False causality between Atlantic hurricane activity fluctuations and seasonal lower atmospheric wind anomalies

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[1] Statistical studies suggest a link between anomalies in seasonally averaged lower atmospheric dynamical fields and Atlantic hurricane activity. Here we show that lower atmospheric seasonal wind anomalies result primarily from the presence of the hurricanes themselves. This is done by assuming a hypothetical vortex structure whose radial structure is constrained by observations derived from aircraft probing of tropical cyclones and whose vorticity magnitude is scaled to time varying, best track intensities. Seasonal vorticity anomalies associated with Atlantic hurricane activity are accumulated by summing these idealized vorticities along observed tropical cyclone tracks. Winds associated with these seasonal vorticity anomalies explain the bulk of observed hurricane activity-related fluctuations in the seasonally averaged lower tropospheric wind. Hence, seasonal wind anomalies appear to have little causal information relevant to understanding why hurricane activity in the Atlantic has fluctuated in the past, and may be of limited value in projecting future hurricane activity. **Citation:** Swanson, K. L. (2008), False causality between Atlantic hurricane activity fluctuations and seasonal lower atmospheric wind anomalies, *Geophys. Res. Lett.*, *35*, LXXXXX, doi:10.1029/2008GL034469.

1. Introduction

[2] There is tremendous interest and importance in understanding the mechanisms underlying fluctuations in tropical cyclone (TC) activity, such as the rise in Atlantic hurricane activity since 1995 [*Bell et al.*, 2006]. The principal reason for this is the need to make informed projections of future hurricane activity, and in particular, to understand the extent to which global warming might impact such activity [*Goldenberg et al.*, 2001; *Emanuel*, 2005; *Webster et al.*, 2005; *Trenberth*, 2005; *Saunders and Lea*, 2008]. To do this properly, it is necessary to understand the dynamical response of TC activity to changes in the atmospheric circulation [*Vecchi and Soden*, 2007a], as well as the thermodynamic response to both local and non-local sea surface temperature anomalies [*Emanuel*, 2005; *Vecchi and Soden*, 2007b; *Swanson*, 2008]. While simulations of Atlantic TC activity are beginning to capture certain aspects of this response, as of now they cannot adequately address this issue [*McDonald et al.*, 2005; *Knutson et al.*, 2007]. Hence, the focus is on understanding how seasonal anomalies in reanalyzed atmospheric fields are connected to (and perhaps control) Atlantic TC activity.

[3] TCs are localized cyclonic vorticity anomalies several orders of magnitude larger than ambient relative vorticity levels in the tropics [*Mallen et al.*, 2005]. Recently, *Sobel and Camargo* [2005] showed that in the Northwest Pacific, ECMWF reanalysis vorticity anomalies regressed against fluctuations in TC activity are significant in magnitude, and last on the order of several weeks. This suggests the possibility that although localized in both space and time, the accumulated impact of TC vorticity anomalies could be substantial in the seasonally averaged vorticity fields. While TCs are only crudely resolved in the various reanalyses [*Maue and Hart*, 2007], their remote impacts upon the wind field still remain, particularly in those regions strongly constrained by observations, i.e., areas with sounding coverage. Therefore, it may be that one particular *effect* of TCs, namely remote wind anomalies, is contained within the reanalyses, even though the *cause* of those wind anomalies may be incorrectly attributed. This represents a contamination of the seasonally averaged wind fields by the TCs themselves.

[4] Here we explore the extent of this contamination, and specifically question the causality of the link between seasonally averaged lower atmospheric wind anomalies and Atlantic hurricane activity. We do this in the context of a forward problem, making reasonable, observationally based assumptions about the vortex structure associated with Atlantic TCs, and accumulating seasonal anomalies in the vorticity field based upon that structure and the observed best Atlantic TC track data. We show that for reasonable assumptions about that vortex structure, a significant fraction of the Atlantic hurricane-activity associated seasonally averaged lower tropospheric wind anomaly may be argued to be the result of the presence of the TCs themselves.

