Outline

• History of TC forecast improvements in relation to model development

• Ongoing developments

• Future direction: A new model
History: Error trends

- Hurricane track forecasts have improved markedly.
- The average Day-3 forecast location error is now about what Day-1 error was in 1990.
- These improvements are largely tied to improvements in large-scale forecasts.

![Official TC Track Forecast Errors: 1990-2020](chart.png)
History: Error trends

- Hurricane track forecasts have improved markedly
- The average Day-3 forecast location error is now about what Day-1 error was in 1990
- These improvements are largely tied to improvements in large-scale forecasts
History: Error trends

- Hurricane intensity forecasts have only recently improved.
- Improvement in intensity forecast largely corresponds with commencement of Hurricane Forecast Improvement Project.
History: Error trends

- Significant focus of HFIP has been the development of the HWRF model.
- As a result, HWRF intensity has improved significantly over the past decade.

HWRF skill has improved up to 60%! 

HWRF Intensity Skill

Day 1               Day 3               Day 5

HWRF better   Climo better

2017-2019 HWRF
2014-2016 HWRF
2011-2013 HWRF
Talk focus:
How better use of data, particularly from recon, has helped improve forecasts
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How better use of data, particularly from recon, has helped improve forecasts.
US has used dropsondes for TC model forecast improvement since 1997

Aberson (2010, 2011) examined impact of dropsondes in GFS

Significant track improvement globally

Impact of dropsondes in September 2008
• Starting in 2008, it became apparent that assimilating 88D Doppler velocity could improve coastal TC forecasts

• Assimilating radar data significantly improved analyses and forecasts of Hurricane Humberto
Starting in 2008, it became apparent that assimilating 88D Doppler velocity could improve coastal TC forecasts.

- Assimilating radar data significantly improved analyses and forecasts of Hurricane Humberto.
Subsequent work showed forecast improvements from assimilating tail Doppler radar (TDR) velocity from NOAA recon.

These results led to a dedicated effort to assimilate TDR operationally.
• TDR data began being assimilated in HWRF in 2013

• For weak storms like Karen (left), there was substantial improvement of a positive intensity bias in HWRF
• Results worse over larger sample

• Major problem was short-term forecast degradation

• Cause was physics and data assimilation deficiencies for strong storms

**2013 HWRF recon impact: Intensity**

- Error (kt) vs Day
- Larger errors with recon
- No recon
- Recon

```
Day1 | Day2 | Day3 | Day4 | Day5
---|-----|-----|-----|-----
20 | 10 | 0 | 0 | 0
```
History: HWRF improvements

• Increasing resolution AND improving physics (diffusion/mixing) are necessary

• The challenge is to make physics changes that don’t make every TD a Cat 5
History: HWRF improvements

- Data assimilation improvements are also necessary
- Experimental OU system with better data assimilation system performs much better

![Graph showing experimental & operational intensity errors](Image)
History: HWRF improvements

GSI-based DA
GSI hybrid
P3 Doppler velocity
Dropsondes (partial)
Global Hawk dropsondes
Warm-start HWRF ensemble
SLP from TCVitals
Satellite radiances/winds (D03)
Flight-level obs.
Fully-cycled DA (EnKF/GSI)
SFMR
Dropsondes (all with drift)
G-IV Doppler velocity
Stochastic physics (DA)
Spectral filter for increments
Dynamic obs. errors for recon
WSR-88D Doppler velocity
CURRENT OBSERVATIONS ASSIMILATED BY HWRF INCLUDE:

- Conventional observations (radiosondes, dropwindsondes, aircraft, ships, buoys, surface observations over land, scatterometer, etc)
- NEXRAD 88-D Doppler velocity
- ALL reconnaissance (HDOB, TDR)
- Atmospheric motion vectors
- Clear-sky satellite radiance observations
History: HWRF improvements

- Recon benefit assessed in 2016-2018 high impact storms
- Many major hurricanes in this sample
- Recon has a clear positive impact on intensity, 10-15% improvement through 72h

Intensity error in 2019 HWRF

<table>
<thead>
<tr>
<th>Day</th>
<th>Error (kt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day1</td>
<td></td>
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<tr>
<td>Day2</td>
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<tr>
<td>Day3</td>
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<tr>
<td>Day4</td>
<td></td>
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<tr>
<td>Day5</td>
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</tr>
</tbody>
</table>

No recon
Recon
History: Recent Performance

- Model intensity skill varies greatly by region
- Highest skill is where we have the most data (esp. HWRF)
“End-point” dropsondes from USAF C-130 missions

- Dropsondes at end-points of “alpha” pattern from C-130 missions tested in 2017
- Data denial tests suggested a 10% impact on intensity skill
- Based on these results, this practice was implemented operationally in 2018
• Track and intensity errors are both improving

• DA & Physics improvements jointly improve model performance

• Significant improvements in HWRF DA system and data usage
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Ongoing developments

- Upgrade to GFSV16 in March included better use of dropsondes and flight-level data
- Added data improves entire NATL sample track by ~5%
- Higher impact in cycles with data & strong storms
Ongoing developments

- Ongoing work assessing how best to deploy dropsondes using basin-scale HWRF

- Dropsondes directly benefit track by 5-10% and intensity by 10-15%

- Removing dropsondes anywhere (e.g., inner core vs. environment, etc.) has negative consequences
Ongoing developments

- Majority of HWRF development thus far has focused over ocean
- Known physics issues over land need to be addressed
- Major sources of data over land not currently assimilated

Mesonet test: Track Error (km)

Mesonet test: Intensity Error (kt)
Ongoing developments

• Ongoing work is examining the impact of mesonet and METAR data on HWRF

• Initial results show a large positive track benefit and smaller benefit for intensity and other metrics
Ongoing developments

Improving the DA system improves analyses

High-frequency full cycling alleviates imbalance.

Courtesy Xuguang Wang, HFIP partner
Ongoing developments

Improving the DA system improves analyses

4DEnVAR alleviates imbalance as well.

3DEnVAR – 6h

4DEnVAR – 6h

Courtesy Xuguang Wang, HFIP partner
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Future direction: HAFS
(Hurricane Analysis and Forecast System)
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**MAJOR BENEFITS OF HAFS:**

- More flexible / capable data assimilation system than HWRF
- Much better use of satellite data than HWRF
- Realistic storm interaction, not possible in HWRF

**RESULT:**

- Better initialization of vortex and environment
- Improved track and intensity forecasts
Conclusions

• NOAA TC prediction is undergoing dramatic advancements, lead by improvements in global models and HWRF

• We are using more of the available data in DA

• Long term plans address ongoing issues and allow for greater data usage

• The above factors should contribute to intensity improvement in particular