Introduction to Earth System

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Evaluation and Scoring

Component	Attendance	Exercises	Practical	Reports	Midterm	Final
Percentage %	10	20	20	0	0	50

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Classroom Rules

- Respect yourself
- Respect others
- HONESTY

  – On time:
  - 5 minutes' rule
  - three absences without explanation result in no final exam

Further reading

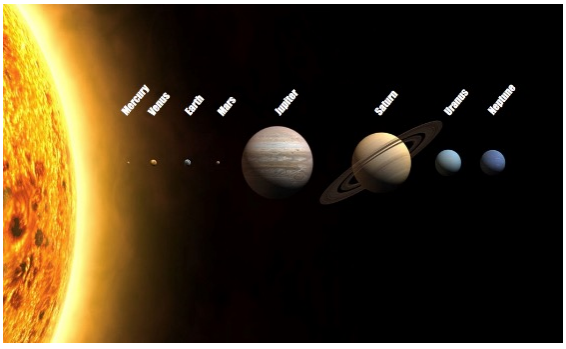
1. Wallace J.M and P.V. Hobbs: **Atmospheric Science, An Introductory Survey**, 2nd Edition, Academic Press, 504pp. [PDF]
2. IPCC assessment reports (TAR, AR4, AR5, AR6) (https://ipcc.ch)

Course content

I. Introduction
II. Earth's components
III. Daisy world
IV. The radiation balance of Earth
V. Climate oscillation and climate change

I. Introduction

Our Earth is:
- 'one point' in the universe
- Age of the universe?
- Why Earth is the only planet presently known to support life?



(distance not to scale)

- Age of the Earth?
- Orbital period?
- Mean radius?

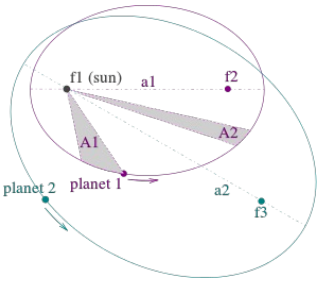
Distance from the Earth to the Sun: 1 Astronomical Unit (1 AU: 150.000.000 km)

Orbits

- **Ptolemy** (AD90–AD168, Greek):
  - geocentric model
- **Nicolas Copernicus** (1473–1543):
  - heliocentric model
    - the Earth circles the Sun
    - the planetary orbit is a circle
- **Johannes Kepler** (1571–1630):
  - **3 Kepler's laws of planetary motion**

1. The orbit of a planet is an ellipse with the Sun at one of the two foci *(1609)*
2. A line segment joining a planet and the Sun sweeps out equal areas during equal intervals of time *(1609)*
3. The square of the orbital period of a planet is proportional to the cube of the semi-major axis of its orbit *(1619*)

Orbits



3 Kepler's laws of planetary motion

$$\frac{a_1^3}{T_1^2} = \frac{a_2^3}{T_2^2} = \ldots\ldots = \frac{a_i^3}{T_i^2} = \ldots.. = K$$

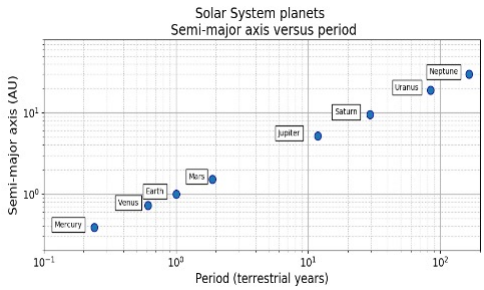
$K = G\,(m_p + m_s)/\,(4\,\pi^2)$
G: gravitational constant
m_s: mass of the sun
m_p: mass of the planet

$G = 6.674 \times 10^{-11}\ \mathrm{N \cdot (m/kg)^2}$

Q. The orbits of the Moon, Hubble telescope, and the ISS have a common focal point, which is …?

Q. Is the speed of planets/ satellites constant along their orbits?

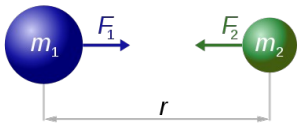
Q. From K & T, which quantity can we estimate?



Orbits

Newton's law of universal gravitation

- G is the gravitational constant (6.674×10^{-11} N · (m/kg)^2)



$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

Q: At what velocity will the satellite not fall back to the Earth?

Q: At what velocity can a satellite escape from the gravitational attraction of the Earth?

Q: At what velocity can a satellite escape from the solar system?

Q: At what speed does the Earth orbit the Sun?

