Column Water Vapor Variability and Its Impacts on Tropical Cyclone Activity over the Atlantic Basin

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Introduction

Column water vapor (CWV) in the tropics is well known to affect tropical deep convection. It has been established that the tropical deep convection required for tropical cyclone formation markedly increases after reaching a critical CWV threshold (Holloway and Neelin 2009). Therefore, CWV values below this threshold represent an atmosphere that is too dry for tropical cyclone formation. Some previous studies indicated/suggested the impacts of dry air (Hopsch et al. 2010; Fritz and Wang 2013, Hankes et al. 2014). In the Atlantic basin, the dry air may be associated with the Saharan Air Layer (SAL) or mid-latitude frontal systems via subsidence/advection around anticyclones (Braun 2010). The interannual variations of the dry air frequency in the tropical North Atlantic, however, remain unclear.

In this study, we examined 1) the interannual variations of dry event frequency over the Atlantic basin, 2) their relationship with the large-scale circulation, 3) possible impacts on the variability of the Atlantic tropical cyclone activity, and 4) the origin of dry air.

Data and Methods

The 6-hourly ERA-Interim reanalysis data were used to evaluate dry air frequency over the Atlantic basin during peak hurricane season (Aug-Oct; ASO). CWV variability is examined using Empirical Orthogonal Function (EOF) analysis from 1979-2014. Best Track data were used to examine the genesis locations and tracks of the storms. The dust optical depth (DOD) dataset developed by Amato Evan was used to evaluate to origin of dry air.

A dry event needs to satisfy the following three criteria:

- CWV <= 50mm
- CWV is at least half a standard deviation below the average
- The above two criteria are satisfied continuously for at least one day.

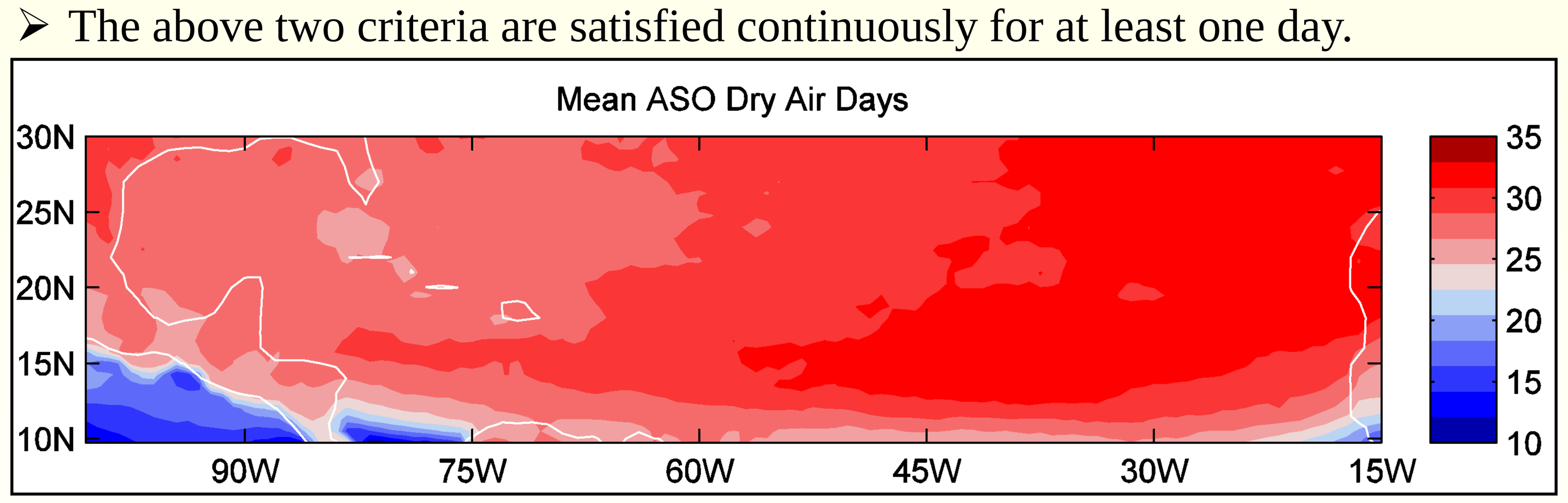

Figure 1. 36-year average of the number of dry events (Aug-Oct) from 1979-2014.

