Mid-Pliocene North American Monsoon in Weather Resolving Coupled Simulations

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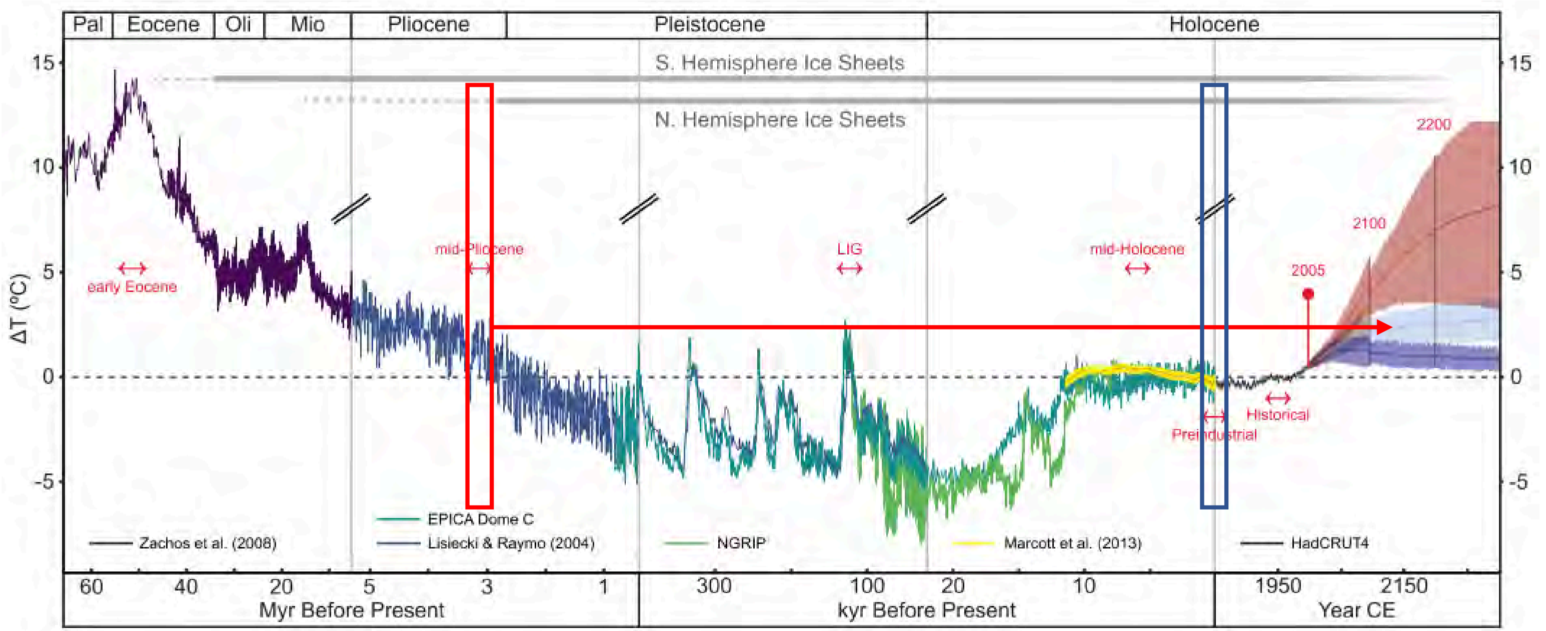
Mid-Pliocene (3.3-3.0 Ma) as an analog for future change

- The Mid-Pliocene featured similar topography and bathymetry to the present, with atmospheric CO_2 levels around 400 ppm and temperatures about 1.8 to 3.6 °C warmer than preindustrial

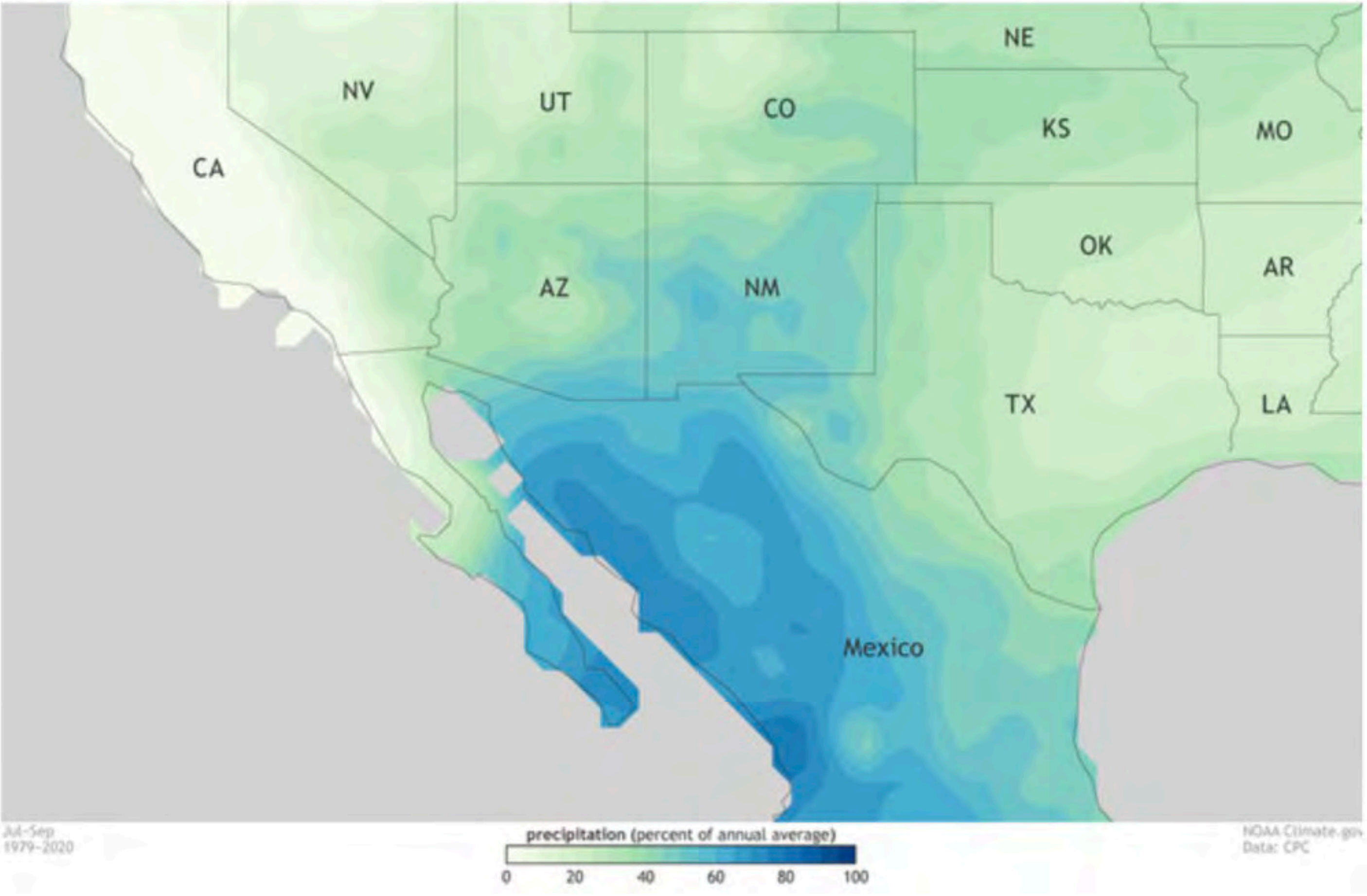


Burke et al., 2018

The North American Monsoon (NAM)

- Atmospheric circulation feature of hydroclimate in the North American Southwest (SW NA)
- Generated by interactions between topography and moisture surge from Gulfs of California and Mexico
- Rainfall is important for those living in SW NA

Percent of annual rainfall that occurs during the NAM

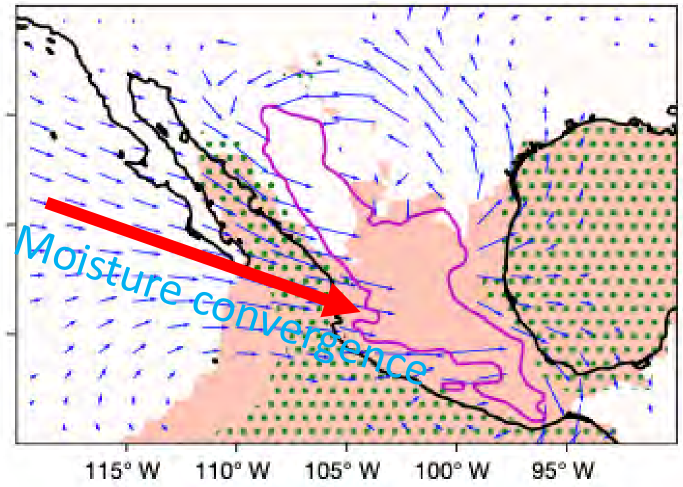


https://www.climate.gov/news-features/blogs/enso/north-american-monsoon

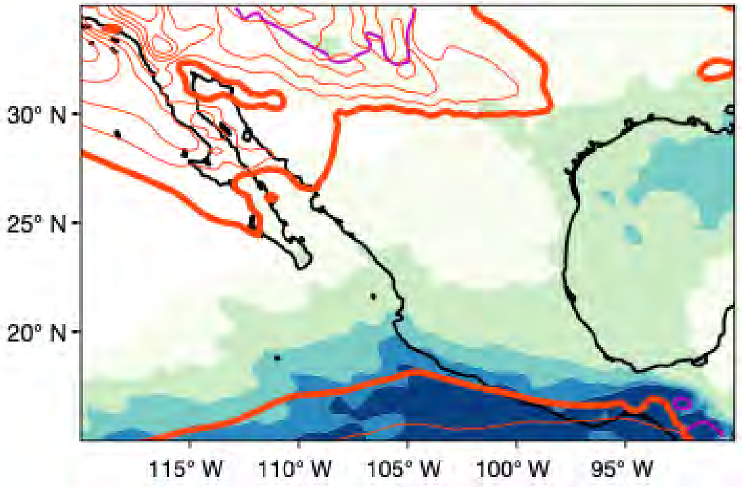
Mechanical forcing of NAM

- Recent research shows that the NAM is mechanically forced by the high orography of Sierra Madre Occidental (SMO)
- A clear difference in JAS precipitation and near-surface eastward wind (orange contours, interval 1 m s^{-1}) between flattened and observed orography

