Dust Transport by Sea Glacier Flow and Termination of Snowball Earth

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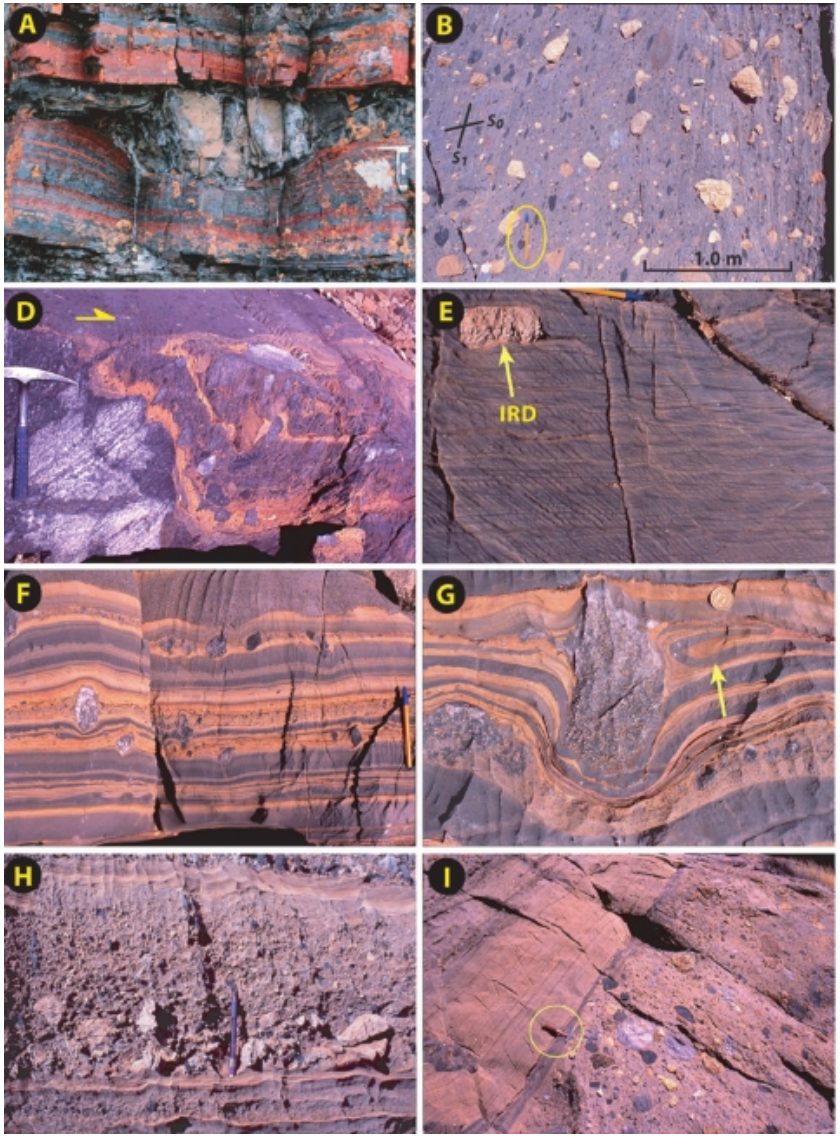
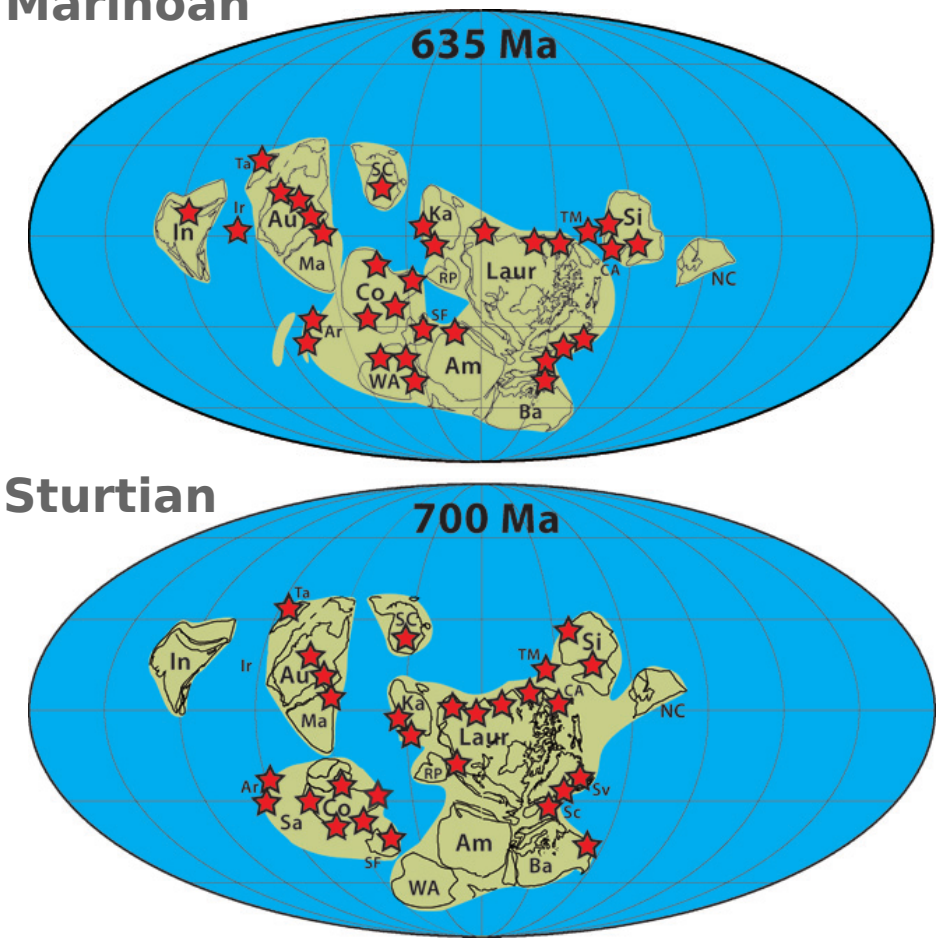
AGU Fall Meeting, Dec 4, 2012

