Representing Multi-scale Interactions in HWRF Modeling System

--Rationale of developing basin-scale modeling system

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Special Acknowledgement

- S. G. Gopalakrishnan and V. Tallapragada lead this effort on developing the basin-scale HWRF modeling system
- F. D. Marks’ thoughtful discussions and inputs
- R. Rogers & S. Murillo’s constructive reviews and comments on this talk

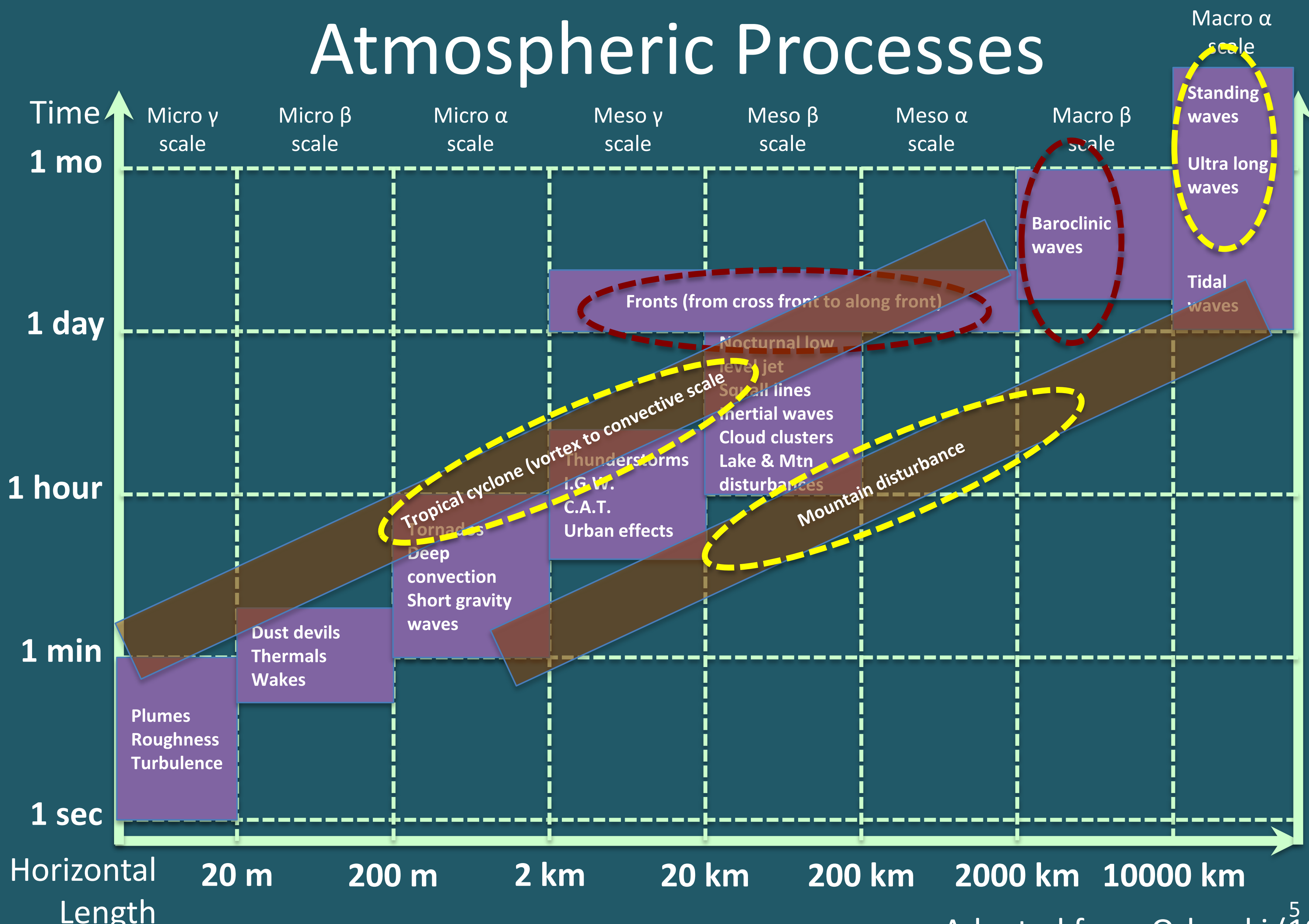
Outline

- Motivation
- Model Configuration
- Forecast Verification
- Seasonal Verification
- Forecast Applications and Further Development
- Summary

Motivation

- Preserve across-scale TC genesis, development, and landfall processes within an integrated modeling system but
  - Represent better on long wave end of scale spectrum

Horizontal-Temporal Scales of Atmospheric Processes



Adapted from Orlanski (1975)

Motivation

- Preserve across-scale on TC genesis, development, and landfall processes within an integrated modeling system but
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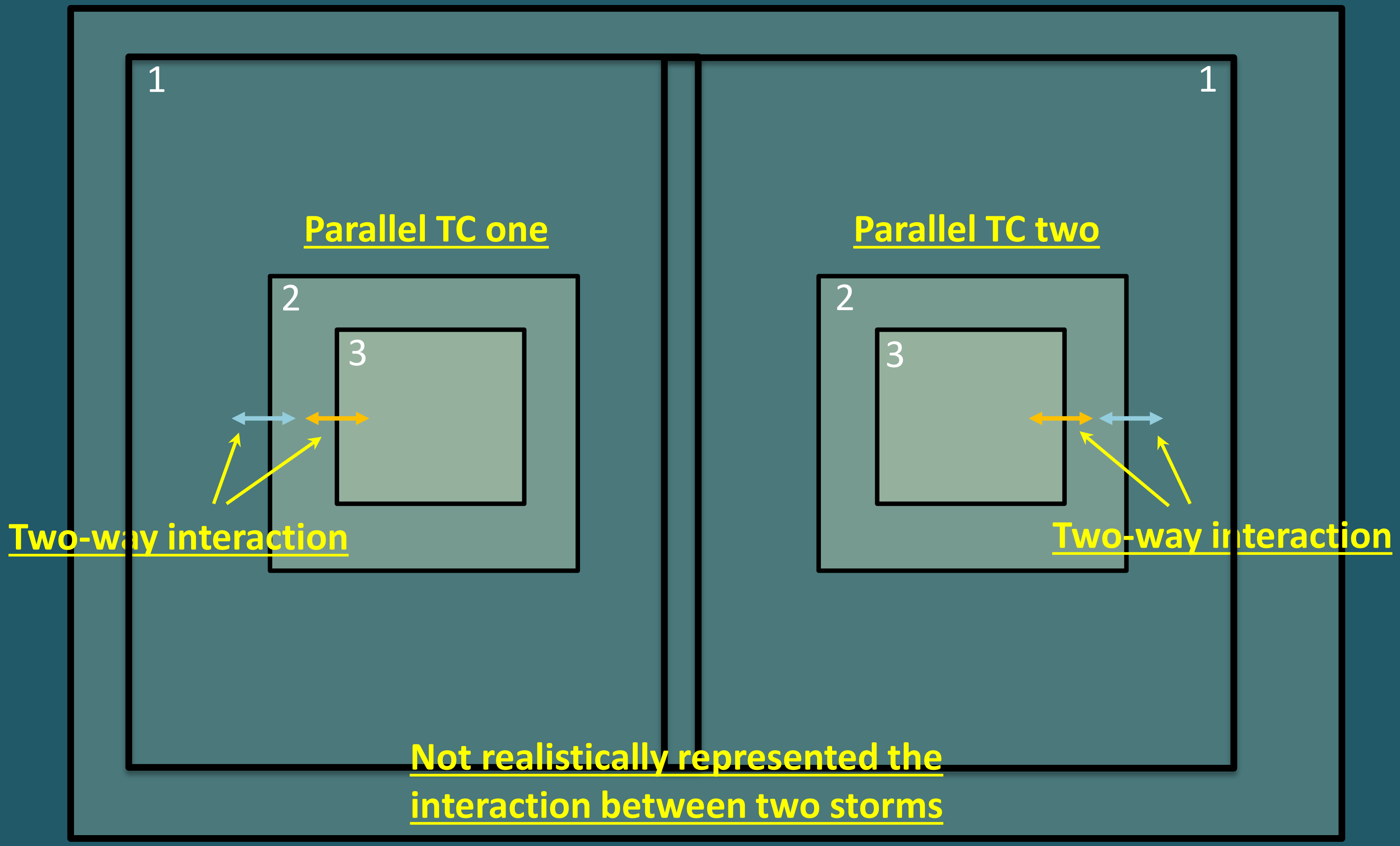
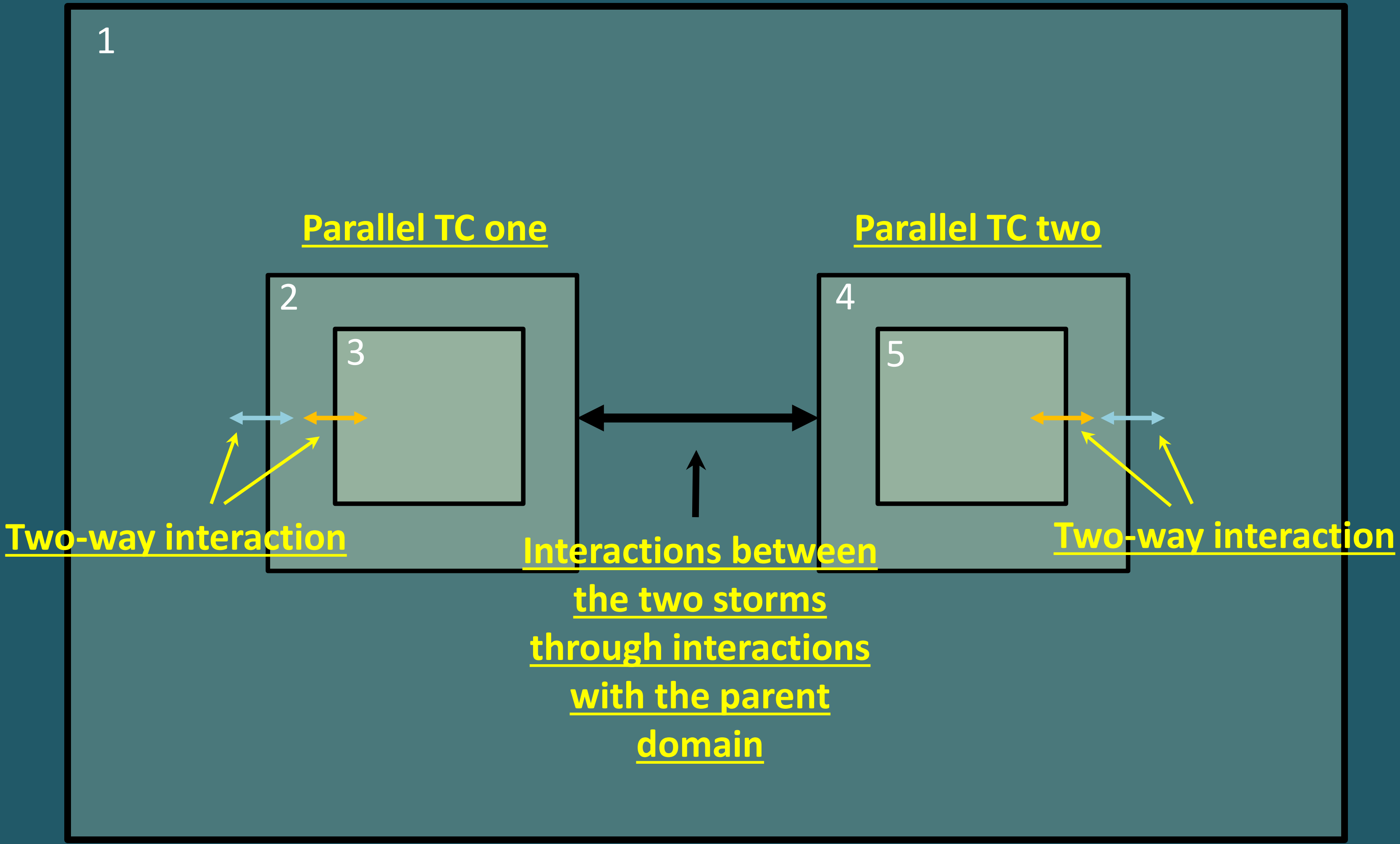
  - Study on multi-scale interactions e.g. storm-storm interaction, vertical shear on TC intensity, TC-terrain interaction, and landfall processes and QPF etc.