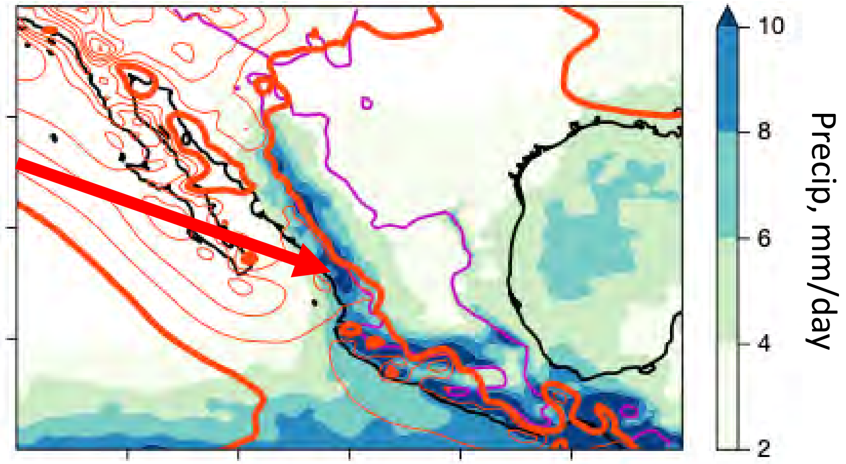
Diff. 700 hPa horizontal wind



With flattened orography



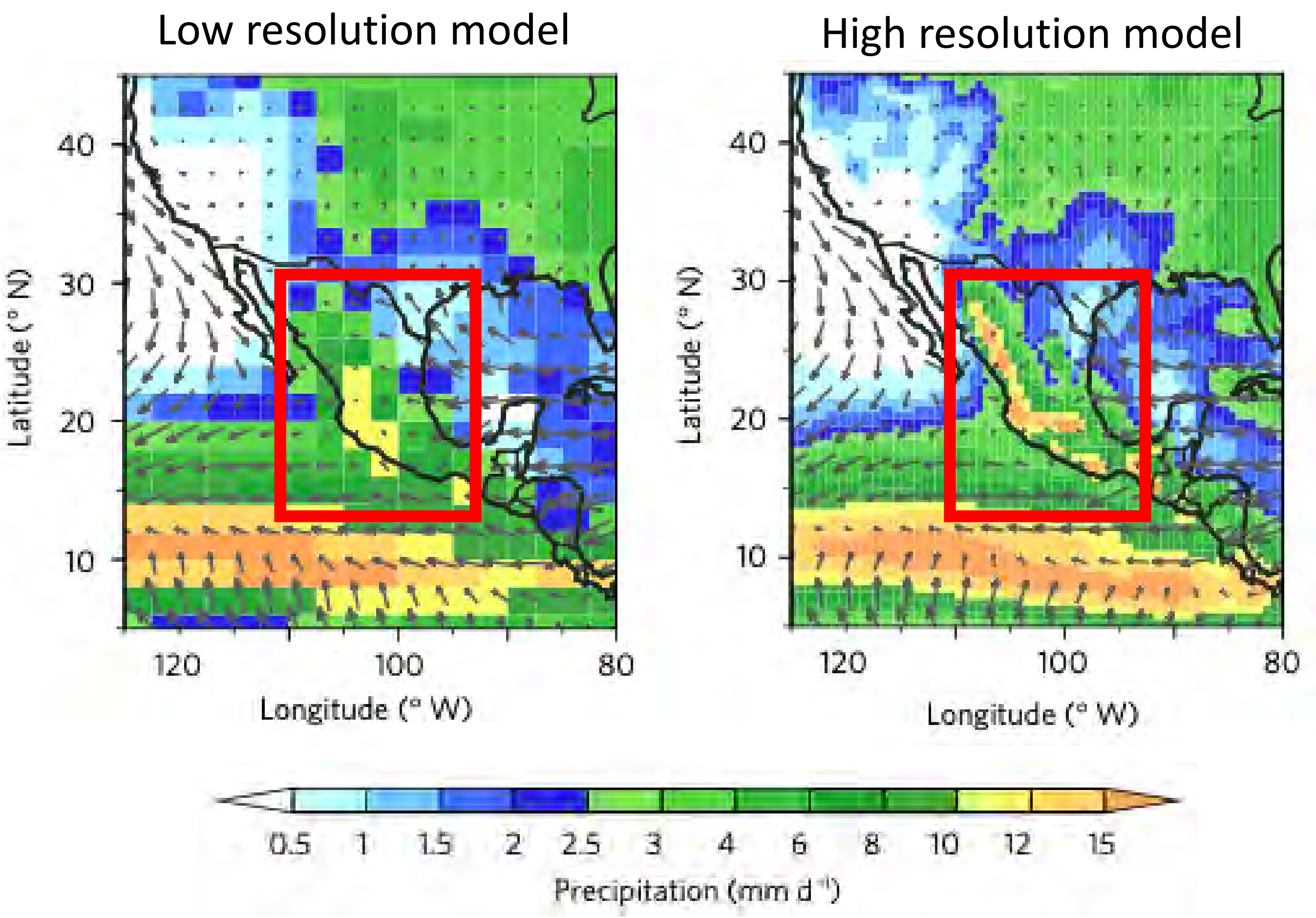
With modern orography



Boos & Pascale, 2021

Importance of horizontal resolution

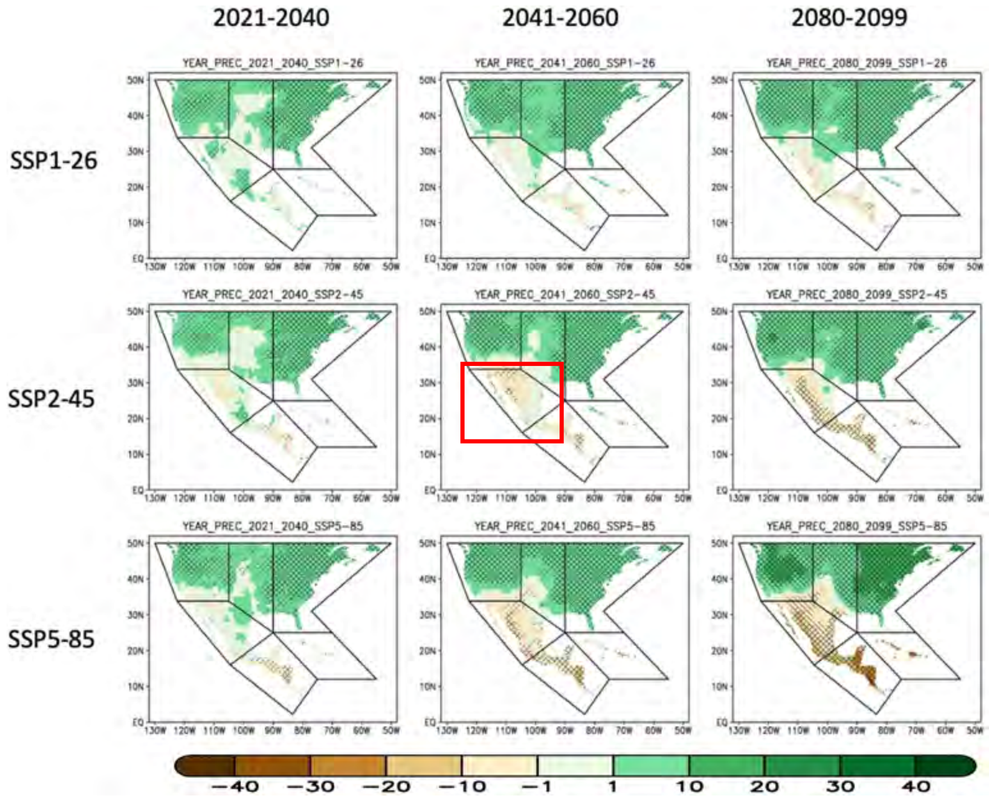
- High horizontal resolution is critical for capturing important features of the NAM
  - The monsoon core region is poorly defined in low resolution



