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

Earth
Atmospheric
Planetary
Sciences

GEWEX WORKSHOP

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INTRODUCTION

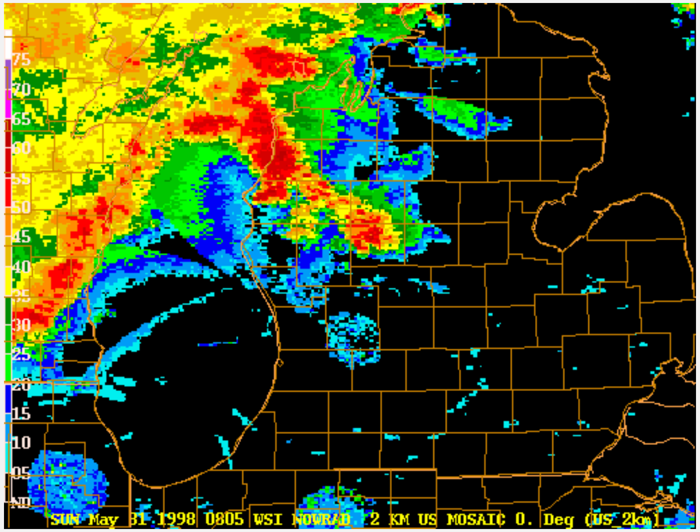
HAZARDOUS CONVECTIVE WEATHER (HCW)

- Severe thunderstorm (**Significant Severe**)
  - Tornado (**F/EF2+**)
  - Wind ≥ 50 knots (**≥65 knots**)
  - Hail ≥ 1” (**≥ 2 inches**)


Walker Ashley, http://newsroom.niu.edu/2015/04/10/in-the-eye-of-the-storm/

- 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 ?***



May 31, 1998 Derecho

ENVIRONMENTAL CONDITIONS

APPLICATION TO GLOBAL CLIMATE MODEL PROJECTIONS

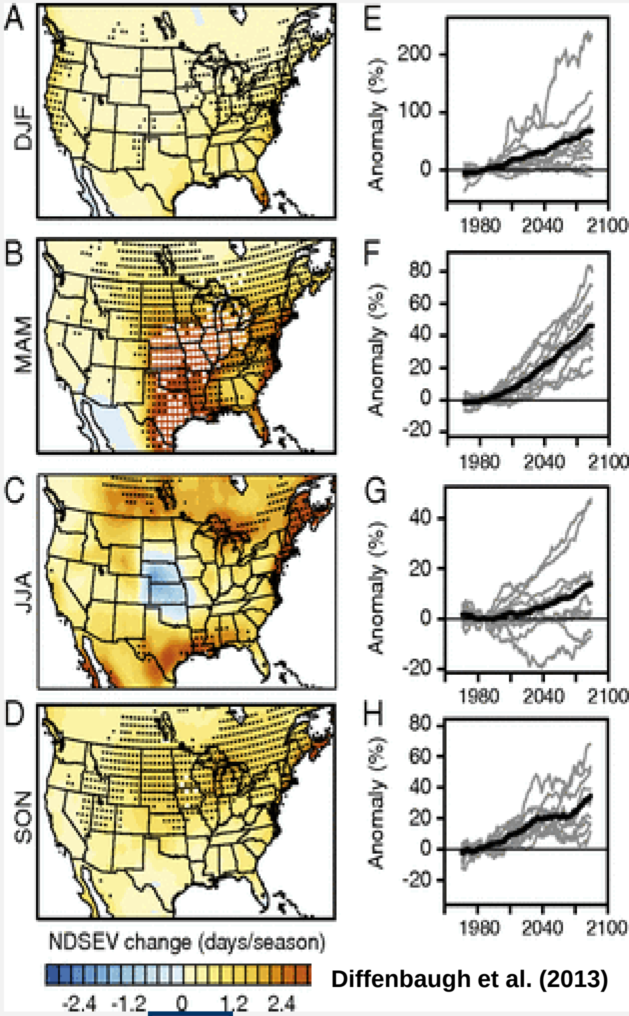
- Convective parameters, namely convective available potential energy (**CAPE)** and 0-6 km vertical wind shear (**S06**)
- ***NDSEV*** = CAPE * S06 ≥ X (X is usually 10,000 or 20,000)
- Many recent studies
  - ↑ mean CAPE, ↓ mean S06, ↑NDSEV

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***

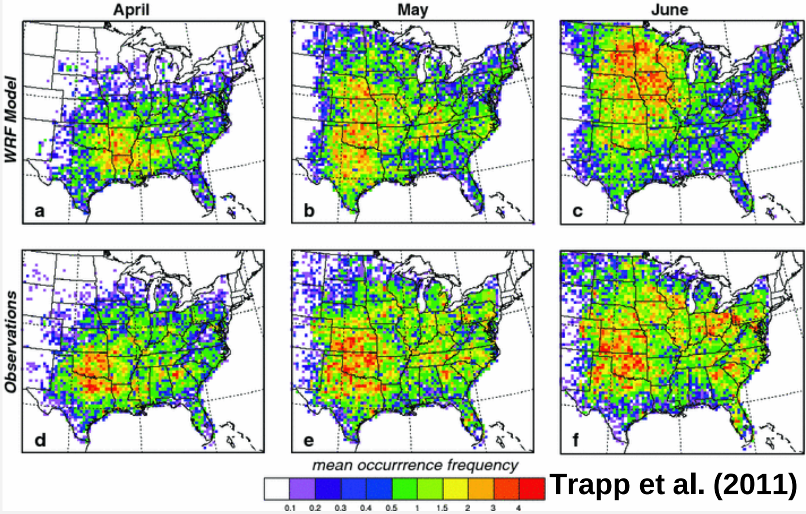


Diffenbaugh et al. (2013)

