Improving Operational Numerical Hurricane Forecast System to Reduce Errors in Tropical Cyclone Track, Intensity and Structure Forecasts

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Outline

- NOAA's Hurricane Forecast Improvement Project (HFIP)
- Hurricane Weather Research and Forecast (HWRF) Modeling System
- Exciting new research findings from HWRF
  - Improved understanding of hurricane intensity and rapid intensification for improved operational forecasts
- ***Next generation global-to-local scale modeling***
  - ***NOAA leading the path for Weather-Ready Nation (and Weather-Ready World)***
  - ***Supported by Sandy Supplemental High-Impact Weather Prediction Project (HIWPP)***

Hurricane Forecast Improvement Project (HFIP)

Key to success: community engagement & accelerated research to operations

Improved forecasts…….. Ambitious goals

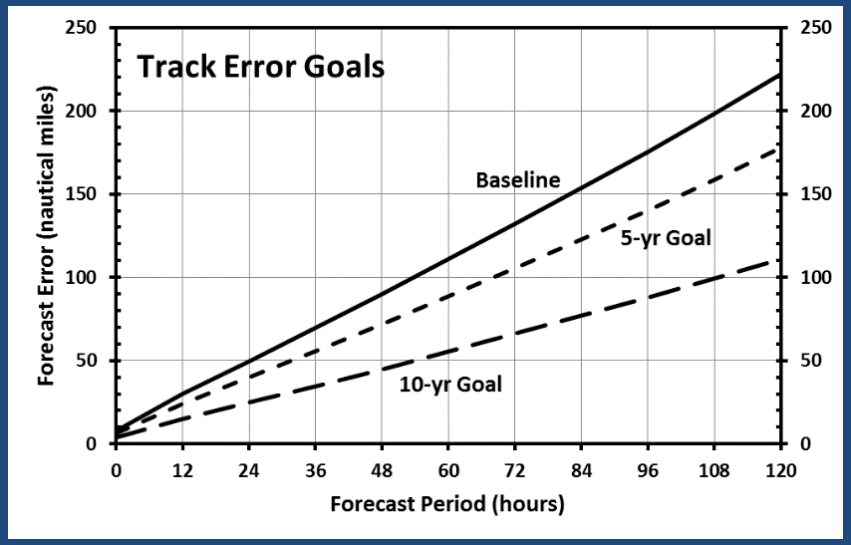
- Increased accuracy at longer lead times, especially during periods of rapid intensity changes
- Raise confidence levels for all forecast periods
- Reduced over-warning

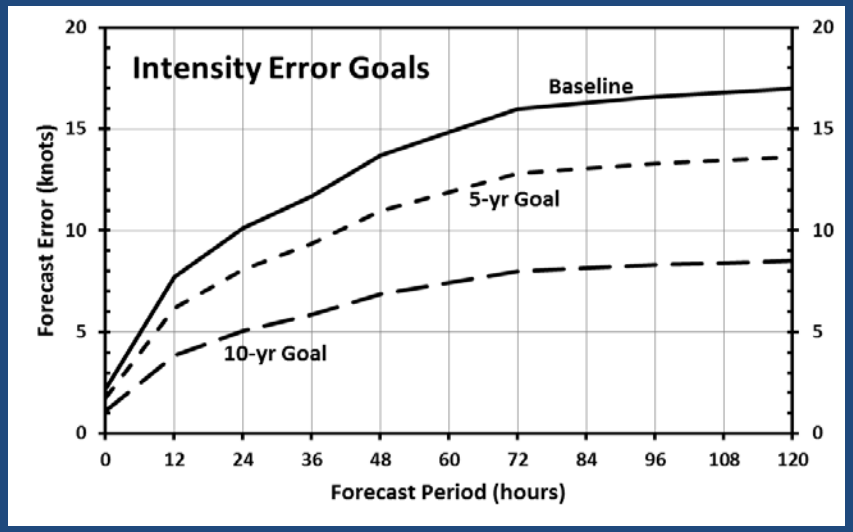
….leads to more effective emergency management response

- Reduced evacuations
- Reduced preventable economic losses
- Hundreds of millions of dollars saved annually

Sandy Supplemental support to HFIP was focused on augmenting….

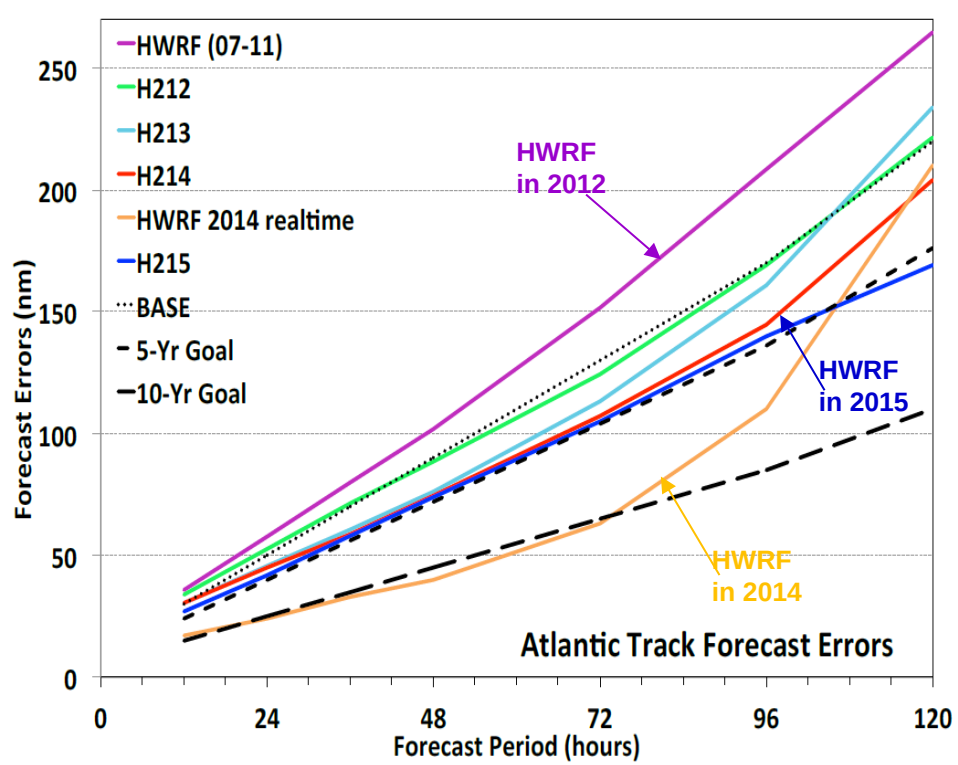
- Support HFIP was providing to the community
- Support to National Center for Atmospheric Research (NCAR)/Developmental Testbed Center (DTC) for accelerated transition of research to operations
- Support to NCEP for accelerated advancements of Hurricane Weather Research and Forecast (HWRF) model transition to Non-Hydrostatic Multi-scale (NMMB) prediction system

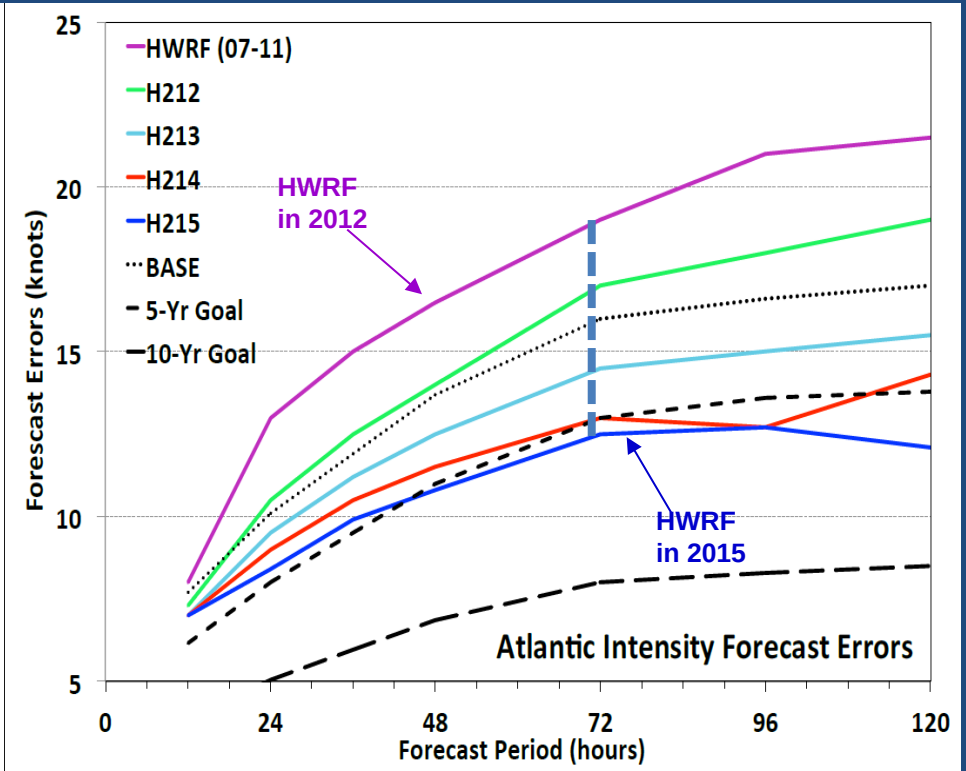




Hurricane Weather Research Forecast Model Improvements

Atlantic track and intensity forecast errors approaching 5-year goals





Improvements of the order of 10-15% each year since 2012

What it takes to improve the models and reduce forecast errors???

