Hail and the Climate System: Large Scale Environment Relationships for the Continental United States 1979-2012

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IRI

WSC 2014, Thursday August 21st 2014
The Challenge

• How do we extend forecasts of severe weather phenomena (e.g. hail, tornadoes) to periods outside a week, or look at links to climatic patterns (e.g. ENSO) or climate change?

Our Approach

• Severe thunderstorm likelihood can be related to the preceding environmental conditions.

• Choice between Dynamical or Statistical approaches.

• Can we define a statistical relationship that describes the occurrence of hail?

• How does this relationship ‘Index’ compare to climatology and inter-annual variability?

• How useful is this index for relationships to climate and seasonal prediction?
Significant Severe Discriminant:
Probability of severe thunderstorm with F2 tornado, 5cm hail, or 120 km/h wind gusts

US radiosonde soundings when launched in the vicinity of severe thunderstorms.

Significant severe parameter (Brooks et al. 20)
CAPE x 0-6 km Shear > 10,000 m³ s⁻³
Figure from Brooks and Dotzek (2008)
Tornado & Hail Observational Climatologies Are Different

(a) Mean Annual Large Hail Reports
(b) Mean Annual Tornado Reports

a) Gridded Mean NCDC observed reports for hail greater than one inch 1979-2012.
b) Gridded Mean NCDC tornado observations, all tornadoes 1979-2012.
You Can’t Just Bias Correct For Population

a) Point reports for hail greater than one inch 1979-2012 for the central great plains.

b) Grid and 1 degree Hail Events greater than one inch 1979-2012
How a change in the extremes (exceeding the 90th percentile) will be represented in the mean of a distribution relative to climatology. (Tippet et al. 2014)
A Monthly Environmental Relationship for Hail

- Use parameters than can be observed-modeled to develop a relationship.

- Assume a Poisson (log-linear) relationship

$$\text{Index} = \exp(c + \log(\Delta x \Delta y T \cos \phi))$$

- 20+ potential Monthly Mean parameters:
  - **Thermodynamic:** (CAPE, CIN, Convective Precip., Lifted Condensation Level, Surface Theta-E, Surface to Freezing level relative humidity, FZL, LI)
  - **Kinematic:** (Bulk Layer Shears, SRH)
  - **Simple:** (Qmean, SoilM01, Temperature at 500mb), Population, Elevation

- Estimate constants using Poisson Regression from observed climatology of hail for the entire U.S. – avoids issues with changing technology and reporting.

- Data: Monthly mean NARR or derived parameters on 1° x 1° grid, NCDC/SPC hail events greater than one inch 1979-2012
A 4-Parameter Hail Index

TOP: Mean annual 4-parameter Hail index for hail greater than one inch 1979-2012.

BOTTOM: Mean annual observed hail events for hail greater than one inch 1979-2012.

\[ \mu(x) = \exp(-10.18 + 0.97 \log(\text{cPrp}) + 1.13 \log(\text{SRH}) + 1.00 \log(\text{MLCAPE}) - 0.31 \text{Q}_{\text{mean}} + \text{offset}) \]

Allen et al. (2014a)
Top: Differences between Mean annual observed hail and hail index.
Left: Mean annual Hail index for hail greater than one inch 2007-2010.
Right: Radar derived mean annual hail frequency from Cintineo et al. (2012)
Comparison to Tornado Index

TOP: Mean annual Hail index for hail greater than one inch 1979-2012.

\[
\mu_{\text{Tornado}}(x) = \exp \left[ -10.59 + 1.36 \log(c\text{Prp}) + 1.89 \log(SRH) + \text{offset} \right]
\]

BOTTOM: Mean annual 2-parameter Tornado index for all tornadoes F0+ 1979-2012.

(Tippett et al. 2012, 2014)
Spatial Seasonality – Hail Index

(a) Mean observed peak month of observed hail events 1979-2012.

