CONUS404 (40+ years at 4 km): Historic and Future Climate Simulations

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On behalf of Andy Newman and the CONUS404 team

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- Built to optimize hydrological forcing
- CONUS simulation of Water Years (WY) 1980-2022+
  - 1 Oct 1979 – 30 Sept 2022
  - Plans to keep the simulation near current
- WRFv3.9.1.1
- ERA5 IC/BC and SST– 3-hrly
  - Also spectral nudging within domain
- Rasmussen et al. (2023) BAMS description paper

BAMS Article

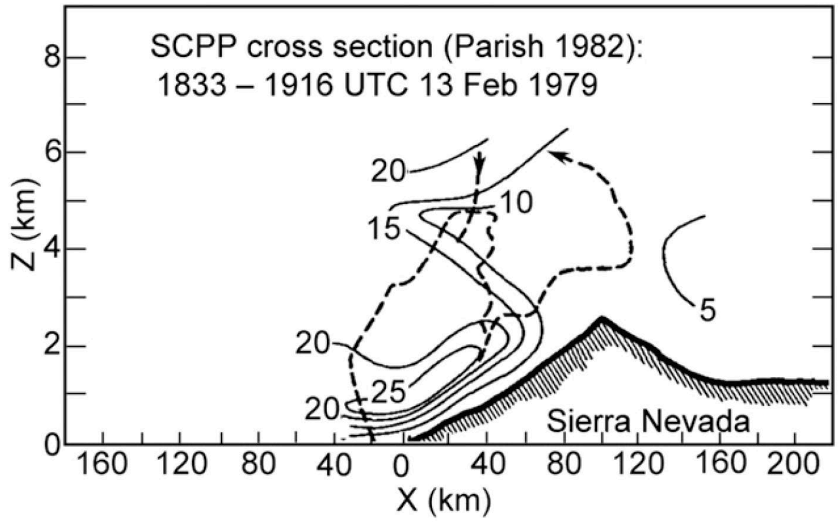
CONUS404

The NCAR–USGS 4-km Long-Term Regional Hydroclimate Reanalysis over the CONUS

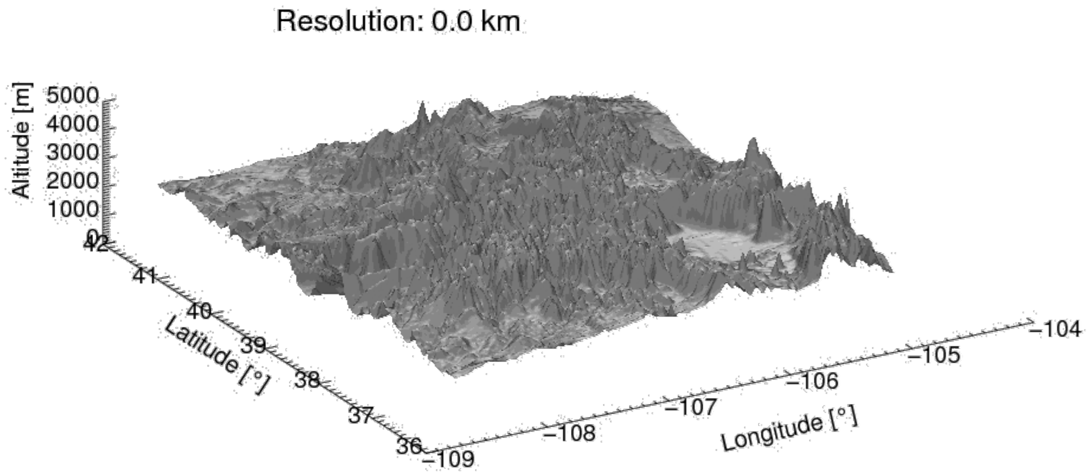
R. M. Rasmussen, F. Chen, C.H. Liu, K. Ikeda, A. Prein, J. Kim, T. Schneider, A. Dai, D. Gochis, A. Dugger, Y. Zhang, A. Jaye, J. Dudhia, C. He, M. Harrold, L. Xue, S. Chen, A. Newman, E. Dougherty, R. Abolafia-Rosenzweig, N. D. Lybarger, R. Viger, D. Lesmes, K. Skalak, J. Brakebill, D. Cline, K. Dunne, K. Rasmussen, and G. Miguez-Macho

doi.org/10.1175/BAMS-D-21-0326.1

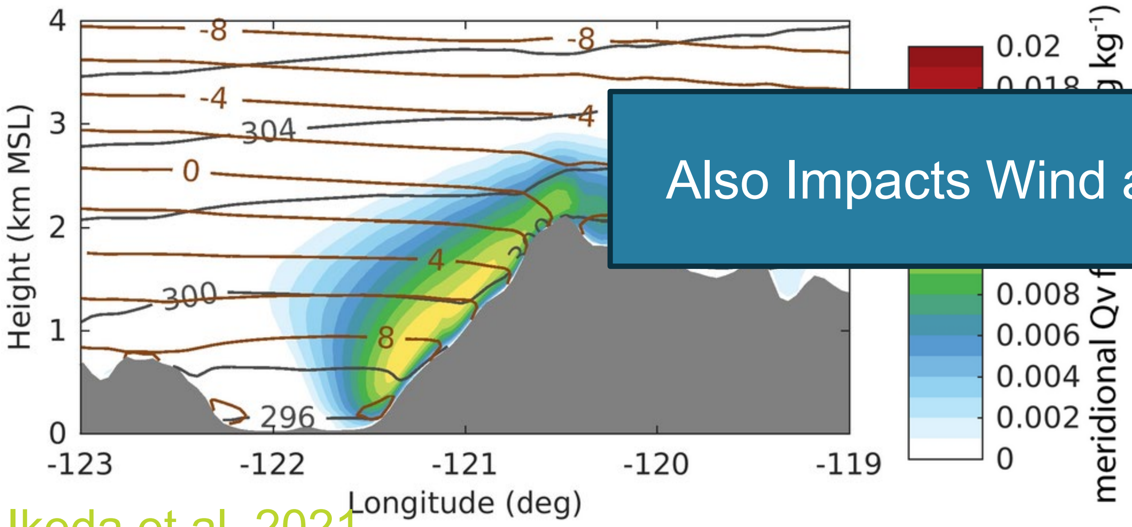
Why CONUS404? Decades of NCAR Convection-Permitting Simulation Experiences



