North Atlantic eddy-driven jet in interglacial and glacial winter climates

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The North Atlantic eddy-driven jet

- Much of the atmospheric variability in the North Atlantic (NA) sector (e.g., the North Atlantic Oscillation and the East Atlantic Pattern) can be regarded as variations in the NA eddy-driven jet.
- The eddy-driven jet is sustained by momentum and heat forcing associated with transient mid-latitudinal eddies in contrast to the subtropical jet, which is associated with polar moving air in the upper branch of the tropical Hadley cell (***Fig. 1***).
- Woollings et al. (2010) found three preferred latitudinal positions of the NA eddy-driven jet for present-day winters.

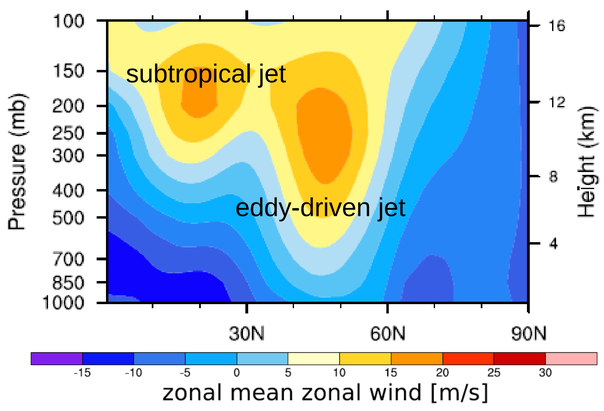

Figure 1: DJF mean of zonal mean zonal wind [m/s] over the NA domain (60W-0) in the PI_{3deg} simulation

Questions

? #1 Is the **NA eddy-driven winter jet** (position and speed) affected by the climate state during **interglacial and glacial times**?

? #2 Is the **model able to reproduce** the observed **trimodality** of the winter latitudinal position and **if so** is it **stable during different climate** states?

→ Approach: We perform CCSM4 climate model simulations for the present climate as well as for the early Holocene (EH), the Eemian (EEM), the last glacial maximum (LGM) and the Wuerm (MW) glacial period to test the behaviour of the NA eddy-driven jet under different interglacial and glacial climate conditions.

NA winter jet in paleo simulations

- For both interglacials periods (***Fig. 2*** top row) the winter mean jet structure only weakly deviates from PI conditions (shown in ***Fig. 1***).
- The jet structure is robust to substantial changes in the orbital parameters and to partial melting of the Greenland ice sheet during warm climates.

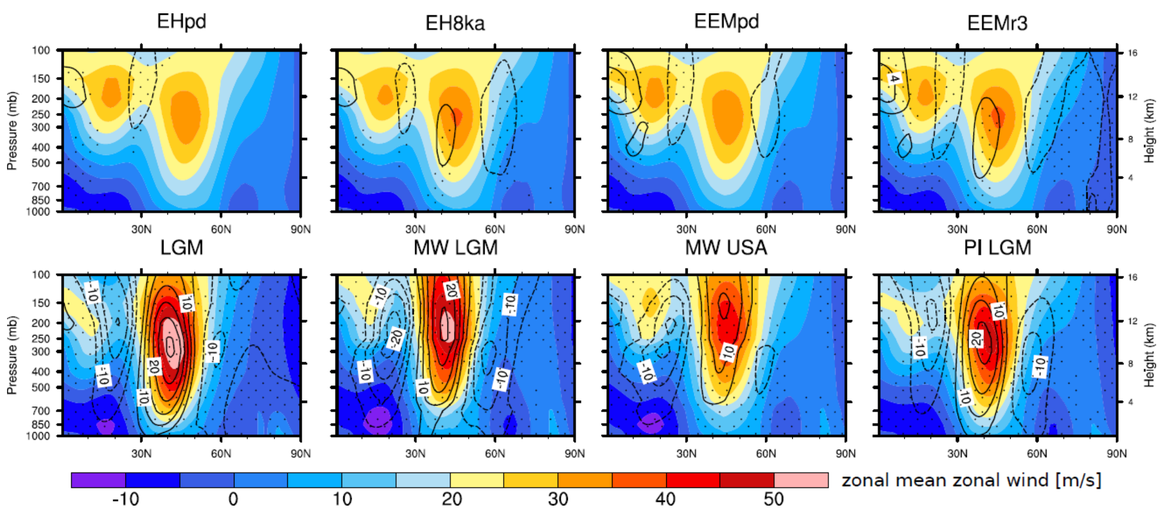

Figure 2: DJF mean of zonal mean zonal wind [m/s] over the NA domain (60W-0) in four interglacial (top row) and four glacial (bottom row) simulations. Absolute values are shaded, contours indicate the difference to the PI simulation shown in **Figure 1**, and stippling denotes significant values according to t-test statistics (5% level). Contour interval is 2 (5) m/s in top (bottom) row and negative values are dashed.

