Quantifying ERA5 Bias Under Urban & Coastal Conditions

Metrics and Quantifications

Team 36 - Codellera Andina

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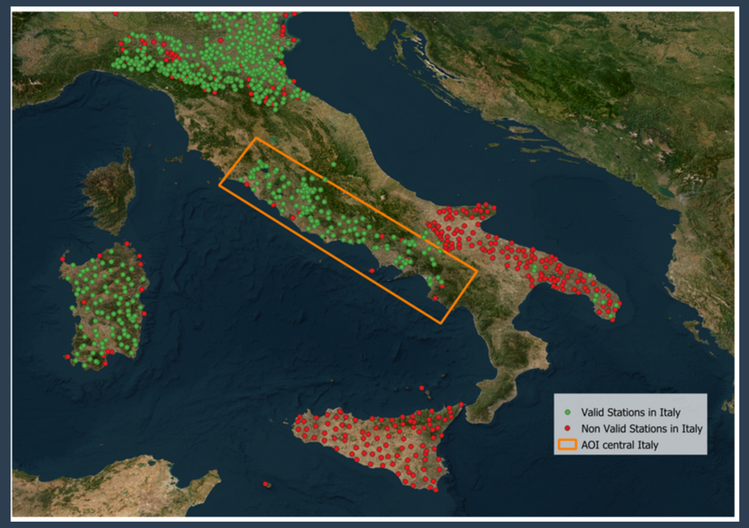
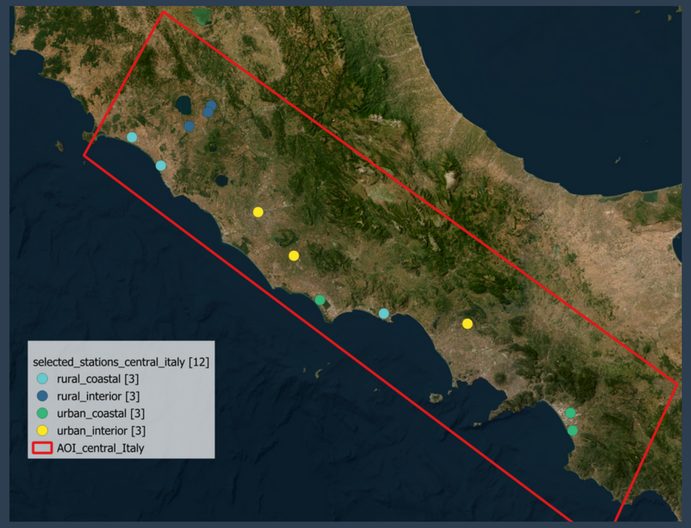
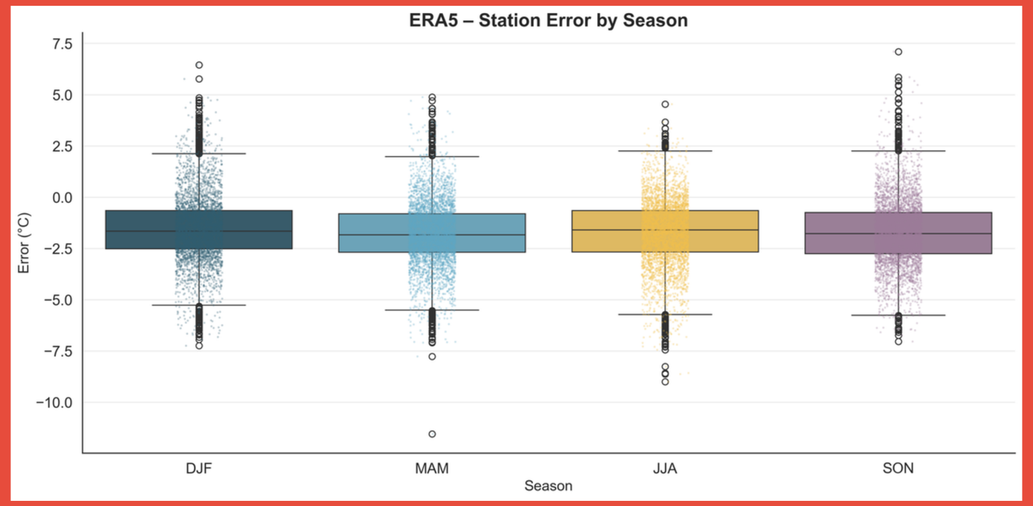
FROM SOUTH TO CENTRAL ITALY: A DATA-DRIVEN REDESIGN