The Sierra Nevada Barrier Jet in CONUS1



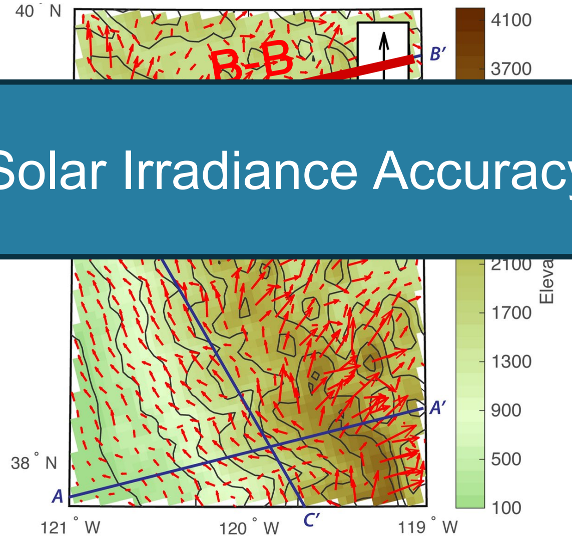
Meridional Qv flux (B-B)



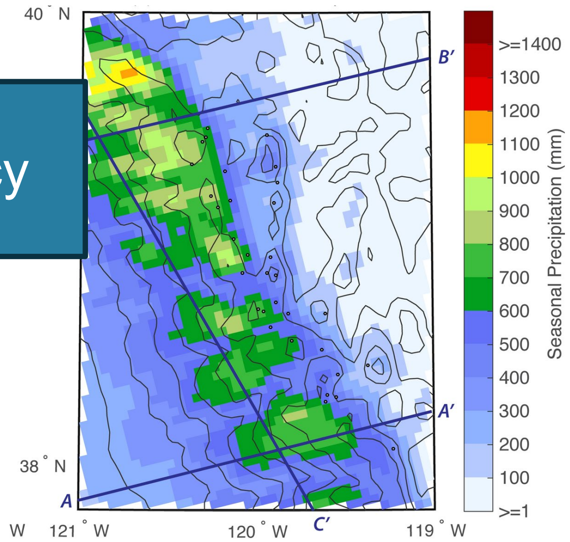
Ikeda et al. 2021

Also Impacts Wind and Solar Irradiance Accuracy

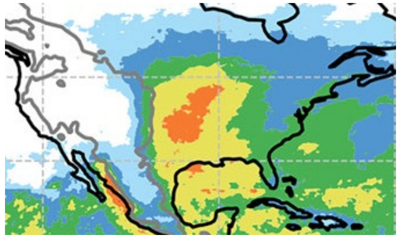
10 m DJF wind



DJF precipitation

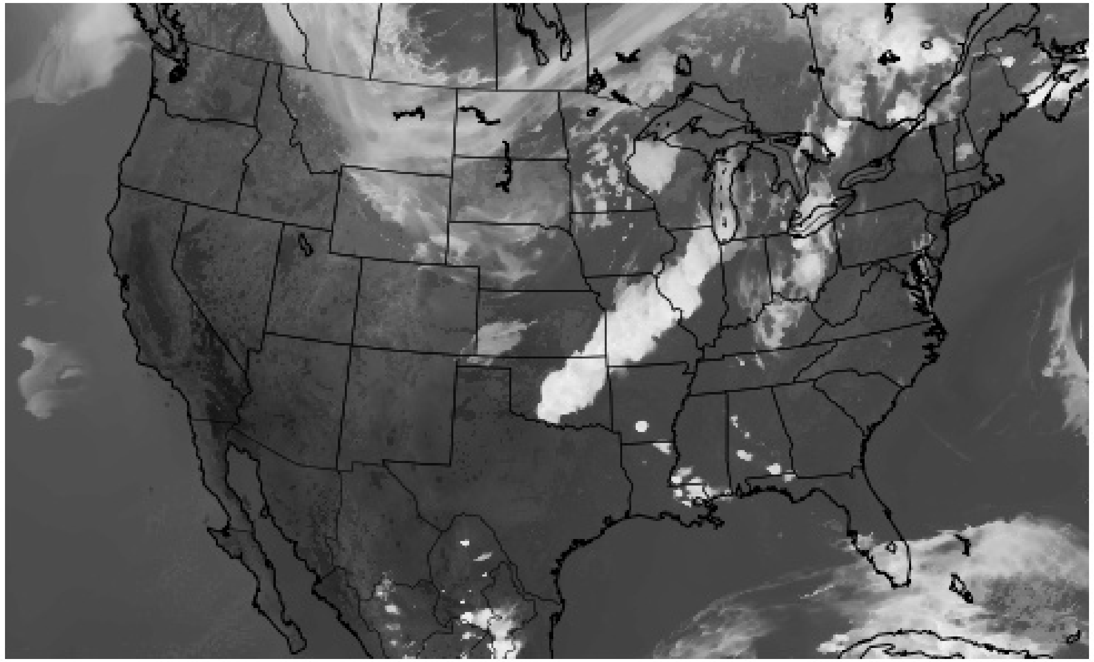


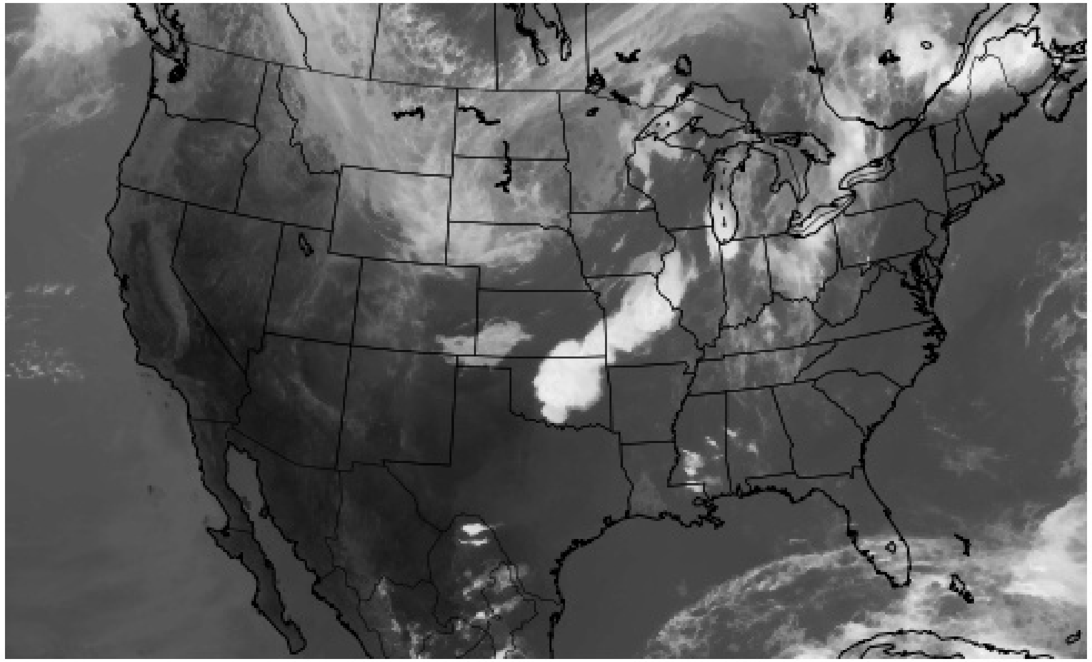