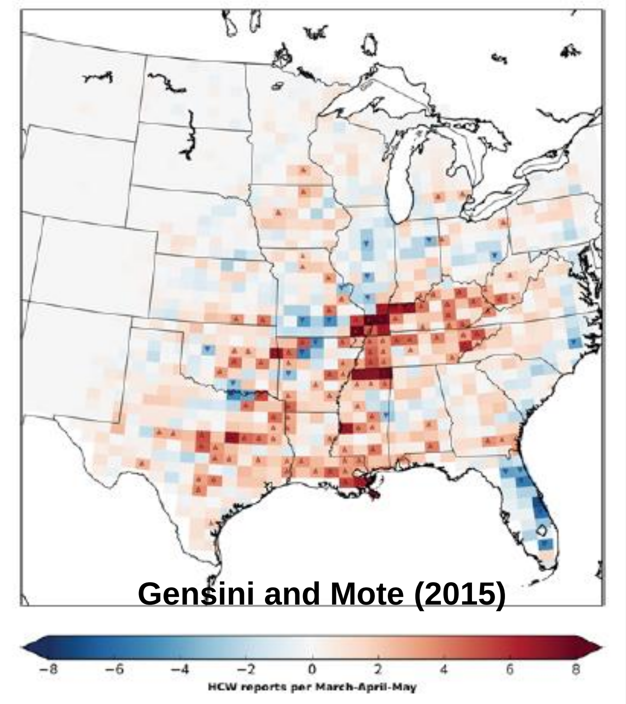
DYNAMICAL DOWNSCALING

PREVIOUS WORK WITH DOWNSCALING HCW

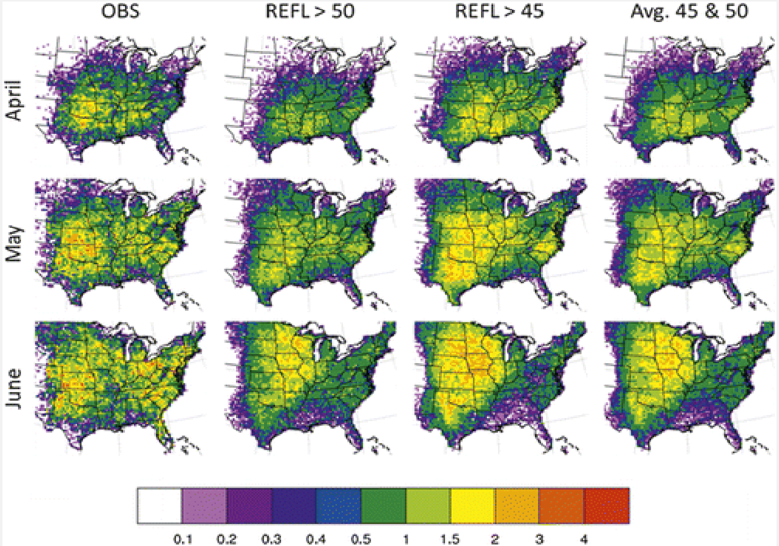
- High-resolution, convection-allowing (~4 km) WRF simulations (reanalysis/GCM)
- Reasonably recreate observed climatology using a model proxy
- Gensini and Mote (2015) downscaled CCSM3 for future climate



Trapp et al. (2011)



Gensini and Mote (2015)

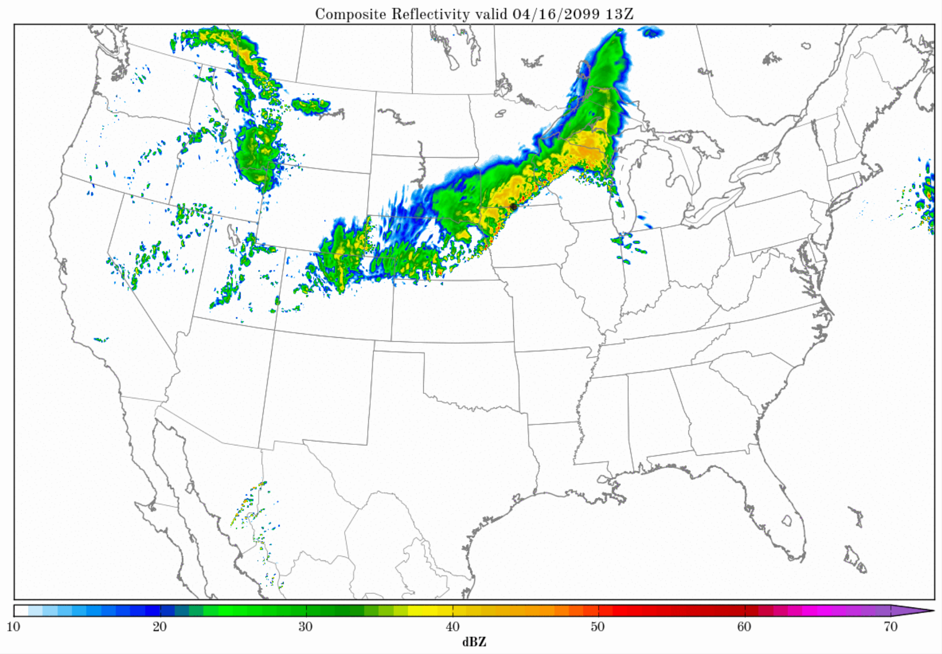


Robinson et al. (2013)

RESEARCH OBJECTIVE

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

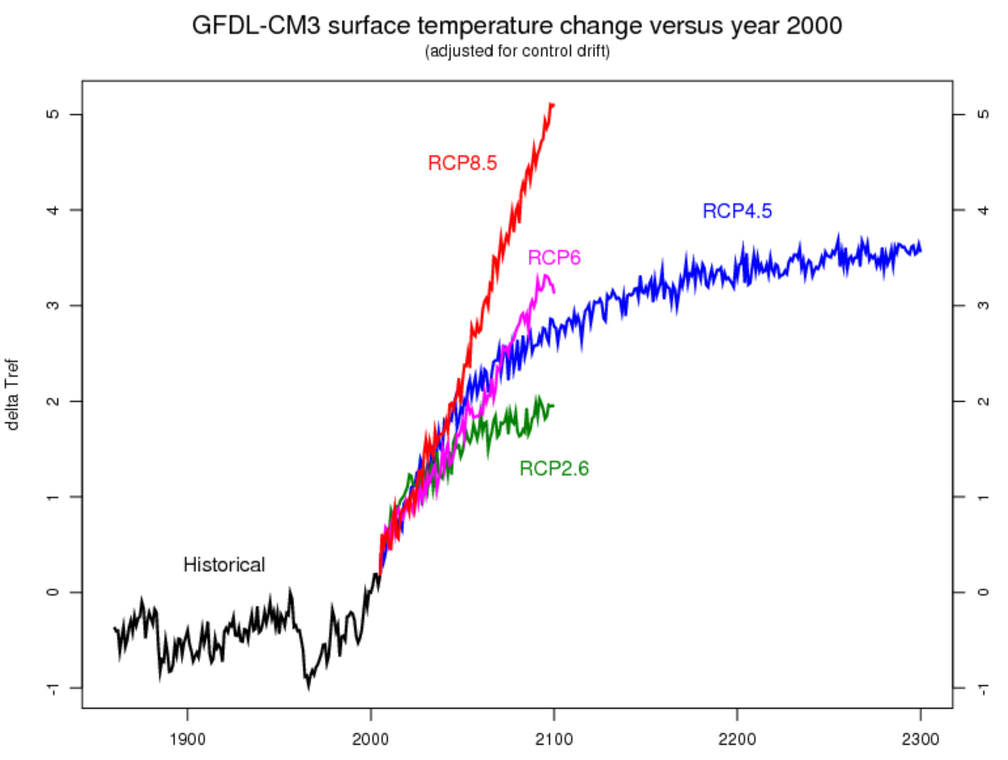
GCM SELECTION

GFDL-CM3

- Coupled atmosphere-ocean model
- 2º x 2.5º 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