- For glacial periods (***Fig. 2*** bottom row) the eddy-driven and the subtropical branch merge to a very strong single jet. Compared to the PI eddy-driven jet this glacial jet is shifted southward and exhibits a narrower structure .
- Among the MW glacial simulations the height of the Laurentide ice sheet (LIS) is the dominant factor responsible for the jet position.
- The PI_{LGM} simulation shows that a LGM-size LIS is sufficient to explain the glacial position of the NA jet (see ***Fig. 2*** bottom right panel) even when all other parameters (e.g., SSTs, GHG concentrations) are held on interglacial level.

Summary & Conclusions

! #1 NA winter mean eddy-driven jet is relatively **stable** for different **inter-glacial climates** and robust to partial melting of Greenland.

! #2 Under **glacial climate** conditions the NA eddy-driven jet **moves south-ward** and **merges** with the **subtropical jet**.

! #3 The resulting **glacial jet** is **strongly accelerated** and located at ~37°N –> **variability** of glacial winter jet **latitudinal position** is highly **reduced**.

! #4 The **LIS topography** is the **dominant** factor for the glacial jet structure in agreement with Pausata et. al. (2011) -> **the higher the LIS**, **the stronger the southward shift**

! #5 **CCSM4** (as many other climate models) **shows** very **limited capability** to capture the winter jet latitude **trimodality** observed in reanalysis data

-> **agreement** between model and reanalysis clearly **improved** when **applying** a **bias correction**.

Climate model simulations and jet stream diagnostics

Model setting:

- atmosphere-land-only setup of CCSM4, 1° x 1° horizontal resolution, 26 sigma-pressure levels (in the atmosphere)

Experiments:

- 21 different sensitivity simulations (***Table 1***)
- For the EH, EEM and MW period: sensitivity due to NH ice sheet topography

Diagnostics:

- NA eddy-driven jet positions in latitude are analyzed with the algorithm of Woollings et al. (2010) using daily low-level (950-700 hPa) zonal wind values, averaged across 60W-0.

Jet latitude variability

- The NA winter eddy-driven jet shows substantial variability in terms of the latitudinal jet position (i.e., latitude of daily maximum zonal wind at low levels).
- The Model shows an unimodal distribution around the central jet position (~ 45°N) thus disagreeing with the observed trimodal distribution (***Fig. 3a***).

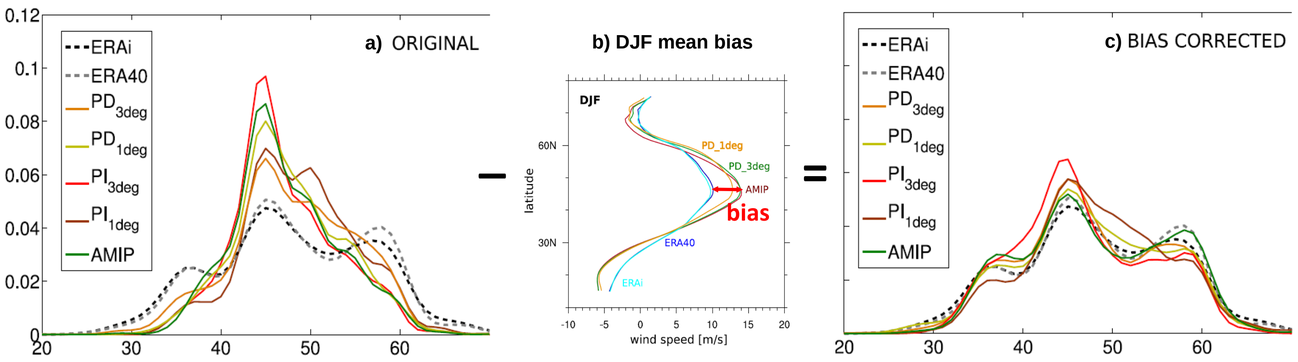

Figure 3: PDFs of DJF daily jet latitude using a kernel smoothing function for the present-day and pre-industrial simulations compared to reanalysis data. In **a)** the algorithm by Woollings et al., 2010 was applied to the original model data whereas for **c)** the daily zonal wind field has been corrected with the DJF mean bias shown in **b)**.

- When correcting the daily zonal wind field with the climatological bias (***Fig. 3b***) the trimodality is found in the present-day and pre-industrial model runs (***Fig. 3c***).
- Using the bias corrections the trimodal structure is also present in the other interglacial simulations (***Fig. 4a,b***).
- In contrast, the glacial simulations exhibit a unimodal distribution with strong kurtosis (**Fig. 4c,b**). The change to the glacial distribution is clearly provoked by the LIS topography with other glacial boundary conditions being of second order importance.

Figure 4: PDFs of DJF daily jet latitude applying a kernel smoothing for
a) the early Holocene,
b) the Eemian,
c) all simulations including a LGM-size LIS ice sheet and
d) the Wuerm glacial simulations.
Note that the bias corrected daily zonal mean data is used.