CONUS404 Validations (Mesoscale Convective Systems)



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."

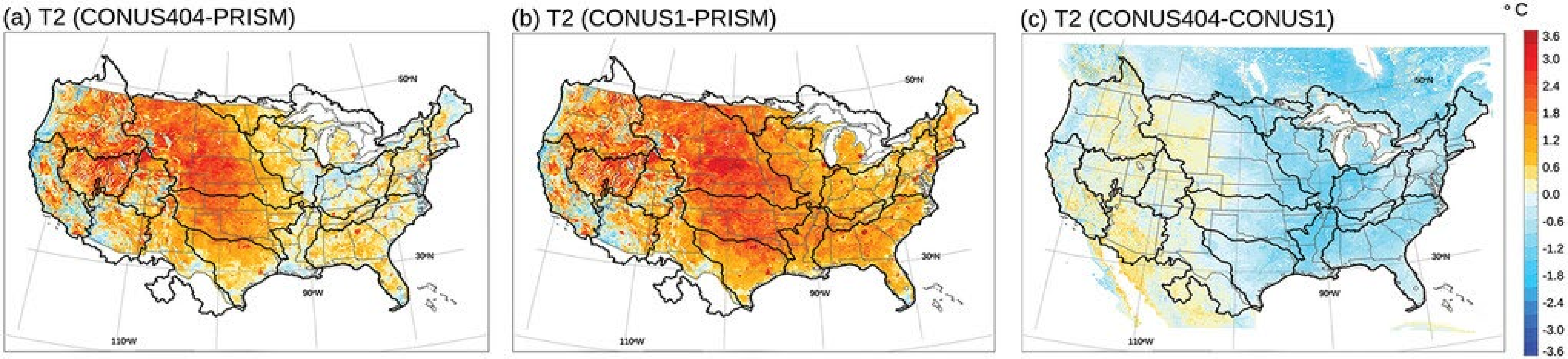
Comparison of Simulated and Observed Cloud Brightness Temperature (CONUS404)





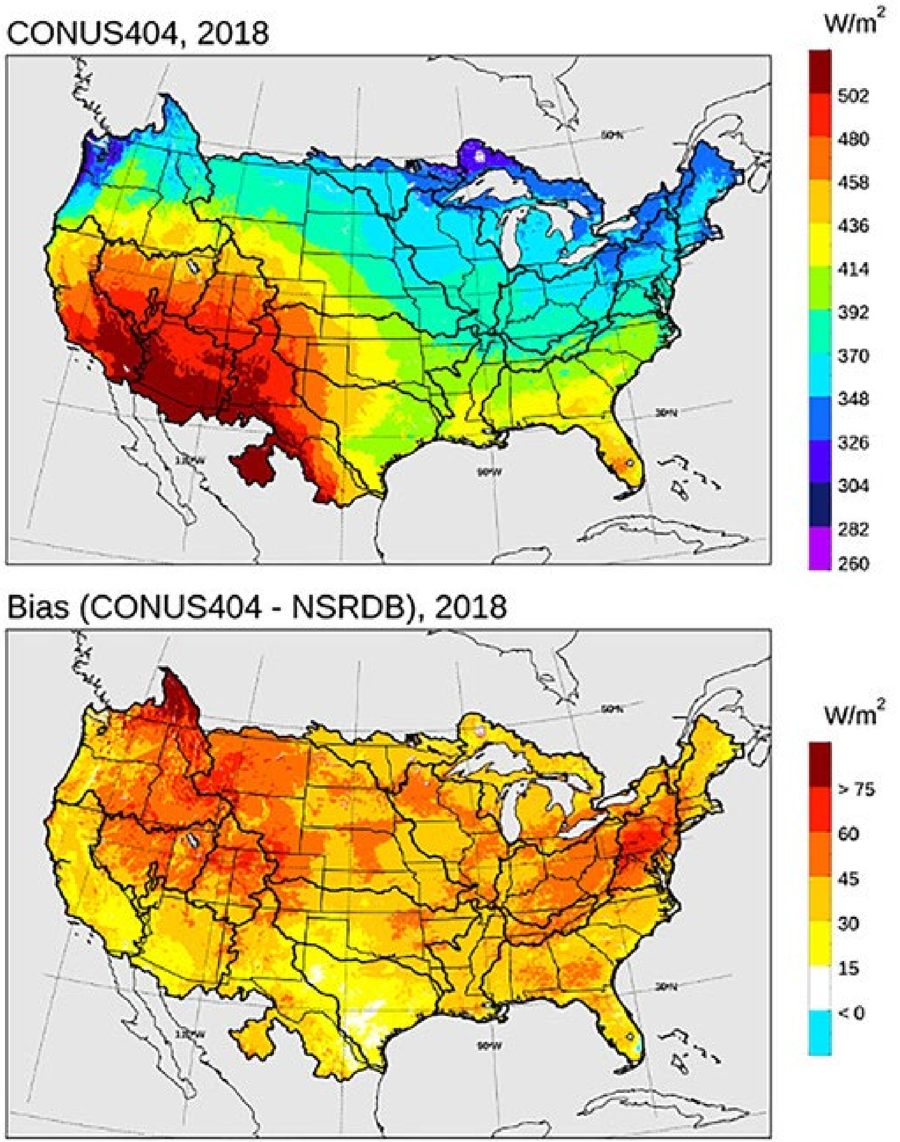
Optimizing for Water Vapor Transport will also Optimize for Renewable Energy Variables