Pascale et al., 2017

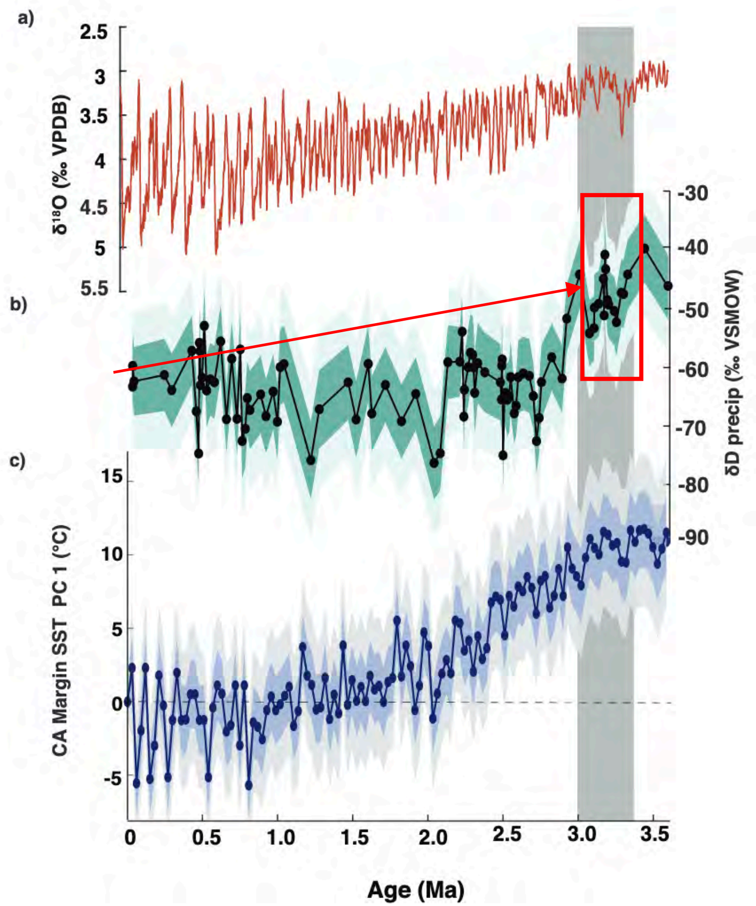
Inconsistency between future predictions of NAM and proxy evidence

CMIP6 Ensemble projections of future precipitation changes (%)



Almazroui et al., 2021

Proxy evidence of wetter conditions



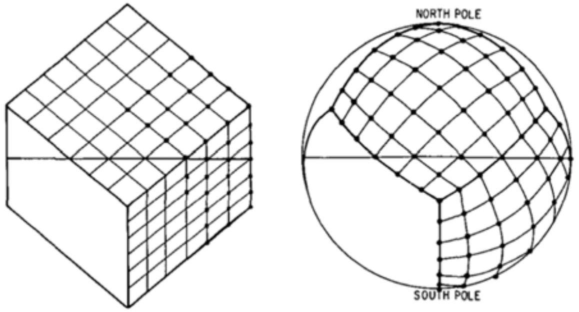
Bhattacharya et al., in review

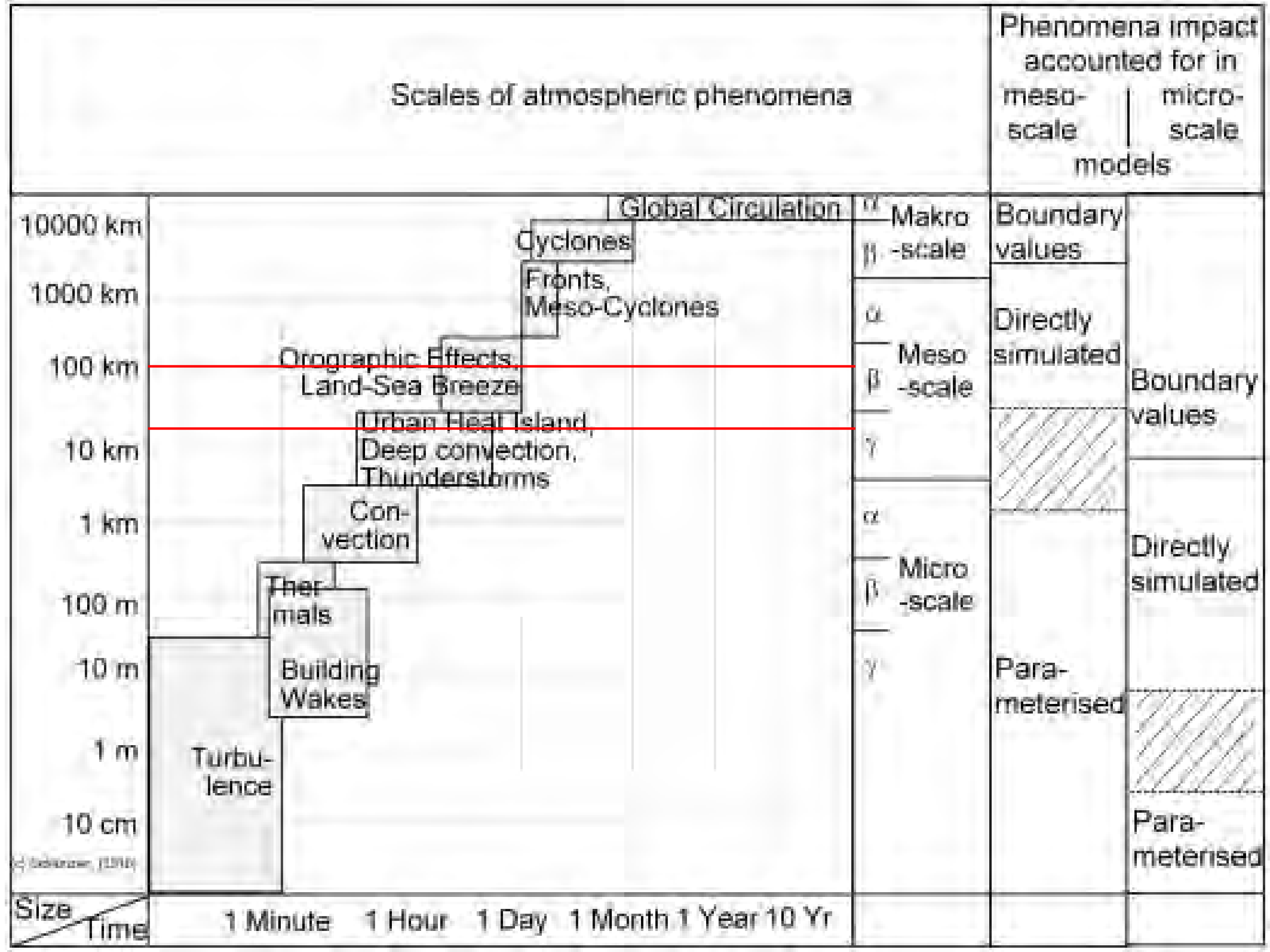
Model version used

- Community Earth System Model 1.3
    - The atmospheric component uses **Spectral Element dynamical core**
        - Previous versions used finite volume dynamical core
    - Community Ice Code version 4 (CICE4) for sea ice
    - Parallel Ocean Program version 2 (POP2) for the ocean
    - Community Land Model version 4 (CLM4) for the land

Model resolutions

- Community Earth System Model 1.3
  - Atmosphere and land
    - High resolution
      - ne120 (about 25 km)
    - Low resolution
      - ne30 (about 100 km)
  - Ocean and sea ice
    - Typical 100 km resolution

