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Quality aspects of the measurements of a wind profiler in a complex topography

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Abstract

It is well known amongst the scientific community that some remote sensing instruments have assumed that sample volumes present homogeneous conditions within a defined meteorological profile. At complex topographic sites and under extreme meteorological conditions, this assumption may be fallible depending on the site, and it is more likely to fail in the lower layers of the atmosphere. This piece of work tests the homogeneity of the wind field over a boundary layer wind profiler radar located in a complex terrain on the coast, under different meteorological conditions. The results reveal the qualitative importance of being aware of the deviations of this homogeneity assumption and evaluate its effect on the final product. Patterns of behaviour in data have been identified in order to simplify the analysis of the complex signal registered.

The quality information obtained from the homogeneity study under different meteorological conditions is useful to look for the best alternatives the system can offer to build wind profiles. Finally, the results are also to be considered in order to integrate them in a quality algorithm implemented at product level.

1 Introduction

The Punta Galea wind profiler uses a Doppler beam swinging (DBS) technique, in a configuration of 5 beams: north, south, east, west and vertical (Strauch et al., 1984; Wuertz et al., 1988; Ecklund et al., 1988).

Improvements in operation are constantly implemented so as to be able to identify non-meteorological targets which have degraded the data. The accuracy of the wind profile depends on the fulfilment of the homogeneity assumption in the DBS technique across the region defined by the beam directions (Cheong et al., 2008).

Besides, several quality studies were proposed at the university with the aim of complementing the quality control algorithm of Weber and Wuertz (1991) or Weber et al. (1993) by testing the consistency between modes in common levels and testing the homogeneity for the wind field over the radar.

The main objective of this work is to study whether the homogeneity hypothesis is fulfilled in a complex site such as the Punta Galea wind profiler. For that purpose, the study compared the vertical components of wind (direct from the vertical beam W_v and derived from the oblique beams W_ns and W_eo), and it classified the situations by behavioural patterns in several meteorological situations. Deviations of the systematic initial hypothesis were identified within the first kilometre related to determined meteorological situations. The detection and evaluation of these deviations associated with each datum had to be considered as other quality metadata information which could be added to the database. The results obtained show how important the homogeneity of the surroundings is in order to fulfil the hypothesis of homogeneity in the lower layers. Therefore, the homogeneity of the wind field must be tested in boundary layer wind profiler radars with similar technical characteristics and a similar geographical situation. We also believe that the methodology used could be indirectly generalized to other DBS remote systems.

2 System description

The LAP-3000 wind profiler radar was installed in 1996. It is located in Punta Galea, a cape on the coast of Biscay, close to one of the urban areas with the highest population density in Basque Country: Bilbao. It is a boundary layer wind profiler with radio acoustic sounding system (RASS) option; a description of the system was made by Alonso et al. (1998). Figure 1 shows the complex site of the Punta Galea wind profiler.

The operating frequency is 1290 MHz. It works in two alternate modes, taking into account height coverage with the best resolution. Low mode (high resolution) uses the shorter pulse (60 m) and reaches 2 km. High mode has a lower resolution (200 m) and reaches higher altitude up to 8 km, under favourable conditions.

Measurements of wind profiles and temperature profiles are obtained every 30 minutes. To obtain information on the wind, the radar sends microwave pulses towards the sky in five directions by means of a multidirectional transmitting antenna. One of the microwave beams is vertically directed to the zenith (a direct measurement of the vertical wind, W_v). The other four beams are directed to the four cardinal points. This information is combined to calculate horizontal wind. Stored data cover all types of data of signal processing, from the time series to the final product (consensus data).

In spite of the fact that the system has been working since 1996, the most recent database is controlled by E-Winprof. Aside from this, the Basque Meteorological Agency (Euskalmet) has established a procedure for preventive maintenance in order to know the antenna and phase shifter conditions at pre-established intervals. These check-ups assure the quality of the historical database at an instrumental level making the interpretation of the data for scientific purposes easier, among other benefits.

Taking into account the bulletins and Euskalmet's observations, the days selected for the study were classified according to the direction and intensity of the wind according to the automatic weather station, and the complexity of the return signal from meteorological targets such as clear air echo, precipitation cases (Ralph et al., 1996, Wuertz et al., 1988), non-meteorological targets such as ground, sea clutter and birds (Wilckzak et al., 1995; Kretzschmar et al., 2003), or a mixture of some of them. In addition, other free sources of meteorological information from the Internet were used when such analysis was required.

3 Methodology

The scheme carried out to study the homogeneity of 5 beams "$W_\mathrm{v} = W_\mathrm{ns} = W_\mathrm{eo}$" ($W_\mathrm{v}$ vertical beam, W_ns vertical beam derived from the north and south, W_eo vertical beam derived from the east and west) is described throughout 5 modules, as can be observed in Fig. 2.

3.1 Module 1: database selection

In order to identify behaviour patterns, more than one meteorological year of study was needed. Therefore, databases from three meteorological years were used in this study (from 2009 to 2011).

Complementary meteorological information was considered, together with a previous analysis of consensus data, mainly in the lower layers the atmosphere. The classification in groups of similar features under similar meteorological conditions was obtained after statistical and visual exploration of the wind profiler data. Besides, additional information such as spectral data (.spc files) was required so as to verify some suspicious patterns associated with each group. The numerous groups obtained led to the organization of the cases in a priority order. The groups of days with poor availability data in the lower layers were analysed first, followed by cases of strong winds. Precipitation cases and bird migration cases were analysed last, due to the fact that the signals were contaminated by targets other than clear air.

Testing period (7 days from December, 2009)

The following selection criterion was taken into consideration: a severe meteorological episode including situations of south wind, north wind and precipitation was analysed. The previous analysis allowed defining a robust work strategy for the mass treatment of days. During this episode, the information was explored to assess whether a homogeneous behaviour existed or not ($W_\mathrm{v} = W_\mathrm{ns} = W_\mathrm{eo}$).

Many statistical tools were developed to decide which one was the most useful for classification purposes. The design was defined by selecting the statistical parameters which emphasized differences between measurements from all beams; the box-plot tool was a favourite because it comprised all the descriptive parameters in a simple plot.

