

Weather Reanalysis Data Products for Everyday Decisions

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METEC

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Introduction

- **Wind sets the number.** In most downwind methods, wind speed multiplies the emission rate and wind direction steers the plume. **Small wind errors → big flux errors.**^[1]
- **Winds are often from models (“reanalysis”).** Wind speed (WS) & direction (WD) propagate directly to flux:
Emissions (Flux) ~ Conc_{meas} × WS × Plume Width
- **Emissions scale linearly with speed.** A +1 m/s wind bias increases the rate → **if true wind = 5 m/s, error ~ +20%.**^[2]
- **When is reanalysis “good enough” to trust?** Here we test an example workflow. A global workhorse—ERA5—stacked up against a short record of METEC’s winds.

Overall Objective: Help you—

- ✓ see where reanalysis fits day-to-day,
- ✓ interpret uncertainty vs. site data, and
- ✓ equip you with a quick, repeatable, easy-to-use workflow; determine usefulness.

Site Meteorological Data

Site Description

Meteorological data were used from the METEC site (METEC), operated by The Energy Institute at CSU in Ft Collins, CO. Site terrain is relatively flat on shortgrass prairie. To the west, Horsetooth Reservoir is held in by a series of four dams connecting the Dakota Hogback, rising 400–500 ft above METEC, oriented NNW-SSE. Soldier Canyon Dam, 1.9 km to the WSW of METEC (Fig. 1), is where elevation increases and can climb to 2,000 ft (~0.6 km) within a few km. These features from the WSW to NNW lead to a strong bimodal wind pattern throughout the day (Fig. 1, inset), using long-term data at nearby Christman Field^[3] (CSU Atmospheric Science).

