Low-level Wind Shear prediction based on Machine Learning techniques: a case study of Palermo-Punta Raisi International Airport

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MOTIVATIONS

Low-level wind shear (LLWS) is one of the major aviation hazards. Caused by a sudden change in the wind direction and/or intensity, it can severely impact airport flight operations causing missed approaches, diversions, holdings, and, in some cases, accidents.

The term "low-level" refers to wind shears that occur below 1600ft during the landing or departing phases of the flight. Since these phases are characterized by a low velocity and low altitude of the airplanes, it turns out that any changes in the wind components correspond to a change in the aircraft's stability with a potentially great impact in terms of safety.

Different phenomena can be responsible for the development of LLWS such as meteorological events (thunderstorms, wind-storms, etc.) or morphological conditions (terrain roughness, orography, etc.).

Since the existing LLWS alarm systems are based only on real-time wind analysis, no useful prediction about possible incoming LLWS events can be obtained.

LLWS video

Goal:

Testing the use of ML models to predict the occurrence of LLWS events

STUDY AREA

Palermo Punta-Raisi International Airport: 38° 10' 53" N - 13° 5' 58" E

ICAO Code: LICJ

Runways: RWY 07/25 with a length of 3326 meters
RWY 02/20 with a length of 2068 meters

Number of movements (arrivals and departures) in 2023: 59 506

Number of passengers in 2023: 8 098 261 (rank 9th in Italy)

Positioned along the Tyrrhenian coast of Sicily, close to the sea to the north and downstream of a mountain massif (with an average height of about 800 m) to the south, LICJ has a very long story regarding LLWS events.

TRAINING DATA

LICJ Meteorological Aerodrome Reports (METAR)
From 2007-2022, with a 30-min temporal resolution (HH.20 - HH.50)

- 10-min averaged Ground Wind Direction and Intensity
- LLWS warning messages based on the pilots' report

LICJ total number of movements (arrivals and departures)
From 2007-2022, with a 1-hour temporal resolution

ERA-5 Reanalysis Data (Copernicus)
From 2007-2022, with a 1-hour temporal resolution

- 875hPa Pressure-level Wind over a box of four grid points (V_{1-4})

