Machine Learning for Climate Change

Prof: Grace Lindsay

Outline for today

- Course Information
- Introductions and informal poll
- Lecture: Intro to Climate Science

Course Logistics

Full syllabus is on Brightspace

Time/Place:

11 AM to 12:15 PM on Tuesdays and Thursdays

Class Location: CDS, 60 5th Ave, Room 110

Lab: 11:15 AM -12:05 PM Fridays

<u>Office hours</u>
With Max: room 763 at CDS and on zoom, Wednesdays 10-11 AM
With Grace: 601 CDS or zoom, by appointment

Course Overview

This is an Advanced Topics course on applications of machine learning to help mitigate and adapt to climate change.

You should walk away from this course with:

- A better understanding of the problem of climate change & potential solutions
- Knowledge of the many roles data science & machine learning can play here
- Confidence and skill to read academic ML papers and seek out new datasets

Evaluation

Weekly Brightspace discussion questions (10%)
Four programming assignments (40%)
In-class midterm (20%)
Final Project (30%)

Students will have 3 “grace days” they can use through the semester that will allow them to turn in assignments late. They can be used all together (allowing a single assignment to be 3 days late) or separately. Once the grace days are used, late assignments will not be accepted. Grace days cannot be used for the final project.

Course Schedule

1. Overview of Course/Intro to Climate Science
2. Overview of the problem of Climate Change
   First assignment given
3. Energy Efficiency - Optimal building design
4. Energy Efficiency - Managing power supply and demand
5. Monitoring GHGs - Methane detection
6. Monitoring GHGs - Transportation
   Second assignment given
7. Food Production - Sustainable farming
8. Food Production - Reducing food waste
9. Alternative Energy Sources - Designing better solar panels
10. Alternative Energy Sources - Accelerating nuclear fission
    Third assignment given
11. Carbon Dioxide Removal - Accelerating materials science
12. Carbon Dioxide Removal - Optimizing biology
13. Midterm Review/ Project Description
    Project proposal assignment given
14. Midterm
    SPRING BREAK
15. Catalyzing Change - Financing in a net-zero economy
16. Catalyzing Change - Influencing people/policy
17. Project Plan Presentations
18. Career Day
19. Better Predictions - Augmenting earth system models
20. Better Predictions - Predicting extreme weather events
    Fourth assignment given
21. Disaster Response - Surveying wildfires
22. Disaster Response - Search and rescue with robots
23. Food Security - Predicting food shortages
24. Food Security - Automated Farming
25. Climate Migration - Tracking human movements
26. Project work day
27. Project Presentations
28. Project Presentations

Lecture Structure

- Reminder of assignments/due dates
- Climate Change in the news
- Recap of previous lecture
- Introduction to the day’s topic
- Overview of how machine learning can be applied
- Deep dive into a paper applying ML to the day’s topic
- Summary

Informal poll

Are you comfortable with...

python

jupyter notebook

pandas

scikit-learn

matplotlib/seaborn

reading academic ML papers

climate change topics

Introductions

Alex Steffen, Climate Writer - *The Snap Forward*

“We don’t get to choose whether the context of all our work is an unprecedented, all-encompassing planetary crisis. It simply is. There is nowhere to stand outside of it. We can pretend that’s not true — insist that our lives or work or special concerns will remain untouched by ecological catastrophe and societal upheaval — but in the long run, we’re just fooling ourselves.”

“You’re not ready for what’s coming.

You’re also not alone in your unreadiness.

I increasingly think *none* of us are ready. We’re not ready for the depth of planetary crisis we already find ourselves in, and completely unprepared for what's on the way.

Here’s the biggest way we’re not ready: We’re trying to understand an unprecedented future with the worldviews of an older age, formed on a different planet. We’re working with slightly broken brains.”

Intro to Climate Science

Assignments

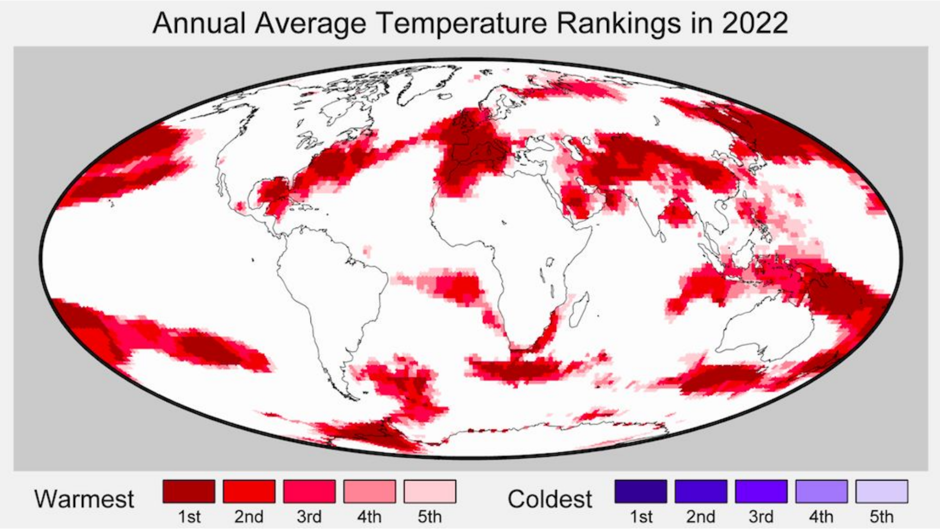
Brightspace discussion question:

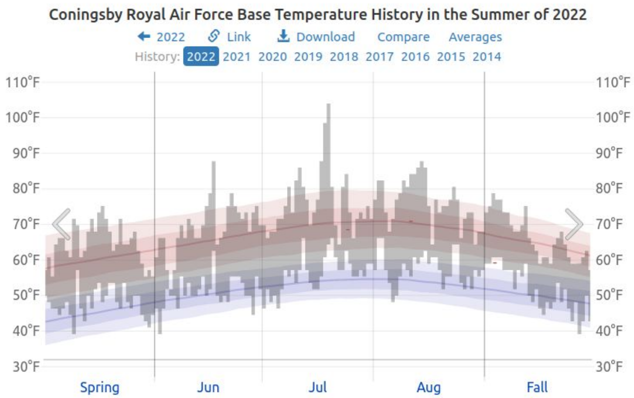
“What year are you in and what do you want to do after graduation?”

Due Friday by 5pm.

Climate change in the news

CarbonBrief
CLEAR ON CLIMATE





The daily range of reported temperatures (gray bars) and 24-hour highs (red ticks) and lows (blue ticks), placed over the daily average high (faint red line) and low (faint blue line) temperature, with 25th to 75th and 10th to 90th percentile bands.

Intro to Climate Science outline

- What is climate?
- Atmosphere
- Water
- Carbon
- Energy
- Historical climate
- Modern climate

What is climate?

The statistical description in terms of the mean and variability of relevant variables such as temperature, precipitation, and wind over a period ranging from months to thousands or millions of years. *-ACS*

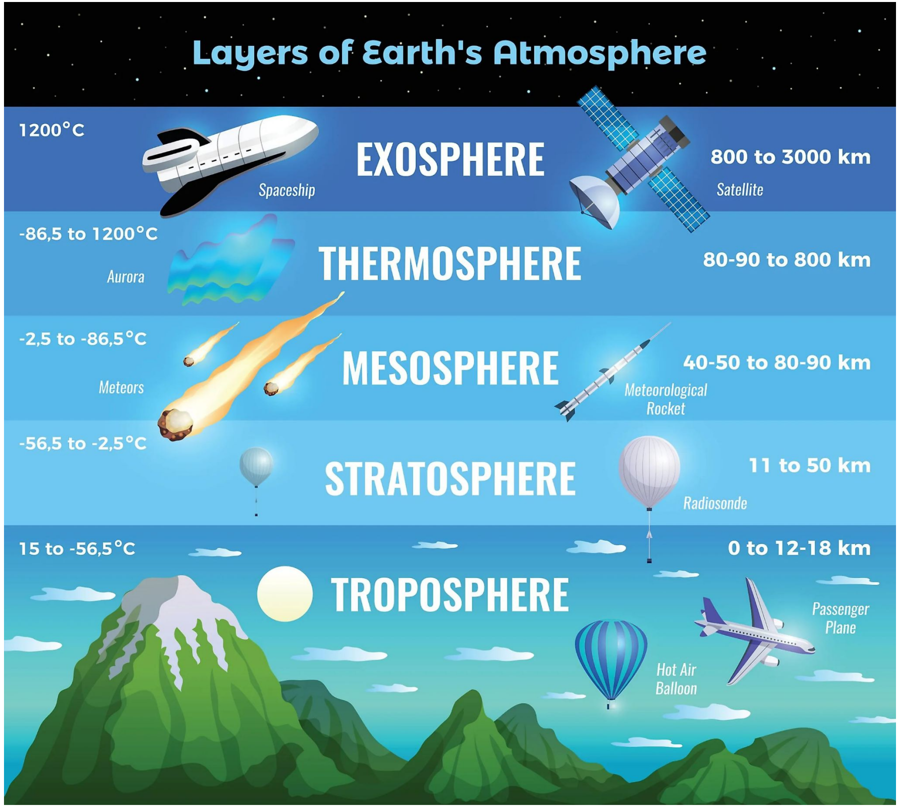
These variables are the result of complex interactions between the atmosphere, water, and land features.

Credit: Adam Sébire / Climate Visuals

Credit:David Gilbert / RAN

Atmosphere

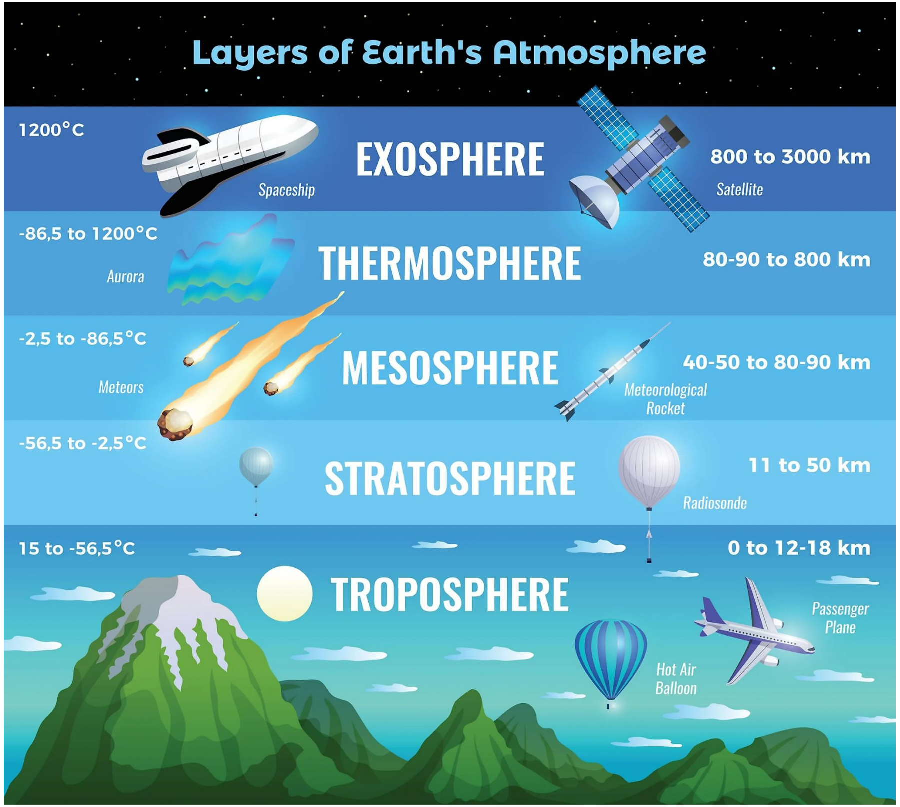
Troposphere: Almost all clouds are in the troposphere, and 99% of the water that vaporizes from earth's surface is found here. Temperature and oxygen levels decrease with increasing altitude.



World Atlas

Atmosphere

Stratosphere: Contains ozone layer, which converts ultraviolet light to heat. This causes temperature to increase with altitude within the stratosphere.

