Assessment of Tropical Cyclone Kinematic and Thermodynamic Structures in the North American Regional Reanalysis (NARR)

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Stephanie E. Zick (sezick@ufl.edu) and Corene J. Matyas (matyas@ufl.edu),

Department of Geography, University of Florida, Gainesville FL

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Introduction

Long-term reanalysis datasets, such as the North American Regional Reanalysis (NARR), are data-rich resources for atmospheric science research. Due to their approximate consistency in time and space, these datasets can be used to study weather and climate phenomena, such as the interaction between a tropical cyclone (TC) and the large-scale environment. However, because of the relatively low horizontal resolution in these datasets, it is unclear whether these models can robustly represent TCs (Manning and Hart 2007, Schenkel 2012).

The ultimate goal of this research is to develop a better understanding of the influence of large-scale moisture on TC size and structure. Researchers have identified large-scale relative humidity as a primary controlling factor of TC size and outer rainband activity (Hill and Lackmann 2009, Matyas and Cartaya 2009) and subsequent redistribution of heating and angular momentum (Kimball 2005, Hill and Lackmann 2009). The NARR may provide a useful framework for studying the larger scale processes associated with these phenomena, if the representation of TCs is determined to be adequate. In this study, we compare output from the NARR with output from the global Climate Forecast System Reanalysis (CFSR) and with precipitation derived from the Tropical Rainfall Measuring Mission (TRMM) satellite.

Objective

To determine the suitability of examining TC water budgets and large scale thermodynamics using the NARR based on:

1) **TC location and intensity**
2) **Warm core, kinematic, and precip structure.**

Data

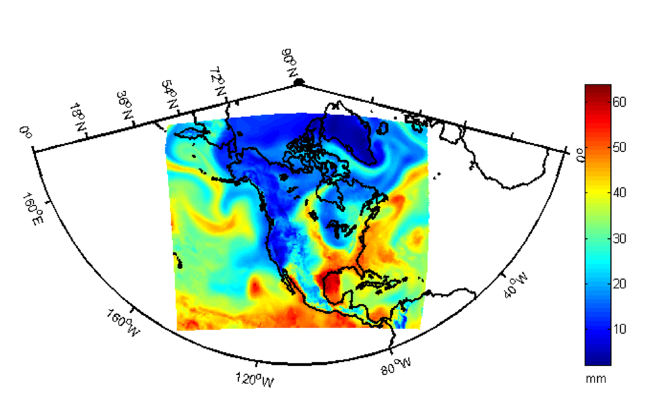

Fig 1. NARR Precipitable Water (mm) 18 UTC Jul 23 2008

- North American Regional Reanalysis (NARR) from NCEP/NCAR uses NCEP Eta Model
- Native grid projected to Lambert Conformal 32 km horizontal grid, with 29 vertical pressure levels, avail. 8 x daily
- Regional Data Assimilation System (RDAS) assimilates high quality 1-hourly precipitation analyses (Mesinger et al. 2006)

From the scientific literature:

- Mesinger et al. 2006: "an improvement over previous global reanalysis data sets"
- Sun and Barros 2009 & Knight and Davis 2009: reproduces spatial patterns of heavy precipitation well but underestimates magnitude and frequency of extreme events
- Royer and Pourier 2010: North of 45°N, NARR data appear to be too warm by about 1°C
- Ruane 2010: 1) A "prime candidate" for hydrometeorological applications & 2) In regions where precipitation draws largely from moisture convergence, the model is sensitive to dynamical processes.

To date, there is no comprehensive evaluation of TCs in NARR!

Objective 1: TC Location and Intensity

NARR TC location is compared with Best Track (∗) for all 1998-2012 U.S. landfalling TCs. To locate the TC within the NARR dataset[1], three dynamic and thermodynamic criteria are used (Figure 2): A) min SLP (**x**), B) max 850 hPa vorticity (**o**), and C) max 700-200 hPa thickness (□).

