Diagnostics for Evaluating Hurricane Model Forecast Errors

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Dave Zelinsky, NOAA/NHC

HFIP Physics Workshop
September 17-18, 2012
Outline

• Summary of HFIP Diagnostics Workshop Aug 2012

• Diagnostics for improving physics
  – Comparison with satellite observations
    • NHC, CIRA, JPL
  – Comparison with radar and in situ observations
    • HRD, SUNYA
  – Verification of model fields
    • DTC, NRL, CIRA
  – Evaluation in theoretical frameworks
    • UCLA, FSU, CIRA
HFIP Diagnostics Workshop

• Mostly Virtual from EMC, Aug 10\textsuperscript{th} 2012
  – http://rammb.cira.colostate.edu/research/tropical_cyclones/hfip/workshop_2012/

• Participants
  – NOAA/NWS
    • EMC, NHC
  – NOAA Research
    • ESRL, GFDL, HRD, NESDIS
  – NCAR
    • DTC, TCMT
  – NASA
    • JPL
  – University
    • CSU, FSU, SUNYA, UCLA

• Progress review of the ADD Team milestones
• Ensure coordination with EMC and NHC priorities
Model Evaluations using Microwave Imagery (D. Zelinsky, NHC)

- Similar to CIRA study with GOES data
- Use radiative transfer model to create synthetic microwave imagery (~89 GHz)
- Compare with imagery from real storm
- Initial study concentrates on eyewall features
Sample Forecast: Debby HWRF forecast (above) and observed microwave images (right)
Methodology: Evaluating Primary Band Forecasts

3) Is deep convection present within clearly defined (unbroken) bands that spiral around the center?
- If no, band = 0.
- If yes, fit the Dvorak log-10 spiral to the middle of the band and count the number of tenths.
- Note: If the band continues unbroken into an eyewall, the eyewall can count as part of the band, as long as at least 3/10 of that band exists completely independently of the eyewall itself.
Preliminary Results:
48 hour Eyewall Forecasts

Contingency Table

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Stats

- Total Cases: **76**
- Contingency Accuracy: **82.89%**
- Probability of Detection: **47.62%**
- False Alarm Rate: **03.64%**
- Success Ratio: **83.33%**
- ETS: **0.34**
JPL Research using the TCIS Data Archive: MODEL EVALUATION – the Microphysics
Comparison of Synthetic and Real GOES Data for Hurricane Maria 2011 (CIRA)

Synthetic GOES WV Image
24 hr HWRF Forecast valid at 00 UTC on 13 Sept 2011

Real GOES WV Image
at 00 UTC on 13 Sept 2011
GOES Water Vapor $T_B$ Histograms for 48 h Maria Forecasts

HWRF Operational

HWRF H212

(Dashed= Model,  Solid=Observed)
HRD Model Evaluations

• Comparison with in situ and radar data
  – Airborne Doppler, SFMR, GPS soundings, flight level data
• Composite vorticity structures, boundary parameters
• Low wavenumber wind fields
Height of $V_{t\text{max}}$

Black dashed line represents the height of maximum tangential wind speed.
DTC Evaluation of Basin-Scale HWRF

- BHWRF forecast fields
  - 570 forecast cases
  - Cold-started from GFS analysis

- GFS analysis fields
  - 615 forecast cases
  - PRE13HI

Compute paired differences

Accumulate differences by forecast lead time

- 3D temp
- 3D u and v
- 3D rel. hum.
- 3D sp. hum.
- 3D geopotential

\[ eVAR = MSE - BIAS^2 \]

~730 possible forecast cases from 2011060318 to 2011112506

cloud water precipitable water precipitation surface pressure skin temperature
COAMPS-TC
High-frequency TC model output (HTCF)

COAMPS-TC intensity prediction for Irene, initial time = 2011082400

Maximum surface wind speed (kt)

Lead time (h)
The GFDL ENSEMBLE PRODUCT ALSO SHOWED HUGE SPREAD IN INTENSITY. LARGEST IMPACT WAS WITH INCREASE / DECREASE OF INNER-CORE MOISTURE BY 10% (PERTURBATION MAXIMUM AT STORM CENTER)

IMPACT OF MOISTURE MORE IMPORTANT THAN +1 degree C SST INCREASE

GFDL Ensemble Forecast for ERNEST005L: Maximum Wind
Initial time: 00Z04AUG2012
CIRA Diagnostic File from HWRF
Used for Large-Scale Parameter Verification

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CIRA Study to Understand Large-Scale Controls on Model Intensity Evolution

Fit simplified LGEM model to HWRF and GFDL Output
UCLA Physics Parameterization Study
Using Motion and PV Diagnostics to Understand Differences

- **Goal #1**: To determine if systematic biases exist in various cumulus parameterization (CP) schemes
- **Goal #2**: To assess how well CP schemes work with microphysics (MP) and radiation assumptions
- **Technique**: construct vortex-following composite fields and analyze differences among physics-based ensemble members, including PV analysis
- Reminder: The PV equation diabatic heating (DH) term is based on gradients of diabatic heating ($Q$) and absolute vorticity ($\mathbf{q}$), not $Q$ or vertical velocity itself
Vortex vs. Environment

Torn and Cook (2012), MWR In Press
FSU ERROR FINDING ALGORITHM

Total tendency errors can be estimated from the following equation:

\[ e_{ijkl} = \left( \frac{\partial Q}{\partial t} \right)_{ijkl}^{\text{mod}} e_l - \left( \frac{\partial Q}{\partial t} \right)_{ijkl}^{\text{analysis}} \]

Where \( i, j \) and \( k \) denote an index for the three co-ordinates, and \( l \) the variable. The three-dimensional (multiple regression based) multiplier \( \lambda_{ijkl} \) is defined such that:

\[ \left( \frac{\partial Q}{\partial t} \right)_{ijkl}^{\text{analysis}} = \sum \lambda_{ijkl} \left( \frac{\partial Q}{\partial t} \right)_{ijkl}^{\text{mod}} e_l \]

The determination of \( \lambda_{ijkl} \) utilizes the least squares minimization procedure based on several multiple linear regression. \( \lambda_{ijkl} \) provides mean for statistically corrected estimates of the forcing for the dynamics and physics of any of the equations while minimizing (towards 0) the total tendency error. The four dimensionally distributed error at a grid location is given by \( (1 - \lambda_{ijkl}) A_{ijkl} \)
Summary

• Diagnostic studies can help evaluate errors due to model physics
  – Comparisons with satellite, radar and in situ data
• Physics errors contribute to large, vortex and cloud scale errors
• Verification combined with diagnostic studies can help identify the source of errors
  – PV budgets, FSU least squares method, SUNYA EOF1, GFDL ensemble system, CIRA fits of statistical models to dynamical model output