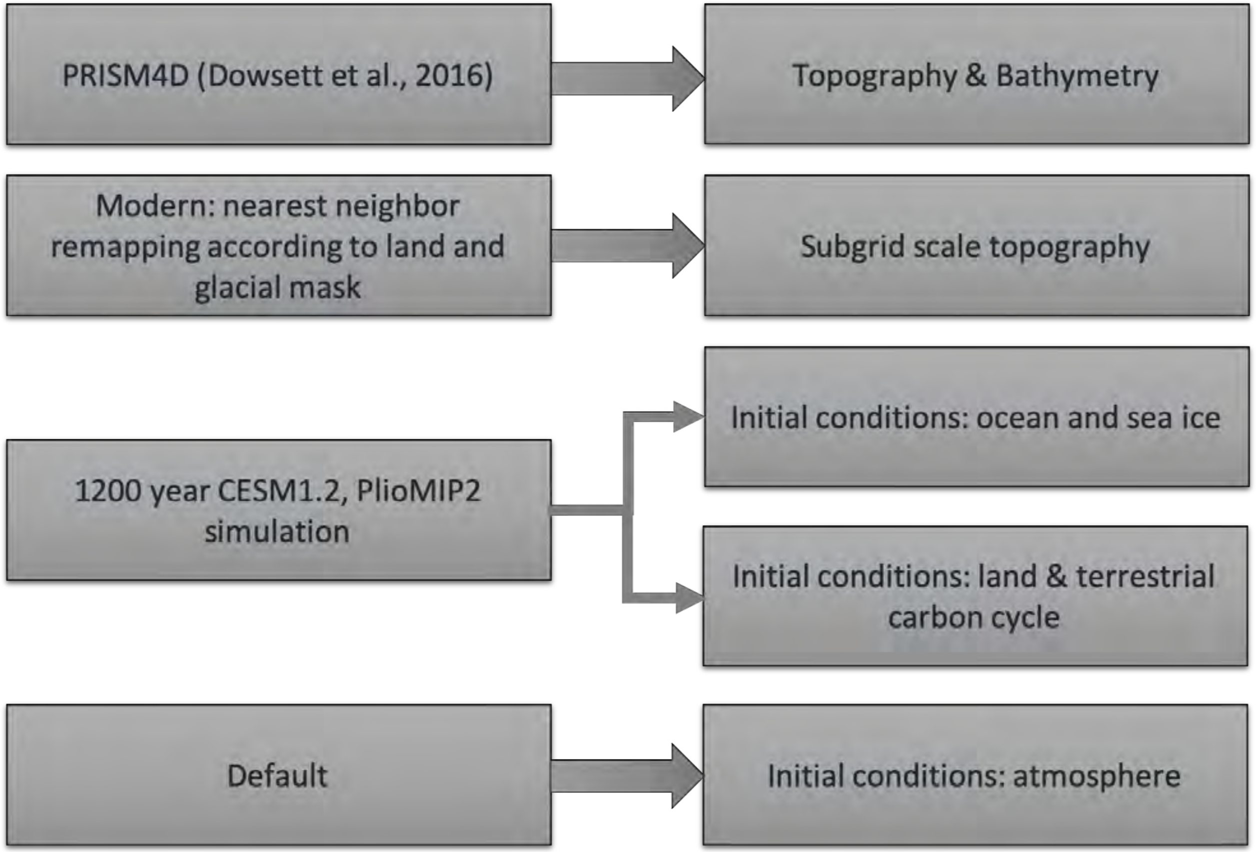


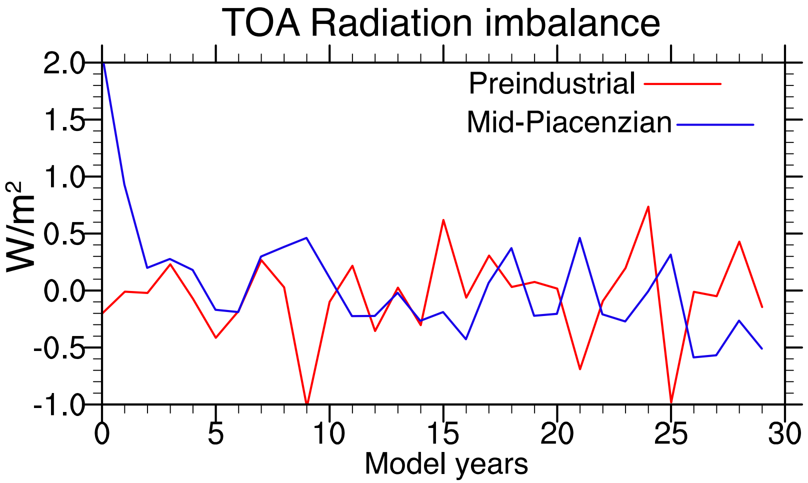


Schlunzen et al., 2011

Experiment setup

- Boundary conditions come from PRISM4D (Dowsett et al., 2016)
  - Maps to the high-resolution topography and bathymetry
- Only short spin-up time is needed
  - High resolution experiment equilibrated very quickly—within the first five years
    - Currently have 45 years of simulations

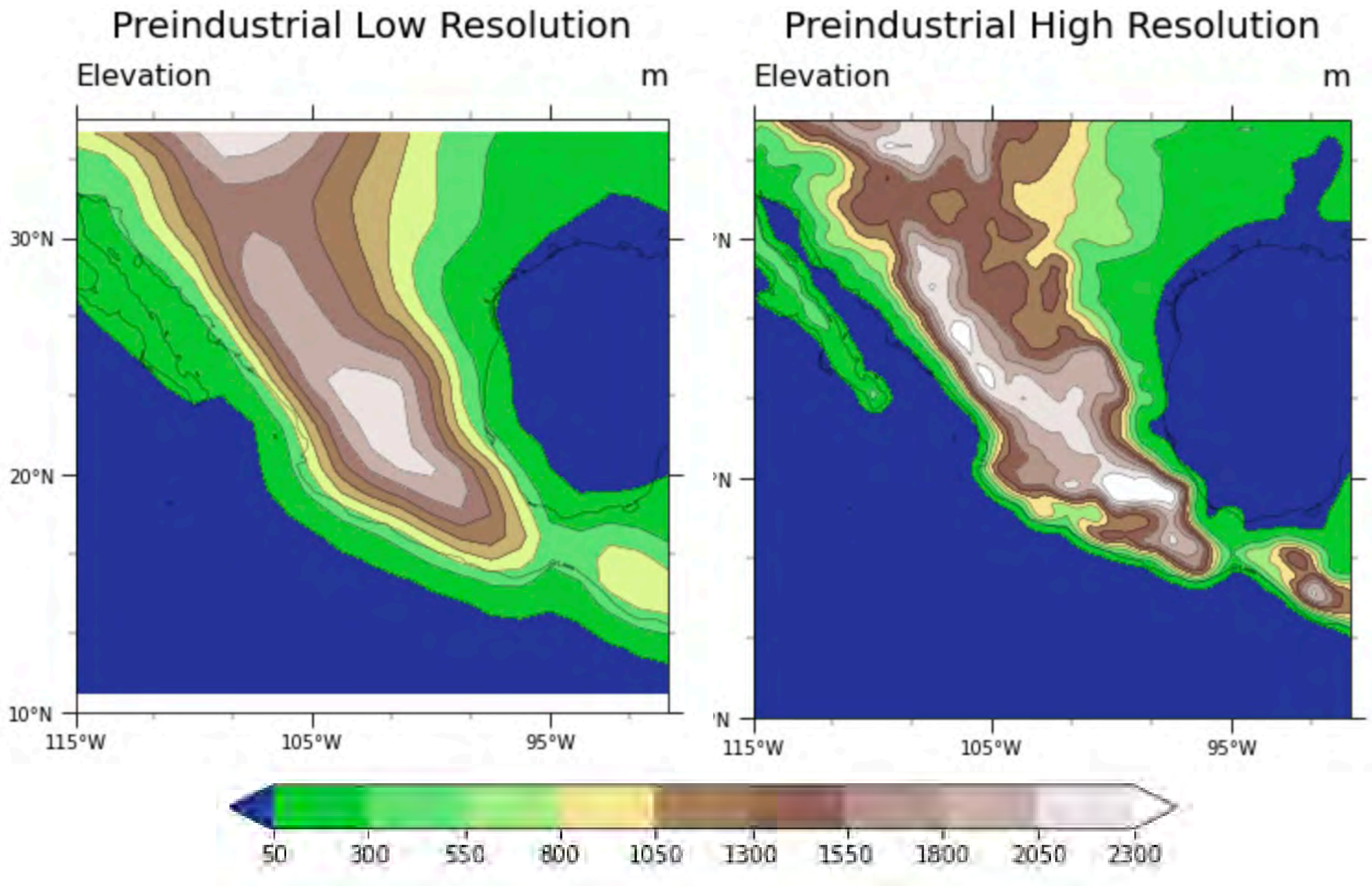




Added benefit of high-resolution in the NAM region – comparison of high and low resolution PI simulations

