



## ESCUELA TÉCNICA SUPERIOR DE INGENIEROS INDUSTRIALES Y DE TELECOMUNICACIÓN

Titulación:

INGENIERÍA DE TELECOMUNICACIÓN

Título del Trabajo Fin de Carrera:

Software development for wind data quality control. An approach to case analysis: Weather analysis in stations in the West Bank (Palestine)

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Pamplona, 25 de Abril, 2013

## ACKNOWLEDGEMENTS

We would like to express our appreciation to the institutions that have made possible the present work:

- The Energy Research Center (ERC) from An-Najah National University (Nablus, West Bank, Palestine), directed by Dr Imad Ibrik, offered as a destination for a 6 months stay in order to finish this work.
- The Government of Navarra for its involvement in the early stage of this project.
- We would also like to thank the Spanish Agency for International Cooperation (AECID) throughout the last stage.
- And finally we would also like to thank to the Public University of Navarra which has helped through the “Formación Solidaria” program, of the Section for External Relations and Development Cooperation Section.

I would also like to show my appreciation to many people:

First of all, I would like to thank Dr Almudena G. Gorostiaga, for being my supervisor and making possible this project, to Alberto Royo, for his help and for answering me all my doubts almost instantaneously, and Dr Imad Ibrik, for being my supervisor in An-Najah National University and taking care about all the aspects of my stay in Palestine.

I am thankful to the staff of the External Relations and Development Cooperation Section of the Public University of Navarra, notably to Susana Irisarri, for her interest and attitude always ready to help.

Thanks to all that people from many nooks in the world, especially to my closest friends and my classmates, who walked with me during these long years of university, and who made the time flown in spite of the hard moments, and gave me great and unforgettable moments. It has been a pleasure.

I am also grateful to all my people in Palestine, in particular to the people I met in Nablus, locals and foreigners, because they gave me the opportunity to discover and try to understand the reality of this country, the awesome hospitality of its people, and made me mature and grow as a person. Thanks for giving me these unforgettable six months.

To Florentino, Lucía, Ángeles, María, and especially to Germán, because they would have loved to live this moment with me (and I would have loved to share this moment with them).

Finally, but not less important, I cannot say thank you enough to all my family, particularly to my parents, Inés y Jacinto, for giving me the education, the values in life and their unconditional support, and for their patience standing my complains (which were numerous), angers and so on during these years, and to my brother Iñaki, for being the best brother in the world, and helping me infinitely in all the possible and impossible things.

شكرا كثير



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Navarra



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para el Desarrollo



Gobierno de Navarra  
Departamento de Asuntos Sociales,  
Familia, Juventud y Deporte

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## 2 INTRODUCTION

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The West Bank is located in the Middle East, in Palestine, surrounded by Jordan to the East, and Israel by the West and the North. The Palestinian population in the area was estimated around 2300000 in 2007 [1] and 325000 Jewish settlers (2013). [2]

The climate in the West Bank and in Palestine in general, is Mediterranean type characterized by a short, cool, rainy winter, and a long, hot and dry summer. Temperatures increase from North to South, and towards the Jordan Valley (East), with annual average value between 15.5°C and 17.8°C. The mean annual relative humidity varies from 52% to 69% depending on the region. [3]

Although it is not a big geographical area, it has a varied topography and it is divided into four zones determined by location, rainfall and altitude: the Central Highlands (from Jenin to Hebron, mountainous, hilly and rocky zone rising up to 1000m above sea level, and the average annual rainfall is about 400 mm), the Semi-Coastal Region (a strip comprising parts of Tulkarem and Jenin with altitudes of 100 to 300 m above sea level and an average annual rainfall of 600 mm), the Eastern Slopes (between the Central Highlands and the Jordan Valley, and from East Jenin to the Dead Sea. It is a semi-arid to desert zone with steep mountains and latitudes from 200 m below the sea level to 800 m above sea level, and 250-300 mm annual rainfall) and the Jordan Valley (located between the Eastern Slopes and the Jordan River; it has very low annual rainfall (100-200 mm), and the latitude drops to about 400 below sea level). [4]

The West Bank is divided in three areas under different jurisdictions: Area A, under full control of the Palestinian Authority and includes primarily urban Palestinian areas, Area C under full Israeli control, and Area B under Palestinian civil control and shared Israeli and Palestinian security control and consists of the vast majority of Palestinian rural areas are included on this area. Over 60% of the West Bank is considered Area C. [5]

With regard to energy, the situation in the Palestinian Territories in general is complicated due to the shortage of natural resources and the need importing energy from other countries (mainly from Israel). Thus, it has a high dependence level in the energy field since imported energy represented 83% of the total energy requirement in Palestine in 2009, and in electricity in particular, the electricity demand have been increased over the last years.

In 2000 2,263,383 MWh were imported (from Israel), in 2006 the importation of electricity was 3,096,400 MWh, and in 2008 3,864,810 MWh were imported, which represent an increase of 26% and 41%, respectively. The internal energy production is based in solar energy and wood, but it represents around 16% of the energy requirements in 2009. [6]

This situation points out the immediate need for the Palestinian Territories in general, and the West Bank in particular, of developing their own energy in order to not depend from the external supply from Israel. Furthermore, owing to the shortage of natural resources, one of the main ways is working in the renewable energy field. This kind of energy could be really effective in rural or isolated areas not connected to the grid as well as being environmentally friendly.

As it was said before the development of solar energy (mainly in thermic) has already started (1,241,893 MWh were produced in 2008 [6]) but wind energy is an incipient field yet. The first step for the wind

exploitation to be used as an energy source is an accurate assessment of the potential of the wind in the area, and the identification of the best areas to obtain this type of energy.

This project is a small contribution for this issue, because it is necessary to have good quality data in order to make a reliable assessment. Once the quality of the data is assured different methodologies can be used, such as the statistics-based methodology and the mesoscale methodology.

In the first method the data recorded in the weather stations is used to obtain conclusions and provide a statistical summary of the observed site-specific wind climate, whereas in the second method the data is used to validate the results accomplished in the mesoscale model procedures. Although this work is mainly focused in the quality control process, an approach to the statistical analysis of the wind data series will be performed as well.

It has been carried out in collaboration with the Energy Research Center (ERC) from An-Najah National University from Nablus, West Bank (Palestine).

The first contact between the Public University of Navarra (UPNA) and the Energy Research Center (An-Najah National University) took place in 2004 in the Azahar seminar on renewable energy organized in Pamplona by the Section for External Relations and Development Cooperation and the Agricultural Projects and Engineering department of the UPNA, and funded by the Spanish Agency for International Cooperation (AECID), UPNA and the Government of Navarra. Later, a collaboration contract was signed, and in 2006, in a new Azahar Seminar, a research about the evaluation of wind energy potential in the West Bank (Palestine) was proposed.

In 2008 the Government of Navarra awarded the UPNA and the ERC with funding for the first part of a project called “Locations of interest sitting for the wind exploitation and technical training for the West Bank” which consisted in the recalibration of six meteorological stations already installed and the collection of wind data to be processed and stored in a database in the second part of the project and make the wind assessment. Furthermore, some seminars were given to the technicians of the ERC about the wind assessment methodology.

The second part of the project was financed by AECID, and four weather stations were installed, and a Wind Atlas of the West Bank was created to evaluate the wind potential, and the main regions of interest were detected.

The ERC was established in 1996 and it is directed by Dr Imad Ibrik. It is concerned in research, development, system design, feasibility studies, training in all conventional and renewable energy fields, energy management and energy conservation [7], and where this project was developed. This scientific center is part of An-Najah National University, located in Nablus (Palestine) and the largest university in the West Bank with over 20000 students and 19 faculties, and established in 1977. [8]

Finally, this project was accomplished through Public University of Navarra “Formación Solidaria” program, funded by UPNA, which offers to the students projects about development and cooperation in countries of the South in collaboration with universities, NGOs and other cooperation agencies in that countries. [9] In the 2011-2012 call the Energy Research Center (An-Najah National University) was offered as a destination for a 6 months stay, so this final project was carried out in the offices of the ERC in Nablus (Palestine).

### 3 OBJECTIVES

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The objective of this work is to develop a software tool for wind data implemented in Matlab with two partial goals:

- Validate the wind data set through the quality control of wind data.
- Analyze the wind data in order to generalize the obtained results.

It is specifically developed to evaluate wind data collected in four weather stations in the Palestinian Territories. However, it is a general program, so wind data from any other source could be analyzed as well.

The main goals of each of the parts, quality control and analysis, are explained below:

- In the part of quality control, the aim is to find erroneous or suspicious values which deteriorate the quality of the data available using different evaluation tests.
- In the part of assessment, once the data has been checked by the quality control, general information is obtained using the statistical methodology, such as the wind rose, Weibull distribution parameters, anemograms of the evolution of the wind in a specific period. Two different analyses will be carried out: a general analysis over a period of 3 years for Hebron, and a period of 2 years for Salfeet and Tubas; and a specific analysis for the year 2011, where the results of the different stations will be compared between each other, and with the results obtained in the general evaluation.



## 4 DATA DESCRIPTION, TOOLS AND PROCEDURES

In the last years many wind energy softwares have been developed for the wind resourcing assessment and model wind farms and turbines. The most commonly used are WAsP (Wind Atlas Analysis Application Program) [10], WindPRO [11] or WindFarmer [12].

All these programs need as an input the wind data file (among others) to be analyzed, so it is necessary to guarantee the quality of these files to ensure that the recorded data truly represents the reality, have a reliable database and get trustworthy results when the data is used in the programs mentioned above.

In this section the data available and the meteorological stations where it was collected will be presented, and the typical methods for quality control and wind analysis will be introduced as well.

### 4.1 DATA COLLECTION AND REPRESENTATION

#### 4.1.1 DATA COLLECTION

The developed software can analyze any wind data (wind speed and direction values) as long as they use the format required by the program (which will be explained further on in this section). It is recommended to have at least one year of data in order to get a reliable analysis. [13]

However, due to the fact that one of the goals of the thesis was to analyze the wind in the Palestinian Territories, in the West Bank in particular, only data collected by some weather stations located in this area was used. Specifically, the data was gathered in four different locations, obtaining data from six different sensors (two of the stations, Salfeet and Tubas, are measuring data at two heights). In all the stations excepting one (Tubas) the data transfer is done manually and these data are sent periodically to the UPNA by email.

In the Figure 1 the location of each station in the West Bank considered for this thesis is shown.



FIGURE 1: THE WEST BANK AND THE LOCATION OF THE FOUR WEATHER STATIONS



Each station is designed with the name of the location where it is situated. A description of each one is given below:

- *Hebron*: This meteorological station is located in Hebron ( $31^{\circ} 33'23.82''$  N,  $35^{\circ}04'59.40''$  E) at 1014 m altitude, on the roof of Al-Ahli hospital. It was installed in 2009 (the first data were measured on 28<sup>th</sup> April 2009) and funded by the UE.



FIGURE 2: HEBRON WEATHER STATION

The sensor is located at 10 m height from the roofline and it is anemometer which measures wind speed and wind direction. The data of this station is collected and averaged each 15 minutes, and transferred to the ERC in An-Najah University, and then to the Public University of Navarra by email. In the Figure 2 both the hospital and the station are shown.

When this thesis was carried out the last data available was on 10<sup>th</sup> April 2012.

This station was installed in the framework of the AWEP (Ahli Hospital Wind Energy Project), which aims to implement a wind generation system, which will be integrated with the existing power supply system provided by the local authorities, in order to decrease the hospital's power consumption costs and the risks of power intermittences. [14]

- *Salfeet*: The station in Salfeet ( $32^{\circ}04'07,5''$  N  $35^{\circ}13'23,82''$  E), located at 815 m altitude, was installed in 2010 (the first data was measured on 2<sup>nd</sup> June 2010) and financed by the Government of Navarra.

The wind direction and speed data is registered each 10 minutes by two anemometers at 10 and 14 m high (the second anemometer it was suppose to be at 20 m high), and the humidity, solar radiation, atmospheric pressure and temperature are registered by a hygrometer, solar radiation sensor, barometer and thermometer respectively. The mast with the two sensors can be observed in the Figure 3.



FIGURE 3: WEATHER STATION IN SALFEET

The data transfer is done manually, so that means it is necessary to go to the station to download the data.

The last data available was recorded on the 29<sup>th</sup> November 2013.

- *Tubas*: This station, located in Tubas ( $32^{\circ} 19.160'N$ ,  $35^{\circ} 21.373'E$ ) at 570 m altitude, as the one in Salfeet was installed in 2010 (the first data was measured on 5<sup>th</sup> June 2010) and financed by the Government of Navarra.

It has two sensors, at 10 and 16 m high (the second one it was planned to be at 20 m) which take wind speed and direction values each 10 minutes. Moreover, the station has a hygrometer, solar radiation sensor, barometer and thermometer that register values of humidity, solar radiation, atmospheric pressure and temperature. The station is shown in the Figure 4.

The data transfer is done remotely to the Energy Research Center. The last data available was taken on the 1<sup>st</sup> March 2013.



FIGURE 4: WEATHER STATION IN TUBAS



FIGURE 5: MKAHAL WEATHER STATION

- *Mkahal*: This station is located in the area of Mkahal ( $32^{\circ} 25,132' N$   $35^{\circ} 7,657' E$ ), also called Yaabad. It was financed by the Public University of Navarra and it was installed in 2011 (the first data analyzed was taken on the 24th May 2011).

On this station the wind speed and direction values are measured each 10 minutes using a sensor installed at 10 m high.

The data transfer is done manually, so a member of the Energy Research Center goes from time to time to the station to download the data.

The last data available from this station was taken on the 5<sup>th</sup> March 2013.

The station is shown in the Figure 5.

- *Altarim*. The last station is located in Altarim. It was installed in January 2013, so the data taken here has not been used because it is a very short period of time and it is not representative (only three months, to be considered representative it is necessary to have at least 1 year of data).

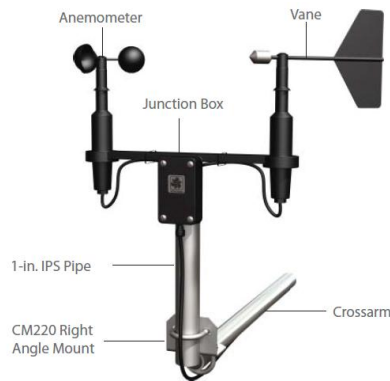
This station has two anemometers at 10 and 20 m height, which record wind speed values each 10 minutes, but the wind direction values are taken only in the highest sensor.

There is available data from the 23<sup>rd</sup> January 2013 to the 5<sup>th</sup> March 2013.

In the Figure 6 the station is shown.



FIGURE 6: NEW STATION IN ALTARIM



In all the cases the wind speed were measured in m/s and the direction in degrees using the Campbell Scientific 03002 model (shown in Figure 7) which includes a three cup anemometer (the cup wheel diameter is 12 cm) for the wind speed and a potentiometer which uses a 22 cm vane to sense the direction. The measuring range is from 0 to 50 m/s, and the accuracy of the value is  $\pm 0.5$  m/s for the speed, and  $360 \pm 5$  degrees for the wind direction.

FIGURE 7: CAMPBELL SCIENTIFIC 03002 ANEMOMETER

In order to carry out the data recorder the Campbell Scientific CR1000 data logger (Figure 8) is installed in all the stations. Even if the data is 10 or 15 minutely averaged and recorded (depending on the station) when the raw data is downloaded the data logger generates a daily data file and an hourly file as well. As it was stated previously the data is downloaded from the data logger manually, so the technician must be situated in the place where the weather station is located, exempting the case of Tubas, where there is installed a telecommunications system and the data is downloaded directly to the Energy Research Center.



FIGURE 8: CAMPBELL SCIENTIFIC CR1000 DATA LOGGER

The datasheets of both sensor and data logger are included in the annexes section.

#### 4.1.2 DATA FORMAT

Two different kind of formats have been used to store and analyze the data: the Excel (.xls) and the text file (.txt) format.

First of all, once the data has been downloaded, the raw data file is opened using Microsoft Office Excel software, and the date, wind speed and direction values are copied from this file to a different Excel file which is used as a database, and where all the values of each station are stored.

Thus, the data of every year for every single station (date, speed and direction) is collected in a single section (each year and station in a different worksheet), so all the data can be looked up in a very simple and quickly way. Regarding the date, it is necessary to do an adaptation in order to prepare the data to be used in Matlab: The raw data usually uses D/M/YYYY H:MinMin format, but it is changed to



YYYYMMDDHHMinMin in order to avoid non numeric characters. This change is made using Excel format cells' options.

Furthermore, in the first worksheet of the Excel file all the information related with the station (latitude and longitude, altitude...) is presented, and in the second and the third worksheets a summary (in both Spanish and English) about the data available showing all the incidences found after analyzing the data is presented.

The database is updated every time that new data is downloaded and sent to the Public University of Navarra.

This file is saved using Excel 97-2003 format to avoid problems opening it in any computer.

Secondly, in order to get a satisfactory analysis using the developed software the data has to be saved also in a text file following some specific rules:

- The file must have three columns containing only the data without any heading or title: In the first column the date should be set, using the YYYYMMDDHHMinMin format mentioned before, in the second column the speed should be placed and in the third one the direction.
- It has to be saved in .txt format in the same directory as the Matlab software is placed.

If these rules are not obeyed the software would not read the file and the analysis would not be made. Therefore, any wind data which is stored using this format could be evaluated using this software, not only the one coming from Palestinian weather stations.

Regarding the file name, it is not compulsory but is recommended to use the name format explained below so as to obtain the graphs of the analysis with all the information available about the station (name, location...) in the title:

- The first character should be the first letter of the name of the station in lower case letters. That is, for Hebron, the first character should be 'h', for Salfeet it should be 's', 't' for Tubas, and finally, 'm' for Mkahal.
- If the station has sensors in two different heights (in Tubas or in Salfeet), the second character should express each one of them. So if the data was measured in the first sensor (at 10 m high) the second character should be '1', and '2' if it was taken in the highest sensor.
- The next letters are not taken into account by the software, but it is usually written the year when the data was measured in order to have the data clearly organized.

Thus, an example of file name could be "t12012.txt", which means the file contains the data from Tubas ('t'), from the lowest sensor ('1') in the year 2012. If the file name is "h2010.txt" the origin of the data is Hebron ('h'), and the year is 2010.

Obviously, this feature is only possible for the data coming for the four Palestinian stations mentioned before (Hebron, Salfeet, Tubas and Mkahal).

## 4.2 DATA SELECTION

The available data was presented in the precedent subsection (4.1 Data collection and representation) when each weather station was introduced, but even so a summary is reminded in the Table 1.

Name of the station	Period (min)	Data from	To
Hebron	15	28-04-2009	10-04-2012
Salfeet 1 and 2	10	02-06-2010	29-11-2012
Tubas 1 and 2	10	05-06-2012	01-03-2013
Mkahal	10	24-05-2011	05-03-2013

TABLE 1: AVAILABLE DATA SUMMARY

Not all the data series can be always used for the quality control procedure and the following analysis, because it is very important to take only completed years in order to avoid any influences caused by the seasonal variation of the wind.

In order to have a general idea of the data and choose the longest period of years completed available the arrangement of the data was checked, a verification of the missing data or repeated date values was done and the anemograms were generated. In the Figure 9 a timeline for each weather station is shown. The green color indicates wind speed data and the blue direction data. Two different colors are used to express incidences: if it is a punctual incidence (one data missing) orange color is used, if it is extended in time red color is utilized.

In consideration of the available data, and selecting the longest period of completed years available, in the first part it was decided to analyze 3 completed years from Hebron, 2 completed years from Salfeet and Tubas (from both 1 and 2) and all the data available from Mkahal due to the lack of data in long periods. The data under analysis is shown in the Table 2.

Name of the station	Data under analysis	Data from	To
Hebron	~ 3 years	28-04-2009	10-04-2012
Salfeet 1 and 2	2 years	01-07-2010	30-06-2012
Tubas 1 and 2	2 years	01-07-2012	30-06-2013
Mkahal	1 year, 10 months	24-05-2011	05-03-2013

TABLE 2: DATA SELECTED

In the second part, the annual data of 2011 will be used for Hebron, Salfeet 1, Salfeet 2 and Tubas 1 and Tubas 2 to compare the results between stations and with the 2 or 3 year data series mentioned before.





## 4.3 TOOLS AND ANALYSIS PROCEDURES

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### 4.3.1 PROGRAMMING LANGUAGE: MATLAB

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The software was developed using Matlab, which is a numerical computing environment, but also a programming language. The main reason for choosing Matlab and not a different programming language is the fact that An-Najah National University acquired some Matlab licences, so therefore the software could be used by the technicians in the Energy Research Center and they could be independent in the assessment of their own data, without the external help of any group or organization outside the center, thus once they downloaded the data from their stations, they could evaluate it and dismiss erroneous registers, and finally analyze it and make the proper reports.

Matlab is the acronym of MATrix LABoratory, which means that it is targeted to the use of matrices and vectors. Matlab can be used as a sophisticated calculator, but also as a programming language. It is a high level language, which means the process of programming is simpler and understandable than a lower-level language, which does not provide abstraction between the programming language and the machine language and the code is less easily legible.

It is one of the products of the mathematical computing specialized corporation MathWorks, and its commercial logo is shown in the Figure 10.

The feature mentioned before about the target of the use of matrices is not trivial, and changes partially the way of programming comparing with other languages, because it usually makes the operations using matrices faster than the equivalent code using loops, so it is recommended to avoid loops when it is possible. [15]

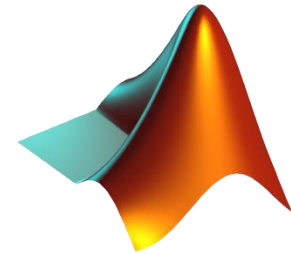


FIGURE 10:  
MATHWORKS'  
MATLAB LOGO

Nowadays the last Matlab version released is the R2013a, but for the development of the software the used version is 7.5.0 (R2007b), which is the only version available in An-Najah National University.

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### 4.3.2 QUALITY CONTROL STATISTICAL TESTS

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In this subsection, a theoretical explanation of some quality control checks for wind data will be given and the flagging system that will be used, in order to introduce the type of tests that are typically used in this field and that will be used afterwards.

The quality control methods for wind data are not standardized procedures, and many different tests can be found depending on each university or research center. For this project three references had been taken into account: First, an analysis and quality control programme for wind data developed by Alberto Royo using Mathematica [16]. It was developed specifically for the Wind Atlas project in the Palestinian Territories, but it can not be used in An-Najah National University owing to the absence of licenses of this software at the university.

Secondly, the Nordic NORDKLIM-OBS project (Nordic Co-Operation between Meteorological Services Within Climate Activities), which ensures high quality of observed climate data [17], and finally some

guidelines were obtained from the World Meteorological Organization (WMO). [18]. These two references were considered due of the complete and well organised quality control assessment procedures.

The assessment methods could be classified in different ways depending on the criteria chosen. The most common are explained below:

- *Methodology*: Depending on the basic methodology used three types of assessment methods can be used:
  - o “In situ”: If the data evaluation is done in the station itself (autodiagnose).
  - o Temporal test: If there is just one station checked
  - o Spatial test: if there are more than one station involved.
- *User’s needs*:
  - o Real-time assessment.
  - o Deferred assessment.

#### 4.3.2.1 FLAGGING SYSTEM

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To carry out a quality control analysis on a data series it is important to understand how the flagging system works. The goal is to have a global mark for each register in the series which would show its quality, that means that each value would have the “correct” (which is usually expressed with a “0”), “suspicious” (which is expressed with a “1”), or “incorrect” (which is expressed with a “2”) flag depending on the result of each test.

Two kind of test will be explained in the subsequent subsections: In the first type, two possible flags are used: “correct” or “erroneous”. When an erroneous data is found it is eliminated from the data series and only the correct data is taken for the next checks. In the second type, each data could have three different statuses: “correct”, “suspicious” or “erroneous” from each test. That means that when all the tests are run, each register will have as many flags as checks of the second type were employed, so it is necessary to have a global mark. The rules created to obtain the final mark are these:

- If in all the checks the register was flagged as “correct” (“0”), the global mark will be “correct” (“0”).
- If in any the checks the register was flagged as “erroneous” (“2”), the global mark will be “erroneous” (“2”).
- If after all the checks the register has at least two “suspicious” (“1”) flags, the global mark will be “suspicious” (“1”), in other case it will be flagged as “correct” (“0”).

To carry out an analysis after the quality control procedure the erroneous values will be deleted from the data series.

#### 4.3.2.2 ANEMOGRAMS

---

An anemogram is a graph where all the data assessed is represented in the order it was collected.

Two types of anemograms could be done depending on the input data: a wind speed anemogram (using the wind speed data) which has in the ordinate axis the speed and the sample number in the abscissa, and a wind direction anemogram (using the values of wind direction), which the sample number in the abscissa and the wind direction in the ordinate axis.

It is not a detailed graph but it gives a general idea of the evolution of the data in the analyzed period and it permits the user to detect visually anomalous performances occurred in a relative long period of time.

When there is missing data in the series the value 0 m/s or 0° (depending on the kind of data) is given in the anemogram and it is represented using a different color in order to identify visually the incidence. The same color is used to show the values corresponding to the same date (when there is repeated data) in the file.

---

#### 4.3.2.3 OUTLIERS TEST

The outliers test is a simple test used to find impossible values in the data series.

For the wind speed data, an outlier is found when the speed has a negative value or it is superior to a limit value, and it is deleted from the data series.

For the wind direction data, if the data is bigger than 360° or negative it is considered an outlier, and the register is eliminated and not included in the analysis.

##### 4.3.2.3.1 DOUBLE-ZEROS CHECK

A special type of outliers test is the “double-zeros check”. This test was created after detecting anomalous amount of registers which have the wind speed and the wind direction value equal to zero. When this fact occurred in any of the stations that have sensors at two heights, in most of the cases one of the anemometers was measuring non zero speed and or direction values even if in the other one the values of speed and direction were zero, which must be impossible because the data of both sensors should be correlated.

Due to this remark, the registers which have speed and direction values equal to zero are considered erroneous and removed from the data series in order to avoid biased results in the part of analysis.

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#### 4.3.2.4 TIME SERIES ARRANGEMENT

The time series arrangement procedure is used to check if all the theoretical date is in the data file, if there is any date repeated and also to confirm that the values are correctly sorted. If any problem is found, the register number is given to the user, to be checked manually.

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#### 4.3.2.5 ANOMALOUS PATTERNS

This test can be used to check data from one station (temporal analysis) or more than one station (spatial analysis). The main objective is to detect anomalous patterns repeated in different parts of a wind speed data series or in wind speed data from different stations (this issue could happen owing to data manipulation errors, among others).

If it is possible to identify which station is the data originally from, this data is kept, and eliminated from the other file or the other part of the series. If it is not possible to know where the correct data comes from, and which are the data copied registers all the data detected is deleted from the series and not used for the analysis subsequent.

If the anomalous pattern has certain duration it can be detected in the wind speed anemogram.

#### 4.3.2.6 RANGE TEST

A range test, also known as limit test, may identify impossible or very unusual values in the data series. It consists of comparing every value with two limits values previously defined. If the data is lower than the first value it would be considered as “correct” data, if it is between this two values it would be considered as “suspicious” (probable error) and finally, if it is bigger than the second limit value it would be considered as “erroneous” register (certain error).

The procedure to define the limit values which would determine the quality of each value is based on the Weibull distribution. This continuous probability distribution is generally used to describe wind speed distributions because the Weibull shape matches with the natural distribution.

The Weibull is determined by two parameters (called shape and scale) and its probability density function (PDF) is given as:

$$p(v; k, c) = \frac{k}{c} \left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^k} \text{ for } k, c > 0 \quad (1)$$

where  $v$  is the wind speed,  $k$  is the shape parameter (dimensionless), and  $c$  is the scale parameter (in m/s) of the Weibull distribution.

Nowadays many methods have been developed to calculate the shape and scale parameters. For the final version of this project the maximum likelihood method was chosen because, as it was said by Bailey and McDonald, it is the one which generally gets the best performance and smaller errors [19]

In the following this method is described. It was proposed by Stevens and Smulders. [20]

Using this method the scale and shape parameters are estimated using iterative calculations by:

$$k = \left( \frac{\sum_{i=1}^n v_i^k \ln(v_i)}{\sum_{i=1}^n v_i^k} - \frac{\sum_{i=1}^n \ln(v_i)}{n} \right)^{-1} \quad (2) \quad c = \left( \frac{\sum_{i=1}^n (v_i)^k}{n} \right)^{\frac{1}{k}} \quad (3)$$

where  $n$  is the number of non zero wind speed values, and  $v_i$  is the wind speed.

