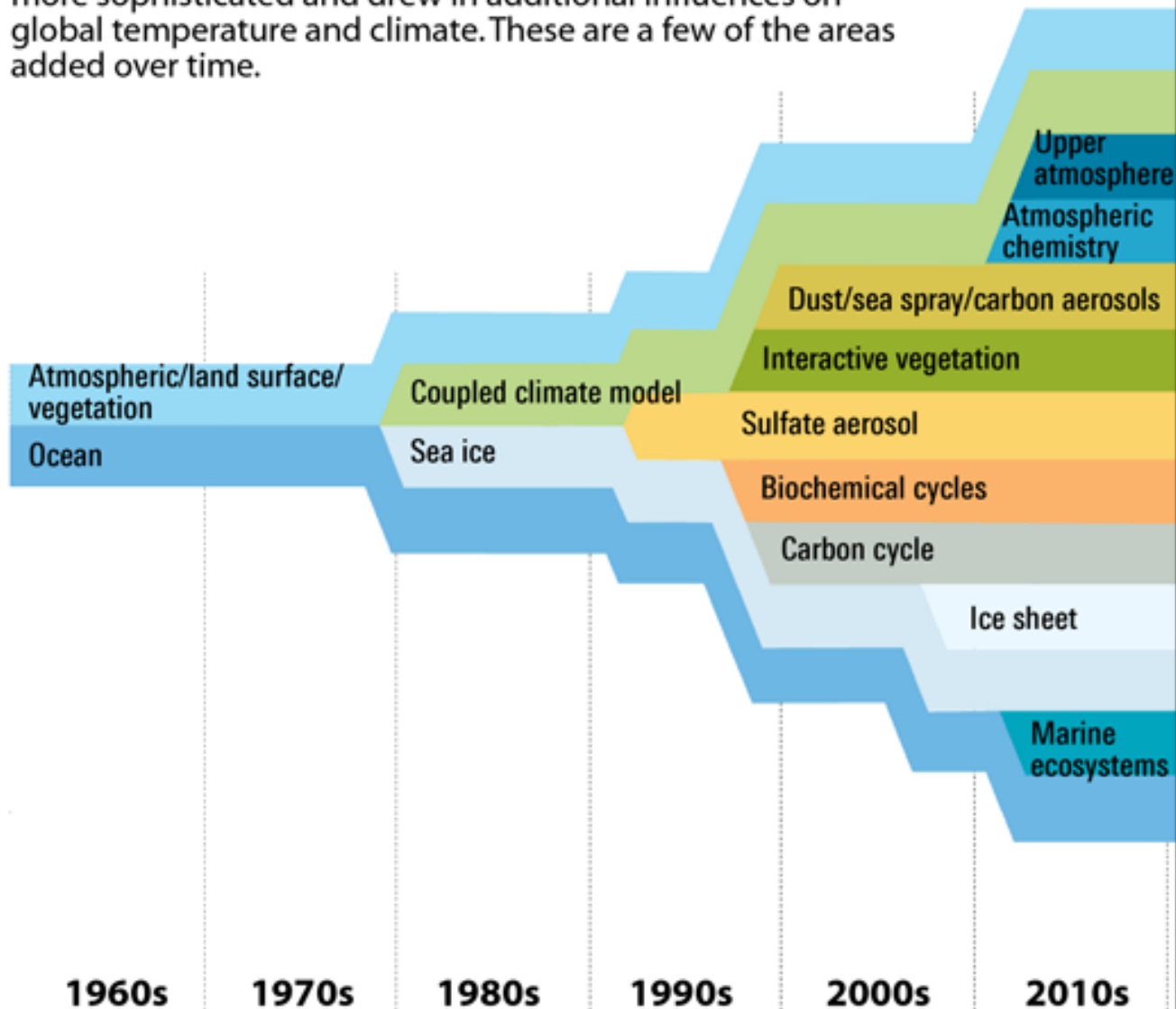
Illustration of the processes added to global climate models over the decades, from the mid-1970s, through the first four IPCC assessment reports: first ("FAR") published in 1990, second ("SAR") in 1995, third ("TAR") in 2001 and fourth ("AR4") in 2007. (Note, there is also a fifth report, which was completed in 2014). Source: IPCC AR4, Fig 1.2 (https://www.ipcc.ch/publications_and_data/ar4/wg1/en/figure-1-2.html)

More and more natural processes have been included in models over time and as extra computing power has made possible.



