Changes in the mid-latitude atmosphere dynamics in the CESM Large Ensemble simulations

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1) CESM-LENS : Arctic Amplification (AA) and mean changes

CESM-LENS : CESM1 simulations useful for studying internal climate variability and climate change

40 members over 1920-2100, historical/RCP8.5 radiative forcing

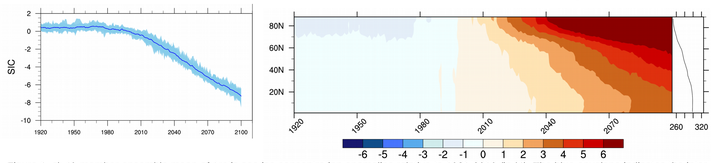
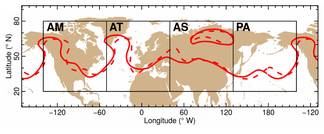


Figure 1. a) 40-member ensemble mean of Arctic sea ice concentration anomalies relative to 1981-2010 (in %). The blue envelope indicates the inter-member spread (min/max values). b) 40-member ensemble mean of 2-meter temperature anomalies relative to 1981-2010 (in °K), in function of latitude and time (Hovmöller plot). The zonal mean of the climatological T2M is given in the right panel (in K).

• **Zonal index (ZON)** : difference of Z500 between [20-50°N] and [60-90°N]. Characterizes the changes in mean state of the NH atmosphere, as the redistribution of mass balance between the pole and the mid-latitudes (close to the NAM and NAO index in the North Atlantic sector).

ZON = $Z500_{mid}$ - $Z500_{pol}$

• **Sinuosity (SIN)** : length of the averaged **Z500 isopleth** between 30 and 70°N for a longitudinal sector (from daily data). Describes the "waviness" of the atmospheric circulation, i.e. meanders of the jet stream at 50°N. Changes are assessed for the entire NH, and also sector by sector (see domains in the following figure).



• **Blocking (BLO) :** 1-D blocking index by Tibaldi and Molteni (1990) and 2-D extension from Scherrer et al. (2006), derived from daily Z500. Identify blocking situations between 40 and 80°N.

Figure 2. Ensemble mean of seasonal changes between the 2071-2100 and the 1981-2010 periods for : a) sea ice concentration (%) ; b) turbulent heat flux (latent + sensible, W/m², global anomaly removed) ; c) 2-meter temperature (°C, global anomaly removed) ; d) 500 hPa geopotential height (m, global anomaly removed) ; e) 10 hPa zonal wind (m/s), red contours indicate the climatology over 1981-2010 (interval 10 m/s from 20 to 70 m/s). Shading indicates anomalies that are significant at the 95% confidence level.

2) Changes in the mid-latitude atmosphere dynamics

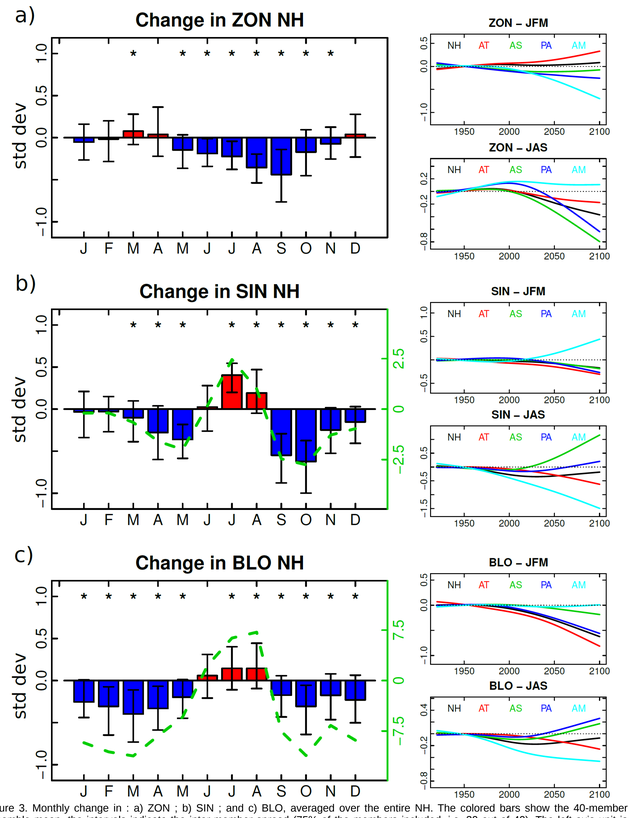


Figure 3. Monthly change in : a) ZON ; b) SIN ; and c) BLO, averaged over the entire NH. The colored bars show the 40-member ensemble mean, the intervals indicate the inter-member spread (75% of the members included, i.e. 30 out of 40). The left axis unit is standard deviation, the right axis (green) gives the changes in %. Corresponding 40-member ensemble mean timeseries of the metrics averaged over each sector (NH, AT, AS, PA and AM) in winter and summer are also shown to the right of each plot. Stars indicate anomalies that are significant at the 95% significance level (Student t-test).