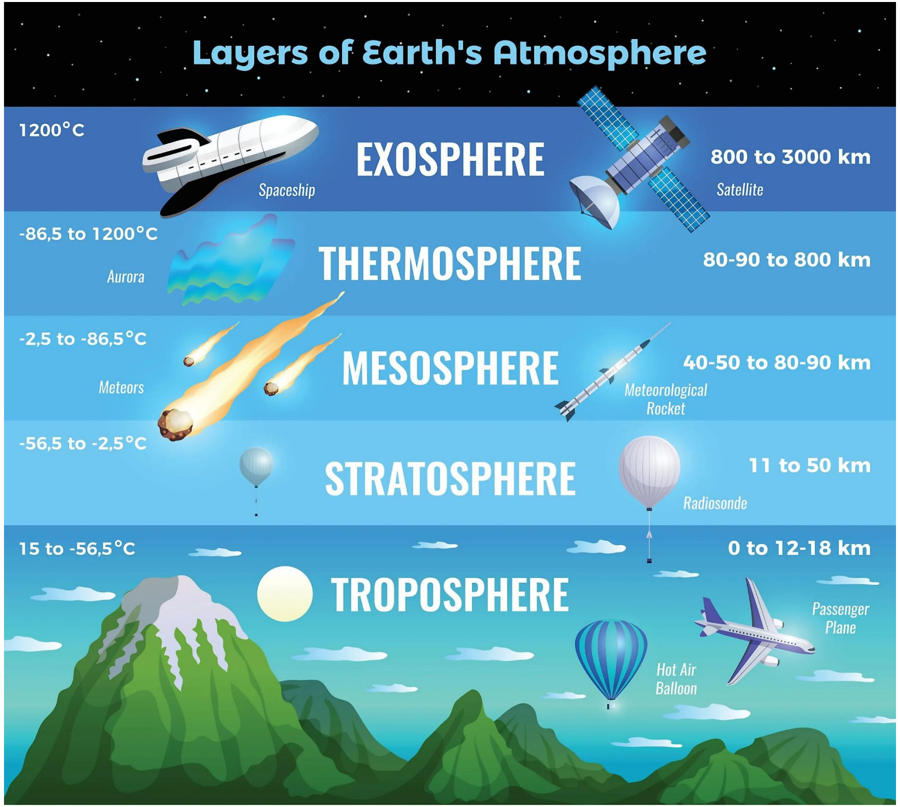


Atmosphere

Mesosphere: coldest layer

Thermosphere: X-ray and UV radiation causes the ionosphere and makes this layer hot

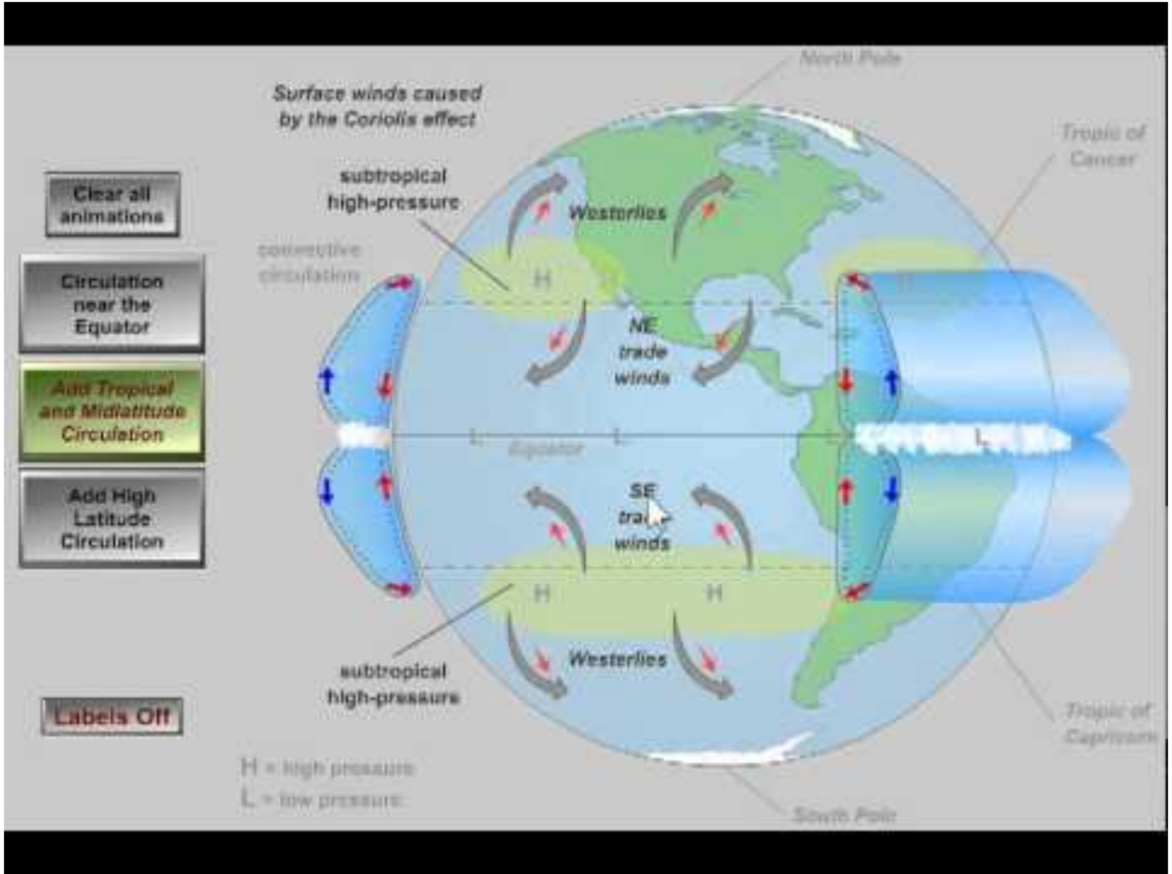
Exosphere: Almost not the atmosphere



World Atlas

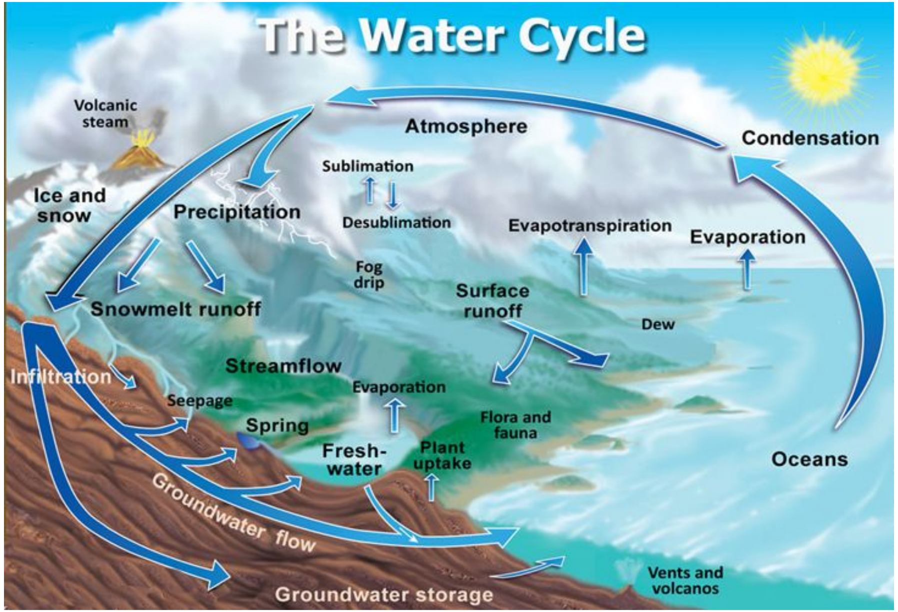
Atmospheric circulation

Heat from the sun along with the Earth's rotation determine the dominant flows of circulation on the planet



Water

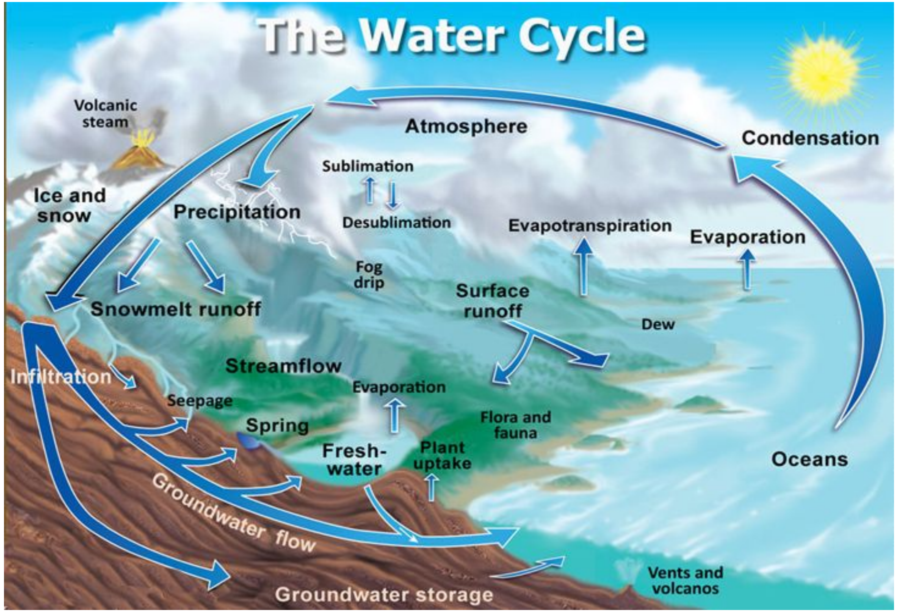
- Energy from the sun heats bodies of water, causing evaporation whereby water vapor enters the atmosphere
- Water can also enter the atmosphere directly from snow and ice and from plants
- Colder temperatures in the upper atmosphere cause condensation of water vapor (clouds)



NMSU/USGS

Water

- Regions of low pressure (as determined by atmospheric circulation) can cause lower temperatures and increased precipitation
- Water can remained stored in snow or ice
- Runoff can return to rivers and oceans or enter the ground

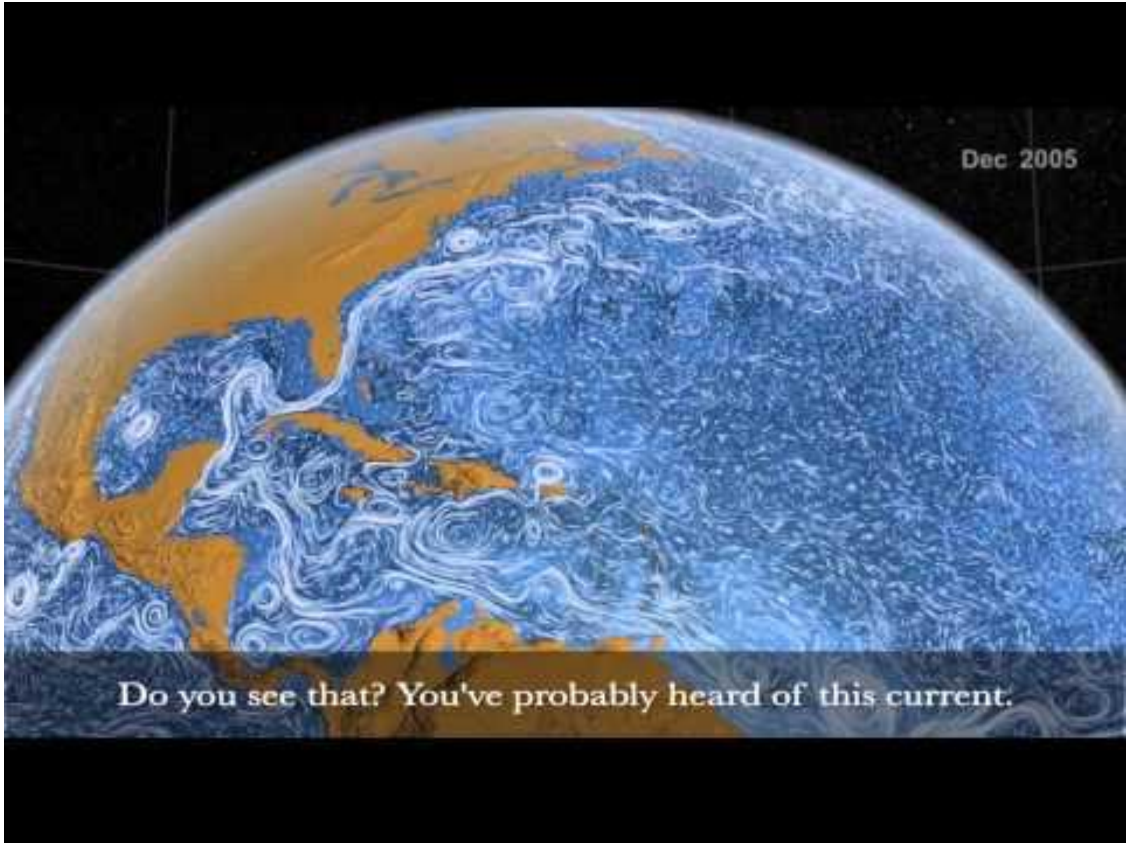


NMSU/USGS

Ocean currents

Currents arise from 3 main forces:

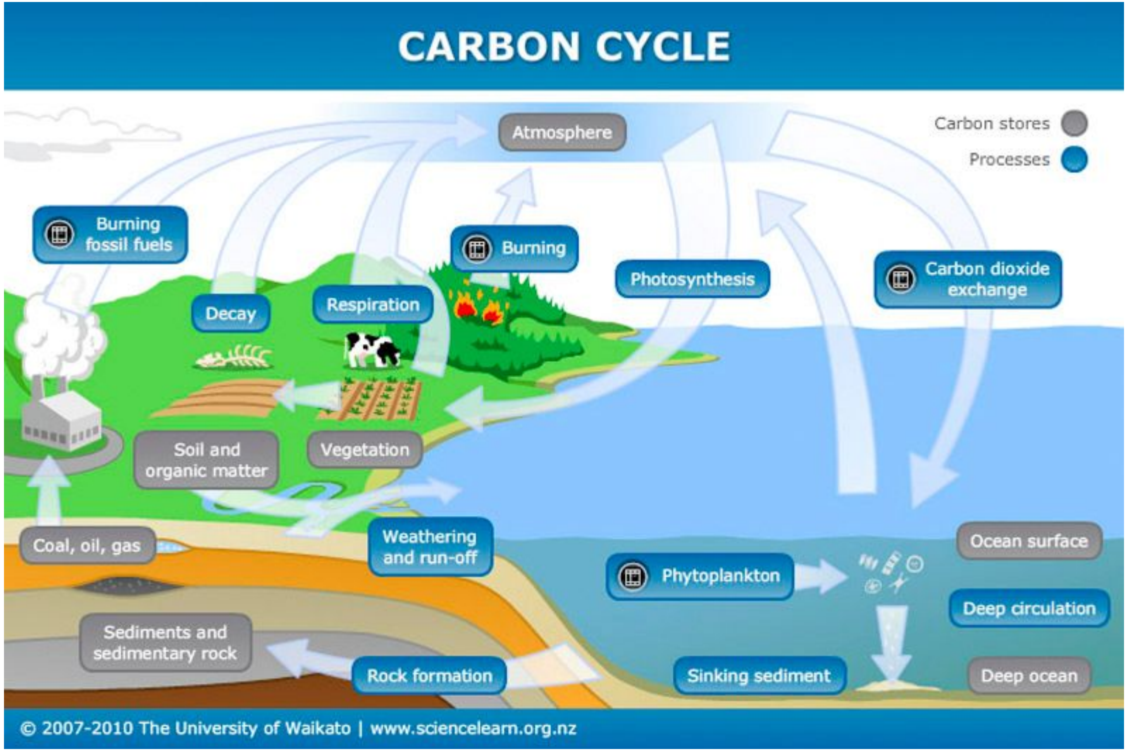
1. Tides
2. Wind
3. Thermohaline effect



Carbon cycle

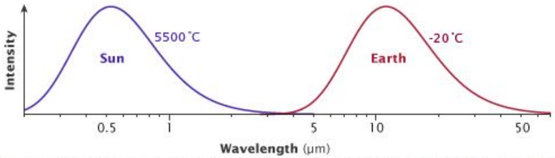
Carbon can be stored in the land, ocean, and atmosphere.

Both biological and abiological processes can convert carbon between different stores.

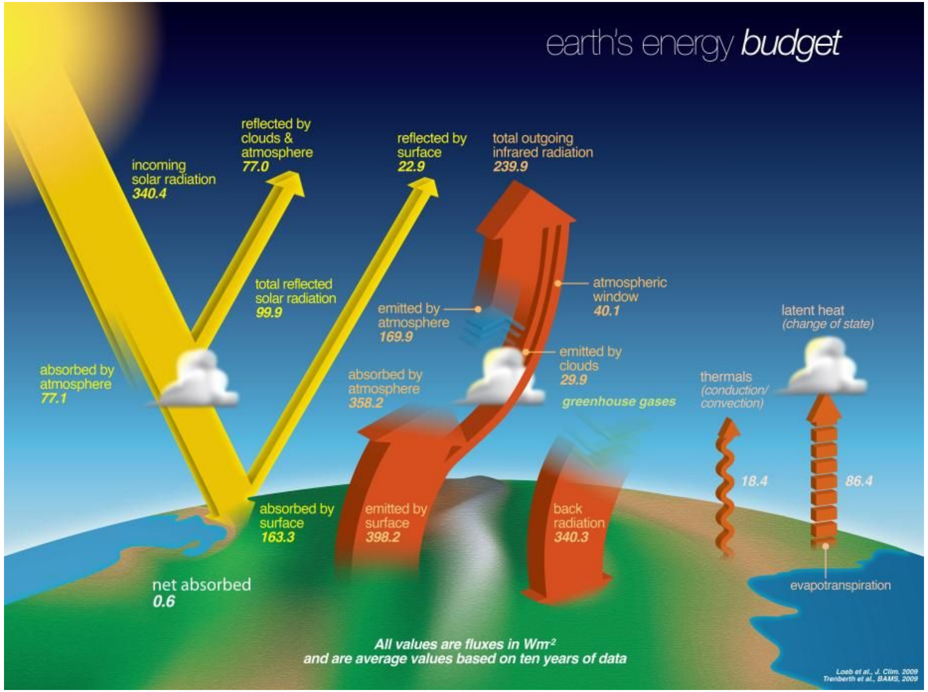


Earth’s energy “budget”

The earth receives energy from the sun, but also radiates energy back into space. The radiated energy is of a longer wavelength.



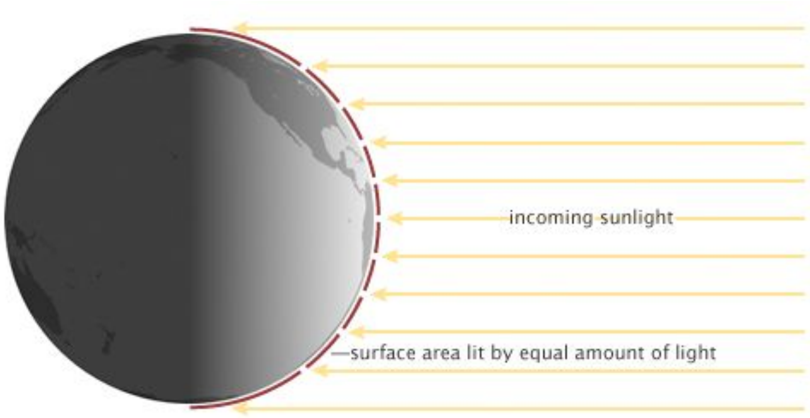
The Sun’s surface temperature is 5,500° C, and its peak radiation is in visible wavelengths of light. Earth’s effective temperature—the temperature it appears when viewed from space—is -20° C, and it radiates energy that peaks in thermal infrared wavelengths. (Illustration adapted from Robert Rohde.)

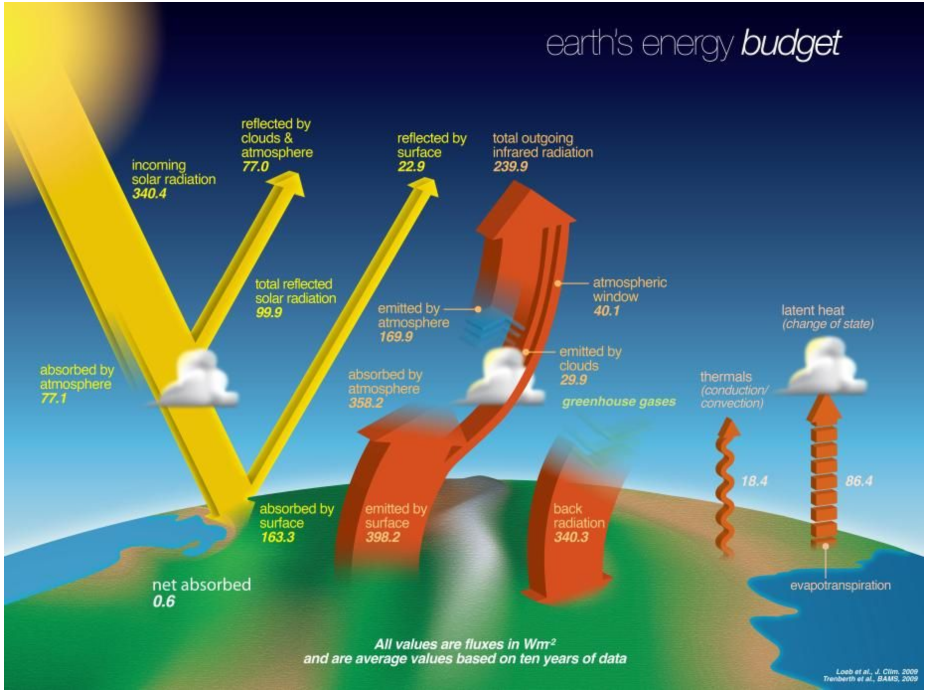


NASA

Earth’s energy “budget”

At different times, different locations on earth receive different amounts of solar input, leading to differences in temperature, winds, currents, etc.

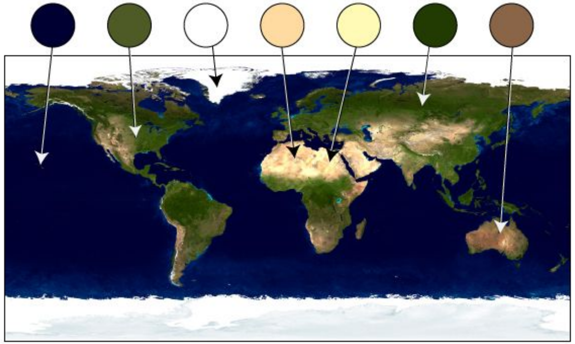


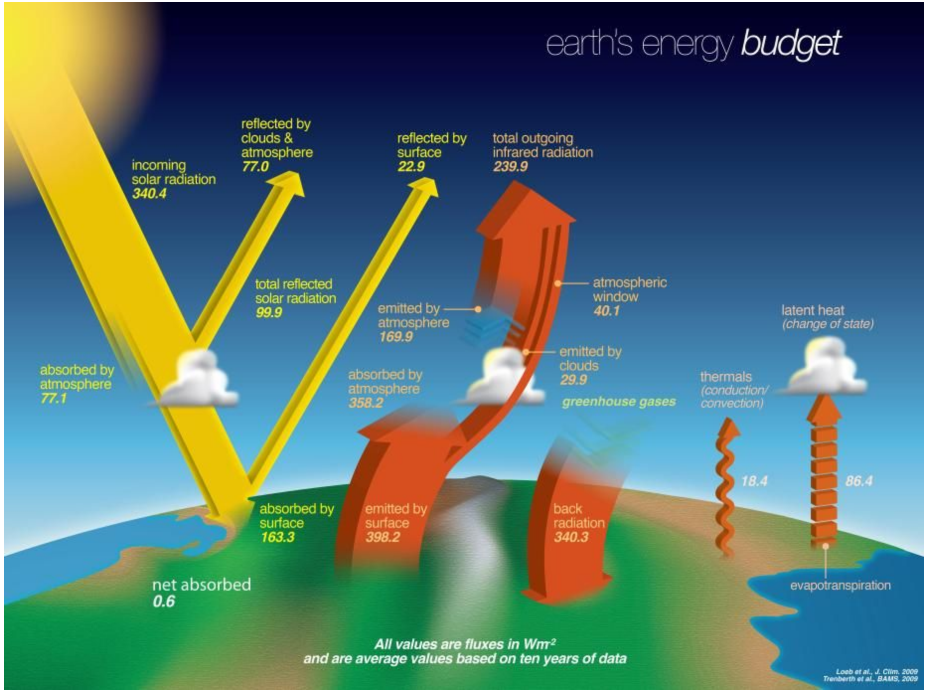


NASA

Earth's energy "budget"

Albedo controls how much of the sun's energy is directly reflected back. Dark colors have low albedo. Light colors can have high albedo; for example, snow can reflect 90% of the solar energy that reaches it