DATA ANALYSIS

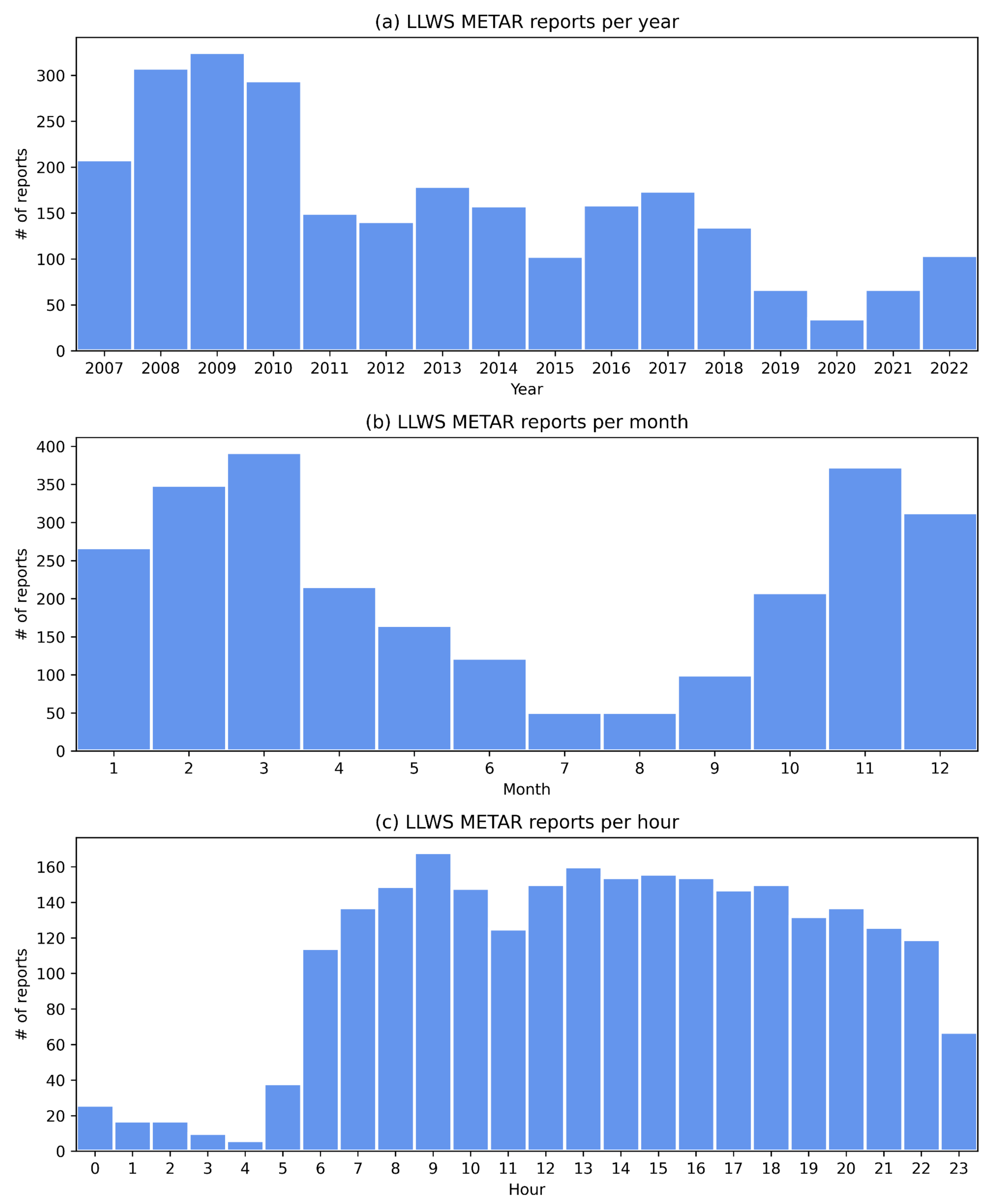


Fig. 1: Annual (a), Monthly (b), and Hourly (c) distribution of LLWS events on LICJ.

The monthly distribution shows a strong seasonality, due to the prevailing seasonal circulation patterns.

The annual and hourly distribution reflects the aerodromes' air traffic operation pattern, with a reduced number of reports during the year 2020 and during the 23-05UTC time, due respectively to the reduced number of flights caused by the Covid-19 pandemic phase and by the low night air traffic.

