Evaluation of Hail Size Forecasting Models during the 2016 Hazardous Weather Testbed Spring Experiment

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Motivation

• Convection-allowing models can partially resolve individual storms but not their associated hazards
• Severe hazard diagnostics provide direct assessments of severe hazard potential and intensity, unlike storm surrogates
• Three hail diagnostic methods were evaluated during the 2016 NOAA Hazardous Weather Testbed Spring Experiment
• Both subjective and statistical evaluations of methods were performed
# NWP Model Output and Hail Observations

<table>
<thead>
<tr>
<th>Ensemble</th>
<th>CAPS Ensemble</th>
<th>NCAR Ensemble</th>
</tr>
</thead>
<tbody>
<tr>
<td>Members</td>
<td>19 WRF-ARW</td>
<td>10 WRF-ARW</td>
</tr>
<tr>
<td>Grid Spacing</td>
<td>3 km</td>
<td>3 km</td>
</tr>
<tr>
<td>Microphysics</td>
<td>Thompson, Morrison, MY, P3</td>
<td>Thompson</td>
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<tr>
<td>PBL Schemes</td>
<td>MYJ, MYNN, YSU</td>
<td>MYJ</td>
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<tr>
<td>Data Assimilation</td>
<td>3DVAR + cloud analysis</td>
<td>DART Cycled Ens. Adjustment KF</td>
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**Hail Observations:** NOAA NSSL Multi-Radar Multi-Sensor Maximum Expected Size of Hail: estimate of maximum hail size derived from radar reflectivity above freezing level. Estimate calculated from 3D radar mosaic.
Hail Forecast Methods

• Thompson Hail Size Method
  • Estimate hail size directly from microphysics size distribution
  • Finds largest diameter that exceeds a specified number concentration

• WRF-HAILCAST
  • 1D hail growth model embedded in each grid cell
  • Grows ensemble of hailstones based on vertical profile
  • Triggered when updraft speed exceeds a certain threshold

• Gagne Hail Model
  • Storm-based machine learning hail forecast method
  • Storm tracker identifies potential hailstorms, extracts storm and environment information
  • Machine learning models predict probability of hail and spatial hail size distribution
Subjective Verification

- A group of forecasters viewed a time series of 4-hour probabilities of 1 inch and 2 inch hail from each method
- Compared with MESH and preliminary storm reports
- Rated the overall forecast quality from 1 (poor) to 10 (great)
- Performance over time was aggregated
- Separate ratings for 1 and 2 inch hail
Subjective Verification Statistics

Observations
• None of the hail diagnostics are clearly superior
• Gagne hail tends to be either best or worst method on a given day
• Gagne hail is more conservative with large hail, which benefits it on days with no large hail
• The average rating for Thompson is higher for 2 inch hail than 1 inch hail
Storm-Based Verification

1. Use enhanced watershed to identify storms in the output of each hail forecast method
2. Apply enhanced watershed to MRMS MESH data
3. Extract statistics on storm and environment variables within each hail object
4. Compare place of objects from each hail model
Microphysics Effects, or the Problem with Multi-Physics Ensembles
Hail Size Distribution Comparisons

- WRF-HAILCAST overestimates the frequency of small hail and underestimates the frequency of large hail.
- Thompson matches the relative frequency of MESH for 50 to 80 mm hail but underestimates the frequency otherwise except between 20 and 30 mm
Hail Storm Biases

- HAILCAST produces hailstorms in the Southeast along the coast associated with wind reports but not hail
  - May not be melting hail enough in those environments
- Thompson under-produces hail in the Southeast but produces many spurious hailstorms in the Mountain West
  - Tied to graupel reaching high altitude surfaces
Large Hail Object Pairings
Ongoing Work

• Hailstorm clustering
  • Grouping storms spatially and examining overlap with observed storms
  • Off-the-shelf clustering methods do not produce desired results
  • Best option so far: agglomerative clustering with maximum distance constraint

• Verification conditioned on environment
  • Want to evaluate each algorithm on how it performs in different parts of storm environment feature space
  • Interested in different combinations of CAPE and shear
Summary

• The 2016 Hazardous Weather Testbed Spring Experiment provided an opportunity to compare 3 hail size diagnostics for convection-allowing models

• Subjective verification shows no model consistently performs the best

• More work needs to be done to optimize other hail algorithms for microphysics other than Thompson

• Both HAILCAST and Thompson produce large hail but often not in the same storms

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