Daily Dataset (2020–2023): 18 Features for the 12 Selected Stations

station_id	name	lat	lon	distance_to_sea_km	NDVI_mean	urban_fraction	env_class	date	season	T_station	T_ERA5	error	u10	v10	WS	wind_regime	precip
16924	CASTEL CELL	42.5855556	12.1605556	53.93899622	0.751874031	0.004584903	rural_interior	7/1/2022	JJA	33.5	33.239136	-0.2608643	0.9980418	1.0714154	1.4642467	NE	4.63E-05
16924	CASTEL CELL	42.5855556	12.1605556	53.93899622	0.751874031	0.004584903	rural_interior	7/2/2022	JJA	36.5	35.23767	-1.2623291	0.16913223	-1.7667603	1.7748374	S	3.43E-06
16924	CASTEL CELL	42.5855556	12.1605556	53.93899622	0.751874031	0.004584903	rural_interior	7/3/2022	JJA	37.2	36.708344	-0.4916565	0.2556858	-1.466451	1.4885745	S	1.27E-07
16924	CASTEL CELL	42.5855556	12.1605556	53.93899622	0.751874031	0.004584903	rural_interior	7/4/2022	JJA	37.9	36.946014	-0.9539856	1.2170881	-0.2821991	1.2493757	E	3.04E-07
16924	CASTEL CELL	42.5855556	12.1605556	53.93899622	0.751874031	0.004584903	rural_interior	7/5/2022	JJA	35.7	35.776154	0.07615356	1.4618124	0.16877492	1.4715232	E	1.20E-06
16924	CASTEL CELL	42.5855556	12.1605556	53.93899622	0.751874031	0.004584903	rural_interior	7/6/2022	JJA	35.3	34.27664	-1.0233582	-0.024488	-1.0219026	1.0221959	S	0.0001734
16924	CASTEL CELL	42.5855556	12.1605556	53.93899622	0.751874031	0.004584903	rural_interior	7/7/2022	JJA	32.8	33.135284	0.33528442	0.2501968	-0.1239989	0.27923858	SE	0.00169142
16924	CASTEL CELL	42.5855556	12.1605556	53.93899622	0.751874031	0.004584903	rural_interior	7/8/2022	JJA	26.5	26.746124	0.24612427	-1.401865	-3.8738232	4.119676	S	0.00024513
16924	CASTEL CELL	42.5855556	12.1605556	53.93899622	0.751874031	0.004584903	rural_interior	7/9/2022	JJA	28.1	28.0495	-0.0505005	-0.9090614	-3.534831	3.6498525	S	1.27E-06
16924	CASTEL CELL	42.5855556	12.1605556	53.93899622	0.751874031	0.004584903	rural_interior	7/10/2022	JJA	30.4	30.148773	-0.2512268	-0.0926984	-1.3195311	1.3227831	S	5.18E-07
16924	CASTEL CELL	42.5855556	12.1605556	53.93899622	0.751874031	0.004584903	rural_interior	7/11/2022	JJA	31.8	31.118866	-0.681134	0.8190365	0.38308164	0.9041971	NE	2.79E-05
16924	CASTEL CELL	42.5855556	12.1605556	53.93899622	0.751874031	0.004584903	rural_interior	7/12/2022	JJA	30.7	31.36081	0.66080933	0.8708102	0.27994028	0.9147005	E	1.28E-05
16924	CASTEL CELL	42.5855556	12.1605556	53.93899622	0.751874031	0.004584903	rural_interior	7/13/2022	JJA	32.3	32.086884	-0.2131165	-0.1107273	-1.6492214	1.6529343	S	3.37E-06



