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Recent Improvements in the Simulation of High-Impact Events using Convective-Permitting Modeling

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NCAR

Presentation CCIS webinar # 7 on Impacts

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NCAR Water System Program

CONUS Project Team

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Three Breakthroughs:

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1. Simulation of snowfall and snowpack and impact of climate change (Colorado Headwaters and CONUS1).

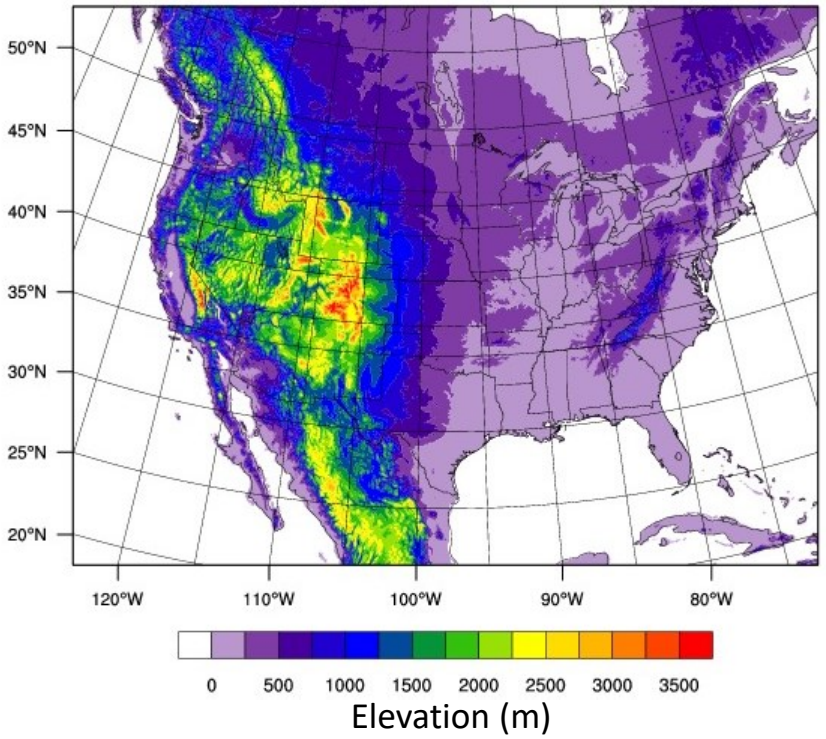
2. Simulation of hurricanes and the impact of climate change on hurricanes.

3. Simulation of Mesoscale Convective Systems (MCSs) in the current and future climate (CONUS1 and CONUS2 WRF simulations)

Weather Research and Forecast Regional Climate Model Setup over CONUS (2000-2013) (called CONUS1)

- V3.4.1 WRF model with a 4-km-spacing domain of ***1360x1016x51*** points
- Physics parameterizations:
  1. Thompson aerosol-aware microphysics
  2. Noah-MP LSM
  3. YSU PBL
  4. RRTMG radiation
- Use of spectral nudging to nudge the model simulation above the PBL
- Initial and laterally forced by ERA-Interim reanalysis for for the current climate simulations, used Pseudo Global Warming technique for the future climate

WRF Model Domain



Liu, Changhai, Kyoko Ikeda, Roy Rasmussen, Michael Barlage, A. J. Newman, A. F. Prein, F. Chen, L. Chen, Martyn Clark, Aiguo Dai, Jimy Dudhia, Trude Eidhammer, David Gochis, Ethan Gutmann, Sopan Kurkute, Yanping Li, Gregory Thompson, David Yates, 2017: Continental-scale convection-permitting modeling of the current and future climate of North America, *Climate Dynamics*, DOI 10.1007/s00382-016-3327-9.

Simulation Domain and Setup

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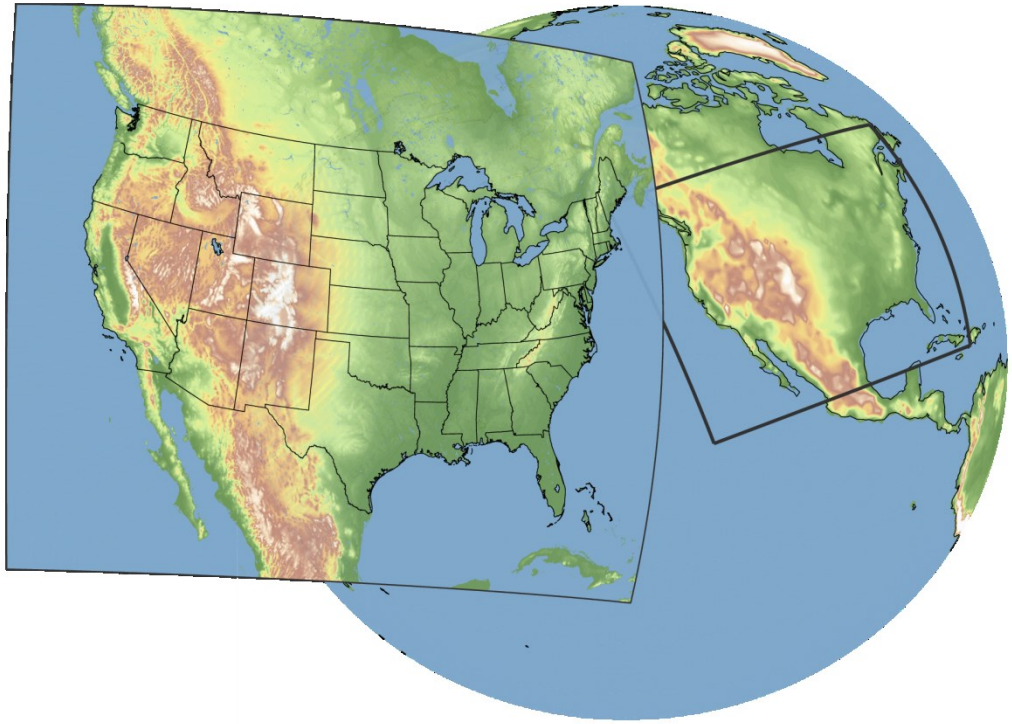
WRF 4 km | 1359 x 1015 grid cells

13 years (2001-13)

ERA-Interim



Liu et al. 2017, Clim. Dyn.

