

Climate Change Feedback

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Feedback

Feedback = when a system is disturbed, how the system's response affects the disturbance

Negative-feedback = damps disturbance (restores equilibrium)

Positive-feedback = amplifies disturbance (disrupts equilibrium)

$I = \sigma T^4$ is a negative feedback,
because it acts to restore equilibrium

What is positive feedback?

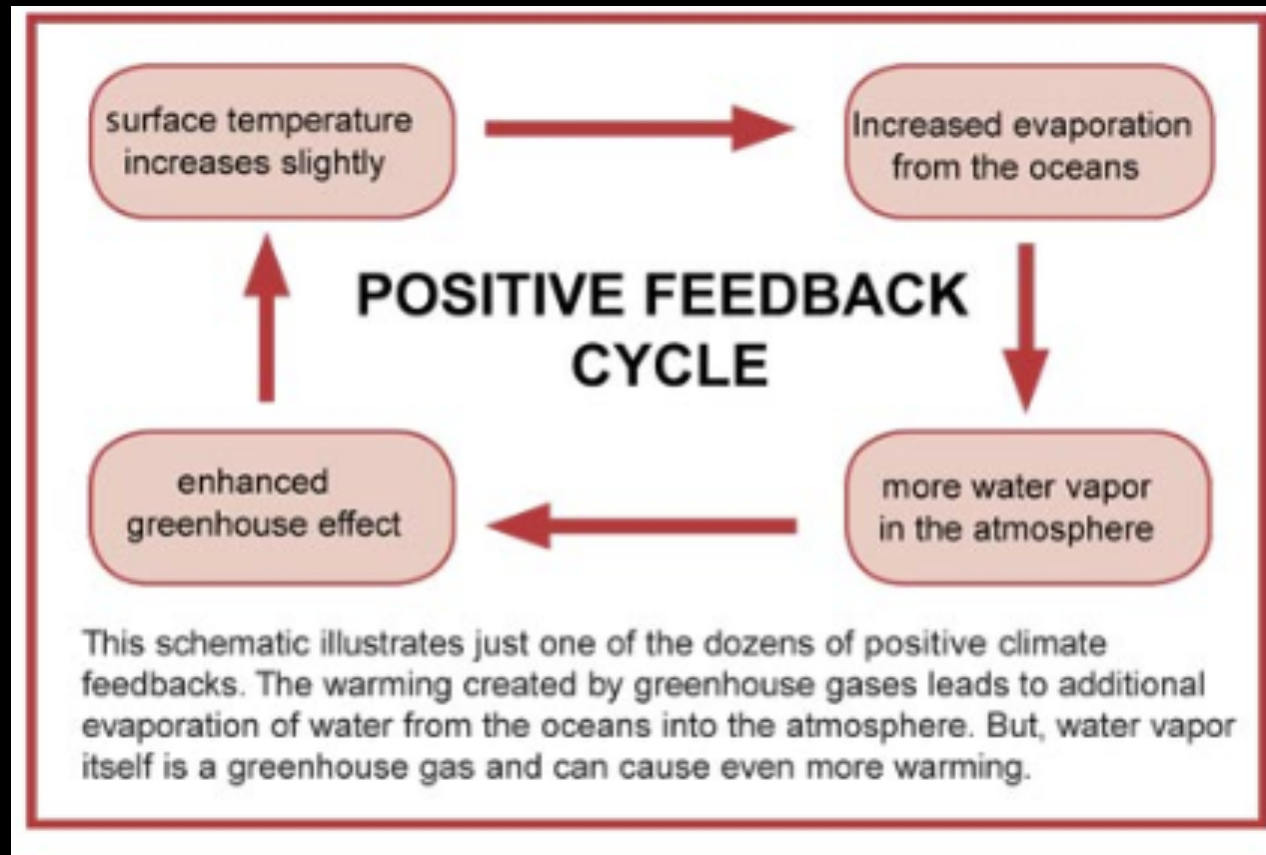
Feedback process that amplifies the effect of climate forcing

- An action causes a reaction, and the reaction causes more of the action, which in turn causes more reaction
- Cause runaway reactions
- Difficult to stop once they reach a tipping point

Main positive feedbacks

- In ocean
 - Methane clathrate
 - Ice albedo
 - CO₂ solubility (warm vs. cold water)
- In land
 - Permafrost (methane release)
 - Forests fires

What is positive feedback?