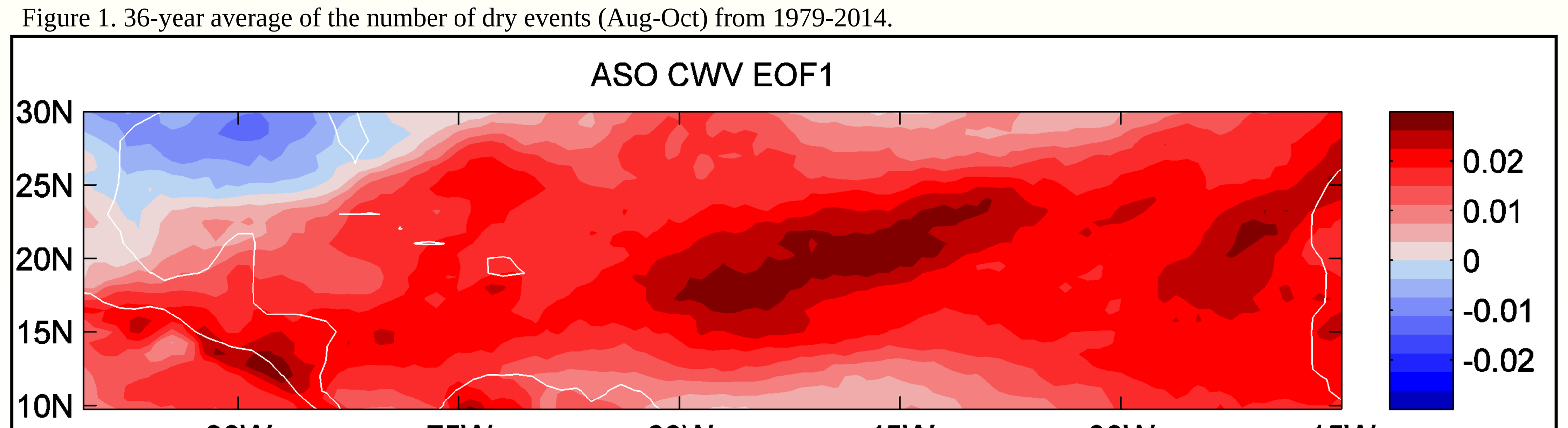

Figure 2. CWV EOF1 pattern. Positive (negative) values correspond to a strong (weak) occurrence of dry air events in the positive phase.

- A pattern of inter-annual variability of dry events is centered over the Central Atlantic along and north of 15N, while the mean CWV peaks over the East Atlantic.
- The first EOF mode (EOF1) explains ~35% of the observed variance for CWV as the singular dominant mode.

