Convection-Permitting WRF Climate Modeling at Continental-Scales

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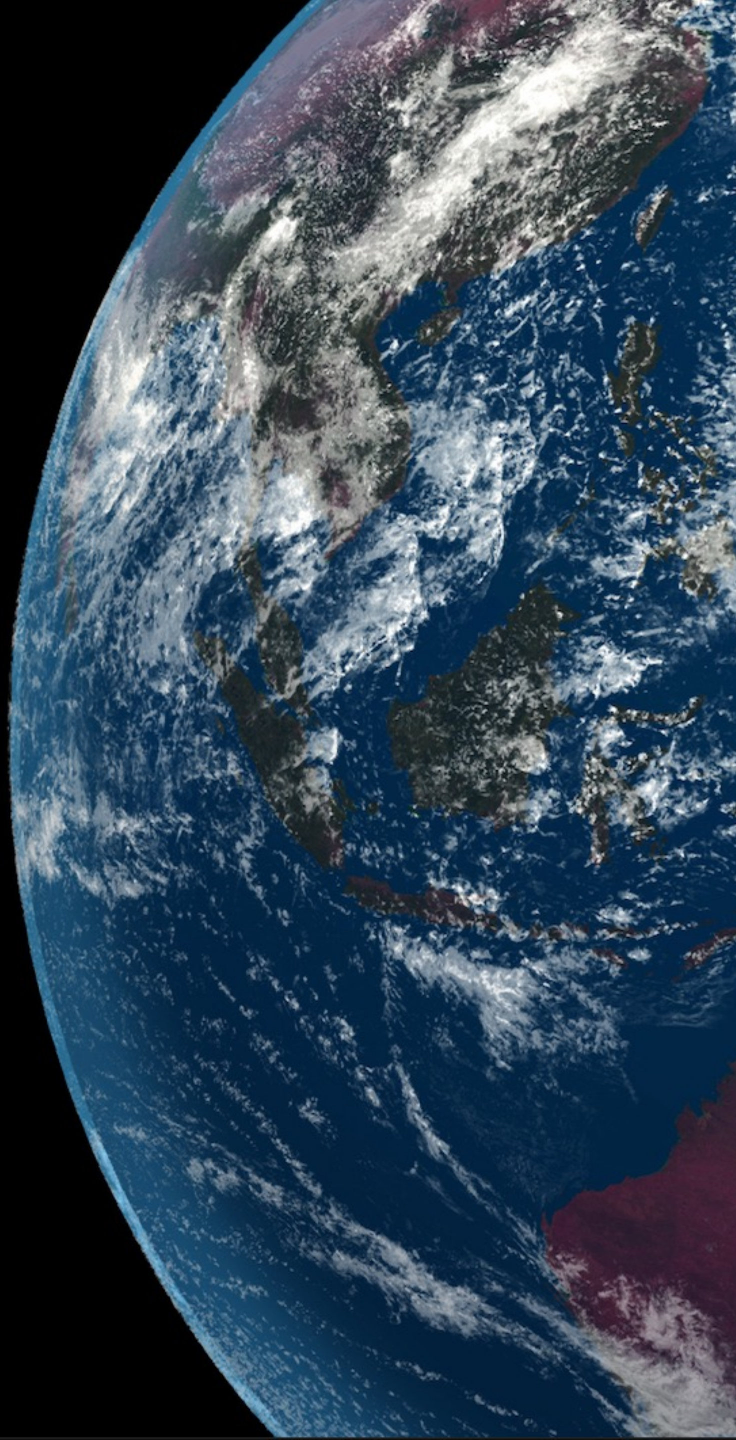
WRF/MPAS Users' Workshop 2021
9 June, 2021 | 10:40 - 11:00 UTC

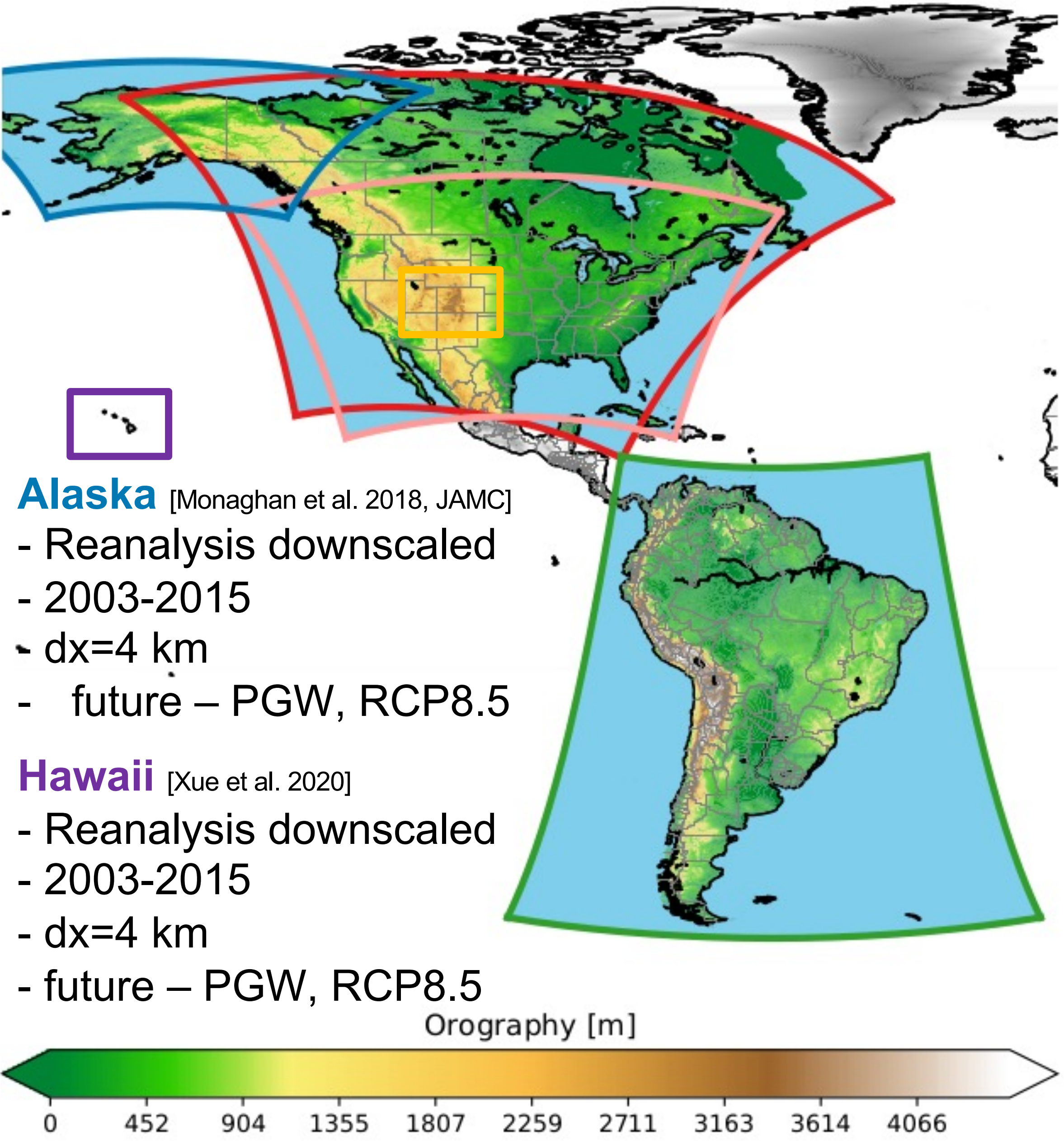
This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

OVERVIEW

1. Convection-Permitting Climate Modeling at NCAR
2. Simulating Precipitation in the Western U.S. & Eastern U.S.
3. Mesoscale Convective Systems in South America
4. Conclusions



NCAR/RAL Kilometer-Scale Climate Simulations



Alaska [Monaghan et al. 2018, JAMC]
- Reanalysis downscaled
- 2003-2015
- dx=4 km
- future – PGW, RCP8.5

Hawaii [Xue et al. 2020]
- Reanalysis downscaled
- 2003-2015
- dx=4 km
- future – PGW, RCP8.5

CO-Headwaters [Rasmussen et al. 2014]
- Reanalysis downscaled
- 2001-2008
- dx=4 km
- future – PGW, RCP8.5

CONUS-1 [Liu et al. 2017, Clim Dyn]
- Reanalysis downscaled
- 2001-2013
- dx=4 km
- future – PGW, RCP8.5

CONUS-2 [in progress]
- GCM downscaled
- 1995-2014
- dx=4 km

CONUS404 [in progress]
- Reanalysis downscaled
- 1979-2019
- dx=4 km

South America [in progress]
- Reanalysis downscaled
- 20-years
- dx=4 km
- future – PGW, RCP8.5

Model Setup

2011
CO Headwaters
NARR forcing

- WRF 3.1.1
- Noah LSM
- Thompson MP
- YSU PBL
- CAM3 radiation

2014
CONUS1
ERA-Interim forcing

- WRF 3.4.1
- **Noah-MP**
- Thompson **aerosol-aware microphysics**
- YSU PBL
- **RRTMG**
- 51 Levels

2019
CONUS2
CESM forcing

- **WRF 3.9.1.1**
- Noah-MP **(incl. groundwater)**
- Thompson microphysics
- YSU PBL
- RRTMG
- 51 Levels