2. Idealized Vortex Structure

[5] All TCs differ in their structure, due to variations in intensity, size, degree of axisymmetry, etc. Unfortunately, aside from intensity this information is not readily available on a best track basis [*Emanuel*, 2005]. To overcome this obstacle in assessing the impact of TC activity on seasonally averaged vorticity fields, assumptions must necessarily be made regarding the structure of the vortices associated with the TCs. Aircraft measurements show that Atlantic TC vortex structure is reasonably well approximated as a modified Rankine vortex of the form [*Mallen et al.*, 2005]

$$\overline{\zeta} = \begin{cases} 2(V_{mw}/r_{mw}) & r \le r_{mw} \\ (1-\alpha)(V_{mw}/r_{mw})(r_{mw}/r)^{(1+\alpha)} & r_{max} \ge r > r_{mw} \\ 0 & r > r_{\max} \end{cases} \quad (1)$$

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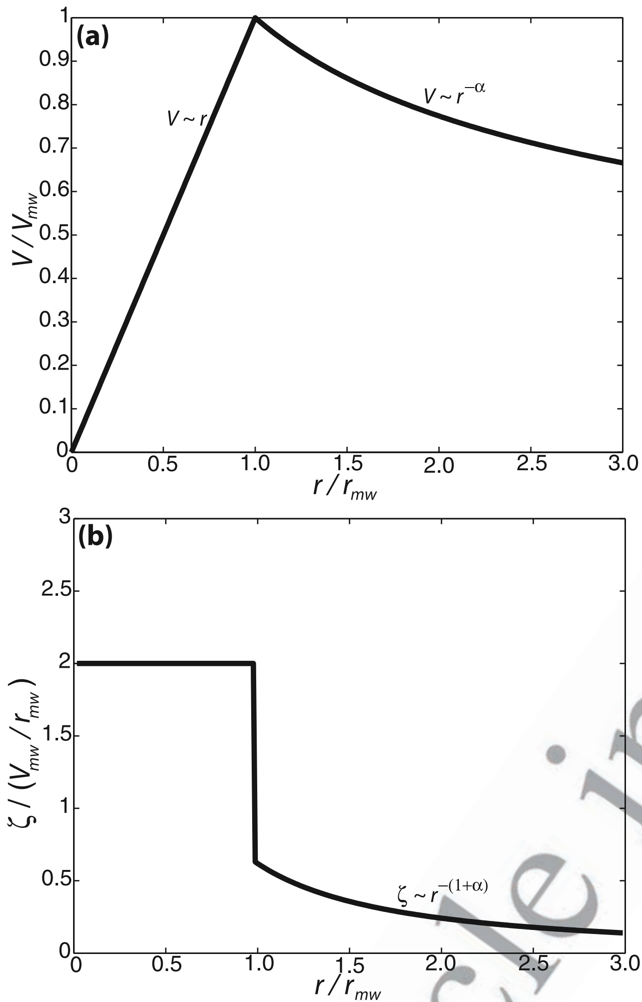

Figure 1. (a) Tangential (swirling) wind component associated with the idealized modified Rankine vortex structure assumed here. (b) Vorticity associated with the idealized modified Rankine vortex.

where $\overline{\zeta}$ is the axisymmetric vertical component of the vorticity. Figure 1 summarizes the details of the radial profile of such a vortex. Here, V_{mw} is the maximum of the tangential (swirling) wind $\overline{V}$, which occurs at the radius of maximum winds r_{mw}. This wind may be associated with the hurricane maximum intensity at any given time found in the best track data. The other factors, namely the radius of maximum winds r_{mw}, the decay parameter α which describes how quickly the tangential wind decays as a function of r for radii larger than r_{mw}, and the radius of maximum extent for the TC vorticity perturbation $r_{\max}$ are necessarily empirical. These values are prescribed from observational studies as follows: First, the radius of maximum winds is chosen to be r_{mw} = 50 km. This value is slightly larger than that observed from aircraft measurements for intense storms ($r_{mw} \simeq$ 40 km [*Zehr*, 2004]), but consistent with *Mallen et al.* [2005] it is expected that intense storms skew a bit small as far as their radial extent is concerned. The parameter $0 \leq \alpha \leq 1$ describes how quickly the winds decay from V_{mw} as one moves radially outward from r_{mw}. We set α = 0.37, consistent with the value shown by *Mallen et al.* [2005], Table 2] as the average across all TCs. This leaves $r_{\max}$, the radius of maximum extent for the TC, as somewhat free parameter. We expect $r_{\max}$ to be bounded from below by 3 r_{mw} (150 km), consistent with *Mallen et al.* [2005], but as shown by *Gray* [1979] and *Zehr* [2004], it can be argued that $r_{\max}$ may extend to at least 10 r_{mw} for intense storms, using the radial extent of tropical storm winds as a proxy for $r_{\max}$. We will leave $r_{\max}$ as a tuning parameter for the discussion to follow.