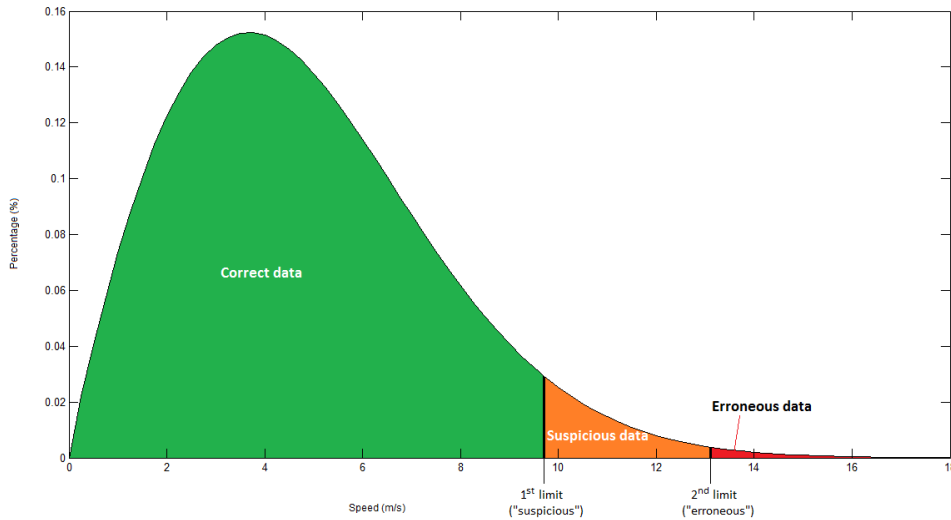


FIGURE 11: EXAMPLE - DISTRIBUTION OF THE CORRECT, SUSPICIOUS AND ERRONEOUS DATA IN A WEIBULL CURVE

Once the shape and scale of the Weibull distribution are estimated, two percentiles are considered to be the limit values for the impossible and very unusual values. It is important to stress that these values will depend always on the data series and will be particular for each series.

In the Figure 11 a Weibull distribution ( $k=1.9$ ,  $c=5.4$ ) is shown with two possible limit values.

#### 4.3.2.7 STEP CHECK TEST

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The step check test checks the variability of the wind speed between consecutive registers. As in the range test, two limit values are established which will determine the maximum allowed variability to be considered the data “correct”, “suspicious” or “erroneous”.

Again, these limit values are calculated using the shape and scale parameters of the corresponding Weibull distribution. The differences between each value and the precedent are carried out, and Weibull’s shape and scale parameters are estimated from this “differences vector”.

Different procedures can be used to verify that this vector is also based in a Weibull distribution. In this case, as the project is developed using Matlab and since this software provides graphical assessment to check whether the input data comes from a Weibull distribution (using ‘wblplot’ function), this method was used.

Firstly, and as it was mentioned in the range test section, the method used to estimate the scale and shape parameters was the graphical, but finally it was opted for the maximum likelihood method.

When Weibull parameters are obtained, two percentiles of the distribution will determine the limit values for the “differences vector”, and the evaluation takes place. If one value in this vector is between the two limit values, the two values in the speed series where this value has obtained from (doing the difference) will be marked as “suspicious”. If the value in the “differences” vector is bigger than the second limit value, the two values of speed this value was obtained from will be marked as erroneous. Of course, if one data has the “erroneous” and “suspicious” mark (obtained from the differences with the precedent and the subsequent values) the worst case would be taken, and that register would be evaluated as “erroneous”.

#### 4.3.2.8 REPETITIONS TEST

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The repetitions test is a temporary test which detects repeated consecutive values in speed data since it is considered improbable to have exactly the same speed value in two (or more) consecutive registers. When this check is carried out a distinction is made to find zero values and non zero values.

Depending on the repetitions founded the system of flagging could be employed in two different ways: all the repetitions are considered erroneous data, so the possible results of this test for each value would be “erroneous” or “correct”, or considering an intermediate situation, considering the data suspicious or erroneous according to the consecutive registers repeated (in this case, obviously the possible flags for each data would be “correct”, “suspicious” and “erroneous”).

#### 4.3.2.9 CORRELATION TEST

Once all the previous tests have been run each register in the data series would have a global assessment (“correct”, “suspicious”, “erroneous”) and only the “correct” or “suspicious” data will be check in the correlation test, the “erroneous” values will be dismissed.

The correlation test is a spatial check which crosses the values between two in order to see if there is any relation between them. The data which is going to be crossed must be coincident in the time, so it is necessary to take the time into account and cross only the values that are in the same moment.

The correlation coefficient  $\rho_{X,Y}$  between the data of two stations X and Y is calculated using the expression below:

$$\rho_{X,Y} = \text{corr}(X, Y) = \frac{\text{cov}(X, Y)}{\sigma_X \sigma_Y} = \frac{E[(X - \mu_X)(Y - \mu_Y)]}{\sigma_X \sigma_Y} \quad (4)$$

where  $\text{cov}(X, Y)$  is the covariance between X and Y,  $\sigma_i$  the standard deviation of each of the stations (where  $i$  is the station),  $\mu_i$  is the sample mean of each station and  $E$  is the expected value operator.

The correlation coefficient (also known as Pearson's correlation coefficient) can take values between [-1, 1].

If the coefficient is 1 there is a perfect positive linear relationship between the stations, if it is -1 there is a perfect negative linear relationship (anticorrelation). In other cases, the value will indicate the degree of linear dependence between the two stations. If it is 0 that means that there is not linear relation between them.

Two data series would be considered correlated if the correlation coefficient is equal greater than 0.8. In that case the regression linear  $y = ax + b$  equation would be calculated. Using the Fisher F distribution again two limit values would be calculated, and the assessment done using the same principles as in the range and step checks.

The regression linear line could be used to estimate missing values between correlated stations as well.

#### 4.3.3 WIND DATA ANALYSIS

Different parameters and graphs can be calculated in order to analyze wind data. In this section the parameters commonly used in wind, as well as in this project, will be explained.

##### 4.3.3.1 MEASURES OF CENTRAL TENDENCY

The measures of central tendency, also referred to as measures of central location or centre are used to describe the center of the data series. The most common and the ones that are used in this project are defined as:

- *Sample mean:* It is the speed average value of the data series:

$$\bar{v} = \frac{\sum_{i=1}^n v_i}{n} \quad (5)$$

where  $v_i$  is each of the speed values, and  $n$  the total number of speed values.

- *Median*: The median is the statistical parameter which separates the higher half of the speed data from the lower half.
- *Mode*: It is the speed value most repeated among the series.
- *Mode of the directions*: The mode is calculated for the wind direction series as well.

#### 4.3.3.2 MEASURES OF DISPERSION

The measures of dispersion, also known as measures of spread, are used to find out how spread out the data series is. Six parameters are used to characterize each data series:

- *Lowest and highest value*.
- *Median absolute deviation (MAD)*. It is the average distance each speed value is from the mean speed. It describes how close are the values between each other:

$$MAD = \frac{\sum_{i=1}^n (v_i - \bar{v})}{n} \quad (6)$$

- *Standard deviation and variance*. These parameters are calculated as below:

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (v_i - \bar{v})^2}{n-1}} \quad (7) \qquad \qquad \qquad Var = \sigma^2 \quad (8)$$

- *Coefficient of variation (CV)*. It is the ratio of the standard deviation to the mean, and it is calculated as:

$$CV = \frac{\sigma}{\bar{v}} * 100 \quad (\text{in \%}) \quad (9)$$

#### 4.3.3.3 WIND SPEED DURATION CURVE

The wind speed duration curve is a graph which has the wind speed in the horizontal axis and the time percentage in the vertical axis (it can be made with the wind speed as the ordinate and the percentage as well). It determines the percentage of time that the wind exceeds a specified level.

#### 4.3.3.4 JOINT WIND SPEED AND DIRECTION FREQUENCY DISTRIBUTION TABLE

This table gives both wind speed and direction at the same time, and it show the amount of wind speed values in 2 m/s intervals with a specific direction. For characterize this parameter 8 intervals of directions are considered: N, NE, E, SE, S, SW, W, NW, but depending on the user's requirements more (or less intervals) could be considered.



The table is organized in 8 columns, one for each wind direction, and as many rows as 2 m/s intervals. It can be made using absolute values or percentages.

#### 4.3.3.5 WIND ROSE

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The wind rose is generated from the joint speed and direction frequency distribution table representing these values in a circular plot, where each radius represents a wind speed direction, and each segment of this radius represents the percentage of values in a 2 m/s interval (different colors are used to distinguish the intervals), and the total length of each radius shows the percentage of time (or the number of values) the wind blew from each direction.

#### 4.3.3.6 WIND POWER DENSITY

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The wind power density is defined as:

$$\frac{P}{A} = \frac{1}{2} \rho \overline{v^3} \quad (10)$$

where  $\frac{P}{A}$  is the wind power density (power per area), and  $\rho = 1.225 \frac{kg}{m^3}$  is the air density. (As it was said before,  $\bar{v}$  is the mean wind speed).

#### 4.3.3.7 WEIBULL PARAMETERS.

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The Weibull distribution scale and shape parameters are estimated using the maximum likelihood method (the method is already explained in the section 4.2.2.6 Range test).

If any value is eliminated from the data series after the quality control procedures the parameters would be the same as the estimated in the range test.

#### 4.3.3.8 MONTHLY / DAILY / 10 OR 15 MINUTES MEAN WIND SPEED

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The following graphs will be plotted in order to show the evolution of certain mean parameters among the year, each month, or the day:

- *Monthly mean wind speed.* It shows how the mean monthly wind speed varies during the year.
- *Daily mean wind speed.* This graph represents the evolution of the daily wind speed among the month. (It can be done for each month in the year).
- *10 or 15 minutes mean wind speed.* The variation of the wind speed during a day is shown on this graph; this graph can be done for a complete year or for each month to see the evolution.

## 5 RESULTS AND DISCUSSION

In this section the obtained results will be explained. First of all the general results of each quality control test introduced in the subsection “Tools and analysis procedures” for each station and for a single year will be presented, and then results obtained in the analysis after the quality control procedures will be shown for this single year and compared with the generals and between the different stations.

### 5.1 QUALITY CONTROL AND ANALYSIS FOR THE WHOLE DATA SERIES

#### 5.1.1 QUALITY CONTROL RESULTS OBTAINED ON EACH TEST

As it was mentioned in the subsection 4.2 (“Data selection”), in this part 3 years of data from Hebron 2, years from Salfeet and Tubas, and all the data available from Mkahal were used: The results obtained in the time series arrangement, anemograms, outliers test, double-zeros test and anomalous patterns test are presented first; the amount of data dismissed after the first part of the quality control procedure is commented and then the results of the second part of the quality control methods (range test, step check test and repetitions test) are shown. Finally the global assessment for each station is given.

##### 5.1.1.1 TIME SERIES ARRANGEMENT

The obtained results are sorted out in the Table 3.

Station	Length of the sample	Theoretical length	Time series' length is: (ok/wrong)	Missing values (date)		Repeated date values	
				Amount	%	Amount	%
Hebron	103487	103483	Wrong	0	0	4	0.0039
Salfeet 1	102205	105264	Wrong	3059	2.9930	0	0
Salfeet 2	102205	105264	Wrong	3059	2.9930	0	0
Tubas 1	105260	105264	Wrong	12	0.0114	8	0.0076
Tubas 2	105260	105264	Wrong	12	0.0114	8	0.0076
Mkahal	69285	93825	Wrong	24546	35.4276	6	0.0087

TABLE 3: TIME SERIES ARRANGEMENT'S RESULTS

In any of the stations the time series length was correct, although the number and kind of incidences was not the same in all the cases.

For the station in Hebron only 4 values (0.0039%) of the values had the date repeated (this means that 4 registers were found that have the same date as other registers, the date was repeated).

In the case of Salfeet, both sensors in the two heights (Salfeet 1 and Salfeet 2) had 3059 values missing, (which is 2.9930% of the data). However no repeated values were found in the period under study.

As in Salfeet, in the station in Tubas the results were the same for the two sensors (Tubas 1 and Tubas 2), and 12 missing values (0.0114%) and 8 repeated date values (0.0076%) were found.

Finally, also in Mkahal missing values and repeated date were found: 6 registers had repeated data (0.0087%), but 24546 missing values, which is 35.4276 %, value that is especially remarkable because it is a huge amount.

Thus, the station which had more incidences was Mkahal (35.4363% in total), and the one who had less is Hebron (0.0039%).

All the incidences mentioned above can be detected easily detected visually in the anemograms shown in the next section.

### 5.1.1.2. ANEMOGRAMS

The wind speed and direction obtained for each station will be shown in this section. For each graph some additional information is included in the title, such as the location, altitude, data measuring period, first and last data under study, and mean speed, standard deviation and the cube of the wind speed (before any test) as well.

Each speed or direction value is represented in blue excepting the registers whose date is repeated and the missing values, which are represented in red.

#### 5.1.1.2.1 HEBRON

##### WIND SPEED AND DIRECTION ANEMOGRAMS

Location: HEBRON. Sensor height: 10 m. 31°33'23.82 N, 35°04'59.40 E. Altitude: 1014 m.  
15 minutes data resolution. From 13:0 28/4/2009 to 11:30 10/4/2012

$v_{avg} = 4.4467$  m/s.  $\sigma = 2.0164$   $[v_{avg}]^3 = 87.9233$

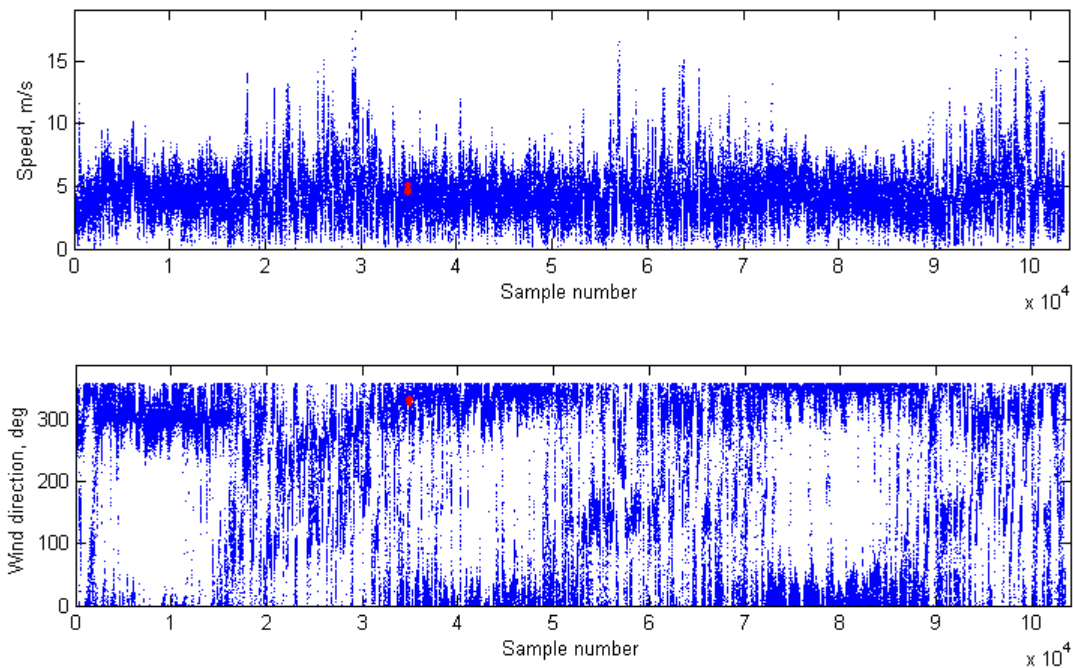


FIGURE 12: WIND SPEED AND DIRECTION ANEMOGRAMS FROM HEBRON STATION

The anemograms of the station in Hebron are shown in the Figure 12. As it was commented in the time series arrangement section, there were 4 values which had the date repeated, and which can be identified very easily as the red color is used to designate the incidences. In this case this registers are found around the register 35000 (it is important to notice that in the abscissa axis the values are multiplied by  $10^4$ ) which corresponds to 26<sup>th</sup> April 2010 at 14:15.

No other incidences are detected in the anemograms.

### 5.1.1.2.2 SALFEET 1

The anemograms of the station Salfeet 1 are shown on the Figure 13.

On them it can be distinguish visually the absence of a long period of values around the register 25000, from 12<sup>th</sup> December 2010 at 08:30 to the 2<sup>nd</sup> January 2011 at 13:30 but it is not the only one, as other missing data are shown by the red points around the register 48000, which corresponds to the value of the 1<sup>st</sup> June 2011 at 00:00 and 100500, which corresponds to 28<sup>th</sup> June 2012 at 17:40.

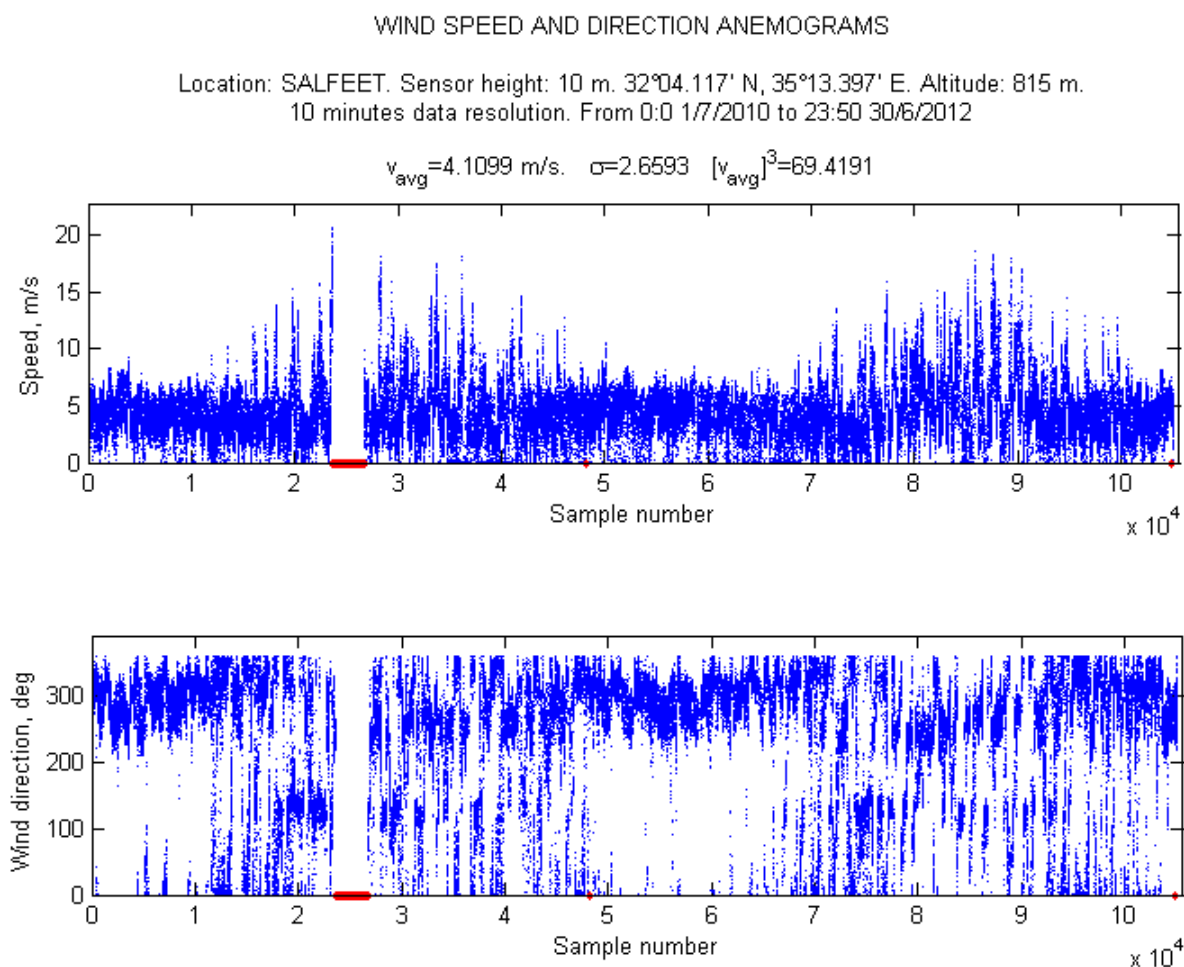


FIGURE 13: WIND SPEED AND DIRECTION ANEMOGRAMS FROM SALFEET 1

### 5.1.1.2.3 SALFEET 2

As was said in the precedent subsection, and can be checked visually on the anemograms of the Figure 14, the incidences in Salfheet 1 and Salfheet 2 are the same (missing values) and they are distributed in the same time, even if the other speed and directions are different. This is probably due to a problem in the data logger, as the sensors in both levels share the same device.

Some similarities can be found between the general distribution of the data of Salfheet 1 and Salfheet 2 (but for the speed the maximum values are always in the sensor at 16 m height) owing to the sensors are located in the same place, in different heights, so they are correlated.

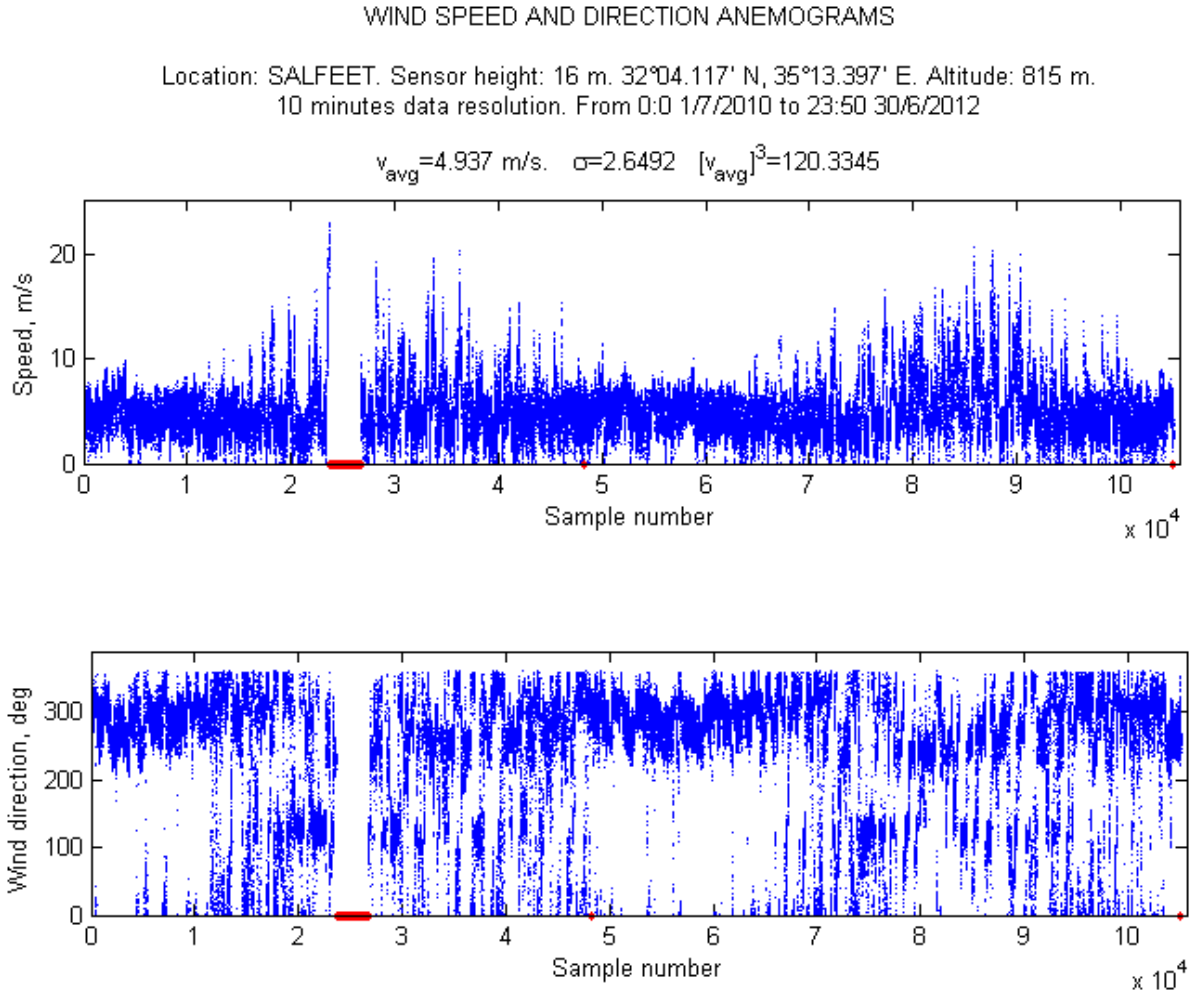


FIGURE 14: WIND SPEED AND DIRECTION ANEMOGRAMS FROM SALFEET 2

#### 5.1.1.2.4 TUBAS 1

For Tubas 1, the Figure 15 shows the missing and date repeated values are distributed among all the data series.

There is a remarkable date repeated chain around the register 7000, which corresponds to repeated data from 18th August 2010 at 12:00 to the same day at 12:40. There are repeated values on the 4th March 2012 at 07:50 (around the sample number 88000) and on the 23rd June 2012 at 10:20 as well (around the sample 104000), and missing data on the 18th August 2010 (sample 7000) at 15:00 and on 1st September 2011 at 00:10 (sample 61000).

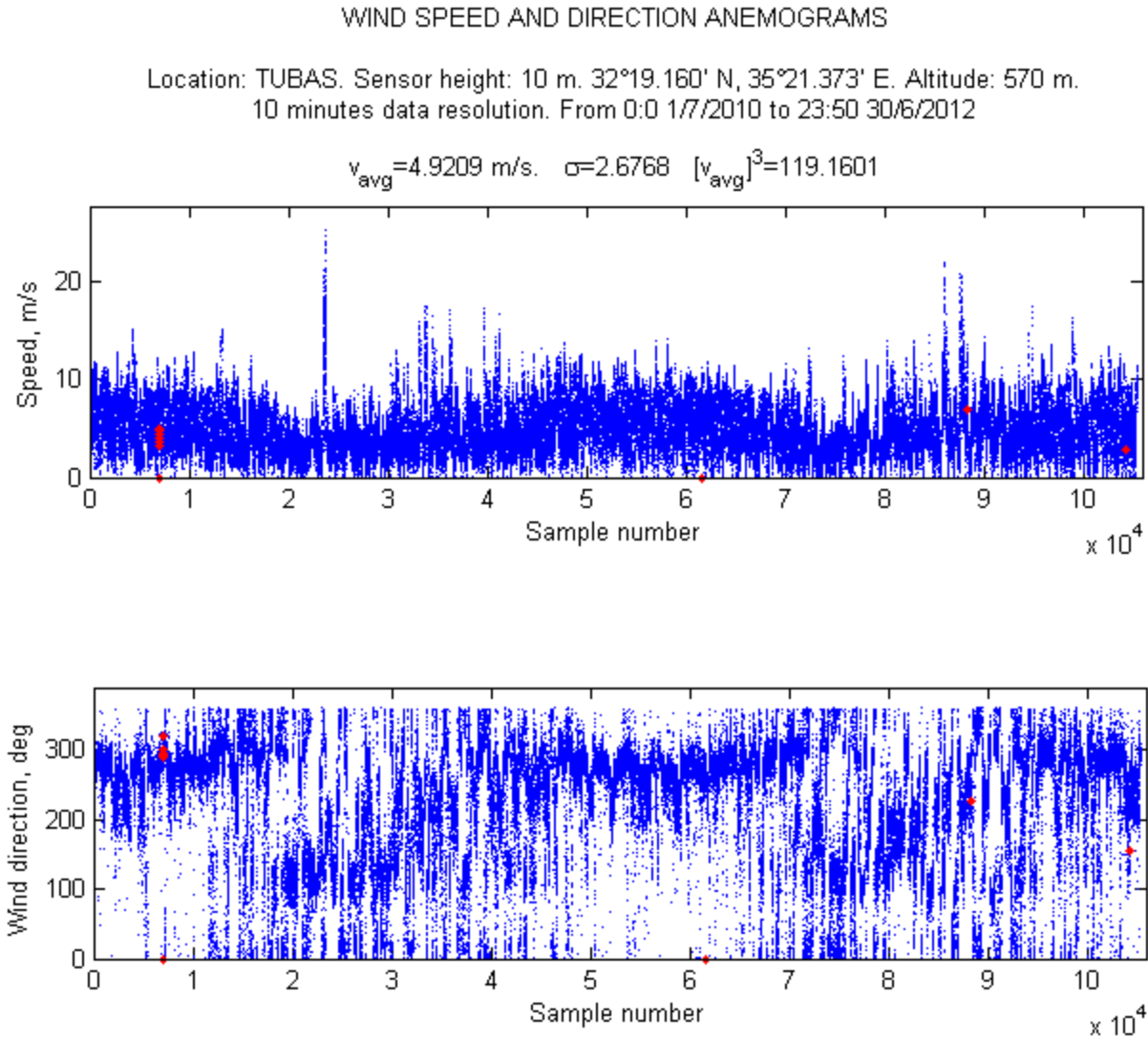


FIGURE 15: WIND SPEED AND DIRECTION ANEMOGRAMS FROM TUBAS 1

### 5.1.1.2.5 TUBAS 2

As in the case of Salfeet 1 and 2, the incidences are distributed exactly in the same moments for both Tubas 1 and Tubas 2 (shown in Figure 16), which points out the problem was in the data logger.