What is negative feedback?

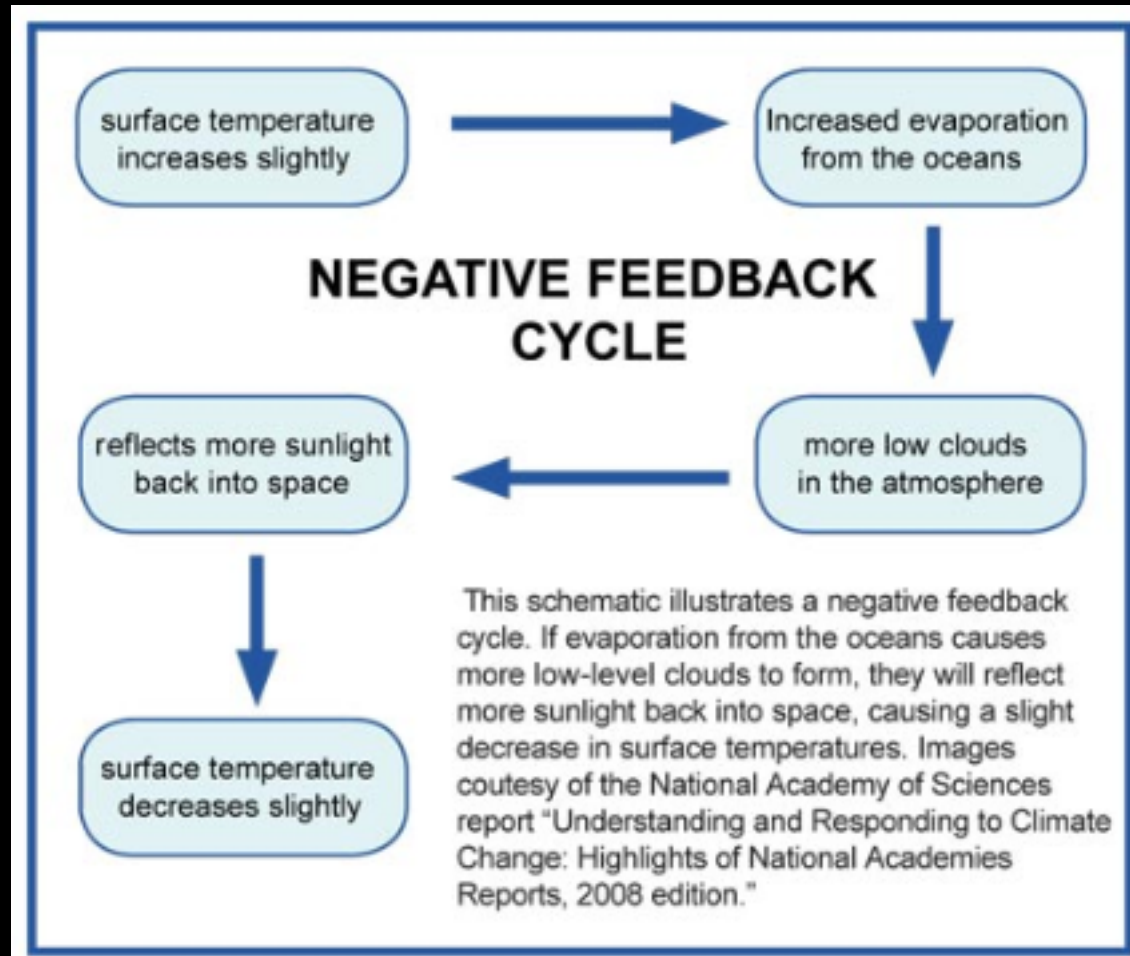
Feedback process that reduces the effect of climate forcing

- Very long time lags

Main Negative Feedbacks

- Le Chatelier's Principle
 - Carbon sinks (ocean - solubility pump)
- Chemical weathering (limestone, shells)
- Net primary productivity (photosynthesis)
- Lapse rate
 - Reduce the rate of temperature decrease with height

What is negative feedback?





