Planning UAV surveys: can we rely on wind forecasts?

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ABSTRACT

Like in other surveying works, UAV flights require prior work that involves flight planning and equipment preparation and, often, many complementary tasks. These may involve bringing together technicians from different domains, booking a car and possibly accommodation, and some time-consuming complementary bureaucratic work. Teams operating UAVs know how much the flights are affected by weather conditions. The wind is the weather variable that, in proportion (number of occurrences per year), causes the major number of changes to a scheduled work. Obtaining reliable information about the intensity of the wind, a few days in advance, is an asset for those who have to carry out the various tasks mentioned previously. There are several websites from which one can access weather forecasts. Is any website better because it presents more reliable data? The data and the analysis presented in the paper will give some clues. The data includes wind speed, registered daily, at 12:00 (pm) for a year, by a meteorological station with online data, which belongs to a meteorological institute. Also on a daily basis, several websites with meteorological data were consulted, and wind speed forecasts for the same hour for up to four days in advance were collected. An analysis of the data can provide information about whether there is a website that stands out for the quality of the forecasts, and if there is a need to consult several websites to have better information.

I. Introduction

Given the effect of atmospheric elements on aerial UAV surveys (light way of referring to a photographic survey using an unmanned aerial vehicle as a carrier of a digital camera), it is imperative that the organization of the travel to carry out photographic surveys includes the collection of meteorological information to assess whether there are adequate atmospheric conditions at the location of the survey. And, if the survey team belongs to an entity that has heavy bureaucratic procedures, that needs several authorizations to provide allowance, a vehicle, sometimes accommodation, to activate insurance for the team members, not to refer the authorizations from official entities, the evaluation of the local conditions is even more important. And, as if this was not enough, it is also important to have in consideration the existence of adequate light conditions during the survey, or, when this happens in coastal areas, the level of the tide. For all the reasons is very important to have access to reliable weather forecasts.

Wind (see Figure 1) and rain are the weather elements that most influence a UAV flight. Of these two, we focused solely on the wind factor (in the form of the speed of wind). The reason why we didn't have interest in analyzing precipitation forecasts is because is very easy to obtain information about the real situation (based in satellite infra-red images and ground-based radar images), being simple to predict the occurrence of rain.

Being the focus the wind forecast, we had to choose a station with reliable data. We chose the online station Peniche (see second section). Data from this station and from several free weather websites (see third section) was gathered. We registered the measurement made at noon and, also, the predictions for that hour up to four days in advance. The analysis is presented in the fourth section and the conclusions in the last section.

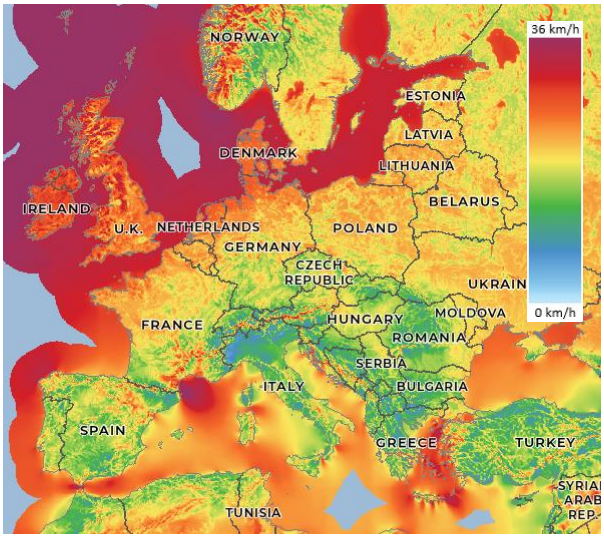

Figure 1. Wind speed at 50 m height (https://globalwindatlas.info/)

II. The weather station

We chose the online weather station Peniche from the Portuguese Institute for Sea and Atmosphere (IPMA). On its website, one can access atmospheric data measured hourly in several online stations (as for beginning of 2022): 136 in Portugal mainland; 21 in Madeira islands; 23 in Azores islands. The data available is air temperature, precipitation, wind speed, air humidity and atmospheric pressure (this one only available in some stations).