Orbits

Balance between gravitational force and centrifugal force

$$mg = \frac{mv^2}{R} \rightarrow v = \sqrt{gR}$$

where $g = \frac{GM}{R^2}$

g~9.8m/s, R~6378km → v_1~7.9km/s

v_3~16.6km/s

velocity that the satellite can escape from the solar system

Conservation of Energy (kinetic energy & gravitational potential energy)

$$\frac{mv_2^2}{2} - \frac{GMm}{R} = 0$$

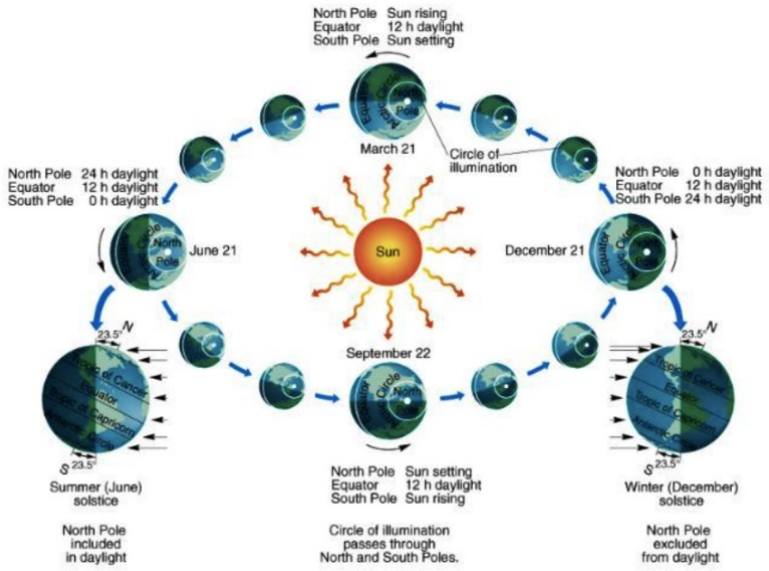
$$\rightarrow \quad v_2 = \sqrt{2}v_1$$ → v_2~11.2 km/s

Escape velocity: The minimum speed needed for an object to escape from the gravitational attraction of a massive body

- Geostationary orbit
- Polar orbit
- Low orbit

- When $v_1 < v < v_2$ → The satellite has an elliptical orbit around the Earth
- When $v_2 < v < v_3$ → become a satellite/planet of the Sun

Milankovitch Theory: The 3 Milankovitch Cycles



Earth's rotation and Revolution

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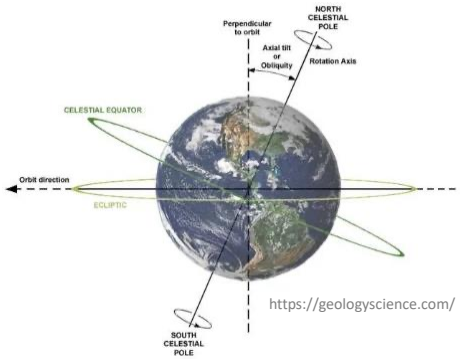
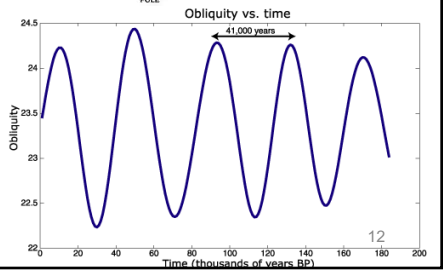
The 3 Milankovitch Cycles: **(1) Obliquity**

- **Obliquity**: the variation of the tilt of the earth's axis away from the orbital plane



https://geologyscience.com/

- ~41000 yrs
- Obliquity Range: 22.2º to 24.5º



Q: What does it mean if the obliquity has a greater tilt?

Q: Where on earth can we observe the most noticeable impact of the obliquity?

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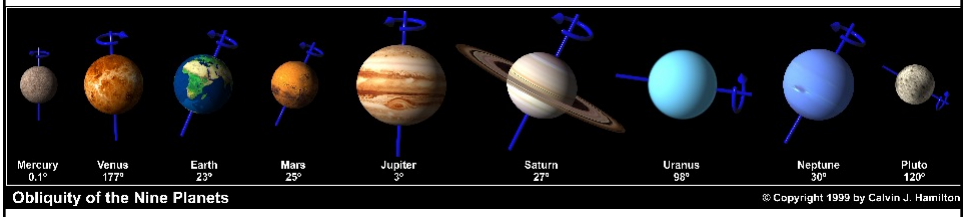
Obliquity of the Planets, and the direction of spin

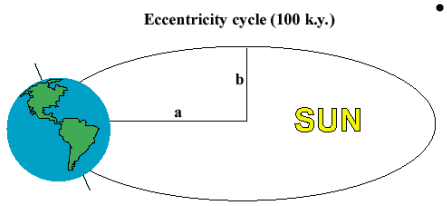


Q: Identify pairs of planets with similar obliquity?

Q: Which planet has the most peculiar spin direction?

