Northern Hemisphere atmospheric variability in a glacial climate: a model intercomparison

Francesco S.R. Pausata[1], Camille Li[1], Justin J. Wettstein[1], Kerim H. Nisancioglu[1], David S. Battisti[2]

[1] Bjerknes Centre for Climate Research, University of Bergen, Norway

[2] Department of Atmospheric Sciences, University of Washington, Seattle, Washington and Geophysical Institute, University of Bergen, Norway

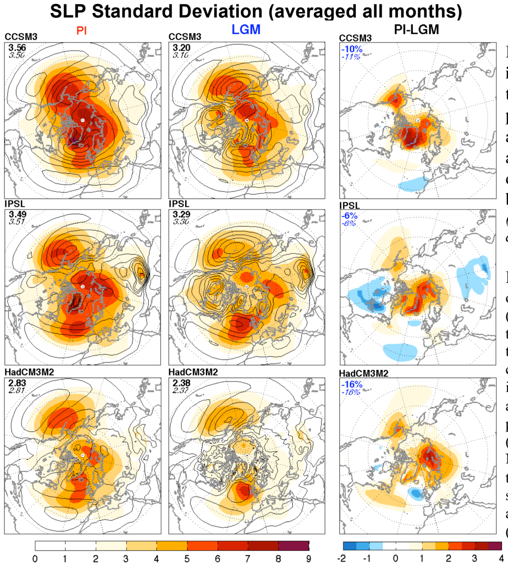
Bjerknes Centre for Climate Research

Email: francesco.pausata@bjerknes.uib.no

ABSTRACT: We investigate the nature of past extratropical (20º-90º) Northern Hemisphere atmospheric variability, in particular in the Atlantic sector, to determine how sensitive the variability and the dominant modes of variability are to the mean climate state. We analyze the sea level pressure (SLP) field in a cold climate (Last Glacial Maximum; LGM, 21 ka) and the pre-industrial climate (PI, 1750 AD) as simulated by four coupled climate models (CCSM3, IPSL, MIROC3.2, HadCM3M2) belonging to the Paleoclimate Modelling Intercomparison Project Phase II (PMIP2). **The models exhibit an equatorward shift of the low pressure systems and a reduction in both the interannual variability (except one) and seasonal cycle of sea level pressure variance during the LGM compared to the PI. An NAO-like behavior is also present in the LGM, though it represents less total variance and the centers of action are weaker.** Such coherent changes in total variance and in the spatial and seasonal distribution of this variance are an indication that climate variability is sensitive to the mean climate state, and are likely to influence the signals recorded in climate proxies.

1. INTERANNUAL VARIABILITY

SLP Standard Deviation (averaged all months)



In three out of four models, the **interannual variability** is **reduced** during the **LGM** compared to the PI climate, particularly during the winter months (see also Fig. 3.1). The change in the annual area averaged interannual standard deviation (shown in top of panels) ranges between -16% and -6%.

(The differences are significant at the 1% confidence level.)

Fig. 1.1: The mean and **standard deviation** of sea level pressure (SLP) in simulations of PI (left) and LGM (center) climate. The difference of the SLP standard deviation (LGM-PI) is shown in the right panels. Contours (4 hPa) show SLP climatology; color shading (hPa) shows the interannual SLP standard deviation averaged over all months. The bold numbers at the top of the panels represent the annual and area-averaged (20°-90° N) standard deviation of SLP in the Northern Hemisphere (σ_{NH}, left and center) and the difference in percentages between the two simulations (right). The italic numbers refer to area averages over the North Atlantic region (20°-90°N, 120°W-45°E).

SLP EOF1 (averaged all months)

An NAO-like feature is the dominant pattern of climate variability in both climates, although it represents **less** of the **total variance** during the **LGM**. The models do not agree on how the structure of this pattern changes between climates, but the **centers of action** are **weaker** in the LGM simulations.

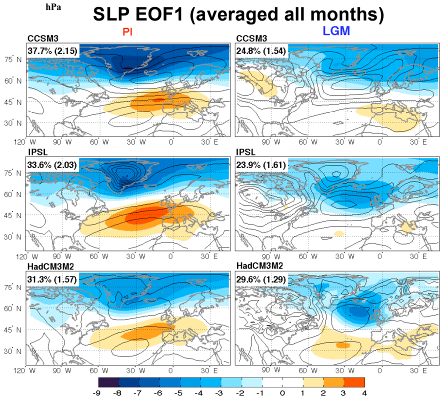


Fig. 1.2: Leading **EOF** of monthly anomalies of SLP (all months) in the North Atlantic sector for PI (left) and LGM (right) simulations. Contours (4 hPa) show SLP climatology; color shading (hPa) shows the EOF in hPa per standard deviation of the principal component. The numbers at the top of the panels represent the explained variance expressed as a percentage ($100\lambda_1$) of the total variance of the field and the standard deviation (hPa) explained by the first mode ($\sqrt{\lambda_1\sigma^2_{NA}}$) in parentheses.

Pausata, F. S. R., Li, C., Wettstein, J. J., Nisancioglu, K. H., and Battisti, D. S.: Changes in atmospheric variability in a glacial climate and the impacts on proxy data: a model intercomparison, Clim. Past Discuss., 5, 911-936, 2009.
http://www.clim-past-discuss.net/5/911/2009/

2. SEASONALITY

Seasonal Cycle of SLP Standard Deviation

As expected, the **seasonal cycle of interannual SLP** variance peaks during the winter months in all the climates, but it is damped in the LGM climate relative to the PI climate. The **change** in the magnitude of the seasonal cycle between LGM and PI ranges from -38% in the CCSM to -19% in the MIROC3.2 (not shown). Analysis of the seasonal cycle of PC1 of SLP corroborates this result.

