Projected changes to Severe Thunderstorm environments as a result of 21st century warming from RegCM CORDEX-CORE simulations

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EGU2020: Regional climate modeling, including CORDEX

4 May, 2020

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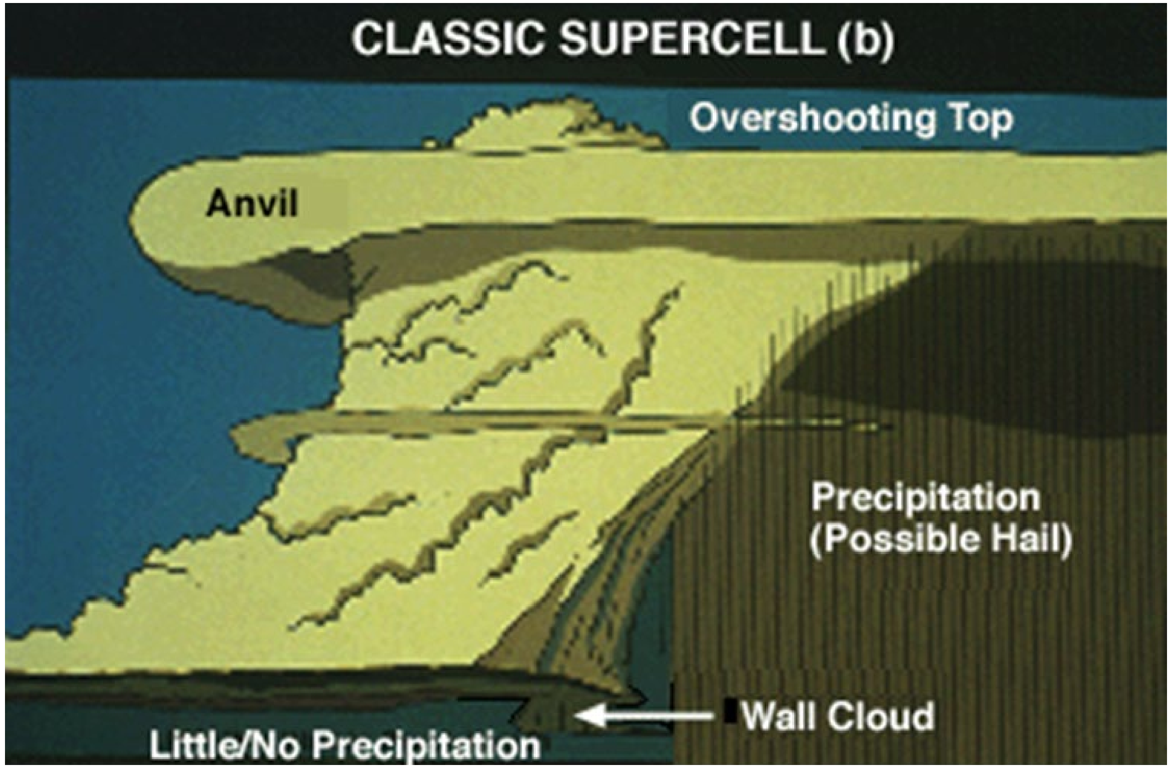
What are Severe Thunderstorms?

- Category of Intense Thunderstorms which produce damaging winds, hail, and/or tornadoes
- This can include storms such as squall lines, Derechos, supercells, etc.
- Greater organization than ordinary (for example: tropical) convection, i.e. mesocyclones, separated updraft and downdraft regions
- Generally form in regions of high convective instability and high vertical wind shear



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Regional Severe Thunderstorm Impacts (Australia, South America, and South Asia)

- Australia: 1999 Sydney Hailstorm (Yeo et al., 1999), recordsetting hailstorms in Perth and Melbourne in 2010, severe hailstorms on Christmas Day 2011 in Melbourne (Allen, 2012)
- Argentina: intense thunderstorm development on eastern side of Andes, Sierras de Cordoba; Mulholland et al. (2018), Romatschke and Houze (2010)
- Southern Brazil: From 1960-2008 158 tornadoes reported (Silva Dias 2011)
- Bangladesh: World's single deadliest tornado April 26, 1989 Daulatpur and Saturia cities, ~1,300 fatalities

