



Challenges and Advances in Simulating Convective Extremes

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What are convective extremes?



What are Convective Extremes?

Straight Line Winds



Flash Flooding



Lightning



Tornados



Giant Hail

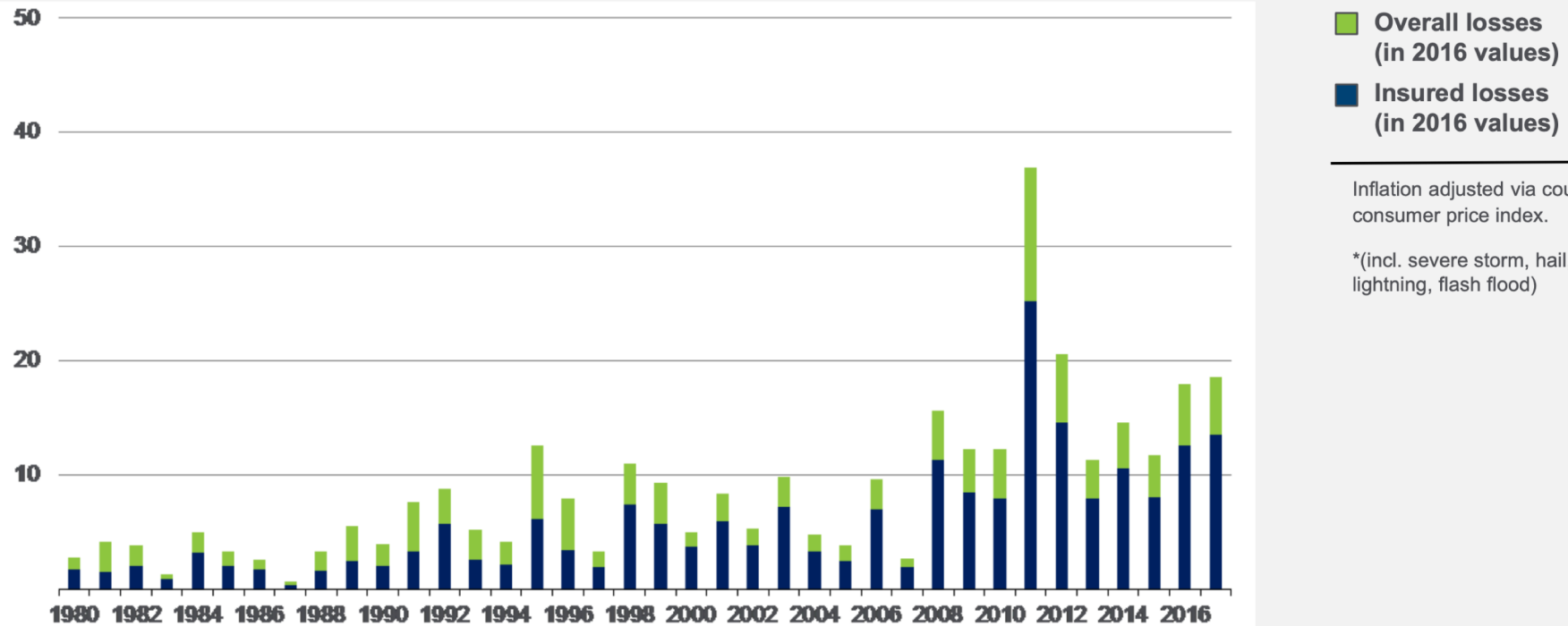


Land Slides



Why are they important?

US\$ bn

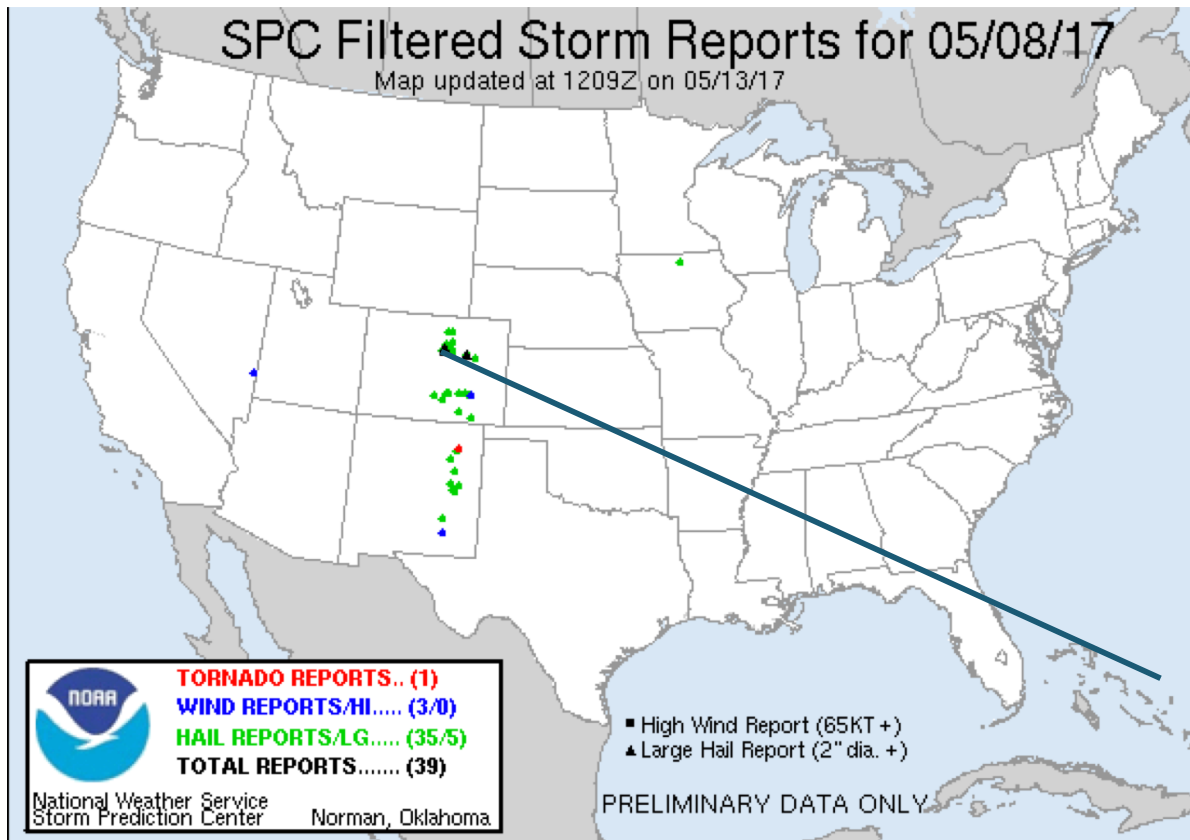


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Munich Re (TOPICS GEO 2017)

- Convective storms cost ~20 US\$ bn per year in the US
- Losses are increasing over time
- Large interannual variability

How often do they happen?