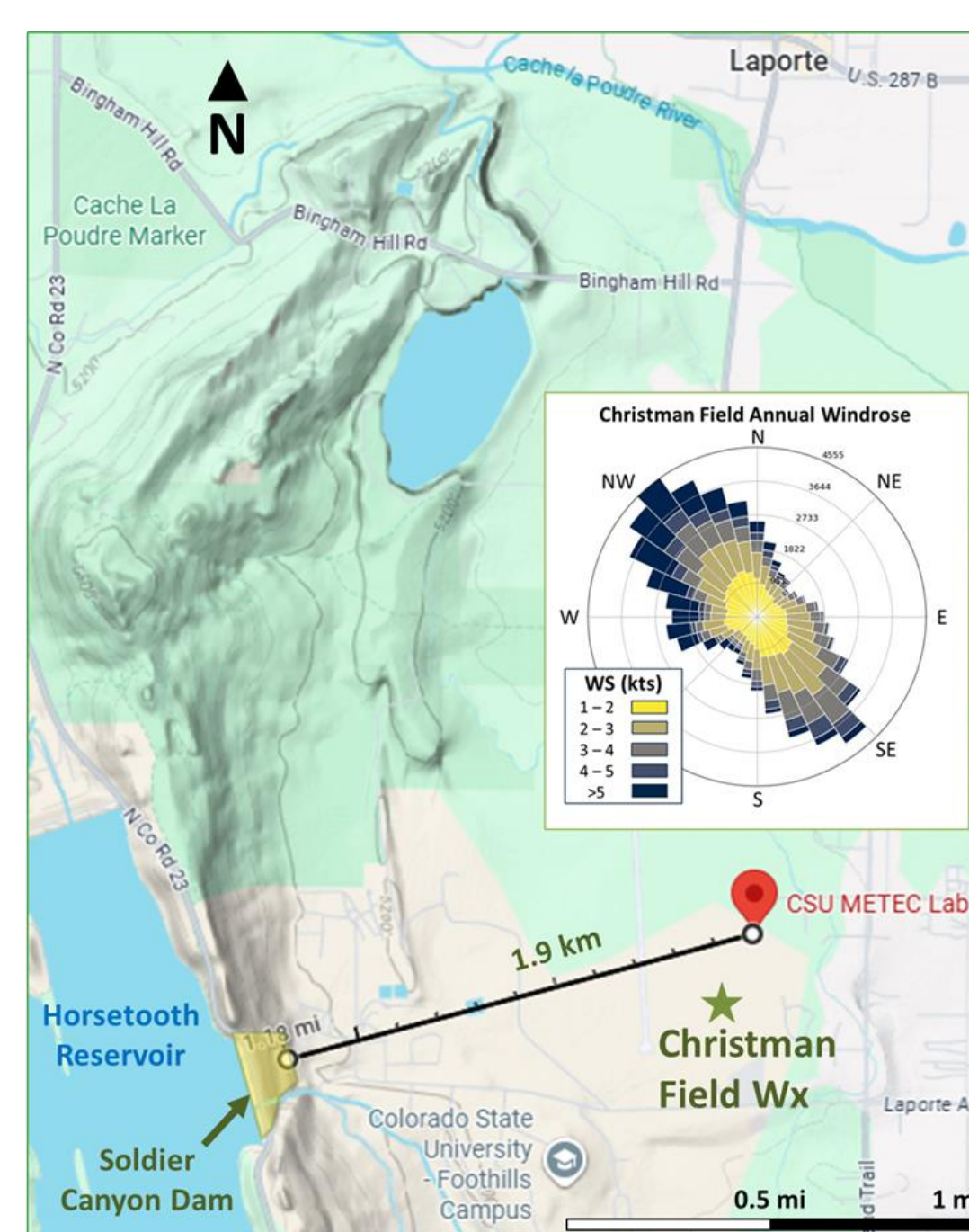


Fig. 1. Terrain influencing winds at METEC. METEC is closest to the ridge at Soldier Canyon Dam (yellow, lower left). Star indicates Christman Field Weather (Wx) Station^[3] (lower right); annual wind rose inset.



Fig. 2. Data are from METEC’s main tower (center).

Weather Data at METEC

METEC 6m Weather Station (Fig. 2)

- 1 Hz output
- RM Young 81000 3D sonic anemometer (WS, WD) @6.7 m
- Temp/RH, Surface Pressure ZX300 Lidar (Fig. 2, lower right)
- 9 heights, 10 scans^a
- Output: U, w, θ (8 Hz)
- Compact weather station
- *Future work—use in workflow*

ERA5 Data:

<https://cds.climate.copernicus.eu/datasets/reanalysis-era5-single-levels-timeseries?tab=overview>

^aHeights (in m): 10, 15, 20, 30, 38, 10, 75, 100, 200, 300

Reanalysis Data

What it is

A long, gridded record built by blending observations with one fixed model—an *always-on* backdrop for your sites.

What it is not

Plan inspections, pick higher-yield windows, convert plumes to rates, and sanity-check when instruments are down.

What it’s for

- **Always On backdrop?**
- Continuous, ready-to-query weather record
- Hourly coverage spanning decades
- Everywhere (global)
- Multi-variable
- Sensor-independent

- **What is higher-yield?**
- Wind “Sweet Spot” U ~ 2–6 m/s
- Well-mixed BL
- Steady wind
- High visibility
- Geometry (clear fetch & downwind alignment)

What it is not

A fence-line sensor; treat as a calibrated backdrop and validate for high-stakes calls.

By product, region, and provider/method—we make that sensitivity visible.

Where it varies

- **Calibrated backdrop?**
- Background meteorology
- Validate locally
- Adjust, flag small biases (low RMSE^b & MAE^c), or apply pattern corrections
- Documentation

^bRoot Mean Squared Error
^cMean Absolute Error

- **Visible sensitivity?**
- Side-by-side metrics
- Directional error-by-sector
- Region toggle (onshore/offshore)
- Evaluate methods
- By case/scenario

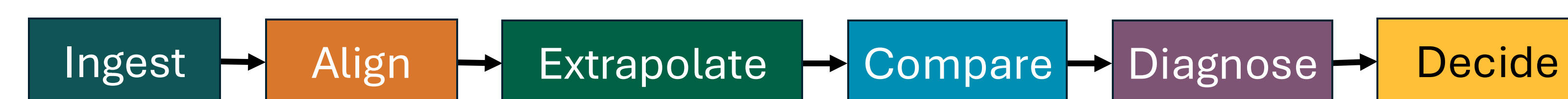
Table 1. Model reanalysis products with details (not a complete listing). Gold rows are used in this analysis.