Allen (2012) – Figure 3a: Supercell over northern suburbs of Melbourne

Tornado near Berazategui, Argentina, February 21, 2014

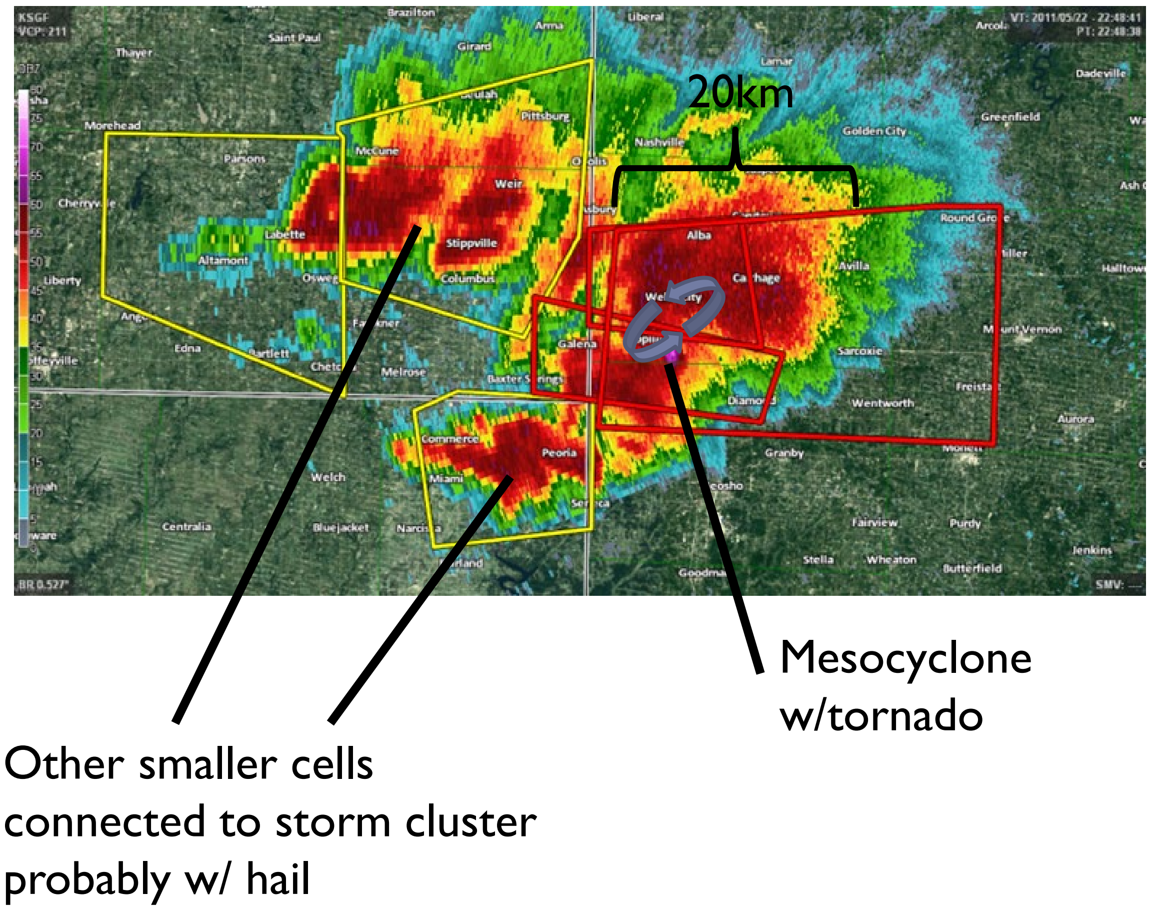
Regional Severe Thunderstorm Impacts (North America and US)

- Between 2000-2004 severe storms caused an annual loss of 2.1 Billion US$ of damage, 108 fatalities, 1,463 injuries; during the same period tropical cyclone annual losses were 5.5 Billion US$, 25 fatalities, and 285 injuries (Trapp et al. 2007)
- 2011 US season alone caused >10 Billion US$ in damages, ~550 fatalities, and >5,000 injuries

https://www.flickr.com/photos/ozarksredcross/8556513652/in/photostream/

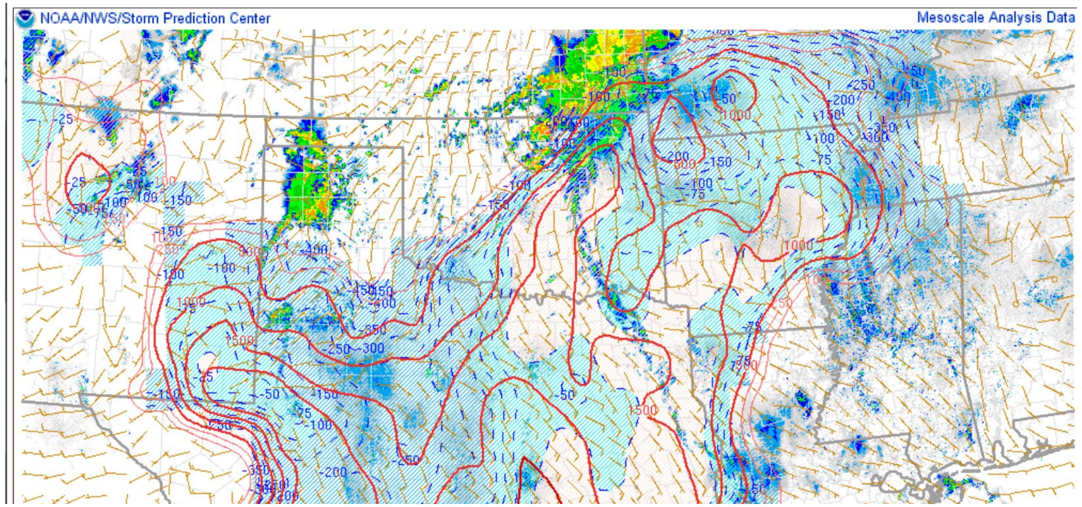
Challenges to Assessing Severe Storm Changes under GW