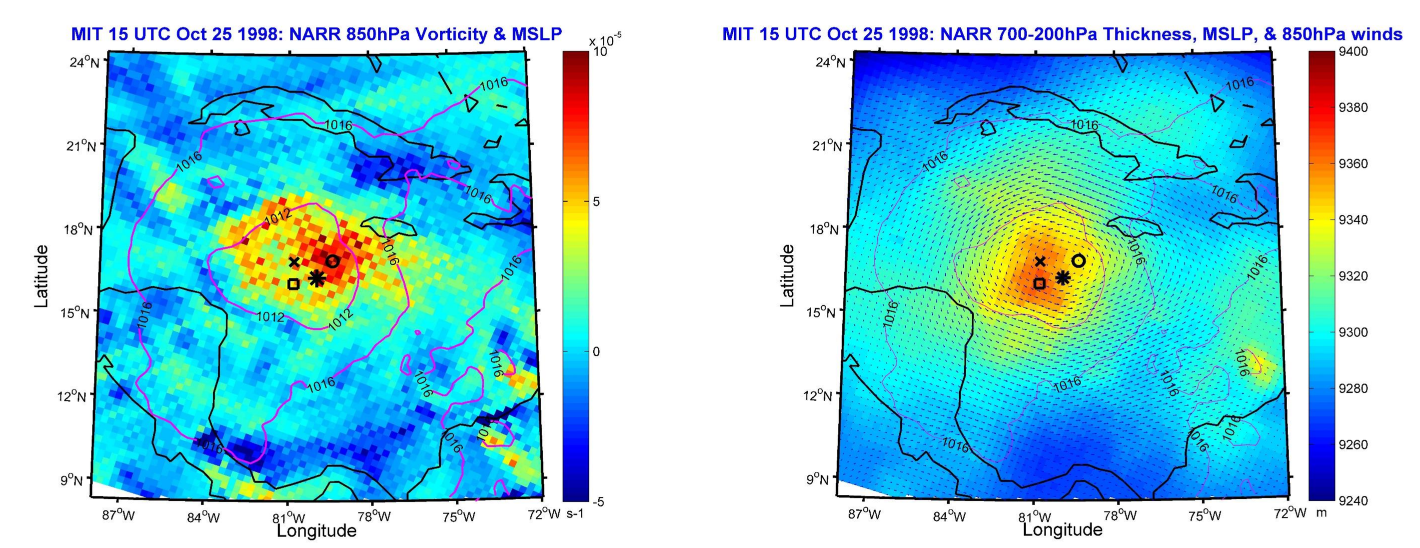

Fig 2. Spatial Demonstration of Best Track vs. NARR TC position.

The NARR TC position error is calculated as 1) the minimum and 2) the average distance between Best Track and these three locations and 3) with respect to 850 hPa vorticity center (Figure 3). Averages over storm lifetime (TS or greater) are plotted.