2020
CONUS404
ERA5 forcing

404

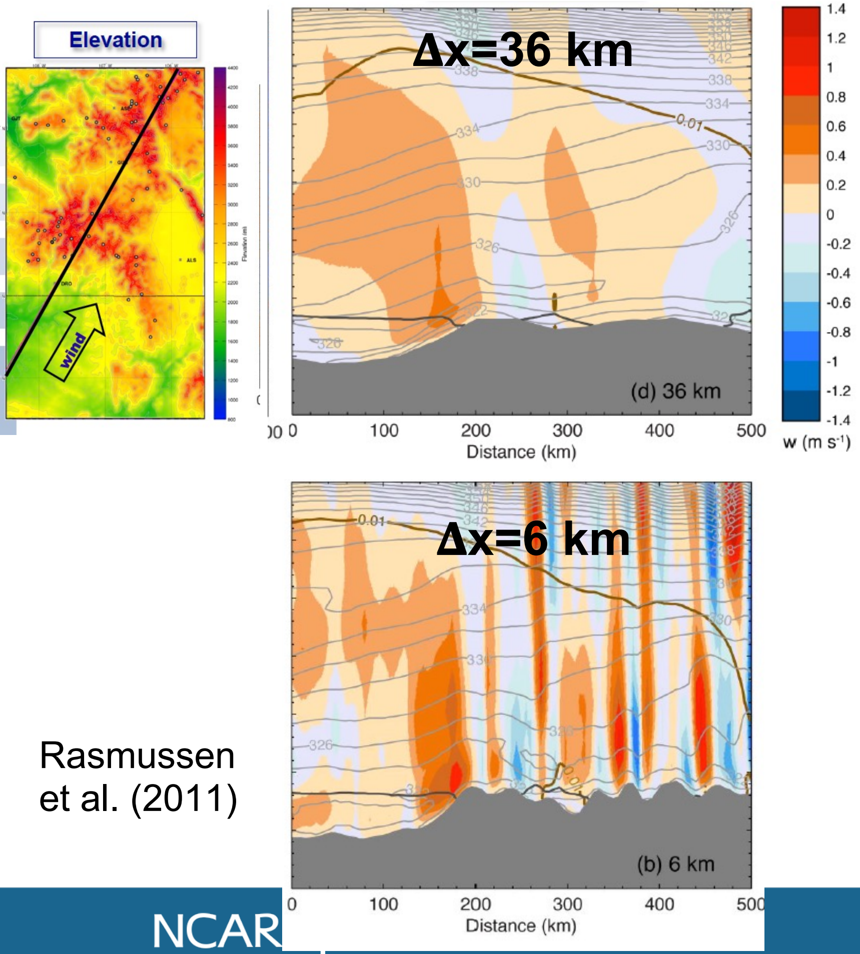
- WRF 3.9.1.1
- Noah-MP (incl. groundwater)
- Thompson microphysics
- YSU PBL
- RRTMG
- 51 Levels

2021
South America
ERA5 forcing

- **WRF 4.1.5**
- Noah-MP (incl. groundwater)
- Thompson microphysics
- YSU PBL
- RRTMG
- **61 levels**

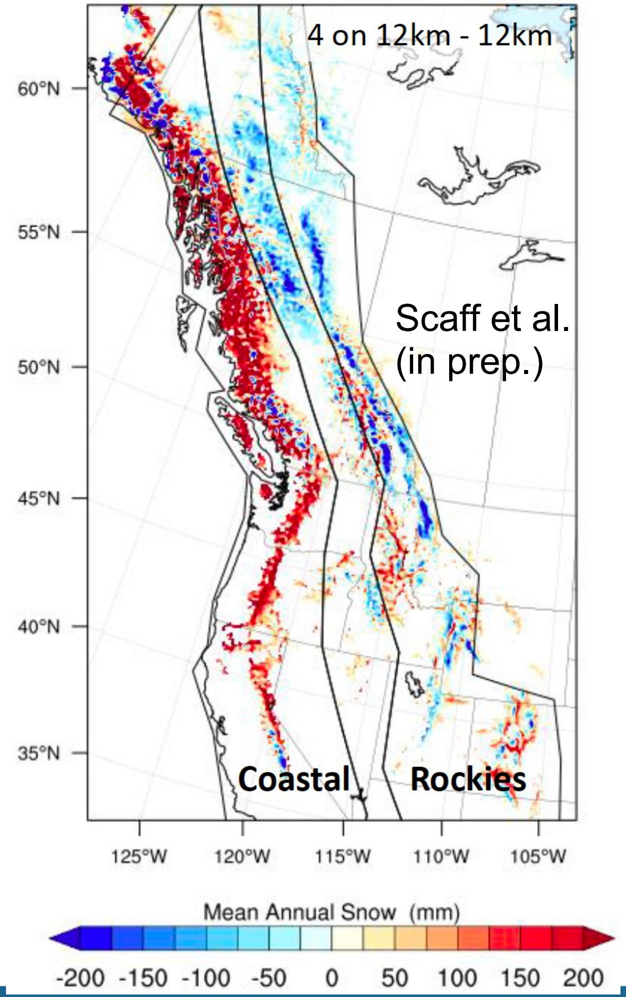
Simulation the Water Cycle in the Rockies

Flow interactions with topography are much improved at kilometer-scale grid spacings.



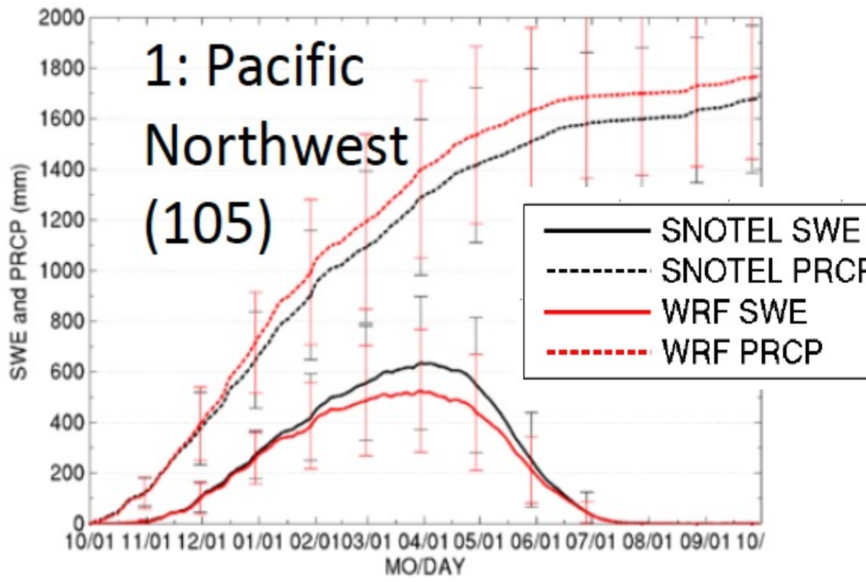
Rasmussen et al. (2011)

Compared to a 4 km model a 12 km model underestimates snowfall in the coastal mountains but overestimates it along the Continental Divide.



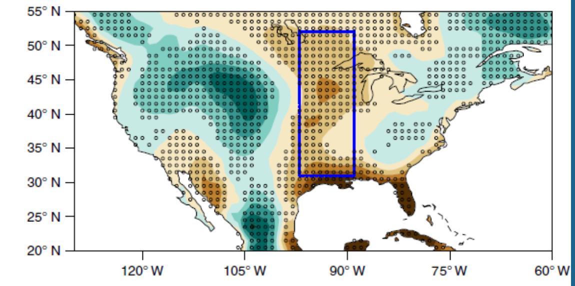
Scaff et al. (in prep.)

Kilometer-scale grid spacing is essential in capturing the accumulation and melt of the snowpack in the western U.S.



Ikeda et al. (2021)

(CAUSES) project
[Lin et al. 2017, Nat. Com.]



Significant improvement in precipitation amount, intensity, and frequency

Substantial reduction of uncertainties due to elimination of deep convection scheme

Convective Precipitation Diurnal Cycle

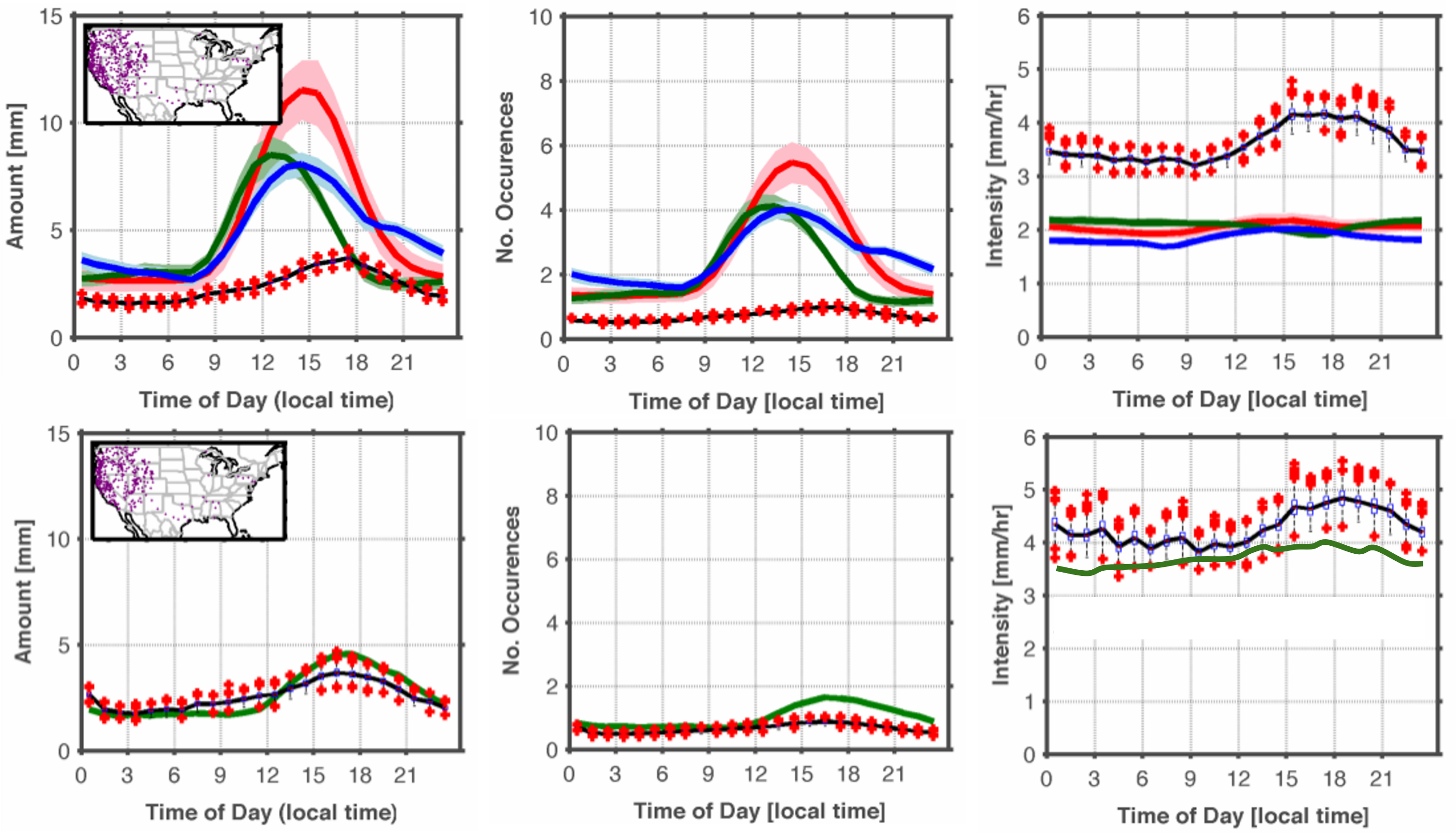
Amount

WRF 36 km

- Observations
- Kain-Fritsch
- Tiedtke
- NSAS

CONUS1
WRF 4 km

- Observations
- WRF-4km



[Mooney et al. 2016; Ban et al. 2015]