At this stage, the consensus information was chosen because of its higher manageability and also because of its capacity to filter random signals that can mask standard situations. In spite of the fact that spectral signal analysis through a sequence would have been more convenient for this study, only information with a 100 % consensus for the 5 beams was considered to ensure we only included persistent behaviours and to reduce low SNR (signal to noise ratio) situations. Low SNR could lead to inconsistency cases where the interpretation would have a random component, which is not the main goal of this study.

In an operational sense, the main advantage of this decision would be the fact that the results could be implemented at the consensus level, as a complement to the Weber and Wuertz (1991) or Lambert et al. (2003) algorithms. Finally, at the end of this module, preliminary groups were defined.

3.2 Module 2: equations and transformations

After selecting the period of study, the equations for the calculation of the vertical components, W_v (vertical beam), W_ns (vertical component derived from the north and south beam), W_eo (vertical component derived from the east and west beam), were calculated for the whole database:

$$\left.\begin{aligned} V_\mathrm{RN} &= v\cdot\cos\theta + w\cdot\mathrm{sen}\theta + \delta_{V_\mathrm{RN}} \\ V_\mathrm{RS} &= -v\cdot\cos\theta + w\cdot\mathrm{sen}\theta + \delta_{V_\mathrm{RS}} \end{aligned}\right\} \rightarrow w = W_\mathrm{NS} \tag{1}$$

$$\left.\begin{aligned} V_\mathrm{RE} &= u\cdot\cos\theta + w\cdot\mathrm{sen}\theta + \delta_{V_\mathrm{RE}} \\ V_\mathrm{RO} &= -u\cdot\cos\theta + w\cdot\mathrm{sen}\theta + \delta_{V_\mathrm{RO}} \end{aligned}\right\} \rightarrow w = W_\mathrm{EO} \tag{2}$$

$$\left.V_\mathrm{RW} = w + \delta_{V_\mathrm{RW}}\right\} \rightarrow w = W_V \tag{3}$$

$$W_\mathrm{NS} = W_\mathrm{EO} = W_\mathrm{V} \tag{4}$$

where $\theta \rightarrow$ off zenith angle of the beam, $\left(\delta_{V_\mathrm{RN}}, \delta_{V_\mathrm{RS}}, \delta_{V_\mathrm{RE}}, \delta_{V_\mathrm{RO}}, \delta_{V_\mathrm{RV}}\right) \rightarrow$ error measurements for each beam, $\boldsymbol{V}(u,v,w) \rightarrow$ wind Vector and $(V_\mathrm{RN}, V_\mathrm{RS}, V_\mathrm{RE}, V_\mathrm{RO}, V_\mathrm{RV}) \rightarrow$ radial components. Directions are as follows: N is north, S south, E east, O west, and V vertical.

Equations (1), (2) and (3) together describe the 3 vertical velocities. Equation (3) shows the direct measurements from the vertical beam. Equation (4) is the homogeneity equation.

Besides, these three vertical velocities were used to calculate the differences among them: $W_\mathrm{v} - W_\mathrm{ns}$, $W_\mathrm{v} - W_\mathrm{eo}$ and $W_\mathrm{ns} - W_\mathrm{eo}$. Throughout these variables the homogeneity of the wind field was studied to check if the wind profiler fulfilled the item hypothesis ($W_\mathrm{v} = W_\mathrm{ns} = W_\mathrm{eo}$).

The whole previous study was done at high and low modes, although the low gates of both modes were studied and questioned in more depth.

3.3 Module 3: pre-analysis and interpretation

In this module we analysed the results obtained during the testing period. A cleaning process was performed after examining all the data during some severe episodes. The study was reduced to data with a maximum consensus number, thereby achieving an accurate analysis.

In spite of this, the testing period (module 1) considered a wide and complete statistical study, but the enormous amount of information obtained was unmanageable. This is the reason why in this module only some of the statistical tools of module 1 were selected, following the criterion of usefulness.

Besides this, a higher relevance of the low mode was observed, caused by the influence of the coastal site, which produced important alterations in the results. On the other hand, during certain periods when the predominant target was a non-clear-air target, such as bird migration, both modes and the full profile were analysed.

The case study groups were analysed in order, using quality criteria as the low availability of consensus data or poor quality data (suspicious groups of data after visual inspection). The reference group was a breeze group because of the high SNR inherent to humid sea winds. This situation was considered homogeneous because it offered high-quality data most days.

The second group was the north group versus the south group according to the low availability and multiple peaks in the lower layers. Groups of suspicious data were frequently detected on visual inspection.

Other groups were classified according to the origin of the inconsistencies associated with non-clear-echo targets. Precipitation group and bird group were also included in this category. Finally, in the west group versus east group, most of the west group days were included in the precipitation group, and the east component did not show great inconsistencies due to the anticyclonic conditions typical of the study area.

The results presented in this communication are mostly focused in the north and south groups because the origin of inconsistencies was mainly related to the "site impact".

3.4 Module 4: homogeneity

After an exploration of the database suitable for analysis (Module 3), and the use of different statistical tools, a final tool for analysing and filtering data was designed. For each group a repetitive normal behaviour was associated, and patterns of homogeneity deviations were detected. More complex groups also had to be analysed according to their characteristic problems (precipitation and bird groups).

The main goal of this module was to develop a tool which discriminates between consistent and non-consistent behaviour along the three vertical components. The tool was supported by visual and numerical descriptive analyses, Tukey plots and statistical parameters.

To achieve the overall objective, a quality homogeneity parameter had to be defined. In general, a quality parameter gives quality information regarding the data (invalid, suspicious, valid data). The quality homogeneity parameter was a threshold which flagged the data in one of these categories according to the homogeneity test being applied. This type of quality parameter was easy to implement using a numerical code in the same way as the quality control module implemented by the system.

