7B.8 TROPICAL CYCLONE ACTIVITY AND EXTRATROPICAL ROSSBY WAVE BREAKING: A SEE-SAW RELATIONSHIP IN THE ATLANTIC BASIN

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1. INTRODUCTION

Despite much recent progress, the seasonal prediction of tropical cyclone (TC) activity remains challenging. A notable example is the seasonal prediction of Atlantic TC activity in 2013 (Vecchi and Villarini 2014). This hurricane season was accompanied by warm SSTA in the Main Development Region (MDR) and cold SSTA in the equatorial East Pacific (Fig. 1a). The SST conditions, along with active tropical easterly waves (TEWs), were expected to elevate TC activity. However, the season only generated two weak and short-lived hurricanes, leaving the accumulated cyclone energy (ACE) well below the climatological value (Fig. 1b). The surprisingly few hurricanes and low ACE sharply contrast most predictions (Zhang et al. 2016), highlighting the insufficient understanding of Atlantic TC activity.

The seasonal activity of Atlantic TCs is often in concert with the tropical variability. The link between tropical SST forcing and TCs serves as the basis for many dynamical and statistical prediction models (e.g., Gray 1984). Nonetheless, the tropics is also subject to the impacts of extratropical processes. For example, the dry air over the MDR may originate from the extratropics (e.g., Dunion 2011), and some extratropical precursors can spawn TCs through the tropical transition (e.g., Davis and Bosart 2004; McTaggart-Cowan et al. 2013). However, how the extratropical variability impacts Atlantic TC activity largely remains unclear. Although the North Atlantic Oscillation (NAO) is often emphasized, no significant simultaneous correlation is found between Atlantic TC activity and the NAO in the hurricane season (Villarini et al. 2010).

Motivated the seasonal prediction bust in 2013, this study shows that extratropical Rossby wave breaking (RWB) is closely tied to Atlantic TC activity. It is possible that this is a missing piece in the seasonal TC prediction.

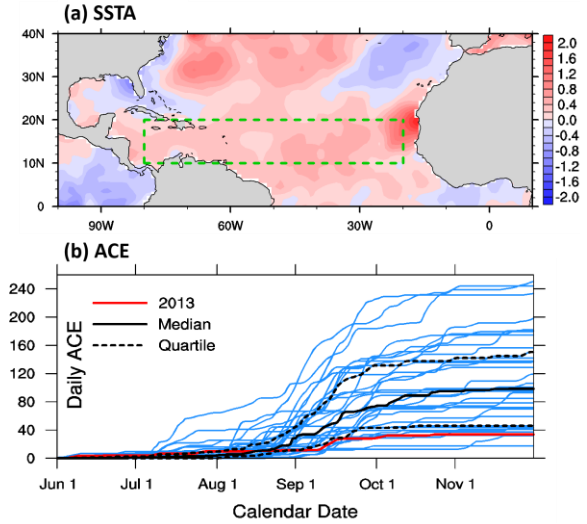

Fig. 1 a) SSTA (degC) in August 2013. b) ACE as a function of calendar dates. a) MDR is highlighted with green dashed lines. b) Red curve represents 2013, and blue curves represent other years during 1979-2012. Median and quartiles are marked with black.

2. A CASE STUDY IN AUGUST 2013

A case study in August 2013 (Fig. 2) helps to illustrate how RWB may impact TCs. At 1200UTC 11 August, a large-amplitude Rossby wave breaks at 350K isentropic surface and results in two high-PV centers (P1 and P2), which slowly move equatorward. Although P1 weakens a couple of days later, but P2 remains robust over the East Atlantic for at least 7 days (Fig. 2a-2c).

The RWB event facilitates the mixing between dry extratropical air (high-PV) and moist tropical air (low-PV). By 0000 UTC 14 August, an outbreak of extremely dry air from the extratropical East Atlantic extends southwestward into the MDR (Fig. 2e). The dry air later sweeps westward and reduces the environmental moisture as far as the Caribbean (Fig. 2f). Meanwhile, the extratropical cold air also intrudes into the tropical upper troposphere. The intrusion deepens the mid-ocean trough and increases the gradient of 200-850 hPa thickness in the tropics (not shown), leading to strong vertical wind shear (VWS).