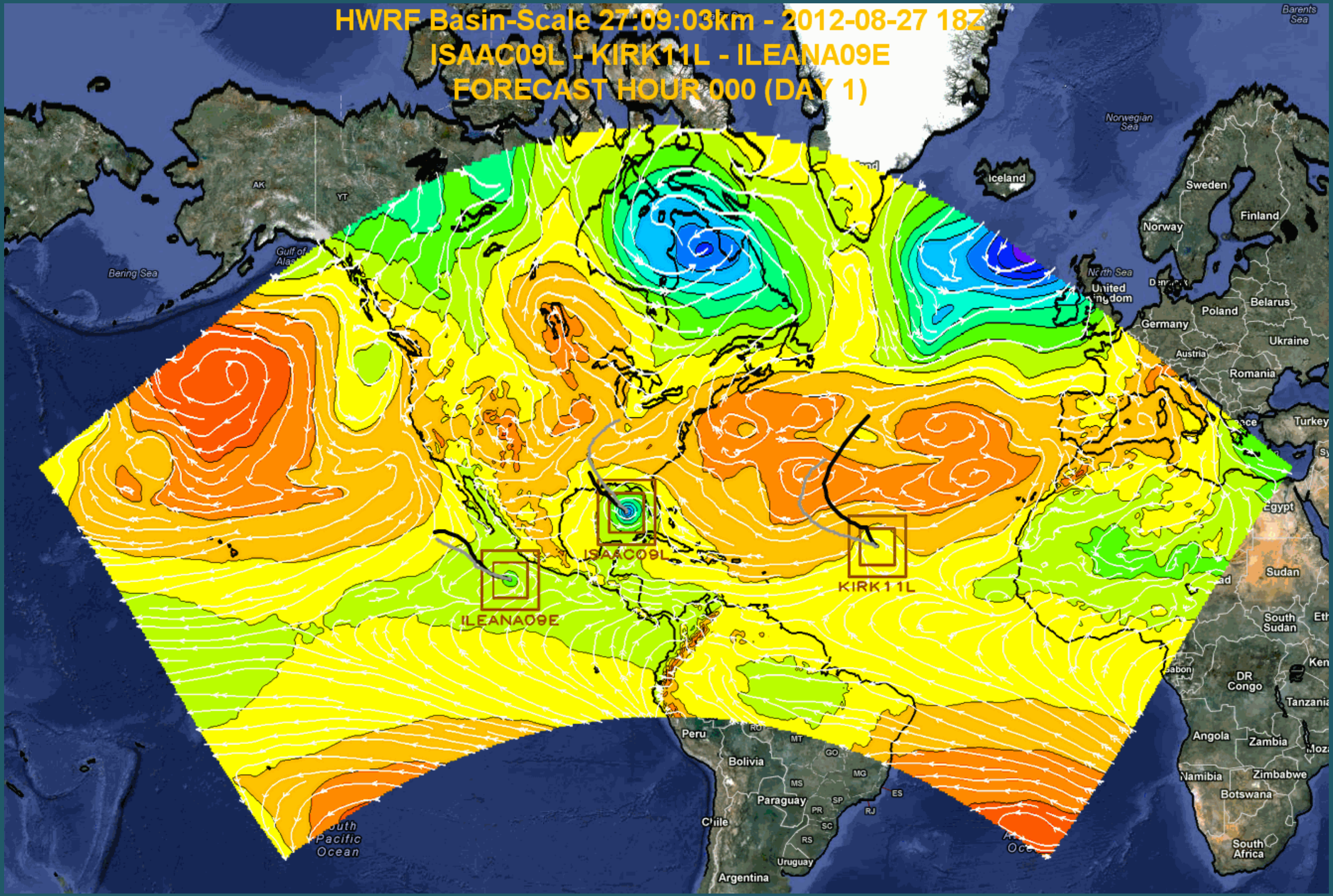
The Operational HWRF system



The basin-scale HWRF system



Multiple Movable Nests HWRF System



Isaac-Ileana-Kirk real-time 3-km predictions

Motivation

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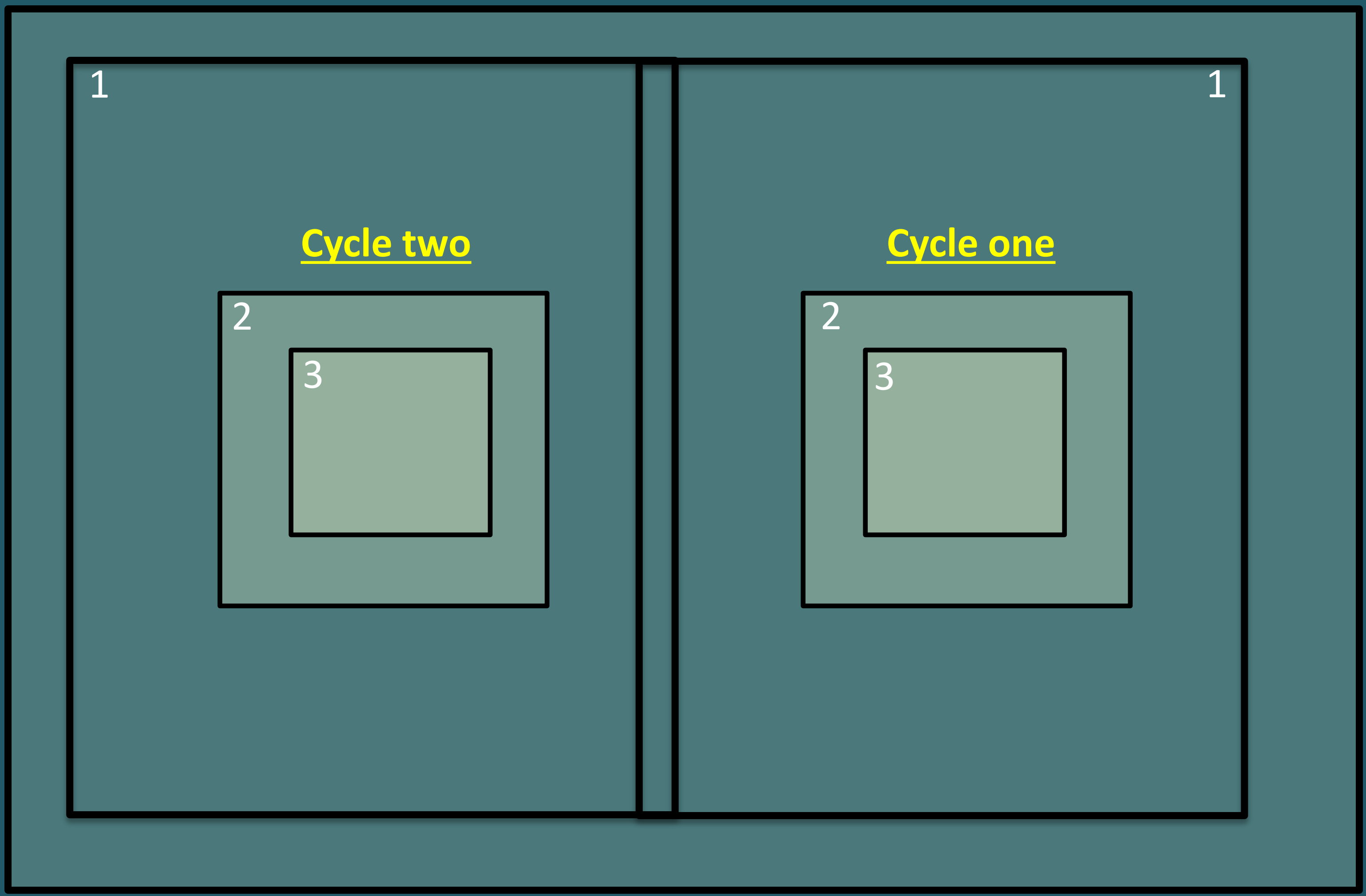
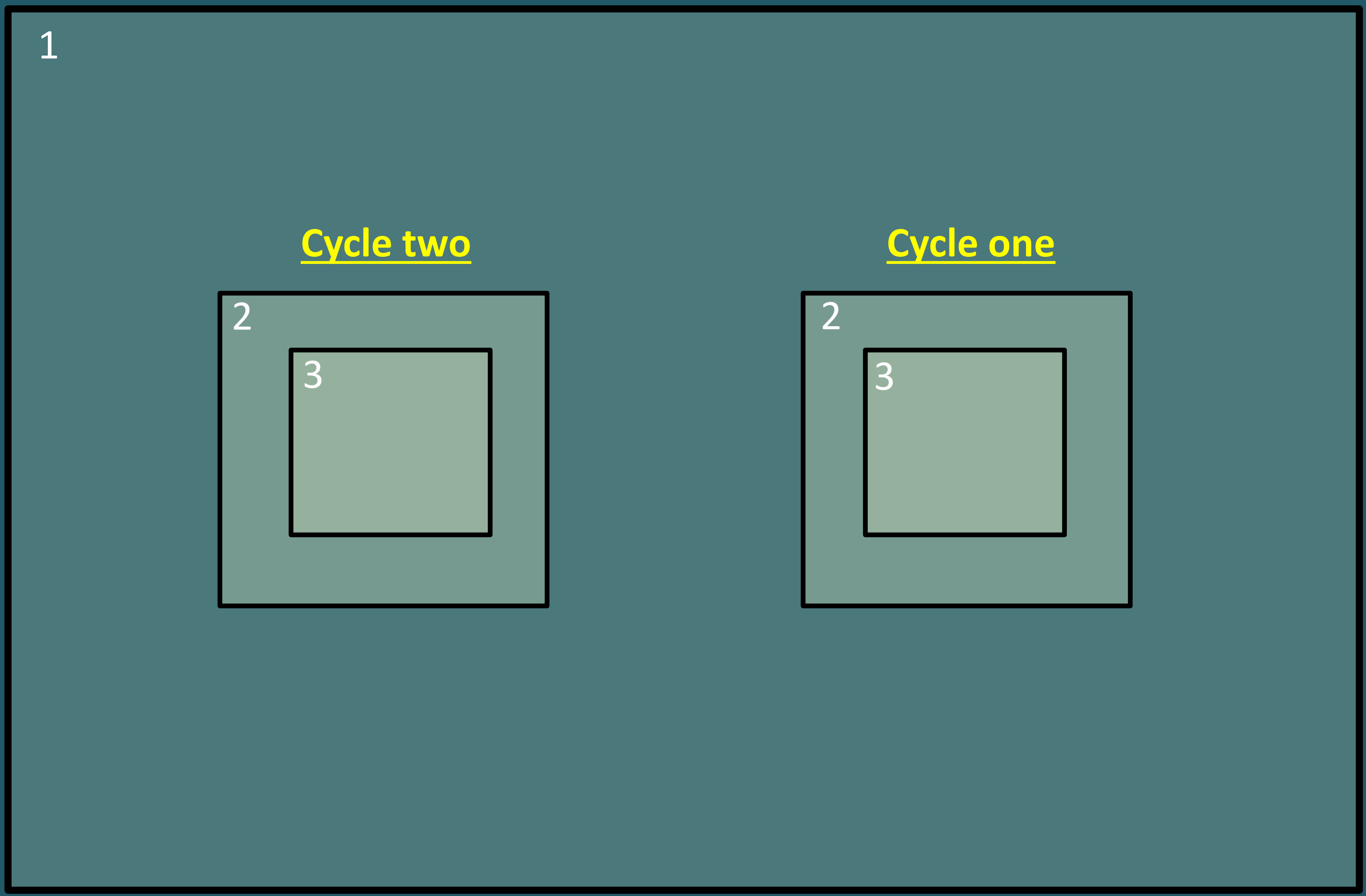
- Facilitate coherent capacity of cycling and initialization that can be utilized for testing high-resolution physics, advanced data assimilation method, ensemble forecast etc.

The Operational HWRF system



The basin-scale HWRF system



Motivation

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- Facilitate coherent capacity of cycling and initialization that can be utilized for testing high-resolution physics, advanced data assimilation method, ensemble forecast, etc.
- Quantify model bias and diagnose sources of model errors
- Tailor a tool that is operationally feasible and transferable at minimum cost
- Experiment global to convective scale next generation hurricane forecast model

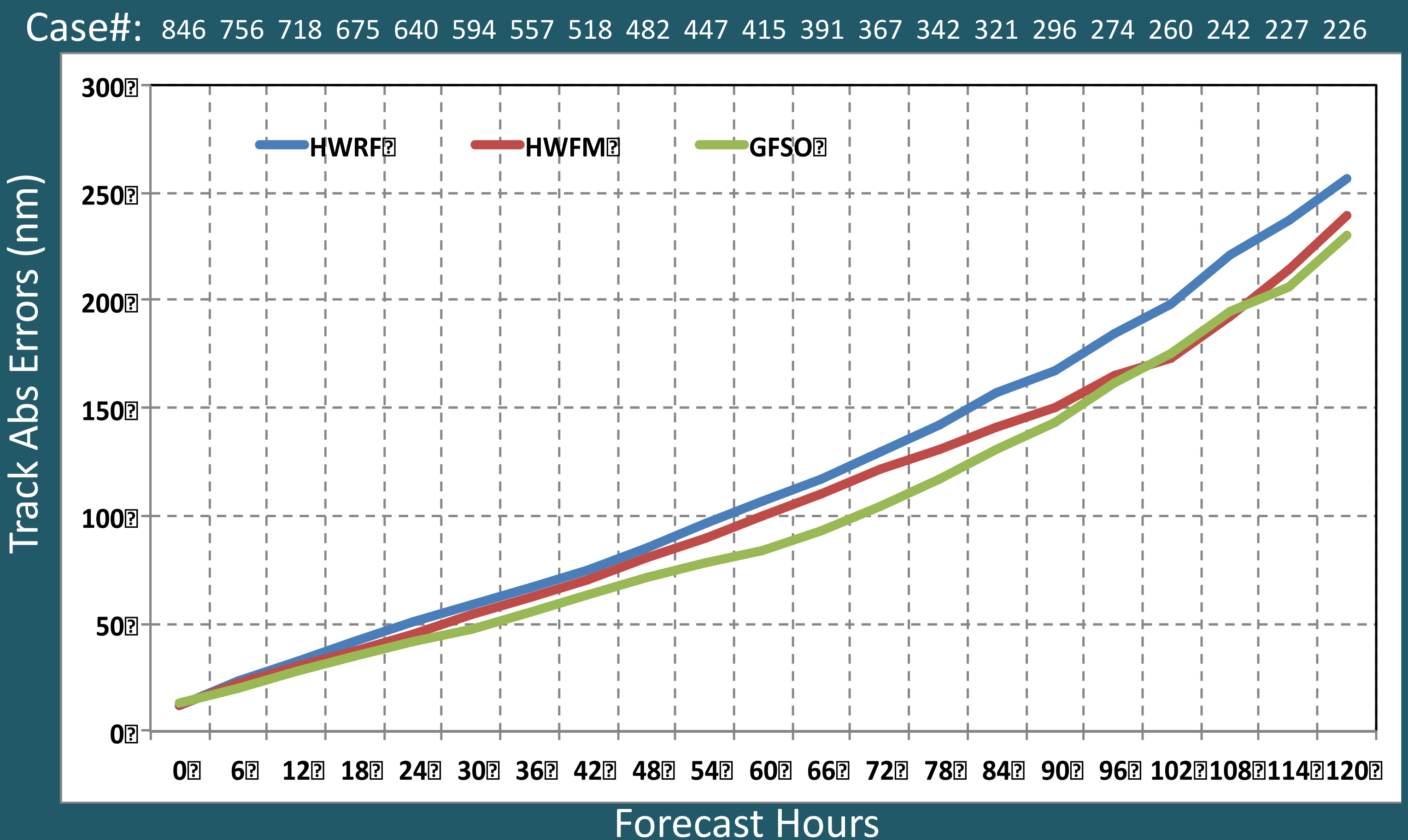
Basin-wide HWRF Configurations

	2013 Operational HWRF	Basin-wide HWRF
Domain	27 KM: 77.76˚ X 77.76˚ 9 KM: 10.56˚ X 10.2˚ 3 KM: 6.12˚ X 5.42˚	27 KM: 178.20˚ X 77.58˚ 9 KM: 10.56˚ X 10.2˚ 3 KM: 6.12˚ X 5.42˚
Vertical Levels and Model Top	42 levels 50hPa	61 levels 2hPa
Vortex Initialization	Modified Vortex Initialization at 3 KM and One-way Hybrid DA	Modified Vortex Initialization at 3 KM
Cycling	Yes (9-3 km vortex only)	Yes (cycle 9-3 km vortex each storm)
Ocean Coupling	27-9 KM: Yes 3 KM: No, Downscaled	No
Physics schemes		
Microphysics	Modified Ferrier (High-Res)	**Modified Ferrier (High-Res)**
Radiation	GFDL	**GFDL**
Surface	GFDL (High_res)	**GFDL (High-res)**
PBL Scheme	2012 GFS (High_res)	**2012 GFS (High-res)**
Convection	SAS (High-Res), No CP (3 KM), Shallow Convection	**SAS (High-Res), No CP (3 KM), Shallow Convection**
Land Surface	GFDL Slab	**GFDL Slab**

Important notes

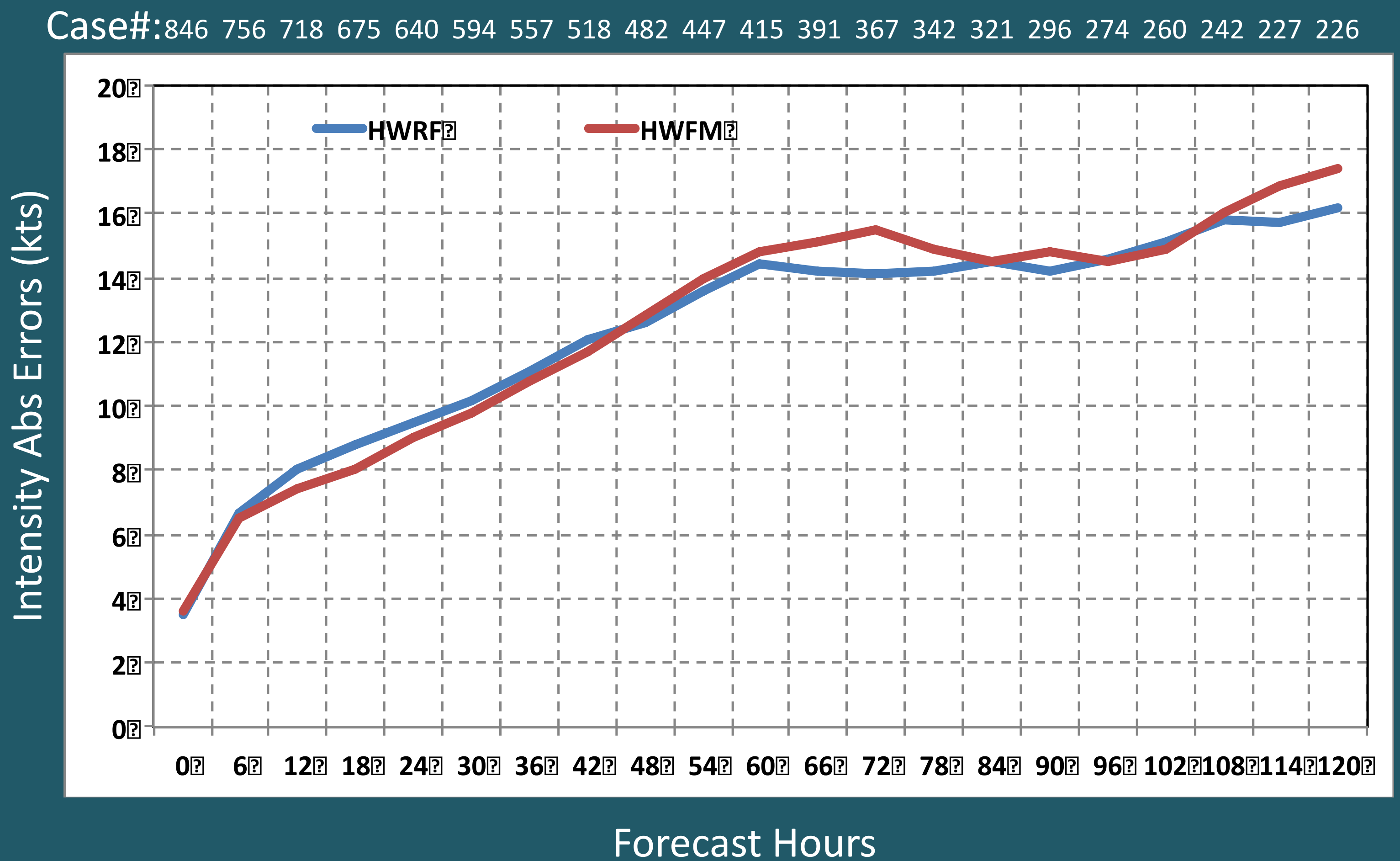
- Three hurricane seasons: 2011-13
- HWRF ATCF files for 2011-12 seasons from EMC H131
- HWRF ATCF files for 2013 season from NHC ftp site
- Storms Andrea & Barry were not verified because of HWRF upgrade on July 2, 2013

