Kilometer-scale downscaling of CESM2 Large Ensemble simulations over CONUS

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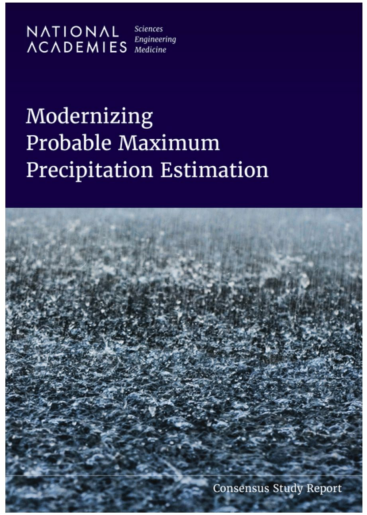
Modernizing estimates of extreme rainfall

- Bipartisan Infrastructure Law and PRECIP Act (2022) tasked NOAA with modernizing probable maximum precipitation (PMP) estimation
    - PMP is defined as the *maximum depth of precipitation over a given area and duration that is meteorologically possible*
- National Academies of Sciences, Engineering, and Medicine (NASEM) report released in 2024 issued short- and long-term recommendations to NOAA



NASEM Report on Modernizing PMP

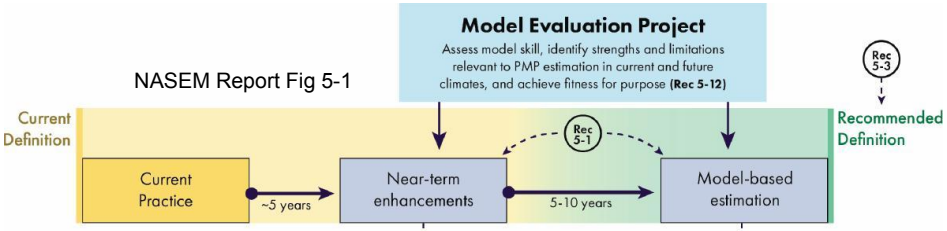
NASEM Long-term Recommendation 5-10

- "In the long term, NOAA should adopt a model-based approach to PMP estimation that aligns with the revised PMP definition, consisting of ***multi-model large ensemble kilometer-scale or finer-resolution modeling*** to construct the probability distribution of precipitation for PMP estimation under different climates."
    - *Revised definition*: depth of precipitation with an extremely low annual probability of exceedance