- Individual Storms have a horizontal scale of < tens of Kilometers and temporal scale of hours
- Assessment of individual storm impacts is impossible at regional scales
- Climatology of Severe reports: there is no reliable long-term dataset of Severe Storms to assess frequency in the present, Kunkel et al. (2013), Diffenbaugh et al. (2008)

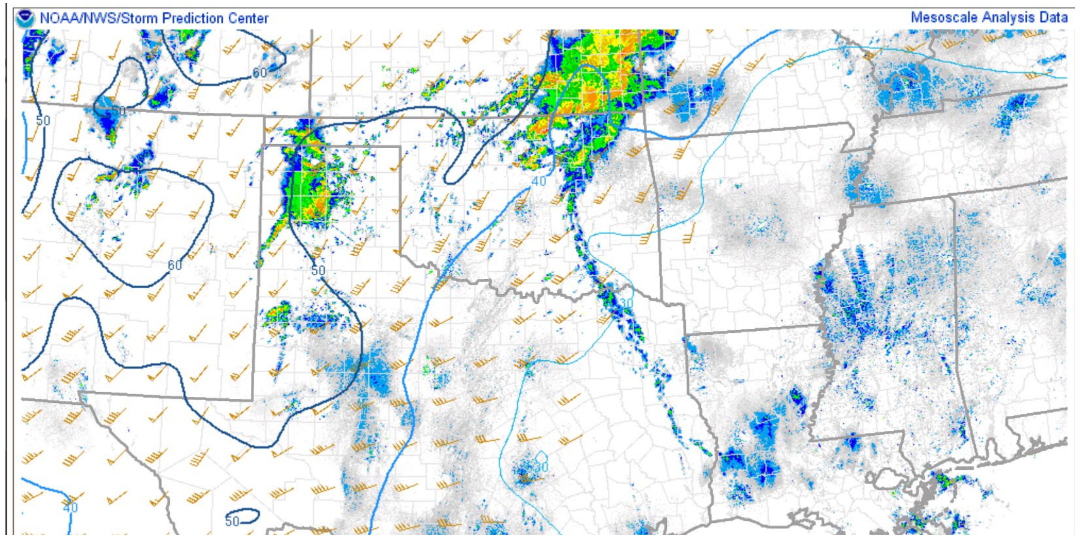


Assessing the Severe Storm Large-scale Environment

- **We cannot asses individual storm impacts, but** we may be able to implicitly analyze their frequency through the large-scale environment
- Severe Storms are known to occur within specific synoptic environmental conditions
- Vertical Wind Shear: $\vec{V}_0 - \vec{V}_6 = V_{06}$
- CAPE (Convective Available Potential Energy): $W_{max} = \sqrt{2\ CAPE}$
- The environment is most favorable when both CAPE and V_{06} are large (Brooks et al. 2003)



Mixed-Layer CAPE (J/kg)



0-6km Vertical-Wind Shear (m/s)

Constructing a Metric to Analyze the Severe Storm Environment

- Set a threshold for important environmental parameters which we will say, if satisfied, will indicate conditions for severe storms on a particular day.
- From Brooks et al. (2003); Trapp et al. (2007; 2009):

If some initial criteria are met; **1)** CAPE $\geq$ 100 J/kg; **2)** abs(V_6) $\geq$ abs(V_0); **3)** $V_{06} \geq$ 5m/s

Then;

We define a severe storm day (SD) at a grid point if the following empirical threshold is met:

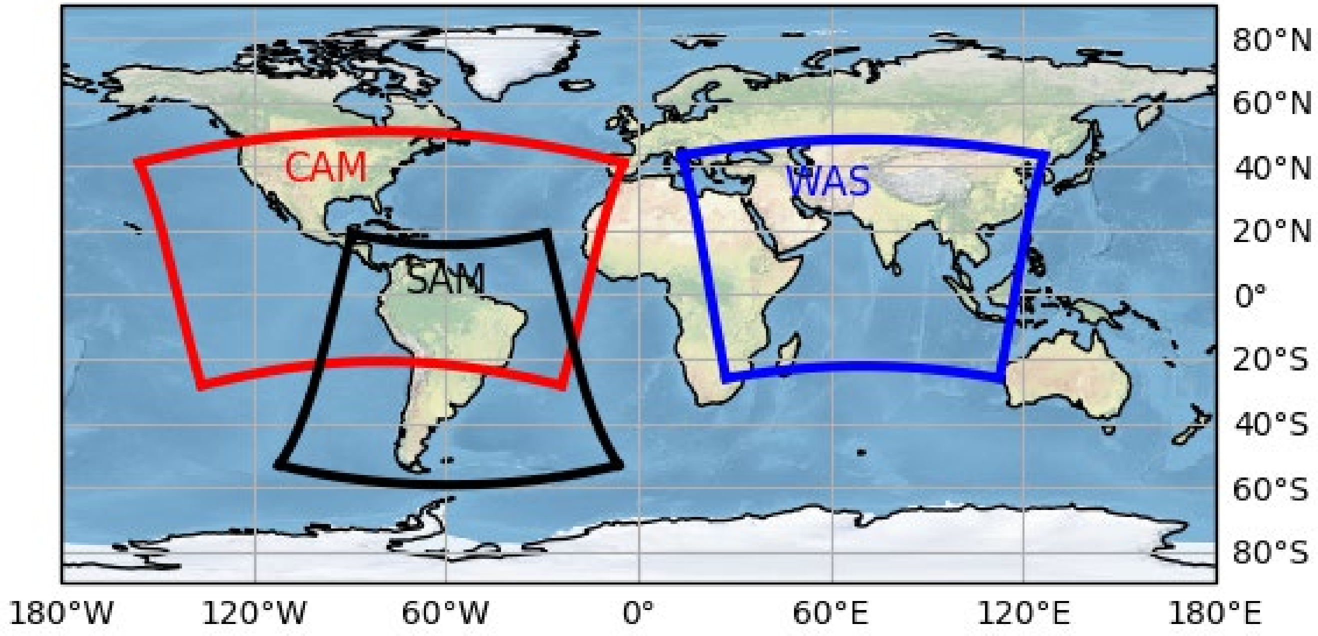
$$\mathbf{V_{06} \times CAPE \geq 10{,}000}$$

- Typical values of CAPE during Severe Outbreaks 1,000-3,000 J/kg; then to satisfy this condition V_{06} needs to be at least 10 m/s
- Thus, SD is a measure of the number of days supportive of severe thunderstorm development if storms should form, i.e. storm initiation is neglected

Proposal for a multi-regional Analysis of future Severe Storm Environments

- Analysis of Severe Storm Days for relevant CORDEX domains:
  - Subtropical South America (SAM)
  - United States (CAM)
  - Eastern India and Bangladesh (WAS)
- Assess CAPE and V_{06} in present vs. future climate RegCM4 simulations
- A comprehensive global analysis of Severe environments using RCMs has not been done – GCM and specific regional studies have been done in the past

CORDEX-CORE Simulation Domains used



Constructing a Metric to Analyze the Severe Storm Environment

- For this study we adopt severe criteria based on Allen et al. (2014a):

$$\text{Eq (1)} \quad \mathbf{(CAPE)(}\boldsymbol{V_{06}}\mathbf{)^{1.67}} \geq \mathbf{25,000},$$

then SD = 1

γ = 1.67, reflects that the Shear is a better discriminator of severe potential (Allen 2018; Allen 2011; Brooks et al. 2003; Brooks 2009)

- Many studies have utilized equal weighting between CAPE and Shear, signifying that they are equally discriminatory of severe environments, e.g. Trapp et al. (2007;2009), Seeley and Romps (2015), Diffenbaugh et al. (2013)
  - However these studies have almost exclusively focused on the US
- On the other hand, similar parameter spaces to Eq. 1 for severe environments have been found across different regional environments (Brooks et al. 2003; Brooks 2009: US and Europe, Allen et al. 2014a; Allen 2011: Australia, Blamey et al. 2017: South Africa)

Model Configuration and Analysis Setup

- All simulations are conducted with the Regional Climate Model version 4.7 (RegCM; Giorgi et al. 2012)
  - 25km Grid spacing; 23 vertical levels
- Emissions Scenarios used: Representative Concentration Pathways (RCP; IPCC 2014) 2.6 and 8.5
- Periods of Analysis:

  Historical – 1995-2014

  Mid-Future – 2041-2060

  Far-Future – 2080-2099
- Forcing GCM for RegCM simulations: Max Planck Institute-Earth System Model-Medium Resolution (MPI-ESM-MR; Stevens et al. 2013) for all time periods
  - An additional simulation forced by ERA-Interim Reanalysis (Dee et al. 2011) for historical period
- Profiles of CAPE (mixed-layer) and Shear are calculated daily at the 6-hourly (0,6,12,18z) time most corresponding to daytime maximum in solar heating

Analysis of Severe Days (US)