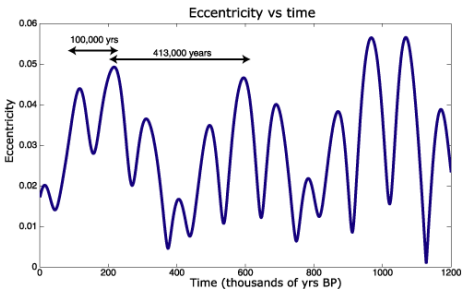
The 3 Milankovitch Cycles: **(2) Eccentricity**

Eccentricity: indicates the shape of Earth's orbit around the sun



$$e = \sqrt{1 - \frac{b^2}{a^2}}$$

- Period: 100,000 dominates and the 413,000 amplifies every 4th one



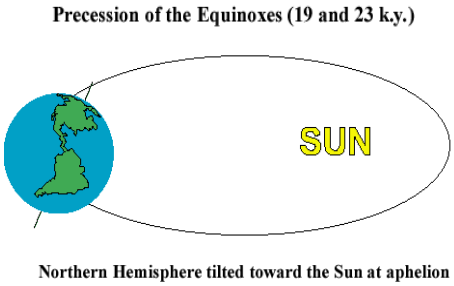
Eccentricity:

- -0.005 to 0.06 (0 → a circle)
- currently 0.017

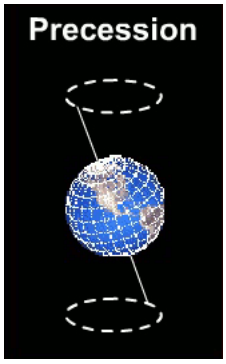
- ~ less than 0.2% change in solar insolation, equivalent to a radiative forcing of ~0.45 W/m^2

The 3 Milankovitch Cycles: **(3) Precession**

Precession: change in orientation of the Earth's rotational axis; 19,000-23,000 years

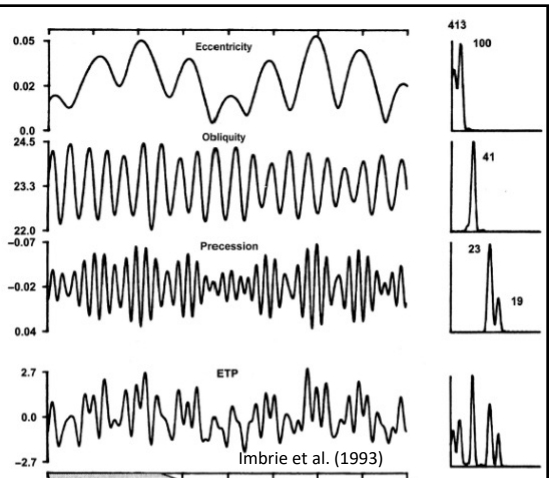


Precession influences the timing of the seasons by changing the orientation of the Earth's rotational axis

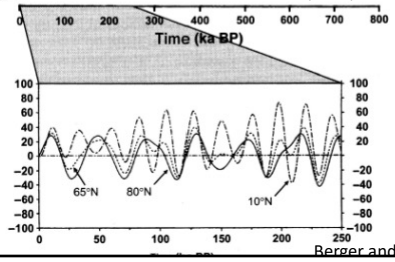


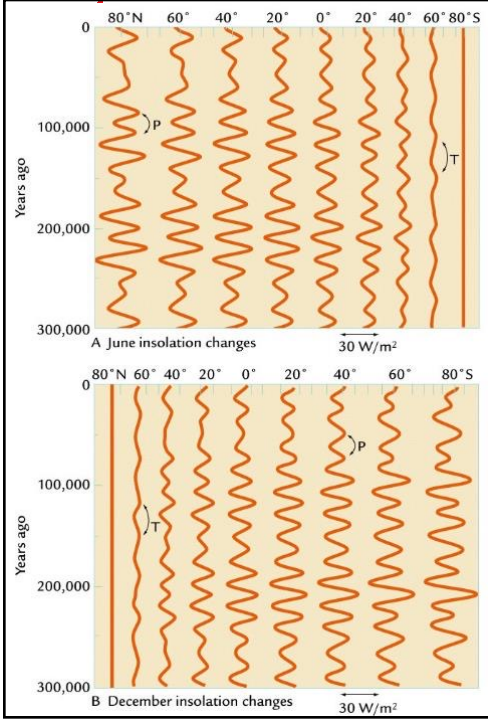
rotation of the Earth's rotational axis

- Variations of all three factors (ETP) over the last 800,000 years & the power spectrum



- July solar radiation anomalies several latitudes
  - High latitudes?
  - Low latitude?





