The Abdus Salam International Centre for Theoretical Physics

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Assessing Changes to Severe Storm Environments

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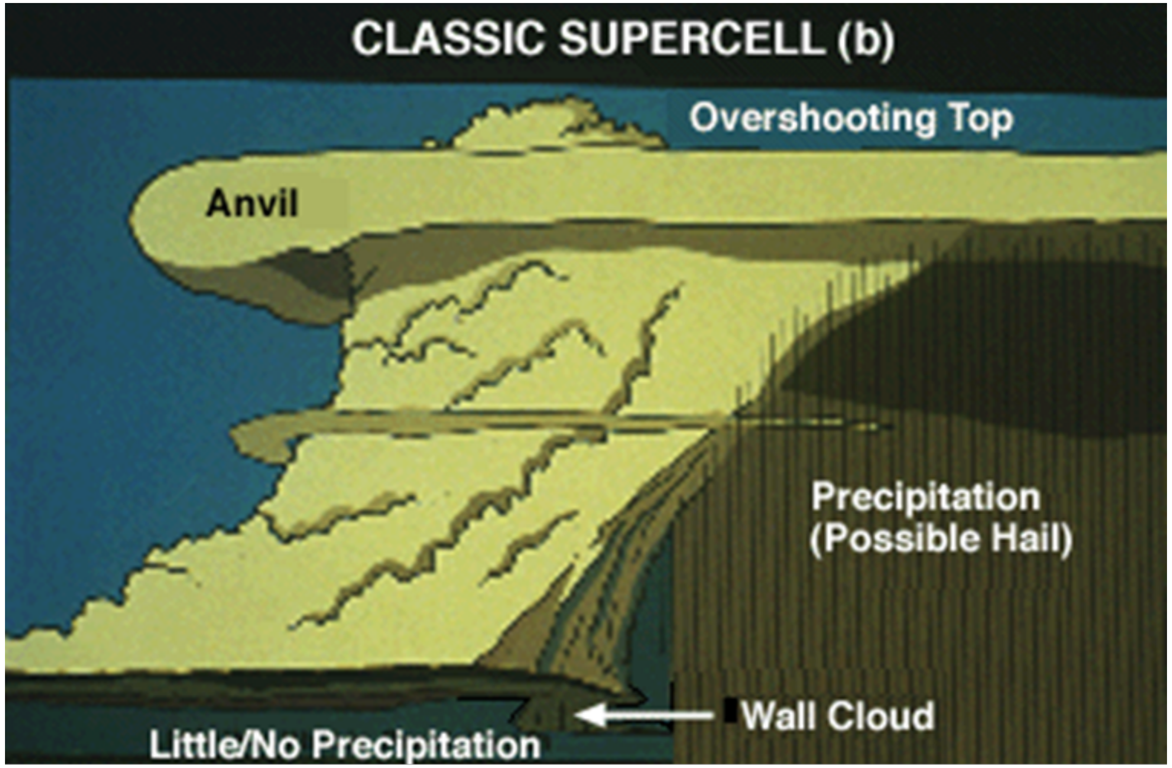
Special Topic: ICTP CORDEX Regional Paper-Writing Workshop

7 May, 2019

A Plan for assessing the expected changes to Regional Severe Storm Environments under GW using RegCM CORDEX simulations