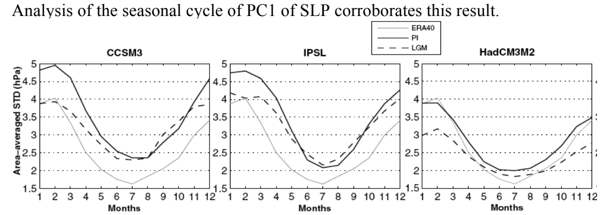


Fig. 2.1: Seasonal cycle of interannual SLP standard deviation area-averaged over the NH. The results show the PI (black, solid), LGM (black, dashed) and ERA40 reanalysis 1957-2002 (gray, solid).

PC1 Seasonal Cycle

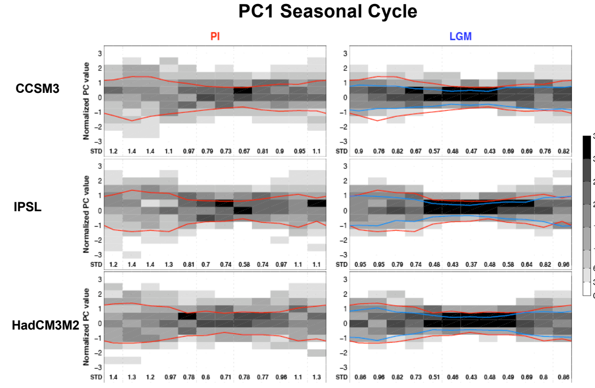


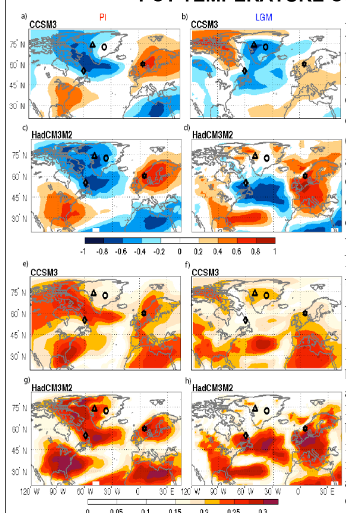
Fig 2.2: Histograms of the leading principal component (PC1) of SLP as a function of month. For each month, the PC has been normalized by the standard deviation of the annually averaged PC1 from the PI simulation in each model. This normalization allows for comparison between climate states within a given model. The standard deviations of the PC in these normalized units are indicated along the x-axis for each month and are marked by the lines (red for PI and blue for LGM).

MODEL SIMULATIONS: The model simulations are described in htttp://pmip2.lsce.ipsl.fr/ and Braconnot et al., 2007.

Period	Orbital Parameters	GHGs	Vegetation	Ice Sheet
PI Pre-industrial	1950	1750 AD	Modern	Modern
LGM Last Glacial Max.	21 ka	21 Ka	Modern	ICE-5G

3. PALEOCLIMATE IMPLICATIONS:

PC1-TEMPERATURE CORRELATION



All models generally reproduce the same correlation pattern between temperature and leading mode of SLP for the PI (panels a, c). The leading mode is able to describe regional scale variability (panels e, g). The models do not agree for the LGM neither for the correlation (panels b, d) nor the capability of the leading mode for describing regional scale variability (panels f, h). Nevertheless in all the models, the **correlation pattern** in the Atlantic basin is **shifted south** in the **LGM** simulations.

Fig. 3.1: PI and LGM correlations between North Atlantic winter surface air temperature (Nov. to Apr.) and PC1 (NAO-like index) for CCSM3 (a, b) and HadCM3M2 (c, d). An indicator of temperature coherence index in the sector for CCSM3 (e, f) and HadCM3M2 (g, h): the value at each point is the absolute value of the area-averaged correlation between temperature at that point and the rest of the North Atlantic basin.

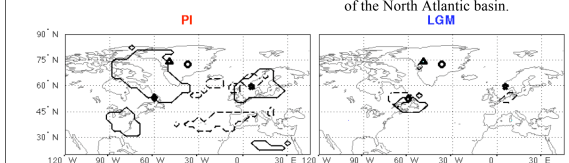


Fig. 3.2: Solid (dashed) lines represent respectively the areas where the correlation between temperature (precipitation) and the PC1 of the SLP for all the models is greater than 0.4 in absolute values in the PI and LGM simulations.

The results suggest that the link between the leading modes of atmospheric and surface climate variability may well change over different climate states. Making an assumption that the link remains stationary could lead to a misinterpretation of proxy signals recorded over periods spanning large climate changes. The ice cores may not be appropriate sites to record the NAO signal and the changes registered could be due to a shift and/or change in the amplitude of the pattern of variability rather than a climate signal.

ACKNOWLEDGEMENTS: This work is part of the modelling component of a multidisciplinary study called ARCTREC (ARCTic REcords of past climate change - dynamics, feedbacks and processes), funded by the Norwegian Research Council (NFR). We acknowledge the participants to the PMIP2 project international modelling groups for providing their data analysis, the Laboratoire des Sciences du Climat et de l'Environnement (LSCE) for collecting and archiving the model data.