There is a big correlation between Salfeet 1 and Salfeet 2, but the maximum wind speed values were collected in Tubas 2 as it is higher than Tubas 1.

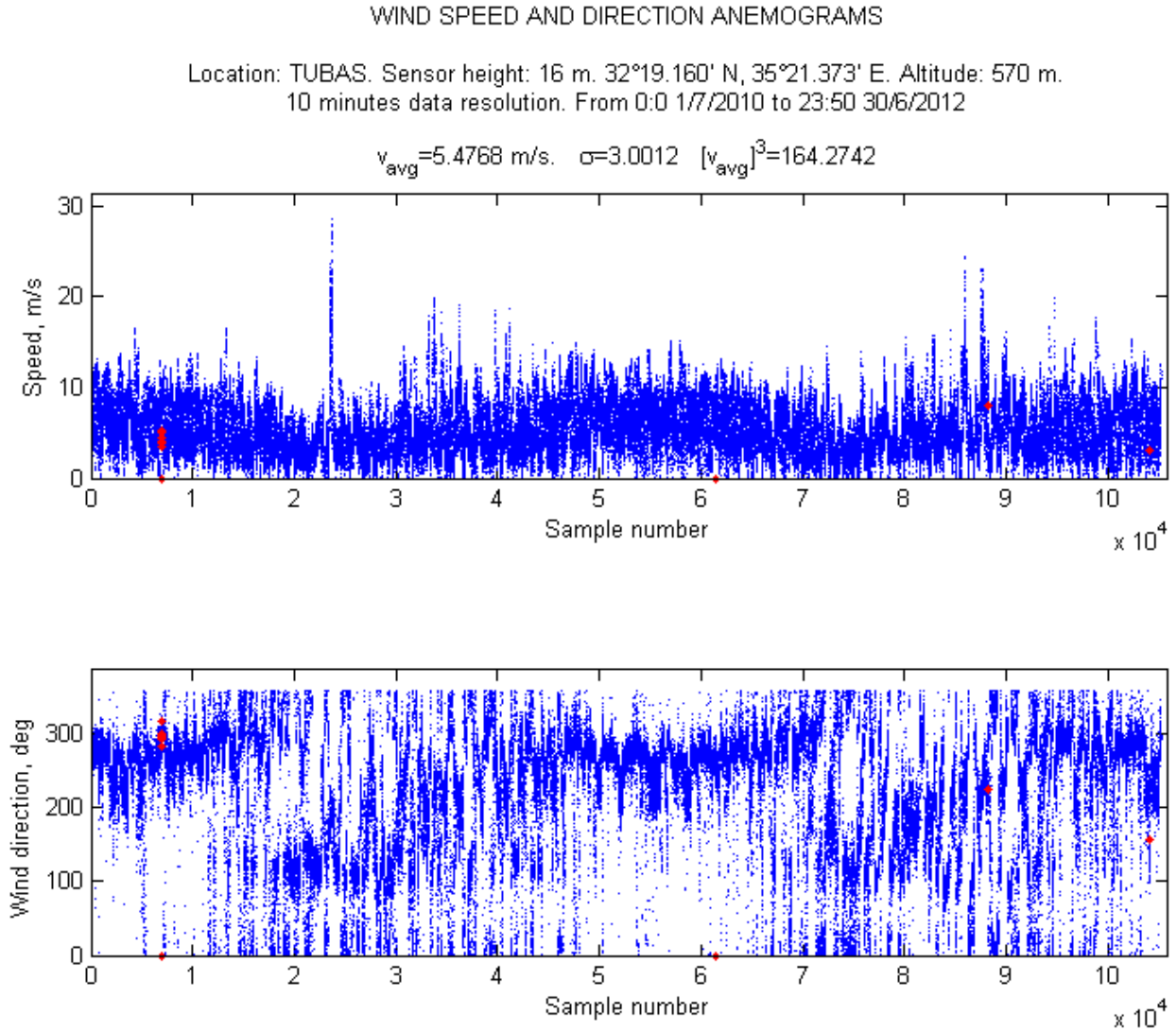


FIGURE 16: WIND SPEED AND DIRECTION ANEMOGRAMS FROM TUBAS 2

On the data from Salfeet 2 an incidence is detected from September 2013 (approximately) until the end of the available data (March 2013) due to the fact that most of the direction values were  $0^\circ$  or  $360^\circ$ , which is not normal (and it is not correlated with Tubas 1, so that rejects a problem in the data logger) and points in a anomalous working of the vane used for sense the direction. However, these data were not under study on this work so they did not interfere on the results.



### 5.1.1.2.6. MKAHAL

In the Figure 17 four long periods of missing data can be detected. At the end of the first period some data which has repeated date are also shown.

In the first period there is more than 2 months missing data from 1<sup>st</sup> October 2011 at 00:00 till 6<sup>th</sup> December 2011 at 09:40. In the second period there is about 18 days of missing data from 5<sup>th</sup> April 2012 at 10:40 until 23<sup>rd</sup> April 2012 at 04:20. In the third period more than 2 months of data are missing: from 28<sup>th</sup> June 2012 at 14:10 until 1<sup>st</sup> September 2012 at 08:30. Finally, in the fourth period 21 days of data are missing: from 10<sup>th</sup> December 2012 at 08:30 till 31<sup>st</sup> December 2012 at 23:50.

The quality of the data of this station is seriously affected, as less than 2 years data were theoretically available and more than 35% of them are missing or repeated.

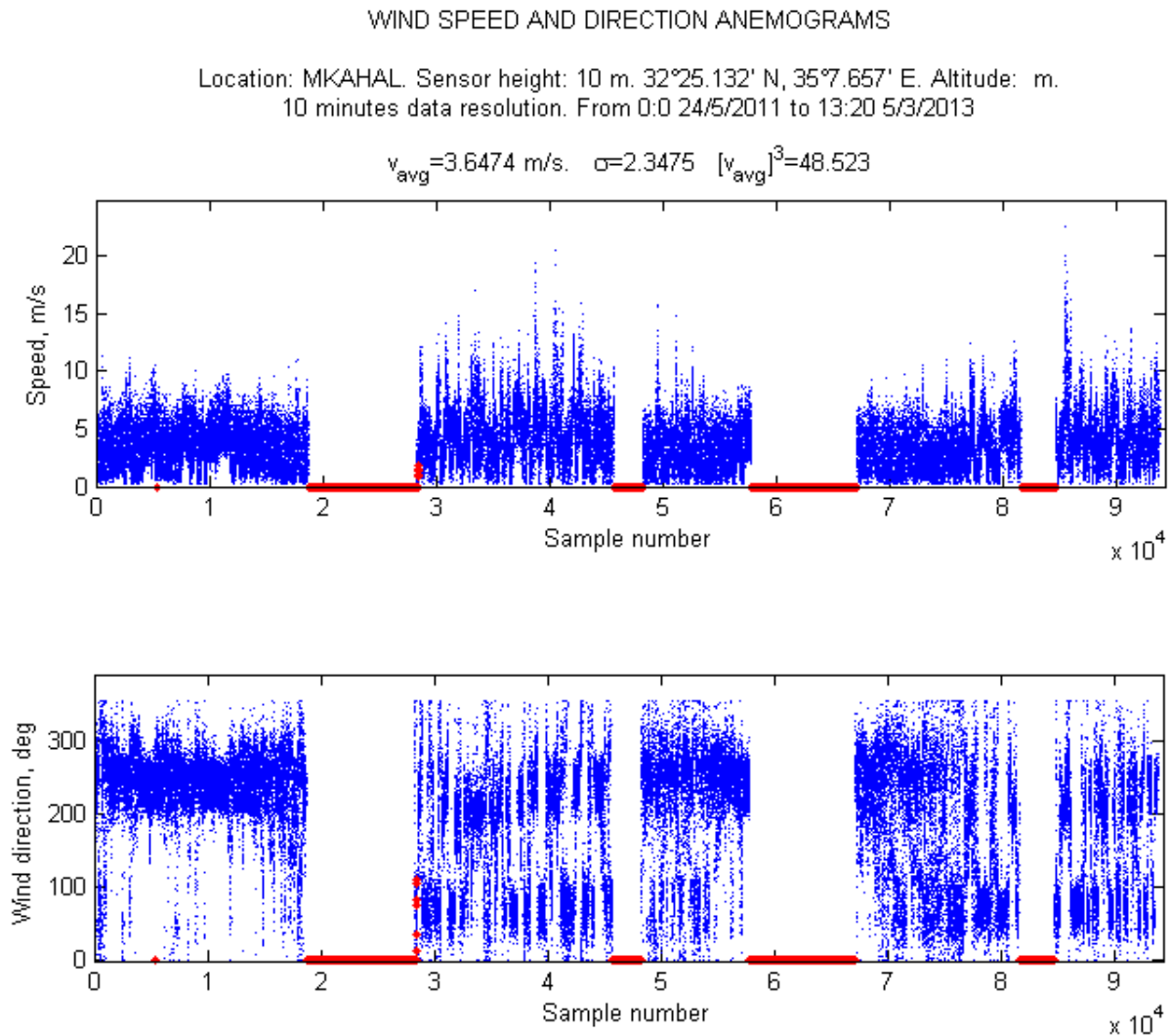


FIGURE 17: WIND SPEED AND DIRECTION ANEMOGRAMS FROM MKAHAL

### 5.1.1.3 OUTLIERS

In this section outliers are detected. The limit value for the speed is considered 50 m/s.

The results, collected in Table 4, show that only in two stations outliers were found:

In Salfeet 2 (in the highest level) 3 registers (0.003%) had wind direction values superior to 360°, and in Mkahal 12 registers (0.0173%) had negative direction.

Station	Vi > Vmax		Vi < 0		Dir > 360°		Dir < 0	
	Inc.	%	Inc.	%	Inc.	%	Inc.	%
Hebron	0	0	0	0	0	0	0	0
Salfeet 1	0	0	0	0	0	0	0	0
Salfeet 2	0	0	0	0	3	0.003	0	0
Tubas 1	0	0	0	0	0	0	0	0
Tubas 2	0	0	0	0	0	0	0	0
Mkahal	0	0	0	0	0	0	12	0.0173

TABLE 4: OUTLIERS TEST RESULTS

The outliers are considered erroneous data and are dismissed from the data series and not used in the following tests.

#### 5.1.1.3.1 DOUBLE-ZEROS TEST

An unusual proportion of zero values in the wind speed and direction simultaneously were detected in the available data. Since the probability of having zero in speed and direction should not be bigger than having other values this case is considered erroneous data.

In the Table 5 the results of the double-zeros test are shown:

Station	Double-zeros	
	Inc.	%
Hebron	4	0.0039
Salfeet 1	8676	8.4889
Salfeet 2	1356	1.3268
Tubas 1	374	0.3553
Tubas 2	409	0.3886
Mkahal	0	0

TABLE 5: DETECTED "DOUBLE-ZEROS"

In all the stations double zeros were found excepting in Mkahal. In the station in Hebron the proportion was very small, 0.004%. However in Salfeet the incidences were much larger, and more than 8% and 1.3% of double zeros appeared in Salfeet 1 and Salfeet 2 respectively. The intermediate case occurred in Tubas, were less than 0.4% double zeros were found (0.36% and 0.39% respectively for Tubas 1 and Tubas 2).

As it happened in the “Outliers test”, the “double-zeros” registers are considered bad data and are rejected from the data series.

#### 5.1.1.4 ANOMALOUS PATTERNS

As it was explained previously, the objective of this test is to find anomalous patterns repeated among the data series from the same station or between data series from different stations.

For this test zero strings (which were plentifully detected) are not considered as anomalous patterns since there is a specific test for repeated zero values.

The available data was checked and anomalous patterns were not found.

#### 5.1.1.5 RESULTS AFTER THE FIRST QUALITY CONTROL PART

The erroneous data found in the precedent tests was eliminated, in order to maintain the quality and do not obtain biased results. Thus, the final results obtained before the second part of the quality control, and after the outliers and the double-zeros tests, are shown in the Table 6.

Station	Initial length	Total incidences found		Final length	Percentage of accepted data
		Amount	%		
Hebron	103487	8	0.00008	103479	99.9923
Salfeet 1	102205	8676	8.4889	93529	91.5112
Salfeet 2	102205	1359	1.3297	100846	98.6703
Tubas 1	105260	376	0.3572	104884	99.6428
Tubas 2	105260	411	0.3905	104849	99.6095
Mkahal	69285	12	0.0173	69273	99.9827

TABLE 6: RESULTS BEFORE THE 2<sup>ND</sup> PART OF THE QC

In all the stations more than 99% of the data were accepted excepting Salfeet: In Salfeet 1 over 8% of the data was refused (a huge amount of double-zeros were found), and in Salfeet 2 more than 1.3% was not accepted.

#### 5.1.1.6 RANGE TEST

On this second part of the quality control procedures first a general brief for the results obtained in all the stations will be given, and then more detailed information of the results of each test for each station will be shown.

This starts with the range test. Even if it is known that the wind speed data it is suppose to come from a Weibull distribution, before applying this test a verification was carried out using the Matlab function ‘wblplot’, which assess graphically if the data follows a Weibull distribution, and if it does the plot will be linear.

The Weibull shape and scale coefficients were estimated, and from that point on the limit for suspicious (RS) and the limit for erroneous data (RE) were calculated. The RS limit was considered the 95% percentile, and the RE was the 99.9%. The election of the limits was based in the idea that it is worse dismiss a correct data (the data series loses quality) than accepting an erroneous one .

Station	Weibull coeffs.		Limit values	
	k	c	RS	RE
Hebron	2,31735	5,0207	8,0609	11,5598
Salfeet1	1,8907	5,0490	9,0207	14,0329
Salfeet2	2,0105	5,6477	9,7472	14,769
Tubas1	1,9281	5,5661	9,8330	15,166
Tubas2	1,9162	6,1974	10,9868	16,991
Mkahal	1,17624	3,8048	9,67033	19,6748

TABLE 7: WEIBULL COEFFS. AND LIMIT VALUES FOR THE RANGE TEST

As it is shown in the Table 7, the shape parameter varied from 1.176 to 2.317 and the scale parameter ranged from 3.805 to 6.2 m/s.

When the limit values were calculated, the available data was classified: if the data was smaller than RS it was considered correct, and it was flagged with a '0', if it was between RS and RE it was considered suspicious, and flagged with a '1' and if the value was bigger than RE, the data was considered erroneous and flagged with a '2'.

Since most of the values were expected to be zeros as the most of the data should be correct, it was decided to use sparse matrices, which are populated mainly with zeros, due to fact that in Matlab the memory space used for sparse matrices and the computing time is less than in dense matrices, and the storage is made more efficiently. [21]

Station	CORRECT DATA ('0')		SUSPICIOUS DATA ('1')		ERRONEOUS DATA ('2')	
	Amount	Percentage	Amount	Percentage	Amount	Percentage
Hebron	98231	94,93	4471	4,32	777	0,75
Salfeet 1	88302	94.41	4794	5.13	433	0.46
Salfeet 2	95013	94.22	5231	5.19	602	0.60
Tubas 1	100191	95.53	4427	4.22	266	0.25
Tubas 2	100052	95.42	4525	4.32	272	0.26
Mkahal	68167	98,40	1101	1,59	5	0.01

TABLE 8: RANGE TEST RESULTS

The obtained results are summarized in Table 8 and show the correct, suspicious and erroneous data obtained for each of the weather stations.

Mkahal was the station with best results, 98.42% of correct data, 1.57% suspicious data and 0.01% of incorrect data. In Tubas the percentage was very similar for both levels, obtaining around 95.5% of correct data, 4.2% of suspicious data, and around 0.25% of incorrect data. In Salfeet and Hebron the percentage of correct data was higher than 94.5% in all the cases, and the percentage of suspicious data was 5.13%, 5.19% and 4.32%, respectively, and the erroneous was 0.46% for Salfeet 1, 0.60% for Salfeet 2, and 0.75% for Hebron.

### 5.1.1.6.1 HEBRON

As it is shown in the graph in the left in the Figure 18, the data series from Hebron comes approximately from a Weibull distribution, so the shape and scale coefficients were calculated using the maximum likelihood method. As it appeared in the Table 7, the estimated k coefficient was 2.3174, and c was 5.0207.

In the graph plotted in the right of the Figure 18, a comparison of the theoretical distribution curve using these parameters (in blue) and the experimental data is presented. The fitting is really accurate excepting the maximum values of the distribution.

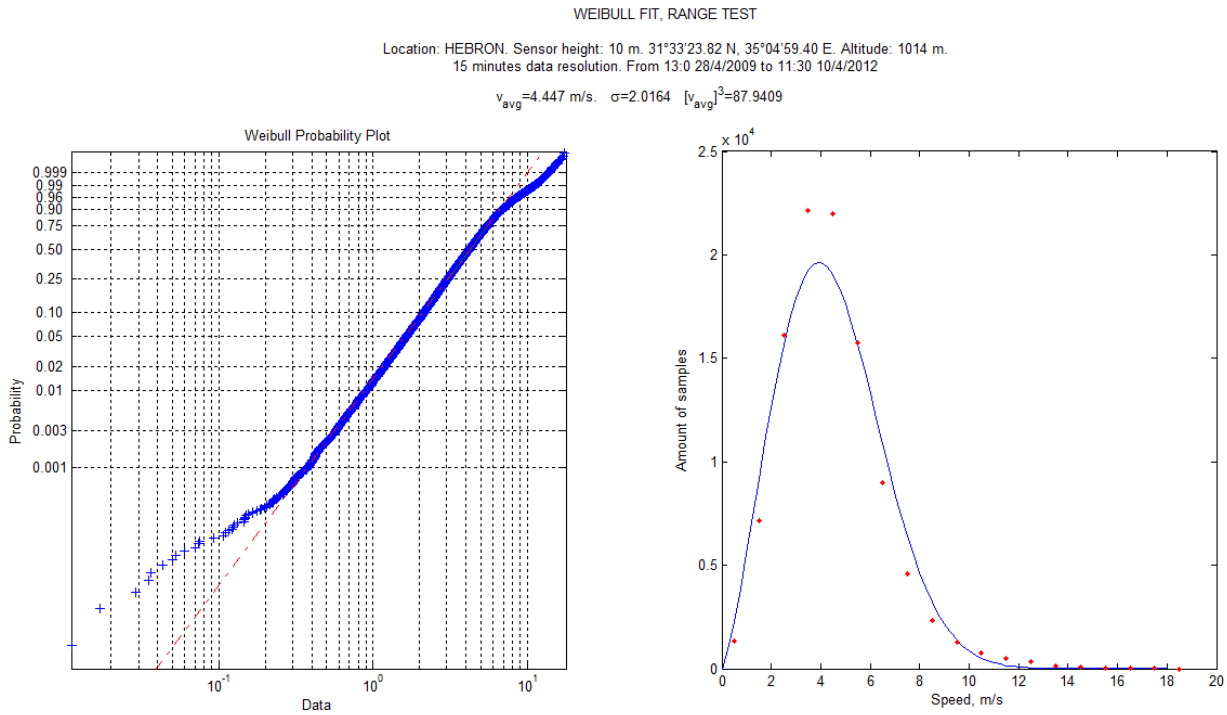


FIGURE 18: WEIBULL FIT, RANGE TEST, HEBRON

Once the Weibull coefficients are estimated the limit values RS and RE were calculated, so as RS was 8.0609 m/s and RE 11.5598 m/s, and the classification of the data was carried out. On the Figure 19 the results are shown in the anemogram itself. Green color was used to describe correct values, yellow for suspicious and red for incorrect data.

The suspicious data were found mainly in autumn and winter seasons (samples 18000-40000, 55000-70000 and 85000-105000), and the erroneous data were found in winter as well (samples 20000-30000, 55000-60000 and 95000-105000).

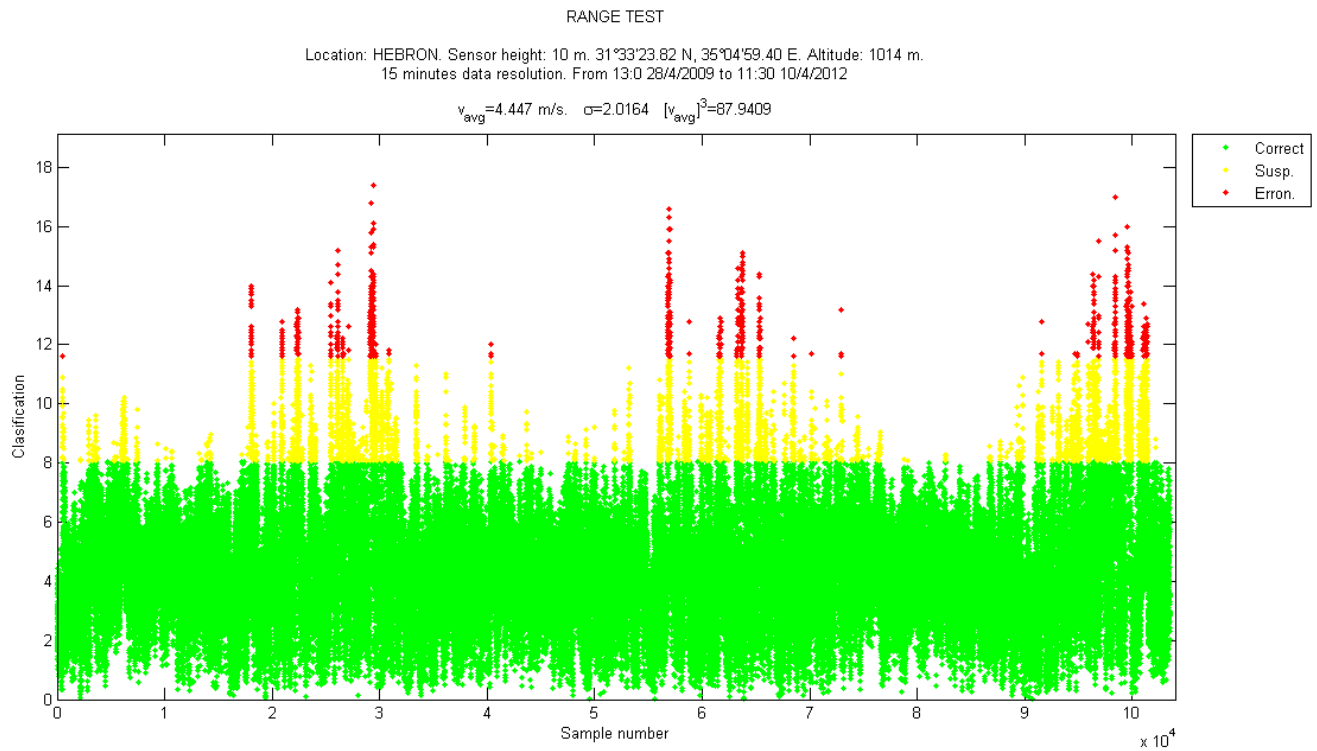


FIGURE 19: CLASSIFICATION ANEMOGRAM, RANGE TEST, HEBRON

#### 5.1.1.6.2 SALFEET 1

The Weibull fit for the data from Salfeet is shown in the Figure 20.

The wind speed data (represented using red dots) follows a Weibull distribution with coefficients:  $k = 1.8907$  and  $c = 5.0490$  m/s (represented using the continuous blue line) and fits it very well excepting the maximum values, and from the estimated parameters the obtained limit values for the range test are  $RS = 9.0207$  m/s and  $RE = 14.0329$  m/s.

On the Figure 21 the anemogram of the data classification is shown.

Two long periods can be observed where most of the suspicious and erroneous data are found: In the first one, which goes from the 15000 to the 40000 sample number (approximately), and the second one goes from the sample 60000 to the 90000. The first period corresponds to October 2010 to April/May 2011 and the second corresponds to the same age in 2011-2012, which it is shown that are the windiest months. The erroneous data belong concretely to the samples 20000 to 30000 and 70000 to 80000, which corresponds to December and January.

WEIBULL FIT, RANGE TEST

Location: SALFEET. Sensor height: 10 m. 32°04.117' N, 35°13.397' E. Altitude: 815 m.  
10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

$v_{avg}=4.4913$  m/s.  $\sigma=2.453$   $[v_{avg}]^3=90.5949$

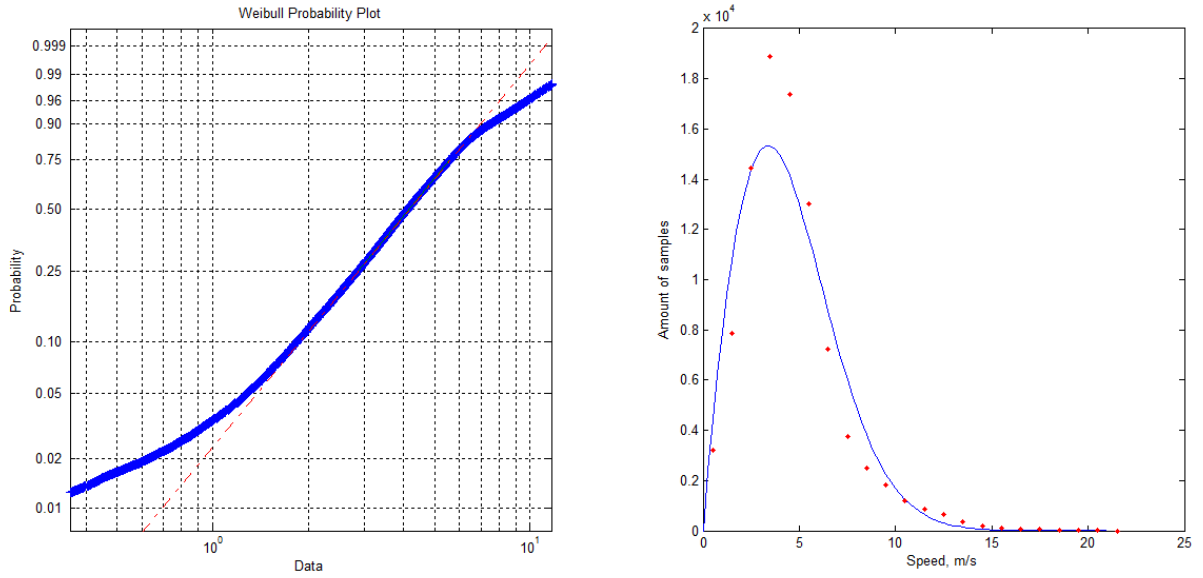


FIGURE 20: WEIBULL FIT, RANGE TEST, SALFEET 1

RANGE TEST

Location: SALFEET. Sensor height: 10 m. 32°04.117' N, 35°13.397' E. Altitude: 815 m.  
10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

$v_{avg}=4.4913$  m/s.  $\sigma=2.453$   $[v_{avg}]^3=90.5949$

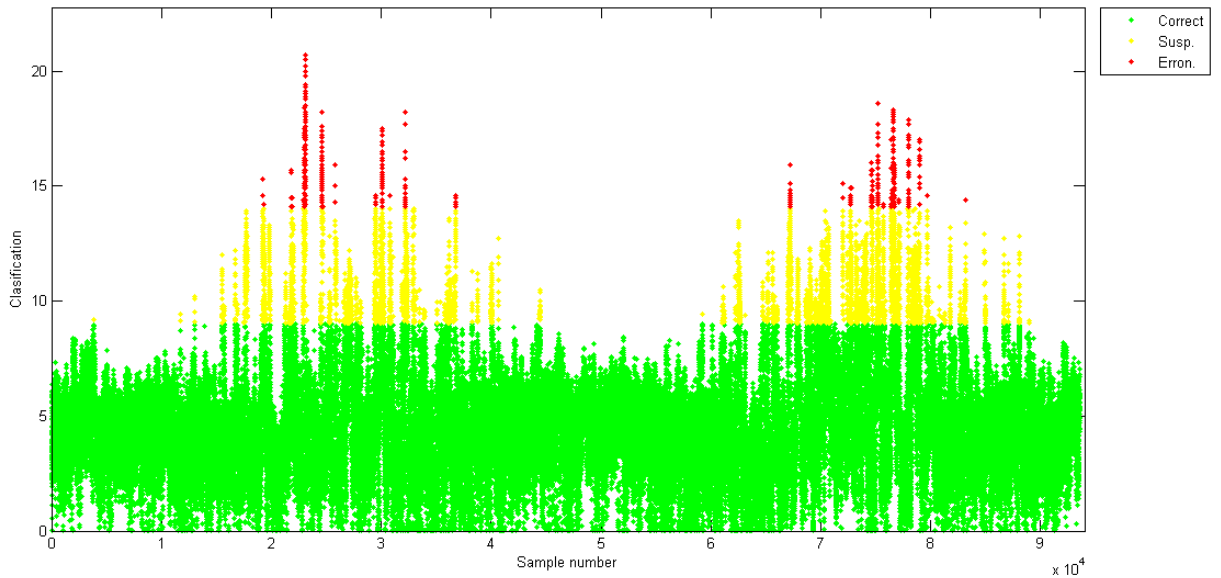


FIGURE 21: CLASSIFICATION ANEMOGRAM, RANGE TEST, SALFEET 1



### 5.1.1.6.3 SALFEET 2

As it happened in Salfheet 1, the data fits properly to a Weibull distribution, and it follows a Weibull with coefficients  $k = 2.0105$  and  $c = 5.6477$  (Figure 22).

