

Does downscaling method matter? Assessing compound hot-dry event impacts on renewable power in Southern China

Zixuan Zhou¹, Haiyang Lin², Haiyang Jiang², Eun-Soon Im¹, and Michael B. McElroy² (Presenting author's email: zzhouh@connect.ust.hk)

¹The Hong Kong University of Science and Technology, ²Harvard-China Project, Harvard University

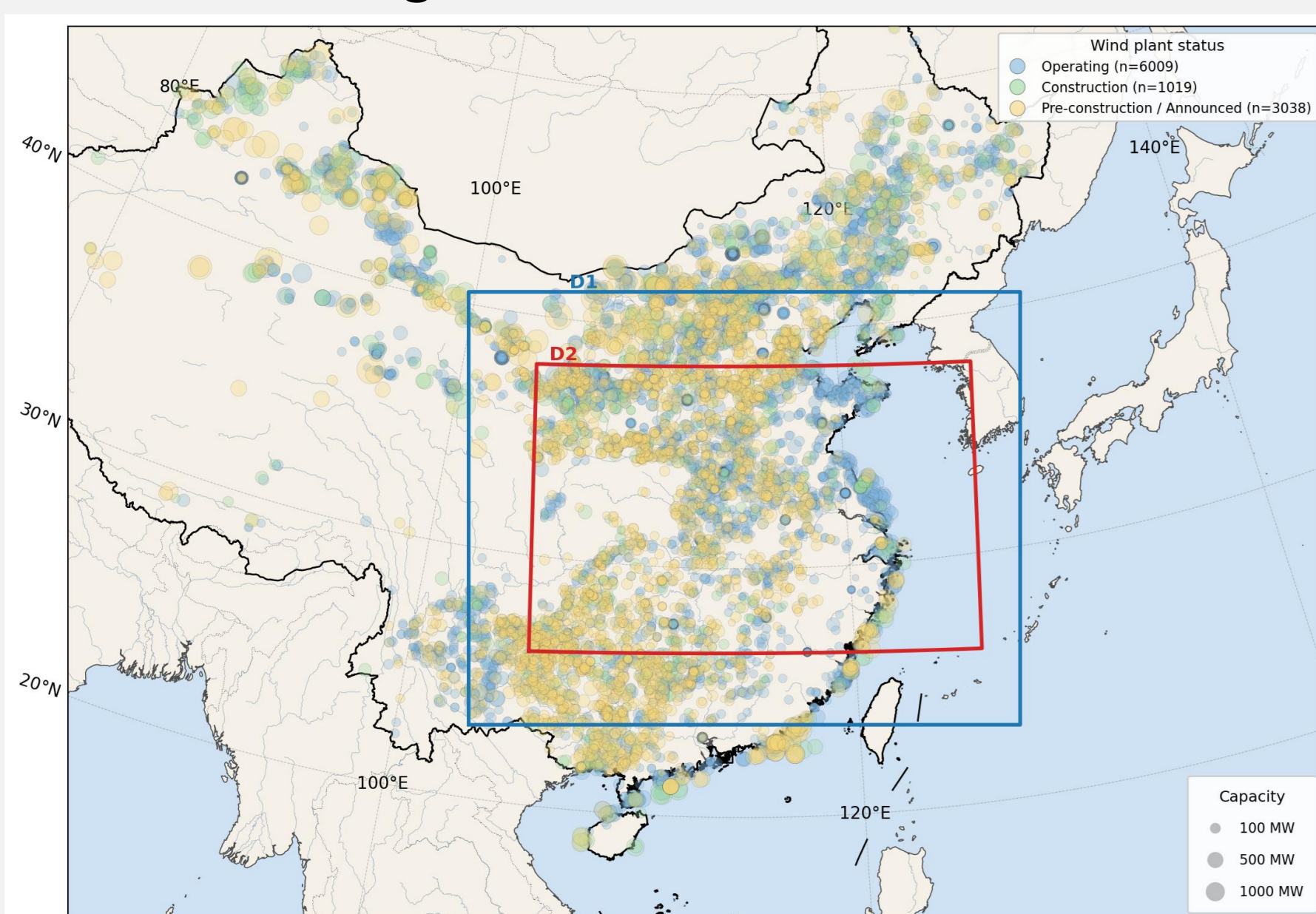


Introduction

- **Background**
 - The 2022 CHDE in Southern China caused widespread blackouts, exposing energy system vulnerability to concurrent heat and drought
 - Understanding these impacts is critical as China transitions to weather-dependent renewables
- **Research Gap**
 - Climate-energy studies rely on coarse GCMs and simplified conversion equations, missing local-scale dynamics
 - The added value of high-resolution downscaling under compound extremes remains untested
- **Objectives**
 - Validate a GAN-based statistical and a dynamical downscaling framework against the August 2022 CHDE
 - Estimate event wind power generation from both datasets
 - Quantify how downscaling choice affects CHDE impact assessment

