EPFL

Exercise session #1

Science of Climate Change

TA also next week (18th Sept)

Michael Lonardi

Teaching Assistant

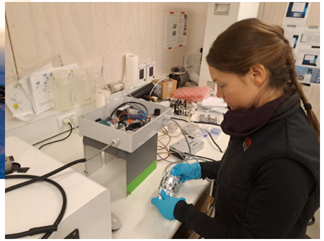
- M.Sc. in Meteorology, Uppsala University, SE
  - 1 year exchange at the University Centre in Svalbard, NO
- Ph.D. in Meteorology (radiative effects of Arctic clouds), University of Leipzig, DE
- PostDoc at EPFL’s Extreme Environments Research Lab (Sion) since Nov. 2023
  - ORACLES project: ORigin of Antarctic CLoud particles and their Effects on the Surface radiation budget

https://www.epfl.ch/labs/eerl

Radiance Calmer

Teaching Assistant

- PhD in Atmospheric Science, Météo-France/CNRS, Toulouse, France
- Postdoc on aerosol-cloud interactions, Laboratoire des Cyclones et de l’Atmosphère, La Reunion Island
- Scientific Collaborator on boundary layer processes and sea ice surface radiation, University of Colorado, Boulder, USA
- Scientific Collaborator at EPFL’s Extreme Environments Research Lab (Sion, Valais) since August 2023



Assignment and poster groups

- Groups of 4 students
- Same group for both assignment and poster
- We would like a mixture of backgrounds in each group (i.e. economics, maths, politics etc...)
    - Rules:
        - Minimum 3 sections represented
        - Maximum 2 students from the same section

- Please organise yourselves and enter your groups in the spreadsheet on moodle: https://docs.google.com/spreadsheets/d/12ciRsNRLwzOoqhVXWVJ32Xbm4dC3B1oPta-1aHIde0I/edit?usp=sharing
- Deadline: 25 September

Deadlines

Important deadlines:

Pre-class survey: 11 September during exercises

Assignment: 27 November 23:59

Poster project proposal: 16 October 23:59

Poster draft submission: 13 November 23:59

Print poster at Repro: 08 December at 10 am latest submission, the SMT master program will pay for the print of 1 poster

Poster presentation: 11 December, 15:00 - 17:30, MED hall

EPFL

Questionnaire

15 minutes

- Please take 15 minutes now to fill this in
- 100% anonymous
- For us to evaluate what you already know (or don't) on the topic
- To help us identify topics to address in class
- Same questionnaire at the end of the semester for you to assess your progress

- One correct choice per question
- If you don't know the answer, don't guess, choose "I don't know"

Science of climate change

Course Settings Participants Grades Reports More

General

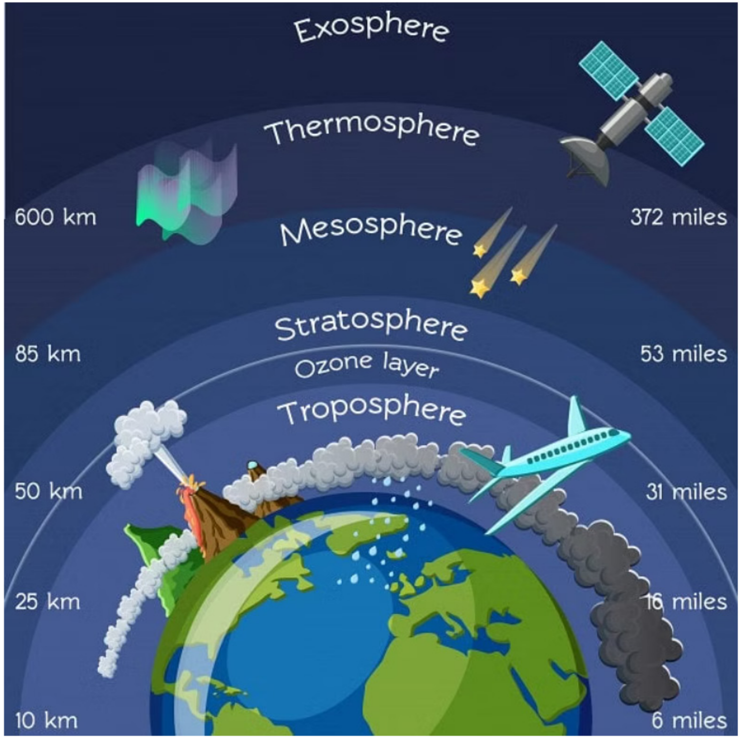
Collapse all

Important to know

Pre-class survey:
Please fill in the survey in the first exercise session: https://forms.gle/VvpZP42rYERh5Xh6A
Results from this form will be used to enhance your learning experience. We will adapt the content of the class according to everyone's background knowledge.