THE ERA5 – STATION ERROR

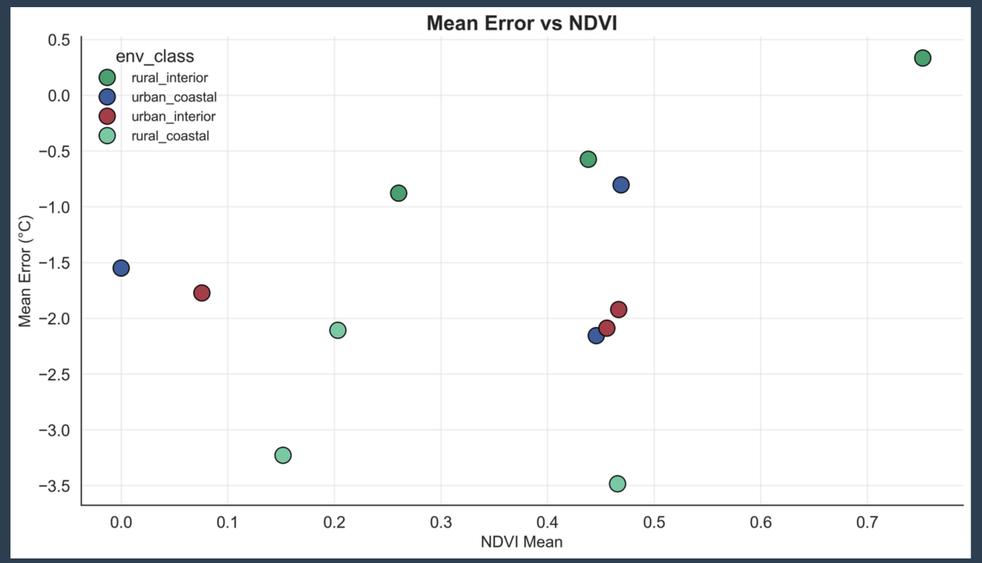
Systematically negative in all seasons.

The average bias ranges from –1.5 °C to –1.75 °C, indicating that ERA5 tends to underestimate daily Tmax in both winter and summer.

THE NDVI MEAN - ERROR

Greener areas shows lower error.

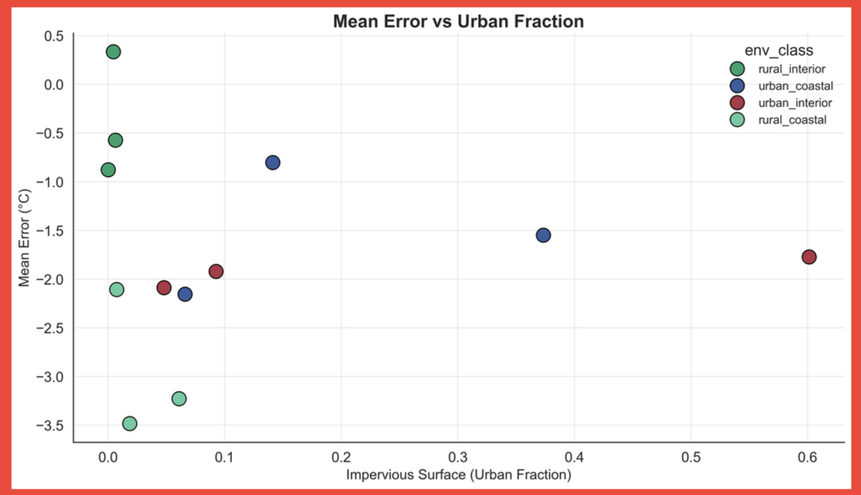
Stations with high NDVI (~0.7) have errors close to 0 °C, while low NDVI is associated with more intense errors (–2 to –3 °C).



Therefore, vegetation modulates thermal bias, consistent with UHI processes.