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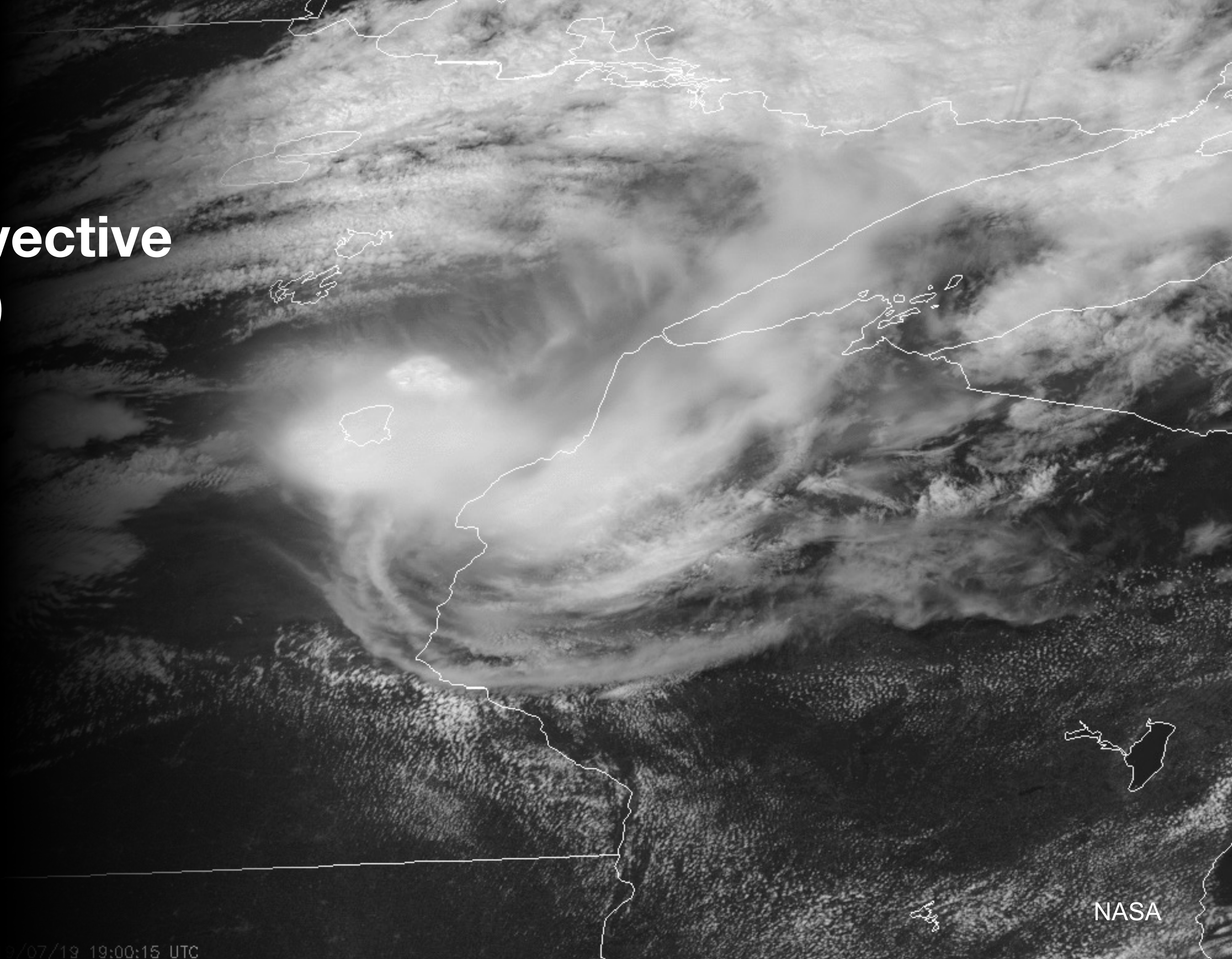
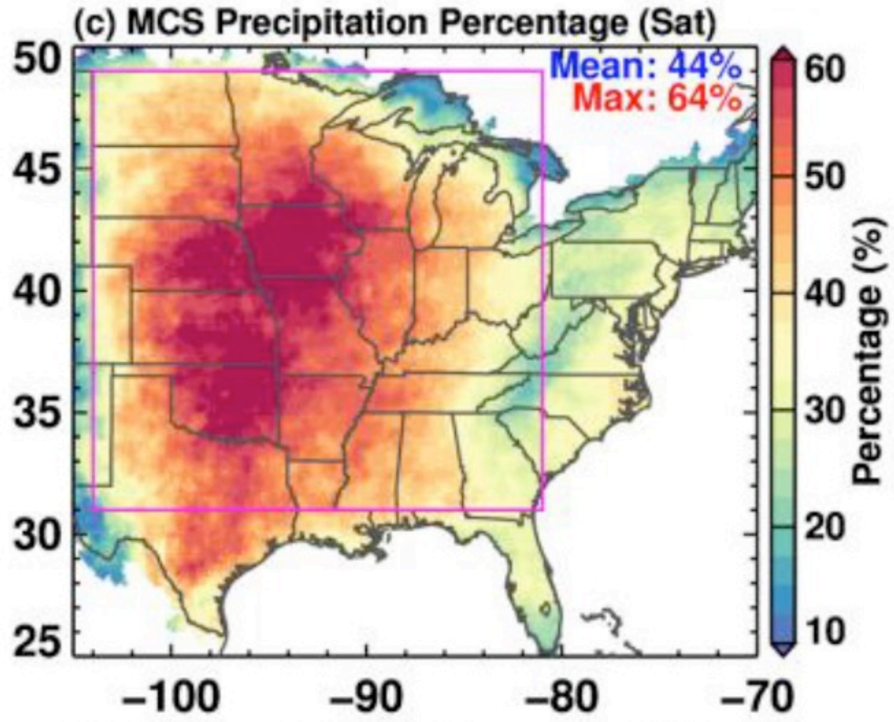
Mesoscale Convective Systems (MCSs)

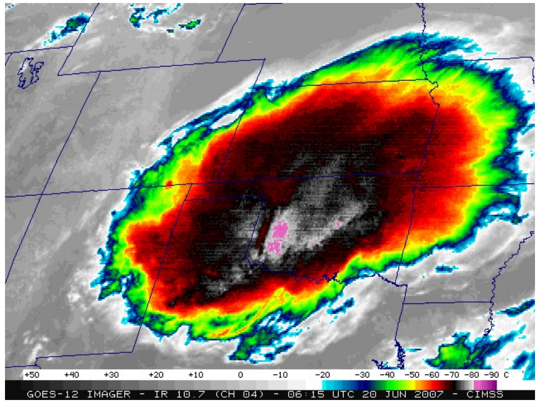


Simulation the water cycle in the Plains

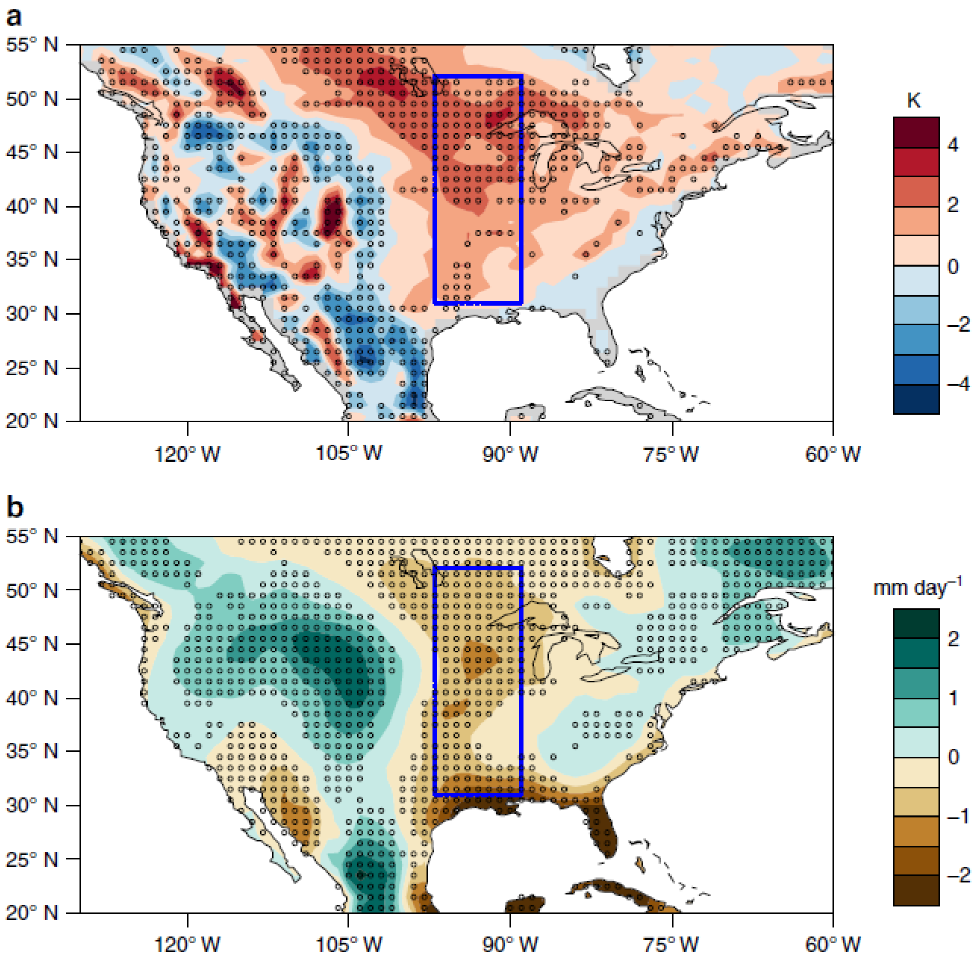
Fritsch et al. 1986:
"MCSs contribute between 30—70% to the warm season precipitation (April—September) in region between the Rocky mountains and the Mississippi River."



[Feng et al. 2016, Nature Com.]



Clouds Above the United States and Errors at the Surface (CAUSES) project
[Lin et al. 2017, Nat. Com.]