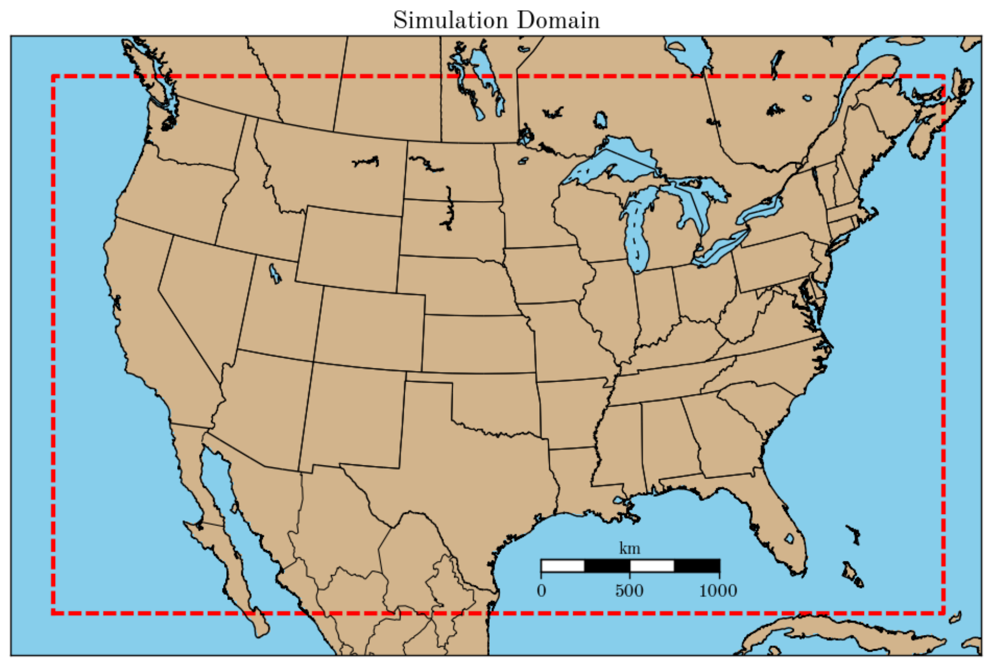
RCM MODEL SETUP

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



Parameterizations	
Microphysics	Thompson (Thompson et al. 2008)
Radiation (LW/SW)	RRTM/Dudhia (Mlawer et al. 1997/Dudhia 1989)
Land surface	Noah (Chen and Dudhia 2001)
Planetary Boundary Layer	MYNN (Nakanishi and Niino 2004, 2006)
Model Parameters	
Horizontal grid spacing	4 km
Domain size	799 x 1149 grid points
Vertical levels	45
Time step	adaptive
Buffer zone	10 grid points
Initial/Boundary Conditions	
Temperature, specific humidity, geopotential height, u and v wind, surface pressure	Surface, near-surface, 40 isobaric levels; 6-h intervals
Soil temperature, soil moisture	0-10, 10-40, 40-100, 100-200 cm
Land use/land cover	USGS 30" with lake category