- Key physics parameterizations: Thompson-Eidhammer microphysics, YSU PBL, RRTMG short and longwave radiation
- Noah-MP land-surface model
- 51 levels, 4-km grid spacing – convective permitting
- Improved 2 m temperature performance over previous version



CONUS404 – Solar Radiation Validation

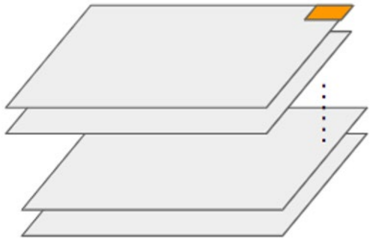
- Key outputs
  - Hourly 2D surface and 3D fields on model levels available
    - 51 vertical levels from ~30 m to 50hPa
    - Roughly 50-100 m vertical spacing in lowest 1 km
  - https:// rda.ucar.edu/datasets/ds559.0/#
- Initial evaluation covered precipitation, temperature, downward shortwave radiation
- No wind energy focused work to my knowledge (yet)



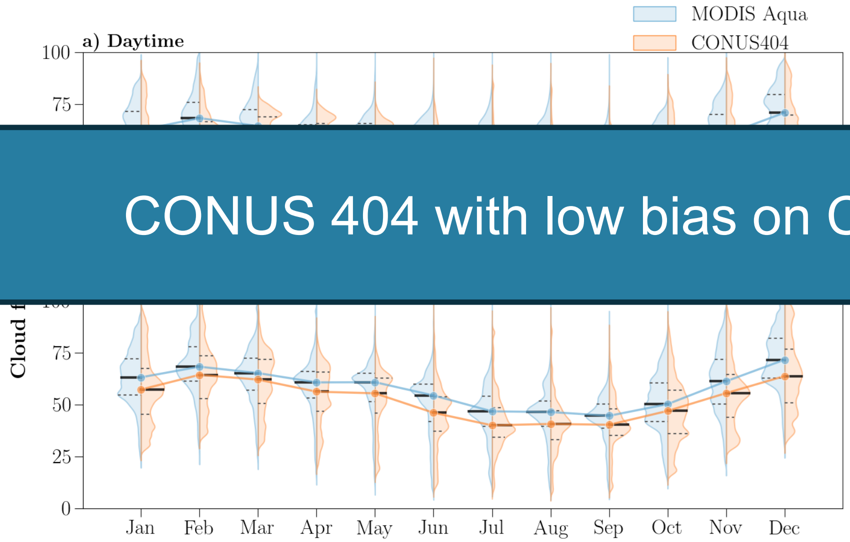
CONUS404 Validations (Clouds)

- Satellite observations (Aqua MODIS Cloud mask layer, MYD35L2)
  - twice a day (~13:30 and 1:30 equator passing time)
  - 2002 - 2020
  - 1 km
- Long-term convection-permitting simulation (CONUS404)
  - Hourly
  - 2002 - 2020
  - 4 km
- Upscaling MODIS to 4 km using Linear interpolation approach
- **Cloud frequency (%)**: the pixel-level percentage of days with cloudy pixels for a certain month within 18 years