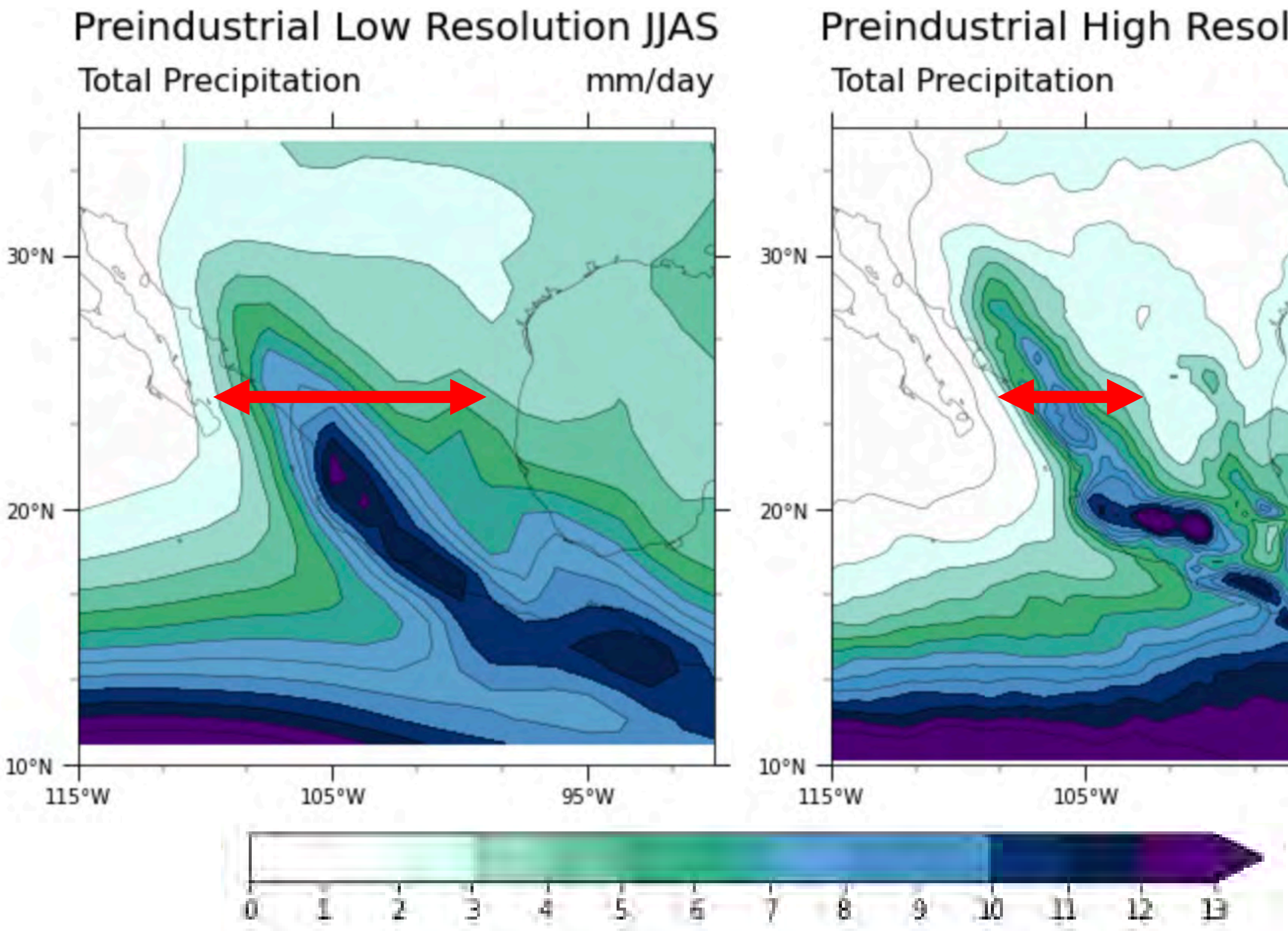
Low res: 50-year averages
High res: 30-year averages

Surface geopotential



- Better resolved elevation and geometry of SMO
  - In the low resolution, diffuse mountain belt covers a wider area

Precipitation differences

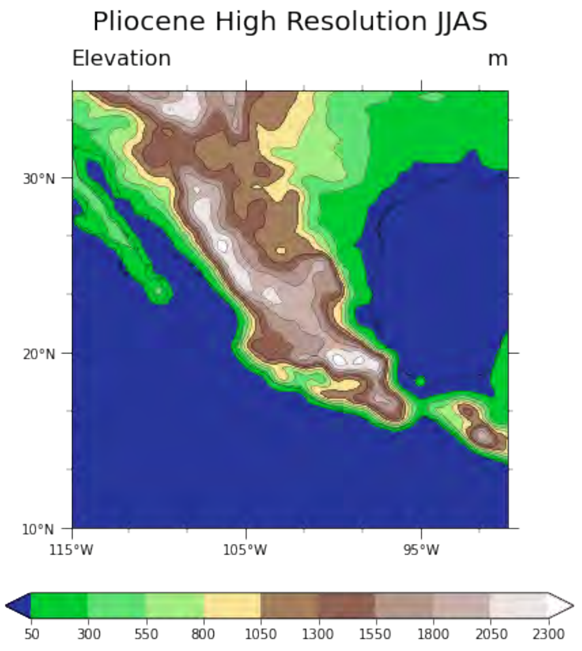


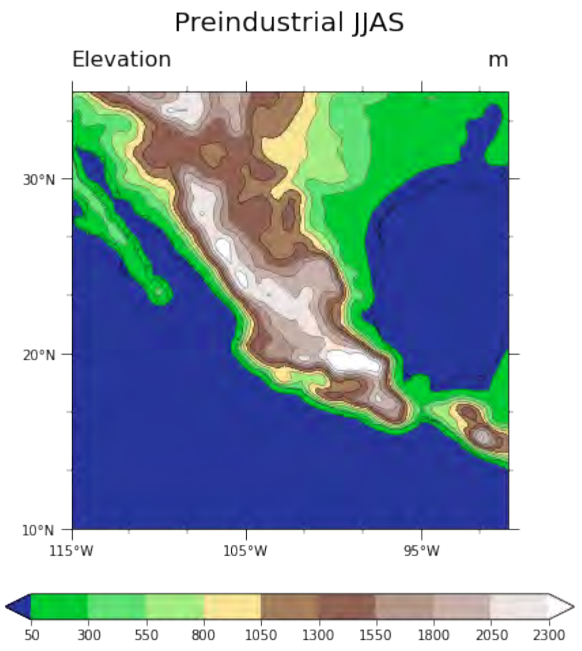
- Narrowly defined band of high JJAS precip in the high res
  - Diffusive band in the low res
  - Potentially relates to enhanced topographic gradient and upslope air compression

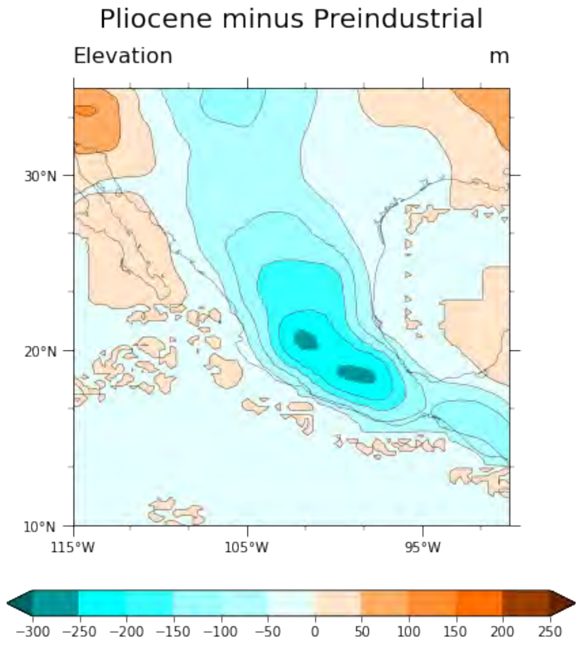
Added benefits of simulated climate change: comparison of mid-Pliocene to Preindustrial between high and low resolution

Changes in elevation between mid-Pliocene and preindustrial

- In PRISM4D reconstructions (Dowsett et al., 2016), Sierra Madre Occidental is lower.







Dowsett et al., 2016

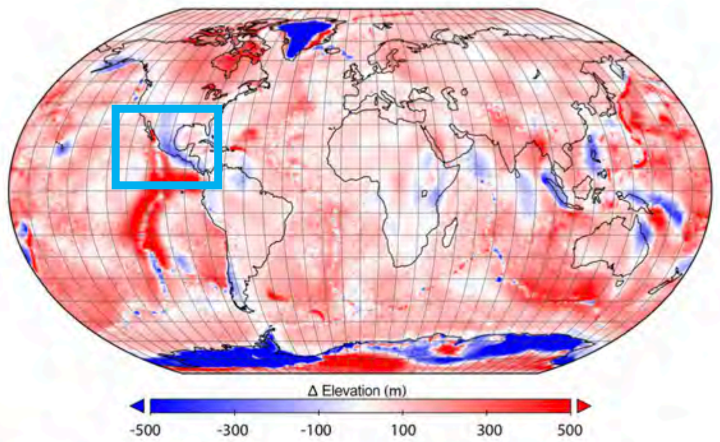
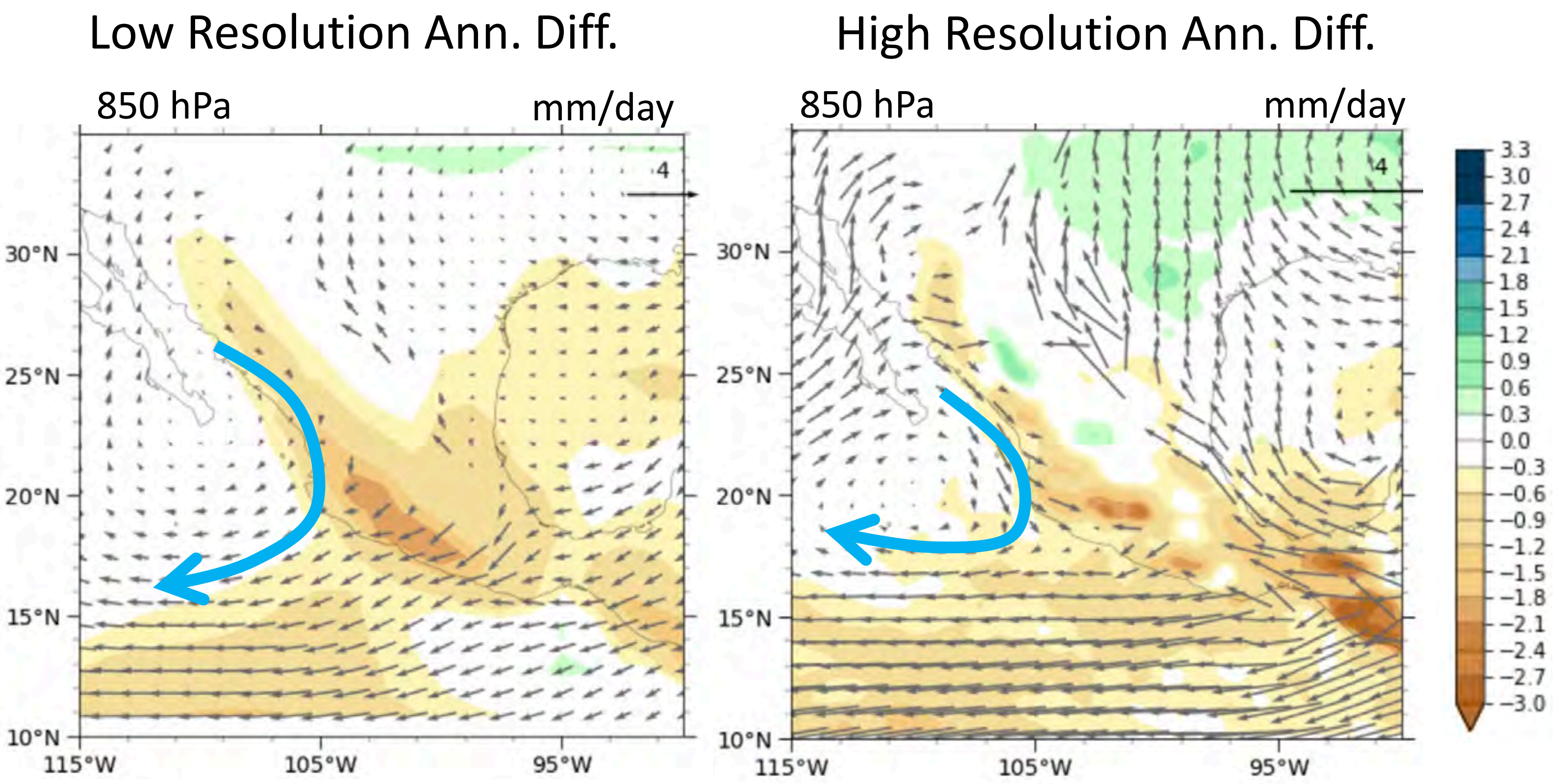