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

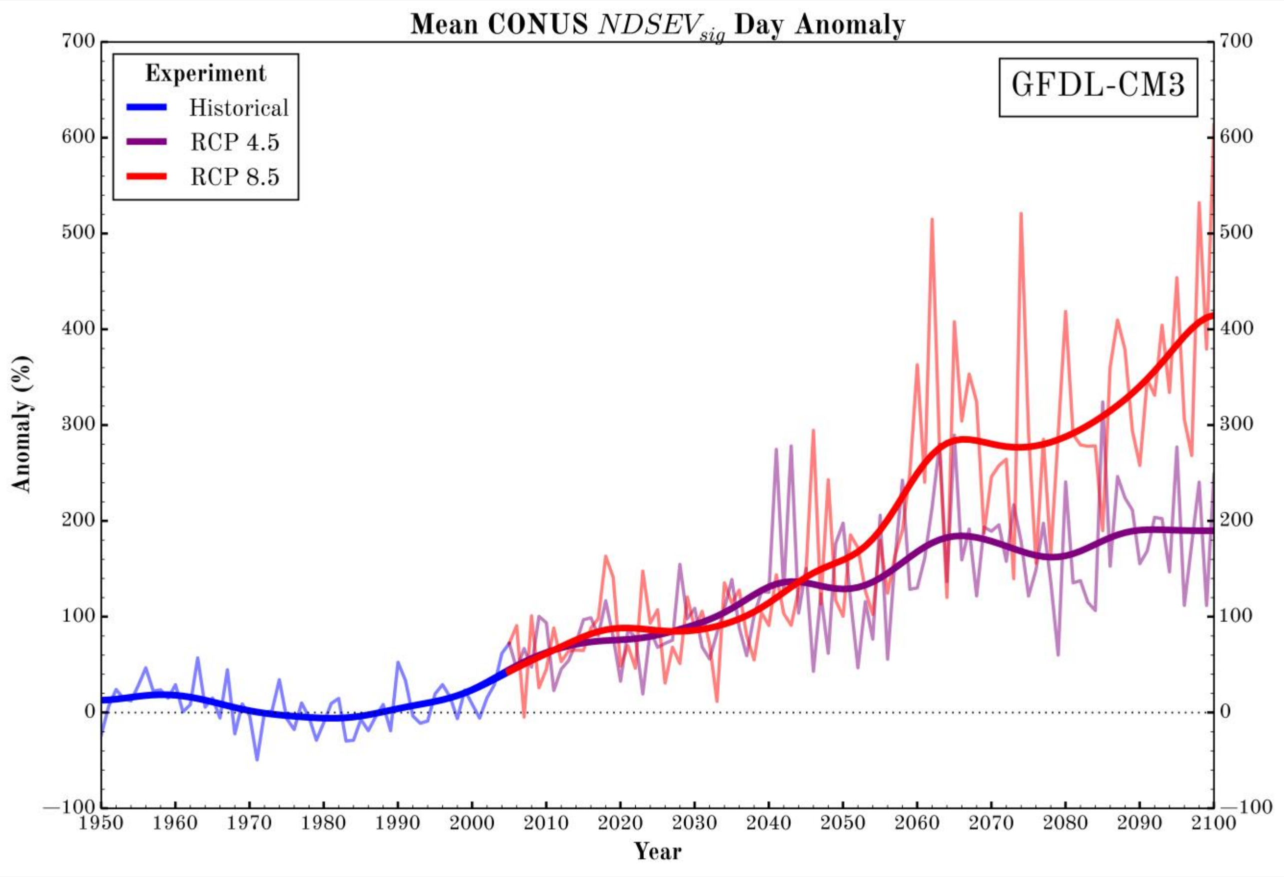
GCM SEVERE ENVIRONMENT DAYS

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

- Projected changes in environments favorable for HCW

- $NDSEV_{sig}$ =

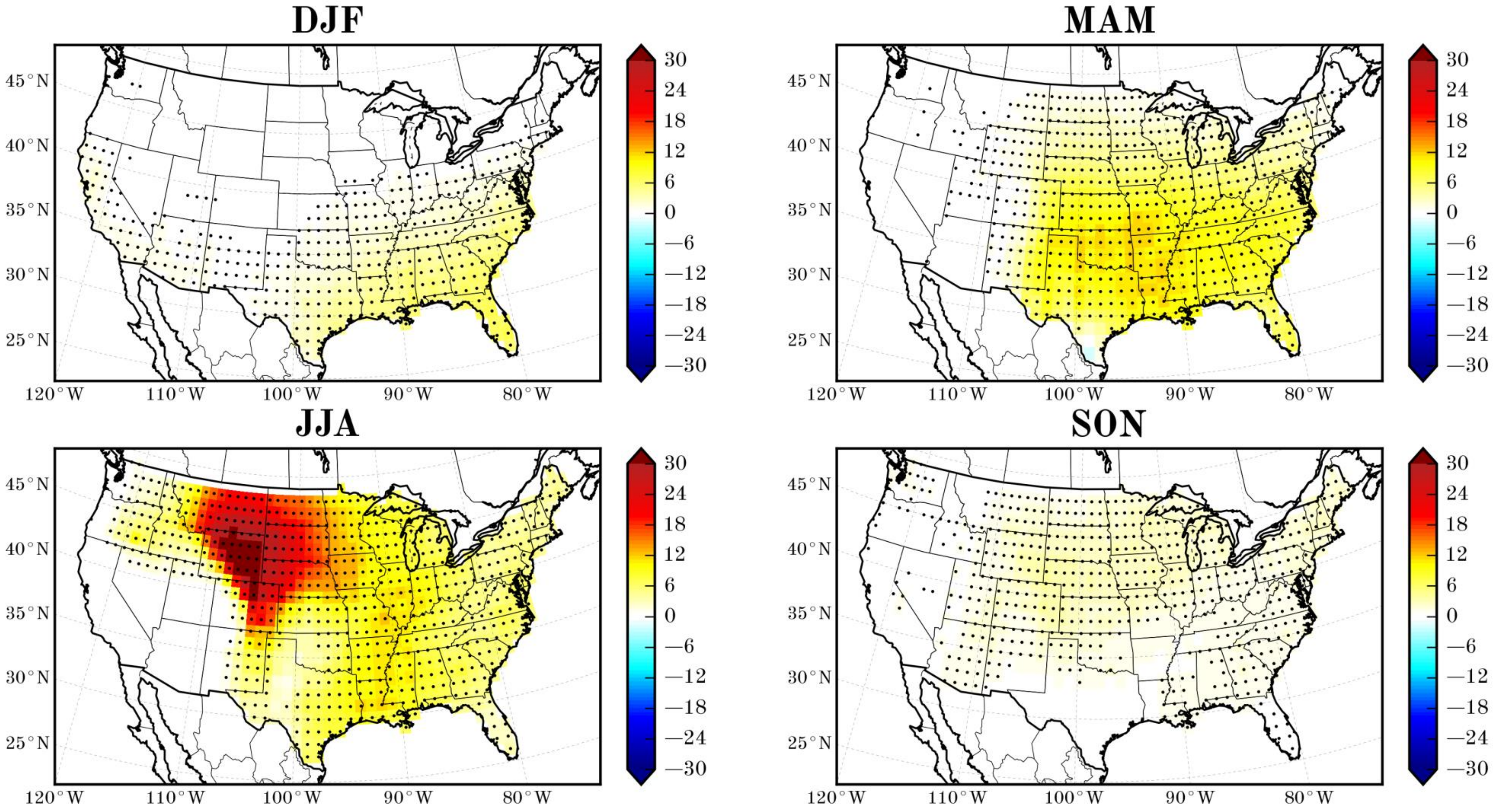
  CAPE x S06 ≥ 20,000
  - CAPE ≥ 100 J kg^{-1}
  - S06 ≥ 5 m s^{-1}
  - CIN ≥ -100 J kg^{-1}
  - Interpolated to 1° lat/lon grid
  - occurs when threshold is met at anytime between1200-1200 UTC



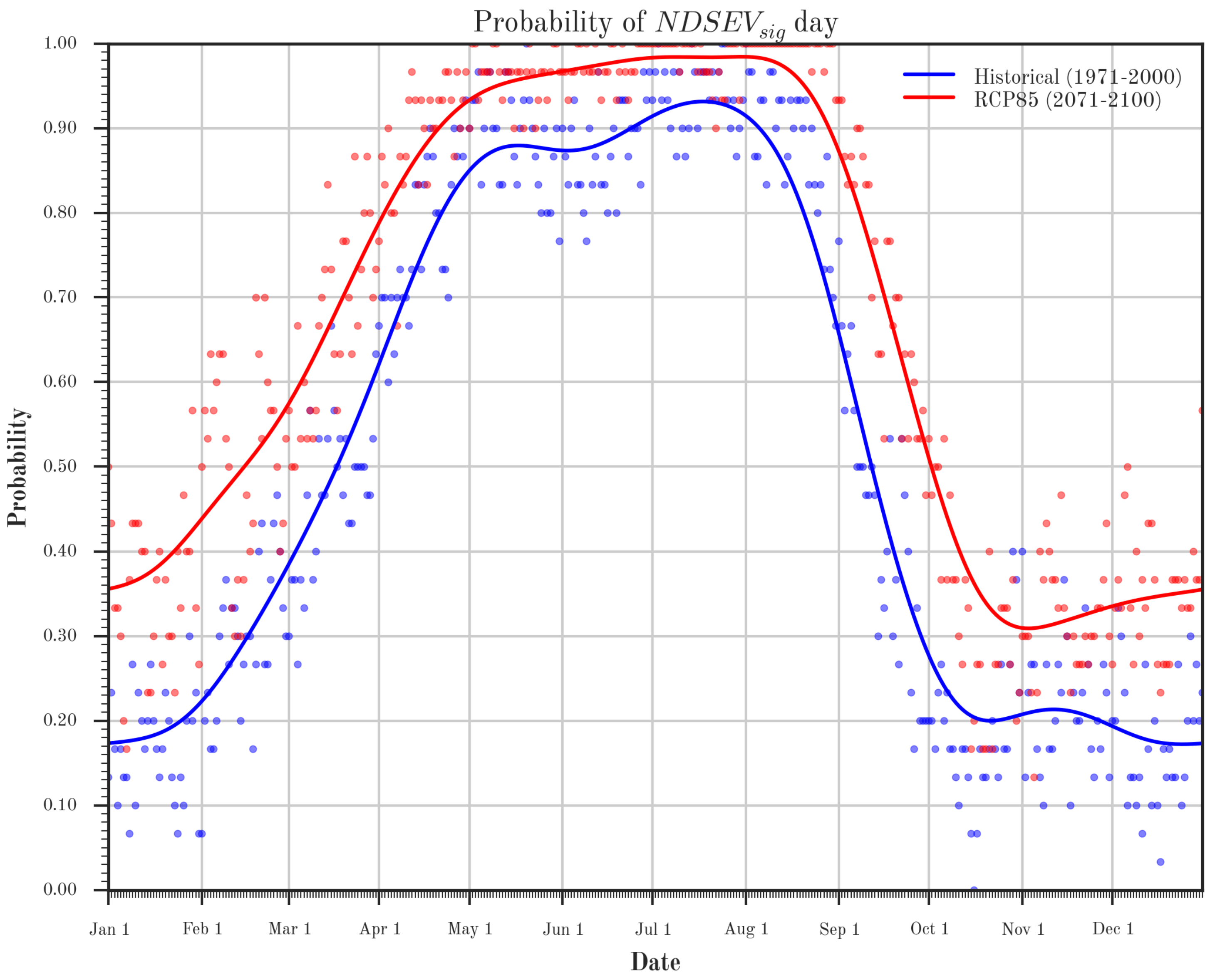
-CONUS regional mean (land points only)
-Smoothed with Gaussian filter (σ=5 years)