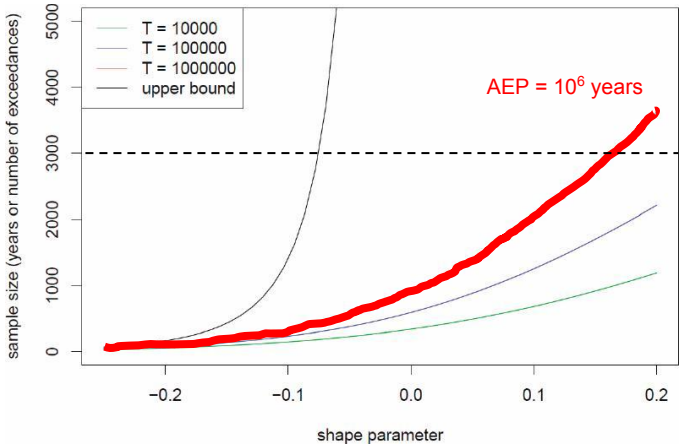
Large ensemble of km-scale simulations

- Compile publicly available model datasets and produce our own

NASEM Report Fig 5-1



NASEM Report Fig 5-3

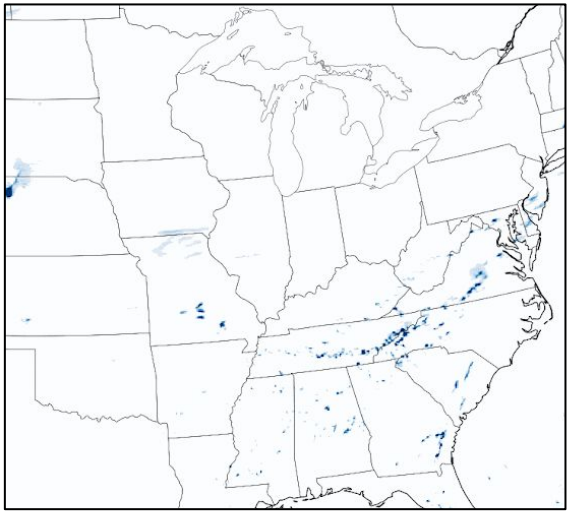


5- to 10-year time horizon

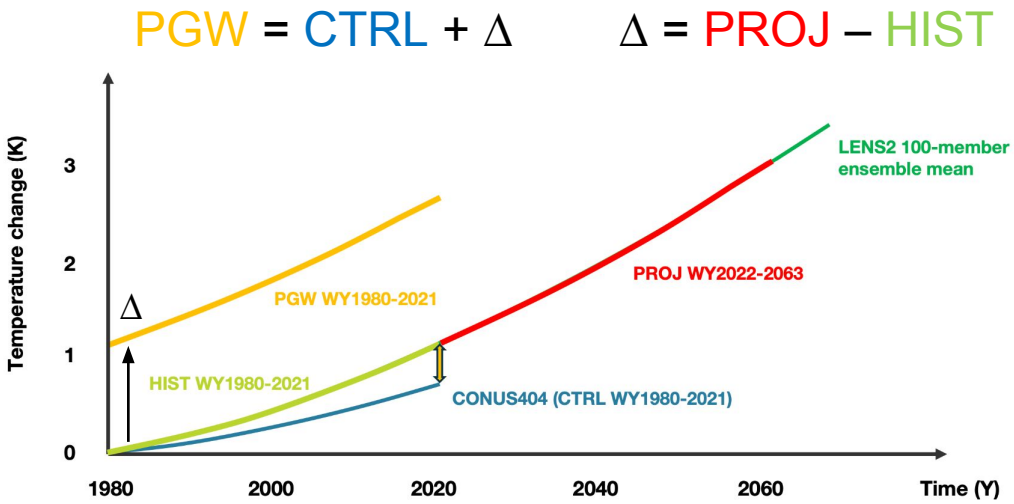
Requires 1000s of simulated years

Existing km-scale simulations

- CONUS404 Historical and Pseudo-Global Warming (PGW)
  - Uses WRF to dynamically downscale ERA5 over 1979–2022 at 4 km resolution



