An Examination of the Spatial and Temporal Extent of the Climate Memory of Tropical Cyclones

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Introduction

One of the great remaining unanswered questions in meteorology is the role of TCs in the climate. The implications of understanding this problem include whether the recent suppression of global TC activity (Maue 2009) is the new norm in a continually warming world. TCs impact the ocean-atmosphere system by creating a net flux divergence of heat from the surface of the ocean through entrainment mixing and upwelling in the ocean and enhanced evaporation of water into the atmosphere from the ocean's surface. The end result of the passage of a TC is anomalous cooling of the ocean and warming of the atmosphere. The following study seeks to determine on what scales, in space and time, TCs redistribute energy and their relative importance in the global climate system.

Data and Methodology

The first portion of this study involves an examination of the fidelity of TC representation within three atmospheric reanalysis datasets: ERA-40 (Uppala et al. 2005), JRA-25 (Onogi 2007), and MERRA (Bosilovich et al. 2006). These datasets serve as the foundation for quantifying the impacts of TCs upon the atmosphere. TCs from the years 1992-2001 in the North Atlantic, North Eastern Pacific, and North Western Pacific basins were manually tracked using MSLP and 925 hPa vorticity fields. TC structure is evaluated in comparison with the NHC best track (Jarivinen 1984) and JTWC ATCF data using standard metrics such as MSLP and maximum surface winds in addition to alternative parameters such as those found in the cyclone phase space (Hart 2003). Absolute track errors within the reanalyses are presented as well.

Following the methodology of Hart et al. (2007), the second part of this study involves constructing storm relative composites of SST anomalies, 1000-200 hPa thickness anomalies, and MPI anomalies (Emanuel, 1988) for all storms equatorward of 35ºN from 1982-2001 for the North Atlantic, North Eastern Pacific, and North Western Pacific basins. SST data was obtained from the NASA OI SST dataset (Reynolds 2006), while atmospheric variables necessary to compute the fields above were obtained from the three reanalysis datasets. For every 6 hr best track data point, anomalies were computed relative to an evolving climatology for up to a year prior to and a year after the passage of the TC. The anomalies were then composited by basin, intensity, latitude, and Julian day. 5º by 5º box averaged time series are presented along with plan views of the three aforementioned fields. Given the sensitivity of the anomalies in the ocean to storm motion, a third type of plot is included in which fields are interpolated to a cylindrical grid and rotated such that all storm motion is to the West.

Evaluation of TC Structure within Atmospheric Reanalysis Datasets

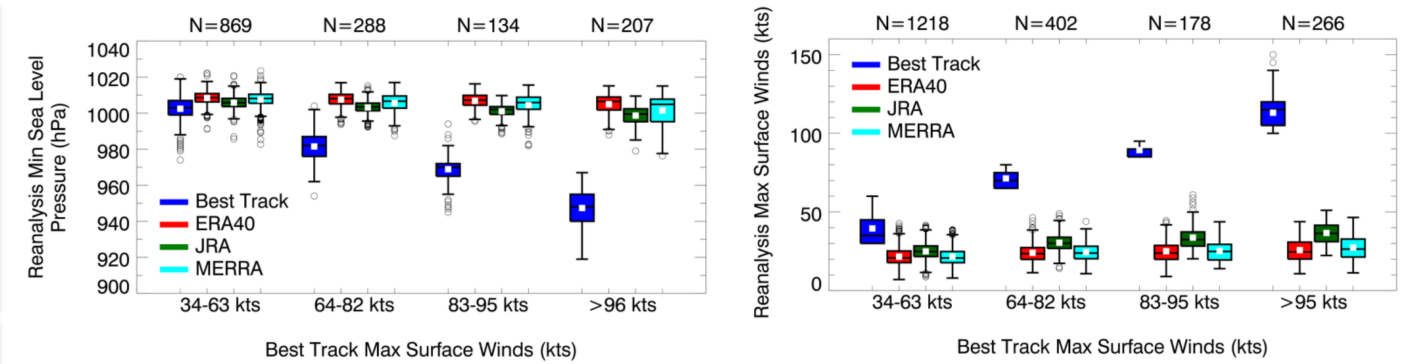

Figure 1: Box and whiskers plots of (left) best track maximum surface winds (kts) versus reanalysis MSLP (hPa) for the North Atlantic and North Eastern Pacific basins and (right) best track maximum surface winds (kts) versus reanalysis maximum surface winds (kts) for the North Atlantic, North Eastern Pacific, and North Western Pacific basins for TCs occurring between 1992-2001. White squares in the middle of the boxes represent the means for each category. Numbers for each intensity bin at the top of plot denote the number of samples in each category.