Data & Method

Domain Configurations



- ❖ **Observation**
 - China Meteorological Forcing Data version 2 (CMFDv2)
 - 0.1° × 0.1°, 3-hourly
- ❖ **Initial and Boundary Conditions:**
 - ECMWF Reanalysis v5 (ERA5)
 - 0.25° × 0.25°, 6-hourly
- ❖ **Dynamical Downscaling:**
 - RegCM5 (by ICTP)
 - D1: 9km 3hourly; D2: 3km hourly
 - Running Time: ~10 days
- ❖ **Statistical Downscaling:**
 - GAN-based Sup3rwind (by NREL)
 - D2: 2km 5min
 - Running Time: ~2 days

• Wind plants information from Global Energy Monitor, Global Wind Power Tracker, February 2026 release <https://globalenergymonitor.org/projects/global-wind-power-tracker/>

Wind Power Calculation

1. Air density based on Ideal gas law

$$\rho = \frac{P}{R_d T}, \quad R_d = 287.05 \text{ Jkg}^{-1}\text{K}^{-1}$$

2. Density-corrected wind speed

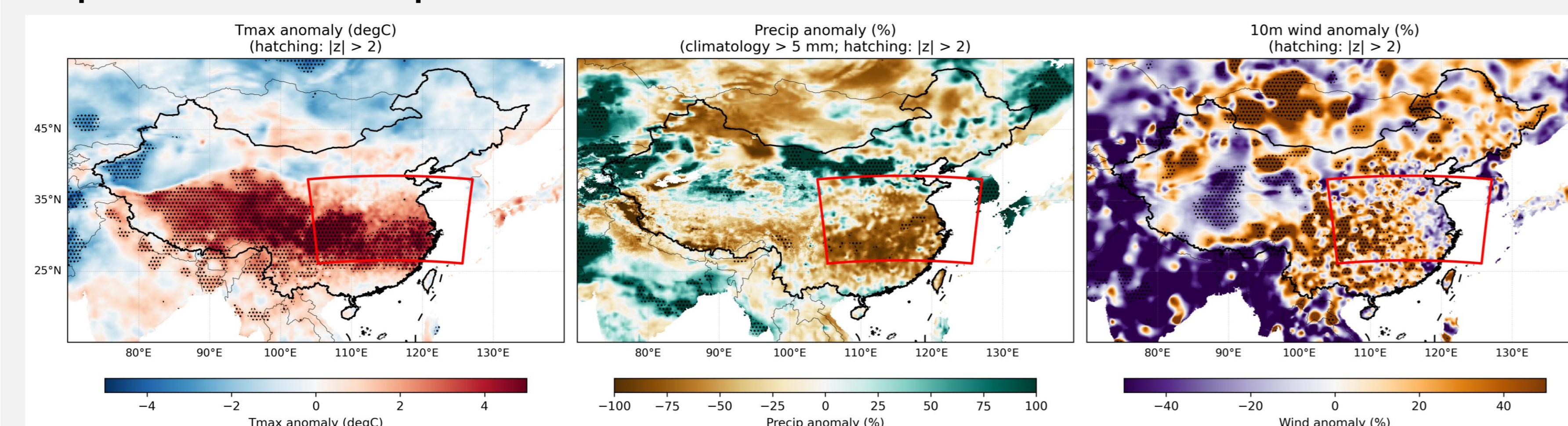
$$v_{std} = v_{100} \left(\frac{\rho}{\rho_0} \right)^{\frac{1}{3}}, \quad \rho_0 = 1.225 \text{ kgm}^{-3}$$