<https://www.spc.noaa.gov/climo/reports/>

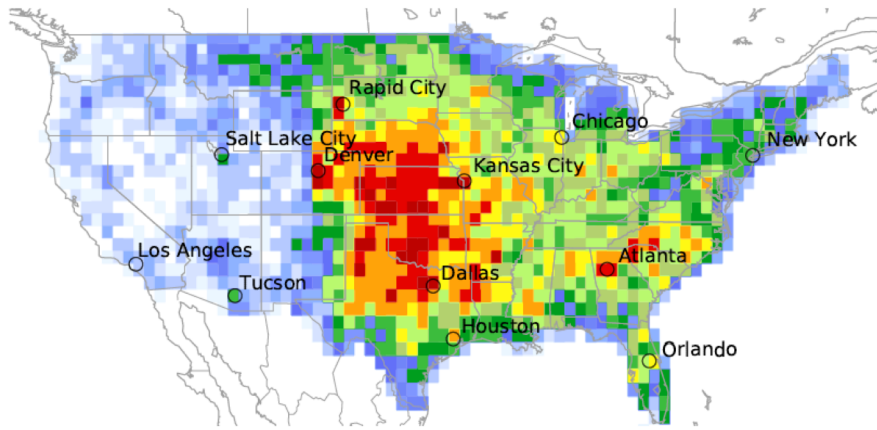
- In summer we see convective extremes almost every day somewhere in the US
- Convective extremes often occur in clusters

Denver hail storm (May 8th, 2017)

- ~1.4 US\$ bn losses



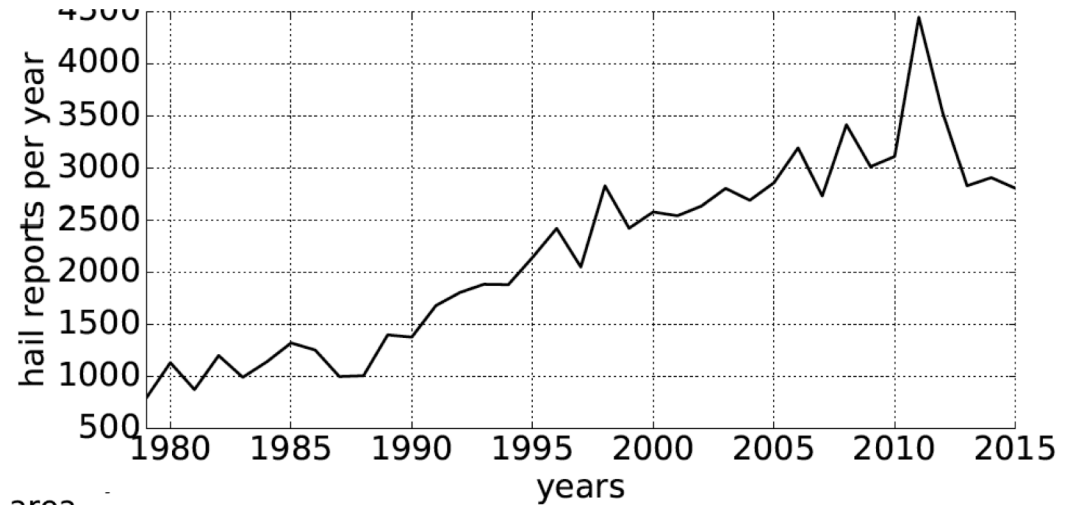
Large Hail Observations



[Prein and Holland 2018]

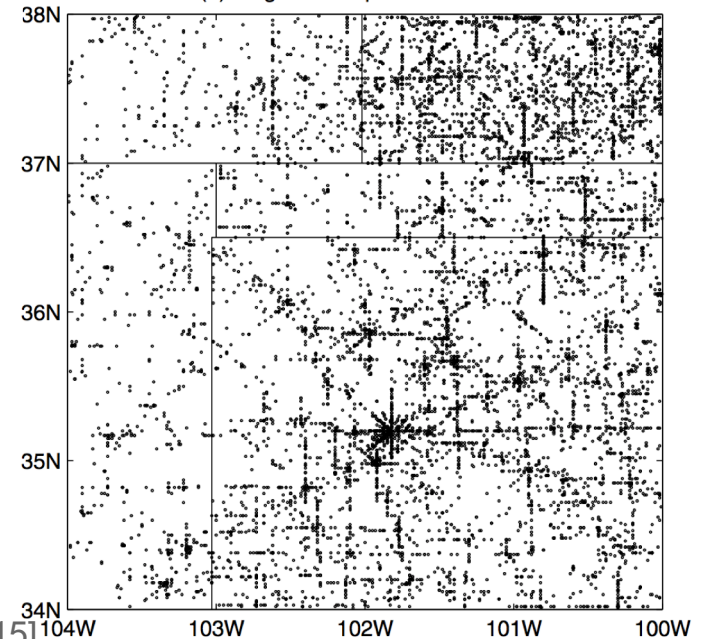
Nr. of hail events per year in $0.75^\circ \times 0.75^\circ$ area

0.00 0.01 0.05 0.10 0.20 0.40 0.60 0.80 1.00 1.30 1.60 2.00 2.50 3.00 4.00 5.00 6.00



- Observations of convective extremes are spatially and temporally very inhomogeneous
- Hail frequency is increasing with population density
- Even the road network can be identified in the observations [Allen et al. 2015]

(a) Large Hail Reports 1979–2012



[Allen et al. 2015]