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



http://ww2010.atmos.uiuc.edu/(Gh)/guides/mtr/svr/type/spr/sch.rxml

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

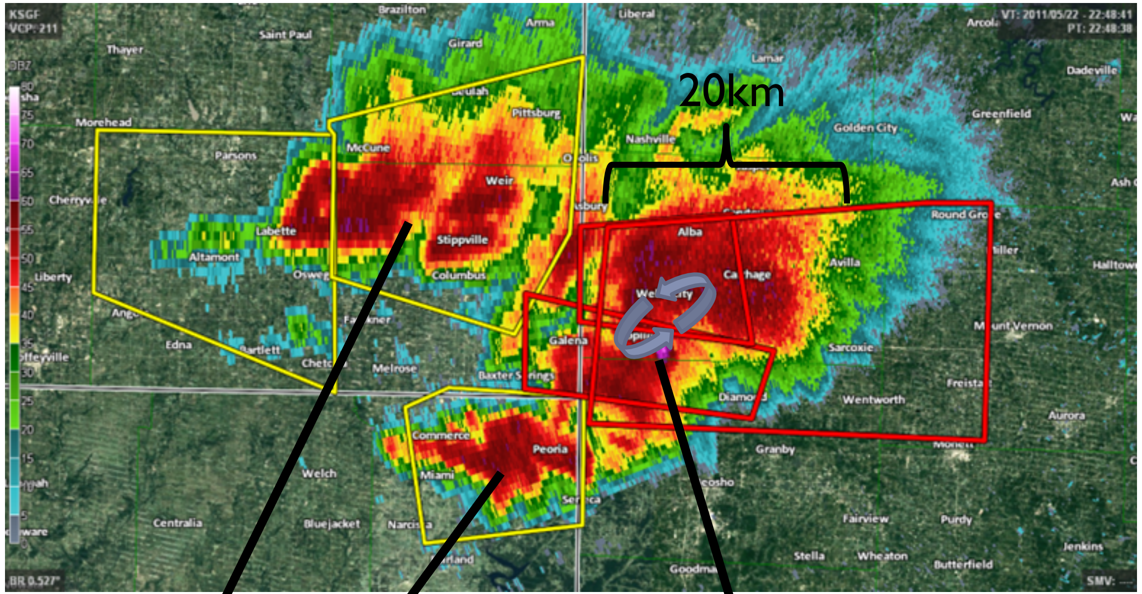
Tornado near Berazategui, Argentina, February 21, 2014

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

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)

