Factors and processes controlling climate variations at different time scales: supporting documents

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Goals

- understand factors and processes controlling climate variations at different time scales
- place present-day climate change in the context of past variations and to identify its specificities.

1. The Earth radiative budget
2. Climate variations at geological time scales (>million years)
3. Climate variations at orbital time scales (tens of thousands years)
4. Anthropogenic climate change
1) The Earth radiative budget

\[ (1 - \alpha) \cdot S_0 = (1 - G) \cdot \sigma \cdot T^4 \]
1) The Earth radiative budget

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(1 - \alpha) \cdot S_0 = (1 - G) \cdot \sigma \cdot T^4
\]

- Exercise 1: vary \(S_0\), \(\alpha\), \(G\)
1) The Earth radiative budget

\[ (1 - \alpha) \cdot S_0 = (1 - G) \cdot \sigma \cdot T^4 \]

- Exercise 1: vary $S_0$, $\alpha$, $G$
- Exercise 2.1: equilibria
Equilibrium states

\[ F_{\text{out}}/B_8 \text{CO}_2 = 62500 \text{ ppm} \]
\[ F_{\text{out}}/B_8 \text{CO}_2 = 12500 \text{ ppm} \]
\[ F_{\text{out}}/B_8 \text{CO}_2 = 30\% \]

\[ F_{\text{in}} \]

\[ F_{\text{out}}, \text{CO}_2 = 100\text{ppm} \]
\[ F_{\text{out}}, \text{CO}_2 = 500\text{ppm} \]
\[ F_{\text{out}}, \text{CO}_2 = 12500\text{ppm} \]
\[ F_{\text{out}}, \text{CO}_2 = 62500\text{ppm} \]
\[ F_{\text{out}}, \text{CO}_2 = 30\% \]

snow ball earth

no ice-sheets
2) Variations at geological time scales

Snow ball evidence

Sediments in Namibia

-cap dolostone
-ice-rafted debris

Ombaatjie section
Snow ball earths in Earth’s history

[Diagram showing geological time periods with snowballs indicating certain epochs]
Geological evolution of temperature

Phanerozoic Climate Change

δ¹⁸O (parts per thousand)

-3
-2
-1
0
1
2
3

Glacial Periods

Short-Term Average
Low Frequency Mode

HOT
COLD

Millions of Years Ago

N  Pg  K  J  Tr  P  C  D  S  O  Cm

0  50  100  150  200  250  300  350  400  450  500  542
Geological evolution of CO2

Phanerozoic Carbon Dioxide

Models
- GEOCARB III
- COPSE
- Rothman

Measurements
- Royer Compilation
- 30 Myr Filter

Carbon Dioxide (ppmv)

Times Quaternary Average

Millions of Years Ago

N  Pg  K  J  Tr  P  C  D  S  O  Cm

0  100  200  300  400  500

0  1000  2000  3000  4000  5000  6000  7000  8000
Carbon cycle

- sources ans sinks?
Carbon cycle

- sources and sinks?

- 110 Gt/yr photosynthesis
- 110 Gt/yr respiration decomposition
- 90 Gt/yr ocean
- 90 Gt/yr vegetation
- 0.083 Gt/yr land alteration
- 0.083 Gt/yr volcanism
- 0.083 Gt/yr carbonates
Carbon cycle

- sources and sinks?

- exercise 2.2
Partial summary (1/2)

- **Cenozoic**
  - Quaternary: 2.6
  - Tertiary: 66
- **Mesozoic**
  - Cretaceous: 146
  - Jurassic: 202
  - Triassic: 251
- **Paleozoic**
  - Permian:
    - Pennsylvanian: 299
    - Carboniferous: 318
  - Devonian:
    - Silurian: 416
    - Ordovician: 444
  - Cambrian: 488
- **Precambrian**
  - Archaean: 3850
  - Proterozoic: 2500
  - Paleozoic:
    - Snow balls
      - Rhodinia fragmentation
    - Late−Ordovician glaciation
      - Volcanism decreases, Gondwana at S pole
    - Carboniferous glaciation
      - Coal storage, Gondwana at S pole
  - Snow balls
    - Antarctica at S pole
  - Secondary glaciaion (alpine orogenesis, Antarctica at S pole)
There has been extreme variations in Earth climate in the past. Climate variations are due to perturbations of the radiative balance. Natural CO2 variations have played a key role in the past. Some climate variations are not reversible beyond some thresholds.
3) Climate variations at orbital time scales

Glacial-interglacial cycles

Vostok ice core records

present

last glacial maximum

CO2 (ppm)

température

PD

CO2

Age (yr BP)
Obliquity

The obliquity is the inclination angle of the poles axis relatively to the perpendicular to the Earth's trajectory.
The eccentricity determines the shape of the ellipse on which the Earth revolves around the Sun.

Case of large eccentricity:

Case of null eccentricity:
The precession determines the evolution of the proximity to the Sun during the seasonal cycle.

For example, now, the Earth is closest to the Sun during the Northern hemisphere winter:

10,000 ago, it was the contrary:
Role of orbital parameters

- Exercise 3
Role of orbital parameters

Exercise 3

Conclusion: ice sheet feedback at orbital scale

orbital parameters

increased insolation in summer in high latitudes

ice melts more

ice sheet retreat

reflected sunlight increases

temperature increase
Carbon cycle feedback

orbital parameters

- temperature increase
  - ocean CO2 solubility decreases
  - atmospheric CO2 increases
  - ocean CO2 degassing increases
Impact on sea level

Causes?
Impact on sea level

Causes?

- thermal dilatation
- ice-sheet melt
Climate varies naturally at the scale of tens of thousands years
We are in an interglacial period, but CO2 concentration is anomalously high
Past variations allow us to test our conceptual understanding of climate feedbacks and to test the realism of climate models used for projections.
4) Anthropogenic climate change

- exercise 4.1
4) Anthropogenic climate change

- exercise 4.1
- IPCC projections:

[Graph showing multi-model mean global surface warming and precipitation change]
Carbone cycle feedbacks

- exercise 4.2
Carbone cycle feedbacks

exercise 4.2

- 800 Gt +4 Gt/yr
- 13 000 000 Gt fossil fuel
- 36 000 Gt ocean
- 500 Gt vegetation
- CO2 fertilizing effect: 2.5 Gt/yr
- 1.5 Gt/yr
- T–dependent degasing
- Water stress, pollution

8 Gt/yr

13 000 000 Gt
Are we sure CO2 increase is anthropogenic?

CO2: +4 Gt/yr
decrease of $^{13}C$ proportion
decrease of $^{14}C$ proportion

photosynthesis depleted in $^{13}C$

human emissions
depleted in $^{13}C$ and $^{14}C$

volcanoes

ocean

8 Gt/yr

0.083 Gt/yr
Climate feedbacks

- exercise 4.3
Climate feedbacks

- exercise 4.3

- albedo decreases
- snow/ice melts
- temperature increases
- greenhouse effect increases
- water vapor increases
- air can bear more water vapor

Feedbacks:
- albedo feedback
- water vapor feedback
Climate feedbacks: quantitative

(a) Temperature change when doubling CO2 concentration

(b) Model spread
Reversibility of changes

- exercise 4.4
Reversibility of changes

- exercise 4.4
Summary

- Recent CO2 increase is anthropogenic
- This leads to an increase in temperature, which is doubled by climate feedbacks
- Still some uncertainties on some feedbacks (especially clouds) and on hydrological impacts of climate change
  ⇒ work on evaluating/improving models still needed.
- Changes are not immediately reversible
  ⇒ consequences for mitigation and adaptation strategies