The quality threshold was calculated statistically using observable deviations in the homogeneity hypothesis ($W_v = W_{ns} = W_{eo}$) in an empirical way. The homogeneity pattern and a potential threshold were then extracted for each study period. The homogeneous case was identified along with the meteorological situations in which the distances between the three measurements were minimum and constant along time and height. In other words, it was a standard feature associated with the system and the signal process. Therefore, the value found was explained by means of technical specifications and operational parameters within the signal processing. The most homogeneous case was the breeze group in which the threshold could be fixed at $0.5\,\mathrm{m\,s^{-1}}$, with a tolerance of $0.25\,\mathrm{m\,s^{-1}}$ in the low mode. A total of $0.25\,\mathrm{m\,s^{-1}}$ was the approximate value of the resolution in $\mathrm{m\,s^{-1}}$ obtained by taking into account the range of measurements and the number of points in the fast Fourier transform.

4 Results

At this stage, the results obtained from the study of the wind profiler historical database from 2009 to 2011 were presented. The results corresponded to the study periods described in the methodology.

The study was focused on the low mode, because the homogeneity hypothesis fails more often in this mode. A systematic pattern related to the meteorological conditions was identified. The reason for this behaviour was the interaction with the site during the occurrence of moderate and strong winds. In other cases the item hypothesis failed because of the presence of targets such as birds or hydrometeors, which contaminated the signal and either did not show a homogeneous behaviour in the 5 beams or even did not follow the regime of the wind field, as usually happens with bird groups. If the degree of contamination is different in each beam, and the signal processor presents difficulties for the identification of the peak of clear air, then this situation can cause inhomogeneity in the selected peaks. In these cases both modes were analysed since the site impact was not the reason for the inhomogeneity.

4.1 Breeze case

The breeze case consists of a wind structure developed over the land near the coast with a day cycle. During the day, the wind blows from sea to land: this is the Basque sea breeze component, which comes mainly from the north, with a slight change from west to east during the day. At night, the situation changes: the wind usually blows from land to sea; that is, the Basque land breeze blows from the south, most commonly SE. In both sea and land breeze, the direction is influenced by coastal orientation. These winds occur when a high temperature gradient between land and sea is present, but the shape, the height and the evolution during the day depend on this gradient among other meteorological factors, and it has a monthly changing behaviour according to the climatology of the area.

The days selected for the study were summer episodes in which the sea breeze happened almost everyday (from June to September 2010, and 2011). The main features of the vertical velocity profile from the three vertical velocities W_v, W_{ns} and W_{eo} showed values between -0.5 and $0.5\,\mathrm{m\,s^{-1}}$. Thus, the standard deviations were lower than in other cases, although in lower layer of the atmosphere (less than 1k˙m) the values of the standard deviations were higher.

Figures 3 and 4 show a typical breeze pattern registered during those days.

4.2 North wind case

In situations of north wind with no rainfall, the vertical velocity from the north–south beams (W_{ns}) showed a negative bias while the W_{eo} showed more variability, which, compared to W_v, could be considered consistent with it (Fig. 8). This pattern had a correlation with wind speed and direction, as all of them had a north component, but there were slight differences depending on whether this north component came from the west or from the east (i.e. the pattern was not the same with NW or NE winds). The performance of the wind profiler in north meteorological situations was satisfactory due to humid air masses from the sea, which generated an adequate SNR in the return signal (Fig. 6). However, we must take into account that many of these situations were combined with precipitation and rough sea conditions (large sea waves), both of which are targets that could mask our results. Besides, the vertical signal from the north–south W_{ns} also had a higher dispersion than the rest, as can be seen in Fig. 8. This dispersion decreased alongside with height until the three vertical velocities were consistent. The most outstanding peak of the mismatch could be observed at about 376 m, and therefore the behaviour analysis of time series at this height was made (Figs. 8 and 9). Figures 5, 6, 7, 8, and 9 show a typical north pattern registered in these days.

4.3 South wind case

During southerly winds the pattern found was similar to northerly winds. The main difference was that the bias was positive instead of negative (Fig. 11). The pattern was a mirror of the north case with a more complex meteorological situation. The performance of the wind profiler in south meteorological situations was not satisfactory due to the humid air masses from the land. The air masses coming from the mountains (and producing Föhn effect) caused lee waves and virga precipitations along their trajectories (Fig. 12). This meteorological situation generated a sinusoidal behaviour with alternative low and high SNR. Low SNR was associated with dry conditions, in which the surrounding signals (clutter) prevailed over the echo sounds. On the contrary, when precipitation was detected in the higher layers of the atmosphere, these signals could overlap clear air signals and then virga precipitation occurred, which is not as homogeneous as stratiform precipitation. All of these features were presented in the time series of the vertical profile data, with sharp changes in the consecutive values. This was the reason for higher dispersion in the lower layers (Fig. 12). Apart from this, higher contamination of ground clutter in the first gates was commonly detected. Figures 10, 11, and 12 show a typical south pattern registered in these days.

4.4 Precipitation case

Precipitation cases are the most complex homogeneity studies. This happens because the nature of the precipitation varies greatly both in time and space. For these cases the methodology presented for the rest of the study was not applied since 30 min is a long period of time compared to the time variability of rainfall. Consequently, the methodology for precipitation was modified, and it considered a complete 5-beam sequence, which meant less than 5 min for each mode. Checking 5-beam precipitation consistency before calculating consensus was crucial. For this reason, more than one statistical pattern were found, and only persistent precipitation situations could be considered homogeneous and provide relevant meteorological information. Some preliminary studies with a temporal 5 min resolution were made at this stage. Figures 13, 14, and 15 show results of the homogeneity study in a stratiform precipitation episode.

5 Discussion

The motivation of this work started during monitoring tasks. The visual identification revealed some bias in the lower layer of the atmosphere, which had a correlation with wind speed and wind direction. Using this information, it was necessary to confirm this suspicious pattern with a statistical tool and quantify and qualify the situation. Besides, once the deviations had been evaluated in a numerical way, the goal was to design a quality homogeneity parameter able to detect those deviations of the homogeneity assumption, at least at the consensus level as a first approach. In that sense, a deep discussion of the results and establishing the possible causes of these deviations were parts of the work of this section. As these deviations were related to severe wind episodes and also, as most wind alerts of the Basque Meteorological Service on these days corresponded to southerly and northerly winds, these two cases are the only ones included in this section.

The two tables in Fig. 16 reveal mirror behaviour depending on the wind direction with regard to the orientation of the coast. This could be related to the aerodynamical explanation of what happens with the airflow when it passes from a sea surface to a land surface and the role of the cliff in trajectories.

