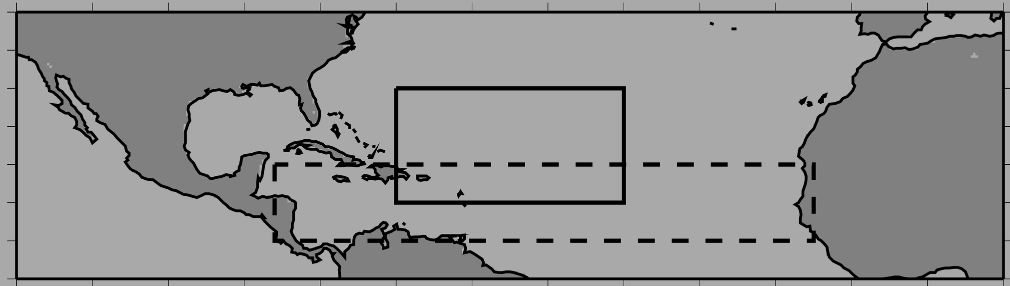

Hurricane Alley SST Variability in 2005 and 2006

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ABSTRACT: The North Atlantic hurricane seasons of 2005 and 2006 were dramatically different for the Gulf Coast and eastern seaboard of the United States. The 2005 hurricane season was one of the most destructive seasons in history, while there was limited impact in 2006. Hurricane activity had been forecast to be above normal in 2006 but was not. One of the conspicuous differences in environmental conditions between these two years was sea surface temperature (SST) anomaly over a region of the Western Atlantic and Caribbean (70W-40W, 15N-30N) important for hurricane formation and intensification. SST anomaly was more than 1.5 standard deviations warm during the 2005 hurricane season, but was much less in 2006 through most of its hurricane season. The intent of this study is to determine the mechanisms responsible for this SST difference. It is shown that the difference can be reproduced using a simple 1-dimensional ocean mixed layer model forced with surface fluxes from the NCEP/NCAR Reanalysis Project. It is found that there are two causes of SST difference over this region during July through September; one is latent heat flux variability caused by wind speed effects, and the second is non-linear ocean warming caused by sub-monthly atmospheric variability. The observed SST difference is reproduced by our model even though the solar forcing used here damps the observed difference. This argues against previous hypotheses[1] which posit that atmospheric-aerosol damping of solar radiation (not included in the NCEP/NCAR Reanalysis) played a major role in determining the 2005 to 2006 SST difference.

1) Model results accurately reproduce observed 2006 minus 2005 SST difference

An array of 1-D ocean models[2] forced with daily average NCEP/NCAR fluxes reproduces the observed area-averaged 2006 minus 2005 SST difference accurately on sub-monthly to seasonal time scales.

