P1.23 EXAMINING TRENDS IN SATELLITE-DETECTED OVERSHOOTING TOPS AS A POTENTIAL PREDICTOR OF TROPICAL CYCLONE GENESIS

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1. INTRODUCTION

Vigorous convection and the associated latent heat release through condensation processes is one of the essential ingredients to the formation of tropical cyclones (TCs) (Adler and Rodgers 1977, Kuo 1965). Theories have evolved as to the exact role of deep convection in TC genesis, beginning with Convective Instability of the Second Kind (CISK; Charney and Eliassen 1964) and more recently with the Vortical Hot Tower (VHT) theory (Montgomery et al. 2006). The latter theory purports that VHTs are an essential mechanism for building vorticity vertically in order for a TC to form.

This study utilizes a satellite-based overshooting top (OT) detection algorithm as a proxy for identifying vigorous convection (VHTs) in the tropics. We identify the frequency and trends in OTs during selected Atlantic tropical disturbance cases, and examine these for correlations with TC genesis. The correlations are then investigated as a tool for probabilistic forecasting of TC genesis. The OT algorithm, originally developed for mid-latitude severe weather applications by research scientists at the University of Wisconsin Cooperative Institute for Meteorological Satellite Studies (CIMSS), utilizes geostationary satellite 11 µm IR-Window (IRW) brightness temperatures (BT) (Bedka et al. 2010). While this algorithm is described as an overshooting top detection algorithm, it is important to note that no measure for evaluating the ambient height of the tropical tropopause has been included in the final modifications based on the analysis from Liu and Zipser (2005), which suggests the equilibrium level is below the tropical tropopause.

2. DATA

The OT detection algorithm utilizes 4-km resolution IRW imagery from the Geostationary Observing Environmental Satellite (GOES) satellite and 3-km resolution IRW imagery from METEOrological SATellite (METEOSAT). The algorithm identifies candidate OTs based on empirically-determined IRW BT thresholds, the first of which is that IRW pixel minima be at least 215 K or colder. Next, the surrounding anvil is sampled at an 8 km radius in 16 radial directions. Candidate anvil pixels must have a BT of at least 225 K with at least 9-out-of-16 potential anvil pixels satisfying this criterion. These pixels are used to calculate the mean anvil BT, and the candidate OT is classified as an OT if the minimum pixel BT and anvil-mean BT difference is at least 9 K. The method utilizes 30-min image sampling in this analysis.

OTs are tracked along the paths of a "marsupial pouch," defined as a lower-tropospheric Lagrangian closed circulation within an easterly wave (Dunkerton et al. 2009). Pouches are manually identified and tracked (courtesy Mark Boothe, Naval Postgraduate School) using lower-tropospheric diagnostics derived from 4 numerical weather prediction (NWP) global models: the United Kingdom Meteorology Office (UKMET), the NCEP Global Forecast System (GFS), the Navy Operational Global Atmospheric Prediction System (NOGAPS), and the European Centre for Medium-Range Weather Forecasting (ECMWF). A consensus pouch track position, as well as values of the coincident relative vorticity, is provided for 2010 and 2011 Atlantic cases.

3. CONFIRM OVERSHOOTING TOPS CAN ACT AS PROXY-VORTICAL HOT TOWERS

To first examine if detected OTs can serve as a reasonable proxy for VHTs, OTs day^{-1} produced within 200 km of the model pouch center are compared to that model's 700 hPa relative vorticity associated with the pouch. The relative vorticity is calculated by taking an area average of a 3x3 degree box centered on the pouch center. This metric is employed since the VHT theory indicates convection enhances the vorticity of the pouch (Montgomery et al. 2006). A radius of 200 km is chosen to be consistent with the radius of the initial vortex Montgomery and Enagonio (1998) initiated when simulating the convection interaction in the "bottom-up" genesis theory.

