On the astronomical forcing of simple conceptual ice age models

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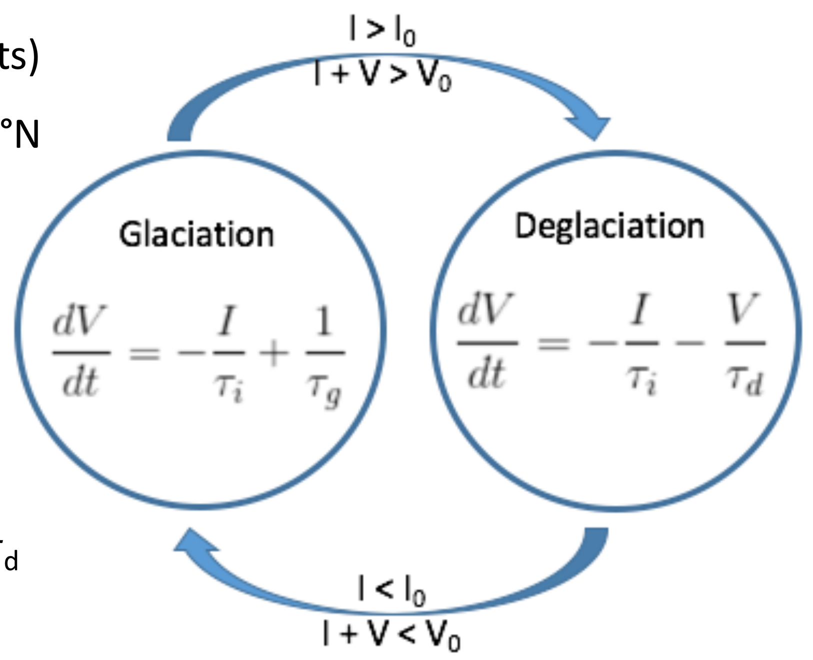
Ice age conceptual model

- Ice volume model, adapted from [1] with summer insolation at 65°N as input
- ➢ What is the influence of the summer insolation choice on the model results ?

- V, **normalized ice volume** (arbitray units)
- I, **normalized summer insolation** at 65°N (arbitrary units)
- **2 states model** : glaciation and deglaciation
- τ_i, τ_g, τ_d : time constants (kyr)
- **Glaciation state** : dV/dt = $-I/\tau_i + 1/\tau_g$
- **Deglaciation state** : dV/dt = $-I/\tau_i - V/\tau_d$



- **Glaciation start** : when insolation is low enough ($I < I_0$).
- **Deglaciation start** : when combination of insolation and ice volume reaches the deglaciation threshold V_0 ($I + V > V_0$).

τ_i, τ_g, τ_d are set to 9, 30, 12 kyr
For each insolation and time period the deglaciation threshold V_0 is varried.
Results for the V_0 value which best fits the data are displayed (optimal V_0).

Summer insolation

Several summer insolation definitions :

- Insolation at the summer solstice (blue)
- Caloric season insolation : energy received during the half of the year with the greatest insolation intensity (brown)
- Integrated summer insolation (ISI) above a given threshold [2] :
  - Above 300 W/m² (violet)
  - Above 400 W/m² (orange)

