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Reply to Comment by R. N. Maue and R. E. Hart on "Low Frequency Variability in Globally Integrated Tropical Cyclone Power Dissipation

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Reply to comment by R. N. Maue and R. E. Hart on "Low frequency variability in globally integrated tropical cyclone power dissipation"

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[1] The field of tropical cyclone (TC)-climate variability is relatively young. Differences remain about the interpretations of methods and terminology and the implications of results. We welcome the opportunity to clarify some of the concepts and results from *Sriver and Huber* [2006] (hereinafter referred to as SH06) by responding to the *Maue and Hart* [2007] (hereinafter referred to as MH07) critique. We thank the authors for verifying the methods of SH06, and we are pleased with the reproducibility of our essential results. The main criticism raised in MH07 is that SH06's results are not independent of previous studies that employ the 'Best Track' (BT) wind data set. In this reply, we refute their main criticism and expand upon MH07's results.

[2] SH06 calculated the annually integrated TC power dissipation (PD) on a global scale. As an integrated measure, PD is the convolution of storm duration, frequency and intensity. SH06 built upon the results of *Emanuel* [2005] (hereinafter referred to as E05) that approximated PD as the power dissipation index (PDI) using BT maximum sustained wind estimates. SH06 investigated how utilizing a wind intensity data set independent of E05 might change PD and made no pretense of using different storm tracks. We considered the winds employed in SH06 independently derived and free from the controversial, 'ad hoc and subjective adjustments' used by E05.

[3] SH06 showed close agreement between ERA40-derived PD and PDI, and all ERA40-derived quantities were highly correlated with E05's PDI for the combined Atlantic and northwestern Pacific regions post-1978. These results showed that post-1978, ERA40 robustly reproduced trends in PD observed in BT winds, PDI was an adequate approximation of PD, and combined trends in integrated intensity in the Atlantic and northwestern Pacific regions were reasonable indicators of low frequency variability in globally integrated TC activity.

[4] MH07's main criticism is that the results of SH06 are not independent of E05 because both studies utilized the same track data—"the relationship between ERA40 PD and BT PDI is a result of dataset interdependence on frequency and lifecycle with less than 10% of the correlation arising from intensity". In other words, their hypothesis is that SH06's results could not stray far from those of E05 because the same track data was used in both studies.

[5] However, as shown in SH06, ERA40-derived PD and E05 PDI prior to 1978 do not agree well (Figure 1 in SH06 and Figure 1 in this paper using unfiltered data). We conjectured that this might be a consequence of less reliable winds in ERA40 during the pre-satellite period, but our analysis never attempted to prove this. Regardless, whichever data set is more correct, the fact that the two time series can differ strongly is sufficient grounds to reject the MH07 hypothesis that the two time series are trivially related. This answers MH07's main criticism, which we thought was clear from Figure 1 of SH06.

[6] MH07 further propose that wind field variations are not an important contributor to integrated TC intensity variability. They claim that the track-sensitive term (frequency and duration) governs PD/PDI. We note that this pattern must be repeated in both ERA40 and BT records for the main MH07 criticism to be valid. MH07's Figure 1b shows that replacing TC winds from ERA40 with a constant value reproduces the variability of Emanuel's PDI time series derived from BT winds. MH07 show that ERA-40 PD and E05's PDI are ~90% correlated, but then inaccurately suggest that 80% of the variance is explained by the track-sensitive term alone, suggesting that TC wind changes are relatively unimportant compared to track length and storm frequency changes when describing trends in integrated intensity.

[7] If true, then the variance in E05's time series is also dominated by variability in the tracks, with little role for wind speed variations, because of the strong correlation between the E05 and ERA-40-derived time series. This would be very surprising given the current debate on the importance of historical TC wind records [*Landsea et al.*, 2006] and the fact that all studies so far have reiterated the importance of better knowledge of TC velocities [*Chan*, 2006; *Hoyos et al.*, 2006; *Webster et al.*, 2006]. Here we show that the MH07 conclusion is not true and is the byproduct of MH07's flawed statistical methodology.