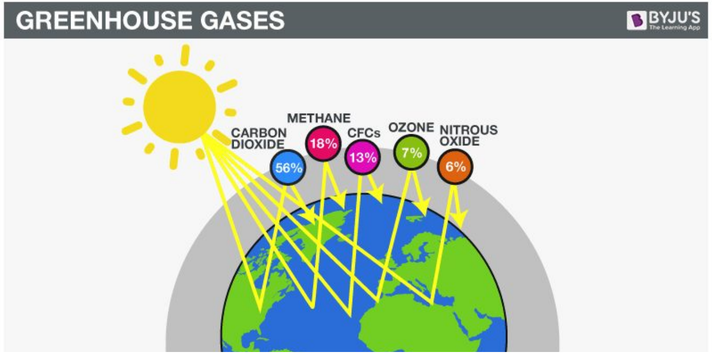


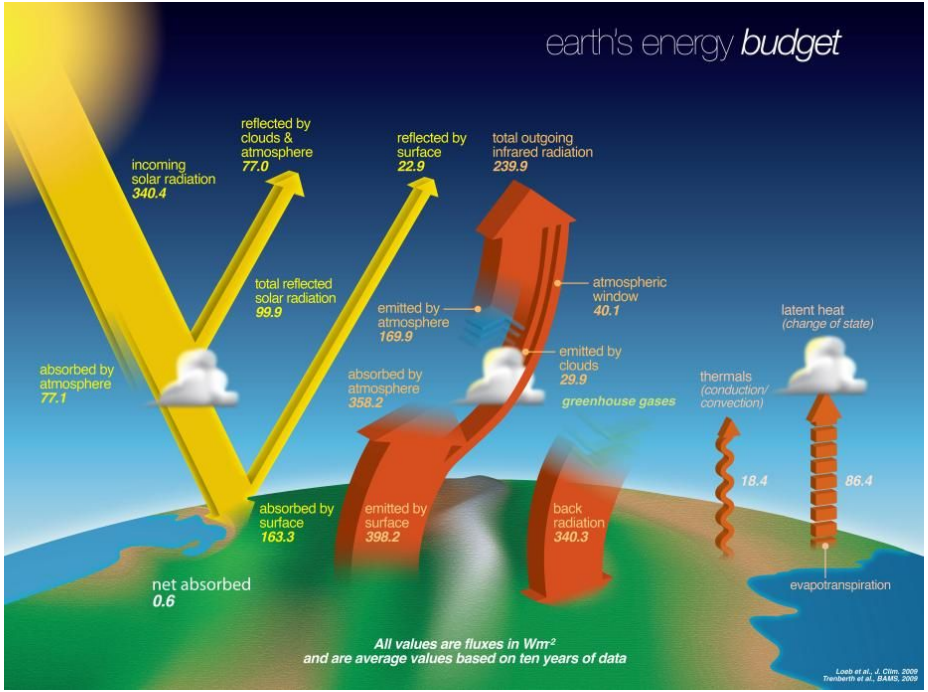
UCAR SciEd/NASA

Earth’s energy “budget”

The greenhouse effect refers to the fact that heat emitted by the Earth’s surfaces radiates back to the Earth.

The composition of the atmosphere determines the amount of back-radiation.



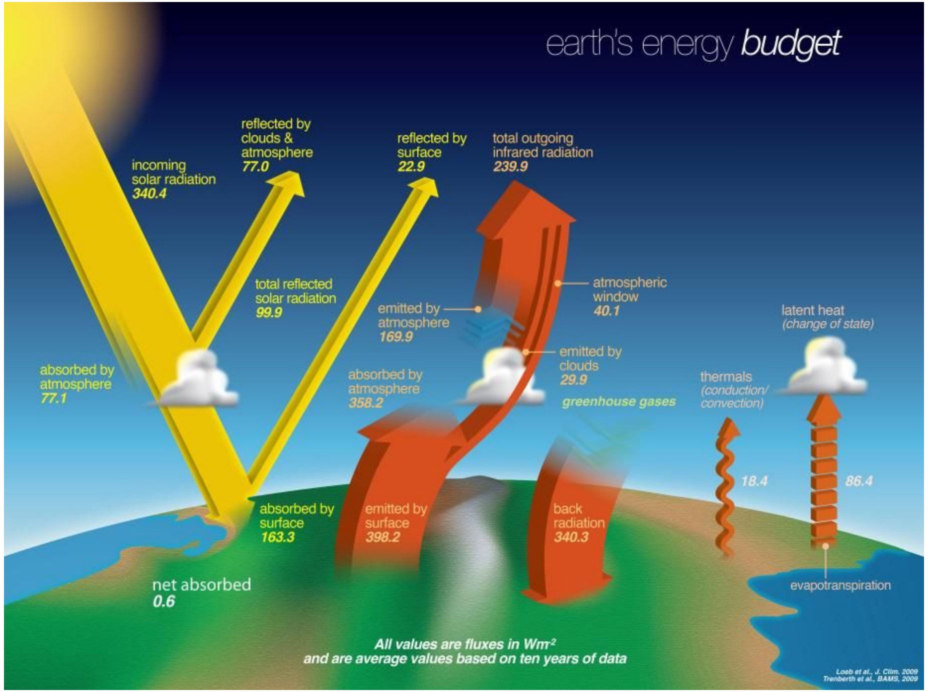


UCAR SciEd/NASA

Earth’s energy “budget”

The greenhouse effect refers to the fact that heat emitted by the Earth’s surfaces radiates back to the Earth.

The imbalance between the amount of energy that enters the earth’s atmosphere and that which leaves is known as “radiative forcing”.



UCAR SciEd/NASA

Historical Climate

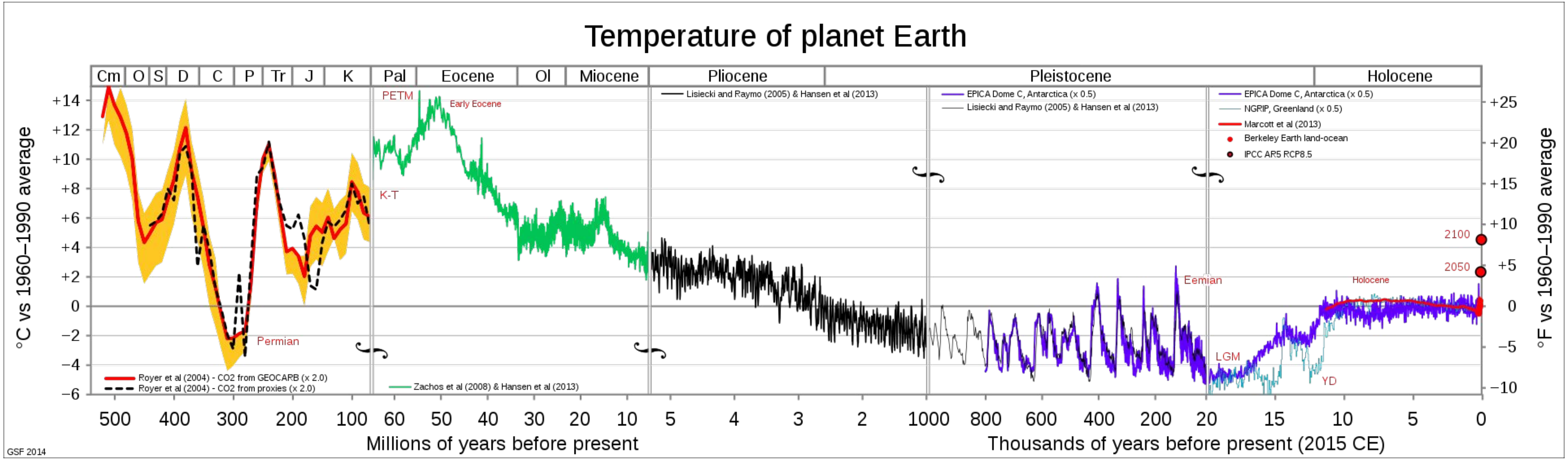
Paleoclimatology uses a variety of techniques to reconstruct past climate trends to understand how Earth systems work.

Proxy methods include: rocks, sediments, boreholes, ice sheets, tree rings, corals, shells, and microfossils

Historical Climate

Paleoclimatology uses a variety of techniques to reconstruct past climate trends to understand how Earth systems work.

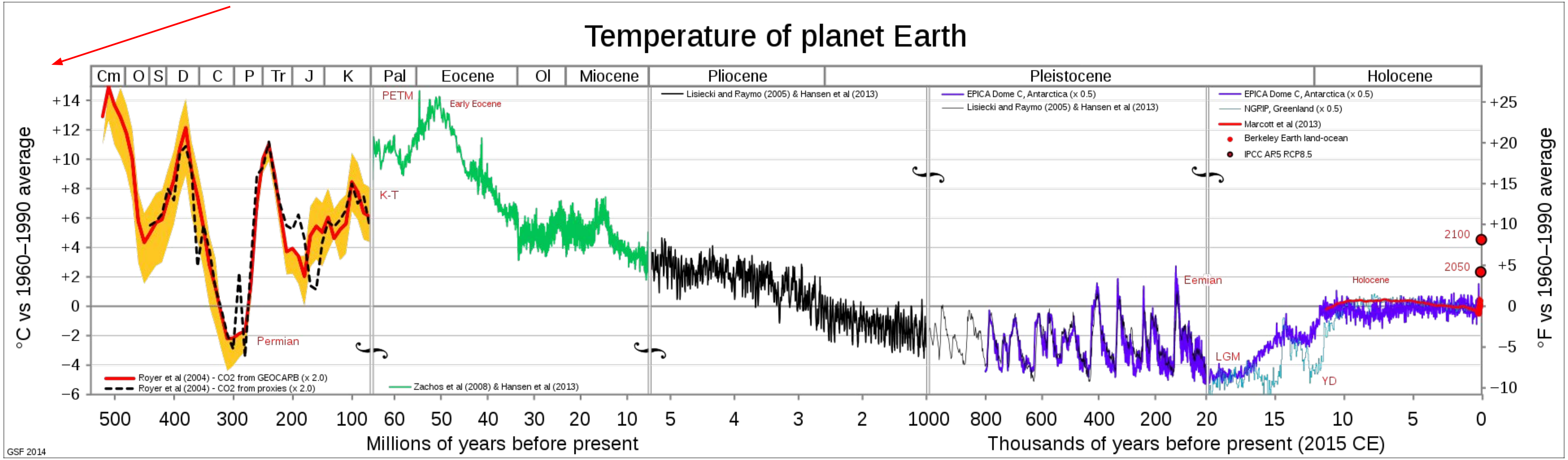
Temperatures have changed dramatically over time



Historical Climate

Paleoclimatology uses a variety of techniques to reconstruct past climate trends to understand how Earth systems work.

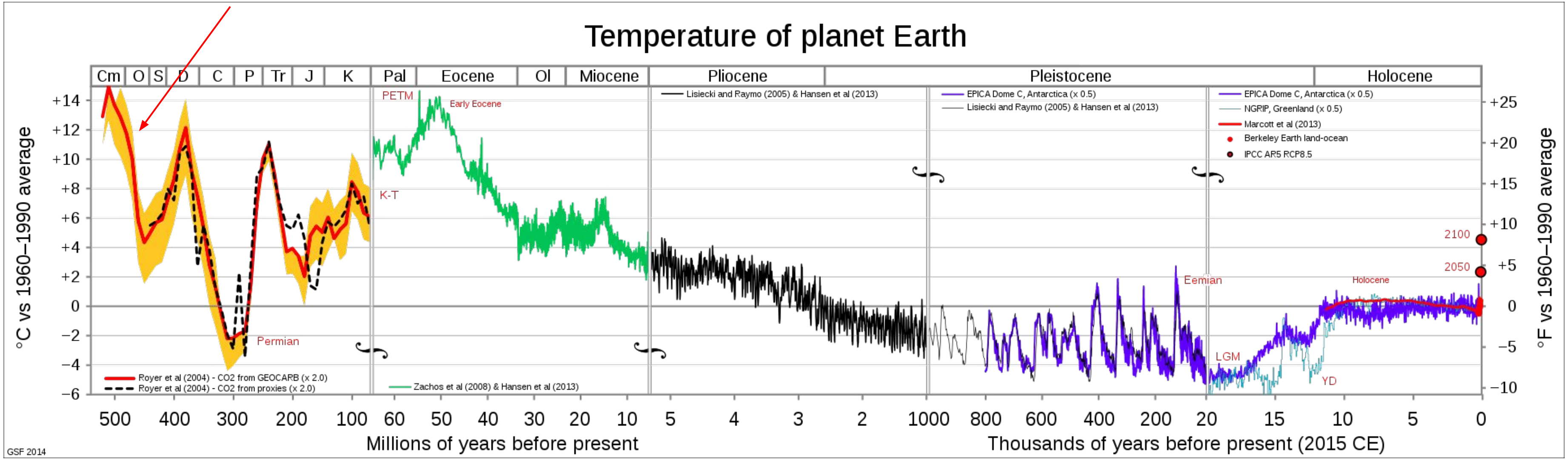
Snowball Earth ~650mya



Historical Climate

Paleoclimatology uses a variety of techniques to reconstruct past climate trends to understand how Earth systems work.