Approaches to model convective extremes



Approaches to simulate convective extremes

High Winds



Flash Flooding



Lightning



Favorable Large-Scale Environments

Statistical Modeling

Hazard is modeled

Dynamical Downscaling

Environment is modeled

Severe Convective Hazard Information

Tornados



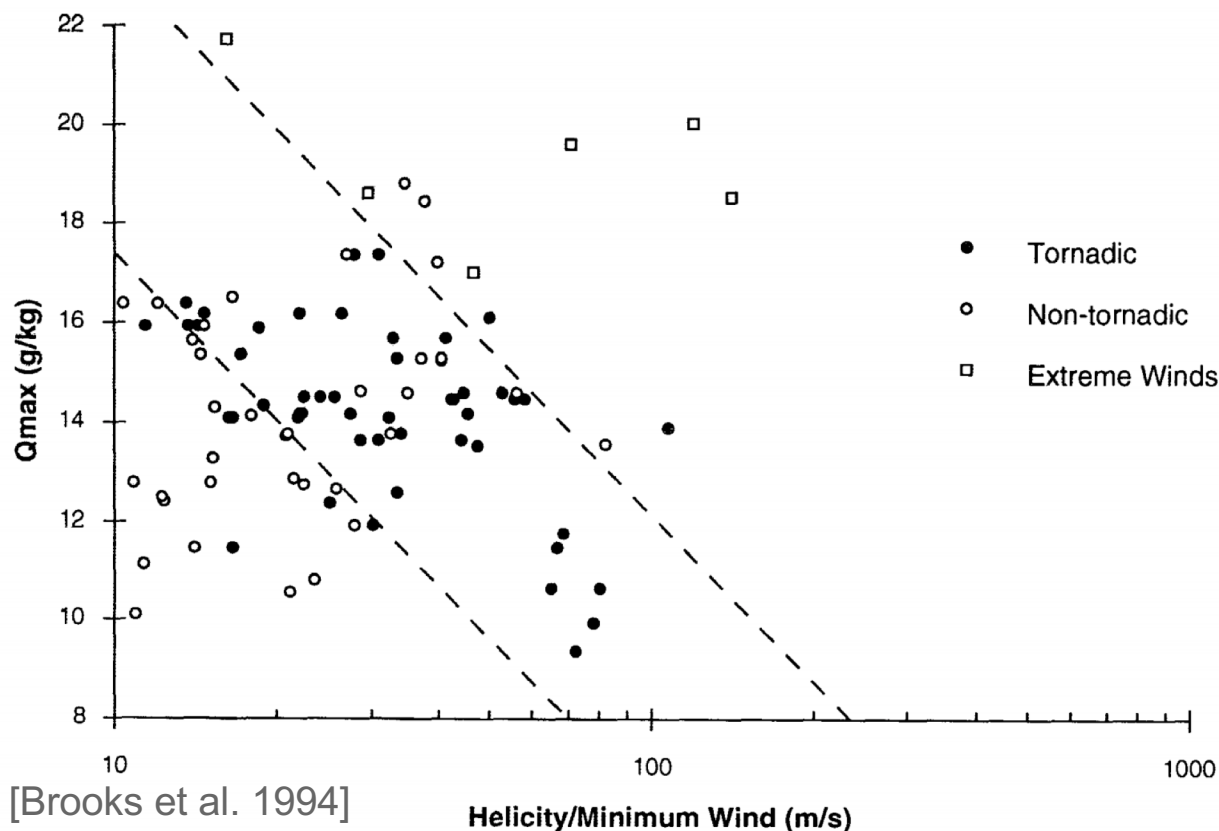
Giant Hail



Land Slides



Favorable Large-Scale Environments



Environmental conditions that are favorable for hazard development are identified

E.g., tornado producing supercells (left figure)



Cheap computation

Environments could be produced by low-resolution models



Neglects a-typical situation

Assumes stationarity

Environmental Proxies



Derechos

Evans and Doswell III (2001) - Weather and Forecasting
Coniglio et al. (2004) Weather and Forecasting



Flash Floods

Doswell III et al. (1996) Weather and Forecasting
Schumacher and Johnson (2005) Monthly Weather Review



Lightning

Romps et al. (2014) Science
Price and Rind (1992) JGR-A



Tornadoes

Brooks et al. (1994) Weather and Forecasting
Brooks et al. (2003) Atmospheric Research



Large Hail

Billet et al. (1997) Weather and Forecasting
Allen et al. (2015) JAMES



Land Slides

Crozier (1999) Earth surface processes and landforms
Larsen and Simon (1993) *Geografiska Annaler: Series A*

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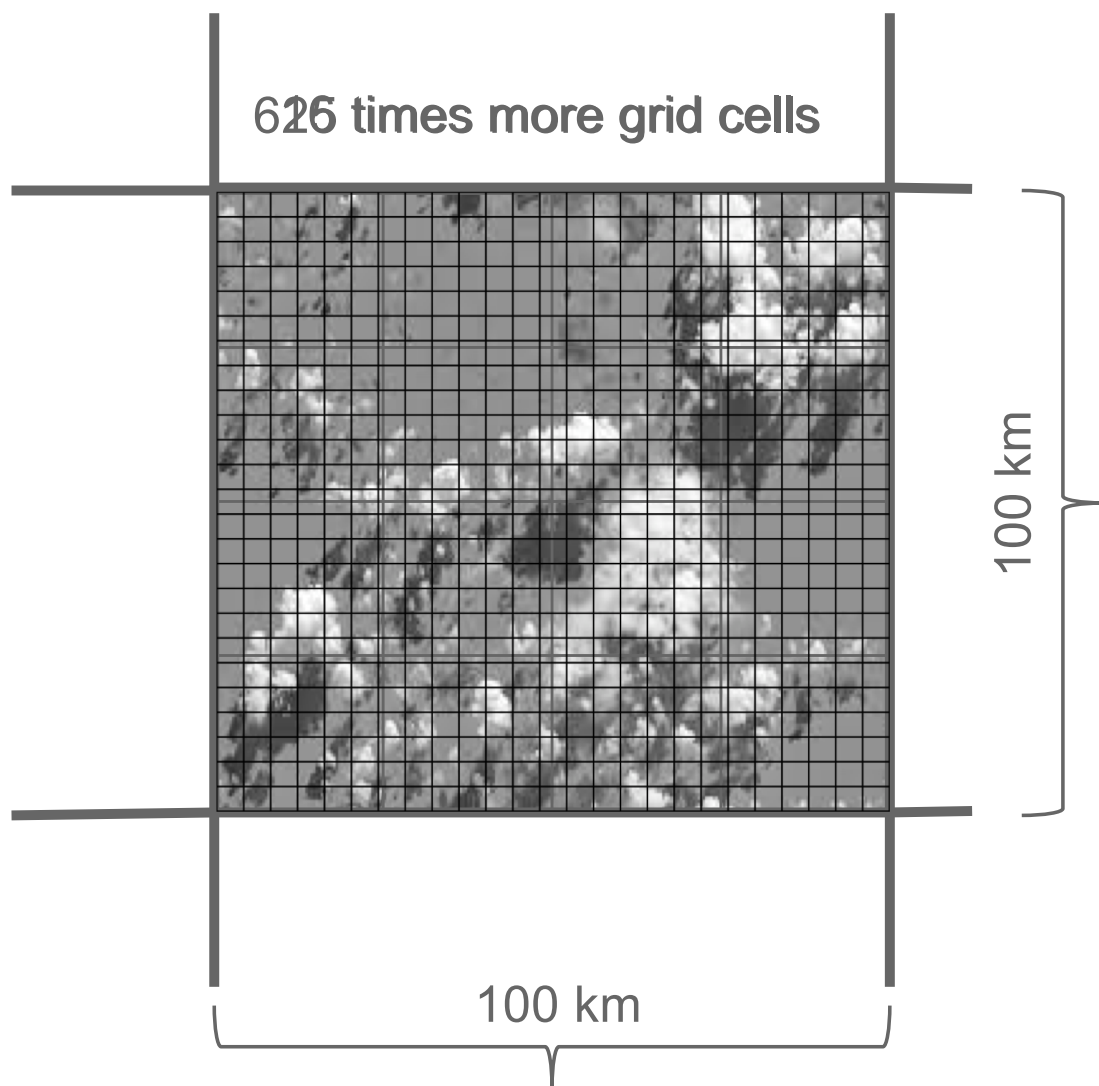
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Deep convection in atmospheric models



GCM grid spacing (~100 x 100 km)

- Deep convection is sub-gridscale process
- Needs cumulus parameterization

When do we start to resolve deep convection?