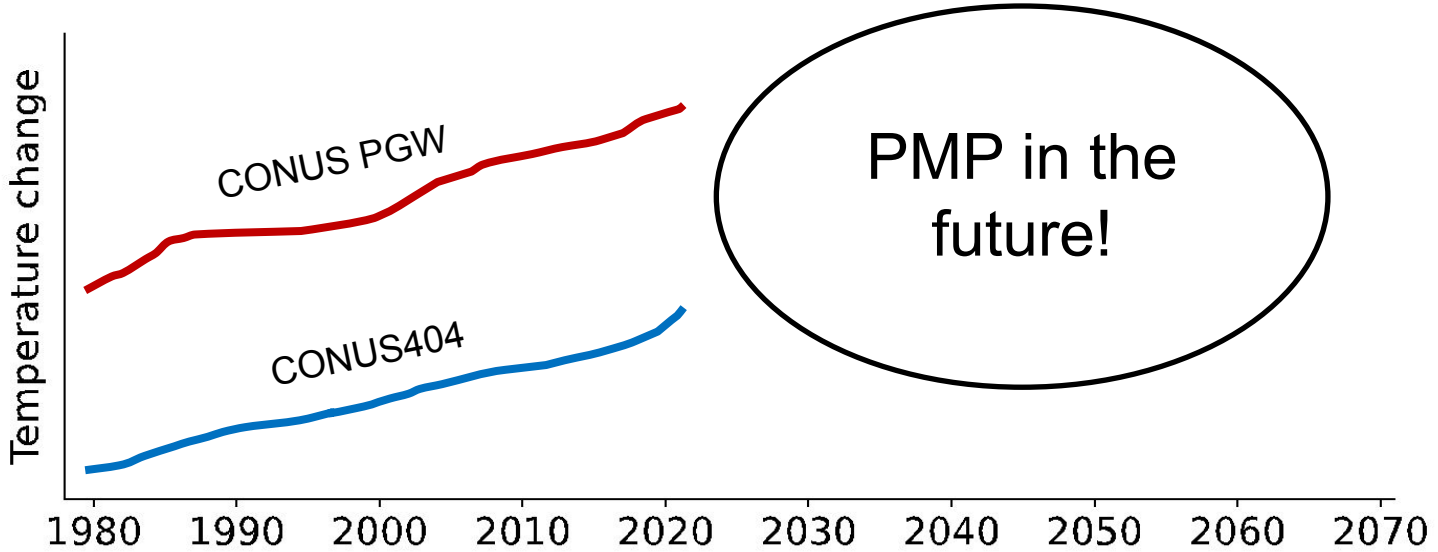
CONUS404: July 26, 2022



Source: Xue (2024), USGS HyTEST Seminar

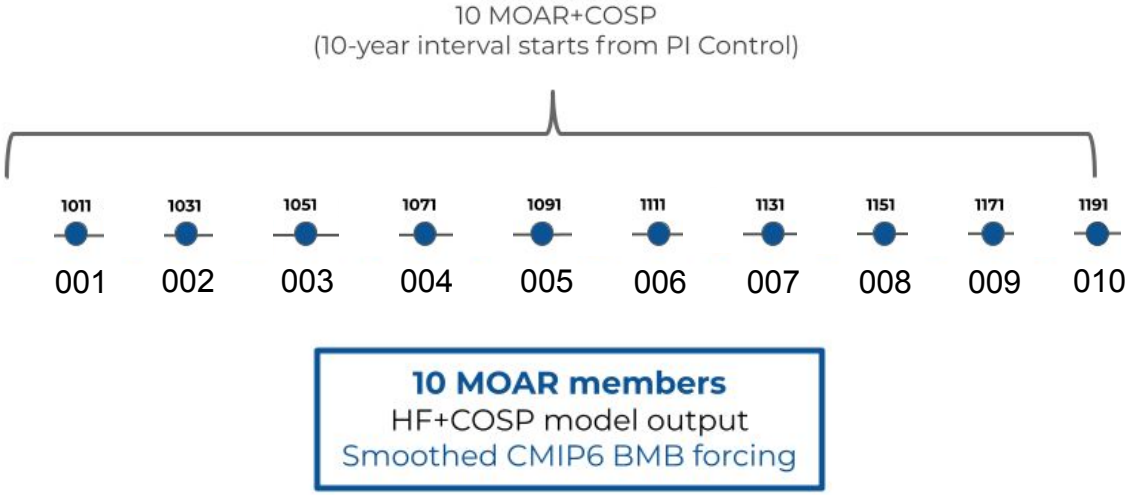
Producing additional simulations

- Follow CONUS404 blueprint to dynamically downscale GCM simulations
- 4 km resolution on same Lambert Conformal grid as CONUS404