The interpretation of the results was not easy because the SNR was not a stable value along these episodes. The statistical values showed a negative/positive bias in the mean and the median regarding the northerly and southerly winds in the vertical velocity derived from the north–south beams. These results confirmed visual inspection.

The threshold of the quality homogeneity parameter could be fixed using these statistical values as a reference, and it could be active under specific meteorological conditions (north and south winds). It would be necessary to add other parameters such as a counter that indicates a constant behaviour with time, as well as a height counter that controls the gates affected below this. Table 1 shows statistical results of the north and south cases.

Besides, it is well known that radar wind profilers are contaminated by birds during their seasonal migration periods (Wilczak et al., 1995; Richner and Kretzschmar, 2001). Removing the bird signals from the registered signal has long been a challenge (Merrit, 1995; Jordan, 1995; Kretzschmar, 2003; Lehmann, 2012). In the case of bird migration, the density of the contamination is a crucial parameter which must be taken into account. The Basque wind profiler was affected by bird migration between February and the beginning of May. During this period, birds migrate to the north of Europe to spend the summer season. Bird types and the wind conditions are correlated, but in any case birds interact with the extreme meteorological conditions studied in the south and north cases. Not only precipitations must be studied in more detail, but also bird contamination as well as the homogeneity assumption. Moreover, the methodology must include specific modules for these types of targets. In the case of bird migration, a bird density parameter and homogeneity must be considered together, to find automatic indicators for these targets.

6 Conclusions

In places where the site does not present homogeneous conditions, the homogeneity of the wind field along the beam directions should not be assumed in the lower layers. The beams could present different interactions (sea clutter, ground clutter, buildings, wind mills, etc). Therefore, it is advisable to make a study of site impact. Under different wind regimes, not only the data from the lower layers, but also the low mode in operational systems must be checked to see if they fulfil the homogeneity test.

The results will help to define the best beam sequence under severe meteorological conditions: whether it is best to use a 3-beam, 4-beam (oblique) or 5-beam sequence (Adachi et al., 2005).

In addition clutter can occur, showing in general a non-homogeneous behaviour. In these cases additional measurements on the vertical component can help to discriminate the most contaminated beam in order to assess the homogeneity and the behaviour throughout the beams.

During the analysis of the time series, the derived beams show a similar trend that sometimes is followed by the vertical beam, and sometimes not. In general, the independence of the measurement of the vertical beam is shown with regard to the measurements derived from the vertical velocity calculated from the oblique beams.

The uncertainties in the final product (wind profiles) are not described in this work, since it is under evaluation at the moment. This is why the work was planned at the spectral level, when more factors than cliff impact are considered. At a consensus level of data, a mathematical exercise of the uncertainties was made in the study group of northerly/southerly winds. In this exercise a deviation of the W_{ns} of $1\,\mathrm{m\,s^{-1}}$ was used. In northerly/southerly winds, in which the radial components of the east and west beams are small, the final product would be biased in the velocity speed (around of $0.5\,\mathrm{m\,s^{-1}}$ approximately). The consensus data available during visual inspection in this meteorological situation show good quality profiles, and the deviation of the homogeneity hypothesis has been proved.

Supplementary material related to this article is available online at: http://www.atmos-meas-tech-discuss.net/6/5217/2013/ amtd-6-5217-2013-supplement.zip.

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Table 1. Statistical results from the north and south case studies.

	North case			South case		
Number of cases	21 616	21 686	27 741	17 769	19 048	25 278
(m s^{-1})	W_{ns}	W_{eo}	W_v	W_{ns}	W_{eo}	W_v
Mean	0.27	0.43	0.48	0.53	0.3	0.21
Median	0.0	0.2	0.2	0.20	0.0	−0.1
25th Percentile	−0.3	−0.1	−0.1	−0.5	−0.26	−0.4
50th Percentile	0.0	0.2	0.2	0.21	0.0	−0.1
75th Percentile	0.62	0.78	0.7	0.73	0.42	0.3

Table 2. Trend of the north case study.

Day	W_V	W_{ns}	W_{eo}	Meteorological notes
W09307 nov-3	0	–	–	NO
W09308 nov-4	0	–	–	Precipitation NO
W09349 dic-15	+	–	+	NNE
W09352 dic-18	+	–	+	NNE
W10028 jan-28	0	–	0	NO
W10029 jan-29	+	–	+	Precipitation NO
W10068 mar-9	0	–	+	NNE
W10069 mar-10	0	–	+	NNE
W10086 mar-27	0	–	0	NNO
W10091 apr-1	0	0	0	NNO
W10093 apr-3	0	–	–	NO
W10113 apr-23	0	0	0	NNO
W10325 nov-21	0	–	–	Precipitation NNO
W10329 nov-25	0	–	0	Precipitation NNE
W10348 dic-14	0	–	+	NNE
W10349 dic-15	0	–	+	NNO
W10357 dic-23	+	–	+	NNO
W10358 dic-24	+	–	+	Precipitation NNE
W11030 jan-30	0	–	+	Precipitation NNE
W11031 jan-31	0	–	+	NNE
W11060 mar-1	0	–	+	NNE
W11061 mar-2	0	–	+	NNE
W11062 mar-3	0	–	+	NNE
W11099 apr-9	0	-	–	NO
W11100 apr-10	0	–	+	NO
W11101 apr-11	0	–	–	NO
W11281 oct-8	0	–	0	N
Results	0	–	(–,0,+)	

Table 3. Trend of the south case study.