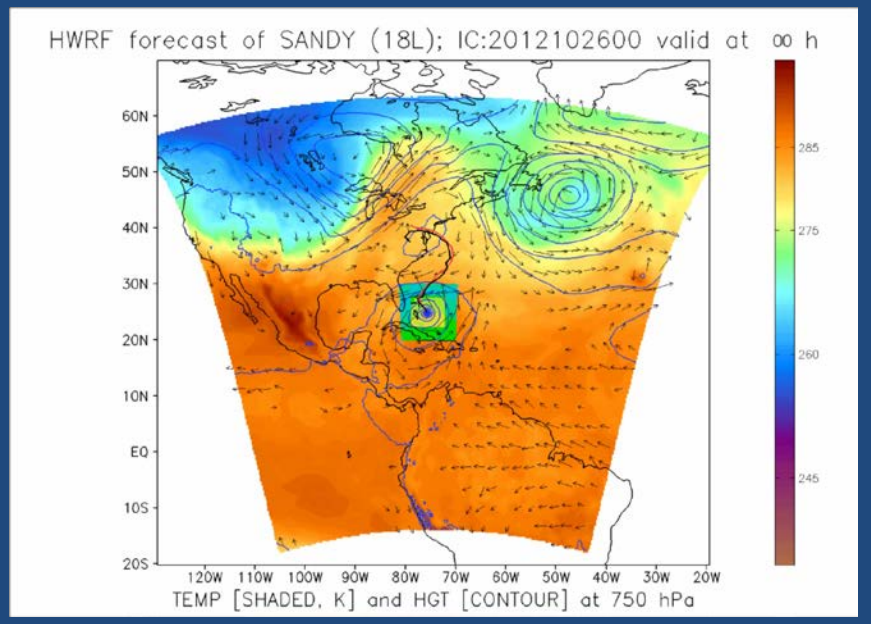
- **Resolution**
- **Physics**
- **Data Assimilation**

Targeted research and development in all areas of hurricane modeling

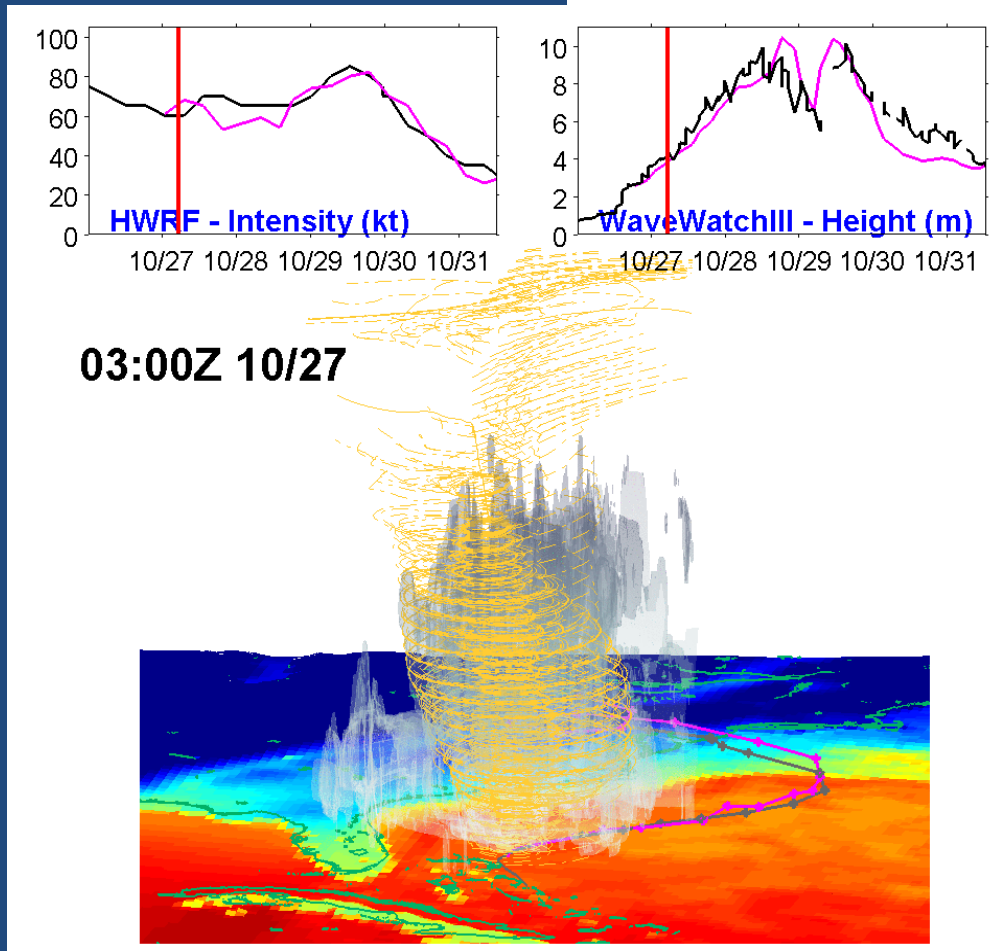
Operational Real-Time Forecasts for Hurricane Sandy

Operational Hurricane Weather Research Forecast Model (HWRF)

- High-resolution (2km) near the storm
- Advanced hurricane physics
- Coupled to ocean model
- Drives the operational wave model



Black: Observed
Pink: HWRF Model

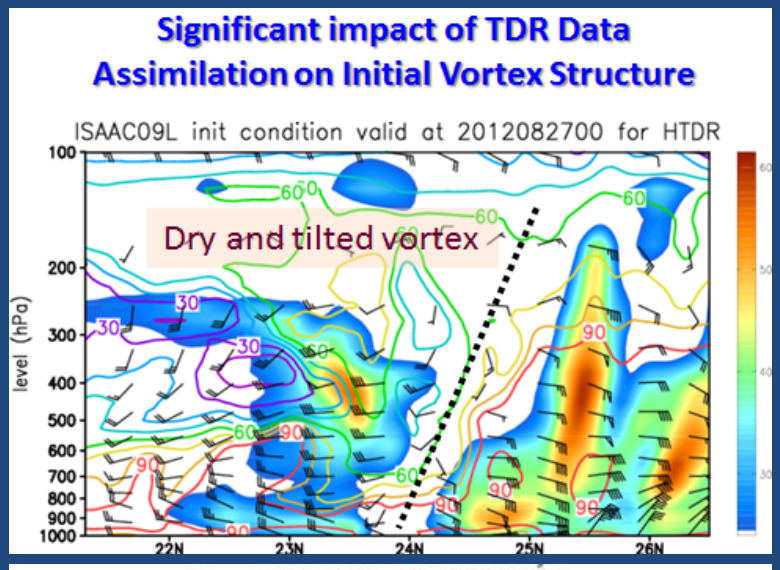


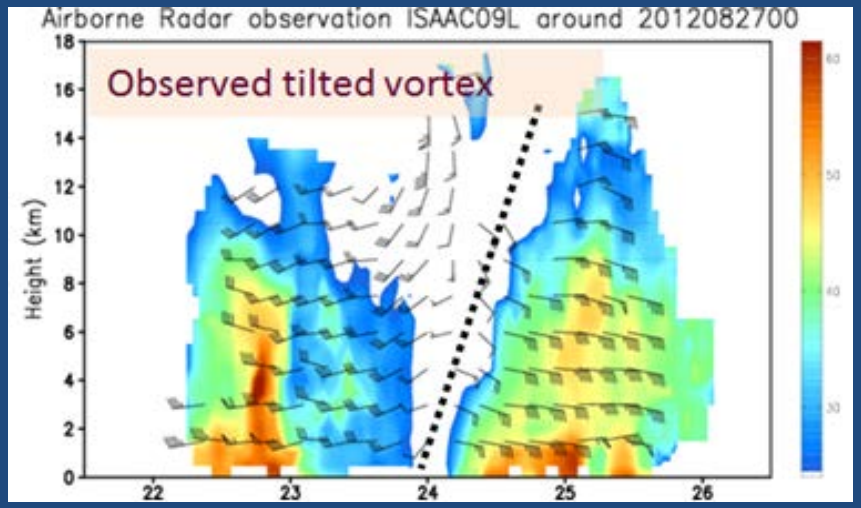
Accurate intensity and structure forecasts from HWRF
→ Better wave forecasts for landfalling storms

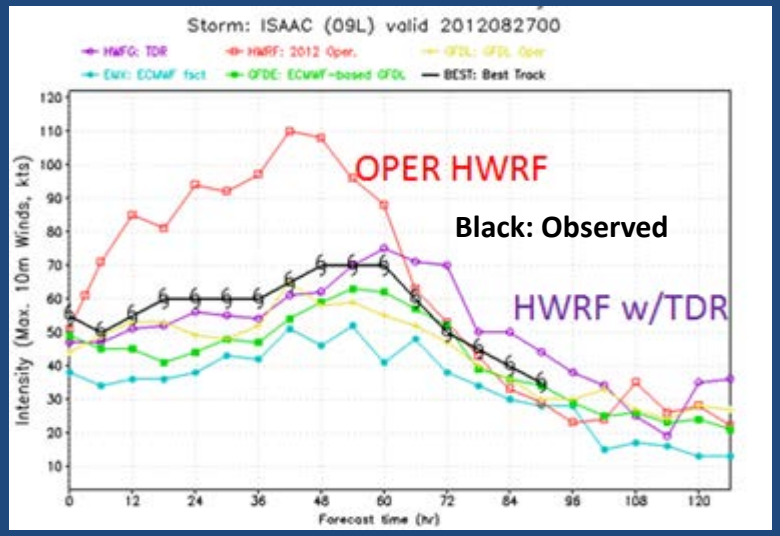
Advanced Research to Operations Transitions

Accurate representation of storm structure using advanced data assimilation methods

Collection, transmission and assimilation of inner core hurricane observations using Tail Doppler Radar directly from NOAA's P3 aircraft