Figure 7. PRISM4 paleogeographic anomaly showing Piacenzian elevation (Fig. 4h) minus modern ETOPO1 (Fig. 4a) elevations (red positive, blue negative).

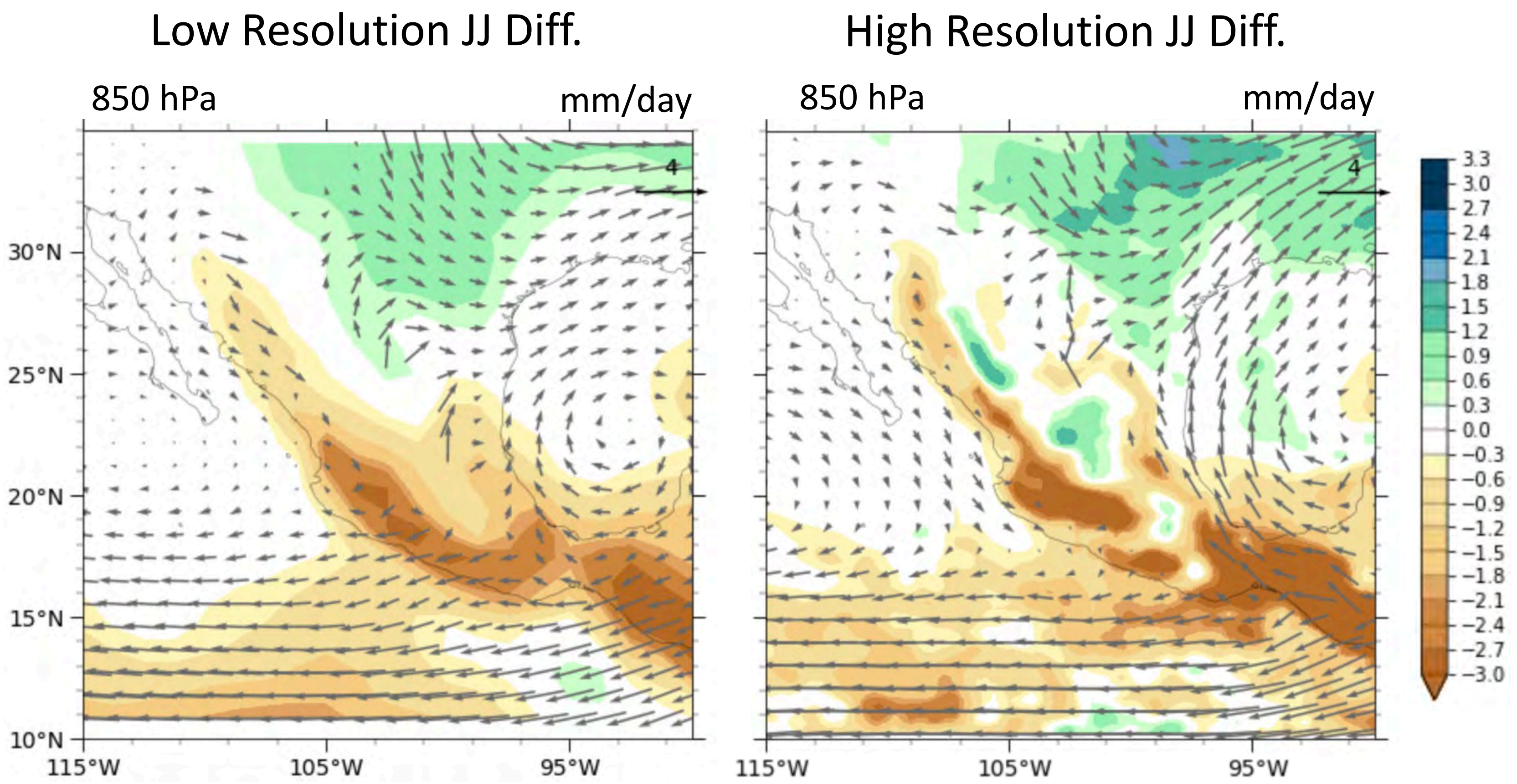
Annual Precipitation Differences (Plio – PI)

- Consistent band of drying in both resolutions
- Cyclonic circulation formation and moisture divergence to the west of Sierra Madre Occidental
    - Consistent with Boos & Pascale (2021)



Early summer precipitation changes

- Enhancement of the eastern monsoon rain belt during the early summer in the high res run
- *Greater mid-Pliocene monsoon precip is supported by proxy evidence* *(Bhattacharya et al., in review)*