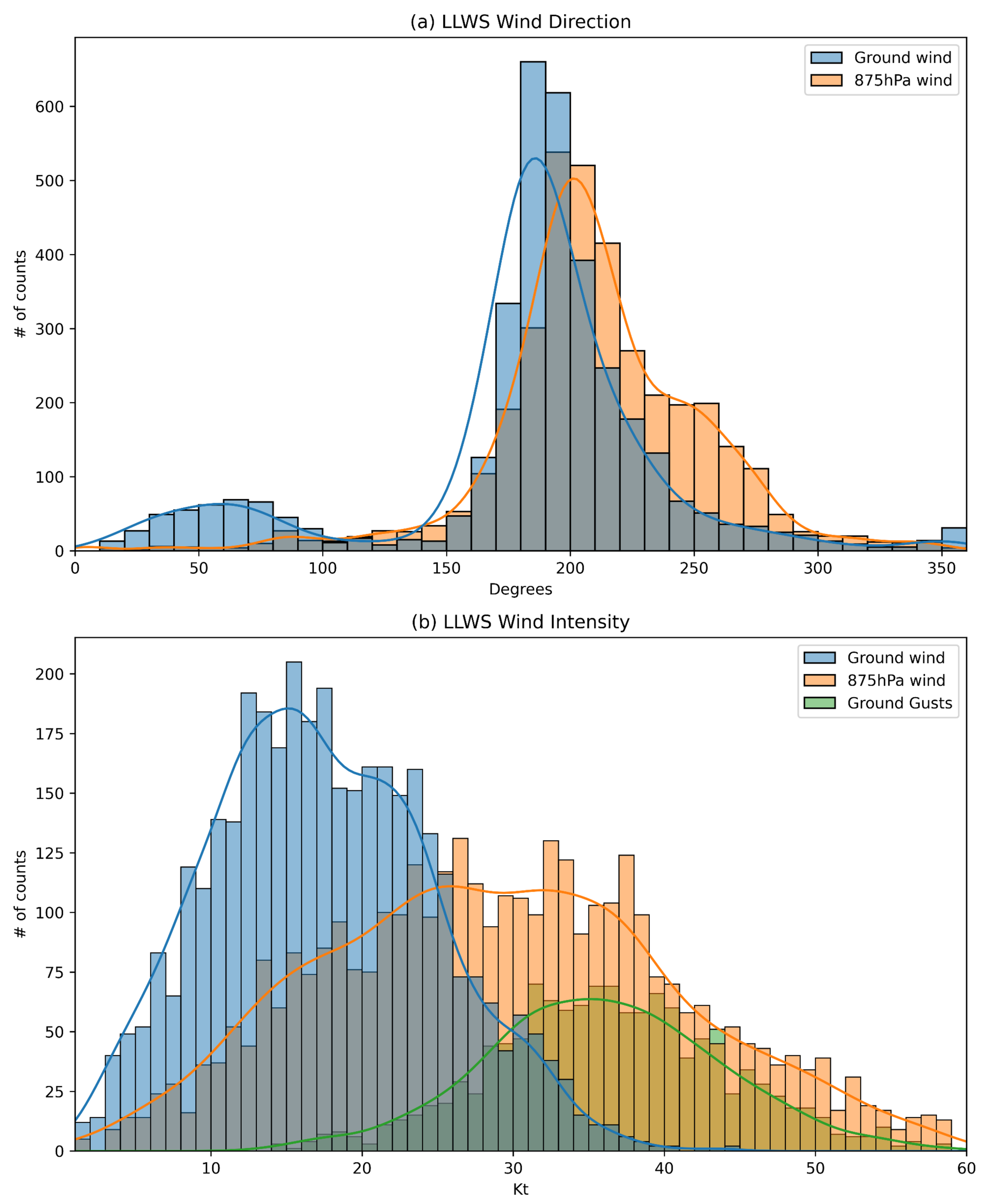


Fig. 2: Ground and 875hPa pressure-level (V_{1-4} average) distribution of (a) wind direction (degrees); (b) wind intensity (kt), during the LLWS events on LICJ from 2007 to 2022.

The major peak in the wind direction (Fig. 2a) reflects the position of the mountain massif relative to the aerodrome, while the small secondary peak in the surface wind direction (in blue) is related to the effects of the sea breeze.

Wind intensity (Fig. 2b) shows a wide distribution, with surface wind gusts (in green) occurring in just about half of the events.

