Indian Institute of Technology, Kanpur

Department of Earth Sciences

ES0213A: Fundamentals of Earth Sciences

Lecture 06. Principles of the Earth

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Aims of this lecture

- Earth Systems – is it a closed or open system
- Positive and negative feedbacks in Earth Sciences
- Cycles of different elements of the Earth

System: Open Vs. Closes

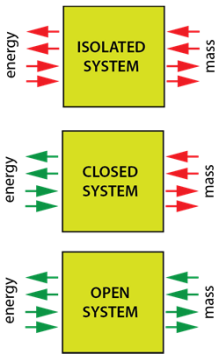
- We have learnt: A system is a group of related objects or parts or components that work together to form a whole. The boundary of the "whole" defines the limit of the system.

  The system is classified and characterized by if it exchanges mass and/or energy across its boundary.

- ISOLATED system: A system that does not allow the exchange of either mass and/or energy with its surroundings.

- CLOSED system: A system that does not allow the exchange of mass, but energy (mostly in the form of heat) with its surroundings.

- OPEN system: A system that allows the exchange of both mass and energy with its surroundings.



The mutual interactions – Earth as a System

- The EARTH SYSTEM -
  - is an open system.
  - is a closed system.
  - is both open and closed system.
- Are we losing and / or gaining something (material/mass)?
  - IN: meteorites, asteroids, comets
  - OUT: hydrogen, helium
- Implications of living inside a near closed system….
  - Everything (e.g., resources) are finite and limited
  - Change in one component affect others
  - Cannot "dump" or throw-away anything

Are you aware of something called "asteroid mining"

The general approach to study Earth as a System

- Identification of the components and their mutual interactions
- Determination of the rate of mutual interactions - the RESIDENCE TIME
- Identification of the FEEDBACK loops – amplification (positive) and / or attenuation (negative) of the features

FEW BASIC TERMS

Reservoir: amount of material of interest in a given time

Flux: amount of material added to (*the source*), or removed from (*the sink*) reservoir, in a given period of time

Steady state: no net change in amount of materials [source =sink]

Resident time: the time requires to empty / fill the reservoir

$$Resedinet\ time = \frac{capacity\ of\ the\ reservoir}{total\ source\ or\ total\ sink}$$

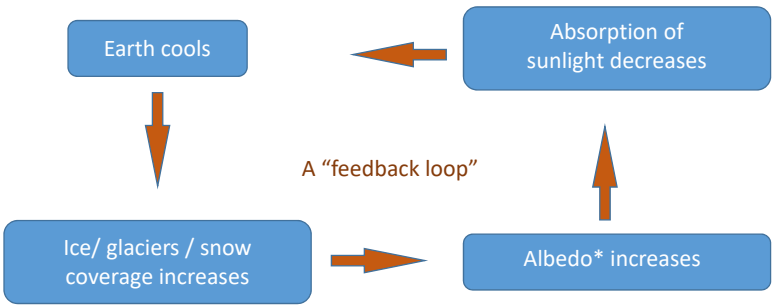
Feedbacks

- **Positive (+) feedbacks** amplify a disturbance and add more to the original sate.
- **Negative (-) feedbacks** return components of a system towards their original state after a small perturbation – act like a stabilizers and eliminates the stimulus.

Remember please: The feedback loops have nothing to do with GOOD (+) or BAD (-)

Feedbacks

- The Earth System, in general, is governed by either positive or negative feedback loops…

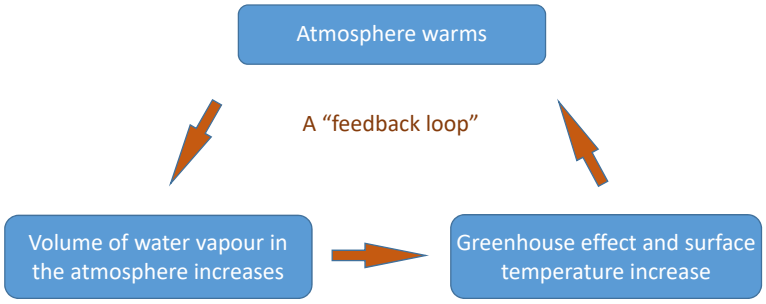


Positive or negative feedback loop?