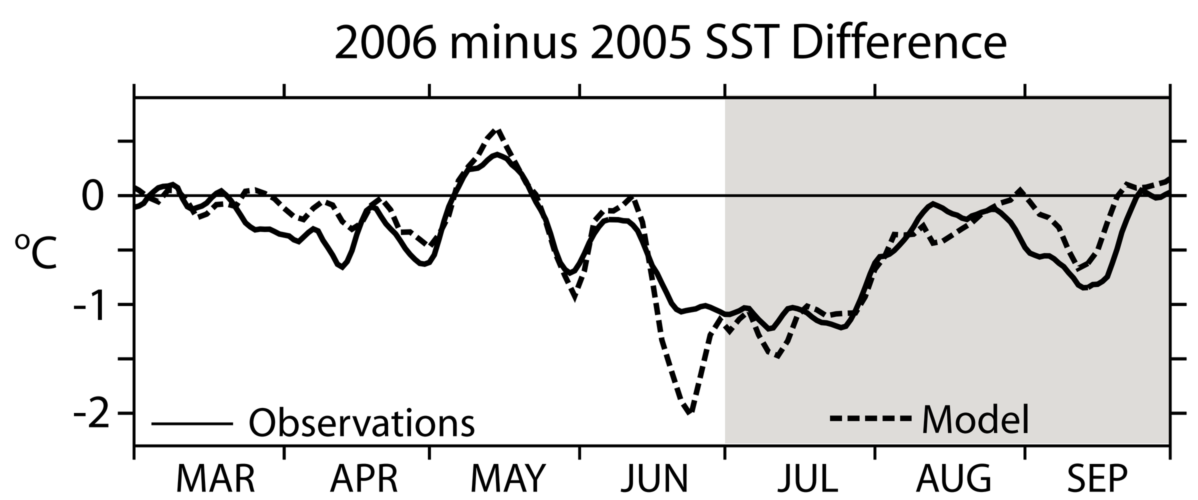

Fig. 1: a) Observed (TMI) and modeled 2006 minus 2005 SST difference averaged over the Western Atlantic and Caribbean (WAC) region. The months of main interest here (just prior to/during hurricane season) are shaded.

2) Latent heat flux variability drives the observed SST difference

Only latent heat flux anomalies have the magnitude and timing necessary to drive the observed SST difference.

