Understanding Hogg's Model of Glacial Cycles and Carbon Dioxide

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Hogg, Andrew. 2008. Glacial cycles and carbon dioxide: A conceptual model. Geophysical Research Letters. Vol 35.

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David Burton 10 minutes ago (edited)

Hogg's model probably overemphasizes the role of CO_2, and understates the role of ice sheet growth and decline.

There are *two* important positive feedback mechanisms at work in glaciation cycles: ***Ice / Albedo Feedback,*** and ***CO2 / Water Temperature Feedback.***

Ice / Albedo Feedback works like this: If warmer climate reduces ice and snow cover, reduced ice cover (on water) and snow cover (on land) will decrease average albedo (reflectivity), and thus increase absorption of sunlight during daytime, a positive feedback. (Ice has a low microwave albedo, but snow is a very effective insulator which also reduces heat loss at night, making ice and snow cover a negative feedback mechanism at night.)

The net ice / albedo feedback effect is thought to be modestly positive during daytime / spring-summer. (Aside: this is a simplification; see the discussion of "Sea Ice / Evaporation (negative) Feedback," here: https://www.sealevel.info/feedbacks.html#seaevap).

However, in the context of North American and Eurasian ice sheets, this is a form of ***"positive integral feedback,"*** which means the effect accumulates/increases as the ice sheets grow or shrink, and over extremely long timespans this feedback mechanism becomes very important. It is certainly a key factor in Milankovitch-cycle-driven glaciation/deglaciation cycles, which occur over (very roughly) 100,000 year periods.

A common misconception is that the dramatic glaciation/deglaciation cycles are evidence that the Earth's climate is very unstable, suggesting that climate sensitivity is high. They aren't. There are two reasons that Milankovitch cycles have a large effect on glaciation, and neither of them implies that climate sensitivity to GHG forcings must be high.

The two reasons Milankovitch cycles have a large effect on glaciation are:

1. Milankovitch cycles change the breadth of seasonal temperature swings at the latitudes where it matters for glaciation: mainly northern North America and northern Eurasia.
When those seasonal swings increase it increases ice melt in the summers and decreases snowfall in the winters. (When temperatures are very low snowfall is greatly reduced, because the cold air cannot carry much moisture; it is said to be "too cold to snow.")

When the seasonal swings are reduced it decreases ice melt in the summers and increases snowfall in the winters.

2. Milankovitch cycles last for tens of thousands of years, which enables them to overcome the extreme damping of the feedback mechanism.

When, due to Milankovitch cycles, the Earth's seasonal swings are reduced to the point that the great northern ice sheets grow a little bit each year, by adding more snow in the winters than they lose in the summers, after thousands of years of ice sheet growth it adds up to a very large increase in planetary albedo. Conversely, when the Earth's seasonal swings are increased to the point that the great northern ice sheets shrink a little bit each year, as the ice sheets dwindle it eventually adds up to a large reduction in planetary albedo.

That is an important ***positive integral feedback*** mechanism, but only on timescales of thousands of years, and it is highly non-linear, because it only works when the extent of the great northern ice sheets can significantly increase or decrease.

Those ice sheets are gone, now. The only remnant is Greenland, so ice sheet albedo feedback could only become important in a warming climate if enough of the Greenland Ice Sheet were to melt to significantly increase the exposed land area, which is not in prospect.

So Milankovitch cycle-driven glaciation cycles are evidence of very large natural long-period climate variability, but they are not evidence of high climate sensitivity to anthropogenic GHG forcings.

Hogg's model is based on ***CO2 / Water Temperature Feedback.*** The solubility of gases like CO_2 (and CH_4) in water decreases as the water gets warmer, so as the oceans warm they outgas CO_2 (or, if they're absorbing CO_2, as is currently the case, they absorb it more slowly). The CO_2, in turn, works as a GHG to cause warming. This is a slight positive feedback mechanism.
http://archive.is/oXxGb#selection-1215.21-1215.30
(There are probably also biological mechanisms at work, but the net effect is that temperature increases cause eventual increases in atmospheric CO_2 level.)

As Hogg notes, that positive feedback loop is certainly one of the causes for the apparent hysteresis in the temperature and CO_2 records. Over the last million years, the Earth's climate has tended to be either mild, as in our current interglacial (the Holocene), or, more often, heavily glaciated and cold, with relatively brief, unstable transitions between.

In paleoclimate reconstructions from ice cores, CO_2 level changes generally lag temperature changes by hundreds of years, which is consistent with the fact that higher CO_2 levels not only cause higher temperatures, but are also caused by higher ocean temperatures, and ocean temperature is slow to respond to air temperature changes.