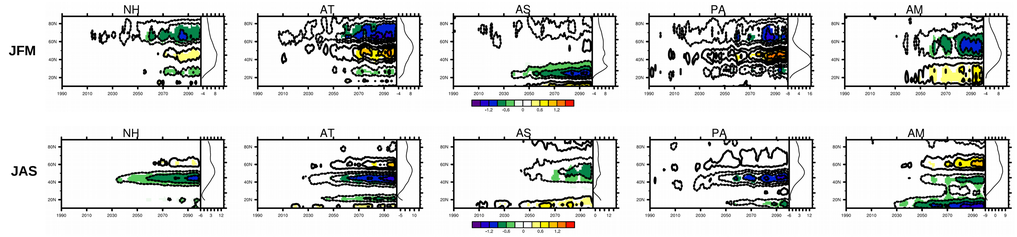


Figure 4. Latitude-time Hovmöller plots of anomalies in zonal mean U700 (m/s) (relative to the 1981-2010 climatology, shown in the right panels) in the NH and in the 4 sub-sectors. (top) JFM, (bottom) JAS. The 40-member ensemble mean is shown, with shading indicating anomalies that are significant at the 95% confidence level based on the 40-member ensemble dispersion.

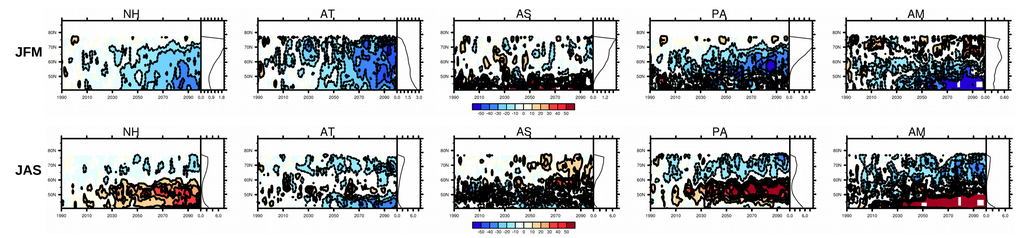


Figure 5. Latitude-time Hovmöller plots of anomalies in 2D blocking index (expressed as a % of change compared to the 1981-2010 climatology, that is shown in % of blocking days in the right panels) in the NH and in the 4 sub-sectors. (top) JFM, (bottom) JAS. The 40-member ensemble mean is shown, with shading indicating anomalies that are significant at the 95% confidence level based on the 40-member ensemble dispersion.

● In winter, the eddy-driven jet stream reinforces and narrows over the Atlantic and Pacific basin, in association with decreased SIN and BLO. Our interpretation is that tropical warming and Arctic Amplification have an opposite effect on each side of the jet, causing a narrower path for mid-latitude synoptic waves to propagate, hence decreased waviness and blocking.

● Only the NA sector shows a southward shift of the jet and increased waviness as expected from the effect of Arctic Amplification alone.

● In summer, the largest signals are found over Asia with negative ZON anomalies associated with increased SIN and BLO.

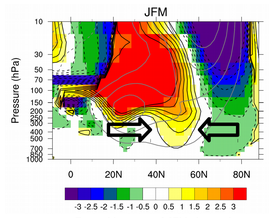


Figure 6. Ensemble mean of JFM change between the 2071-2100 and the 1981-2010 periods for the zonal mean zonal wind (m/s). Grey contours indicate the climatology over 1981-2010 (interval 10 m/s).