Product	Coverage	Horiz. Grid Spacing	Δt	Heights (type) [†]	Includes BL? [‡]	Notes
20CRv3	GLM	~75 km	3 h	Model/P-levels (sfc winds via SLP assimilation)	—	Long historical record; surface-pressure-only data assimilation
ASRv2	Arctic***	15 km	3 h (typ.)	10 m diagnostic; model/P-levels	PBLH	Arctic-focused regional reanalysis (2000–2016)
CERRA	Europe (pan-Euro domain)	5.5 km	1 h**	10 m diagnostic; model levels	PBLH	European regional reanalysis; ensemble (CERRA-EDA)
CFRSR/CFRSv2	GLM	~38–100 km	6 h*	10 m diagnostic; P-levels	PBLH	Coupled atmos–ocean–ice system (NCEP)
ERA5	GLM	~31 km	1 h	10 m & 100 m diagnostic; full model/P-levels	BLH	Widely used global baseline; ensemble available for uncertainty
ERA5-Land	GL	9 km	1 h	10 m diagnostic (land points only)	—	Land-surface focused; pair w/ ERA5 for BLH over land
HRRR-Reanalysis	CONUS (+ near-shore)	3 km	1 h	10 m & ~80 m diagnostic; model levels	PBLH	High-res U.S. regional; useful in complex terrain
JRA-3Q	GLM	~55 km	3–6 h	10 m diagnostic; P-levels	PBLH	Newer JMA reanalysis, 1947→; successor to JRA-55
JRA-55	GLM	~55 km	6 h	10 m diagnostic; P-levels	PBLH	JMA legacy global baseline, 1958→
MERRA-2	GLM	~50 km	1 h	10 m diagnostic; model/P-levels	PBLH	Long, stable NASA record; aerosol-coupled

[†]“10 m” & “100 m” winds diagnosed at fixed heights AGL—not pressure levels (P-levels). Profiles are extrapolated to sensor heights (e.g., 6.7 m sonic).
[‡]BLH vs PBLH – Model-computed heights (m AGL); labels differ by system. Regime/stratification diagnostics for bin, mismatch checks.
*Varies by stream; **Analyses 3-hourly; *** ≥ High-latitude domain

Acronyms/Abbrevs: AGL (Above Ground Level), Atmos (Atmospheric), BL (Boundary Layer), BLH (BL Height), CONUS (Continental U.S.), EDA (Ensemble Data Assimilation), HRRR (High Resolution Rapid Refresh), GL (Global, Land only), GLM (Global, Land & Marine), JMA (Japan Meteorological Analysis), NASA (National Aeronautics & Space Agency), NCEP (Nat’l Centers for Environ. Prediction), P-level (Pressure level), PBLH (Planetary BL Height), Sfc (Surface), SLP (Sea Level Pressure)

Example Workflow: Is Reanalysis “Good Enough”?



Preliminary Workflow

- | Step | Tasks |
|-------------|--|
| Ingest | <ol style="list-style-type: none"> 1. Pull ERA5 (time series CSV) for your site: → 10 m wind, 2 m Temp & Dewpoint 2. Record product, version, variables, latitude, longitude, dates, and units |
| Align | <ol style="list-style-type: none"> 1. Clean site data → 10 min means; find calms (< 0.5 m/s^d), find insufficient n 2. For each hour, use a centered ±30 min window and circular mean for direction |
| Extrapolate | <ol style="list-style-type: none"> 1. Match heights: 10 m → sensor height (use power-law vertical wind profile equation) 2. Clearly label estimates and work off copies (i.e., keep all originals to avoid unrecoverable errors) |
| Compare | <ol style="list-style-type: none"> 1. Compute bias and error metrics 2. Split by day, night, and wind sectors; display sample counts ERA5 v METEC |
| Diagnose | <ol style="list-style-type: none"> 1. Identify patterns: day/night, sector bias, wind speed dependence, ERA5 v METEC matches or mismatches 2. Note sensitivities: Stability, “Sweet Spot”? |
| Decide | <ul style="list-style-type: none"> • Low speed error, direction error ≤ 20° • One fails or large sector bias—add met • Both fail in night/stable or complex fetch |

^dCalm winds in AERMOD and CALPUFF are both < 0.5 m/s (causes unstable/unreliable wind directions).

Ingest → Align → Extrapolate → Compare → Diagnose → Decide

Table 2. METEC completeness for 10 min, hourly summaries from 1 Hz data.