Orbital scale insolation change

- Strong 23 ky (precession) and 40 k cycles (Obliquity)
- 100 ky cycle is not obvious

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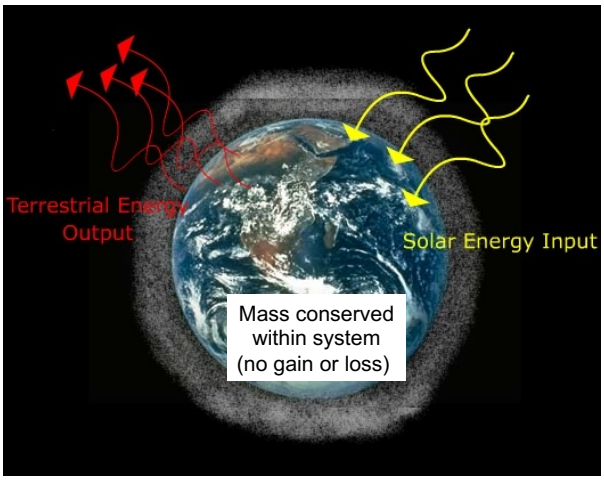
The Earth

- exchange of energy but negligible exchange of mass with surroundings



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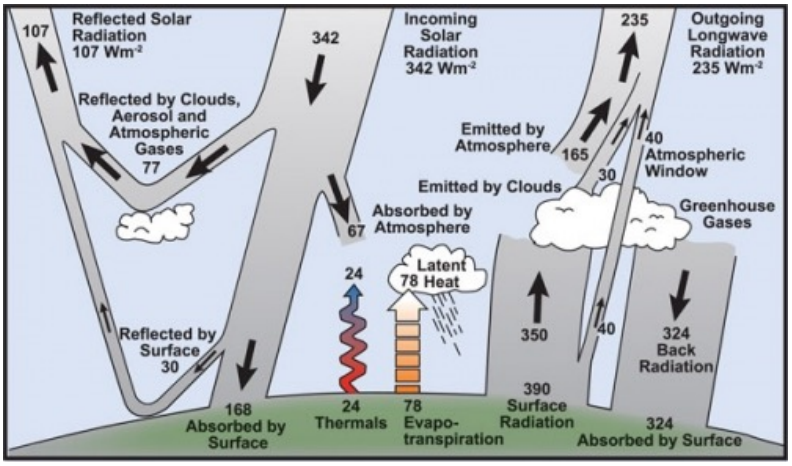
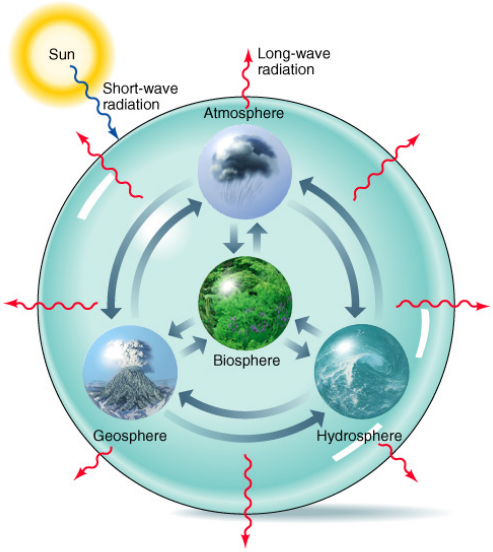
Energy balance



- When the climate system reaches steady state, i.e. temperature stops changing → amount of energy going out = amount of energy coming in
- **Radiative forcing**

Four Spheres of the Earth System

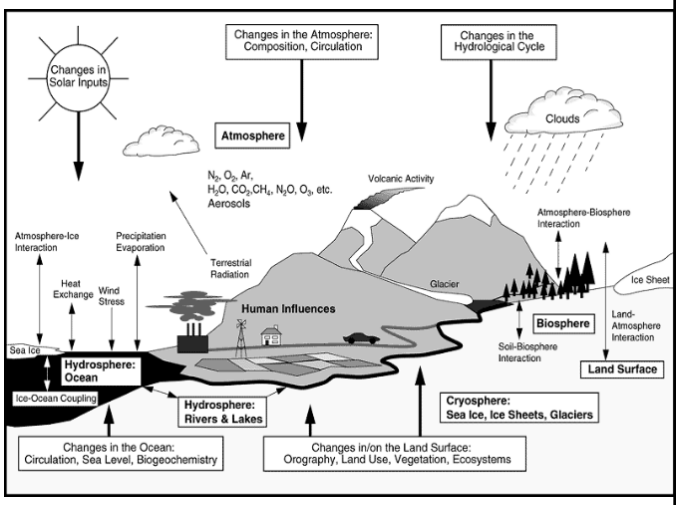
- **A system**: is a group of components that interact



We focus more on the Atmosphere in this course

Components of the Earth System

Q: How do the different components interact in response to various internal and external influences, or forcings?