***Albedo** is a measure of how much light that hits a surface is reflected without being absorbed.

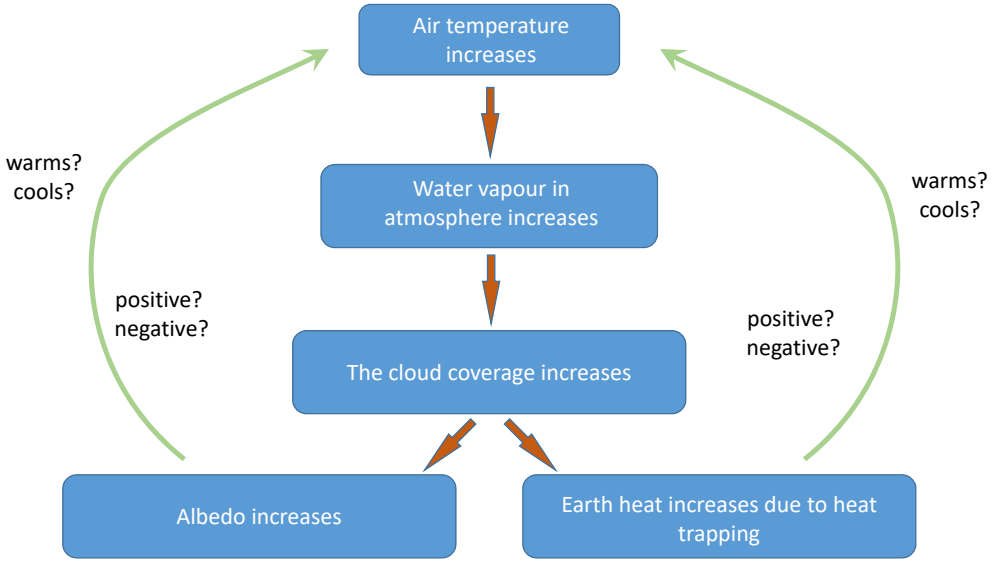
Feedbacks

- The Earth System, in general, is governed by either positive or negative feedback loops…



Positive or negative feedback loop?

Feedbacks – more examples



Chaos

- The feedback loops and the mutual interactions are so complicated that the best explanation / prediction is provided by **CHAOS THEORY** – a science of surprises, extreme nonlinearity and unpredictability.
  - Butterfly effect (sensitivity): some complex dynamical systems exhibit unpredictable behaviors such that small variances in the initial conditions could have profound and widely divergent effects on the system's outcomes.
  - Fractal Geometry (Self-similarity): An object looks the same at any scale. Many natural objects approximate fractal geometry, such as clouds, snowflakes, river drainage systems, and coastlines.
  - Self-organized criticality (SOC): A dynamic system will move toward a critical or emergent, state, by natural processes.

Fractal Geometry and Natural Power Law

- The relationship between the size of an earthquake and its frequency of occurrence follows fractal statistics. Very large earthquakes are rare (M>8 - 9) and very small earthquakes (M<2-4) are very frequent.

Magnitude	Last week	Last month	Last year
< 2	132	635	7384
2 - 3	168	776	10267
3 - 4	17	95	1527
4 - 5	6	57	547
5 - 6	0	4	75
>= 6	0	0	4
Total	323	1567	19804

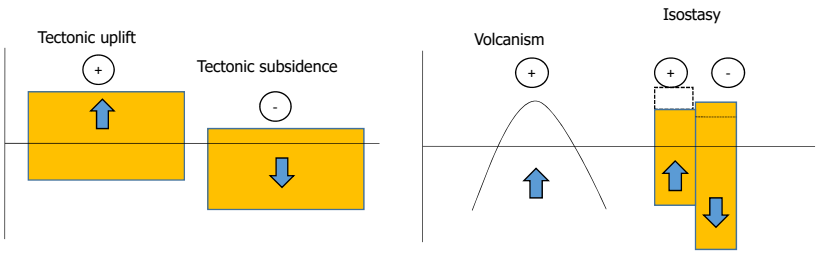
Earthquake Data, New Zealand (Geonet)

- There is a power law relationship between how many large and how many small earthquakes there must be in a given region per unit time. For instance, every year and globally, there is on average just one earthquake of magnitude eight, ten magnitude seven, one hundred magnitude six, one thousand magnitude five, and so on.