Image: Dylan Taylor

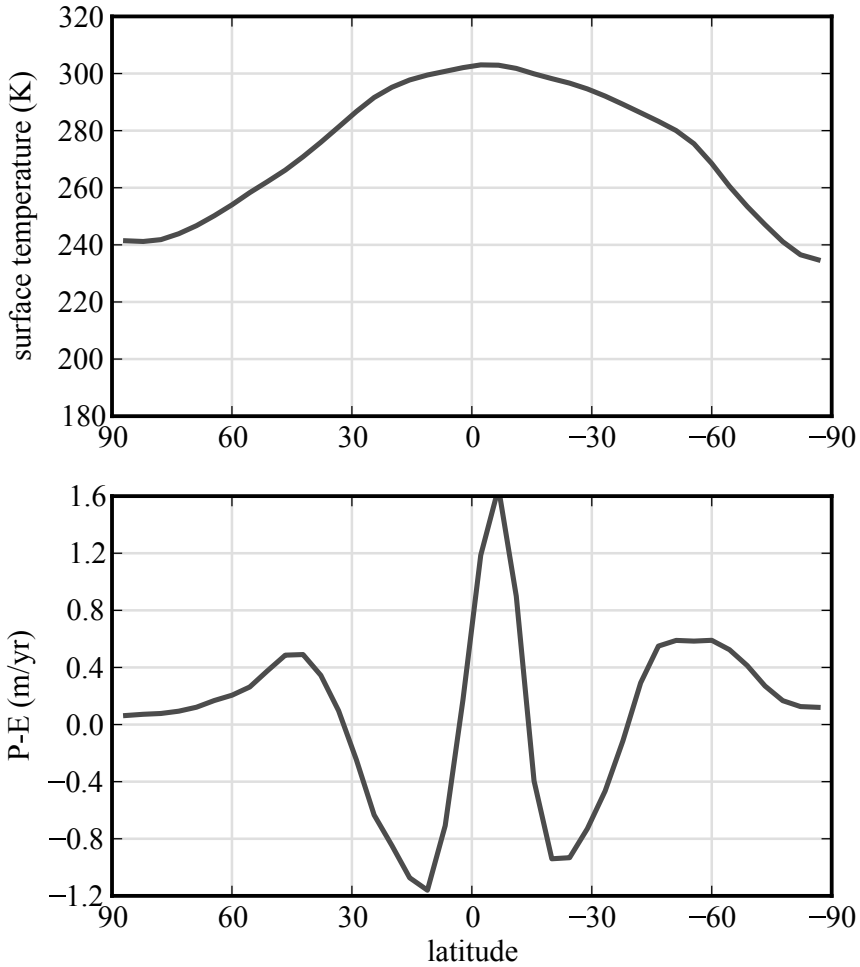
Neoproterozoic Snowball Earths



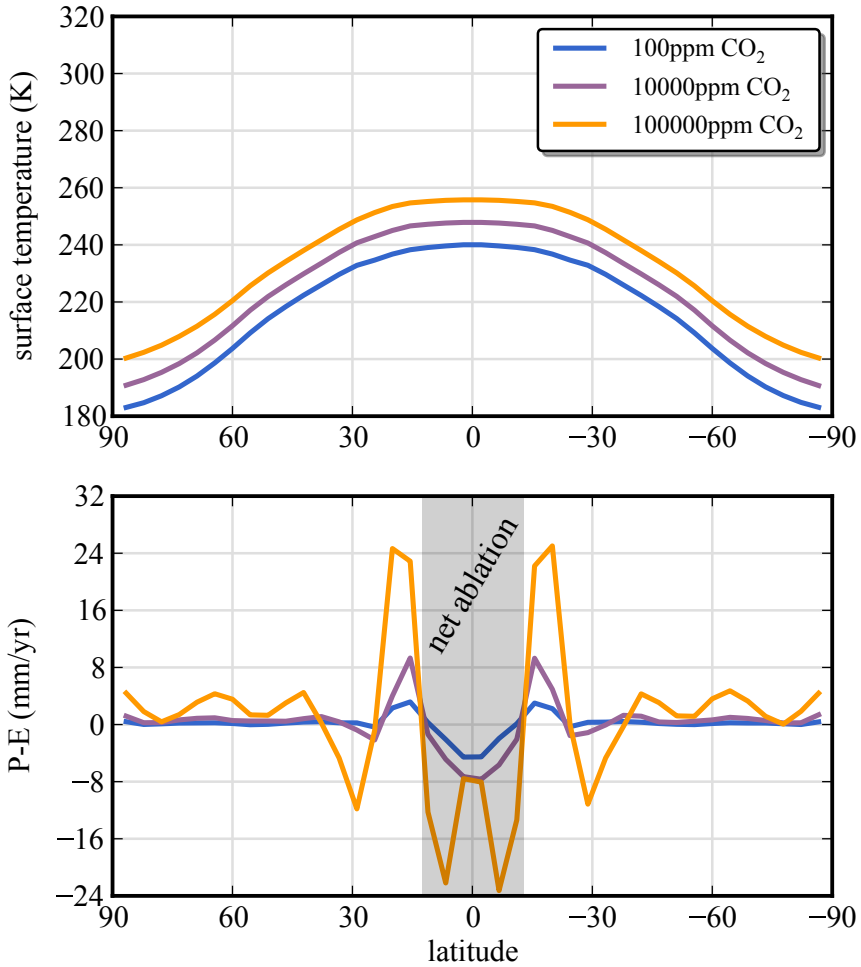


Hoffman and Li (2009)