An example is illustrated in Figure 1, which shows the correlation between the average OTs day^{-1} within 200 km of the UKMET model pouch locations from initial pouch identification to 4.5

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days, compared to the model pouch relative vorticity at 4.5 days (maximum correlation in our sample). Overall, moderate correlation exists, and it is readily apparent that most of the higher OTs day^{-1} cases went on to be named TCs, while the weaker ones did not. This provides the impetus to explore the relationship further.

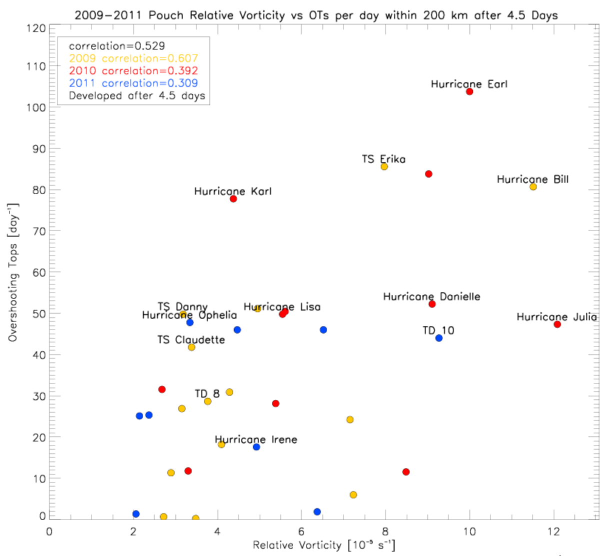

Figure 1: Correlation between the average OTs day^{-1} within 200 km of the UKMET model center and the pouch relative vorticity at 4.5 days after initial pouch identification. Labeled points went on to be TCs.

4. PREDICTING IF AND WHEN TROPICAL CYCLOGENESIS WILL OCCUR

Predicting if and when a pouch will undergo genesis is found by optimizing OT parameter combinations within 200 km of the pouch center. Each combination includes one of the following:

- OT BT maxima: 215 K, 205 K, 200 K
- averaging timeframes: 2 h, 3 h, 6 h, 12 h, 24 h, 36 h
- model of choice
- OT scan^{-1} (per image) thresholds

Forecasts for genesis are made every 2 hours, therefore consecutive forecasts with an averaging timeframe longer than 2 hours will share some OT data. OTs eastward of 19° W (i.e. over Africa) are not included in this analysis.

The results of the different combinations are compared using their Peirce Skill Score (PSS), with a PSS of 1 (0) representing a perfect (random) genesis forecast (Wilks 2006). The PSS is equal to the probability of detection (POD), the ratio of the correctly forecasted genesis occurrences to the actual number of genesis occurrences, minus the probability of false detection (POFD), which is the number of false alarms divided by the total number of non-occurrences. The False Alarm Ratio (FAR) is calculated by dividing the number of incorrect forecasts of genesis by the total number of genesis forecasts.

Table 1 reveals the best forecast skill for predicting IF a candidate pouch will undergo TC genesis is realized when a 24-h average of ≥2 OTs scan^{-1} with an OT BT maximum of 215 K is achieved along at least one of the model pouch tracks. With a POD of 82.6%, this forecast correctly predicts 19 out of 23 genesis events from 2010 and 2011, and only has 5 false alarms.

Forecast Skill	
Probability of Detection	82.6%
False Alarm Rate	20.8%
Probability of False Detection	15.2%
Peirce Skill Score	0.675

Table 1: Forecast skill for predicting genesis to occur once a threshold of ≥2 OTs scan^{-1} over a 24-h period is observed along at least one of the available model pouch tracks.

Predicting WHEN tropical cyclogenesis will occur is accomplished by calculating the linear regression between the magnitude of the first occurrence of ≥2 OTs scan^{-1} over a 24-h averaging period, and the days until genesis from the time that forecast is made. The correlation and variability is shown in Figure 2. It should be mentioned that the higher magnitude events shown in this figure were values derived from the first available 24-h period associated with pouches that would become Nate (2011) and Igor (2010).