CESM2 Large Ensemble as driving data

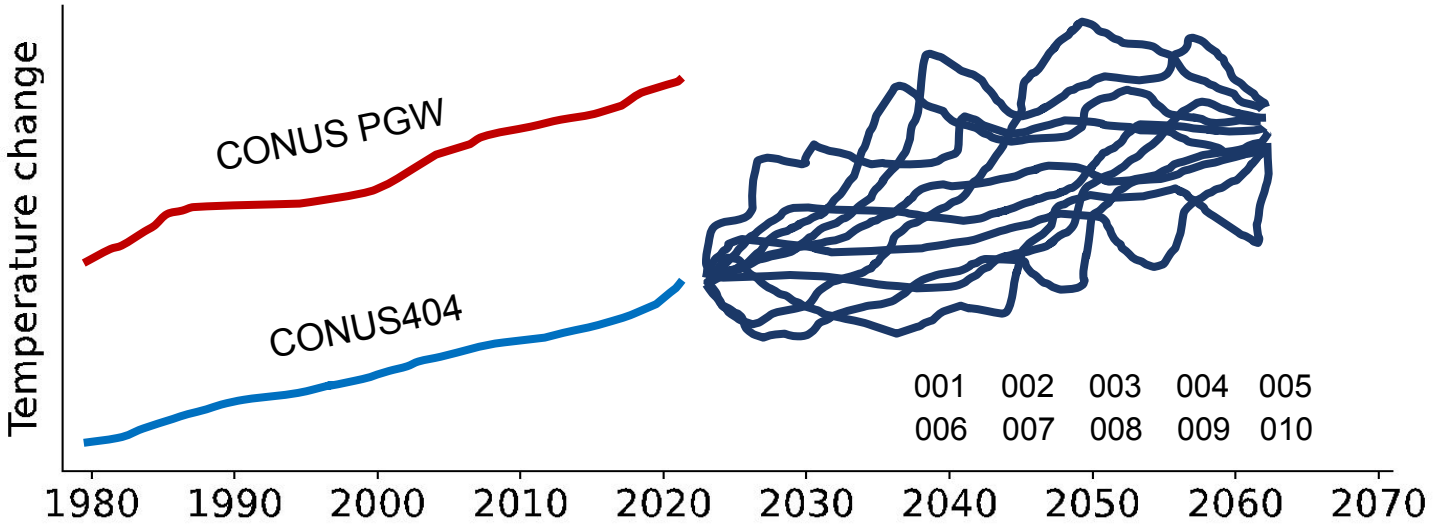
- CESM2 run over 1850–2100 at 1° horizontal resolution globally
- 100 ensemble members → 10 with six-hourly outputs
  - Input data to WRF requires high frequency (six-hourly) output data



Source: Rodgers et al. (2021), Fig. S3

CONUS-Futures Ensemble

- Use WRF to dynamically downscale CESM2 Large Ensemble high frequency members (001–010) at 4 km over entire CONUS