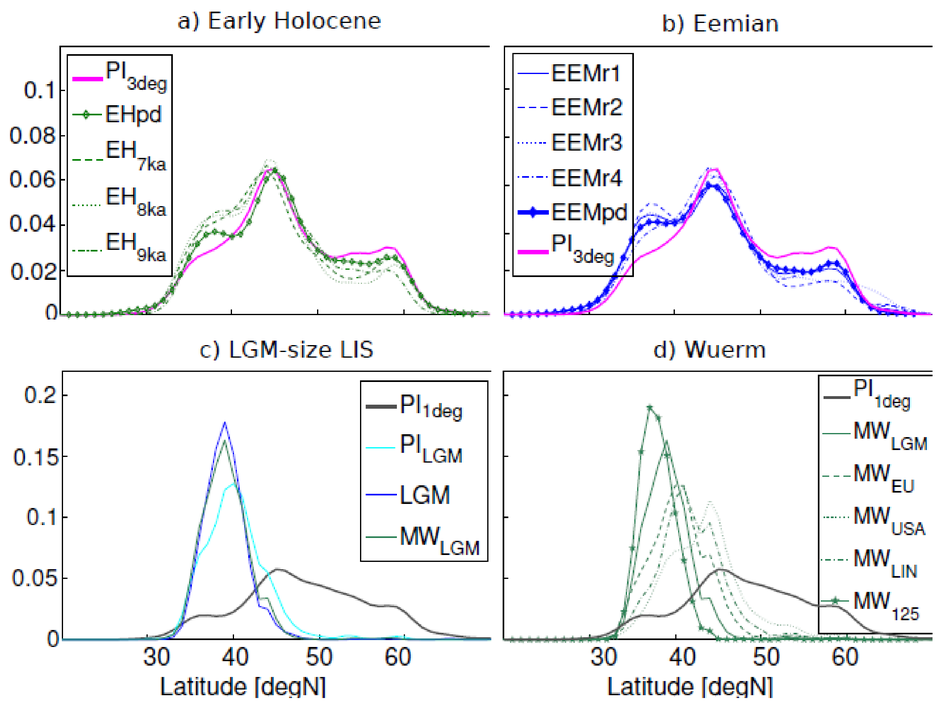

Table 1: List of model simulations and the forcing used in the experiments.
The simulations are grouped in 4 categories:
1) present-day (PD) and pre-industrial (PI),
2) Early Holocene (EH),
3) Eemian (EEM)
4) glacial simulations (LGM & MW)

Simulation	Orbital parameters	SST/ sea ice	CO_2 [ppm]	CH_4 [ppb]	N_20 [ppb]	TSI [Wm^{-2}]	Ice sheets
Present/pre-industrial							
AMIP 1972-2001	pd	obs	obs	obs	obs	1361.8	pd
PD_{1deg}	pd	pd 1deg	354	1694	310	1361.8	pd
PI_{1deg}	pd	pi 1deg	280	760	270	1360.9	pd
PD_{3deg}	pd	pd 3deg	354	1694	310	1361.8	pd
PI_{3deg}	pd	pi 3deg	280	760	270	1360.9	pd
Early Holocene							
EH_{PD}	8ka	8ka 3deg	280	760	270	1360.9	pd
EH_{7ka}	8ka	8ka 3deg	280	760	270	1360.9	7ka
EH_{8ka}	8ka	8ka 3deg	280	760	270	1360.9	8ka
EH_{9ka}	8ka	8ka 3deg	280	760	270	1360.9	9ka
Eemian							
EEMpd	125ka	125ka 3deg	272	622	259	1360.9	pd
EEMr1	125ka	125ka 3deg	272	622	259	1360.9	EEM GrIS r1
EEMr2	125ka	125ka 3deg	272	622	259	1360.9	EEM GrIS r2
EEMr3	125ka	125ka 3deg	272	622	259	1360.9	EEM GrIS r3
EEMr4	125ka	125ka 3deg	272	622	259	1360.9	EEM GrIS r4
Glacial simulations							
LGM	21ka	21ka 1deg	185	350	200	1360.9	LGM
MW_{LGM}	65 ka	65 ka 1deg	205	460	210	1360.9	LGM
MW_{USA}	65 ka	65 ka 1deg	205	460	210	1360.9	low LT
MW_{lin}	65 ka	65 ka 1deg	205	460	210	1360.9	67% LGM
MW_{EU}	65 ka	65 ka 1deg	205	460	210	1360.9	low FS
MW_{125}	65 ka	65 ka 1deg	205	460	210	1360.9	125% LGM
PI_{LGM}	pi	pi 1deg	280	760	270	1360.9	LGM

Woollings, T., Hannachi, A., and Hoskins, B.: Variability of the North Atlantic eddy-driven jet stream, *Quarterly Journal of the Royal Meteorological Society,* 136, 2010.
Pausata, F. S. R., Li, C., Wettstein, J. J., Kageyama, M., and Nisancioglu, K. H.: The key role of topography in altering North Atlantic atmospheric circulation during the last glacial period, *Climate of the Past*, 7, 2011.