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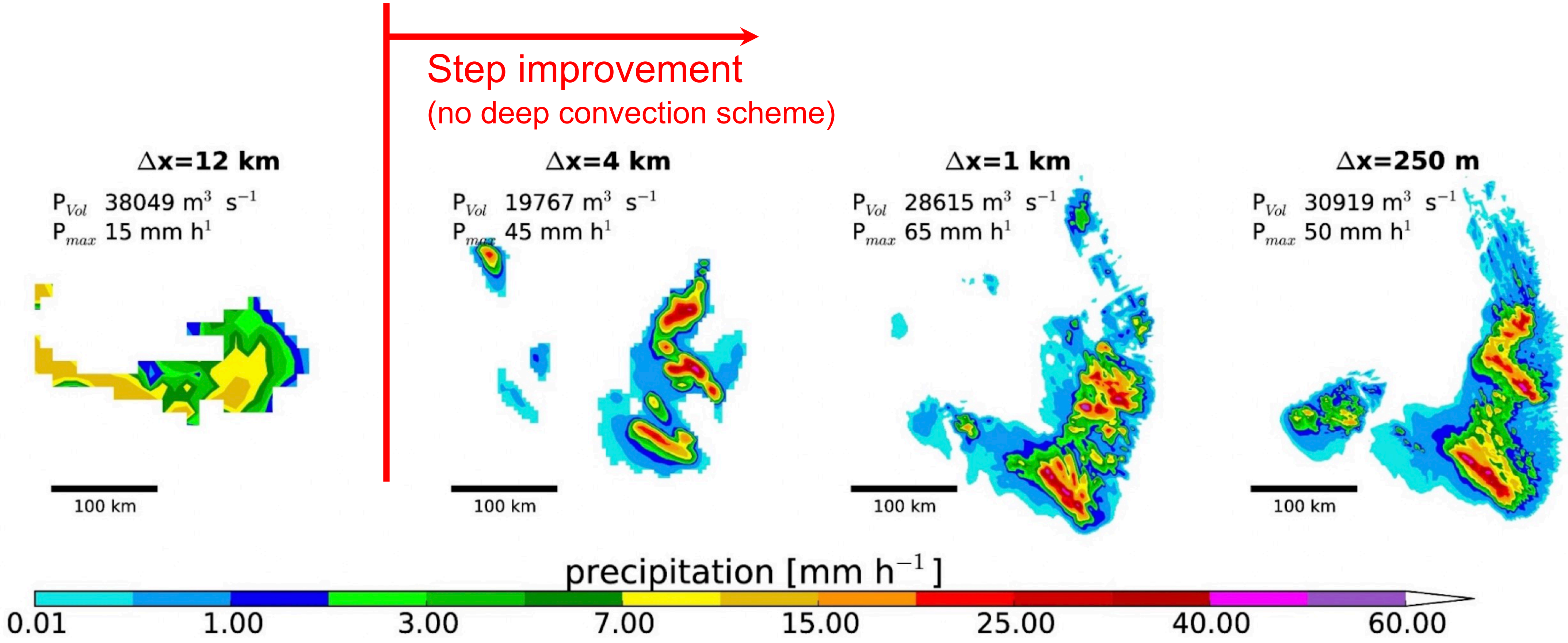
We Need Kilometer-Scale Models to Simulate MCSs

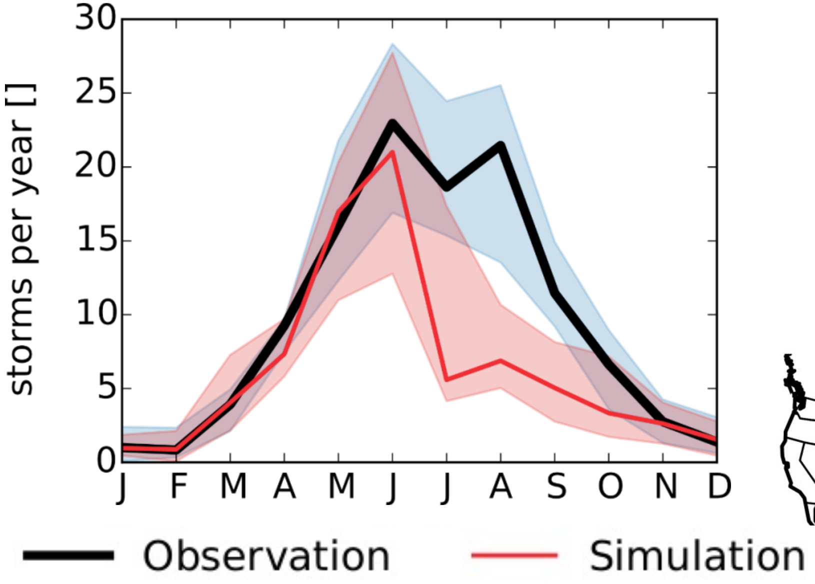


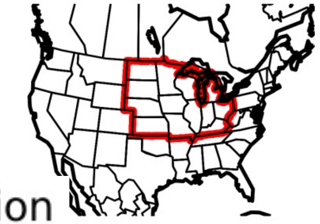
Prein et al. 2021

Kilometer-sale (convection-permitting) models feature step improvement in simulating heavy rainfall.

Annual Cycle of Mesoscale Convective Systems

MCSs per Year



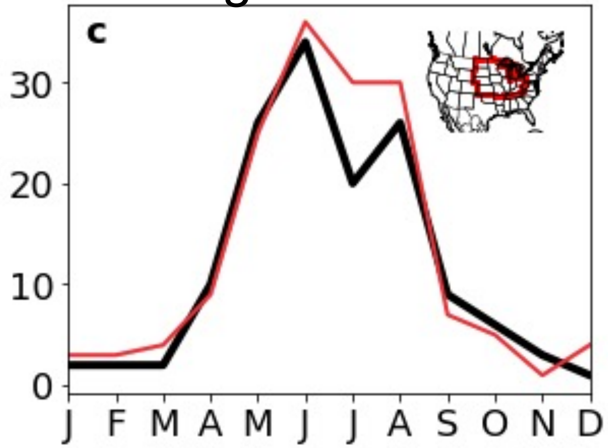


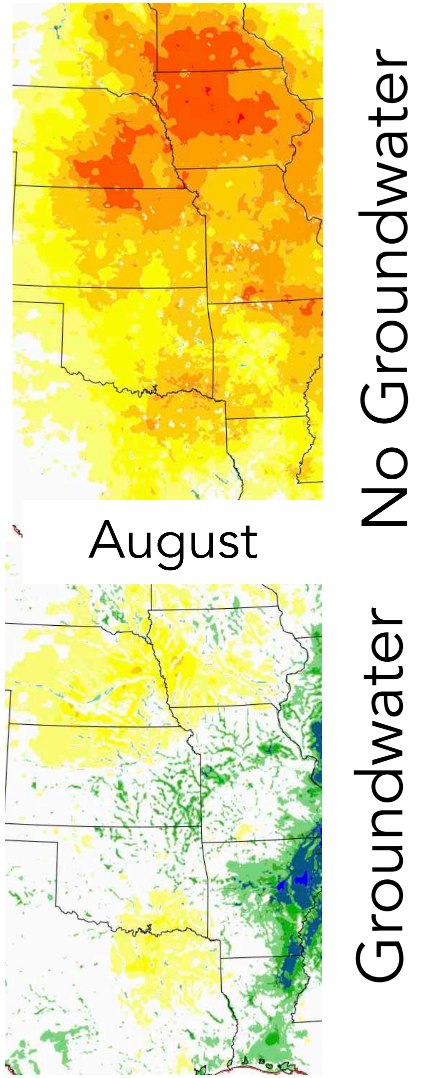
CONUS1

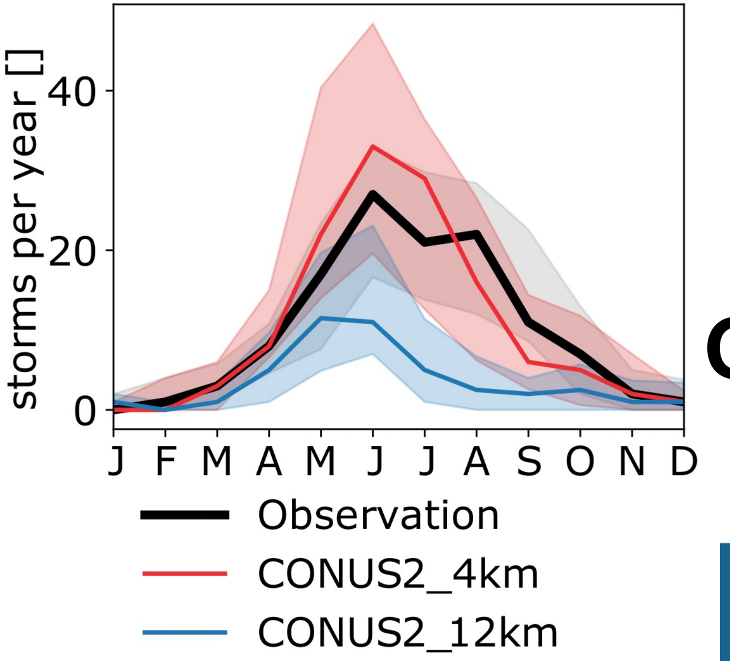
Liu et al. (2017)
Prein et al. (2017)