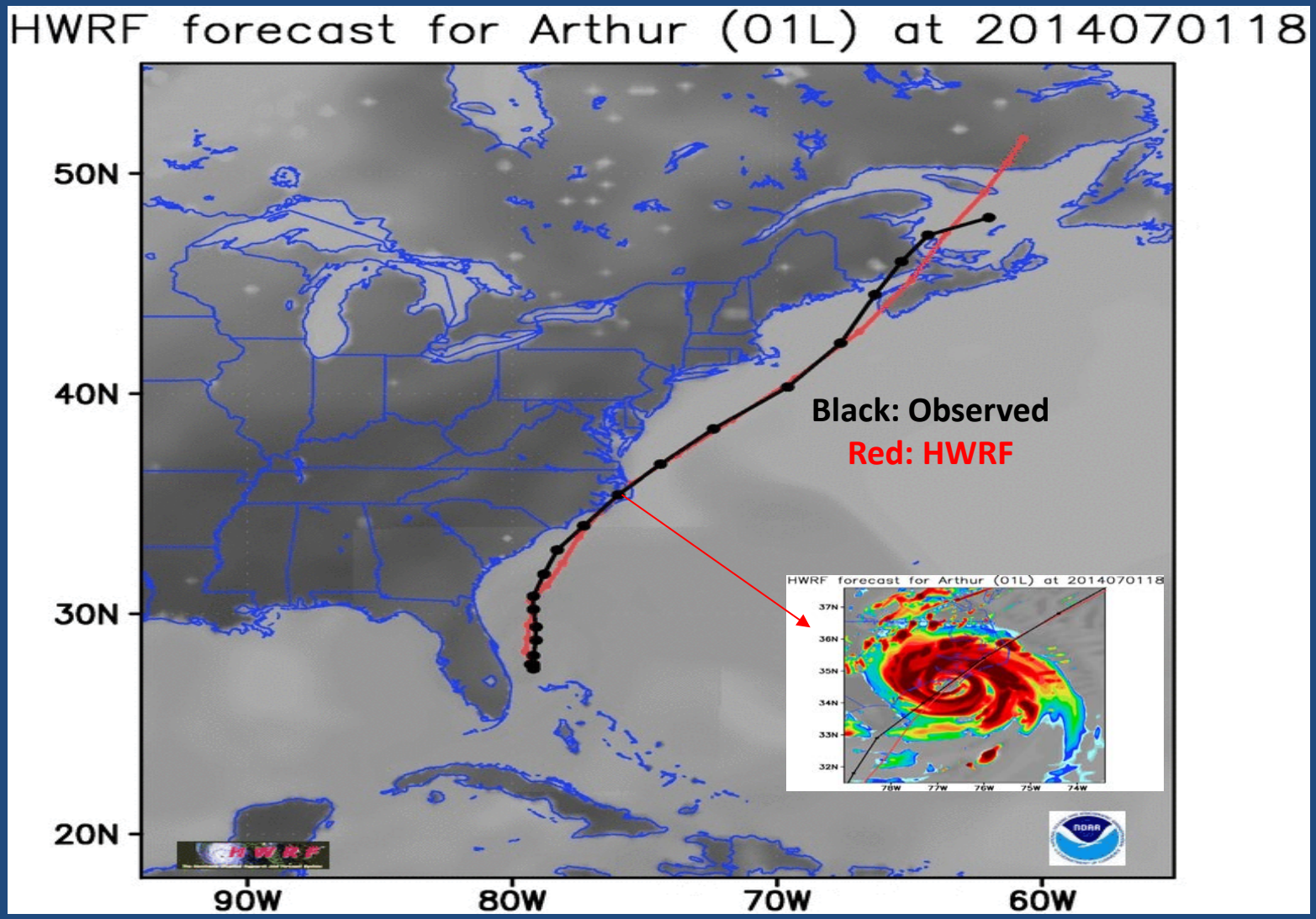






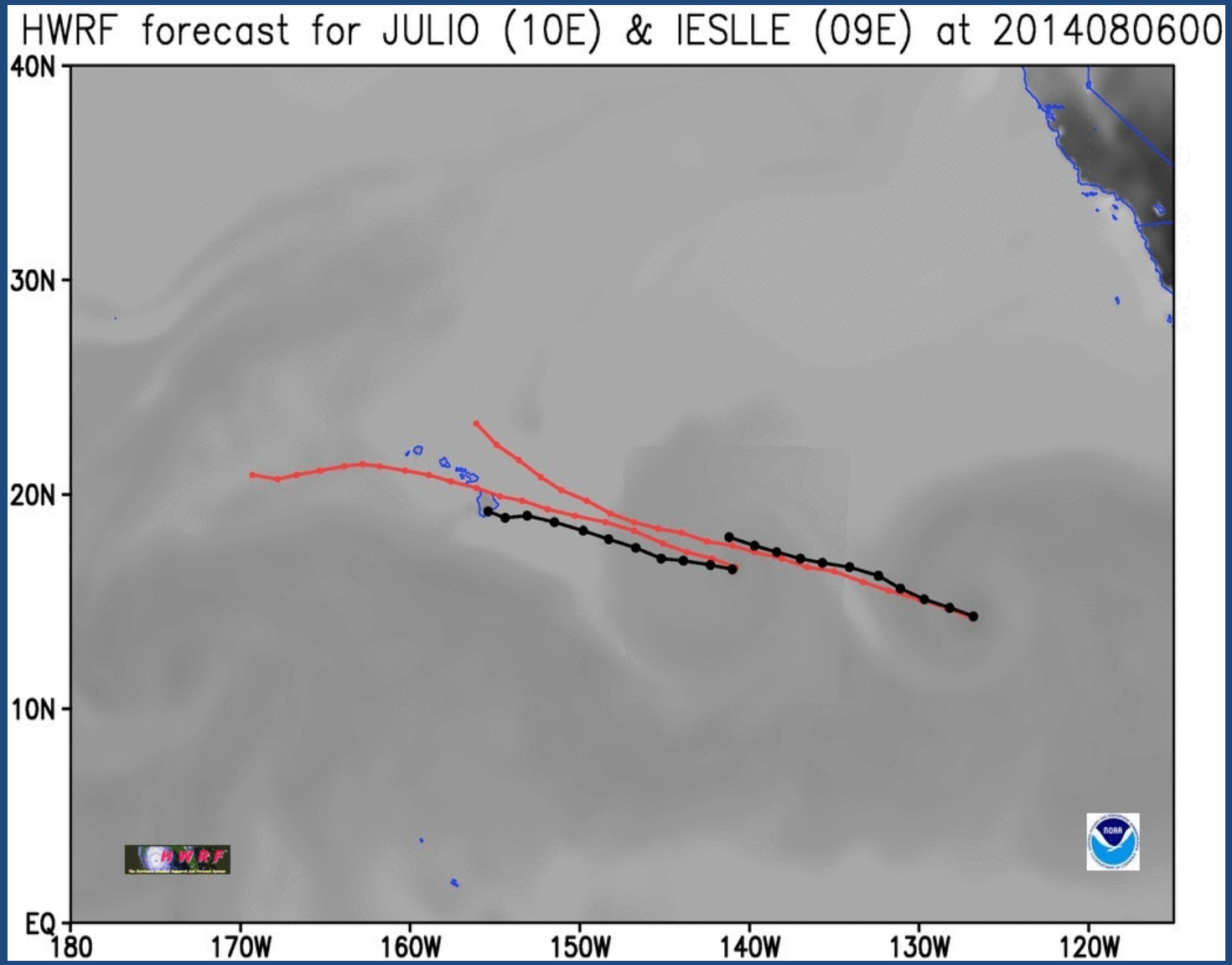
HWRF is the only model in the world assimilating real-time hurricane inner core Tail Doppler Radar (TDR) data from NOAA's P3 aircraft

Superior Track, Intensity and Structure Forecasts Support NOAA's National Hurricane Center



HWRF predicting Hurricane Arthur landfall along the North Carolina outer banks

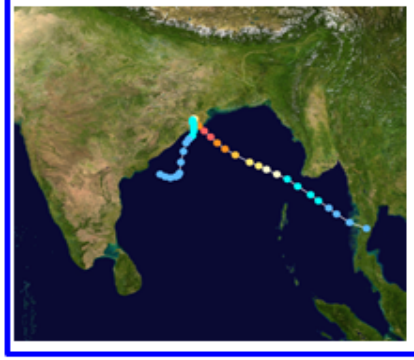
HWRF Forecasts Help People Prepare 3-4 days in Advance

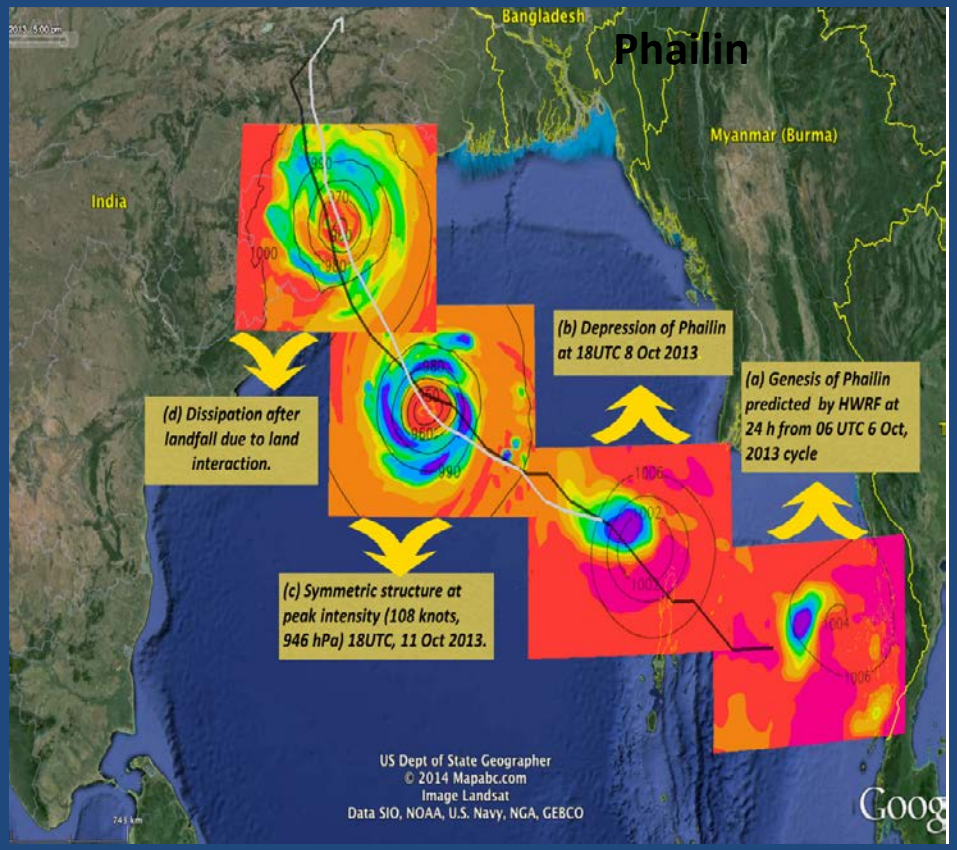


Dual hurricanes near Hawaiian Islands (Iselle & Julio)

Lives Saved

- **1999 Orissa Cyclone**
  - Deadliest storm since 1971
  - 155 mph winds and 8m (26 ft) storm surge at landfall
  - *10000 causalities, damages ~5 Billion USD*
  - Operational NWP at IMD based on 24-hr forecasts from NCEP QLM
  - Accurate 48-hr forecast lead time for tracks, no skill for intensity forecasts
  - Inadequate guidance on storm surge, rain & flood