Day	W_{V}	W_{ns}	W_{eo}	Meteorological notes
W09300 oct-27	0	+	0	SSE
W09301 oct-28	0	+	0	SSE
W09302 oct-29	0	0	0	SSE
W09323 nov-19	0	+	0	S
W09325 nov-21	0	+	0	S
W09339 dic-5	0	–	–	S
W09354 dic-20	0	+	–	S
W09355 dic-21	0	+	–	S
W10276 oct-3	0	+	–	SSO
W10278 oct-5	0	+	–	S
W10280 oct-7	0	+	0	SSE
W10281 oct-8	0	+	0	SSE
W10339 dic-5	+	+	+	S
W10341 dic-7	0	+	–	S
W10361 dic-27	0	+	0	SSE
W10362 dic-28	0	+	0	SSE
W10363 dic-29	0	+	0	SSE
W10364 dic-30	0	+	0	SSE
W10365 dic-31	0	+	0	SSE
W11015 jan-15	0	+	0	SSE
W11017 jan-17	0	+	0	SSE
W11274 oct-1	0	+	0	SSE
W11275 oct-2	0	+	0	SSE
W11296 oct-23	0	+	0	S
W11299 oct-26	0	+	–	S
W11316 nov-12	0	+	0	SSE
W11317 nov-13	0	+	0	SSE
W11318 nov-14	0	+	–	SSE
W11322 nov-18	0	+	0	SSE
W11323 nov-19	0	+	0	SSE
W11332 nov-28	0	0	0	SSE
W11333 nov-29	0	0	0	SSE
W11334 nov-30	0	+	0	SSE
Results	0	+	(0)	

Fig. 1. Geographical location of the site of Punta Galea wind profiler.

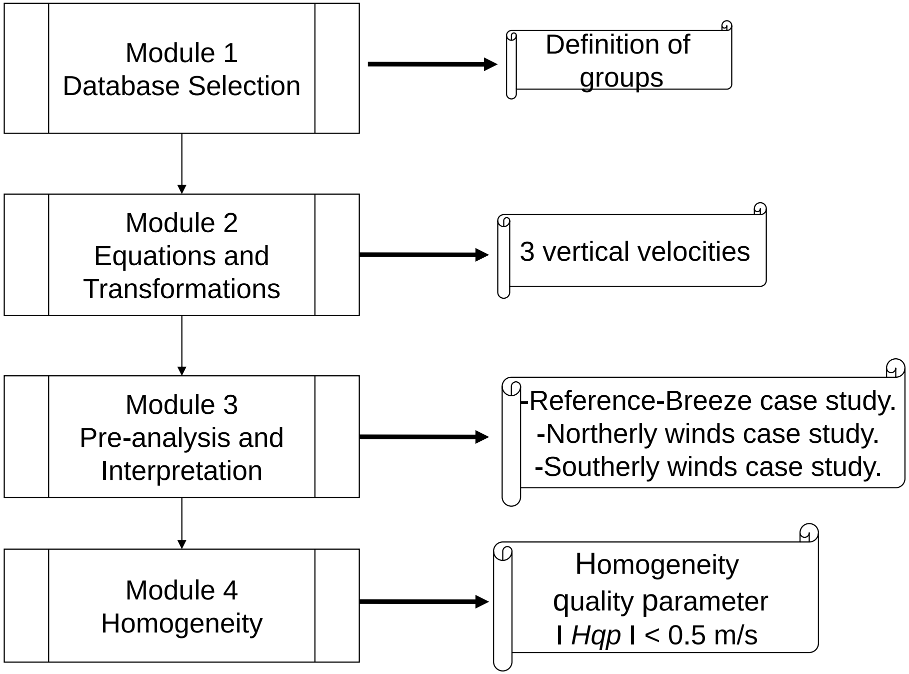

Fig. 2. Methodology.

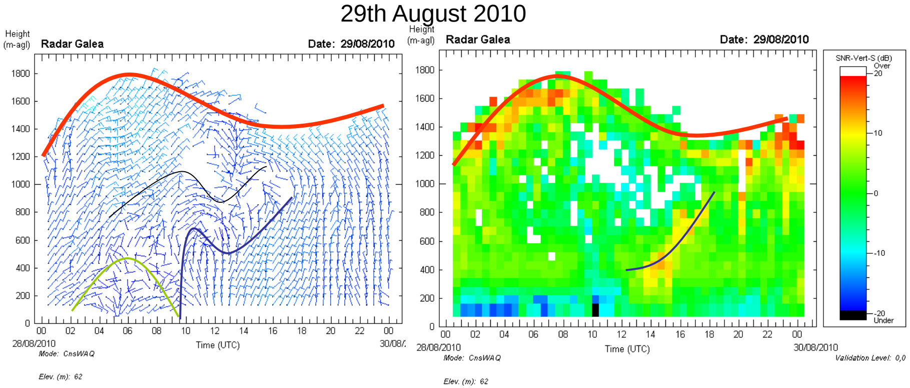

Fig. 3. Breeze pattern: wind profiler observations, on 29 August 2010.

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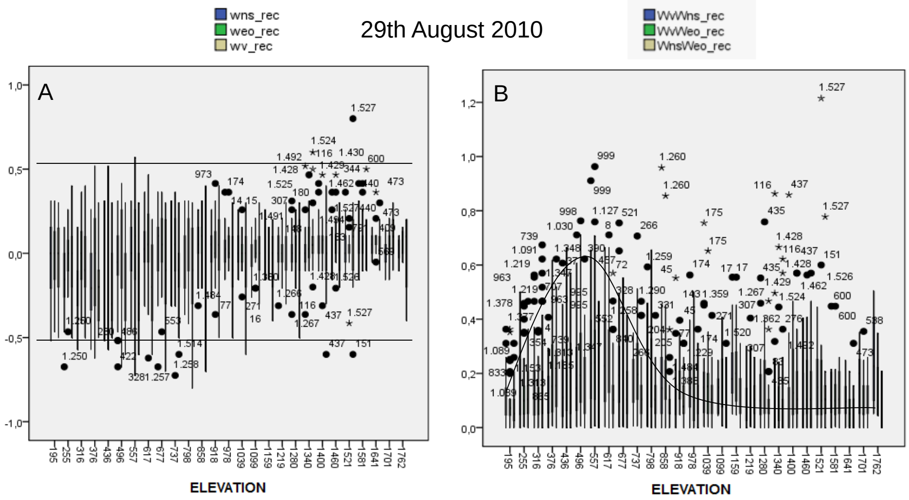

Fig. 4. Breeze pattern: (**A** and **B**) box plots of vertical velocities and absolute values of the differences between them on 29 August 2010.

