Supplemental Material

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Supplementary material

What Governs the Interannual Variability of Recurring North Atlantic Tropical Cyclones?

Elliott Sainsbury¹, Reinhard K. H. Schiemann², Kevin I. Hodges², Alexander J. Baker², Len C. Shaffrey², Kieran T. Bhatia³

¹Department of Meteorology, University of Reading, Reading, Berkshire, UK
²National Centre for Atmospheric Science, University of Reading, Berkshire, UK
³Guy Carpenter, New York, United States

Corresponding author: e.sainsbury@pgr.reading.ac.uk
1) Sensitivity to the reanalysis

This section contains a repeated analysis of Figures 5, 6, 7 and 9 in the main manuscript. In the manuscript, the ERA5 reanalysis (1979-2018) is used. This time we use MERRA2 (1980-2016) data instead. Everything else (spectral filtering methodology) is kept constant.

For figures S1 and S2, the sample size for very high, high, low and very low activity years are 6, 18, 19 and 3 respectively.

Figure S1: As in Figure 5 but using spectrally filtered ASO MERRA2 data to calculate the Deep layer flow.

Figure S2: As in Figure 6 but using spectrally filtered ASO MERRA2 MSLP data.

For figure S3, the sample size for the very high, high, low and very low composites are 5, 16, 21 and 5 respectively.
Figure S3: As in Figure 7 but using spectrally filtered ASO 700hPa flow data from MERRA2.

Figure S4: As in Figure 9, but this time the steering flow index is created from spectrally filtered ASO mean MERRA2 data, instead of ERA5.

2) Investigation of the collinearity between the steering flow index and MLR model predictors

Figure S5 shows the relationship between the steering flow index (as described in the main manuscript), and recurving TC frequency in the MDR and SUB regions. It also shows the relationship between the steering flow index and the two predictor terms of the MLR model, in order to test that steering and regional hurricane activity are not strongly correlated. Figure S5 shows that the relationship between the steering flow index and the predictor terms in the MLR model is weak and non-significant.
Figure S5: Scatterplots of the steering flow index against: (top left) recurving MDR TC frequency, (top right) recurving SUB TC frequency, (bottom left) MDR hurricane frequency, and (bottom right) SUB TC frequency. Steering flow index used here is calculated using ERA5 data as in Figure 9 on the main manuscript.

Figure 7 in the main manuscript shows that a cyclonic circulation difference exists in the subtropical North Atlantic during years in which there are high number of recurving TCs. This could be due to the relationship between NAO and SUB TC frequency. To investigate the strength of the relationship (SUB TC frequency and 700hPa flow), a correlation map is constructed and is shown in Figure S6. While there may be some link between SUB TC frequency and the flow, it is relatively weak and nonsignificant across the majority of the subtropical North Atlantic.
Figure S6: Correlation map showing the Pearson’s correlation coefficient between SUB TC frequency and the meridional component of the ASO spectrally filtered 700hPa flow from ERA5. Stippling indicates significance at 95%.

3) Sensitivity of Figures 4 and 6 (main manuscript) to the flow level.

TCs of different intensities extend to different heights in the troposphere and are steered by different levels. Figures S7 and S8 are recreated versions of Figures 5 and 7 from the main manuscript, but this time using a different flow level. Figures S7 and S8 show that there is very little sensitivity of the composites to the flow layer used.

Figure S7: As in Figure 5, but created using the spectrally filtered ASO mean 700hPa flow (ERAS).
4) The role of spectral filtering

In our analysis, we use seasonal mean environmental fields and so it might be expected that the spectral filtering has negligible impact on the seasonal (ASO) timescale. To investigate this Figure 5 from the main manuscript is recreated using the full field data from ERA5. The only difference between Figure S9 below, and Figure 5 in the main manuscript, is the spectral filtering on the 6-hourly fields before the ASO means are calculated.

There are some small differences in the flow between the full field version (Fig S9) and the filtered version (Figure 5). This justifies the need to use the spectral filtering so that we are not attributing apparent circulation patterns to the signature of the vortices.

Despite some differences between the filtered and non-filtered composites, the large-scale flow is very similar between them.

5) Multiple Linear Regression model sensitivity analysis

In this section, Figure 8 from the manuscript is reproduced with a number of changes to investigate the sensitivity of the MLR fit. Figure S10 shows the figure reproduced using MERRA2 matched tracks, figure S11 shows the figure reproduced considering only the cyclones in HURDAT2 which have 10m winds > 17m/s (i.e. named storm strength), figure S12 shows the results reproduced with a Poisson regression model, using a logarithmic link function (more information given directly above figure...
S12), and figure S13 shows the results for a different recurvature domain. In all cases, the regression equations are shown in the title of the figures.

