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Relationship between African Outgoing Longwave Radiation and Tropical Cyclone Genesis in the Last Millennium Simulations

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1. Background

Former research showed that outgoing longwave radiation (OLR) index over Africa is a good proxy to predict the named storms in North Atlantic (e.g., Karnauskas and Li 2016). The possible mechanism of this relationship is the linkage of OLR gradient and the instability of African easterly jet (AEJ). Stronger instability of AEJ leads to more African easterly waves (AEWs) production through a reversal of the meridional potential vorticity (PV) gradient (Hsieh and Cook 2008). AEWs are possibly the seeds for Atlantic tropical cyclone (TC) genesis (Zhang et al. 2017).

Whether the relationship between African OLR index and North Atlantic storms number remain the same in other climates has not been explored. Also, what internal and/or external factors (e.g., aerosols and GHGs) drive the evolution of African OLR index in history is a key question to be further studied. The Community Earth System Model Last Millennium Ensemble (CESM-LME) simulations provided us a great resource to answer these questions in millennium time scale. In this study, we further investigate how the reversal of the meridional PV gradient is related to the instability of AEJ, and then further affect the OLR index in CESM-LME. We analyze the three simulations including full forcing ensemble, volcanism-only forcing ensemble and GHG-only forcing ensemble to explore the relationships and evolution. This study could help us better understand the physical relations of African OLR and Atlantic TC genesis and make possible better predictions for the future.

2. Data and Methods

- We apply the tropical cyclone (TC) downscaling technique developed by Emanuel (2006) to Community Earth System Model-Last Millennium Ensemble (CESM-LME) simulations.
- CESM-LME simulations are conducted at NCAR as contributions to the Paleoclimate Intermodal Comparison Project (PMIP). There are 36 ensemble members, about 1/3 of which use the full set of forcings and the remainder test responses to individual forces (e.g., greenhouse gas, solar, volcanism, etc.).
- We have downscaled 100,000 TCs for one full forcing ensemble member and another 100,000 TCs for a second forced only by volcanic eruptions (solar irradiance and other time varying forces all set to their 1850 values).
- Under the quasi-geostrophic assumption, the conservation of PV is approximately equivalent to the conservation of the quasi-geostrophic potential vorticity (q), q is defined as

$$q = \zeta_g + f + \frac{\partial}{\partial p}\left(\frac{f_0}{\sigma}\frac{\partial \Phi}{\partial p}\right)$$

- The meridional gradients of PV and q can be equivalently represented as

$$\frac{\partial q}{\partial y} = \beta - \frac{\partial^2 u_g}{\partial^2 y^2} - \frac{f_0{}^2}{\sigma}\frac{\partial^2 u_g}{\partial^2 p^2}$$