The Peniche station (Figure 2) is located on the rocky peninsula where the city with the same name was built. The peninsula is a relatively flat plain, at 30 m of altitude, with low vegetation. The station is only 60 m away from the sea (Figure 3).

Next to the city is a major fishing port, the westernmost port in continental Europe. This port is protected by two breakwaters being the western frequently hit by huge waves. This breakwater is often chosen as case study for projects, such as BSafe4Sea, a funded project that aims to develop, test and prove the concept of forecasting the structural behaviour of rubble mound breakwaters, which will form the basis of an innovative decision support system (LNEC, 2020).

Figure 2. Peniche weather station

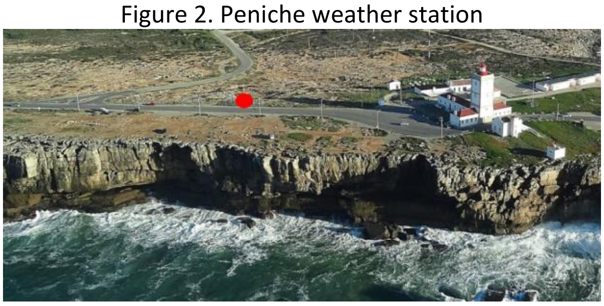

Figure 3. Peniche peninsula near the weather station (red dot in the photo)

III. The weather websites

There are many websites with wind forecasts. We chose seven websites with free access. One of this (windy.com) can present, at the same time, data from several services of weather. Concerning the models of forecast used, some websites provide complete information, while others not that much. We also included, between square brackets, the name of the model used by the services, the resolution, and the update frequency (the number of times the model runs per day). If data of the wind gust is available, we join the letters WG.

As an example of the models used: i) ECMWF (developed by the European Centre for Medium-Range Weather Forecasts); ii) Arome (Application of Research to Operations at Mesoscale, used operationally by Meteo France, is the result of the cooperation between organizations from France and other countries); iii) WRF (Weather Research and Forecasting Model, developed by U.S. entities); iv) GFS (Global Forecast System, run by the U.S. National Weather Service, a service from NOAA); v) ICON-EU (ICOsahedral Nonhydrostatic, a model worldwide created by the German Weather Service, with a higher-resolution model for regional forecasts for Europe, ICON-EU).

The websites were:

a) ipma.pt developed by the Portuguese state laboratory IPMA whose mission is to promote and coordinate scientific research, technological development, innovation and service on the seas and atmosphere. It provides forecasts for mainland Portugal and islands. In situations of significant differences between forecast and reality, forecasts made available for district capitals and islands can be corrected by meteorologists [Arome, 2.5 km, and ECMWF, 9 km; 2];

b) meteo.tecnico.ulisboa.pt developed by a research group of the university of Lisbon (IST) that works in high-resolution meteorological modeling and forecasting. It provides forecasts for Portugal mainland, only [WRF, 9 km; 4];

c) wunderground.com developed by The Weather Underground, that has its roots at the University of Michigan, and was acquired by The Weather Channel in 2012 [IBM GRAF, 3 km; 24];

d) windy.com owned by Windy, a Czech company. The website can present data from several weather services (namely, through the "compare" link available at the bottom of the webpage) being that the values of the wind gust are not presented in the "compare" mode. In the case of Peniche, windy presents forecasts of five models:

d1) the US National Oceanic and Atmospheric Administration, NOAA [GFS, 22 km; 4; WG];

d2) the European Centre for Medium-Range Weather Forecasts [ECMWF, 9 km; 4; WG];

d3) MeteoBlue, developed by Swiss company Meteoblue [combines over 25 different weather models; 2; WG];

d4) Deutscher Wetterdienst, DWD, the German Weather Service [ICON-EU, 7 km; 4; WG];

d5) Meteo France: in France and nearby countries is used a model [Arome, 2.5 km; 8] while in the rest of the world another model is used [Arpège, from 7.5 km in France to 35 km in the antipodes; 4];

e) otempo.pt owned by the Canadian enterprise Pelmorex Corporation. It has weather websites dedicated to several countries in the world [OnPoint, 5 km];

f) ventusky.com developed by the Czech meteorological company InMeteo, focused on weather prediction and meteorological data visualization. The main providers of meteorological data are DWD and NOAA [WG];

g) windfinder.com developed by a German company to provide information on weather and waves in relevant spots for water sports and outdoor activities. The provider of meteorological data is NOAA [WG].