- Even modest warming by mid-century results in 2-4 more SDs in MAM and JJA
- Increases in SDs in **JJA** over the northern mid-west due to both increased CAPE **and Shear**
- During **MAM** increases in CAPE mainly drive increased SDs
- By Far-Future in the RCP8.5 scenario robust increases in SDs are seen in MAM and JJA

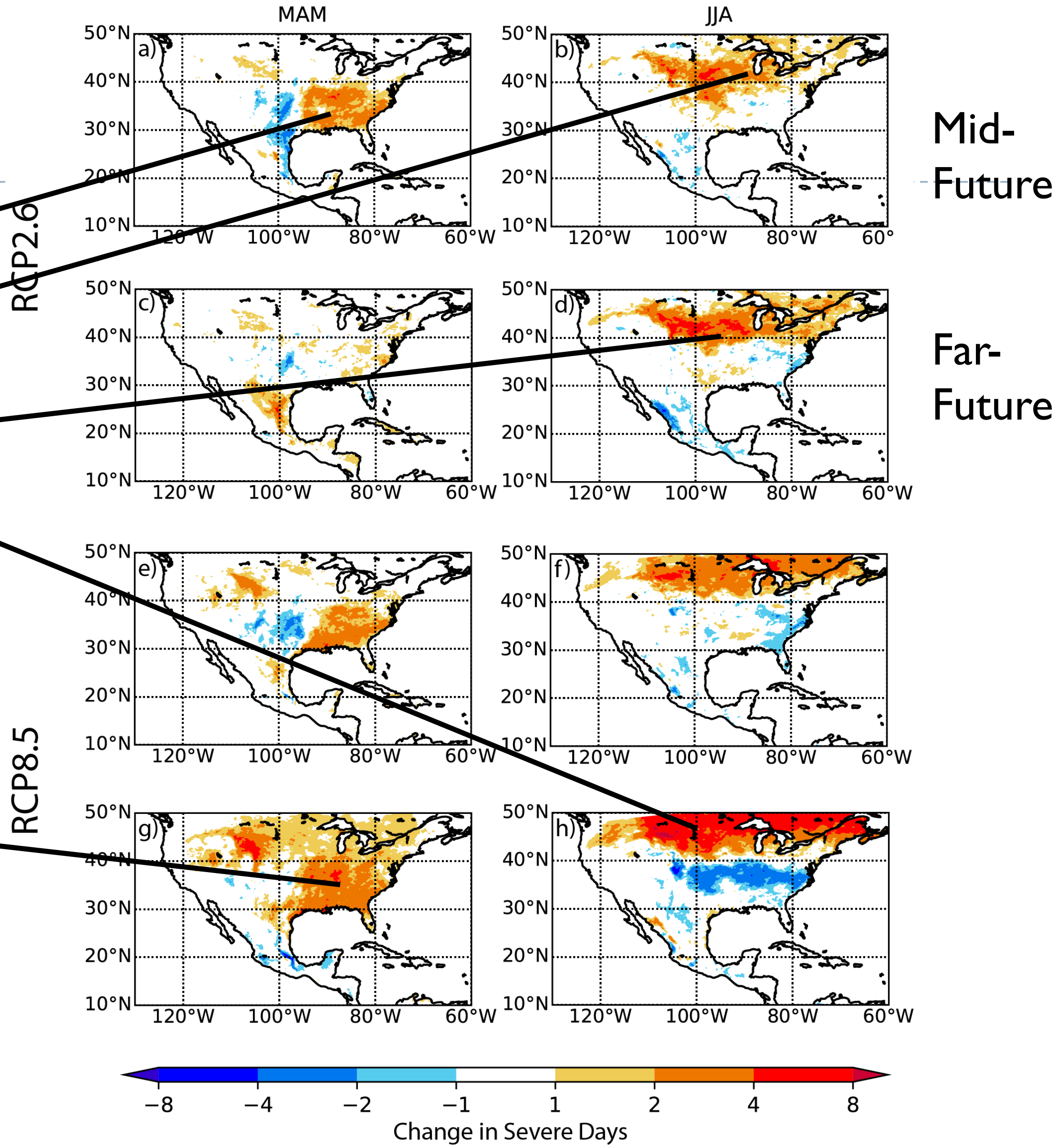


Figure 1. The CAM domain shaded difference in the number of severe days relative to the historical period (historical-future) at the Mid-future (2041-2060; a, c, e, f), and Far-future (c, d, g, h) time period in RCP8.5 (a-d) and RCP2.6 (e-h). The left panel shows MAM (a, c, e, g) and the right panel shows JJA (b, d, f, h).