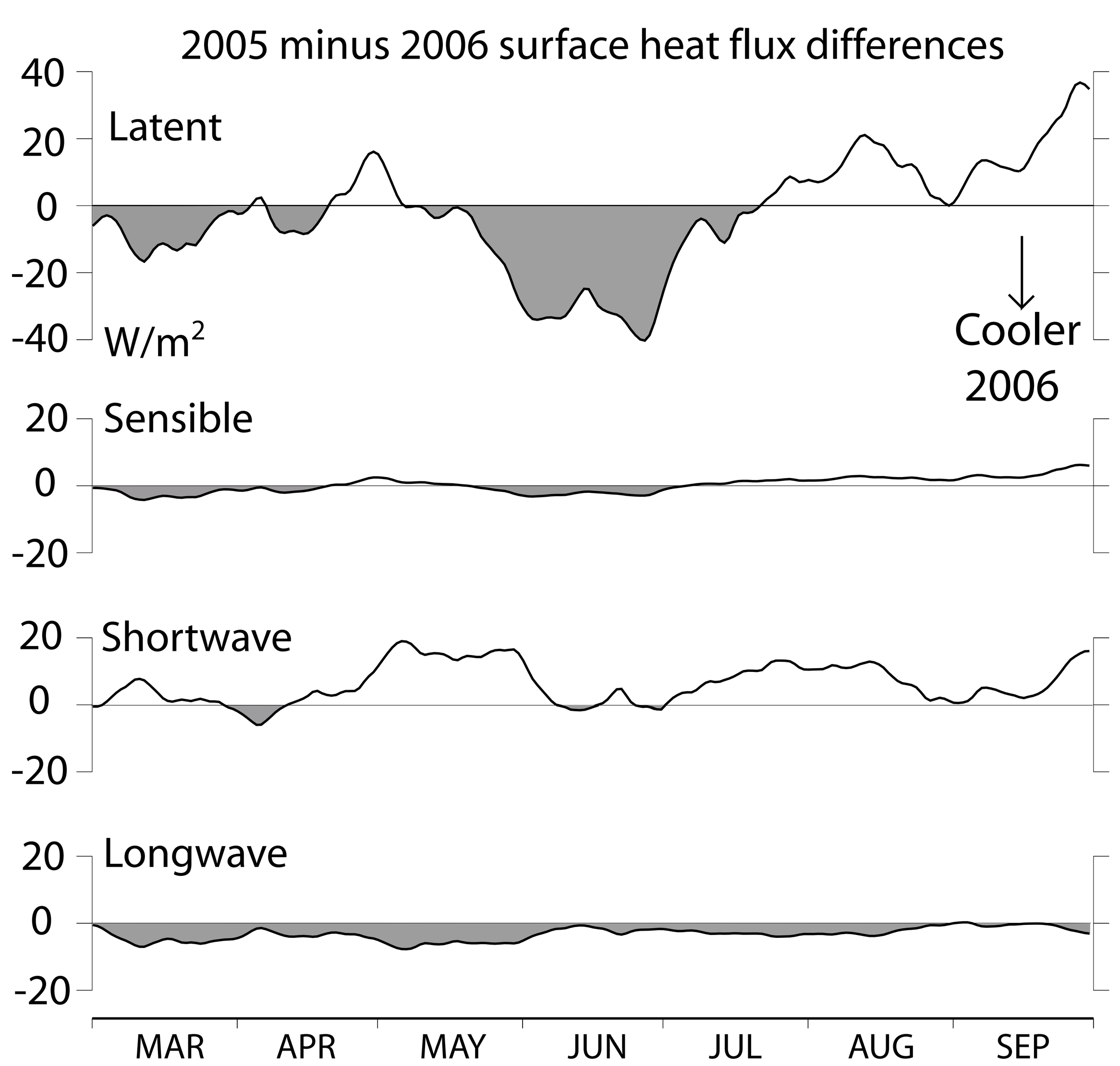

Fig. 2: Area-averaged, 2005 minus 2006 surface heat flux differences for the WAC. Please note that negative (shaded) values correspond to differences that tended to cool SST in 2006, relative to 2005 (the convention here is that upward fluxes are positive).

3) Latent heat flux variability is mainly controlled by wind speed

Previous work[3] has shown that latent heat flux anomalies can be accurately split into two parts, one driven by wind speed anomaly and another driven by anomalous surface-to-near-surface humidity difference. Comparison shows that wind speed effects drive the majority of the 2005 to 2006 difference in latent heat flux. Humidity effects generally damp the wind speed effects, but are highly correlated with surface-to-near-surface differences in enthalpy. The combination of these factors made SST warmer in 2005 than in 2006 and created surface conditions that were more conducive to the formation of intense storms[4] in 2005.