Sep 2025 Days	Dataset	n	Out of	Complete ness	Calms (%)	Low n (< 70%)	Total Filtered
4, 5, 6, 7, 9, 12, 13	10 min Hourly	910	1008	90.3%	9.0%	0.7%	9.7%
		151	168	89.9%	4.8%	5.4%	10.1%

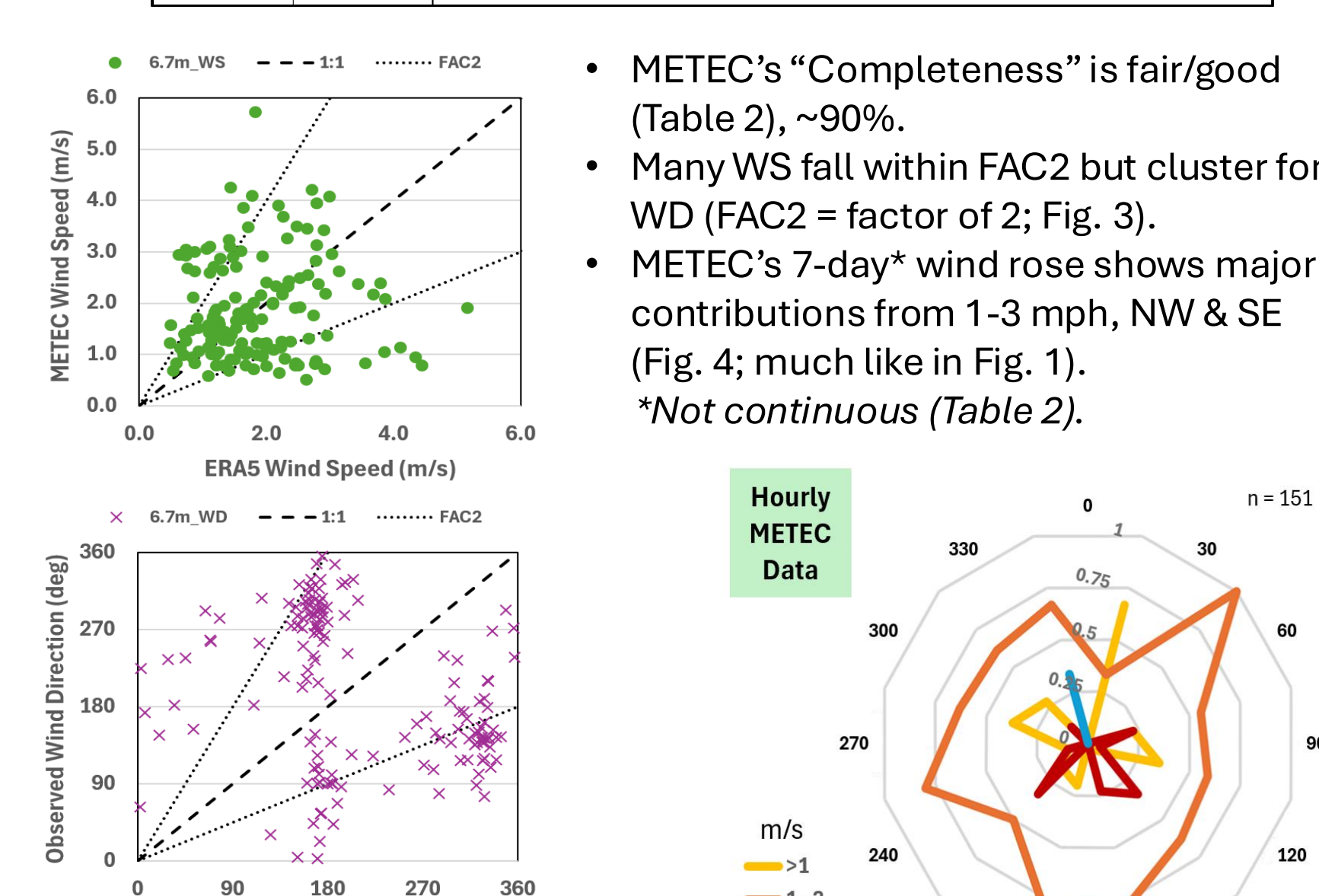


Fig 3 (above). METEC vs ERA5 hourly winds for the 7 days. Wind speed (top) & direction (bottom).