Except for the services a), b) and d5), all the others provide worldwide forecasts. All the models use data, official and/or personals, from weather stations, radars, satellites (Figure 4). Several websites refer in their FAQ and other help information, the need for correct inconsistencies because data is not homogeneous neither in space nor in time (Meteo France, 2015). Some also refer the use of orographic databases.

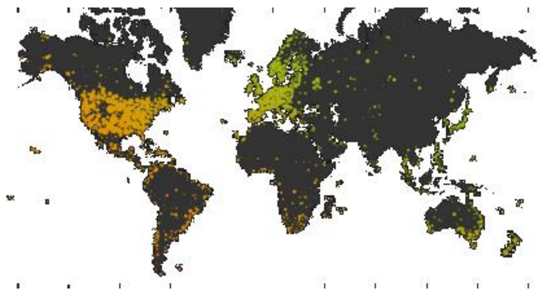

Figure 4. Wunderground: location of the personal weather stations

Concerning the forecasts, it was recorded the speed at 12 h of the first four days available. Some websites can have up to two weeks of forecast. Some websites have the possibility of choosing hourly forecast or a presentation more condensed (three to four sets of data/day). In these websites we collect the data only from the hourly forecasts. On the third day and beyond, some websites reduce the frequency of the data provided (to, usually, every three hours).

IV. THE DATA

A. *From the weather station*

During a period of 369 days, almost every day, data at the 12 h was registered. There are very few periods with no data, a few due to forgetfulness (a total of 4 days) others because no data from the Peniche station was available when the website was consulted (4 days).

The values of the wind speed registered in Peniche are presented in Figure 5. The frequency of days in the five classes of wind speed by month, are presented in the graph of Figure 6. For instance, April was the month with a larger number of days with light wind. The classes were chosen according to a classification made by IPMA, presented in Table 1. The most common drones used for surveys, monitoring, etc., can fly with light or moderate wind speed, a smaller number also with strong wind.

There are days when, in a short period of time, very significant variations may occur. See an example in Figure 7, a graph presented by IPMA with values measured at Peniche station for a day in January 2021, where one can notice a decrease of almost 20 km/h in one hour.

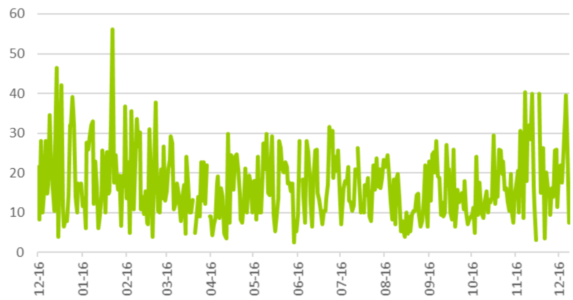

Figure 5. Wind speed (km/h) measured in Peniche

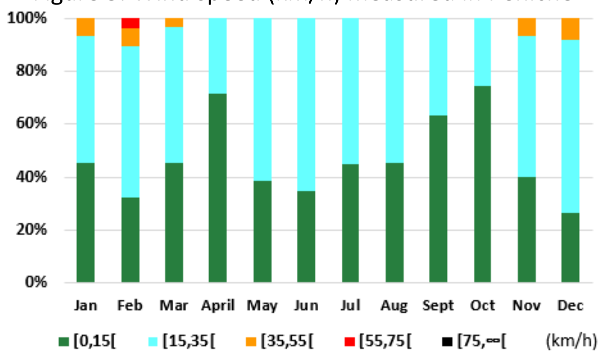

Figure 6. Frequency of the five groups of speed (km/h) in each month

Table 1. Classification of the wind speed (km/h)