Snowball Climate

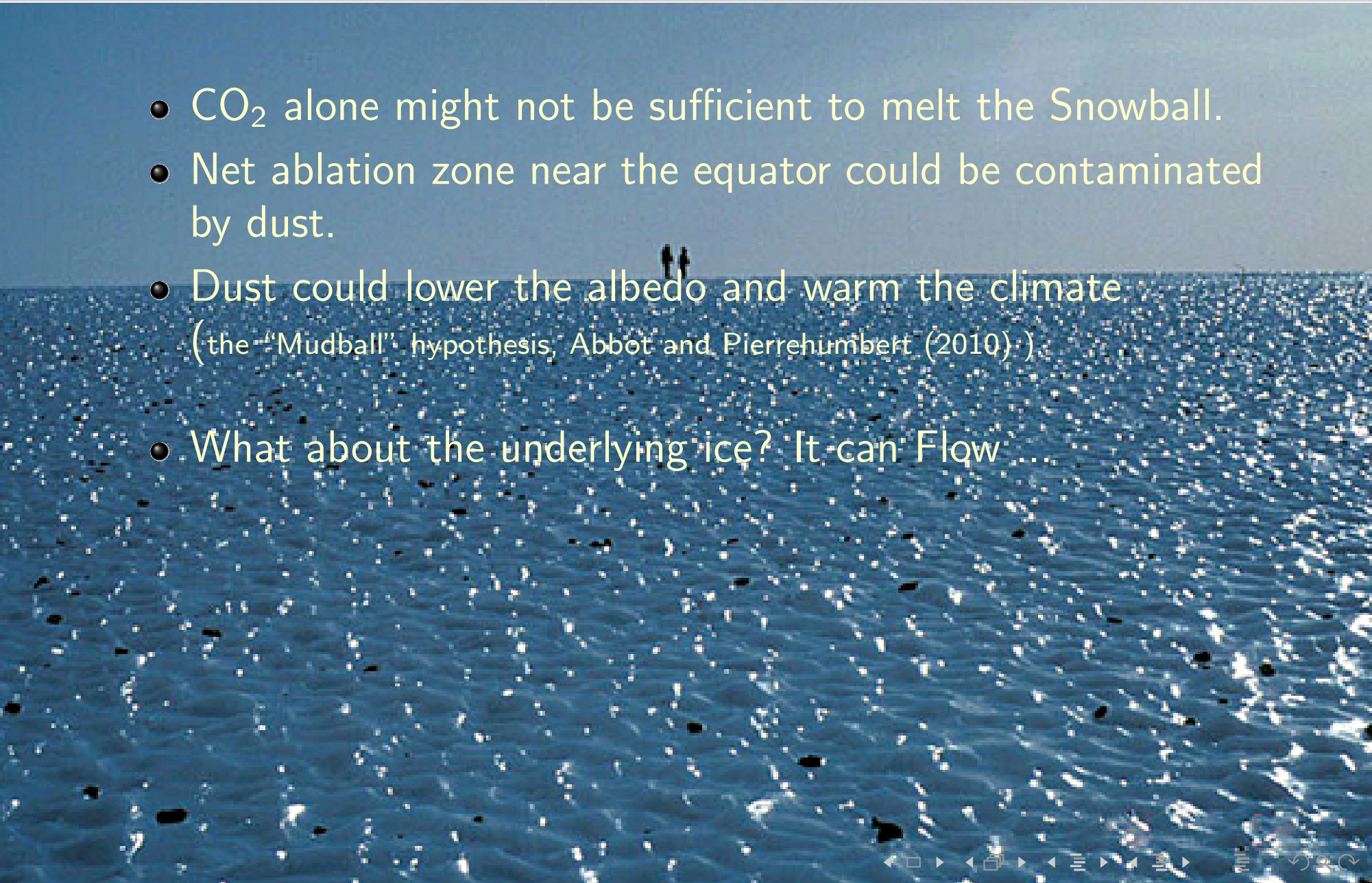


FOAM GCM Current



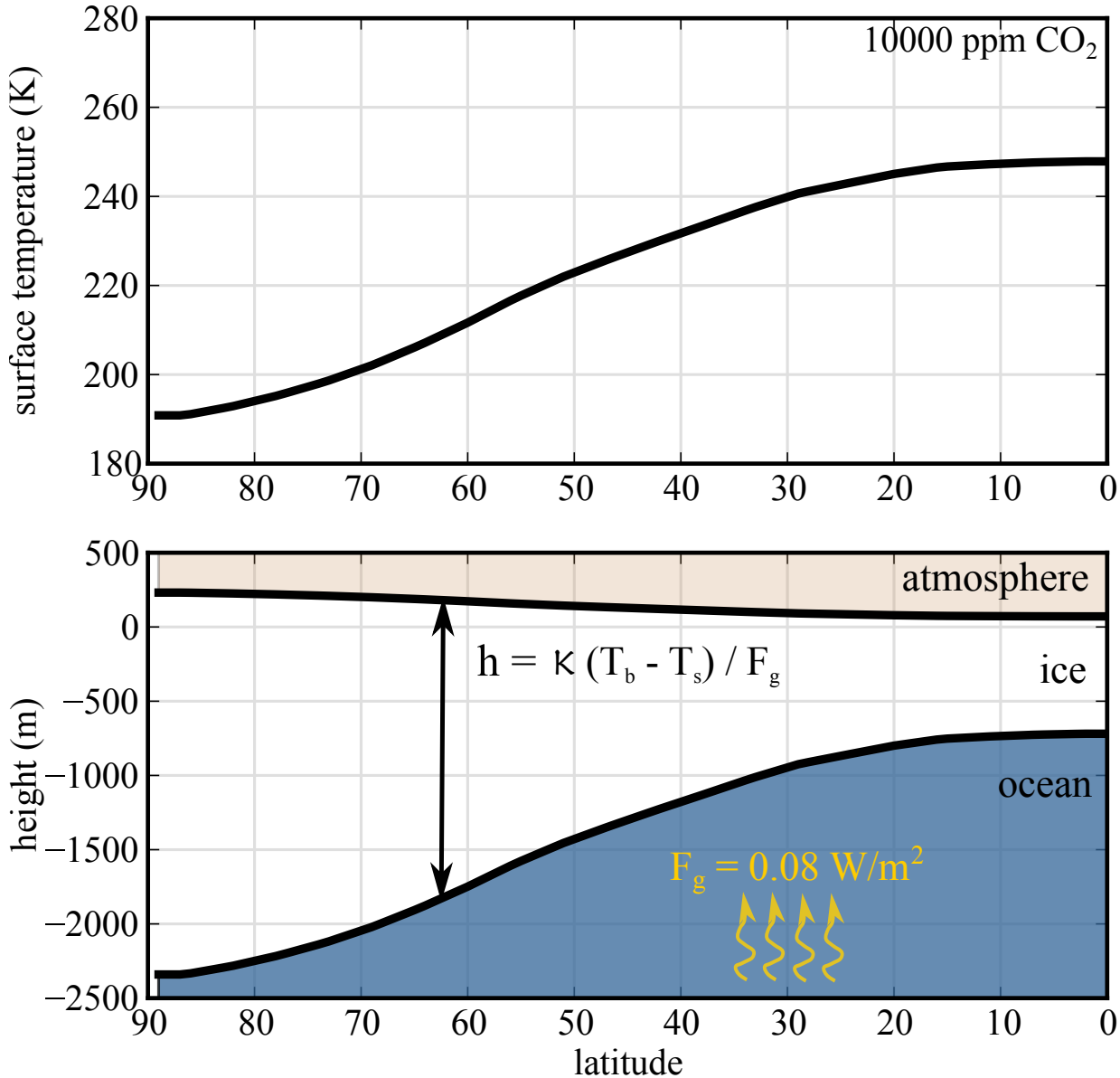
FOAM GCM Snowball

Tropical Ablation Zone



- CO_2 alone might not be sufficient to melt the Snowball.
- Net ablation zone near the equator could be contaminated by dust.
- Dust could lower the albedo and warm the climate (the "Mudball" hypothesis, Abbot and Pierrehumbert (2010))
- What about the underlying ice? It can Flow ...

Sea Ice ... or Sea Glacier?