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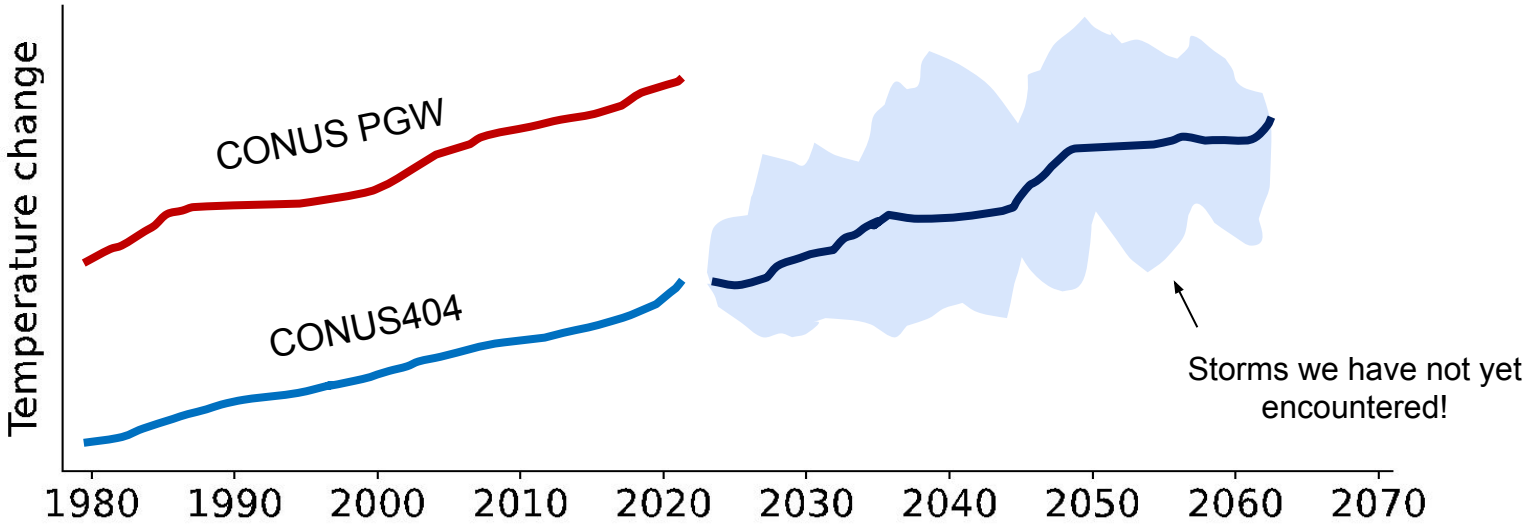
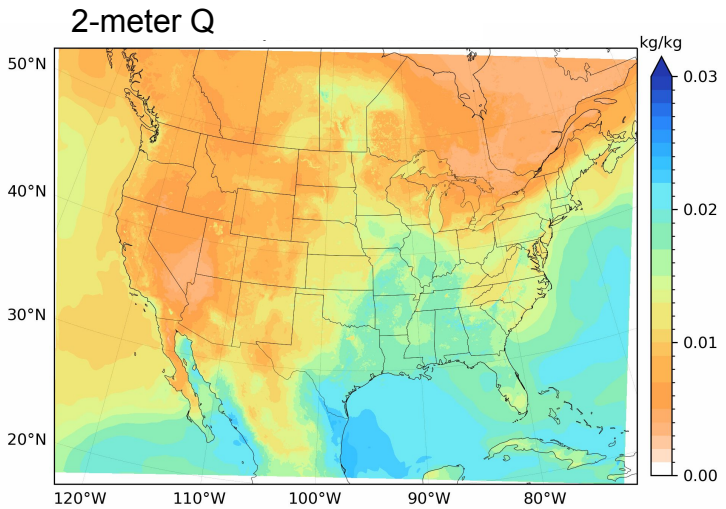


CONUS-Futures Simulation Design

- WRF version 4.6.1
- 4 km resolution as CONUS404
- Dynamically downscale CESM2 model output approximately during 2025–2064
- Bias correct input data from CESM2 (e.g., T, Q, U, V, etc.)
    - Using Bruyère et al. (2014) method → ERA5 used as reference data