3. Accumulated TC Vorticity Anomalies

[6] To go from the idealized vortex profiles outlined above to seasonally averaged vorticity anomalies that are useful in assessing TC-associated contamination in the seasonally averaged lower tropospheric winds, it is necessary to transform the TC vorticity anomalies onto a grid on the sphere. For each 6-hour best-track TC observation, an equal magnitude vorticity anomaly is assigned to all grid-points within a radius $r_{\max}$ of the TC center as defined at 6-hour intervals in the best track analysis (Figure 2), constrained so the spatially integrated vorticity anomaly on the sphere is identical to the spatial integral of (1). Since we are interested primarily in lower tropospheric wind anomalies remote from the region containing the bulk of the TC activity, the precise form of this 'smearing' of TC-associated vorticity onto the grid points is unimportant. This vorticity anomaly is scaled so that the associated globally integrated vorticity anomaly is equal to that of an axisymmetric vortex with vorticity profile given by (1), where the radial distance in (1) is assumed to be calculated at 20°N. The anomalies for all named TCs at any given time for each year's active hurricane season (August–October) are accumulated, and appropriately averaged with respect to time, yielding a seasonally averaged vorticity anomaly. This seasonal vorticity anomaly is then inverted to find the associated non-divergent wind field. To do this, we use a spectral transform

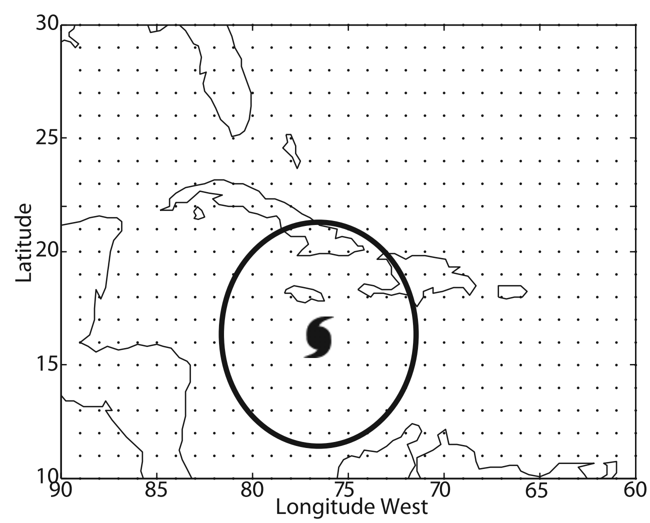

Figure 2. Schematic of the 'smearing' of a TC vorticity anomaly onto the spherical harmonic transform grid. All grid points within the circle of radius $r_{\max}$ (here taken to be 500 km) are assigned the same value of vorticity, such that the spatial integral of the vorticity perturbation over the sphere is equal to that of the idealized modified Rankine vortex of equation (1).