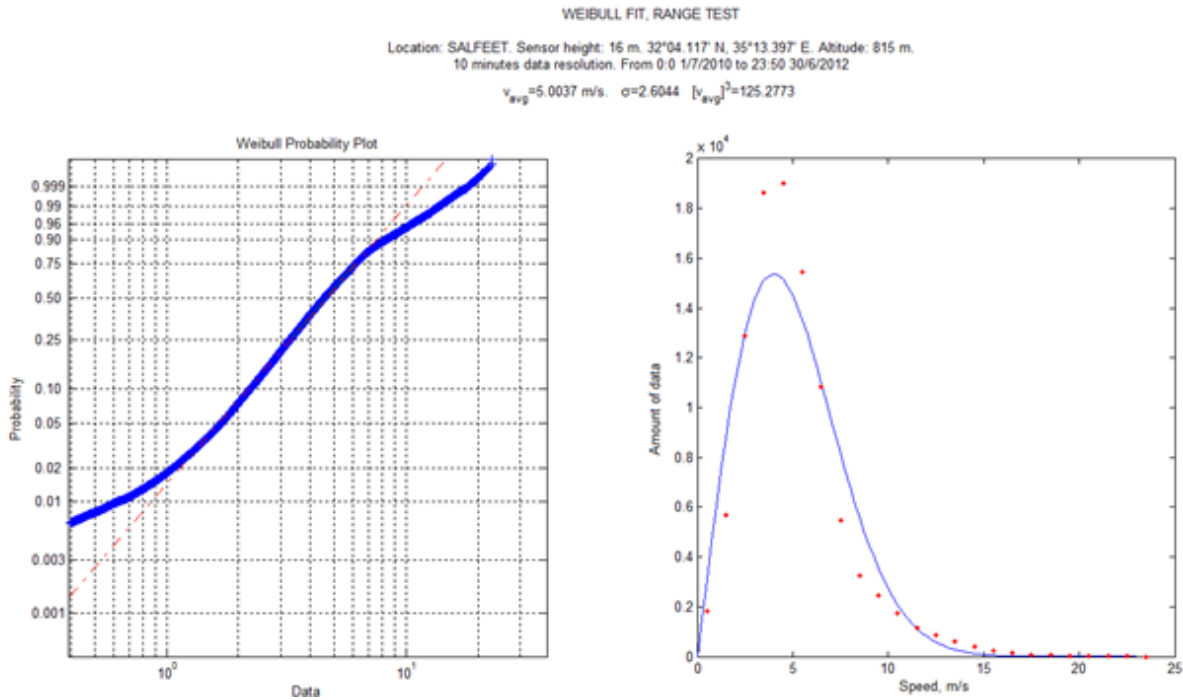


FIGURE 22: WEIBULL FIT, RANGE TEST, SALFEET 2

The limit values for suspicious data (RS) was 9.7472 m/s, and 14.769 m/s for erroneous data (RE). As it happened in Salfheet 1, and it is shown in Figure 23, the period where most of the suspicious data were found was from October to April/May, and in December and January came most of the erroneous 5.1.6.4.

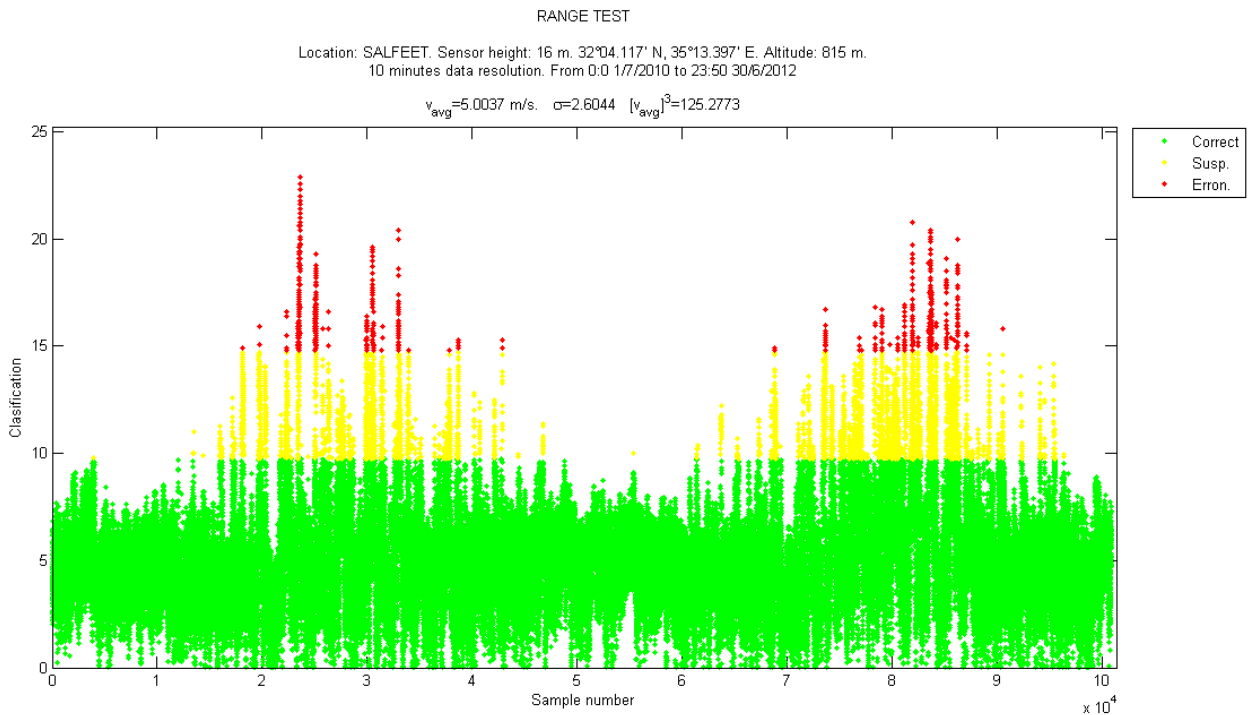


FIGURE 23: CLASSIFICATION ANEMOGRAM, RANGE TEST, SLAFEET 2

#### 5.1.1.6.4 TUBAS 1

In regards to the weather station in Tubas at 10 m high (Tubas 1), it was verified that the data came from a Weibull distribution using the appropriate Matlab command, and it fitted properly to a Weibull distribution when  $k = 1.9281$  and  $c = 5.5661$ . Both results are shown in the graphs of the Figure 24.

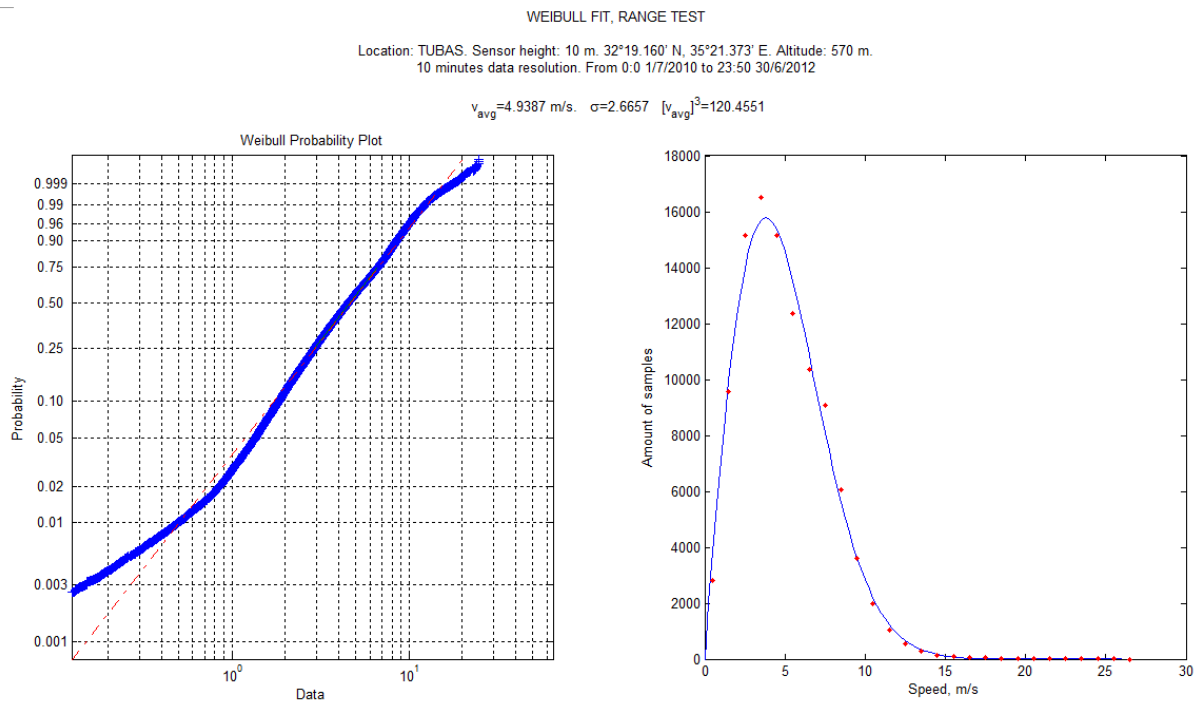


FIGURE 24: WEIBULL FIT, RANGE TEST, TUBAS 1

Using these coefficients the 95<sup>th</sup> percentile (RS) and 99.9<sup>th</sup> percentile (RE) of the related Weibull distribution were calculated, and the data series flagged. The results can be seen in the figure below:

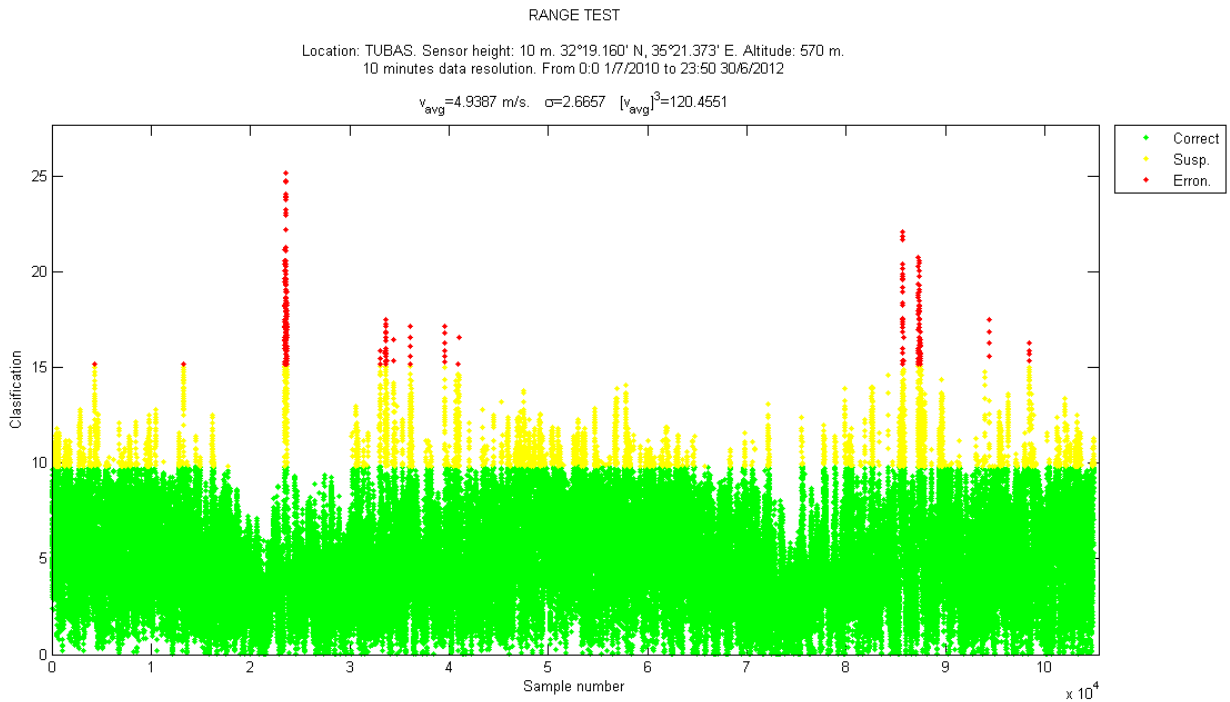


FIGURE 25: CLASSIFICATION ANEMOGRAM, RANGE TEST, TUBAS 1

Unlike the suspicious data allocation in the precedent stations, in Tubas 1 the suspicious values were found over the course of the whole year. However, the erroneous data detected were found only around November and December.

#### 5.1.1.6.5. TUBAS 2

A good fit to the pertinent Weibull distribution ( $k = 1.9161$ ,  $c = 6.1974$ ) was found for the data series from Tubas 2 (Figure 26).

From the estimated coefficients the RS and RE limit values were calculated and the data was flagged. The erroneous and suspicious data are distributed mostly in the same way as in Tubas 1 (Figure 27).

WEIBULL FIT, RANGE TEST

Location: TUBAS. Sensor height: 16 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

$$v_{avg} = 5.4984 \text{ m/s. } \sigma = 2.988 \quad [v_{avg}]^3 = 166.2318$$

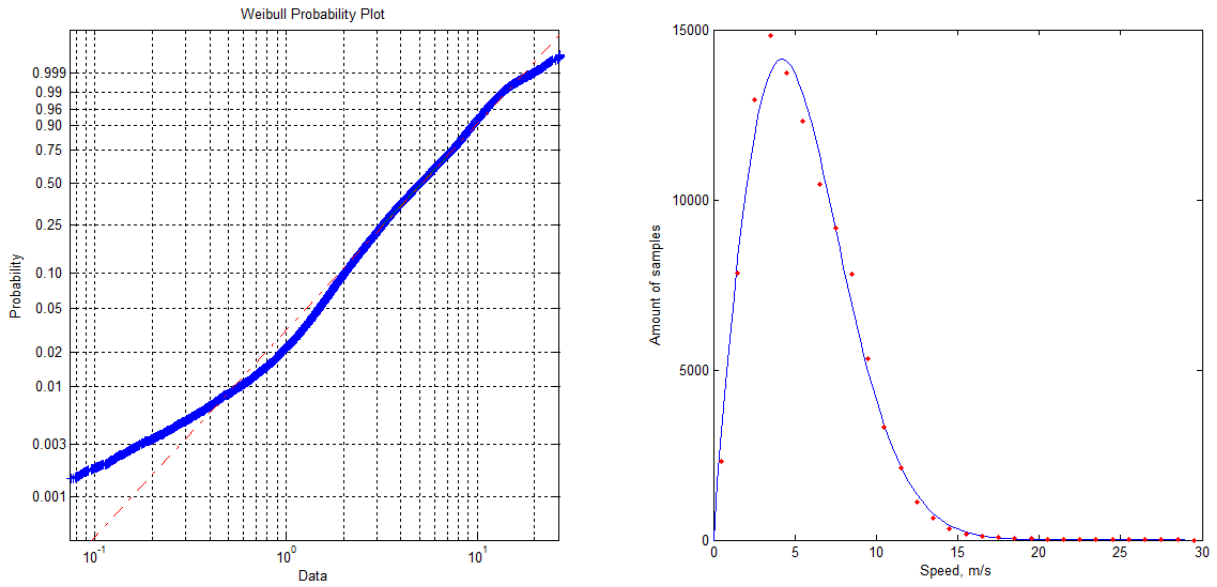


FIGURE 26: WEIBULL FIT, RANGE TEST, TUBAS 2

RANGE TEST

Location: TUBAS. Sensor height: 16 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

$$v_{avg} = 5.4984 \text{ m/s. } \sigma = 2.988 \quad [v_{avg}]^3 = 166.2318$$

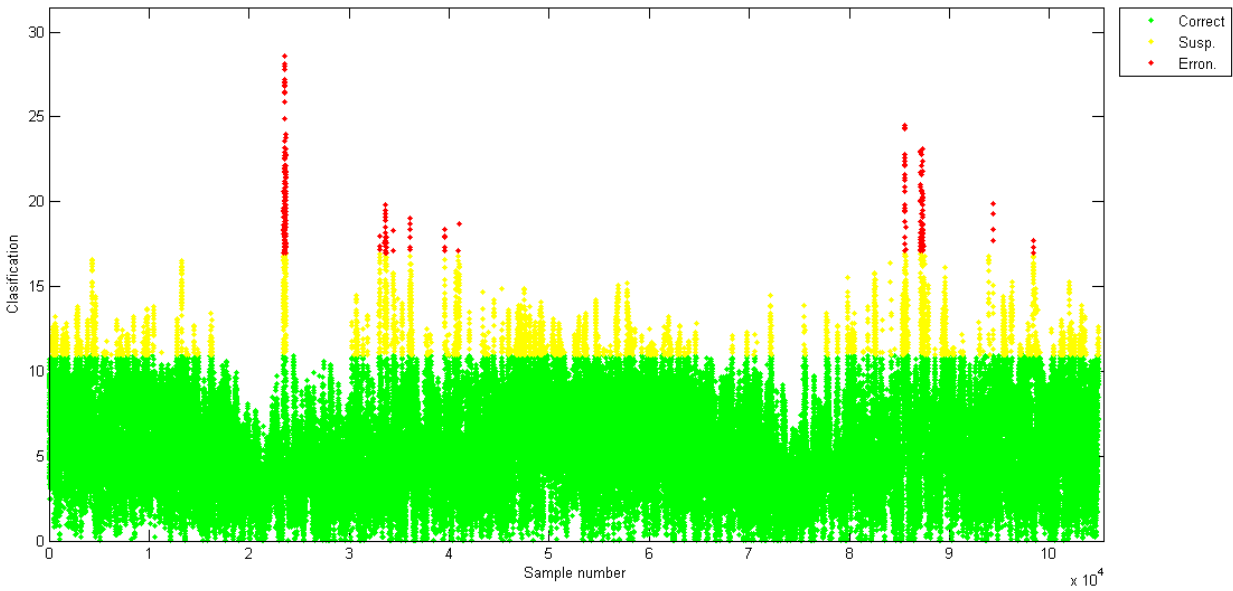


FIGURE 27: CLASSIFICATION ANEMOGRAMS, RANGE TEST, TUBAS 2

### 5.1.1.6.6. MKAHAL

In the data from Mkahal the fit to the Weibull distribution was apparently good (Figure 28), but when the theoretical probability density function ( $k = 1.1762$ ,  $c = 3.8048$ ) was plotted with the data the fitting is not as good as it was for other weather stations.

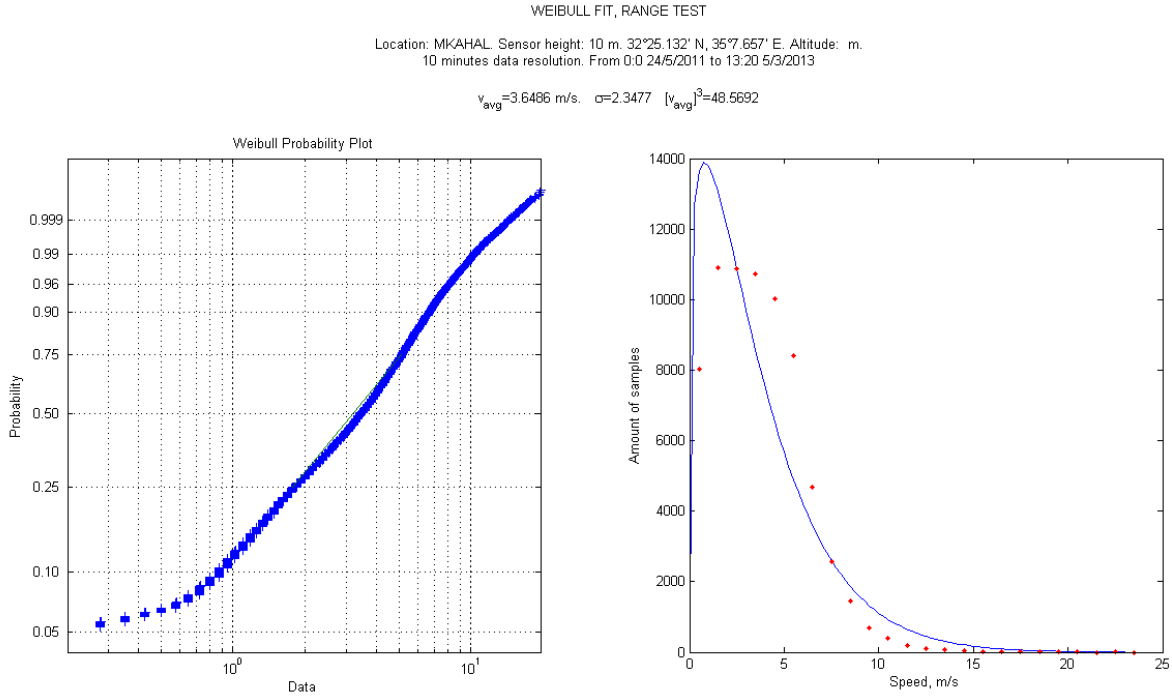


FIGURE 28: WEIBULL FIT, RANGE TEST, MKAHAL

As it is shown in the Figure 29, not many erroneous data were found, but a big amount of suspicious data was detected in the windiest periods.

When the classification anemogram was plotted the missing values were not considered under study, so they do not appear in the graph.

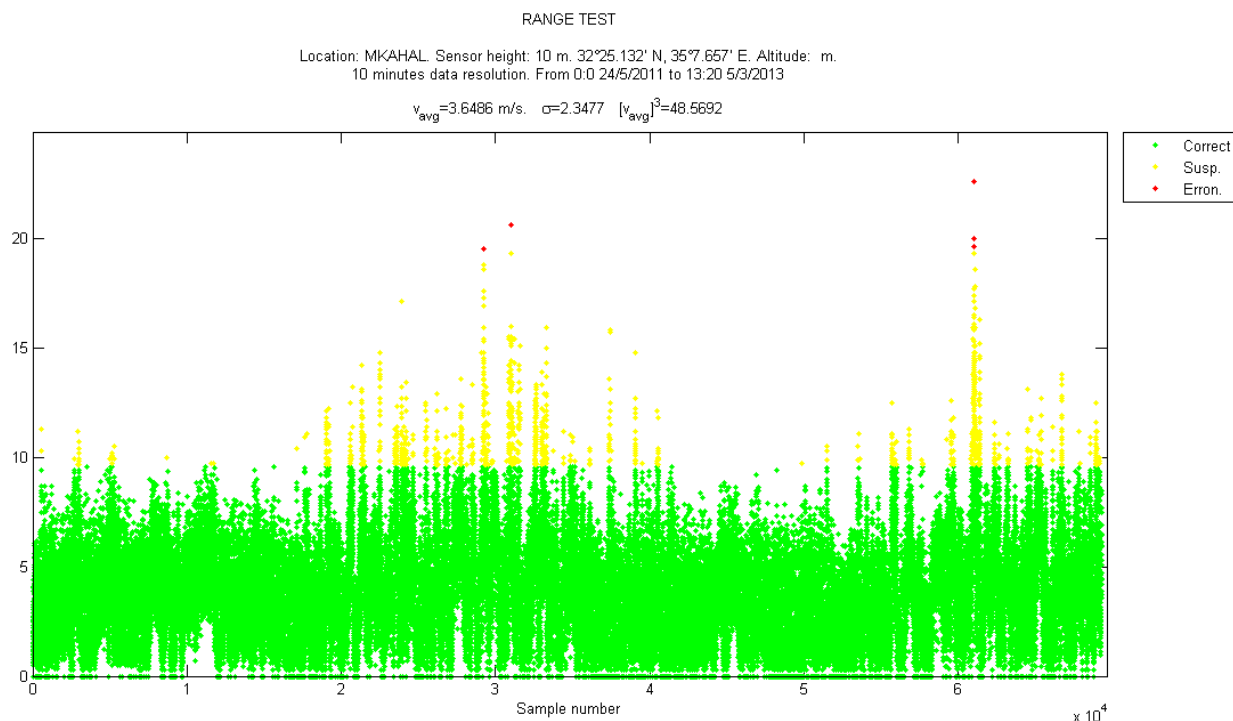


FIGURE 29: CLASSIFICATION ANEMOGRAM, RANGE TEST, MKAHAL

#### 5.1.1.7 STEP CHECK TEST

The next quality control test applied to the data was the step check test, which checked the difference between each consecutive data. Once it was verified the data come from a Weibull distribution the coefficients of the distribution were estimated, and from them the limit values were calculated. Thus, the obtained results for all the stations are collected in the Table 9.

Station	Weibull coeffs.		Limit values	
	k	c	SS	SE
Hebron	1.0859	0.4674	1.2838	2.7710
Salfeet1	0.9583	0.4642	1.4586	3.488
Salfeet2	1.0616	0.4462	1.2543	2.7552
Tubas1	1.0605	0.4788	1.3474	2.9624
Tubas2	1.0470	0.5134	1.4651	3.2540
Mkahal	0.9234	0.8590	2.8186	6.9657

TABLE 9: WEIBULL COEFFS. AND LIMIT VALUES FOR THE STEP CHECK TEST

Using the same criteria as in the range test the limit value for the suspicious data was set in the 95<sup>th</sup> percentile of the Weibull distribution and the value for erroneous data was determined in the 99.9<sup>th</sup> percentile. Then the data classification was made, and the results summarized in the Table 10.

Station	CORRECT DATA ('0')		SUSPICIOUS DATA ('1')		ERRONEOUS DATA ('2')	
	Amount	Percentage	Amount	Percentage	Amount	Percentage
Hebron	94812	91.62	8170	7.90	497	0.48
Salfeet 1	86185	92.15	6266	6.70	1078	1.15
Salfeet 2	92161	91.39	8249	8.18	436	0.43
Tubas 1	96025	91.55	8295	7.91	564	0.54
Tubas 2	96228	91.78	8037	7.67	584	0.56
Mkahal	64758	93.48	4456	6.43	59	0.09

TABLE 10: STEP CHECK TEST CLASSIFICATION

In all the stations more than 91% of the data were flagged as correct, and the suspicious data was around 6.4 to 8.2%. The erroneous data was less than 0.6% in all the stations excepting Salfeet 1, where 1.15% was incorrect.

The best results were found in Mkahal, where 93.48% of the data was correct, 6.43% suspicious and 0.09% erroneous data, and the worst were occurred in Salfeet 1, 1.15% of the data were incorrect, even if the percentage of correct data was 92.15%.

For all the stations, and following the same method as for the range test, the first step carried out was check if the Weibull was the best distribution for the data. The fit was almost perfect for all the cases, better than in the range test. Then, once the Weibull coefficients and the limit values were calculated the data was flagged. These results will be shown graphically for each station.