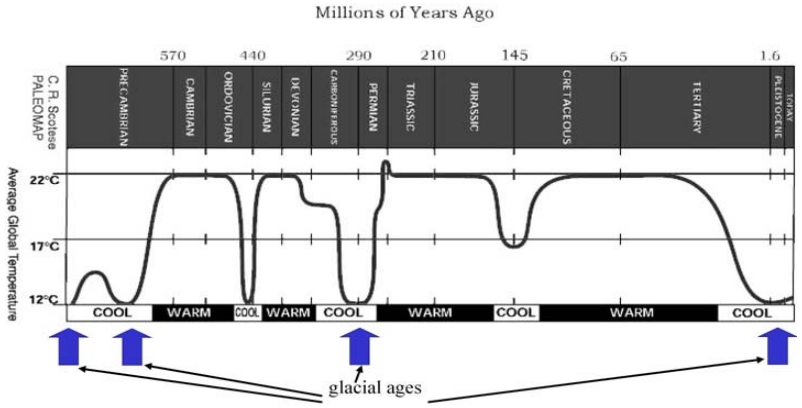


IPCC, 2001

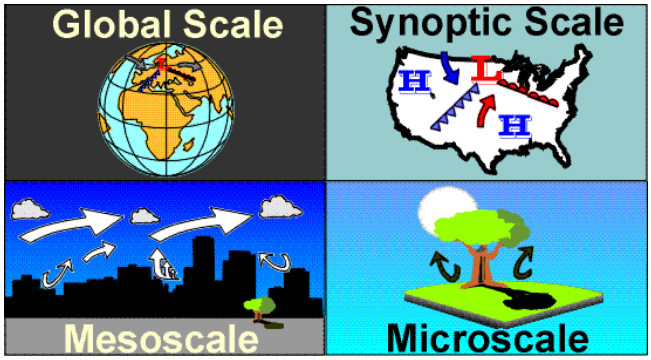
Temporal scales

- **Millions of years**: tectonic, species distributions, etc.
- **Thousands years**: evolution of Earth's orbit
- **Decades to centuries**: recent global warming
- **Days/seasons**: weather, plant growth
- **Day**: heating & cooling, volcanoes, earthquakes, etc.

Temporal scales

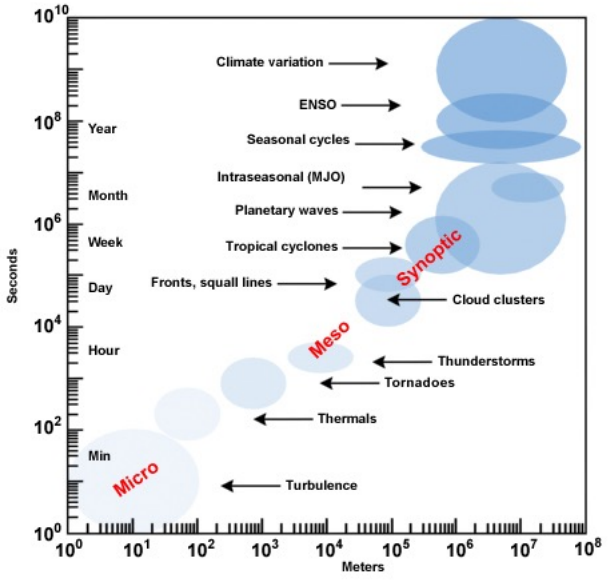


Spatial (meteorology) scales



Scale	Time	Distance	Example
Planetary	Weeks, or longer	1000 to 40,000 km	Westerlies, trade winds
Synoptic	Days to weeks	100 to 5000 km	Cyclones
Mesoscale	Minutes to hours	1 to 100 km	Tornado, T-storm
Microscale	Seconds to minutes	< 1 km	Turbulence, wind gusts

Spatial scales



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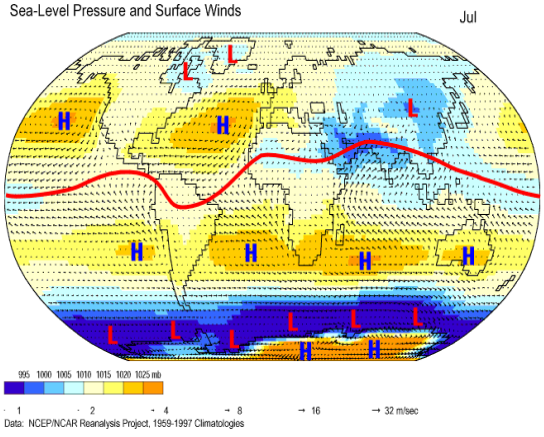
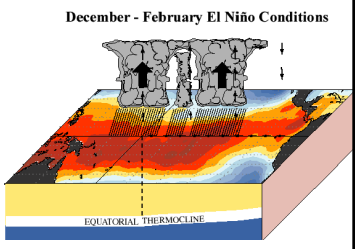
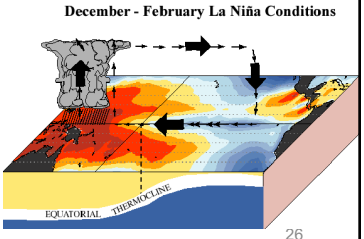
- Planetary scale