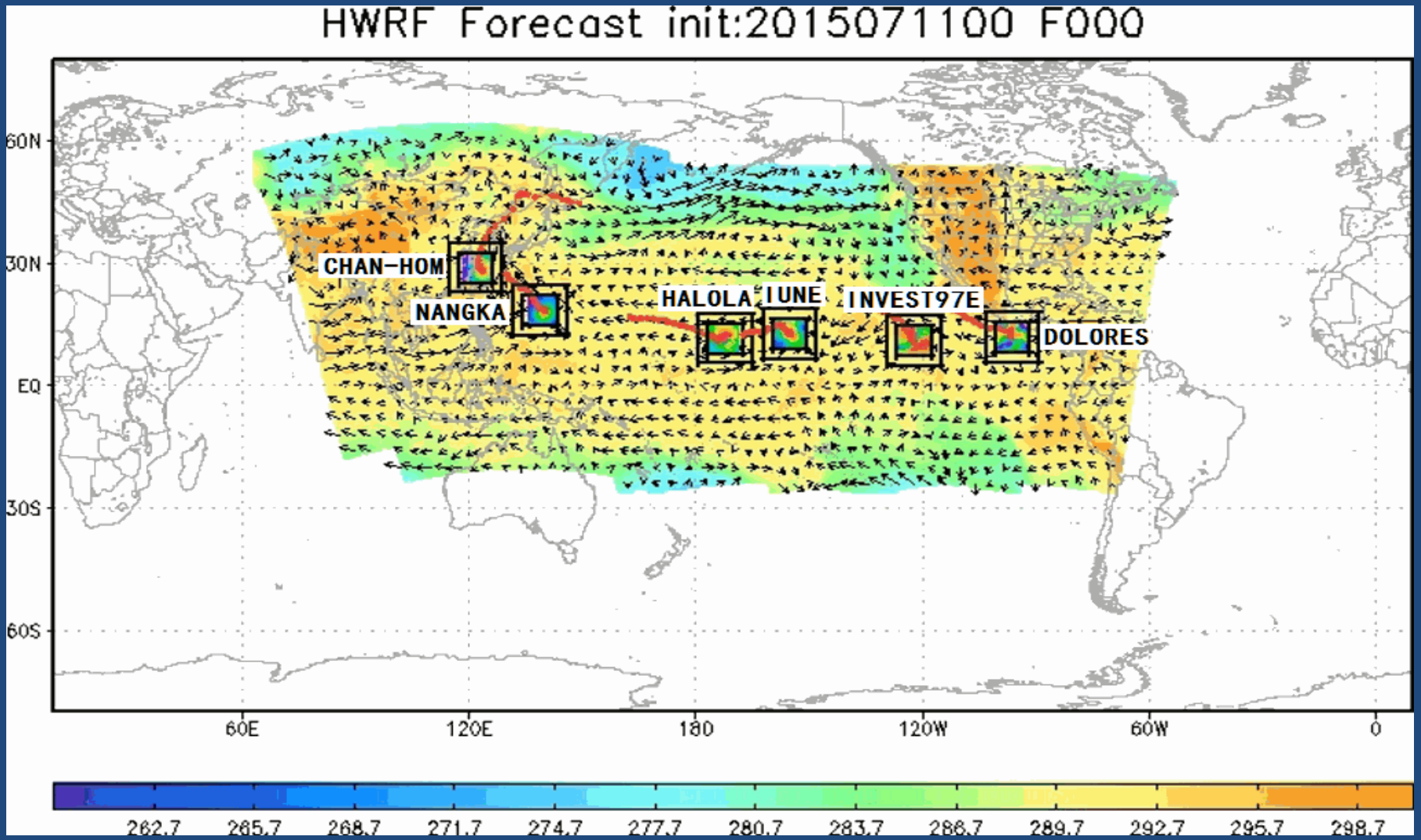




Advanced modelling and forecast products given to India Meteorological Department in real-time through the life of Tropical Cyclone Phailin

Only 36 casualties compared to >10000 deaths due to a similar storm in 1999

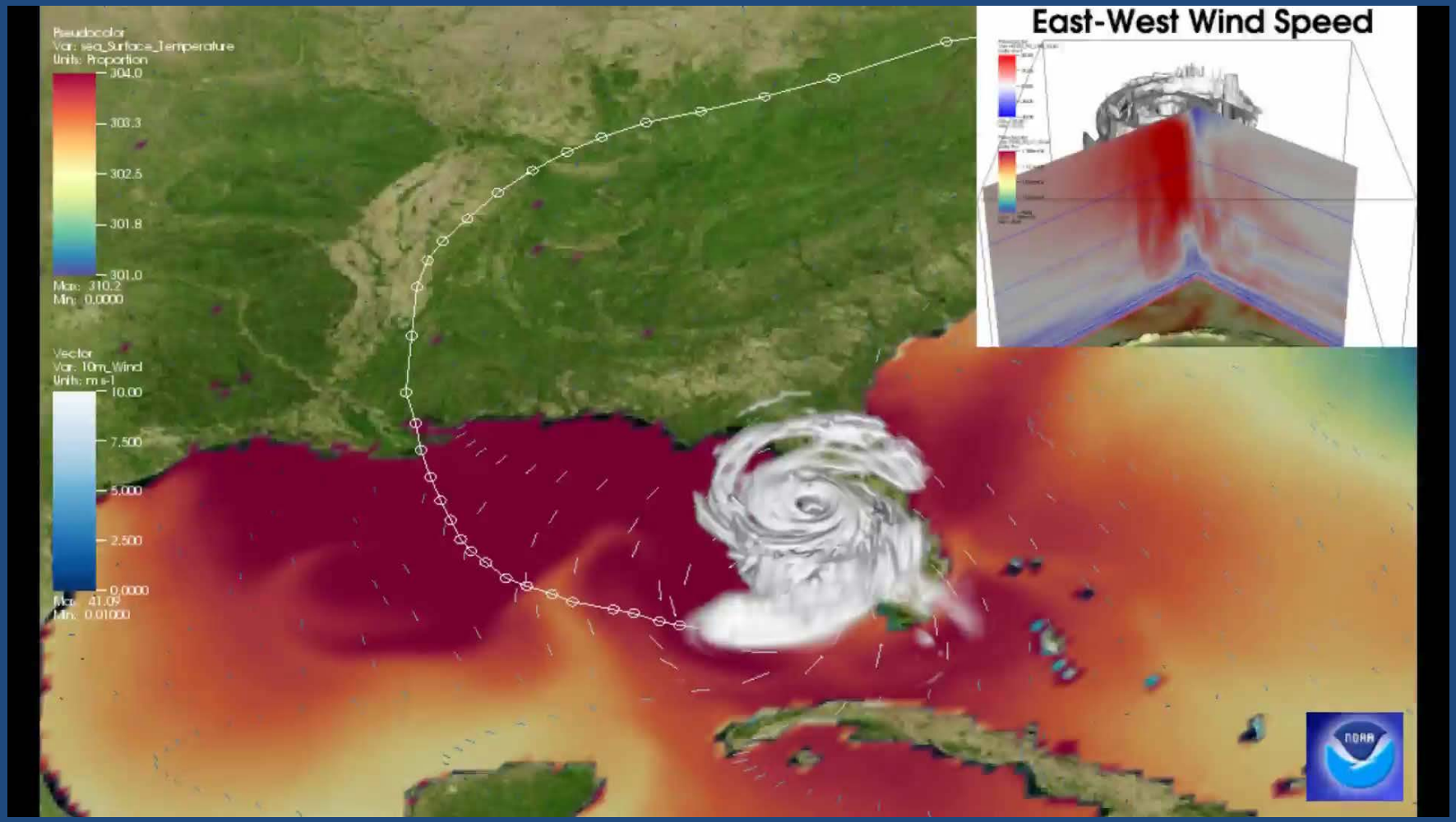
Expansion for All Global Tropical Cyclones in 2015



HWRF is now used globally in all regions of the world, seen here in this 2015 forecast

Have Operational Models Improved in the Past Decade?

Revisiting Hurricane Katrina through high-definition 3-D View

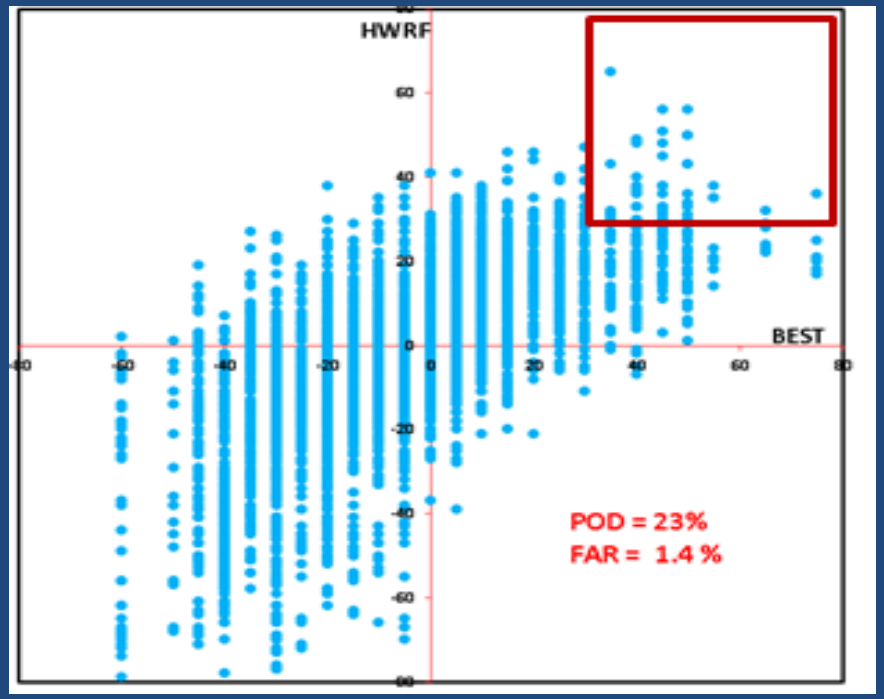


Dramatic reduction of intensity errors with today's technology compared to what was available a decade ago in operations….

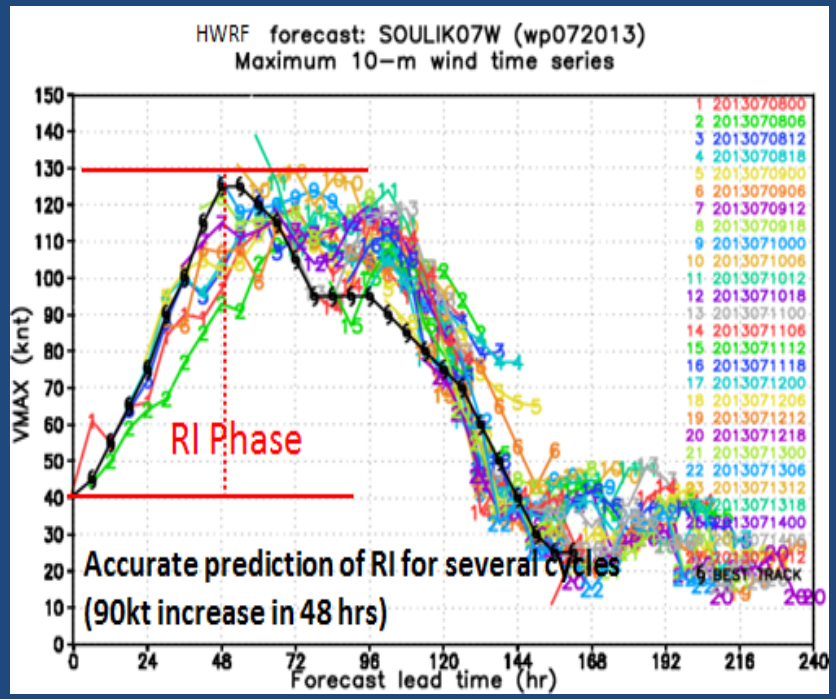
Advanced Research Findings from HWRF Model

Promoting cutting-edge research on Rapid Intensification (RI) Forecasts (intensity change >30 kts in 24 hr period)