CARBON FEEDBACK LOOPS

Important Data

- Total carbon currently stored in peatlands
390–455 gigatonnes
= 1/3 total land-based carbon store
= 1/2 amount of carbon already in the atmosphere
- Amount of carbon stored in the oceans
50 x amount of carbon in the atmosphere

Positive Feedback 1: Oceans

Temperature

- warmer water = decreased solubility of CO₂
 - increases atmospheric CO₂
 - accelerates global warming

Ecosystem Sequestration

- warmer water = lesser ability to sequester carbon
 - reduces nutrient levels
 - phytoplankton do not pump as much carbon

Positive Feedback 2: Terrestrial

Forest Cover

- Loss of forest cover = loss of biomass to sequester carbon
+ increased soil respiration
→ accelerates global warming

Productivity

- Higher atmospheric CO₂ → stimulates primary productivity
→ increases release of dissolved organic carbon (DOC) from peat bogs into water courses
→ more DOC enters the atmosphere
→ accelerates global warming

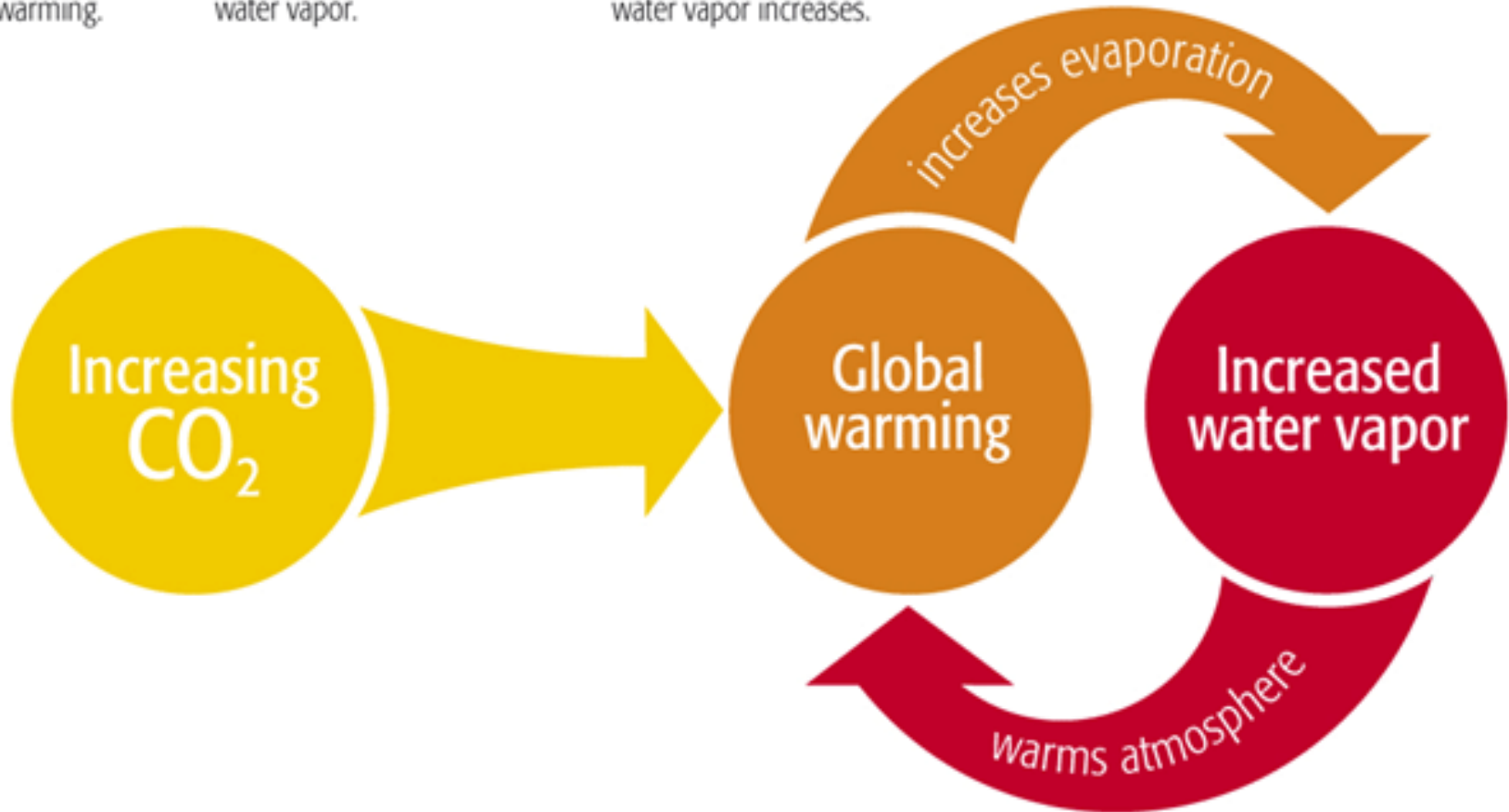
Positive Carbon Feedback Loop

POSITIVE FEEDBACK LOOP

Adding carbon dioxide to the atmosphere tends to warm the atmosphere, causing global warming.

The warm atmosphere causes surface water to evaporate and become water vapor.

Since water vapor is a greenhouse gas, the atmosphere tends to warm even more as water vapor increases.



Negative Feedback Loops

1) Le Chatelier's principle: shift in chemical equilibrium.

- Ultimately, 75% of CO₂ emitted by human activities will dissolve into the ocean over a period of centuries.

2) Chemical weathering: removes CO₂ from the atmosphere.

3) Biosequestration: captures and stores CO₂ by biological processes.

- Formation of shells by organisms in the ocean
- Conversion of CO₂ to limestone

4) Net Primary Productivity

- Plant photosynthesis increases in response to increasing concentrations.