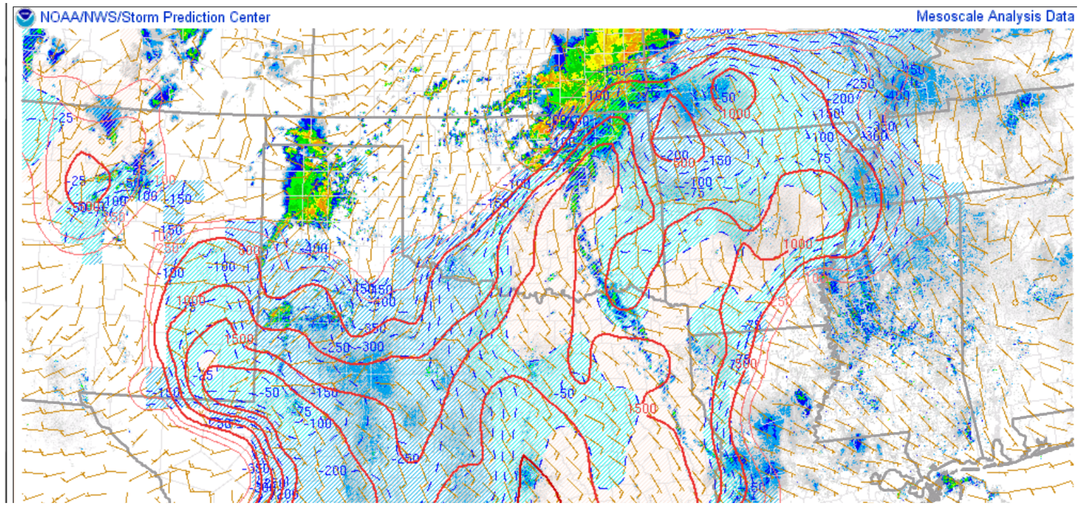


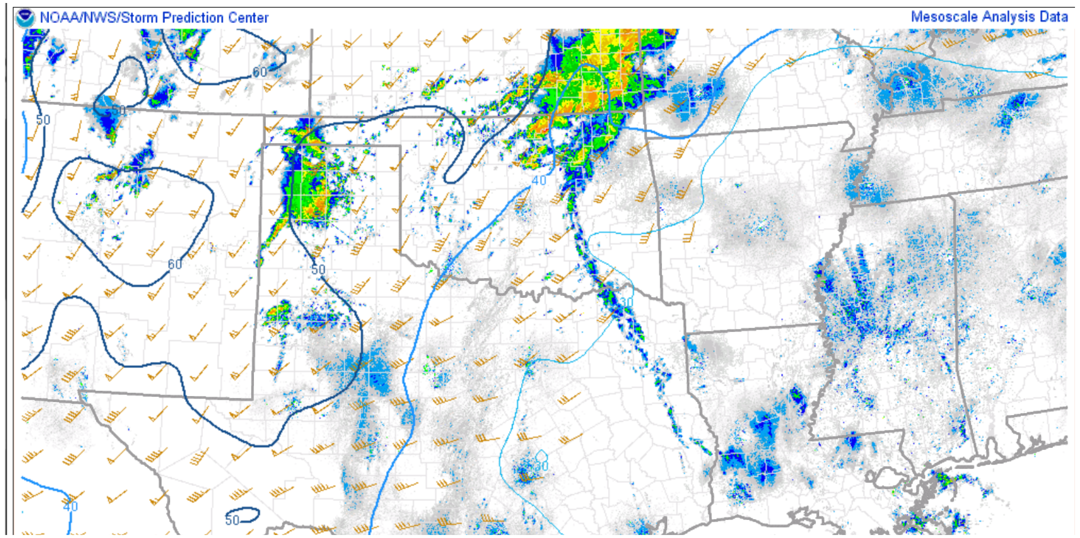
Mesocyclone w/ tornado

Other smaller cells connected to storm cluster probably w/ hail

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: $V_o - V_6 = V_{06}$
- 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)





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:

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

- 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

Constructing a Metric to Analyze the Severe Storm Environment

- A general form of this threshold (Seeley and Romps 2015):

$$\text{Eq (1)} \quad \mathbf{(CAPE)(V_{06})\gamma \geq \beta,}$$

then SD = 1

For $\gamma = 1$, Shear and CAPE have the same weight, i.e. they are equally important to determining Severe potential

- Allen et al. (2014) determined that $\gamma = 1.67$ was most effective at detecting severe potential, reflecting that Shear is apparently more important than CAPE
  - In the case of Trapp et al. (2007;2009) $\gamma = 1$
- Seeley and Romps (2015) tested sensitivity of γ and found that a $\gamma = 1$ is similarly effective as $\gamma > 1$
- Thus, SD is a measure of the number of days supportive of severe thunderstorm development if storms should form

Analysis of Severe Days (US)

- Using RegCM3 Trapp et al (2007): Number of severe days (NDSEV) is increasing in eastern US during JJA and MAM
- Shear generally decreases in future scenarios due to decreasing thermal gradient
- However, increases in CAPE more than offset decreases in Shear
- Increase in CAPE is primarily due to increasing moisture in a future climate

