Assessment of Tropical Cyclone Moisture Budgets and Thermodynamics in the North American Regional Reanalysis (NARR)

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Introduction

Long-term reanalysis datasets, such as the North American Regional Reanlysis (NARR), are data-rich resources for weather and climate. Precisely because of their approximate consistency in time and space, it is appealing to take advantage of these datasets to study a wide range of meteorological and climate phenomena, including the spatio-temporal interactions between a tropical cyclone (TC) and the large-scale environment (e.g., Maloney and Hartmann 2000, Schenckel 2012). However, because of the relatively low horizontal resolution in these datasets, it is unclear whether reanalysis models are able to robustly represent TCs (Manning and Hart 2007, Schenkel 2012).

In particular, the ultimate goal of this research is to develop a better understanding of the influence of large-scale moisture on TC size and structure. Recent research has identified large-scale relative humidity as a primary controlling factor of TC size and rainband activity (Harr and Lackmann 2009, Matyas and Cartaya 2009) outside the inner core region and subsequent redistribution of heating and angular momentum (Kimball 2005, Harr and Lackmann 2009). The NARR may provide a useful framework for studying the larger scale processes associated with this phenomena, if the representation of TCs is determined to be robust.

Objective

To determine the suitability of examining TC water budgets and large scale thermodynamics using the North American Regional Reanalysis (NARR) based on:

1) TC location, 2) Warm core structure, and 3) TC moisture budgets

Data

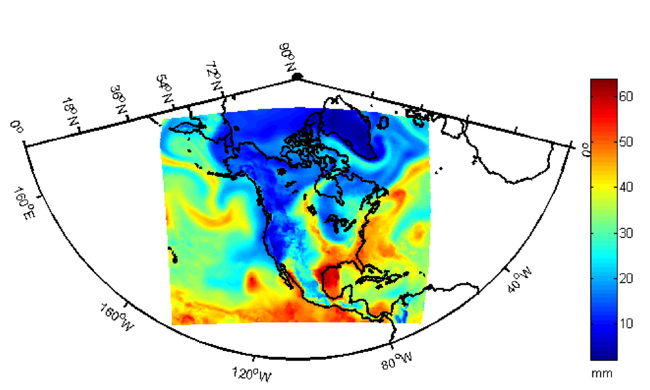

Fig 1. NARR Precipitable Water (mm) 18 UTC Jul 23 2008

- 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 (Ruane 2010).

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

Objective 1: TC location

NARR TC location is compared with Best Track (∗) for all U.S. landfalling TCs in the 1998-2012 North Atlantic hurricane seasons. 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 (□).

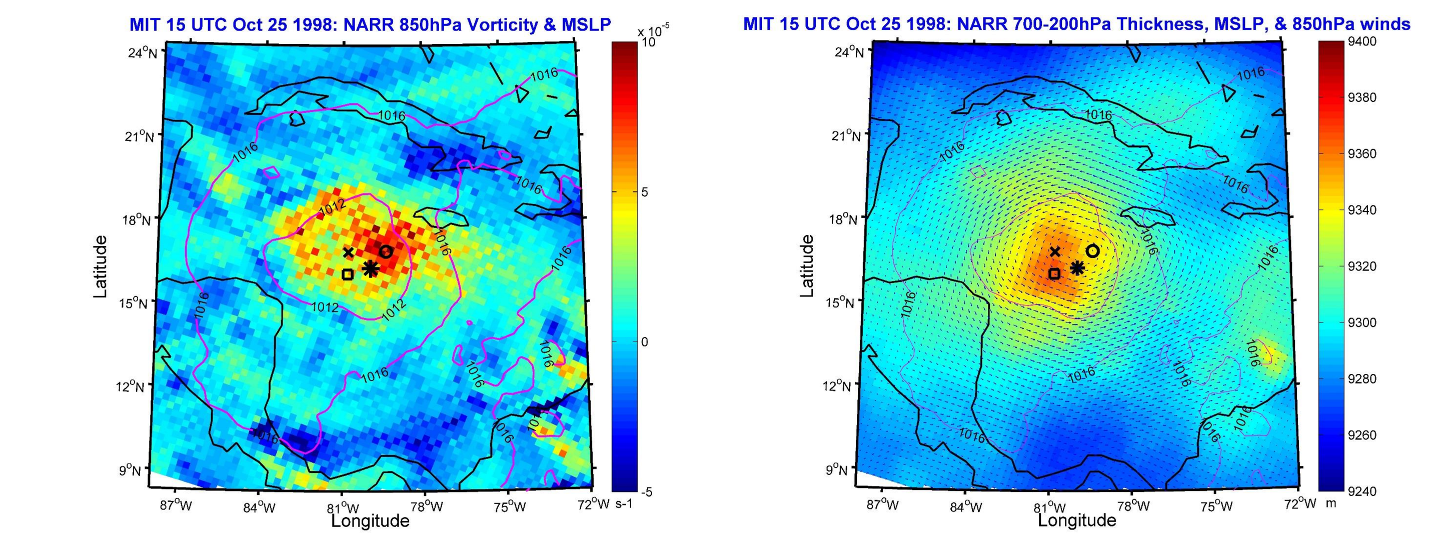

Fig 2. Spatial Demonstration of Best Track vs. NARR TC position.