Today's goal:
Basic concepts of the Earth System

Structure of the Atmosphere



Troposphere

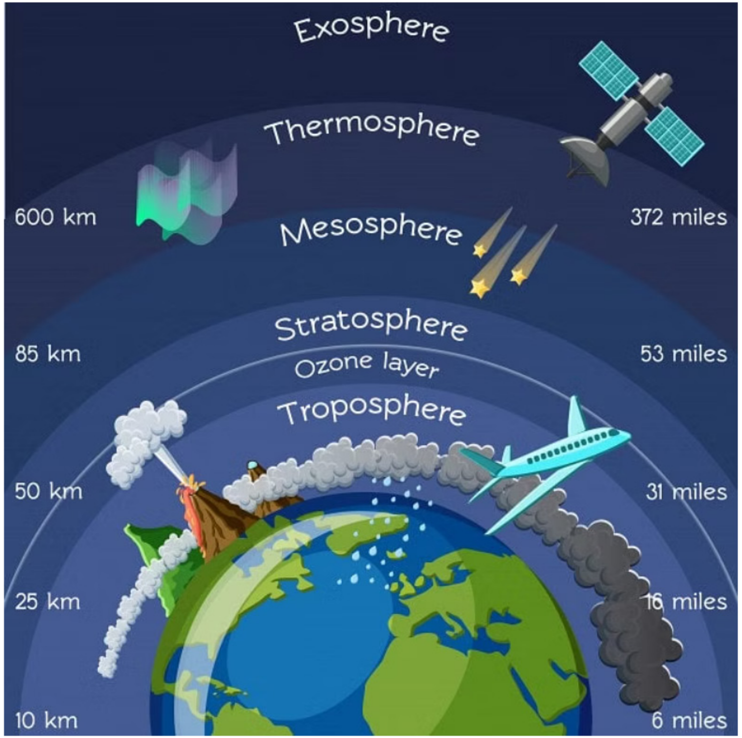
- Lowest layer of the atmosphere, containing the turbulent atmospheric boundary layer
- Further away from surface heat, the air gets cooler which means the troposphere is warmest at the surface
- Nearly all weather occurs in this layer and most clouds appear here
  - This is because 99 % of H2O(v) in atmosphere is here

Stratosphere

- Extending from the top of the troposphere to ~50 km
- Ozone layer is found here
  - Ozone absorbs high energy UV light converting it to heat which means the higher up the stratosphere you go the warmer it is
- Rising T with altitude means that air lacks turbulence and mixing compared to the troposphere. Planes fly here for this reason

https://edurev.in/t/180319/Earth-s-Atmosphere-Composition-Structure

Structure of the Atmosphere



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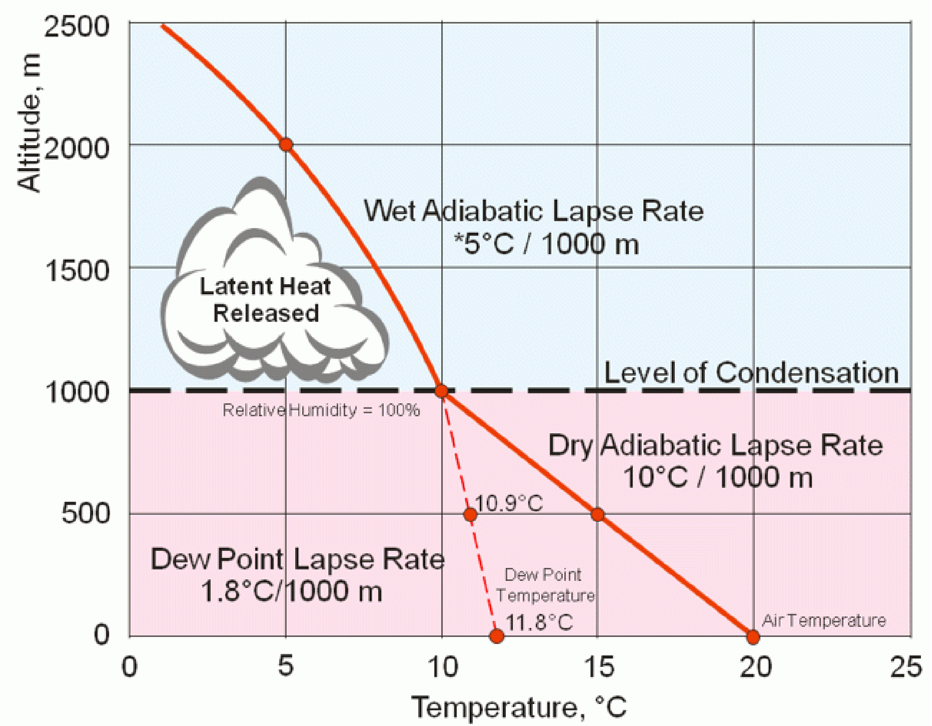
Mesosphere