### 5.1.1.7.1 HEBRON

The classification anemogram of Hebron is shown below:

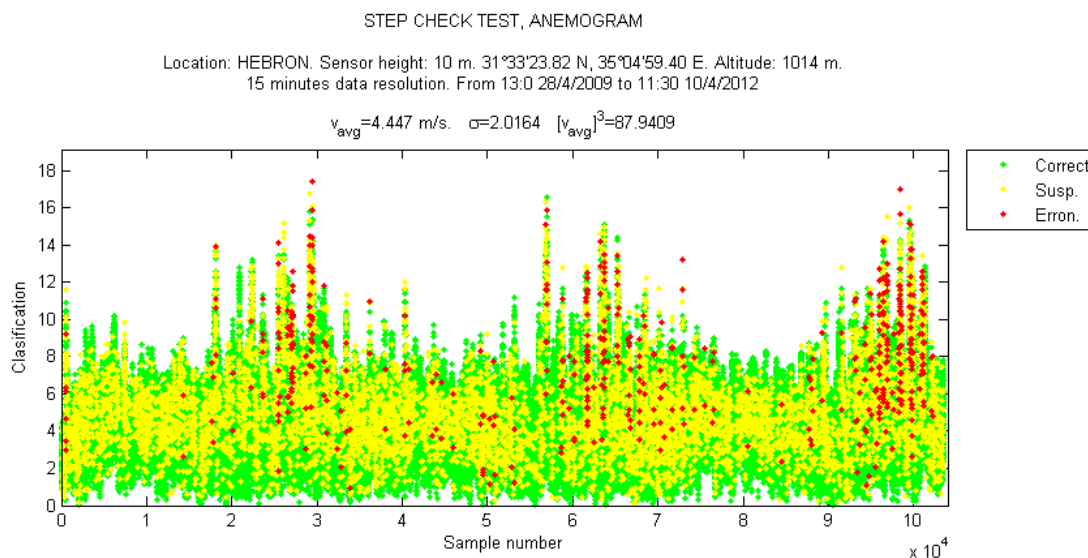


FIGURE 30: CLASSIFICATION ANEMOGRAM, STEP CHECK TEST, HEBRON

The suspicious values were distributed along all the data series, but most of the erroneous data were found in the windiest periods, which correspond to the months from October to April approximately.

### 5.1.1.7.2 SALFEET 1

The classification anemogram for the step check test is shown in Figure 31.

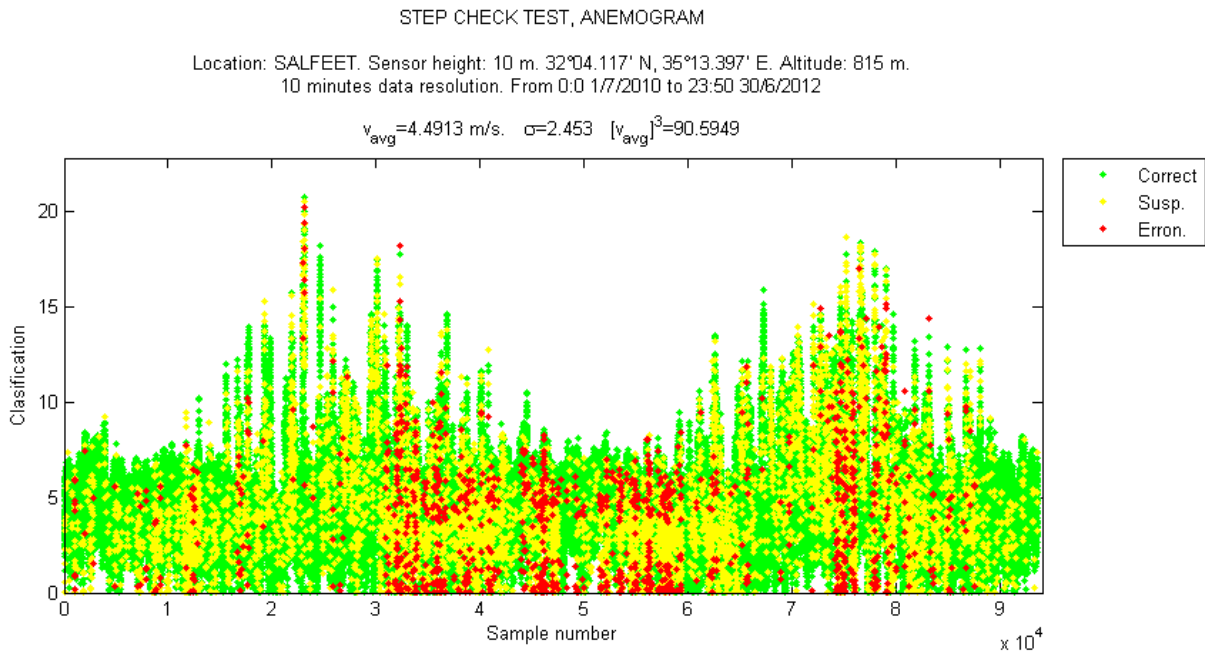


FIGURE 31: CLASSIFICATION ANEMOGRAM, STEP CHECK TEST, SALFEET 1

Regarding the anemogram, there is a period which was especially bad because a huge amount of erroneous data was detected from the sample 30000 to the 60000 (it corresponds to the second half of 2010 and the first half of 2011), and also around the samples 75000 to 80000 (October-November 2011).

There is suspicious data along all the data series.

### 5.1.1.7.3. SALFEET 2

On the classification anemogram in the Figure 32, the results of the step check test from Salfeet are shown. The suspicious values are distributed regularly along the data series, and the erroneous data was found mainly in the windiest periods under study, but in a lower proportion than in Salfeet 1.



STEP CHECK TEST, ANEMOGRAM

Location: SALFEET. Sensor height: 16 m. 32°04.117' N, 35°13.397' E. Altitude: 815 m.  
10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

$$v_{avg} = 5.0037 \text{ m/s. } \sigma = 2.6044 \quad [v_{avg}]^3 = 125.2773$$

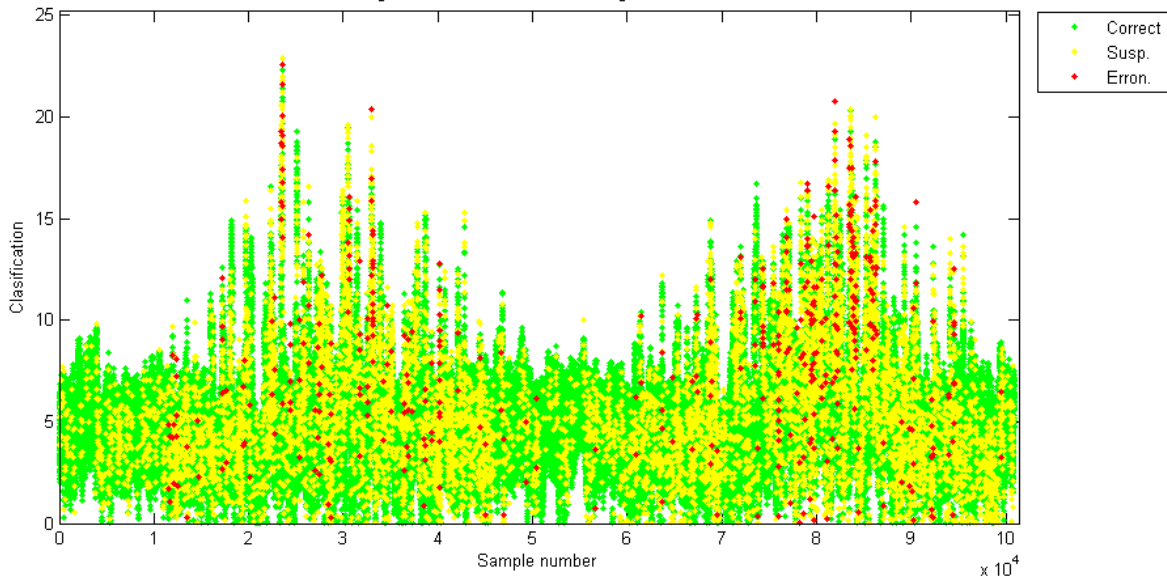


FIGURE 32: CLASSIFICATION ANEMOGRAM, STEP CHECK TEST, SALFEET 2

5.1.1.7.4. TUBAS 1

In Tubas 1 the suspicious and erroneous data were uniformly distributed along the complete data series (Figure 33).

STEP CHECK TEST, ANEMOGRAM

Location: TUBAS. Sensor height: 10 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

$$v_{avg} = 4.9387 \text{ m/s. } \sigma = 2.6657 \quad [v_{avg}]^3 = 120.4551$$

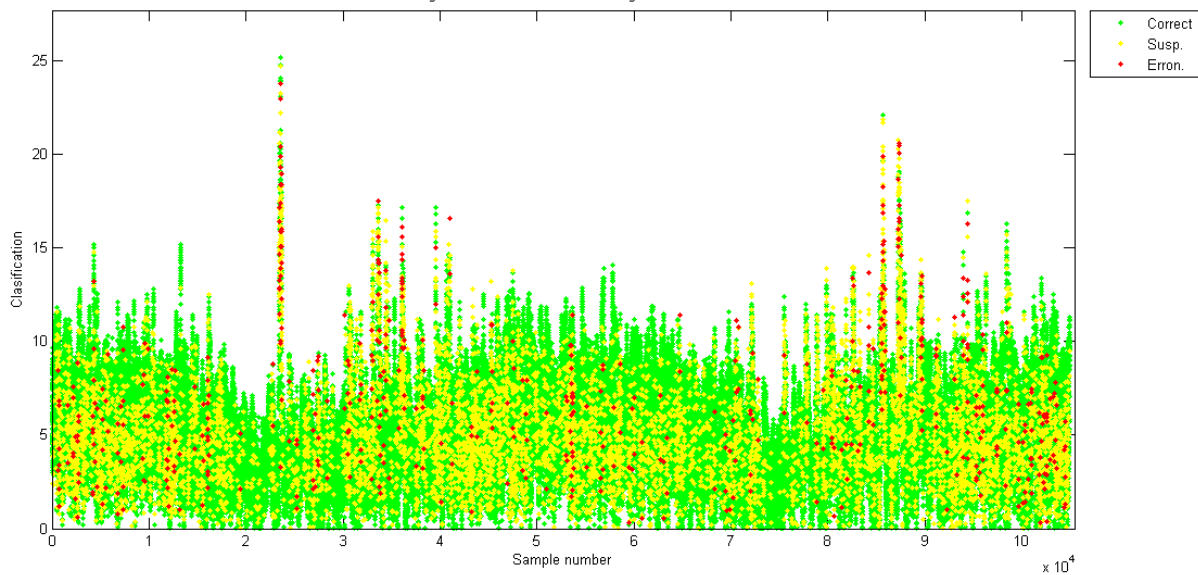


FIGURE 33: CLASSIFICATION ANEMOGRAM, STEP CHECK TEST, TUBAS 1

### 5.1.1.7.5. TUBAS 2

As it is shown in the Figure 34, the obtained results in the step check test for Tubas 2 were very similar to the ones in Tubas 1.

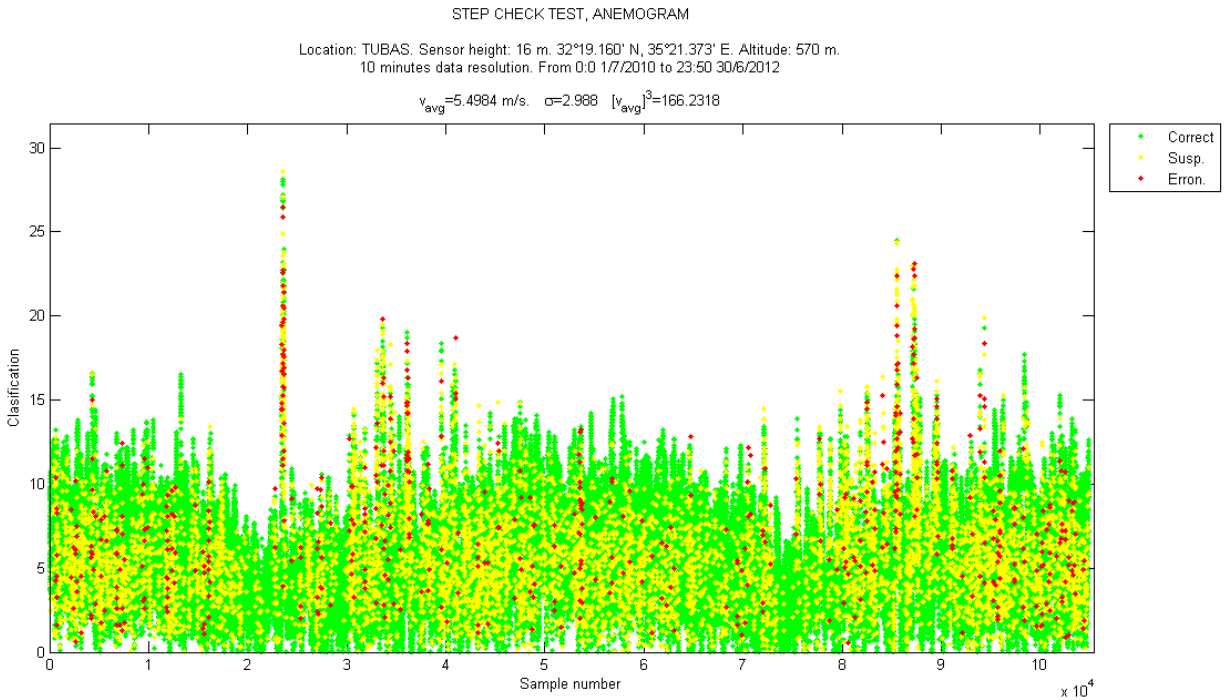


FIGURE 34: CLASSIFICATION ANEMOGRAM, STEP CHECK TEST, TUBAS 2

### 5.1.1.7.6. MKAHAL

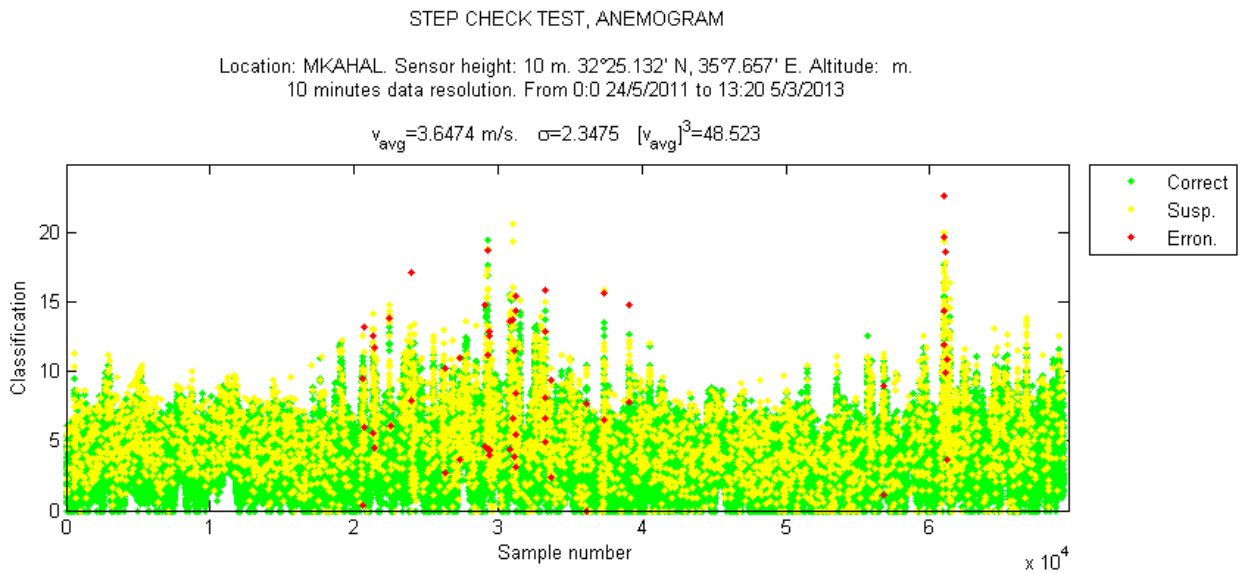


FIGURE 35: CLASSIFICATION ANEMOGRAM, STEP CHECK TEST, MKAHAL

### 5.1.1.8 REPETITIONS TEST

This test checked the existence of repeated consecutive wind speed values. The table below shows that repeated zeros were found only in Mkahal (3.77%), in the other stations only repeated non-zeros were found. The repetitions percentage varied from 1.77% to 2.5% for these stations. For Mkahal, the repeated non-zeros percentage was much higher, 6.16%, which is an indicator of the bad quality of the data, since almost 10% of the data were repeated.

Station	Zeros		Non-zeros	
	Amount	%	Amount	%
Hebron	0	0	906	1.7704
Salfeet1	0	0	948	2.0507
Salfeet2	0	0	1121	2.2190
Tubas1	0	0	1104	2.1347
Tubas2	0	0	1291	2.5227
Mkahal	717	3.77636	4266	6.1582

TABLE 11: REPETITIONS TEST RESULTS

Thus, excepting the mentioned station in Mkahal, in the other cases around 98% of the data were accepted and tagged as correct (Table 12).

Station	CORRECT DATA ('0')		ERRONEOUS DATA (2')	
	Amount	Percentage	Amount	Percentage
Hebron	101647	98.23	1832	1.77
Salfeet 1	91611	97.95	1918	2.05
Salfeet 2	98578	97.75	2268	2.25
Tubas 1	102645	97.87	2239	2.13
Tubas 2	102204	97.48	2645	2.52
Mkahal	62391	90.07	6882	9.93

TABLE 12: REPETITIONS TEST CLASSIFICATION

In the following subsections the classification anemogram of each station will be shown. In all the cases the erroneous data was distributed randomly along the period under study.

### 5.1.1.8.1 HEBRON

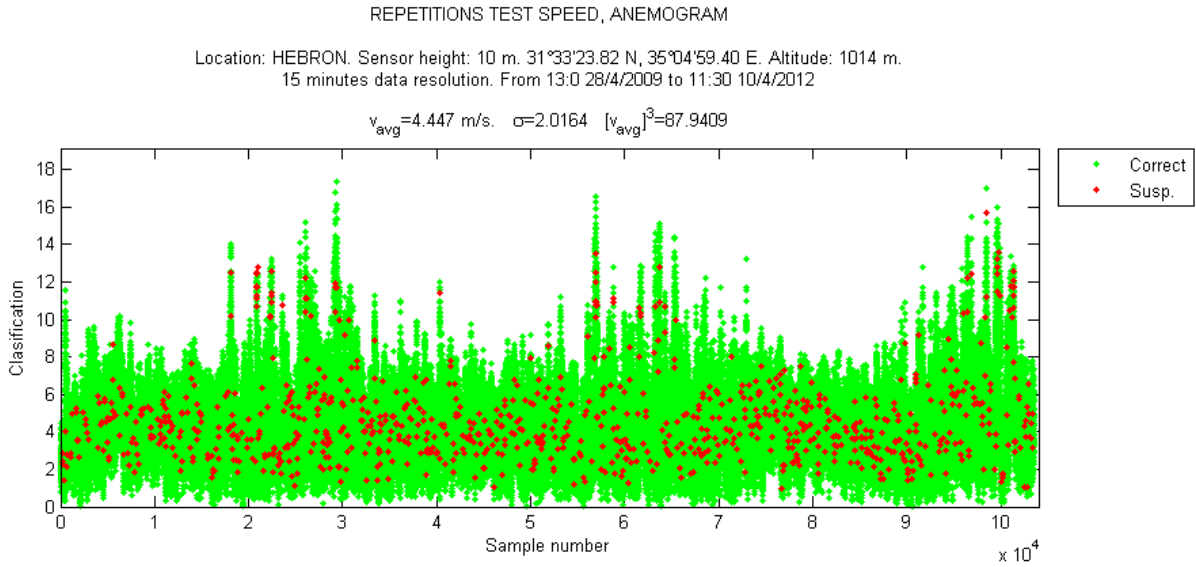


FIGURE 36: CLASSIFICATION ANEMOGRAM, REPETITIONS TEST, HEBRON

### 5.1.1.8.2 SALFEET 1

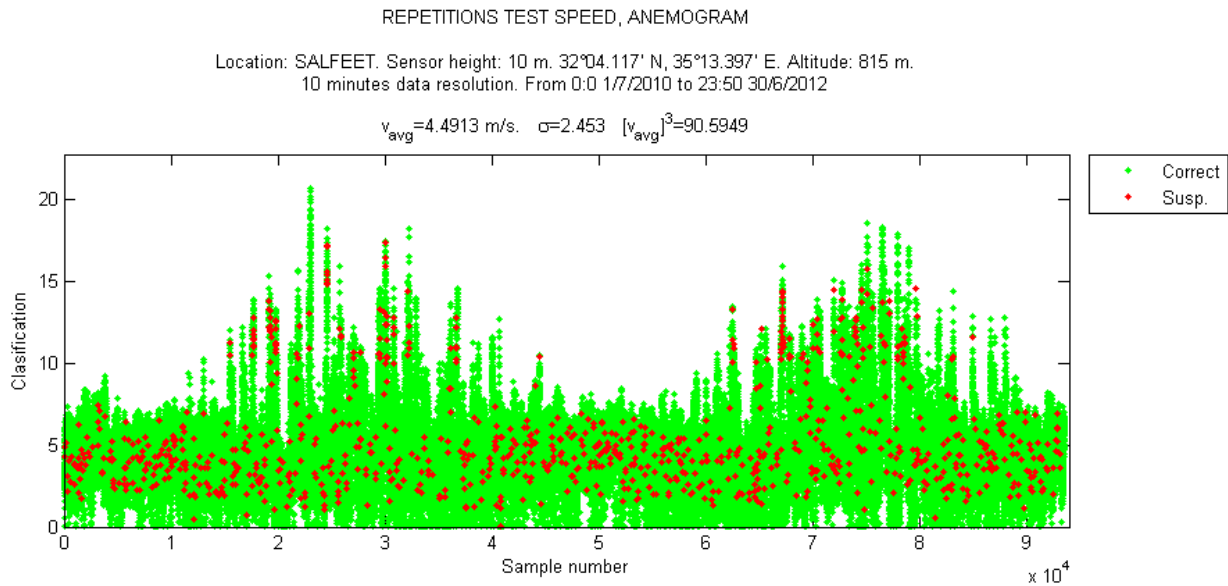


FIGURE 37: CLASSIFICATION ANEMOGRAM, REPETITIONS TEST, SALFEET 1

### 5.1.1.8.3. SALFEET 2

#### REPETITIONS TEST SPEED, ANEMOGRAM

Location: SALFEET. Sensor height: 16 m. 32°04.117' N, 35°13.397' E. Altitude: 815 m.  
10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

$$v_{avg} = 5.0037 \text{ m/s. } \sigma = 2.6044 \quad [v_{avg}]^3 = 125.2773$$

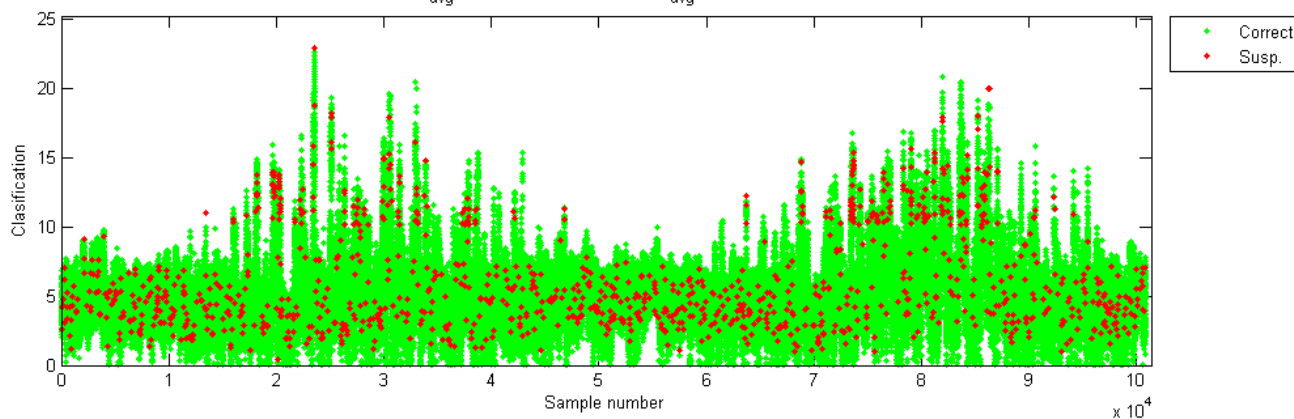


FIGURE 38: CLASSIFICATION ANEMOGRAM, REPETITIONS TEST, SALFEET 2

### 5.1.1.8.4. TUBAS 1

#### REPETITIONS TEST SPEED, ANEMOGRAM

Location: TUBAS. Sensor height: 10 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

$$v_{avg} = 4.9387 \text{ m/s. } \sigma = 2.6657 \quad [v_{avg}]^3 = 120.4551$$

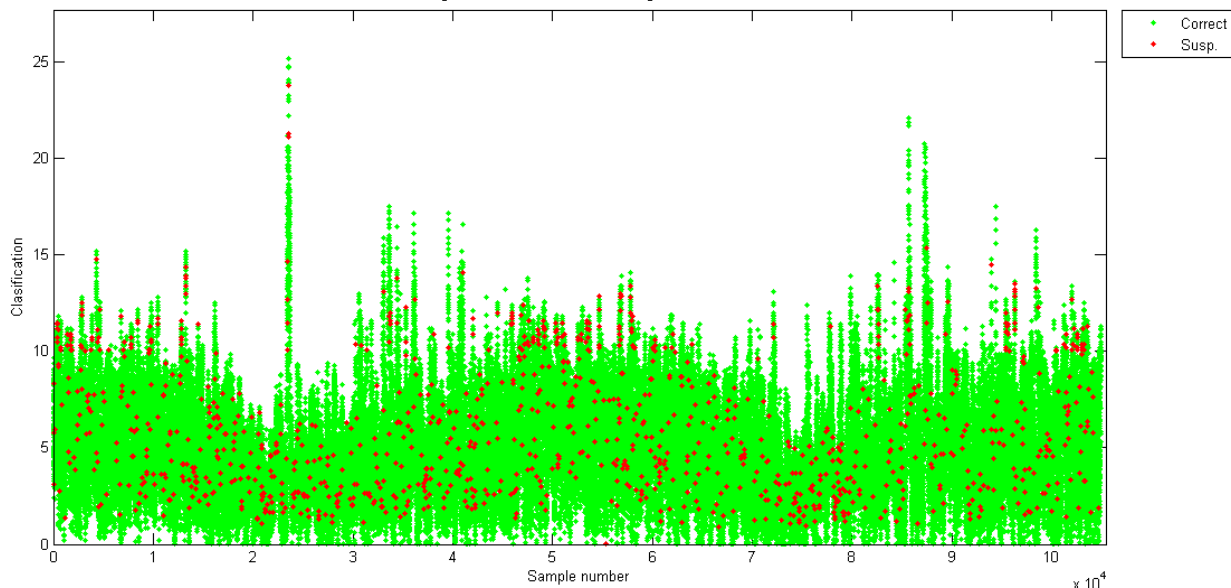


FIGURE 39: CLASSIFICATION ANEMOGRAM, REPETITIONS TEST, TUBAS 1

### 5.1.1.8.5. TUBAS 2

#### REPETITIONS TEST SPEED, ANEMOGRAM

Location: TUBAS. Sensor height: 16 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

$$v_{avg} = 5.4984 \text{ m/s. } \sigma = 2.988 \quad [v_{avg}]^3 = 166.2318$$

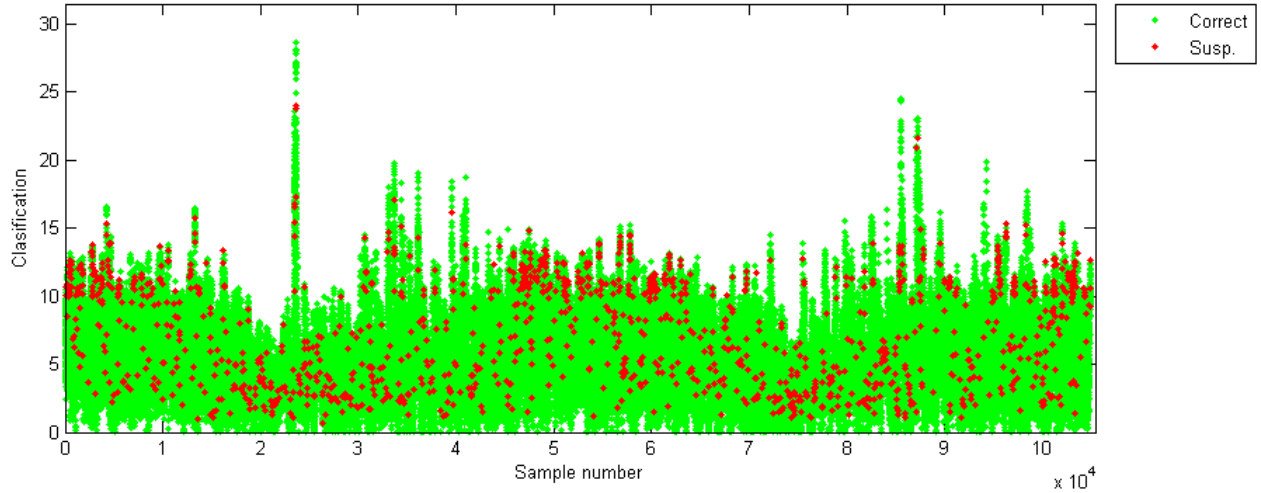


FIGURE 40: CLASSIFICATION ANEMOGRAM, REPETITIONS TEST, TUBAS 2

### 5.1.1.8.6. MKAHAL

#### REPETITIONS TEST SPEED, ANEMOGRAM

Location: MKAHAL. Sensor height: 10 m. 32°25.132' N, 35°7.657' E. Altitude: m.  
10 minutes data resolution. From 0:0 24/5/2011 to 13:20 5/3/2013

$$v_{avg} = 3.6474 \text{ m/s. } \sigma = 2.3475 \quad [v_{avg}]^3 = 48.523$$

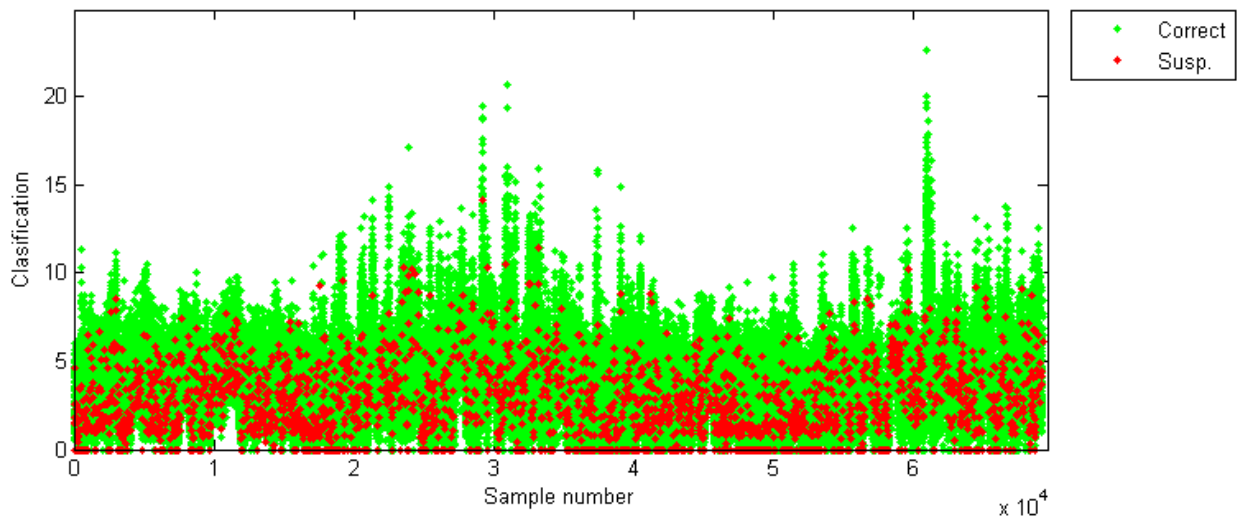


FIGURE 41: CLASSIFICATION ANEMOGRAM, REPETITIONS TEST, MKAHAL

### 5.1.1.9 GLOBAL RESULTS AFTER THE SECOND QUALITY CONTROL PART

Once all the tests are applied to the data series, a global assessment will be given for each data depending on the results obtained on each test. Thus, if the data obtained an erroneous flag in any test, the final flag will be erroneous as well, and it will be dismissed; if the data obtained at two suspicious flags the final flag will be suspicious. In other case the data will be flagged as correct.