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.

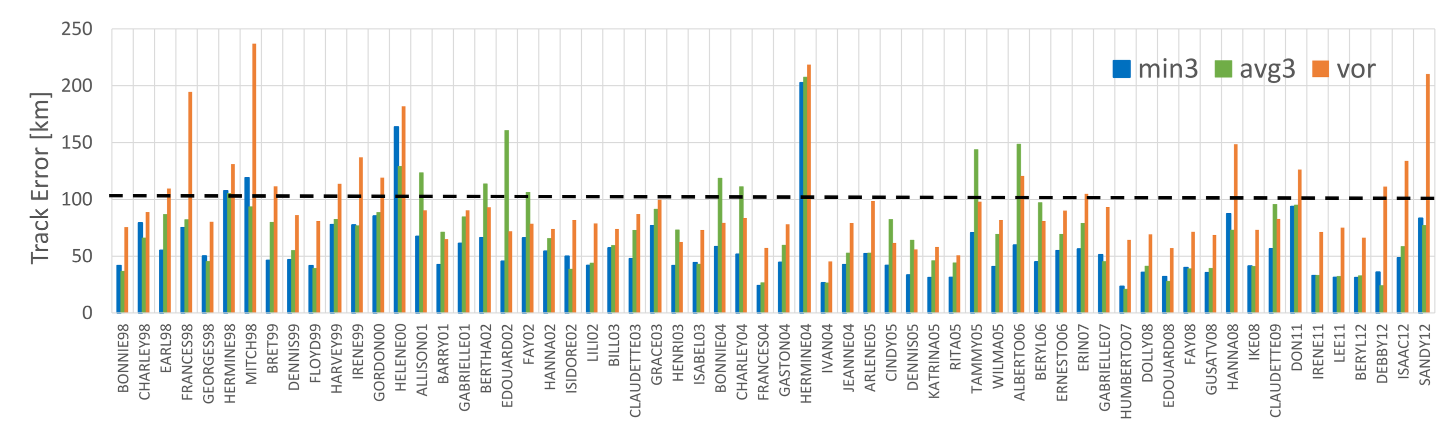

Fig 3. NARR 1998-2012 US Landfalling TC Track Errors Averaged over Storm Lifetime

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

Objective 2: Warm Core

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 diabatic processes in order to develop a TC warm core and realistically represent TC moisture budgets.

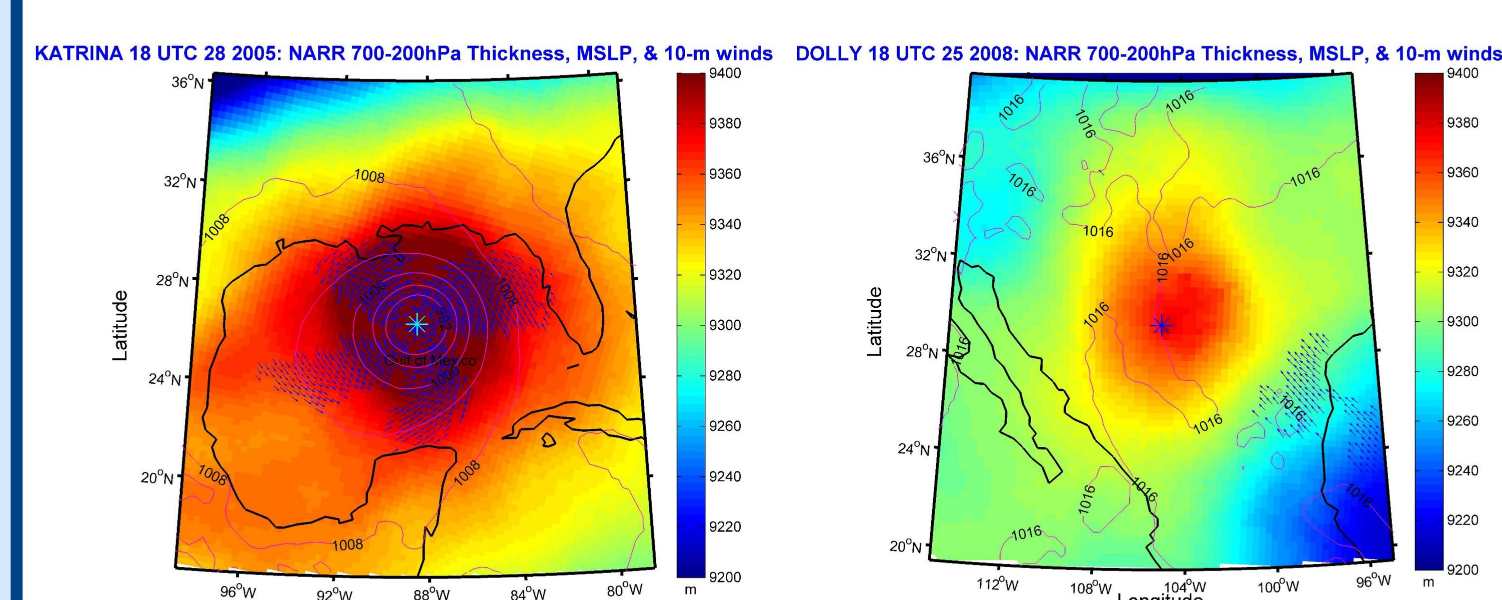

Fig 4. Warm Cores, represented by 700-200 hPa thickness, for Hurricane Katrina (2005) at peak intensity (left) and Hurricane Dolly (2008) two days after landfall (right).