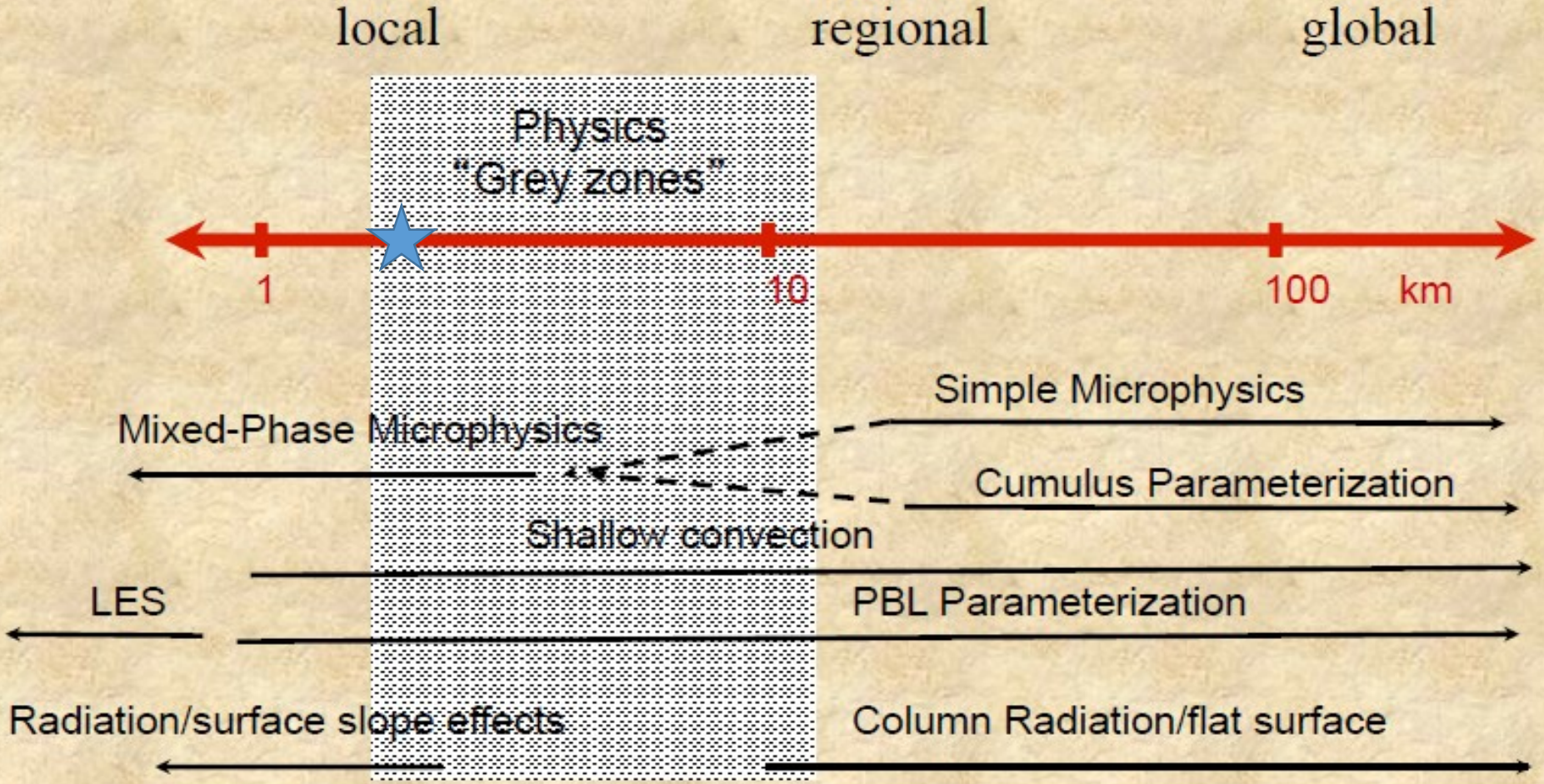
Physics

- Microphysics
  Thompson aerosol-aware
  [Thompson and Eidhammer 2014]
- Radiation RRTMG [Iacono et al. 2008]
- Land-surface model NOAH-MP
- Boundary layer YSU [Hong et al. 2006]

Spectral Nudging

U, V, T, and ZG above the PBL

Physics in Multiscale Model



Clouds in a 4 km WRF climate run

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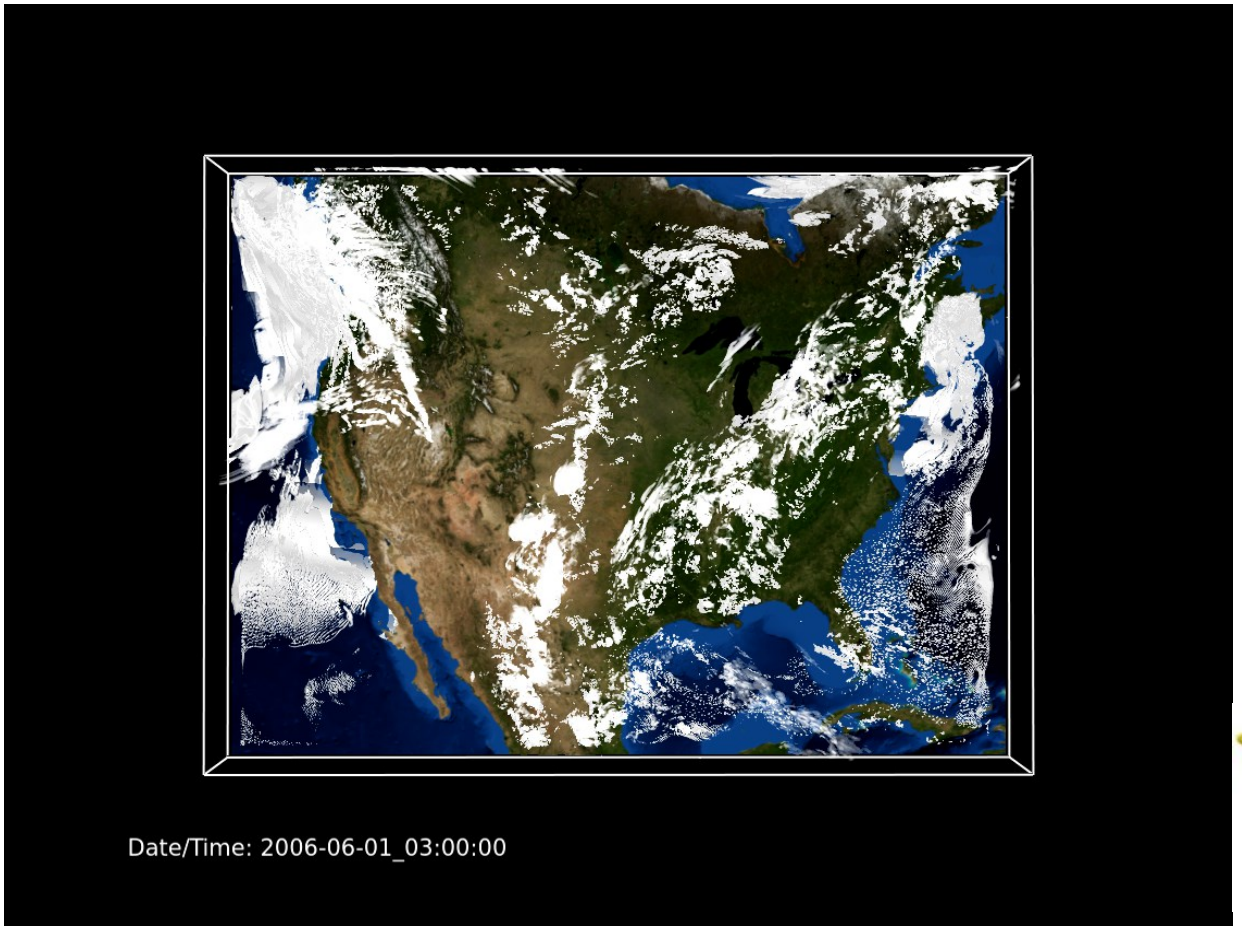
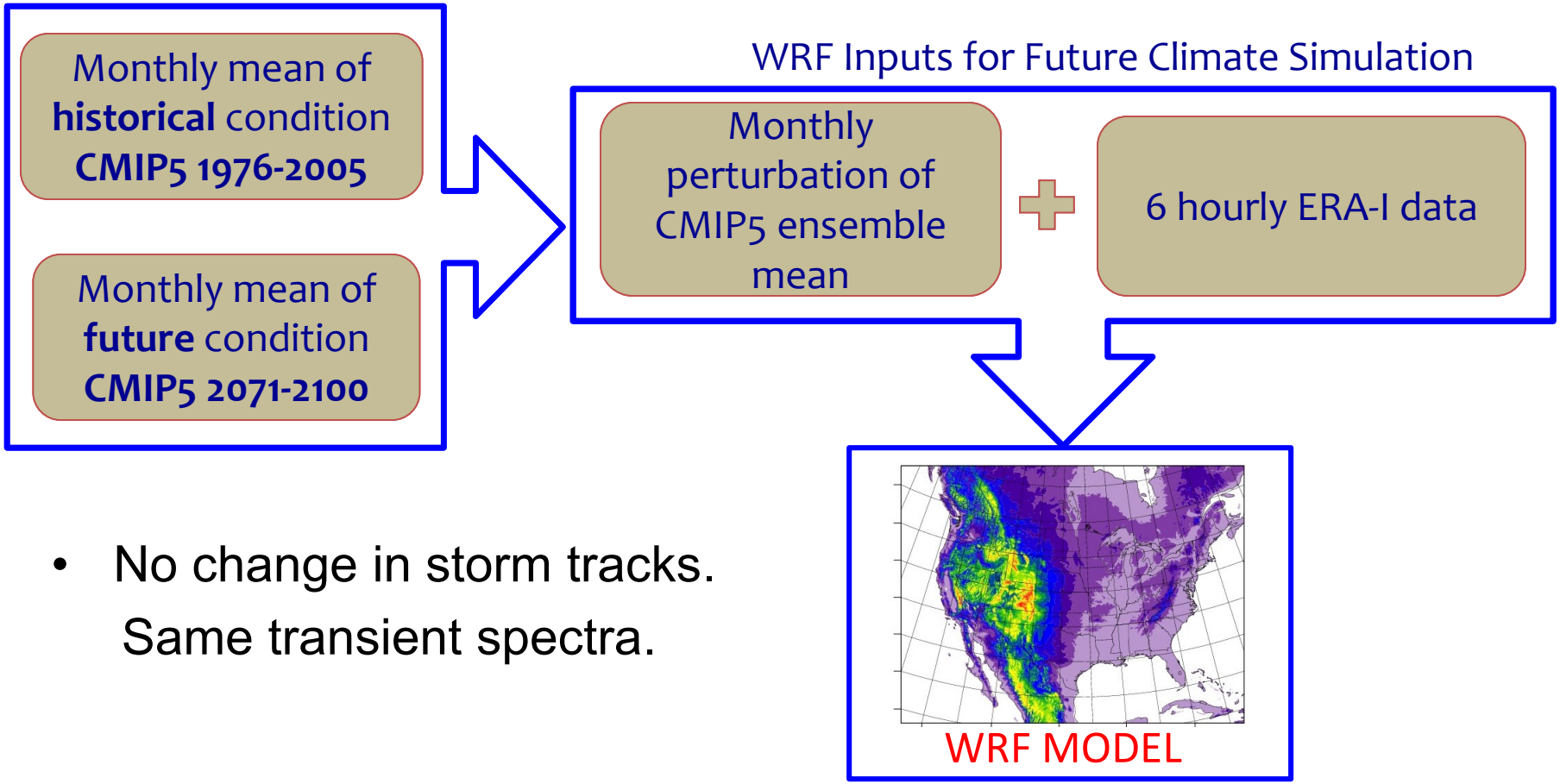


VAPOR
Visualization & Analysis Platform

What is PGW approach?