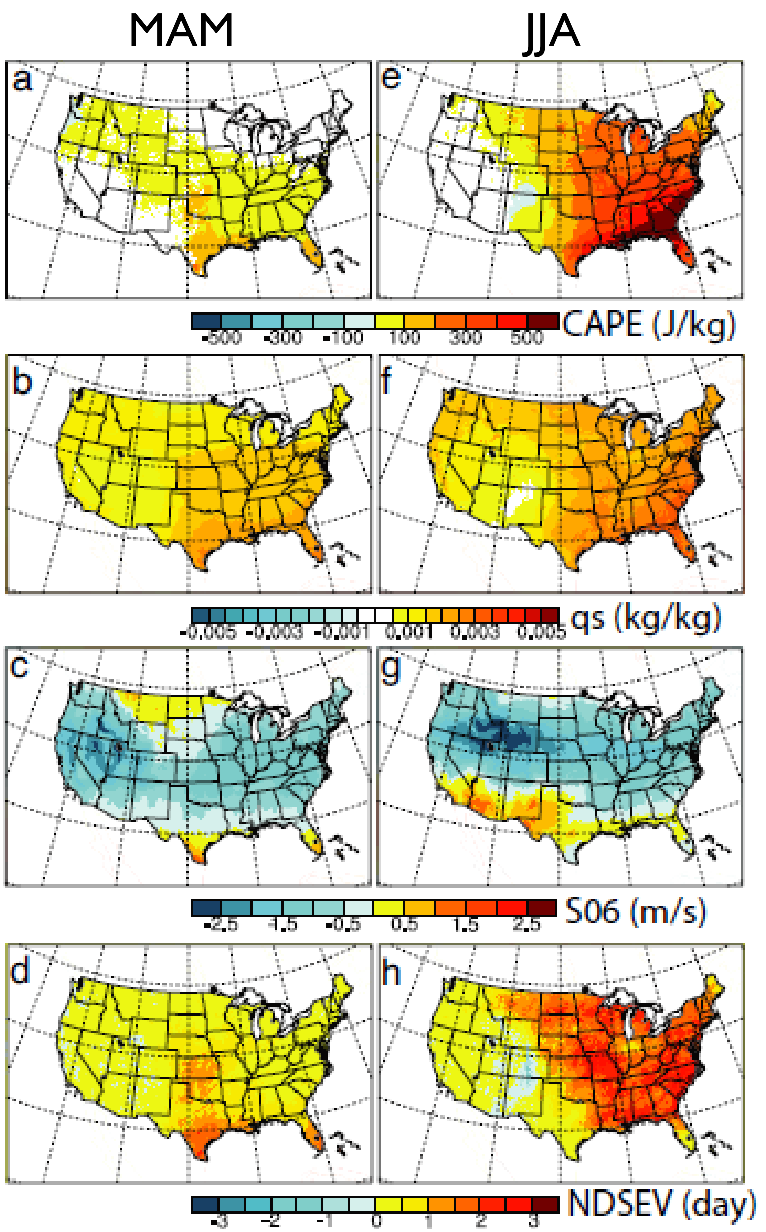
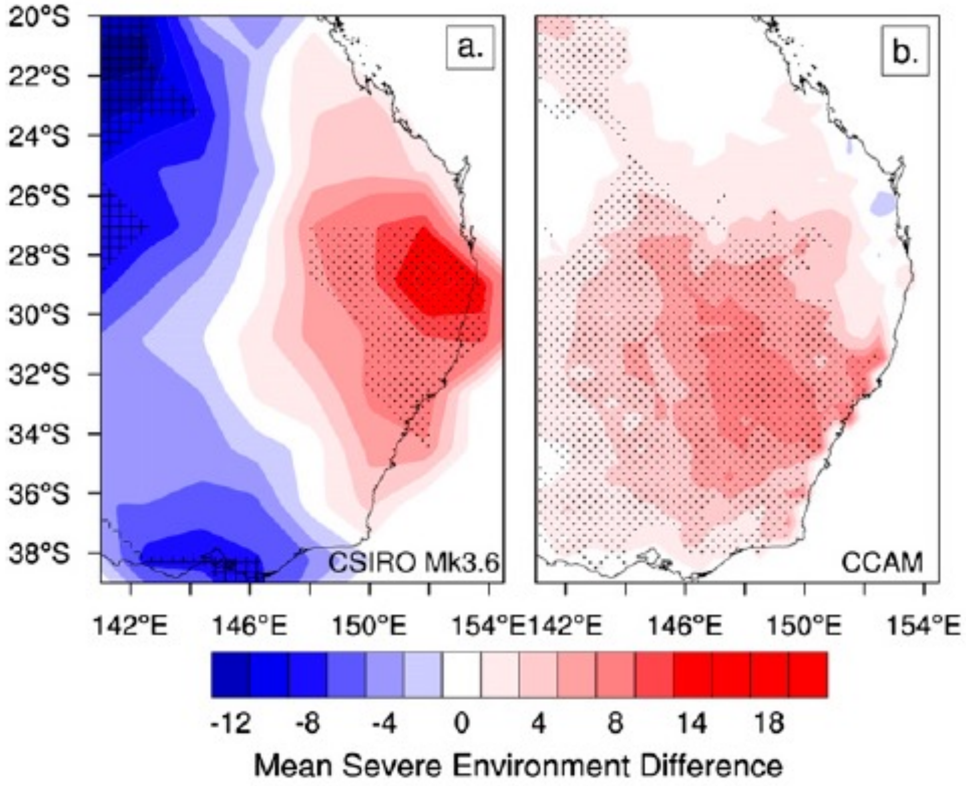


Fig. 1. Difference (A2 – RF) in mean CAPE, vertical wind shear over the surface to 6 km layer (S06), mean surface specific humidity (q_s), and severe thunderstorm environment days (NDSEV) for March–April–May (MAM) (*a–d*) and June–July–August (JJA) (*e–h*), respectively. The RF integration period is 1962–1989, and the A2 integration period is 2072–2099.