METHANE FEEDBACK LOOPS

Methane

- Global Warming Potential

20 years	100 years	500 years
56	21	6.5

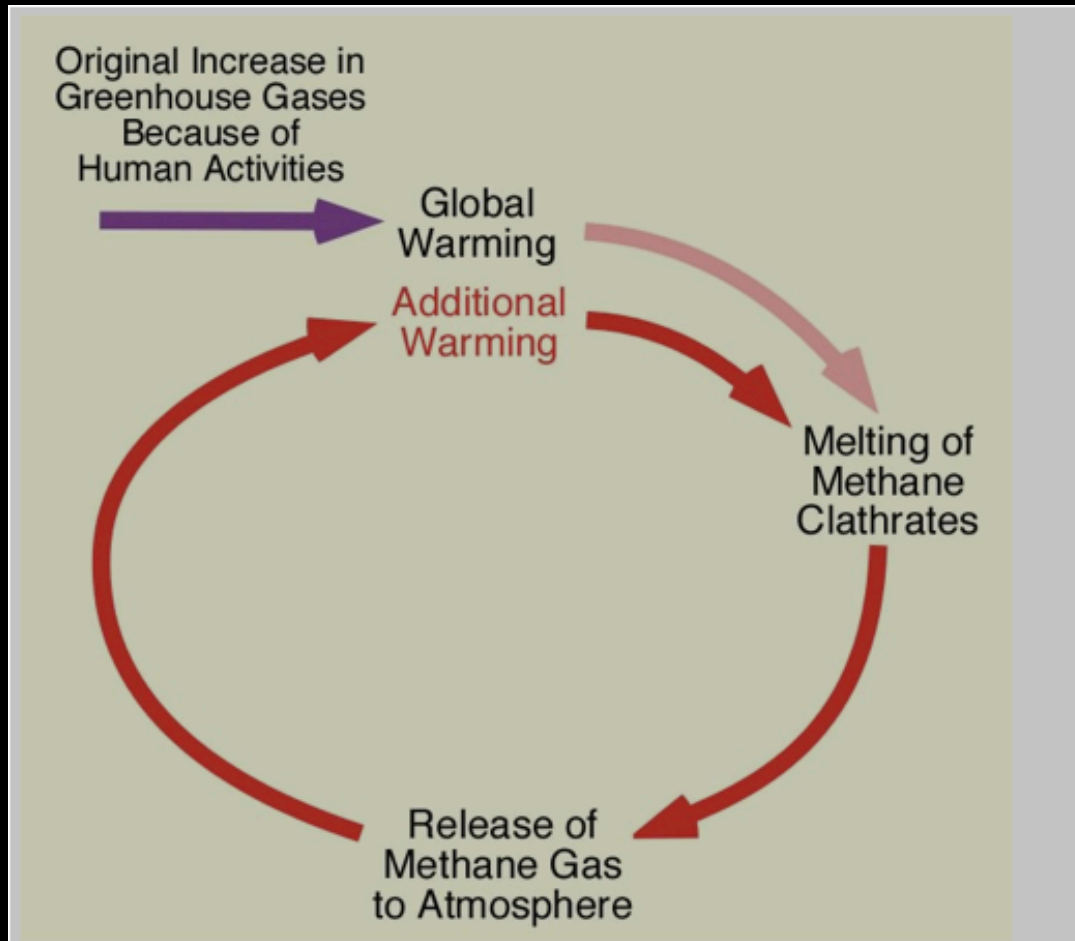
Positive Feedback 1: Methane Clathrate

- Methane clathrate is a molecular cage made up of ice water which holds methane gas in its crystal structure.
- Typically found at the bottom of the ocean where the temperature is low and pressure is high.
- Scientists believe clathrates hold 5-20% of fossil carbon.
- Clathrates can be "explosively" unstable if the temperature increases or the pressure decreases.



Specific structure of a gas hydrate piece, from the subduction zone off Oregon
Source: Wusel007

Methane Clathrate Feedback Loop



Positive Feedback 2: Permafrost

- Arctic soils lock away billions of tonnes of methane.
- Increasing temperatures → melting permafrost
→ releases methane → accelerates global warming
- Methane emissions from the Arctic have risen by over **30%** in last 5 years.
- Potential to release **700,000 million tonnes** over the next few decades