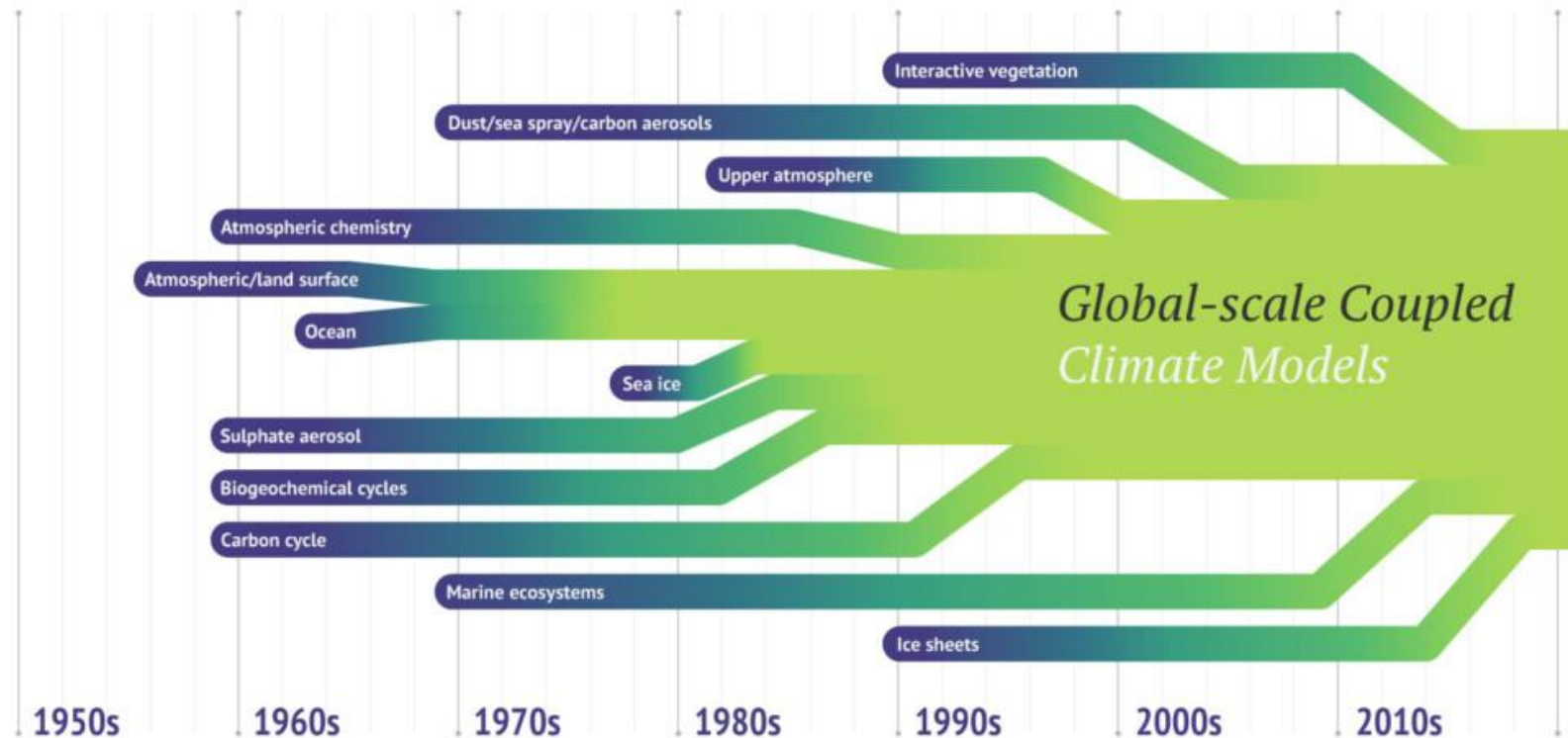
Growth of Climate Modeling

As computing power expanded, climate modeling became more sophisticated and drew in additional influences on global temperature and climate. These are a few of the areas added over time.



Climate models

For decades scientists have been using **mathematical models** to help us learn more about the Earth's climate. Known as climate models, they are driven by the fundamental physics of the atmosphere and oceans, and the cycling of chemicals between living things and their environment. Over time they have increased in complexity, as separate components have merged to form **coupled systems**.



Note: There were some very simplified models before the dates mentioned.

