How Long does the Climate Record "Remember" a Tropical Cyclone?

Numerous studies of atmospheric and oceanic phenomena (such as ENSO, Saharan dust, and global warming) have investigated climate change effects on tropical cyclones (TCs). Yet, comparatively few have considered the converse: what is the purpose of TCs in climate, how do we quantify that role, and how much does that role vary year to year? Prior work has argued that TCs serve as one of the many balancing mechanisms in redistributing excess tropical heat poleward within the atmosphere through convection, eddy heat transport, and in the ocean through upwelling. Despite this, we are still unable to answer one of the most fundamental questions in tropical meteorology: why are there approximately 100, rather than 10 or 1000, TCs annually? While we cannot answer that question definitively, our research does seek an answer to at least one of the great mountain of exciting questions in meteorology by addressing the "memory" of a TC in the climate record: How long does the climate "remember" that a TC occurred in the past? The answer is that the memory is longer than imagined, and has a surprisingly curious structure.

The memory of a TC is quantified through examination of atmospheric and oceanic evolution for 20 days prior to the arrival of a TC through 60 days after TC passage. Rapid warming of the atmosphere and slower cooling of the SST occurs shortly before TC arrival (the "calm before the storm"). The atmosphere and SST are not restored to the evolving climatology until weeks after the TC has departed.
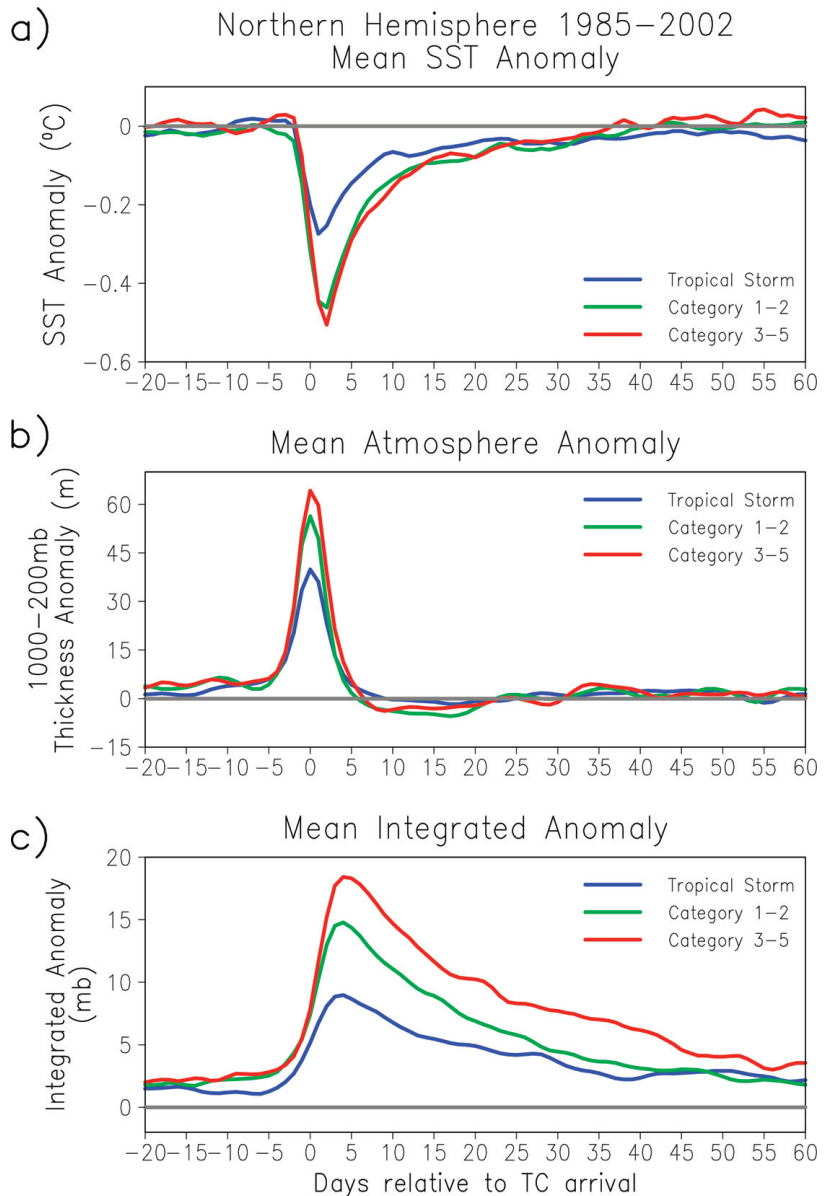
Measuring the memory a tropical cyclone has on the region it passes from 20 days before arrival to 60 days after departure for (a) sea surface temperature (SST) anomaly; (b) 1000–200-mb thickness anomaly; and (c) an anomaly that measures the integrated atmosphere and SST. This analysis was performed using approximately 32,000 6-h TC times from 1985 to 2002 over the Northern Hemisphere and uses ERA40 reanalysis data for the atmosphere and NCEP Global Ocean Data Assimilation System data for the sea surface temperature.