Results

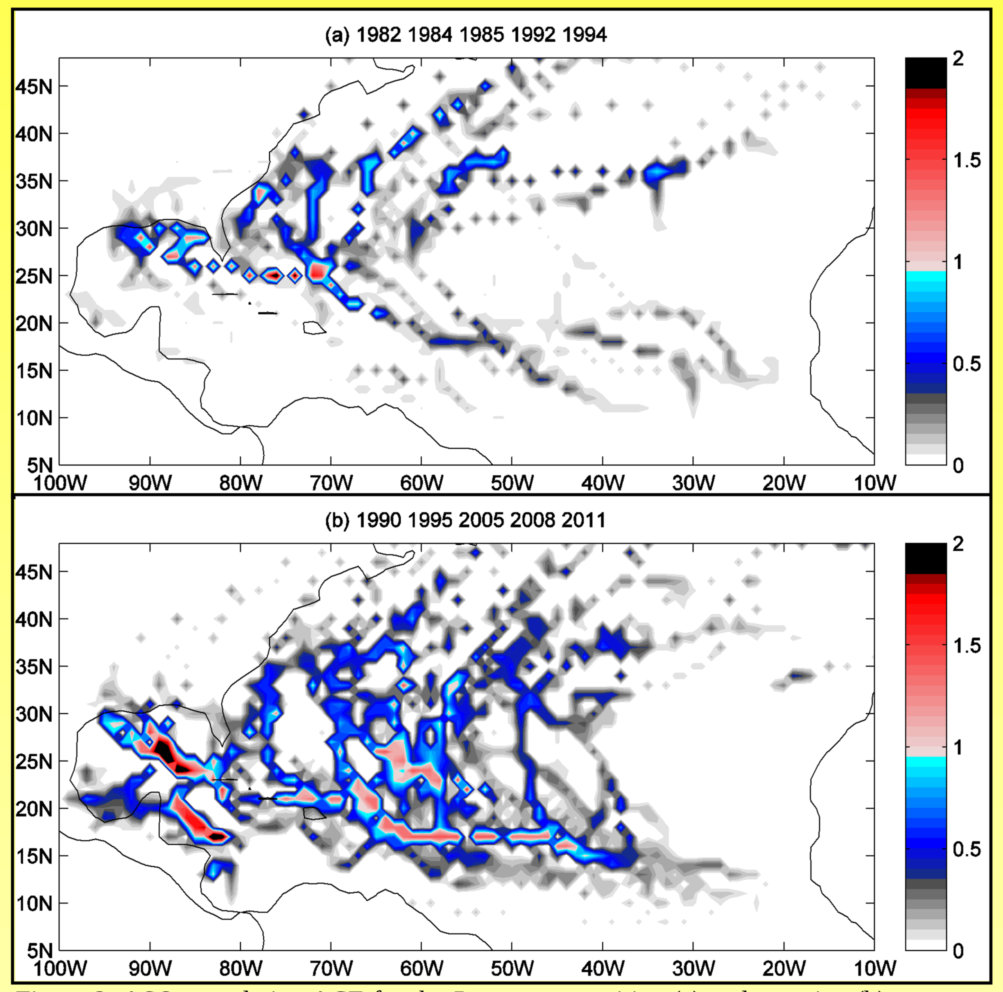

Figure 3. ASO cumulative ACE for the 5 strongest positive (a) and negative (b) phase years of the CWV EOF1. Gray shading corresponds to a cyclone of tropical storm intensity, blue shading corresponds to category one and two hurricanes, red corresponds to categories three and four, and black shading corresponds to a hurricane of category five intensity.

Table I. Cumulative ACE and TC counts for the five most positive and negative phase years of the CWV EOF1.

CWV EOF1	ACE
POS	274
NEG	758
	TC Count
POS	45
NEG	75

TELECONNECTIONS	CWV EOF1	
Pacific	Correlations	Peak Month
Nino 3.4	0.11	Oct (Yr-0)
WIOD	**-0.62**	**Feb (Yr-0)**
PDO	**0.45**	**Jul (Yr-1)**
Atlantic		
AMO	**-0.77**	**Jul (Yr-0)**
AMM	**-0.77**	**Sep (Yr-0)**
ATLANTIC TRIPOLE	**-0.77**	**Jun (Yr-0)**
Midlatitudes Upper Trop.		
NAO	-0.32	Sep (Yr-0)
PNA	**-0.50**	**Aug (Yr-0)**
TC Activity		
ATLANTIC ASO ACE	**-0.51**	**N/A**

Table II. Correlations between the CWV EOF1 and various teleconnections. Statistically significant correlations to the 95% confidence level shown in bold. Correlations to teleconnections with lead time extending into the prior calendar year are denoted as Yr-1, while correlations occurring in the same year as the EOF1 time series are denoted as Yr-0.