Atlantic Basin 2011-13



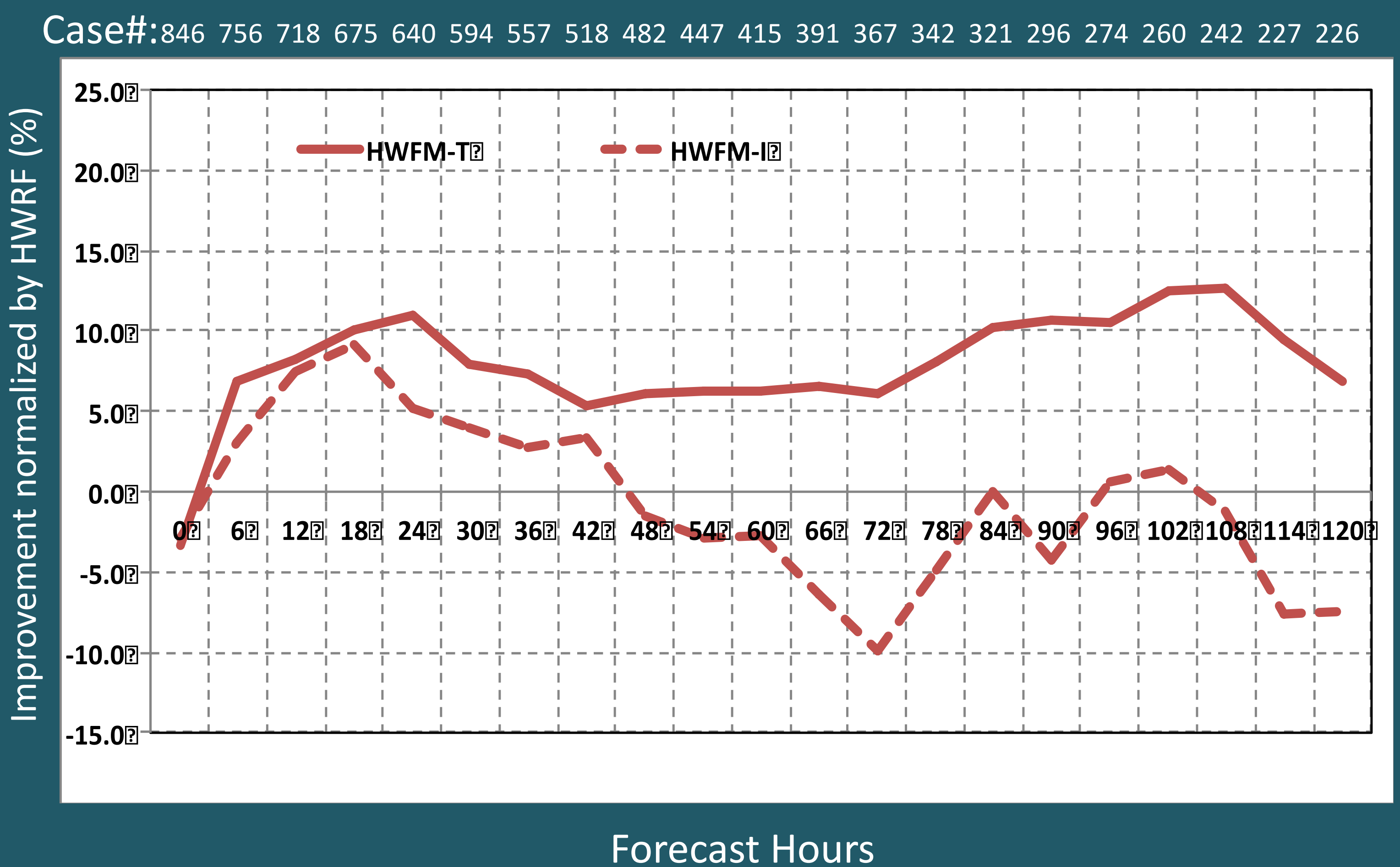
Track Verification

Atlantic Basin 2011-13



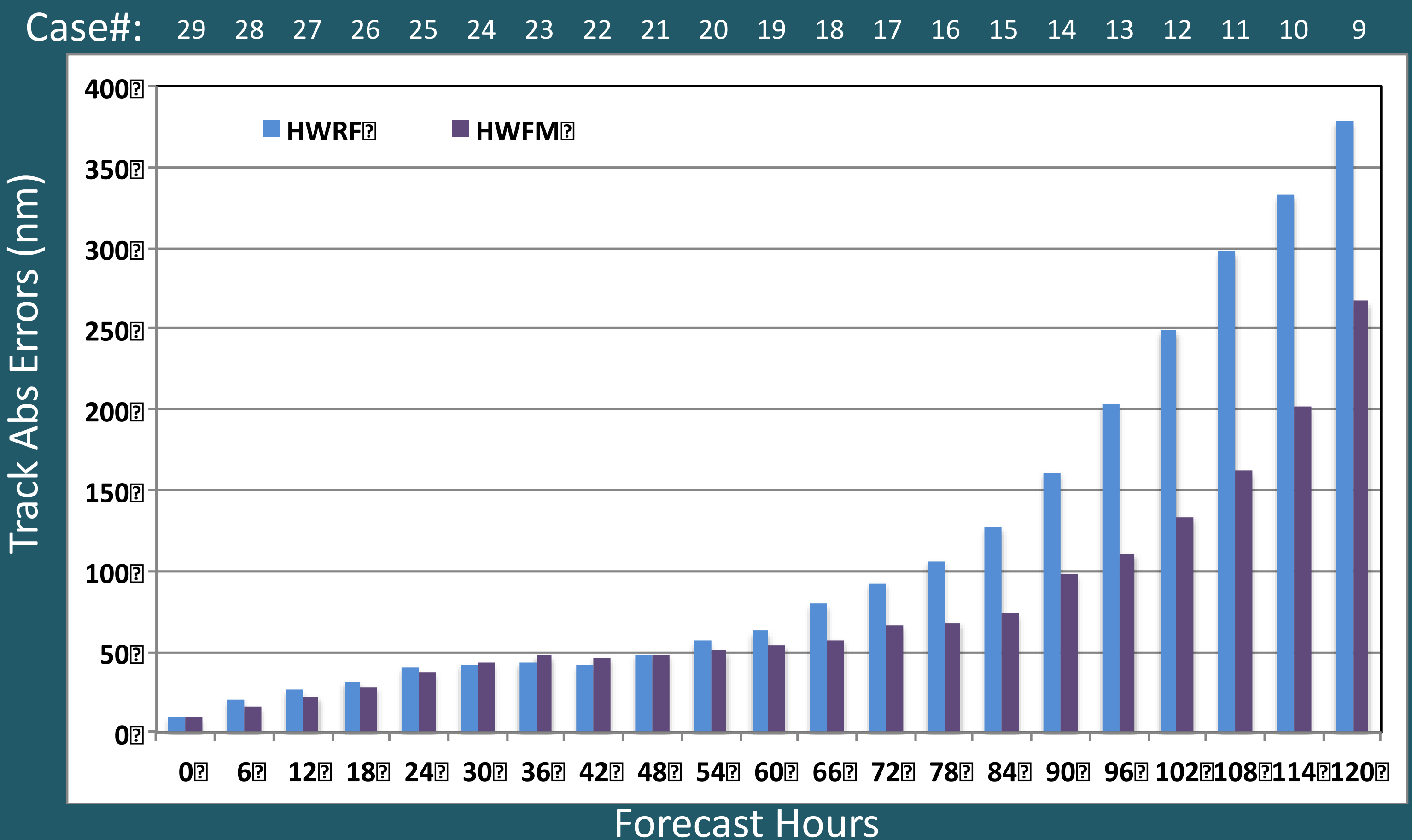
Intensity Verification

Atlantic Basin 2011-13



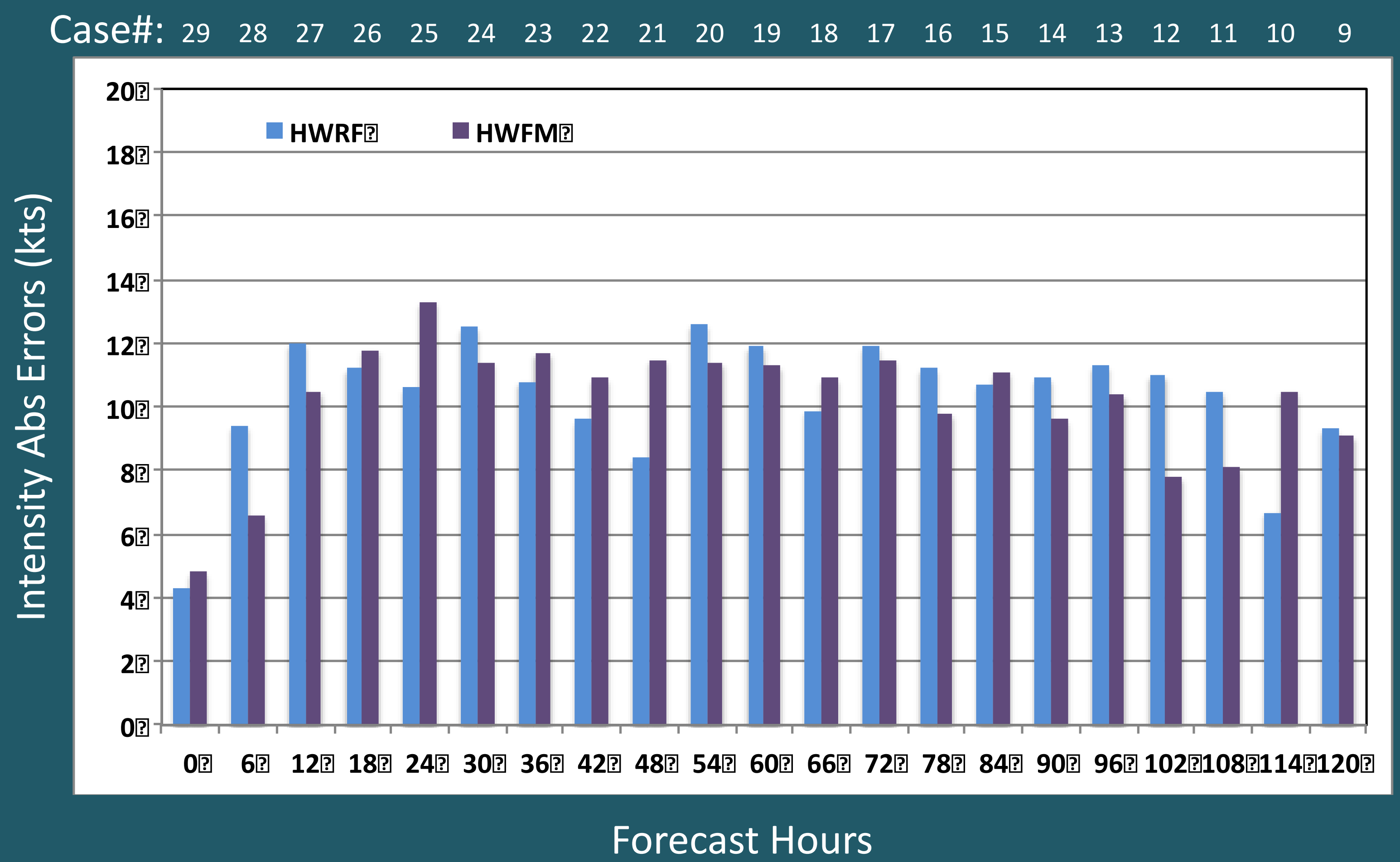
Intensity Verification

Hurricane Sandy



Track Verification

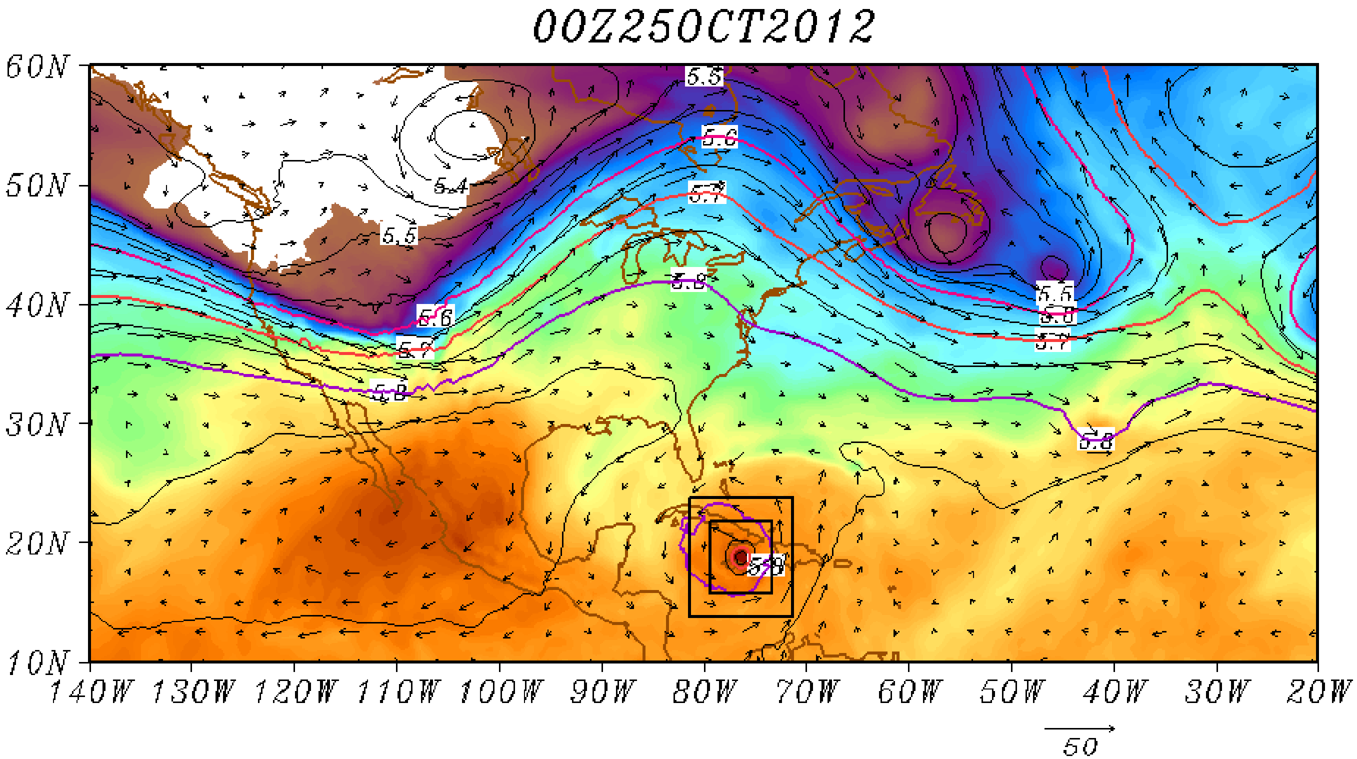
Hurricane Sandy



Intensity Verification

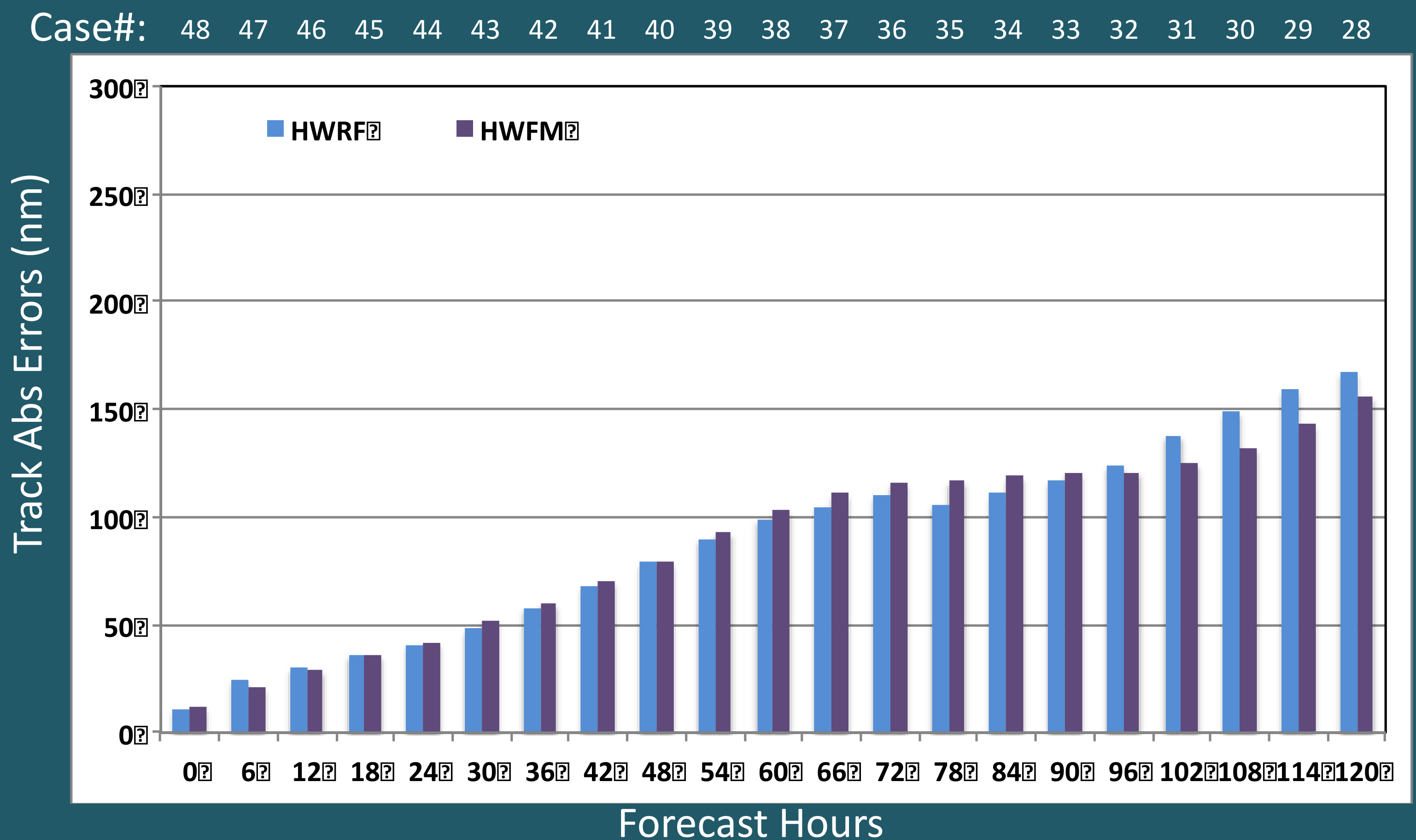
BASIN SCALE HWRF: HURRICANE SANDY

Improved Multi-scale Interactions and Improved Track and Size Forecasts (Initial at 00Z Oct. 25, 2012)



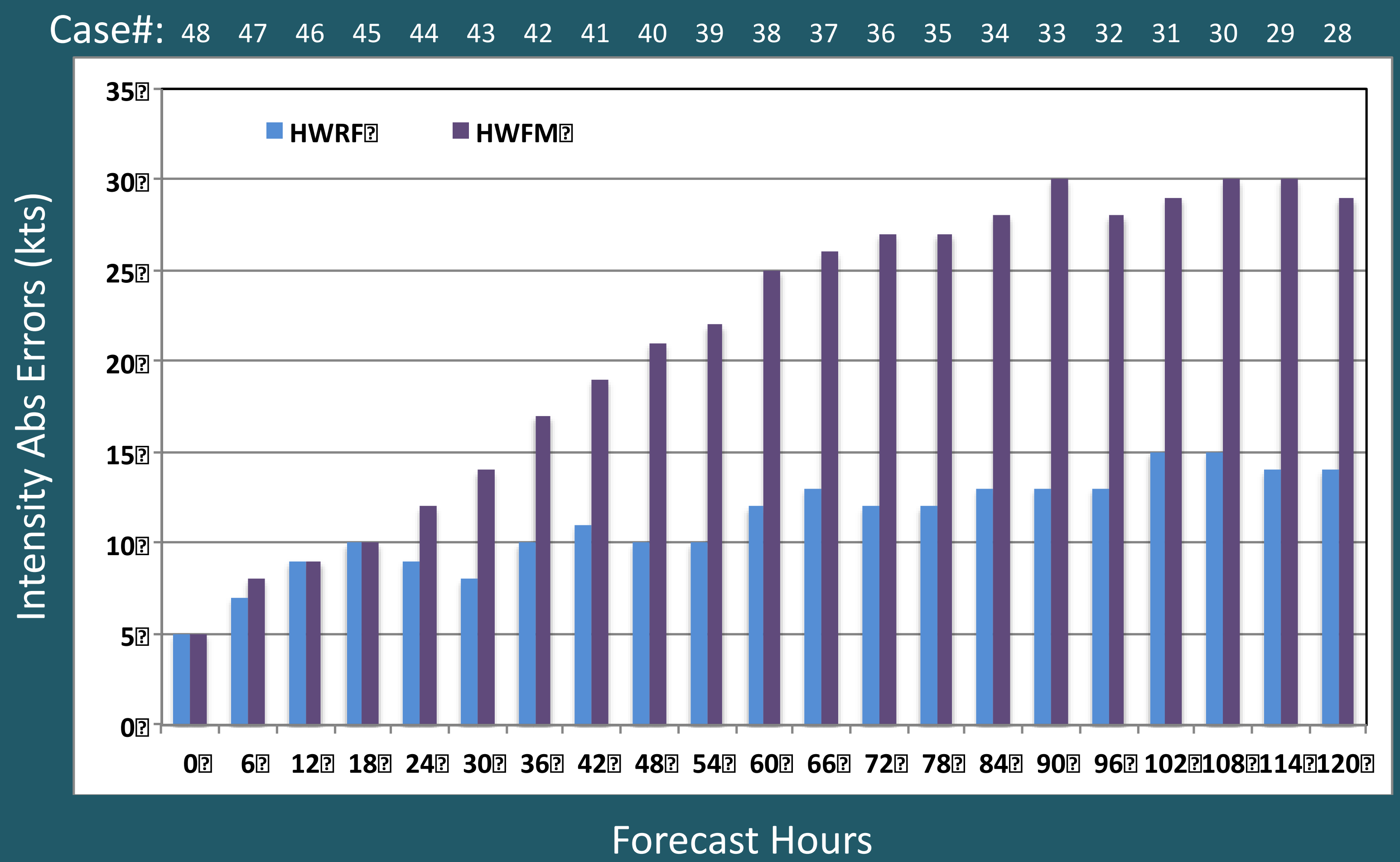
Shading: T at 500 hPa; Contour: GHT at 500 hPa Vector: Flow averaged between 500 hPa and 200 hPa (credits to Dr.Hua Chen, AOML/HRD)