- Compute 30-year CMIP5 19 model ensemble monthly mean
  - Historical period : *1976-2005* Future period (RCP8.5): *2071-2100*
- Compute perturbation – difference between two climates
- Add perturbation to the 6-hrly ERA-I data



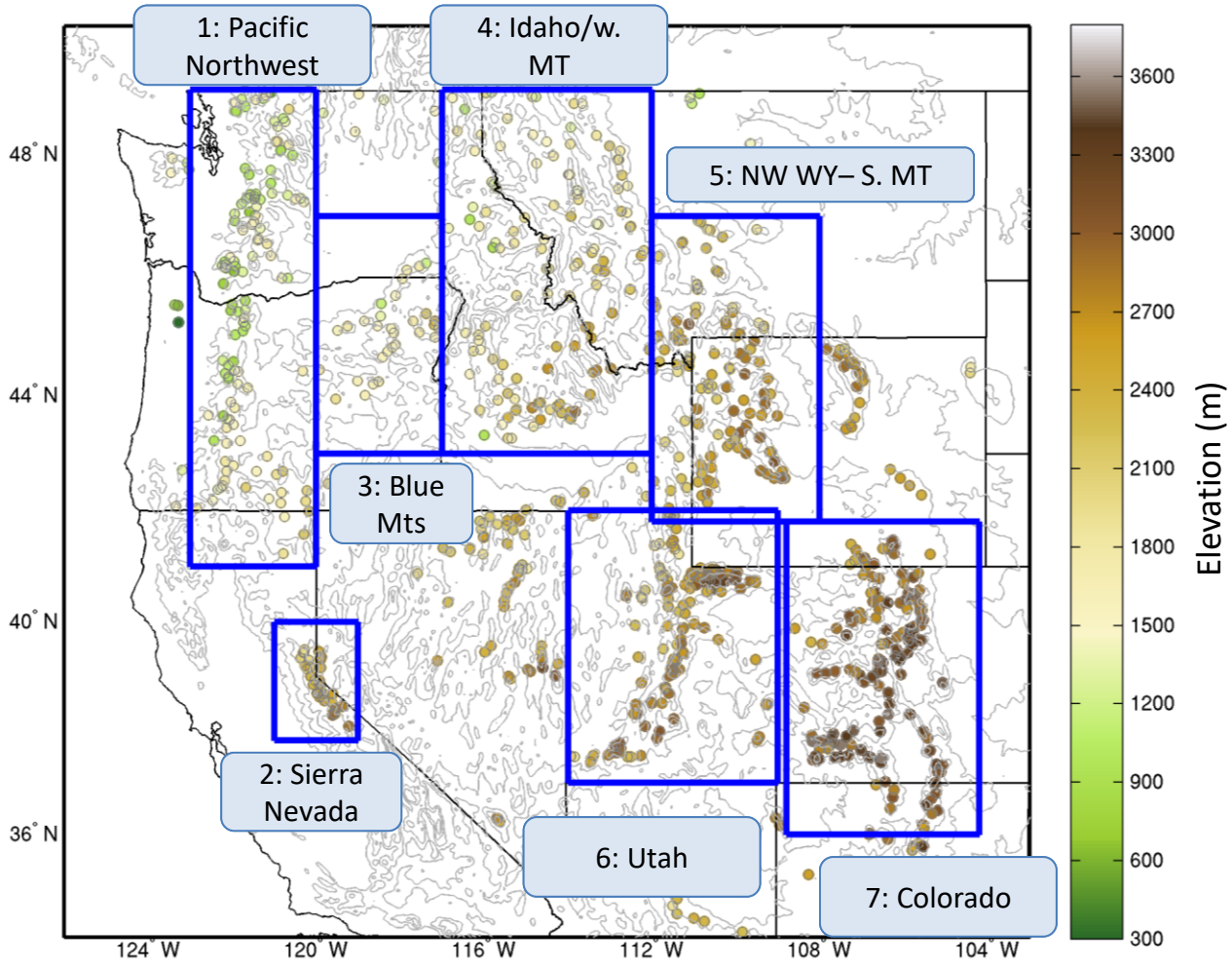
- No change in storm tracks.
  Same transient spectra.

Model Evaluation at Western SNOTEL Sites

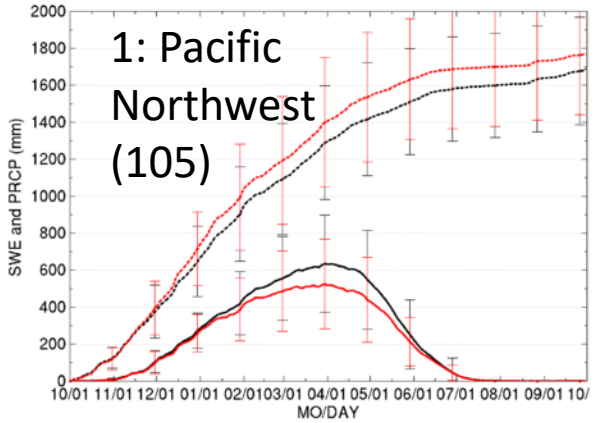
SNOTEL site at
Brooklyn Lake, WY

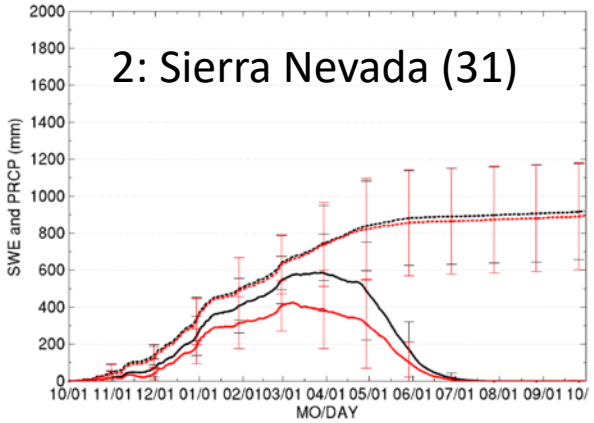
Snow gauge

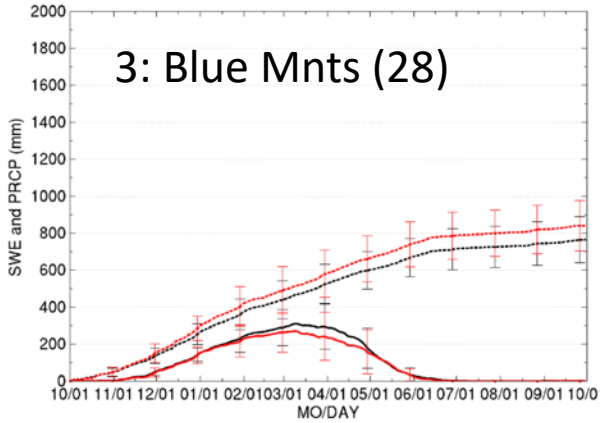
Snow pillow

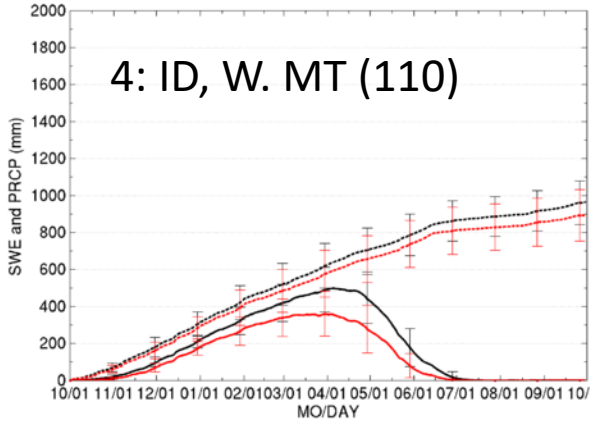


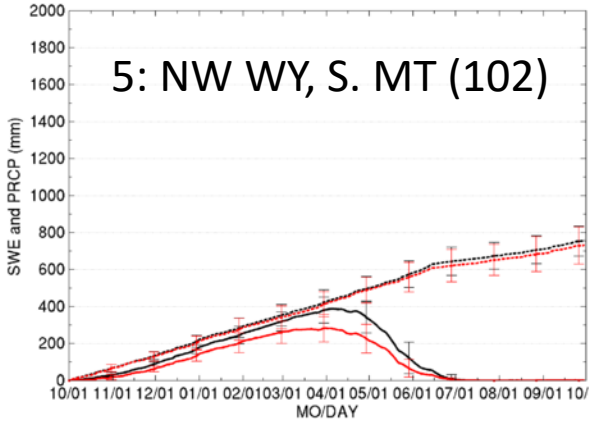
SNOTEL vs WRF at Western SNOTEL sites: 13-year climatology