Superior rapid intensification forecast skill of the HWRF model



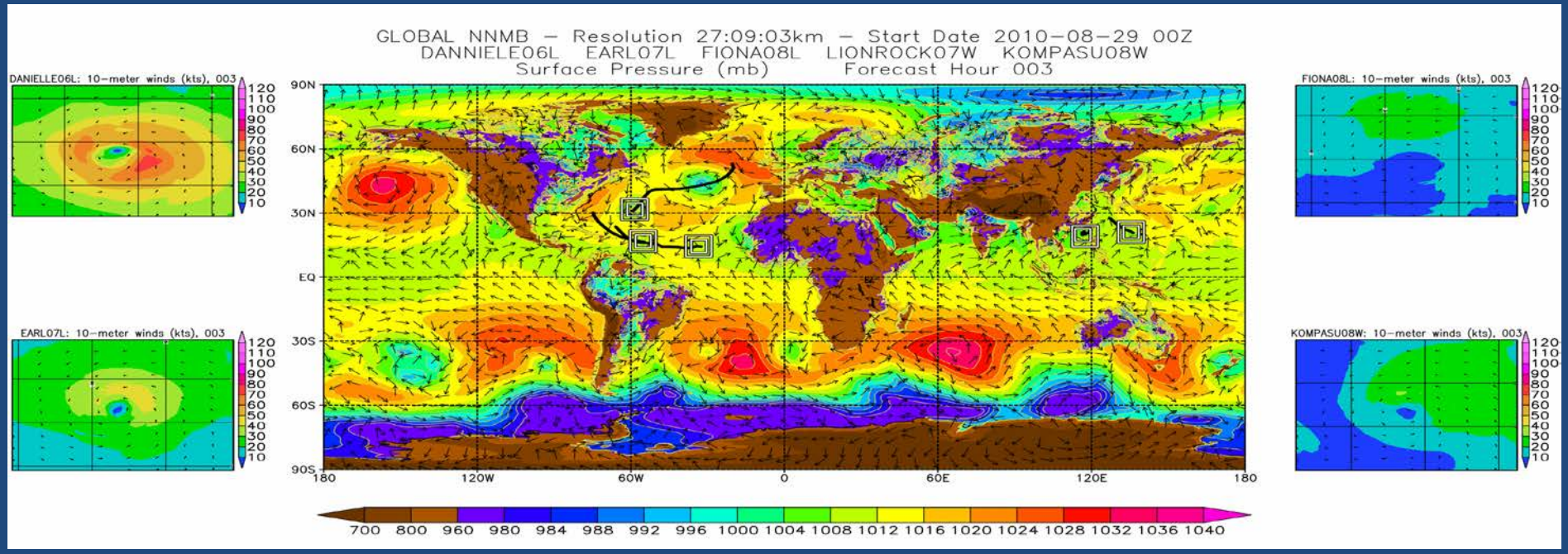
HWRF captured rapid intensification for all 25 Super Typhoons



- Presence of Double Warm-Core in Extremely Intense Hurricanes
- Secondary Eyewalls and Eyewall Replacement Cycles
- Rapid Weakening and New “Hook” Feature

HWRF Future Plans

Next generation hurricane prediction system in a Non-Hydrostatic Multi-Scale Modeling (NMM) framework
Research supported by Sandy Supplemental (HIWPP)



Global-to-local scale hurricane modeling system with multiple moveable nests in a unified NOAA Environmental Modeling System (NEMS)

Advanced scale-aware and stochastic physics with multi-scale interactions

Atmosphere-Land-Ocean-Wave-hydrology coupled with self cycled ensemble data assimilation system

Critical for addressing the next generation forecaster needs, and for more accurate and reliable tropical cyclone forecasts across the world

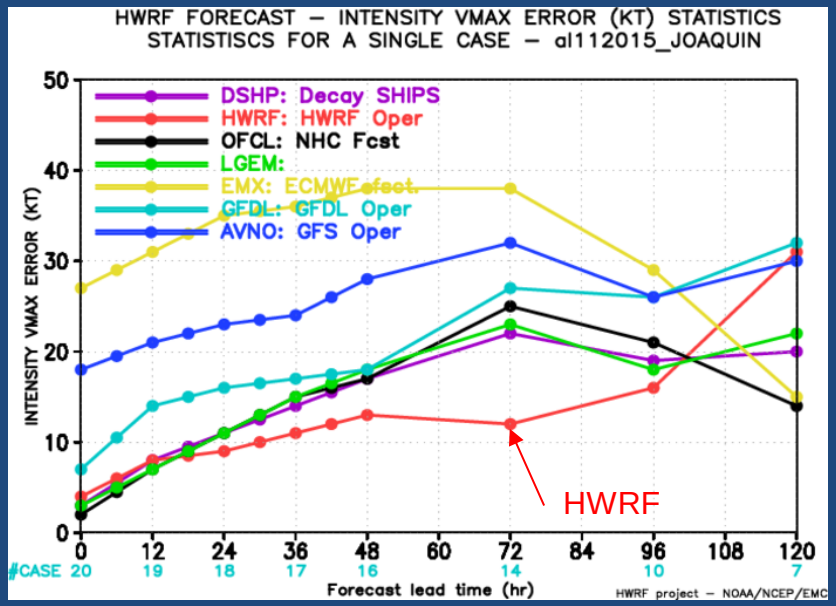
Challenges Ahead: Accomplishing 10-year HFIP Goals

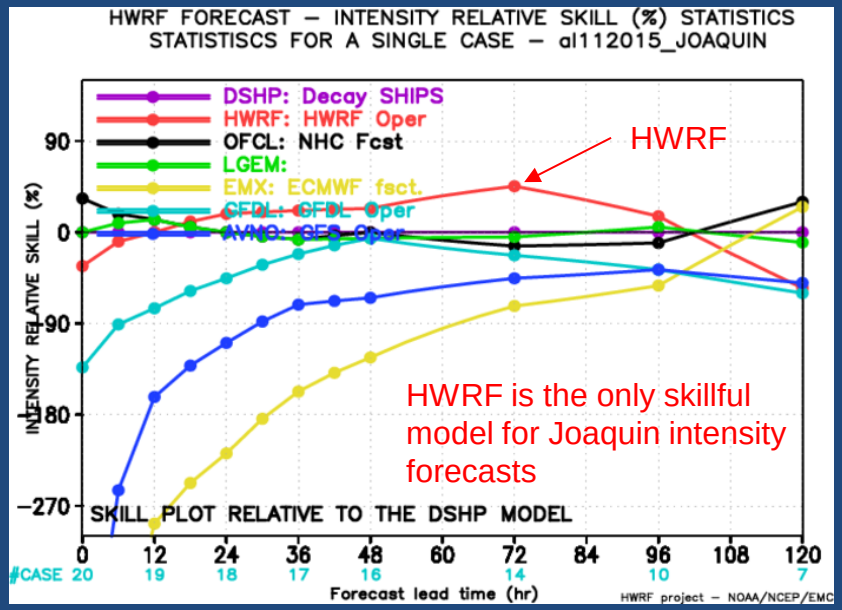
Can we predict rapid intensity changes accurately all the time?
Can we accurately predict hurricane tracks 7-days in advance?

- Comprehensive tropical cyclone forecast solutions for next generation forecaster needs
- Advanced global-to-local scale modeling in operations for reliable, accurate and timely forecast guidance
- Accelerated transition of advanced research into operations initiated by support from HFIP and Sandy Supplemental HIWPP projects
- Support from NOAA's Next Generation Global Prediction System (NGGPS)
- Extend tropical cyclone track and intensity forecast guidance to aid the Decision Support System

Reduction of hurricane forecast errors directly translate to protecting lives and property…….

HWRF continues showing it's superior hurricane intensity forecast performance in real-time…. as seen for Hurricane Joaquin





Support from Sandy Supplemental is accelerating the Research and Development for future operational benefits … Listen in to the next talk by Tim Schneider….

Thanks for your attention!

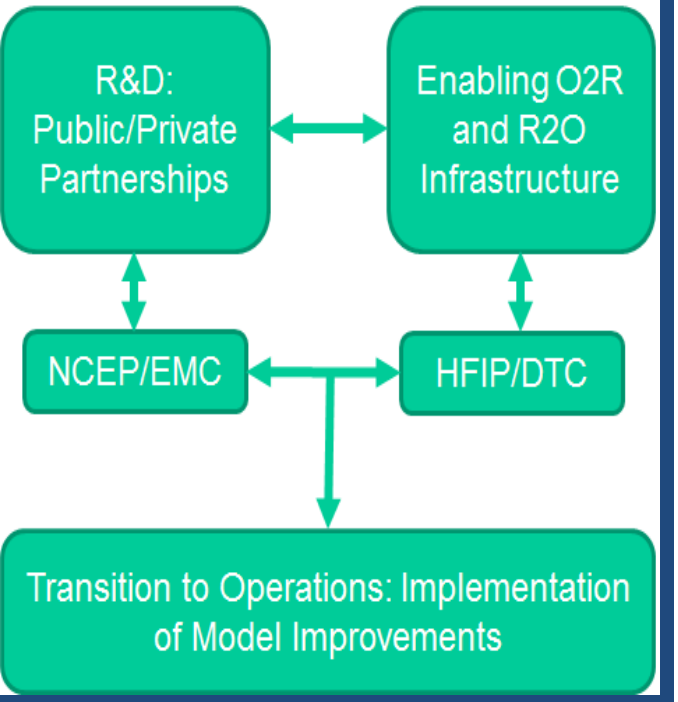
Questions?

Backup Slides

Rapid Progress in Hurricane Forecast Improvements

Key to Success: Community Engagement & Accelerated Research to Operations

Operational Hurricane Modeling System Development



Developmental Testbed Center Support

www.dtcenter.org/HurrWRF/users

- Yearly releases, code downloads, datasets, documentation, helpdesk
- 700 registered users
- Stable, tested code
- Benchmarks available
- Support to HWRF developers in code management

Current release: HWRF v3.5b (2013 operational with several patches)
Next: HWRF v3.6a (2014 operational) 08/2014, concurrent with operational implementation