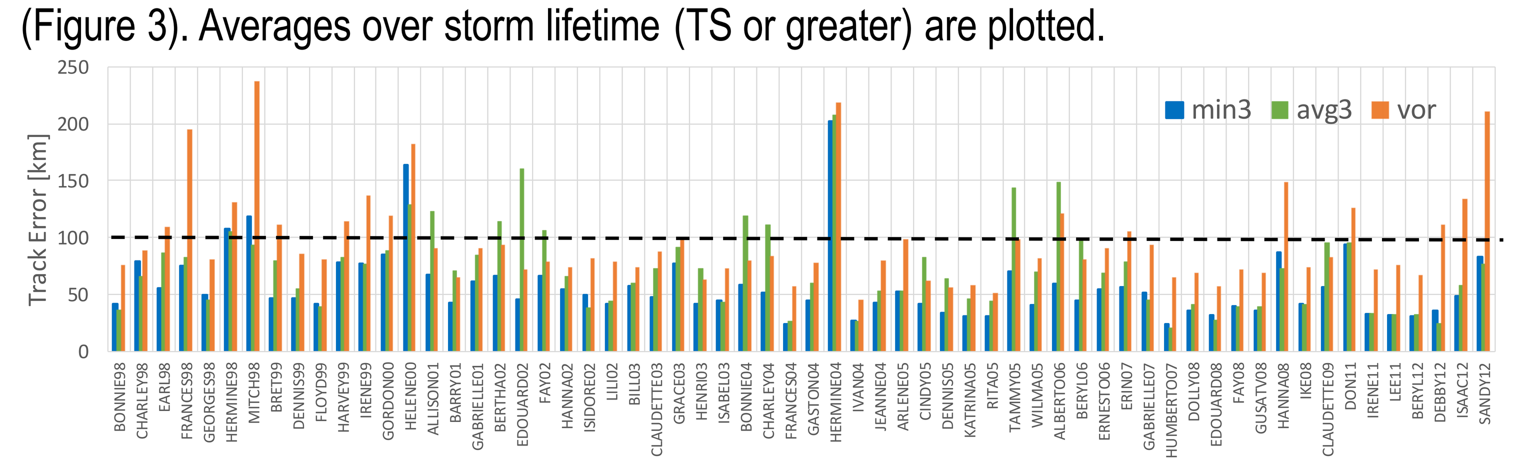

Fig 3. NARR 1998-2012 US Landfalling TC Track Errors Averaged over Storm Lifetime

Track error is frequently constrained to within 100 km, as compared with Best Track. TCs with stronger intensities have more accurate tracks.

1: Algorithm searches a 5°lat x5°lon box centered on the Best Track position. Only BT positions >5° from domain boundary are included.

A Tale of Two Storms: in-domain VS out-domain

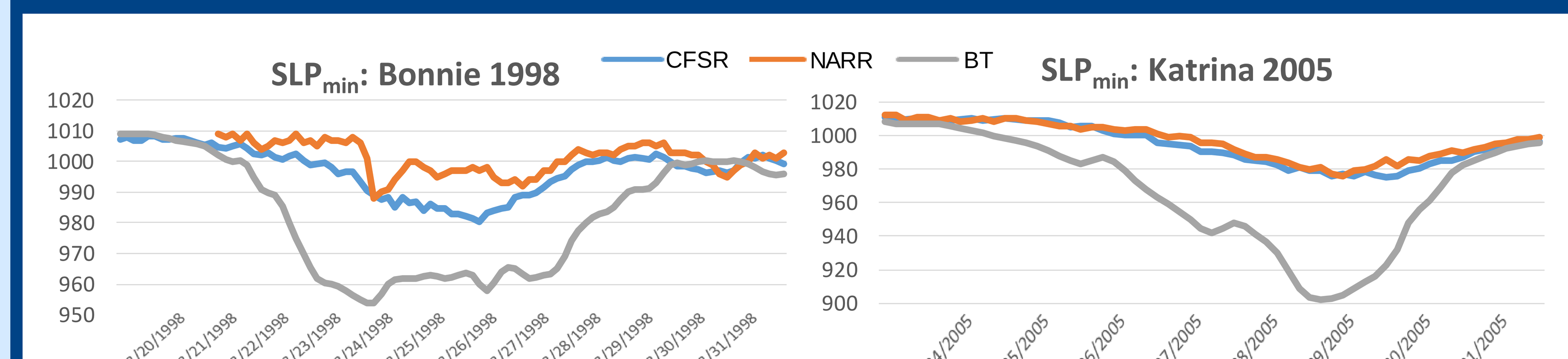

Fig 4. Comparison of NARR, CFSR, and Best Track (BT) Minimum Sea Level Pressure (SLP_{min}) in Hurricane Bonnie 1998 (left) and Hurricane Katrina 2005 (right)

Intensity is underrepresented, compared with reduced resolution criteria (Walsh et al. 2007).

Limitations due to restricted spatial coverage of NARR:
TCs that form outside the domain and move onto the grid (e.g. Cape Verde storms) tend to be more poorly represented. Storms that track near the domain boundary (e.g. Hurricane Mitch 1998) are also problematic.