METHODS & RESULTS

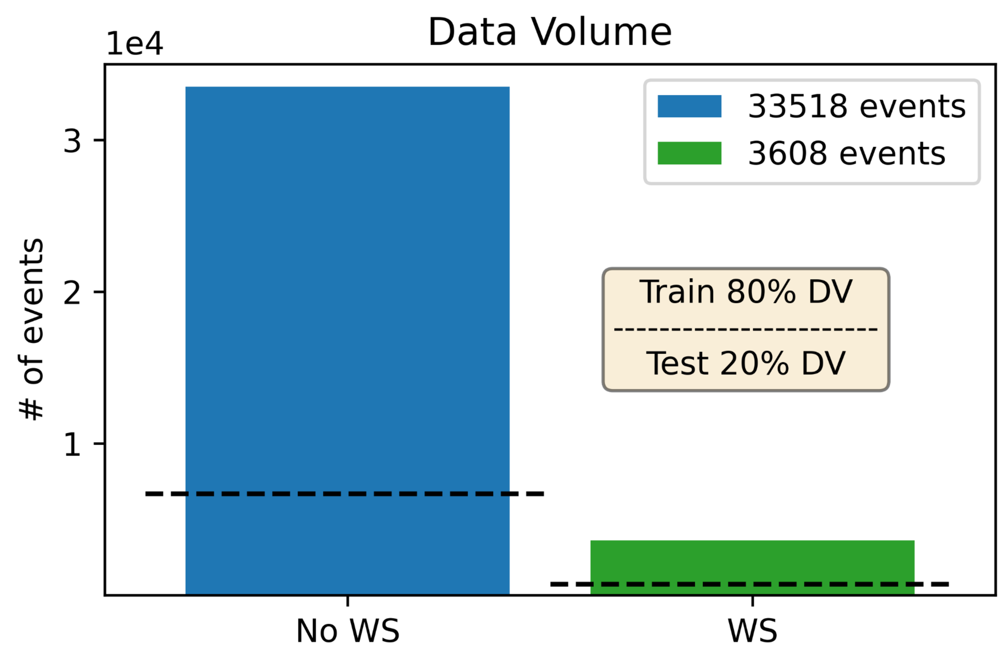


Fig. 3: Data Volume for NoWS-WS events used for Training & Testing ML models.

The Train & Test datasets correspond to 80% and 20% of the Data Volume, respectively, sampled using stratified random techniques.

Unbalanced binary classification problem

- **Original Dataset**: 248447 No-WS, 2607 WS events
  - **Downsampling** of the majority class (No WS), filtering out data with #movements <10/h
  - **Upsampling** of the minority class (WS), aggregating data from the time-step immediately before the LLWS report
- **Final Dataset:** 33518 No-WS, 3608 WS events
  - **Stratified random sampling** for the Train & Test datasets
  - **Class weight balance** for the training of ML models