Analysis of Severe Days (Subtropical South America)

- During SON in all periods, clear shift in SDs to the south – this is the result of poleward shift in polar jet where shear is concentrated
- By the end of century in RCP8.5: robust increases in SDs to the east of the Andes, northern Argentina in austral summer
- Increases in SDs over subtropical South America are driven partially by CAPE, but mostly by a poleward shift in the polar jet which is forecast in the future (Reboita et al. 2018; Yin 2005)
  - The shifting polar jet moves belts of shear into regions favorable for severe weather

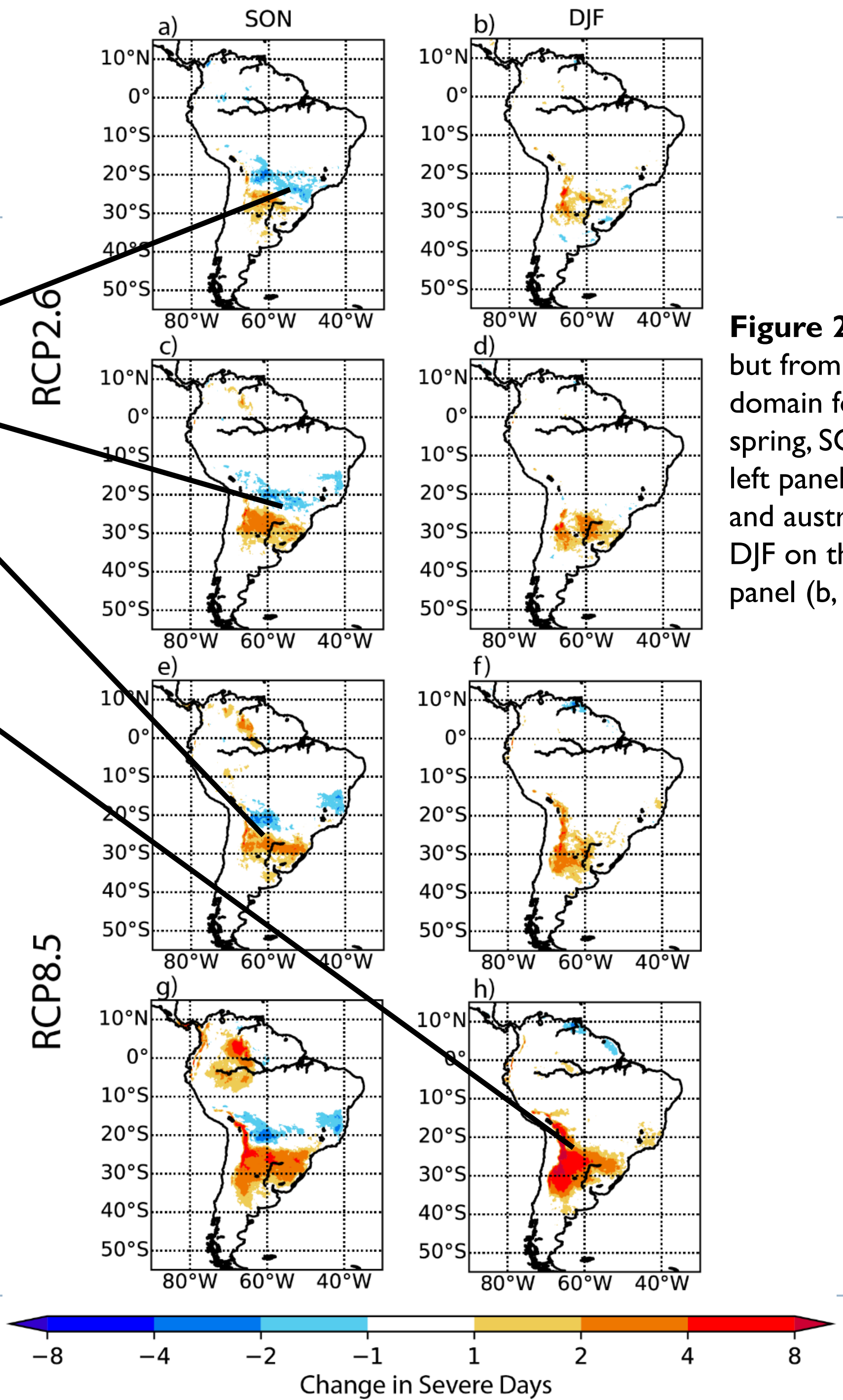


Figure 2. As in Fig. 1 but from the SAM domain for austral spring, SON on the left panel (a, c, e, g) and austral summer, DJF on the right panel (b, d, f, h).

