Using the CESM Large Ensemble to project future changes in the distribution and impacts of eastern North American snowstorms

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Northeastern snowstorms

- The eastern United States is vulnerable to impacts from extratropical cyclones (ETCs) during winter months
  - Heavy precipitation
  - High winds
  - Coastal flooding
- Impacts amplified by proximity of population centers such as Boston, New York City, Philadelphia, Baltimore, and Washington D.C. to ETC tracks
- Potential for
  - Risks to health and welfare
  - Massive transportation disruption
  - Lost spending/productivity
  - Widespread power outages
  - Structural damage
- Blizzard of 2016 (#Jonas) - $2.5 billion to $3 billion economic impact (Moody’s)
What types of storms?

- Intense snowfall associated with two storm pathways
- Miller “A” storm forms in Gulf, tracks up East Coast
- Miller “B” storm initiated by transfer of energy from continental low to coastal baroclinic zone
- Heavy snowfall (in almost all cases) associated with NE’ward moving surface low along coast
Tracking storms

- Here, ETCs are discretely tracked using an automated, objective, algorithm
- TempestExtremes (C++, flexible codebase for tracking features on unstructured grids, [https://github.com/paullric/tempestextremes](https://github.com/paullric/tempestextremes), Ullrich et al., in prep.)
  1. Storm must occur between October 1\textsuperscript{st} and April 31\textsuperscript{st}
  2. Local minimum in sea level pressure (SLP) must exist, surrounded by closed contour of at least 2 hPa within 4\degree defines cyclone center
  3. Storm must pass within 5\degree of 41\degree N, 73\degree W
    - At closest pass to 41\degree N, 73\degree W, storm heading must be between due north and due east (inclusive)
  4. Storm must persist for at least 36 consecutive hours
Sample storm trajectories

LENS members #2-9, 1990-2005
Regional Snowfall Index (RSI)

- Individual storms are then classified using **Regional Snowfall Index (RSI)** (Squires *et al.*, BAMS, 2014)
  - RSI -> collocation of magnitude/spatial extent of snowfall AND population density = impact
  - Snowfall integrated along ETC trajectory (out to a radius of 20° from cyclone center) for duration of event
  - Snowfall is conservatively mapped to 0.1° population density grid
    - Population grid held fixed!
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### RSI Value

<table>
<thead>
<tr>
<th>CAT.</th>
<th>VALUE</th>
<th>IMPACT</th>
<th>RETURN (YRS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1–3</td>
<td>Notable</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>3–6</td>
<td>Significant</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>6–10</td>
<td>Major</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>10–18</td>
<td>Crippling</td>
<td>13</td>
</tr>
<tr>
<td>5</td>
<td>18.0+</td>
<td>Extreme</td>
<td>30</td>
</tr>
</tbody>
</table>

RSI value: **23.9**
LENS application

- Need to use 6-hourly/daily data files
  - 1990-2005
  - 2026-2035
  - 2081-2090
- Produces ~320-500 years of analysis over 32 members
- Snowfall determined by internal model classification (PRECSC + PRECSL)
- Uniform 10:1 snowfall:liquid ratio assumed
  - Consistent hydrological impact
Changes in storm intensity

Shift towards stronger ETCs in a warming world, consistent with previous research (see Colle 2015)
LENS compared to observations

- General profile reproducibility
- LENS produces too many storms at “weak” end of the spectrum; too few at “stronger” end
- Could be resolution signature? (more on that later)
Future changes using LENS

- Across the board decrease when comparing historical with 2026-2035
- More significant decreases by 2081-2090
## Change in annual frequency

<table>
<thead>
<tr>
<th>CAT</th>
<th>1990-2005</th>
<th>2026-2035</th>
<th>2081-2100</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>-7%</td>
<td>-29%</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>-10%</td>
<td>-28%</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>-7%</td>
<td>-44%</td>
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<tr>
<td>4</td>
<td>0</td>
<td>3%</td>
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</tr>
<tr>
<td>5</td>
<td>0</td>
<td>-15%</td>
<td>-58%</td>
</tr>
</tbody>
</table>
Going forward...

- Resolution
- Precipitation typing
- Pseudo-prognostic snowfall ratios
Resolution going forward...

Uniform 1° (~111km)

0.25° (~28km)
Precipitation typing

• CAM roughly partitions frozen/liquid precip (snow or rain in standard outputs)
• Apply more comprehensive thermal energy criterion to further break down into rain, snow, mix, sleet, freezing rain (Bourgouin, WAF, 2000)
• Needs to be “reverse engineered” for use in LENS
Pseudo-prognostic snowfall ratios

- Snowfall amount depends on dendritic growth zones RH/vertical velocity collocation
- For snowfall, apply Cobb (2005, AMS) algorithm to diagnose time and spatial dependent snow-to-liquid equivalency ratios
- More “reverse engineering”
(Very preliminary) conclusions

• Objective tracking algorithm used to find eastern North American coastal cyclones in CESM Large Ensemble dataset

• Application of Regional Snowfall Index (RSI) implies that CESM produces reasonable climatology of northeastern US snowstorms

• ALL classifications of snowstorms projected to decrease by end of century

• This despite shift in frequency towards stronger ETCs