CONUS404

with groundwater



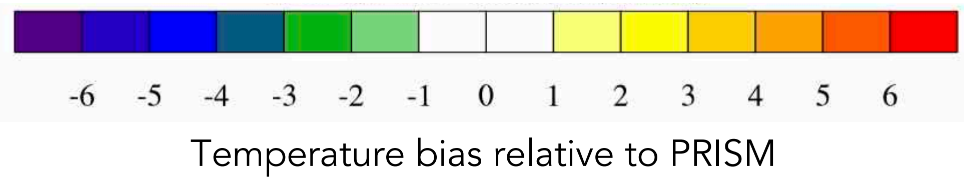




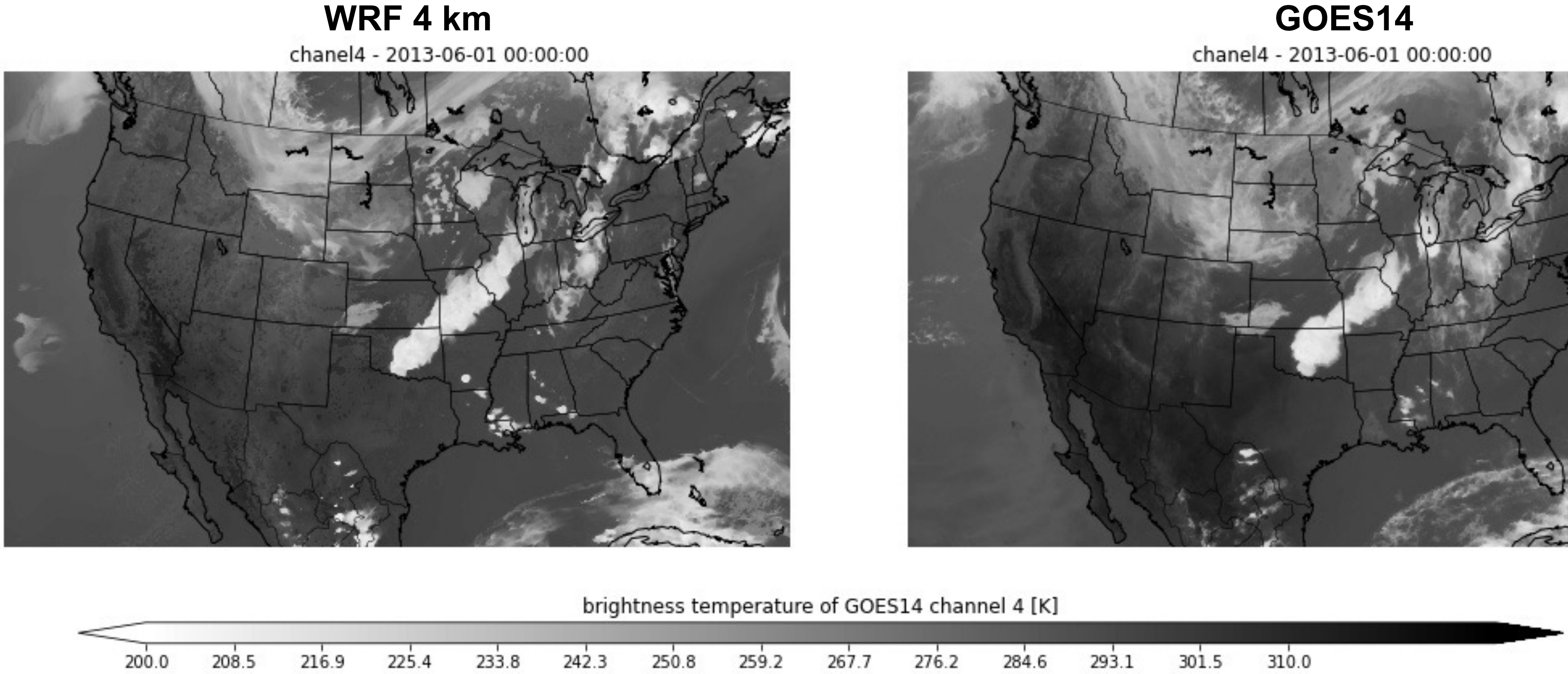
CONUS2 GCM driven

with groundwater

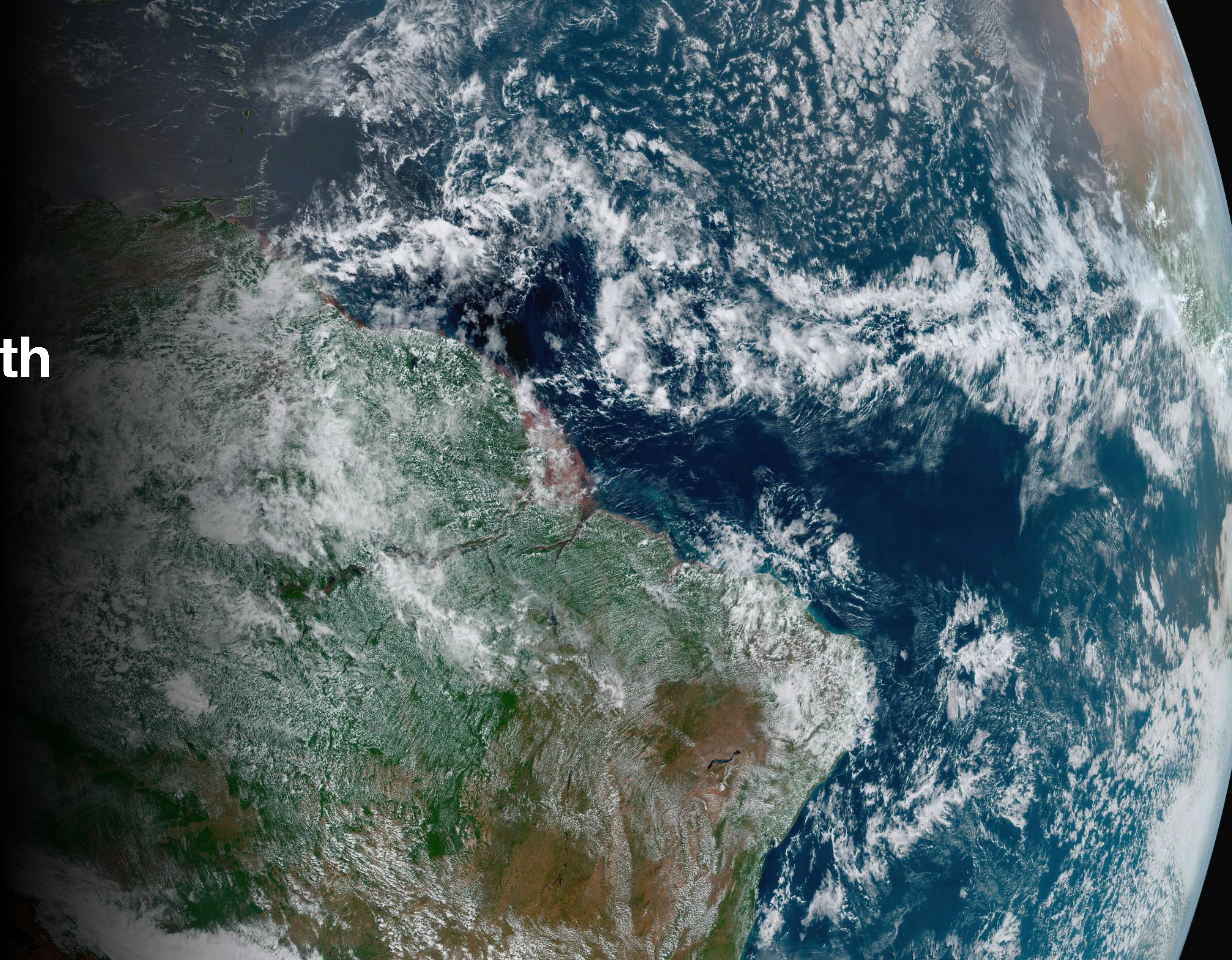
[Barlage et al. 2021]

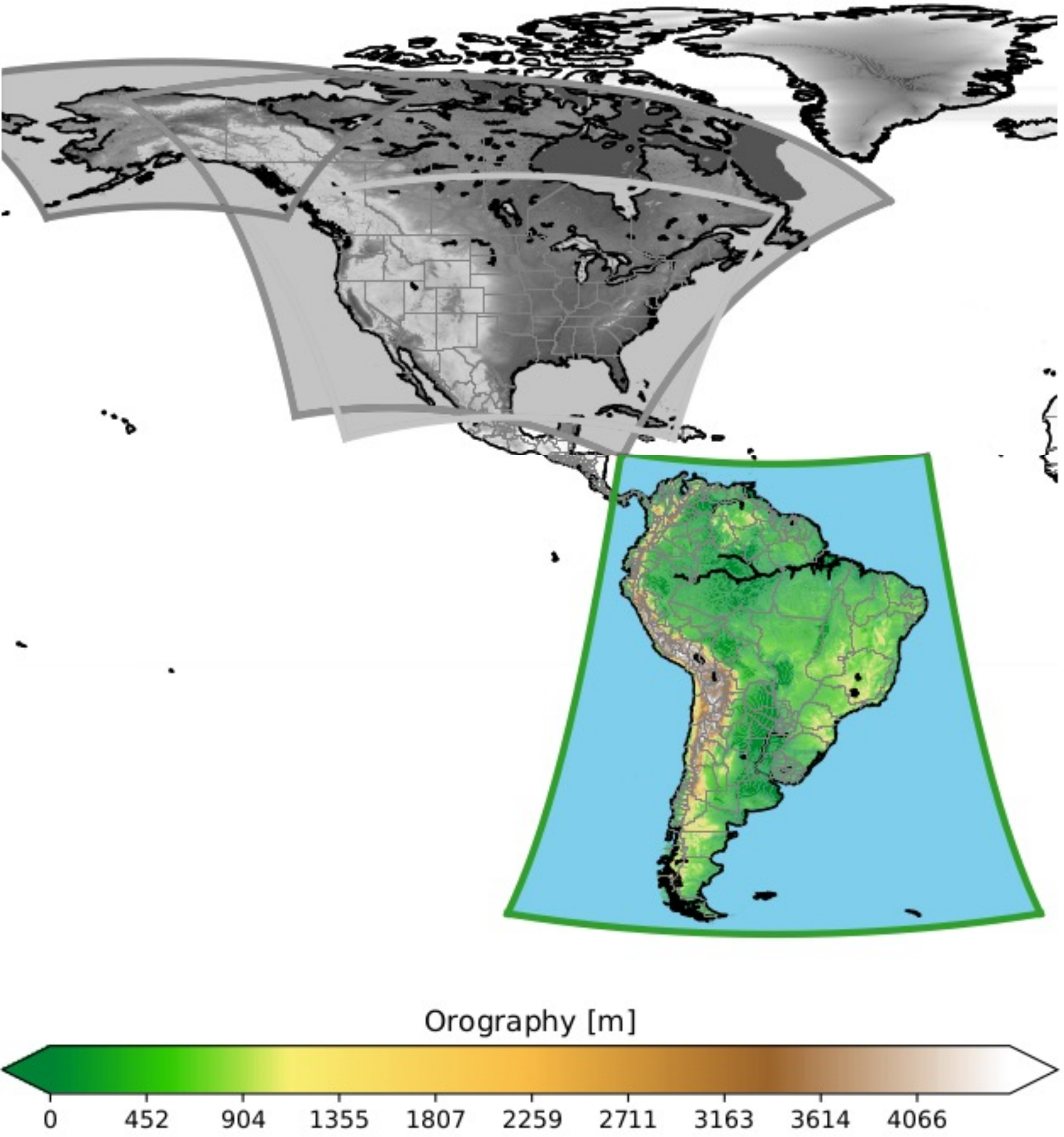


Comparison of Simulated and Observed Cloud Brightness Temperature (CONUS404)