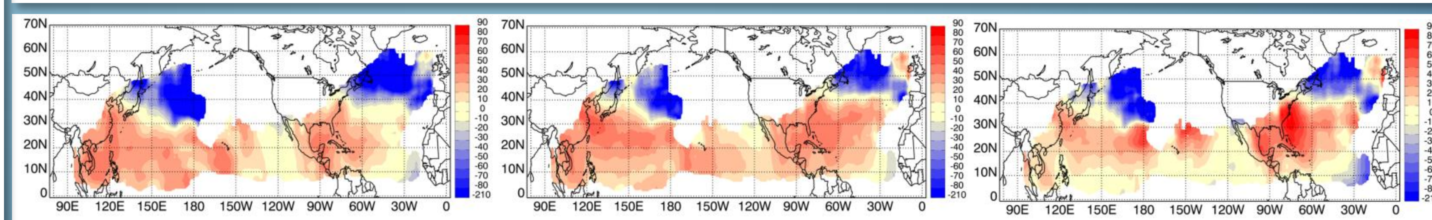

Figure 2: Plan view of low level thermal wind for (left) ERA40, (middle) JRA, and (right) MERRA for TCs between 1992-2001 in the North Atlantic, North Eastern Pacific, and North Western Pacific basins. Lower level thermal wind was interpolated to a 0.5° by 0.5° grid with each grid point representing the average of the lower level thermal wind within 5° of that point. The grid was smoothed twice in order to reduce noise.

Atmospheric Reanalysis TC Track Error

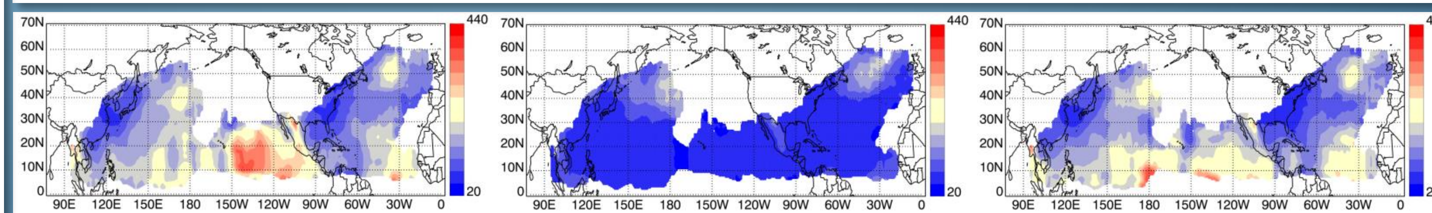

Figure 3: Same as figure 2, but for absolute track error (km) in the (left) ERA40, (middle) JRA, and (right) MERRA. Absolute track error is defined as the absolute value of the difference between the best track and the reanalysis data. TC track in the reanalysis data was determined via manual tracking using MSLP and 925 hPa vorticity.

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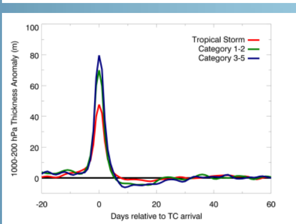
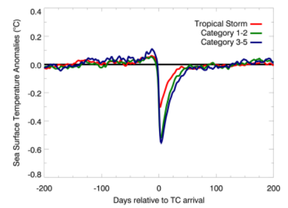
Evolution of TC Climate Memory in Time





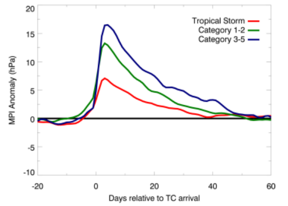


Figure 4: Time series of 5° by 5° box averaged (top left) 1000-200 hPa thickness anomalies (m), (top right) SST anomalies (°C), and (bottom left) MPI anomalies (hPa) for all northern hemisphere TCs from 1982-2001 categorized by intensity. The red line represents tropical storms, the green line corresponds to Category 1-2 TCs, and the blue line represents Category 3-5 TCs. Both thickness and MPI anomalies were calculated using data from the JRA.

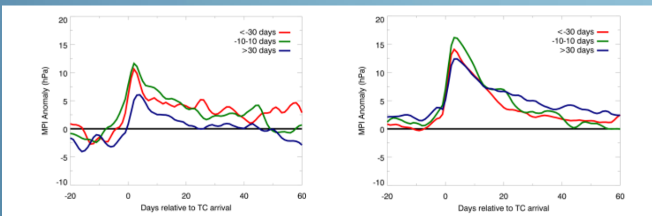


Figure 5: Time series of 5° by 5° box averaged MPI anomalies (hPa) for the (left) North Atlantic and (right) North Western Pacific basins stratified by date of occurrence relative to the climatological maximum frequency of TC occurrence in each basin during the period studied. The red line represents TCs occurring prior to 30 days before the climatological peak, the green line corresponds to TCs occurring between 10 days prior or 10 days after the peak, and the blue line represents TCs occurring 30 days after the climatological peak. MPI anomalies were computed using data from the JRA.