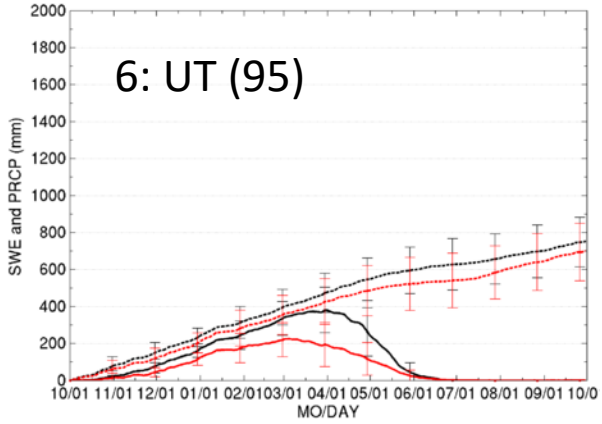


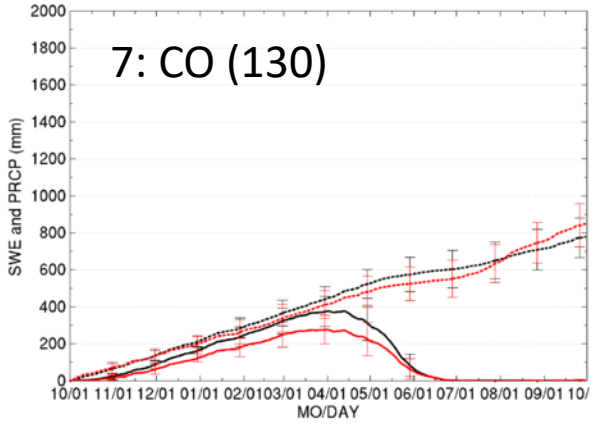


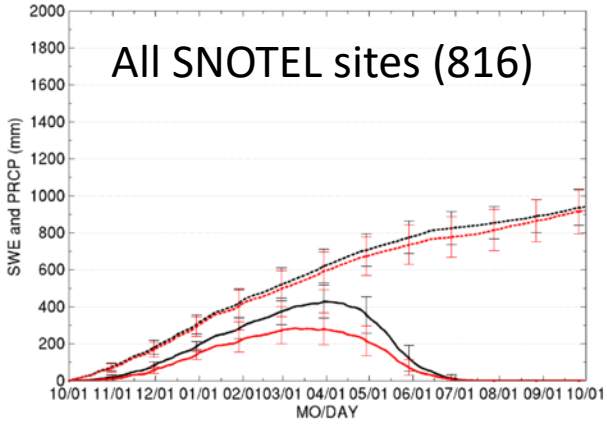


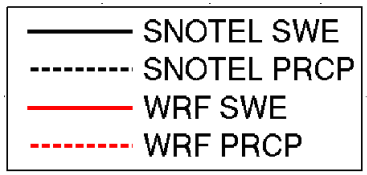






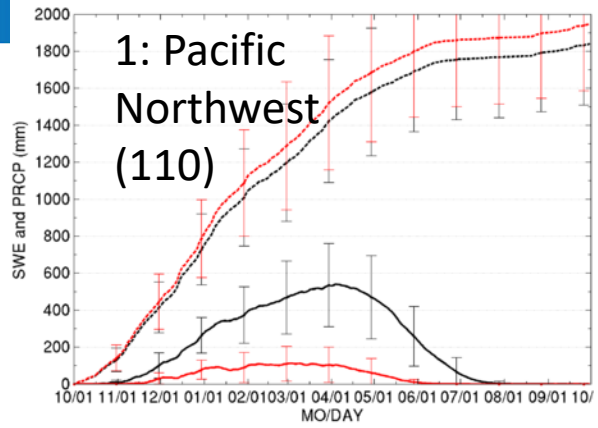


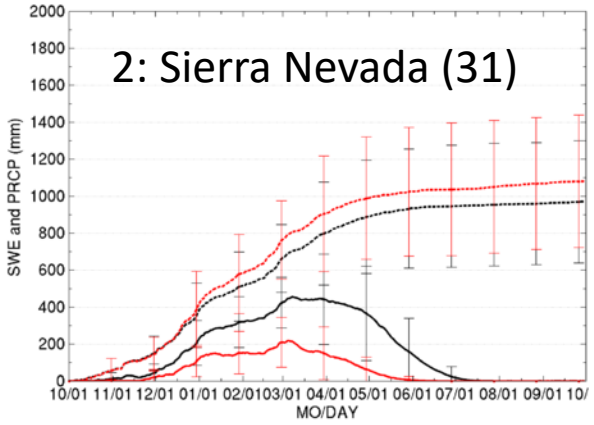


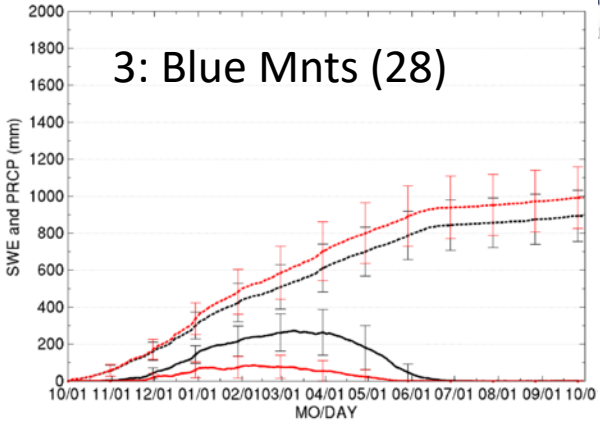


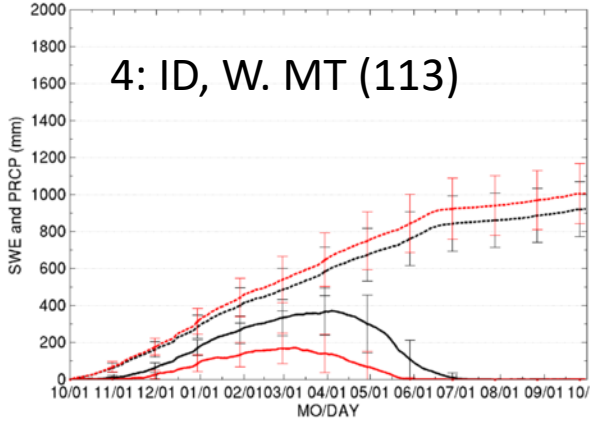
PRCP bias: -2% – 9%
SWE bias : -10% – -40%

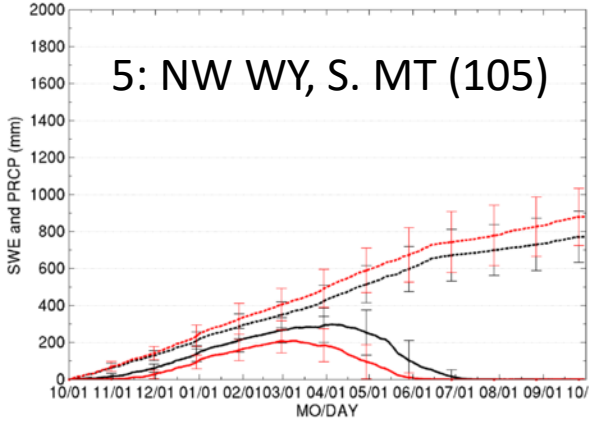
WRF CTRL vs PGW at SNOTEL sites : 11-year climatology