SEVERE ENVIRONMENT DAYS

FUTURE CHANGES



PROBABILITY BY CALENDAR DAY



GCM ENVIRONMENT

SUMMARY

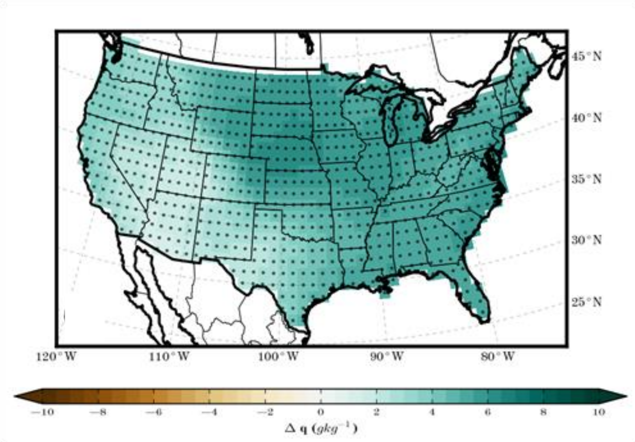
- Like other GCMS, GFDL CM3 depicts:
    - ↑ sfc temperature, specific humidity
    - ↑ CAPE, CIN
    - ↓ S06 (concentrated on days with lower CAPE)
    - ↑ $\text{NDSEV}_{\text{sig}}$

- Changes largely a result of robust increases in CAPE

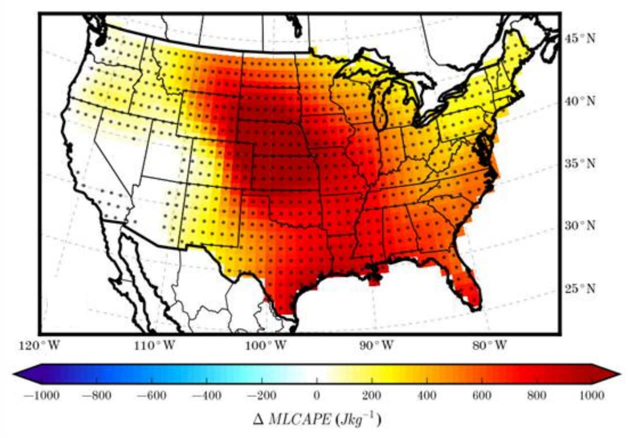
- Overall “season” is lengthened

- Other parameters show marked increase also (e.g., STP, SCP, EHI)

JJA ∆q



JJA ∆CAPE



DOWNSCALING RESULTS

IDENTIFYING A SIMULATED STORM

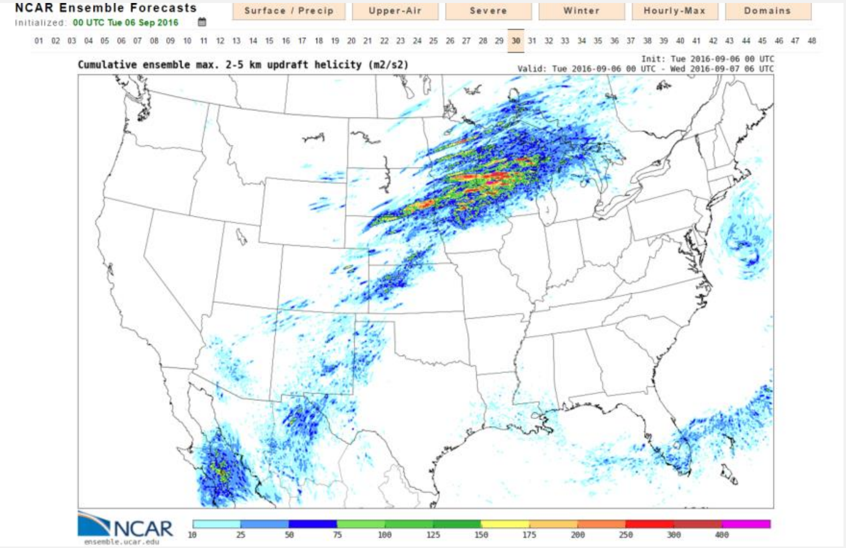
- Cannot explicitly simulate severe hazards at 4 km grid spacing, so we must use a model proxy

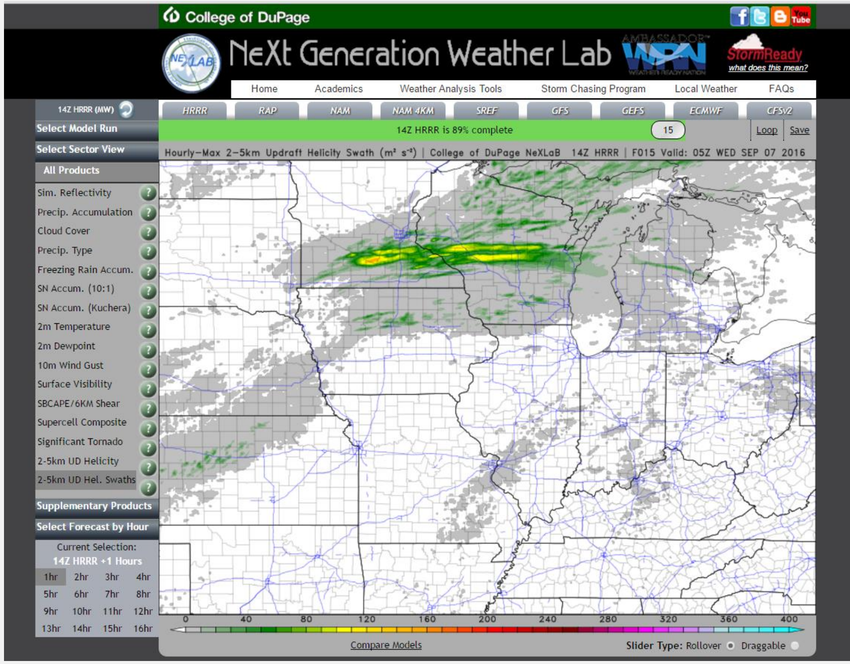
- **Hourly maximum updraft helicity (UH)**
  - Mid-level mesocyclone detection
  - Commonly used in short term severe storm forecasting
  - **50 $m^2 s^{-2}$ minimum threshold (~99.995 percentile)**