3. Results

Response of storm genesis to African OLR index

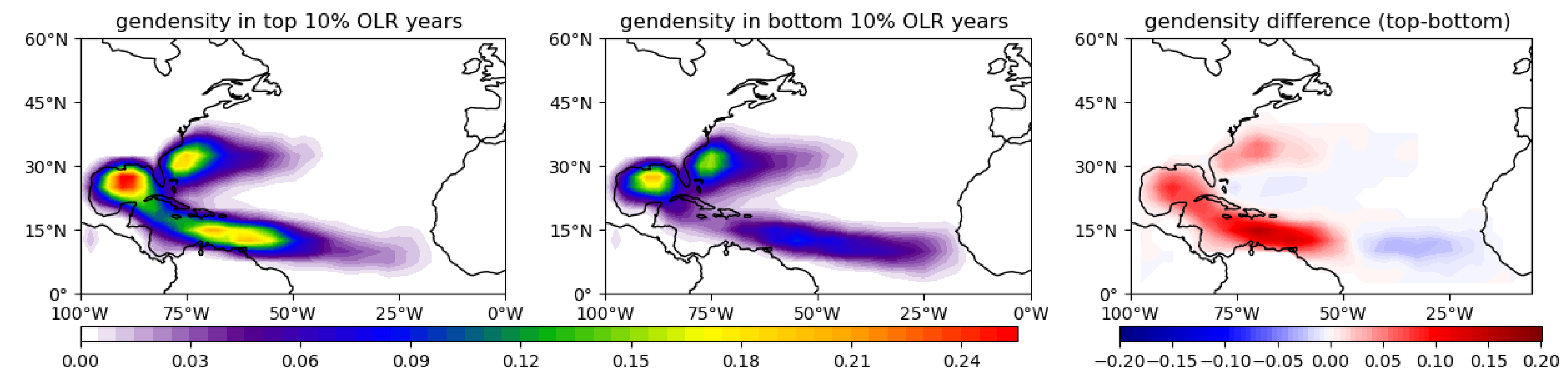

Fig. 1 From left to right: June-November genesis density in the years with top 10% African OLR indices, bottom 10% African OLR indices, and their differences. Storms are downscaled from CESM-LME full forcing member 7.

Fig. 1 shows downscaled storms genesis density is larger in top African OLR indices years than that in bottom African OLR indices years, especially in Mexico Gulf and Caribbean Sea. The genesis density in the east coast also slightly increased.

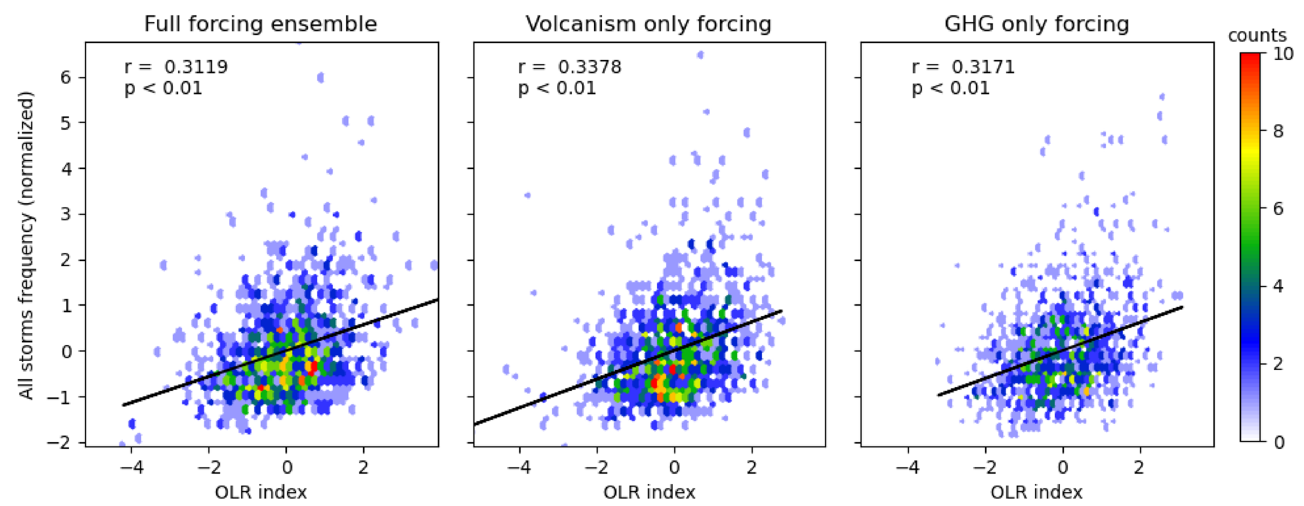

Fig. 2 Point number distribution of normalized annual storms frequency over North Atlantic against July OLR index during 850-2005 for full forcing, volcanism only forcing, and GHG only forcing ensembles . Black lines are the linear regressions of the two variables.

Fig. 2 shows that downscaled storm genesis density are positively correlated with African OLR indices. Correlation coefficients don't differ much in the full forcing ensemble, volcanism only forcing, and GHG only forcing ensemble, indicating the relationship is persistent when different external forcings are applied.