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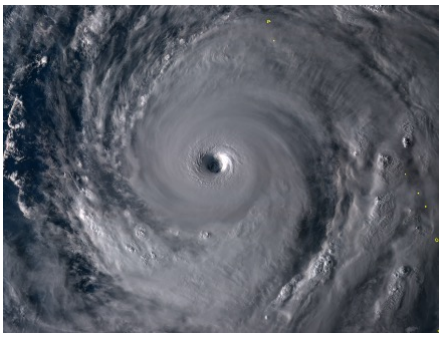
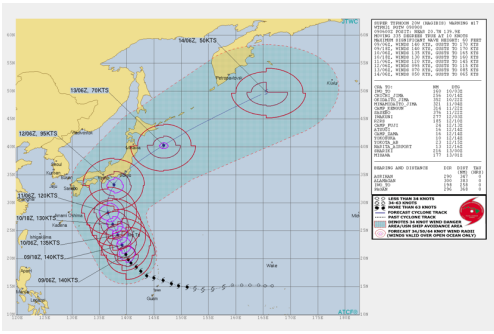
- Synoptic scale

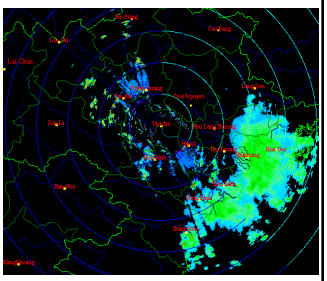


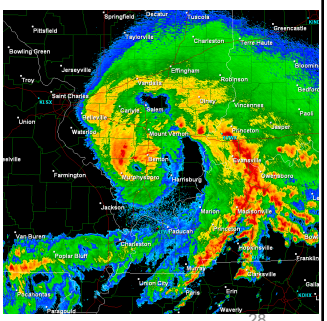
From Himawari satellite



Forecast track of Super Typhoon Hagibis until October 14th, 2019 (JTWC)

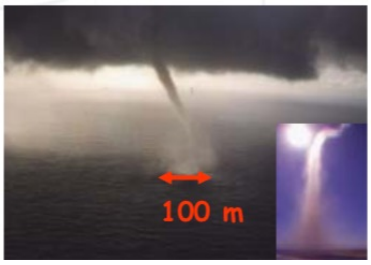
- Mesoscale





- e.g. cumulus, showers, thunderstorms, tornadoes (between microscale & mesoscale)

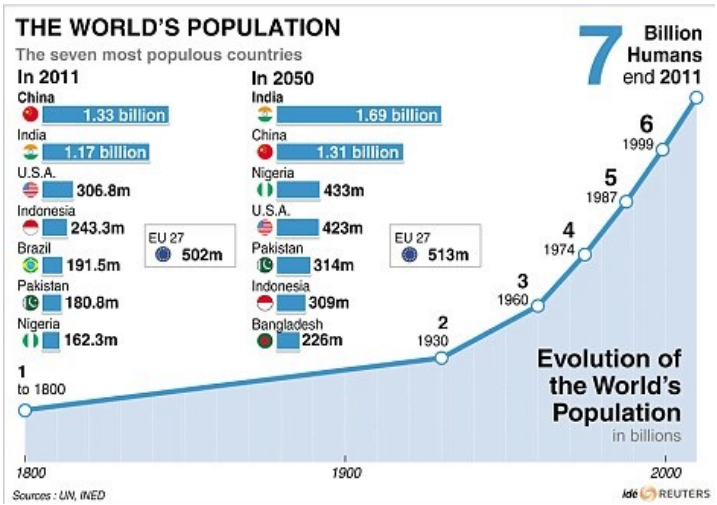
- Microscale



300m

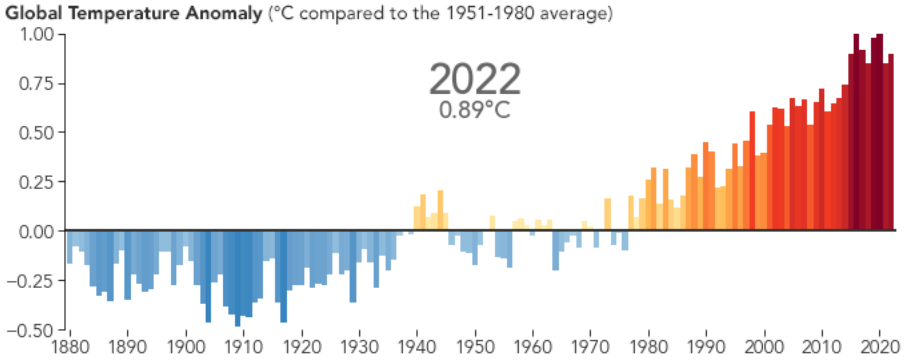
The Earth is changing

7.7 billion (2019)