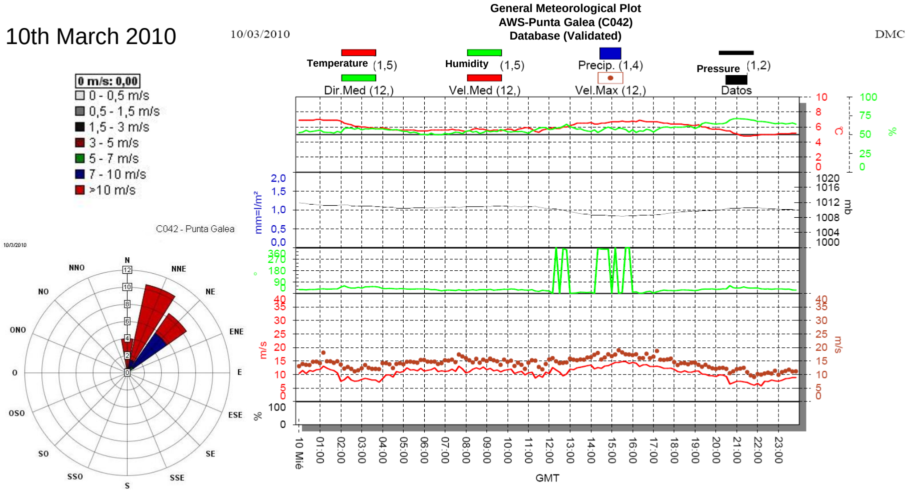

Fig. 5. North pattern: automatic weather station observations on 10 March 2010.

10th March 2010

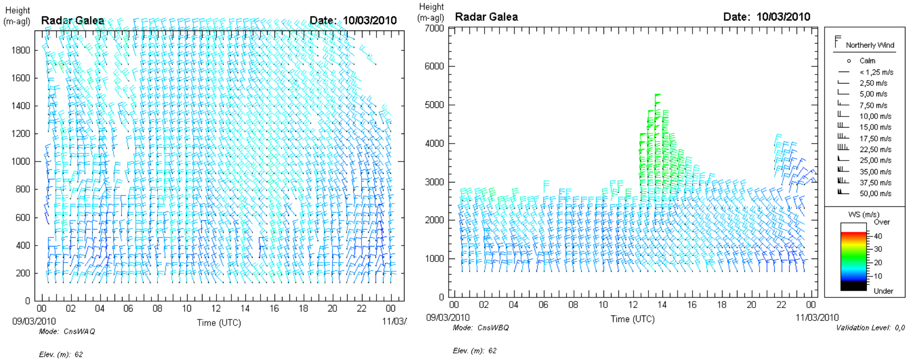

Fig. 6. North pattern: wind profiler observations on 10 March 2010.

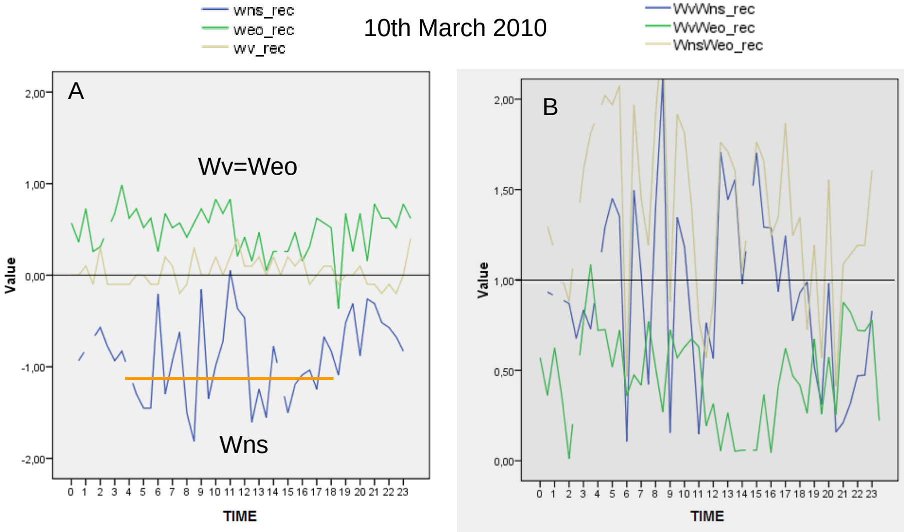

Fig. 7. North pattern: time-series plots of the vertical velocities and the absolute values of the differences between them on 10 March 2010.

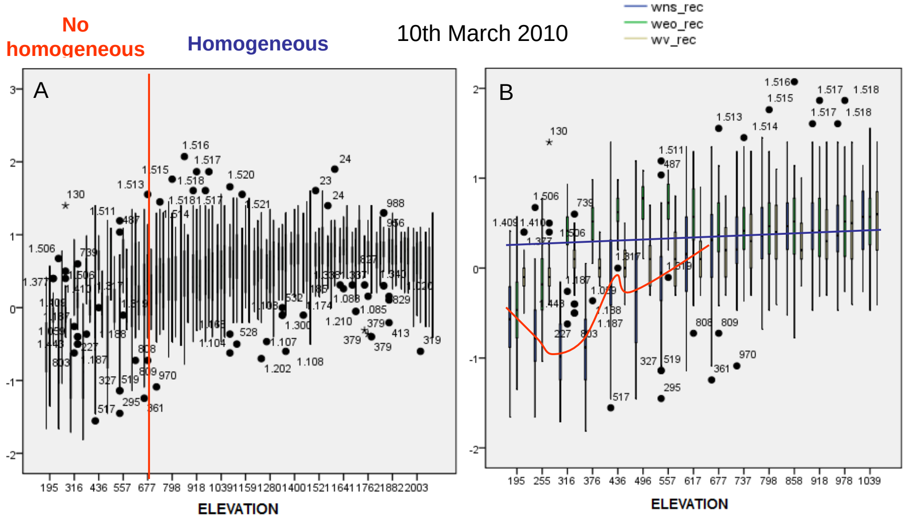

Fig. 8. North pattern: (**A** and **B**) box plots of the vertical velocities on 10 March 2010.