African QG PV meridional gradient at 700mb

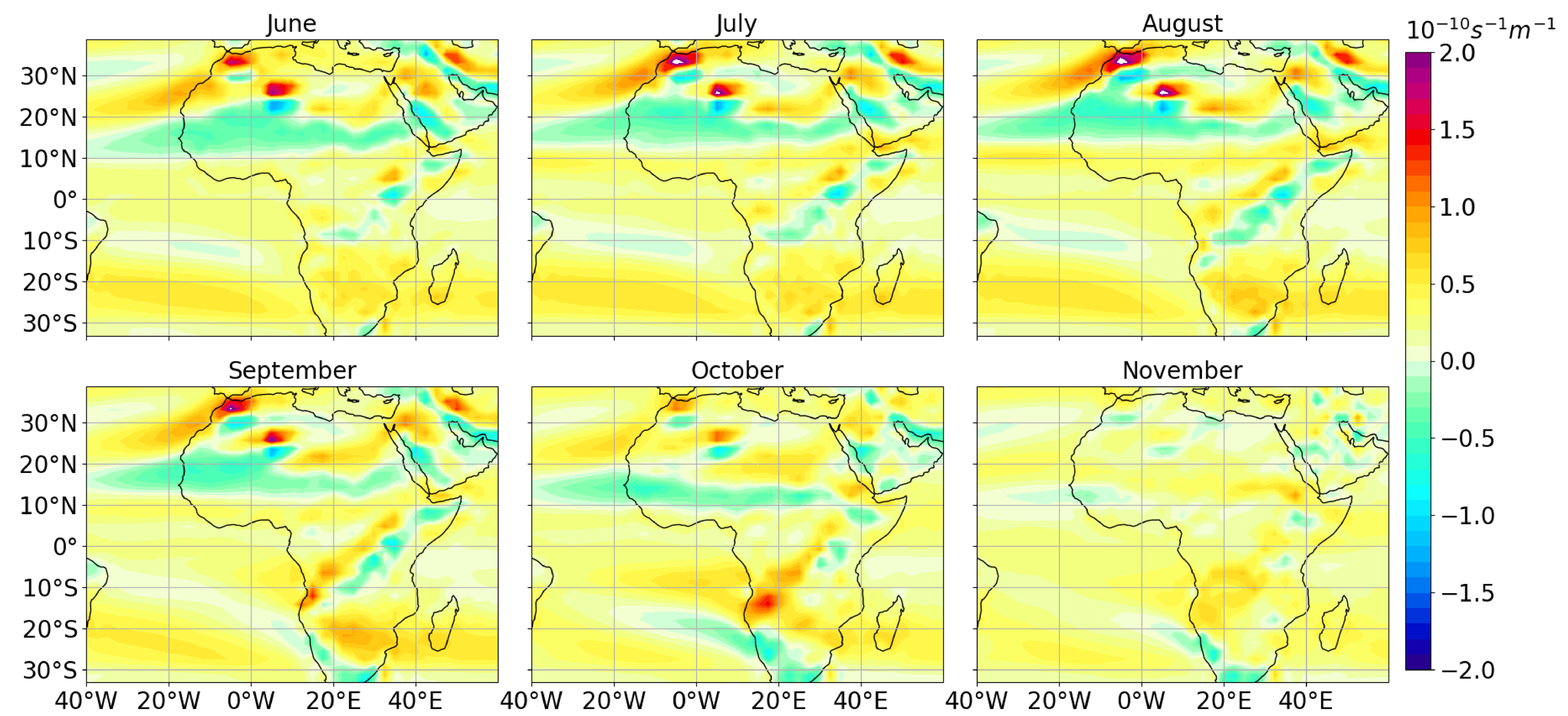

Fig. 3 Long term mean (850-2005) quasi-geostrophic potential vorticity meridional gradient at 700 mb over Africa and east North Atlantic in full ensemble member 7

The African q meridional gradient at 700mb changes its sign (from positive to negative in meridional direction) at around 5-15°N, which varies with season.

