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Ground-Based Estimation of Low-Altitude Turbulence Over Milan for Safer Airship and UAV Operations

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INTRODUCTION & AIM

Context: Low-altitude aerial vehicles (e.g., UAVs, solar airships) operate in the atmospheric surface layer (below 300 m AGL), where flights are highly susceptible to building-induced shear and thermally driven convection.

The Problem: Unsteady gust loads cause severe attitude excursions and structural stress. Conventional high-fidelity observation systems (Doppler radars, sonic anemometers) are expensive, spatially sparse, and impractical for continuous metropolitan deployment.

Aim of the Study: To develop a low-cost, computationally lightweight turbulence-intensity proxy (TI_b) derived purely from standard 10-minute ground meteorological data, providing actionable insights for risk-aware urban trajectory planning.

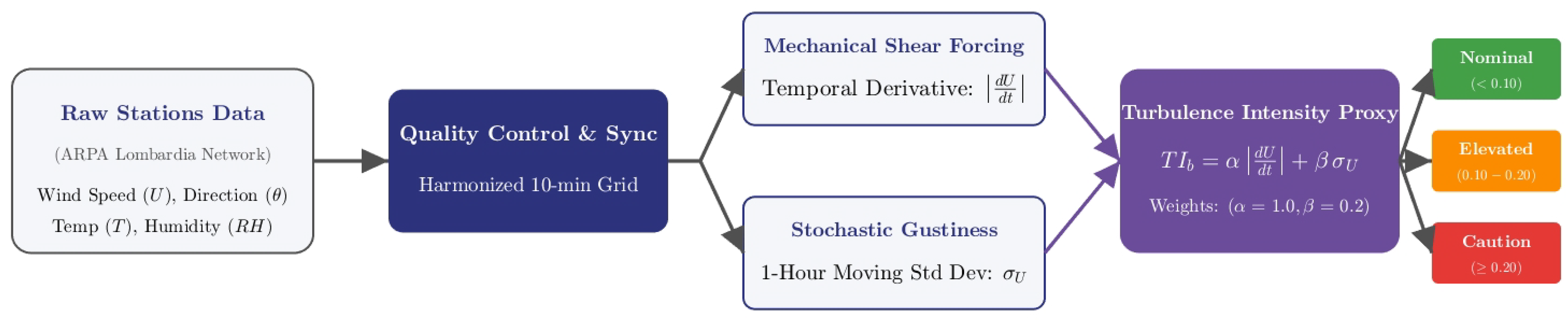
METHOD

We propose a blended shear-fluctuation diagnostic avoiding the need for 3D anemometer data. The proxy is defined as:

$$TI_b(t) = \alpha \left|\frac{dU}{dt}\right| + \beta\sigma_U$$

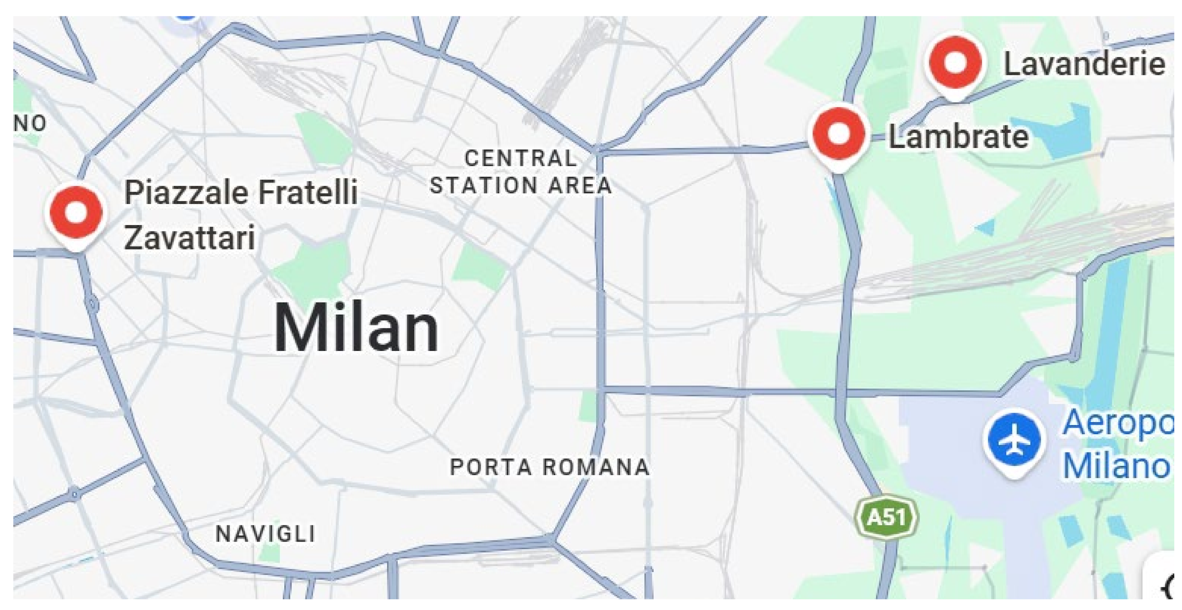
- $|dU/dt|$: First-order temporal derivative of the 10-minute mean wind speed U, capturing impulsive shear forcing.
- σ_U: Moving standard deviation of U over a trailing 1-hour window, capturing sub-hour stochastic gustiness.
- **Calibration Weights**: α = 1.0 (penalizing sharp transients) and β = 0.2 (baseline variance scaling).

Flowchart of the working principle:



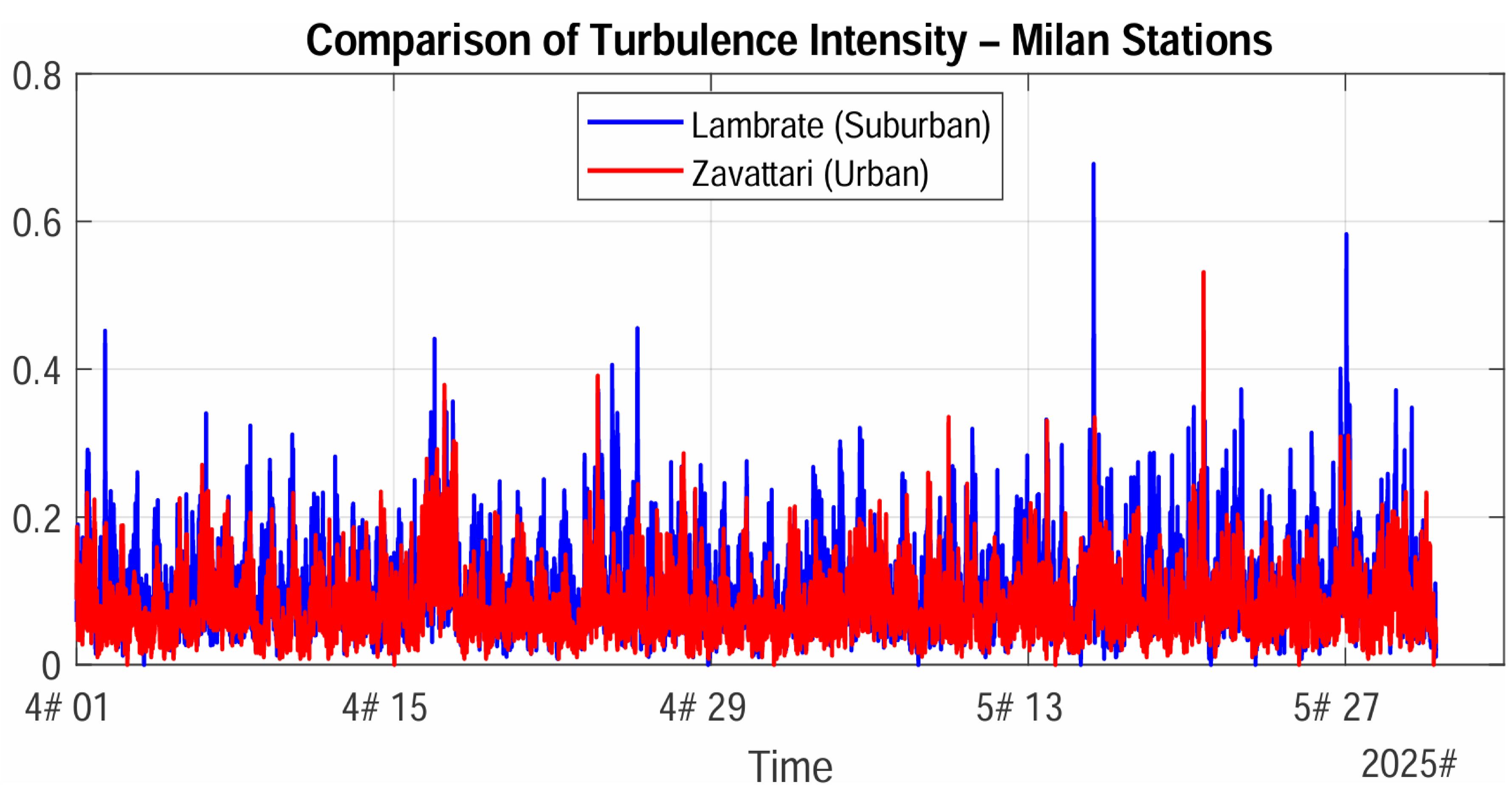
Data Source and Study Area:
Analyzed standard weather mast data from ARPA Lombardia (April–May 2025) at two aerodynamically contrasting sites in Milan:

1. **Lambrate (Site A):** Eastern suburban edge; open terrain, lower roughness.
2. **P.za Zavattari (Site B):** Dense urban core; complex building wakes.



RESULTS & DISCUSSION

Spatial Variability in Urban Turbulence:



- **Suburban Edge (Lambrate):** Exhibits higher mean turbulence (TI_b = 0.142) and is characterized by repeated, sharp high-amplitude bursts (peaks > 0.6). Open terrain allows stronger horizontal shear layers to develop.
- **Urban Core (Zavattari):** Displays a lower, smoother baseline (TI_b = 0.097, max 0.284). Dense buildings act as roughness elements that locally dissipate turbulent kinetic energy, creating a statistically "damped" environment.
- **Key Insight:** Gust hazards are highly non-uniform within a single city. Vehicles traversing from the core to the periphery face hostile shear events with no warning from regional METARs.

Operational Implementation
We map TI_b to actionable flight-planning heuristics:

- TI_b < 0.10 (**Nominal**): Routine operations feasible; high station-keeping accuracy.
- 0.10≤ TI_b < 0.20 (**Elevated Workload**): Anticipate strong control corrections and payload swing.
- TI_b ≥ 0.20 (**Caution**): Severe instantaneous shear. Recommend trajectory re-planning or reduced-speed transits.

CONCLUSIONS

- **Feasibility:** TI_b is a field-deployable metric that effectively translates routine meteorological data into aviation-relevant mechanical turbulence warnings.
- **Decision Support:** The proposed categorization provides simple go/no-go logic and routing criteria for low altitude operations, bridging the gap between standard meteorology and UAV/airship flight dynamics.
- **Urban Navigation:** High-resolution, ground-based hazard mapping is strictly necessary, as standard regional forecasts fail to capture localized mechanical shear gradients within the urban canopy.

FUTURE WORK/ REFERENCES/ACKNOWLEDGMENT

Future work:

- Integration of thermal/convective turbulence production models.
- Development of vertical extrapolation models to map ground-based TI_b to 50–300 m flight altitudes.
- Fusion with onboard flight-dynamics models to generate 3D "turbulence occupancy maps" for autonomous routing.

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