Developmental Testbed Center

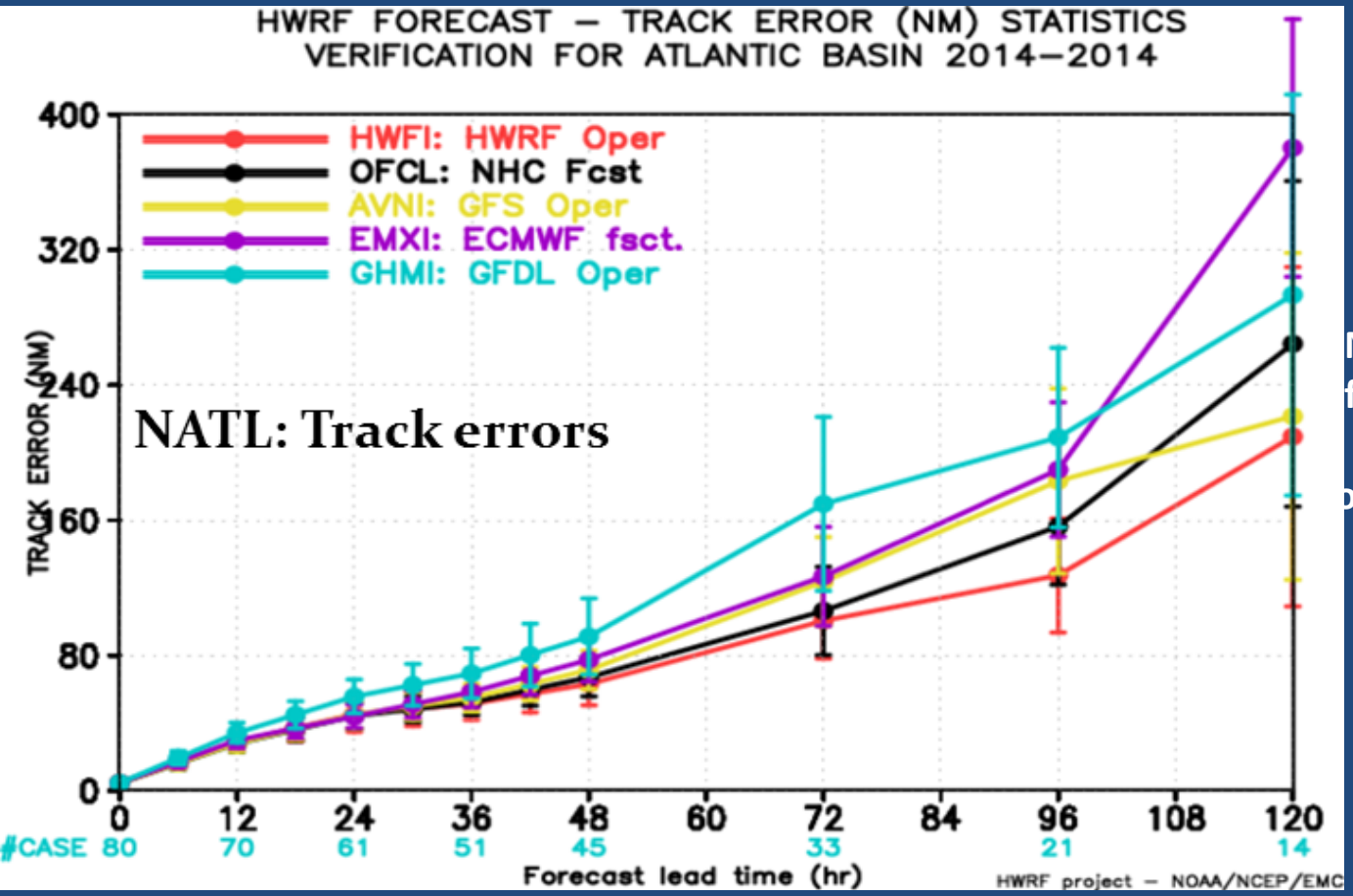
Continue the community modeling approach for accelerated transition of research to operations

International partnerships for accelerated model development & research

Effective and accelerated path for transitioning advanced research into operations

Superior Track, Intensity and Structure Forecasts

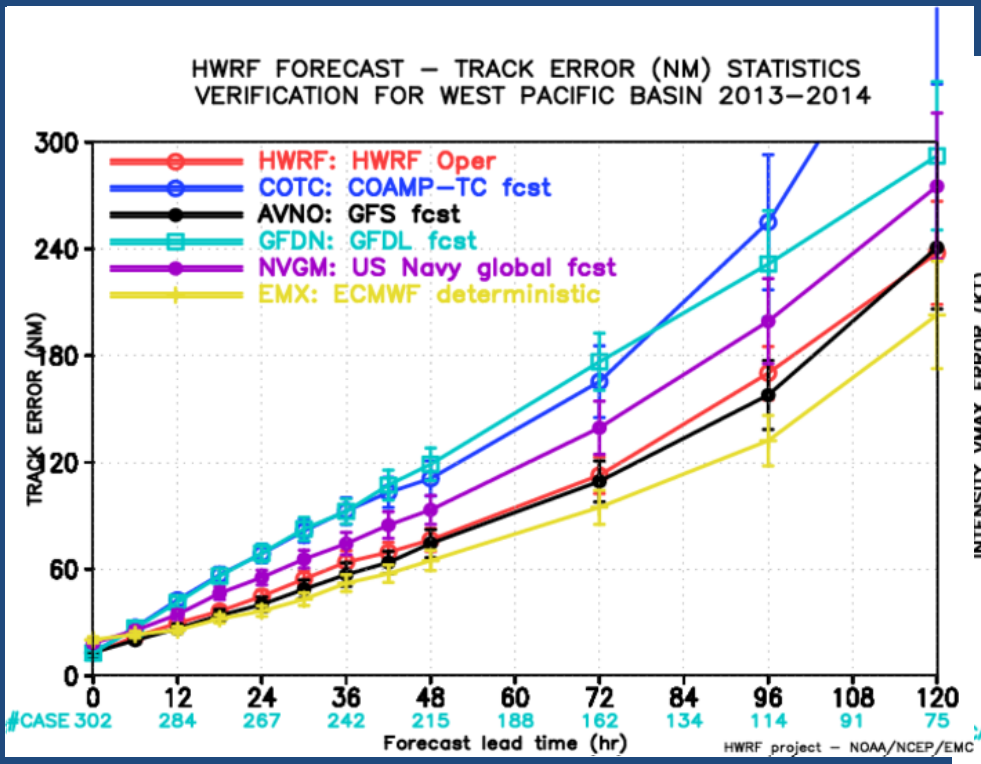
Performance of Operational HWRF in the North Atlantic Basin in 2014

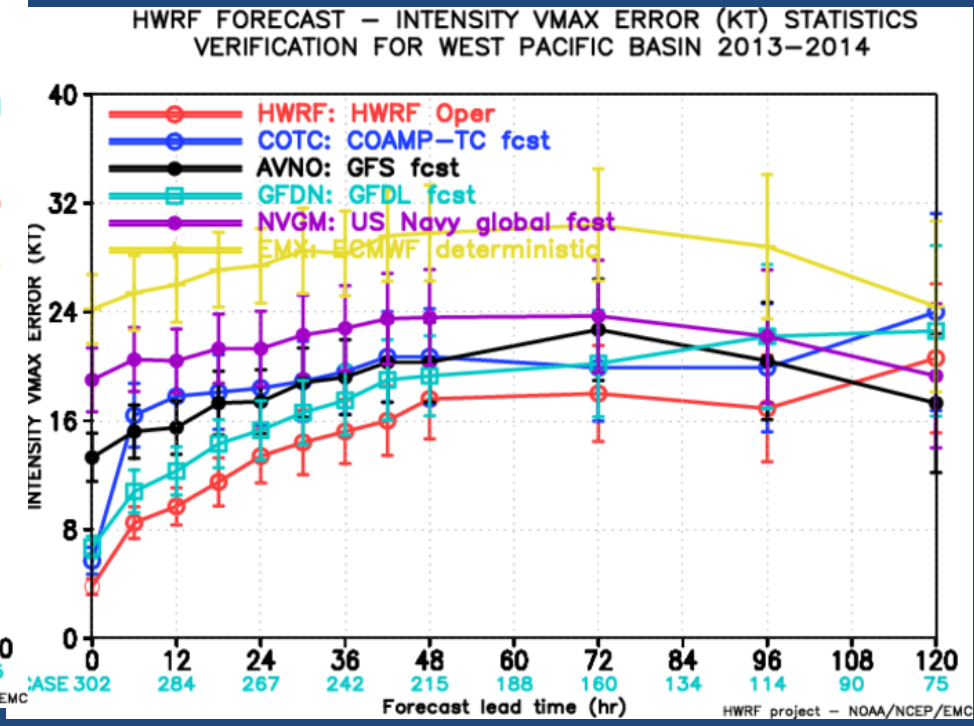


North Atlantic hurricane track forecast errors in 2014: HWRF performed better than any other NWP guidance, including ECMWF

Superior Track, Intensity and Structure Forecasts

Performance of Operational HWRF in the Western North Pacific Basin in 2013-2014



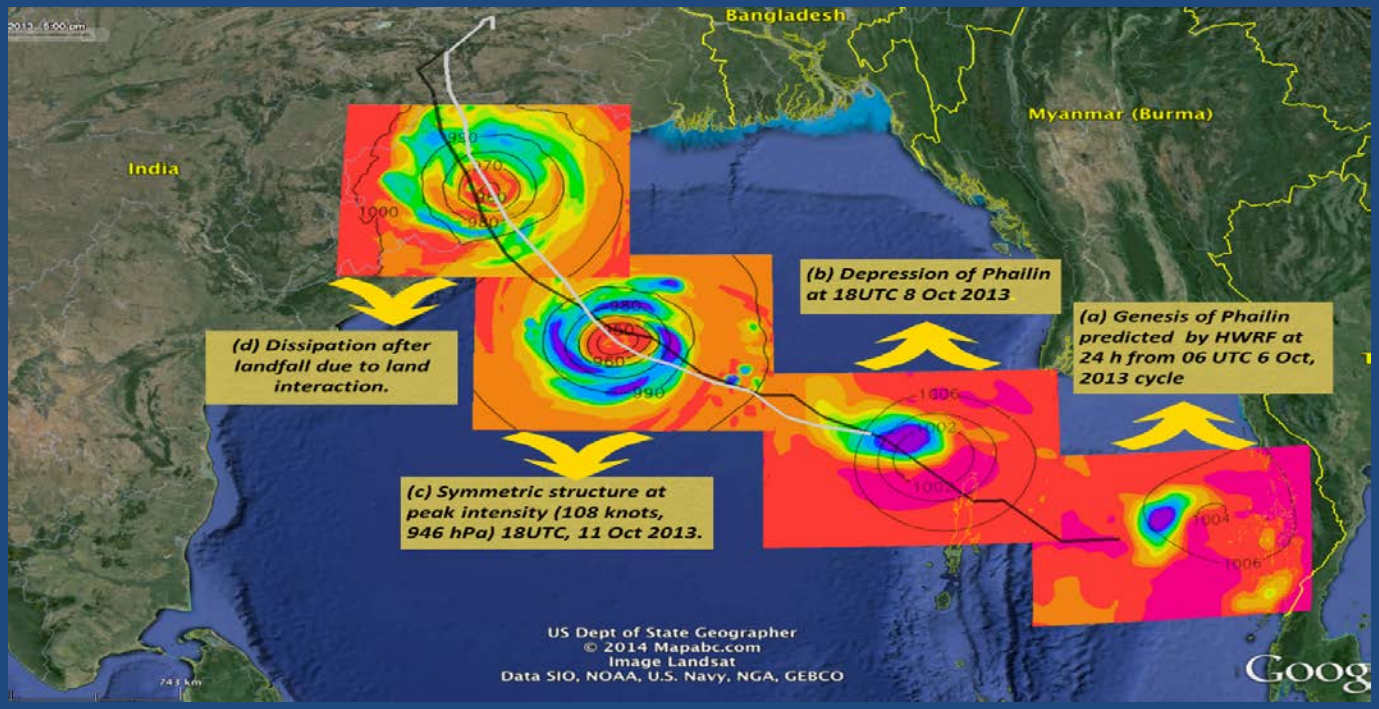


HWRF track forecasts outperformed all regional models; very close to GFS forecasts (ECMWF the best)