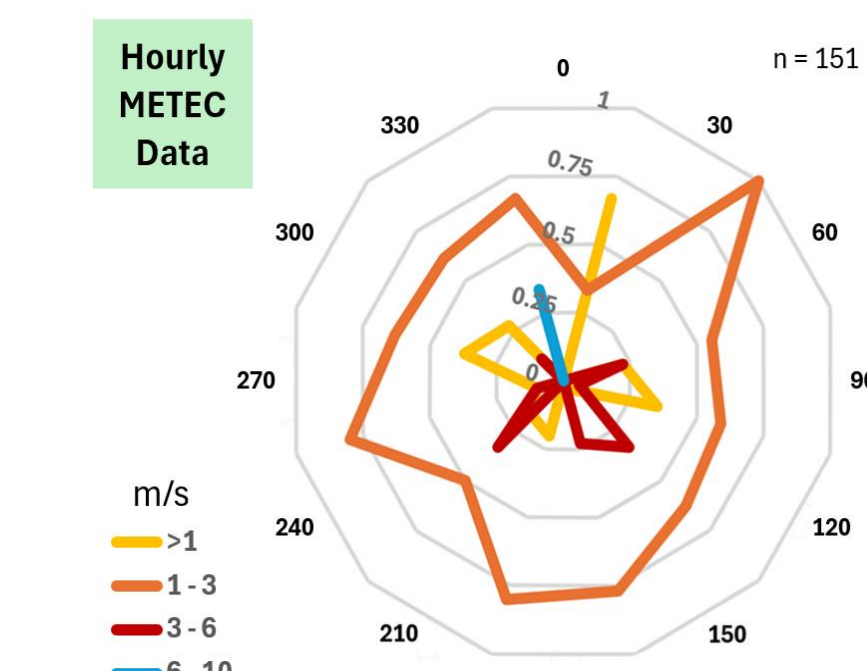


Fig 4 (below). Radar plot of hourly METEC winds for the 7 days (not stacked).

Preliminary Results for METEC Sample

Compare → Diagnose

- Height matched WS bias small (<±1 m/s), with all mismatched biased high (Fig. 5).
- Day Bias → WS underestimated
- Night Bias → WS overestimated
- Overall → Low bias (Fig. 6, Table 3)
- WD shows systematic deviation >90° in cMAE & cRMSE (c means circular, Table 3). **Terrain-induced errors?**
- RMSE is ~40% > MAE (1.0 m/s, Table 3).