WATER VAPOR FEEDBACK LOOPS

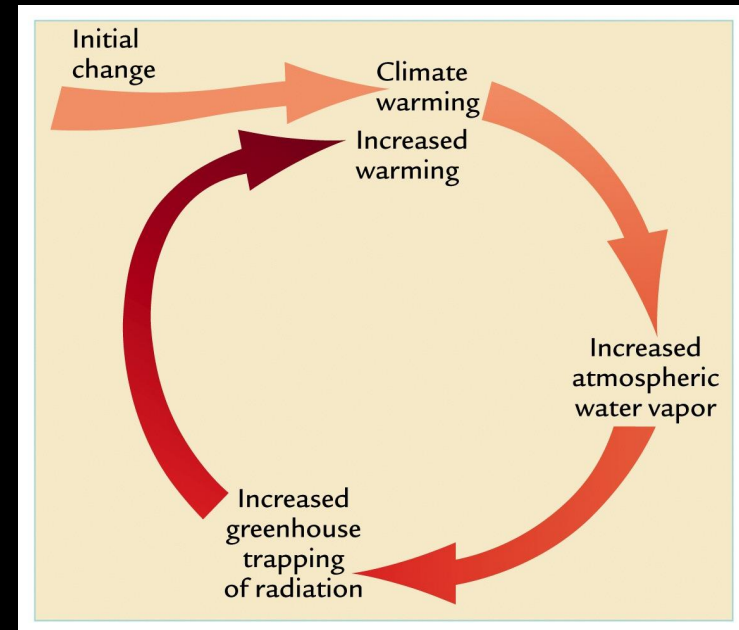
Water is a greenhouse gas

- Water is the most abundant greenhouse gas in the atmosphere (80% by mass of all greenhouse gases)
- It is also the most potent owing to the presence of the hydroxyl bond which strongly absorbs infra-red photons.
- Water vapor is responsible for 60% of the global warming effect
- However, water's global warming potential (GWP) is not calculated because of its very short residence time (around 10 days) compared to CO₂ (100 years)

Positive Feedback 1: Atmospheric Vapor

Water's concentration in the atmosphere is dependent on air temperature, and cannot be directly influenced by human action

According to the Clausius - Clapeyron relation, vapor pressure of any substance increases non-linearly with temperature, which in the case of water leads to an increase in the amount of vapor in the atmosphere.



Stratospheric vapor is even worse

- Research led by Susan Solomon of NOAA showed that 31% of the global warming recorded during the 1990s was caused by increased concentrations of water vapor in the upper stratosphere.
- A subsequent decline in water vapor concentration in 2000 might be the reason for the slowdown in global warming since 2000
- The reasons behind the rise and fall of vapor concentration are not clear but could be related to changes in the temperature of sea surface

Positive Feedback 2: Ice-Albedo

Albedo is the reflection coefficient of an object, between 1 (most reflective) and 0 (black object).