- Extends up to ~ 85 km
- Temperatures are colder compared to the stratosphere and the thermosphere
- Coldest temps of ~ -90 °C in our atmosphere are found at the top of the Mesophere

Thermosphere

- Layer at the top of the atmosphere which absorbs high-energy x-rays and UV radiation from the sun
- This means it is 100s or 1000s °C in T
- Many satellites orbit within Thermosphere
- Karman line is found in the Thermosphere
    - Approx. boundary between our atmosphere and space

Lapse Rate



https://weatherworkedout.weebly.com/air-masses-and-weather-systems.html

Environmental Lapse Rate: Rate at which temperature decreases with height

Dew point temperature: Saturation temperature for water vapor in air

Dry Adiabatic Lapse Rate: Lapse rate without condensation

Wet Adiabatic Lapse Rate: Lapse rate with condensation

Dew Point Lapse Rate: Rate at which the dew point temperature decreases with height

Level of Condensation: The altitude of the intersection of the dew point lapse rate and dry adiabatic lapse rate given their surface temperature

Lapse Rate

Rate at which temperature changes with altitude

Lapse rates depends on T, pressure and degree of saturation in air parcel
→ all affected by altitude

Adiabatic Lapse Rate

Rate at which temperature of an air parcel decreases with height

Adiabatic – no heat is exchanged with the surroundings

Environmental Lapse Rate

Rate at which temperature of the atmosphere decreases with height
(the lapse rate of non-rising air)

Adiabatic Lapse Rate

Rate at which temperature of an air parcel decreases with altitude

Dry Adiabatic Lapse Rate

- Does not consider condensation
- Depends only on specific heat capacity of air at constant pressure and the acceleration due to gravity.

Wet Adiabatic Lapse Rate

- Considers condensation
- When an air parcel that is saturated with water vapour rises, some of the vapour will condense and release latent heat. This process causes the parcel to cool more slowly than it would if it were not saturated.
- Therefore, this rate would be lesser than the dry adiabatic lapse rate.

Unstable vs Stable atmospheres

Lapse rates help determine atmospheric stability – dependent on the wet or dry adiabatic lapse rate vs the environmental lapse rate
i.e. rate of change in T of air parcel vs the surrounding air

In an unstable atmosphere:
|Environmental lapse rate| > |Moist Adiabatic lapse rate|