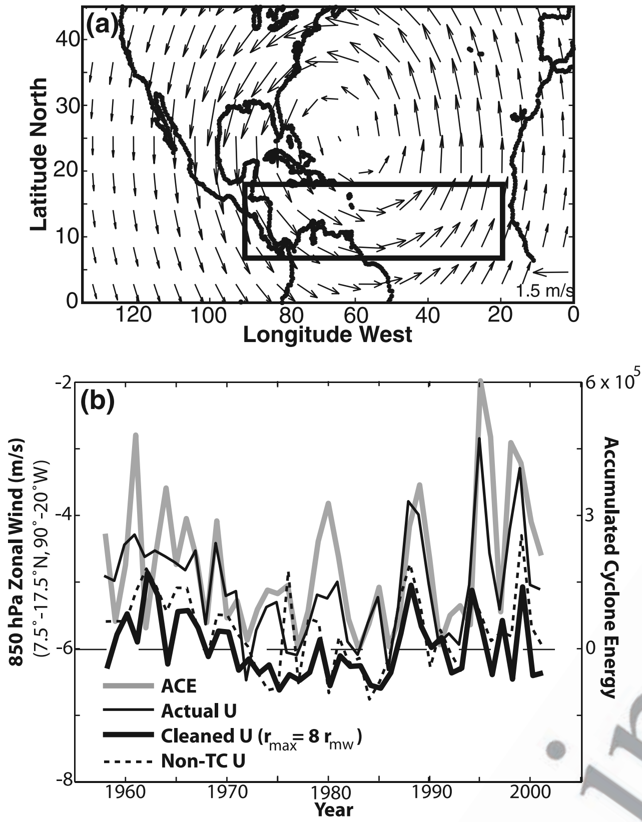

Figure 3. (a) 850 hPa non-divergent winds associated with Atlantic tropical cyclones assuming the 'smearing' of the idealized cyclone vorticity structure onto the model grid for $r_{\max}$ = 8 r_{mw}. (b) Seasonal fluctuations in the lower tropospheric zonal wind [850 hPa; 7.5°–17.5°N, 90°–20°W] (shown in Figure 3a) with and without the TC contamination removed, where $r_{\max}$ = 8 r_{mw} for the case where the hurricane contamination is removed, along with the seasonally averaged Atlantic ACE index for reference. Also shown is the observed zonal wind averaged over the box including only those 6-hour intervals with no tropical cyclones in the Atlantic basin for a given year.

based upon spherical harmonics. The particular version used here is derived from the spectral dynamical core described by *Held and Suarez* [1994], and is triangularly truncated retaining 127 wavenumbers (T127), which represents a grid of roughly 1° by 1° resolution in the subtropical Atlantic region of interest. Note that reanalysis vorticity fields are not directly used in this analysis; only the hypothetical vorticity profile (1) with the appropriate adjustable parameters figures in the construction of the seasonally averaged vorticity anomalies.

[7] Under this approach, the most important quantity is the spatially integrated vorticity associated with a given TC. One of the more surprising results of *Mallen et al.* [2005] is the importance of the contribution of vorticity outside the inner vortex core to the spatially integrated vorticity anomaly associated with a given TC. The parameter α describes this importance; the smaller α, the slower the decay of the tangential wind with radial distance from the radius of maximum winds, and the more important the contribution of vorticity outside the vortex core to the TC's spatiotemporally integrated vorticity. Specification of the parameter $r_{\max}$ is necessary, as for $\alpha < 1$, the spatially integrated vorticity anomaly associated with a given TC is unbounded as $r_{\max} \rightarrow \infty$. Hence, we examine wind anomalies associated with a variety of values of $r_{\max}$.