Similar curves but **different contributions from obliquity and precession**

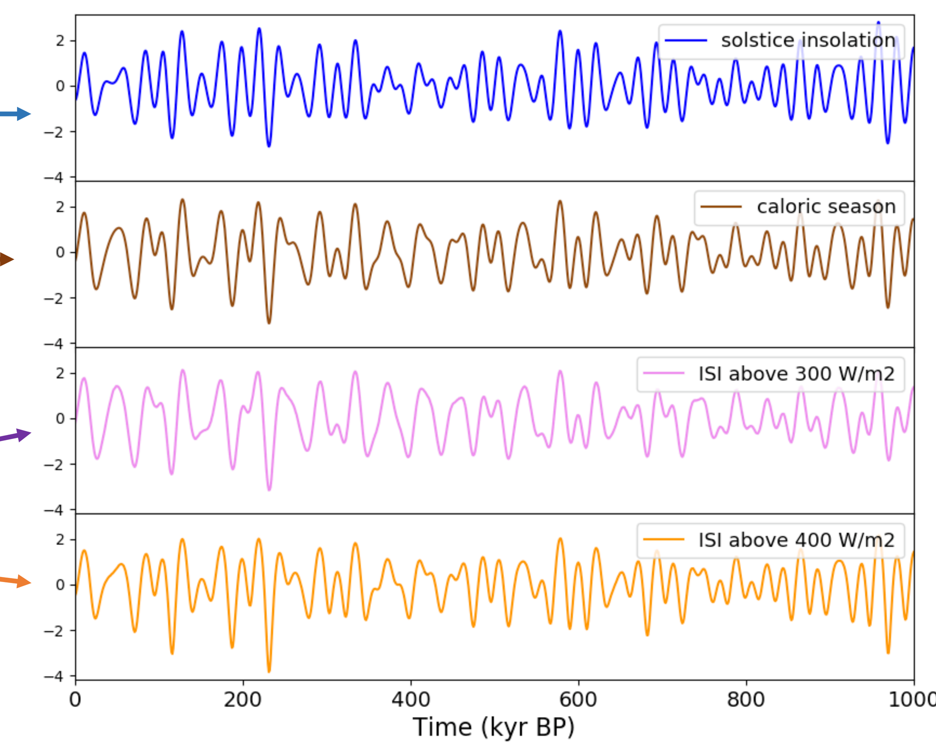


Fig 1a) : Normalized summer insolation

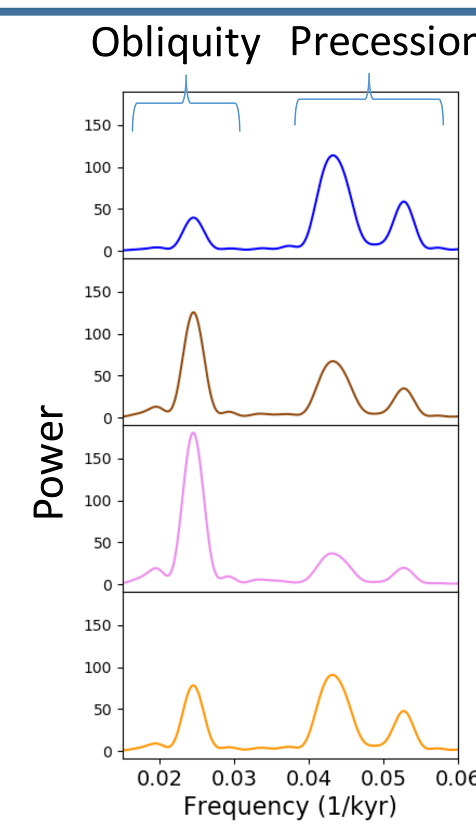


Fig 1b) : Spectral analysis

Model results Data comparison

« 100 kyr world » Larger ice sheets — 1 000 kyr BP — « 41 kyr world » Smaller ice sheets — 1 800 kyr BP — Time (kyr BP)

5 : Optimal threshold V_0

The deglaciation threshold V_0 is held constant over each time period and choosen to fit best the data (optimal threshold V_0).
Model results and data are normalized on each time period.