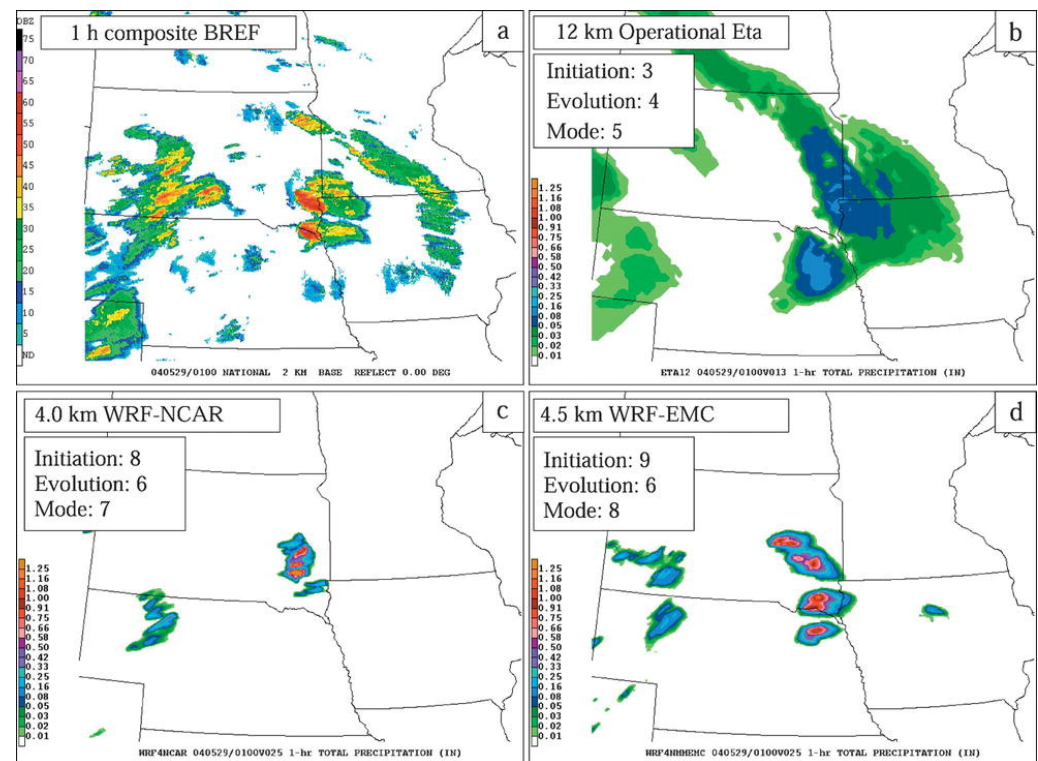
- ~4 km horizontal grid spacing (Weisman et al. 1997)

First demonstrations of real-time CAM forecasts

2004 Storm Prediction Center / National Severe Storms Laboratory Hazardous Weather Testbed Spring Program

Kain et al. (2006): “Collectively, results from the [2004] Spring Program provide compelling evidence that the tested experimental models provided added value for forecasters of severe weather.

...Increasing resolution to that afforded by 4–5-km grid spacing seems particularly attractive because it obviates the need for parameterization of deep convection, which is viewed by many as the Achilles’ heel of current operational NWP models.”



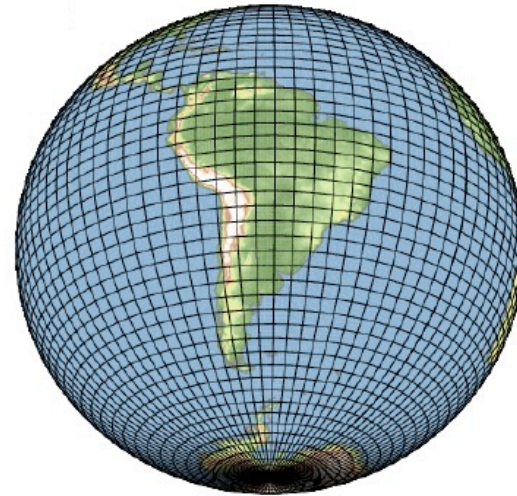
Kain et al. 2006

CPM approaches

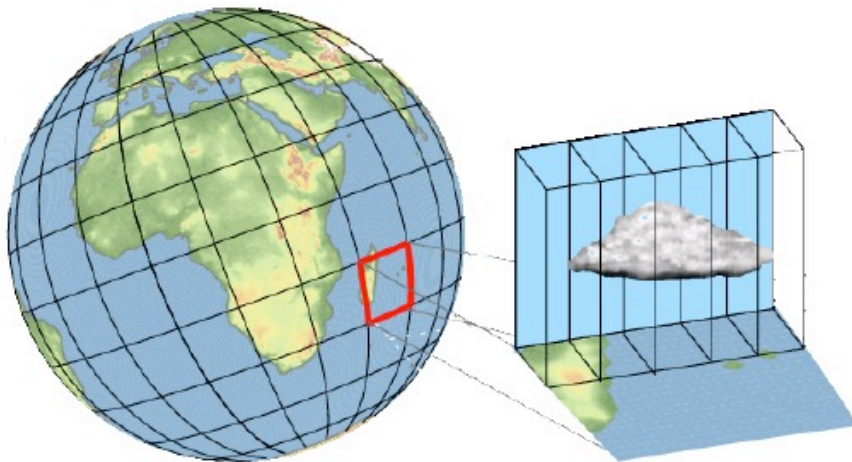
limited-area modeling



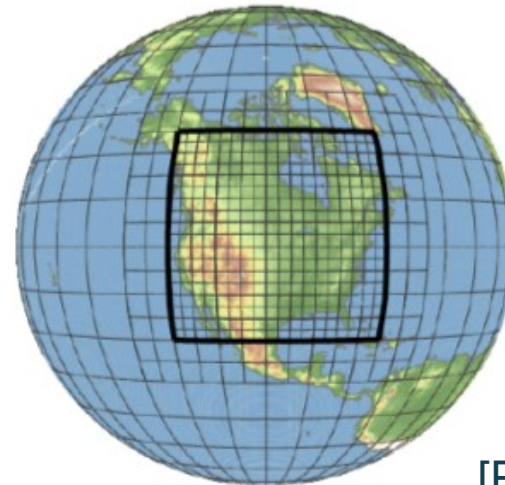
global CPM climate simulations



superparameterizations



stretched-grid models



[Prein et al. 2015]