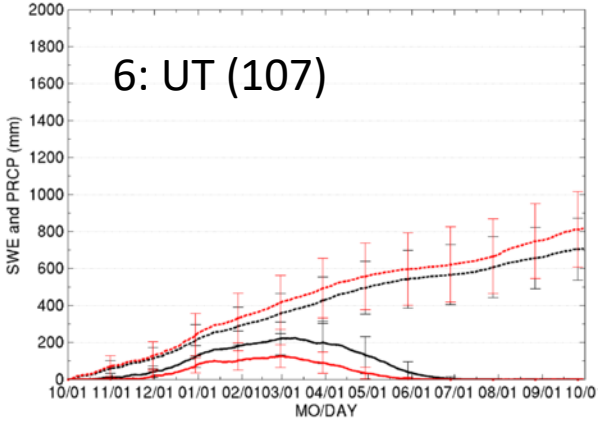


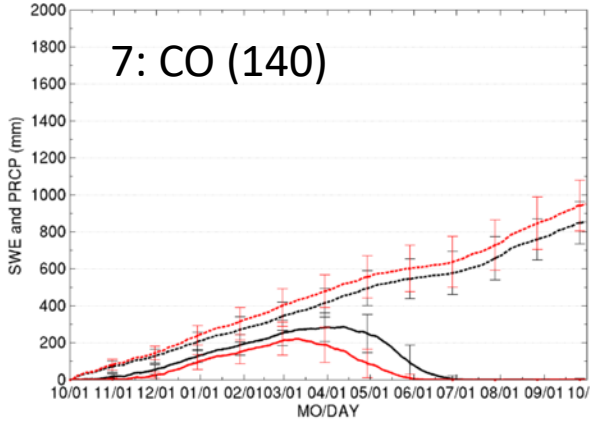


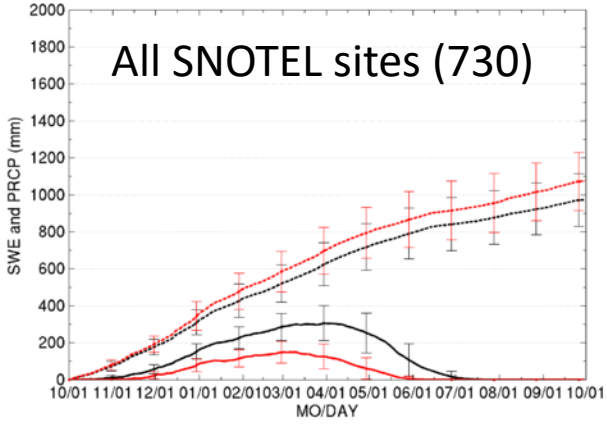


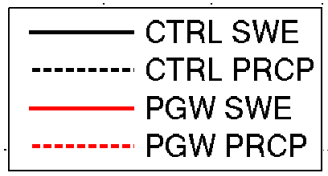












PRCP: 6% – 15%
SWE : -46% – -20%

Second advance: Current and future hurricanes

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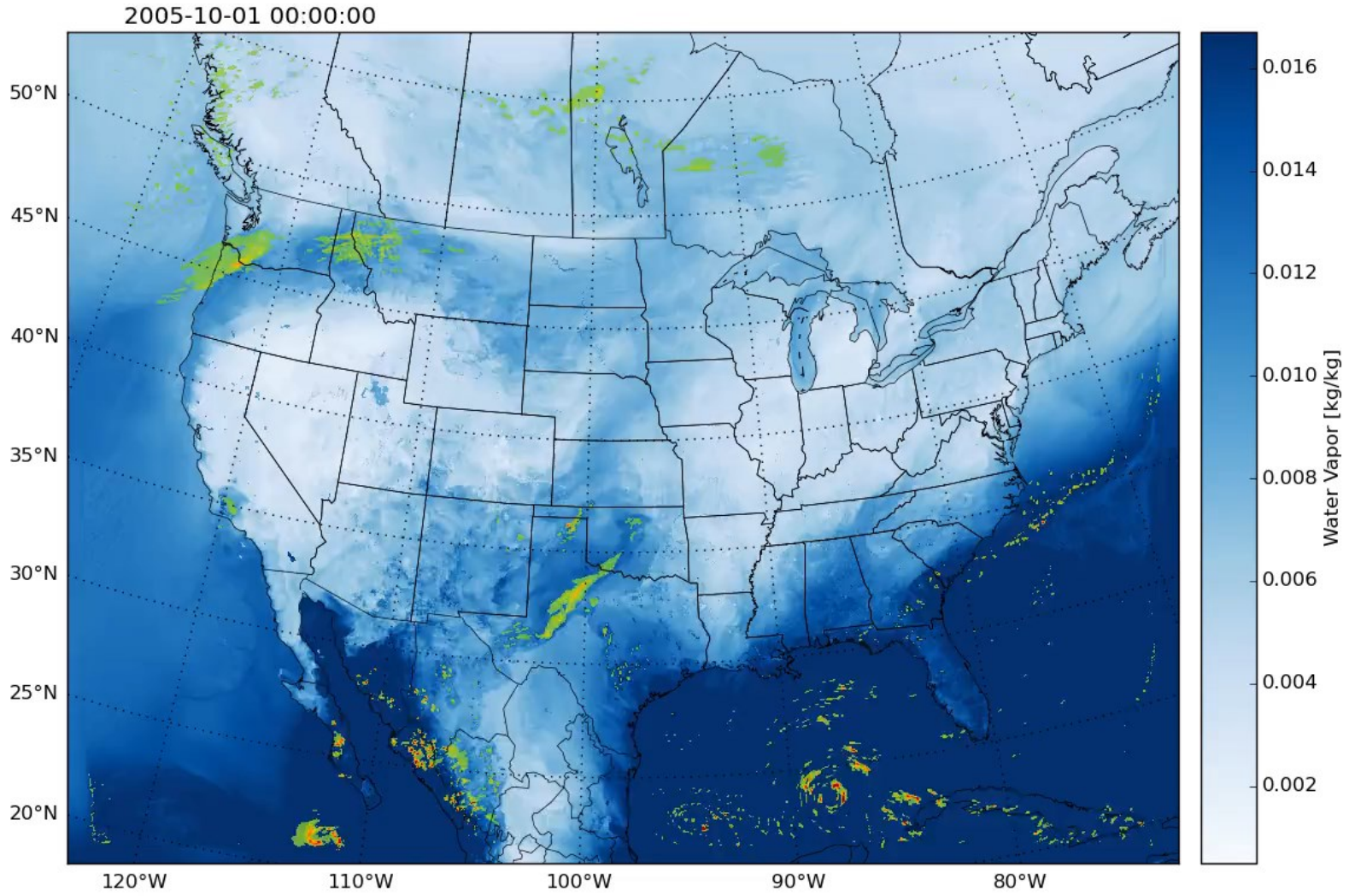
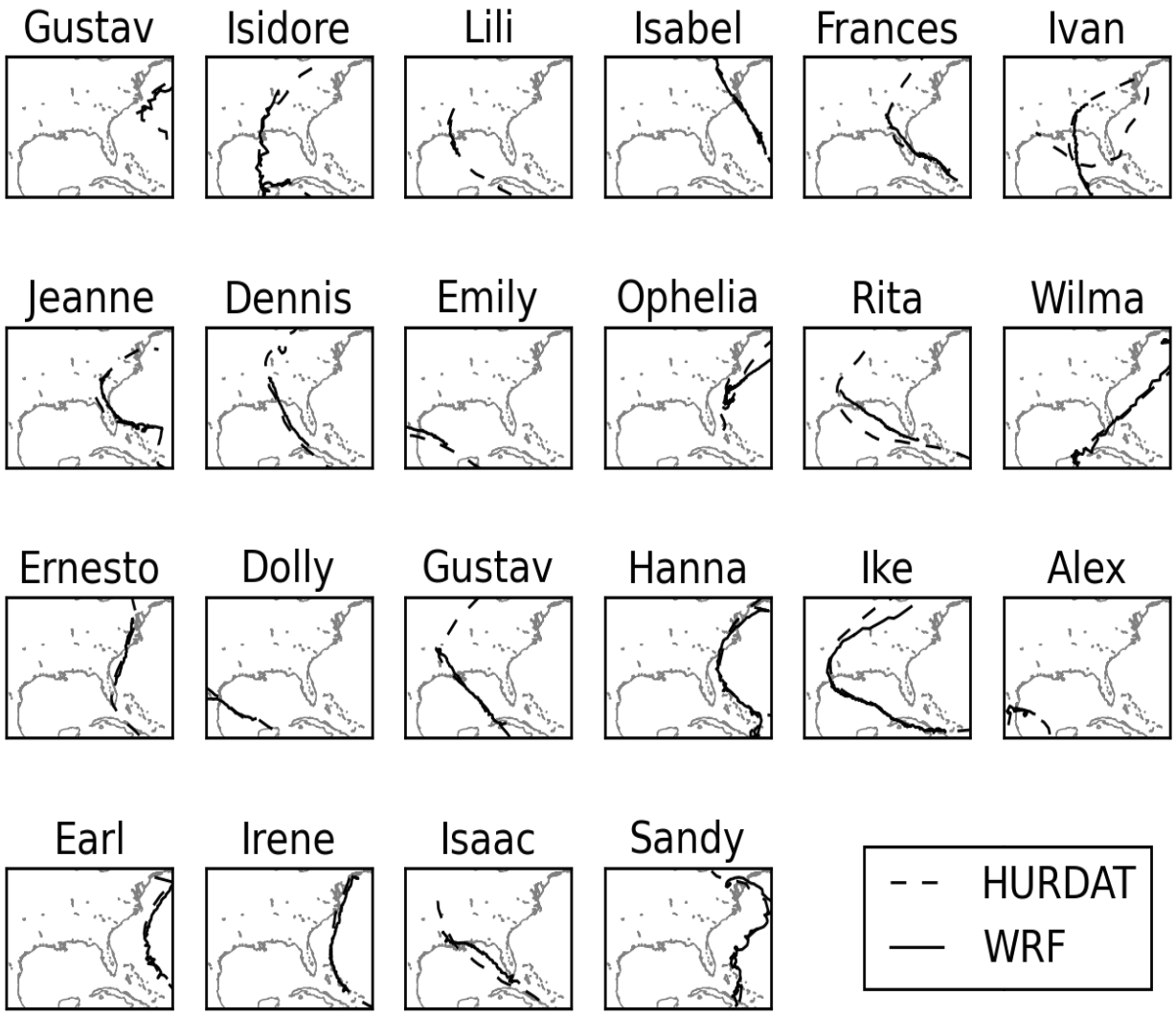
Movie of CONUS1 model water vapor and precipitation of October, 2005