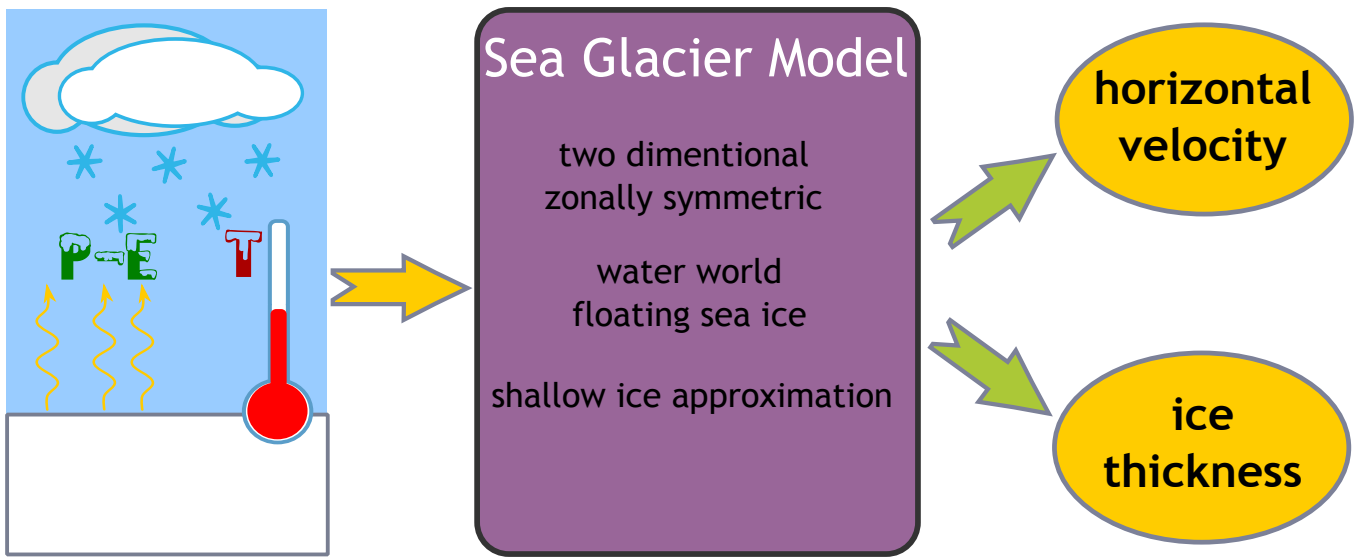
The Sea Glacier Model

Goodman and Pierrehumbert (2003)

$$\frac{\partial}{\partial t}h + \frac{v}{r_0}\frac{\partial}{\partial \theta}h + \frac{1}{r_0 \sin\theta}\frac{\partial}{\partial \theta}v \sin\theta = m_t + m_b$$

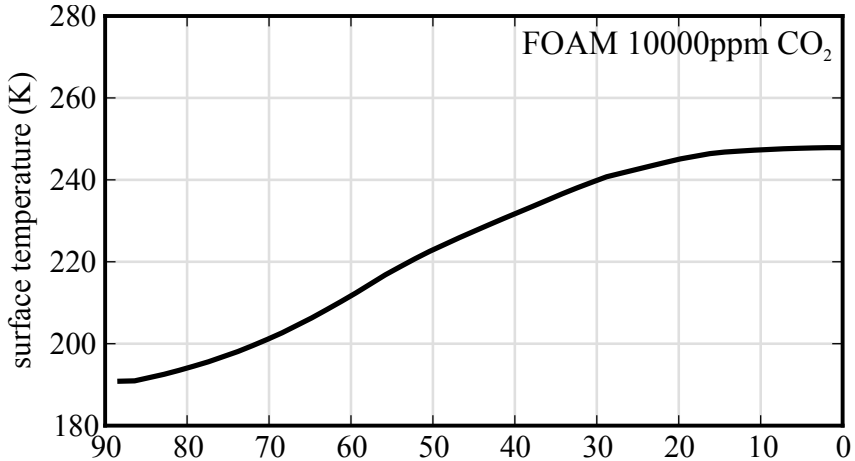
$$m_b = \frac{-\kappa(T_s - T_f) - F_g h}{\rho_i l h}$$

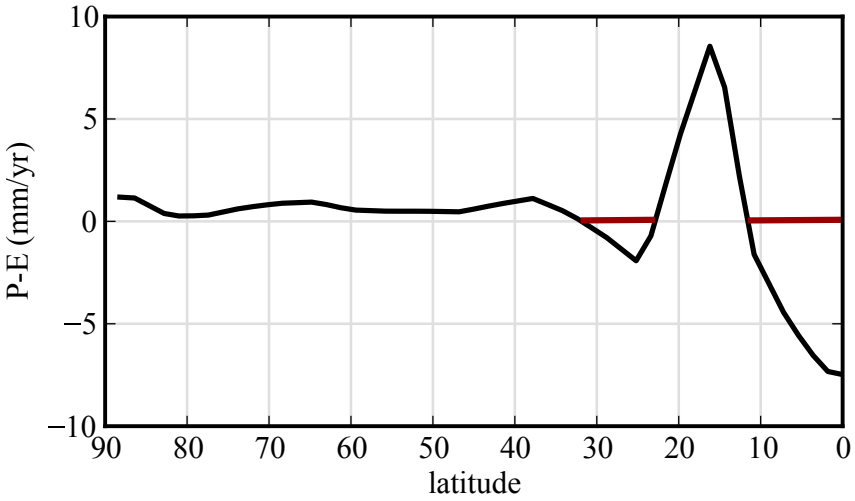
$$v(\theta = \frac{\pi}{2}) = r_0 \int_0^{\pi/2} \mu^n (h - \frac{b}{h})^n \sin\theta d\theta = 0$$