Hurricane Leslie



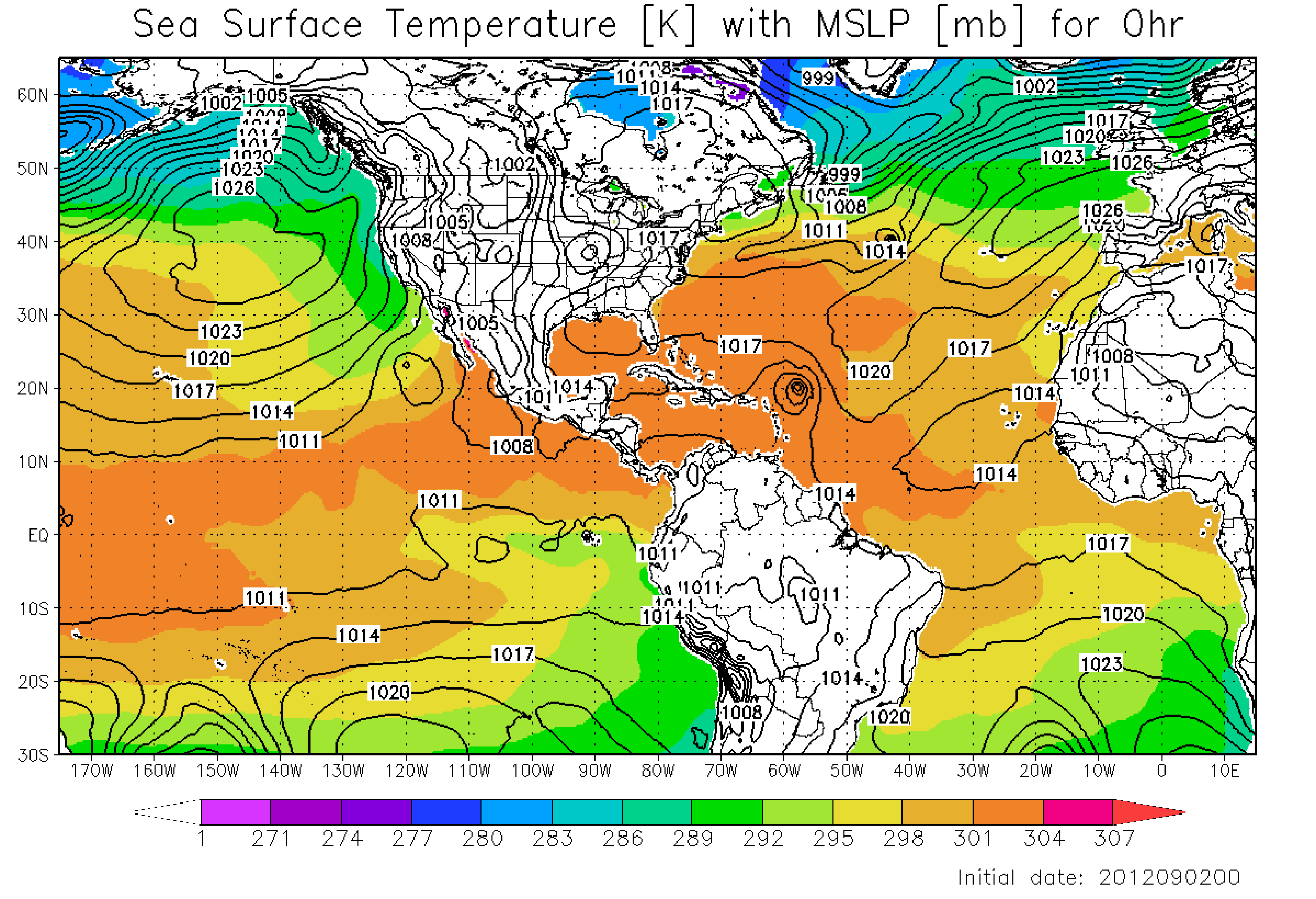
Track Verification

Hurricane Leslie



Intensity Verification

Experimental Product

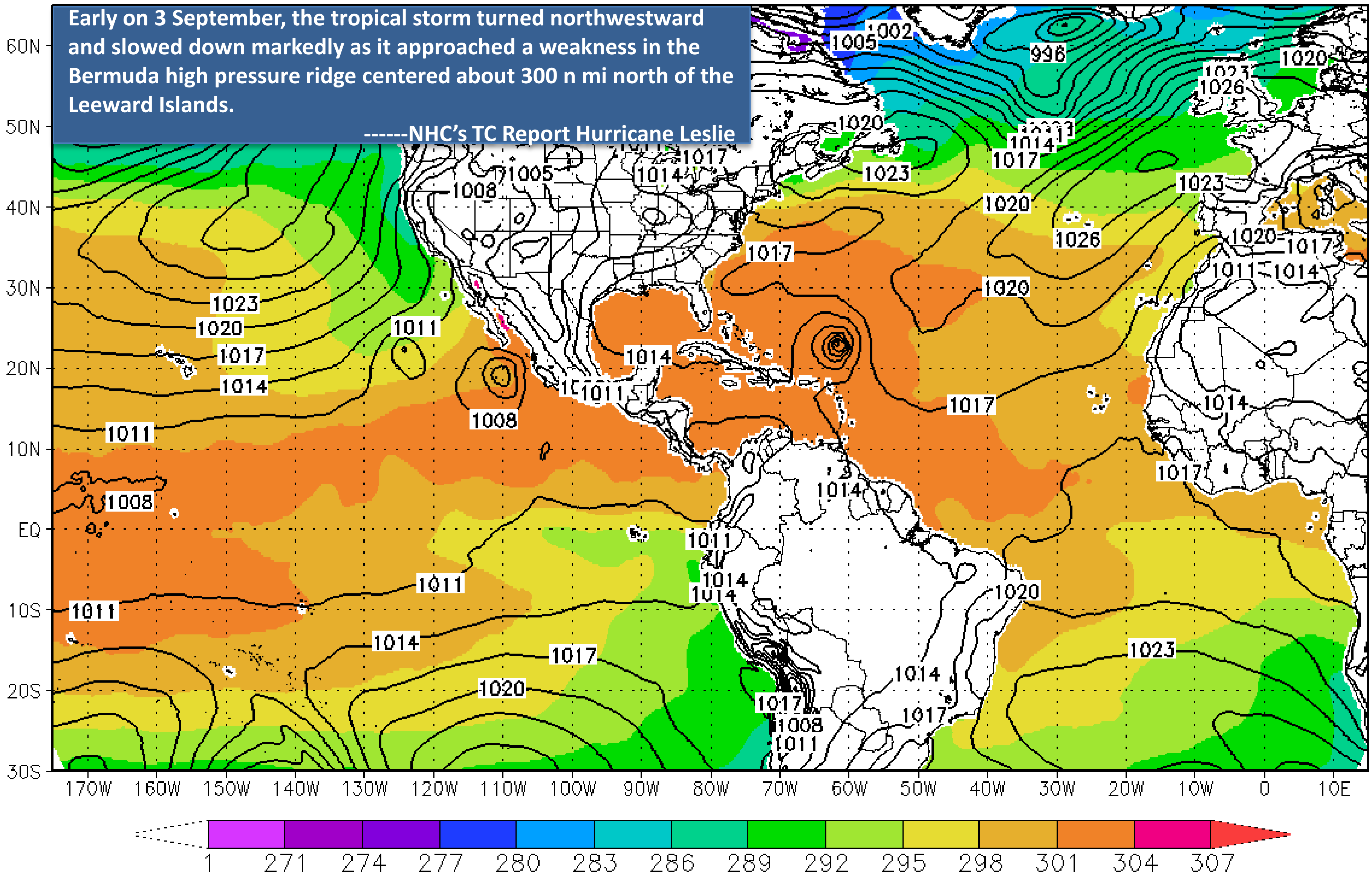


Experimental Product

Sea Surface Temperature [K] with MSLP [mb] for 0hr

Early on 3 September, the tropical storm turned northwestward and slowed down markedly as it approached a weakness in the Bermuda high pressure ridge centered about 300 n mi north of the Leeward Islands.

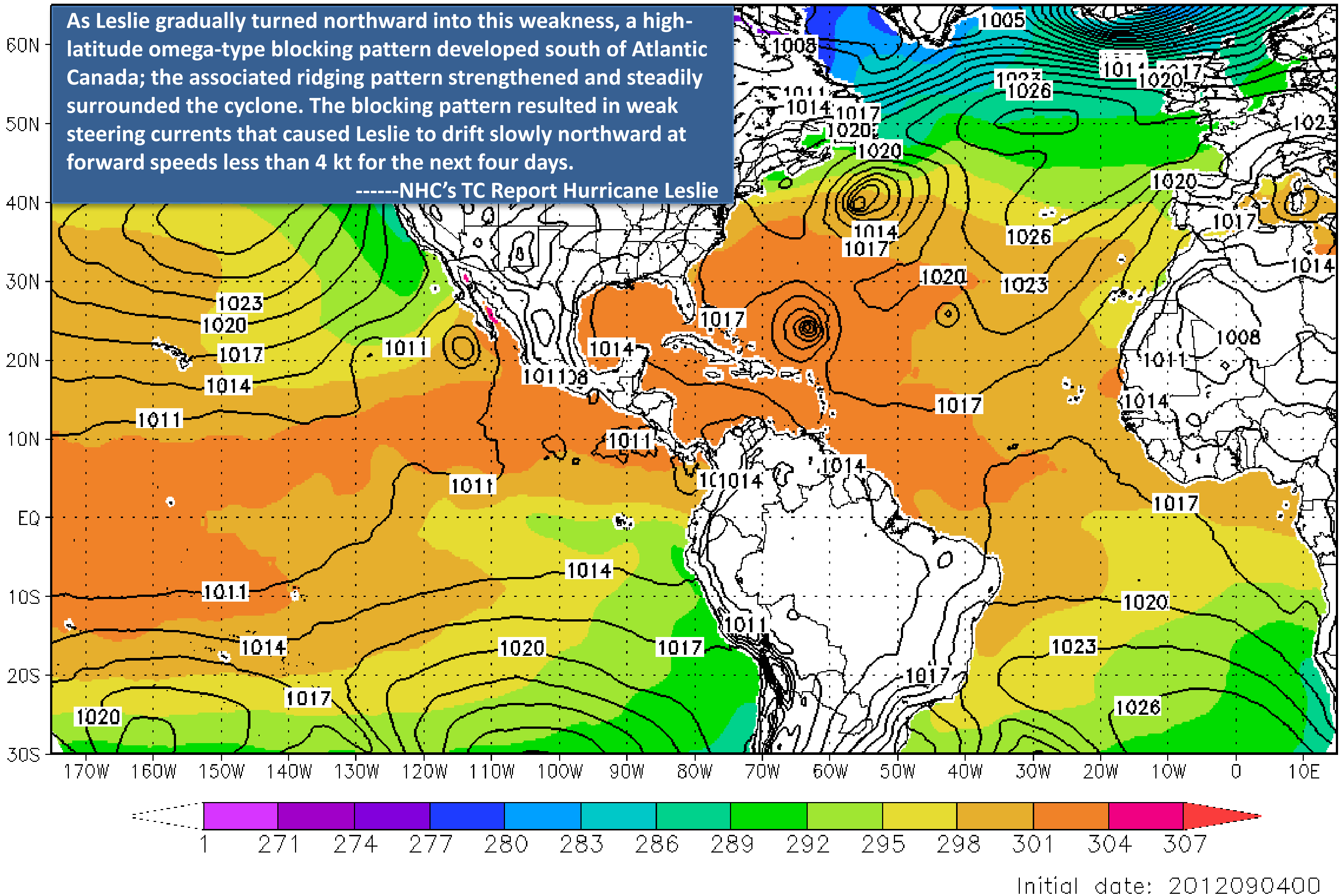
------NHC's TC Report Hurricane Leslie



Initial date: 2012090300

Experimental Product

Sea Surface Temperature [K] with MSLP [mb] for 0hr



As Leslie gradually turned northward into this weakness, a high-latitude omega-type blocking pattern developed south of Atlantic Canada; the associated ridging pattern strengthened and steadily surrounded the cyclone. The blocking pattern resulted in weak steering currents that caused Leslie to drift slowly northward at forward speeds less than 4 kt for the next four days.

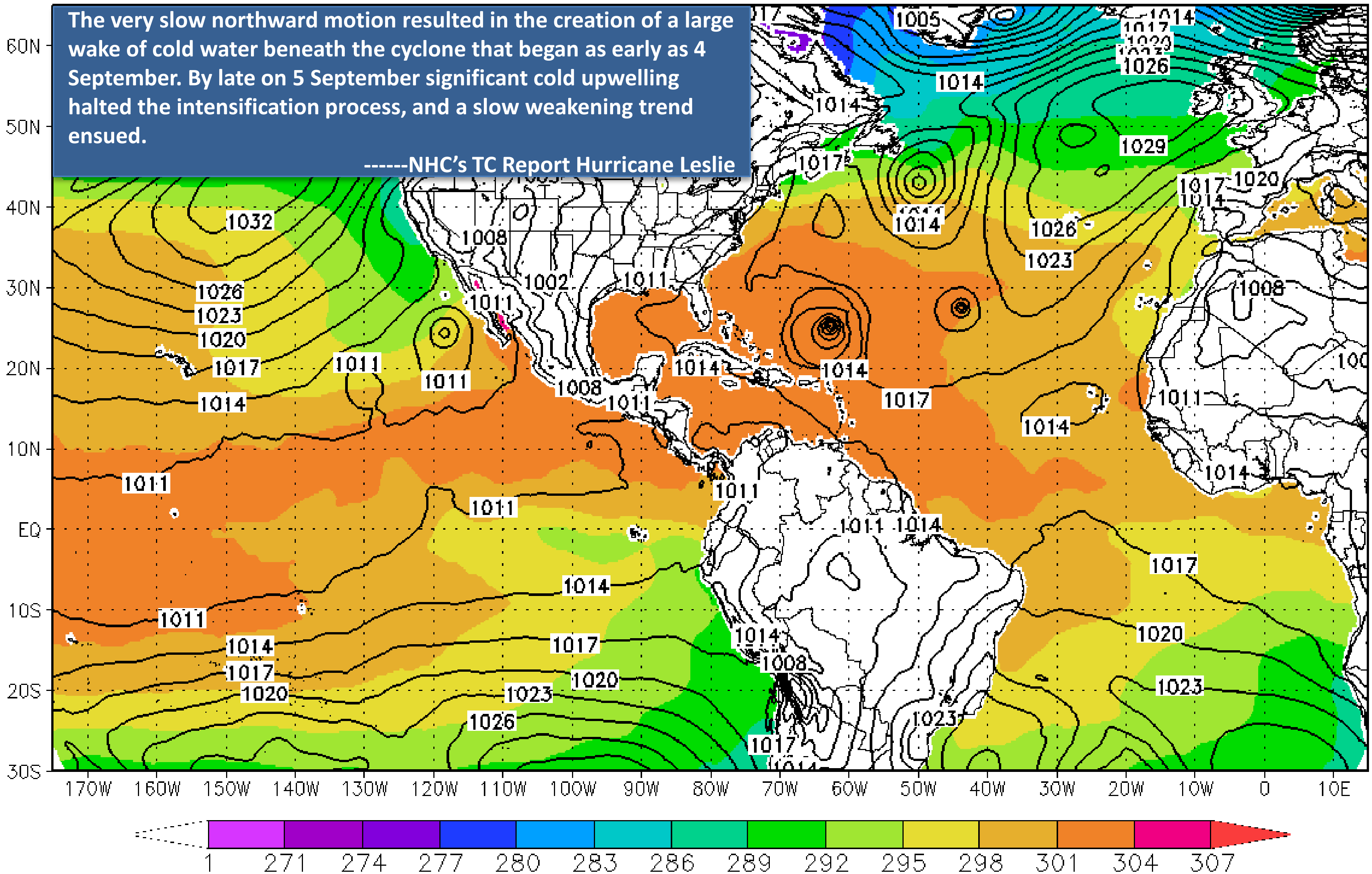
------NHC's TC Report Hurricane Leslie

Experimental Product

Sea Surface Temperature [K] with MSLP [mb] for 0hr

The very slow northward motion resulted in the creation of a large wake of cold water beneath the cyclone that began as early as 4 September. By late on 5 September significant cold upwelling halted the intensification process, and a slow weakening trend ensued.

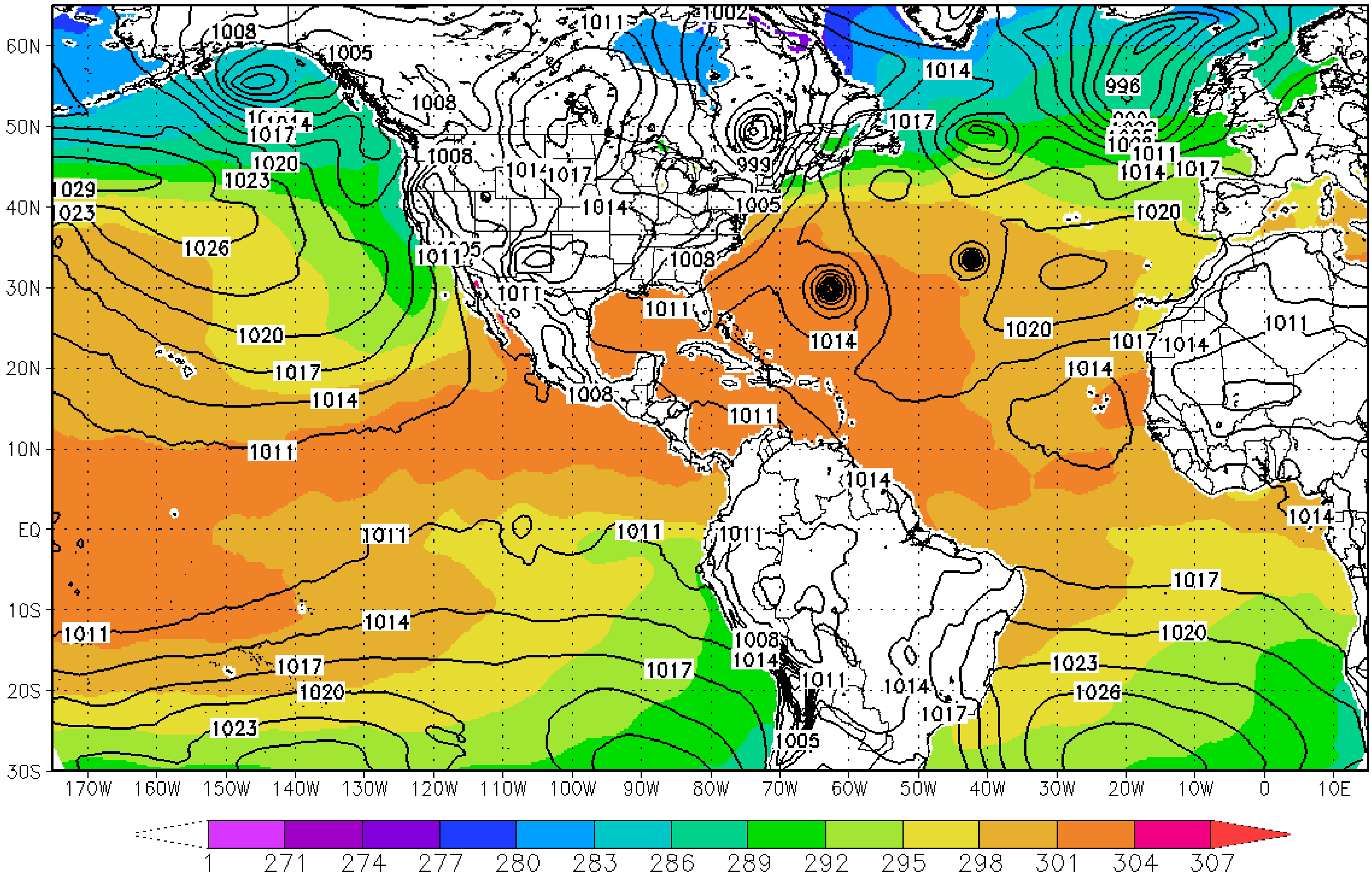
------NHC's TC Report Hurricane Leslie



Initial date: 2012090500

Experimental Product

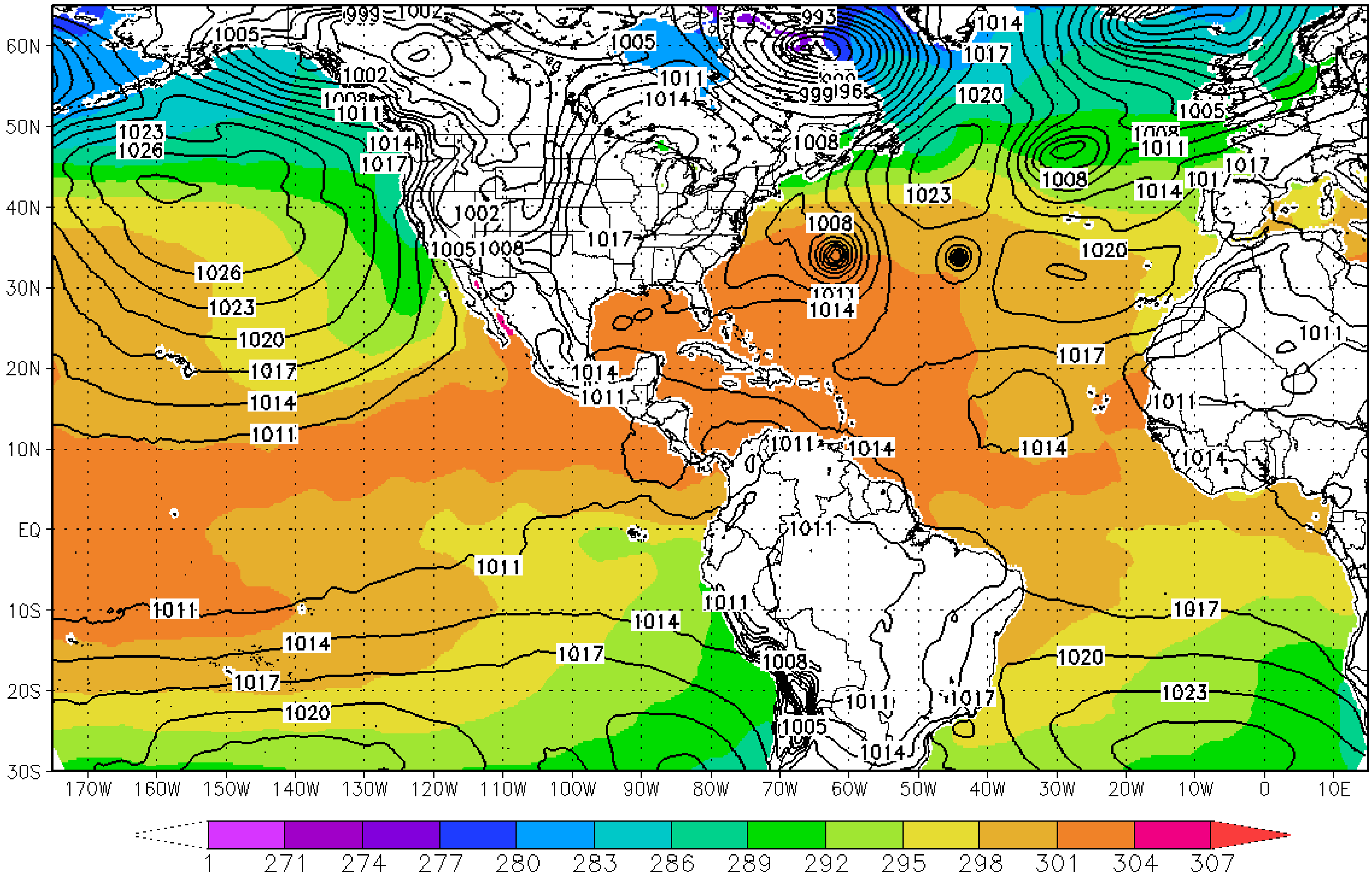
Sea Surface Temperature [K] with MSLP [mb] for 0hr



