Tropical Cyclones at the Last Glacial Maximum

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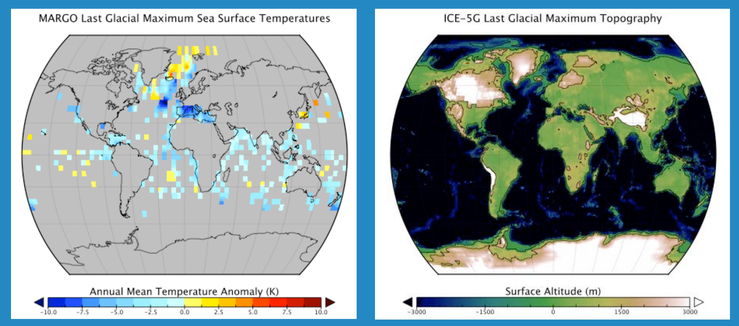
Introduction

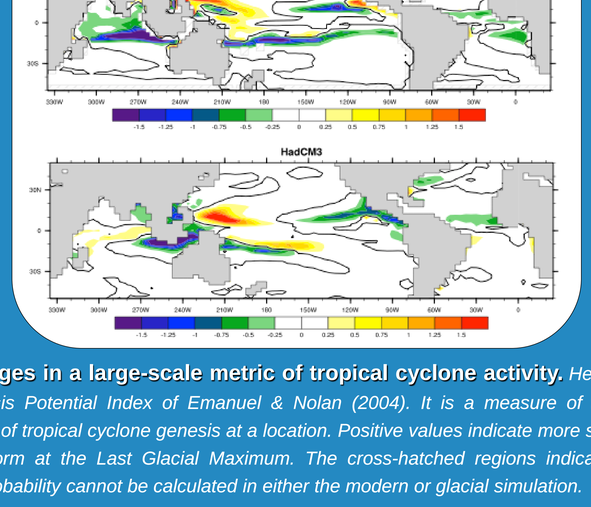
The impacts of future climate changes on tropical cyclones are still uncertain. Here, we investigate their response to past climate changes with a model downscaling technique. During the last glacial, the earth was substantially cooler with ice sheets covering large portions of Europe and North America. The climate of 21,000 years ago is particularly well studied as the ice-sheets were at their largest (**1**). Although the largest changes were at high latitudes, the tropics saw significant changes that may have influenced the tropical cyclone distribution.



1: Changes at the Last Glacial Maximum derived from paleobservations. *The most recent global compilation of sea surface temperature estimates from the MARGO group showing cooler tropics, and the reconstructed topography from the ICE-5G ice sheet model.*

Paleoclimate Model Intercomparison Project

Several modelling groups from around the globe created simulations with identical boundary conditions for the Last Glacial Maximum and placed their output at http://pmip2.lsce.ipsl.fr. The content of the archive varies from model to model. However it is possible to estimate the response of tropical cyclones to the changing climate conditions using several recently developed metrics (e.g. **2**) for two models. These metrics indicate a broadly coherent behavior between the climate models. There appears to be further concentration of tropical cyclone activity in the West Pacific.

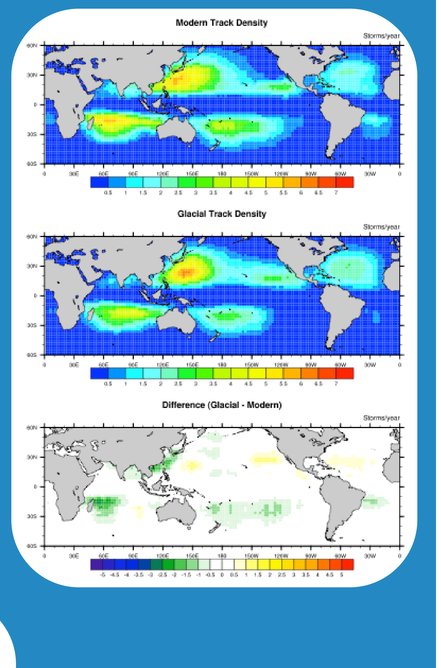


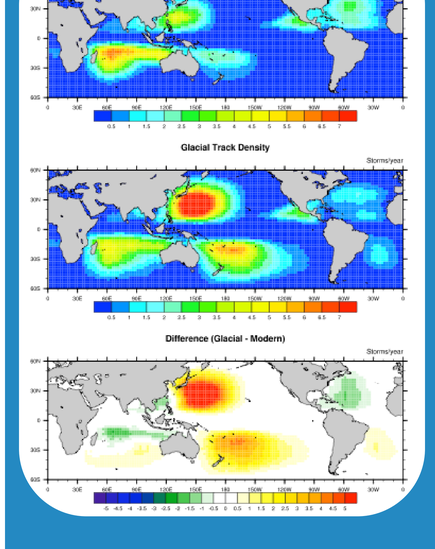
2: Changes in a large-scale metric of tropical cyclone activity. *Here we show the Genesis Potential Index of Emanuel & Nolan (2004). It is a measure of the relative probability of tropical cyclone genesis at a location. Positive values indicate more storms were likely to form at the Last Glacial Maximum. The cross-hatched regions indicate that the relative probability cannot be calculated in either the modern or glacial simulation.*