Analysis of Severe Days (Australia)

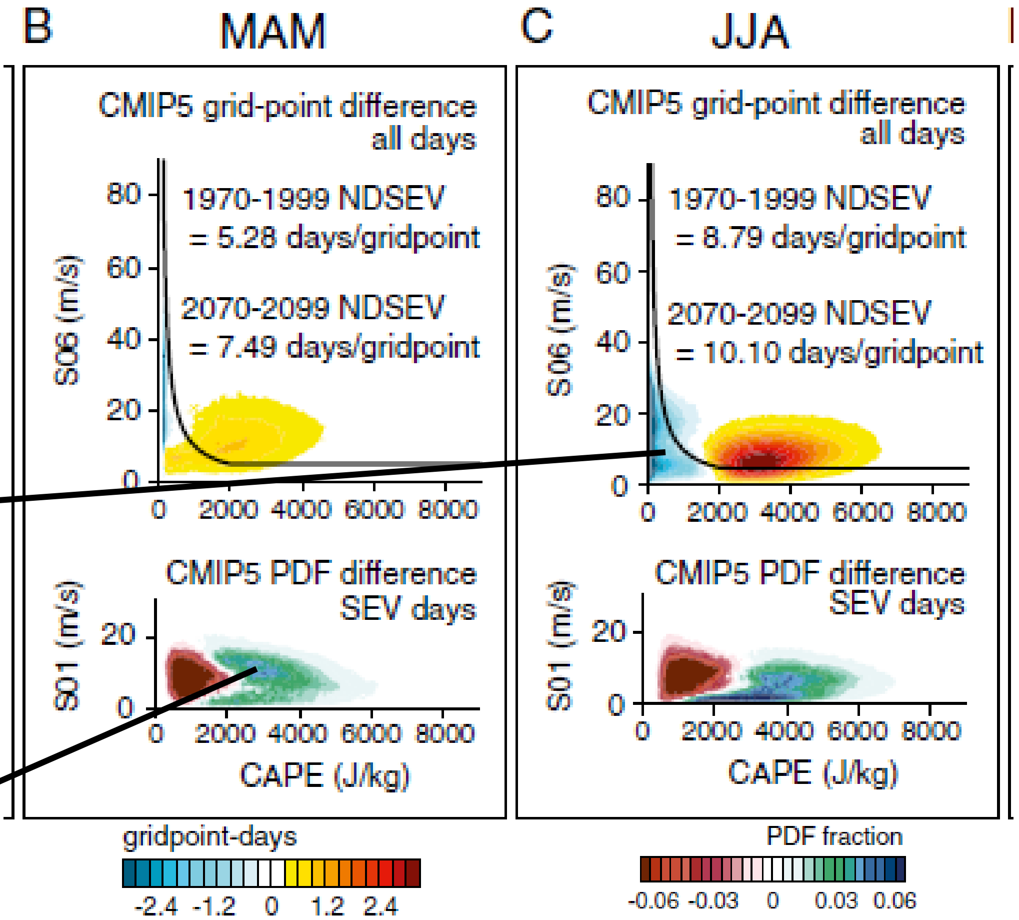
- Using a slightly different Eq (1) Allen et al. (2014) finds significant increases in SD over eastern Australia
- Similar to Trapp et al. they find the increased SD is due to increased CAPE from higher moisture availability
- Shear again is decreasing – poleward shift of subtropical jet



Allen et al. (2014) Fig. 10. Differences between the mean seasonal frequency of SEV environments for the twenty-first-century period and the twentieth-century period over the EAReg for (a) CSIROMk3.6 and (b) CCAM. Stippling is indicative of significant increases.

Changes to CAPE and Shear with GW

- Diffenbaugh et al. (2013) again, decreasing shear is found while increasing CAPE accounts for the increased severe days
- But decreased shear is mostly found on days with low CAPE thus not affecting the number of severe days
- Increased CAPE occurs generally in both low and high shear environments
- During MAM increased CAPE is found on days with high S01 (0-1km) shear



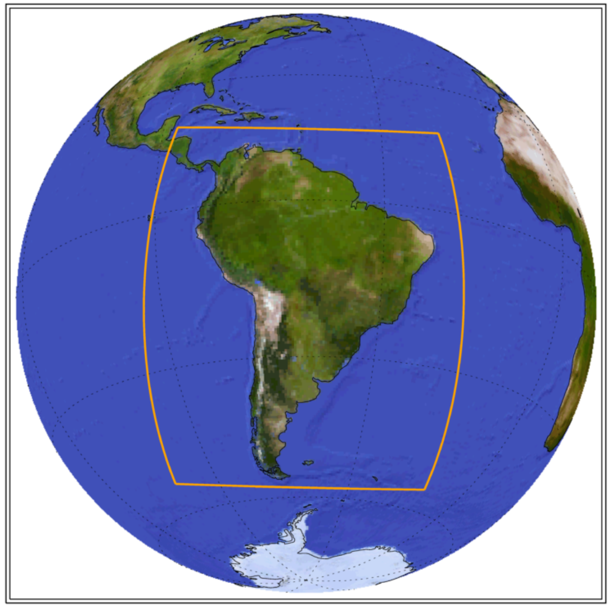
From Diffenbaugh et al. (2013) Fig. 4. Change in the frequency of occurrence of daily CAPE and shear in the Spring and summer seasons in the late 21st century period of RCP8.5. Occurrences are counted for land grid points in the eastern US.