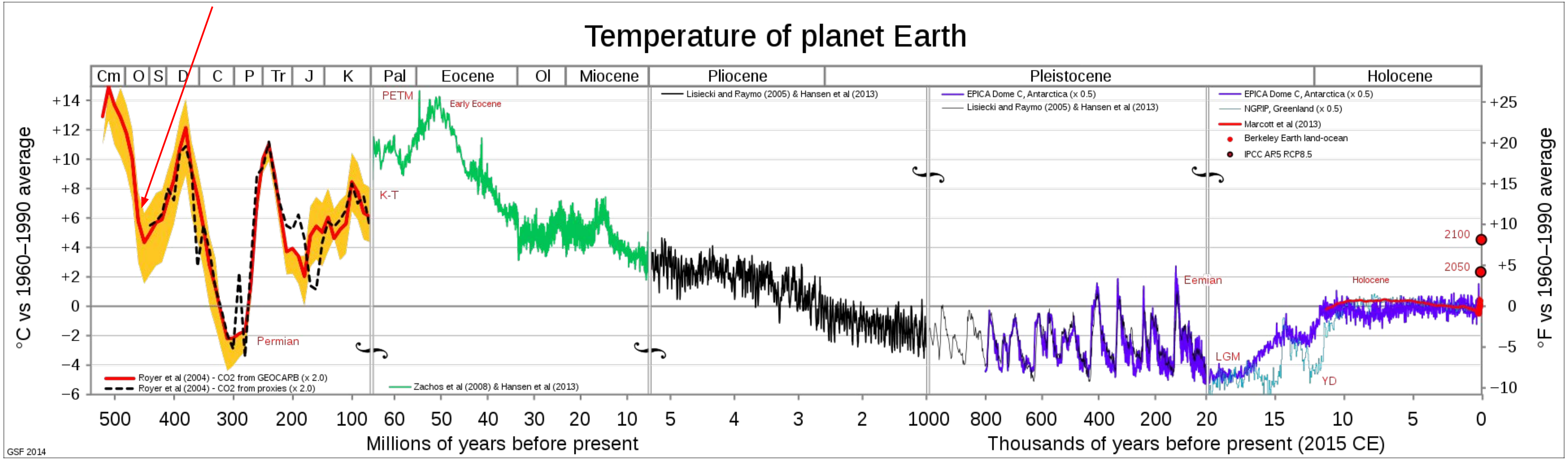
Warm and wet without distinct seasons



Historical Climate

Paleoclimatology uses a variety of techniques to reconstruct past climate trends to understand how Earth systems work.

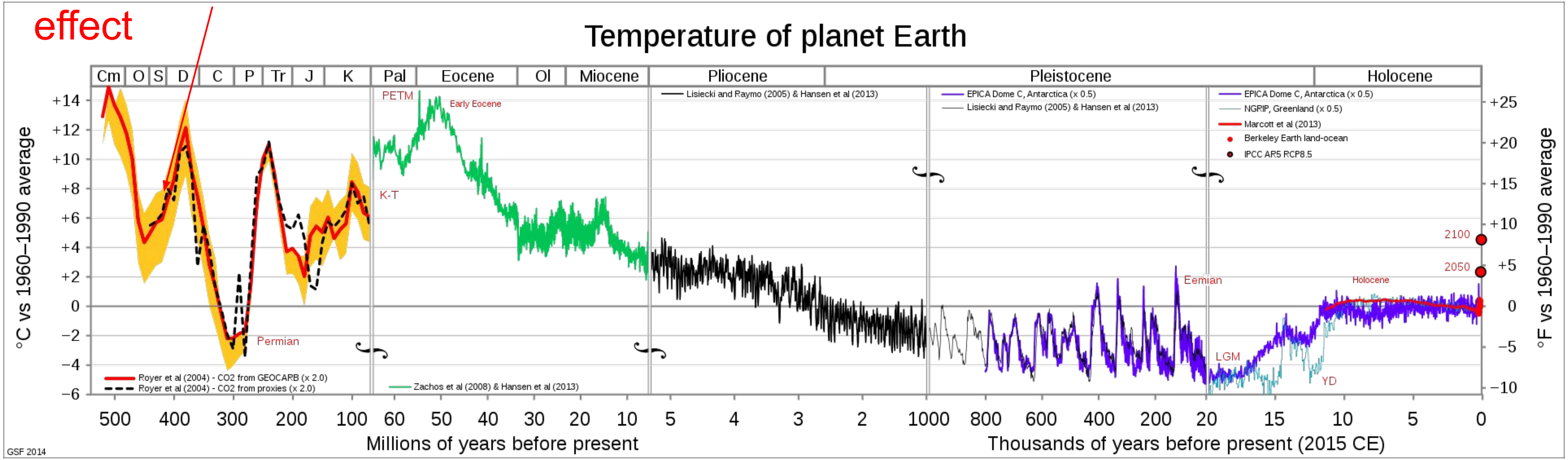
Ice age



Historical Climate

Paleoclimatology uses a variety of techniques to reconstruct past climate trends to understand how Earth systems work.

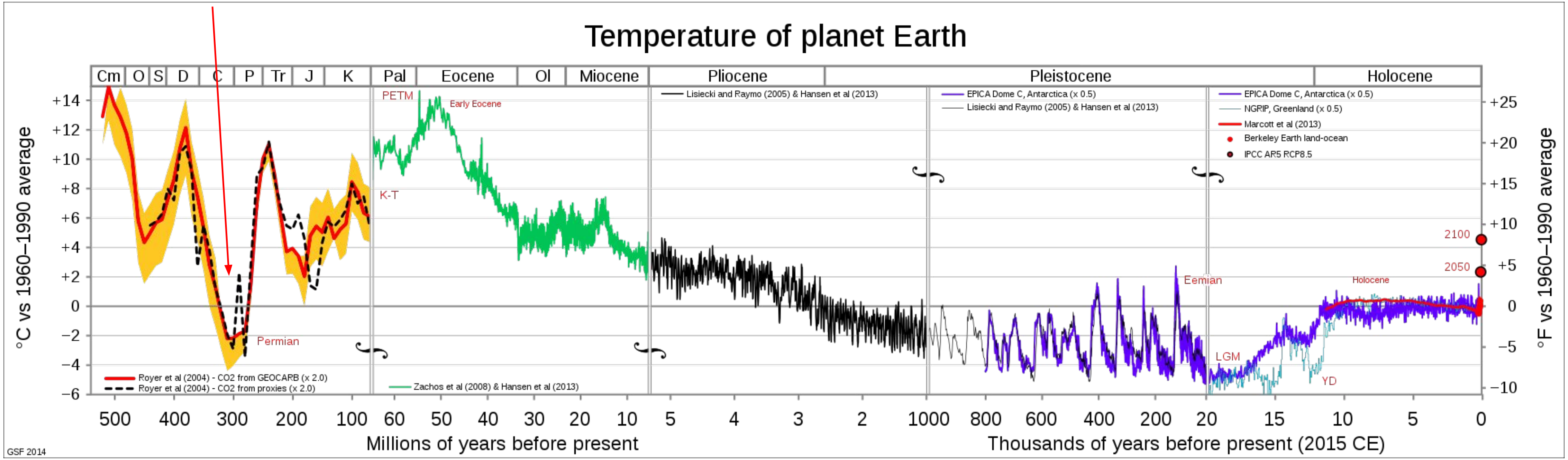
Glaciers melt, sea levels rise, cold south pole and hot at the equator, greenhouse effect



Historical Climate

Paleoclimatology uses a variety of techniques to reconstruct past climate trends to understand how Earth systems work.

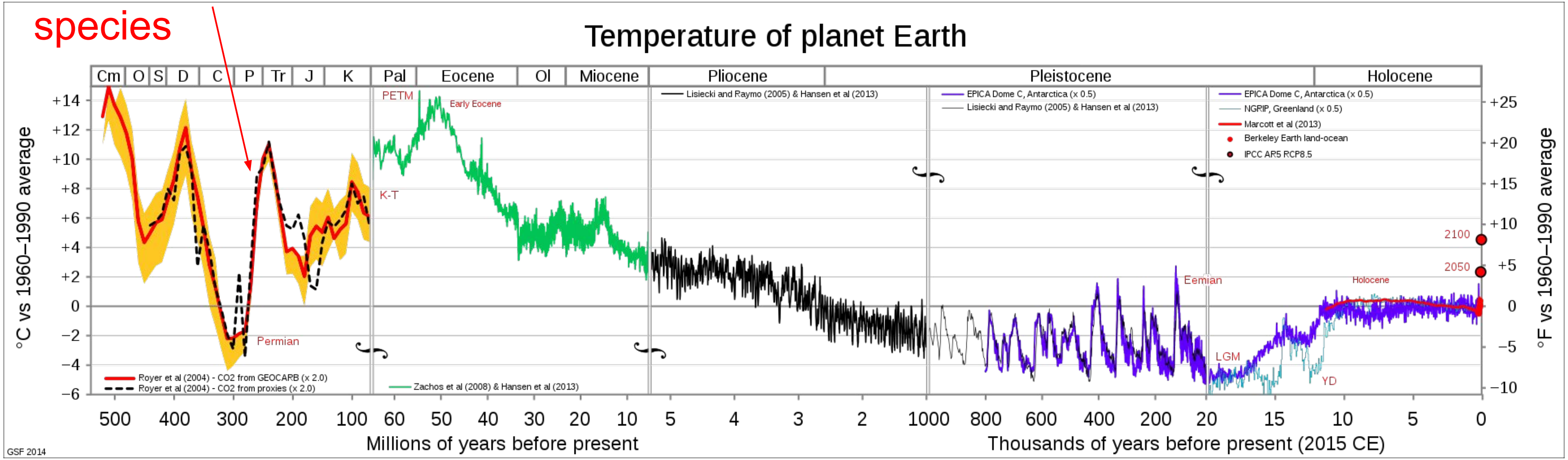
Swings between ice ages and ice melts, equator still tropical



Historical Climate

Paleoclimatology uses a variety of techniques to reconstruct past climate trends to understand how Earth systems work.

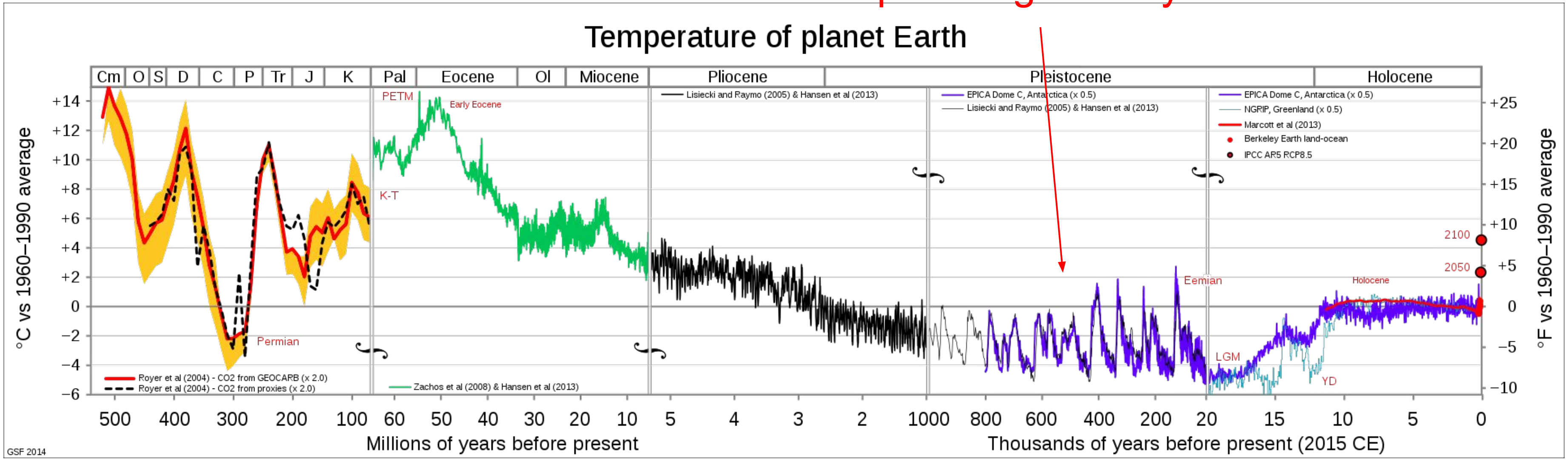
Pangea formation led to deserts. Huge warming led to extinction of 95% of species



Historical Climate

Paleoclimatology uses a variety of techniques to reconstruct past climate trends to understand how Earth systems work.