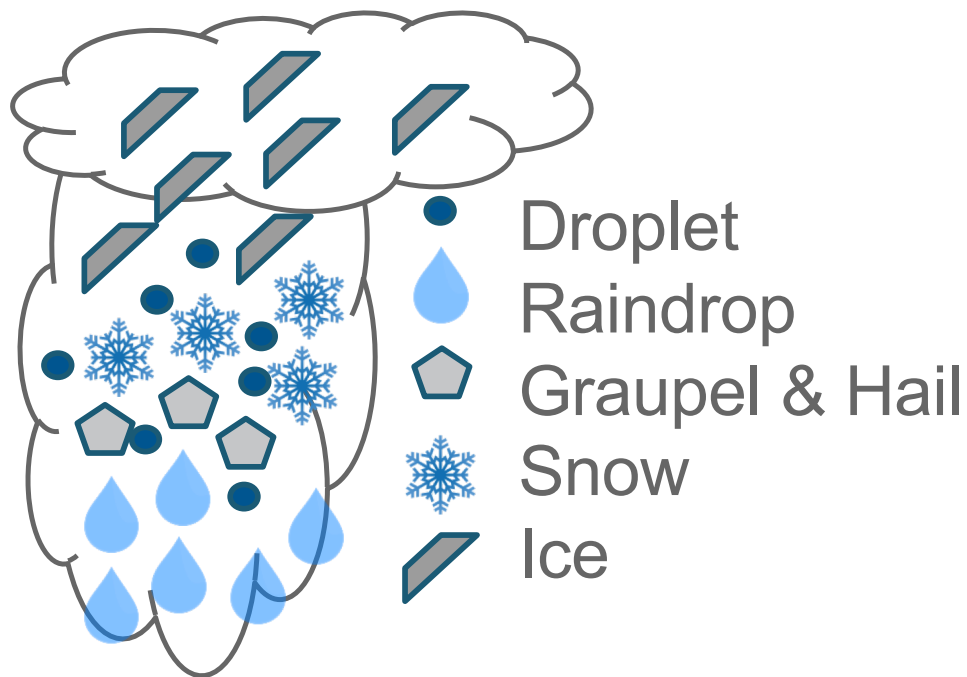
Model Physics

Physics setup
adapted from
weather forecasting
models



Difficult to test
setups on climate
time-scales

Clouds, Aerosols, and



Turbulence

Shallow convection

Soil-atmosphere coupling

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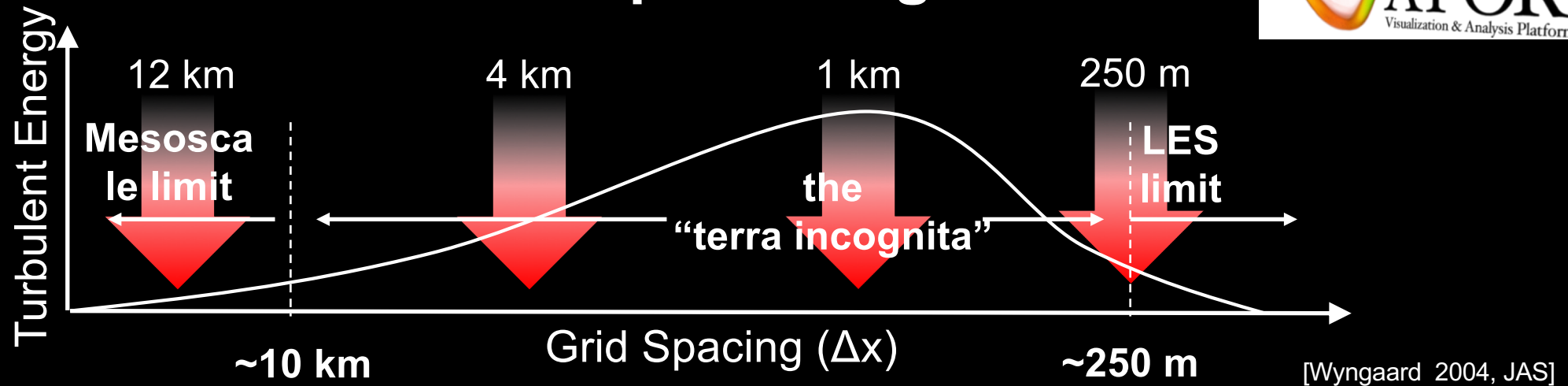
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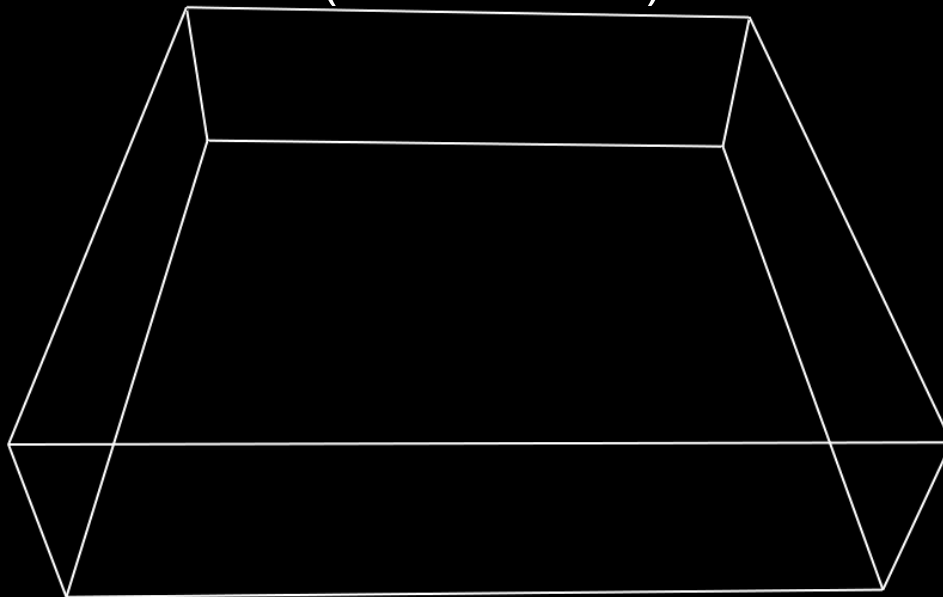
Land Slides



MCS in 3 atmospheric regimes

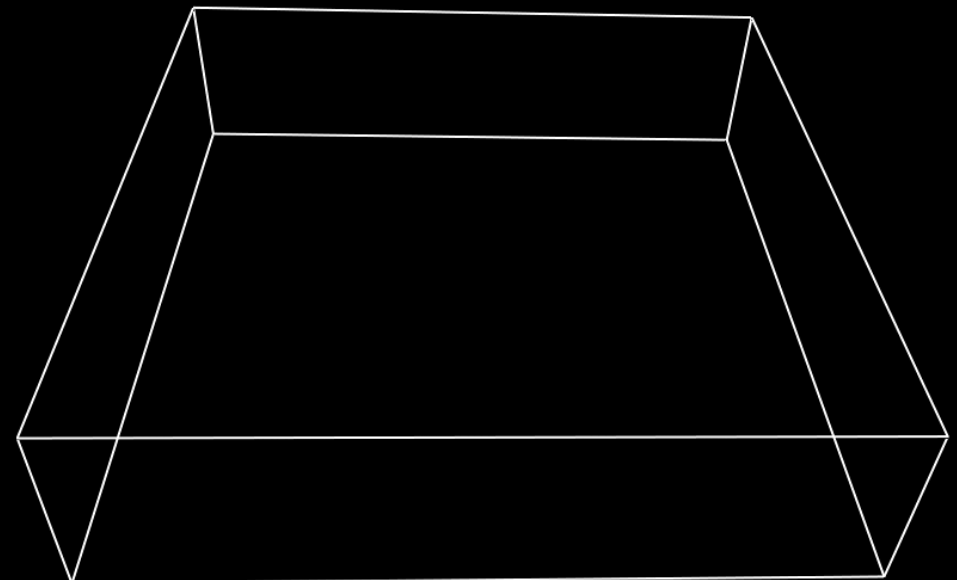


$\Delta x = 12$ km
(K-F scheme)