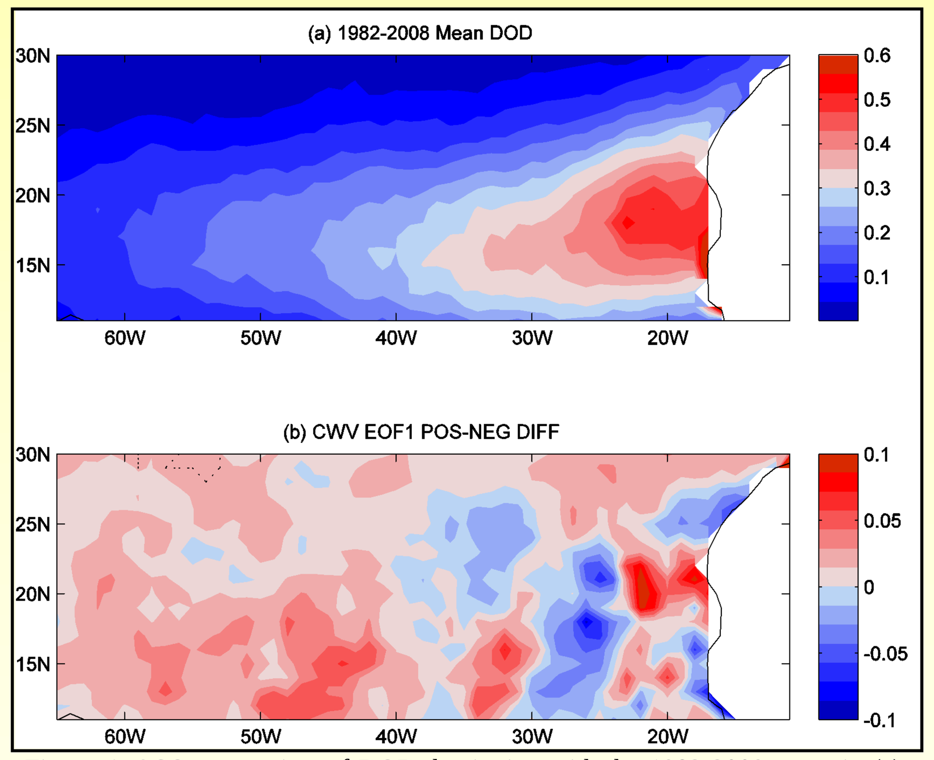

Figure 4. ASO composites of DOD, beginning with the 1982-2009 mean in (a). Positive – negative phase differences for the five strongest positive and negative phase years of the CWV EOF1 are highlighted in (b). Dotted contours represent statistically significant differences to the 95% confidence interval.

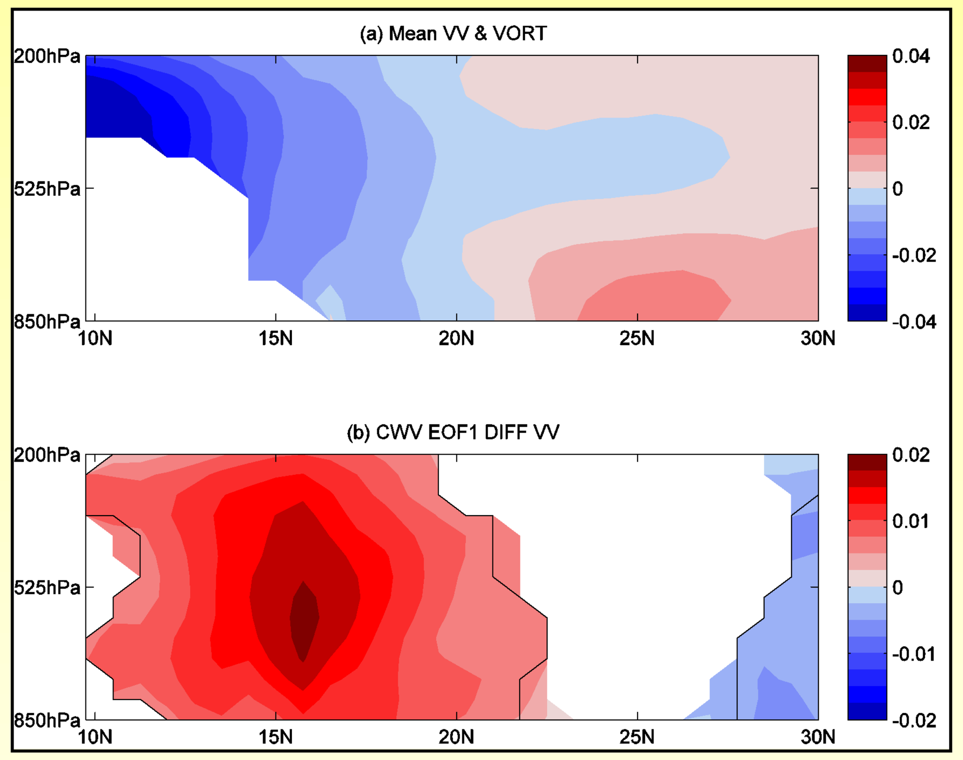

Figure 5. ASO N-S vertical cross section averaged from 100-15W for vertical velocity, beginning with the 1979-2014 mean in (a). Values are only shown for regions of anticyclonic (negative) relative vorticity. Positive – negative phase differences for the five strongest positive and negative phase years of the CWV EOF1 are presented in (b). Values in the difference plot are only shown if one of two conditions is met: 1) the relative vorticity is more negative in the positive phase than in the negative phase of the EOF1 pattern; 2) the differences in vertical velocity are significant. Positive values of vertical velocity represent sinking motion (Pa s^{-1}). Solid black contours in the difference plot enclose regions of statistically significant differences at the 95% confidence level between the positive and negative phase years.