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

- Focus on proxy “day” occurrences tallied within 1º lat/lon bounding boxes

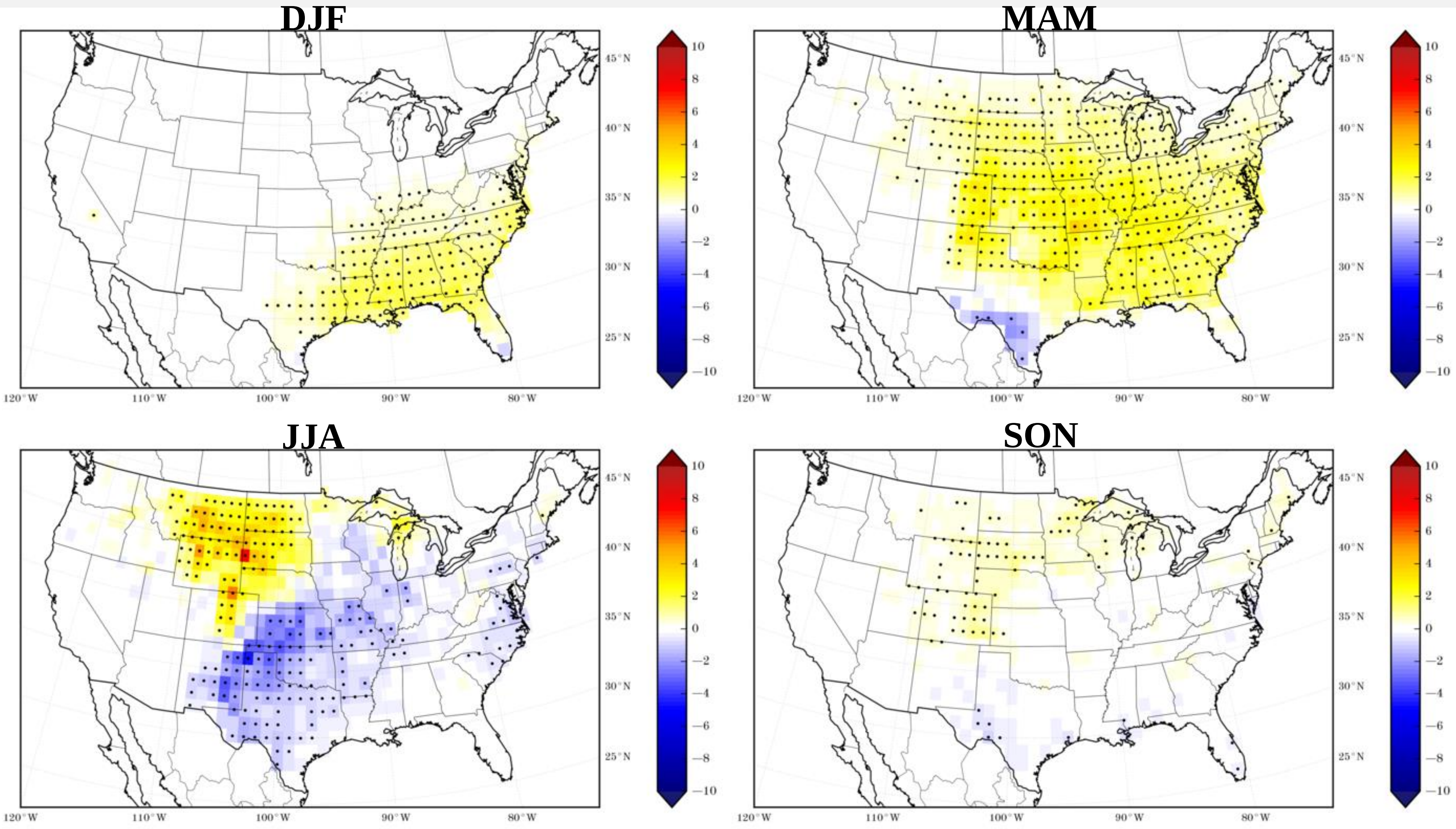
  —“Yes” if any grid point within lat/lon bounding box exceeds the specified threshold at anytime over the 24-hour period (1200-1200 UTC)