Regarding the results obtained after the second part of the quality control process (Table 13), the best results were found in Hebron and Tubas, where more than 96% of the data was accepted, around 3% was flagged as suspicious and less than 1% as suspicious. In both Salfet 1 and Salfet 2 over 95.5% of the data was correct, around 3% was erroneous, and 0.8% and 1.2% respectively were suspicious.

The worst results were found in Mkahal, where more than 10% of the initial data was rejected. It is necessary to stress the bad quality of the data from this station, in addition to the percentage of erroneous data detected more than 35% of the data of the period under analysis were missing.

Station	INCIDENCES		CORRECT DATA (‘0’)		SUSPICIOUS DATA (‘1’)		ERRONEOUS DATA (2’)	
	Amount	Percentage	Amount	Percentage	Amount	Percentage	Amount	Percentage
Hebron	14047	13.5747	99548	96.20	956	0.92	2975	2.87
Salfet 1	13069	13.9732	89378	95.56	782	0.84	3369	3.60
Salfet 2	14481	14.3595	96399	95.59	1242	1.23	3205	3.18
Tubas 1	14324	13.657	101222	96.51	646	0.62	3016	2.88
Tubas 2	14439	13.7712	100780	96.12	623	0.59	3446	3.29
Mkahal	11894	17.1697	61854	89.29	476	0.69	6943	10.02

TABLE 13: GLOBAL RESULTS

For all the stations excepting Mkahal and Salfet the percentage of incidences found was around 13.6%. In Salfet 2 it was higher, 14.3%, and the highest took place in Mkahal: over 17%.

In the next subsections the anemogram of the global classification will be shown for all the stations. The erroneous data are distributed uniformly among the data series, but also in the windiest points due to the results of the range test. The suspicious data are always in the range between the 95<sup>th</sup> and 99.9<sup>th</sup> percentiles defined on the range test (RS and RE), because to be flagged as suspicious in the global test the data must have two flags named suspicious in the precedent tests, and this is only possible if it is flagged as suspicious in the range test as well.



### 5.1.1.9.1 HEBRON

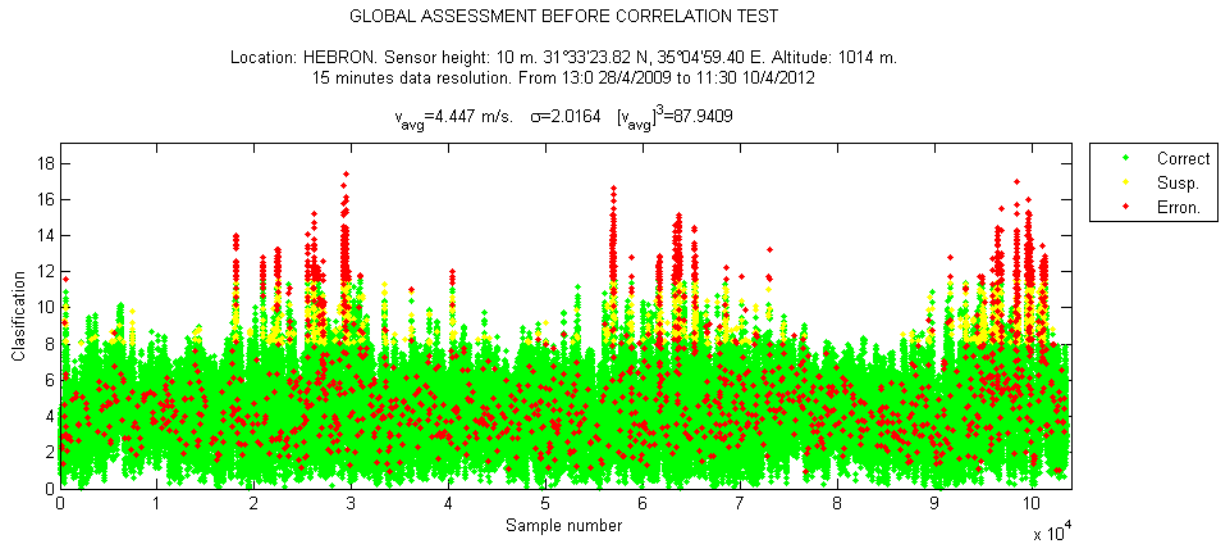


FIGURE 42: GLOBAL ASSESSMENT FOR HEBRON

### 5.1.1.9.2 SALFEET 1

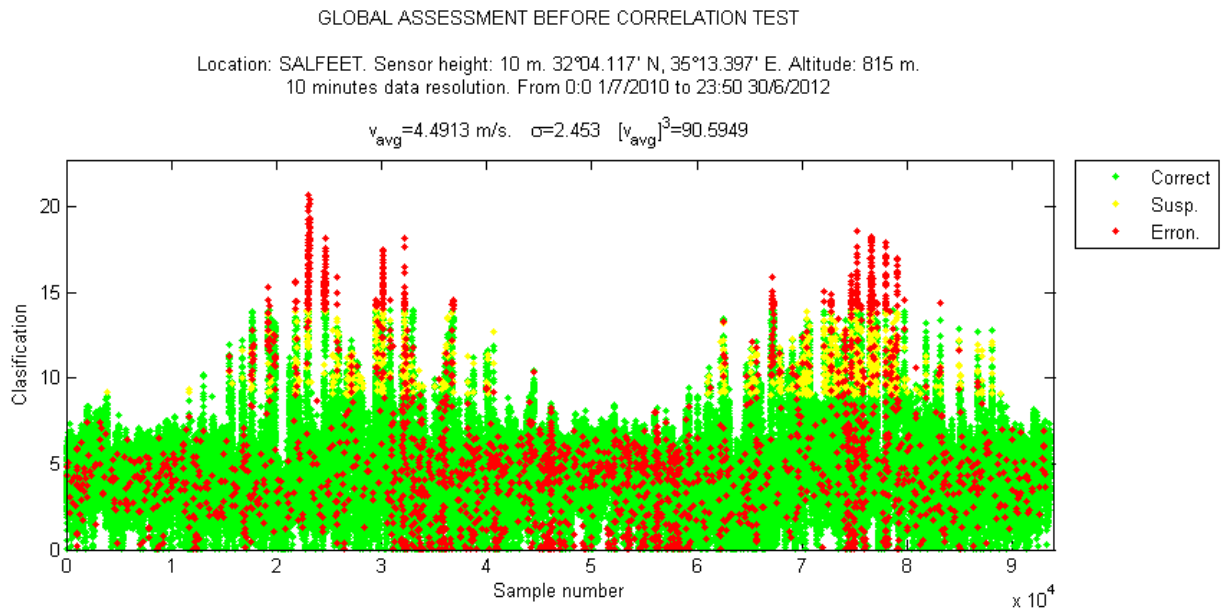


FIGURE 43: GLOBAL ASSESSMENT FOR SALFEET 1



### 5.1.1.9.3. SALFEET 2

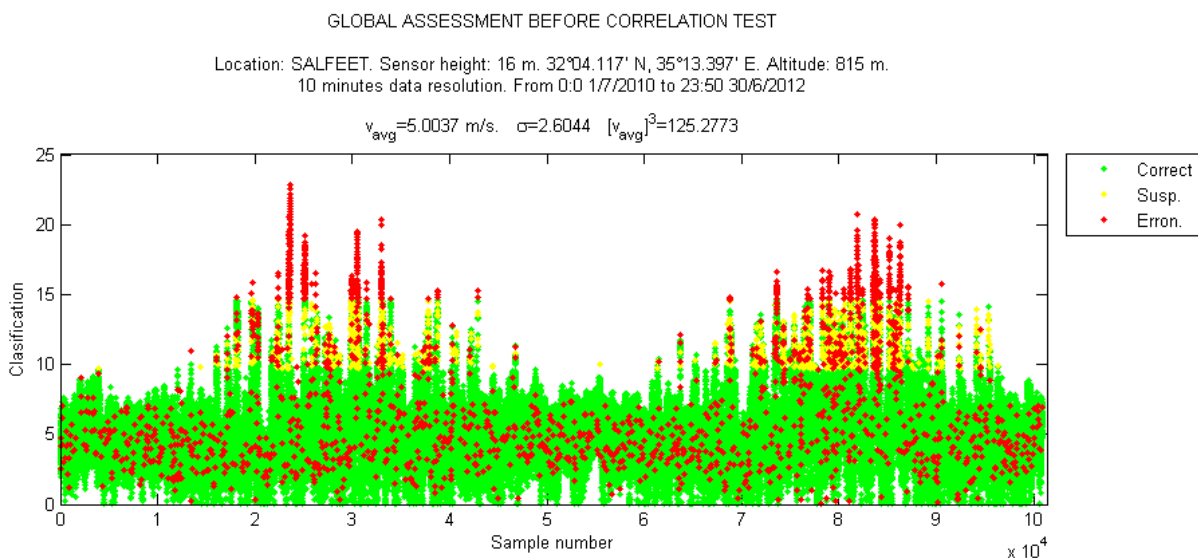


FIGURE 44: GLOBAL ASSESSMENT FOR SALFEET 2

### 5.1.1.9.4. TUBAS 1

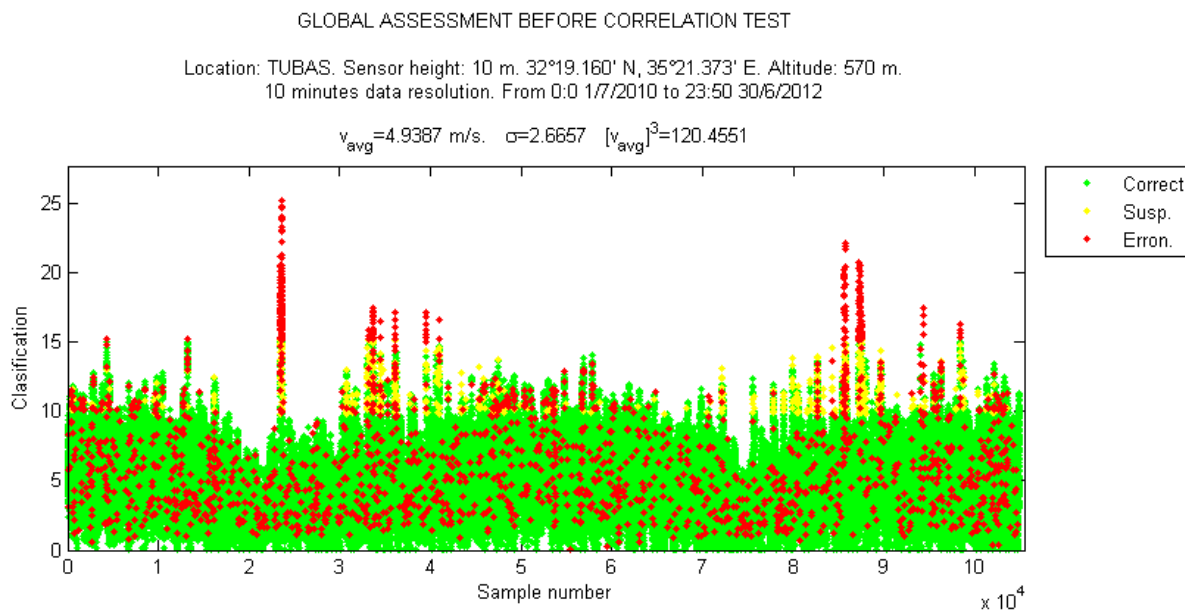


FIGURE 45: GLOBAL ASSESSMENT FOR TUBAS 1

### 5.1.1.9.5. TUBAS 2

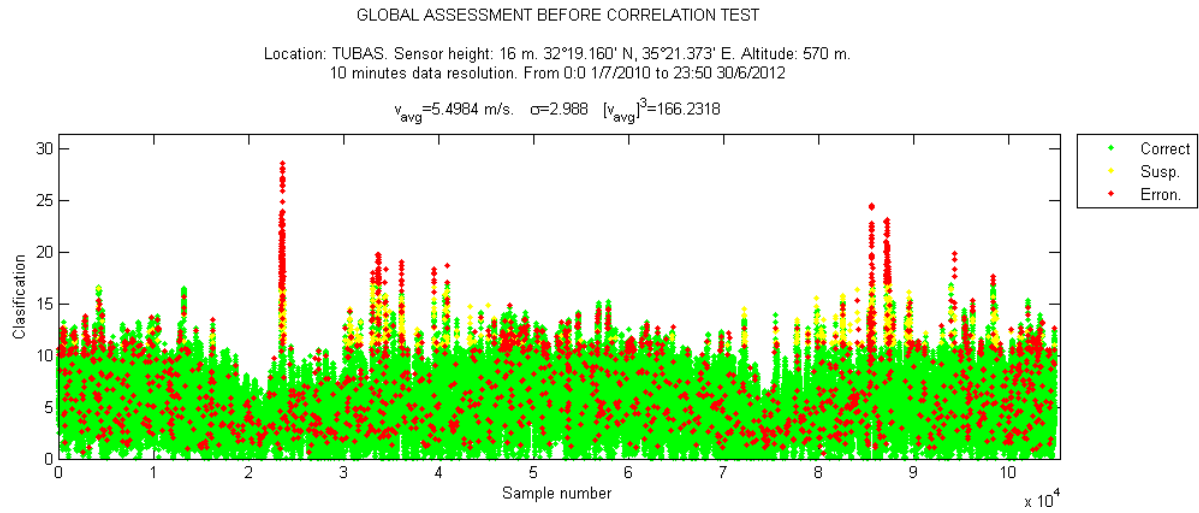


FIGURE 46: GLOBAL ASSESSMENT FOR TUBAS 2

### 5.1.1.9.6. MKAHAL

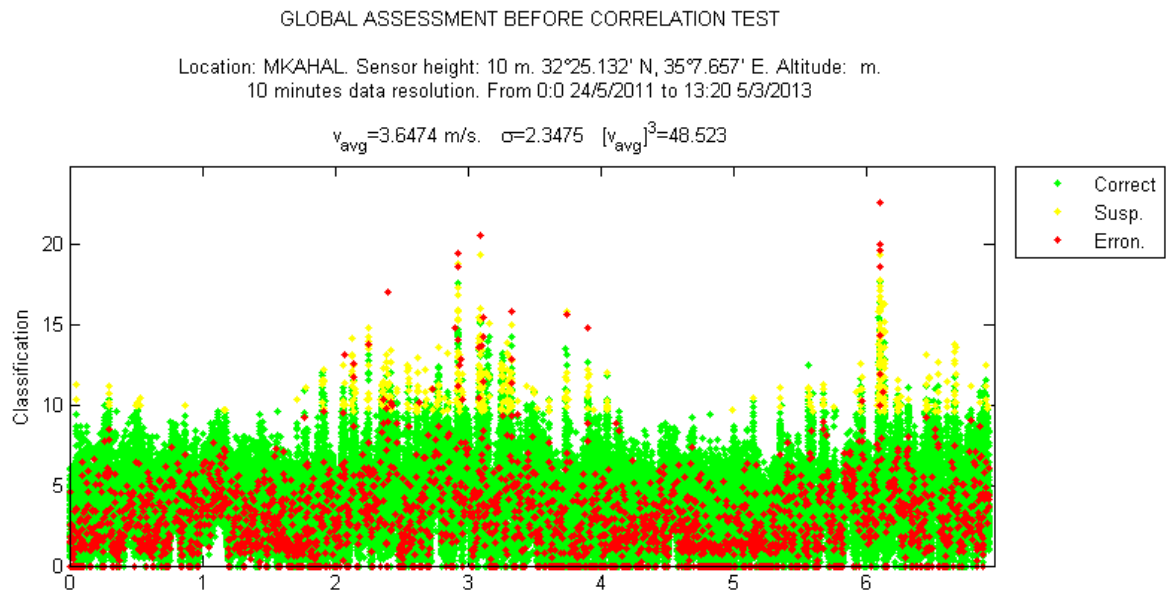


FIGURE 47: GLOBAL ASSESSMENT FOR MKAHAL

### 5.1.1.10 CORRELATION TEST

The last step of the quality control process is the correlation test. Therefore, the correlation coefficient,  $\rho$ , was calculated for each pair of weather stations.

The matrix of results is presented in the table below. It is symmetric because the correlation is a commutative operation.

Stations	Hebron	Salfeet 1	Salfeet 2	Tubas 1	Tubas 2	Mkahal
Hebron	1	0.5978	0.6141	0.4180	0.4206	0.3889
Salfeet 1	0.5978	1	0.9709	0.4112	0.4068	0.5705
Salfeet 2	0.6141	0.9709	1	0.4006	0.3972	0.5784
Tubas 1	0.4180	0.4112	0.4006	1	0.99463	0.2381
Tubas 2	0.4206	0.4068	0.3972	0.99463	1	0.2206
Mkahal	0.3889	0.5705	0.5784	0.2381	0.2206	1

TABLE 14: CORRELATION COEFFICIENTS

The stations were not correlated, the coefficient was always lower than 0.8 excepting in the stations which have two sensors at different heights (Tubas and Salfeet), therefore the quality control process is finished.

## 5.1.2 WIND ANALYSIS

On this section the data which passed the quality control tests and was accepted will be analyzed using the statistical methods. The statistical results, the wind power and Weibull coefficients obtained before and after the quality control tests will be compared as well.

### 5.1.2.1 STATISTICAL RESULTS AND COMPARISON OF THE RESULTS BEFORE AND AFTER THE QUALITY CONTROL CHECKS

In this subsection the data which passed the quality control tests and was accepted will be analyzed using the statistical methods. The statistical results obtained before and after the quality control tests will be compared as well.

#### MEASURES OF CENTRAL TENDENCY

In the Table 14 there are collected the measures of central tendency calculated after and before the quality control process, and the percentage of variation between both results.

The first statistical parameter calculated was the arithmetical mean.

Station	Measures of central tendency									
	Mean			Median			Mode (speed)		Mode (directions)	
	Before QC	After QC	%	Before QC	After QC	%	Before QC	After QC	Before QC	After QC
Hebron	4.45	4.37	-1.73	4.21	4.19	-0.52	4.48	4.13	338.40	338.40
Salfeet1	4.11	4.42	7.62	3.89	4.10	5.29	0	3.92	0.00	319.20
Salfeet2	4.94	4.90	-0.81	4.53	4.54	0.13	0	4.34	0.00	312.70
Tubas 1	4.92	4.82	-2.11	4.52	4.50	-0.46	0	10.10	0.00	289.60
Tubas 2	5.48	5.39	-1.52	5.04	5.00	-0.70	0	10.40	0.00	289.20
Mkahal	3.65	3.83	4.96	3.43	3.65	6.57	0	0	59.62	59.62

TABLE 15: MEASURES OF CENTRAL TENDENCY

The station that has the best highest value after the quality control process is Tubas 2, with 5.39 m/s, followed by Salfeet 2 and Tubas 1 (with 4.90 m/s and 4.82 m/s respectively), and Hebron with 4.37 m/s. The worst result was found in Mkahal with 3.83 m/s.

The highest value after the quality control checks was found again in Tubas 2 (5 m/s) and it varied in the range from 4.10 m/s (in Salfeet 1) to 4.52 m/s in Salfeet 2. The lowest value was found in Mkahal (3.65 m/s).

The mode for the speed and direction initially was 0 m/s and 0° for Salfeet and Tubas. However, after the quality control process this result was corrected (there was probably due to the double-zeros check) and the values changed to around 4 m/s and 315° in Salfeet and 10.20 m/s and 289° in Tubas. In Hebron the mode for the directions did not change, it was 338.40°, but in the speed it changed from 4.48 to 4.13 m/s.

In Mkahal the mode did not change and it was 0 m/s and 59.62°.

## MEASURES OF DISPERSION

The measures of dispersion were calculated after and before the quality control process and they are presented in the Table 15.

The lowest value was 0.002 in Salfeet and Tubas, 0.01 in Hebron and 0 in Salfeet, and the highest value of the data series varied from 11.50 m/s in Hebron to 16.90 in Tubas 2.

The mean deviation, which shows the average of the absolute variations, was the highest in Tubas (1 and 2), so that means the values were more dispersed in this station, and the lowest in Salfeet 1, so the values were closer to the mean value in this station.

The variance and standard deviation show that the largest mean distance between the values and the arithmetic mean occurred in Tubas 2. The least dispersed data was found in Hebron, and the intermediate values were found in Salfeet, Tubas 1 and Mkahal, with a variation from 2.28 m/s to 2.55 m/s.

The coefficient of variation shows in all the cases an important dispersion of the data, and it was between 42.88% in Hebron and 59.54% in Mkahal. The intermediate values were found in Tubas and Salfeet1, about 52%, and Salfeet 2, where the value of the coefficient was 49%.

Station	Measures of dispersion (for the speed)																	
	Lowest value			Highest value			Mean deviation			Variance			$\sigma$			Coeff of variation		
	Before QC	After QC	%	Before QC	After QC	%	Before QC	After QC	%	Before QC	After QC	%	Before QC	After QC	%	Before QC	After QC	%
Hebron	0	0.01	-	17.40	11.50	-33.91	1.53	1.47	-4.35	4.07	3.51	-13.63	2.02	1.88	-6.89	45.35	42.88	-5.43
Salfeet1	0	0.002	-	20.73	14.00	32.47	1.99	1.41	28.92	7.07	5.29	25.18	7.07	2.30	67.47	64.70	52.00	19.63
Salfeet2	0	0.002	-	22.94	14.70	35.92	1.96	1.82	-6.75	7.02	5.76	17.88	2.65	2.40	-9.38	53.66	49.02	-8.64
Tubas 1	0	0.002	-	25.21	15.10	40.10	2.15	2.08	-3.00	7.17	6.52	-9.03	2.68	2.55	-4.62	54.40	52.41	-3.66
Tubas 2	0	0.002	-	28.60	16.90	40.91	2.41	2.32	-3.88	9.01	8.05	10.59	3.00	2.84	-5.44	54.80	52.62	-3.98
Mkahal	0	0	0	22.63	19.30	14.70	1.87	1.81	-3.04	5.51	5.20	-5.72	2.35	2.28	-2.91	64.36	59.54	-7.49

TABLE 16: MEASURES OF DISPERSION

## WIND POWER DENSITY

About the wind power density, the maximum value was found in Tubas 2, with 184.34 W/m<sup>2</sup>, and the minimum was found in Hebron, with 82 W/m<sup>2</sup>, and Mkahal, with 78.79 W/m<sup>2</sup>. In Salfeet it was about 133 W/m<sup>2</sup> in both levels, and Salfeet 1 it was over 103 W/m<sup>2</sup>.

Station	Wind power density [W/m <sup>2</sup> ]		
	Before QC	After QC	Variation (%)
Hebron	92.1885	82.001	-11.05
Salfeet1	106.717	103.569	-2.95
Salfeet2	151.529	132.364	-12.65
Tubas 1	147.391	135.294	-8.21
Tubas 2	204.809	184.357	-9.99
Mkahal	72.9077	76.7878	5.32

TABLE 17: WIND POWER DENSITY

## WEIBULL COEFFICIENTS

The Table 17 shows that the highest k coefficient was found in Hebron, 2.47, and in Salfeet 2, 2.21, which means that the wind was least variable than in the remaining stations. In Salfeet 1 and Tubas it was around 1.98, and finally, in Mkahal it was 1.56. About the scale coefficient, it varied in the range of 4.19 m/s in Mkahal to 6.08 m/s in Tubas 2.

Station	Shape coefficient, k [dimens]			Scale coefficient, c [m/s]		
	Before QC	After QC	%	Before QC	After QC	%
Hebron	2.3167	2.4713	6.673	5.02	4.9272	-1.849
Salfeet1	0.98541	1.9841	101.348	4.096	4.9767	21.501
Salfeet2	1.7863	2.1296	19.218	5.4615	5.5249	1.161
Tubas 1	1.8645	1.9867	6.554	5.5142	5.4924	-0.395
Tubas 2	1.8468	1.9798	7.202	6.1334	6.0815	-0.846
Mkahal	1.1807	1.5605	32.167	3.7881	4.194	10.715

TABLE 18: WEIBULL COEFFICIENTS

Using the Weibull coefficients the theoretical distribution was compared graphically with the data series as it was done in the range test and with the frequency distribution curve as well.

## COMPARISON BEFORE AND AFTER THE QUALITY CONTROL PROCESS

A comparison presented results before and after the quality control test will be carried out in this subsection.

In all the cases excepting Salfeet 1 and Mkahal the mean value was reduced from 0.81% to 2.11% after the quality control check. However, in Salfeet it was increased 7.62% and 4.96% in Mkahal.

Regarding the median, in Hebron and Tubas the value was decreased about 0.50% after the quality control check, and in the other stations it was increased: 5.29% in Salfeet 1, 0.13% in Salfeet 2 and 6.57% in Mkahal.

About the range of the data series, before the quality control process the lowest value was 9 in all the stations. After these procedures it was modified, probably due to incidences the double zeros test, and the minimum value changed in Hebron, Salfeet and Tubas. The highest value of each data series was modified as well and it became smaller, the biggest variation took place in Tubas, where the value was reduced about a 40%. In Salfeet and Hebron the decrease was less, around 33%, and finally in Mkahal the least variation was found, a 14.7%.