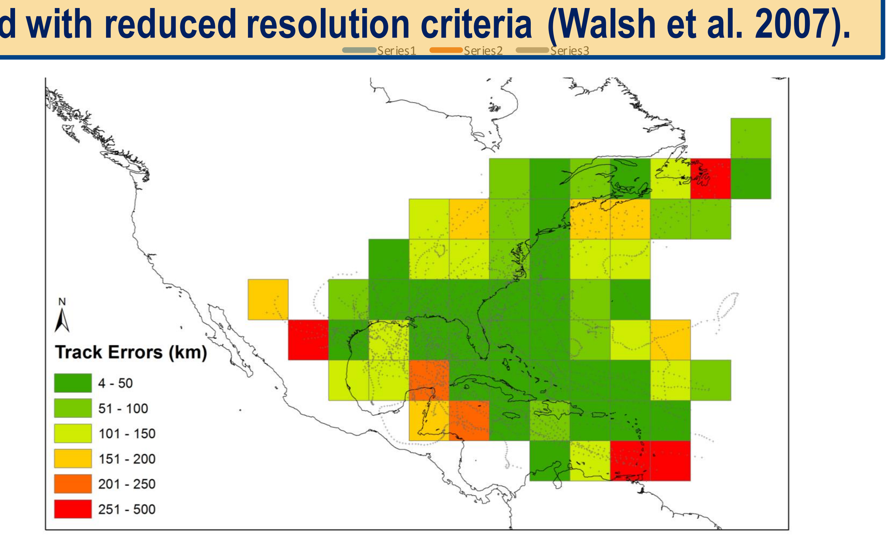

Fig 5. NARR Track Errors in 1998-2012 Landfalling TCs, averaged over 2.5°x2.5° lat-lon grid boxes.

Objective 2: Warm Core, Kinematic & Precip Structure

By Sawyer-Eliassen, a mid-tropospheric heat/momentum source induces outflow in the upper troposphere and inflow in the lower troposphere. In a warm core TC, this is the basis for the forced secondary circulation (e.g. Shapiro and Willoughby 1982), which transports low-level moisture inward. It is therefore crucial that the NARR physical parameterizations are able to capture sub-gridscale processes in order to develop a TC warm core, the primary and secondary circulations, and a realistic TC moisture budget.