Speed	Classification
[0,15[	Light wind
[15,35[	Moderate wind
[35,55[	Strong wind
[55,75[	Very strong wind
[75, ∞[	Exceptionally strong wind

Figure 7. Wind speed (km/h) and direction registered during 22 hours in Peniche (winter of 2021)

B. *From the websites*

Each day all the seven websites were consulted and the data of the forecasts of the next four days were registered. Taking as example IPMA, IPMA.1 refers to the forecast for the following day, IPMA.4 the forecast for the 4th day. Concerning the lack of data on the websites, model b-IST was the less reliable, with no data in 25 days (some of these due to an update of the website). For a period of six days in February of 2021, there was no data in d5-MeteoFrance.4. All the websites provide forecast data in an hourly format, except for d-windy that, in compare mode, provides values with three hours intervals.

Comparing the forecasts, it is noted that, sometimes, on the same day, there are large differences between the values presented on the websites. Sometimes this is because a model predicts that an event (either a large increase of the speed, or a large decrease) will occur sooner than another model does. The data presented in Figure 8 was designed with information from d-windy and illustrates well the differences between forecasts. It presents the values of the wind speed predicted by the five models every three hours for 3,5 days. In the first two days the predictions were very similar; the third day the differences between models attained 16 km/h; the last period was again more homogeneous. During the third day, four models presented a large decrease in three hours, with a large increase the following day.

The data included in the graph of Figure 8 was transferred to a graph (presented in Figure 9) which was supplemented with the speed measured at Peniche station. This graph also highlights a general fact (it happened in 77% of the days) that the dispersion of the values of the data (forecasts) is lower with the proximity of the dispersion day.

The largest difference between predicted values occurred for the 3rd day forecast of 30 November 2021. The predicted values vary between 9 km/h (d2-ECMWF) and 50 km/h (b-IST). In Figure 10 we present the forecast (4d until 1d) of all websites and the value measured (which was 14 km/h). The best forecast was presented by a-IPMA.

Each model presents also, sometimes, big changes from a day to the next. The biggest one was a variation of -33 km/h on model g-windfinder: a day it was predicted a value of 54 km/h, the following day a value of 21 km/h. In Figure 10 we can also notice this kind of occurrence: a variation of 30 km/h presented by d5-MeteoFrance from 3d to 2d.

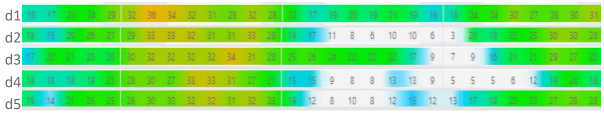

Figure 8. Wind speed (km/h) presented by the five models included in Windy.com (data starts the 30 July 2021, at 9 h)

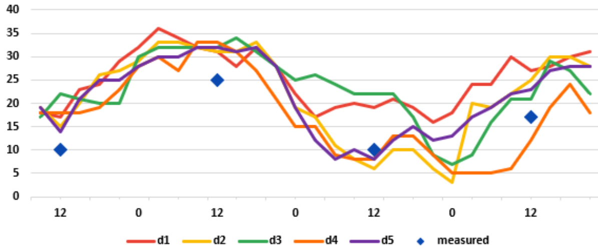

Figure 9. Wind speed (km/h) forecast every 3h (graph with data presented in Figure 8), supplemented with the values measured at 12 h

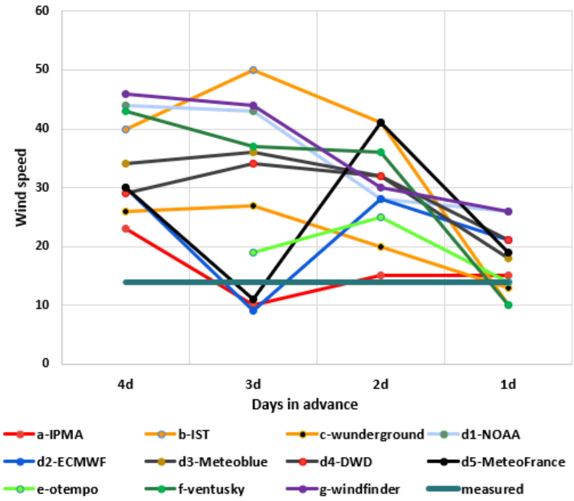

Figure 10. Wind speed (km/h) forecast for 30 November 2021 supplemented with the value measured