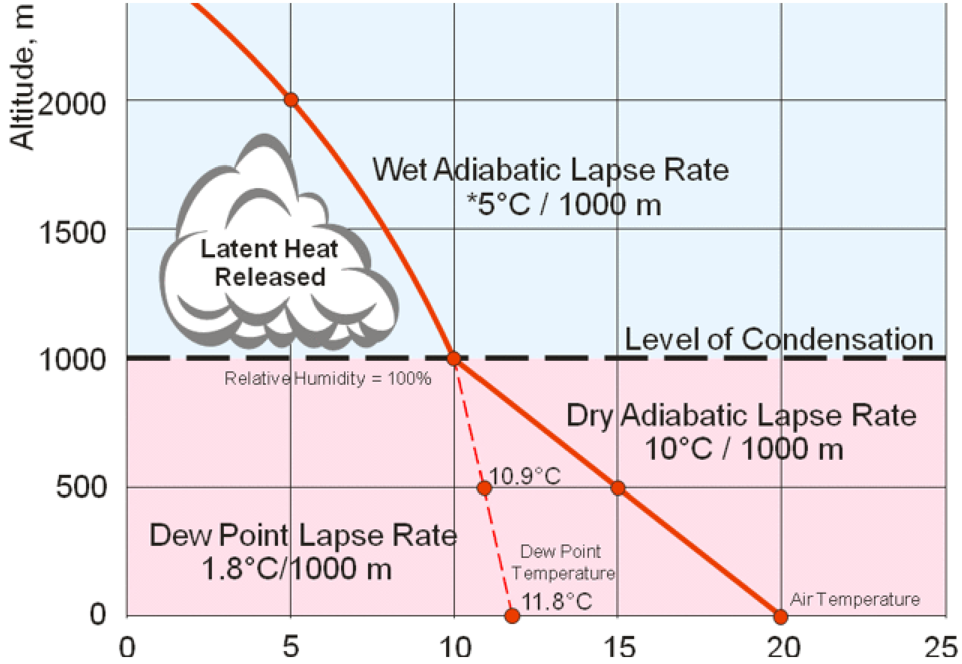
A rising parcel will therefore change temperature, i.e. cool down, more slowly than the environmental lapse rate.

The air parcel will stay warmer and less dense than the surrounding air. – This means that the parcel will rise as it is less dense.

Unstable environments lead to quick changes in weather such as sudden storms.

At which height does the cloud form?

- Ground air temperature is 35 °C.
- Ground dew point temperature is 20 °C.



Exercises

Exercise – Ocean Warming

The specific heat capacity (C_s) is the amount of energy (q) required to change a substance, with mass (m), by a certain temperature (ΔT)

Mass (g)

Temperature change (°C)

Heat (J)

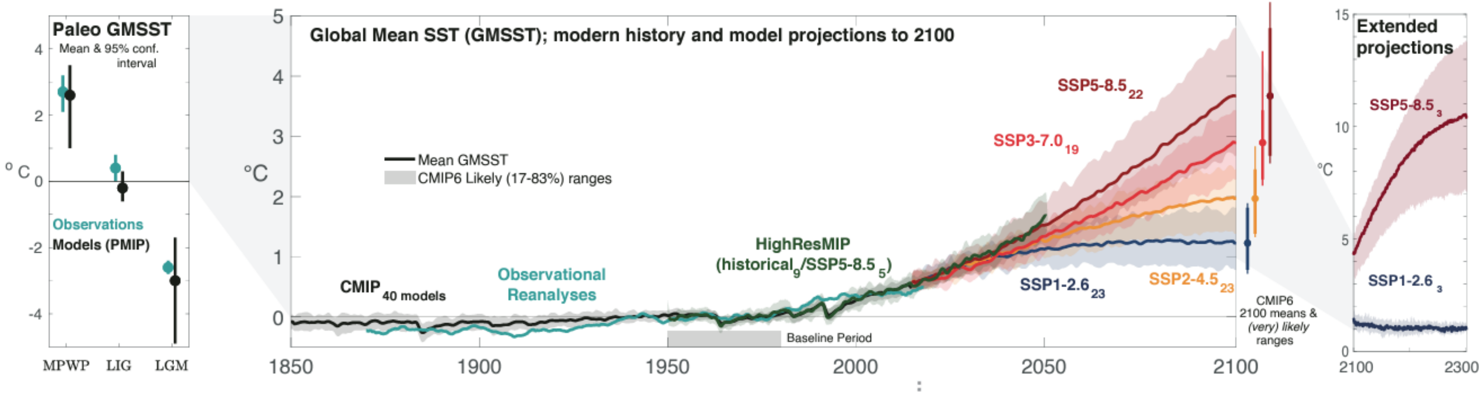
$$q = m \times C_s \times \Delta T$$

Specific heat capacity (J/g · °C)

IPCC report – Ocean Warming

Sea surface temperature (SST) anomalies and maps

Observation-based estimated and CMIP6 multi-model means, biases and projected changes



This is a time series of global mean SST anomaly relative to 1950-1980 climatological mean.
Added to this are paleoclimate reconstructions and observational reanalysis to take us back before 1950.