3. Capacity factor (piecewise cubic, IEC Class 2 turbine, $v_{ci} = 3, v_r = 12, v_{co} = 25\text{m/s}$)

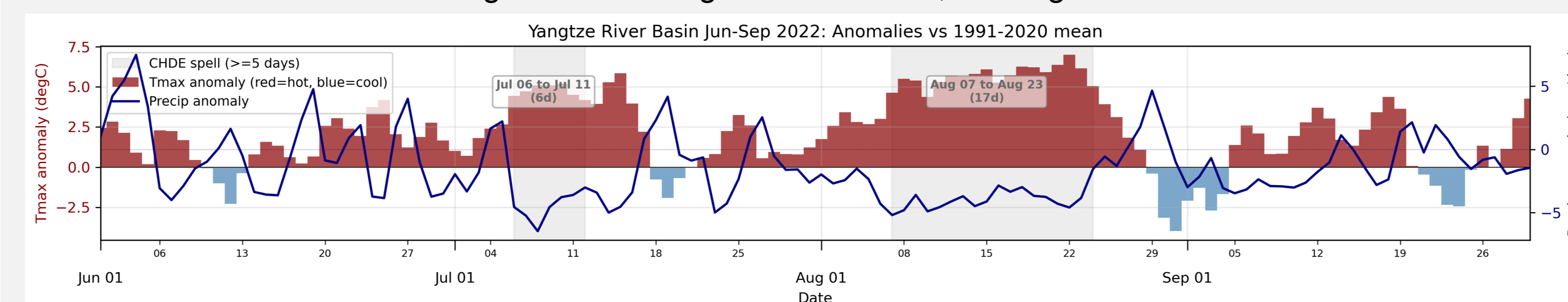
$$CF(v_{std}) = \begin{cases} 0 & v_{std} < v_{ci} \\ \left(\frac{v_{std} - v_{ci}}{v_r - v_{ci}} \right)^3 & v_{ci} \leq v_{std} < v_r \\ 1 & v_r \leq v_{std} \leq v_{co} \\ 0 & v_{std} > v_{co} \end{cases}$$

Observed and Simulated CHDE

Spatial Extent and Temporal Evolution of CHDE

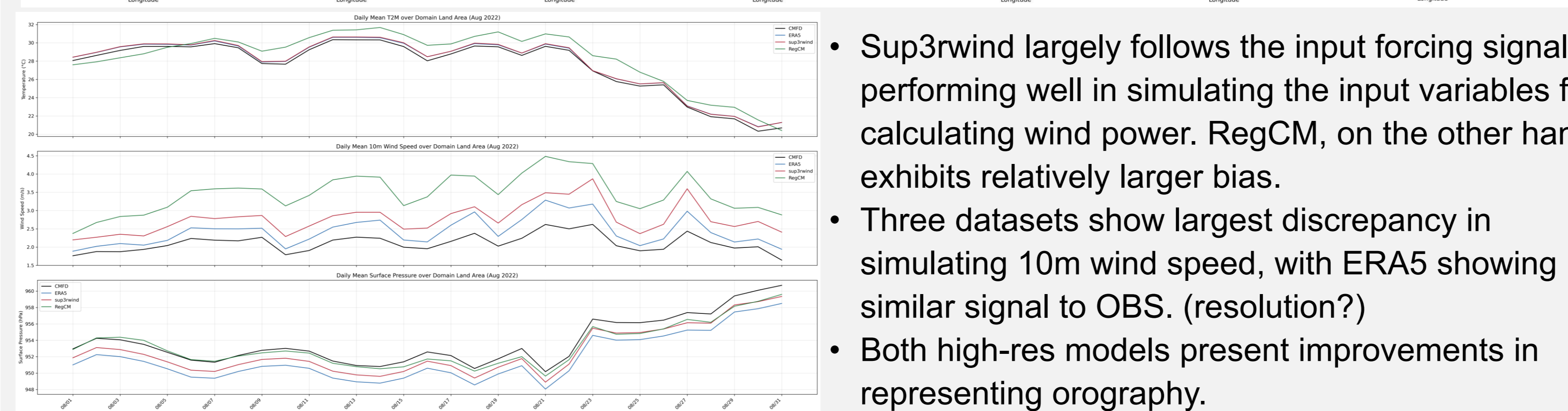
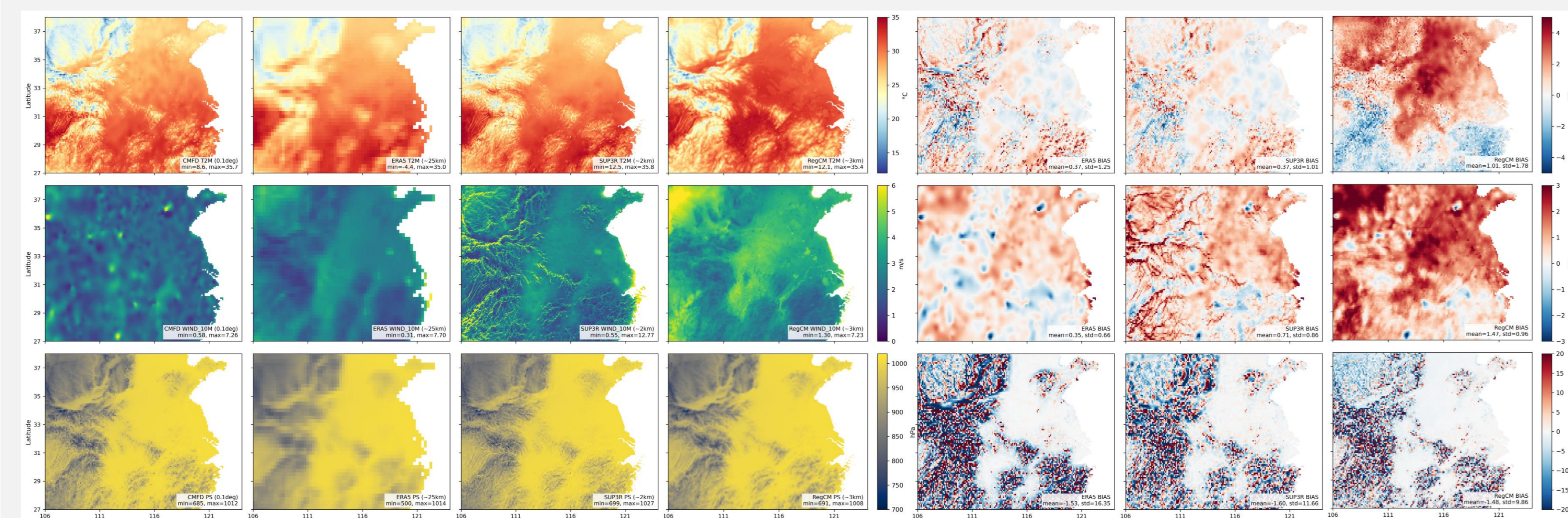


