The Value of a Basin-Scale Domain to Improve Tropical Cyclone Track Forecasts in HWRF

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1. Introduction

The effort to reduce tropical cyclone (**TC**) track errors is one of the Hurricane Forecast Improvement Project (**HFIP**; Gall et al. 2013) goals, in addition to the broader mission of improving community comprehension of the fundamental and complex processes at work within a TC. One important aspect of HFIP is to improve TC forecasts made by the operational Hurricane Weather Research and Forecasting (**HWRF**) model, which is updated every year to reflect the latest research advances made by the HFIP community. The HWRF model has been a critical tool to help improve TC track forecasts.

However, even as the efforts of HFIP collaborators are integrated into each new version of HWRF, broader shortcomings have been identified with the current system. For example, the operational HWRF features an outer domain that lacks the horizontal expanse to capture critical multi-scale interactions that influence TC tracks, especially in greater lead times. In an effort to build a more robust operational HWRF system for the future, a parallel version of the HWRF model, called the basin-scale HWRF (Zhang et al. 2015, in prep.), has been developed in the AOML/HRD. The basin-scale HWRF features a large domain that covers most of the Northeast Pacific and North Atlantic basins and is capable of including several moving nests (i.e., more than one TC).

The goal of this study is to compare the track skill of the 2013 basin-scale HWRF to the track skill of the operational HWRF versions from 2013, 2014, and 2015 in order to assess the value of a basin-scale domain.

2. Model Configurations

- The versions of the operational HWRF used in this study are: 2013 operational HWRF (**H213**)
  2014 operational HWRF (**H214**)
  2015 operational HWRF (**H215**)
- The 2013 basin-scale HWRF (**H3HW**) is a simpler version of the operational HWRF system that covers close to ¼ of the Earth.
- CLIPER5 (**CLP5**) is used as a baseline to assess track skill.
- **GFS Analysis** and **NHC Best Track** are used as observations to compute model errors.

	2013 Basin-Scale HWRF	2013 Operational HWRF	2014 Operational HWRF	2015 Operational HWRF
Domain	27 KM: 178.2° × 77.6° 9 KM: 10.6° × 10.2° 3 KM: 6.1° × 5.4°	27 KM: 77.6° × 77.6° 9 KM: 11.0° × 10.0° 3 KM: 7.2° × 6.5°	27 KM: 77.6° × 77.6° 9 KM: 12.0° × 12.0° 3 KM: 7.1° × 7.1°	18 KM: 77.6° × 77.6° 6 KM: 12.7° × 12.2° 2 KM: 7.9° × 7.1°
Model top	2 hPa	50 hPa	2 hPa	2 hPa
Vertical levels	61	42	61	61
Vortex initialization	at 3 km	at 3 km	at 3 km	at 2 km
Data assimilation	No GSI DA	GSI DA	Hybrid DA	Hybrid DA HWRF ensemble DA (TDR)
Ocean coupling	No coupling	27-9 KM: Yes 3 KM: Downscaled	27-9 KM: Yes 3 KM: Downscaled	18-6 KM: Yes 2 KM: Downscaled
Multi-Storm	Yes	No	No	No
Physics Scheme				
Microphysics	Modified Ferrier (High Resolution)	Modified Ferrier (High Resolution)	Modified Ferrier (High Resolution)	Modified Ferrier-Aligo (High Resolution)
Radiation	GFDL	GFDL	GFDL	RRTMG
Surface	GFDL	GFDL	GFDL	Modified GFDL
PBL	Modified GFS	Modified GFS	Modified GFS	Modified GFS
Convection	SAS, No CP (3 KM), Shallow Convection	SAS, No CP (3 KM), Shallow Convection	SAS, No CP (3 KM), Shallow Convection	SAS, No CP (2 KM), Shallow Convection
Land surface	GFDL Slab	GFDL Slab	GFDL Slab	NOAH LSM

Table 1. Configuration and physics for the four HWRF versions analyzed in this study. In general, newer versions are to the right. Red text signifies an upgrade from the previous version.