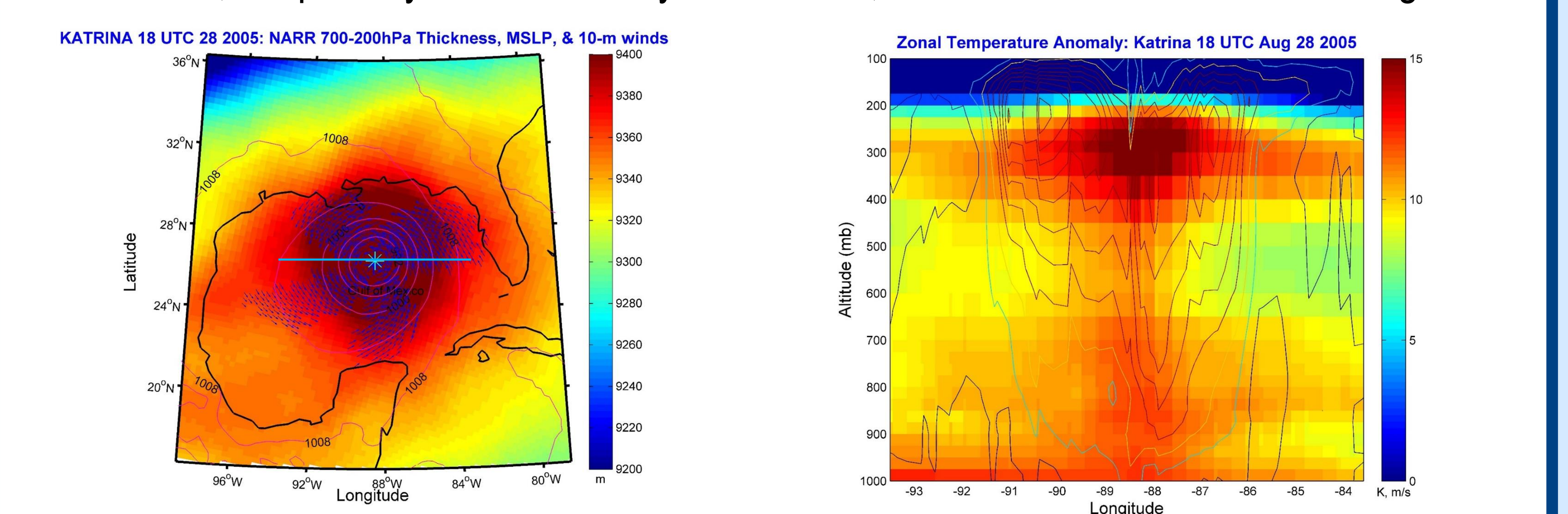

Fig 6. Representation of Hurricane Katrina (2005) warm core and kinematic structure at peak intensity via 700-200 hPa thickness and 10-m winds (left) and cross section of zonal temperature anomaly and vertical velocity (right).

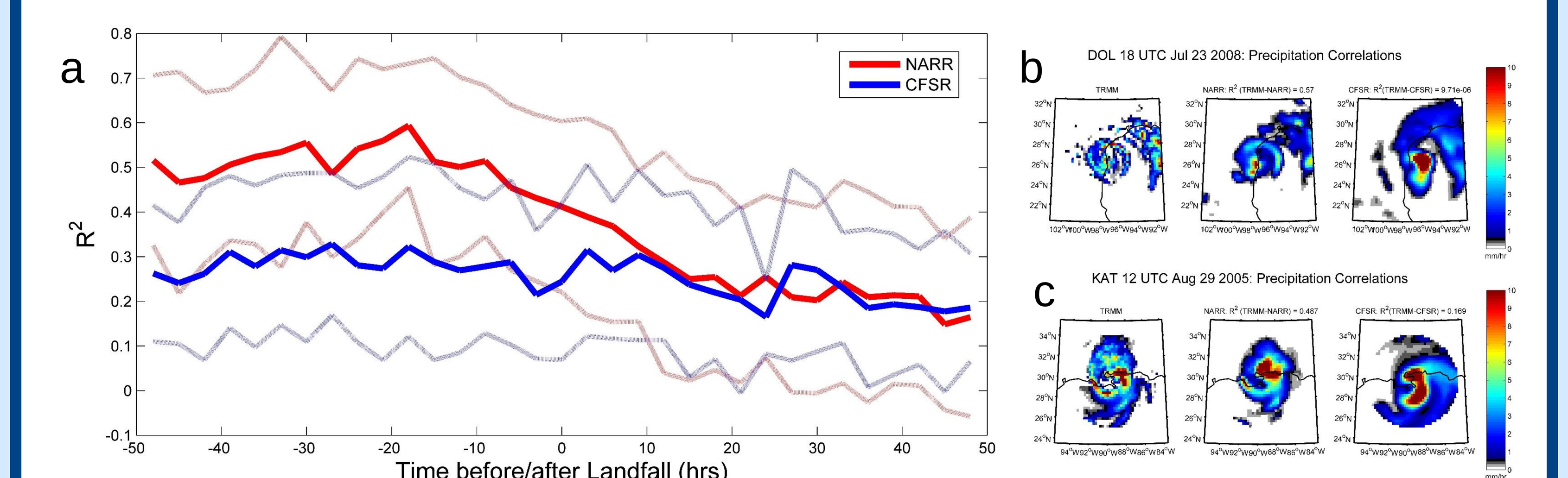

Fig 7a. NARR and CFSR precipitation correlations (R^2) with TRMM-derived precipitation, composited over 96-hr window centered on landfall. R^2 is calculated using n=200 randomly selected gridpoints over a radius of 800 km from the Best Track center, weighted more heavily inside r=150 km. Dashed lines indicate +/- 1 standard deviation within the sample of storms at each timestep. Figures 7b (Hurricane Dolly 2008 at landfall) and 7c (Hurricane Katrina 2005 at landfall) provided for illustration of improved precipitation structures.

Atmospheric thicknesses and upper tropospheric temperature anomalies indicate well-developed warm cores. As compared with CFSR, the NARR represents large-scale and mesoscale precipitation more realistically.

Conclusion

Away from the domain boundary, the NARR dataset is a suitable resource for studying TC moisture budgets and large-scale thermodynamics

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