[8] A fundamental aspect of statistical analysis is that the explainable variance of a time series is only separately attributable to uncorrelated components of the series. In this respect, MH07's analysis contains a basic statistical flaw in their attempt to attribute explained variance in PD/PDI. They attribute explainable variance in PD/PDI to the track-sensitive term while holding the wind-sensitive term constant. However, these terms are not independent of one another (i.e. not orthogonal), thus their technique fails to account for colinearity and covariance between the wind-sensitive and track-sensitive terms. For example, in the case of two perfectly co-linear time series, the track-sensitive term might appear to explain 100% of PD variance, which

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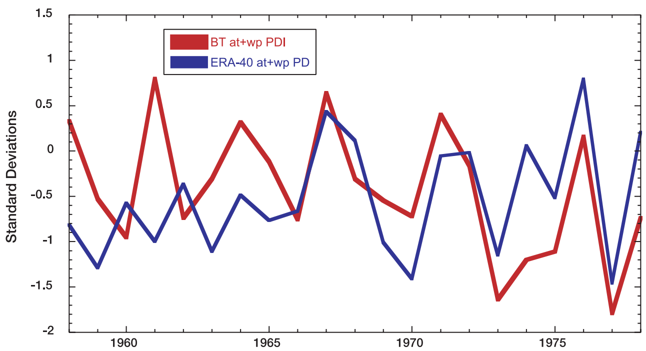

Figure 1. 'Best Track' PDI (red curve) and PD derived from ERA40 winds (blue curve) for the Atlantic and northwestern Pacific regions during the time period corresponding to the pre-satellite era in ERA40. Both series are normalized by their respective standard deviations and the correlation between the curves is $R^2 = 0.13$.

would not preclude the wind-sensitive term from also appearing to explain 100% of the variance. Indeed, the reality is not far from this.

[9] Here we expand on MH07's hypothesis to show their results emerge naturally as a subset of terms from a Reynold's decomposition of the PD/PDI time series. We define V and T to be the respective wind velocity-sensitive and track-sensitive terms of PD (or PDI) and decompose these quantities as the long-term time mean plus annual perturbation:

$$V = \bar{V} + V'$$

$$T = \bar{T} + T'$$

The product VT can be written as:

$$VT = \bar{V}\bar{T} + \bar{V}T' + V'\bar{T}$$

where $\bar{V}T'$ and $V'\bar{T}$ are the track-sensitive and wind velocity-sensitive contributions to the integrated intensity, respectively. The 2nd order perturbation term ($V'T'$) is much less than the other terms and is ignored. This technique is in contrast to MH07, who examined only the $\bar{V}T'$ term and ignored $V'\bar{T}$, forgetting the importance of colinearity, covariance and compensation with the other terms.

[10] Figure 2 displays the decomposition for the Atlantic and northwestern Pacific regions based on PDI for BT winds and PD for ERA40. Table 1 shows correlation coefficients (R^2) for these time series. Table 1 reveals that substantial correlation can exist between the wind-sensitive term ($V'\bar{T}$) and the track-sensitive term ($\bar{V}T'$). Therefore, R^2 between the explanatory variables ($V'\bar{T}$ and $\bar{V}T'$) and integrated intensity (VT) cannot be interpreted as explainable variance. Utilizing BT winds, both $\bar{V}T'$ and $V'\bar{T}$ contribute to the total trend in the Atlantic, with $V'\bar{T}$ dominating the peak near 1980 and $\bar{V}T'$ dominating the peak near 1998 (Figure 2a). Figure 2b shows that $\bar{V}T'$ largely controls the total trend in the northwestern Pacific region near the end of the record. Furthermore, the trend in average per storm intensity decreases in the northwestern Pacific during the latter half of the record, while the trend in integrated intensity increases. Figures 2c and 2d show that ERA40-derived winds reproduce the general trends shown in Figures 2a and 2b (see Table 1). Interestingly, $V'\bar{T}$ is highly correlated with integrated intensity (VT) for both data sets after 1978 in the Atlantic region, while the correlation drops significantly for ERA40 in the northwestern Pacific. This relationship may attest to differences in wind data quality in ERA40 between the Atlantic and Pacific regions.