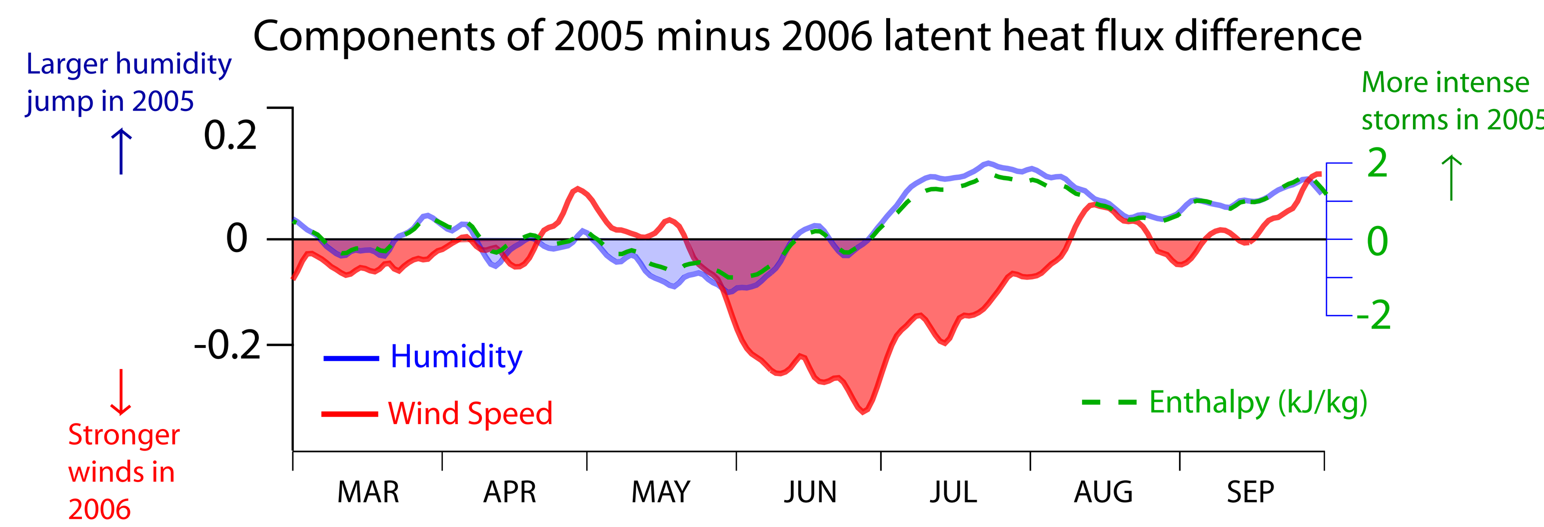

Fig. 3: 2005 minus 2006 difference in area-averaged, normalized wind speed (red curves) and surface-to-near-surface humidity difference (blue curves). The values shown are ratios of absolute differences normalized by their climatological monthly means. Note that negative (shaded) values indicate a tendency to cool 2006 relative to 2005. The 2005 minus 2006 surface-minus-near-surface difference in enthalpy is also shown (green curves). In this case, positive values indicate times in which near-surface conditions were more conducive to the formation of intense hurricanes in 2005.

4) Sub-monthly surface flux variability drives abrupt warming of SST

Instances of abrupt warming followed by abrupt cooling of SST have previously been shown to occur in summer in the subtropics[5]. At least a few such basin-scale warming events are seen each summer. They are usually caused by conditions (e.g. low wind speeds) prevalent near the centers of atmospheric anti-cyclones. Observations show greater intensity and frequency of these events in 2005 relative to 2006.

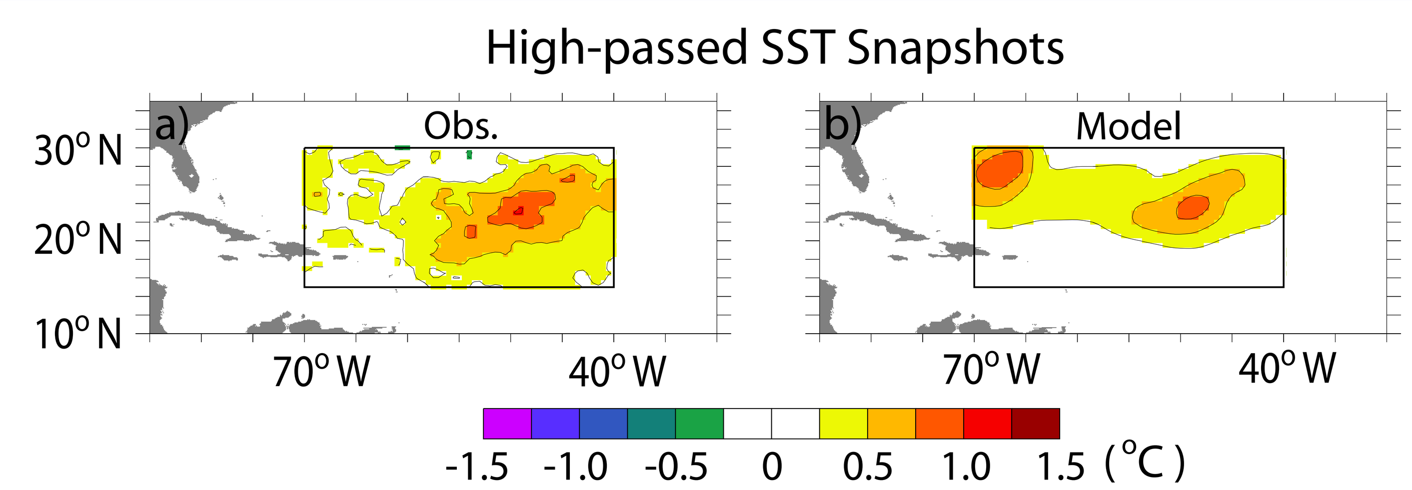

Fig. 4: Snapshots of high-passed SST for (a) TMI data in the WAC on 13 Sep 2005, (b) Model data in the WAC on 13 Sep 2005. TMI data is microwave-satellite-based and available at near-daily resolution from http://www.remss.com. Here, high-passing is achieved by subtracting 30-day from 7-day running-mean filtered data.

5) Sub-monthly variability warms 2005 relative to 2006

When sub-monthly surface flux variability is removed prior to integration, model results predict a smaller absolute 2005 to 2006 SST difference, averaged over Jul-Aug-Sep. In the model used here, sub-monthly heat flux variability accounts for 43 percent of the Jul-Aug-Sep SST difference.