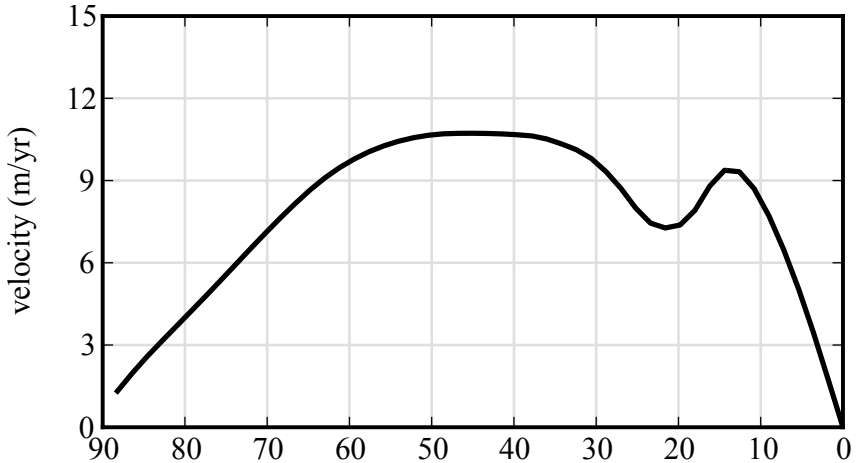
Model Input and Output

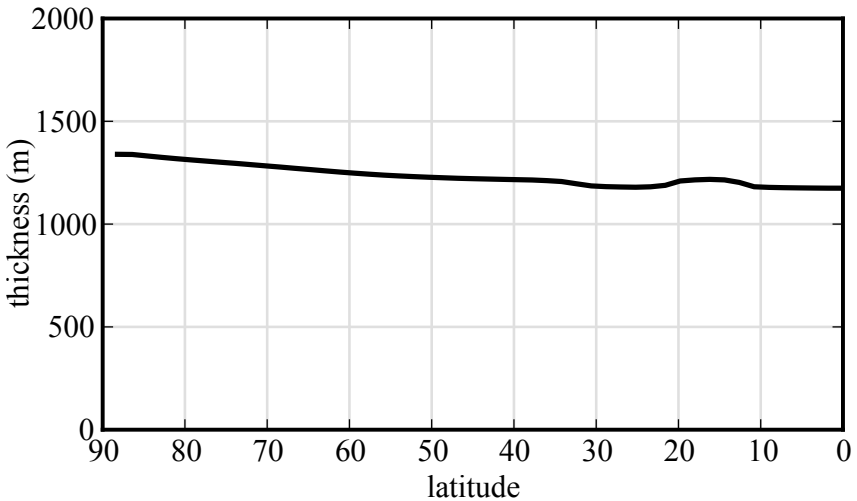
Input



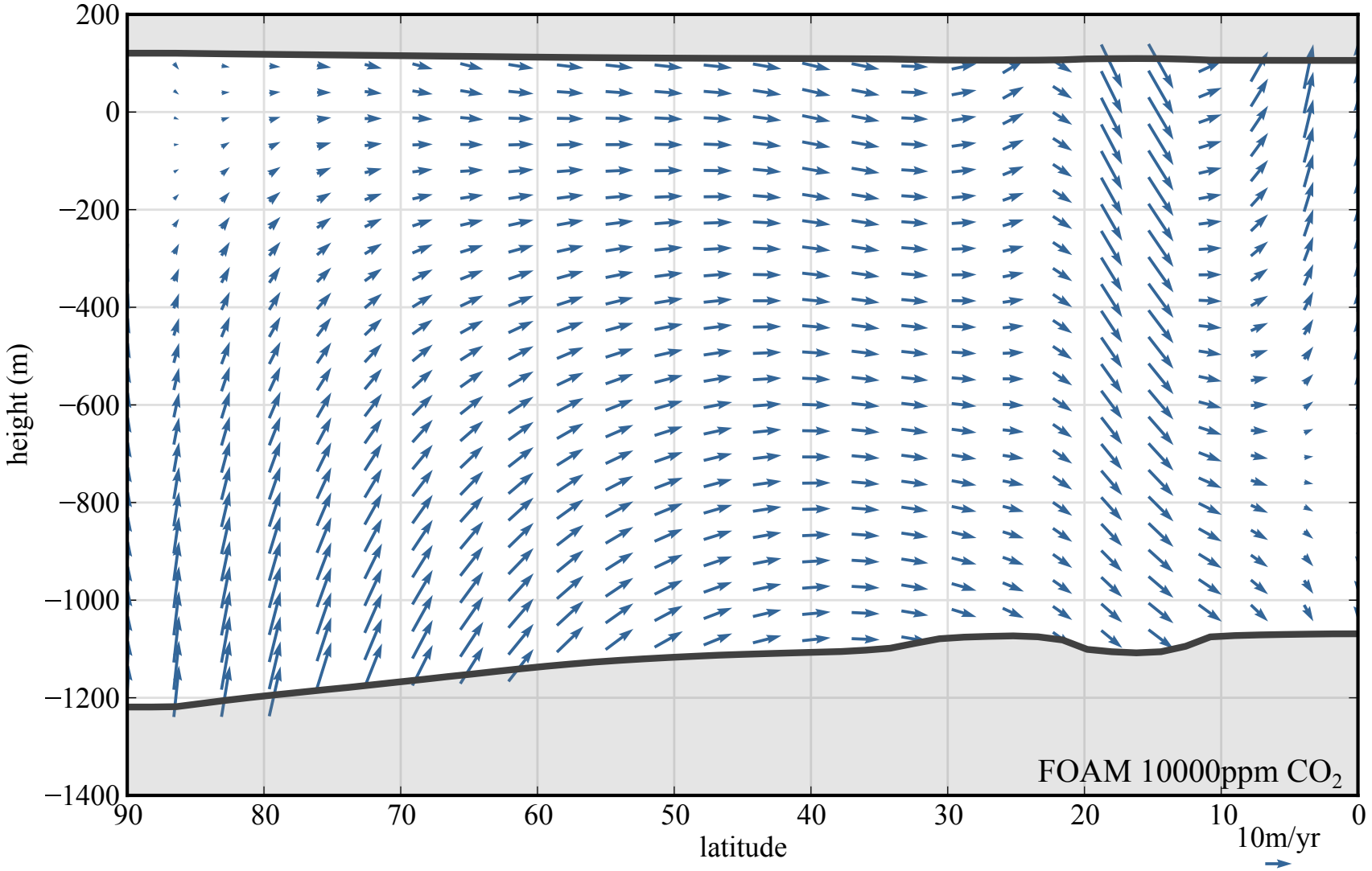


Output





The Flow Field

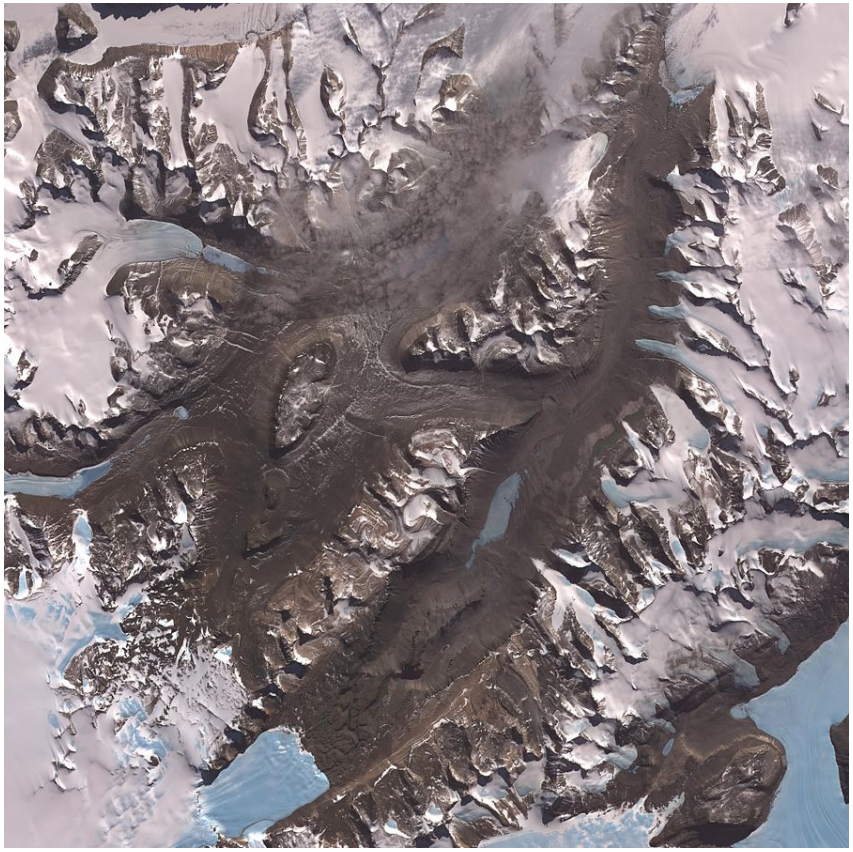