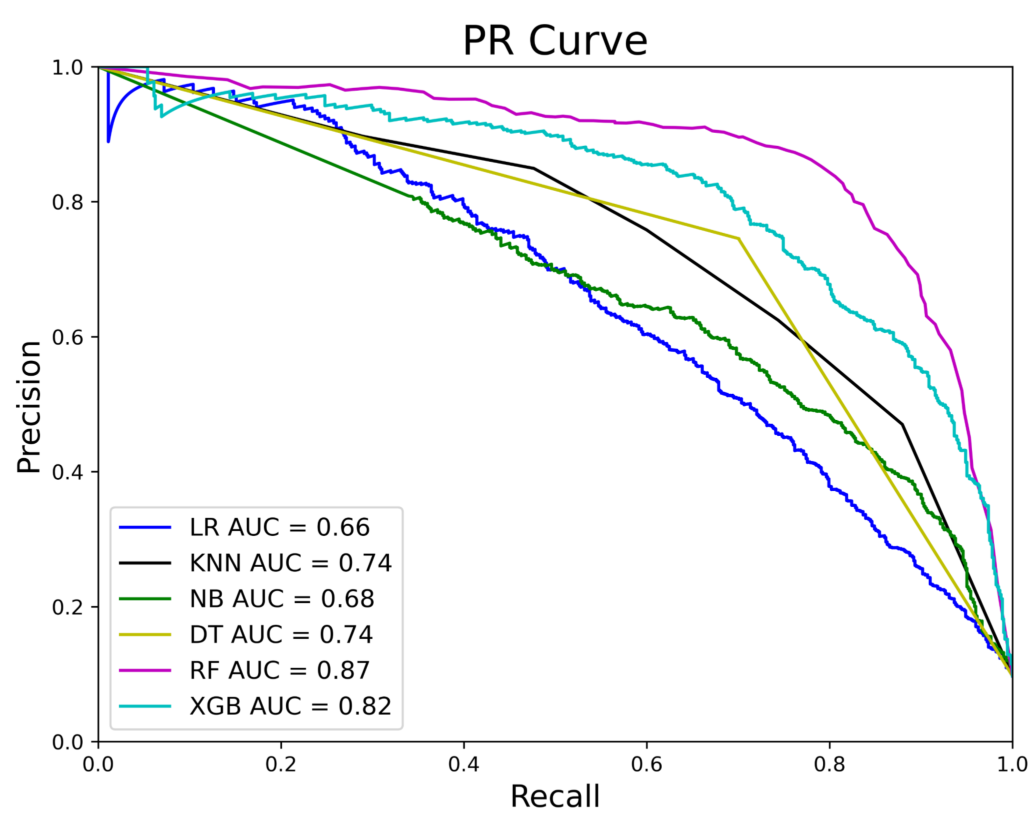
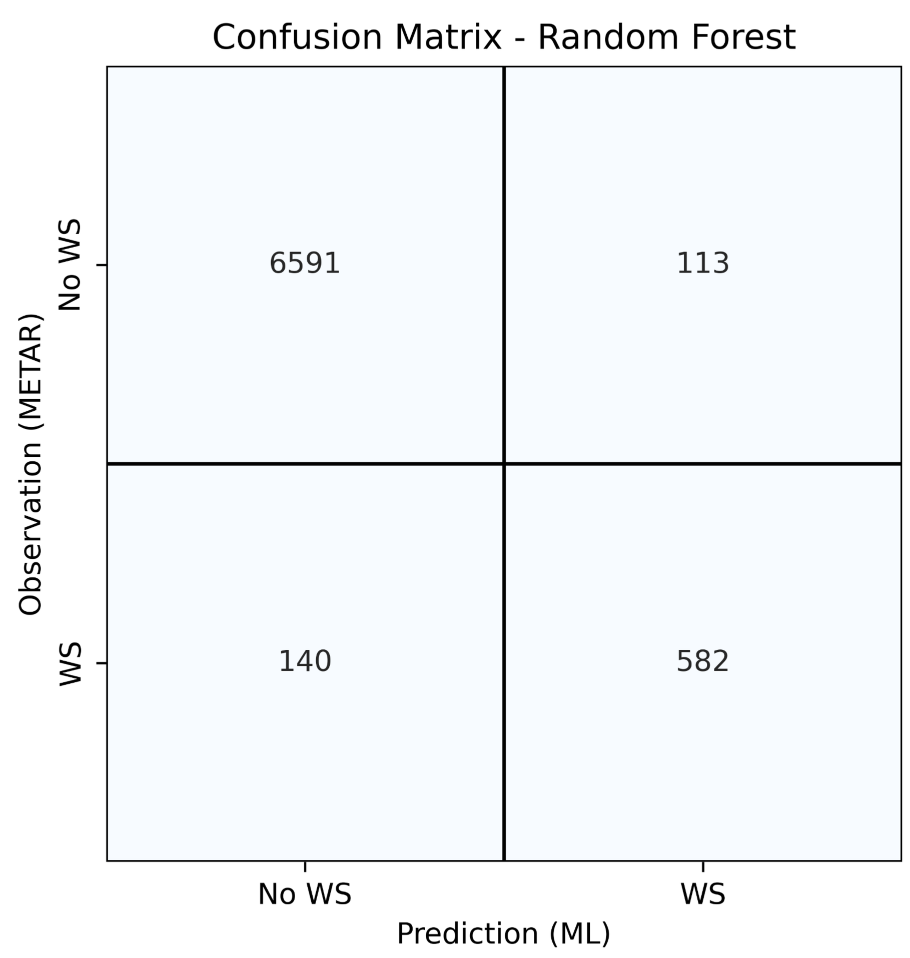


Fig. 4: Precision-Recall curve and AUC score for Logistic Regression (LR, blue), K-nearest neighbors (KNN, black), Naive Bayes (NB, green), Decision Tree (DT, yellow), Random Forest (RF, purple) and XGBoost (XGB, cyan) classification model.



CONCLUSIONS

1. The use of Machine-Learning models can be very useful in predicting the possible occurrence of LLWS events
2. Model training is performed using wind data obtained from both ground station measurement and Pressure-level NWM, along with LLWS reports and hourly aerodrome movements
3. The case study developed on the site of Palermo Punta-Raisi International Airport shows good applicability of the methodology presented, obtaining good values of the PR-AUC for almost all the models tested, with the Random Forest the best performer one

Future Work:

Development of a fully operational tool for the prediction of LLWS events, to support the provision of ATS (MET) and ATC (TWR) services by Enav

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