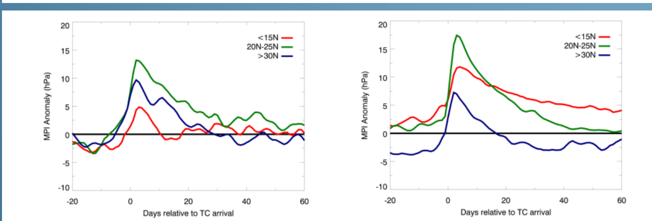


Figure 6: Same as figure 5, but for the (left) North Atlantic and (right) North Western Pacific basins for various latitude bands. The red line represents TCs passing equatorward 15°N, the green line is for TCs that occur between 20°N and 25°N, and the blue line corresponds to TCs that pass poleward of 30°N. MPI anomalies were computed using data from the JRA.

Evolution of TC Climate Memory in Space

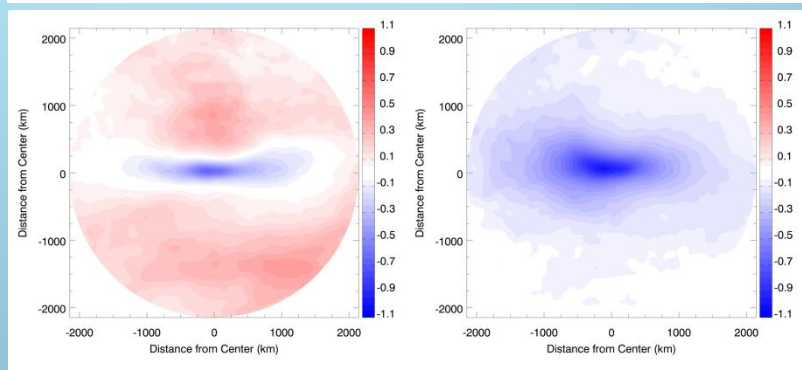
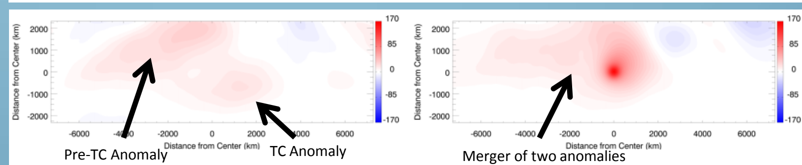


Figure 7 (top): Storm motion relative SST anomalies (°C) for category 3-5 TCs at 3 days after TC passage in the (left) North Eastern Pacific and (right) North Western Pacific basins. SST anomalies have been interpolated to a cylindrical grid and rotated such that storm motion is to the West. The direction of storm motion is calculated by taking a centered finite difference in time of the position of the TC from the best track data.

Figure 8 (below): 1000-200 hPa thickness anomalies (m) for category 1-2 TCs in the North Atlantic at (left) 5 days before and (right) the day of TC passage.



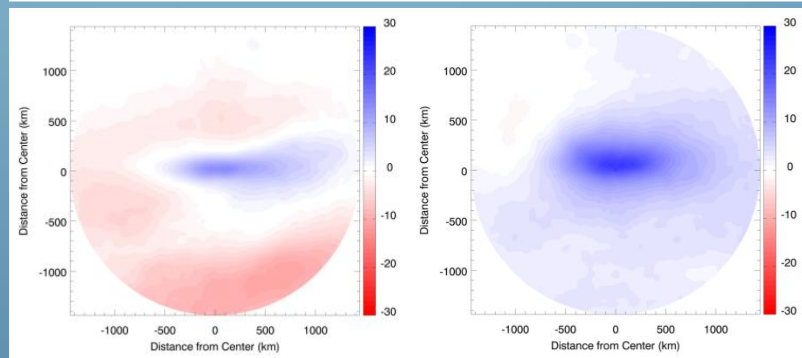


Figure 9 (top): Same as figure 7, but for MPI anomalies (hPa) in (left) North Eastern Pacific and (right) North Western Pacific basins. MPI anomalies were computed using data from the JRA.

Discussion

The reanalysis evaluation conducted in the first portion of this study indicates that while these datasets do not capture the true intensity of TCs, they GENERALLY are able to represent the large scale features such as the more diffuse upper level warm core. Of the reanalyses examined, the JRA performed most truthfully with both structure and track due to the inclusion of wind profile retrievals (essentially TC bogussing) in its data assimilation. With regards to TC climate memory, figures 4-6 show that the SST and MPI anomalies take approximately 50-60 days for restoration to climatology with considerable variability depending on the time and location of TC passage. The anomalous cooling in the ocean associated with TCs extends up to 1500 km in either direction away from the track in the North Western Pacific with a more localized response in the North Eastern Pacific. In contrast to this, while TC passage does generate a large scale warming in the atmosphere, the response is more temporally transient. Given the long time scales required for the recovery of the ocean to climatology, the aggregate impact of TCs over an entire TC season cannot be ignored. These results also beg the question as to whether large scale forcings (e.g. ENSO) known to change TC frequency, intensity, and track can fundamentally change the relative role of TCs in the climate on an interannual basis.

References and Acknowledgements

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