CLIMATE CHANGE AND HAZARDOUS CONVECTIVE WEATHER IN THE UNITED STATES: INSIGHT FROM HIGH-RESOLUTION DYNAMICAL DOWNSCALING

GEWEX WORKSHOP

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INTRODUCTION

HAZARDOUS CONVECTIVE WEATHER (HCW)

- Severe thunderstorm (Significant Severe)
  - Tornado (F/EF2+)
  - Wind $\geq 50$ knots ($\geq 65$ knots)
  - Hail $\geq 1''$ ($\geq 2$ inches)

- Hazards associated with severe convection have important social and economic impacts
  - Risk to life and property

- **Q:** How might severe thunderstorm activity respond to anthropogenic climate change?
Convective parameters, namely convective available potential energy (CAPE) and 0-6 km vertical wind shear (S06)

\[ \text{NDSEV} = \text{CAPE} \times S06 \geq X \] (X is usually 10,000 or 20,000)

Many recent studies
- ↑ mean CAPE, ↓ mean S06, ↑NDSEV

**Limitations**
- Storms must be initiated in order to realize environment/CAPE!
  - Neglects “lift” ingredient
- Must assume that “efficiency” of environment remains the same in future climate
- Environments are an overestimate in occurrence and coverage
- Unable to infer risk for individual hazard type due to environment overlap

**Alternative approach**
- High-resolution dynamical downscaling
  - Use IC/BC from GCM to drive high-resolution (~4 km) convection-permitting model
  - *Let the model develop relationship between environmental conditions and events*

Diffenbaugh et al. (2013)
PREVIOUS WORK WITH DOWNSCALING HCW

- High-resolution, convection-allowing (~4 km) WRF simulations (reanalysis/GCM)
- Reasonably recreate observed climatology using a model proxy
- Gensini and Mote (2015) downscaled CCSM3 for future climate
Build upon literature

- A longer term (~30 year) climatology of historical and future synthetic severe climatologies from GCMs
- Simulate entire annual cycle
- What do we gain by downscaling?
  - Are we getting same story as environment approach?

Outline:

1. Data and Methods
2. GCM environment changes
3. Downscaled estimates of HCW
4. Comparing approaches
   - i.e. relationship between environment response and storms produced via dynamical downscaling
GCM SELECTION

GFDSL-CM3

- Coupled atmosphere-ocean model
- 2° x 2.5° lat/lon grid (~200 km)
- Model top of 1 hPa, 48 vertical levels

- **High-performing GCM** compared to NCEP-NCAR reanalysis and radiosonde observations for simulated CIN, CAPE and NDSEV
  - Diffenbaugh et al. 2013; Seeley and Romps 2015

- Historical and RCP8.5 experiments
  - Member r1i1p1

http://www.gfdl.noaa.gov/coupled-physical-model-cm3
RCM MODEL SETUP

REGIONAL CLIMATE MODEL

- WRF-ARW version 3.6
  - CONUS domain
  - 4 km horizontal grid spacing
  - 45 vertical levels, 50 hPa model top
- Two time-slices
  - **Historical baseline:** 1971-2000
  - **Future:** 2071-2100
- Hourly output
- Post processed with NCEP Unified Post Processor (>250 variables)
- Converted to GRIB2
- ~65-70 TB for 60 years of simulations

<table>
<thead>
<tr>
<th>Parameterizations</th>
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</thead>
<tbody>
<tr>
<td>Microphysics</td>
</tr>
<tr>
<td>Land surface</td>
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<td>Planetary Boundary Layer</td>
</tr>
</tbody>
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<thead>
<tr>
<th>Model Parameters</th>
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<tbody>
<tr>
<td>Horizontal grid spacing</td>
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<tr>
<td>Domain size</td>
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<td>Vertical levels</td>
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<td>Time step</td>
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<td>Buffer zone</td>
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<th>Initial/Boundary Conditions</th>
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<tr>
<td>Temperature, specific humidity,</td>
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<td>geopotential height, u and v wind,</td>
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<tr>
<td>surface pressure</td>
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<td>Soil temperature, soil moisture</td>
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<td>Land use/land cover</td>
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INTEGRATION PROCEDURE

Daily 0600 UTC re-initialization
• 30 hour integration, first 6 forecast hours discarded due to spin-up
• Runs valid 1200-1200 UTC
• Not widely used in downscaling future climate; more common with reanalyses to retain sequence of observed weather events (e.g. Trapp et al. 2011, Robinson et al. 2013)
• Hong and Kanamitsu (2014) advocate for the frequent re-initialization or spectral nudging approach to limit error growth within the domain