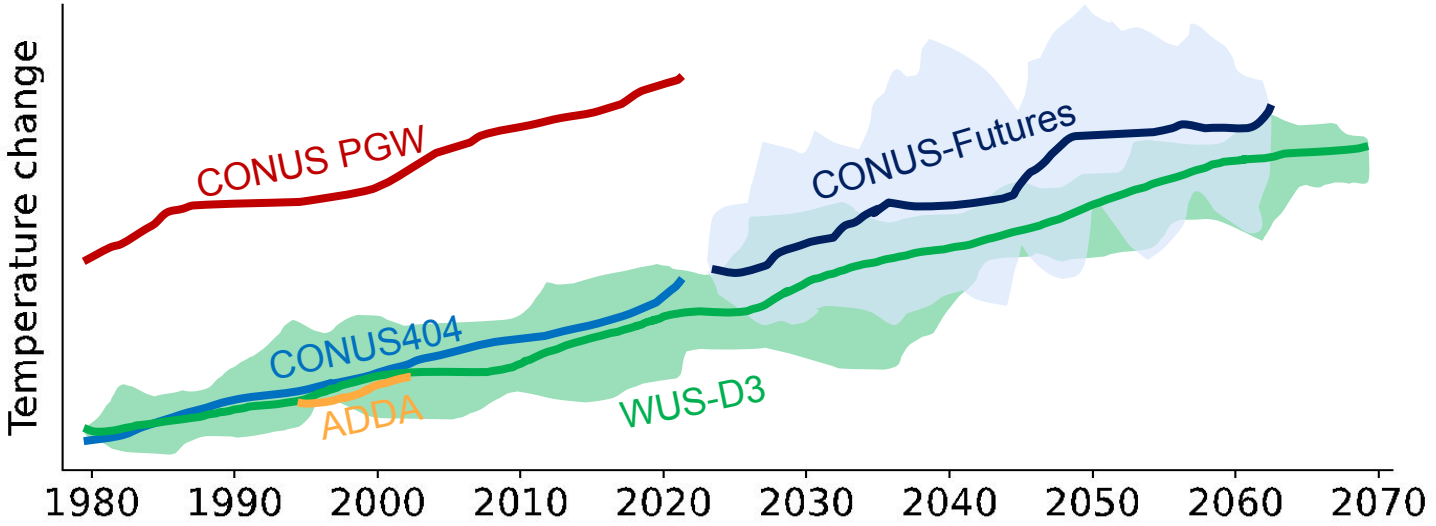


Project Timeline

1. Process and bias correct CESM2 output data ✅
2. Test and confirm WRF model configurations ☐ - in progress
3. Produce historical control simulation (~2010-2020) ☐
4. Downscale first CESM2 ensemble member for ~40 years ☐
5. Downscale the rest of the CESM2 ensemble members ☐

Looking towards the future

- ***Community Effort:*** Produce and compile all simulations deemed “fit-for-purpose” for probable maximum precipitation



Thank you!

Contact info

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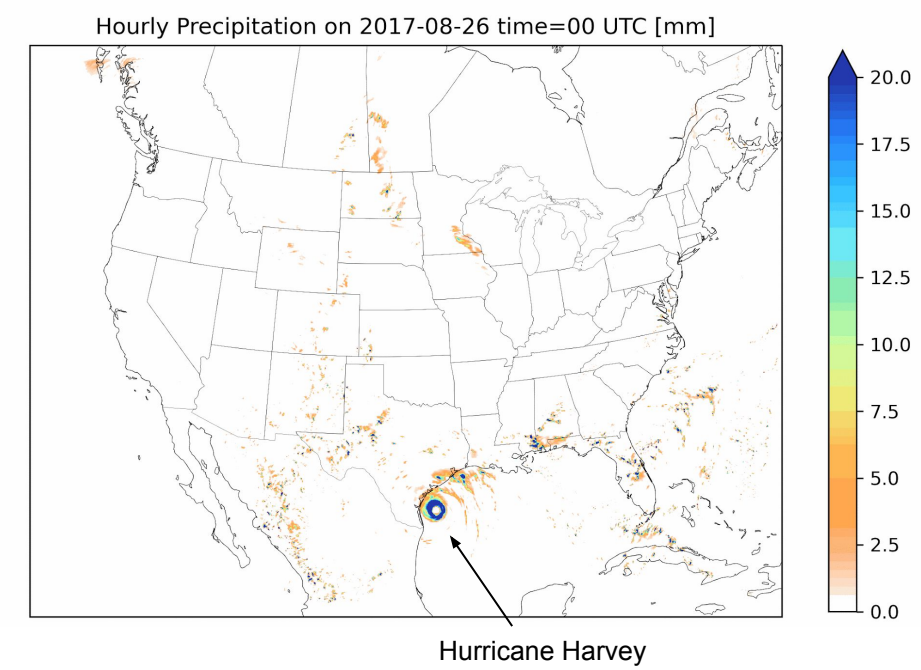
NOAA PMP Webpage