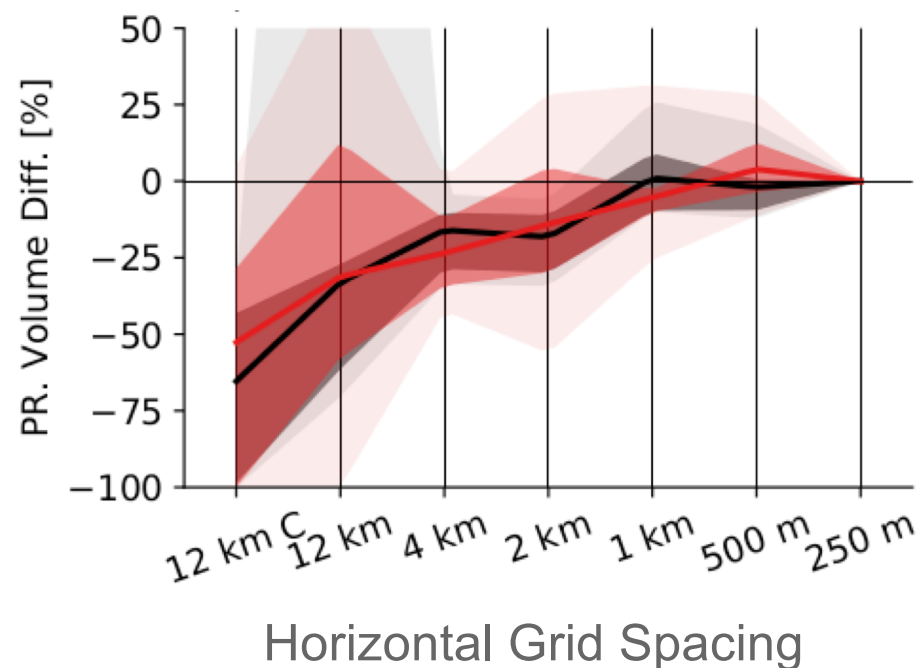
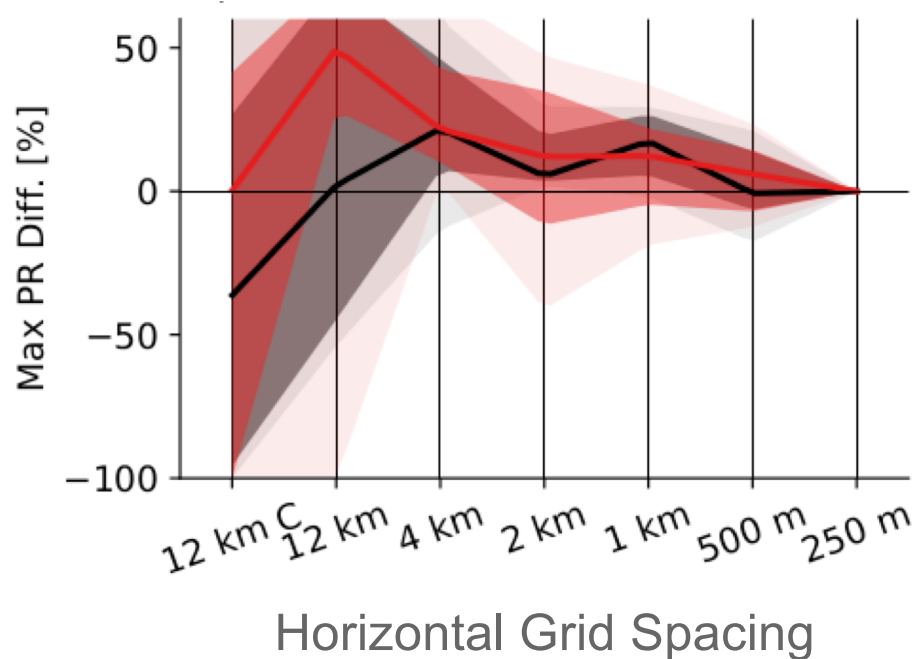
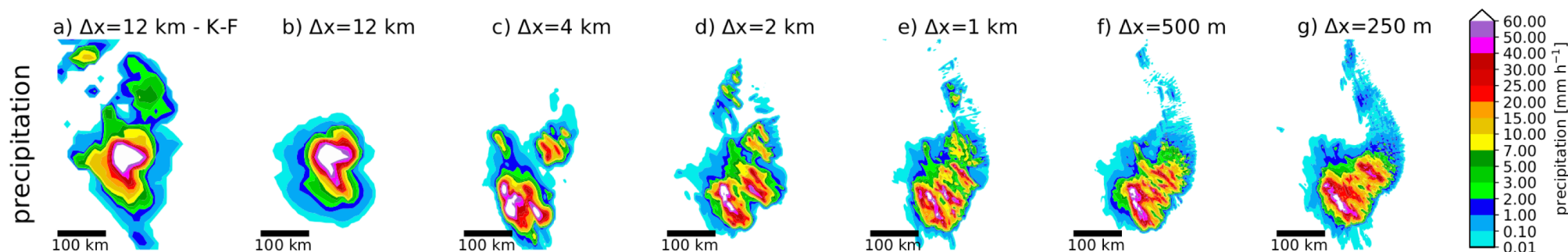
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$\Delta x = 4$ km