3. Track Skill Verification

- Retrospective forecasts for each HWRF version for all Atlantic and East Pacific TCs from 2011-2013.
- Track skill is higher in Atlantic basin.
- **H3HW** produces more skillful tracks than **H213** (Fig. 1).
  - Importance of the increased vertical levels and model top (Table 1).
- **H3HW** is competitive with (or more skillful than) **H214** and **H215**.

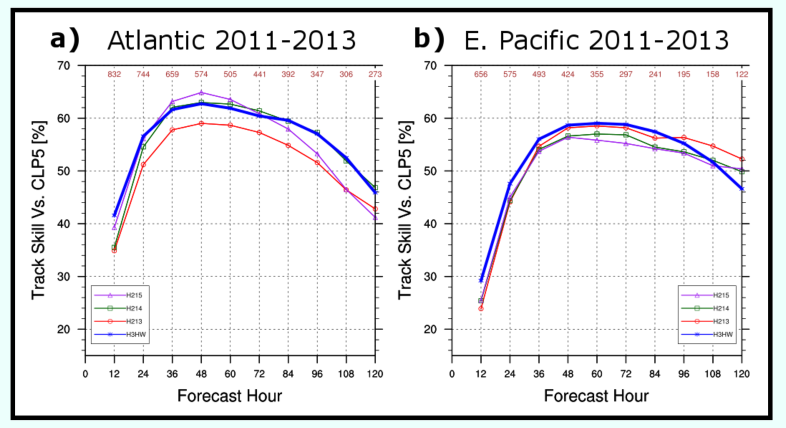

Fig. 1. Track skill scores for various HWRF models versus CLP5.

- Larger domain and multi-storm capability in **H3HW** offset **H215** upgrades:
  - e.g., horizontal resolution, model physics, data assimilation, ocean coupling.

4. Sensitivity to TC Initial Location

- The operational HWRF domain moves from one forecast cycle to the next.
- TC initial location is used a proxy for the location of the operational HWRF outer domain.
- At *24h*, **H3HW** is more skillful in the East Atlantic compared to **H213**, **H214**, and **H215**.
- At *120h*, **H3HW** is more skillful in the West Atlantic and Caribbean Sea.
  - Operational HWRF outer domain boundary is located over the Rocky Mountains.
  - This introduces mesoscale errors that may grow to the synoptic scale 3-5 days into the forecast.

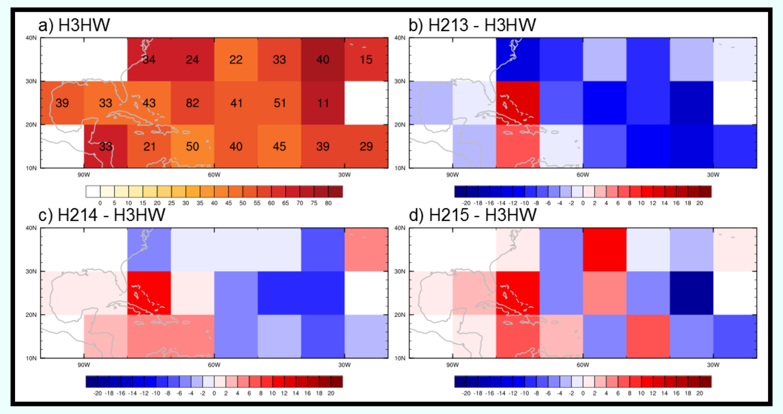

Fig. 2. a) *24h* track skill scores for **H3HW**. The number of cases is shown for each tile. b-d) 24h track skill score differences between **H3HW** and operational HWRF versions.

