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Specific extreme wind probabilities for the Ariane 6 space launch system at the French Guiana Space Center

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SUMMARY:
In the context of Ariane 6 space launch system development, the launch vehicle and its different sub-structures are exposed to winds during transfer or waiting phases and lift-off. The duration of exposure may vary from a few hours to a day. Meanwhile, those winds generate loads on the structures, and may cause disastrous events due to structural damage. To evaluate the risk that the mean wind speed exceeds a certain value in the exposure period, we estimate the statistical distribution of the daily maximum of the mean wind speed in the launch zone located in the French Guiana Space Center. This distribution is month-dependent to account for local (equatorial) climate and enables one to derive mean wind speeds associated to extreme probabilities of exceedance ($\leq 10^{-2}$).
Based on a Measure-Correlate-Predict-like method, we estimate those statistical distributions with a 90% confidence interval.

Keywords: space launch system, winds in the atmospheric boundary layer, extreme probabilities estimation

1 CONTEXT

Ariane 6, newest launch vehicle of the European space launch vehicle family Ariane, will take over from Ariane 5 at the French Guiana Space Center (CSG). As every structure exposed to winds, the launch vehicle and its different sub-structures must sustain loads generated by winds during transfer, waiting and lift-off. These winds are those in the lowest portion of the atmospheric boundary layer at the CSG (from 0 to 100 meters above ground level).

1.1 *Problematics*

Loads generated by the winds on the launch vehicle may lead to disastrous events such as structural damage to the launch vehicle, environment pollution, nearby infrastructures damage and human injuries or death. In consequence, the risk that the mean wind speed (10-minutes average) exceeds a certain value near the Ariane 6 launch zone (ELA4) while the launch vehicle is exposed must be estimated (Johnson, 2008). Literature for design wind speed for temporary structures deals with structures that would be exposed for a week or more or would be erected at different sites, like stages or construction cranes for example (Barré and Artarit, 2015, Boggs and Peterka, 1992, Li, 2022, Wang and Pham, 2011).
However, the maximum duration of exposure for Ariane 6 is 24 hours and it only takes place in its launch zone, making the problematics very specific.

Hereafter, we estimate the statistical distribution of the daily maximum of the mean wind speed above the ground of the ELA4, for each calendar month in order to account for local seasonality and particularity of the equatorial climate (no hurricane or cyclone) (Mayne, 1979, Skandrani et al., 1999).

1.2 *Data*

1.2.1 *Measurements near launch pad*

We have 4 years of measurements of the 10-minutes average mean wind (speed and direction) every 10 minutes near the launch pad, at 55m above local ground level. Since the life expectancy of the operational phase of a European launch system program generally exceeds a decade, and according to global consensus on minimum dataset size for extreme wind studies (Cook, 1982, Gomes and Vickery, 1977, Palutikof et al., 1999), this dataset is not sufficiently long to ensure a correct statistical description of extreme wind events. Thus, we need to use another and longer database.

1.2.2 *Measurements at the reference site*

Historically, the reference site in CSG for meteorological measurements such as wind is the KOUROU-CSG meteorological station, located 8km away from the launch site (see Fig. 1).
The dataset of mean wind at this location is constituted of more than 45 years of measurements of the 10-minute average mean wind (speed and direction) at 10 meters above ground level.

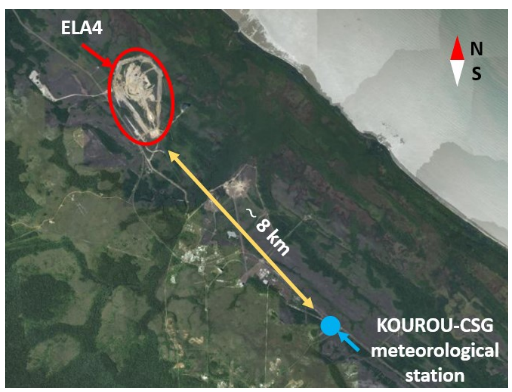

Figure 1. Satellite view of the launch site and the reference site. Photo from geoportail.gouv.fr

2 METHODOLOGY

2.1 *Estimations of the daily maximum mean wind at the reference site*

First, we evaluate the daily maximum of the mean wind speed and its associated direction, for each day of the dataset at the reference site. However, this dataset does not have a unique sampling step (time difference between two consecutive values). This issue is called *disjunct sampling* (Larsen and Mann, 2006), or *downsampling* (Chiodi et al., 2011, Chiodi and Ricciardelli, 2014). It varies over years, from 3 hours to 6 minutes. Consequently, the daily maximum of the mean wind could have been missed because it occurred between two successive measurements.