THE URBAN FRACTION

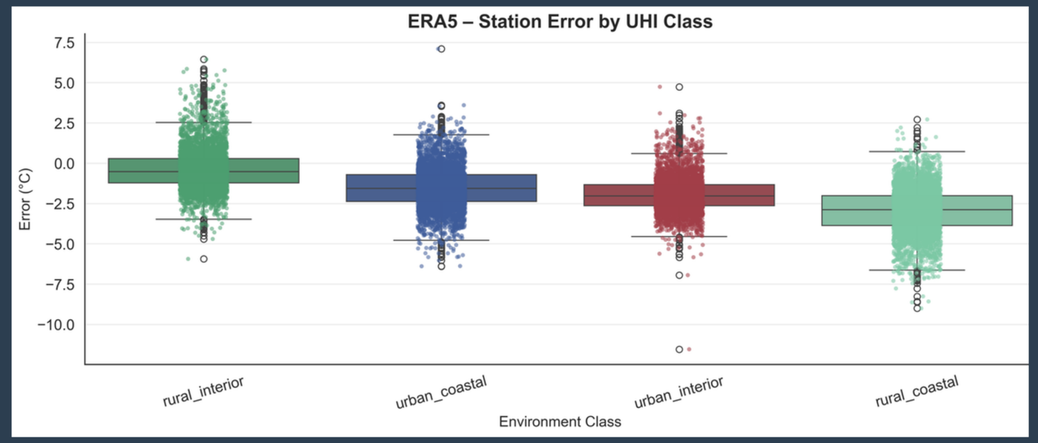
Shows a positive relationship with bias: more impervious surface means, more underestimation. Stations with urban_fraction ≥ 0.3–0.6 have more negative errors (≈ –2 to –2.5 °C).



Therefore, ERA5 underestimates more in densely urbanized areas due to its relatively coarse resolution and lower ability to capture local UHI.

THE UHI – STATION ERROR

Urban stations have higher errors than rural stations.
urban_interior and urban_coastal show higher errors (≈ –1.5 to –2.0 °C), while rural_interior has the lowest bias (≈ –0.37 °C).



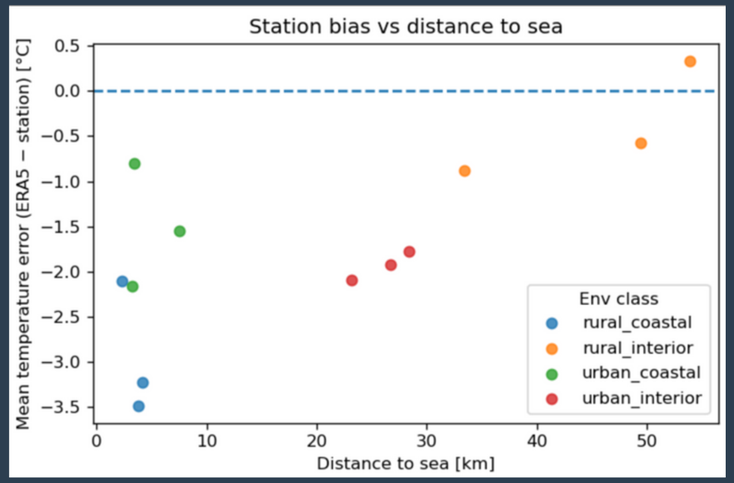
Therefore, the urban environment amplifies the negative bias of ERA5

METEOROLOGICAL ANALYSIS

BY DISTANCE TO THE SEA

dist_cat	error_mean	error_std	error_rmse	n
< 10 km	-2.218346	1.552554	2.707619	8630.0
10–50 km	-1.438600	1.250088	1.905798	7012.0
> 50 km	0.334215	1.357429	1.397504	1422.0