q meridional gradient v. African OLR indices

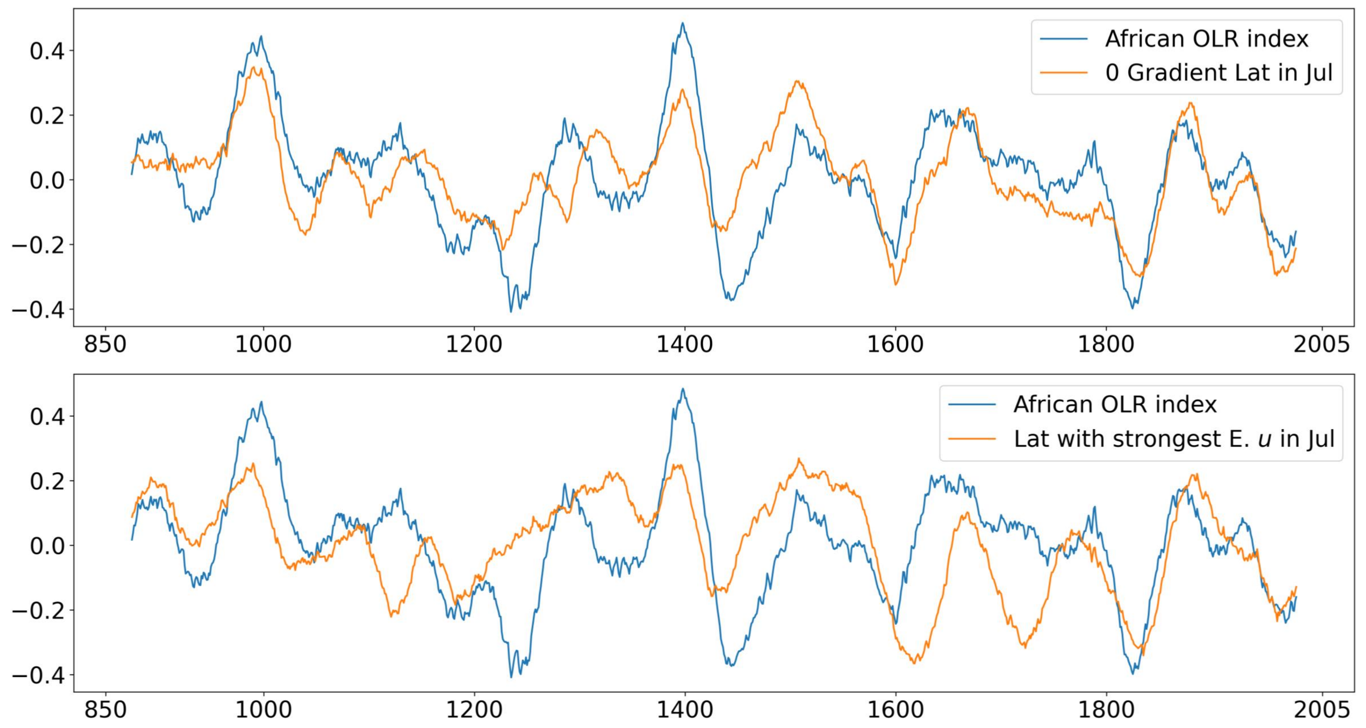

Fig. 4 Upper: Normalized time series of latitudes where the q meridional gradient changes its sign (averaged over 15°W-10°E, a 51-year Gaussian rolling mean with std=15 is applied) versus the OLR index. Bottom: Normalized time series of latitudes where the eastern zonal wind is strongest (averaged over 15°W-10°E, , a 51-year Gaussian rolling mean with std=15 is applied)versus the OLR index.

Fig. 4 shows the latitudes where the q meridional gradient reversal happened are positively related to the African OLR indices. Their correlation coefficients are 0.57 and 0.70, before and after the rolling mean, respectively. This means in years when OLR is larger, the zero q meridional gradient latitudes are more northern and vice versa. Latitudes with strongest eastern zonal wind is also positively correlated with OLR index, with correlation coefficients around 0.40. Results are similar for other forcing ensembles (volcanism or GHG only forcings, not shown here.)

4. Summary and Conclusions

1. Downscaled storm genesis density in the CESM-LME simulation is enhanced in the years with large African OLR indices, in the area of Mexico Gulf, Caribbean sea, and the US east coast.
2. Downscaled storm genesis in the CESM-LME simulation is significantly correlated with African OLR indices in all the three ensembles, suggesting this relationship is not climate dependent.
3. When the strongest eastern zonal wind moves north, the quasi-geostrophic PV meridional gradient reversal also moves north, leads to larger African OLR indices.
4. The downscaled storms are generated using the local environmental variables by randomly distributed seeds, while they are still affected by the jets in the western Africa.

Acknowledgements and References

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1. Karnauskas et al., (2016), *Geophys. Res. Lett.*, **43**, 7152–7159.
2. Hsieh, (2008), *J. Atmos. Sci.*, **65**, 2130–2151.