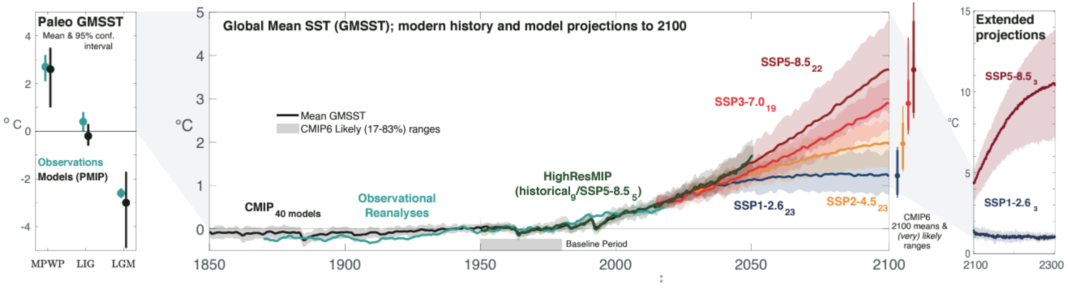
Projecting us forwards are the SSP1 to 5

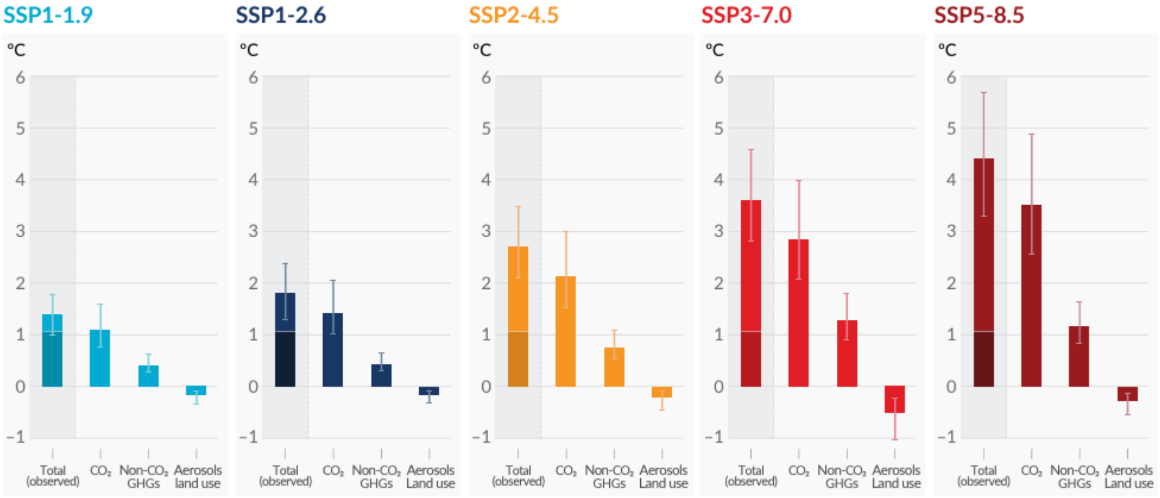
These are **Shared Socioeconomic Pathways** which describe different pathways for continued global development based on varying degrees of climate action, mitigation efforts and socioeconomic growth and decline.

IPCC report – Ocean Warming

Sea surface temperature (SST) anomalies and maps

Observation-based estimated and CMIP6 multi-model means, biases and projected changes





Total warming (observed warming to date in darker shade), warming from CO_2, warming from non-CO_2 GHGs and cooling from changes in aerosols and land use

Exercise – Ocean Warming

Lets consider ocean warming in the context of SSP5 – the pathway with the least mitigation.

The ocean surface temperature is projected to increase on average by 2.89 °C in SSP5-8.5 between 1995 to 2014 and 2081 to 2100. [1]

1. Calculate the amount of energy required to heat the top 1 km of the ocean from this temperature increase.

   Assume the total surface area of the ocean is 361 million km^2 [2]

   Density of seawater is about 1025 kg m^{-3} and the specific heat is about 3850 J $(kg\,°C)^{-1}$ [2]

Be careful with the units

2. How does this compare to the maximum output of large-scale hydropower in Switzerland over roughly the same period (100 years)?