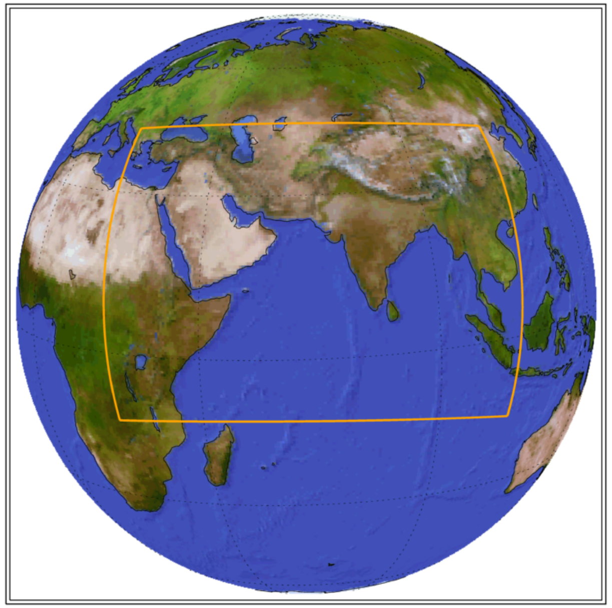
Summary of Previous Work

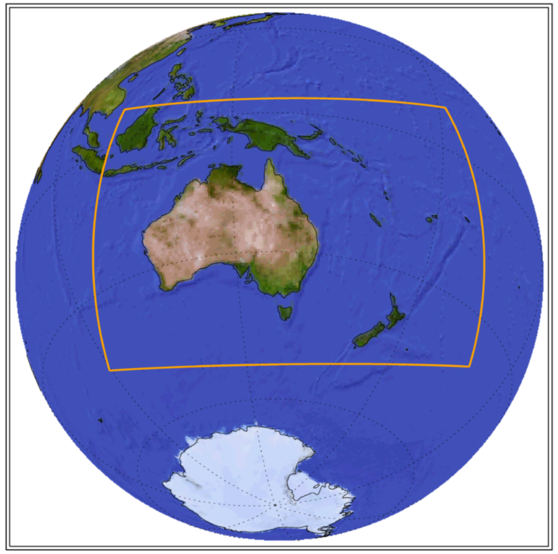
- Multiple studies report increasing severe thunderstorm environments under greenhouse gas emission scenarios (Trapp et al. 2007;2009, Diffenbaugh et al. 2013, Allen et al. 2014, Seeley and Romps et al. 2015) – mostly focused on US, Europe, and Australia
- Vertical Wind Shear generally decreases due to thermal wind arguments in a warming world while CAPE increases due to increasing surface available moisture (Trapp et al. 2007;2009, Diffenbaugh et al. 2013, Allen et al. 2014)
- Changes to V_{06} and CAPE should offset somewhat but the changes to V_{06} are concentrated in environments with low CAPE while changes to CAPE are robust across the distribution, thus the number of severe days is affected less by decreasing V_{06} (Diffenbaugh et al. 2013)

Proposal for Analysis of CORDEX Domains

- Analysis of Severe Storm Days for relevant CORDEX domains:
  - South America (Brazil and Argentina)
  - Australasia (Eastern Australia)
  - Central America (Southern US)
  - South Asia (Bangladesh)
- 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