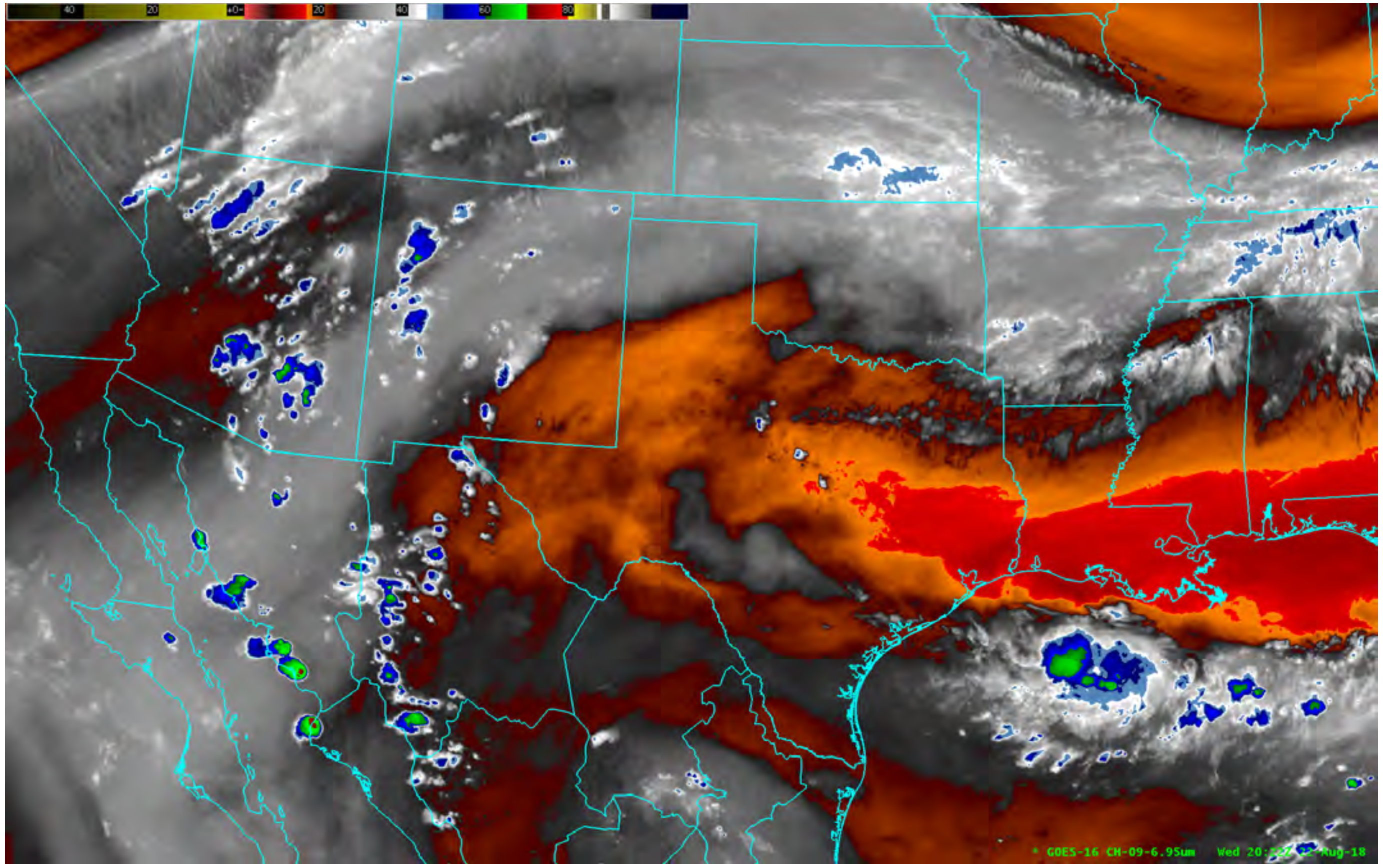


Are differences due to mesoscale convective systems?

Tracking MCSs in simulations

NAM pattern: 22 Aug 2018

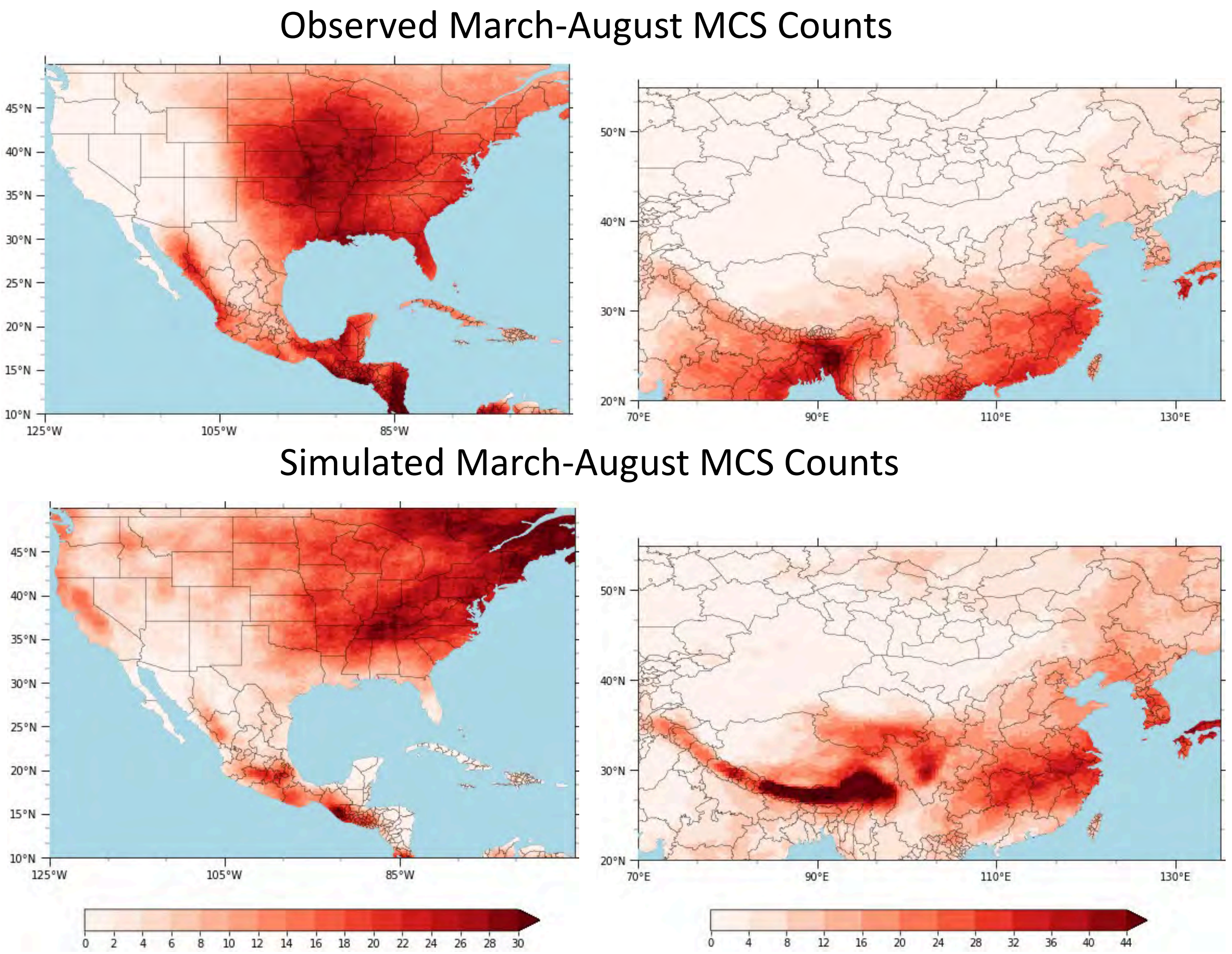
- TempestExtremes (Ullrich et al., 2021)
  - First detects intense precipitation in simulations
  - Then determines if the event is a propagating feature



https://www.weather.gov/abq/northamericanmonsoon-intro

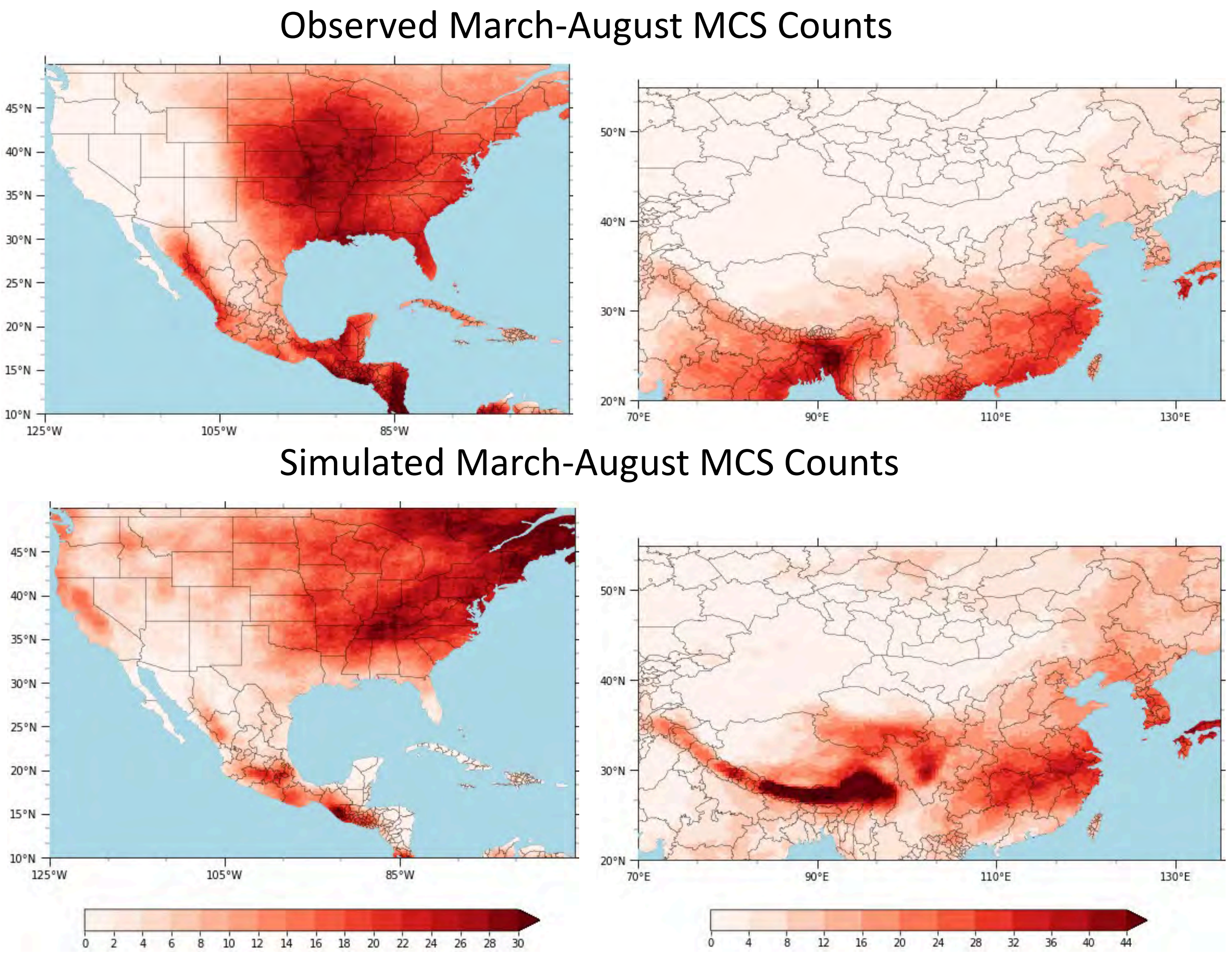
Parameter selection

- Detection determined by hourly precipitation threshold
- Monte Carlo search to decide parameters
  - Guided by root mean square error