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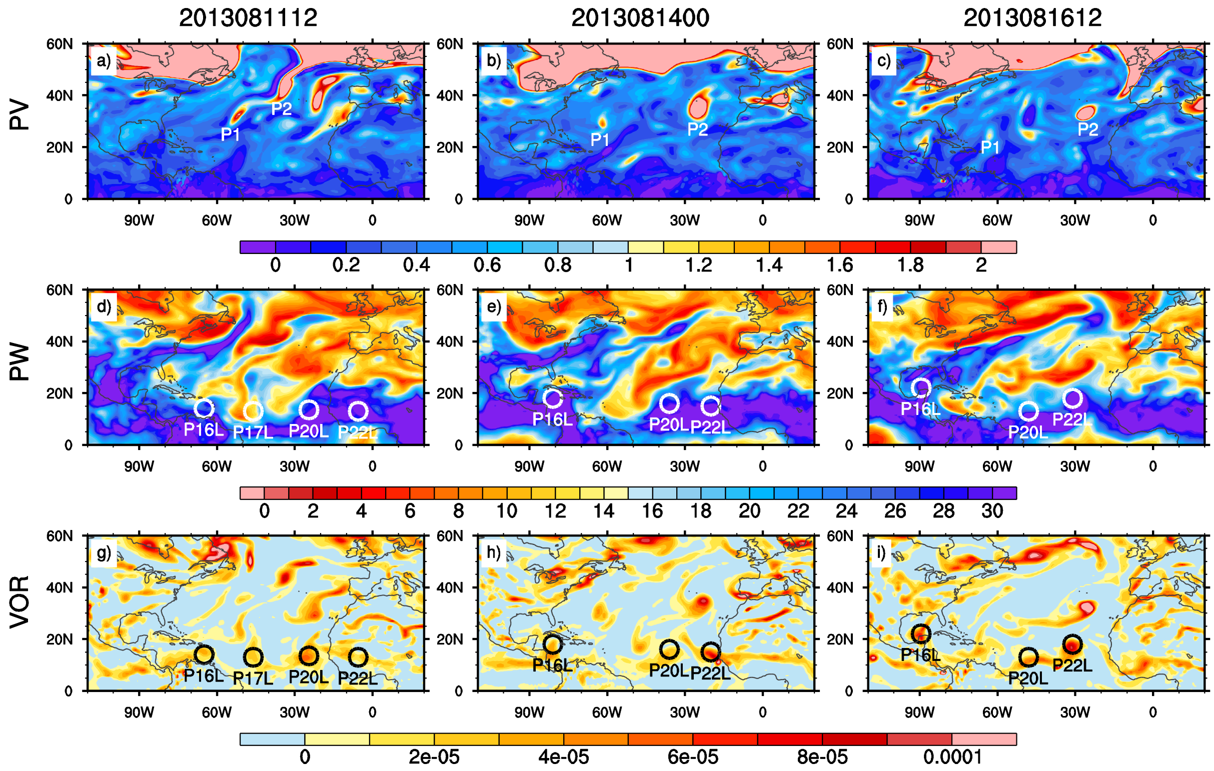


Fig. 2 Evolution of an RWB event. From up to bottom are 350K potential vorticity (PV; pvu), 200-850hPa precipitable water (PW; mm), and 700hPa relative vorticity (VOR; s^{-1}). From left to right, the time are 1200 UTC 11 August, 0000 UTC 14 August and 1200 UTC 16 August of 2013, with the 60-h interval. P1 and P2 in the PV plots denote the two high-PV centers resulting from RWB; the circles in PW and VOR plots denote wave pouches.

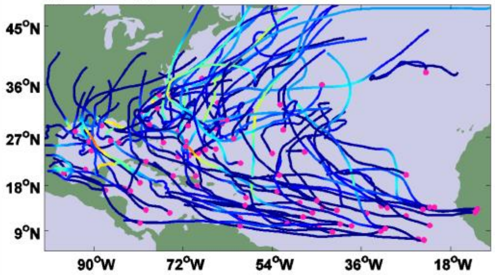
The dry air and strong VWS hinder TC development from TEWs, as shown by the evolution of four wave pouches (circles in Fig. 2d-2i). A wave pouch is the preferred location for tropical cyclogenesis in TEWs (Dunkerton et al. 2009). As discussed in Zhang et al. (2016), P16L and 17L fail to develop in the vicinity of strong VWS; P20L's convection remains weak and scattered, and develops a short-lived TC only after moving to the Gulf; P22L, initially embedded in moist environment, develops into a weak TC but is short-lived due to the impacts of the P2-related dry air and VWS.

We further note that RWB is exceptionally frequent in the 2013 season, and many TEWs weakened when approaching the Central Atlantic due to the extratropical impacts.

3. VARIABILITY OF RWB FREQUENCY

Using an automatic algorithm (Strong and Magnusdottir 2008), we identified the RWB events in July-October (1979-2013) with the ERA-Interim dataset; and an index, RWBFreq, was defined to represent the basin-wide frequency of RWB occurrence. RWBFreq