https://www.psl.noaa.gov/precip/pmp

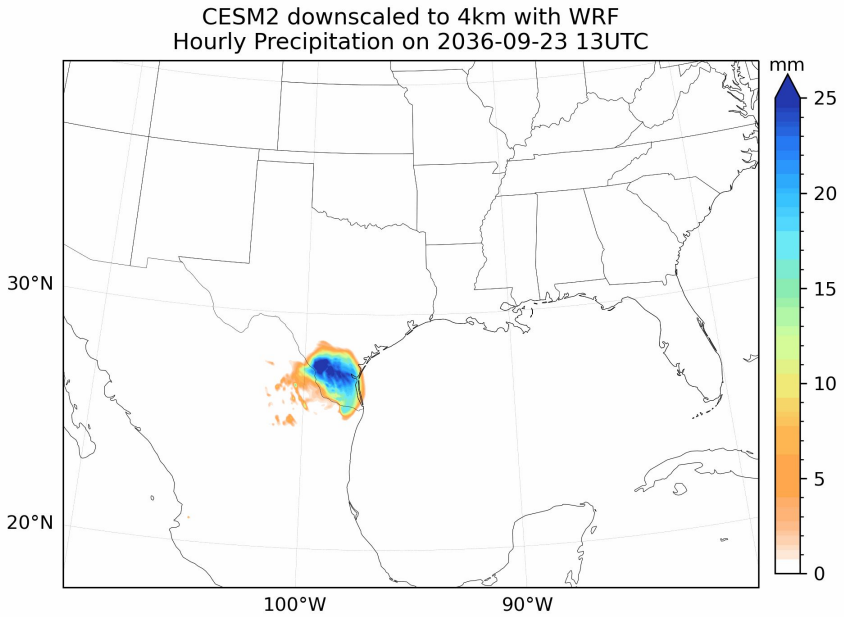
NOAA Boulder, David Skaggs Research Center

- CONUS404 Historical Simulation
  - Downscales historical reanalysis (ERA5) with weather model (WRF) over period 1980–2022
  - 4km grid across CONUS
  - Explicitly resolves convective processes
  - Skillfully simulates extreme precipitation



Extreme precipitation in CESM2 Large Ensemble

- Decades of storms that can be downscaled with WRF
- Example from model year 2036 in ensemble member 1191.010



CESM2 Variable Name	Description	Dimensions	Units	Output Frequency	WRF Variables Created
T	Temperature	lev, lat, lon	K	6-hour	TT
Q	Specific humidity	lev, lat, lon	kg kg^{-1}	6-hour	SPECHUMD
U	Zonal (U) wind	lev, lat, lon	m s^{-1}	6-hour	UU
V	Meridional (V) wind	lev, lat, lon	m s^{-1}	6-hour	VV
Z3	Geopotential height	lev, lat, lon	m	6-hour	GHT
PS	Surface pressure	lat, lon	Pa	6-hour	PSFC
PSL	Sea level pressure	lat, lon	Pa	6-hour	PMSL
TS	Surface/skin temperature	lat, lon	K	1-day	SKINTEMP, SST, TAVGSFC
TSOI	Soil temperature	levgrnd, lat, lon	K	1-day	ST: 000010,010040,040100,100200
H2OSOI	Volumetric soil water	levgrnd, lat, lon	mm^3 mm^{-3}	1-month	SM: 000010,010040,040100,100200
LANDFRAC	Fraction covered by land	lat, lon	fraction	1-month	LANDSEA
PHIS	Surface geopotential	lat, lon	m^2 s^{-2}	1-month	SOILHGT (units = m)

3D Variables

Atmosphere

Land

Bruyère et al. (2014) Bias Correction Method

$$ERA5 = \overline{ERA5} + ERA5' \qquad CESM = \overline{CESM} + CESM'$$

$$CESM_{biascorr} = \overline{ERA5} + CESM'$$