- Prevalent heatwave and drought across Yangtze River Basin, with significant **increases** in surface wind.



- Tmax anom > 2.0 sigma AND precip < 50% of climatology, min length: 5 days, gap tolerance: 1 day
- The peak period is **Aug 7 to Aug 23, 2022**, but the CHDE started accumulating in July.

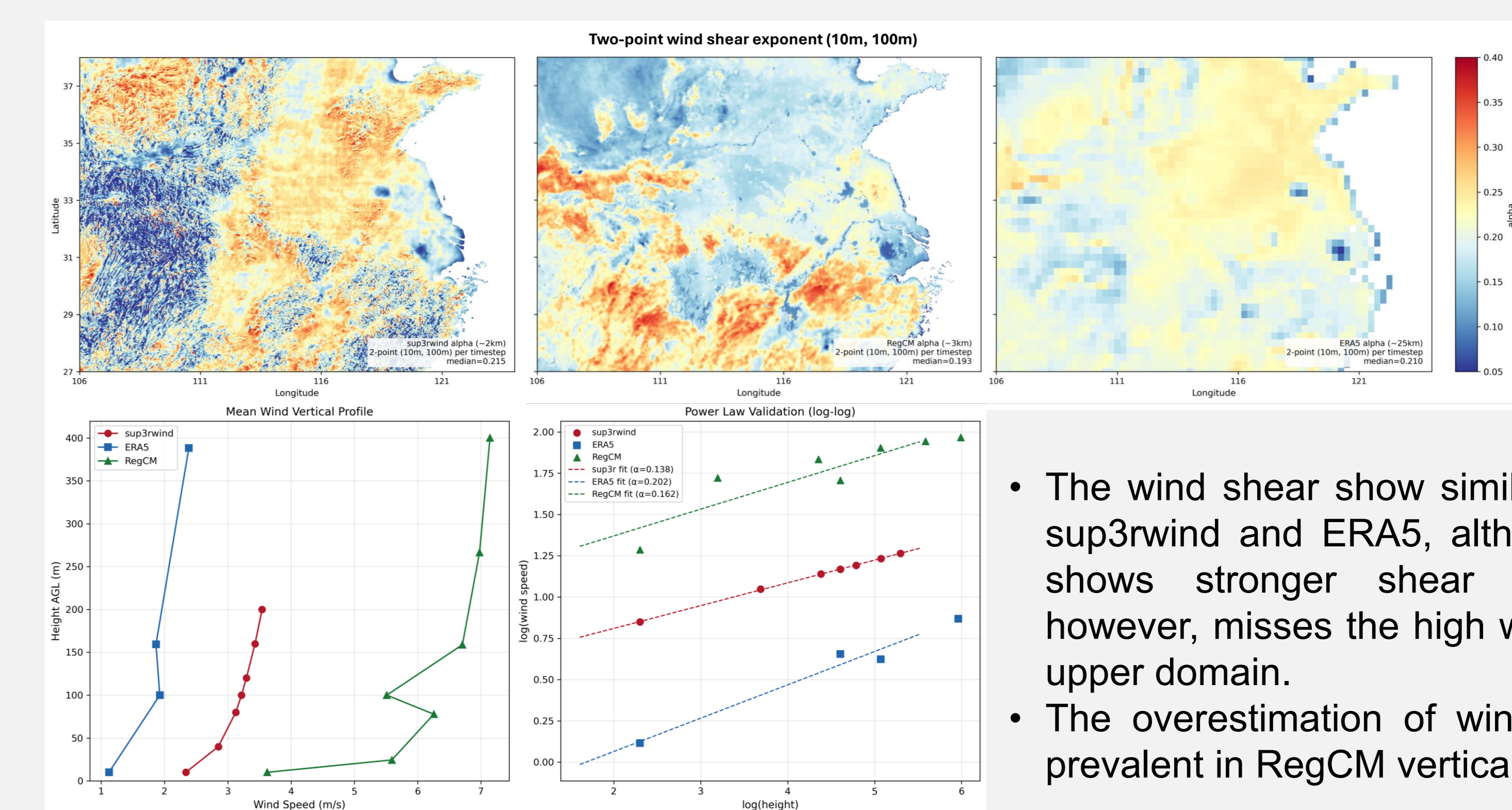
Validation of Downscaled Variables



- Sup3rwind largely follows the input forcing signal, performing well in simulating the input variables for calculating wind power. RegCM, on the other hand, exhibits relatively larger bias.
- Three datasets show largest discrepancy in simulating 10m wind speed, with ERA5 showing similar signal to OBS. (resolution?)
- Both high-res models present improvements in representing orography.

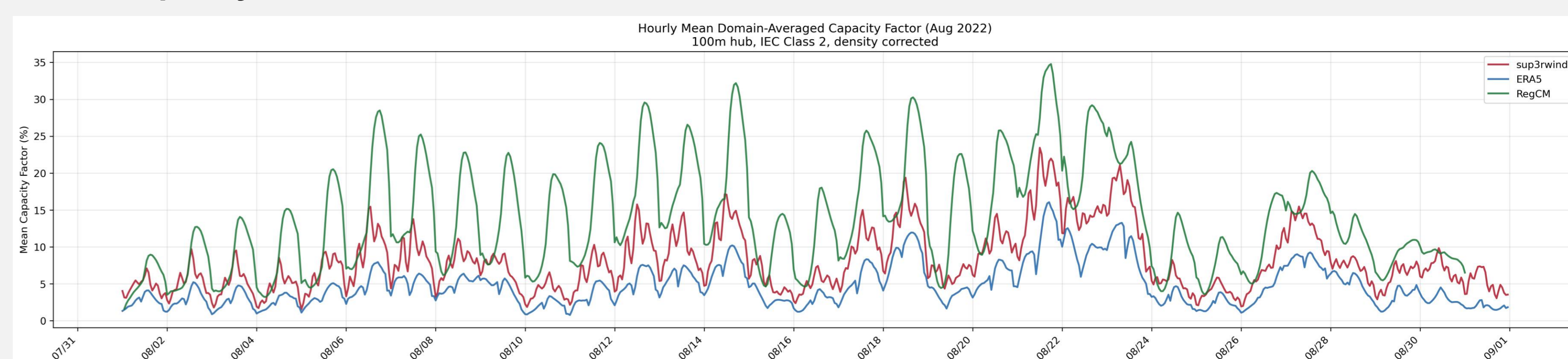
Wind Power during CHDE

Vertical Wind Profile



- The wind shear show similar distribution in sup3rwind and ERA5, although the former shows stronger shear value. RegCM, however, misses the high wind shear at the upper domain.
- The overestimation of wind speed is also prevalent in RegCM vertical profiles.

Mean Capacity Factor Over Each Domain Cell



- Input forcings and both downscaled data follow similar temporal cycles.
- RegCM presents much higher CF than sup3rwind, which may contain positive bias.
- Although ERA5 (25km) contains coarsened wind field, its discrepancy with sup3rwind (2km) is not large.

Summary

- Sup3rwind generalizes well from US training data to China, with substantially higher computational efficiency than dynamical downscaling. RegCM shows systematic biases in wind power-relevant variables, indicating a need for further parameterization tuning.
- High resolution is critical for wind power simulation, but the choice of downscaling method introduces significant uncertainty that warrants careful evaluation.

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