More on this in the Earthquake lecture

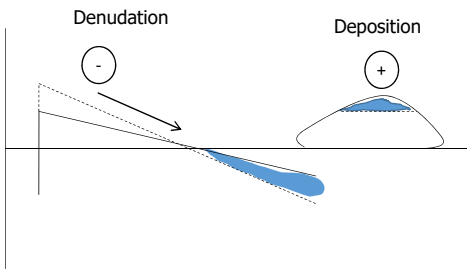
Some key concepts - ENDOGENIC processes

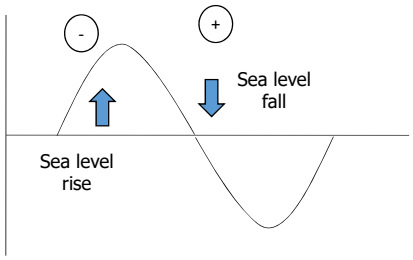
- **Endogenic Processes –** An action/object coming from within a system. The process originates in the earth's interior and are governed by the forces inherent in the earth and affected little by external influences.



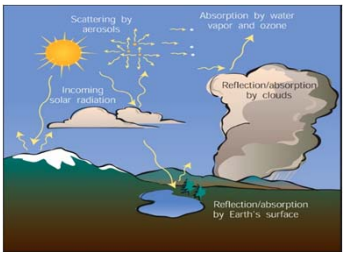
Some key concepts - EXOGENIC processes

- **Exogenic Processes –** an action/object coming from outside a system. The processes derive their energy from sources external in relation to the earth – i) solar radiation, ii) wind-action; iii) impacts by extra-terrestrial objects etc.

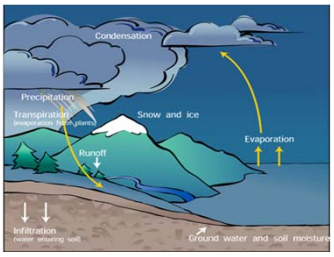




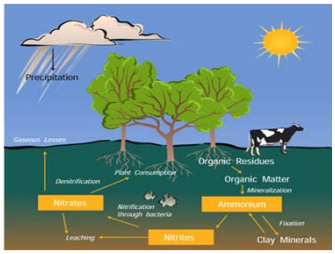
Earth's various cycles



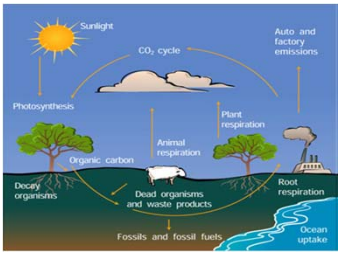
Energy Cycle



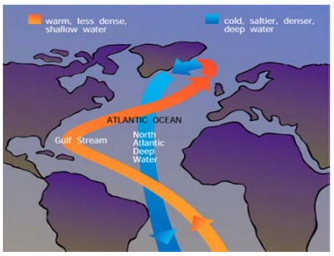
Water Cycle



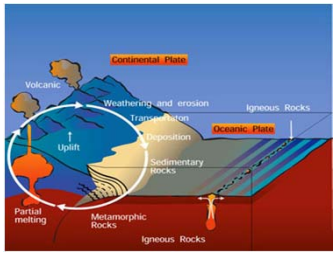
Nitrogen Cycle



Carbon Cycle



Ocean Cycle



Rock Cycle

Next Lecture

Energy in Earth: Sources and Distributions