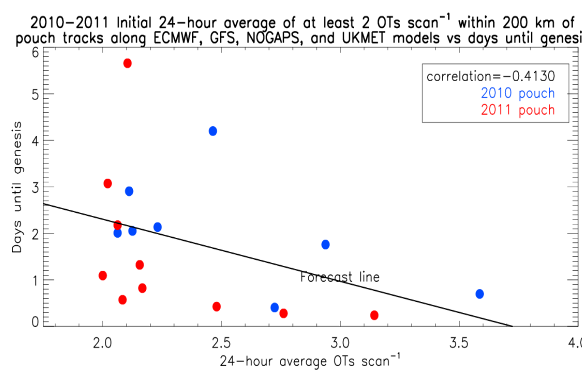

Figure 2. Linear regression between the magnitude of the first occurrence of 24-hour average OTs scan^{-1} greater than or equal to 2, and the days until genesis from the time that forecast is made.

Based on this regression, the forecast for genesis is:

$$\text{Days until genesis} = -1.16 \times \text{OT mag.} \geq 2(\text{24-h avg.}) + 4.29$$

Using this equation, the 2010 and 2011 genesis forecast cases are plotted with respect to timing error in Fig. 3. While there are a couple of bad misses, the majority of TC genesis events are correctly forecast within +/- 1 day. While promising, it is noted that the sample is dependent, and small, and the results are therefore not to be considered statistically significant.

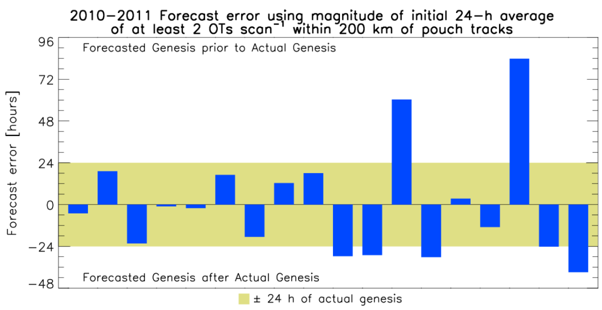

Figure 3. Forecast error between OT-forecasted genesis time and actual genesis time.

5. PRELIMINARY EXPERIMENTS WITH THE TC FORMATION PROBABILITY PRODUCT

Recognizing that there are many other environmental elements at play in TC genesis, the OT information as a proxy for VHT activity will not in of itself be a competing predictor. However, the promising results above indicate it could be a contributor to a multi-parameter TC genesis scheme. In this regard as a preliminary experiment, OTs scan^{-1} prior to synoptic times from 2009 and 2010 Atlantic pouch tracks were added as a predictor to the Tropical Cyclone Formation Probability (TCFP) product by Andrea Schumacher [Cooperative Institute for Research in the Atmosphere (CIRA)]. Developed by the Regional and Mesoscale Meteorology Branch (RAMMB) at CIRA, the TCFP product objectively estimates the probability of genesis within 5º of latitude by 5º of longitude boxes covering the tropical Atlantic domain over the subsequent 24 h based on 10 input parameters (Office of Satellite Data Processing and Distribution 2011). More information about the TCFP can be found in Schumacher et al. (2009).

OT scan^{-1} averages every 1, 3, 6, 12, and 24 hours prior to the synoptic times within selected radii of 200, 300, 400 and 500 km were tested in attempts to assess any positive impacts on the TCFP forecast skill. The skill of the TCPF product with the addition of the OTs is assessed using the Brier Skill Score (BSS). The BSS compares the difference between predicted probabilities, with the

$$\text{BSS}=1-\frac{\text{BS}_{\text{TCPF}}}{\text{BS}_{\text{ref}}} \text{ where BS} = \frac{1}{n}\sum_{k=1}^{n}(y_k - o_k)^2$$

where y_k and o_k are the predicted and observed probabilities (Wilks 2006). For our study, the BS_{ref} represents the Brier Score of the climatological formation probability. Overall, the highest BSS observed with OTs are found using a 3-h average OTs within 300 km of the UKMET pouch center, and results in a small 0.7% increase compared to the TCPF BSS without the OTs.