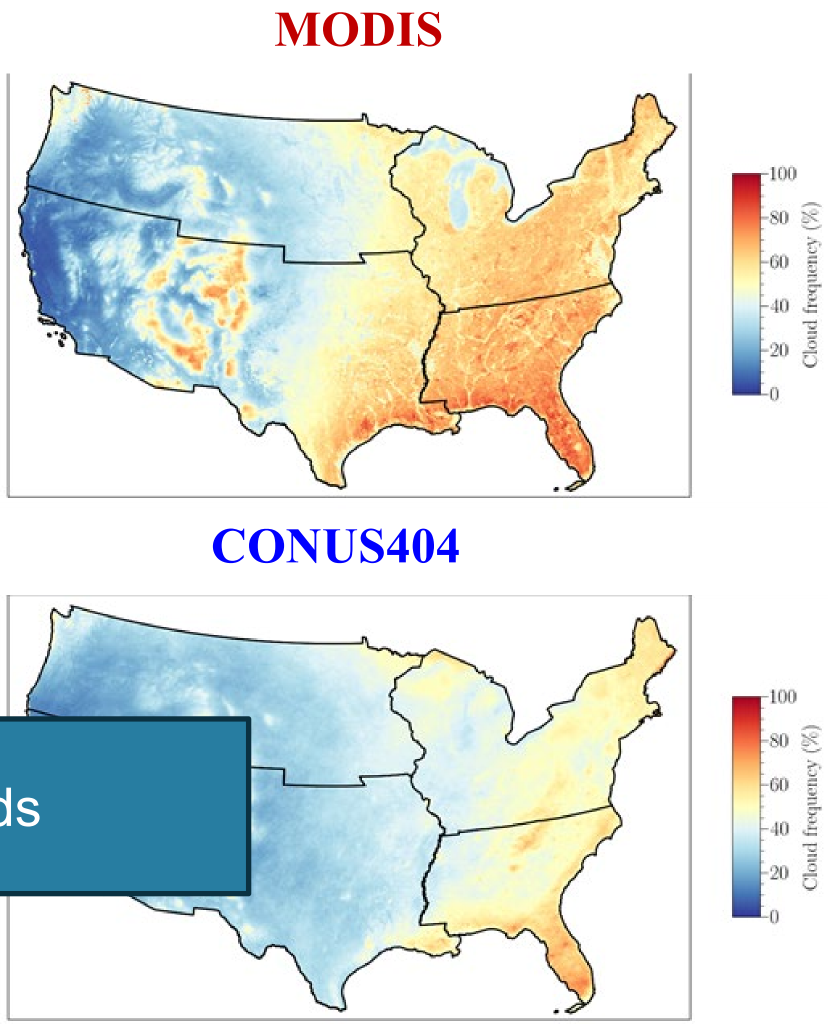
Cloud Frequency estimation



% of **cloudy** pixels over 31 days x 18 years

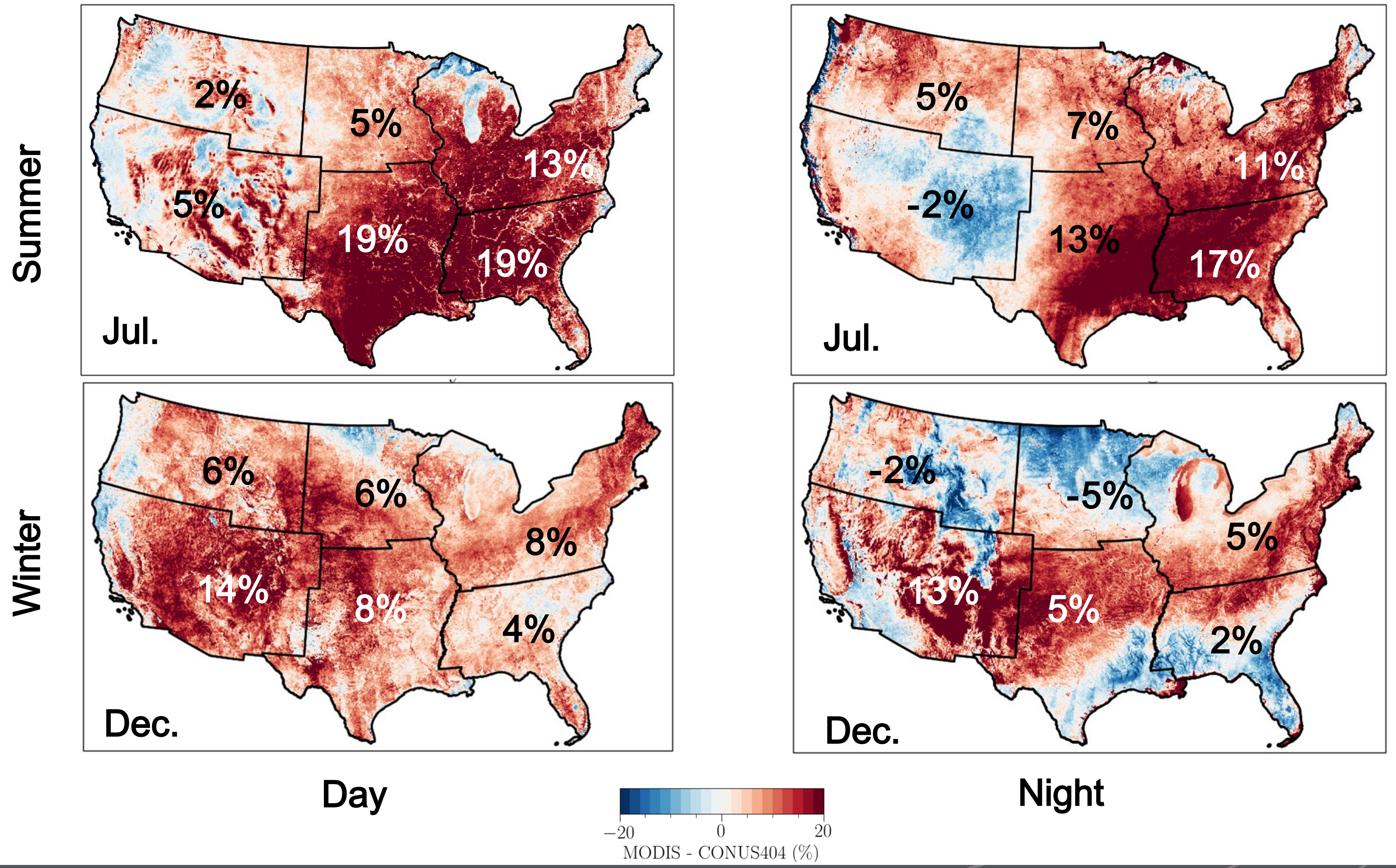


CONUS 404 with low bias on Clouds



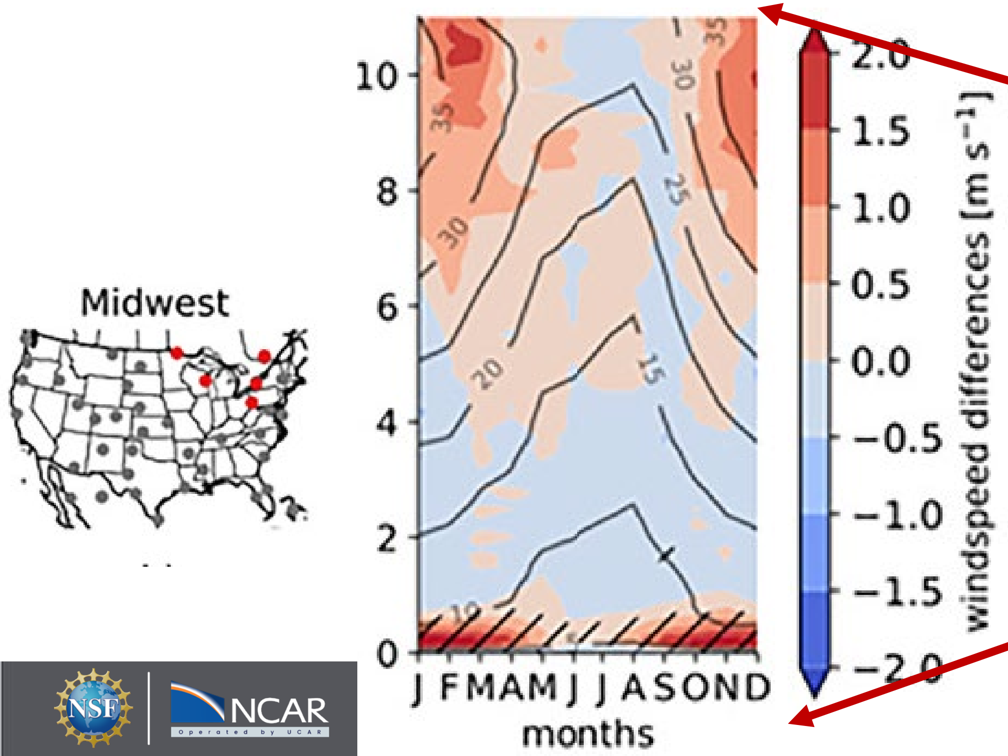
MODIS (top) and **CONUS404** (bottom) composite cloud frequency maps