Near the sea, ERA5 tends to underestimate temperature by about 2 °C

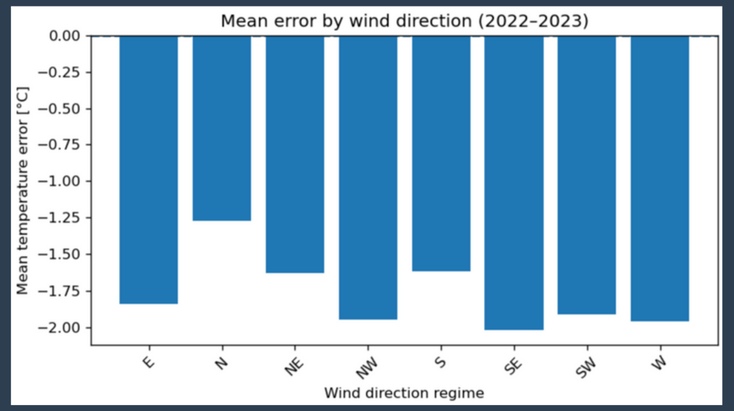


Inland stations (>50 km from the sea) the bias becomes slightly positive (around +0.3 °C)

BY WIND

WS_cat	error_mean	error_std	error_rmse	n
weak	-1.710095	1.624797	2.358627	2078.0
medium	-1.751598	1.750037	2.475881	4156.0
strong	-1.741684	1.524984	2.314719	2078.0

ERA5 exhibits a persistent cold bias of roughly −1.7 °C across all wind speeds.

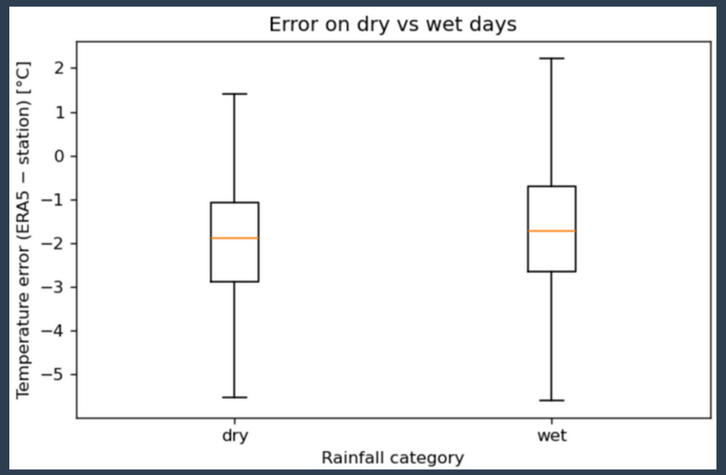


Northerly winds reduce it to about −1.3 °C, while southerly and westerly regimes push the bias toward −2 °C

BY RAINFALL

rain_cat	error_mean	error_std	error_rmse	n
dry	-2.006669	1.460937	2.480371	242.0
wet	-1.680592	1.589769	2.313353	16822.0