3) Link with tropical and polar temperature anomalies

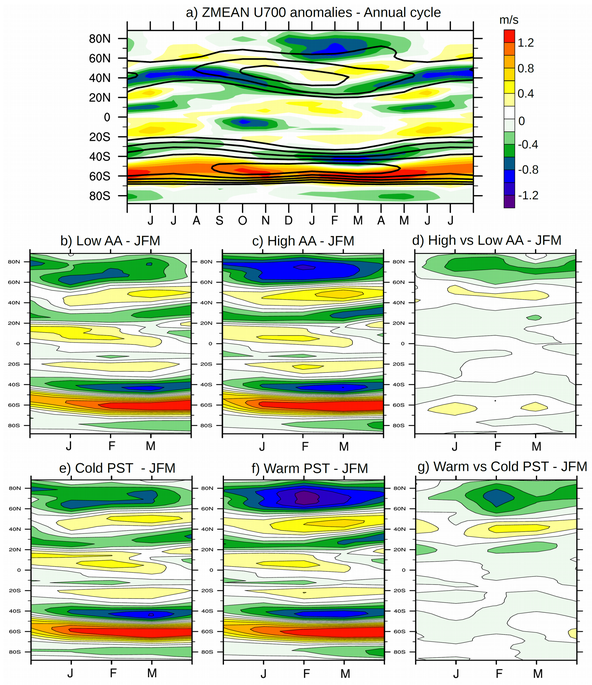


Figure 7. a) 40-member ensemble mean of annual cycle of the difference in 700 hPa zonal wind (shading, m/s) between 2071-2100 and 1981-2010. Contours indicate the 1981-2010 climatology with a contour interval of 3 m/s. b) Same as a but for the 10 members with the lowest AA (small polar surface warming). Only winter is shown. c) Same as b but for the 10 members with the highest AA (large surface polar warming). d) Difference between c and b (high versus low AA). e-g) Same as b-d but for warm vs cold PST.

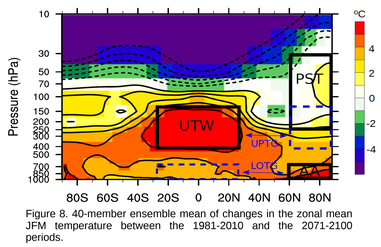


Figure 8. 40-member ensemble mean of changes in the zonal mean JFM temperature between the 1981-2010 and the 2071-2100 periods.

● A greater AA increases the constraint exerted on the polar flank of the jet. The resulting ZON- anomaly is more largely felt over AM where the competition with the upper-troposphere tropical warming (UTW) seems to be less pronounced.

● In the North Atlantic sector, changes in ZON exhibit greater correlations with the polar stratospheric temperature (PST) than with AA, a ZON- anomaly being associated with a warmer PST.

ZON ~	UTW	AA	PST	UTW+AA	UTW+PST	AA+PST	UTW+AA+PST
NH	0	0	**29 %**	0	2 %	23 %	5 %
AT	0	0	**30 %**	0	6 %	28 %	6 %
AS	2 %	10	3 %	0	3 %	**34 %**	6 %
PA	3 %	4 %	0	**10 %**	1 %	9 %	10 %
AM	0	**18 %**	2 %	18 %	1 %	15 %	15 %

Table 1. Percentage of variance explained by different linear regression models using combinations of UTW, AA, and PST to predict inter-member spread in ZON changes in each sector. The skill of the statistical models is evaluated using a leave-one-out cross-validation method, and the adjusted variance is given (the power of the different models is corrected according to the number of predictors included). For each sector, the highest explained variance is in bold.

Caveat : inter-member variance in UTW is very small in CESM-LENS

4) Conclusions

• The late 21st century changes in the wintertime mid-latitude atmospheric circulation do not correspond to changes that are expected from the Arctic Amplification mechanism only (negative NAM/NAO, increase in blocking events and in waviness of the jet stream, Francis and Vavrus 2015), except over North America (consistent to Vavrus et al. 2017). Other sectors rather exhibit a decrease in blocking and waviness. These findings are robust among models since they are also supported by similar analyses of CMIP5 simulations (Cattiaux et al. 2017).

• The response to AA is only one aspect of the overall changes due to anthropogenic forcing. In winter, AA exerts an equatorward constraint on the polar flank of the jet stream that mitigates the poleward shift due to global warming. This pole vs tropics competition results in a narrower path for the jet stream and for the meridional extent of synoptic waves in mid-latitudes, hence in less waviness and blocking events.

• Over the Atlantic sector, changes in the mid-latitude dynamics are more correlated with the response of the polar stratosphere that with AA. Further work will be needed to determine to which extent the stratosphere controls the tropospheric changes.

References

Cattiaux J., Y. Peings, D. Saint-Martin, N. Trou-Kechout and S.J. Vavrus (2016) Sinuosity of mid-latitude atmospheric flow in a warming world, Geophysical Research Letters, 43, 8259-8268.

Francis J. and S. Vavrus (2015) Evidence for a wavier jet stream in response to rapid Arctic warming, Environmental Research Letters, 10, 1, 014005.

Scherrer S. C., Croci-Maspoli, M., Schwierz, C. and Appenzeller, C. (2006) Two-dimensional indices of atmospheric blocking and their statistical relationship with winter climate patterns in the Euro-Atlantic region. Int. J. Climatol., 26: 233–249.

Peings Y., J. Cattiaux, S. Vavrus and G. Magnusdottir (2017) Late 21st Century Changes of the Mid-latitude Atmospheric Circulation in the CESM Large Ensemble. J. Climate, in revision.

Tibaldi S., and F. Molteni (1990) On the operational predictability of blocking, Tellus, 42A, 343–365, 1990.

Vavrus S., F. Wang, J. Martin, J. Francis, Y. Peings and J. Cattiaux (2017) Changes in North American Atmospheric Circulation and Extreme Weather: Evidence of an Arctic Connection. Journal of Climate, in revision.