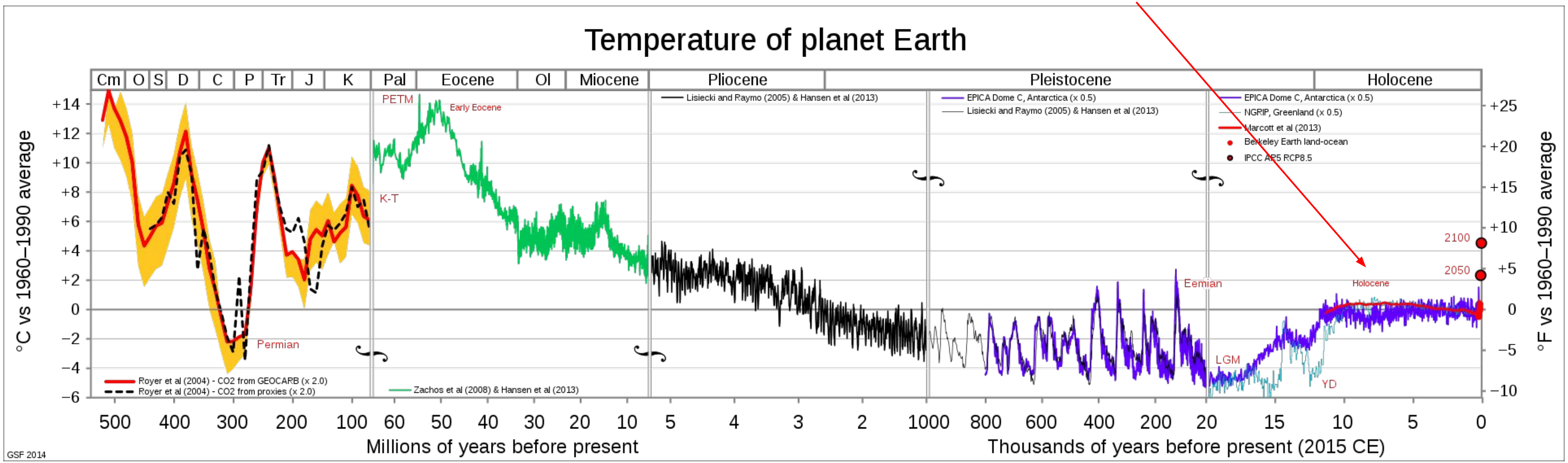
Repeated glacial cycles



Historical Climate

Paleoclimatology uses a variety of techniques to reconstruct past climate trends to understand how Earth systems work.

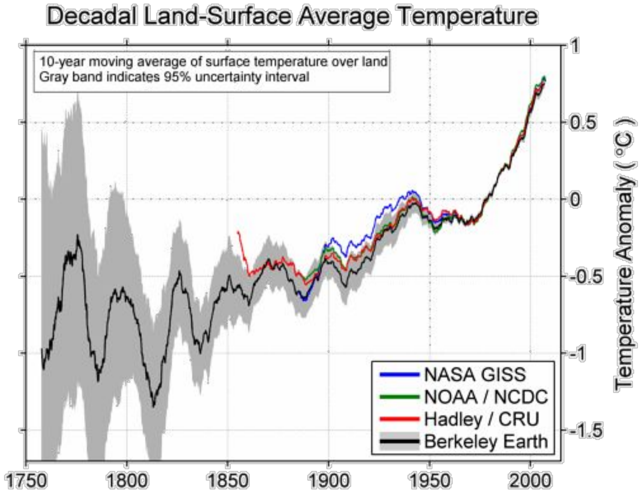
Holocene era aligns with expansion of human civilization



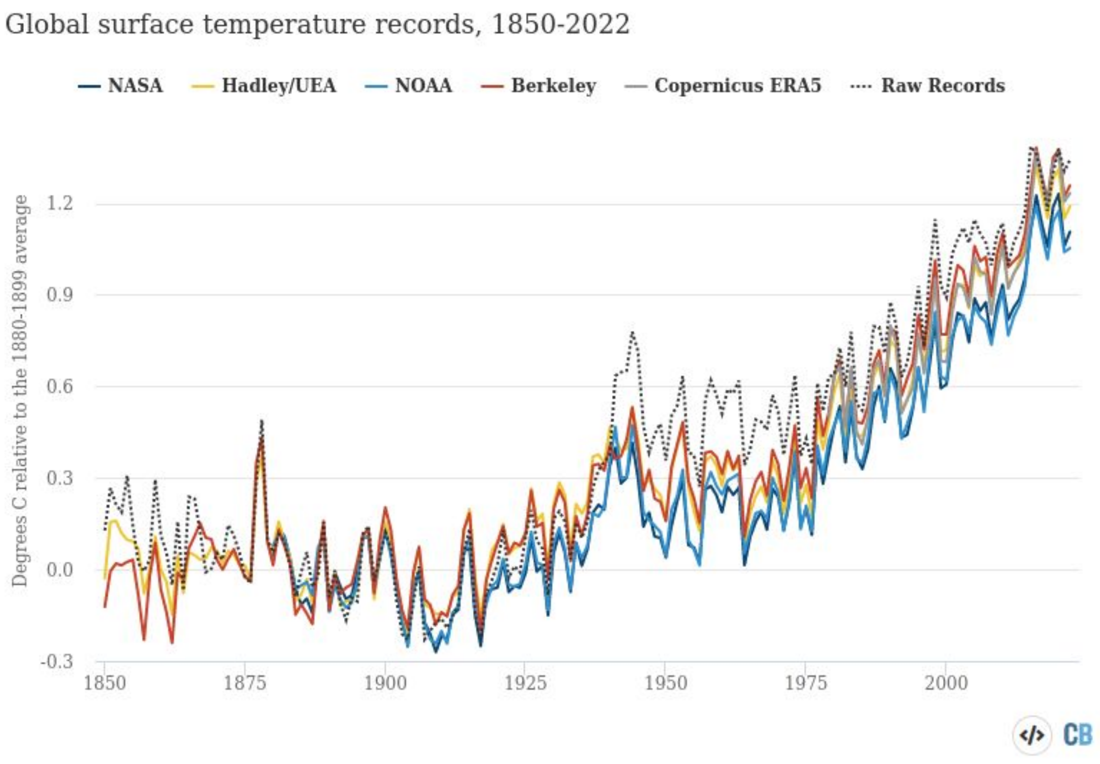
Modern Climate

More recently (e.g. the past 200 years) humans have explicitly kept records of climate variables like temperature, sea level, carbon dioxide levels, etc.

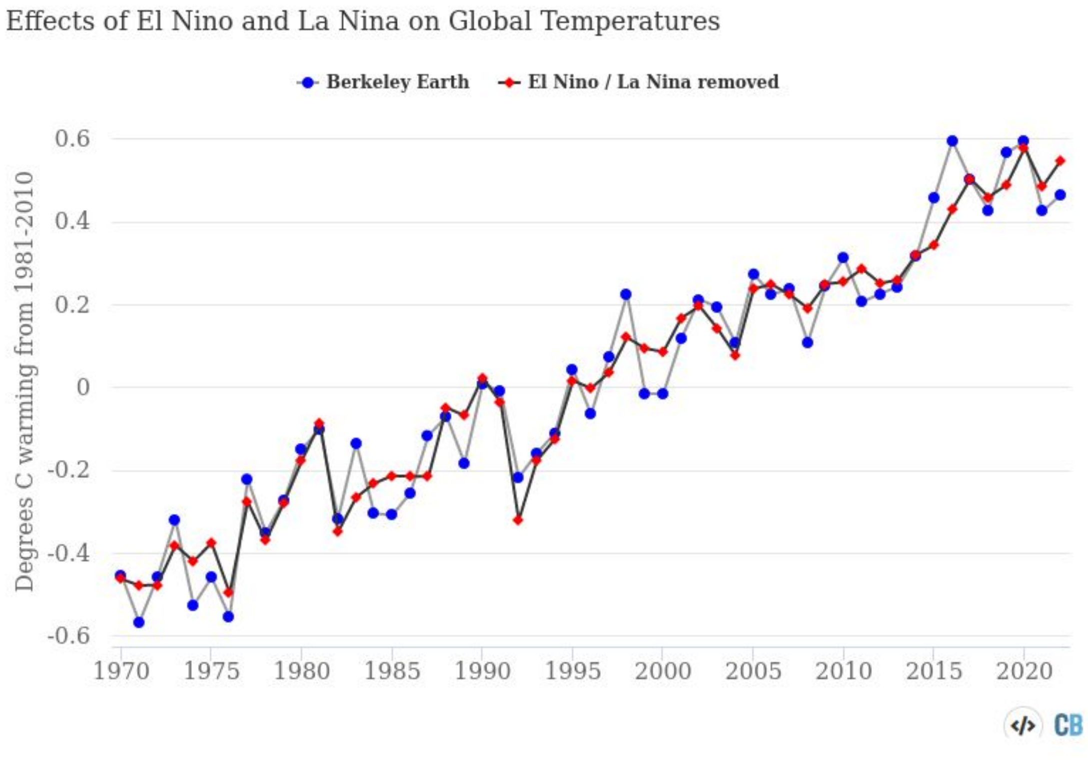
Formal, reliable records are considered to start around 1880.



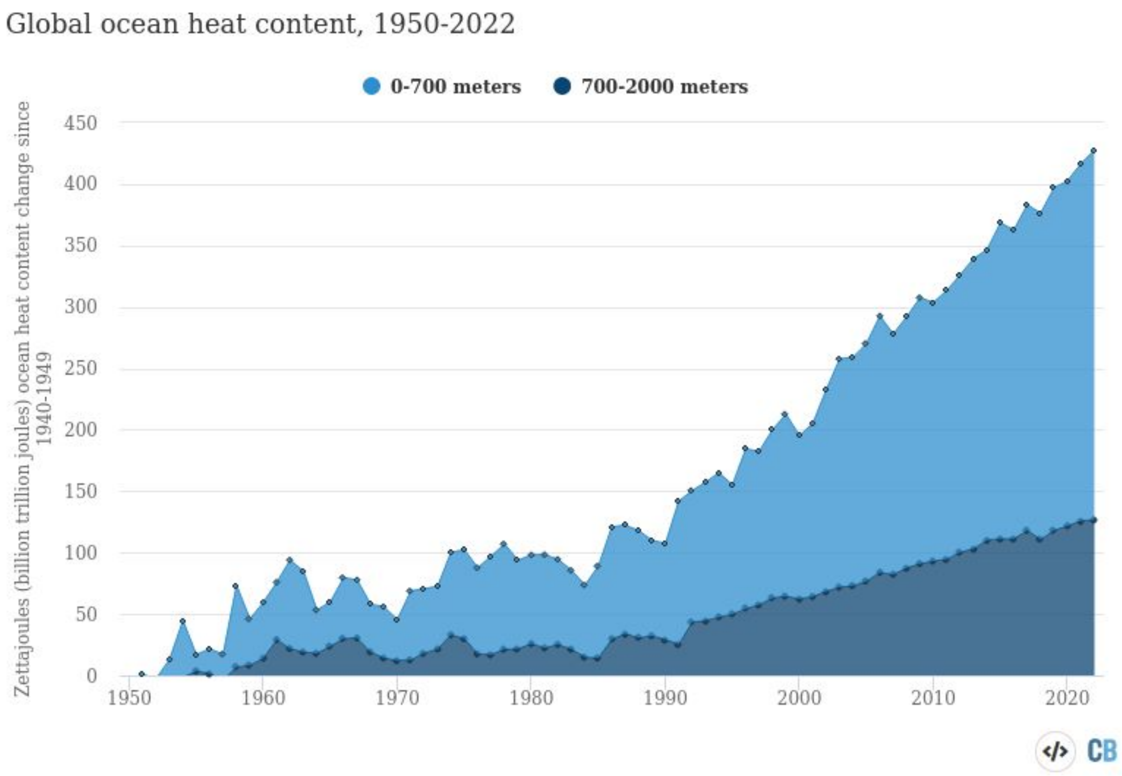
Modern Climate Trends: Many heat records are being set