Objective 3: Moisture Budgets

Following (Mesinger et al. 2006) and (Ruane 2010), the moisture budget is:

$$\Delta PWAT = Evap - Precip + MoistConv\ (+\epsilon)$$

Volume-averages of each moisture budget term are calculated for radii of 100 km, 500 km, and 1000 km from the TC center every 3 hours over a 96-hours period centered on landfall. [The ε term accounts for residuals]

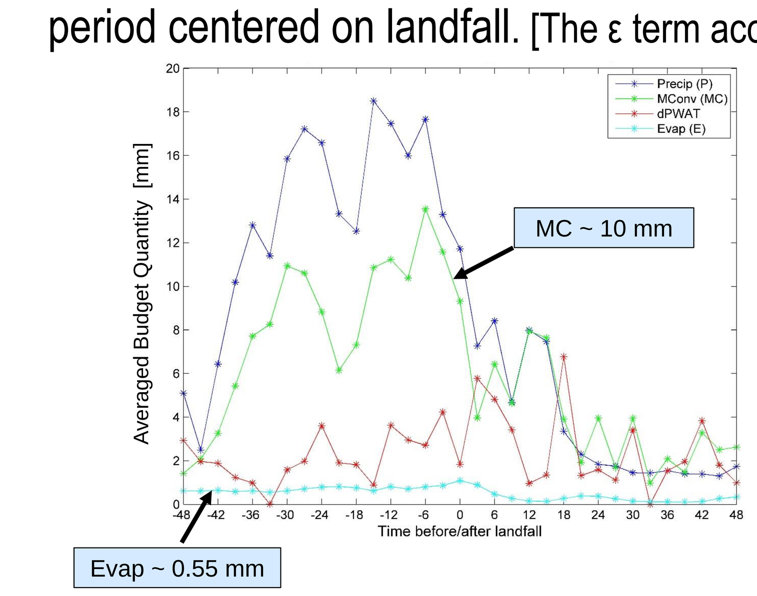

Fig 5. Inner-100km Volume-Averaged Moisture Budget for Hurricane Dolly (2008)

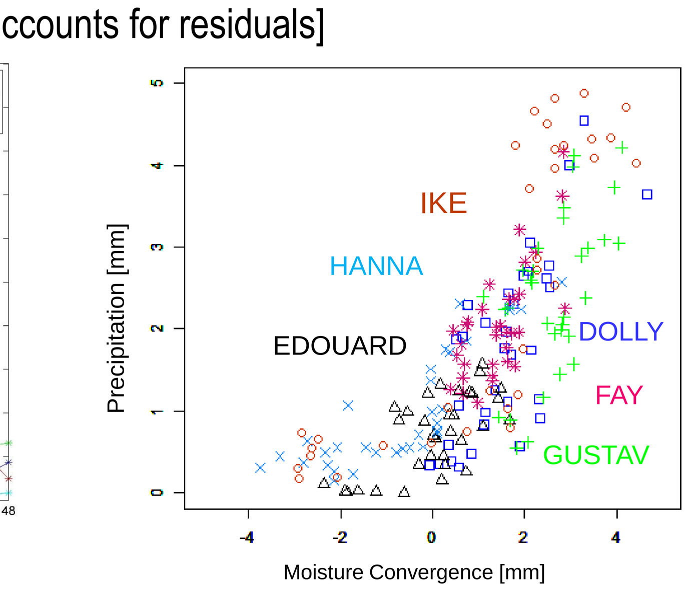

Fig 6. Scatterplot of Precipitation vs. Moisture Convergence for 2008 TCs

Results

1) The track error is frequently constrained to within 100 km, as compared with best track positions. TCs with stronger intensities (e.g. 2004 Hurricane Ivan and 2005 Hurricane Rita) have the most accurate tracks while degraded tracks occur near the domain boundary and high terrain (e.g. 1998 Hurricane Mitch).
2) Atmospheric thicknesses indicate well-developed warm cores. At landfall 12UTC Aug 29, upper tropospheric temperature anomalies of approximately 8-10°C are analyzed in Hurricane Katrina (2005) [not shown]. TCs, such as Hurricane Dolly (2008), can maintain a clear warm core temperature anomaly after landfall.
3) Consistent with previous studies (Braun 2006; Trenberth et al. 2007), moisture convergence is the dominant budget term in inner core precipitating regions of TCs, with evaporation to moisture convergence ratios of approximately 0.4-0.13. Moisture convergence is also a strong predictor of precipitation, in agreement with previous research by Jiang et al 2008.

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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