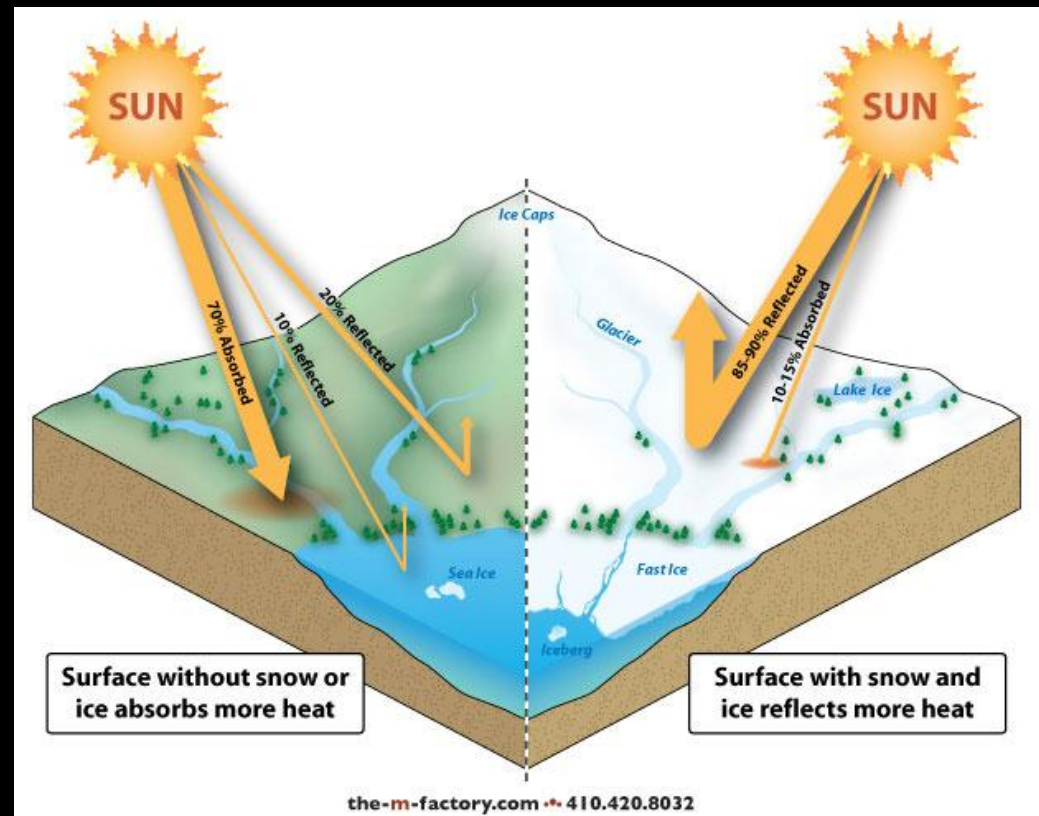
Relevant Albedos

Ocean Ice: 0.5-0.7

Fresh snow: 0.8 - 0.9

Green Grass: 0.25

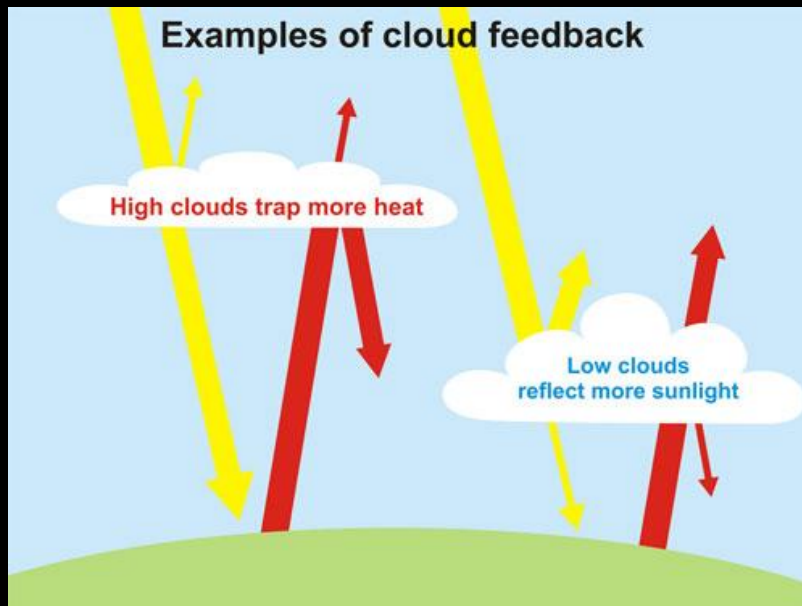
Bare soil: 0.17



Positive/Negative Feedback: Clouds

Global warming will lead to the formation of more clouds

Clouds act as two-sided



The net effect of the the cloud cover on global temperature is uncertain. Different climate models use different assumptions