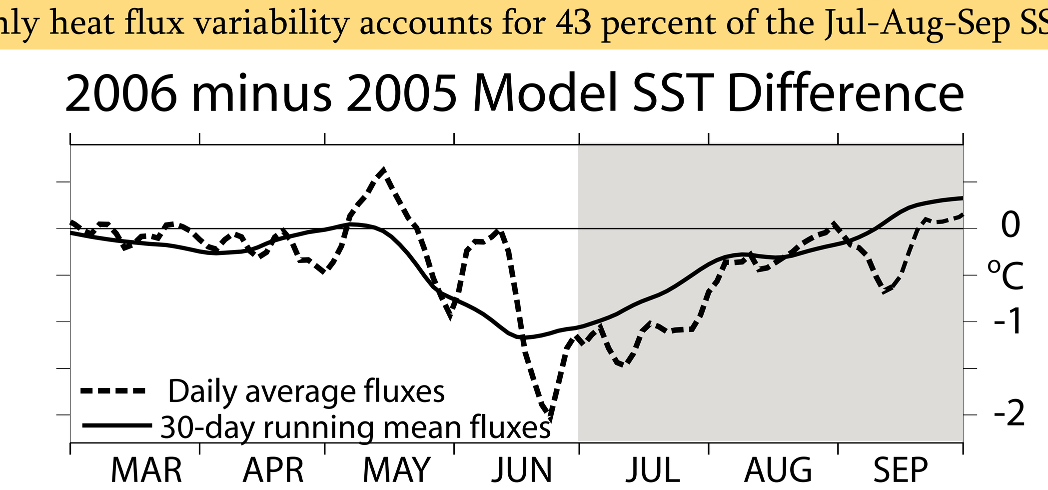

Fig. 5: Area-averaged 2006 minus 2005 SST from integrations of daily-average fluxes (dashed curve) and fluxes that have been smoothed with a 30-day running mean filter (solid curve).

6) Atmospheric circulation during times of relative 2005 warming

Certain basin-scale patterns of atmospheric circulation appear to be conducive to the development of warm SST anomalies in the WAC region. Strong relative (to 2006) warming of SST in 2005 occurred in June and the first half of September (see Fig. 1). Atmospheric circulation patterns during these times were typical of the average conditions during times of low wind speed over the WAC. Conversely, the 2006 patterns are consistent with average circulations associated with high-winds.