(b) Mean observed peak month of Hail index 1979-2012.
Seasonal variability of the hail index as compared to observations. Lines are mean index (grey) and obs. (black) seasonal cycle, whiskers reflect 2.7sigma (99.3%) of the potential monthly totals. Dots show outlying years.
Seasonal Performance – NOAA Climate Regions

Not all regions are well represented reflecting index regional sensitivities and parameter biases.
Variability in annual total of hail reports as compared to the index for the period 1979-2012. The adjusted observations have been linearly detrended.
Seasonal Climatology of Hail (Observations and Index)

Mean DJF and MAM Climatology for Hail Index and Events 1979-2012

Allen et al. (2014b)
Composites of El Niño and La Niña DJFs based on 7 and 6 year composites respectively selected using ONI ±1. Stippling is for Monte Carlo derived significance at the two-tailed 95% level.
Composites of El Niño and La Niña MAMs based on 7 and 6 year composites respectively selected using ONI ±0.5. Stippling is for Monte Carlo derived significance at the two-tailed 95% level.
MAM Composites of Environmental variables for El Niño and La Niña

ENSO Teleconnection MAM – Synoptic and Environment
Scatter of box (bounded by 100-90W and 31-36N) total index for hail and observed hail events against seasonal ONI for a) MAM ONI b) Preceding DJF ONI. Shapes are as indicated in the legend. Red shapes correspond to the 7 El Niño seasons and blue icons correspond to the 6 La Niña seasons used in the composite respectively.
Anomaly Composites El Niño/La Niña based on DJF Oceanic Niño Index greater than 0 or -1.
Conclusions

• High time that *indices for severe thunderstorms are more representative* of their respective phenomena – sample size is decreasingly important.

• *Hail index based on monthly environmental characteristics* produces a generally *good representation of both annual cycle and interannual variability* in hail.

• The hail index can *be applied to resolve climate problems that were otherwise difficult to solve using observations* only.

• Application to the ENSO teleconnection problem reveals a *strong dipole relationship with hail that persists into spring* (La Nina +, El Nino -), pointing to *seasonal predictability in years with moderate/strong ENSO signal*.

Caveats

• This is a ‘good’ model, *not ‘the’ model*.

• A monthly index is somewhat removed from the highly diurnal structure of some variables critical to the development of severe hail.
## Monthly Pearson Correlations Hail Index vs Observed

<table>
<thead>
<tr>
<th>Region</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Ann</th>
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</thead>
<tbody>
<tr>
<td>US Wide</td>
<td>0.85</td>
<td>0.66</td>
<td>0.61</td>
<td>0.66</td>
<td>0.44</td>
<td>0.42</td>
<td>-0.10</td>
<td>-0.10</td>
<td>-0.03</td>
<td>0.32</td>
<td>0.63</td>
<td>0.44</td>
<td>0.22</td>
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<tr>
<td>South</td>
<td>0.81</td>
<td>0.77</td>
<td>0.44</td>
<td>0.65</td>
<td>0.41</td>
<td>0.54</td>
<td>0.59</td>
<td>0.47</td>
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<tr>
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<td>0.52</td>
<td>0.54</td>
<td>0.40</td>
<td>0.07</td>
<td>0.03</td>
<td>0.32</td>
<td>0.00</td>
<td>0.05</td>
<td>0.51</td>
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<td>0.72</td>
<td>0.72</td>
<td>0.76</td>
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<td>0.22</td>
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<td>Upper MW</td>
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<td>0.79</td>
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<td>0.81</td>
<td>0.48</td>
<td>0.33</td>
<td>0.06</td>
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<td>0.48</td>
<td>0.50</td>
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<td>0.43</td>
<td>0.65</td>
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<td>0.42</td>
<td>0.25</td>
<td>0.22</td>
<td>0.35</td>
<td>0.63</td>
<td>0.29</td>
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<tr>
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<tr>
<td>Northwest</td>
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<td>0.41</td>
<td>0.40</td>
<td>-</td>
<td>-</td>
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<tr>
<td>West</td>
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