S#.1 THE TROPICAL CYCLONE RESPONSE TO SMOOTHLY CHANGING WIND SHEAR USING THE METHOD OF TIME-VARYING POINT-DOWNSCALING

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1. INTRODUCTION

Until now, idealized numerical simulations of the tropical cyclone (TC) response to time-varying wind shear have used instantaneous changes in the TC environment. This was typically accomplished by pausing the simulation, constructing a new environmental vertical wind profile, rebalancing the mass field, and then restarting the simulation. We present a new modeling framework that allows for smoothly transitioning environmental wind states: time-varying point-downscaling (TVPDS). TVPDS is an enhancement of the point-downscaling technique developed for the Weather Research and Forecast (WRF) Model by Nolan (2011). It uses analysis nudging to smoothly transition between environmental vertical wind (and/or temperature and moisture) profiles while coordinating the point-downscaling method such that the environment remains in balance. Using this new framework, results from previous studies are reexamined to test whether the instantaneous 'shock' to the environment has implications for TC intensity evolution.

2. TIME-VARYING POINT-DOWNSCALING

TVPDS coordinates nudging and point-downscaling in the WRF model to allow smoothly transitioning background states of environmental wind without imbalances such as inertial oscillations. Nudging in the WRF model follows the methodology of Stauffer and Seaman (1990,1991) in which nudging of the environment is defined such that:

$$\frac{d\boldsymbol{u}(z)}{dt} = -\frac{1}{\tau}(\boldsymbol{u}(\boldsymbol{z}) - \boldsymbol{u_n}(\boldsymbol{z})) \qquad (2)$$

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where $\boldsymbol{u}(\boldsymbol{z})$ defines the zonal wind at level $\boldsymbol{z}$, $\boldsymbol{u_n}(\boldsymbol{z})$ defines the prescribed nudging value for the zonal wind at level $\boldsymbol{z}$, and $\boldsymbol{\tau}$ is the nudging time scale. TVPDS simply applies this formula to update the base environmental profile which is required by the point-downscaling functionality in WRF. With this addition, smoothly transitioning background states of temperature, moisture, and wind with doubly periodic boundary conditions are possible.

3. COMPARING TO PREVIOUS STUDIES

Frank and Ritchie (2001), Wang et al. (2004), and Riemer et al. (2010, 2013) performed simulations in which TCs developed in quiescent conditions and then were instantaneously subjected to shear. In their results, these authors found that TCs generally weaken when shear is imposed, but then frequently recover to their pre-shear intensities some time later. Frank and Ritchie and Riemer et al. both speculated that the spontaneous switching-on of shear had little or no effect on their conclusions. In this study we test that proposal by smoothly transitioning from environments of low to high shear. TVPDS simulations of quasi-steady state, moderately intense (~50 ms^{-1}) TCs show that the response to increasing wind shear is a steady reduction in intensity without a recovery to the pre-shear intensity. Figure 1 shows maximum 10 m wind speed vs time for a TVPDS simulation where shear transitions relatively rapidly from 5 to 15 ms^{-1}. This result is considerably different from that of Riemer et al. (2010, 2013) in which TCs subjected to similar shear (post-transition shear of 15 ms^{-1}) weakened for a period and then recovered to intensities stronger than the prior to shear imposition. This result suggests that perhaps the instantaneous transition between states does have implications for TC future intensity. The sea surface temperature (SST) in this simulation was fixed at 27° C, however, even when SST is set to 30° C, TC recovery failed to occur.

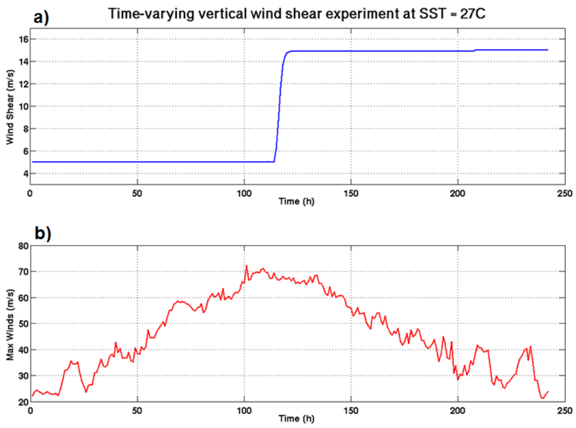

Fig. 1. Time series of environmental wind shear (a) and maximum 10 m wind speed (b: ms^{-1}) for a TVPDS simulation that transitions from westerly shear of 5 ms^{-1} to 15 ms^{-1} over a 6 h period.