CONUS404 Validations (Clouds)



Comparison of Soundings

- Wind speed bias of ~2 m/s in boundary layer, especially in winter months



ΔT

ΔRH

ΔWS

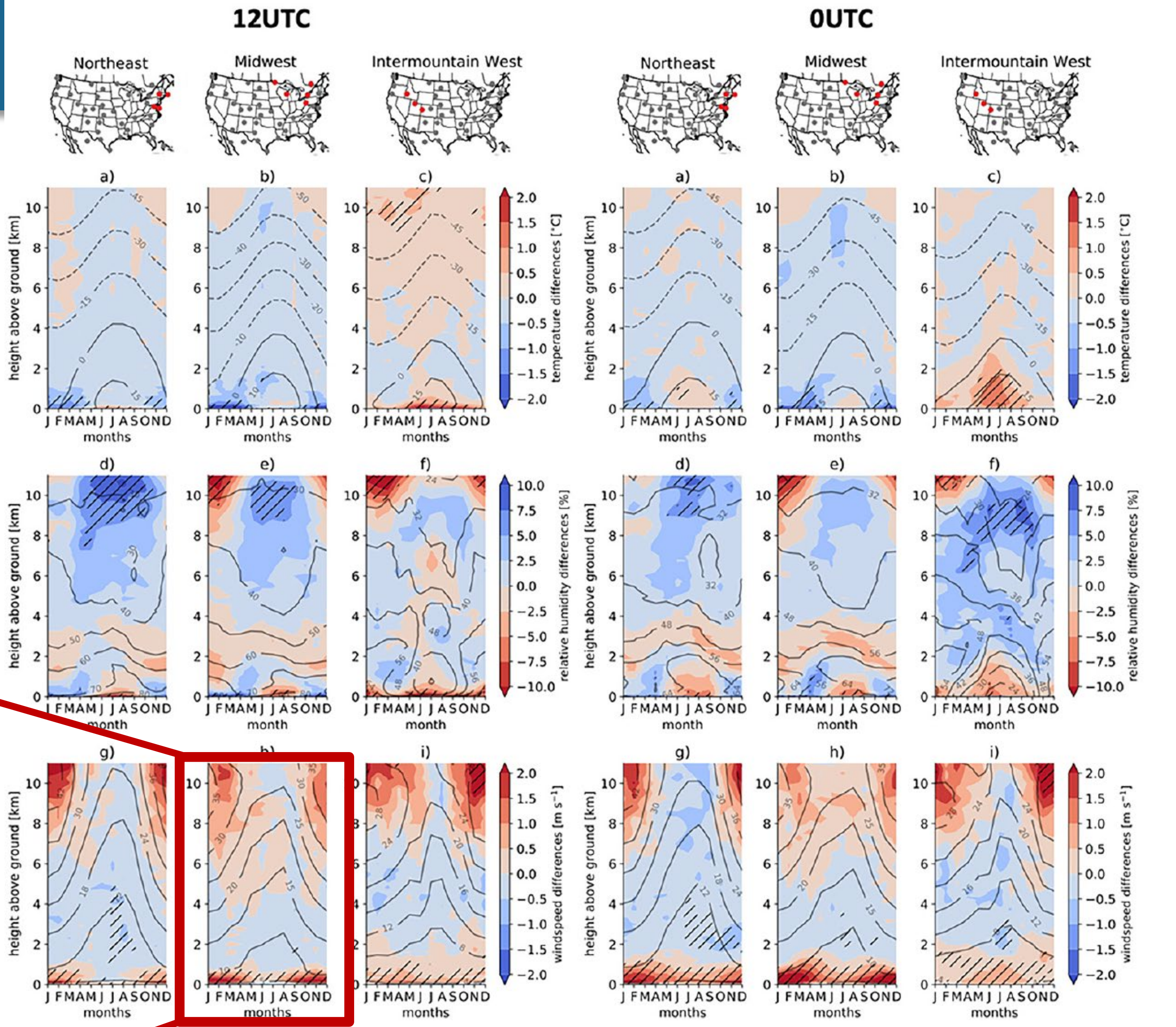


Fig. 2. Comparison of CONUS404 simulated vertical profile of temperature to radiosonde data at (left) 1200 and (right) 0000 UTC over the regions indicated by the radiosonde dots on the U.S. map above each column (e.g., the Northeast region is defined by the four radiosonde points shown in red on the map). Black dots represent all radiosonde sites in the United States. (top) The difference in temperature between CONUS404 and radiosonde), (middle) the difference in relative humidity, and (bottom) the difference in wind speed averaged over the 42 years. The *y* axis in the plots is elevation. The hatched regions of the plots indicate differences that are statistically significant (less than 5% on the Mann–Whitney *U* test) than the background. Black contours are observed average values over the 40 years of the specified variable. The key for each row is given on the right.