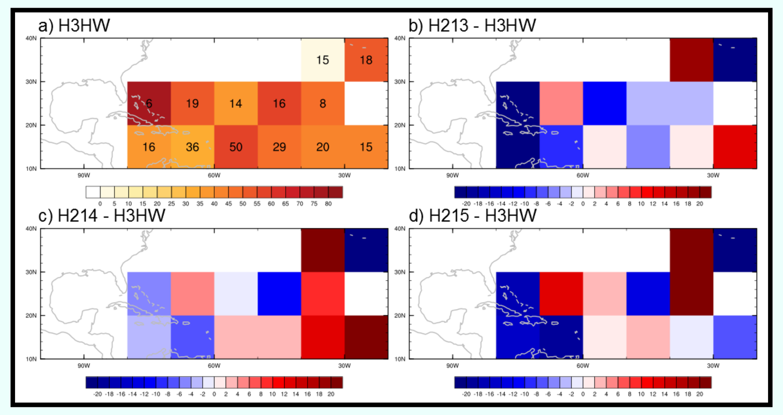

Fig. 3. As in Fig. 2, except for *120h* forecasts.

5. Isaac (2012) Case Study

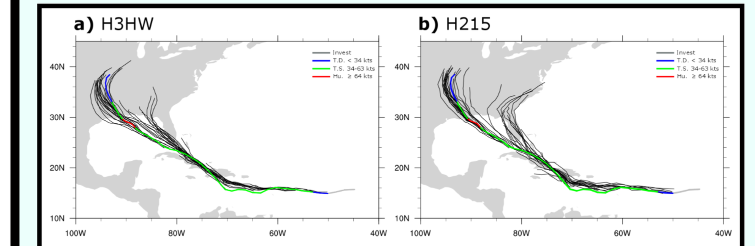

Fig. 4. The best track (multi-colored line) and all forecast tracks (black lines) of Isaac (AL092012).

- **H215** erroneously turns Isaac to the North.
- **H3HW** has smaller track errors than **H215**.

Analyzed Cycle:
12Z, 24 Aug. 2012

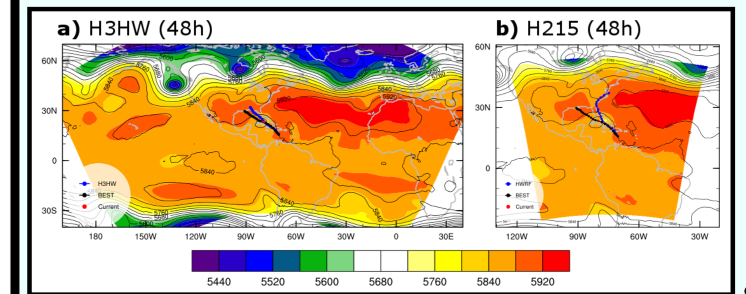

Fig. 5. Shaded fields represent 48h model forecasted 500 hPa geopotential height. Contoured fields represent the GFS Analysis 500 hPa geopotential heights at the valid time (18Z, 26 August 2012). Tracks shown are the Best Track (black), corresponding model (blue). The red dot represents the current TC position.