The mean deviation was reduced in all the cases after the quality control procedures (because the extreme values were dismissed from the data series). In Hebron the value decreased a 4.35%, in Tubas 1 and 2 3% and 3.88% respectively and in Mkahal a 3%. In Salfeet 1 the decrease was notably, around a 29%, but not in Salfeet 2, where it was 6.75%.

The variation of the standard deviation (and the variance) was very different depending on the station. The least decreased was found in Mkahal, a 3%, and in Tubas, a 4.62 in Tubas 1 and 5.44 in Tubas 2. In Hebron and Salfeet 2 the percentage of decrease was higher, 6.9% and 9.38% respectively, and finally in Salfeet 1 it was particularly high, 68%.

As it happened with the other measures of dispersion already explained, the coefficient of variation decreased in all the cases, but the percentage was different depending on the station: In Hebron it was reduced a 5.4%, around a 3.7% and 4% in Tubas 1 and 2 respectively, in Mkahal a 7.5%, in Salfeet 2 a 8.6% and finally in Salfeet 1 the decrease was much more notably, a 19.6%.

Concerning the wind power density, in all the stations was decreased after the quality control process, the percentage varied from 2.95% to 12.65% in Salfeet 2, excepting in Mkahal, where it increased 5.32%.

Weibull coefficients also changed after the quality control process (Table 17). In all the cases the shape coefficient increased, which means the speed values are less dispersed. About the scale parameter, in some cases it was reduced (Hebron and Tubas) in a range from 0.4% to 1.85%, and in the rest it was increased (Salfeet and Mkahal) in a range from 1.16% to 21.50%.

### 5.1.2.2 GRAPHICAL RESULTS

In this section some graphical results for each station will be introduced. First of all the wind speed duration curve will be presented, the wind rose and finally some graphs which show the behavior of the wind yearly, monthly and also during a day.

#### 5.1.2.2.1 HEBRON

##### WIND SPEED DURATION CURVE

The first graph generated was the wind speed duration curve, which shows the percentage of the time that the wind exceeds a specified level. In the Figure 45 it is shown that about 80% of the values exceeded 4 m/s, and 25% exceeded 6 m/s.

### WIND SPEED DURATION CURVE

Location: HEBRON. Sensor height: 10 m. 31°33'23.82 N, 35°04'59.40 E. Altitude: 1014 m.  
15 minutes data resolution. From 13:0 28/4/2009 to 11:30 10/4/2012

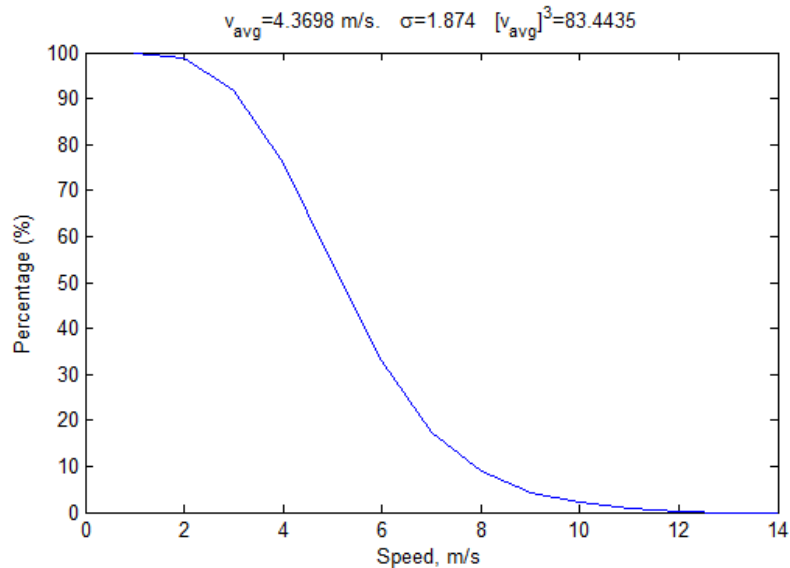


FIGURE 48: WIND SPEED DURATION CURVE, HEBRON

### WIND ROSE

The next step is the generation of the joint speed and direction distribution table, and from there the wind rose is created. The wind rose for Hebron shown in the Figure 46.

In the period under study the wind was predominantly from the north (more than 25%) and the northwest (around 28% of the time) mainly from 1 to 7 m/s. Then, about 10% of the time it was from the west and northeast, the speed was generally in the same range. It rarely was from the southwest, south or east, although 8% of the time was from the southeast.

Location: HEBRON. Sensor height: 10 m. 31°33'23.82 N, 35°04'59.40 E. Altitude: 1014 m.  
15 minutes data resolution. From 13:0 28/4/2009 to 11:30 10/4/2012

$v_{avg} = 4.3698 \text{ m/s}$ ,  $\sigma = 1.874$ ,  $[v_{avg}]^3 = 83.4435$

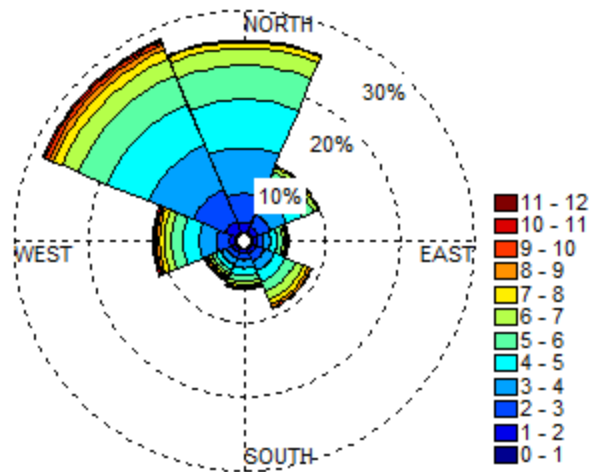


FIGURE 49: WIND ROSE, HEBRON



## MONTHLY MEAN WIND SPEED

In the Figure 47 in the left side it is represented the monthly mean wind speed for Hebron for the 3 years, and it shows that the windiest months occurred in winter (from December to March) but also in June, and the month with the highest mean value was February. In all the months in spring and autumn the wind speed was lower than the mean value (plotted in red), 4.37 m/s, and October was the lowest value.

## 15 MINUTE MEAN WIND SPEED

In the Figure 47 in right side the mean evolution of the wind during a day is shown. When the program is run the user can choose the type of graph in order to obtain the main day of each month under study as well. In Hebron the windiest moment of the day was in the afternoon from 15h to 19h, and least windy moment was in the morning, from 7h to 10h.

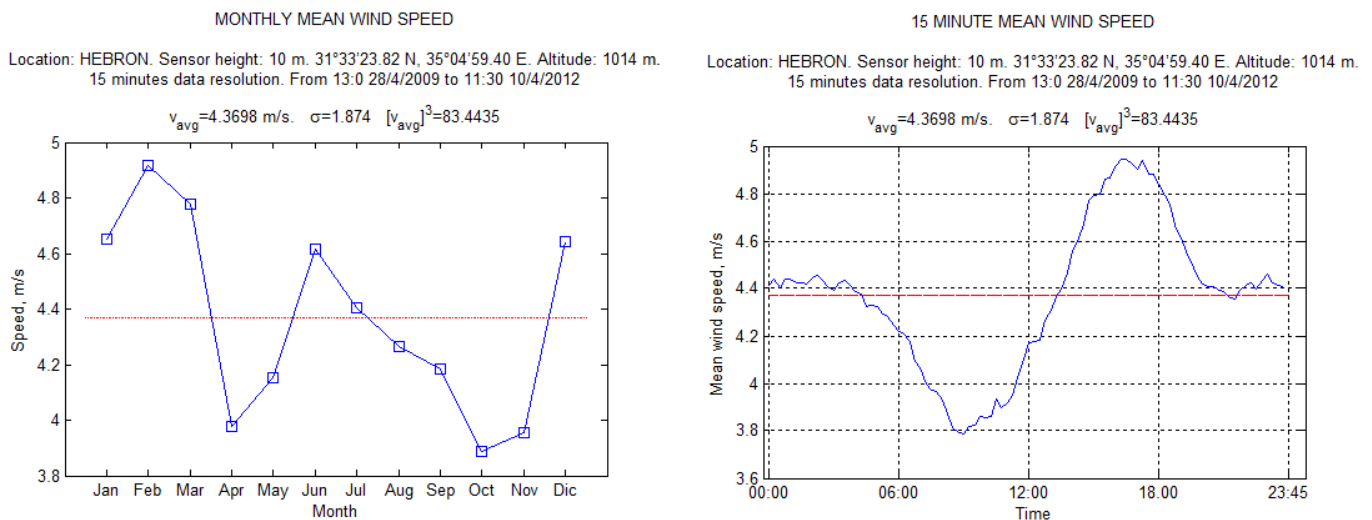


FIGURE 50: MONTHLY AND 15 MINUTE MEAN WIND SPEED, HEBRON

## DAILY MEAN WIND SPEED

In the last generated graph (Figure 48) was the daily mean wind speed, so the mean wind speed for each day was represented and displayed separately in months.

As it was mentioned before, the maximum values were found in winter and the beginning of the spring (from December to April), but the wind is not very unstable and the mean value usually changed notably from one day to the subsequent. In the rest of the year some peak values were found (in June and July) but in general the wind speed fluctuated around the mean speed.

Location: HEBRON. Sensor height: 10 m. 31°33'23.82 N, 35°04'59.40 E. Altitude: 1014 m.  
 15 minutes data resolution. From 13:00 28/4/2009 to 11:30 10/4/2012

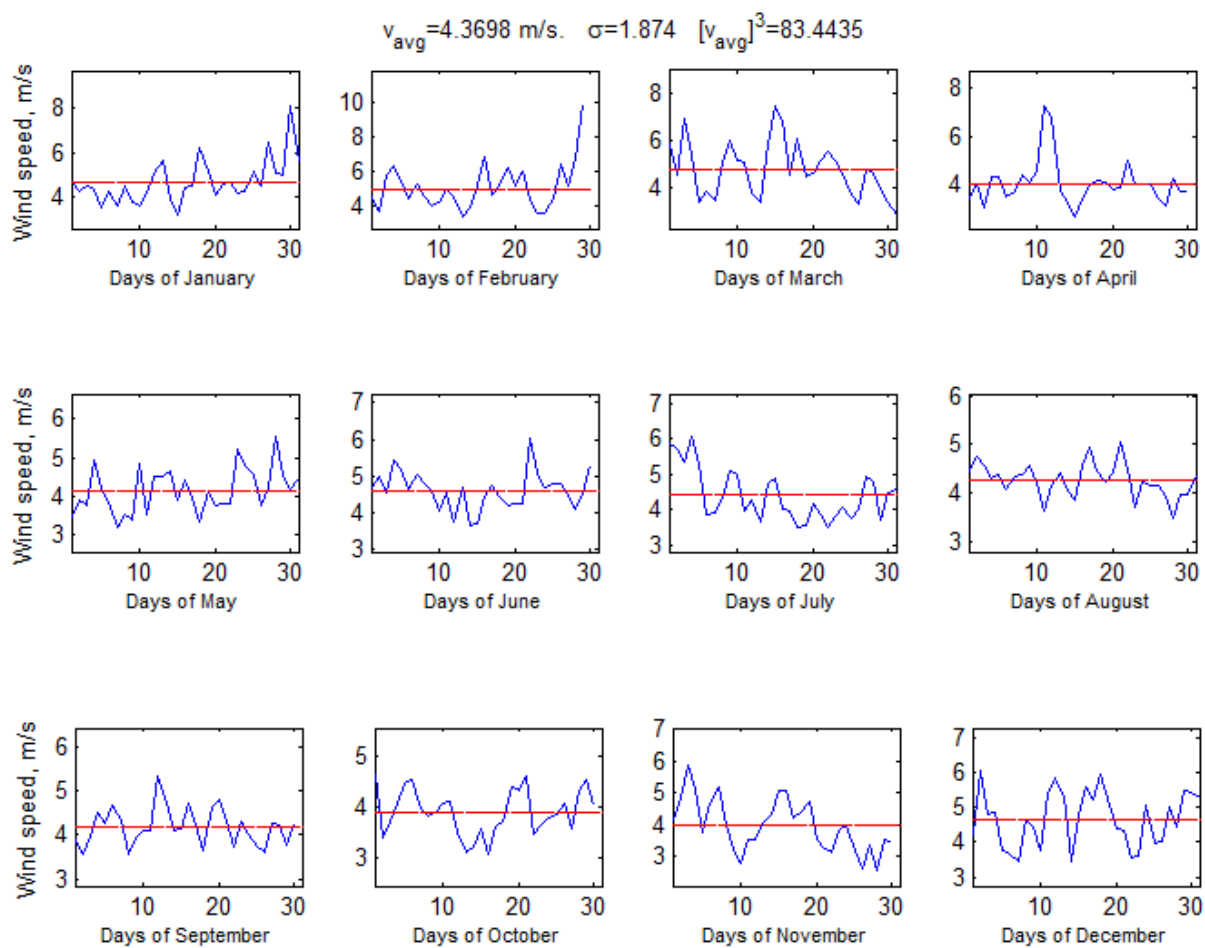


FIGURE 51: DAILY MEAN WIND SPEED, HEBRON

### 5.1.2.2.2 SALFEET 1

#### WIND SPEED DURATION CURVE

The wind speed duration curve from Salfeet 1 is shown in the Figure 52.

Along the 2 years under analysis, about 75% of the time exceeded 4 m/s, the wind was greater than 5 m/s in 40% of the time, and finally, it exceeded 8 m/s only 10% of the time.

Location: SALFEET. Sensor height: 10 m. 32°04.117' N, 35°13.397' E. Altitude: 815 m  
10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

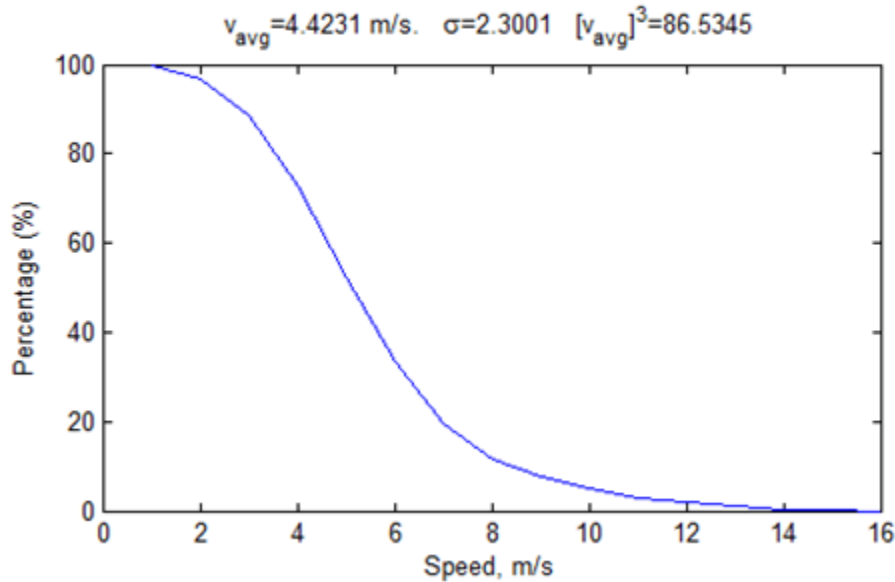


FIGURE 52: WIND SPEED DURETION CURVE, SALFEET 1

#### WIND ROSE

About the wind rose (Figure 53), it shows that 55% of the time the direction of the wind varied from west to northwest, since 30 % of the time it was northwest, and 25% the direction was west. About 10% of the time it was from the southwest, southeast and north.

Regarding the wind speed, when the direction was the northwest, 13% of the time it was in the range of 2 to 4 m/s, the same percentage of the time it was between 4 and 6 m/s, and about 5% of it the wind speed varied from 6 to 8 m/s. When the direction was the west, about 8% of the time the wind speed was between 2 and 4 m/s, a 12% varied from 6 to 8 m/s, a 5% between 8 and 10 m/s, and about 4% of the time the wind speed exceeded these values.

Location: SALFEET. Sensor height: 10 m. 32°04.117' N, 35°13.397' E. Altitude: 815 m  
 10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

$$v_{avg} = 4.4231 \text{ m/s. } \sigma = 2.3001 \quad [v_{avg}]^3 = 86.5345$$

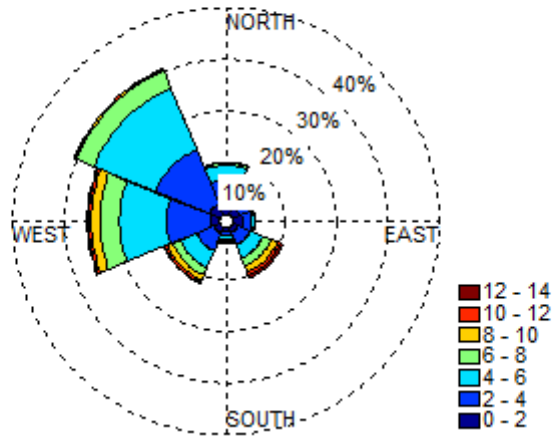


FIGURE 53: WIND ROSE, SALFEET 1

### MONTHLY MEAN WIND SPEED

The monthly mean wind speed graph represented in the Figure 54 (left side) shows that the windiest months in Salfeet 1 took place in winter, and the speed was about 5 and 5.5 m/s. In the rest of the year the mean wind speed of each month was lower than the mean value, and it did not exceed 4.4 m/s in any case.

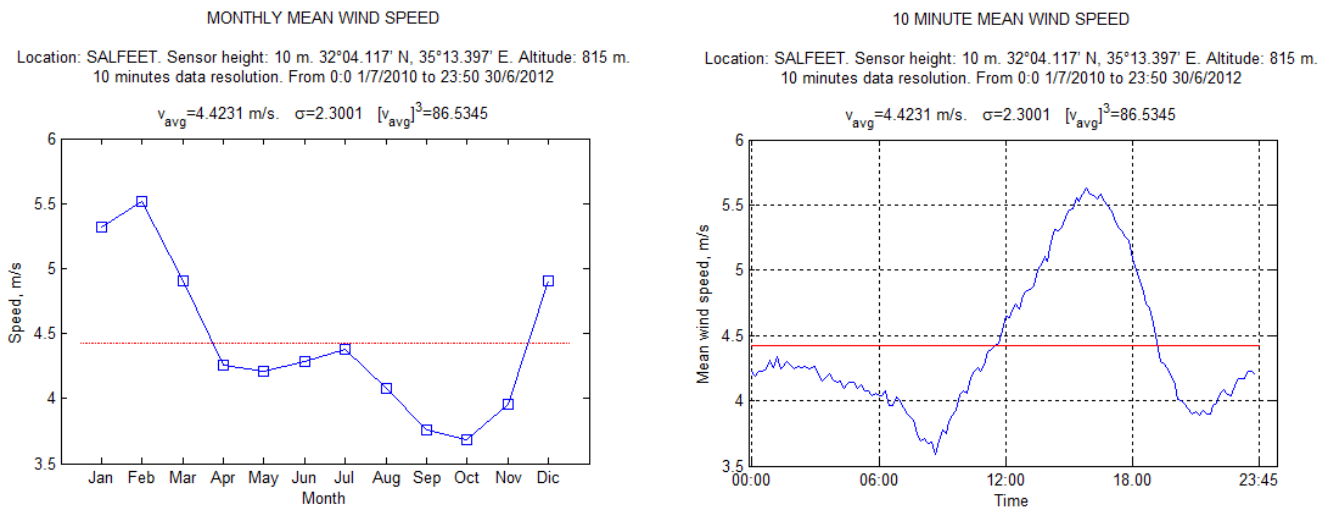


FIGURE 54: MONTHLY AND 10-MINUTE MEAN WIND SPEED, SALFEET 1

### 10 MINUTE MEAN WIND SPEED

The right side of the Figure 54 shows the main day in Salfeet, where the windiest values of wind speed were found in the afternoon, between 13h and 18h. The least windy moment of the day took place in the morning, at about 9h.

Only from noon to the evening, at about 19h the wind speed exceeded the average speed found in Salfeet 1, along the rest of the year it was always smaller.

### DAILY MEAN WIND SPEED

The Figure 55 shows the daily mean wind speed for Salfeet 1.

In general, there are abrupt changes from one day to the next, especially in winter, but as it was mentioned before, the windiest period occurred from November to February, where 8 m/s (and greater) daily mean speeds are found. In the rest of the year the wind fluctuated between 3 and 5 m/s.

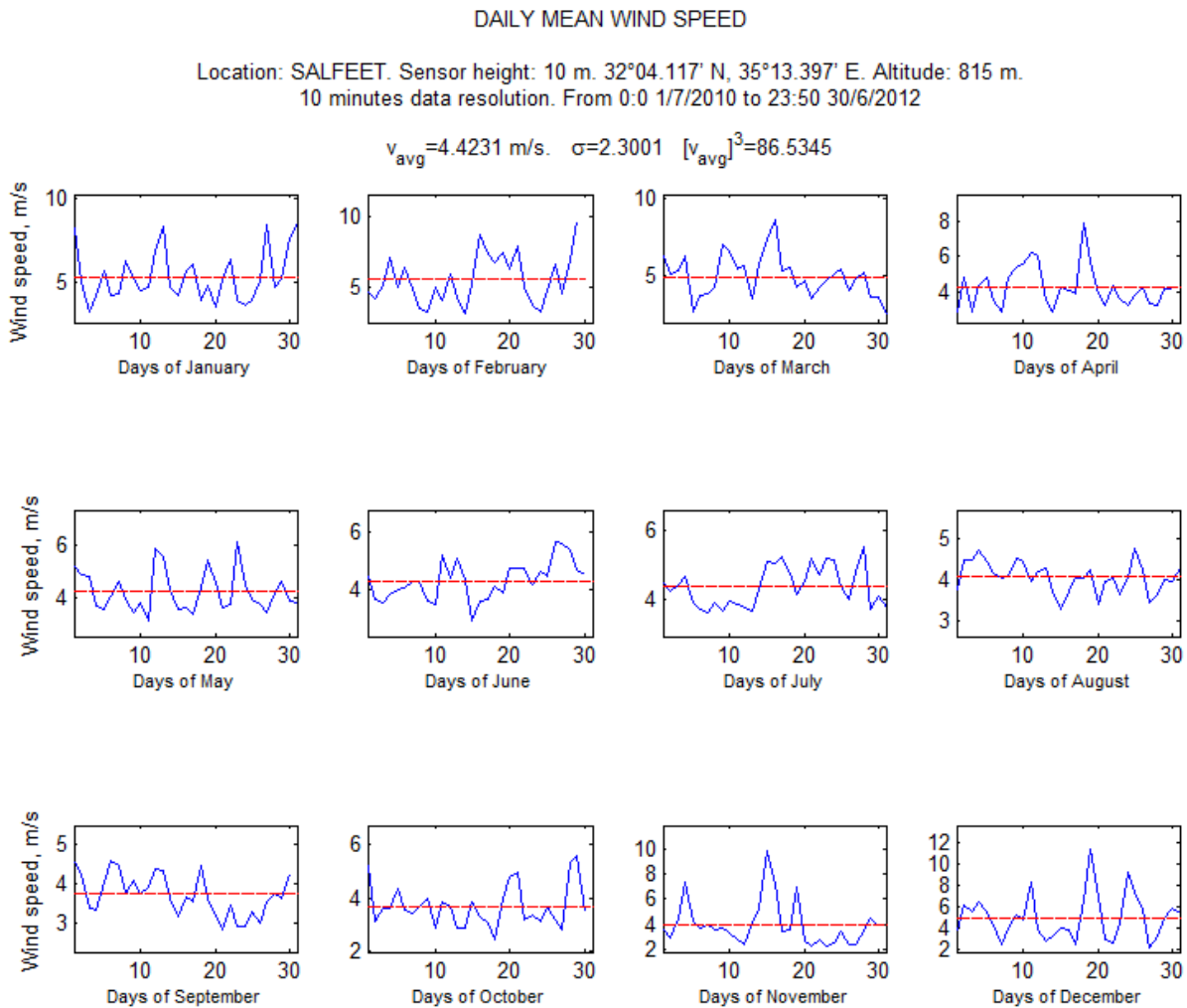


FIGURE 55: DAILY MEAN WIND SPEED, SALFEET 1

### 5.1.2.2.3 SALFEET 2

#### WIND SPEED DURATION CURVE

As it is shown in the Figure 56, Salfeet 2 is a windy place where 80% of the data was over 4 m/s, 40% exceeded 6 m/s and the speed of more than 15% or the data was higher than 8 m/s.

Location: SALFEET. Sensor height: 16 m. 32°04.117' N, 35°13.397' E. Altitude: 815 m.  
10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

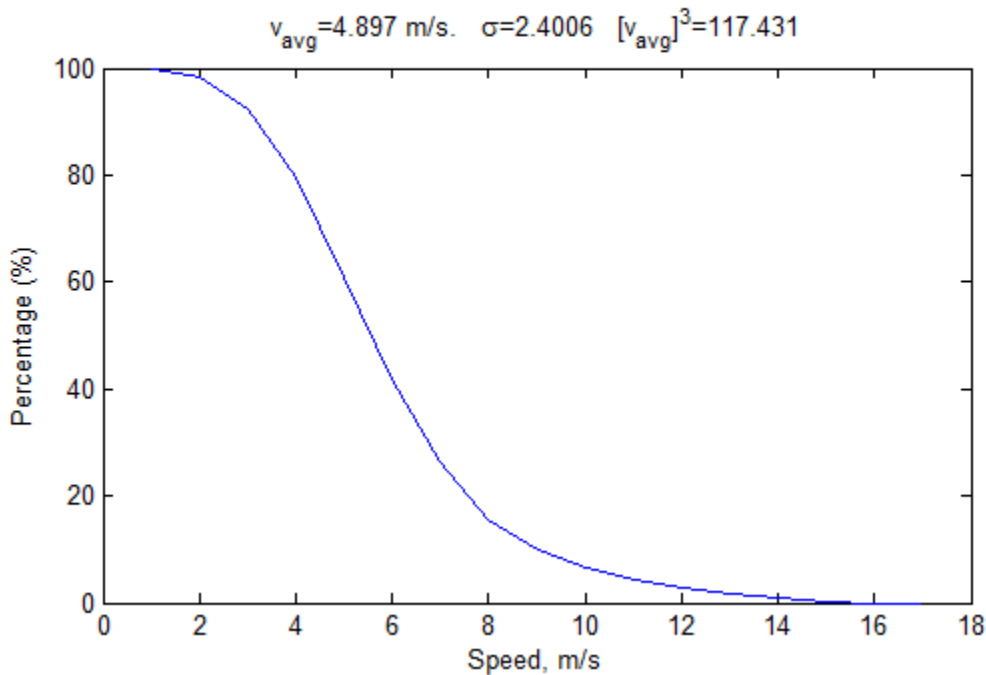


FIGURE 56: WIND SPEED DURATION CURVE, SALFEET 2

#### WIND ROSE

The wind rose obtained for Salfeet 2 (Figure 57) is very similar to the wind rose from Salfeet 1, and more than 55% of the time the wind was from west and northwest. About 10% of the time the wind was from the southwest, and from the southeast. The rest of the time it was from other directions. The speed of more than 25% of the data was in the range of 4 to 6 m/s, and about a 15% was between 6 to 8 m/s.

Location: SALFEET. Sensor height: 16 m. 32°04.117' N, 35°13.397' E. Altitude: 815 m.  
 10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

$$v_{avg} = 4.897 \text{ m/s. } \sigma = 2.4006 \quad [v_{avg}]^3 = 117.431$$

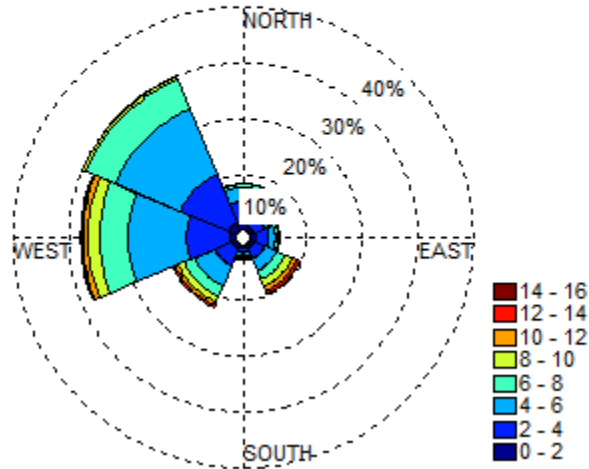


FIGURE 57: WIND ROSE, SALFEET 2

### MONTHLY MEAN WIND SPEED AND 10 MINUTE MEAN WIND SPEED

In the Figure 58 the monthly mean wind speed and 10 minute mean wind speed were plotted. Again, the tendency of the data in Salfeet 2 was exactly the same as in Salfeet 1, but the wind speed was higher, and therefore, the mean value as well (4.9 m/s).