Snowball Dust Sources

Volcanic

Eyjafjallajökull, Iceland, April 17, 2010

Continental



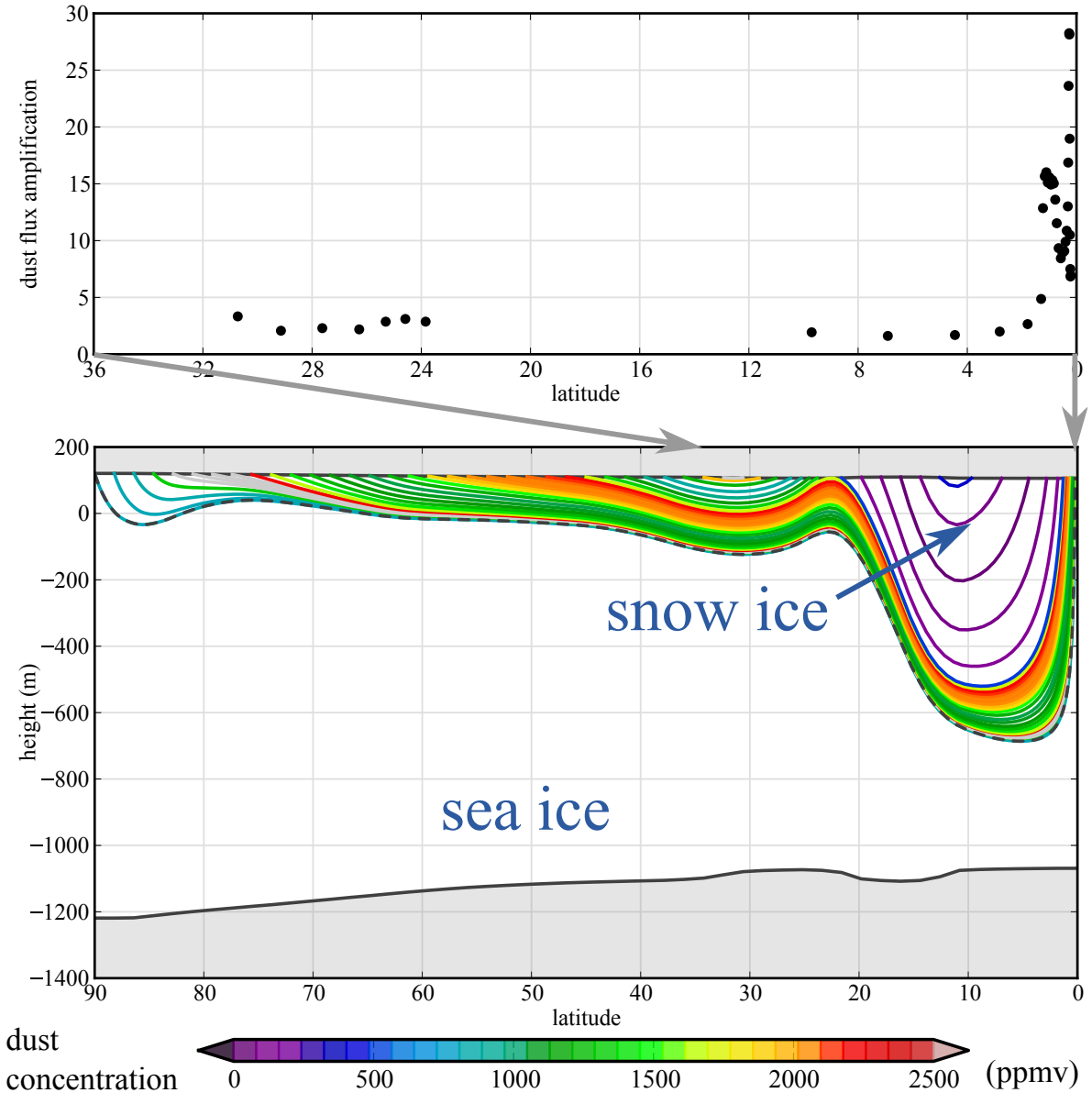
McMurdo Dry Valleys, Antarctica

Average dust accumulation rate: $10^{-6} m/yr$ (Abbot and Pierrehumbert 2010)