Analysis of Severe Days (South Asia)

- Modest increases in SDs over Bangladesh by end of century RCP2.6
- Modest increases in SDs found over central India, foothills of the Himalayas, during SON
- Robust increases in SDs found over southeast China in MAM
- Large increases in CAPE in RCP8.5 scenario lead to increase in SDs over Bangladesh of 4-8 days in MAM; partially reduced due to influence of decreased shear to the west

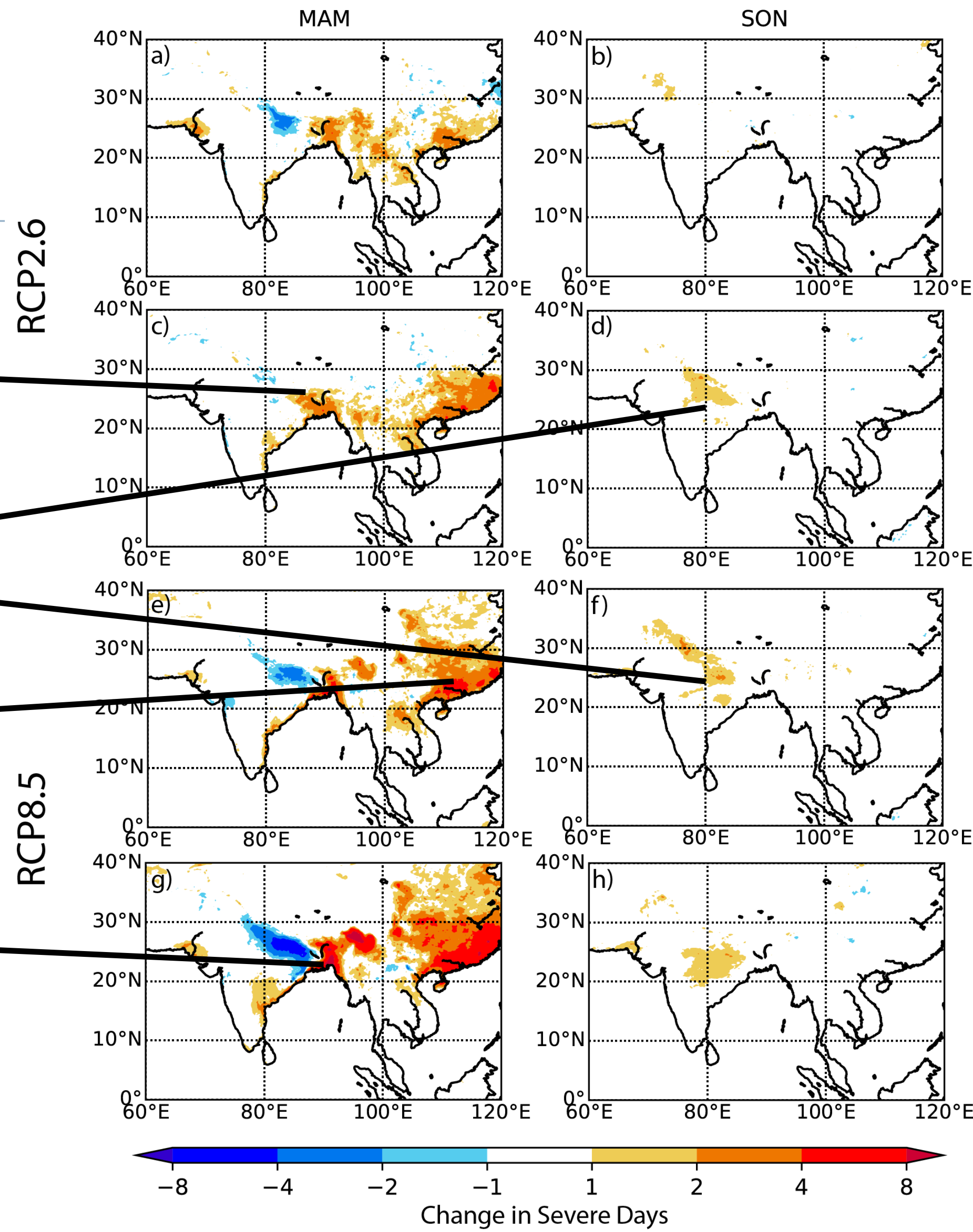
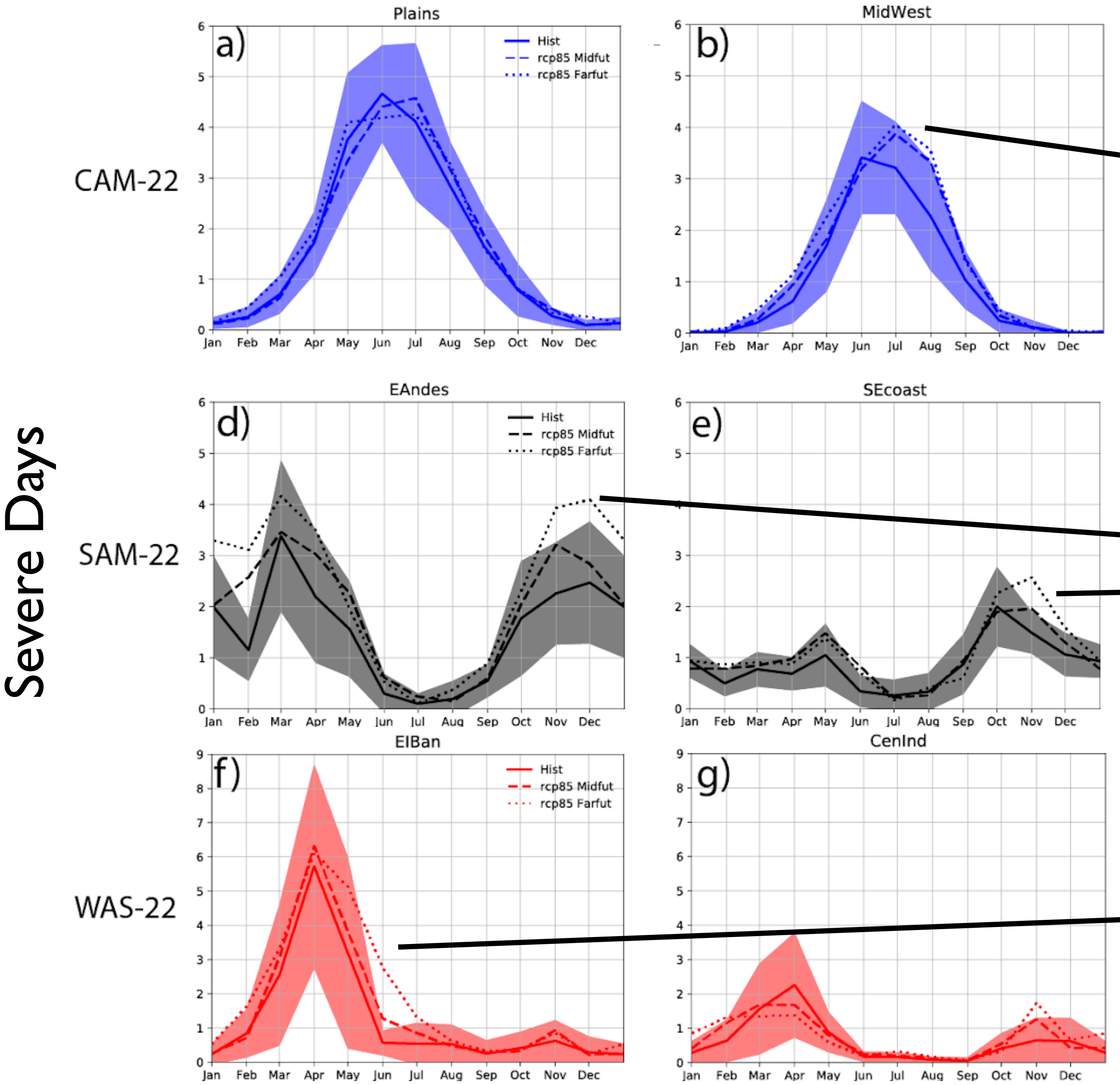