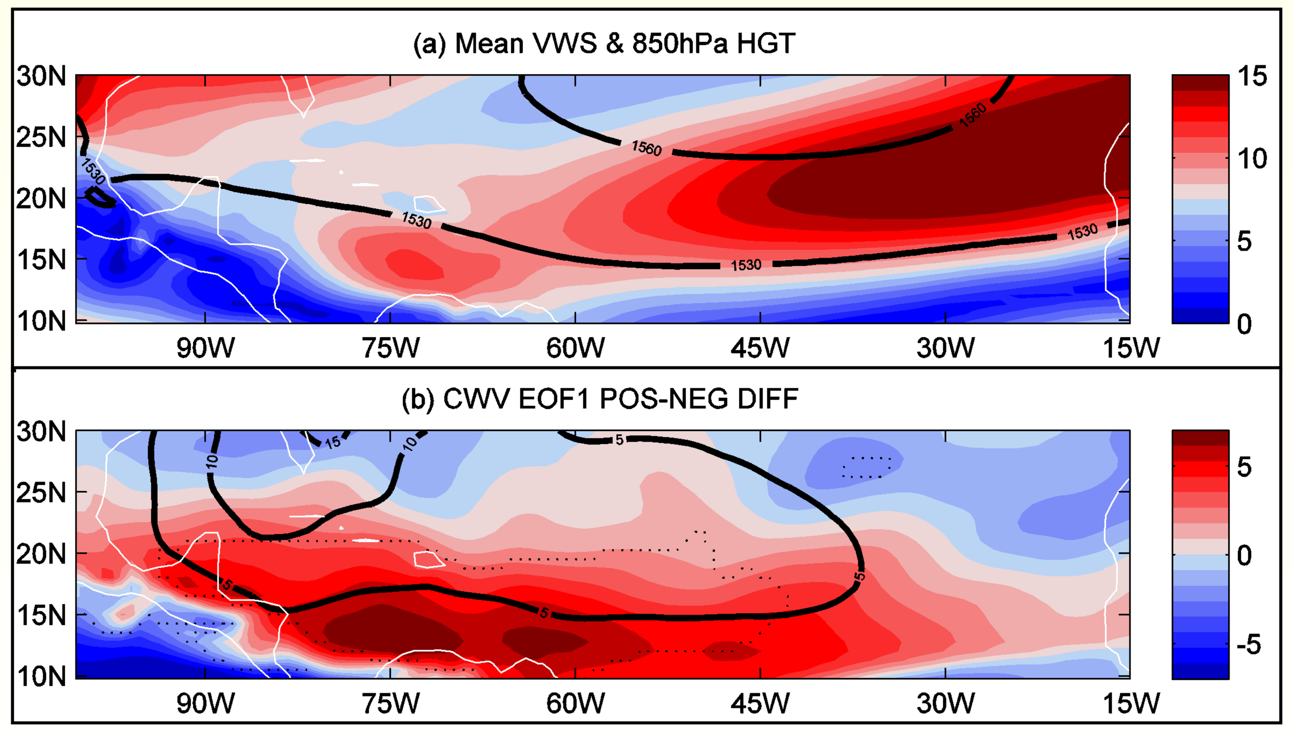

Figure 6. ASO 200-850 hPa vertical wind shear (VWS) (shading, ms^{-1}) and 850 hPa geopotential height (contours) for the 1979-2014 mean is shown in (a). Positive – negative phase differences for the five strongest positive and negative phase years of the CWV EOF1 are shown in (b). The contour interval of the height contours is 30m, and 5m for the difference plots. Dotted contours in (b) represent areas of statistically significant differences in VWS to the 95% confidence level.