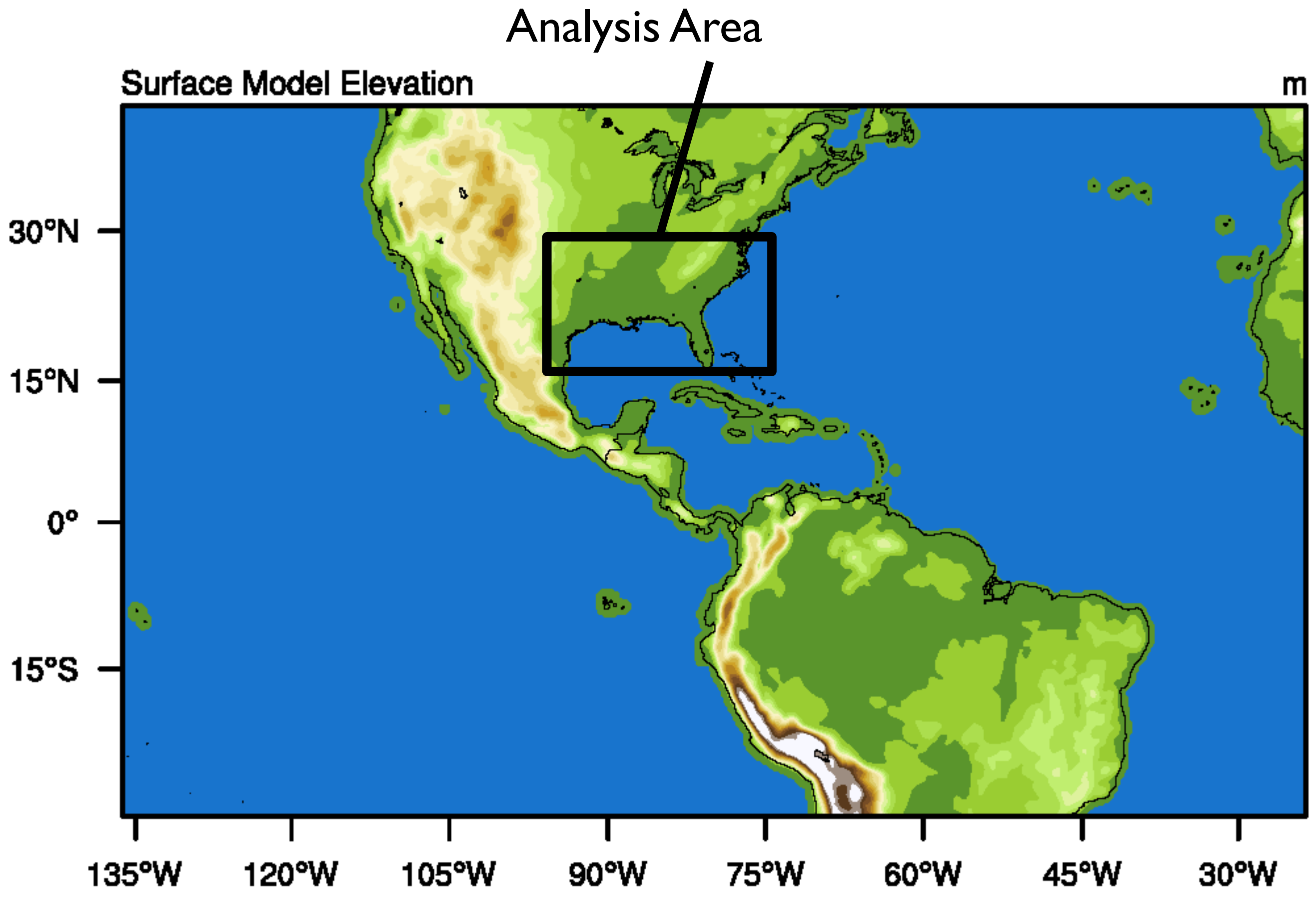


Initial Analysis of Southern US

- Using Central America Domain, count Severe Days for these periods:
  - RegCM-ERA-Int 1995-2014
  - RegCM-GFDL-Hist 1986-2005
  - RegCM-GFDL-RCP8.5 2070-2099
- Threshold to use for detection of Severe Day: Seeley and Romps (2015)