4. THE TC RESPONSE TO VARYING SHEAR-TRANISTION RATES AND FINAL STATES

One interesting result from TVPDS simulations was that the rate at which TCs weaken depends upon the rate at which shear transitions. Figure 2 shows how a smaller value of τ (shear increases at a faster rate) leads to a larger rate of weakening for the TC.

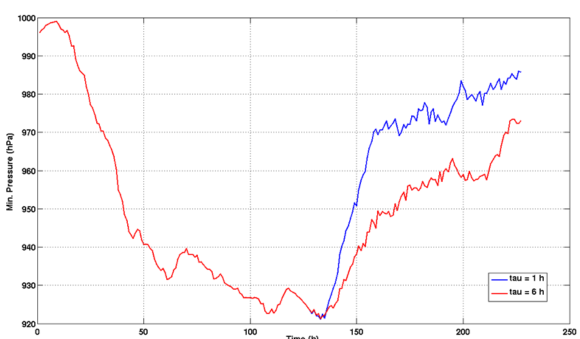

Fig. 2. Time series of minimum central pressure (hPa) for a TVPDS simulation transitioning from westerly shear of 5 to 15 ms^{-1} with τ = 1 h (blue) and τ = 6 h (red).

Note that regardless of the rate at which shear increases, the TCs weaken and do not recover to strong intensity. Another interesting result is that the shape of the final-state environmental wind profile also dictates the rate at which TCs weaken and their final-state intensity. Onderlinde and Nolan (2014, 2016) showed that positive tropical cyclone-relative environmental helicity (TCREH) is more favorable for TC intensification. TVPDS simulations transitioning from a common environmental wind state to varying final states of TCREH show that TCs are more resilient to shear when the final-state environment is characterized by positive TCREH. Figure 3 shows three simulations transitioning to positive (blue), neutral (yellow), and negative (pink) TCREH states. Notice that the magnitude of 850 – 200 hPa wind shear always remains equal for the 3 simulations (Fig. 3b).

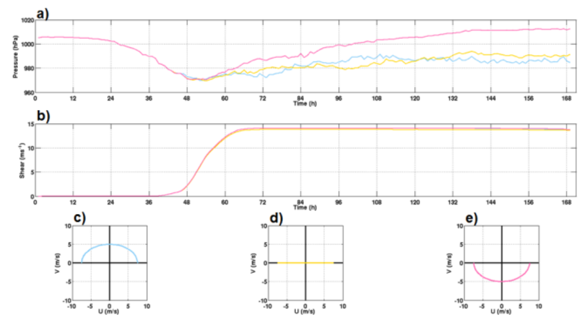

Fig. 3. TVPDS simulations of 3 TCs in environments transitioning from low-shear environments to environments characterized by positive (blue), neutral (yellow), and negative (red) TCREH. Panel (a) shows time series of minimum central pressure (hPa), panel (b) shows the magnitude of 850 – 200 hPa wind shear, and panels (c-e) show the end-state environmental hodographs for the simulations with positive (c), neutral (d), and negative (e) TCREH.

5. SUMMARY

A new modeling framework allows for the idealized simulation of TCs in environments characterized by smoothly transitioning wind shear. Previous studies instantaneously imposed shear by pausing the simulation and rebalancing the mass field. Those studies found that TCs often were resilient to shear even up to magnitudes of 15 ms^{-1}. TVPDS simulations in the present study show a more expected response to increasing shear which is a gradual weakening to lower intensity without recovery to pre-shear intensity. Results also show that TCs are sensitive to the shear transition rate and to the characteristics of the final-state vertical wind profile. TVPDS maintains control of the large-scale environment and creates smoothly transitioning vertical profiles of wind, temperature, and moisture thus allowing virtually any conceivable experiment regarding the TC response to a changing environment.

6. REFERENCES

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