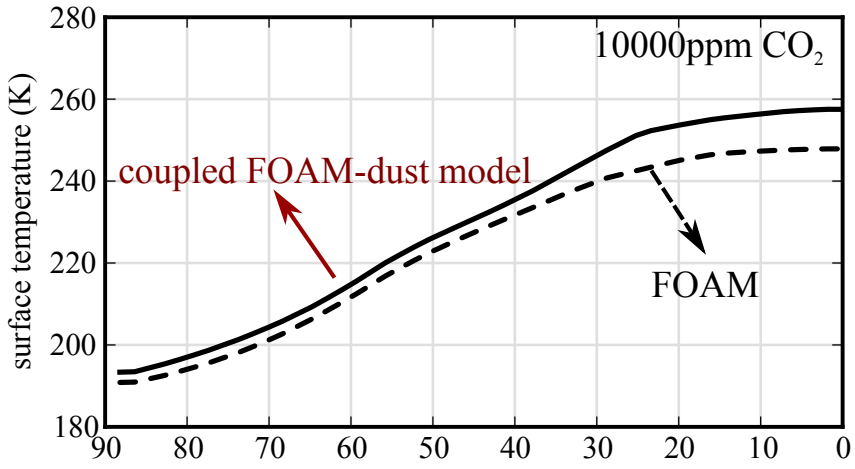
Tracking the Dust Tracers

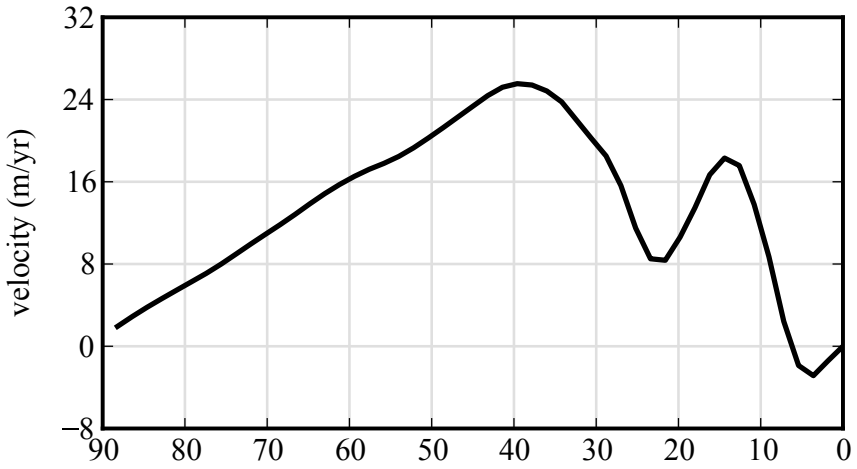
color – dust concentration

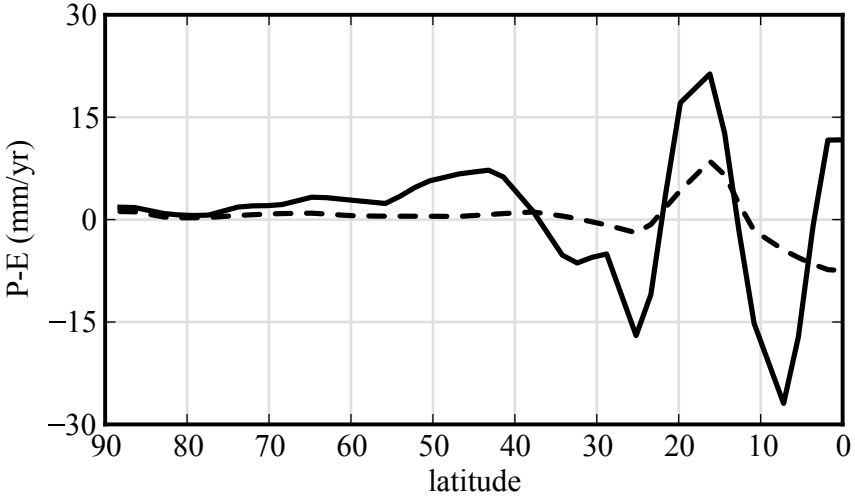
Dust Transport

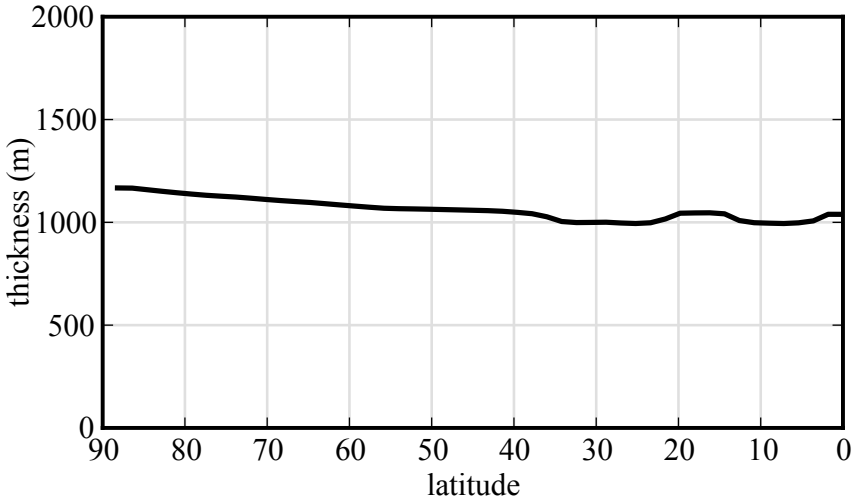


Dust-Albedo Feedback

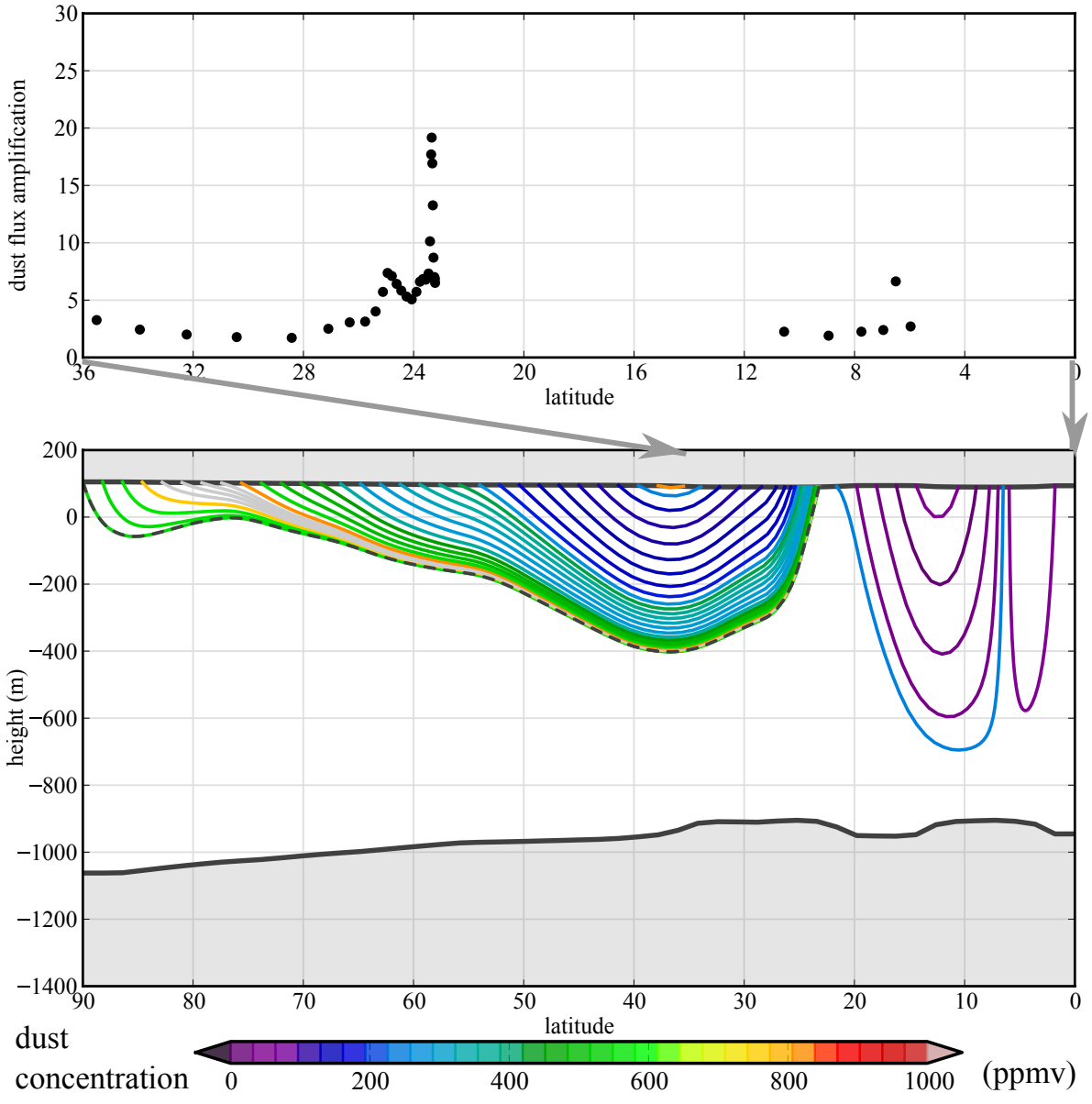








Dust Transport with Albedo Feedback



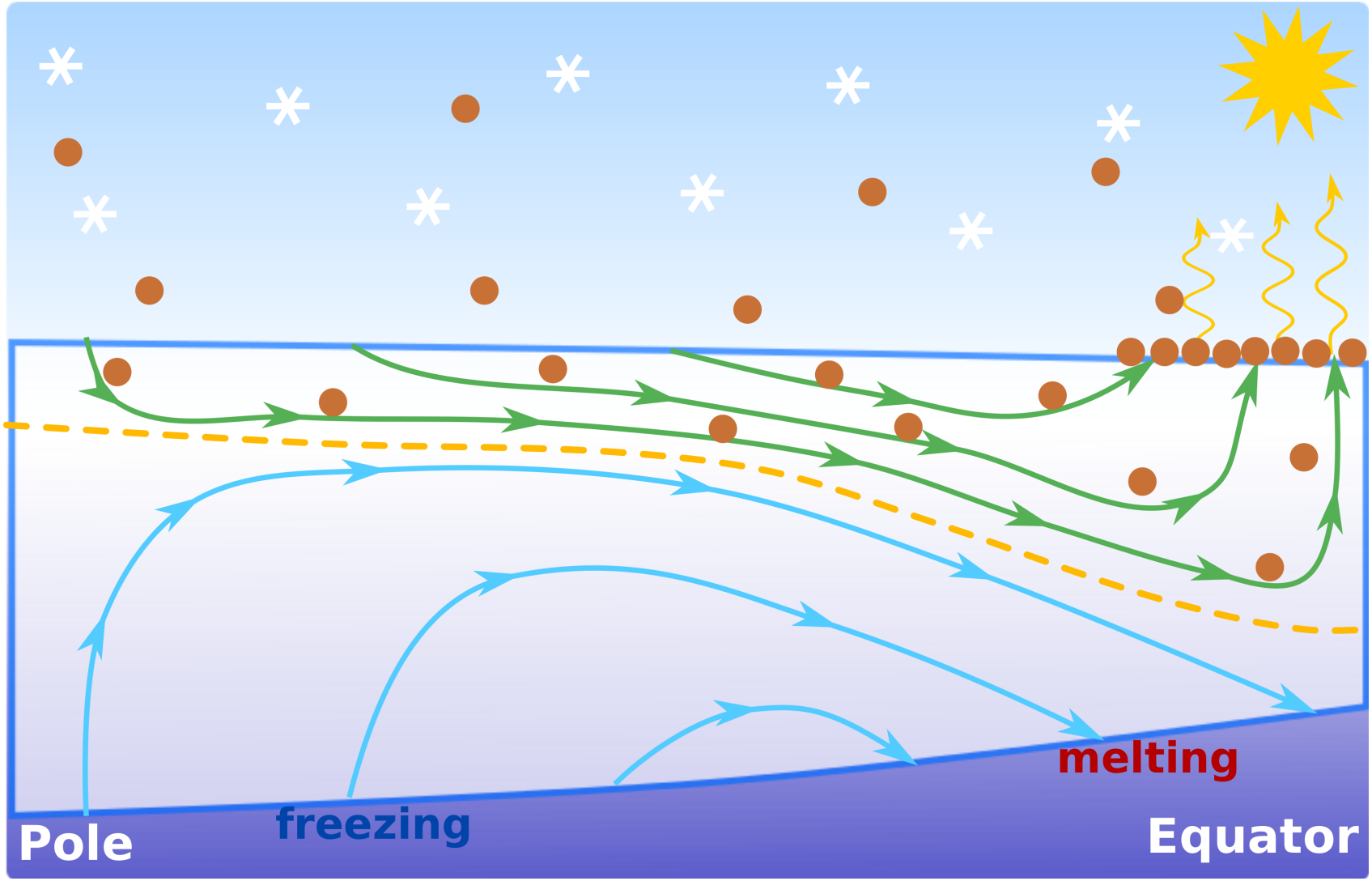
Blow Me Away – Aeolian Transport

- Surface of ablation zones had enough exposure time (10^4 — 10^5 yr) to get contaminated by dust.
- An extreme scenario: The dust deposited being instantly blown off the surface and redistributed over the globe.
- Dust only stays in the "snow-ice", which is blocked from the ocean by sea ice.
- Estimating the dust concentration in the strong aeolian transport scenario:
  - average snow-ice thickness: $\approx 200\ m$
  - average dust concentration in snow-ice after 10 million years from the onset of Snowball Earth:

$$\frac{1\ m/myr \times 10\ myr}{200\ m} = 5\%$$

- The ice could be as **dark** as dust!

Mudball – A Refined Picture



Summary

Take Home Message:

- Dust accumulation at the tropical ablation zone could be enhanced by the sea glacier flow.
- Albedo feedback of the dust-rich zone could warm the climate, and might have helped in saving the world from everlasting Snowball.

For Further Reading:

- Li, D., and R. T. Pierrehumbert (2011), Sea glacier flow and dust transport on snowball earth, *Geophys. Res. Lett.*, *38*(L17501), doi10.1029/2011GL048991.
- Goodman, J. C., and R. T. Pierrehumbert (2003), Glacial flow of floating marine ice in "snowball earth", *J. Geophys. Res.*, *108*(C10), 3308, doi10.1029/2002JC001471.
- Abbot, D. S., and R. T. Pierrehumbert (2010), Mudball: Surface dust and snowball earth deglaciation, *J. Geophys. Res.*, *115*(D03104), doi10.1029/2009JD012007.

Image: Dylan Taylor