[8] Figure 3a shows the climatological nondivergent 850hPa winds generated by the tropical cyclone vorticity anomalies smeared onto the T127 grid for $r_{\max}$ = 8 $r_{mw} \sim$ 400 km. The winds are obviously cyclonic, have a typical magnitude on the order of 1 ms^{-1}, and are centered just off the east coast of Florida consistent with the climatological concentration of TC storm tracks in that area. This wind varies significantly from year-to-year based upon fluctuations on TC activity. The metric that we use to measure this variability is motivated by *Saunders and Lea* [2008], and consists of the zonal wind averaged over the box [90°–20°W, 7.5°–17.5°N] shown in Figure 3a. Figure 3b shows the observed zonal wind at 850 hPa averaged over that box for the months August–October 1958–2001 derived from the ECMWF/ERA-40 reanalysis, along with the accumulated cyclone energy (ACE), a measure of integrated Atlantic hurricane activity for the same period (see, e.g., *Sobel and Camargo*, 2005). Consistent with *Saunders and Lea* [2008], the zonal wind in this box is strongly correlated with the Atlantic basin-averaged ACE (ρ = 0.73). *Saunders and Lea* [2008] suggest that such anomalies in the zonal wind, which they hypothesize arise from fluctuations in the tropical atmosphere's Walker circulation, might control Atlantic hurricane development through association with lower tropospheric vorticity and/or shear. Figure 3b also shows how this particular area-averaged zonal wind index is modified by removing the component of wind associated with the seasonally averaged TC vorticity anomaly calculated by accumulating over the best track cyclone centers, as described above. For the lower bound of TC extent $r_{\max} = 3r_{mw} \simeq$ 150 km, the correlation between this zonal wind index and the ACE drops to ρ = 0.5, i.e., more than half of the variance in Atlantic TC ACE 'explained' by this zonal wind index can be attributed to the presence of the TCs themselves. Increasing $r_{\max}$ to 8 $r_{mw} \simeq$ 400 km, well within reasonable bounds according to observed analysis [*Gray*, 1979; *Zehr*, 2004], reduces the correlation to ρ = 0.1. This result suggests that for reasonable assumptions about TC vortex structure, the bulk of the hurricane-activity signal in this particular zonal wind index results from the contamination of the seasonally averaged wind fields by the TCs themselves. Similar reductions in the fraction of variance explained are found for other, more general subtropical lower tropospheric wind field indices, such as basin-wind empirical orthogonal functions/principal components, when the direct TC-associated winds calculated in the manner above are removed from the actual observed fields.

[9] An alternative verification of the contamination of seasonal wind fields by TCs may be obtained by correlating the ACE index against the ASO ERA-40 850 hPa zonal winds averaged over the box of Figure 3a, but only including those 6-hour intervals when there are no TCs within the Atlantic basin. The year 1995 must be excluded in such an analysis, as only 10 6-hour intervals are without tropical cyclones for that particular year. The resulting averaged wind (Figure 3b) is correlated with the ACE index

with $\rho = 0.34$, consistent with a value of $r_{\max} \simeq 6\ r_{mw}$, i.e., similar to the values of $r_{\max}$ considered above.

4. Discussion and Conclusions

[10] There are few problems in the area of near-term climate change impacts more pressing than quantifying which climatological factors underlie observed interannual fluctuations in hurricane activity, such as the increase in Atlantic hurricane activity since 1995. Such quantification is vital if accurate projections are to be made about how Atlantic hurricane activity may respond to future climate change. However, the results here suggest straightforward causal links between seasonally averaged observed atmospheric anomalies and hurricane activity in the Atlantic are strongly contaminated by the presence of TCs themselves. This contamination presumably also impacts seasonally averaged vertical shear, which has been cited as an important factor in determining hurricane activity [*Goldenberg et al.*, 2001]. However, a similar analysis of TC contamination of shear goes beyond this study, as additional assumptions must be made about the vertical structure of TCs. Regardless, it appears as if a fundamental gap still remains in understanding the atmosphere's dynamical role in determining how Atlantic hurricane activity might fluctuate due to climate change. Filling this gap is vital if hurricane-related risks associated with climate change, perhaps the most important short- to medium-term factor in economic terms, are to be fully quantified.

[11] To this end, it appears as if further efforts must be made to find the optimal means by which the reanalysis fields may be 'cleaned' of the influence of TCs. Ultimately, this is a problem in signal/noise discrimination, where the 'noise' in this case is the TCs themselves. Advanced data assimilation techniques, along the lines of techniques used to remove TCs prior to generating forecasts [*Kurihara et al.*, 1993; *Zou and Qingnog*, 2000] must be applied consistently to seasonally averaged fields if the response of TCs to past climate change is to be fully understood.

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