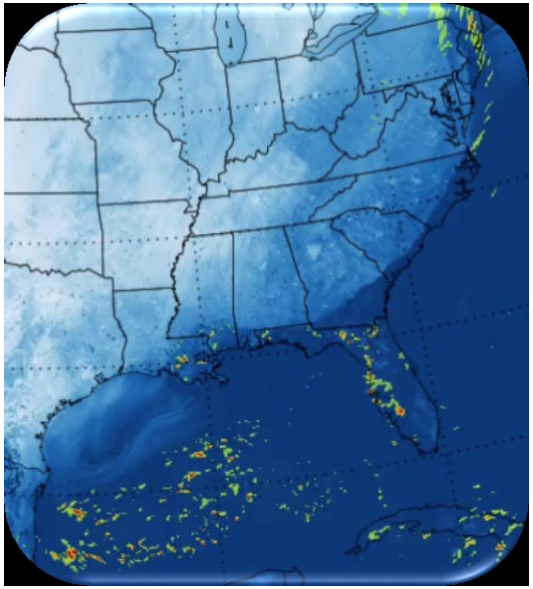
Comparison of track of 22 hurricanes from WRF CONUS I to HURDAT actual track



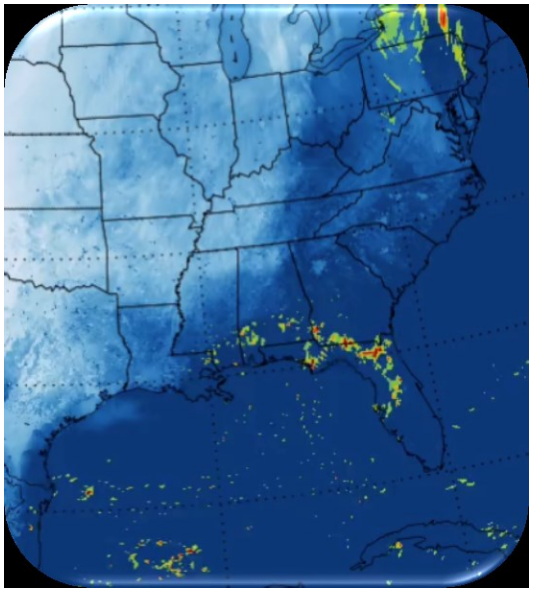
Changes in Hurricanes in a Warmer Climate

- Convection Permitting 13 year CONUS domain simulation (current and future climate)
- >30 named hurricanes in current climate and same hurricanes in warmer and moister climate
- Increases in maximum wind speed
- Large increases in maximum precipitation rates (> 50%)
- Substantial variability in change signal in different hurricanes

Hurricane Ivan (2005)
Current climate



Hurricane Ivan (Future climate)
(Pseudo Global Warming approach, warmer and moister)



Water Vapor (Blues)
Precipitation (Green to Red)

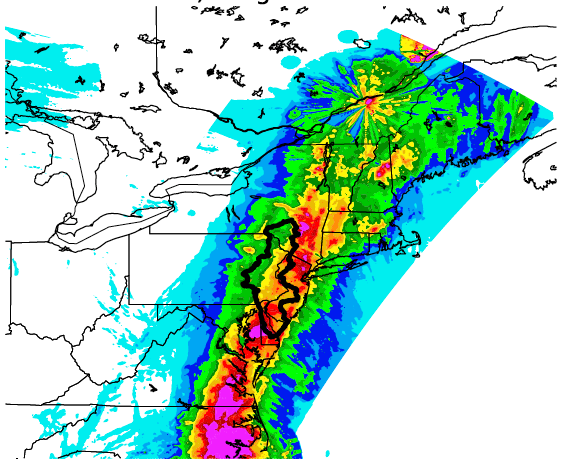
Changes in Hurricanes from a 13 Year Convection Permitting Pseudo-Global Warming Simulation, Gutmann et al. 2018, (Journal of Climate)
Corresponding Author: Ethan Gutmann, gutmann@ucar.edu
Analysis funded by Den Norske Veritas (DNV) and CONUS simulation by NSF under NCAR Water System Program

Hurricane Irene – Aug. 29, 2011

Accumulated Rainfall between Aug. 27-30, 2011

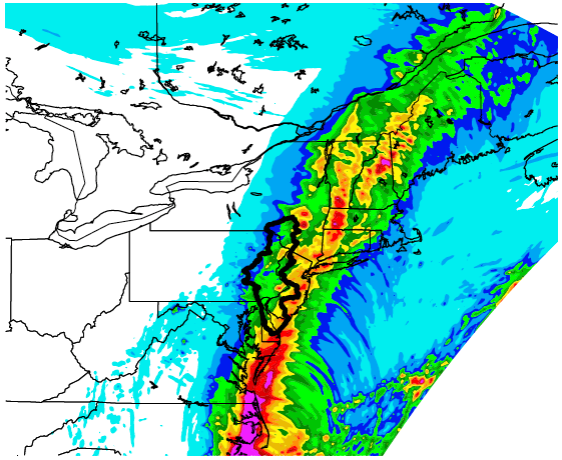
Stage IV observations

a) Stage-IV obs.



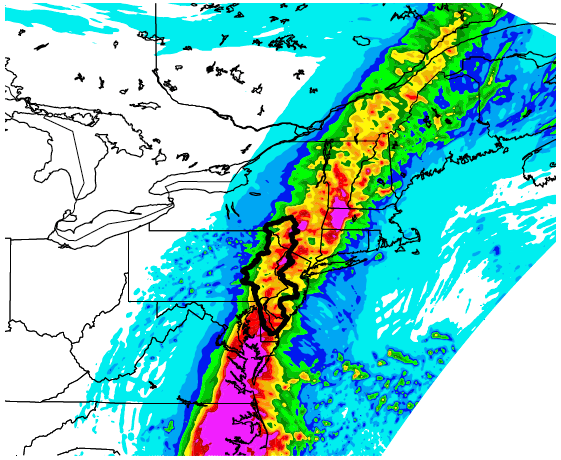
CONUS 1 – Current Climate

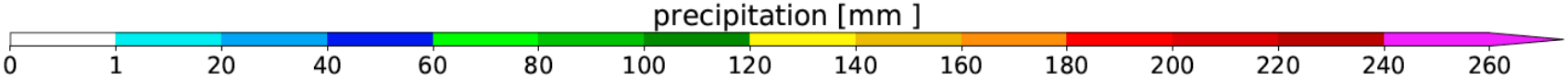
b) CONUS1 - CTRL



CONUS 1 - End of Century

c) CONUS1 - PGW





Hurricane Irene – Aug. 29, 2011

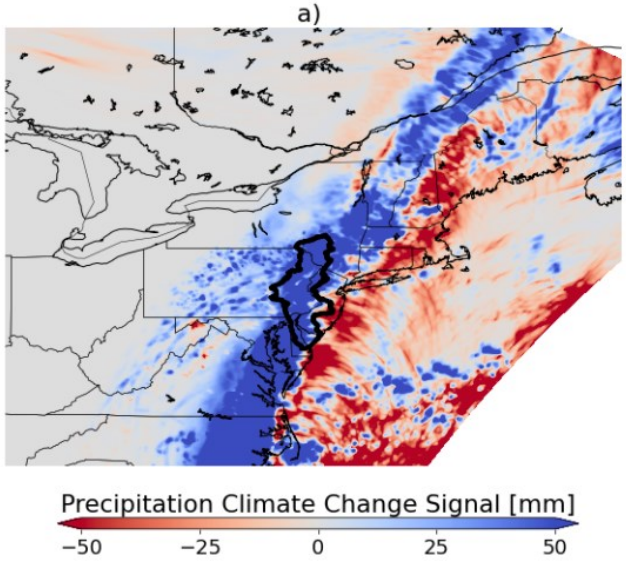
Accumulated Rainfall between Aug. 27-30, 2011