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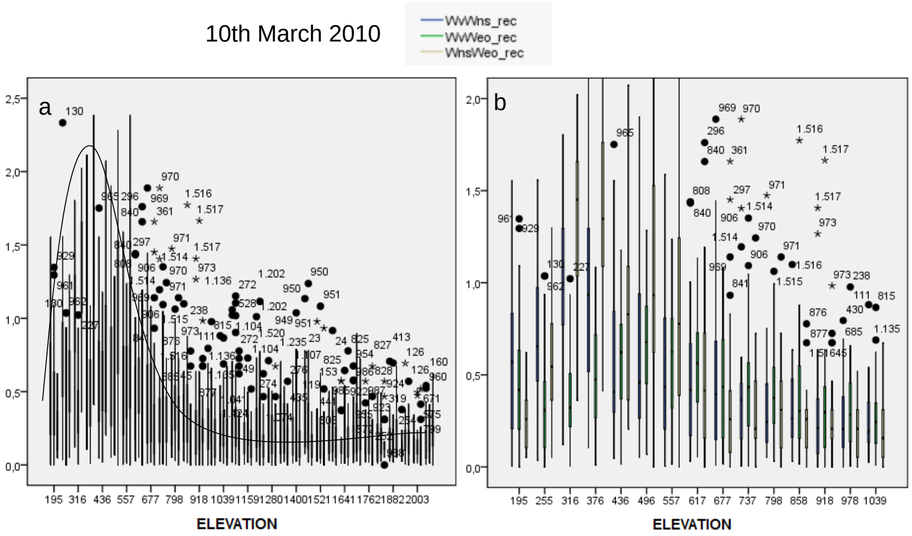

Fig. 9. North pattern: (**a** and **b**) box plots of the absolute values of the differences between them on 10 March 2010.

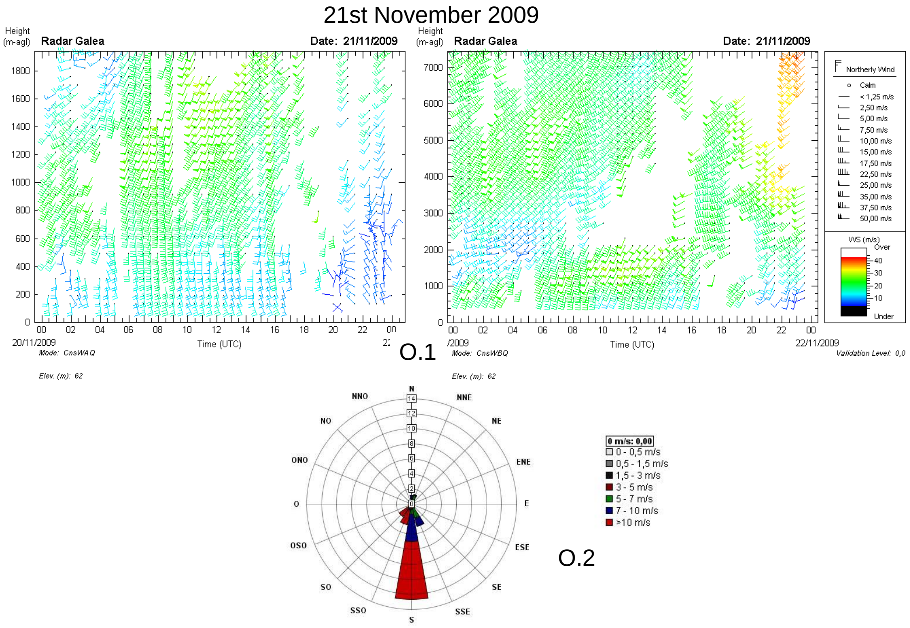

Fig. 10. South pattern: O.1 and O.2 – meteorological observations wind profiler (WPR) and wind rose of the automatic weather station (AWS) on 21 November 2009.

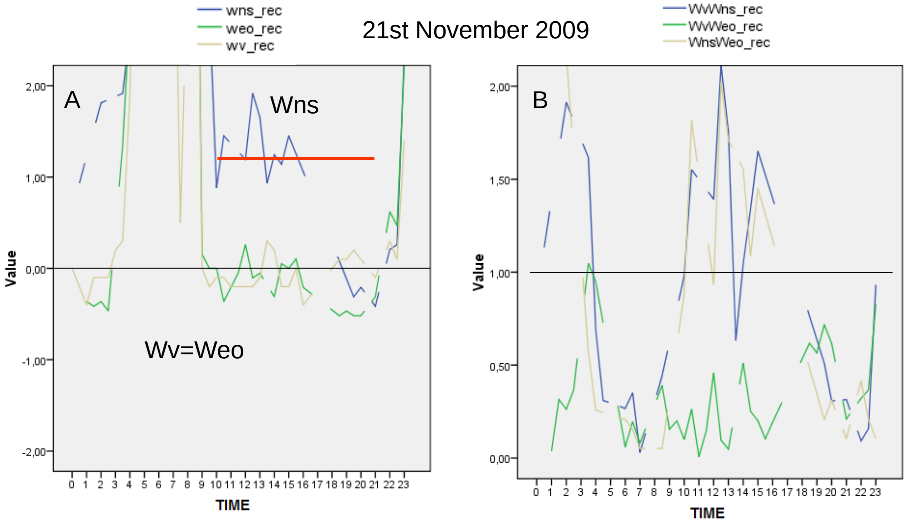

Fig. 11. South pattern: (**A** and **B**) time-series plots of the vertical velocities and the absolute values of the differences between them on 21 November 2009.