Initial date: 2012090900

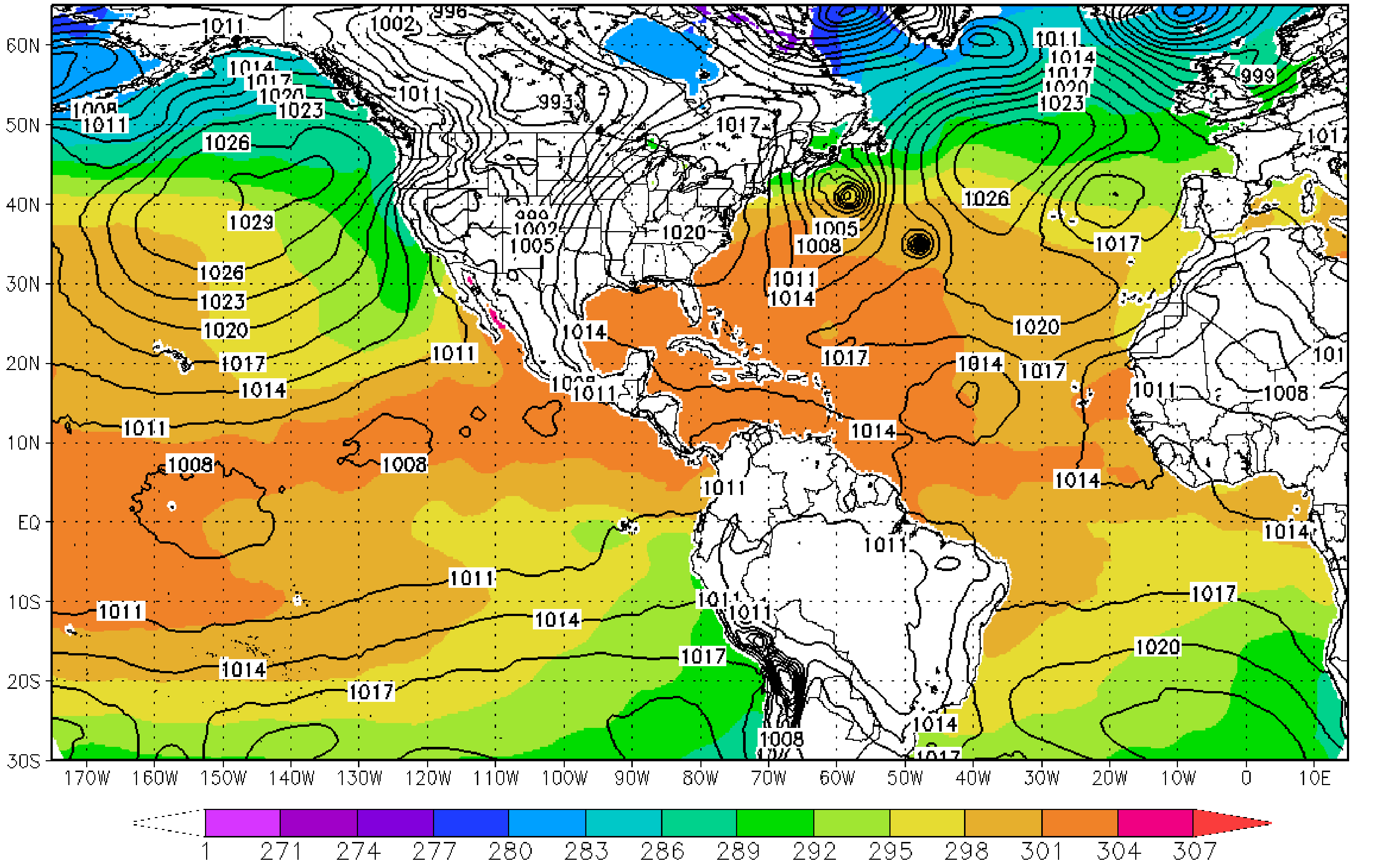
Experimental Product

Sea Surface Temperature [K] with MSLP [mb] for 0hr



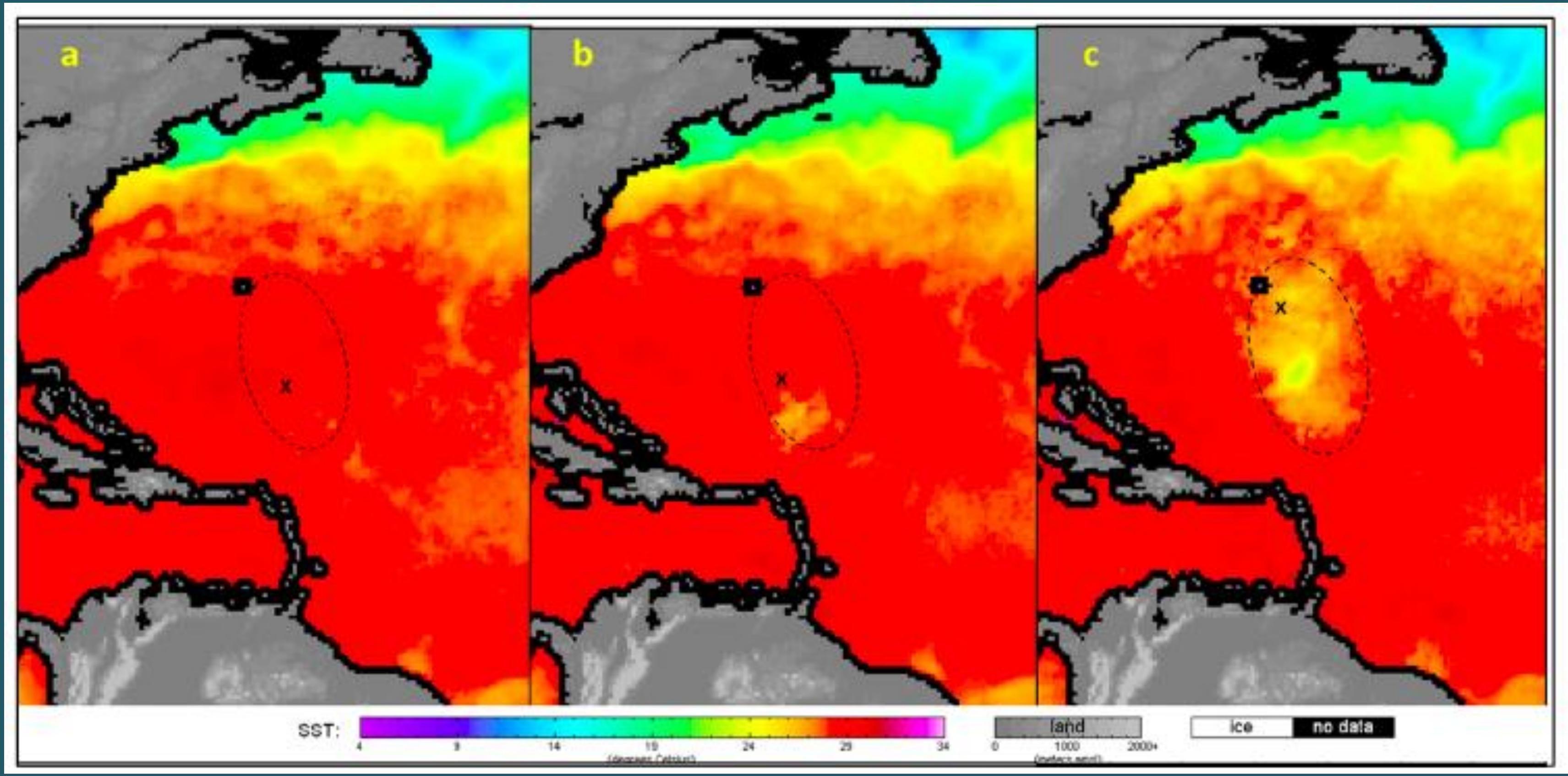
Initial date: 2012091000

Sea Surface Temperature [K] with MSLP [mb] for 0hr



Initial date: 2012091100

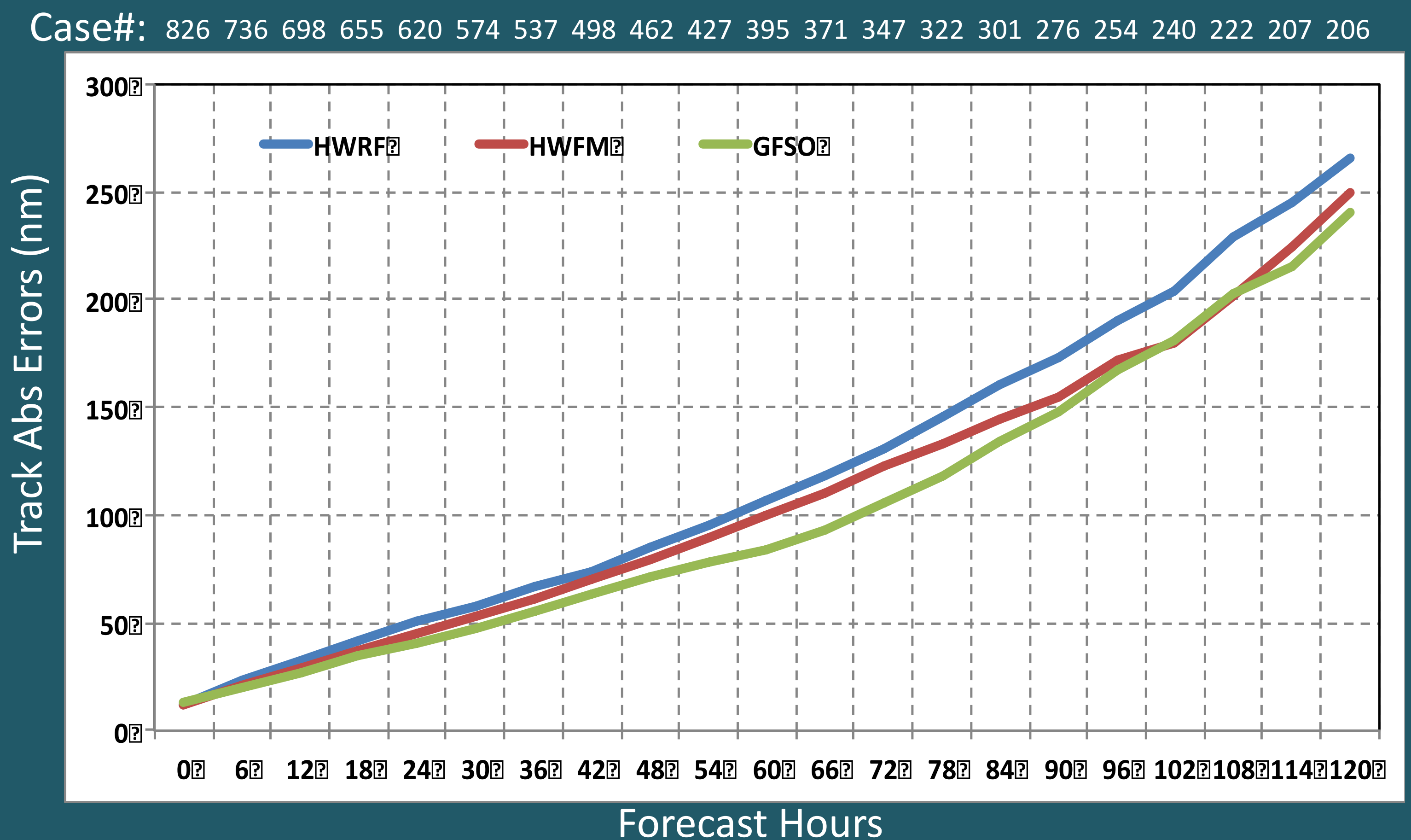
Observed SST



Atlantic microwave sea-surface temperature analyses -- (a) 1200 UTC 3 September 2012 before Hurricane Leslie slowed down to the southeast of Bermuda and began to generate cold upwelling; SST values greater than 29o C were present inside the dashed lined area; (b) 1200 UTC 4 September 2012 when slow-moving Hurricane Leslie began to produce cold upwelling along the storm track; (c) 1200 UTC 9 September 2012 after slow northward-moving Hurricane Leslie had generated significant cold upwelling with minimum SST values less than 23o C. Black "X" marks the location of Leslie at the time of the SST analysis. (images courtesy of Remote Sensing Systems, Santa Rosa, CA)

Stewart, TCP-Hurricane Leslie 2013)

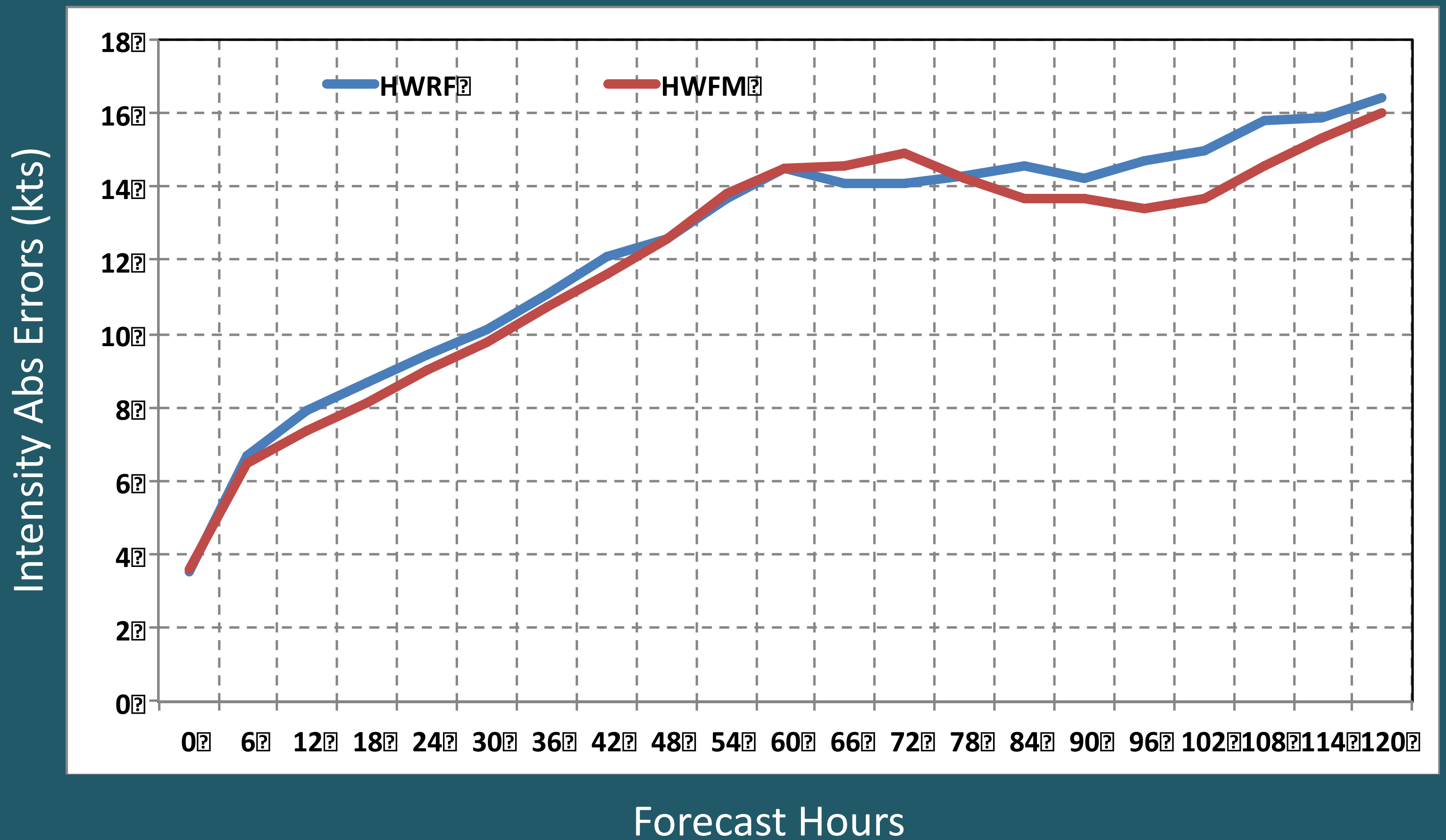
Atlantic Basin 2011-13 w/o Leslie



Track Verification

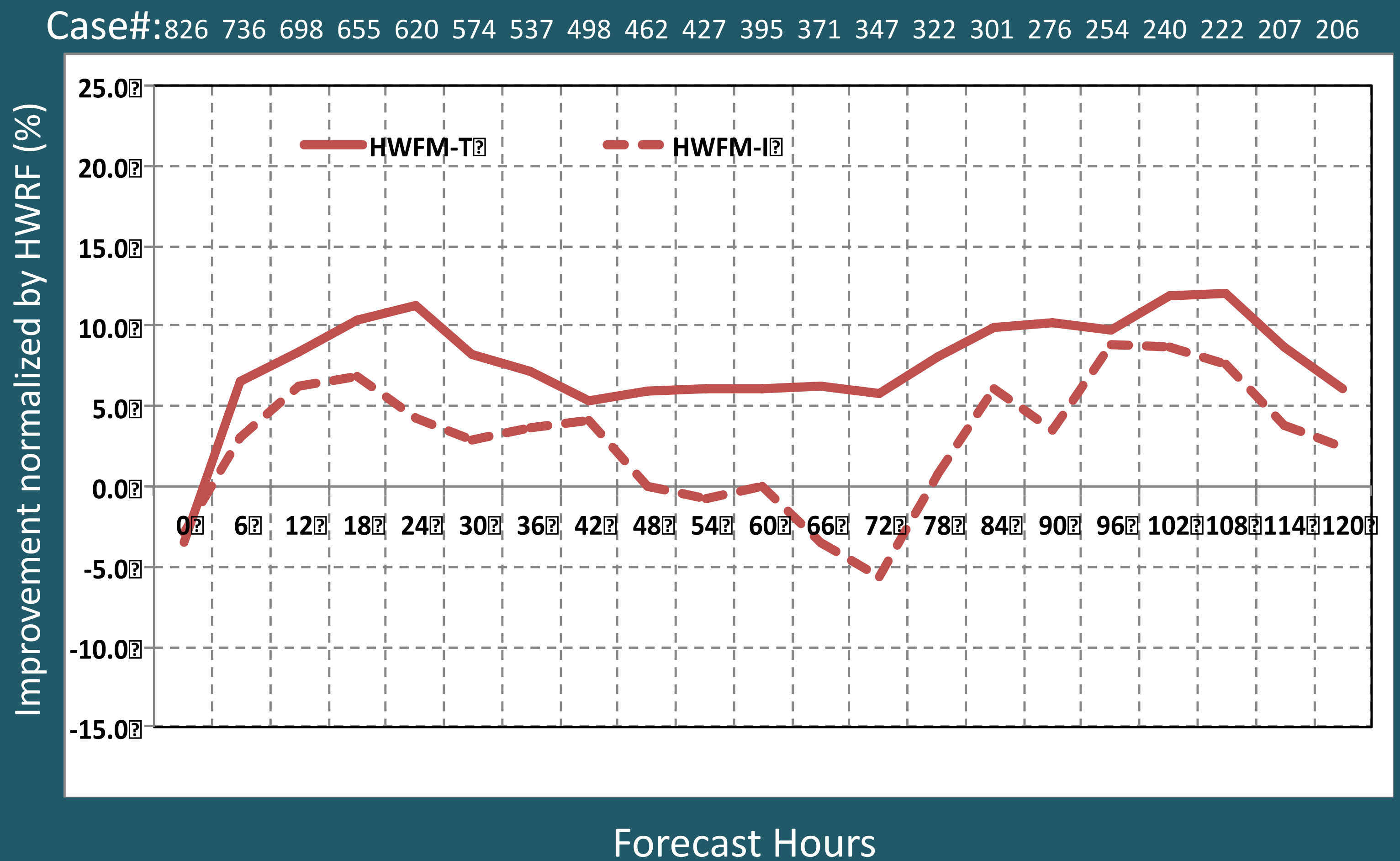
Atlantic Basin 2012-13 w/o Leslie

Case#: 826 736 698 655 620 574 537 498 462 427 395 371 347 322 301 276 254 240 222 207 206