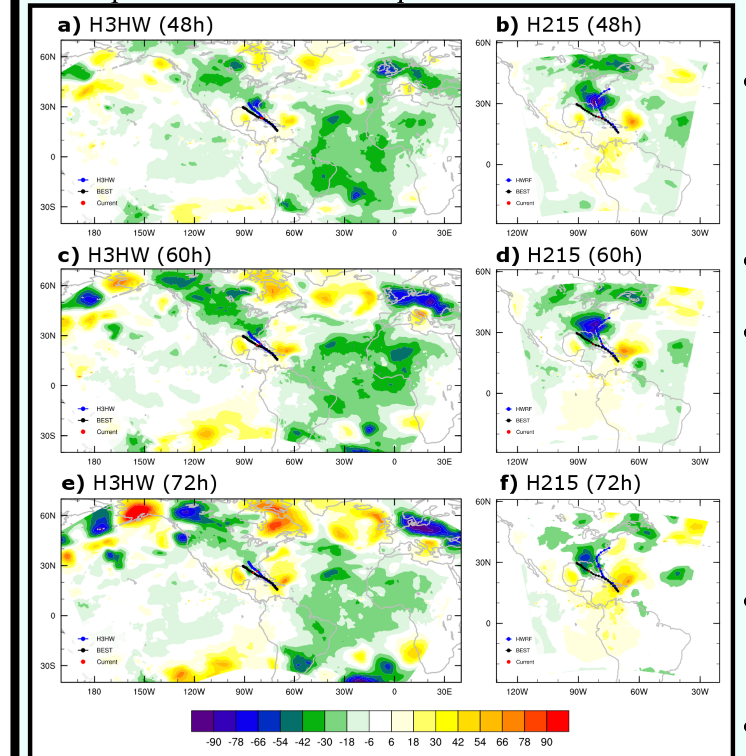

Fig. 6. As in Fig. 5, except for the difference between *48h*, *60h*, and *72h* model forecasted 200 hPa geopotential height and GFS Analysis 200 hPa geopotential heights at the corresponding valid times.

H215

- By *48h*, the U.S. East Coast trough is too strong and the central U.S. ridge is too weak.
- Isaac is steered erroneously by the U.S. East Coast trough.
- 200 hPa geopotential height errors approach -100 m north of Isaac.
- Isaac forward speed is slower.
- Errors may originate from western boundary near Rocky Mountains.

H3HW

- Much better simulation of the large-scale environment.
- Isaac is correctly steered by the central U.S. ridge and generally tracks to the WNW.

Other Cases

- Isaac tracks improve in other **H215** forecasts when flow over Rocky Mountains is resolved in the outer domain.
- Ernesto (2012) is another case with poor H215 tracks and troublesome boundary placement.

6. Land Surface Model Sensitivity

- In **H215**, the land surface model (**LSM**) is upgraded from the GFDL slab scheme to the Noah LSM.
- A similar upgrade will be present in 2015 basin-scale HWRF (**H5HW**).
- We test an identical version of **H215**, except for the LSM, which is reverted to the GFDL slab scheme (**H15G**).
- For now, we have only run a few Isaac forecast cycles. In future work, we will test the LSM sensitivity for many TCs, but that work will be performed for **H5HW**.

The track of Isaac is <u>not</u> very sensitive to choice of LSM.

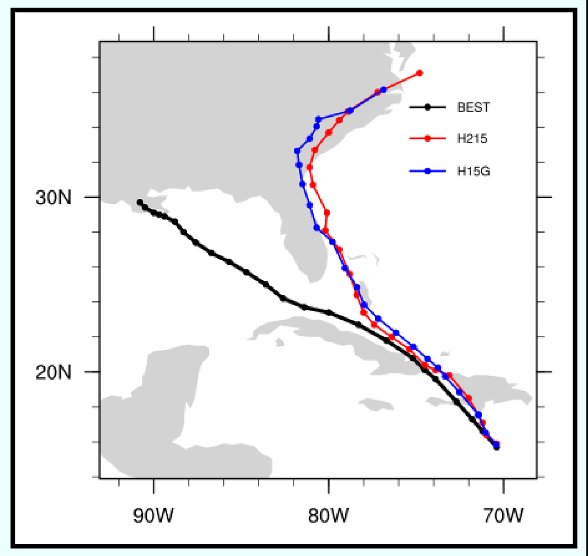

Fig. 7. Isaac track for the Best Track (black), H215 (red), and H15G (blue). The two model tracks are from a forecast cycle initiated at 12Z, 24 August 2012.

7. Conclusions

- From 2011-2013, **H3HW** is more skillful in track forecasts than **H213** and is competitive with or better than **H214** and **H215** track skill scores.
- Track skill scores for the operational HWRF versions (**H213**, **H214**, **H215**) are sensitive to the outer domain location.
- When the operational HWRF boundary is located over topography, as is the case when TCs are initialized in the Western Atlantic and Caribbean Sea, errors are introduced and track skill scores are reduced.
- Boundary-induced errors can grow to the synoptic scale, impact the mid-latitude trough-ridge pattern, and negatively influence TC tracks.
- Forecasts of the mid-latitude trough-ridge pattern improves when the flow over the Rocky Mountains is captured within the **H215** outer domain.
- TC propagation speed is an important factor for its interaction with the large-scale environment.
- **H215** exhibits weak sensitivity to LSMs. More extensive tests will be performed with the latest basin-scale HWRF (**H5HW**).

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