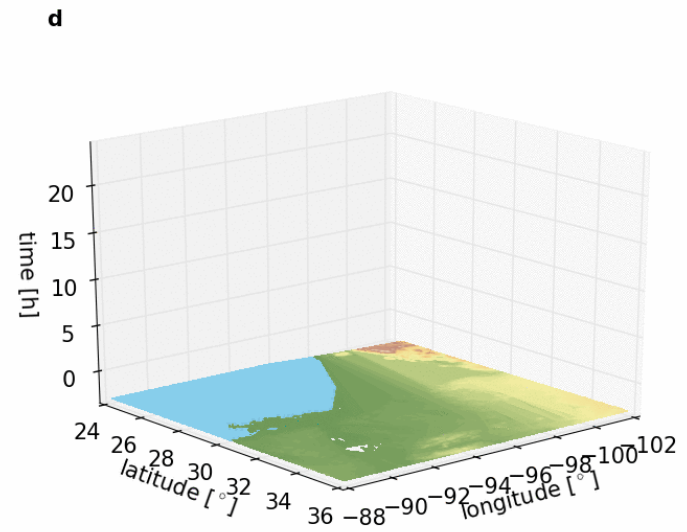
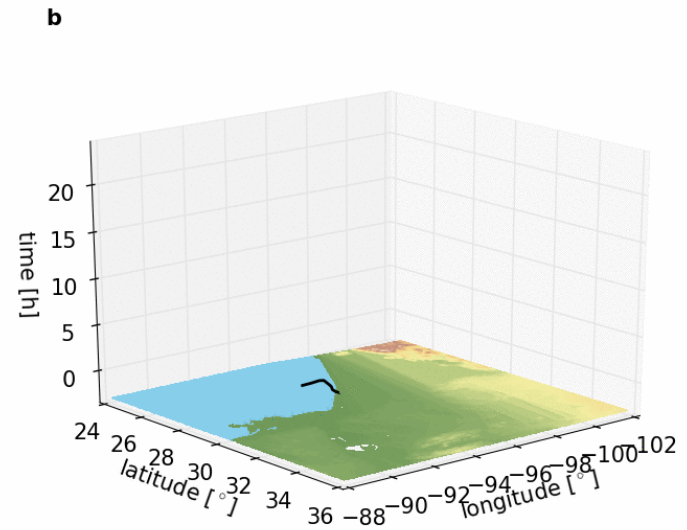
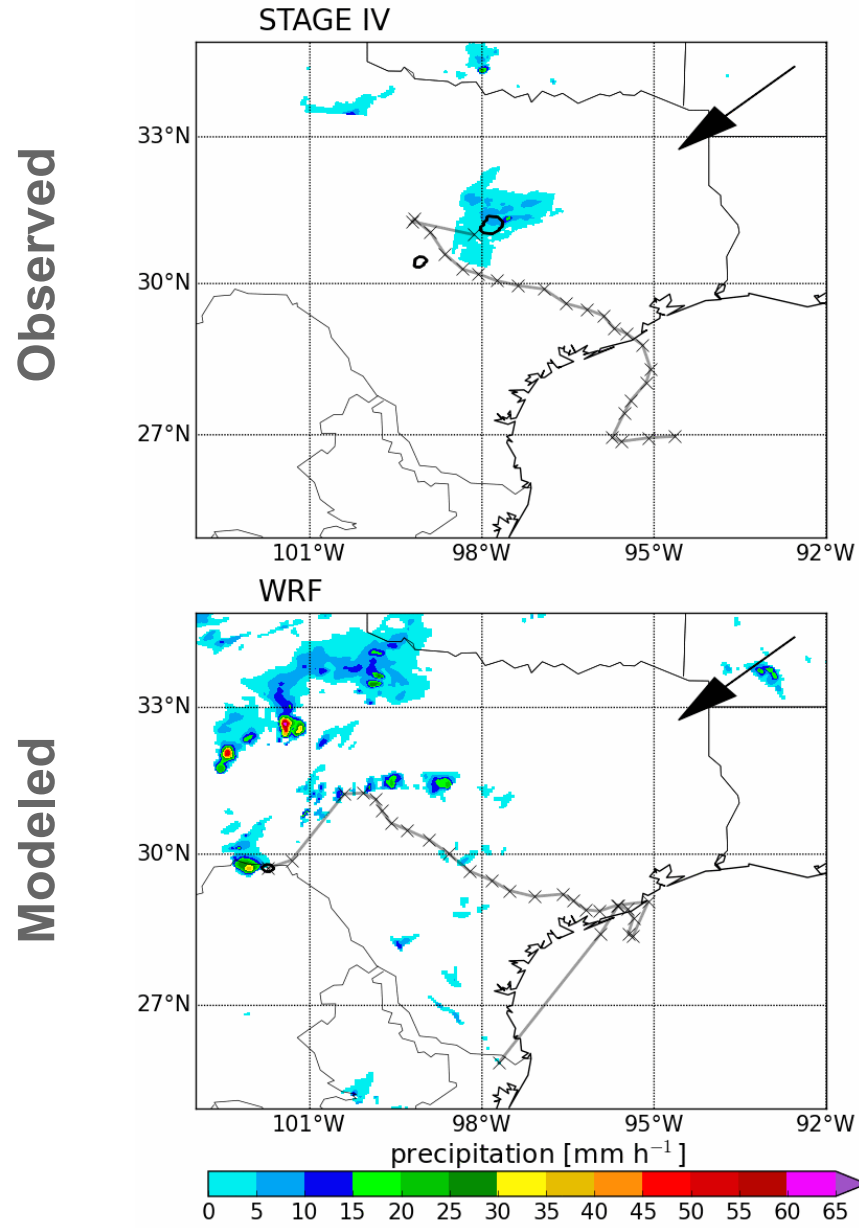


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Grid Spacing Dependence on Storm Precipitation



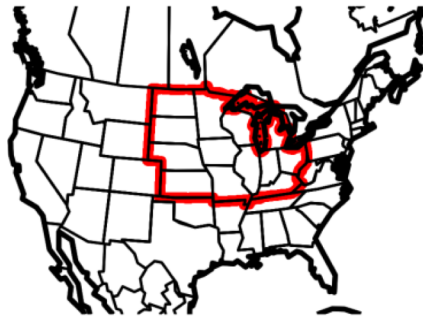
Mesoscale Convective System (MCS) in Texas during March 2007



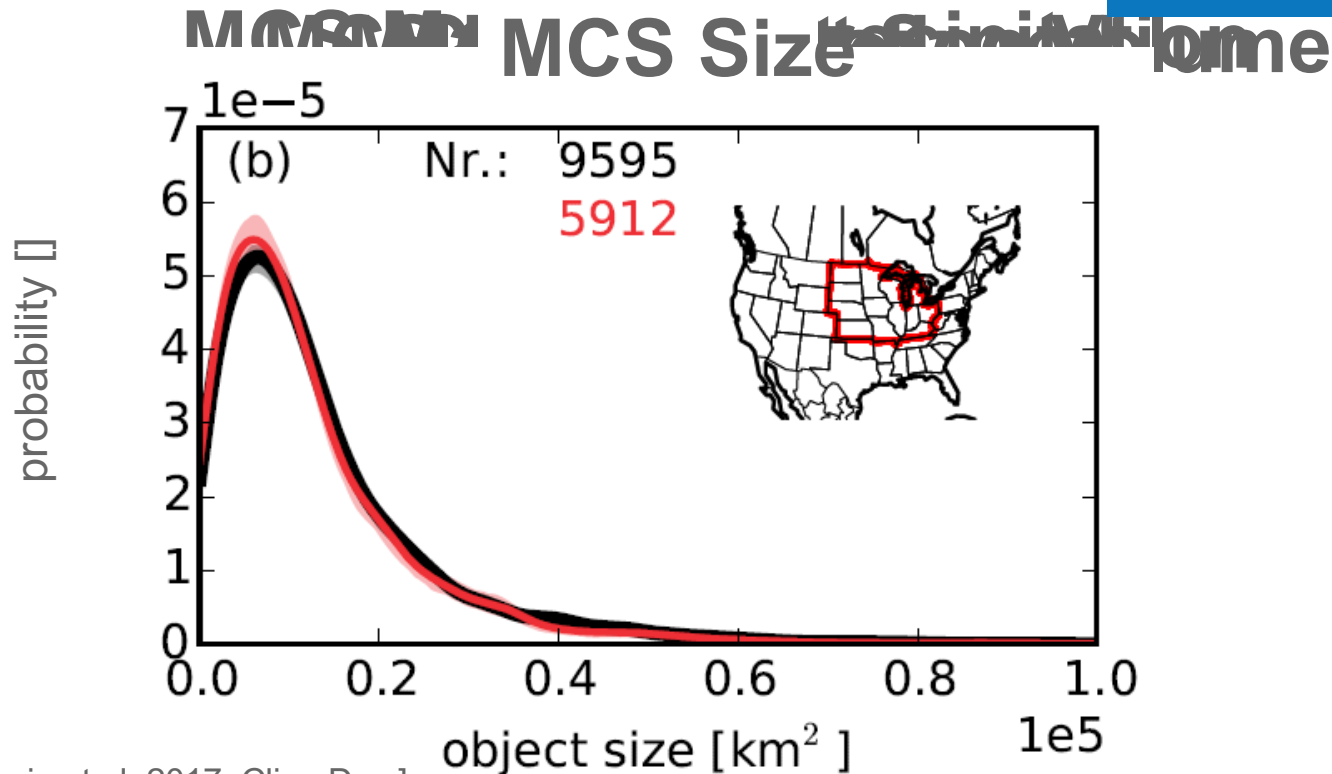
[Prein et al. 2017]