CONUS 1 – Current Climate

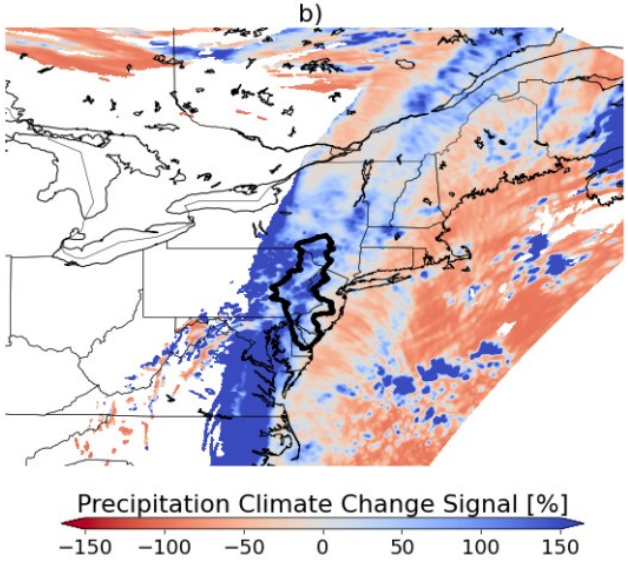
CONUS 1 - End of Century

- Contraction of precipitation towards hurricane center [Patricola, C.M. and Wehner 2018]
- Precipitation volume in Delaware river basin increases by 63 % consistent with Prein et al. (2017)

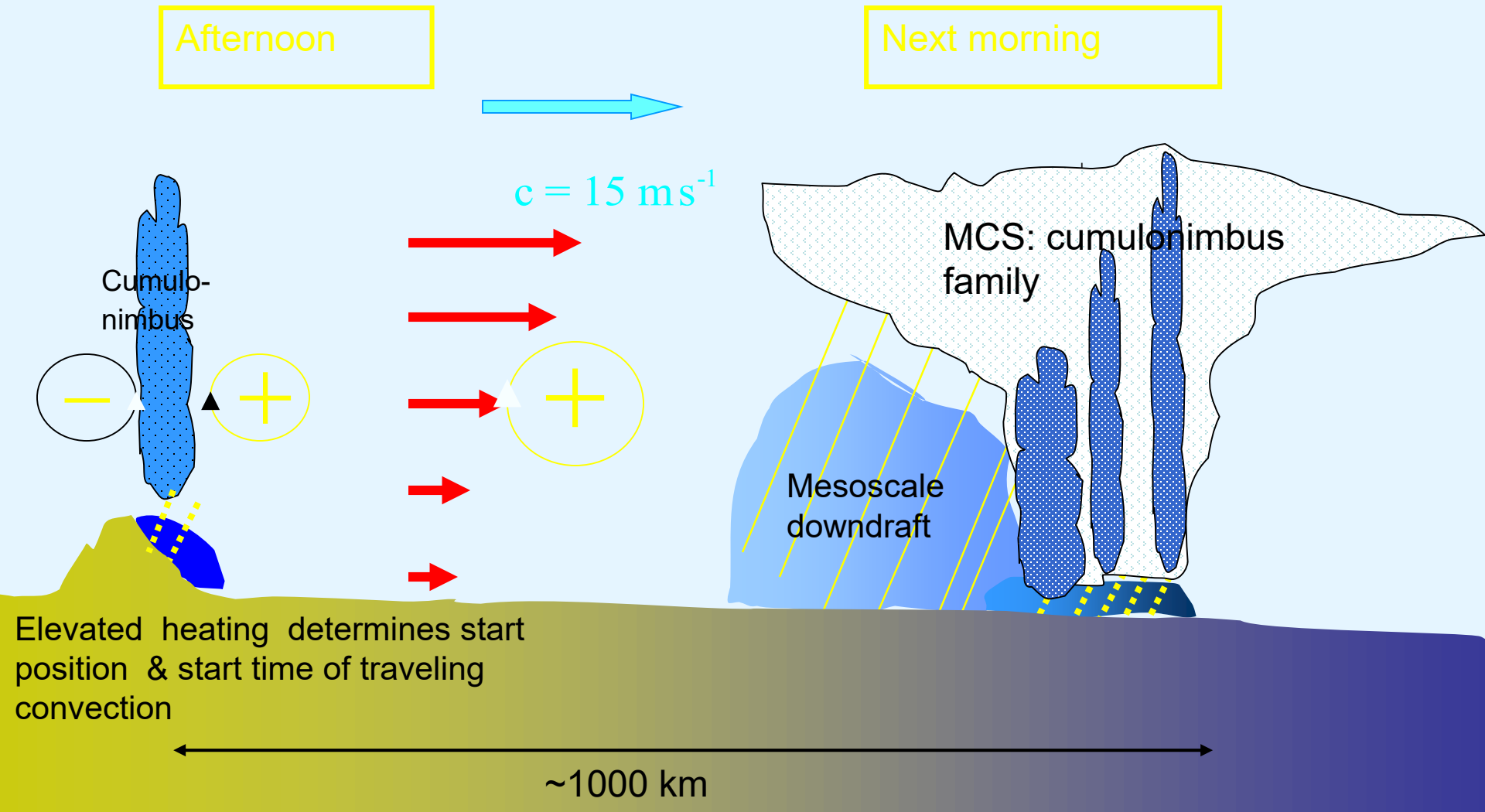
Absolute Climate Change Signal

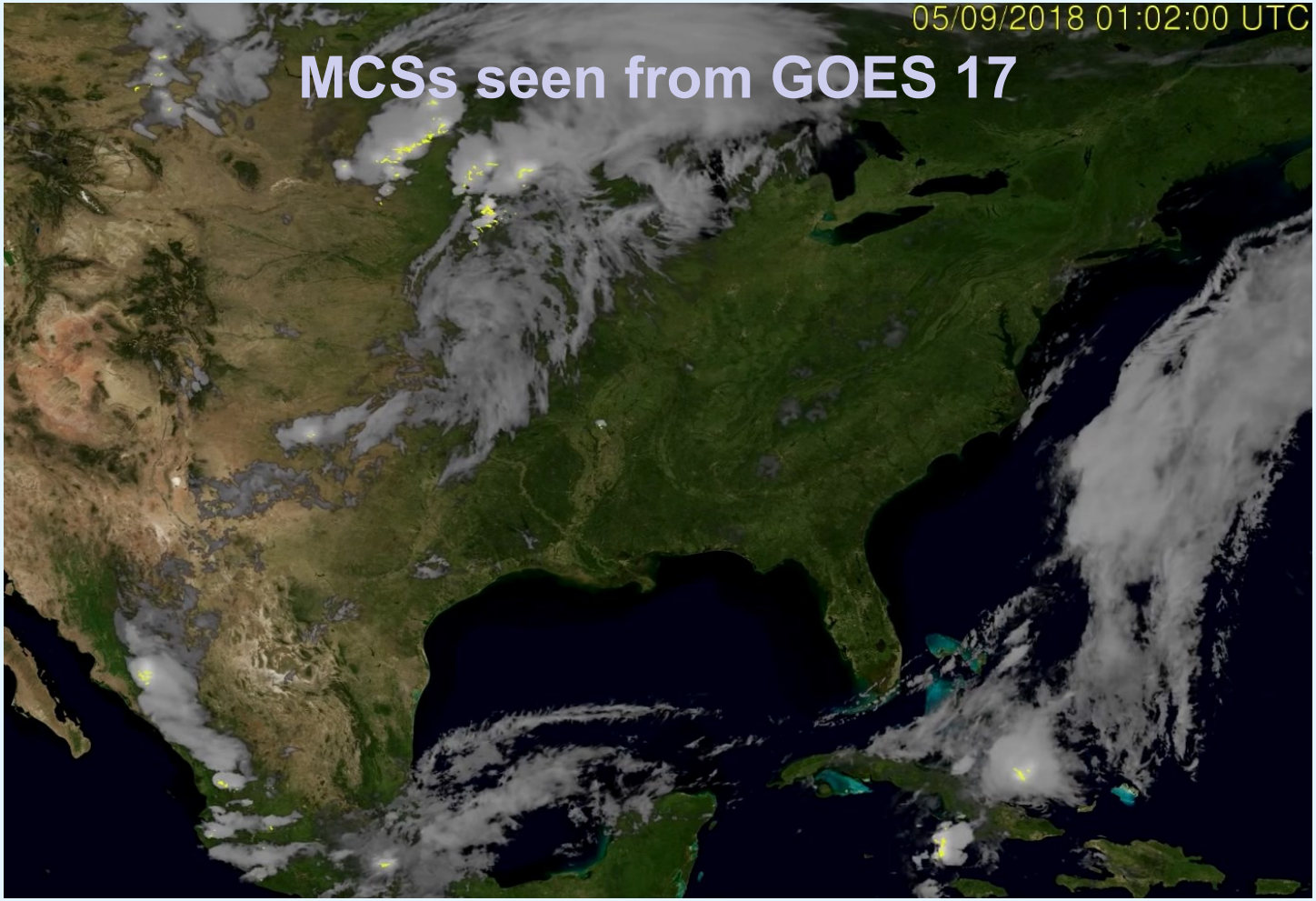


Relative Climate Change Signal



Advance #3:
Simulating Mesoscale Convective Systems (MCS) downstream of mountains