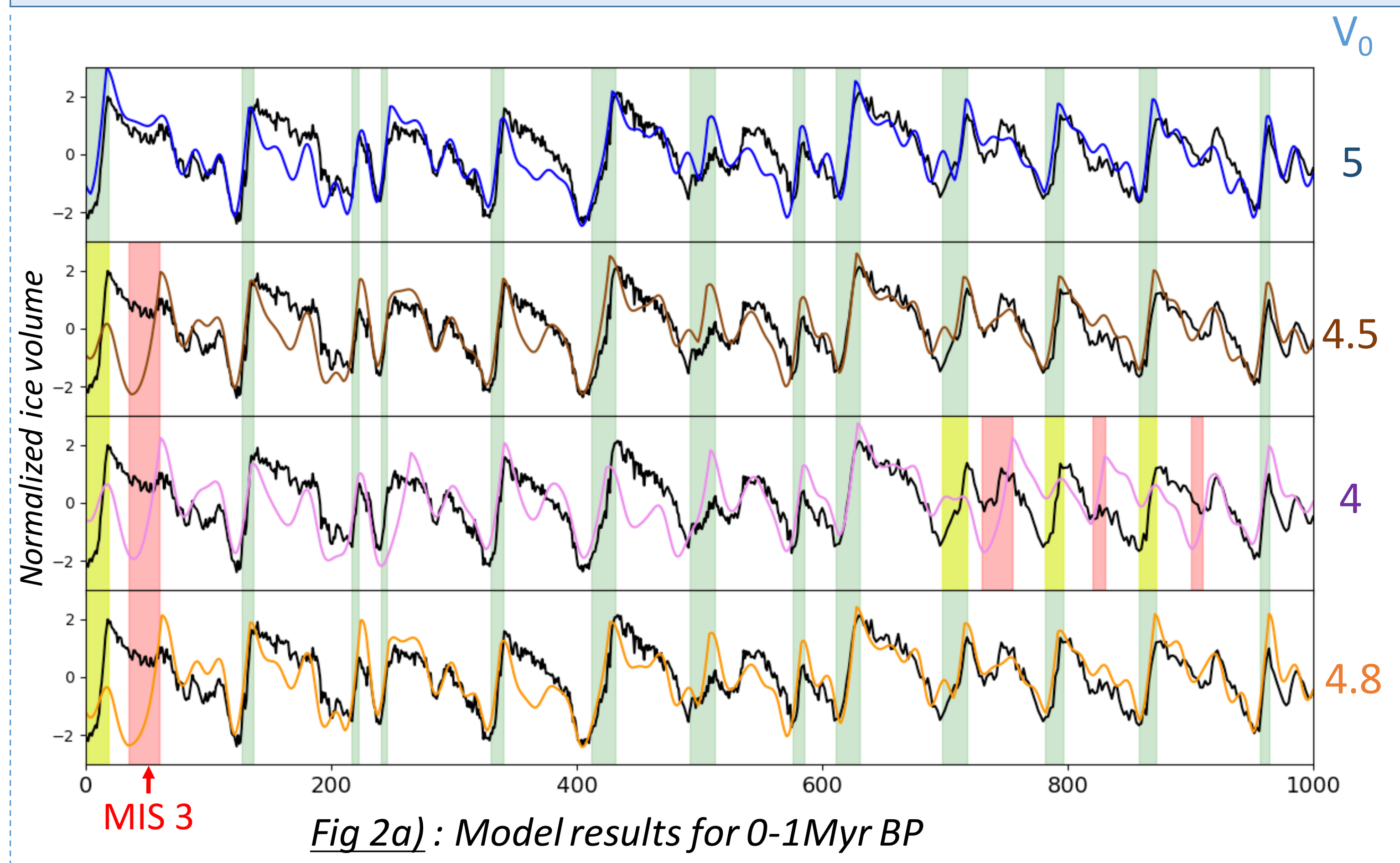


Fig 2a) : Model results for 0-1Myr BP

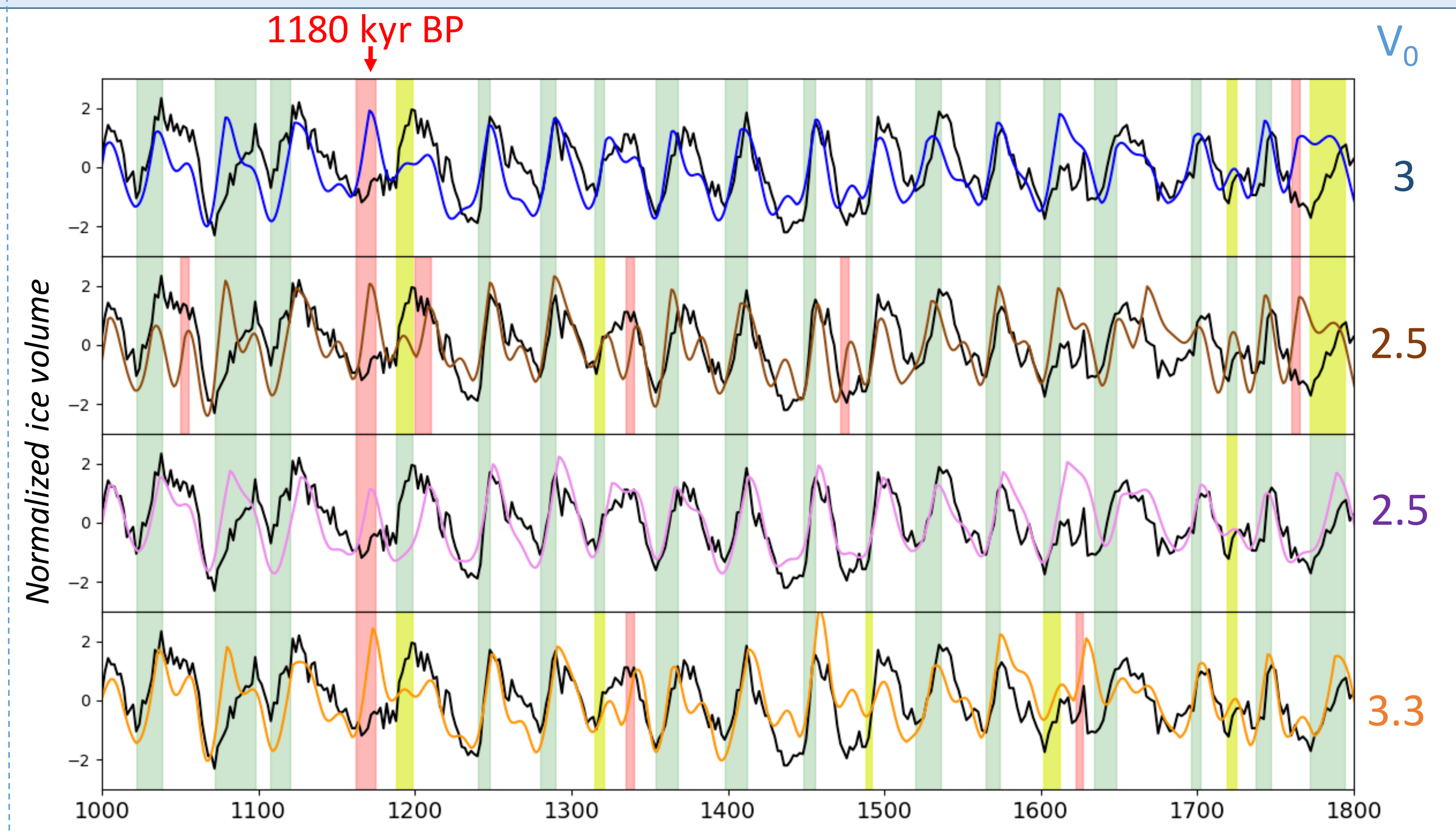


Fig 2b) : Model results for 1- 1.8 Myr BP

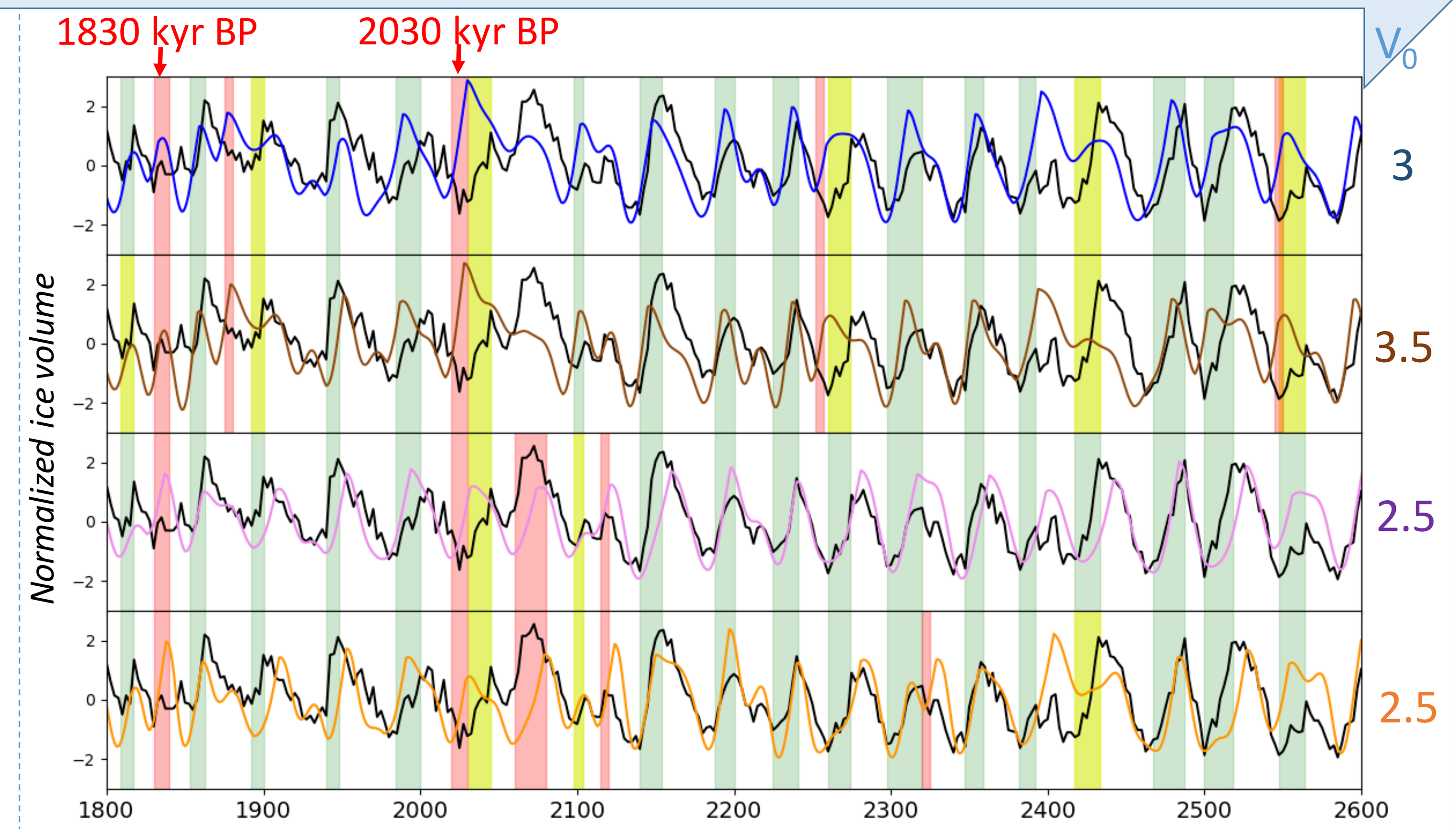


Fig 2c) : Model results for 1.8 – 2.6 Myr BP

Only the solstice insolation model works for the whole Myr with a constant V_0. For the 3 other summer insolation, the **last deglaciation occurs one insolation peak too early** (at MIS 3, around 50 kyr BP) but would occur at the right time with an increased deglaciation threshold V_0 for the last transition.

The **optimal V_0 is lower than for the 0 – 1 Myr BP period** for each insolation.
Model/ data agreement is not as good as for the 0 – 1 Myr BP period.
No clear trend (increase or decrease) of the optimal deglaciation threshold V_0 between the 1 – 1.8 and 1.8 – 2.6 Myr BP periods.