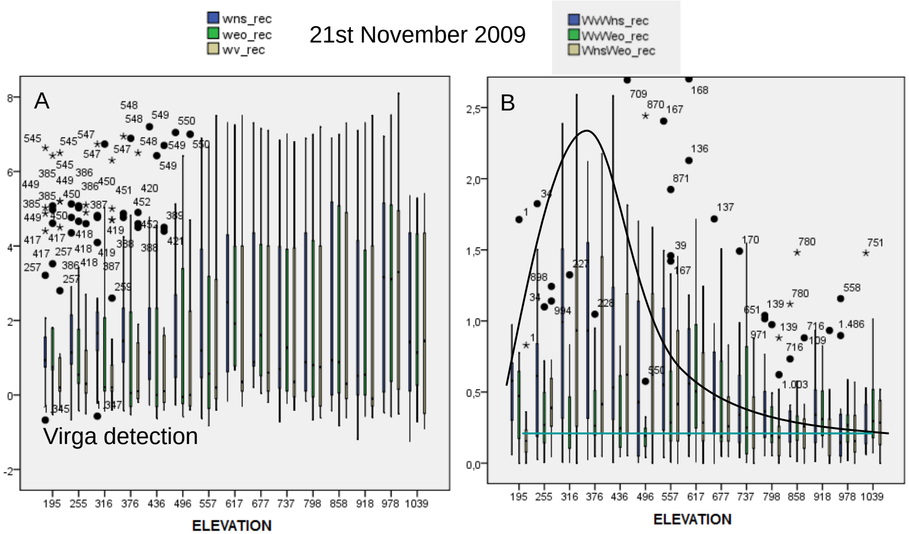

Fig. 12. South pattern: (**A** and **B**) box plots of vertical velocities and absolute values of the differences between them on 21 November 2009.

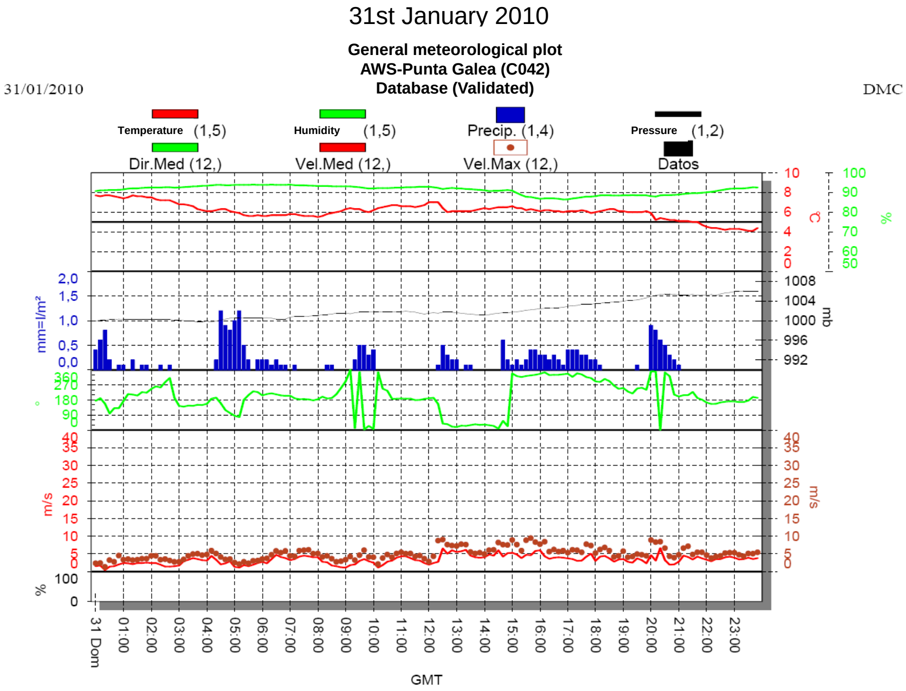

Fig. 13. Stratiform precipitation pattern: meteorological observations plot of the automatic weather station (AWS) on 31 January 2010.

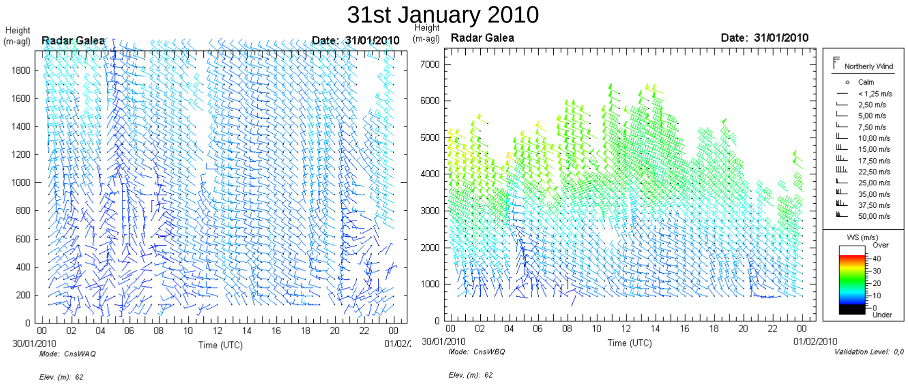

Fig. 14. Stratiform precipitation pattern: meteorological observations plot of the wind profiler (WPR) on 31 January 2010.

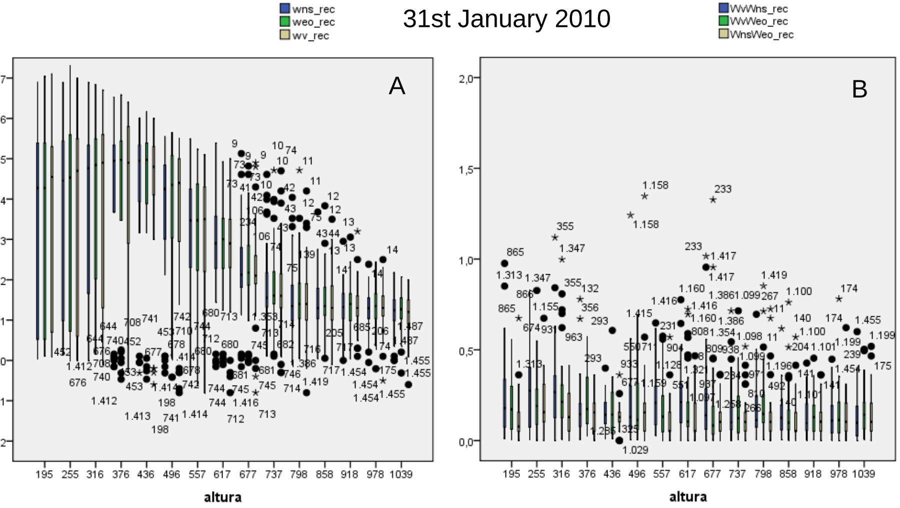

Fig. 15. Stratiform precipitation pattern: **(A)** box plots of vertical velocities and **(B)** absolute values of the differences between them) on 31 January 2010.