Figures S10 through S13 clearly show that the result is very robust.

![Graph showing recurvature](image)

**Fig S10:** As in Figure 8 of the main manuscript but using MERRA2 matched tracks instead of ERA5 matched tracks.
Equation: \( \text{Rec}_\text{TC} = 1.273 + 0.684 \text{UB}_\text{TC} + 1.005 \text{MDR}_\text{m} \)

Fig S11: As in Figure 8 of the main manuscript but considering only TCs which have 10m winds in excess of 17m/s (i.e., named storm strength storms only).
In many previous studies, Poisson regression is used to model TC statistics. To test the sensitivity of our results to the regression method, a Poisson regression model is constructed using the same predictors (MDR hurricane frequency and SUB TC frequency) and predictand (recurring TC frequency). A model of the form

\[
\ln(\text{Rec}_{TC}) = \beta_0 + \beta_1 \text{MDR}_H + \beta_2 \text{SUB}_{TC} + \epsilon
\]  

(S1)
is used.

Figure S12b shows that the \( R^2 \) distribution is very similar to in Figure 8b of the main manuscript, so the relationship between recurring TC frequency and the two predictors is relatively insensitive to the regression model used to explore the relationship.

Figure S12: As in Figure 8 of the main manuscript, but this time the fit is made using a Poisson regression model with a logarithmic link function.
Figure S13: As in Figure 8 of the main manuscript but using a different recurvature domain: 36-70N, 70W-30E.

6) Steering flow index derivation

Figure S14 shows correlation maps between the recurving TC frequency (MDR and SUB regions) with the meridional deep layer steering flow (ASO) using spectrally filtered ERA5 data. The left-hand panel in particular is used to identify the region to use for the steering flow index, used in Figure 9 of the main manuscript.
Figure S14: Correlation maps showing the Pearson’s correlation coefficients between the meridional component of the seasonal mean deep layer flow (using spectrally filtered ERA5 data) and the MDR/SUB recurving TC frequency (left and right panels respectively).

7) SST anomaly analysis

To investigate the role of SST on TC activity in the MDR and SUB regions, we repeat the composite analysis shown in Figures 5-7, but this time looking at the ASO SST anomalies. ASO SST anomalies for each year are calculated between 1979 and 2018 by subtracting the ASO mean SST from 1979-2018. Linearly detrending the SSTs before compositing does not significantly alter the results, and so is not done in this instance. We separate years of very high, high, low, and very low activity (as defined in section 3c.1 of the main manuscript), where ‘activity’ refers to MDR hurricane frequency (Figure S15) and SUB TC frequency (Figure S16). These activity metrics are chosen because they are the predictors used in the multiple linear regression model and are shown to have a very strong relationship with recurving TC frequency.
Figure S15: Composite differences in the SST anomaly based on the number of hurricanes forming in the MDR. (top left): MDR very high, (top right): MDR high, (bottom left): MDR very low, (bottom right): MDR low. Very high represents years in which the number of recurving TCs originating in the MDR is greater than the mean plus 1 standard deviation. Very low represents years in which the number of recurving TCs originating in the MDR is less than the mean minus 1 standard deviation. High represents years in which the number of recurving TCs originating in the MDR is greater than the mean. Low represents years in which the number of recurving TCs originating in the MDR is less than the mean.

During years which see high MDR activity (high MDR hurricane frequency), negative SST anomalies are present in the eastern Pacific and positive SST anomalies are present in the tropical North Atlantic. La Nina conditions and above average SSTs in the tropical North Atlantic are both strongly correlated with TC activity (Landsea et al. 1999). During years of low MDR hurricane frequency, El Nino conditions are present and there is a negative SST anomaly in the tropical North Atlantic.

Figure S16: As in Figure S15, but for SUB TC frequency.

In the SUB region, there does not seem to be a relationship between TC activity and ENSO. This agrees with previous studies which show that, unlike the tropical Atlantic, higher-latitude forming TCs do not have a strong relationship with SSTs (Kossin et al. 2010). However, during years of high SUB TC frequency, positive SST anomalies can be seen along the midlatitude US East coast.

Figures S15 and S16 have been repeated using MDR recurving TC frequency and SUB recurving TC frequency, and the results are the same as shown in Figures S15 and S16.