(a) RWBFreq(+): 2013 1983 1984 1985 1990 1982 2002 1993



(b) RWBFreq(-): 1999 1998 2010 2012 1988 2005 1995 2006

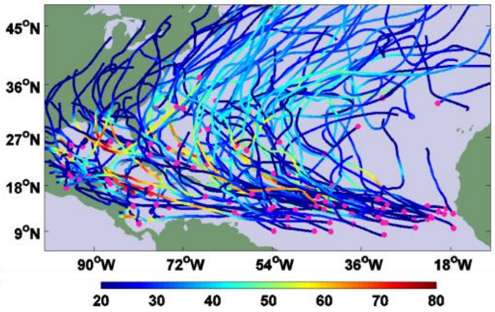
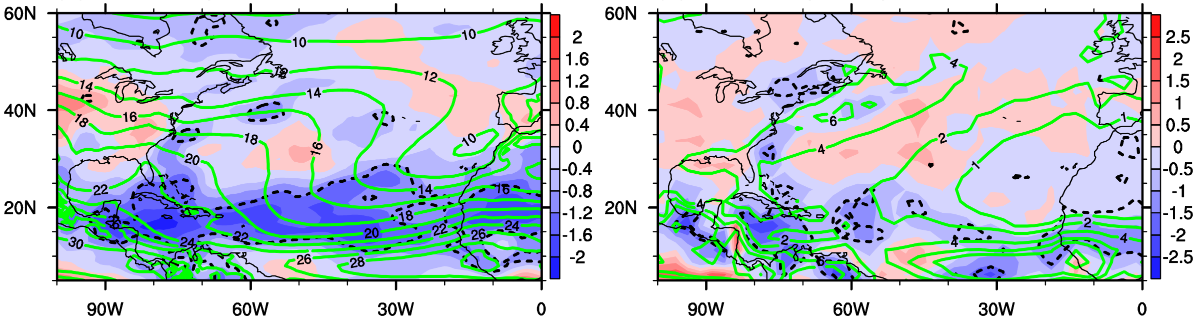
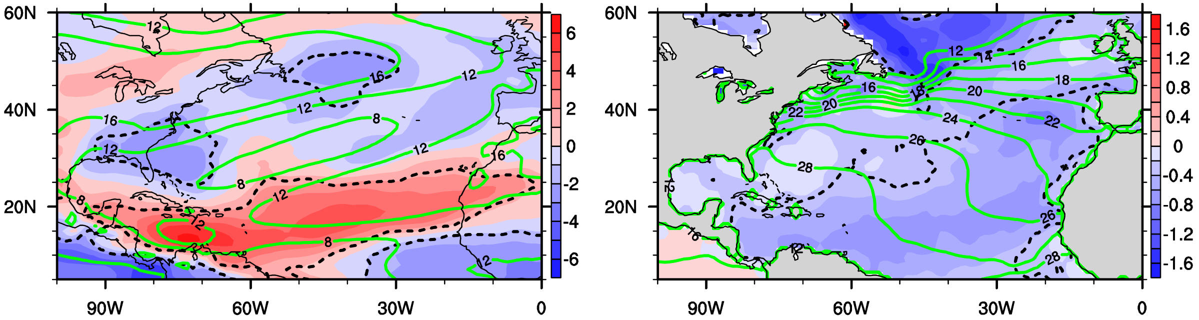


Fig. 3 Composite of July-October TC tracks of (a) RWBFreq(+) group and (b) RWBFreq(-) group. The pink dots highlight the locations of TC geneses, and the coloring represents the wind speed (m s^{-1}) of TCs. The composite members of each group are denoted in the subplot titles.



(a) RWBFreq PW Diff.

(b) RWBFreq Precip. Diff.



(c) RWBFreq VWS Diff.

(d) RWBFreq SST Diff.

Fig. 4 RWBFreq composite differences of the seasonal mean (a) PW (mm), (b) Precipitation (mm day^{-1}), (c) VWS (m s^{-1}), and (d) SST (degC). The green contours show the 1981-2010 climatology; black dashed lines highlight the parts above the 95% confidence level.

reaches a record high in 2013, and has a remarkable correlation with Atlantic hurricane counts (r=-0.67). The correlation is stronger than that between the MDR-SST/Niño-3.4 and the hurricane counts (r=0.64/-0.42).

The strong anti-correlation between RWBFreq and TC activity is also evident in the composite analysis. In the eight seasons with high RWBFreq (RWBFreq(+) group), there are 87 TCs, including 31 (35.6%) hurricanes (Fig. 3a); in contrast, 127 TCs, including 70 (55.1%) hurricanes, form in the opposite group (Fig. 3b). Notably, far fewer TCs form in the MDR in the RWBFreq(+) years, and many of them remain weak or dissipate over the tropical ocean; in addition, hurricane landfalls are greatly reduced.

The above relation is consistent with the variations of large-scale environment (Fig. 4). When RWB occurs more (less) frequently, the precipitable water (PW) decrease (increase) in the MDR and the West Africa, and VWS increases (decreases). Along with cold (warm) SSTAs in the MDR, these factors suppress (encourage) TC activity in the Atlantic. Further analysis suggests that RWBFreq and its impacts are partly independent of the tropical SST forcing (not shown), which explains the seasonal prediction bust in 2013.

4. SUMMARY AND IMPLICATIONS

This study highlights the extratropical impacts on Atlantic TC activity via RWB. More specifically, frequent RWB tends to suppress TC activity through reducing moisture and enhancing VWS in the tropics, which contributed to the surprisingly quiet 2013 season. The study suggests that RWB overall suppresses Atlantic TC activity, although some RWB-associated PV remnants may facilitate TC development over the West Atlantic (Davis and Bosart 2004; Galarneau et al. 2015).

The variability of RWB occurrence and its impacts are partly independent of tropical SST forcing. This suggests that the extratropical processes are possibly a missing piece in the seasonal prediction schemes of TC activity. The extratropical processes help to understand the uncertainties in the seasonal prediction. Or more optimistically, better representing these processes may improve the seasonal predication.

5. ACKNOWLEDGEMENT

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