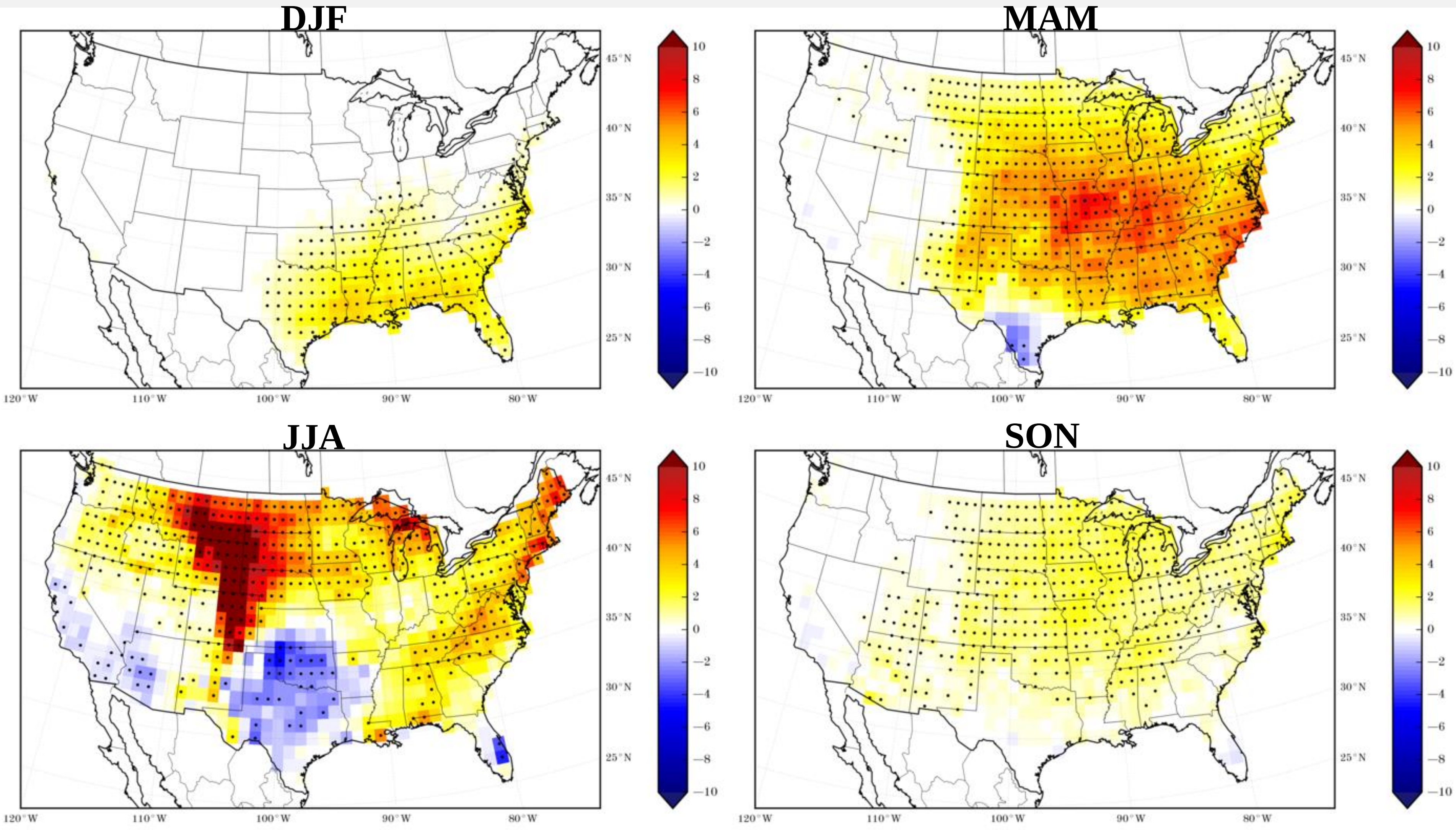
SEASONAL CHANGES

CHANGES IN DAYS WITH UH > 50 m^2 s^{-2}

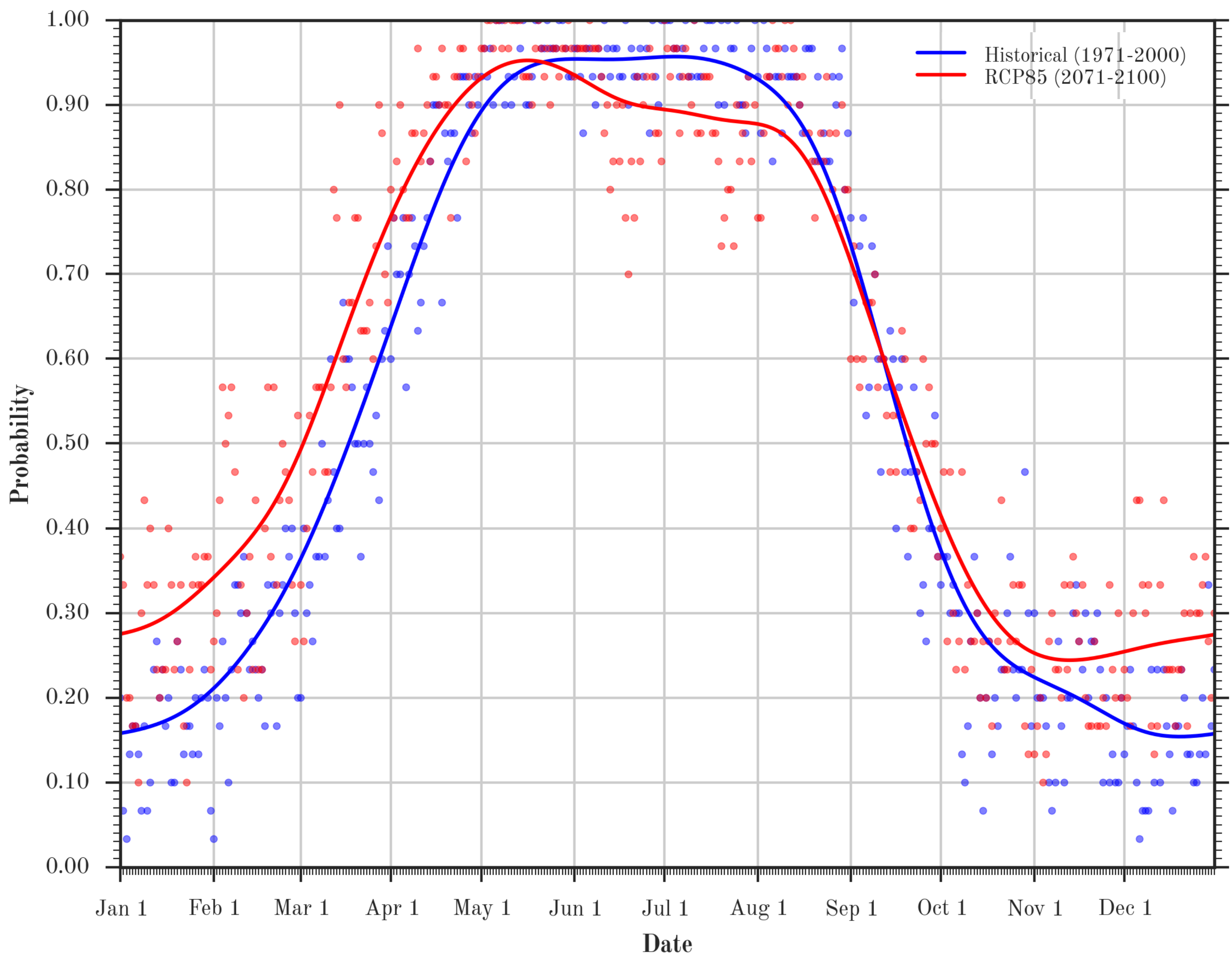


SEASONAL CHANGES

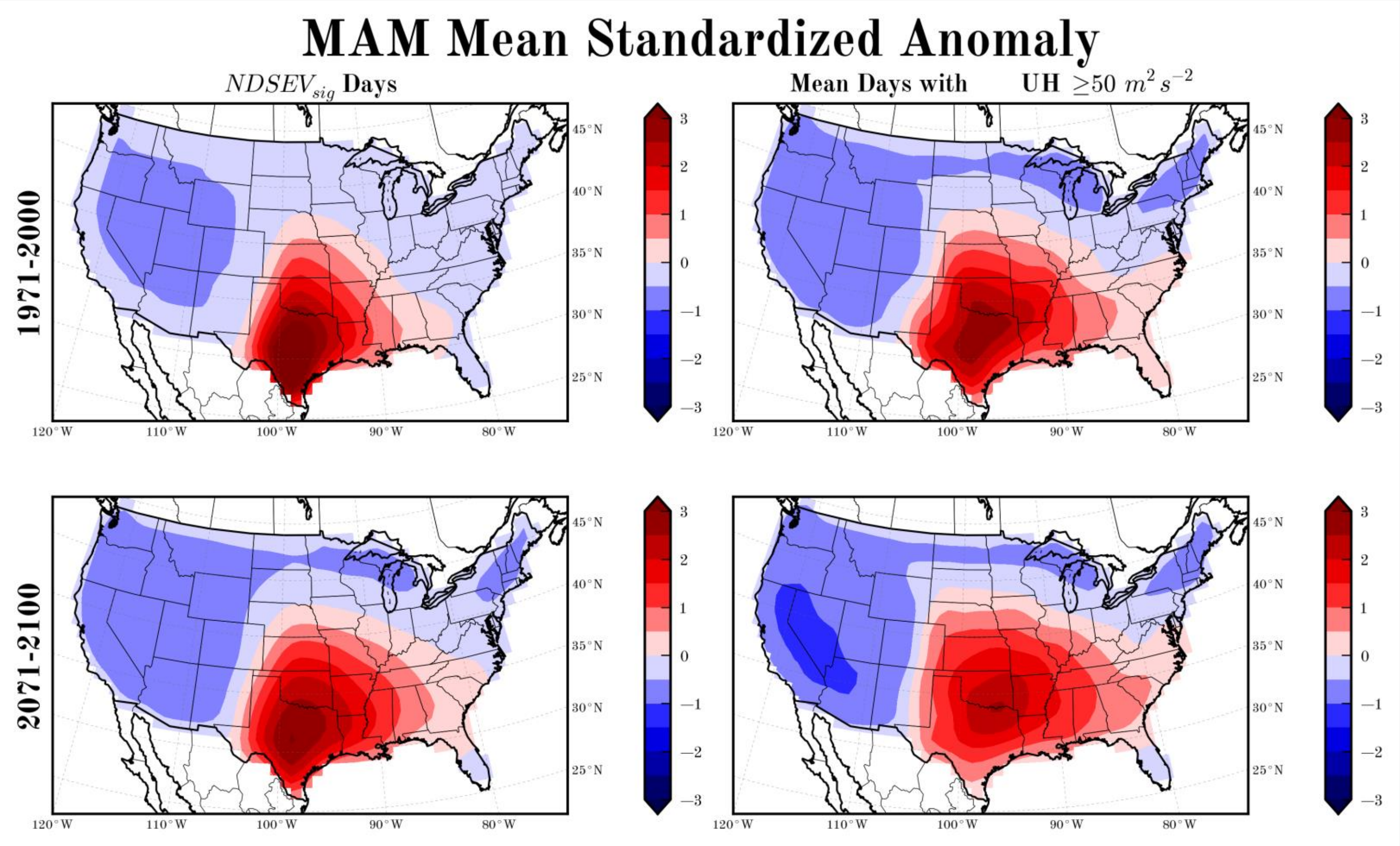
CHANGES IN DAYS WITH UPDRAFT VERTICAL VELOCITY > 20 m s^{-1}