A reliability diagram (Figure 4) can better signify in which situations the OTs have a positive contribution to the TCPF product that is not indicated by the scalar BSS. In Fig. 4 (top), the 45° dotted-dashed line represents perfect reliability for all forecast probabilities, with points above the dotted-dashed line indicating forecast probabilities that are too low and points below the dotted-dashed line indicating forecast probabilities that are too high. The TCPF probability magnitudes are small (<10%) because climatological formation probabilities within each 5°x5° latitude/longitude box are low, and this is one of the inputs into the model. [In practice for forecaster interpretation, the box probabilities are converted into a "summation TC formation probability," which is the sum of the TC formation probabilities at all grid points within a 20° latitude by 20° longitude sub-regions. This is then converted to 'poor', 'possible', 'fair', and 'good' categories.] As observed in the middle forecast probabilities (3-7%), the blue dots representing the OT inputs are closer to a perfect reliability than the red dots (no OTs), indicating the OT predictors improve the TCPF genesis forecasts at those probabilities.

6. SUMMARY AND FUTURE DIRECTIONS

This pilot study looks at the potential of satellite-detected overshooting tops in IR imagery as a proxy for active convective activity in African Easterly Waves preceding tropical cyclogenesis. There are promising aspects, although the sample size is small. Further exploration of the OT product as a potential predictor in TC genesis schemes is planned.

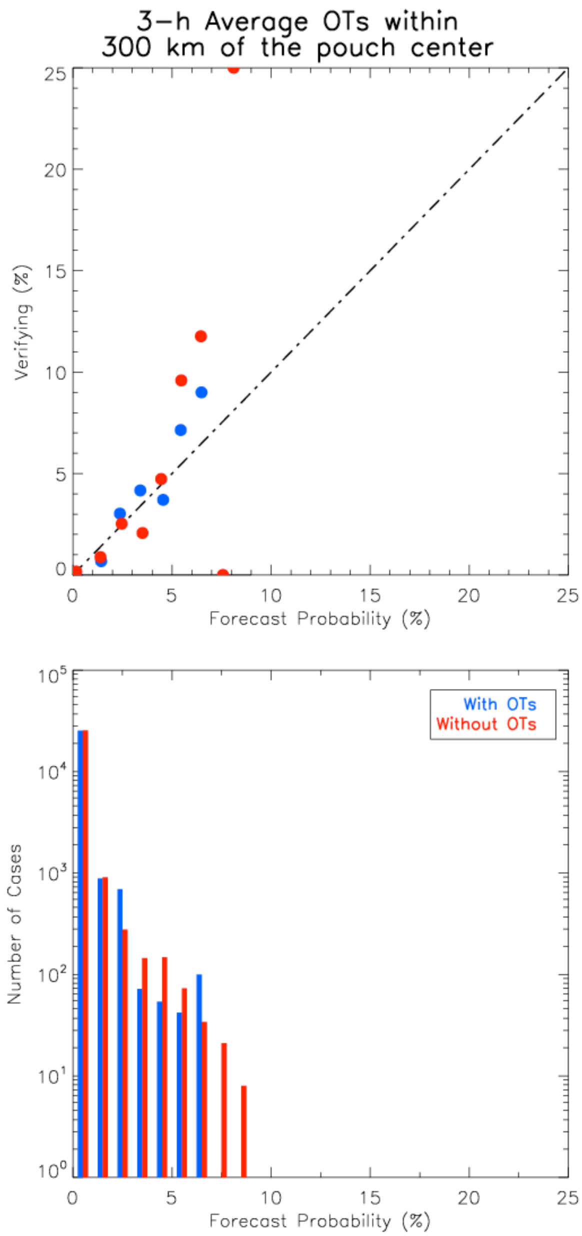

Figure 4. Reliability diagram (top) from Tropical Cyclone Formation Probability produced with OTs (blue) and without OTs (red) for 2009 and 2010 pouches, and (bottom) the corresponding number of cases with shown forecast probabilities.

Acknowledgements

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