Kilometer-Scale Modeling in South America



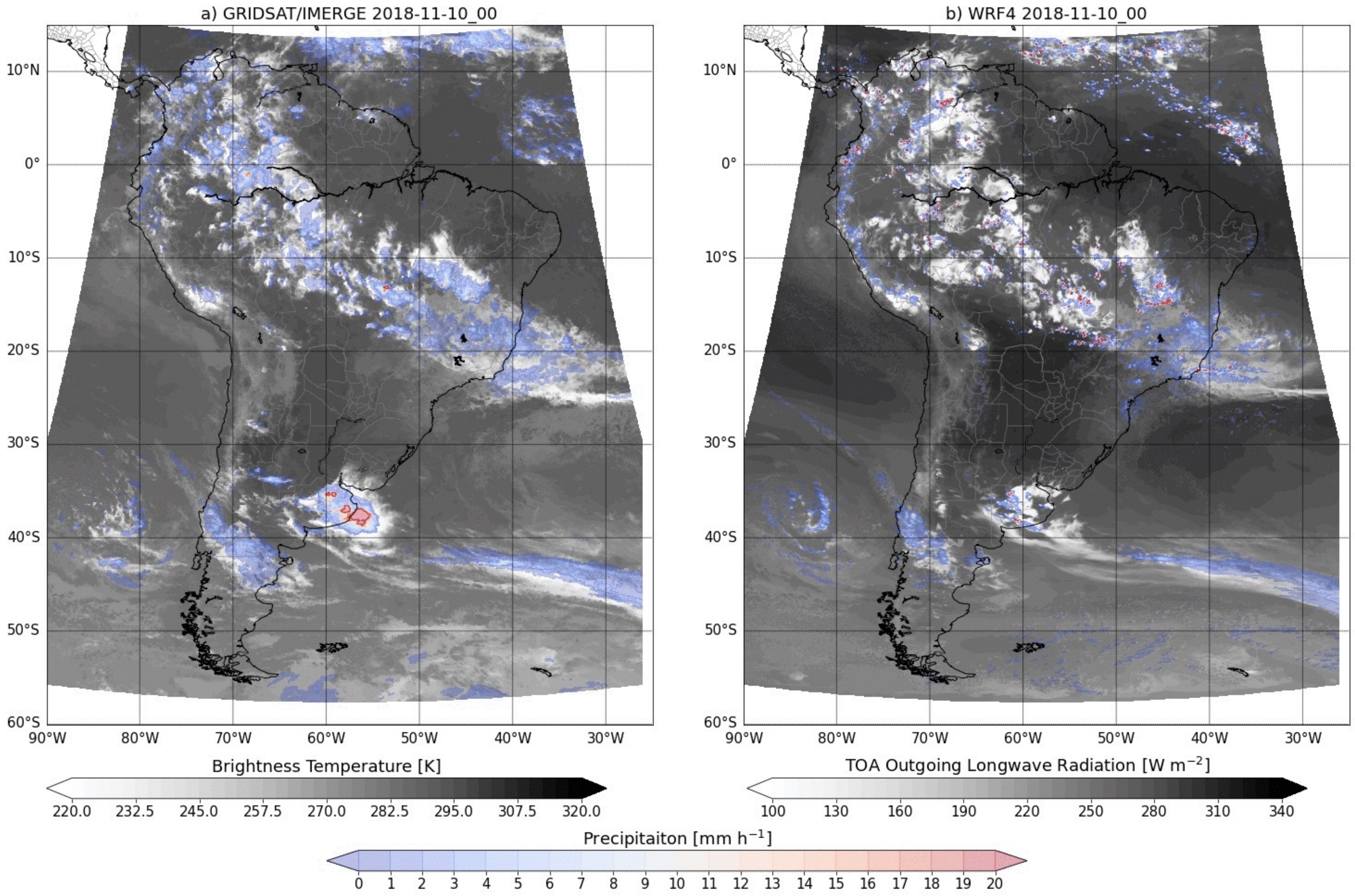


South America Affinity Group

- 81 community members
  - From Americas and Europe
  - In support of the ANDEX RHP (GEGEX)