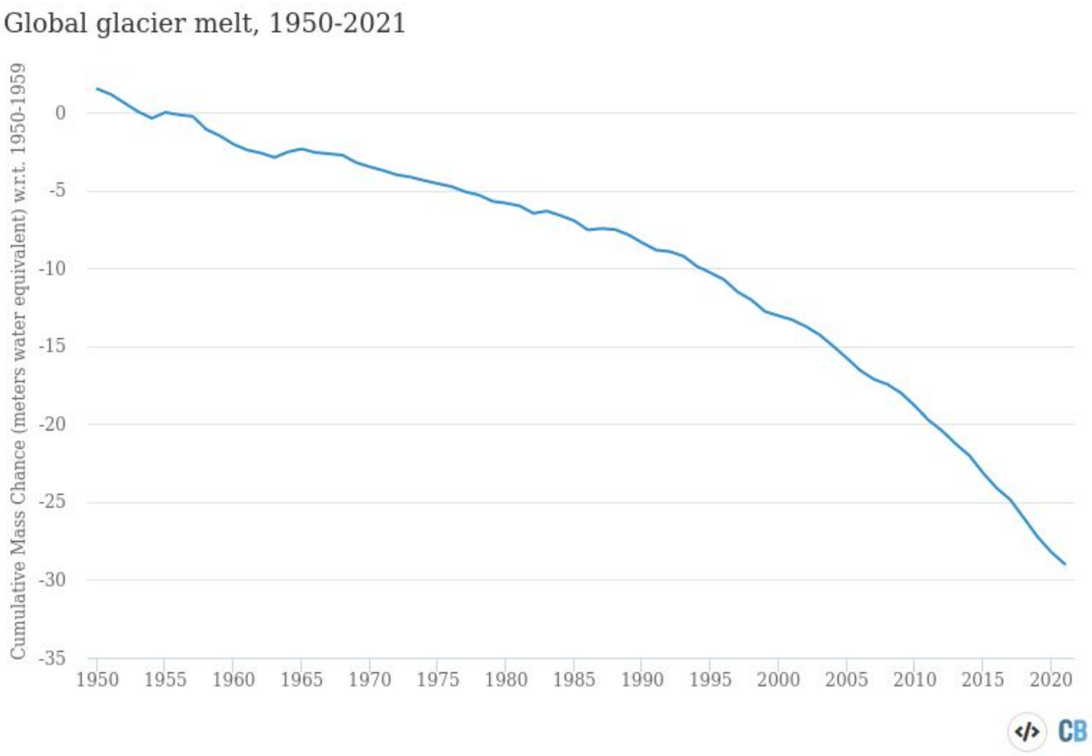
Modern Climate Trends: Many heat records are being set



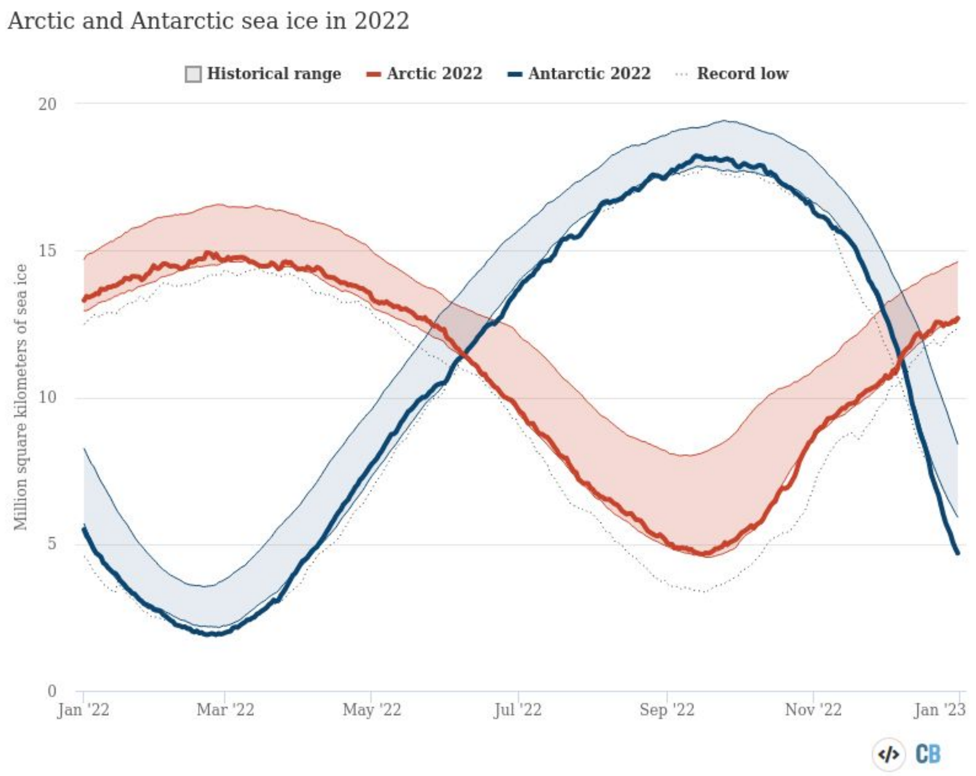
Modern Climate Trends: Many heat records are being set



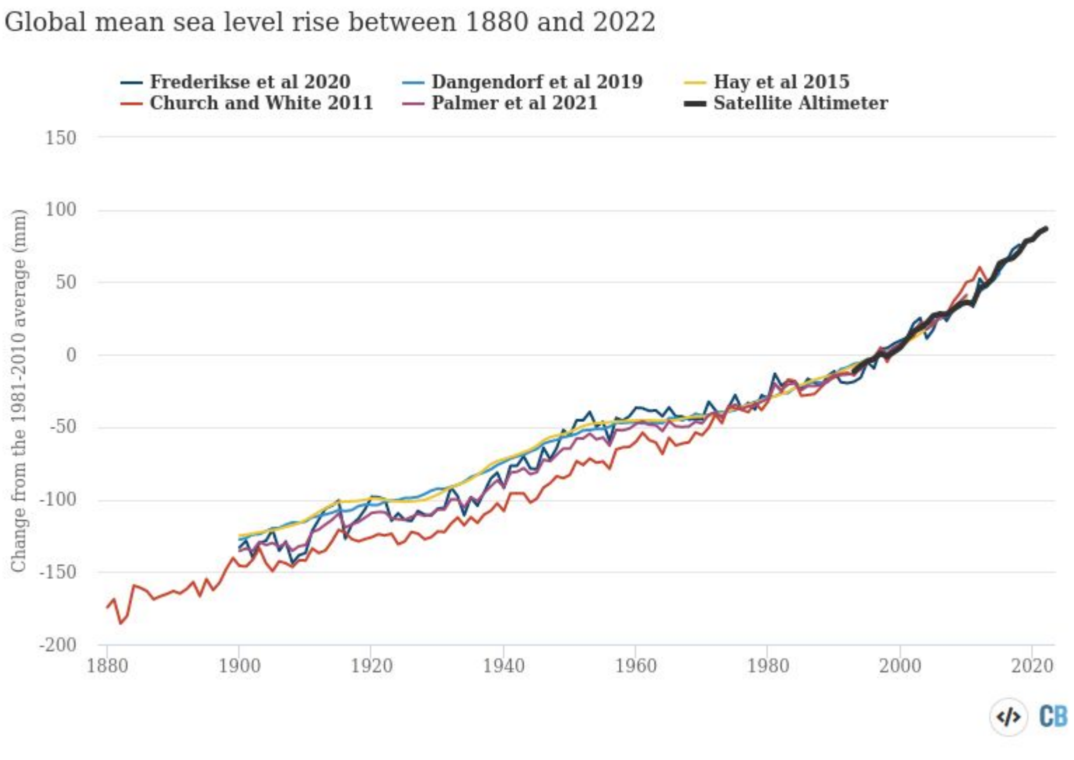
Modern Climate Trends: Many heat records are being set



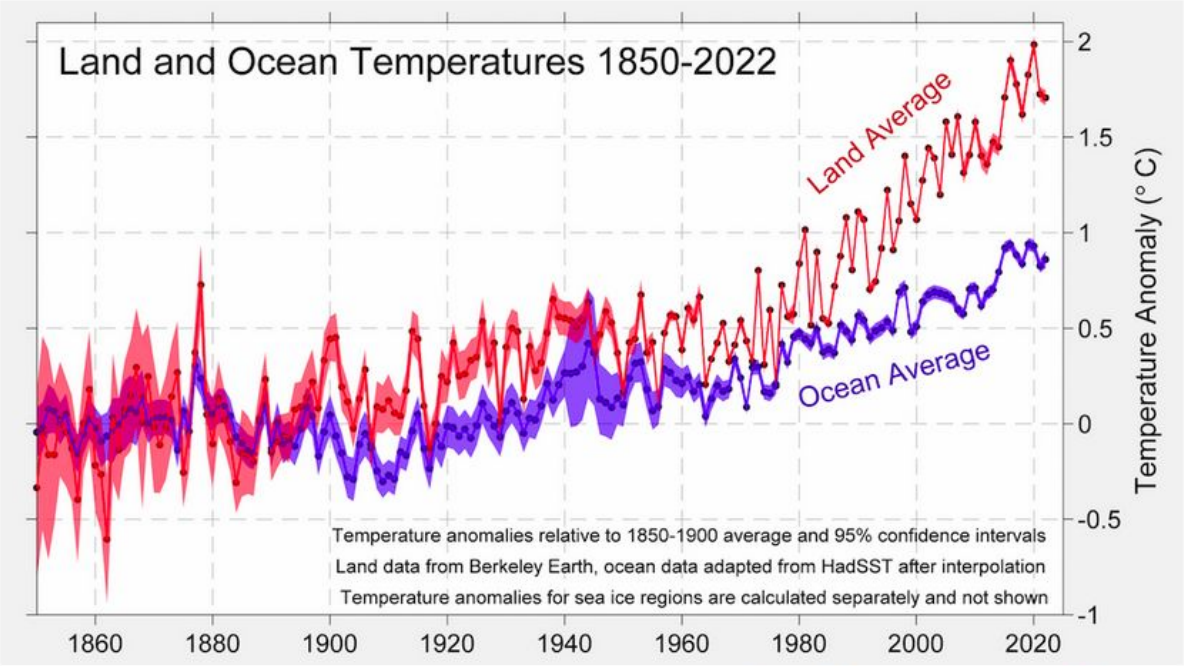
Modern Climate Trends: Many heat records are being set