HWRF intensity forecasts were best with highly accurate forecasts for many of the strongest storms of 2013-2015

Operational Forecasts for the North Indian Ocean

A success story demonstrated through better preparedness and reduced loss of life for Tropical Cyclone Phailin (2013)



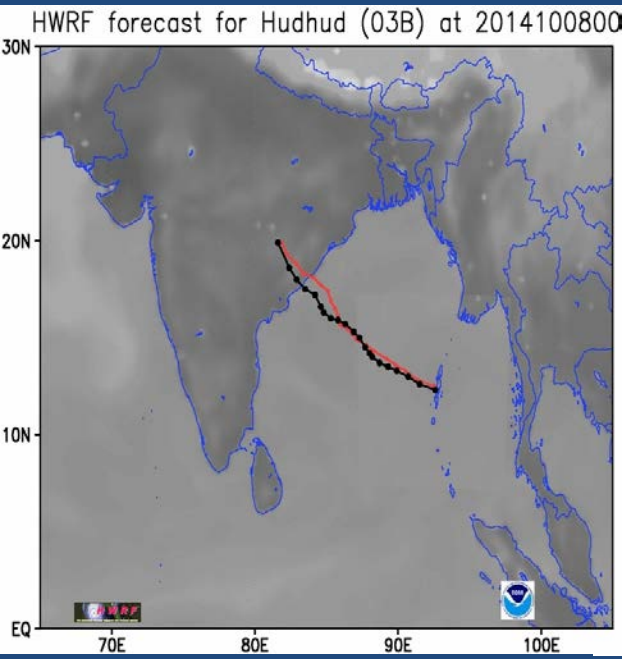
Advanced modelling forecast products given to India Meteorological Department in real-time through the life of Tropical Cyclone Phailin

Numbers of lives saved?

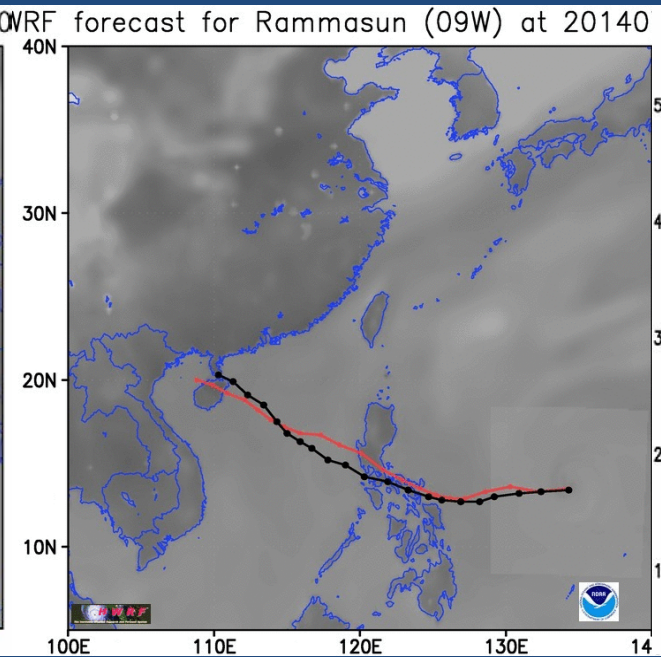
Advanced Forecast Products from HWRF Model

Extended support for Joint Typhoon Warning Center and other international agencies

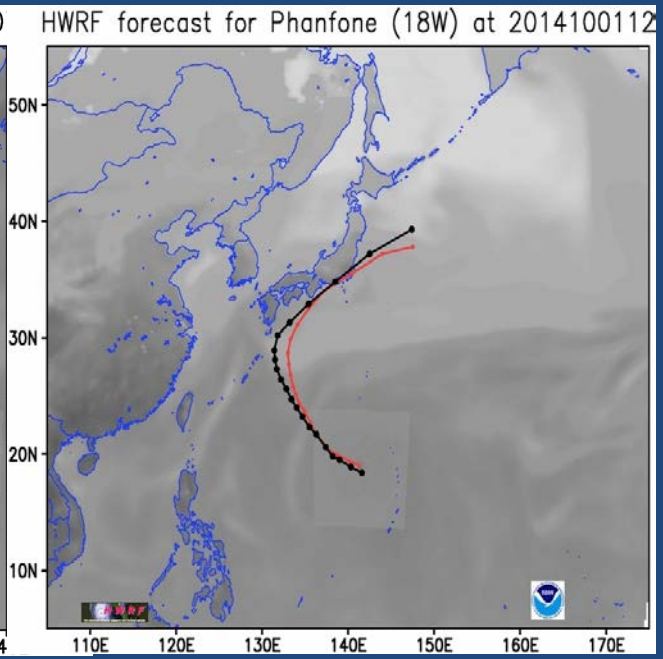
Super Cyclone Hudhud
Bay of Bengal (2014)



Super Typhoon Rammasun
Western Pacific (2014)



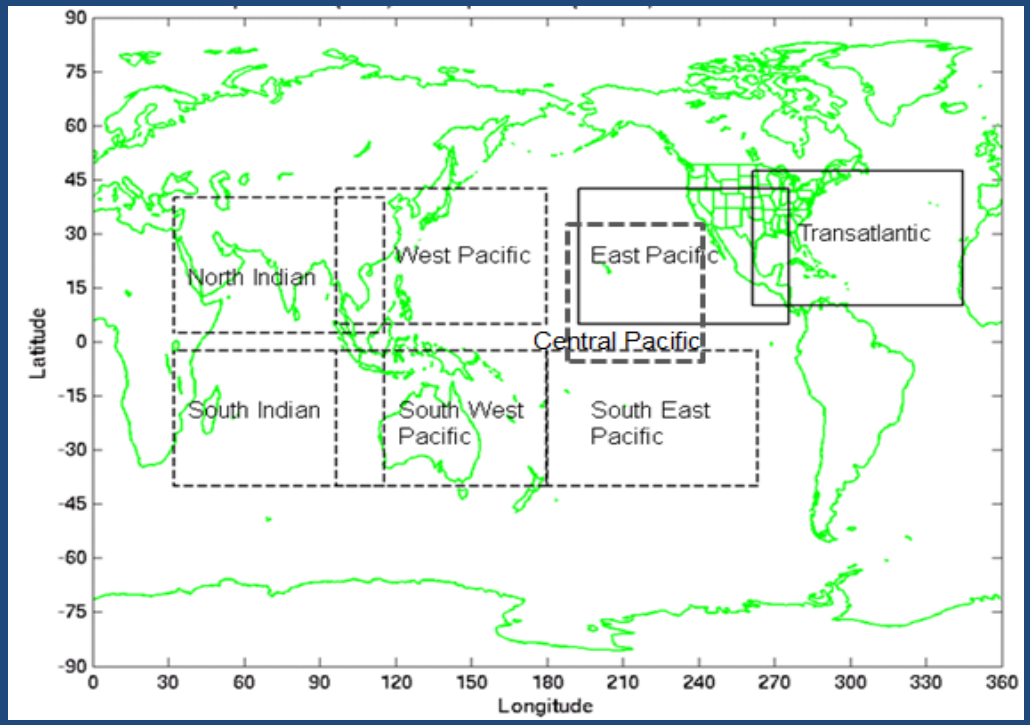
Super Typhoon Phanfone
Western Pacific (2014)

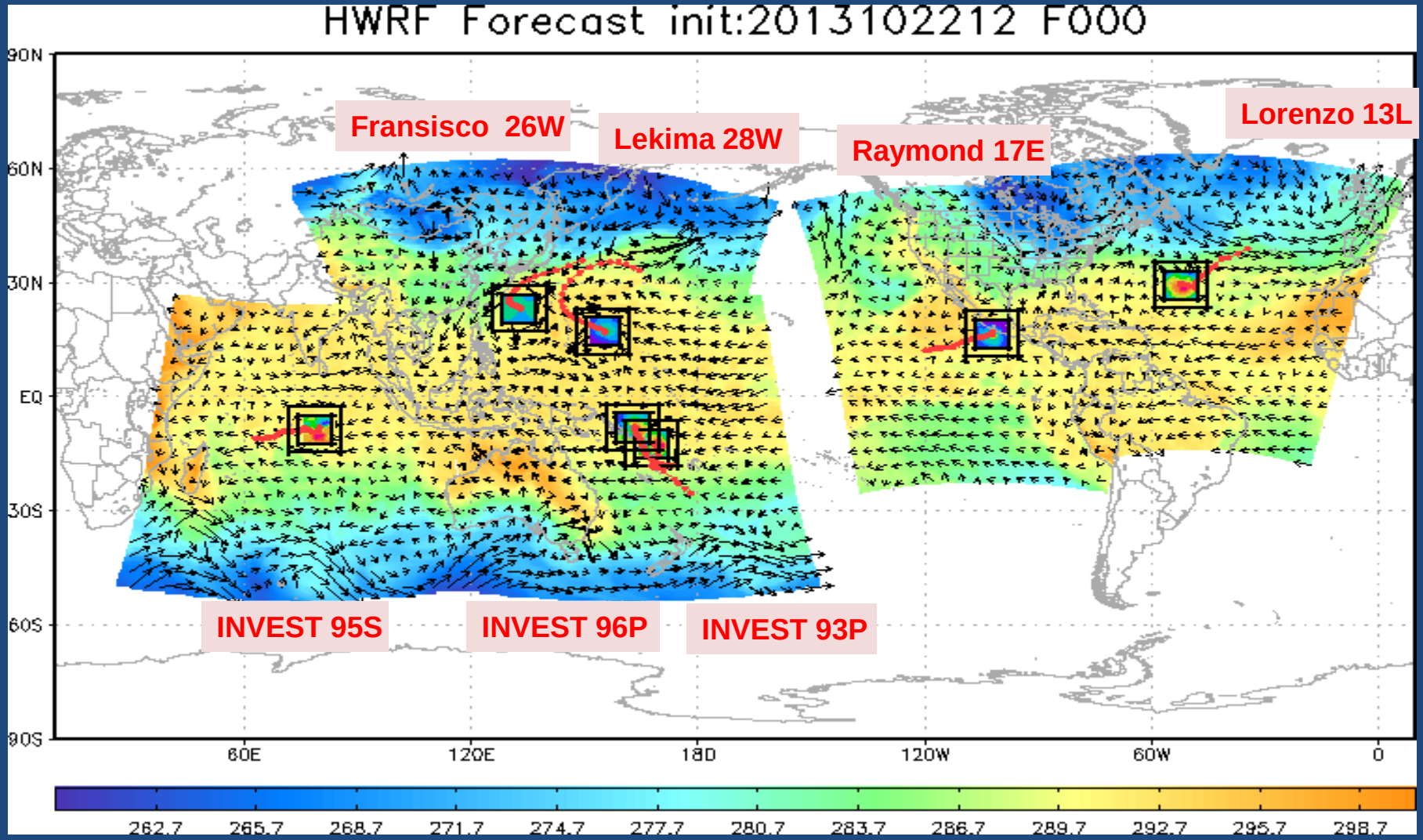


Accurate and skillful track and intensity forecasts from operational HWRF for major land-falling typhoons in the Western North Pacific Basin and tropical cyclones in the North Indian Ocean.