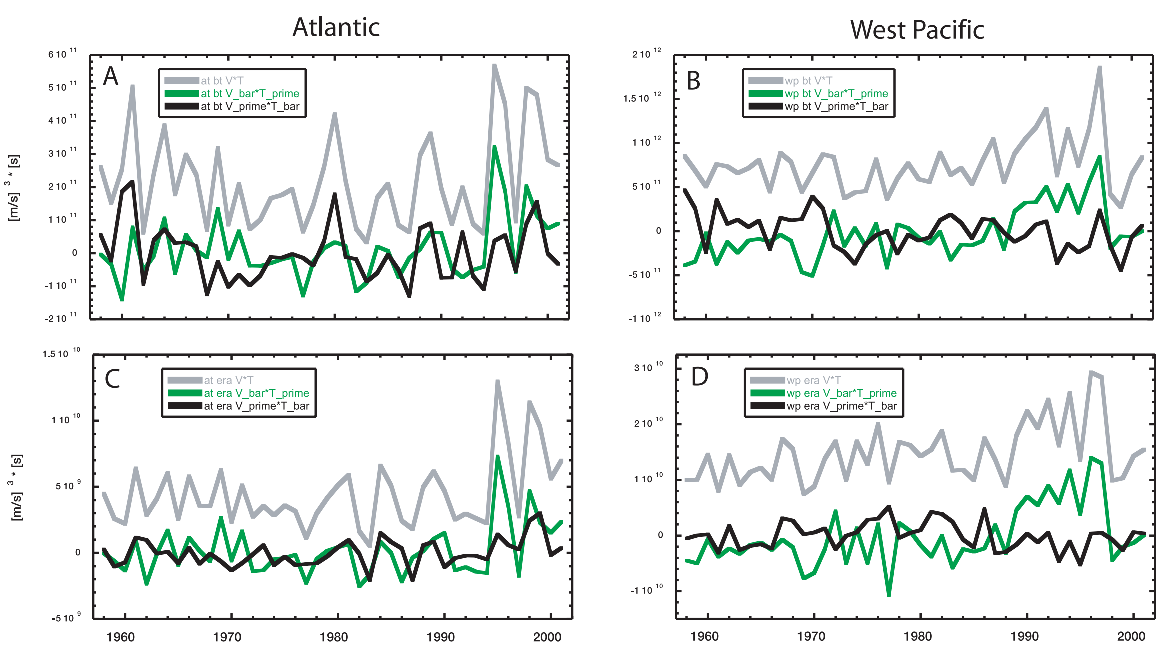

Figure 2. Integrated TC intensity (gray curves) for the Atlantic and northwestern Pacific regions and the relative contributions from the track-sensitive (green curves) and wind-sensitive (black curves) components from 1958–2001. (a, b) Results using 'Best Track' maximum wind estimates. (c, d) Results from ERA40 winds.

Table 1. Correlations for the Quantities Shown in Figure 2[a]

	$\bar{V}T'$		$V'\bar{T}$	
	Pre	Post	Pre	Post
At BT, Figure 2a				
$\underline{VT}$	0.43	0.79	0.65	0.66
$\bar{V}T'$	—	—	<0.01	0.21
At ERA-40, Figure 2c				
$\underline{VT}$	0.78	0.90	0.24	0.61
$\bar{V}T'$	—	—	<0.01	0.30
WP BT, Figure 2b				
$\underline{VT}$	0.04	0.76	0.33	0.28
$\bar{V}T'$	—	—	0.46	0.002
WP ERA-40, Figure 2d				
$\underline{VT}$	0.65	0.81	0.12	0.06
$\bar{V}T'$	—	—	0.08	0.04

[a]Correlation is R^2. Correlations are calculated for 2 separate time intervals: 1958–1978 (pre) and 1979–2001 (post). R^2s are given for each basin and for both wind data sets.

[11] Figure 2 suggests that the $\bar{V}T'$ and $V'\bar{T}$ terms cannot be easily separated in the Atlantic, while in the northwestern Pacific, the $\bar{V}T'$ term dominates the integrated intensity trend. In some regions, such as the western Pacific, trends in PD are largely due to changes in track length, consistent with MH07's results. In some regions, such as the Atlantic, both terms co-vary much of the time and both play a significant role in overall PD/PDI variance.

[12] MH07 make some other points which, while interesting, have little to do with the crucial parts of SH06 and they are impossible to interpret without the kind of component decomposition we introduced here. We encourage Maue and Hart to pursue those issues in a full-length original paper where the merits of their results can be evaluated.

[13] In summary, the results presented here further demonstrate that in both ERA40 and BT data sets, storm velocity perturbations can play a major and dynamic role in integrated measures such as PD and PDI. Consequently SH06 does provide independent confirmation of the results of E05, post-1978, and ERA40 provides some useful information about TC intensity especially toward the end of the time series. Integrated TC intensity measures such as PD may be important and useful indicators for TC activity on a global scale and provide insight to potential climatic feedback mechanisms such as enhanced ocean mixing due to TC winds.

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