ERA5 performs slightly better on rainy days than on dry days

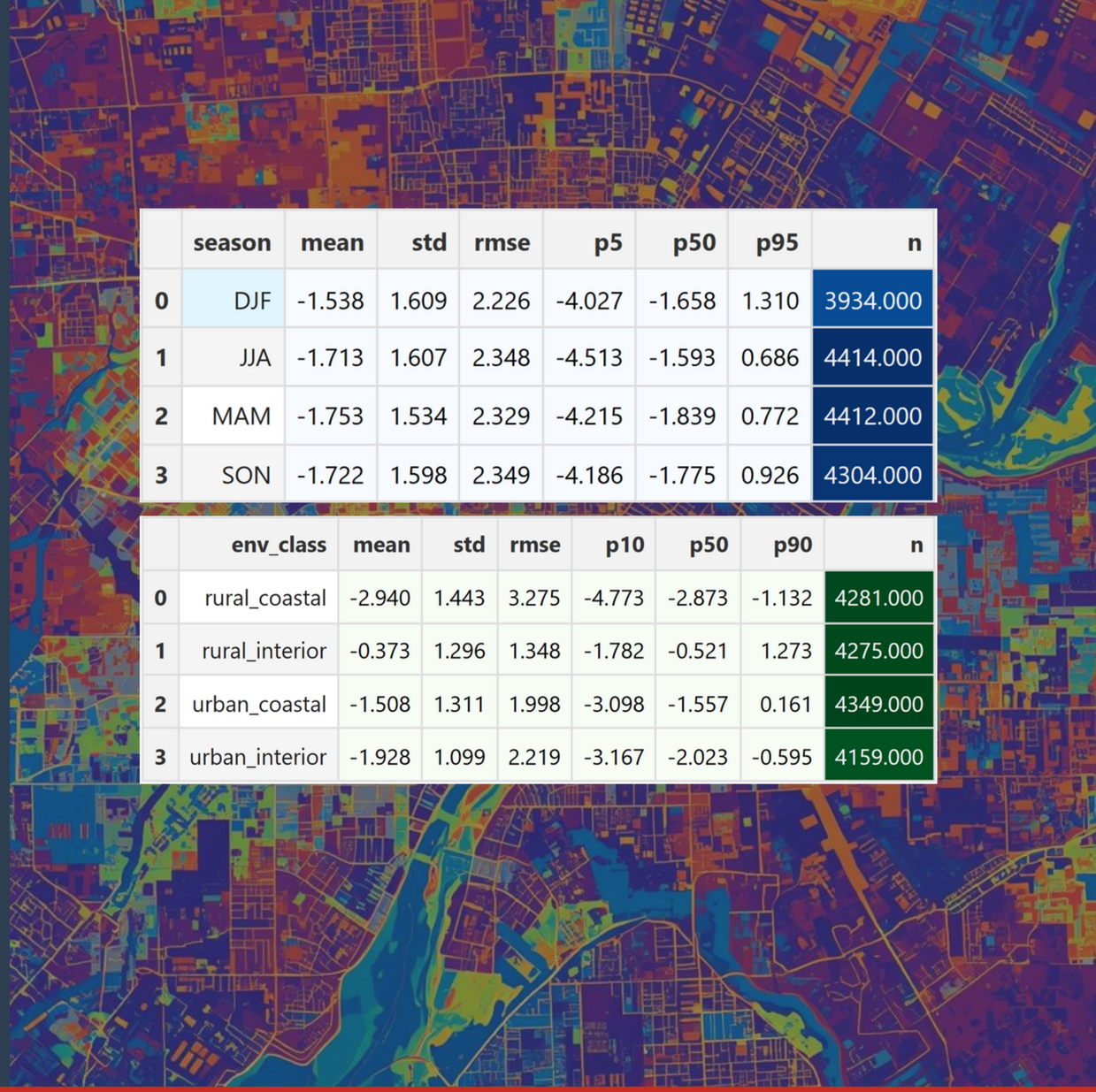


METRICS SHOW

ERA5 tends to systematically underestimate the daily maximum temperature in all seasons of the year, with an average bias of between −1.5 and −1.8 °C and greater variability in summer.

When analyzed by type of environment, error depends heavily on the local context:
rural inland stations → accurate
urban areas → intense and dispersed errors.

ERA5 captures large-scale temperature variability reasonably well, but its accuracy is sensitive to coastal influence, circulation regime, and precipitation conditions.



	season	mean	std	rmse	p5	p50	p95	n
0	DJF	-1.538	1.609	2.226	-4.027	-1.658	1.310	3934.000
1	JJA	-1.713	1.607	2.348	-4.513	-1.593	0.686	4414.000
2	MAM	-1.753	1.534	2.329	-4.215	-1.839	0.772	4412.000
3	SON	-1.722	1.598	2.349	-4.186	-1.775	0.926	4304.000

	env_class	mean	std	rmse	p10	p50	p90	n
0	rural_coastal	-2.940	1.443	3.275	-4.773	-2.873	-1.132	4281.000
1	rural_interior	-0.373	1.296	1.348	-1.782	-0.521	1.273	4275.000
2	urban_coastal	-1.508	1.311	1.998	-3.098	-1.557	0.161	4349.000
3	urban_interior	-1.928	1.099	2.219	-3.167	-2.023	-0.595	4159.000