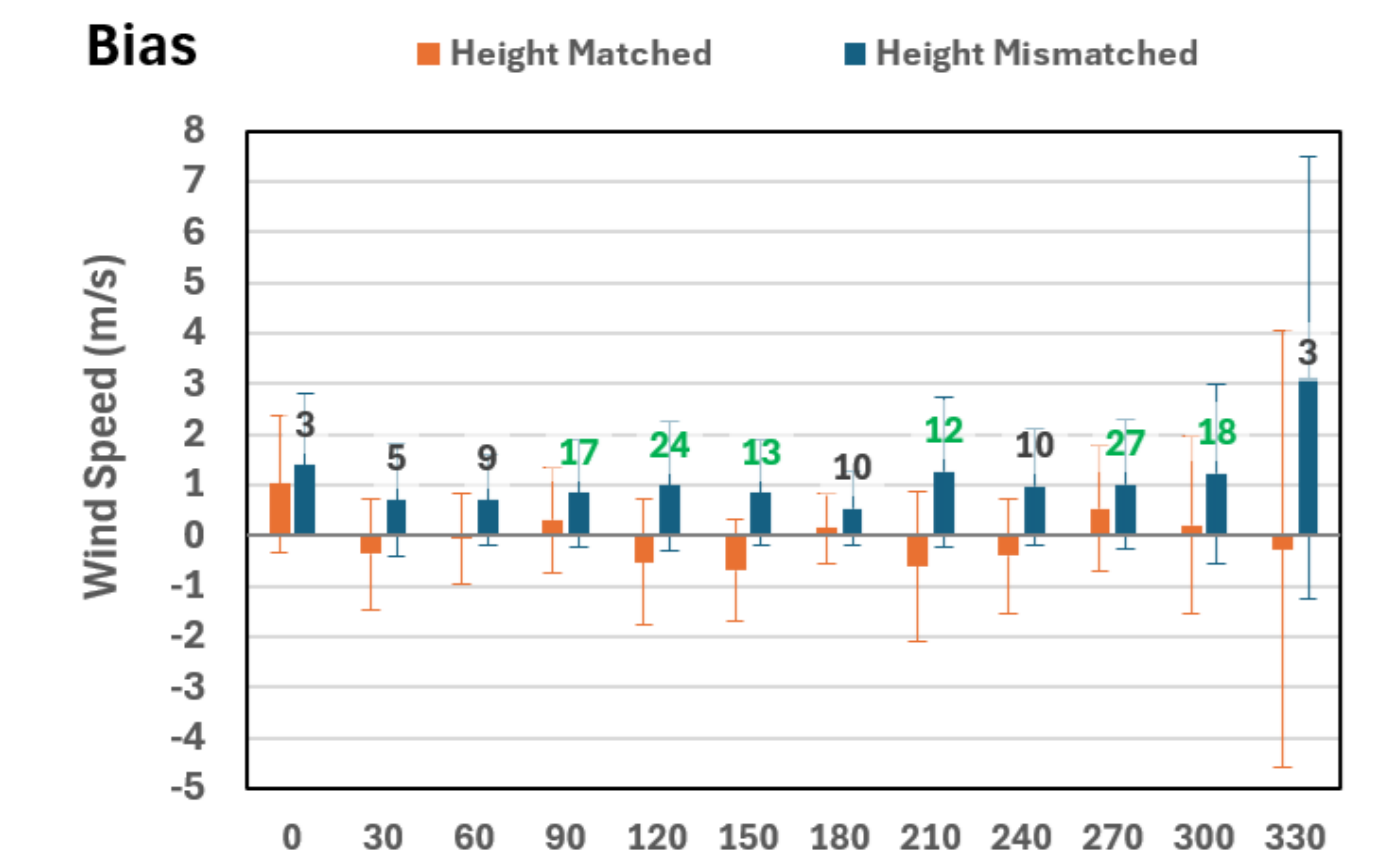


Fig 5. Hourly WS bias by wind sector (n, green is n > 12). Bars indicate the standard deviation of bias for that n.

Bias

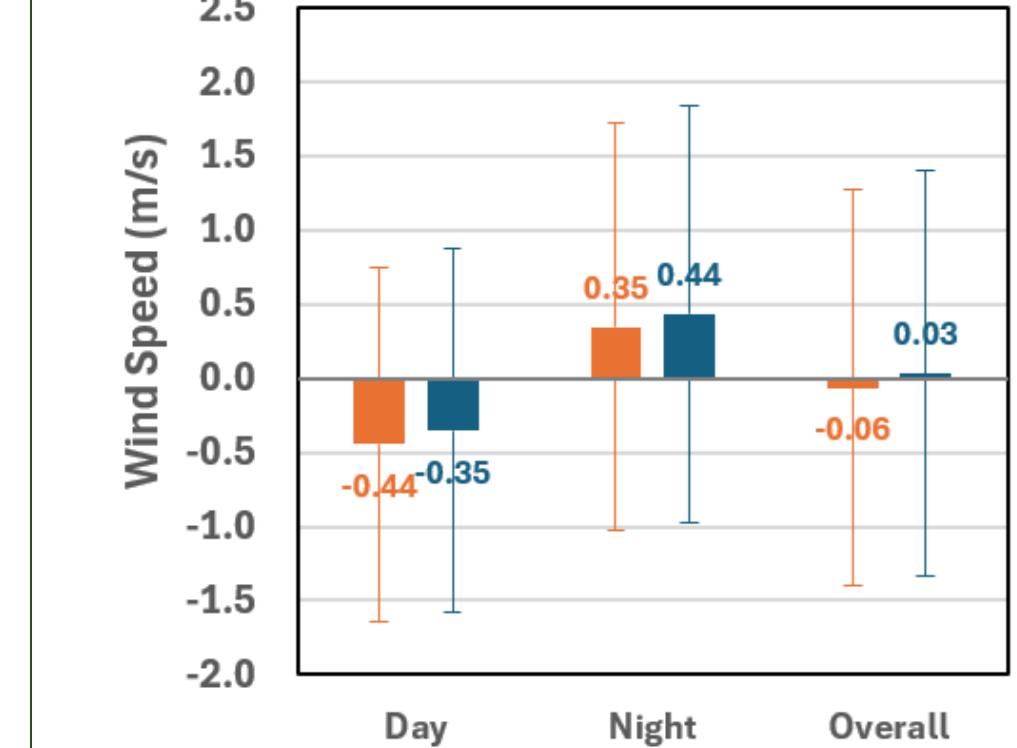


Fig 6. WS bias by day/night.