Figure 1. As in Fig.1 but from the WAS domain for MAM on the left panel (a, c, e, g) and SON on the right panel (b, d, f, h).

Regional Analysis of Annual Cycle in SDs



Southern US sees an extension of severe season into earlier spring months; the Mid-Western US sees a lengthening of the summer severe season into later months

Figure 4. The annual cycle in severe days calculated over the three regions of North America from the CAM simulation (blue): (a) Plains (32°N-45°N, 105°W-95°W), (b) Mid-west (38°N-45°N, 50°W-80°W), and (c) southern Gulf coast (SGulf; 28°N-38°N, 95°W-78°W), two regions from the SAM simulation (black): (d) the region east of the Andes and northern Argentina (EAndes; 35°S-25°S, 68°W-60°W) and (e) the southeast coast of Brazil (SEcoast; 35°S-20°S, 60°W-45°W) the historical (solid line), and two region from the WAS simulation (red): (f) east India and Bangladesh (EIBan; 22°N-27°N, 87°E-93°E), and (g) central India (CenInd; 20°N-27°N, 77°E-87°E). The monthly mean in severe days is calculated from the historical (solid-lines), Mid-future RCP8.5 (dashed lines), and Far-future RCP8.5 (dotted lines) periods in each domain. The shaded region in each plot represents +/-1 standard deviation in the annual severe day counts over the historical period.

Robust increases in SDs during austral spring; severe season peaks later

Lengthening of Spring severe season into Monsoon months

Conclusions and Summarize

- **In every region** environments supportive for severe thunderstorms are projected to increase during the warm season months in both RCP2.6 and RCP8.5 during the 21st century
- **21st century surface warming is clearly driving a robust increase in CAPE** in all regions, however poleward displacement of vertical shear in the future leads to the movement of severe environments over North America and South America
- The non-uniformity of the regional changes indicate that **severe impacts in the future cannot be generalized globally**, and that regionally specific changes in vertical shear may drive future movement of regions prone to severe weather

See Full Study: Glazer et al. (2020) Projected changes to Severe Thunderstorm environments as a result of 21st century warming from RegCM CORDEX-CORE simulations. Climate Dynamics (In Review)

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