Simulated Tropical Cyclone Tracks

The modeling of tropical storms in this study is performed using a statistical downscaling technique (Emanuel et al., 2008). We use monthly climatologies of temperature and humidity, along with daily wind statistics. No model has all these diagnostics in the PMIP2 database. We acquired the HADCM3 data from the Hadley Centre and re-ran CCSM3 with additional diagnostics. To increase track variations, self-consistent random realizations of the winds are created using the means, variances and covariances from the GCM simulations. Weak vortices are seeded at random throughout the tropics and their subsequent progression is computed from advection by the vertically averaged winds, corrected for a β-drift. Over 2,000 synthetic cyclones were produced for each climate simulation.

3. Tropical cyclone track density from the CCSM3 simulations. The modern simulation gives a fairly accurate distribution of storm tracks. The last glacial maximum saw more storms in the West Pacific, however they did not travel as far north or east before dissipating. The largest changes occurred in the Southern Indian ocean, which had substantially fewer storms. These three features are in accord with **2**. The East Pacific was slightly more active, as was the Atlantic, although there are some biases in the modern simulation in the Carribean.



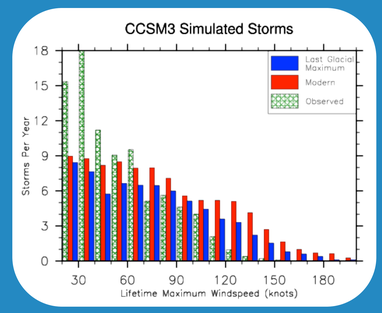


4. Tropical cyclone track density from the HadCM3 simulations. The modern simulation shows storms in approximately the correct distribution. There are too many storms in the southern Indian Ocean at the expense of those in the West Pacific. The last glacial maximum sees a doubling of the storm activity in the West Pacific. This increase is mirrored in the South Pacific to a lesser extent. There is a decrease in activity in the North Atlantic, although the East Pacific remains unchanged. This pattern would not have been expected from inspection of the differences in HadCM3's genesis potential index (**2**).

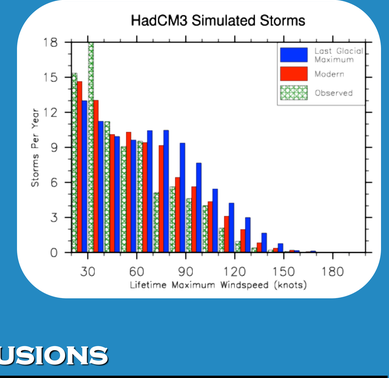
Changes in Intensity

Operational forecasts of a tropical cyclone's intensity are much less certain than those of its track. This is also true of the tropical cyclone response to climate change. Most studies lean toward fewer total storms, but with more devastating ones. Previous work with this downscaling technique (Emanuel et al., 2008) has shown large deviations between different climate model projections. However, there did appear to be some support for the "fewer but stronger" hypothesis from the study. It would be logical to expect the Last Glacial Maximum to show the opposite trends – more, generally weaker storms.

5. Global storm counts from the CCSM3 simulations. There is a systematic over-estimation of the intensity in the CCSM3 modern simulation, in comparison to 50 years of the IBTRACS observations. The glacial simulation shows reduced tropical cyclone frequency in every intensity class. The fractional reduction is largest for stronger storms.



6. Global storm counts from the HadCM3 simulations. Although there is an over-estimation of the intensity in modern simulation, it is much less than in CCSM3. The glacial simulation has fewer storms below hurricane strength, with more frequent storms in every hurricane class. In total there are 10% more tropical cyclones in the glacial simulation.



Conclusions

- **Tropical cyclone distributions have been synthesized for the Last Glacial Maximum (21,000 years ago)**
- **The regions of cyclone activity were roughly the same, with increased dominance of the West Pacific**
- **Changes in storm intensity are model dependent: CCSM3 predicts a decrease and HadCM3 an increase**
- **Understanding these differences would improve future predictions of tropical cyclone behavior**

References

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