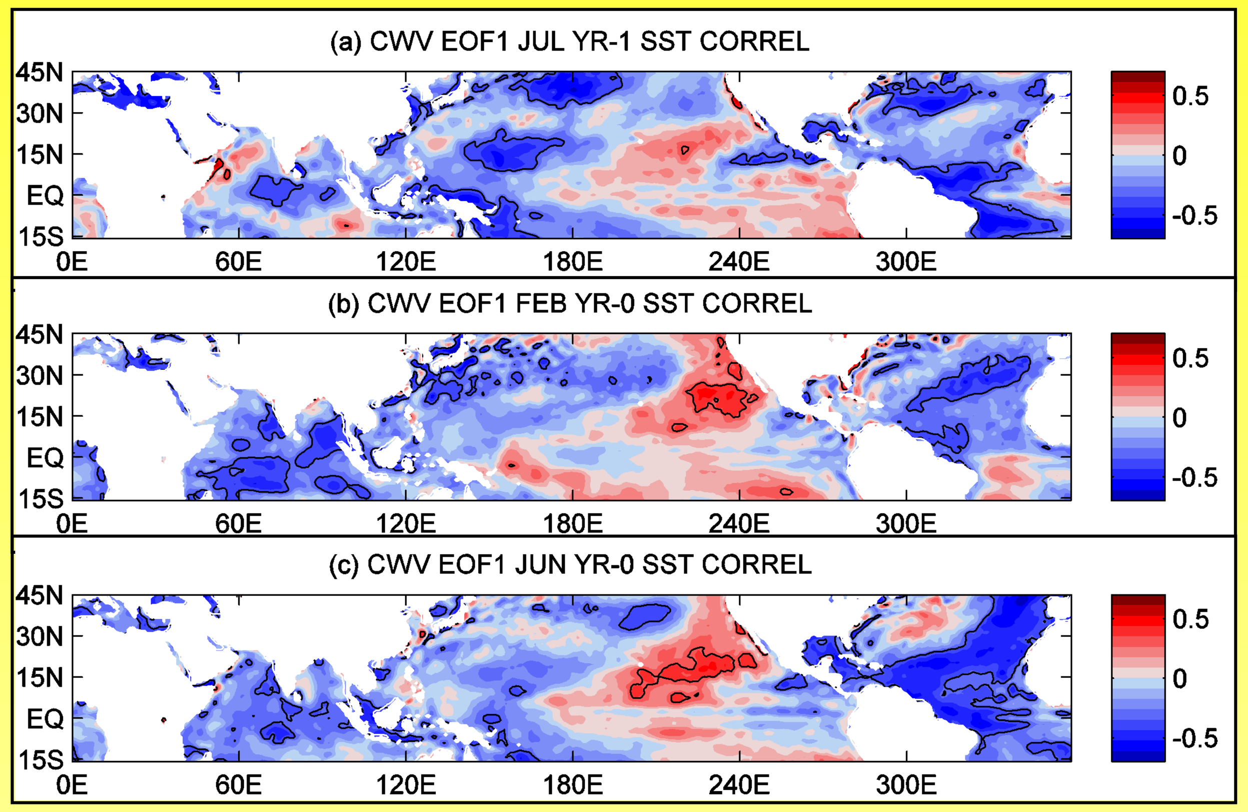

Figure 7. Monthly sea surface temperature (SST) correlation maps to the CWV EOF1 time series. Solid black contours represent areas of statistically significant correlations to the 95% confidence level. Positive (negative) correlations correspond to warm (cold) SST during the positive (negative) phase of the CWV EOF1.

Conclusions

- When dry events occur more frequently, TC activity tends to be reduced over much of the Atlantic basin, and many fewer major hurricanes form.
- The dry event frequency shows no significant correlation to DOD.
- The CWV EOF1 displays a weakened or southward shifted Hadley Cell, as large-scale subsidence and anticyclonic vorticity are stronger along the MDR during the positive phase.
- Dry air is associated with an enhanced, westward extended subtropical high. This acts to increase VWS over the Caribbean and to steer cyclones toward the West Atlantic. The modulation of the steering flow is also supported by the correlation to the Pacific North American Pattern (PNA).
- The CWV EOF1 shows relationships to several large-scale climate oscillations through significant SST correlations, including the Atlantic Multi-decadal Oscillation (AMO), Atlantic Meridional Mode (AMM), Atlantic Tripole pattern, Pacific Decadal Oscillation (PDO), and western pole of the Indian Ocean Dipole (WIOD).

References

Braun SA, 2010. Reevaluating the Role of the Saharan Air Layer in Atlantic Tropical Cyclogenesis and Evolution. Mon. Wea. Rev. 138: 2007-2037.

Fritz C, Wang Z. 2013. A Numerical Study of the Impacts of Dry Air on Tropical Cyclone Formation: A Development Case and a Nondevelopment Case. J. Atmos. Sci. 70: 91–111.

Hankes I, Wang Z, Zhang G, Fritz C. Merger of African easterly waves and formation of Cape Verde storms. Q. J. R. Meteorol. Soc. 141: 1306–1319.

Holloway CE, Neelin JD. 2009. Moisture Vertical Structure, Column Water Vapor, and Tropical Deep Convection. J. Atmos. Sci. 66: 1665–1683.

Hopsch SB, Thorncroft CD, Tyle KR. 2010. Analysis of African Easterly Wave Structures and Their Role in Influencing Tropical Cyclogenesis. Mon. Wea. Rev. 138: 1399–1419.