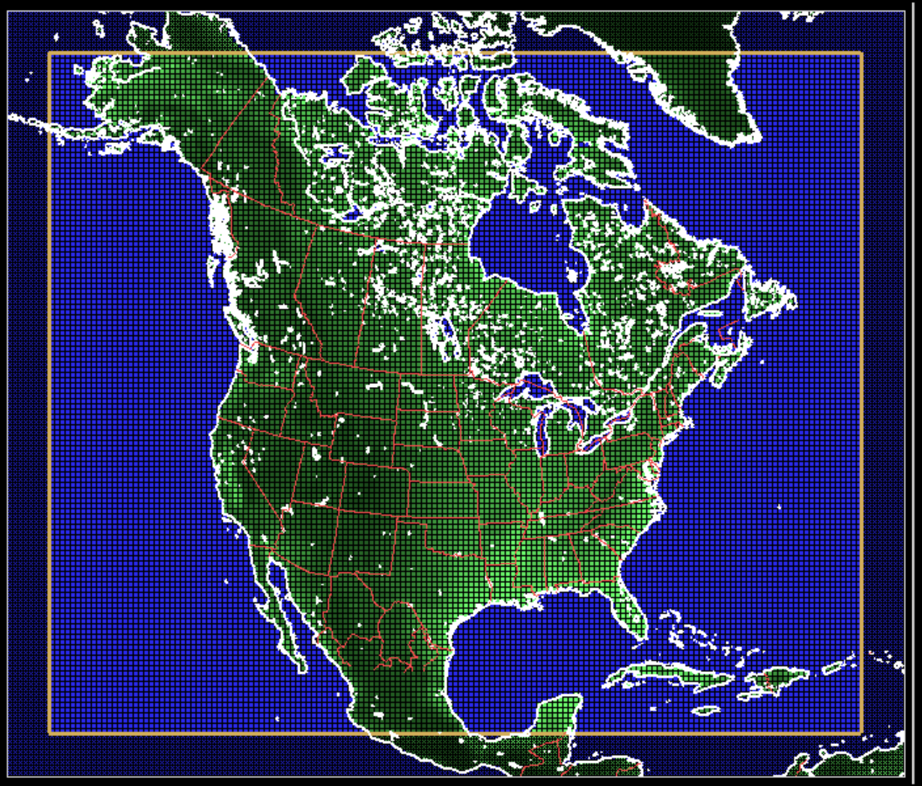
$$(\mathbf{CAPE})(V_{06}) \geq \mathbf{36300}$$

- CAPE and V_{06} are calculated each day during convective maximum at 00Z (subdaily analysis of T,q,u,v is needed)



North America Simulations from NCAR

- In communication with Melissa Bukovsky at NCAR to use RegCM4 simulations
- Namelist and Physics information: https://na-cordex.org/rcm-characteristics
- NA domain information: https://na-cordex.org/simulation-matrix
- Data access and more information: https://na-cordex.org/



CORDEX-NA simulation domain, 0.44°/50km resolution

References

- Allen, J.T., 2012: Supercell storms: Melbourne's white Christmas 2011. *Bull. Aust. Meteor. Oceanogr. Soc.*, 25, 47-51.
- ------------, Karoly, D. J., and Walsh, K. J., 2014a: Future Australian Severe Thunderstorm Evnironments. Part I: A Novel Evaluation and Climatology of Convective Parameters from Two Climate Models for the Late Twentieth Century. J Clim, 27, 3827-3847.
- ------------,----------------,------------------, 2014b: Future Australian Severe Thunderstorm Evnironments. Part II: The Influence of a Strongly Warming Climate on Convective Environments. J Clim, 27, 3848-3868.
- Diffenbaugh, N. S., Scherer, M., Trapp, R. J., 2013: Robust increases in severe thunderstorm environments in response to greenhouse gas forcing. P Natl Acad Sci USA.
- Mulholland, J.P., Nesbitt, S. W., Trapp, R. J., Rasmussen, K. L., Salio, P.V., 2018: Convective Storm Life Cycle and Environments near the Sierras de Córdoba, Argentina. Mon Weather Rev, 146, 2541-2557.
- Romatschke, U., and Houze, R. A. JR., 2010: Extreme Summer Convection in South America. J Clim, 23, 3761-3791.
- Silva Dias, M. A., 2011: An Increase in the Number of Tornado Reports in Brazil. *Weather Clim Soc*, 3, 209-217.
- Trapp, R. J., Diffenbaugh, N.S., Brooks, H. E., Baldwin, M. E., Robinson, E. D., Pal, J. S., 2007: Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing. P Natl Acad Sci USA, 104, 19719-19723.
- ---------------,-----------Gluhovsky, A., 2009: Transient response of severe thunderstorm forcing to elevated greenhouse gas concentrations. Geophys Res Lett, 36, L01703.
- Yeo, S., Leigh, R. and Kuhnel, I., 1999: The April 1999 Sydney Hailstorm. Australian Journal of Emergency Management, 14, 23–25.