Advantages
• Generate mesoscale details and still preserve consistency of large-scales between RCM and GCM
• Allows for parallelism of simulations

Disadvantages
• Discontinuous across re-initialization point
• Boundaries from previous convection not carried over
• Long memory processes not accounted for (e.g. soil moisture)
  • Secondary importance to atmospheric forcing (Pan et al. 1999)
  • Assuming these adequately handled by GCM
GCM SEVERE ENVIRONMENT DAYS

ANNUAL ANOMALIES (% CHANGE RELATIVE TO 1971-2000 MEAN)

• Projected changes in environments favorable for HCW

• $\text{NDSEV}_{\text{sig}} = \text{CAPE} \times S06 \geq 20,000$
  • CAPE $\geq 100 \text{ J kg}^{-1}$
  • S06 $\geq 5 \text{ m s}^{-1}$
  • CIN $\geq -100 \text{ J kg}^{-1}$
  • Interpolated to $1^\circ$ lat/lon grid
  • occurs when threshold is met at anytime between 1200-1200 UTC

Mean CONUS NDSEV$_{sig}$ Day Anomaly

- CONUS regional mean (land points only)
- Smoothed with Gaussian filter ($\sigma=5$ years)
SEVERE ENVIRONMENT DAYS

FUTURE CHANGES

DJF

MAM

JJA

SON
GCM ENVIRONMENT

SUMMARY

• Like other GCMS, GFDL CM3 depicts:
  ↑ sfc temperature, specific humidity
  ↑ CAPE, CIN
  ↓ S06 (concentrated on days with lower CAPE)
  ↑ NDSEV_{sig}

• Changes largely a result of robust increases in CAPE

• Overall “season” is lengthened

• Other parameters show marked increase also (e.g., STP, SCP, EHI)
Cannot explicitly simulate severe hazards at 4 km grid spacing, so we must use a model proxy

- **Hourly maximum updraft helicity (UH)**
  - Mid-level mesocyclone detection
  - Commonly used in short term severe storm forecasting
  - 50 m² s⁻² minimum threshold (~99.995 percentile)

\[
UH = \int_{2km}^{5km} w \zeta dz
\]

- Focus on proxy “day” occurrences tallied within 1° lat/lon bounding boxes
  - “Yes” if any grid point within lat/lon bounding box exceeds the specified threshold at anytime over the 24-hour period (1200-1200 UTC)
SEASONAL CHANGES

CHANGES IN DAYS WITH UH > 50 m² s⁻²
SEASONAL CHANGES
CHANGES IN DAYS WITH UPDRAFT VERTICAL VELOCITY > 20 m s\(^{-1}\)
GCM VS. RCM

MAM Mean Standardized Anomaly

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<th>DJF</th>
<th>MAM</th>
<th>JJA</th>
<th>SON</th>
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<tbody>
<tr>
<td>Historical</td>
<td>0.888</td>
<td>0.912</td>
<td>0.895</td>
<td>0.784</td>
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<tr>
<td>future</td>
<td>0.983</td>
<td>0.930</td>
<td>0.947</td>
<td>0.865</td>
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GCM VS. RCM

MONTHLY MEAN NDSEV<sub>sig</sub> DAYS VS. MONTHLY MEAN UH DAYS

CONUS

- **Historical**
  - $y = 0.6229 x + -0.047, R^2 = 0.9011$

- **RCP8.5**
  - $y = 0.3419 x + -0.088, R^2 = 0.7643$

1971-2000

2071-2100
SUMMARY AND CONCLUSIONS

• This study produced high-resolution, dynamically downscaled simulations from GFDL-CM3
  1. 2 30-yr periods (1971-2000 and 2071-2100 (RCP8.5))
  2. Entire annual cycle captured
  3. Insight into the storm-scale response to changes in ambient environmental conditions

• Consistent agreement between GCM and RCM in terms of areas of increased/decreased days of activity
  • The “when and where”, but environments alone cannot infer the “how much”
• Changes in environment efficiency between historical and future periods
  • Addresses initiation problem
    • Environment-event relationship has weakened
    • Justifies downscaling approach

• Cause(s)?
  • Weakening circulation
    • Chang (2012) found reduction in extratropical cyclones in all seasons (e.g. -24.5% in JJA)
    • Coumou (2015) decrease in JJA eddy kinetic energy
  • Increased CIN
ONGOING/FUTURE WORK

- Hazard type
  - Hail, wind, tornadoes

- Variability and sub-daily frequency of HCW

- Convective mode
  - object based approaches

- Perform continuously integrated simulations to compare
THANK YOU!
QUESTIONS?

"Essentially, all models are wrong, but some are useful."


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