PROBABILITY BY CALENDAR



GCM VS. RCM



MAM Mean Standardized Anomaly

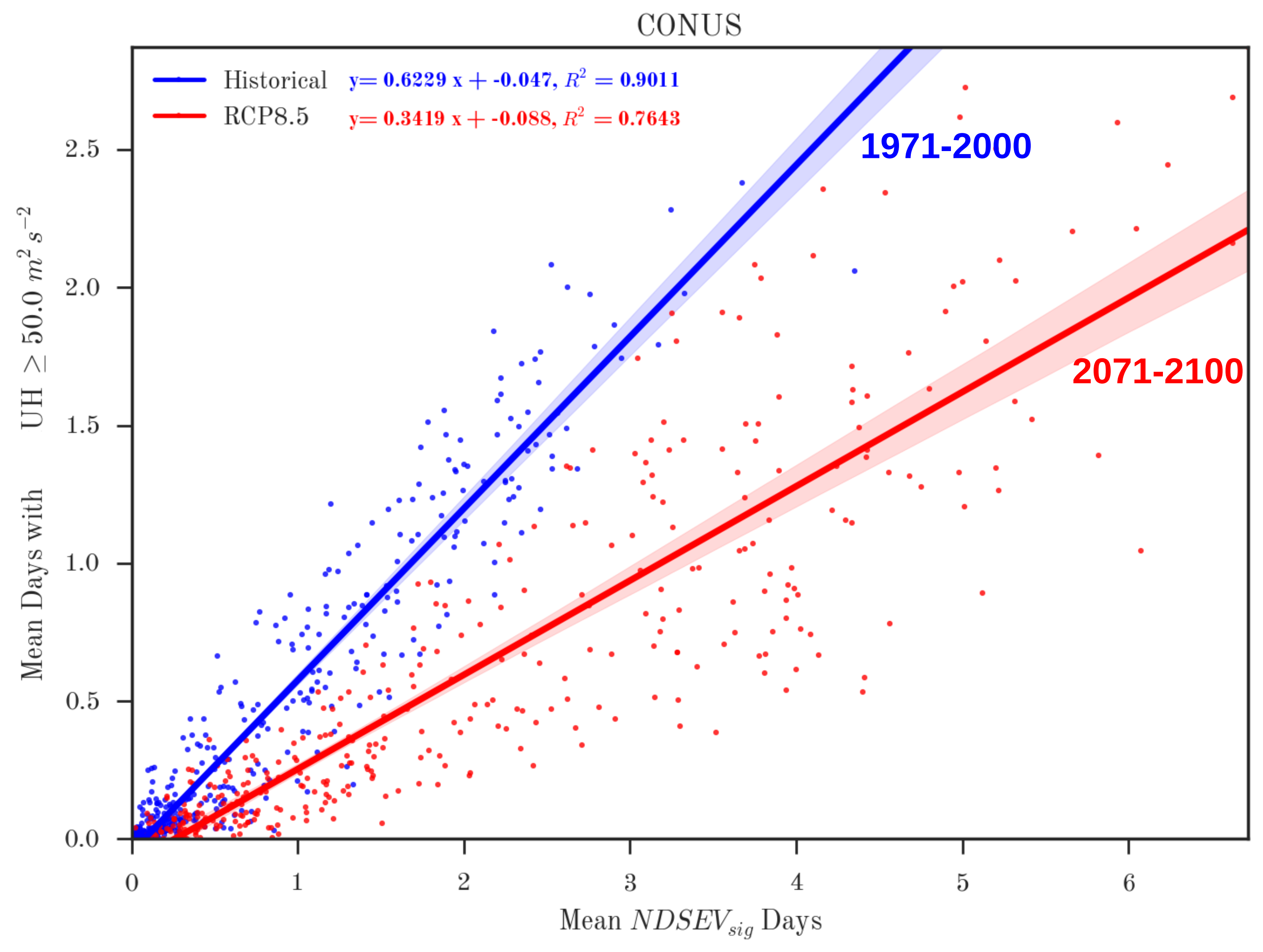
$NDSEV_{sig}$ Days

Mean Days with UH $\geq 50\ m^2 s^{-2}$

	DJF	MAM	JJA	SON
Historical	0.888	0.912	0.895	0.784
future	0.983	0.930	0.947	0.865

GCM VS. RCM

MONTHLY MEAN NDSEV$_{SIG}$ DAYS VS. MONTHLY MEAN UH DAYS



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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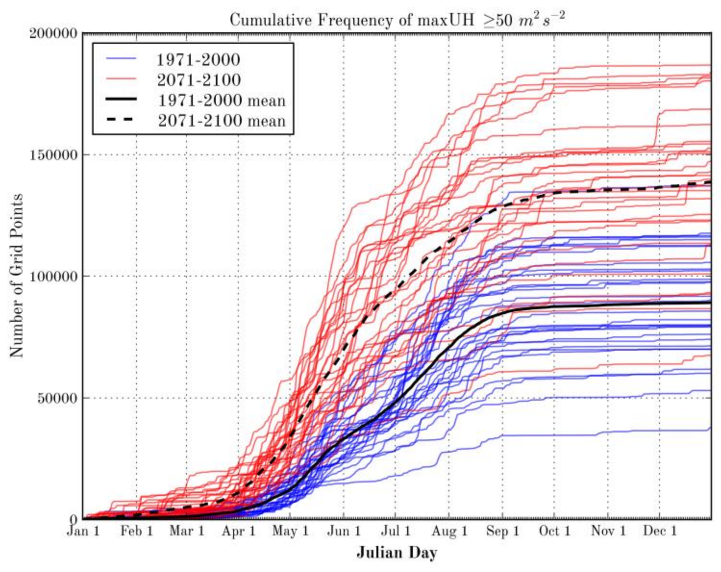
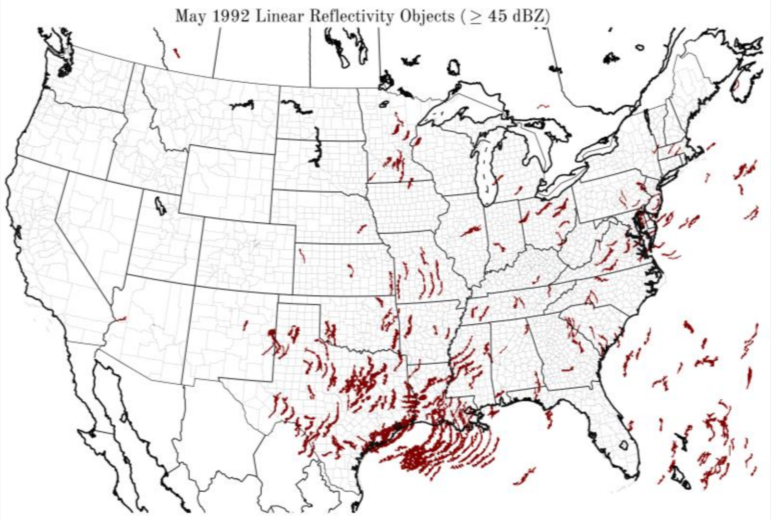
ONGOING/FUTURE WORK

- 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."

Box, G. E. P. and N. R. Draper,1987: Empirical Model-Building and Response Surfaces, p. 424, Wiley.

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ACKNOWLEDGMENTS

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