The Earth is changing

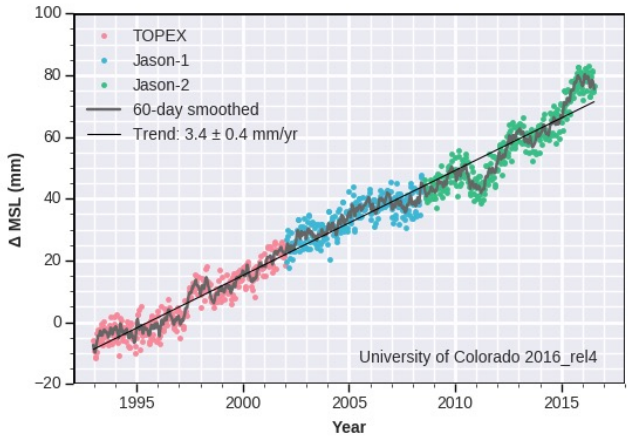
Why?



https://earthobservatory.nasa.gov

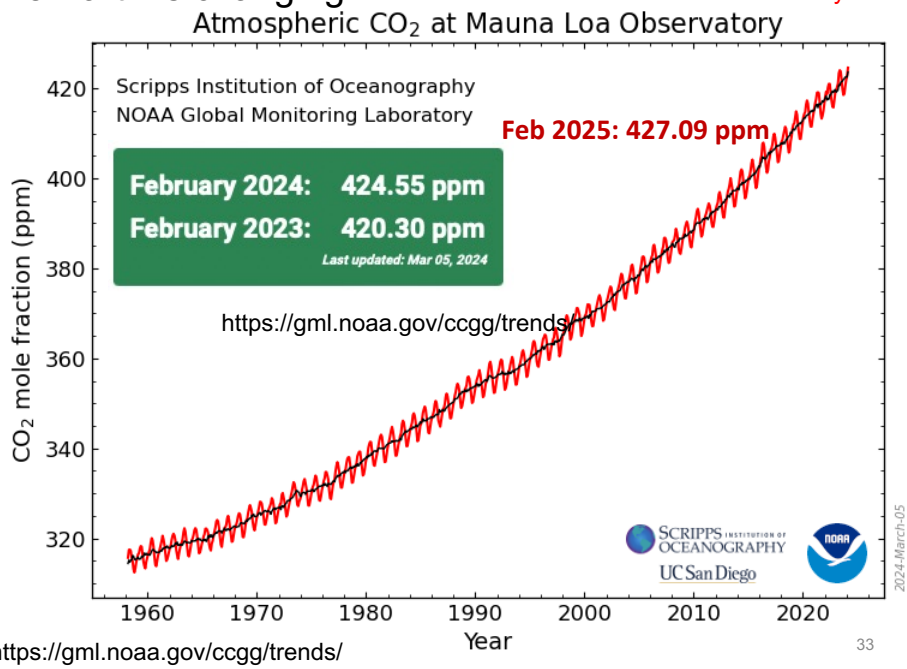
The Earth is changing

Why?



The Earth is changing

Why?



https://gml.noaa.gov/ccgg/trends/

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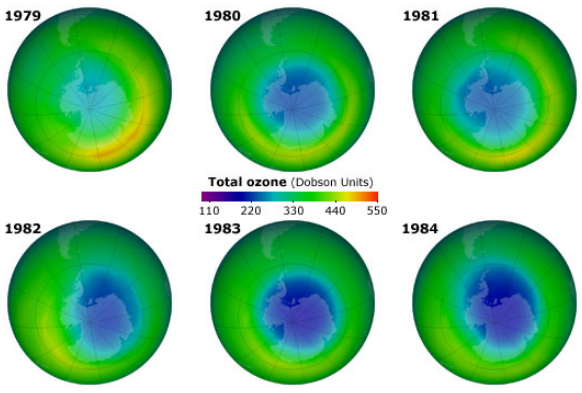
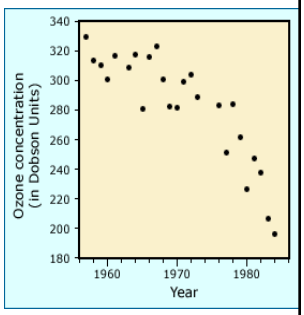
The Earth is changing

Why?



http://undsci.berkeley.edu



Average October ozone levels recorded by Farman's group at Halley Bay, Antarctica