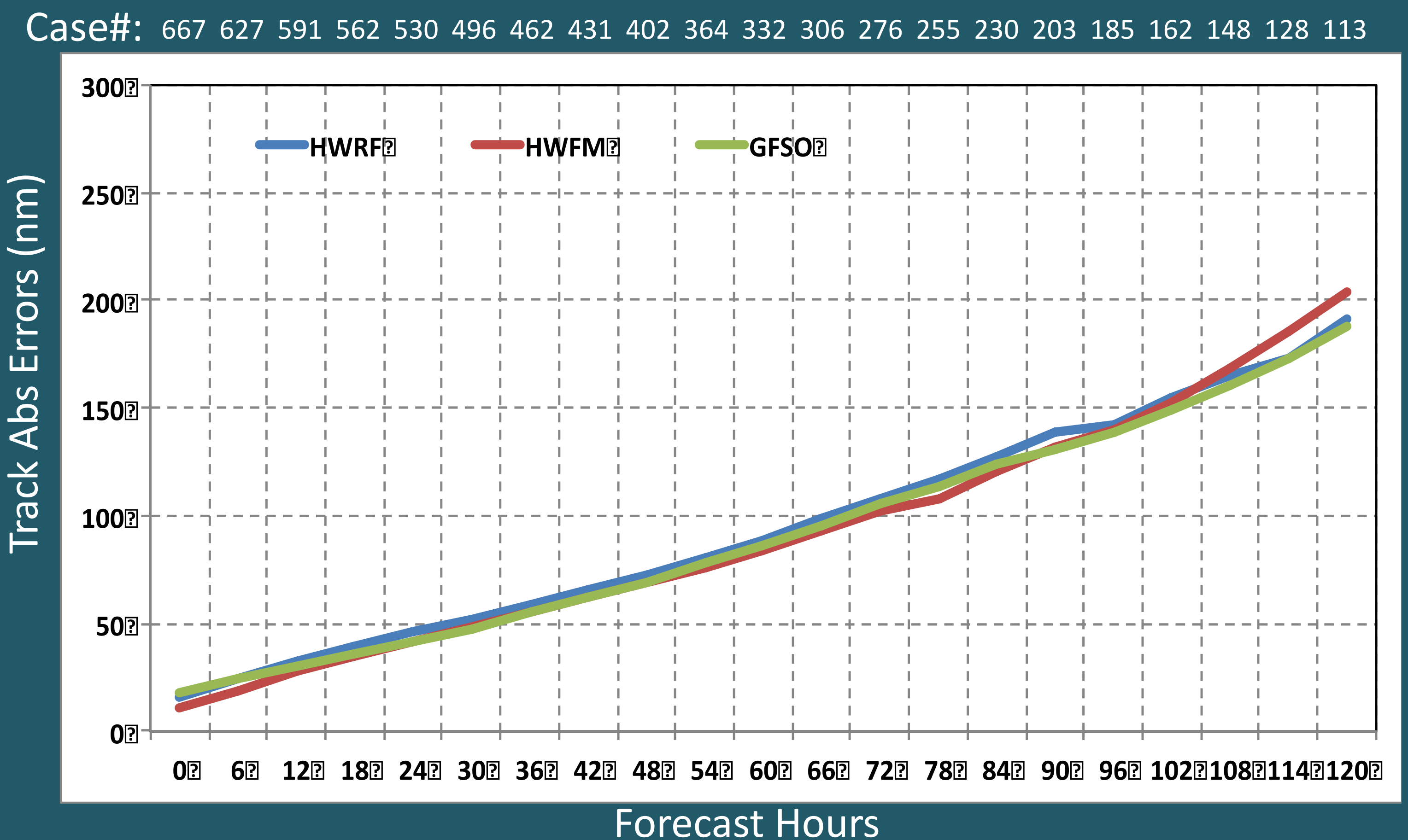
Intensity Verification

Atlantic Basin 2011-13 w/o Leslie



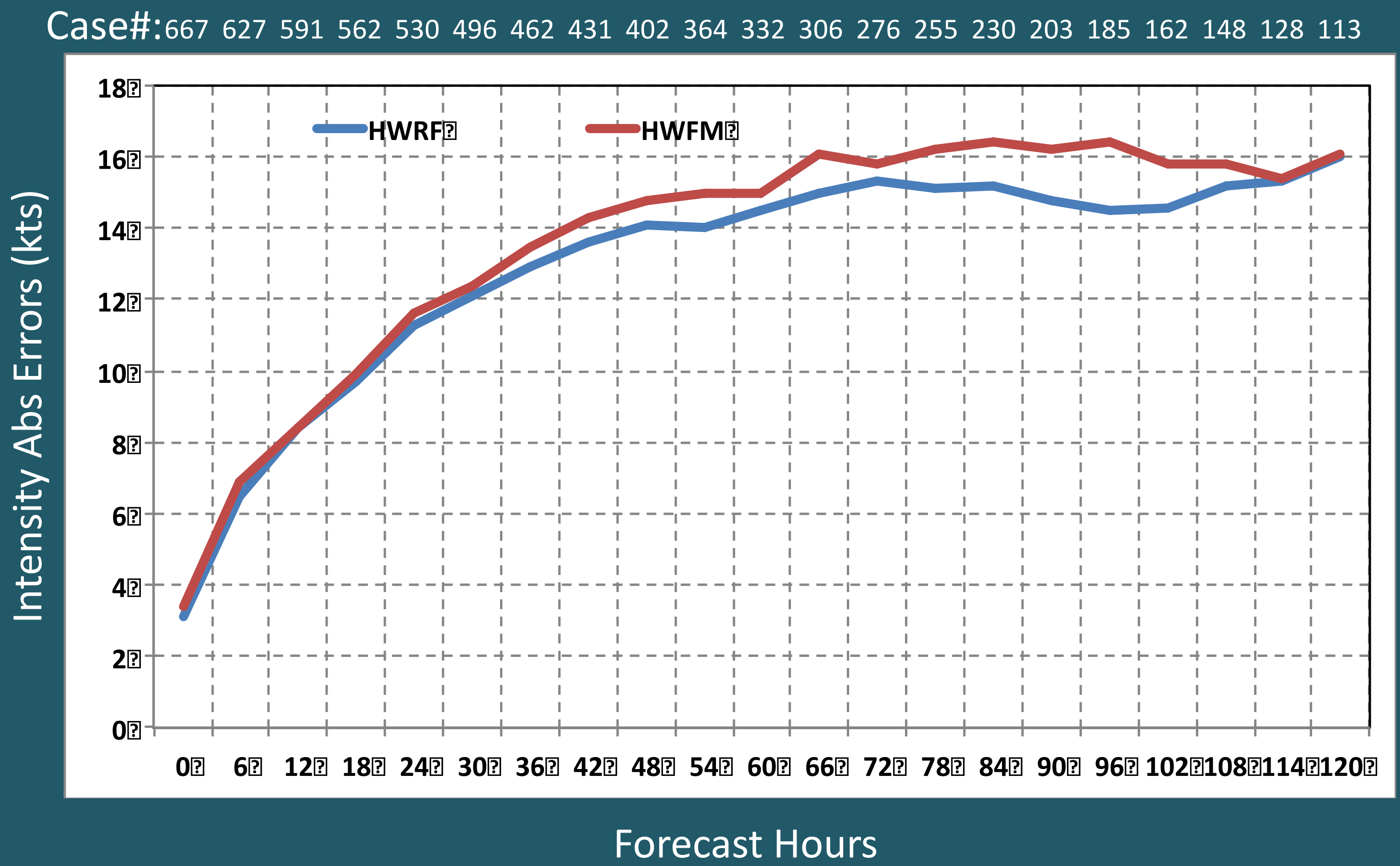
Intensity Verification

E. Pacific Basin 2011-13



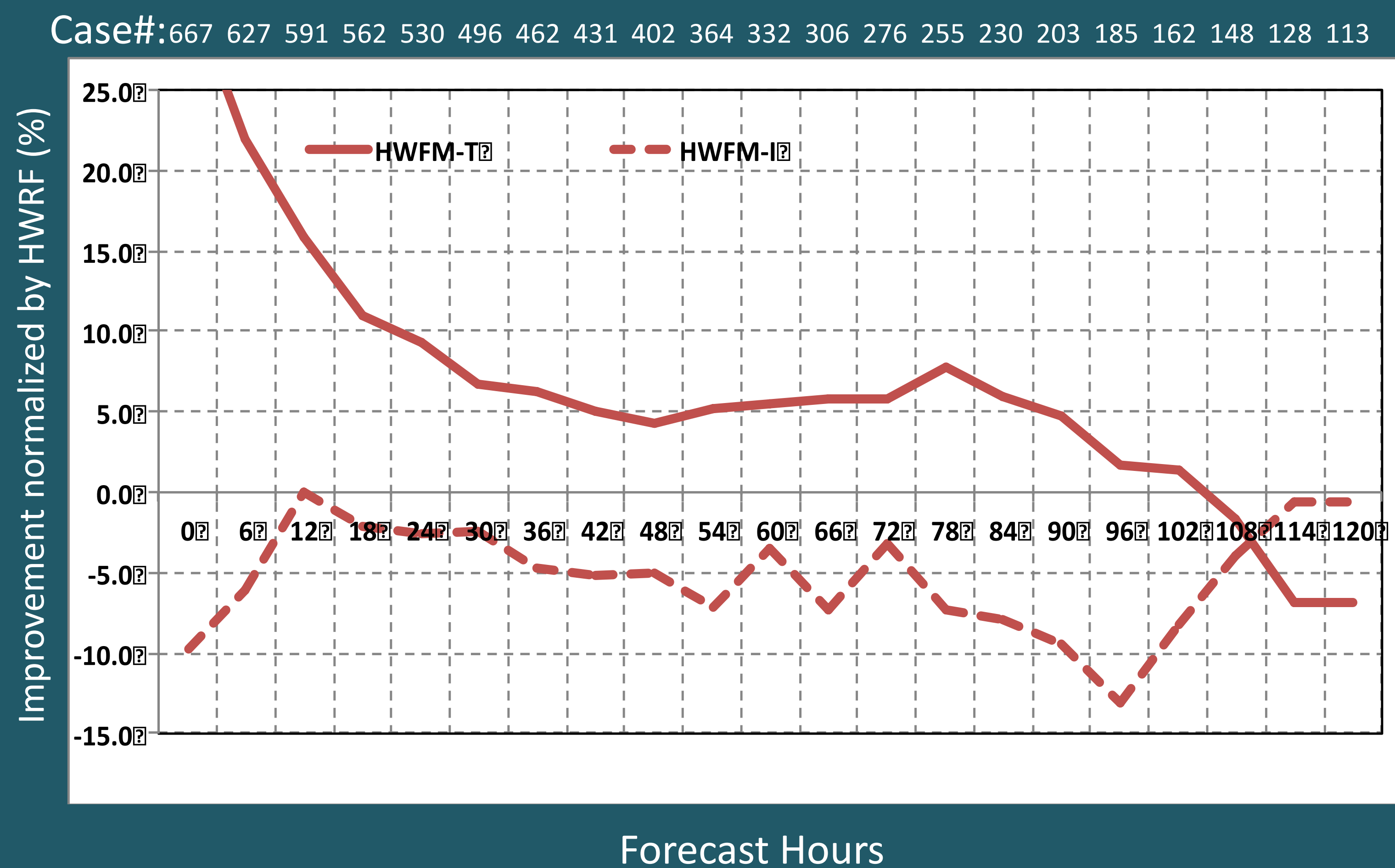
Track Verification

E. Pacific Basin 2011-13



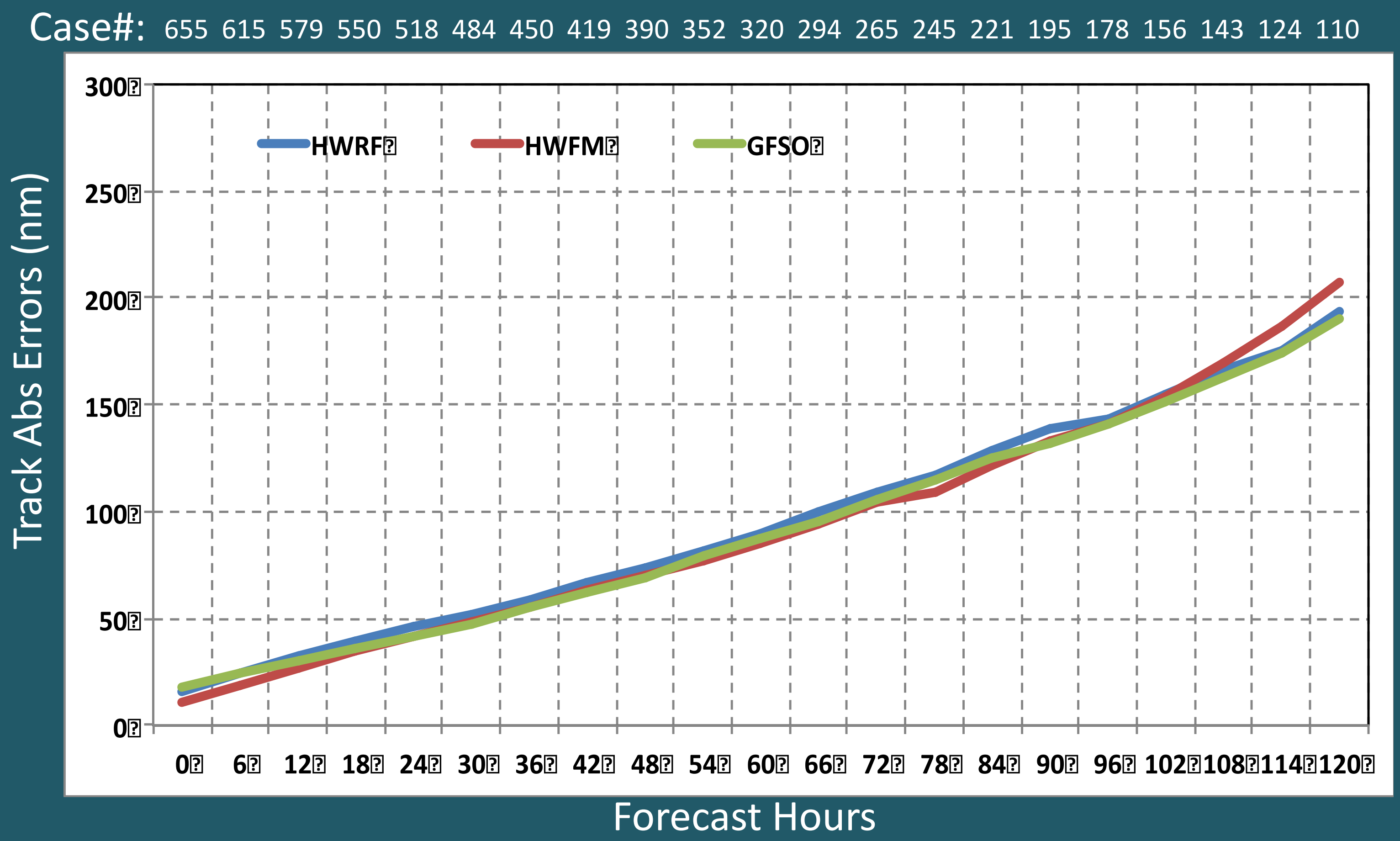
Intensity Verification

E. Pacific Basin 2011-13



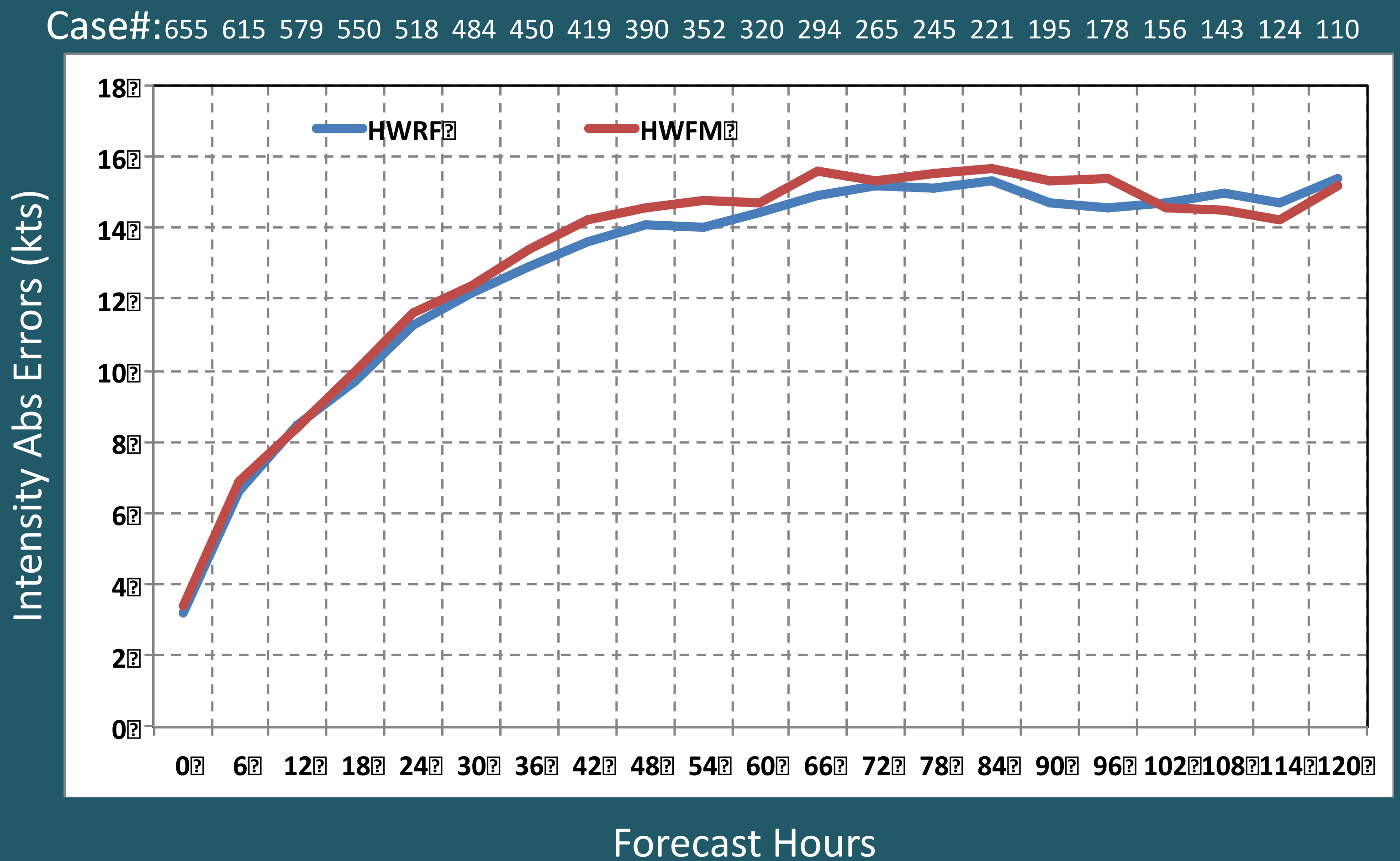
Intensity Verification

E. Pacific Basin 2011-13 w/o Miriam



Track Verification

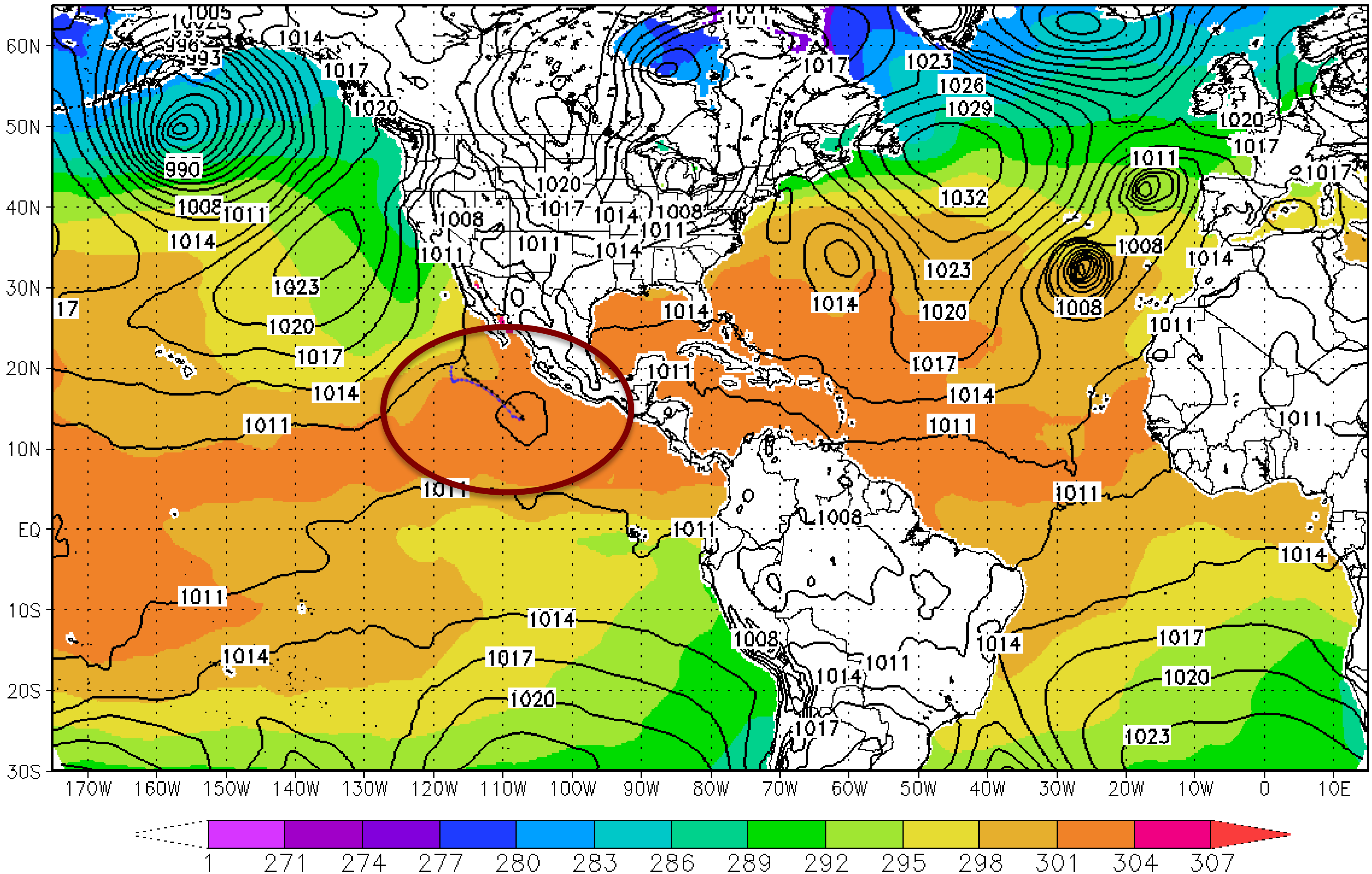
E. Pacific Basin 2011-13 w/o Miriam



Intensity Verification

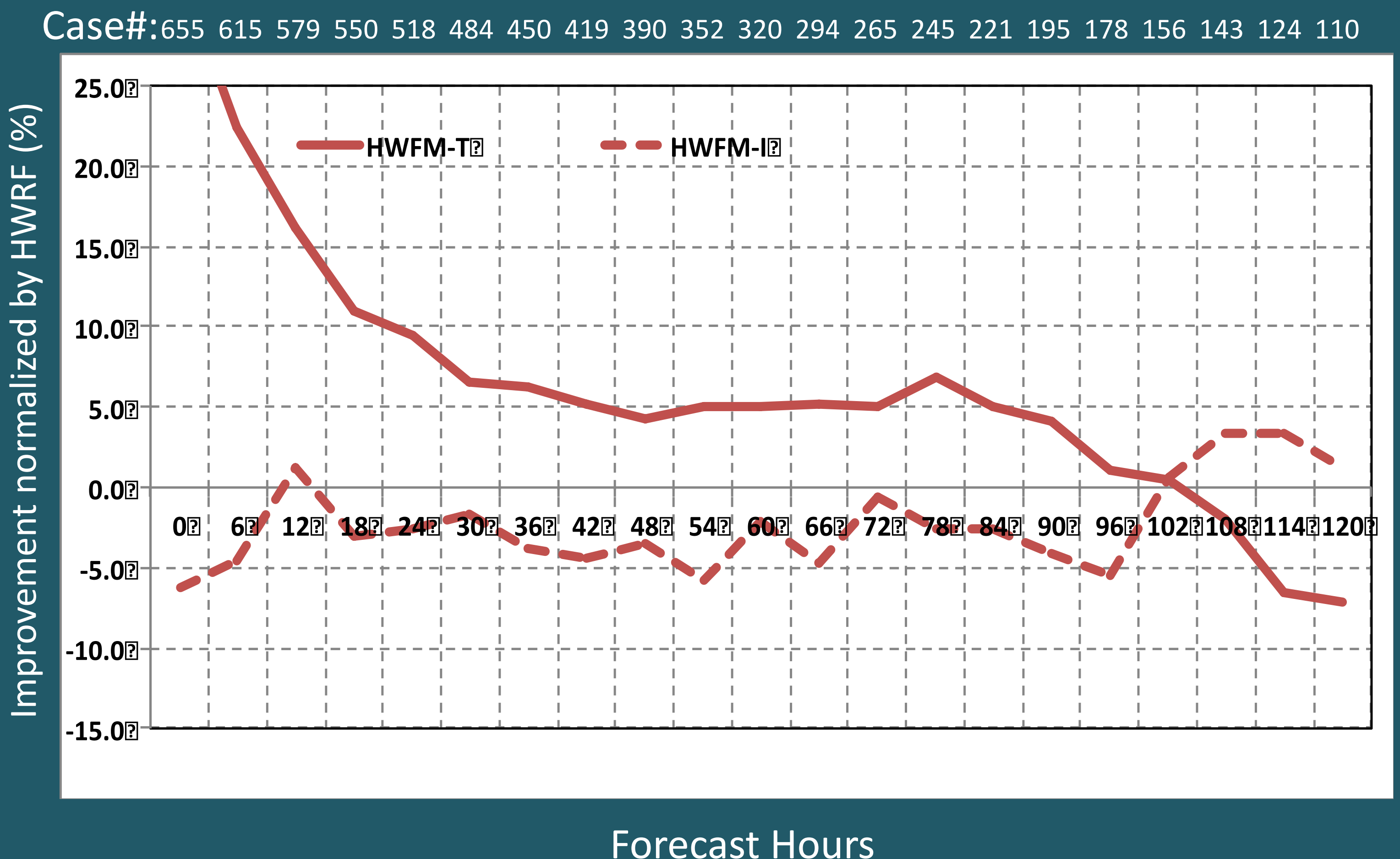
Experimental Product

Sea Surface Temperature [K] with MSLP [mb] for 0hr



Initial date: 2012092206

E. Pacific Basin 2011-13 w/o Miriam