To compensate those *downsamplings*, we use the 6-minute-sampled data at the reference site, from which we obtain the daily maxima of the mean wind speed and their directions. These maxima will be called “real daily maxima”. Then, we resample the data with the desired sampling steps (for example, 3 hours), and we also derive the daily maxima of the mean wind speed and their directions. These will be called “undersampled daily maxima”. Eventually, the relations between the real daily maxima and the undersampled daily maxima are investigated (both for speed and direction). Results show very good agreements with Weibull distribution fitting for speed and Normal distribution fitting for direction. These statistical distributions are called “temporal transfer functions” and enable us to estimate the daily maximum of the mean wind speed (and its direction) from the “undersampled daily maximum” for years where there is *downsampling* in our dataset. Since the temporal transfer functions are statistical distributions, we use a Monte Carlo process to cover a wide range of estimations for the daily maximum of the mean wind speed at the reference site.

2.2 *Transfer function from reference site to launch pad*

An analytical relationship (in speed and direction) is derived between daily maxima measured at the reference site and near the launch pad. This geographical transfer function depends on the direction of the daily maximum of the mean wind at the reference site, and enables us to transfer the estimations from the Monte-Carlo to the launch pad.

2.3 *Estimation of the statistical distribution & confidence interval*

A large dataset of daily maxima estimations is now available at the launch site. Splitting this dataset by calendar month, we fit each subset distribution with an extreme value distribution. Results show that the General Penultimate Fisher Tippett type 1 Distribution (Cook and Harris, 2004, Fisher and Tippett, 1928, Gumbel, 1958, Holmes, 2015) is an excellent fit.

3 VALIDATION STEPS AND CONCLUSION

We validated each transfer function (temporal and geographical) independently from each other, before validating the complete methodology. To do so, we compared probability density functions (PDF) and cumulative density functions (CDF) of estimations and measurements. Fig. 2 shows that the estimations are very satisfying.

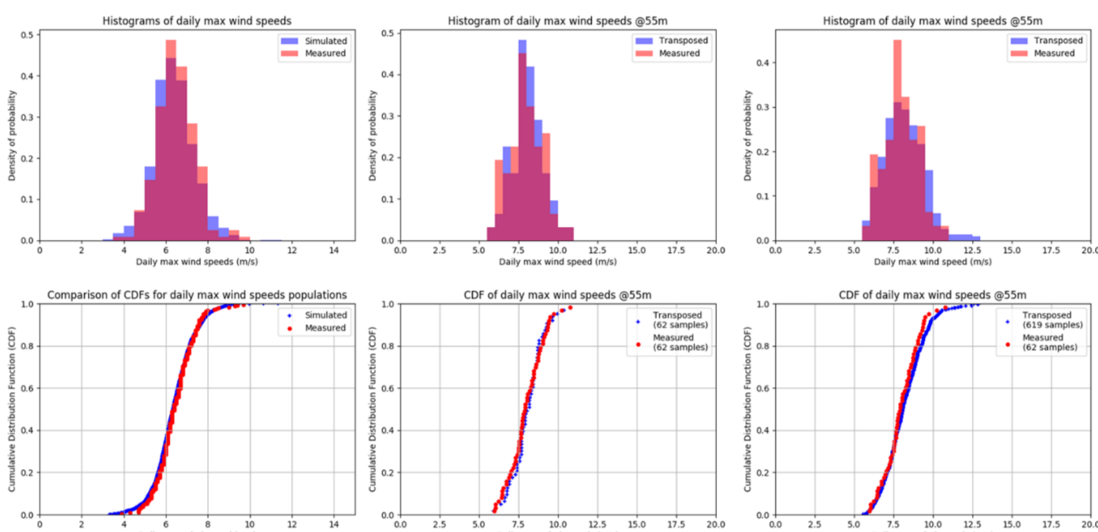

Figure 2. Temporal transfer function (left), geographical transfer function (middle) and complete methodology (right) validation steps. Results for a 1-hour sampling step in January.

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