Assessing uncertainties on the stability of the AMOC during Heinrich events using simulations from one Earth System model.

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Heinrich Stadial events are millennial scale cooling events associated with the drying in the northern tropics (Mulitza et al., 2008; Niedermeyer et al., 2009).

Increased dust over the north Atlantic. (Mulitza et al., 2008; Niedermeyer et al., 2009). HS1 dust fluxes over the North Atlantic were a factor of $\sim 2.6$ higher than mean 0–2ka fluxes.
Objective: What is the impact of the enhanced dust loading on ocean circulation during HS1?

• University of Victoria Earth system model (UVic2.9).
• 1000 year simulations with at least 3000 years of spinup under LGM boundary conditions.
• HS1 FW forcing applied as a virtual flux hosing between 45°N and 65°N.

The Role of African Dust in Atlantic Climate During Heinrich Events (Murphy, Goes, and Clement, Paleoceanography 2017).
Dust cools and freshens the North Atlantic

The shortwave fluxes due to Saharan dust are parameterized as a perturbation of the local surface albedo ($\alpha_s$). Outgoing (TOA) and surface longwave radiation follow surface albedo changes ($\alpha_s$).

Dust feedbacks can potentially amplify Heinrich events by cooling and freshening the North Atlantic.
Uncertainties: Wind forcing

**CAM LGM Winds** — Derived from CAM4 anomalies (LGM – PI).

**Uvic LGM winds** — Calculated in Uvic.

**NCEP PD winds** — NCEP reanalysis climatology.

Two wind forcing:

i) Standard **UVic** winds;

ii) **CAM4** SLP anomalies (LGM – PI; Murphy et al., 2014). Wind anomalies are calculated using a geostrophic/ diffusive approximation (Goes et al., 2014).
Effect of dust radiative forcing dependent on the state of the AMOC

**Uvic winds**: Weaker AMOC (13 Sv). Dust decreases strength by 20-25%.

**CAM winds**: Stronger AMOC (22Sv). Negligible difference.
Mean freshwater fluxes

\[ \frac{1}{S_0} \frac{\partial S'}{\partial t} = Mov + Maz - E_{NET} + Res = 0 \]
Uncertainties: FW forcing (hosing)

Different amount of hosing applied for 200 years.

- Bifurcation may occur from dust feedback in Uvic winds (bistable).
- Dust may delay the recovery for a couple decades in CAM winds (stable).
- All simulations consistent with salinity feedback.

Mov becomes positive (imports freshwater) in collapsed cases.

Mov reduces or becomes negative before recovering.
Assessing the uncertainties of the AMOC strength on the AMOC stability

• LGM boundary conditions (~19ka).
• 2 Background wind forcings: Uvic x CAM.
• Hosing experiments: 0.2 Sv applied to the North Atlantic between 45°N-70°N.
• Background vertical mixing: Brian-Lewis parameterization with variable $\alpha$ values:

$$K\nu = \alpha + \frac{\beta}{\pi} \cdot \arctan \gamma(z - z_0)$$

Range (units): $\alpha \sim 0.6-1.0 \times 1e^{-4} \text{ m}^2\text{s}^{-1}$
AMOC collapses in all simulations using Uvic winds.
AMOC recovers in all simulations using CAM winds, with recovery time shorter for stronger Kv.
Stronger NH winds shortens the recovery time.
Stronger CAM winds shifts ice edge and ventilation depth northward relative to Uvic winds.
The AMOC in CAM winds shows the NADW in a denser range.
NADW flows further southward.
Salinity differences (CAM-UVic)

- Stronger NH winds increase evaporation in the North Atlantic and salinity in the northern subpolar gyre (positive feedback).
- Stronger SH winds increase upwelling of the AAIW in the tropics, decreasing salinity there (negative feedback).
Summary

• **NH winds** drive the stability of the AMOC, strengthens depth stratification and deepens the NADW.

• Stronger **SH winds** have a destabilizing effect on AMOC. Results suggest that they increase the AAIW and upwelling in the tropics, freshening the surface. However, it is a secondary effect.

• **Vertical mixing** changes the mean state of the AMOC, but not its structure/stratification.
Thank you