POSSIBLE PATHWAYS TO A DANSGAARD-OESCHGER (D-O) PMIP PROTOCOL

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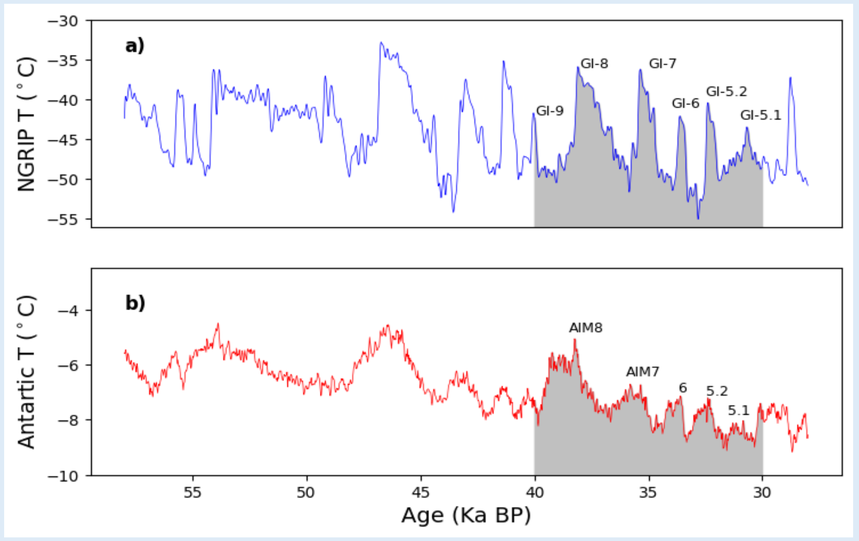
1. INTRODUCTION

- **Abrupt warming episodes** punctuate Greenland ice core records throughout the last glacial period and are generally referred to as **D-O events** (Dansgaard et al., 1993).
- During an event, **Greenland transitions from cold stadial (GS) to warmer Greenland Interstadial (GI) conditions within a decade** (e.g. Kindler et al., 2014). **Surface air temperatures (SATs) over Greenland increase by 10-15°C** and local snow accumulation almost doubles (e.g. Kindler et al., 2014).
- These events occur at the onset of an oscillation that is of **millennial timescale** and are **rather pronounced during Marine Isotope Stage 3** (MIS3; between approximately 25 – 60 thousand of years BP, hereafter ka) (Voelker et al. 2002).



2. MOTIVATION / OBJECTIVES

- The **D-O events** of the last ice age represent one of the best studied abrupt climate transitions, yet **we still lack a comprehensive explanation for them**.
- There is **uncertainty whether** current **IPCC-relevant models can effectively represent the processes that cause D-O events** (Valdes, 2011).
- **Can our models simulate D-O events? Are models too stable?**

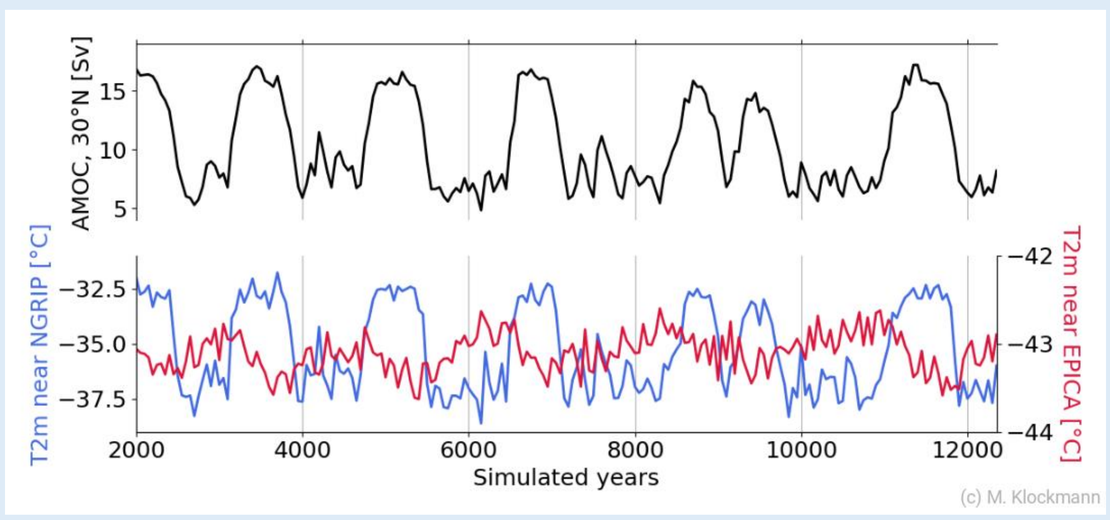
In this task, the objectives of this study are

(1) Bring together a model intercomparison project of spontaneously D-O type oscillating simulations.