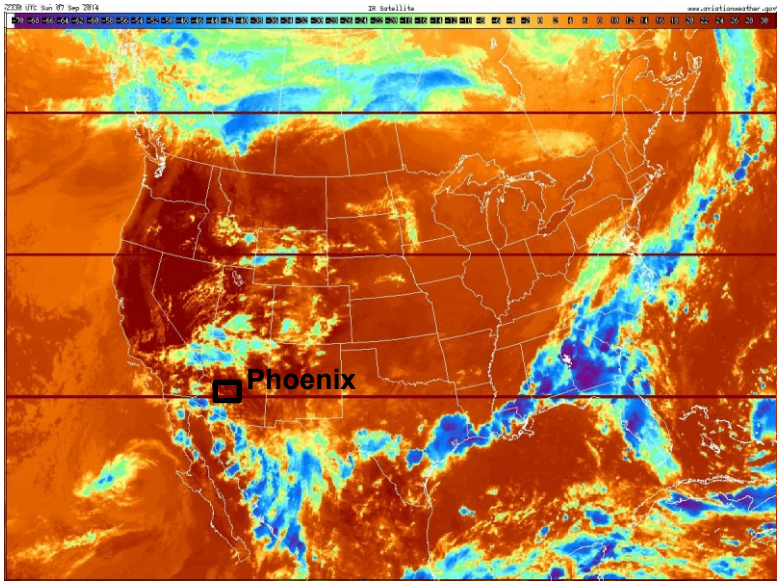

05/09/2018 01:02:00 UTC
MCSs seen from GOES 17

Most major flooding events during the warm season are caused by MCSs

West Virginia 2016
- 23 fatalities
- 250 mm in 12 h

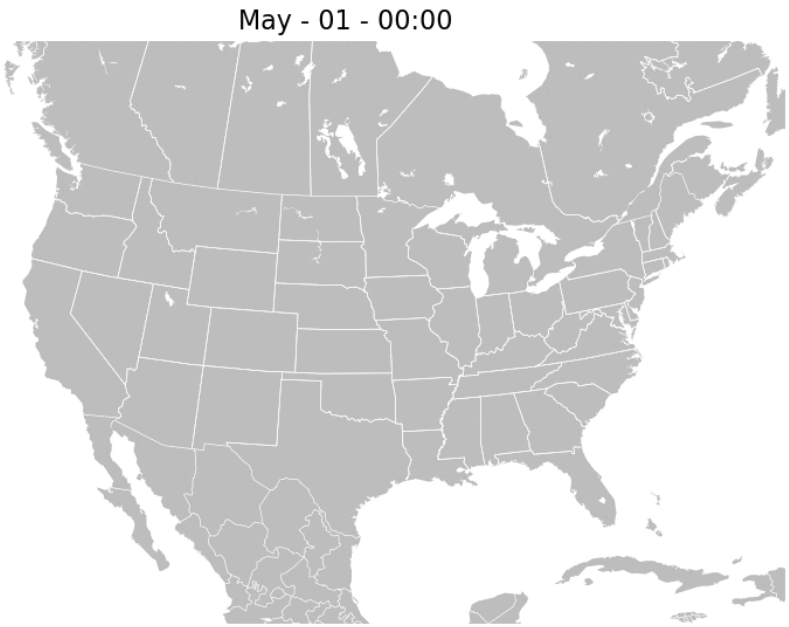
Louisiana 2016
- 13 fatalities
- 797 mm event

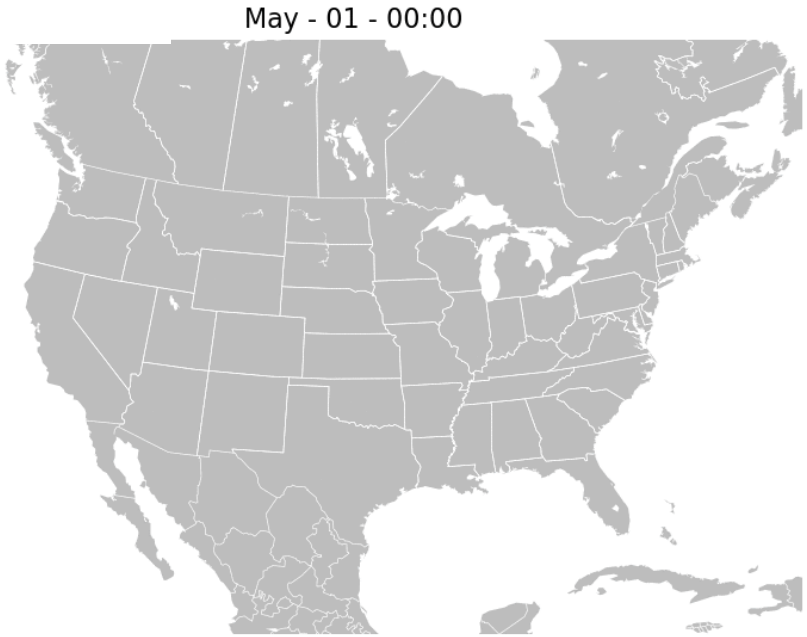
Phoenix AZ 2014
- 2 fatalities
- 84 mm in 7 hours
- M$17.4



Recent PhD work by Erin Dougherty, Colorado State University, shows that the CONUS I able to well simulate the precipitation associated with 600 major flooding events (Dougherty and Rasmussen (2020) Accepted in J. of Hydrometeorology

MCS tracks: observed vs. modeled





All MCS tracks from 13-years (2001-2013)
Tracks fade out after 7-days

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

MCS tracks: observed vs. modeled

WRF - Current Climate

May - 01 - 00:00

STAGE4 - Observation

May - 01 - 00:00

All MCS tracks from 13-years (2001-2013)
Tracks fade out after 7-days

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

Ability to simulate these three mesoacale features will enable

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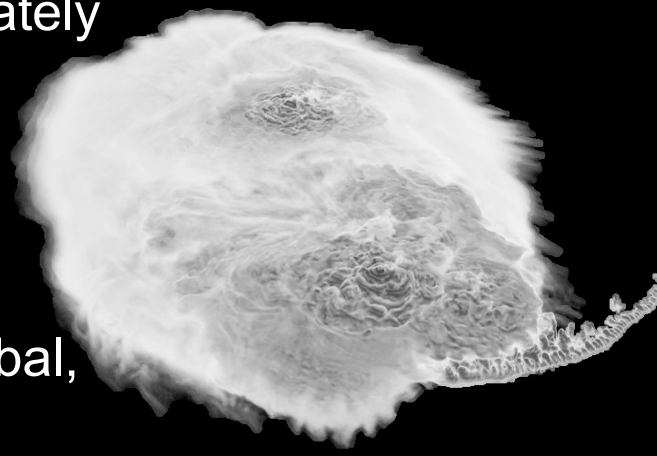
Ability to simulate these three mesoscale phenomenon (snowstorms, hurricanes, MCSs) will enable significant improvements in our ability to estimate the impact of climate change on high impact weather, impacts that matters to users!

Conclusions

1. Convection-permitting models (spatial resolution < 4 km) have revolutionized our ability to accurately simulate high impact weather and climate
   - Mesoscale Convective Systems (floods and hail)
   - Heavy snowfall
   - Hurricanes



2. Likely that climate modeling will evolve to global, convective permitting in the next 5-10 years.

3. This suggests that our CCIS work needs to be connected to the global CPM effort in order to properly estimate the impact of GHG reduction and reduction in solar radiation on phenomenon producing high impact events (floods, droughts, hurricanes, severe storms and hail, etc).

Questions?
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