Modern Climate Trends: Many heat records are being set

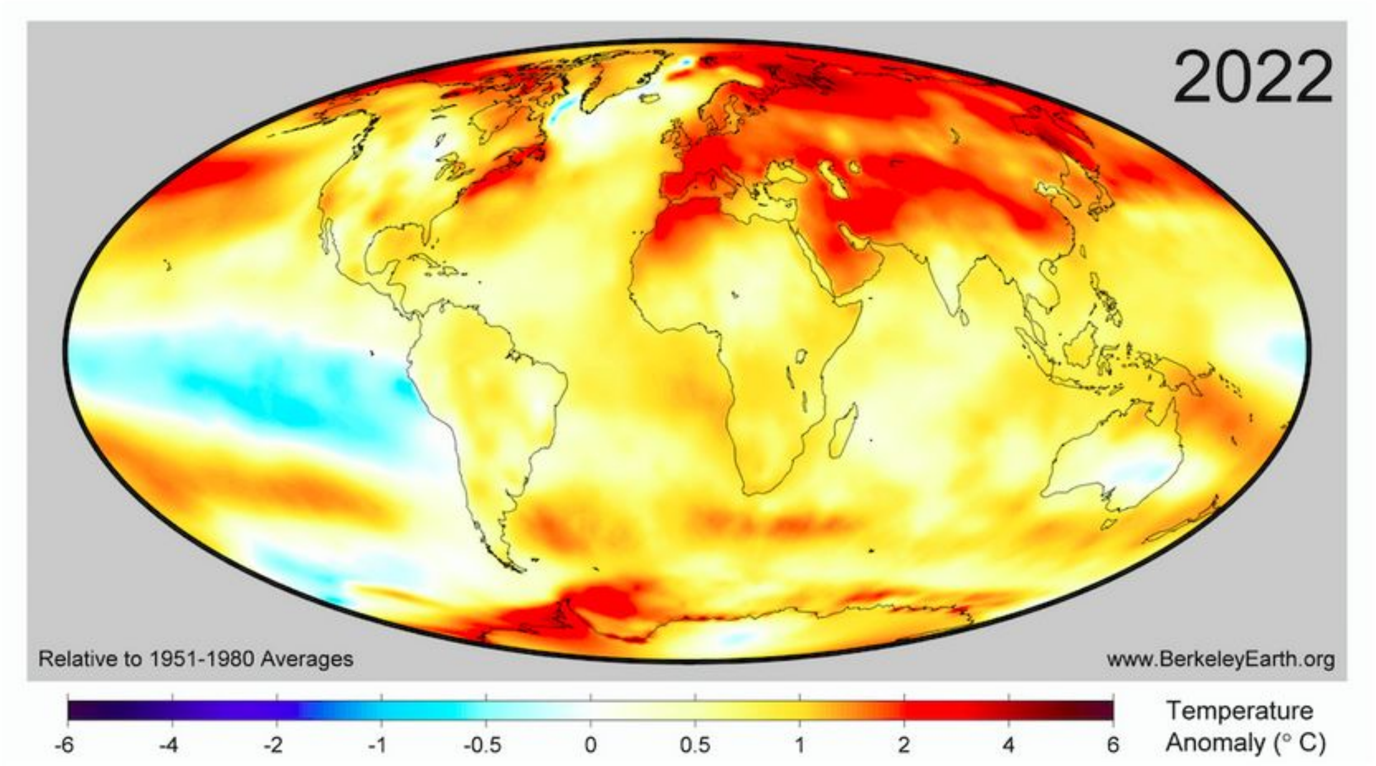


Modern Climate Trends: Many heat records are being set

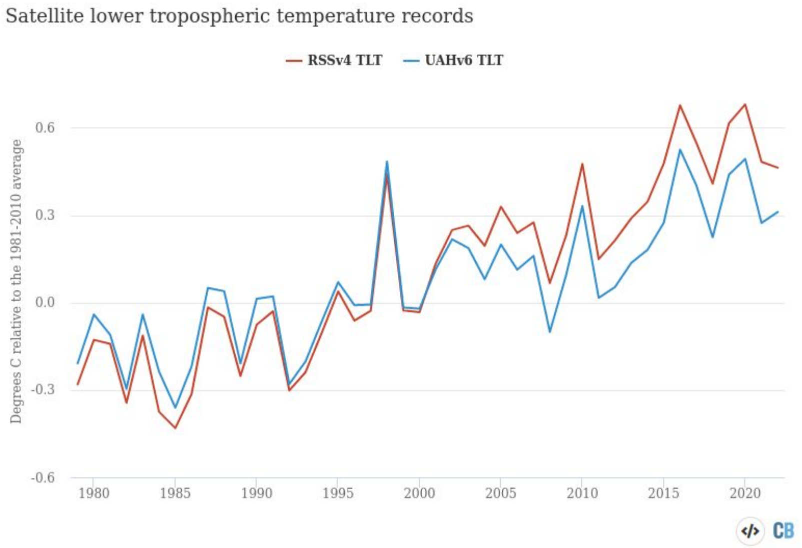


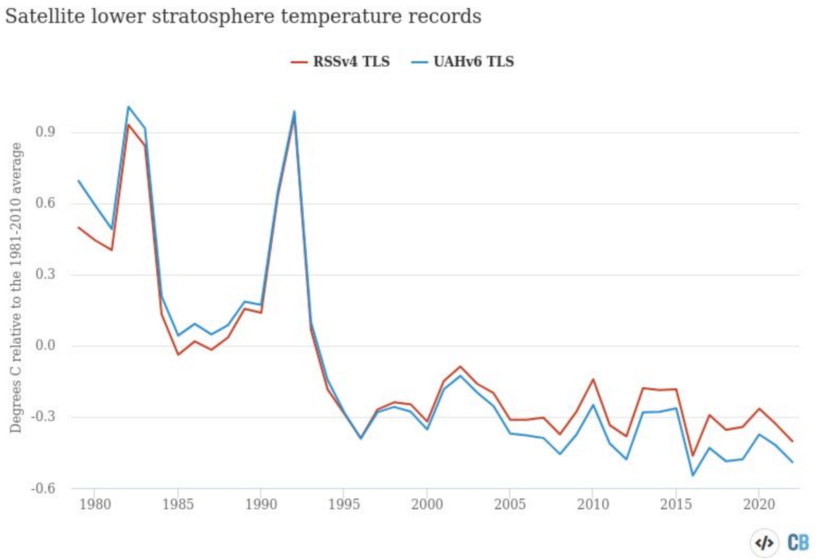
Land and ocean temperature rise since the pre-industrial 1850-1900 period from Berkeley Earth. Figure produced by Dr Robert Rohde.

Modern Climate Trends: Many heat records are being set

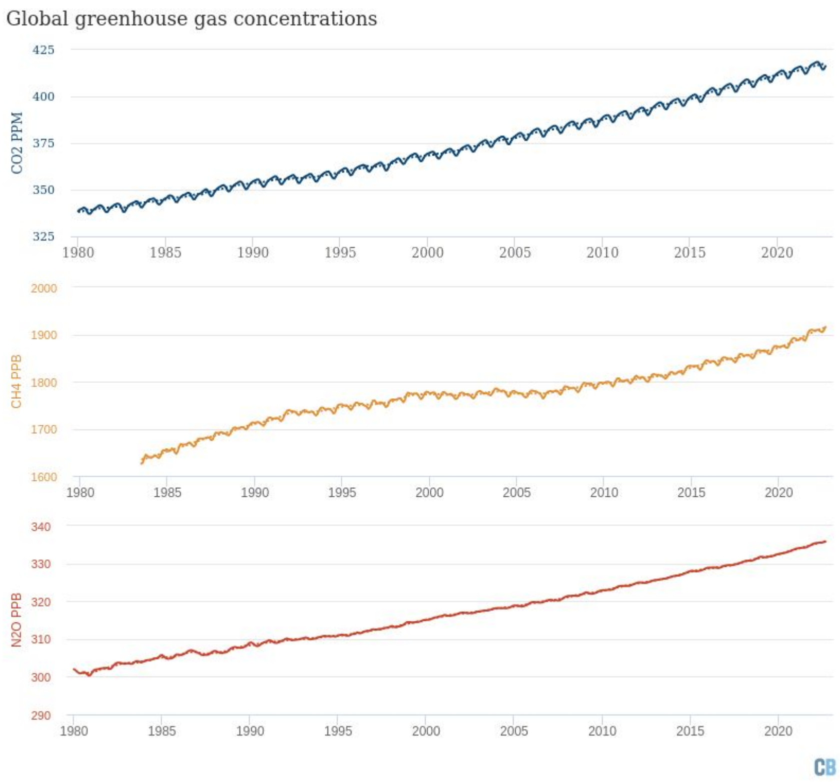


Modern Climate Trends: Many heat records are being set

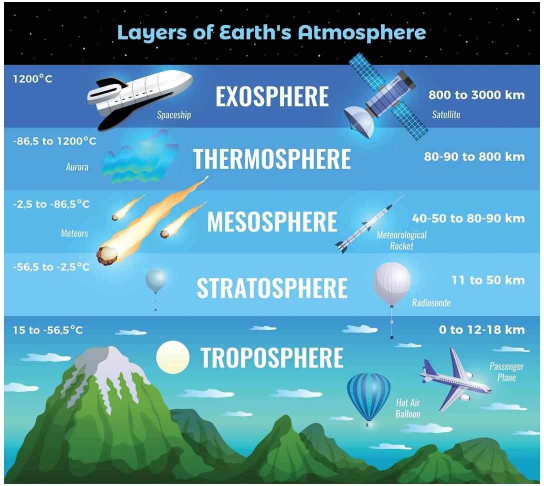


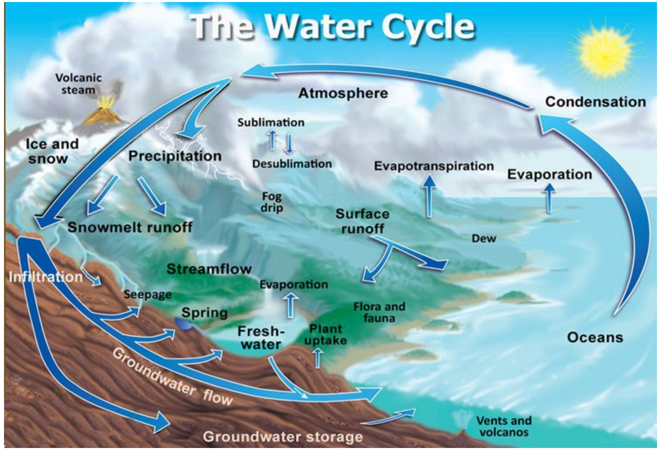


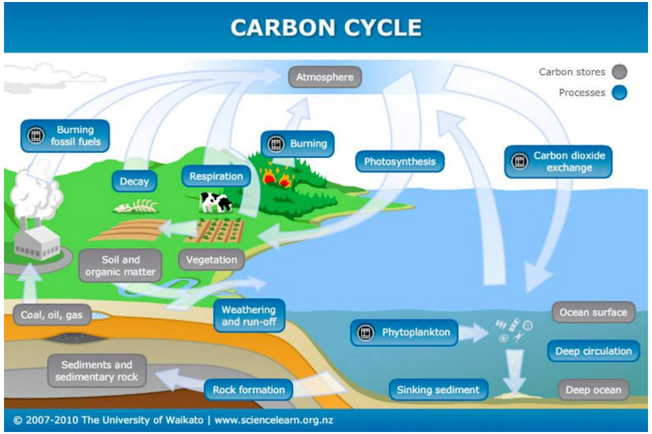
Modern Climate Trends: Many heat records are being set

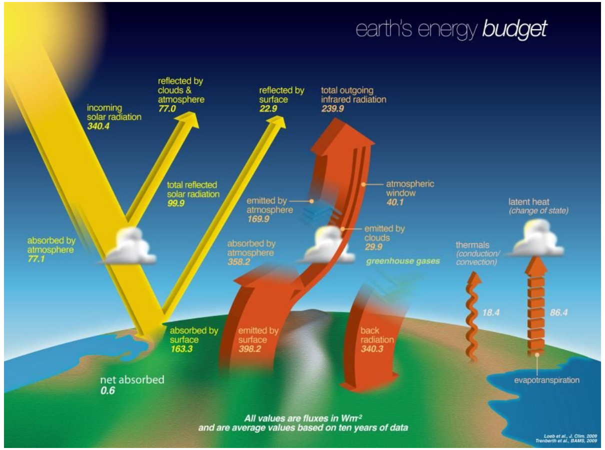


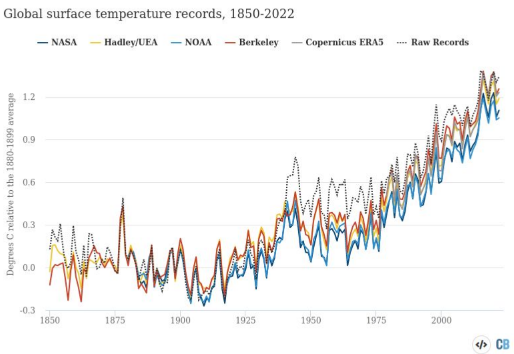
Summary


Layers of Earth's Atmosphere
1200°C
EXOSPHERE
800 to 3000 km
Spaceship
Satellite
-86,5 to 1200°C
THERMOSPHERE
80-90 to 800 km
Aurora
-2,5 to -86,5°C
MESOSPHERE
40-50 to 80-90 km
Meteors
Meteorological Rocket
-56,5 to -2,5°C
STRATOSPHERE
11 to 50 km
Radiosonde
15 to -56,5°C
TROPOSPHERE
0 to 12-18 km
Passenger Plane
Hot Air Balloon


The Water Cycle
Volcanic steam
Atmosphere
Condensation
Sublimation
Desublimation
Ice and snow
Precipitation
Evapotranspiration
Evaporation
Fog drip
Surface runoff
Snowmelt runoff
Dew
Infiltration
Streamflow
Seepage
Evaporation
Flora and fauna
Spring
Fresh-water
Plant uptake
Oceans
Groundwater flow
Vents and volcanos
Groundwater storage


CARBON CYCLE
Atmosphere
Carbon stores
Processes
Burning fossil fuels
Burning
Photosynthesis
Carbon dioxide exchange
Decay
Respiration
Soil and organic matter
Vegetation
Coal, oil, gas
Weathering and run-off
Phytoplankton
Ocean surface
Deep circulation
Sediments and sedimentary rock
Rock formation
Sinking sediment
Deep ocean
© 2007-2010 The University of Waikato | www.sciencelearn.org.nz


earth's energy budget
incoming solar radiation 340.4
reflected by clouds & atmosphere 77.0
reflected by surface 22.9
total outgoing infrared radiation 239.9
total reflected solar radiation 99.9
emitted by atmosphere 169.9
atmospheric window 40.1
latent heat (change of state)
absorbed by atmosphere 77.1
absorbed by atmosphere 358.2
emitted by clouds 29.9
greenhouse gases
thermals (conduction/ convection)
18.4
86.4
absorbed by surface 163.3
emitted by surface 398.2
back radiation 340.3
evapotranspiration
net absorbed 0.6
All values are fluxes in Wm⁻²
and are average values based on ten years of data


Global surface temperature records, 1850-2022
NASA
Hadley/UEA
NOAA
Berkeley
Copernicus ERA5
Raw Records
Degrees C relative to the 1880-1899 average
1.2
0.9
0.6
0.3
0.0
-0.3
1850
1875
1900
1925
1950
1975
2000
CB