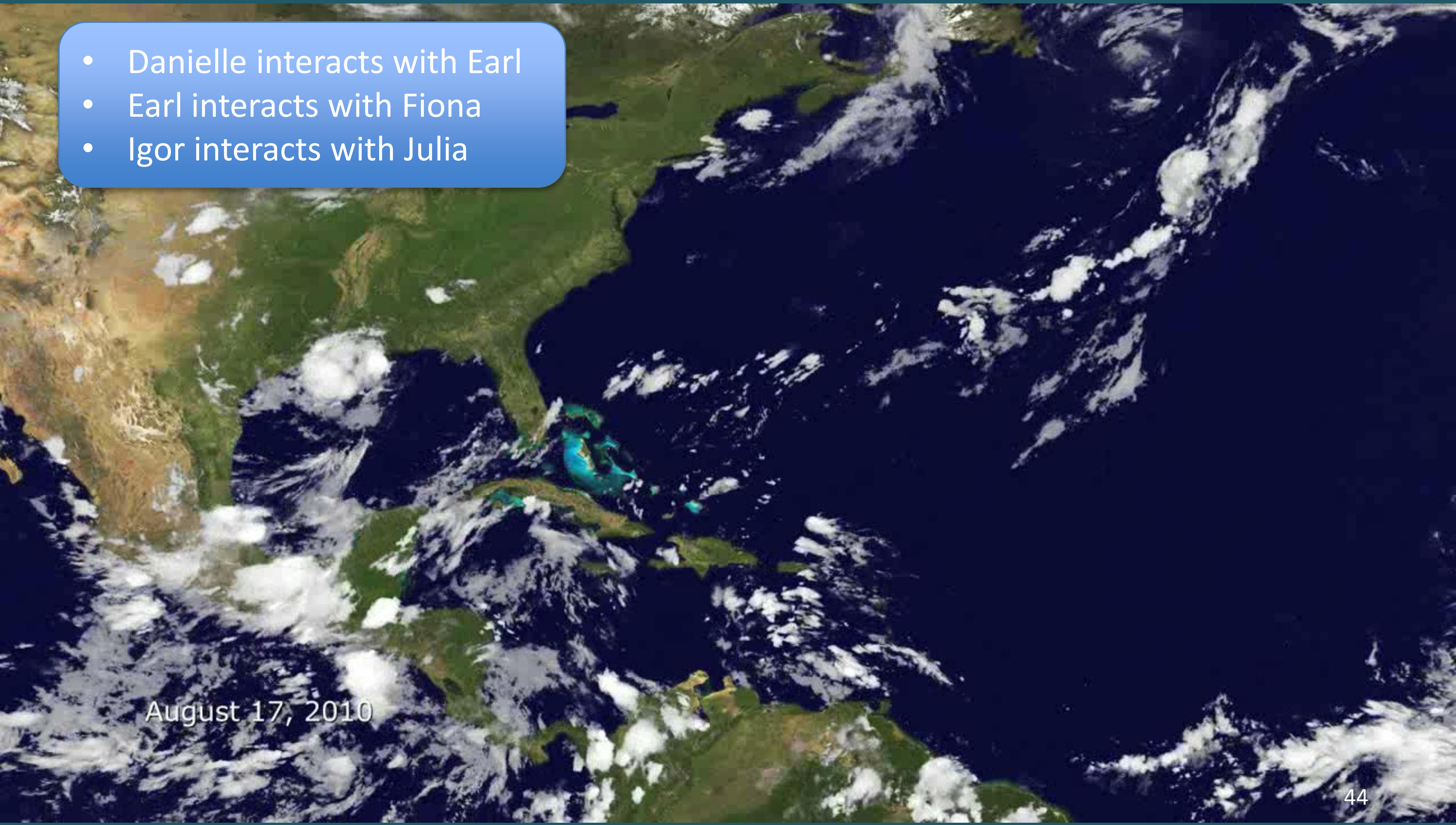
Intensity Verification

Storm-Storm Interaction

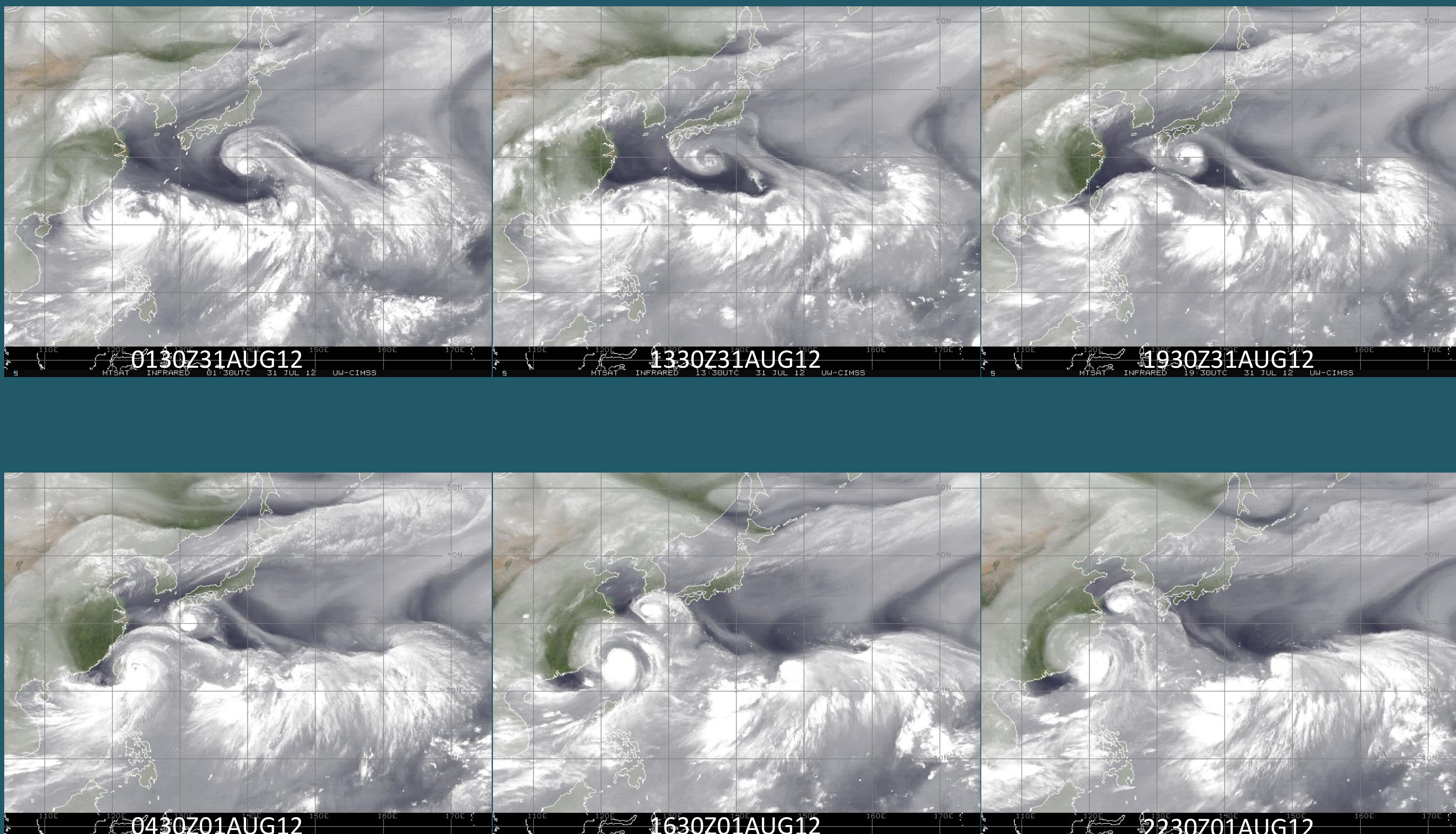
- How often does the storm-storm interaction happen?
- What is the forecast implication?
- What are the interaction process?

2010 Hurricane Danielle-Earl-Fiona-Gaston-Hermine-Igor-Julia-Karl-Lisa-Matthew

- Danielle interacts with Earl
- Earl interacts with Fiona
- Igor interacts with Julia



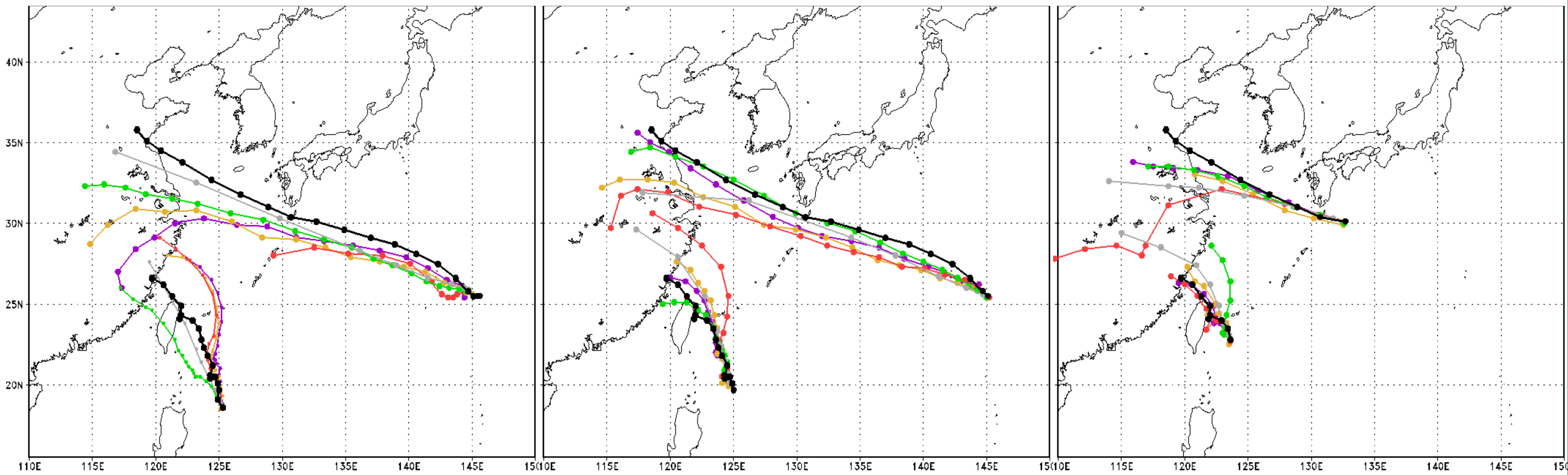
Example of Binary TC interaction



Forecast Issue

- Basin-wide model forecast produced superior tracks after 3000Z
- JTWC operational forecast struggled except at early stage because of the complicate interactions
- All models including GFS have bigger landfall location errors even 48 hour forecast