CONUS404: Advantages

		Gridded station observation based	Observation-Model fusions	Reanalyses	Convection-Permitting Downscaled Reanalyzes	Climate Models	Convection-Permitting Downscaled Climate Models
		PRISM, Livneh, Daymet	AORC, NLDAS, gridMET	NARR, ERA5, MERRA2	**CONUS404**	CMIP6, CORDEX	Planned CONUS-scale future scenarios
Biases	Systematic differences to in-situ observations						
Realism climate variability	Representation of interannual and decadal variability						
Realism seasonal variability	Representation of seasonal variability						
Realism diurnal variability	Representation of diurnal variabilities	typically daily					
Large-scale extremes	Representation of e.g., droughts, heatwaves, pluvial conditions						
Small-scale extremes	Representation of downpours, convective extremes						
Homogeneity	Occurrence of artificial signals in the long term record						
Spatial coverage	Data availability for all CONUS watersheds including lakes and surrounding oceans						
Intervariable consistence	Physical consistency between variables (e.g., precipitation and evapotranspiration)						
Record length	Length of the data record						
Future projections	Availability of future climate projections				PGW		

- good performance
- medium performance
- sub-optimal performance
- not available

Methods for Future Hydroclimate Assessment: Pseudo-Global Warming (PGW)

Concept of the PGW approach

$$PGW = CTRL + \Delta$$

CTRL and PGW represent the boundary conditions of two regional climate model (RCM) simulations of the **past and future climate conditions**, respectively, and Δ is the future changes often referred to as climate change deltas. Δ must be computed from a separate climate projection as

$$\Delta = PROJ - HIST$$

where PROJ is a future time slice of a climate projection and HIST is the corresponding historical time slice coming from simulations under the **same radiative forcing scenario**. Both PROJ and HIST periods must be chosen to be long enough to reduce the effects of internal variability (average of ~ 30 years) or constructed using ensemble means.

With additions to Brogli et al. 2023, GMD

	Pros	Cons
PGW	- Low costs - Representative for ensemble mean - Capture the main climate change signal due to the thermodynamics - **No internal variability issues** - Not impacted by GCM biases	- <u>Does not capture systematic changes in weather patterns</u> - Does not represent climate change variability and uncertainties
Direct GCM Down-scaling	- Captures systematic changes in weather patterns - Can sample larger range of variability	- Long-simulations and large ensembles needed to differentiate between forced climate change and internal variability - Affected by GCM biases (can be mitigated through bias corrections)

CONUS404 PGW: Design

PGW = CTRL + Δ   Δ = PROJ - HIST

Both PROJ and HIST periods must be chosen to be long enough to reduce the effects of internal variability (average of ~30 years) or use ensemble means.

CONUS404 used **ERA5** initial and boundary conditions from ~WY1980 - 2021 (**CTRL**).

Δ represents a near-term climate change signal: **PROJ** covers WY2022 - 2063 and **HIST** covers WY1980 – 2021.

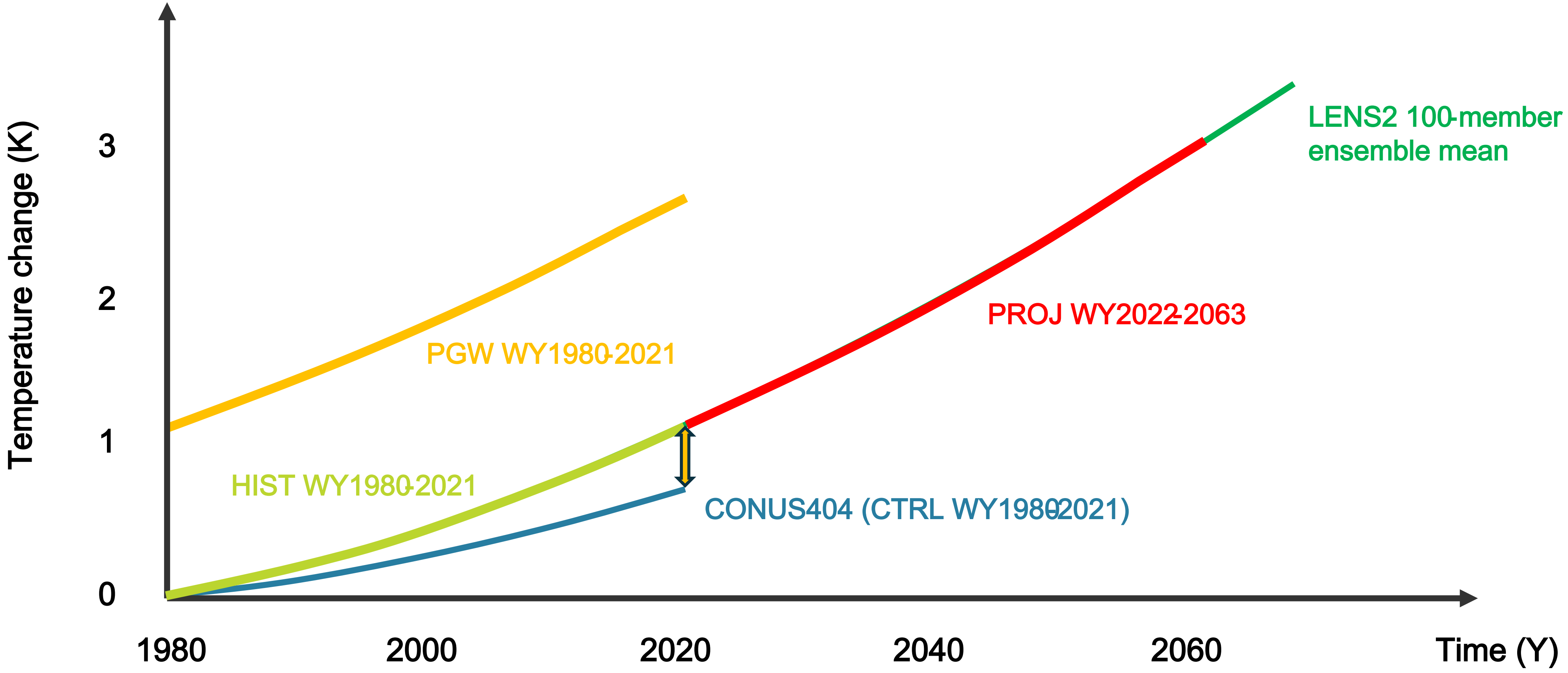
PROJ and HIST are based on the **100-member ensemble mean data** of NCAR's CESM2 Large Ensemble Community project (**LENS2**).