Expansion of HWRF for All Global Tropical Cyclones in 2015

- NOAA leading the path in high-resolution global tropical cyclone forecast guidance:
  - 2 km resolution near the storm area
  - Operates worldwide in the tropics, forecasts up to seven storms, 4x daily throughout the year
  - Coupled to ocean in the Atlantic & Eastern Pacific basins
  - Advanced assimilation of inner core aircraft data
  - Hurricane specific physics based on observations




HWRF Forecast init:2013102212 F000
Fransisco 26W
Lekima 28W
Raymond 17E
Lorenzo 13L
INVEST 95S
INVEST 96P
INVEST 93P
90N
60N
30N
EQ
30S
60S
90S
60E
120E
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120W
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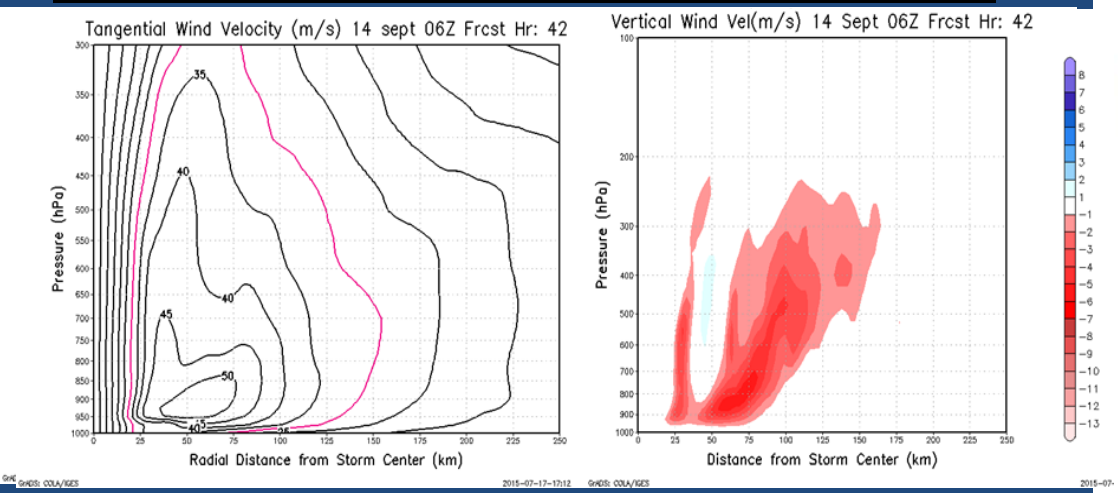
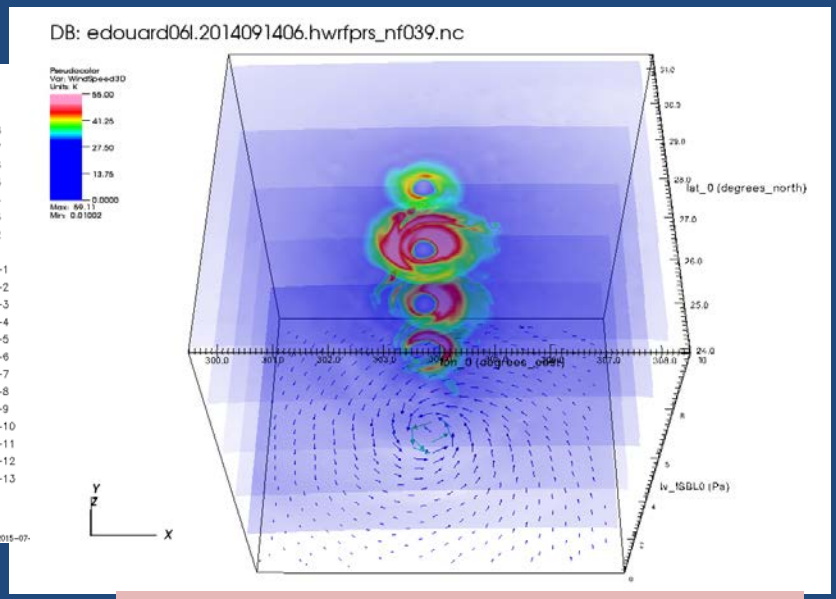
280.7
283.7
286.7
289.7
292.7
295.7
298.7

Advanced Research Findings from HWRF Model

Operational HWRF producing secondary eyewalls in Hurricane Edouard

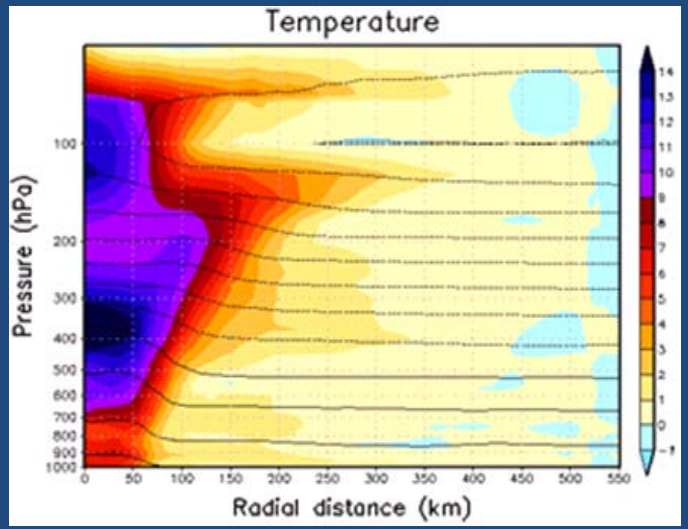
Radius Height Profile of Winds: Forecast Hour 42





Operational HWRF producing secondary eyewalls in Hurricane Edouard

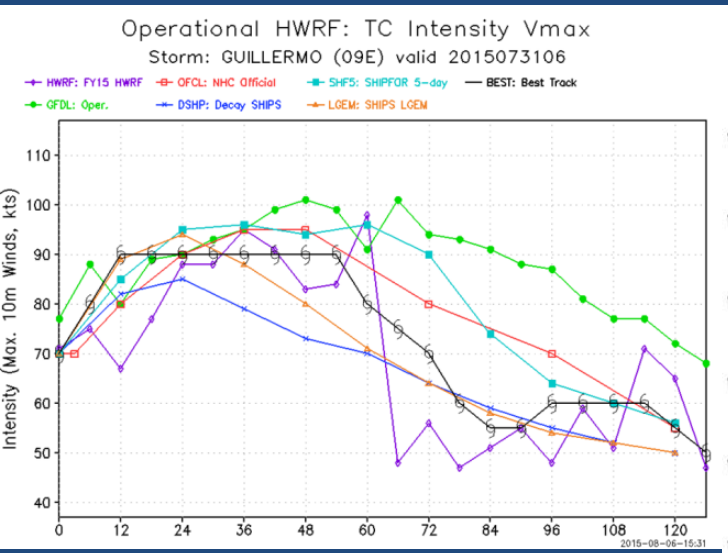
Structure of secondary eyewalls in HWRF



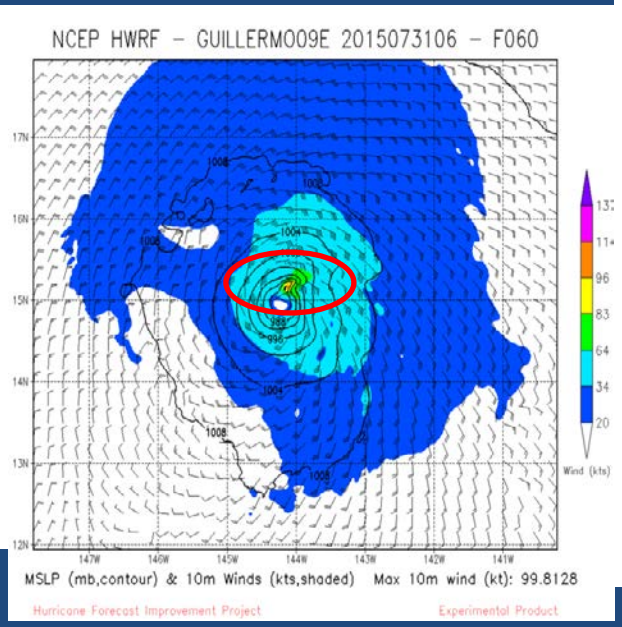
New findings from HWRF on RI: persistent double warm core structure at peak winds >120 kts

Advanced Research Findings from HWRF Model

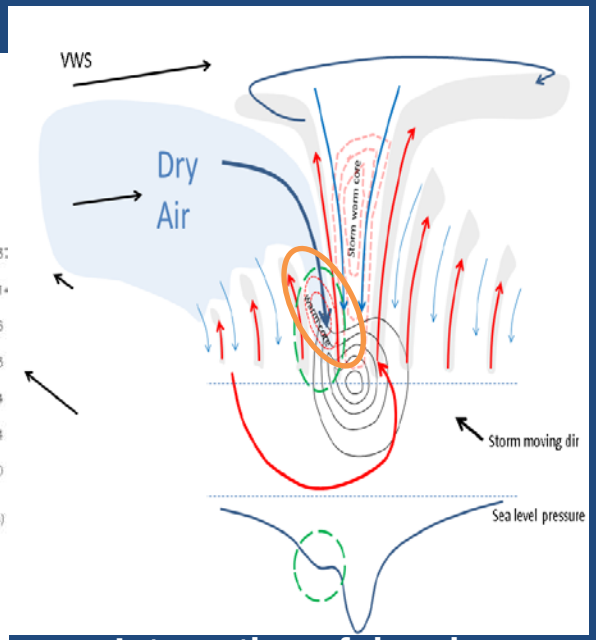
Rapid weakening and a new “hook” Feature triggering sudden demise



Sudden weakening of Hurricane Guillermo (2015)



Indication of local wind maximum with “hook” type MSLP structure



Interaction of dry air, vertical wind shear, and creation of local lower level warm cores

- **Vertical wind shear (VWS) and dry air intrusion weaken the storm by tilting the warm core**
- **Downdrafts associated with dry intrusion generate a local warm core leading to formation of MSLP hook pattern**
- **HWRF model is providing new opportunities to explore tropical cyclone dynamics and intensification**

2014 DOC Gold Medal - HWRF Team

A reflection on Collaborative Efforts between NWS and OAR for accomplishing rapid advancements in hurricane forecast improvements

NWS: Vijay Tallapragada; Qingfu Liu; William Lapenta; Richard Pasch; James Franklin; Simon Tao-Long Hsiao; Frederick Toepfer

OAR: Sundararaman Gopalakrishnan; Thiago Quirino & Frank Marks, Jr.

HWRF™
The Hurricane Weather Research And Forecast System

NOAA HURRICANE FORECAST IMPROVEMENT PROJECT