Conclusions

Ice ages can be well represented by a 2 state - glaciation and deglaciation - conceptual model.

Most of the transitions are modelled correctly, but the ice volume around 1180, 1830 and 2030 kyr BP periods is not, irrespective of the insolation used.

Some transitions are more sensitive to the input insolation (I) and the deglaciation threshold V_0 than others.

Larger glaciations (« 100 kyr world ») correspond to higher deglaciation threshold V_0 than smaller glaciations (« 41 kyr world »).

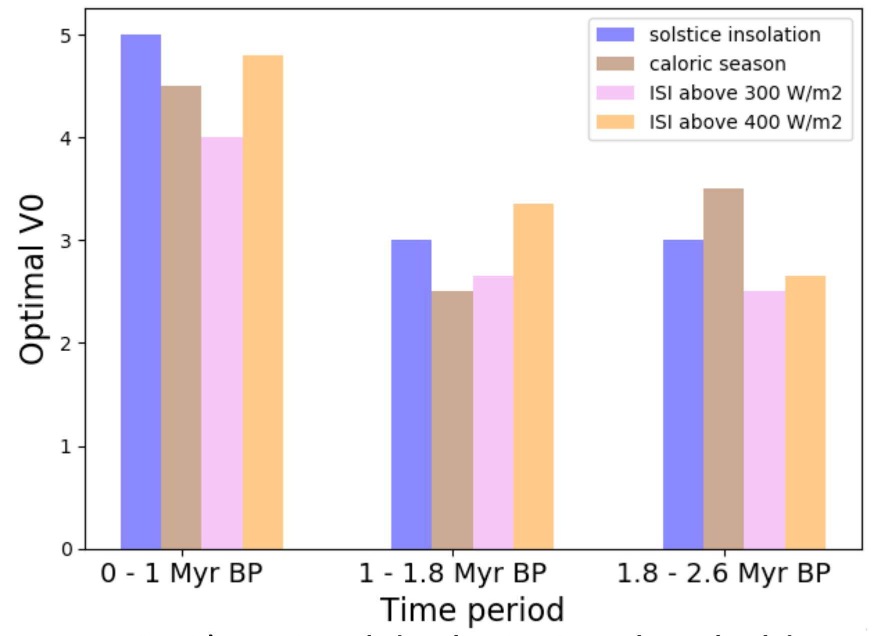


Fig 3) optimal deglaciation threshold V_0 for each time period

Perspectives and open questions

- ➢ Which physical mechanisms could explain the changes over time of the deglaciation threshold V_0 ?
- ➢ How sensitive to parameter changes is the timing of deglaciations ? And what are the most frequent alternative deglaciations with different parameters ?

Results suggest that the last deglaciation corresponds to a further increase in V_0, to avoid a too early deglaciation at MIS 3.

As found in [3], a deglaciation at MIS 3 (around 50 kyr BP) instead of MIS 1 is a frequent alternative.

References

[1] Amplitude and phase of glacial cycles from a conceptual model, Parrenin Paillard, 2003, EPSL.
[2] Early Pleistocene Glacial Cycles and the Integrated Summer Insolation Forcing, Huybers et al., 2006, Science
[3] A simple rule to determine which insolation cycles lead to interglacials, Tzedakis et al., 2017, Nature

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