LENS2 used the Shared Socioeconomic Pathways radiative forcing scenario 3 (**SSP3-7.0**) for future projection.

CONUS404 PGW = ERA5_WY1980-2021 + LENS2_WY2022-2063 – LENS2_WY1980-2021

CONUS404 PGW: Climate Change Signal

PGW = CTRL + PROJ – HIST = PROJ - (HIST – CTRL)



CONUS404 PGW Data: Preview (PGW progress)

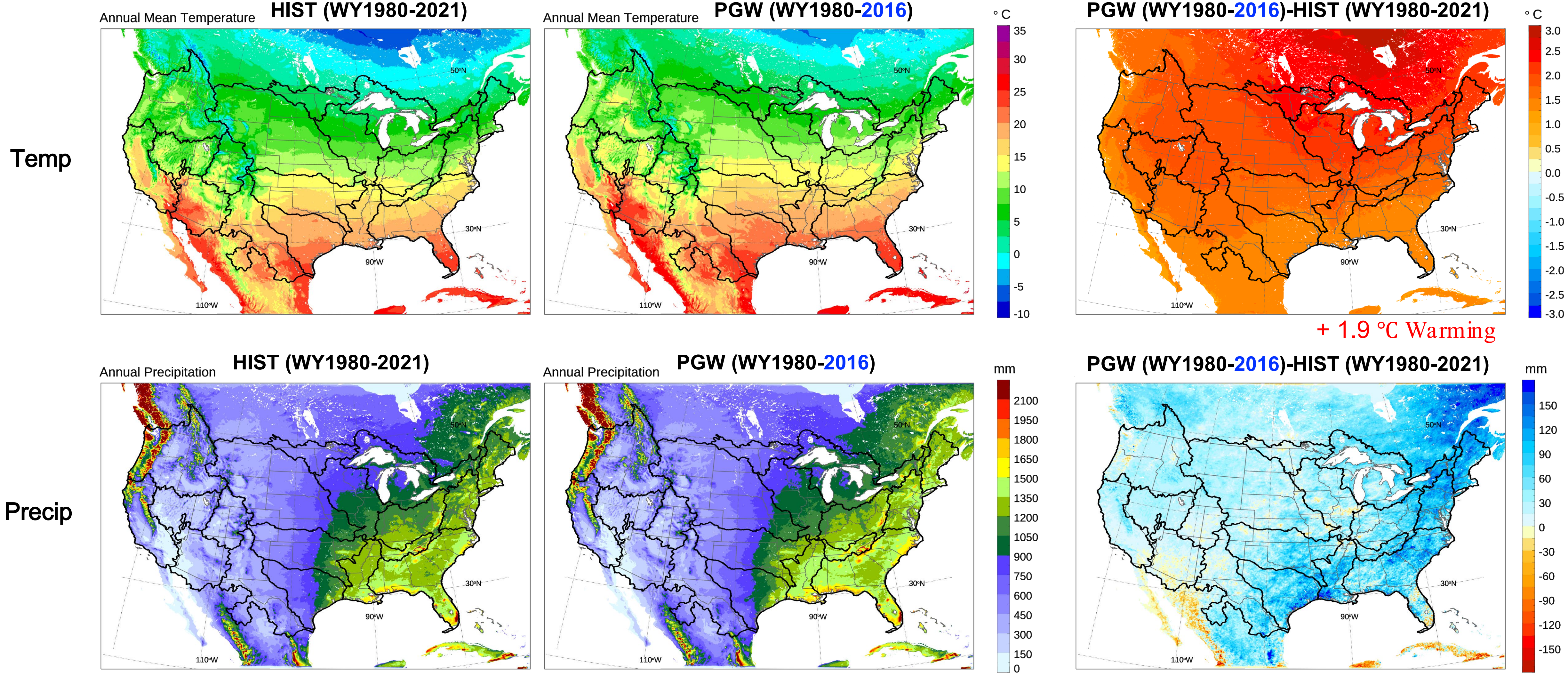
Historical Run: WY1980 – WY2021

WY1980	WY1981	WY1982	WY1983	WY1984	WY1985	WY1986	WY1987	WY1988	WY1989
WY1990	WY1991	WY1992	WY1993	WY1994	WY1995	WY1996	WY1997	WY1998	WY1999
WY2000	WY2001	WY2002	WY2003	WY2004	WY2005	WY2006	WY2007	WY2008	WY2009
WY2010	WY2011	WY2012	WY2013	WY2014	WY2015	WY2016	WY2017	WY2018	WY2019
WY2020	WY2021	WY2022							

PGW Run : WY1980 – WY2021, currently in the PGW WY2016 (completed 37yrs). ***5 more years to go!***

WY1980	WY1981	WY1982	WY1983	WY1984	WY1985	WY1986	WY1987	WY1988	WY1989
WY1990	WY1991	WY1992	WY1993	WY1994	WY1995	WY1996	WY1997	WY1998	WY1999
WY2000	WY2001	WY2002	WY2003	WY2004	WY2005	WY2006	WY2007	WY2008	WY2009
WY2010	WY2011	WY2012	WY2013	WY2014	WY2015	WY2016	WY2017	WY2018	WY2019
WY2020	WY2021	WY2022							

CONUS404 PGW Data: Preview (Annual Mean)



+ 1.9 °C Warming

+ 44.2 mm (5.6% Wetter)

Summary

- CONUS 4 km simulation of Water Years (WY) 1980-2022+
  - Plans to keep the simulation near current
- WRFv3.9.1.1
- ERA5 IC/BC and SST
  - Also spectral nudging within domain
- Hourly 2D surface and 3D fields on model levels available
  - Roughly 50-100 m vertical spacing in lowest 1 km
- https:// rda.ucar.edu/datasets/ds559.0/#
- May have reasonable wind speed performance (at least climatology)
- Pseudo-global warming scenario is in progress and data will be made available