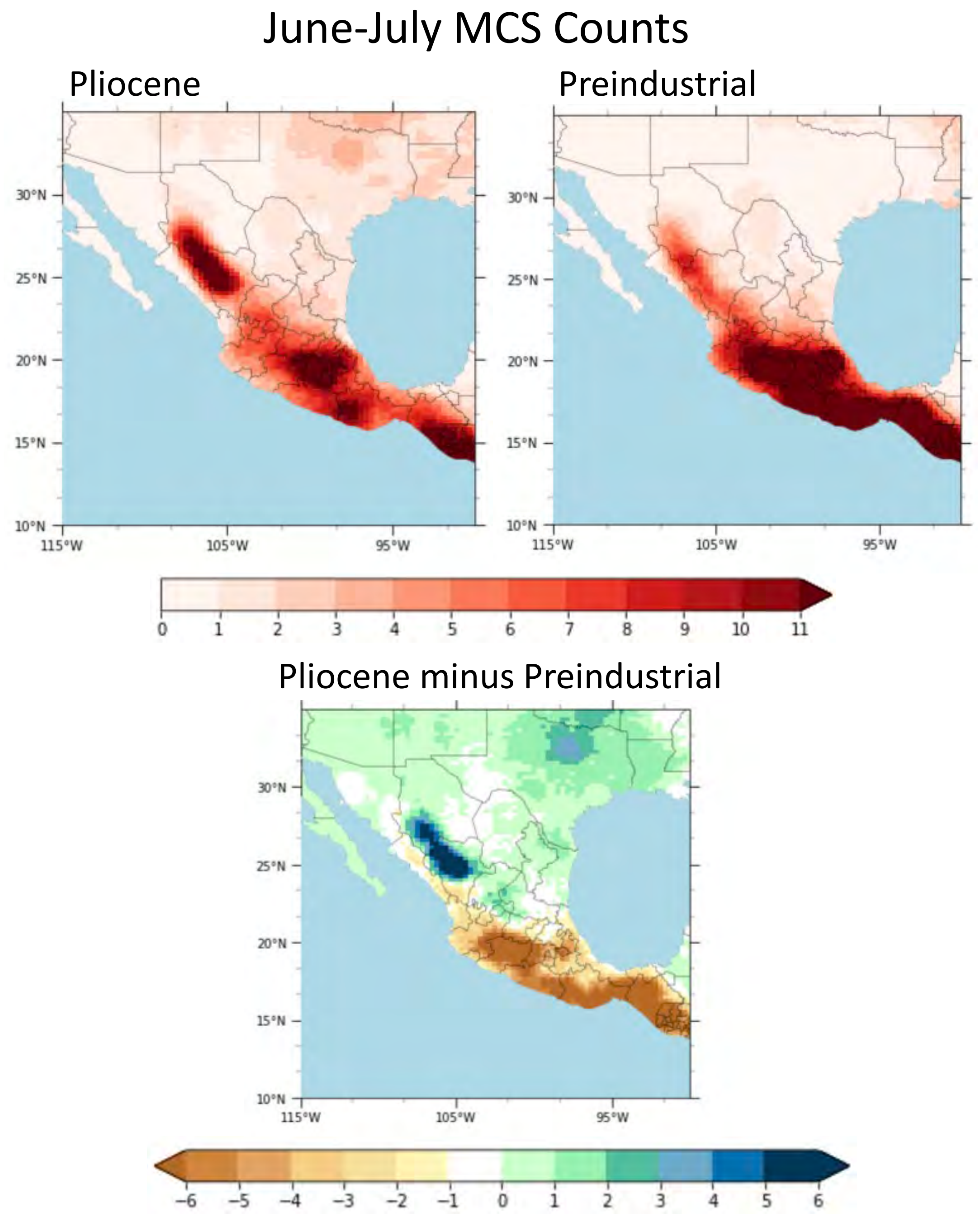
Parameter selection

- Precipitation threshold of ~2.15 mm/hr
- Minimum size of ~4,500 km^2
- 0.7-degree radius of smoothing
- Persist for a minimum of 2 hours
- Minimum 10% and maximum 60% overlap of area from one timestep to next



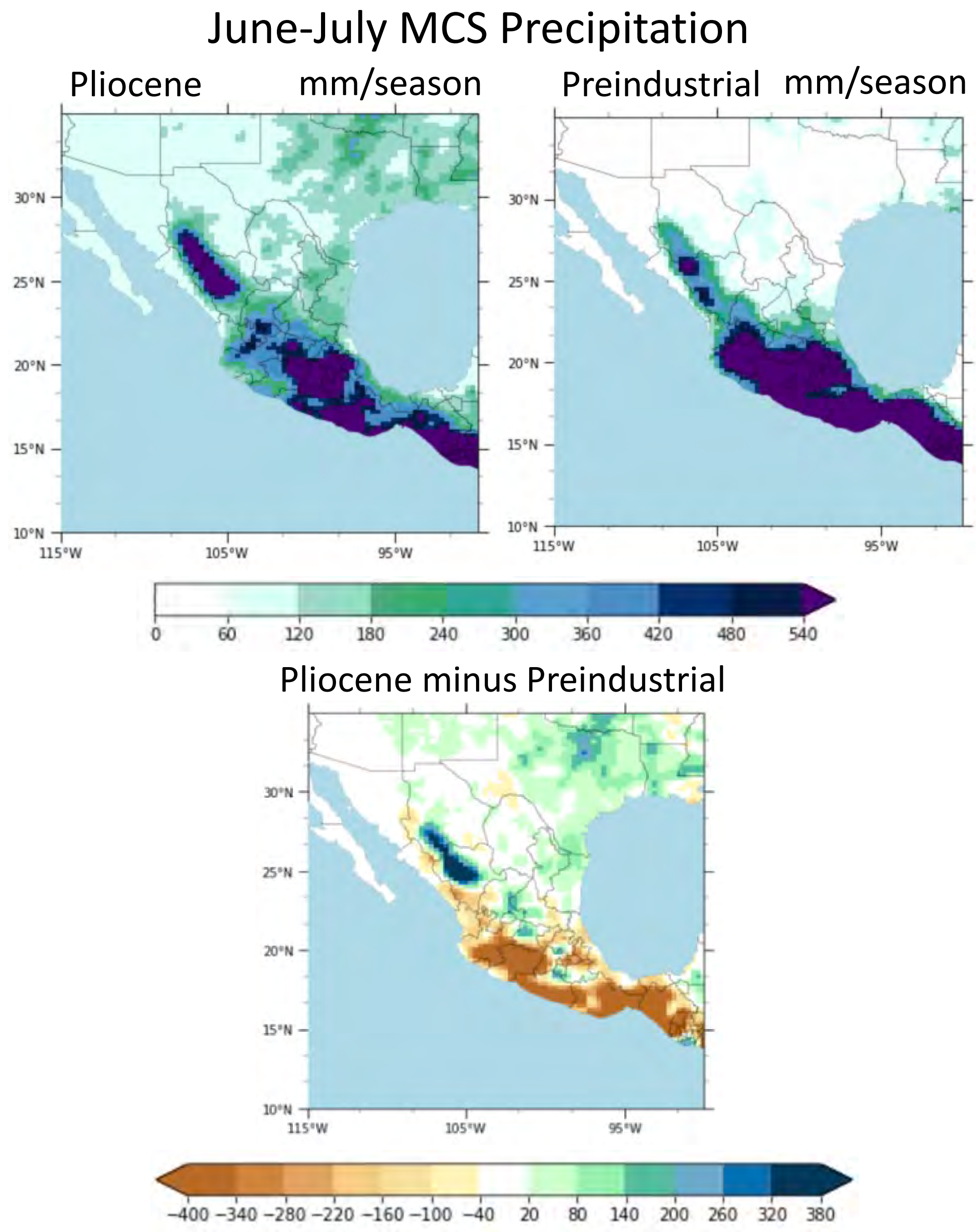
Results of MCS Tracking

- Overall increase of MCS frequency in the NAM region during the Pliocene



MCS contribution to precipitation

- Increased frequency of NAM MCSs corresponds to greater amount of precipitation brought by MCSs to this region



Conclusion

- Substantial differences in monsoon state in the preindustrial simulations attributable to better resolved topography
- Mid-Pliocene annual precipitation controlled by elevation of SMO
- In the high res run, enhanced eastern monsoon rain belt in the mid-Pliocene early summer precipitation
- Preliminary results suggest the increase in summer precip is associated with an increase in MCS frequency

Future Directions

1. Quantify differences in storm occurrences and precipitation attributable to mesoscale convective systems
2. The version of high-res code with 10 km resolution ocean and sea ice has not been explored for paleoclimate
3. Looking at water isotopes in high-res simulations when these runs become available
4. Use ClimateNet (Prabhat et al., 2021) to track storms

Acknowledgements

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