We also calculated the correlation between models. For each pair of models, we calculated the correlation coefficients between the predicted values along the year, for each of the four days of forecast. Some results of the analysis are presented in Table 2. This is divided in two areas: i) upper triangle (reddish colors): the average of the fours values of correlation; ii) lower triangle (greenish colors) the amplitude of the four values.

From the information available on the websites, we know that some only explore new formats of presenting the forecasts, more friendly for the users. It is the case of d-windy, f-ventusky and g-windfinder. The data they present are calculated by other services. For instance, the results of model ICON-EU, calculated by DWD, are presented by d4-windy and f-ventusky. The results of model ECMWF are presented by d1-windy and g-windfinder. Consulting Table 2 we can see that, in both cases, the values of correlation are high, in the interval [0.9,1]. But the highest correlation is between models ECMWF and Arome (presented by windy, models d2 and d5).

Table 2. Correlation between values presented by the websites (upper triangle). Amplitude of the four values of correlation (lower triangle)

	a	b	c	d1	d2	d3	d4	d5	e	f	g
a		0,74	0,89	0,78	0,90	0,73	0,80	0,90	0,91	0,79	0,75
b	0,22		0,82	0,78	0,76	0,75	0,75	0,75	0,85	0,76	0,76
c	0,18	0,09		0,89	0,91	0,83	0,88	0,90	0,95	0,88	0,85
d1	0,16	0,19	0,07		0,82	0,81	0,83	0,82	0,90	0,87	0,94
d2	0,24	0,03	0,07	0,18		0,76	0,84	0,98	0,95	0,82	0,79
d3	0,18	0,19	0,08	0,08	0,18		0,77	0,77	0,83	0,77	0,77
d4	0,24	0,17	0,09	0,15	0,15	0,15		0,84	0,89	0,90	0,80
d5	0,23	0,01	0,07	0,18	0,02	0,18	0,16		0,94	0,82	0,79
e	0,11	0,03	0,01	0,05	0,01	0,10	0,05	0,01		0,89	0,88
f	0,21	0,22	0,11	0,14	0,21	0,15	0,21	0,21	0,07		0,84
g	0,17	0,21	0,08	0,03	0,20	0,16	0,16	0,19	0,06	0,10	

a-IPMA; b-IST; c-wunderground; d1-NOAA; d2-ECMWF; d3-Meteoblue; d4-DWD; d5-MeteoFrance; e-otempo; f-ventusky; g-windfinder

V. THE ANALYSIS

Data of the websites was compared with the data measured. The frequency of occurrences is presented in Figure 11. Negative values mean that the value predicted was lower than the measured; positive higher than the measured. All the models tend to be “pessimistic”, as they predict higher wind speed than the value measured.

The following analysis were performed using the R software package (R Core Team, 2018).

The comparison between the time series of observed and predicted wind speed values provides information on the forecasts quality along the year. The comparison is performed through the determination of dissimilarity measures between a pair of time series, such as the distance between them (Esling and Agon; 2012; Fu, 2011). In this case, Euclidean distance between the time series of observed and predicted wind speeds was used. The Euclidean distance between two time series corresponds to the sum of the Euclidean distances between each observed value and a prediction for the corresponding day, for all days in the considered time interval.

It was verified that, for each model, the dissimilarities decrease with the proximity to the chosen day (Figure 8), showing the forecasts improve as the that day gets closer.