MCS attributes – JJA Central U.S.

— Observation
— Model



- Realistic representation of MCS attributes
- But underestimation of MCS frequency



[Prein et al. 2017, Clim. Dyn.]

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Supercell Simulation

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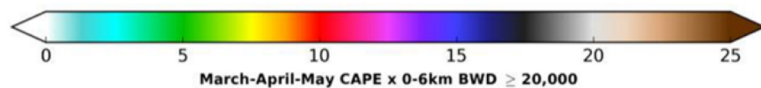
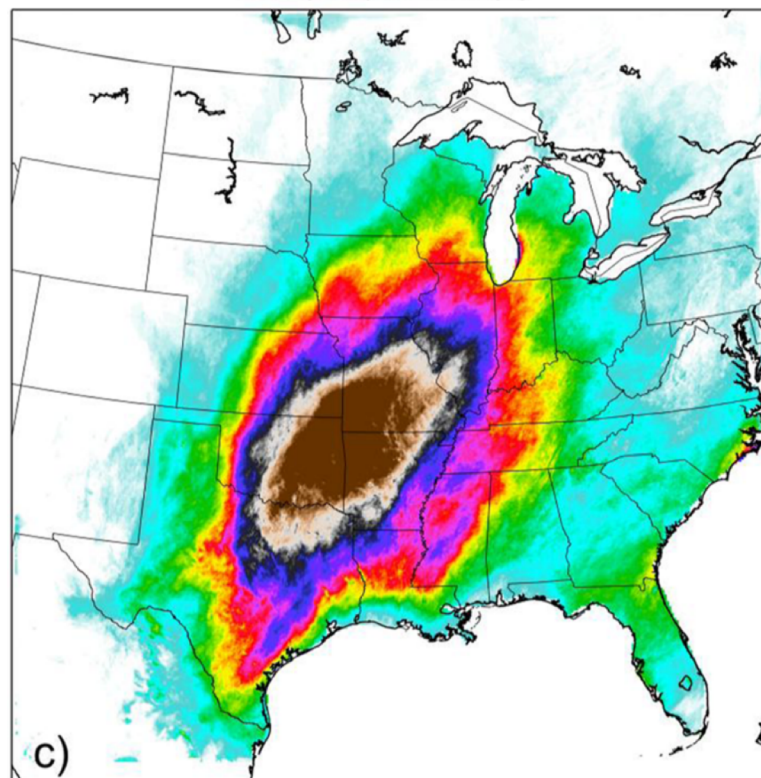
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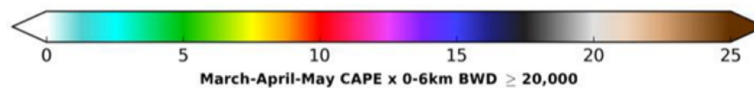
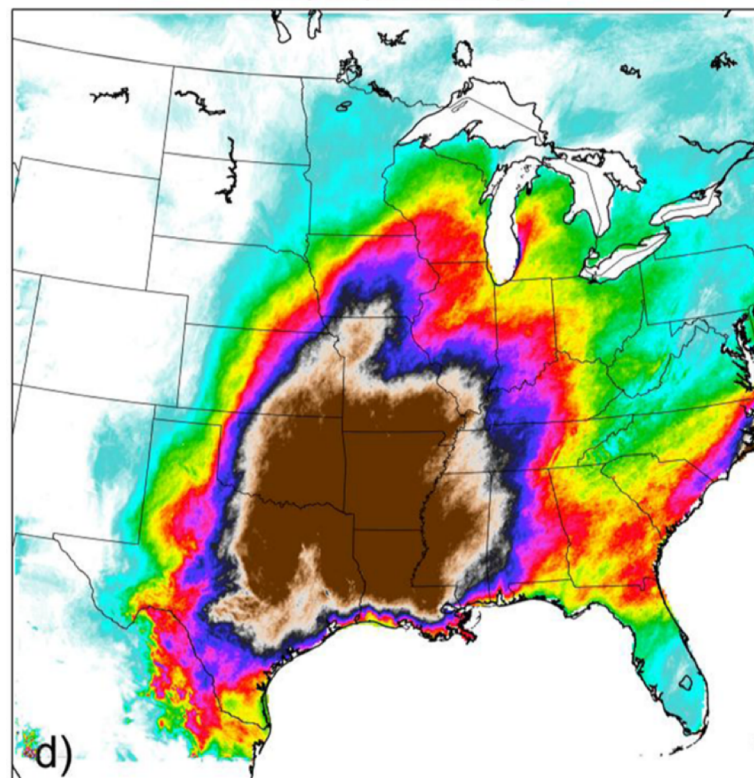
Convective Hazards under Climate Change

Frequency of March, April, and May CAPE times 0–6-km bulk wind difference

Current Climate



End of century; A2 scenario



Gensini and Mote 2015; *Climatic Change*

Observational Datasets

Event based observations

- NOAA Storm Events
<https://www.ncdc.noaa.gov/stormevents/ftp.jsp>
- BoM Severe Storms Archive
<http://www.bom.gov.au/australia/stormarchive/>
- ESSL's European Severe Weather
<https://www.eswd.eu/>

Hourly Precipitation records

- Stage-4 gidded precipitation for US
http://data.eol.ucar.edu/cgi-bin/codiac/fgr_form/id=21.093
- INTENSE project – global hourly precipitation
<https://research.ncl.ac.uk/intense/aboutintense/>

Satellite products

- Lightning
https://lightning.nsstc.nasa.gov/data/data_lis.html
- Overshooting tops
Meteosat Second Generation (access from Meteosat)
- 4 hourly precipitation from GPM
<https://pmm.nasa.gov/data-access/downloads/gpm>

Final Remarks

- Convective extremes have severe impacts on the economy and society
- Traditionally studied in weather forecasting but convective extremes & climate change is a novel and fast-growing research area
- Many challenges that need to be addressed
observations, high-resolution modeling, process understanding