SAAG website
https://ral.ucar.edu/projects/south-america

Precipitation and Cloud Field | Nov. 10—16, 2018

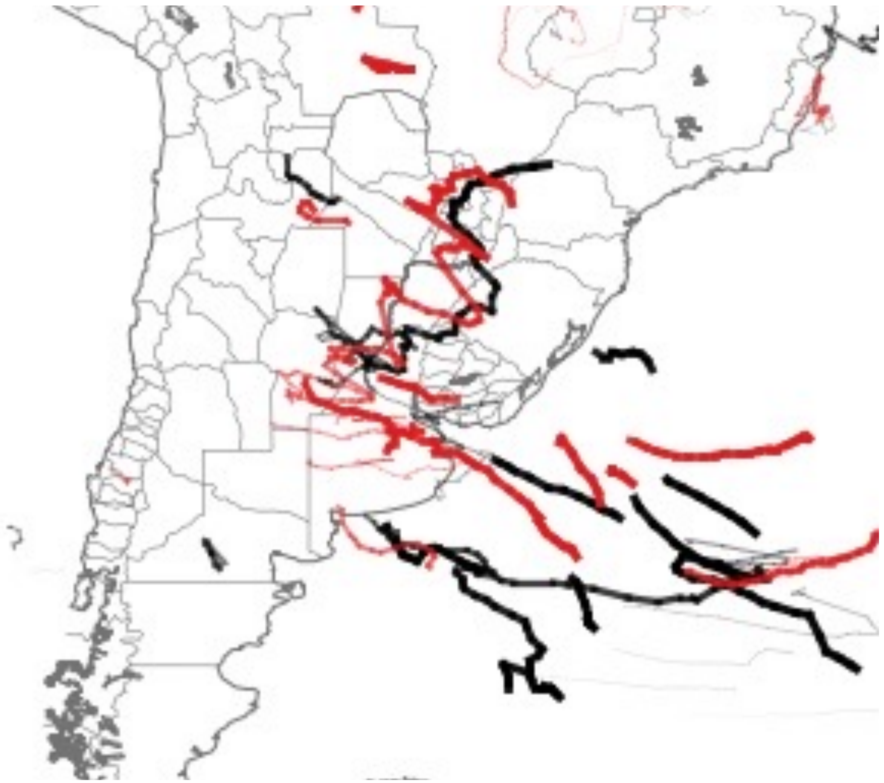


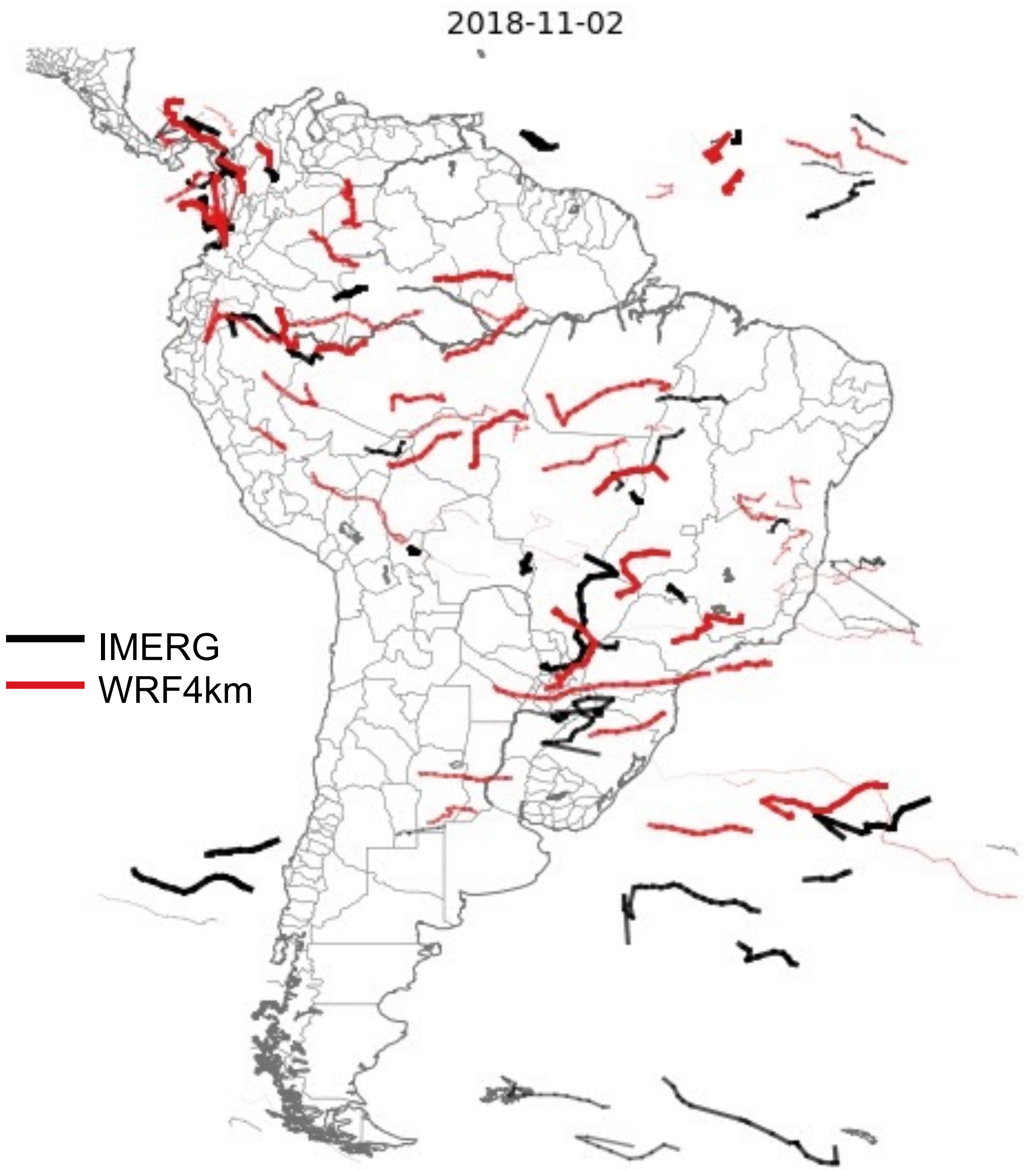
Observations

- Brightness Temperature
  GRIDSAT
- Precipitation
  IMERG

Observed and Simulated Tracks of Organized Precipitation Nov. 2018

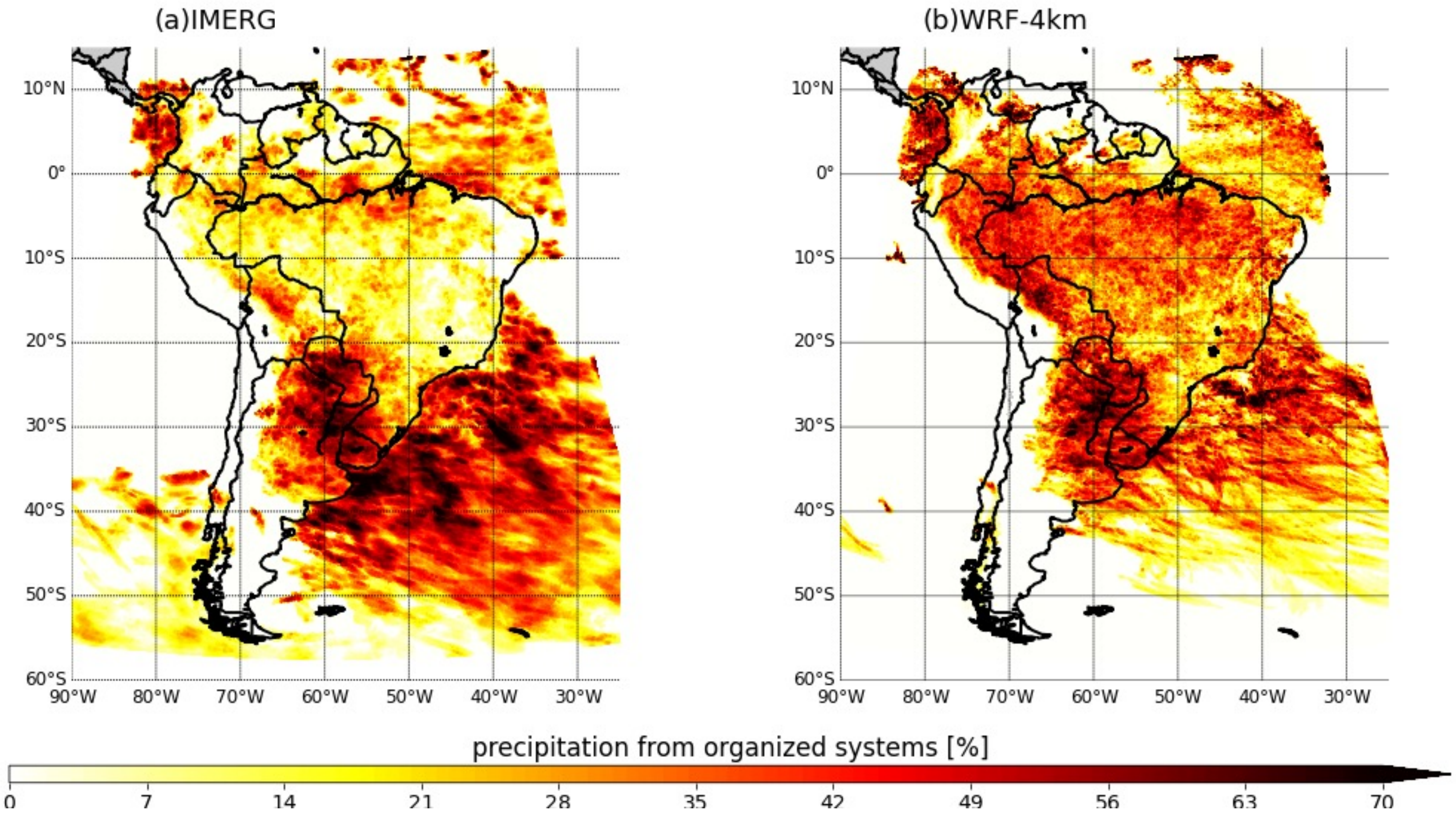
RELAMPAGO/CACTI event on Nov 11-13, 2018

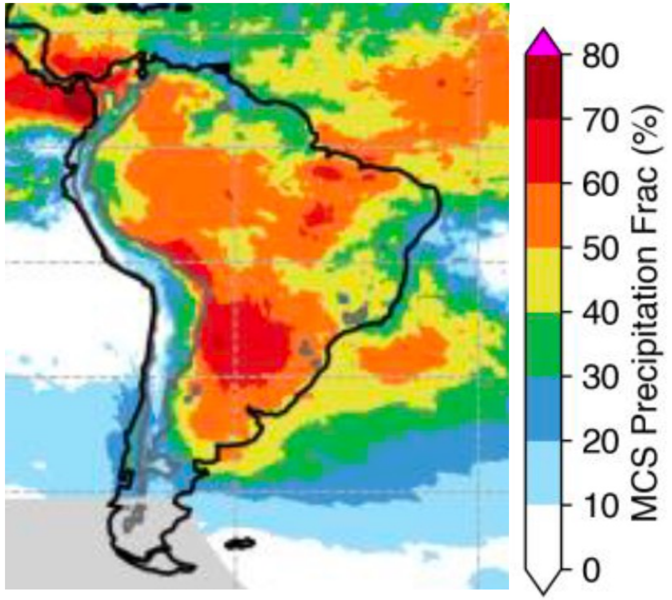




Ratio of Precipitation from Organized Systems

June 2018 – May 2019

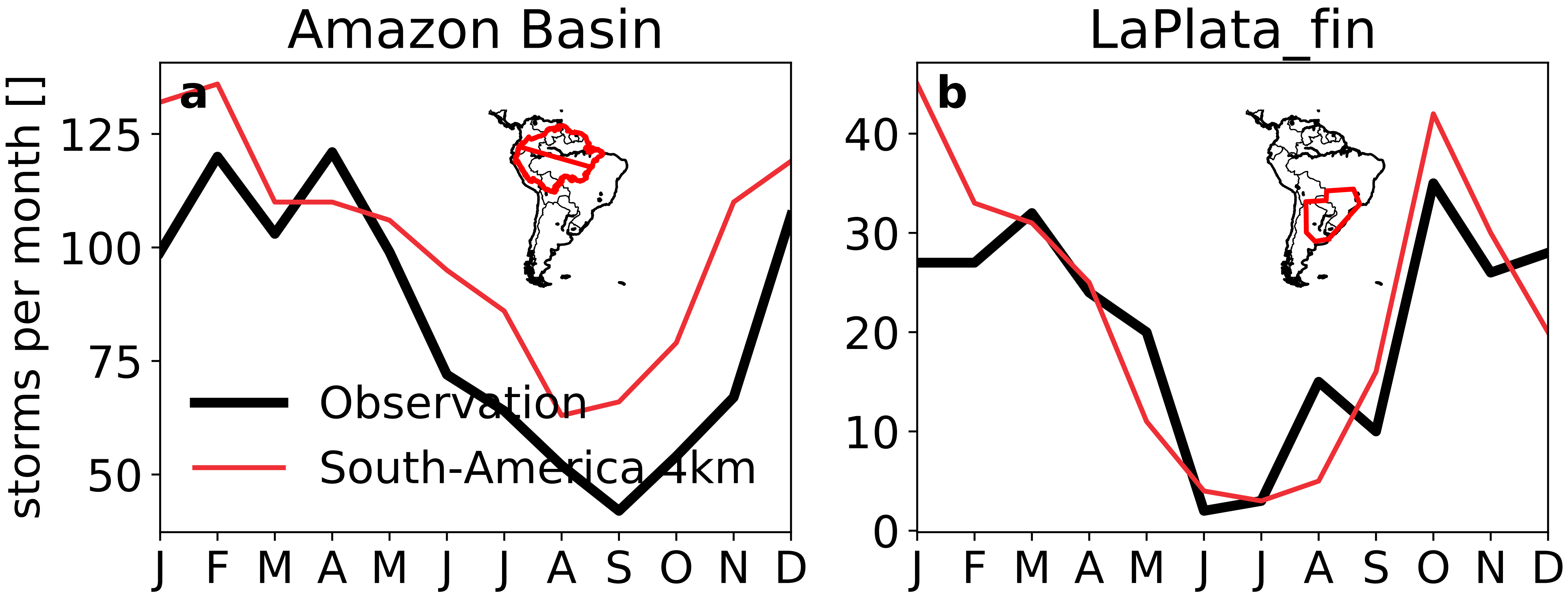




Feng et al. 2021

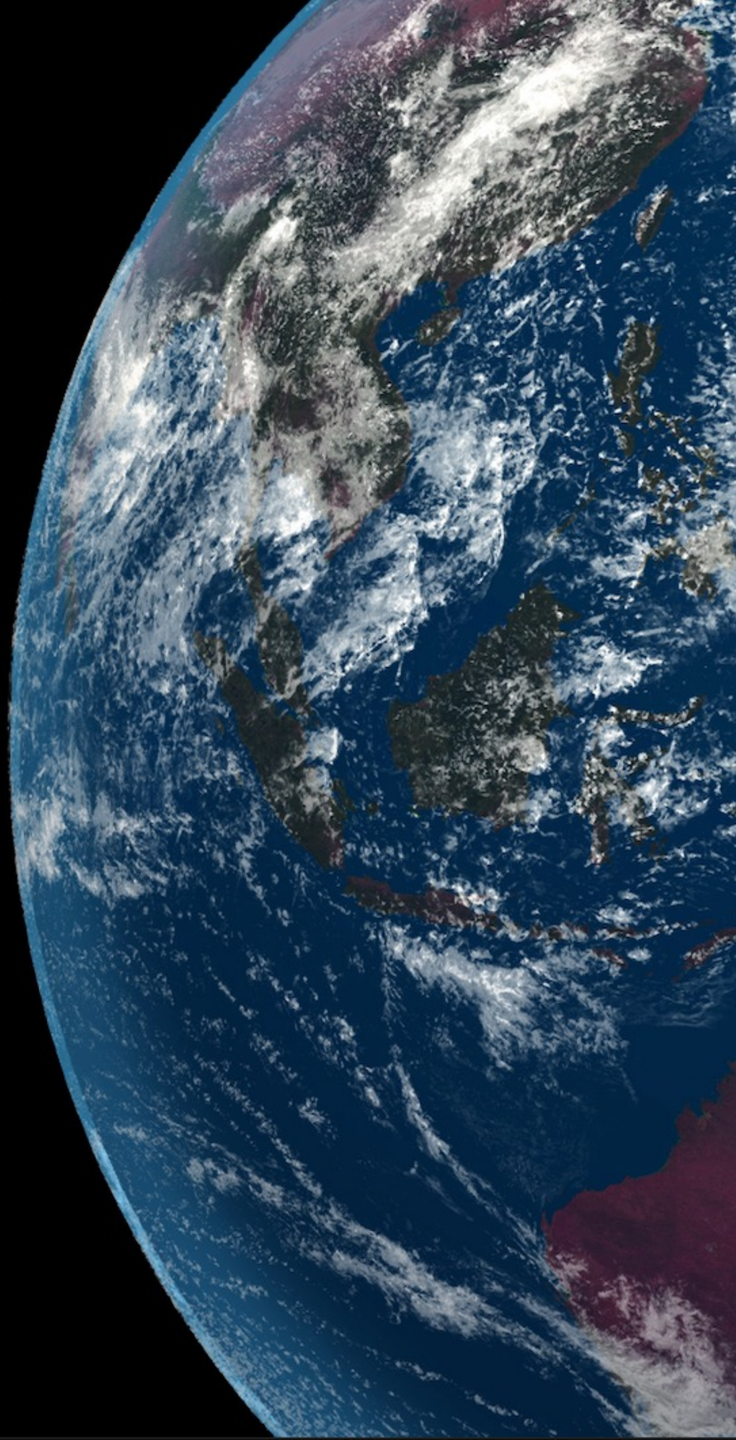
Annual Cycle of Organized Storms

June 2018 – May 2019



Conclusion

1. Kilometer-Scale WRF Climate Simulations Largely Improve
    a) The amount, frequency, intensity, and phase of precipitation
    b) Simulation of snowpack dynamics
    c) Simulating of the convective precipitation diurnal cycle
    d) The frequency and intensity of mesoscale convective systems
2. Correctly simulating land surface processes is essential
3. The same model physics work well over tropical, mid-, and high-latitude land areas