For each day in advance, the dissimilarities between the time series of observed and predicted values were compared for the several models. It was observed (see Figure 12) that for the forecasts up to three days in advance, a-IPMA leads to the smallest dissimilarities, which suggests that its predictions are the most similar to the observed values along the year in analysis. Four days in advance, both a-IPMA and c-wunderground present the lowest values.

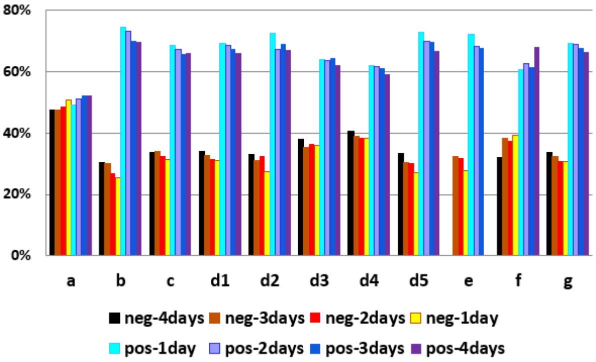

Figure 11. Frequencies of over and underestimation of wind speed for each model up to four days in advance

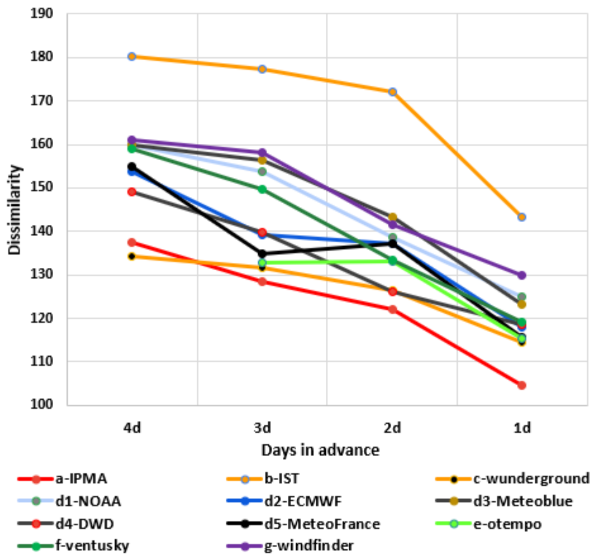

Figure 12. Dissimilarities between the time series of observed wind speeds and the time series of forecasts, for each day in advance

These results are in accordance to Figure 11, which shows that a-IPMA tends to equally over- and underestimate the wind speed values. The balance between over- and underestimations leads to a large similarity between observed and predicted time series. On the other hand, the other models tend to overestimate the wind speeds (Figure 11), which results in a larger distance between the forecasts and the observations.

The dissimilarities between the time series of observed and predicted wind speeds provide an assessment of each model’s performance along the year. To evaluate the quality of individual forecasts, scatter plots between observed and predicted values were computed. They show that the dispersion of the forecasted values decreases with the proximity to the prediction day (Figure 13), i.e., forecasts become closer to the observed values. For almost all models, the forecasted values are larger than the observed ones (more dots are above the red lines), suggesting the models tend to overestimate the wind speeds, as already seen in Figure 11.

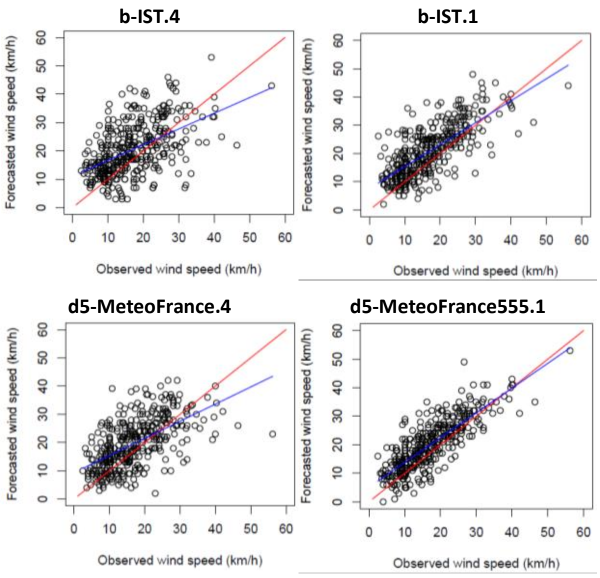

Figure 13. Scatter plots of observed and forecasted wind speeds for b-IST and d5-MeteoFrance models; the numbers in the chart titles are the number of days in advance of the forecast; the red lines correspond to the situation where forecasted values are equal to the observations and the blue lines are the regression lines