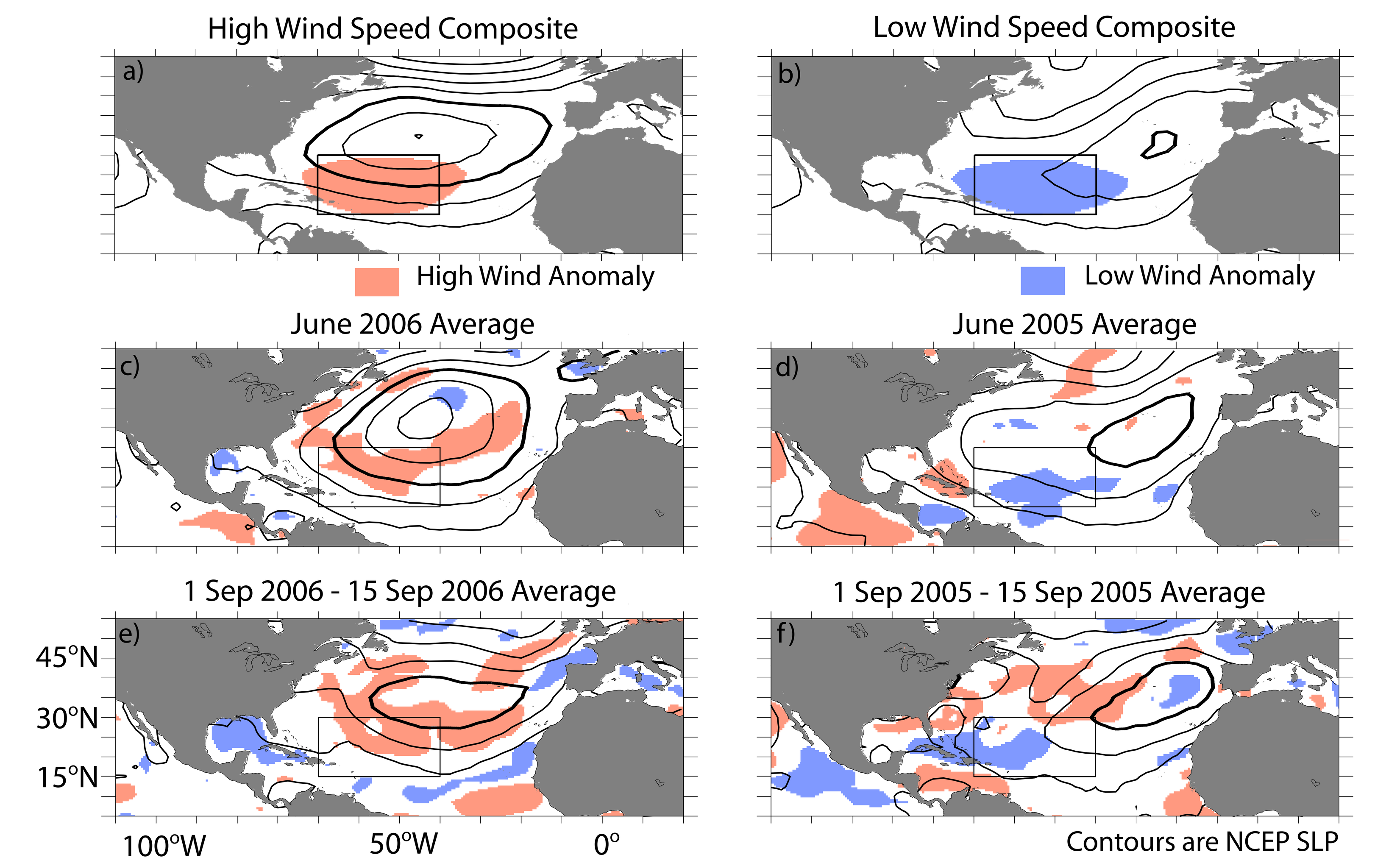

Fig 6: Composite mean sea level pressure (SLP, contours) and wind speed anomaly (color field) in the WAC region. The contour interval is 300 Pa and the 102000 Pa contour is dark. a) Composite-average for high-wind conditions (> 1 standard deviation) in the WAC region. Wind speed anomaly exceeding 1 standard deviation (approximately 1.1 m/s) is shown. b) The same as (a) except for the low-wind (< -1 standard deviation) composite. Panels (c) through (f) are averages over the time intervals listed in the figure. In (c)-(f), wind speed anomaly is shown where it exceeds 0.5 standard deviations. The composite base period is 1992-2004.

Conclusions

The 2005 to 2006 difference in SST, in a region important to hurricane activity affecting the Gulf Coast and eastern seaboard of the United States, can be accurately reproduced by forcing a simple 1-D ocean model with NCEP/NCAR daily-average surface fluxes.

The observed SST difference can be well reproduced without considering the direct effects of atmospheric aerosols on solar radiation. This suggests that atmospheric-aerosols play, at most, a minor role in determining the observed SST difference.

Model results show that sub-monthly surface flux variability, driven by sub-monthly atmospheric variability, is important to the SST anomalies considered here. This potentially presents a challenge to the traditional paradigm of forecasting in which estimates of future mean atmospheric conditions are used to forecast the future.

Results from a similar analysis of SST variability in the so-called Main Development Region (not shown for brevity) produced results similar to those discussed here in terms of, i) reproducibility of observed SST anomaly, ii) the roles of latent heat and solar radiative fluxes and iii) the relative importance of sub-monthly variability.

The 2005 to 2006 difference in the Maximum Potential Intensity[4] (MPI) of hurricanes was found to be significantly correlated with the 2005 to 2006 SST difference, averaged over monthly timescales and both the WAC and Main Development Region (not shown). This suggests SST is important to MPI over these regions, but more work is necessary to determine the processes which control Maximum Potential Intensity.

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