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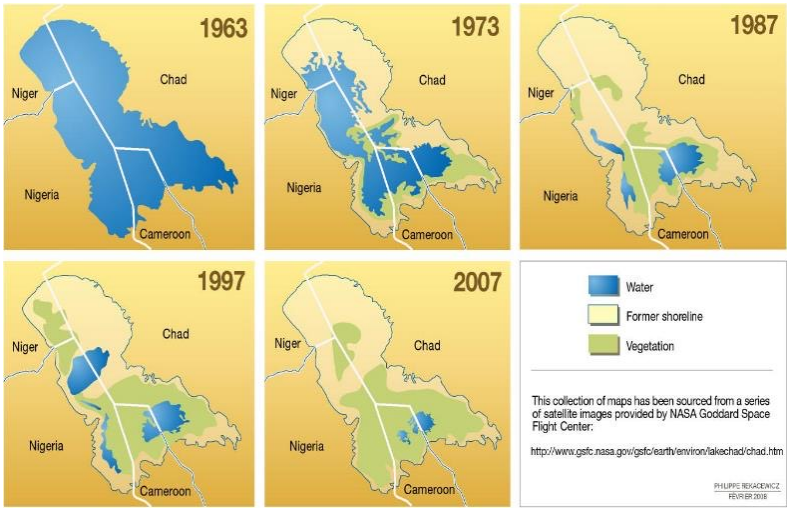
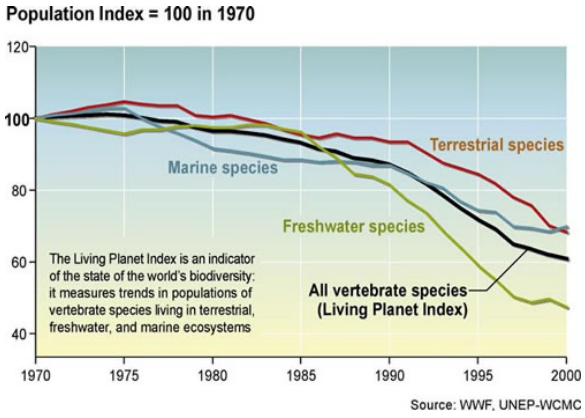
The Earth is changing

Why?



Lake Chad: Freshwater **lake** located in the Sahelian zone of west-central Africa at the conjunction of **Chad**, Cameroon, Nigeria, and Niger

The Earth is changing



Biodiversity:

- The rate of extinction is now ~100 times greater than the natural rate
- → our modern period is often called "The Sixth Mass Extinction" with reference to biodiversity loss

- Our world maybe changing faster than it ever has
- What is the cause?
  - Human activity

Among the following changes, which should be the most serious problem?

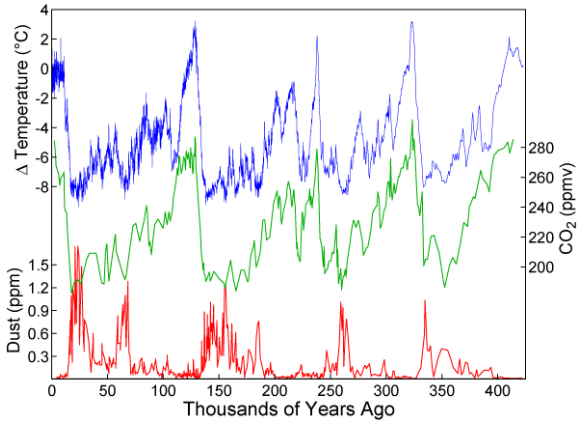
✓ Global warming
✓ Ozone depletion
✓ Biodiversity changes (e.g. the loss of tropical species)

To answer the above question, one way of judging the severity of a problem is to estimate how long it would take Earth to recover

Summary

1. Earth: general characteristics & orbit
2. Milankovitch theory
3. 4 components of the Earth
4. Temporal & spatial scales
5. Changing Earth

Vostock ice core 3623 m (Antarctic) → 420 k yr ago



Q: period of these natural cycles?
Q: relationships: dust, CO2, Temperature?
Q: why there is such a cycle for CO2?

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B2-SA-NDT-Earth System

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Homework 1

1. Download the Vostock Ice Core data:
   - https://www.ncei.noaa.gov/pub/data/paleo/icecore/antarctica/vostok/deutnat.txt
   - https://www.ncei.noaa.gov/pub/data/paleo/icecore/antarctica/vostok/co2nat.txt
   - https://www.ncei.noaa.gov/pub/data/paleo/icecore/antarctica/vostok/ch4nat.txt
   - https://www.ncei.noaa.gov/pub/data/paleo/icecore/antarctica/vostok/dustnat.txt
2. Where is Vostock, and why is this station used for ice core sampling?
3. Plot the figures showing temporal evolutions of CO2, CH4, temperature, and dust
4. Comment on the relationships between these variables and highlight and periods

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B2-SA-NDT-Earth System

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Practice 1: Preparation for Practical session using Python

Install Anaconda/Jupyter-lab

- Install anaconda https://www.anaconda.com/products/individual
- Then launch Anaconda Navigator → Choose Jupyterlab
- Go through the tutorial

https://www.dataquest.io/blog/jupyter-notebook-tutorial/

Or Visual Studio, etc.