Black: best track; Purple: Basin HWRF; Orange: Oper. HWRF; Red: GFS; Green: GFDL



Initial time 2012072912

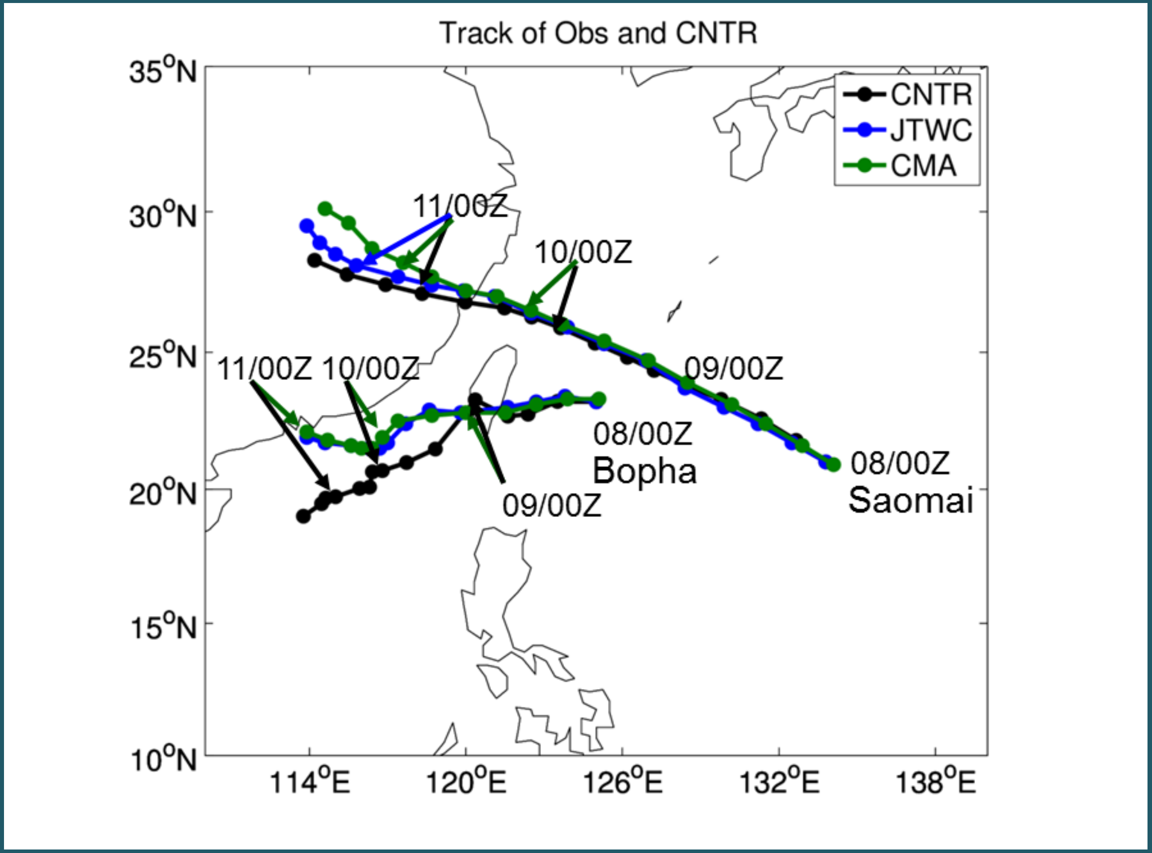
Initial time 2012073000

Initial time 2012080100

Binary TC interaction

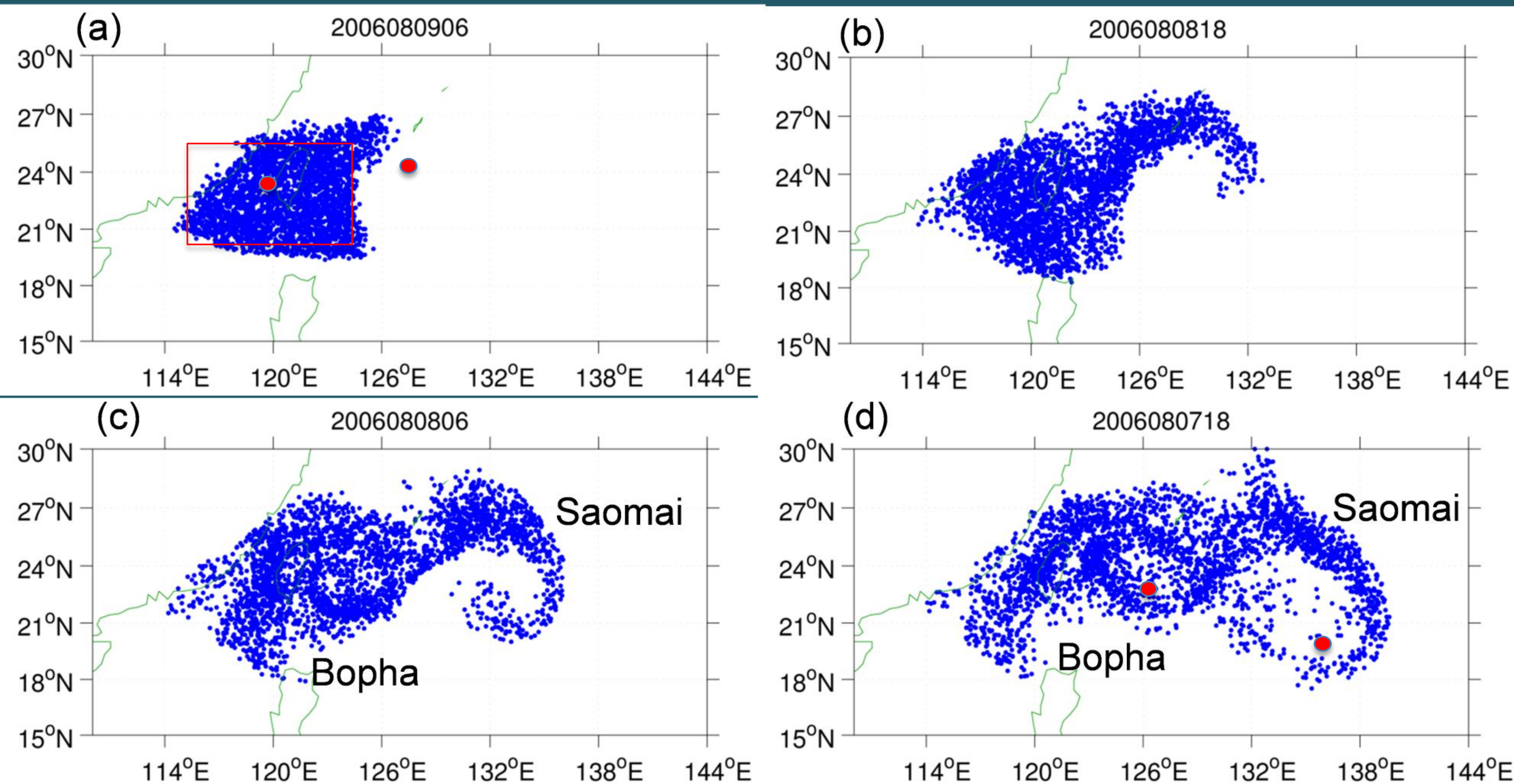
- Fujiwhara effect (Fujiwhara, 1921, 1923, 1931)
  - Two cyclonic vortices can orbit each other and close the distance between the circulations of their corresponding areas
  - Smaller circulations can cause the development of a larger cyclone or cause two cyclones to merge into one

Saomai & Bopha Interaction



Xu et al. AIM, 2013

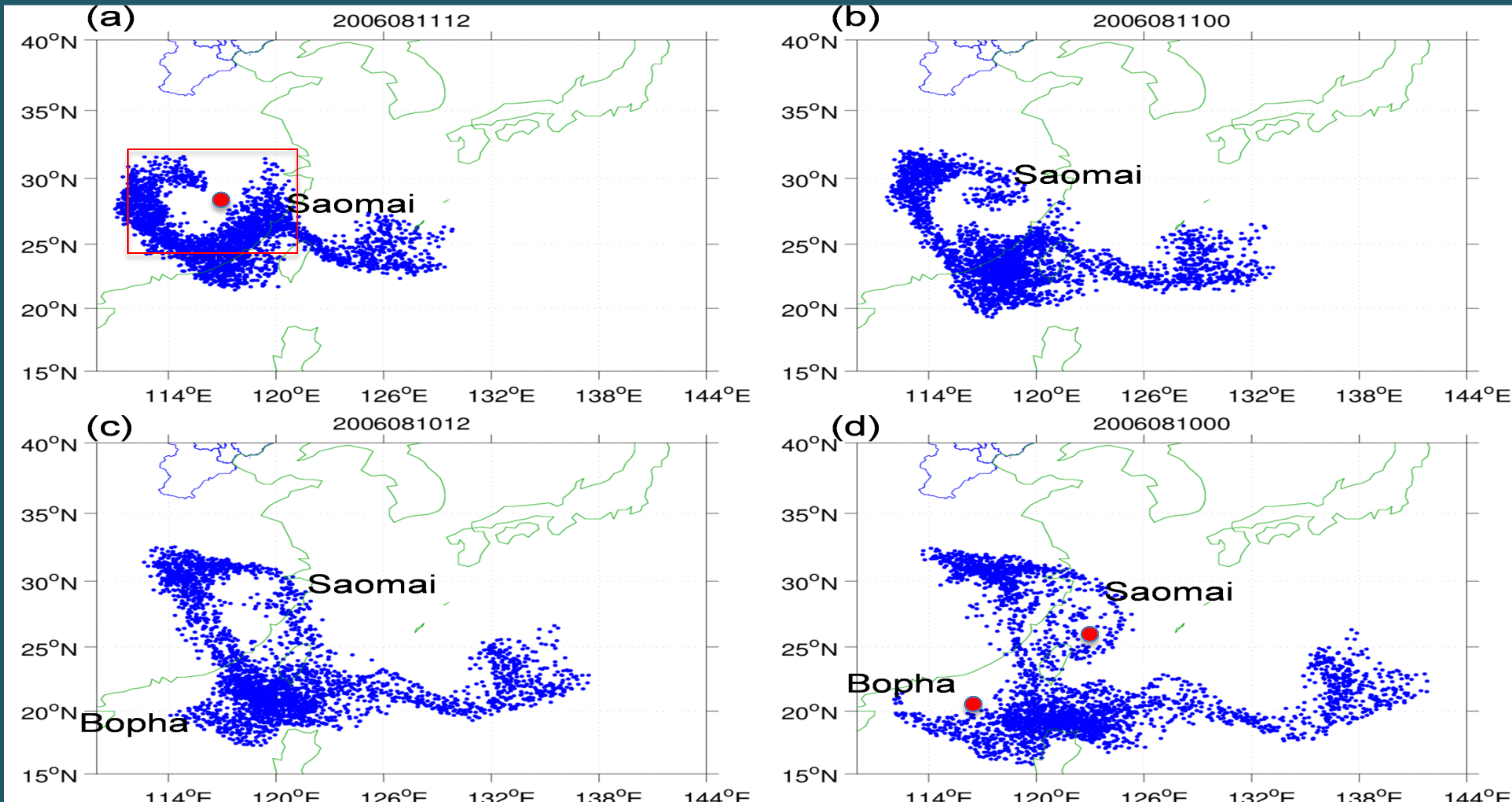
Moisture transport process



Back trajectories of the cluster of moisture particles released at 1200 UTC 9 August in Bopha (115.5~125.5∘E, 20.1~25.0∘N) in the FLEXPART model at (a) 0600 UTC 09 August, 2006, (b) 1800 UTC 08 August, (c) 0600 UTC 08 August, and (d) 1800 UTC 07 August.

Xu et al. AIM, 2013

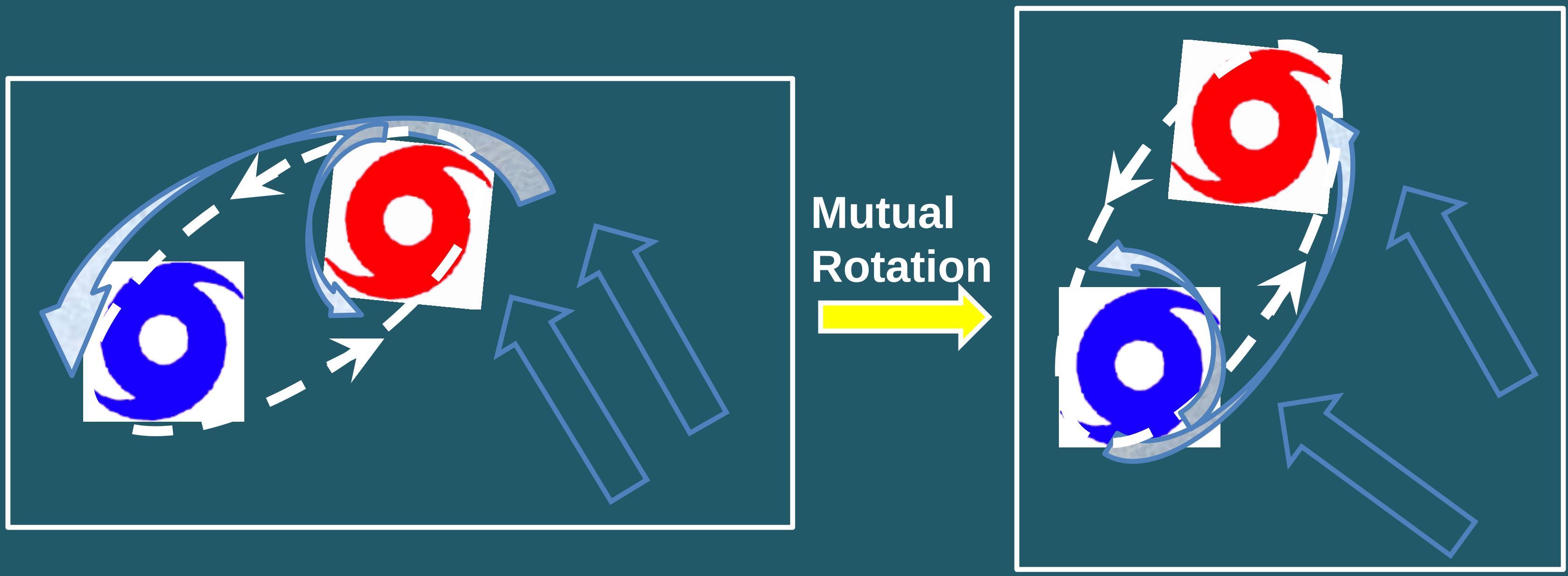
Saomai & Bopha Interaction



Back trajectories of the cluster of moisture particles released at 0000 UTC 13 August in Saomai (114.5~120.5∘E, 26~33.5∘N) in the FLEXPART model at (a) 1200 UTC 11 August, (b) 0000 UTC 11 August, (c) 1200 UTC 10 August, and (d) 0000 UTC 10 August, 2006.

Xu et al. AIM, 2013

Moisture transport process

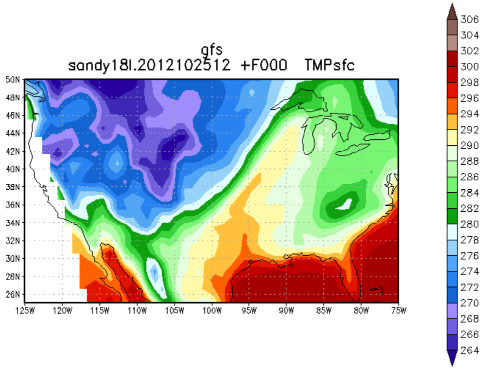


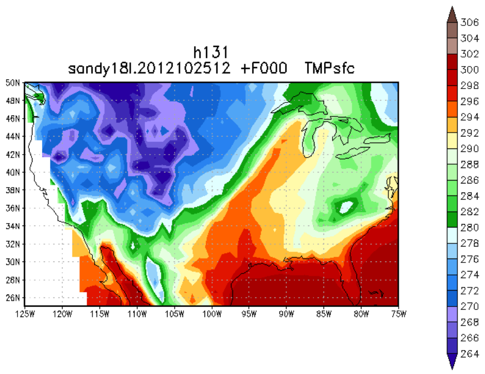
Xu et al. AIM, 2013

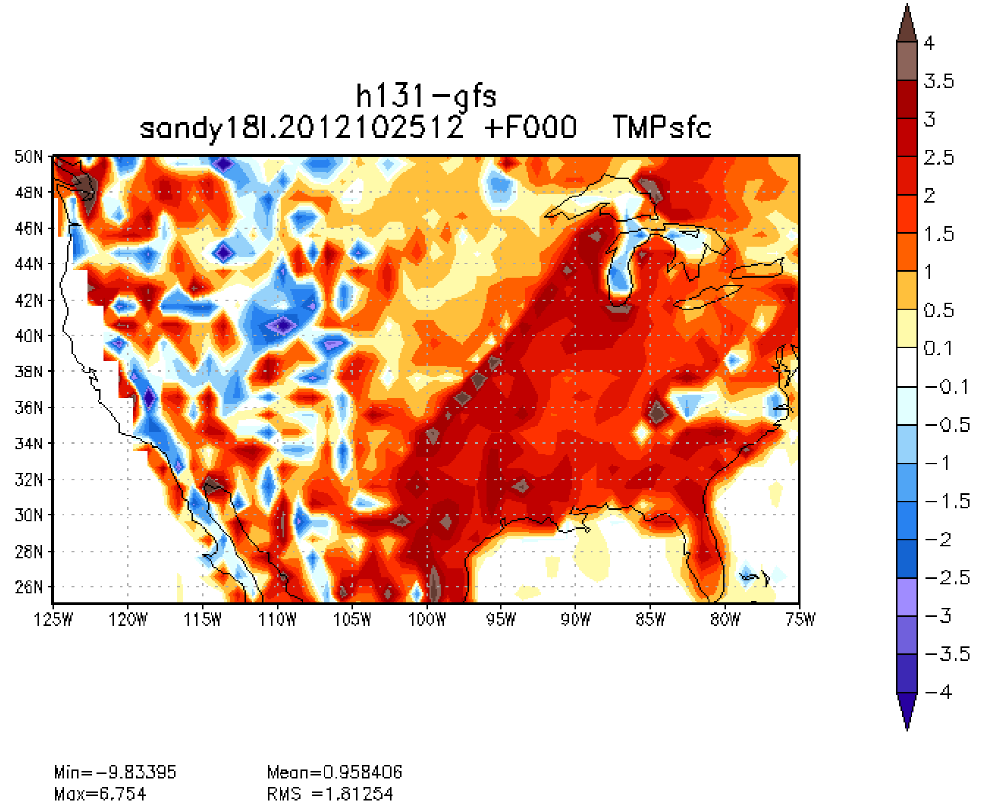
Transition to Operation

- Transfer all developments into HWRF repository
  - Multiple movable nest capacity (completed)
  - Multiple nest initialization (ongoing)
  - Code speed up framework (completed)
  - Forecast scripts (ongoing)
- Transfer current capacity into next generation hurricane model
  - Planned according to operational priority

BASIN SCALE HWRF: NEED FOR IMPROVED LAND MODEL







- HWRF currently uses a bulk LSM (GFDL scheme)
- NOAH LSM – important for basin scale HWRF

Credits: Weiguo Wang, NCEP/EMC

Future work

- Quantify LSM bias in basin-scale HWRF and diagnose sensitivity on track and intensity forecast
- Upgrade to 2014 HWRF
- Ocean coupling

Summary

- We have developed a basin-scale multiple movable nest experimental forecast system
- The system can better represent multi-scale processes and interactions of TC that may translate into better forecast guidance both on track and intensity
- The system provides very promising forecast results during 2011-13 hurricane seasons
- The system can also be utilized as a research tool to explore advanced DA, genesis, terrain-TC interaction, landfall processes, storm-storm interactions, etc.
- The development can also be applied and transferred to next generation global hurricane model development
- Real-time products website: https://storm.aoml.noaa.gov/basin