Table 3. Slope and coefficient of determination (R^2) for the regression lines, for two models

Model	.4	.3	.2	.1
b-IST				
Slope	0.55	0.65	0.74	0.78
R^2	0.26	0.34	0.41	0.53
d5-MeteoFrance				
Slope	0.61	0.72	0.77	0.87
R^2	0.34	0.49	0.52	0.67

The regression lines (blue lines in Figure 13) also provide information about the quality of the forecasts. The closer the slope of the regression line is to 1, the larger is the similarity between the forecasts and the observed wind speed values. It is verified that the slope gets closer to 1 as the number of days before the chosen date decreases. The values of the coefficient of determination provide insight into the dispersion of the forecasts. The larger the coefficient of determination, the lower is the dispersion of the predicted values and forecasts have larger precision. Dispersion tends to decrease with the proximity to the chosen day.

The best situation would be a regression line matching the diagonal line (blue line equal to the red line) i.e., regression line with a slope of 1, in conjunction with a low dispersion. This can be parameterized by coefficient of determination, R^2, where 1 is the best value. The values obtained for two models, b-IST and d5-MeteoFrance, are presented in Table 3. This data (slope and R^2), for all models, is presented in the Figure 14. To identify the data of each model more easily the points were connected by lines. In all models the highest values for "slope" are obtained for the forecasts of the previous day (day .1)

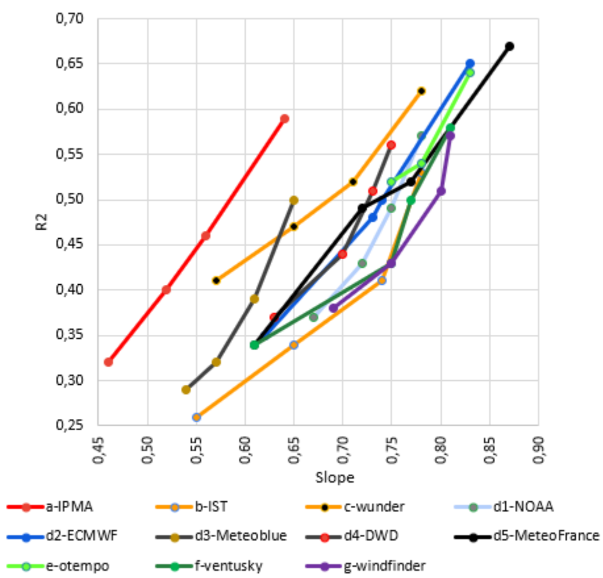

Figure 14. Relationship between slope and coefficient of determination for the regression lines associated to each model

VI. CONCLUSIONS

In this paper we present the analysis of values of wind speed presented in several websites. The data is the wind speed at 12h, from the forecasts one day until four days of Peniche, in Portugal. Peniche has a meteorological weather station with data available online every hour.

From the analysis of the values of the wind speed measured and predicted we concluded that we could reduce the number of websites visited, due to correlation between data presented in different websites and, also, because some don't present very high values of similarity with the values measured.

It was also noted a tendency of the models to over-estimate the speed of the wind. The authors think this over-estimation is better than the under-estimation: it is less harmful not to travel, even it turns out that, on the day, the conditions were adequate to carry out flights. Worse is to travel to find that there are not good conditions to flight.

On the days that proceed the chosen day, it is advisable to consult, daily, several websites. Those websites that also provide wind gust (data that is available on few websites) should be included.

We finish answering to "Planning UAV surveys: can we rely on wind forecasts?": Yes, we can.

VII. ACKNOWLEDGEMENT

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