(2) To formulate a protocol for a single baseline MIS3 PMIP experiment, with one Heinrich kicked variant. This will enable multiple model groups to investigate cold-period instabilities using a common specified insolation-, freshwater-, GHG-, and NH ice sheet-related forcing set-up.

3. SPONTANEOUS D-O TYPE OSCILLATIONS IN CLIMATE MODELS (SDOO)

- **Spontaneous Dansgaard-Oeschger type oscillations in climate models (SDOO) is an ongoing model intercomparison project to study spontaneous, D-O type oscillations in climate models (https://www.bas.ac.uk/project/sdoo).**
- SDOO is currently gathering model output for any spontaneously oscillating simulations (published or unpublished).
- The only condition to participate is a simulation that shows spontaneous, long time scale, oscillations.
- There are currently few examples of spontaneous D-O type oscillations occurring in coupled climate models, under any climate conditions, glacial-state or otherwise (e.g. Klockmann et al., 2018; Peltier and Vettoretti, 2014) (See figure below).



The table below shows the **simulations and models currently involved in this initiative**.

Model	Time period - Simulation	Run length	GHGs	Ice sheets	Insolation
MPI-ESM	3 runs - mixed forcing	8,000-12,000 yrs	CO2 = 195-206 ppm CH4 = 396-444 ppb N2O = 209-218 ppb	PI	LGM – 21ka
GISS E2-R (TCADI)	3 runs - Future warming scenarios	2,500-4,300 yrs	a) CO2 = 4 x PI CO2 b) CO2 = CO2 increases at 1%/year until 4xCO2 c) RCP85 emissions	Modern	Real-time
GISS E2.1-G (NINT)	Future warming scenario	650 yrs	SSP45 concentrations	Modern	Real-time
EC-Earth3-Veg-LR	2 runs – Holocene & LIG	3,000-4,000 yrs	Köhler et al (2017)	PI	Berger (1978)
UVIC 2.8	2 runs – glacial period (19ka)	10,000 yrs	CO2 = 190 ppm	19ka - ICE-4G	19 ka
CESM1	LGM (21ka)	5,000 yrs	21ka	ICE-6G (VM5a)	21ka
CLIMBER-3α	2 runs – Devonian & Mesozoic	5,000 yrs	CO2 = 500-2000 ppm depending on time slice	None	Various depending on time slice
PlaSim v16	21ka to 6ka	15,000 yrs	following PMIP4 except older CO2 dataset (Luthi et al, 2008)	transient following GLAC1-D	Transient
PlaSim v17	38 ka	1,000 yrs	CO2 = 185 ppm CH4 = 405 ppb N2O = 207.5 ppb	38ka GLAC1-D	38 ka
HadCM3	20 ka - LGM	10,000 yrs	following PMIP	GLAC-1D	LGM

Cross compare existing simulations, which show spontaneous D-O type oscillations, using a common set of diagnostics so we can compare the mechanisms and the characteristics of the oscillations.

4. A BASELINE MIS3 EXPERIMENT PROTOCOL

Such a model protocol is crucial since (i), **there is currently no PMIP common guidance to investigate D-O events**, (ii) it could help **carry out simulations** in ESM and EMIC **under a common framework**, and (iii) it will be essential in **guiding a more methodical search for D-O events in current models.**

Boundary condition / Forcing	Value MIS3-control expt
Atmospheric trace gases	CO2: Bauska et al. (2021) CH4: Loulergue et al., (2008) N2O: Schilt et al., (2010)
Insolation	Eccentricity: Berger, (1978) Obliquity: Berger, (1978) Perihelion - 180°: Berger, (1978)
Solar constant	1360.9 W m^{-2}
Ice sheets	Lev Tarasov - data constrained
Global freshwater budget	Closed to avoid drifts
Vegetation	Fixed or dynamic as in PI
Dust	As in PI

MIS3 baseline experiment using boundary conditions for an specific time slice **between 30 ka and 40** ka (most probably 38 ka) which is a period characterised by a **rather regular sequence of D-O events**.

This MIS3 baseline experiment alone could help answer the question, "are models too stable?".

4.1 AN ADDITIONAL KICKED HEINRICH EVENT (HE) PRECONDITIONED OPTION

- During MIS3, the individual D-O oscillations seem in clusters following H events H5 and H4.
- **We suggest that simulations may need to be kicked with a "pseudo-Heinrich" event before they can effectively reproduce D-O type oscillations**.
- Indeed, this is the case of the UofT CCSM model, in which a H event "kick" is the precursor to the D-O type oscillatory behaviour (Peltier et al., 2020).

We suggest running more idealised MIS3 freshwater forced simulations. All forcings are set to MIS3 values except for additional freshwater fluxes injected into the North Atlantic ranging from 0.05 Sv to 0.1 Sv freshwater fluxes (Zhang and Prange, 2020; Kawamura et al., 2017). Simulations can be run with this freshwater forcing for 500 model years; this could yield a wide range of stadial climates.

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