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Importance of Model Resolution on Discriminating Rapidly and Non-Rapidly Intensifying Atlantic Basin Tropical Cyclones

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Abstract

The ability to discriminate rapidly intensifying tropical cyclones (TCs) from their non-rapidly intensifying counterparts remains a major forecasting challenge in operational meteorology. Primarily, approaches to this forecast problem utilize dynamic model data as input into either numerical weather prediction models or statistical algorithms. Recent work suggested higher spatial resolution dynamic simulations will have greater success in distinguishing rapid intensification (RI) of TCs from those that do not, owing to the dynamic model's ability to depict smaller scale features explicitly within the simulation. Despite these preliminary findings, this approach has not been tested with a statistical modeling approach. As such, the scope of this work was to identify the importance of spatial resolution on the ability to forecast the onset of RI and non-RI TCs at 24 hour lead times. To accomplish this, 8 storms of each type were simulated using the Weather Research and Forecasting (WRF) model at varying spatial resolutions (54 km, 18 km, and 6 km). Meteorological fields from the WRF were used as input into a support vector machine classification algorithm trained to discriminate RI and non-RI TC environments.

Keywords: Tropical cyclones, principal component analysis, support vector machines

1. Introduction

The prediction of tropical cyclone rapid intensification remains a relevant forecast challenge in operational meteorology. Tropical cyclones (hereafter known as TCs) which undergo rapid intensification (RI) are consistently associated with the highest intensity storms, as all category 4 and 5 hurricanes and a vast majority of category 2-3 hurricanes undergo RI at least once in their evolution, and often multiple times [1]. As such, the threat to coastal locations from hurricanes which undergo RI is tremendous. Considerable work on forecasting RI [2-5] has suggested a series of predictors that are useful for distinguishing TCs that rapidly intensify from those that do not

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(hereafter non-RI) with little forecast success (forecast skill scores less than 0.3). However, these approaches have been constrained to primarily linear regression techniques, despite the recent calls for artificial intelligence-based algorithms for distinguishing RI and non-RI storms. Preliminary studies into the application of AI techniques [1,5] have revealed some promise at reproducing model skill observed with the current operational implementation, but improvements using AI techniques above these current methods remain limited.

Recent work in numerical modeling of TCs has focused on the importance of higher resolution simulations when diagnosing RI. In particular, Chen and Gopalakrishnan [6] looked at the utility of the Hurricane Weather Research and Forecasting (HWRF) model to diagnose RI within Hurricane Earl (2010). They configured the HWRF with horizontal spatial resolutions of 27 km, 9 km, and 3 km, focusing specifically on the 3 km resolution results when diagnosing the onset of RI within the storm. Additional work utilizing the high-resolution HWRF model [7] has demonstrated potential value of the increases in resolution of the model, though HWRF coupling with an ocean model, and model parameterization configurations are likely affecting this improvement as well.

While the advantages of higher spatial resolution are clear when resolving smaller-scale processes within the TC, these simulations require considerable computing power and time for completion. Additionally, other research [2-4] has shown value in discriminating RI and non-RI TCs with lower spatial resolution prognostic fields. The current operational RI forecast model (the Statistical Hurricane Intensification Prediction Scheme Rapid Intensification Index – SHIPS-RII [2,3]) retains its peak forecast skill (Heidke Skill scores of roughly 0.2) with these lower resolution data. The SHIPS-RII is a multivariate linear regression scheme that has been blended into an ensemble approach, incorporating a Bayesian version of the model, a logistic regression, and a linear discriminant analysis. These techniques are limited by their inherent linearity, which could potentially be reducing forecast skill given the highly nonlinear meteorological relationships within a TC. The work of Grimes and Mercer [1,5] attempted to address this limitation through the introduction of a support vector machine (hereafter SVM) based classification scheme for RI/non-RI storms. Their work, while successful in achieving RI/non-RI discrimination skill on par with the current SHIPS-RII implementation (HSS of roughly 0.3, albeit in diagnostic mode), retains the spatial resolution limitations of the original SHIPS-RII studies [6,7].

To address this known deficiency, the goal of this project was to determine the ability of model forecasts to discriminate RI and non-RI storms relative to varied spatial resolutions of the input data. Discrimination was completed using a SVM (following [1,5]). The primary research hypothesis was that increases in spatial resolution in the model will yield improved classification ability by the SVM.

2. Data and Methods

2.1 Datasets

This project required a database of TCs with all associated intensification information. The National Hurricane Center (NHC) hurricane database (HURDAT) [8] contains 6 hourly TC position information, as well as peak wind gusts and central pressure. The current operationally implemented RI definition is an increase in peak wind speed of 30 kt in 24 hours, and this definition of RI is used in this study as well.

In addition to a database of TCs, meteorological fields were required for input in the Weather Research and Forecasting model (WRF model – [9]). While numerous global reanalysis databases exist, they are constrained with coarse spatial resolution (e.g. the NCEP/NCAR reanalysis [10] – 2.5° global resolution), meaning very few gridpoints would be available to resolve processes within TCs. To gain horizontal spatial resolution in the meteorological fields, a regional reanalysis was required. As such, the North American Regional Reanalysis (NARR – [11]) was selected as the input database for the model simulations. The NARR are provided from 1979-present every 3 hours on a Lambert-conformal grid centered on North America with 32 km grid spacing and 29 vertical levels. Unfortunately, the southeastern edge of the NARR domain (Fig. 1) extends very little into the southwestern Atlantic. This requires TC selection from the HURDAT to be constrained such that all storms maintained their entire track sufficiently within the NARR domain to capture relevant meteorological processes happing in the TC. This limited the study to a considerably smaller subset of candidate storms, resulting in 8 RI and 8 non-RI storms (Table 1) selected for the WRF simulations.