CarbonBrief
CLEAR ON CLIMATE

<https://www.carbonbrief.org/qa-how-do-climate-models-work>

Current resolution of some global models

ECMWF

137 levels in the vertical

Equivalent horizontal grid spacing of 9 km (effective equatorial wavelength of 31 km) T1279

US GFS

127 levels 13 km

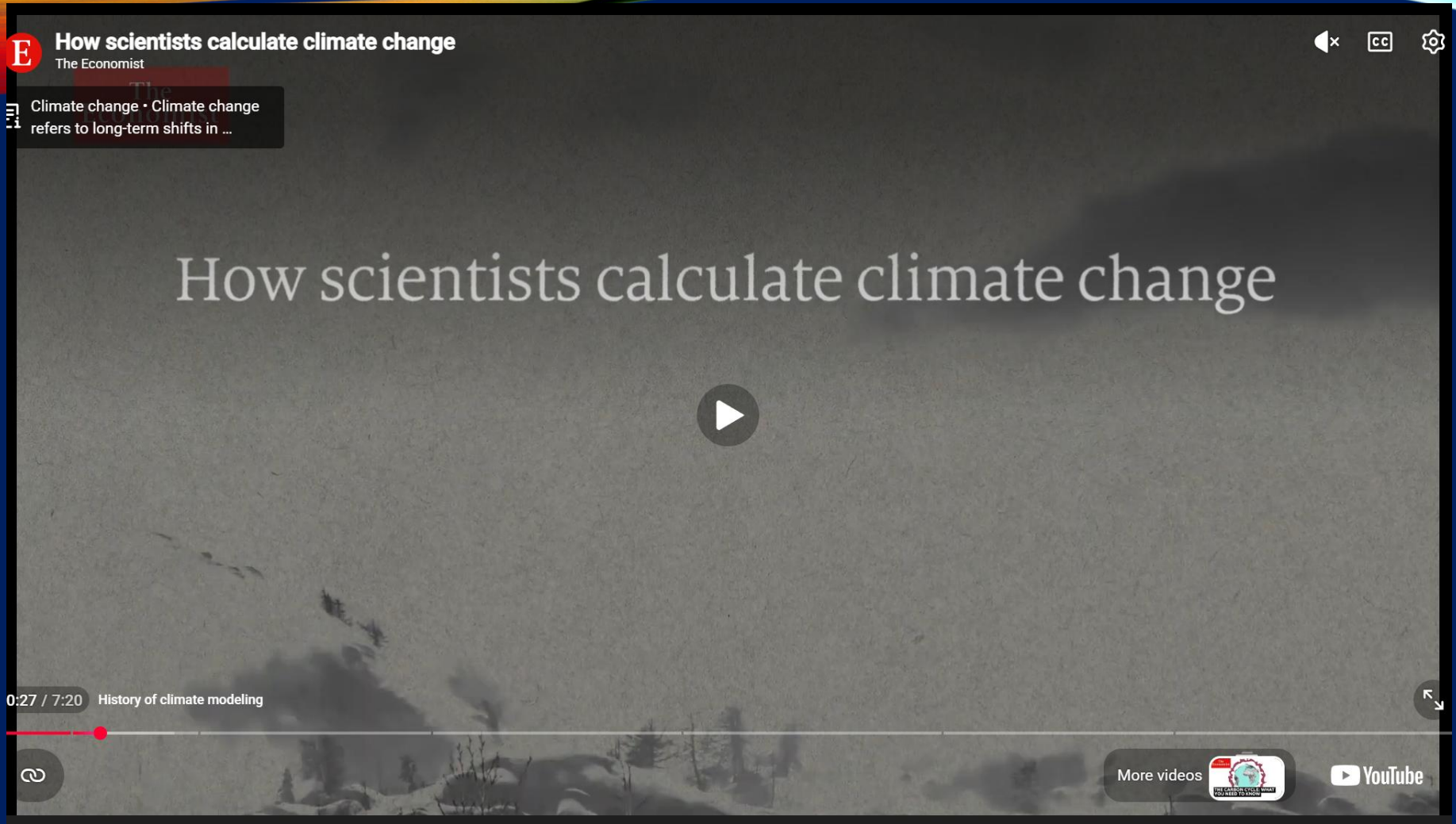
https://www.emc.ncep.noaa.gov/emc/pages/numerical_forecast_systems/gfs.php

Typical climate model resolutions:

6th IPCC Assessment (2023) typically 100 – 200 km with some high-resolution models with finer grids of 25 to 50 km

7th IPCC Assessment – starting now

Likely to be 80 – 140 km typically with some higher resolution.



A good video on climate modelling from the Economist journal (2020)

<https://www.youtube.com/watch?v=fSGorwtY-zM>

Some useful links

<https://www.climatechangeinaustralia.gov.au/en/learning-support/climate-models/>

<https://youtu.be/toCFqOGVs54>

<https://www.climatechangeinaustralia.gov.au/en/learning-support/modelling-and-projections/>

<https://www.climate.gov/maps-data/climate-data-primer/predicting-climate/climate-models>