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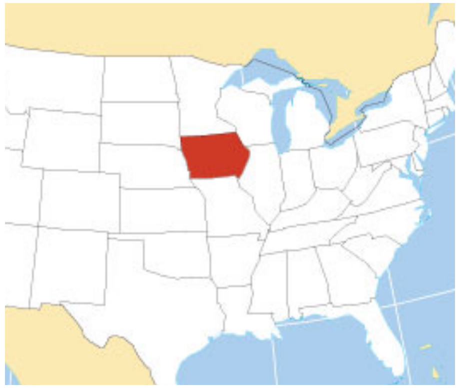
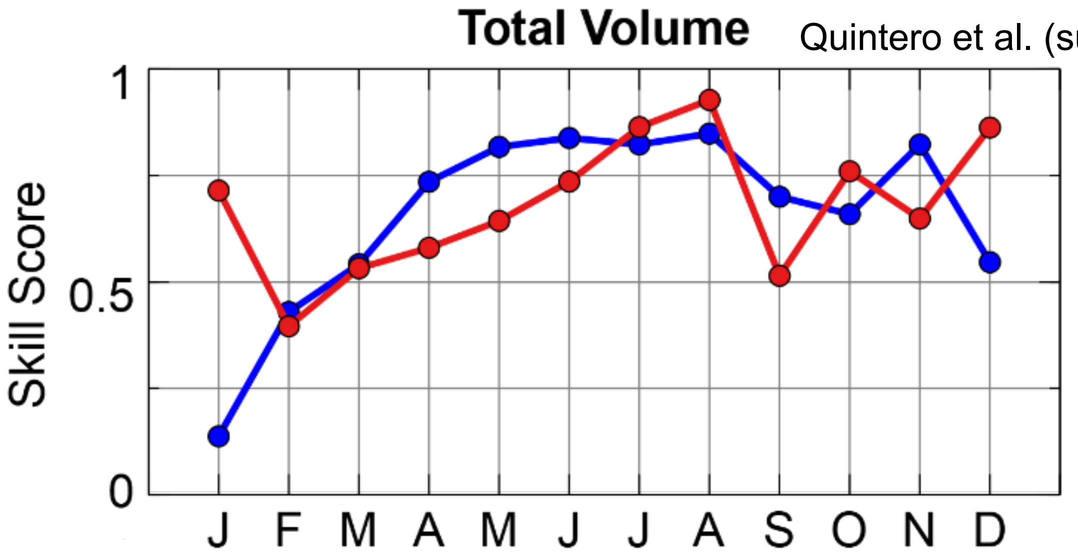
Models are approaching observational quality



Streamflow volume forecasts using precipitation from CONUS1 model outperform forecasts that use precipitation observations during the flood season in Iowa.

Quintero et al. (submitted)



4 km WRF hindcast simulation (Liu et al. 2017)

Stage IV radar/gauge based observations

OUR SKILL IN MODELING MOUNTAIN RAIN AND SNOW IS BYPASSING THE SKILL OF OUR OBSERVATIONAL NETWORKS

JESSICA LUNDQUIST, MIMI HUGHES, ETHAN GUTMANN, AND SARAH KAPNICK

In mountainous areas, high-resolution atmospheric models can represent total annual precipitation better than the collective network of precipitation gauges.

International Journal of Climatology RMetS

RESEARCH ARTICLE

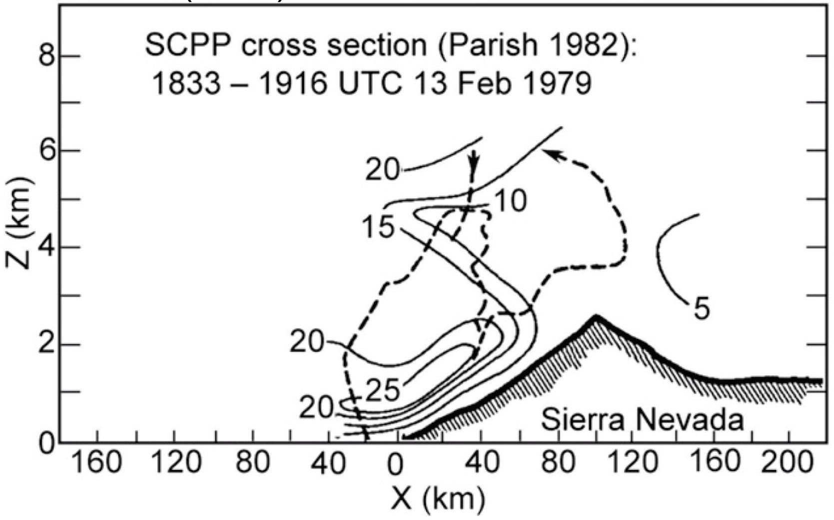
High-resolution monthly precipitation climatologies over Norway (1981–2010): Joining numerical model data sets and in situ observations

Alice Crespi[1] | Cristian Lussana[2] | Michele Brunetti[3] | Andreas Dobler[2] | Maurizio Maugeri[1,3] | Ole Einar Tveito[2]

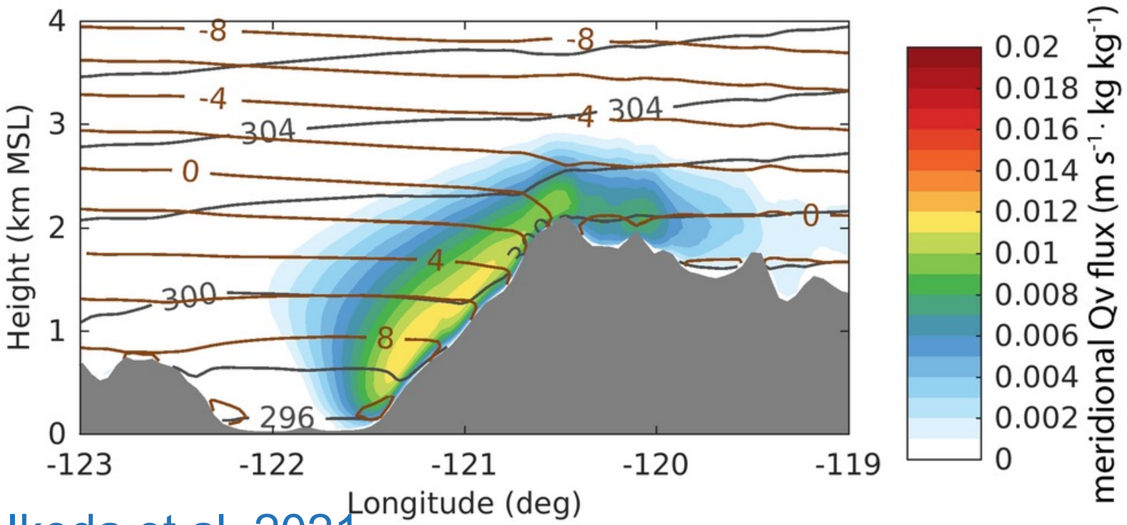
Flow Interaction with Topography

The Sierra Nevada Barrier Jet in CONUS1

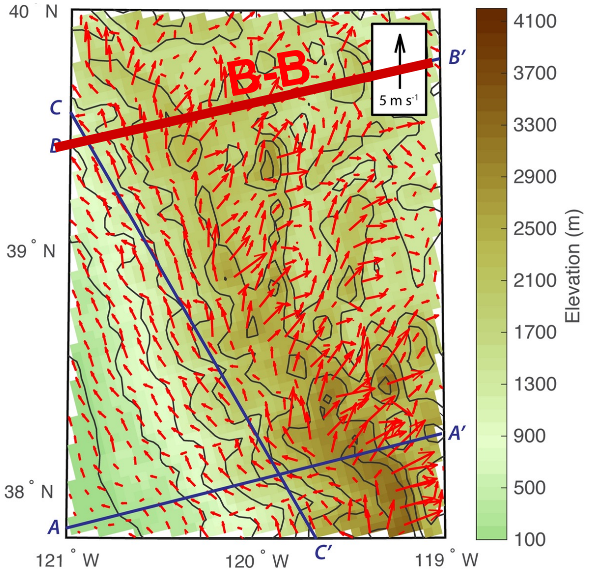
Parish (1982)



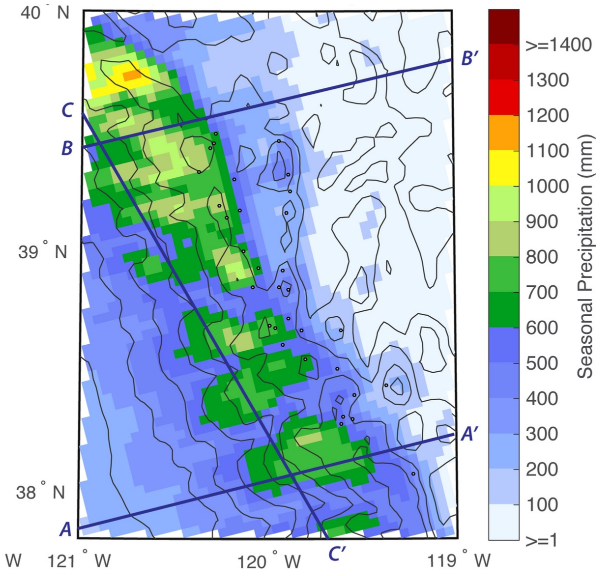
Meridional Qv flux (B-B)



10 m DJF wind



DJF precipitation



[Ikeda et al. 2021]