When this analysis is performed for all Northern Hemisphere TCs between 1985 and 2002, the average length of the TC memory is revealed: 30–35 days for a tropical storm to a stunning 50–60 days for a Category 3–5 hurricane, with significant storm-specific and basin-specific variability. Paradoxically, the occurrence of

a TC does not always lead to a stabilization of the SST with respect to the atmosphere in some regions. That is, the atmosphere becomes more unstable after TC passage in some regions of the world. Also curious is that there exists a striking wave structure to the atmospheric component of the memory trace of a TC, even when averaged over 18 years of TCs. This wave nature has a period of 1–2 weeks and is speculated to be the tropical easterly wave periodicity revealing itself throughout many basins of the hemisphere, including the Western Pacific. While these results raise fascinating questions and we speculate on possible answers, a great volume of new research is needed to satisfactorily answer them.

Naturally, the energy utilized to restore the TC track region back to climatology would not necessarily have been utilized (and certainly not for that purpose) had the TC never occurred. Thus, the energy budget of the basin and hemisphere as a whole is altered by the formation of a long-lived and intense TC. As a result of anomalous aggregate TC occurrence (for example, the Northern Hemispheric TC activity in 2005 compared to 2007), subtropical and tropical SSTs can easily be a few degrees Celsius warmer or colder than normal at the start of winter. Such anomalous SSTs and atmospheric profiles could potentially drive larger-scale atmospheric circulation anomalies and even snowcover anomalies into the start of winter, nonlinearly extending in time or space, or amplifying in magnitude, the memory of the TC through other climate components. Is it a coincidence, then, that the most impressive (since 1966) Northern Hemisphere snowcover in winter 2008 followed the least active hemispheric TC season since 1977?

Further, when the memory time scale quantified here is combined with the typical translation speed of a TC as well as the size of a basin and the periodicity of TC genesis also shown in this and other studies, an explanation as to why there are approximately 100 TCs globally, rather than 10 or 1000, may be possible.

Such results beg for further research. Mesoscale modeling should extend these results by tracking with higher resolution the forcing introduced by a TC that otherwise would not have existed. How far from the track does this memory extend in space? Climate modeling should examine the changes in overall climate means and variability when TCs are aggressively encouraged (or prevented) from forming through creative use of physical parameterization options. Certainly such studies are warranted in order to examine the potential unexpected consequences of weather modification to divert or diminish TCs.

Finally, it has been argued that trade winds in climate models are too strong, in part, because of the inability of those models to resolve TCs. Something must pick up the slack to balance the heat and angular momentum budget of the atmosphere, and in this case, the trade winds (likely among other mechanisms) are stepping forward. When this argument is combined with the results of our research, a daunting task presents itself: to correctly simulate the global climate for the correct reasons it is imperative to accurately simulate the intensity and track of TCs within those models.—ROBERT E. HART (FLORIDA STATE UNIVERSITY), R. N. MAUE, AND M. C. WATSON. *"Estimating Local Memory of Tropical Cyclones through MPI Anomaly Evolution,"* in the December Monthly Weather Review.