Check the Swiss Federal Office of Energy

3. What are the potential effects of this energy absorption on marine ecosystems and sea level rise?

Hint: 1 W = J s^{-1}

[1] https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-9/ [2] https://rwu.pressbooks.pub/webboceanography/chapter/1-1-overview-of-the-oceans/#:~:text=Oceans%20cover%20an%20area%20of,the%20surface%20area%20(Figure%201.1
[3]http://sam.ucsd.edu/sio210/lect_2/lecture_2.html#:~:text=The%20density%20of%20seawater%20is,3850%20J%2F(kg%20C)

Exercise – Ocean Warming (Solution)

The ocean surface temperature is projected to increase on average by 2.89 °C in SSP5-8.5 between 1995 to 2014 and 2081 to 2100. [1]

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Assume the total surface area of the ocean is 361 million km^2 [2]

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First we need to convert to SI units:

$$area = 3.61 \times 10^{14} m^2$$

We then need to calculate the volume of the top of the ocean by multiplying the area by the depth:

$$Volume = area \times depth = 3.61 \times 10^{14} m^2 \times 1000 = 3.61 \times 10^{17} m^3$$

To calculate the energy required, Q, we need the mass:

$$m = v \times p = 3.61 \times 10^{17} m^3 \times 1025\, kg\, m^{-3} = 3.7 \times 10^{20}\, kg$$

Therefore Q is:

$$\mathrm{Q} = m \times c \times \Delta T$$

$$Q = 3.7 \times 10^{20}\, kg \times 3850\, J kg^{-1} {}^{\circ}C^{-1} \times 2.89\, {}^{\circ}C$$

$$Q = 4.1 \times 10^{24} J$$

Exercise – Ocean Warming (Solution)

$Q = 4.1 \times 10^{24} J$

2. *How does this compare to the <u>maximum output of large-scale hydropower in Switzerland</u> over roughly the same period (100 years)?*

From https://www.bfe.admin.ch/bfe/en/home/supply/renewable-energy/hydropower/large-scale-hydropower.html#:~:text=They%20generate%20a%20maximum%20output,Limmat%20flow)%20and%20the%20Rhone

maximum output of hydropower in Switzerland is 16 576 MW

1 MegaWatt = 100 000 J s^{-1}
16 576 MW = $1.6576 \times 10^{10} J\ s^{-1}$

Convert years to seconds :
$100 \times 365 \times 24 \times 60 \times 60 = 3.1536 \times 10^{9}\ seconds$

$Total\ energy = 1.6576 \times 10^{10} Js^{-1} \times 3.1536 \times 10^{9}\ seconds = 5.2 \times 10^{19} J$

Exercise – Ocean Warming (Solution)

2. *How does this compare to the <u>maximum output of large-scale hydropower in Switzerland</u> over roughly the same period (100 years)?*

$$Total\ energy = 1.6576 \times 10^{10}\ J\ s^{-1} \times 3.1536 \times 10^{9}\ seconds = 5.2 \times 10^{19} J$$

$$\frac{Energy\ required\ to\ heat\ ocean}{Energy\ required\ from\ Swiss\ hydropower} = \frac{4.1 \times 10^{24} J}{5.2 \times 10^{19} J} = 7.9 \times 10^{4}$$

Energy required to heat the top 1km of ocean by 2.89 °C is ~80,000 times that of the total energy output from large scale hydropower in Switzerland over 100 years.

Exercise – Ocean Warming (Solution)

3. What are the potential effects of this energy absorption on a) marine ecosystems

Ocean warming

- Coral bleaching
- Disrupted migration patterns
- Algal bloom frequency increases

Ocean acidification

Ocean stratification and deoxygenation

- Surface waters become less dense causing stratification of stable warmer ocean layers on top of cooler layers
- Limits mixing reducing vertical transport of nutrients, oxygen levels in deeper waters reduce and marine organisms dependant on this upwelling for food will die
- Decrease in biodiversity and disruption of food chain

and b) sea level rise?

Thermal expansion

- Absorption of increased energy expands upper layers of the ocean directly contributing to sea level rise

Melting of ice caps and glaciers

- Melting of ice caps and glaciers adds freshwater to the ocean accelerating sea level rise

Coastal erosions and flooding

Saltwater intrusions

- Rising sea levels cause saltwater to intrude into freshwater aquifers
- Threatens drinking water and agriculture in coastal regions