Skeptics say the net impact is negative - cooling

Believers say there is enough evidence to believe it is positive

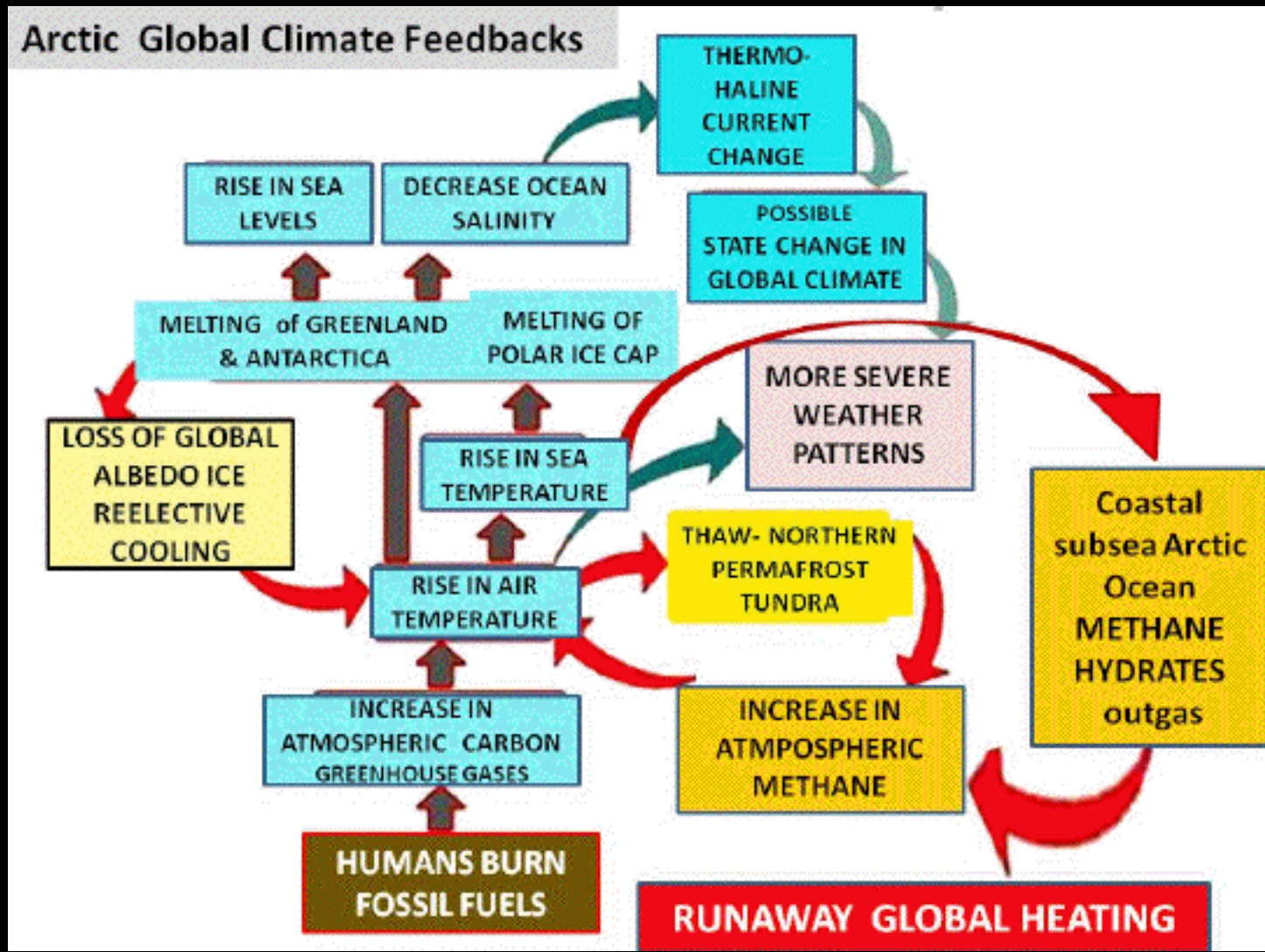


POLAR AMPLIFICATION

Polar Amplification in the Arctic

- Global warming in Arctic = **2 x** as fast
- Current increase, 2.5°C
- Projected increase, 10°C by 2100
- Past tipping point

Arctic Global Climate Feedbacks



Key Terms

- Feedback loop
- Runaway climate change
- Albedo
- Stefan Boltzmann Law
- Clathrate Gun Hypothesis
- Permafrost
- Le Chatelier's principle
- Polar Amplification
- Equilibrium vapor pressure

References

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- [2] http://www.giss.nasa.gov/research/features/200409_methane
- [3] http://www.eoearth.org/article/Greenhouse_gas?topic=60586
- [4] <http://www.guardian.co.uk/environment/2010/jan/14/arctic-permafrost-methane>
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- [7] <http://en.wikipedia.org/wiki/Albedo>
- [8] <http://www.skepticalscience.com/clouds-negative-feedback.htm>
- [9] <http://www.time.com/time/health/article/0,8599,1986010,00.html>

Possible Exam Questions

- 1) Give 2 examples of positive climate change feedback cycles, and explain their effect on global warming.
- 2) Give 2 examples of negative climate change feedback cycles, and explain their effect on global warming.
- 3) Explain why the Arctic experiences an amplified global warming effect.