Overall, height-matched:

- Bias = -0.06 m/s
- MAE = 0.98 m/s
- RMSE = 1.3 m/s
- FAC2 69% → not a universal metric. Use sector filtering & additional met for tough decisions.

Decide

- Use ERA5 for sectors (Table 3, green):
- RMSE ~ 0.7-1.1 m/s, FAC2 ~ 80-100% → “Good Enough” for scheduling/triage
- Caution/anchor (Table 3; yellow or red):
- Anchor with short met → RMSE > 1.1 m/s, FAC2 ≤ 71%
- **Weakest 270-360** → RMSE > 1.3 m/s, FAC2 ≤ 41% → Needs more anchor data, or use site-level data

Table 3. Summary statistics. FAC2 is % of n within a factor of 2.

Wind Sector	n	Bias (m/s)		MAE (m/s)		RMSE (m/s)		FAC2 (%)		Wind Direction cMAE	cRMSE
		Match	Mismatch	Match	Mismatch	Match	Mismatch	Match	Mismatch		
0	3	1.0	1.1	1.4	1.5	1.5	1.6	100	100	108.2	112.5
30	5	-0.4	-0.3	0.7	0.7	1.1	1.0	80	80	116.4	117.5
60	9	-0.1	0.0	0.7	0.7	0.8	0.8	89	89	114.0	120.2
90	17	0.3	0.4	0.8	0.9	1.1	1.1	71	76	109.7	122.0
120	24	-0.5	-0.4	1.0	1.0	1.3	1.3	71	71	138.8	143.9
150	13	-0.7	-0.6	0.8	0.9	1.2	1.2	62	62	134.9	140.9
180	10	0.1	0.2	0.5	0.6	0.7	0.7	80	80	93.7	105.8
210	12	-0.6	-0.5	1.3	1.2	1.5	1.5	50	58	100.4	114.8
240	10	-0.4	-0.3	1.0	1.0	1.1	1.1	80	80	108.6	115.6
270	27	0.5	0.6	1.0	1.0	1.3	1.4	41	41	104.7	112.4
300	18	0.2	0.3	1.2	1.3	1.7	1.8	61	56	124.1	133.2
330	3	-0.3	-0.1	3.1	3.2	3.5	3.6	33	0	128.3	137.9
OVERALL	151	-0.06	0.03	1.0	1.0	1.3	1.4	69	68	115.7	124.9
Day	78	-0.44	-0.35	0.98	0.98	1.3	1.3	69	71	121.0	129.9
Night	73	0.35	0.44	0.98	1.02	1.4	1.5	68	66	110.0	119.2
OVERALL	151	-0.06	0.03	0.98	1.00	1.3	1.4	69	68	115.7	124.9

Future Work

More bins, comparisons with other models (HRRR-R), and especially-- more data

Let’s Help Each Other

Uncertainty in reanalysis-based errors in emissions attribution requires further research [1]. Technological advances push new boundaries but exist in narrow markets where detection uncertainties are not well understood across a range of equipment, methods, or weather conditions on a global scale. *There’s still a lot to do!*

We are looking for collaborators!

We are consulting with experts in the field and receiving valuable input, but we aim to develop tools and materials for technical staff in the energy sector that help fill gaps, streamline processes, and ultimately save you time and effort.

Wanted: Site-Level Weather Data

- **What wind datasets are available that we can prototype through our workflow?** → Compare anonymized data vs others^[1] (on/offshore)
- **How much uncertainty?** → What areas are of the highest importance to you?
- **How does this impact dispersion modeling that uses reanalysis?**
- This work is most useful using a wide range of locations— **help us better quantify uncertainty in ways that help you!**

References, Acknowledgments and Contact Information

- [1] Conrad BM, Johnson MR. 2025. Accounting for spatiotemporally correlated errors in wind speed for remote surveys of methane emissions. *Atmos. Meas. Tech.* [Manuscript in review]
- [2] NIST (overview guide): *Reanalysis Data Comparison Methods for Emissions Measurement Campaigns.* <https://nvlpubs.nist.gov/nistpubs/jr/2025/NIST.IR.8575.pdf>
- [3] Christman Field, CSU Atmospheric Science. www.atmos.colostate.edu/fccw/fccw_latest.php and https://coagmet.colostate.edu/station/fcc01_main.html

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Acknowledgments:

This work is in preparation for future data collection efforts onshore at METEC and other project locations, as well as offshore wind data measurement deployments managed by METEC.