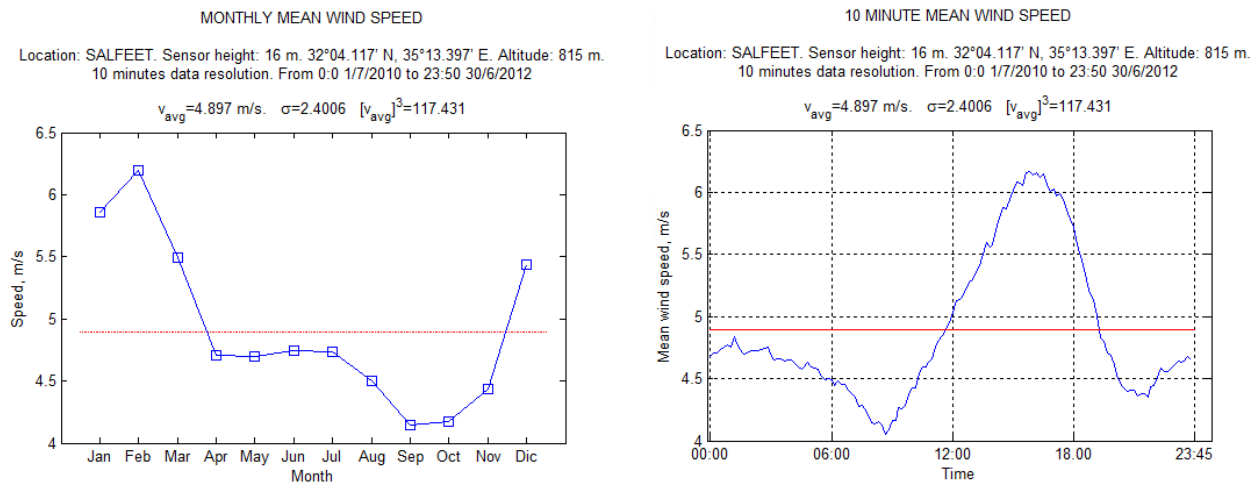


FIGURE 58: MONTHLY AND 10-MINUTE MEAN WIND SPEED, SALFEET 2



## DAILY MEAN WIND SPEED

Regarding the daily mean wind speed (Figure 59), from May to September varied around the mean value in the range from 3.5 to 6 m/s. However, from the end of October to the end of the year, and from January to April many fluctuations took place, and winds of 8 to 10 m/s were recorded.

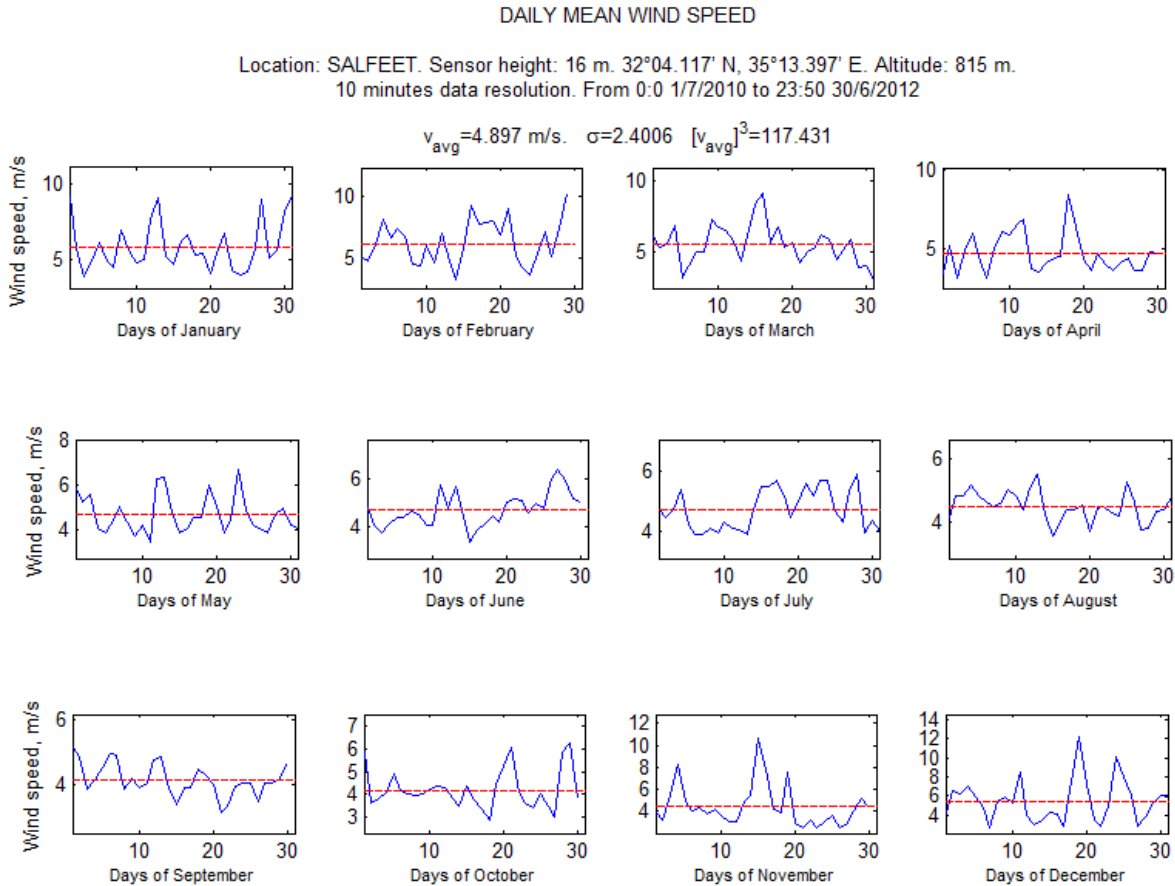


FIGURE 59: DAILY MEAN WIND SPEED, SALFEET 2

### 5.1.2.2.4 TUBAS 1

#### WIND SPEED DURATION CURVE

In the wind speed duration curve of Tubas 1 (Figure 60) is shown the percentage of values which exceed a value. Thus, 80% of the values exceed 3.8 m/s, 40% are greater than 6 m/s. 20% of the time the wind speed was larger than 8 m/s, and less than 10% of the time the speed was higher than 10 m/s.

Location: TUBAS. Sensor height: 10 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
 10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

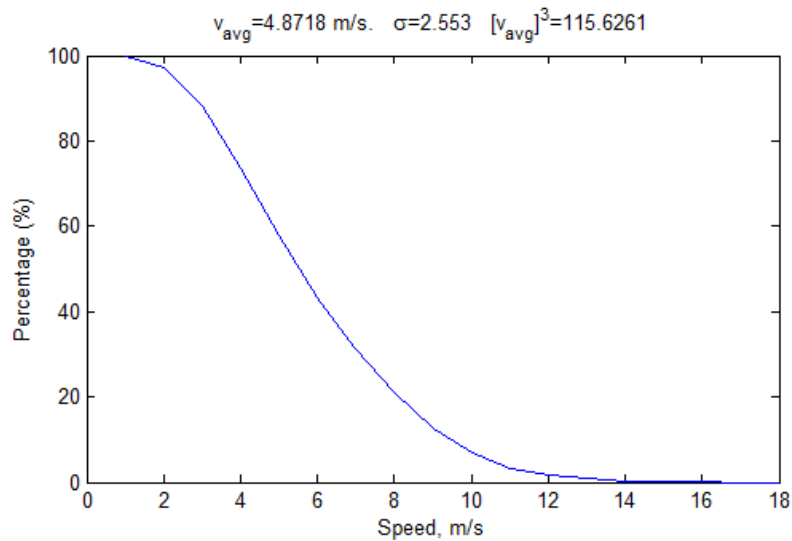


FIGURE 60: WIND SPEED DURATION CURVE, TUBAS 1

### WIND ROSE

The wind rose of Tubas 1 is introduced in the Figure 61. It shows the wind direction was mainly from the west (more than 30% of the time), and the wind speed was in the range of 4 m/s to 6 m/s more than 20% of the time. Higher speeds were recorded during 5% of the time.

Furthermore, about 18% and 15% of the time the wind direction was southwest end northwest. It is remarkable that 10% of the time the wind direction was southeast, as it happened in Salfet and Hebron.

Location: TUBAS. Sensor height: 10 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
 10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

$v_{avg} = 4.8718 \text{ m/s}$     $\sigma = 2.553$     $[v_{avg}]^3 = 115.6261$

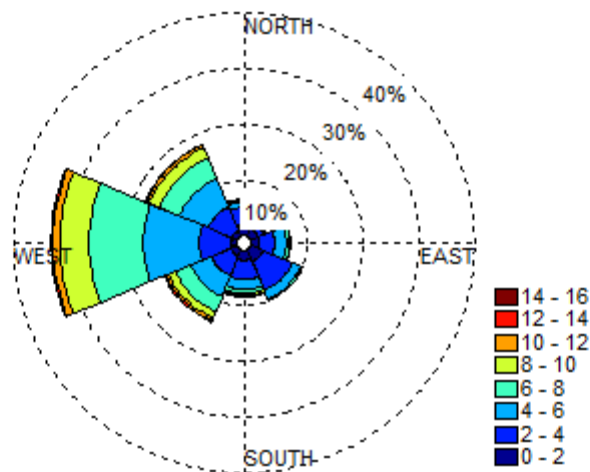


FIGURE 61: WIND ROSE, TUBAS 1

## MONTHLY MEAN WIND SPEED

In the graph of the monthly mean wind speed (Figure 62) a big difference with the other stations is noticed: In Hebron and Salfeet the windiest months were found in winter; however, the opposite happened in Tubas since spring and summer were the windiest months, and the lowest monthly mean values were occurred in winter.

The windiest month was July, the mean wind speed was 6 m/s, and the least windy month was November, where the mean wind speed was 3.5 m/s.

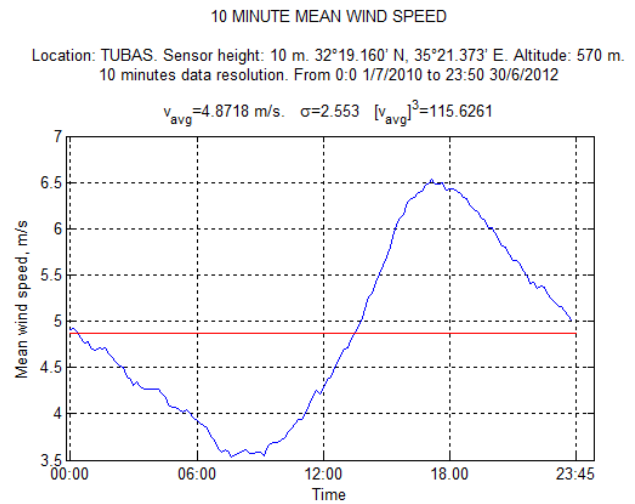
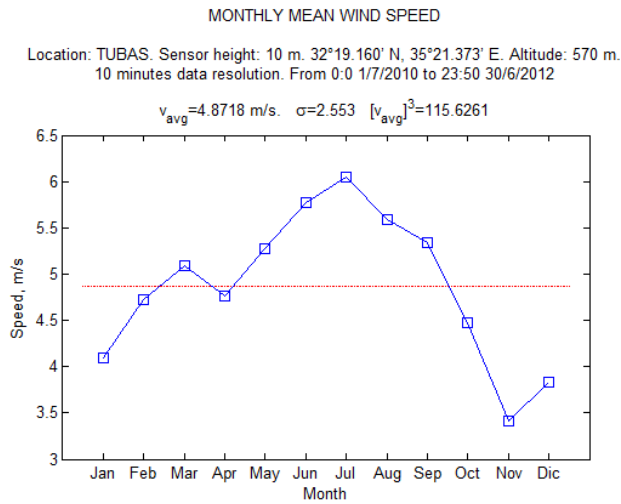


FIGURE 62: MONTHLY AND 10 MINUTE MEAN WIND SPEED, TUBAS 1

## 10 MINUTE MEAN WIND SPEED

As it happened in other stations and it is shown in the Figure 62, the windiest period was between 16h and 19h, where the wind speed reached 6.5 m/s, and the calmest period took place between 6h and 11h and the minimum value was 3.5 m/s. Thus, half of the day (from 13h to 0h) the wind speed exceeded the mean value, and half of the day it was lower.

## DAILY MEAN WIND SPEED

In the graph of the daily mean wind speed in the Figure 63 the evolution of the wind during each month in Tubas 1 is shown.

In the windiest months, in spring and summer, the monthly mean value (in red) was around 6 m/s, and days where the daily mean was 7 m/s were frequent. The minimum values in this period varied from 4 to 5 m/s.

In autumn the monthly mean speed decreased to 5 m/s, and finally in winter to 4 m/s, but big variations were found in this period and many days had 6 m/s of mean speed but also 2 or 3 m/s.

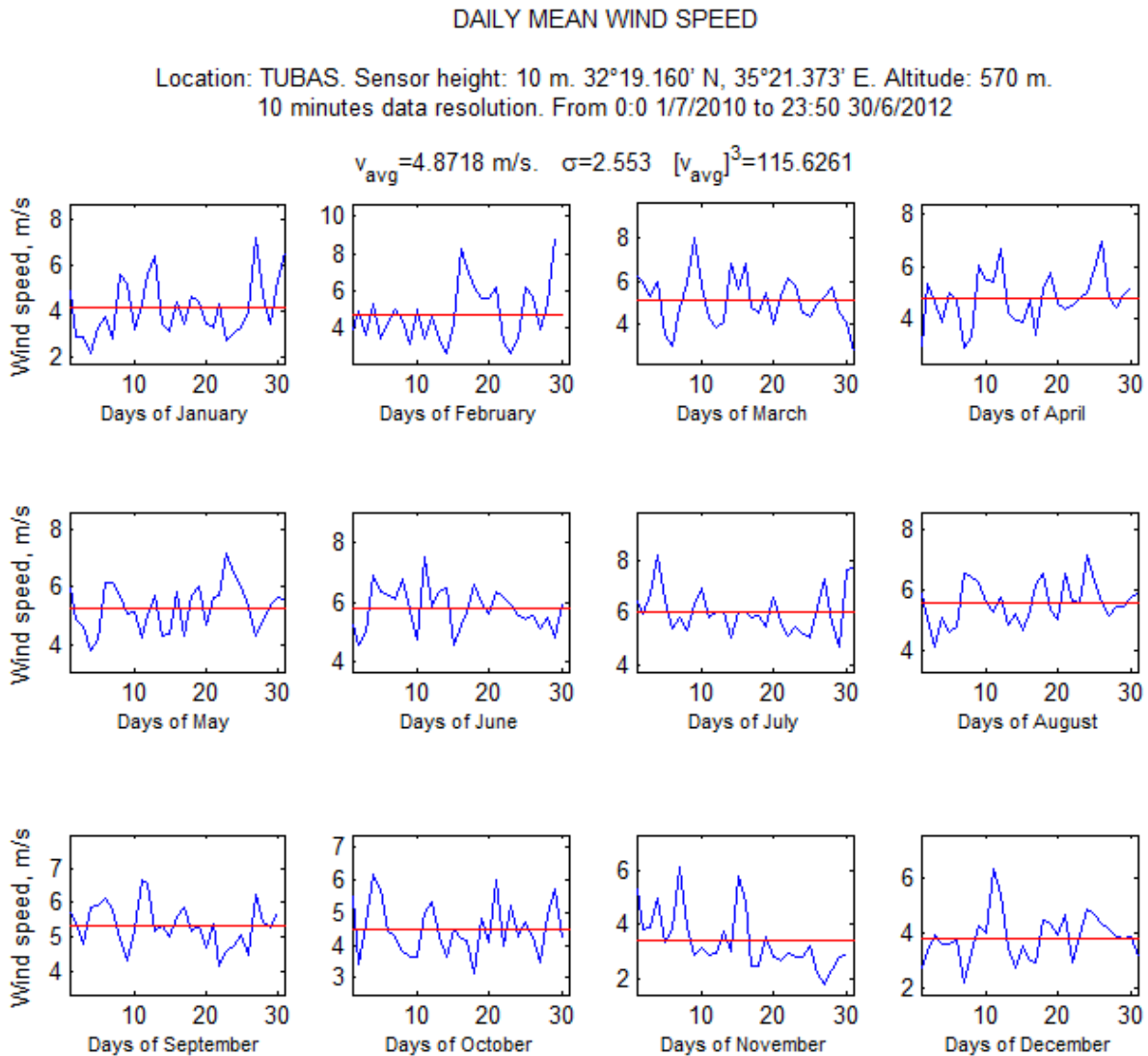


FIGURE 63: DAILY MEAN WIND SPEED, TUBAS 1

### 5.1.2.2.5 TUBAS 2

#### WIND SPEED DURATION CURVE

The wind speed duration curve of Tubas 2 (Figure 64) was very similar to the curve of Tubas 1, but the percentages are larger for Tubas 2, due to the fact that the sensor is installed in a higher position so it would record higher wind speed values. So, 80% of the time the wind speed exceeded 4 m/s, 40% of the time 6 m/s, and in 20% it was greater than 9 m/s. Finally, the speed of about 10% of the values was larger than 10 m/s.

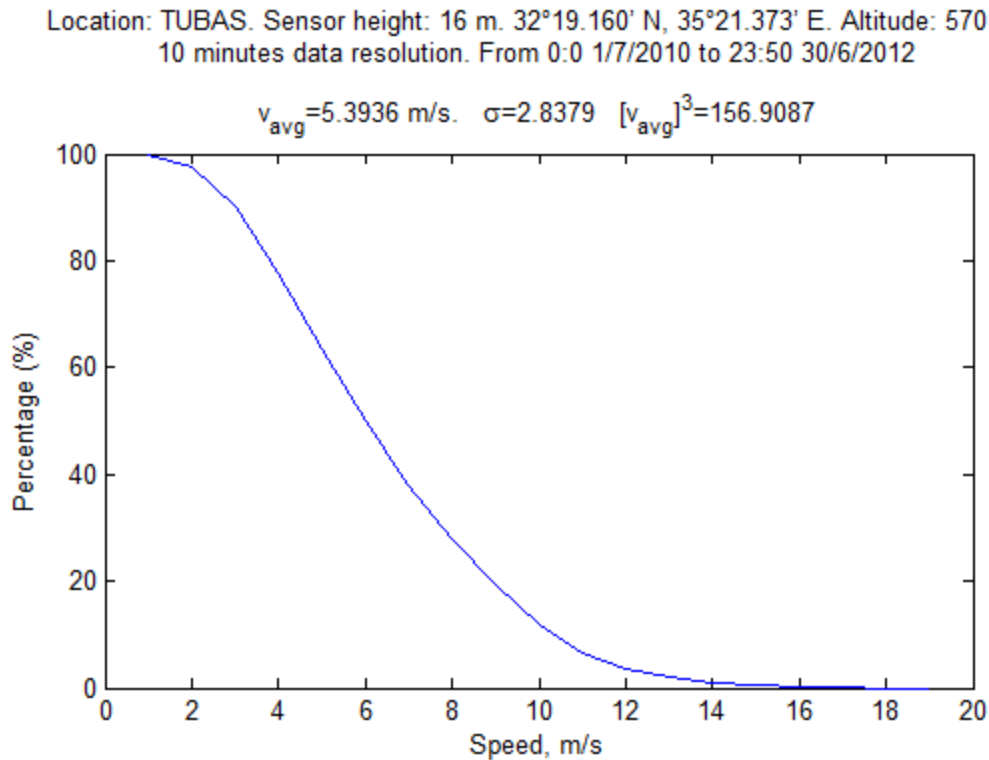


FIGURE 64: WIND SPEED DURATION CURVE, TUBAS 2

#### WIND ROSE

The wind rose for Tubas 2 (Figure 65) shows the same amount of data on each direction as in Tubas 1. However, the wind values are bigger for this station because it is installed at 16 m high, and Tubas 1 is at 10 m.

Location: TUBAS. Sensor height: 16 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
 10 minutes data resolution. From 0:0 1/7/2010 to 23:50 30/6/2012

$$v_{avg} = 5.3936 \text{ m/s. } \sigma = 2.8379 \quad [v_{avg}]^3 = 156.9087$$

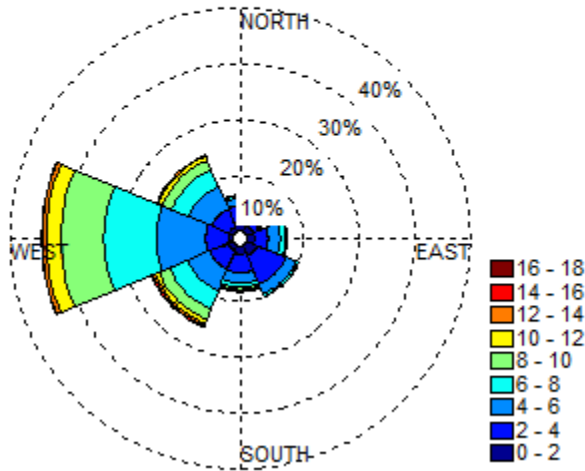


FIGURE 65: WIND ROSE, TUBAS 2

### MONTHLY MEAN WIND SPEED AND 10 MINUTE MEAN WIND SPEED

As it happened for Salfeet 1 and Salfeet 2, in Tubas 2 the results are very similar to Tubas 1, and the shape of the monthly mean wind speed, and for the 10-minute mean wind speed graph were the same in both stations, but the speed in Tubas 2 was higher, and the mean value was around 5.4 m/s.

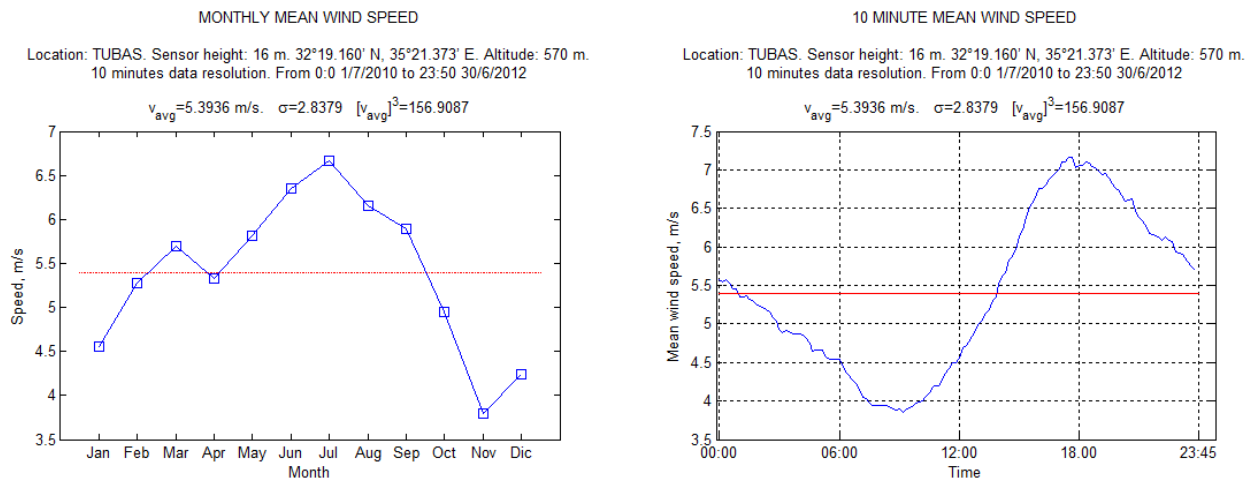


FIGURE 66: MONTHLY AND 10 MINUTE MEAN WIND SPEED, TUBAS 2

## DAILY MEAN WIND SPEED

In Tubas 2, as it happened in Tubas 1 the windiest months and days were found in spring and summer, and the daily mean speed varied between 5 and 8 m/s during this period (the monthly wind speed was around 6 m/s). In winter and autumn the wind speed was smaller, and it was in the range from 3 to 6 m/s in general, but some peak days where the mean speed was around 7 m/s or 8 m/s were also detected.

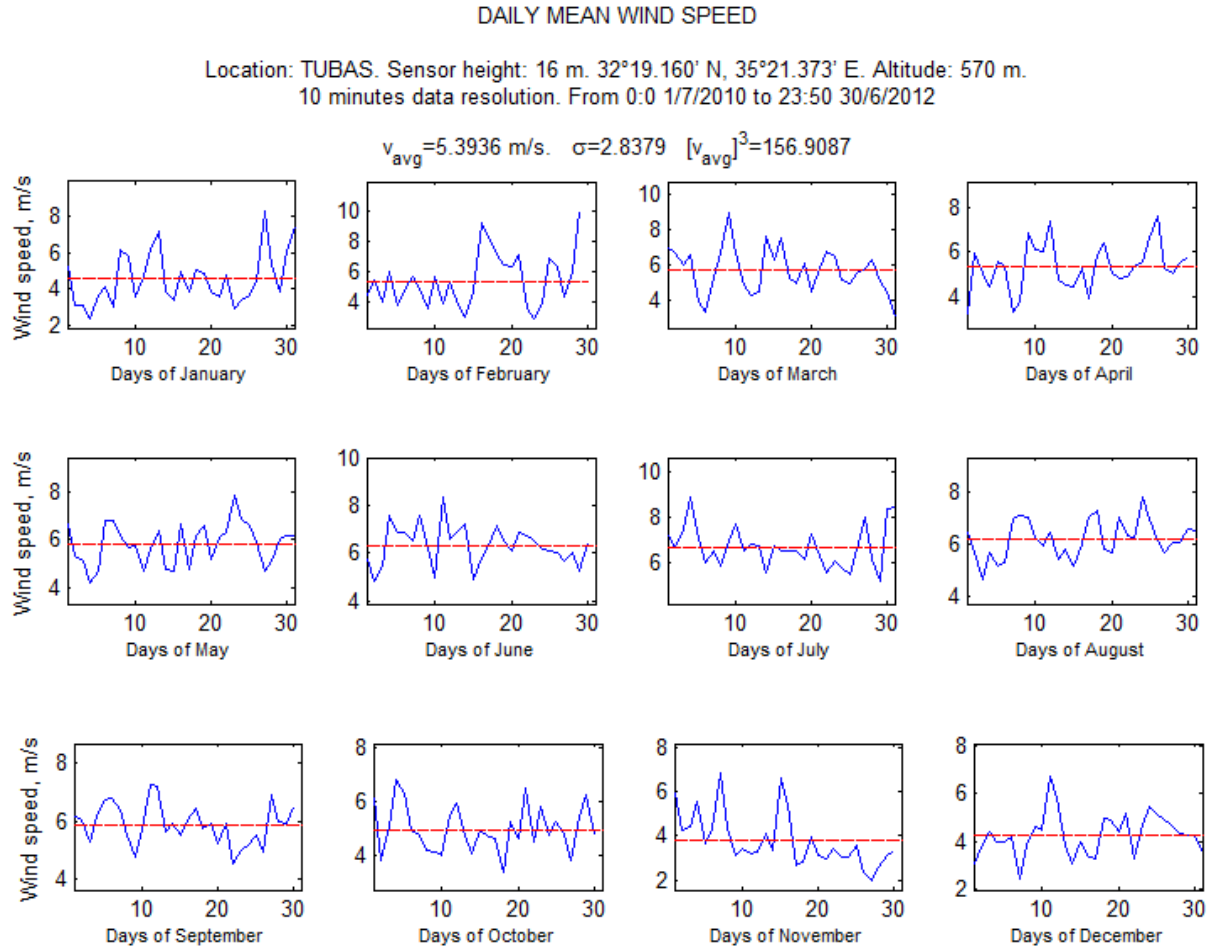


FIGURE 67: DAILY MEAN WIND SPEED, TUBAS 2

### 5.1.2.2.6 MKAHAL

#### WIND SPEED DURATION CURVE

In Mkahal the speed values were lower than in other stations. As it shown in the Figure 68, 80% of the data exceeded 2.5 m/s, 50 % of them were higher than 5 m/s, and about 10% of the data exceeded 7.5 m/s.

### WIND SPEED DURATION CURVE

Location: MKAHAL. Sensor height: 10 m. 32°25.132' N, 35°7.657' E. Altitude: m.  
10 minutes data resolution. From 0:0 24/5/2011 to 13:20 5/3/2013

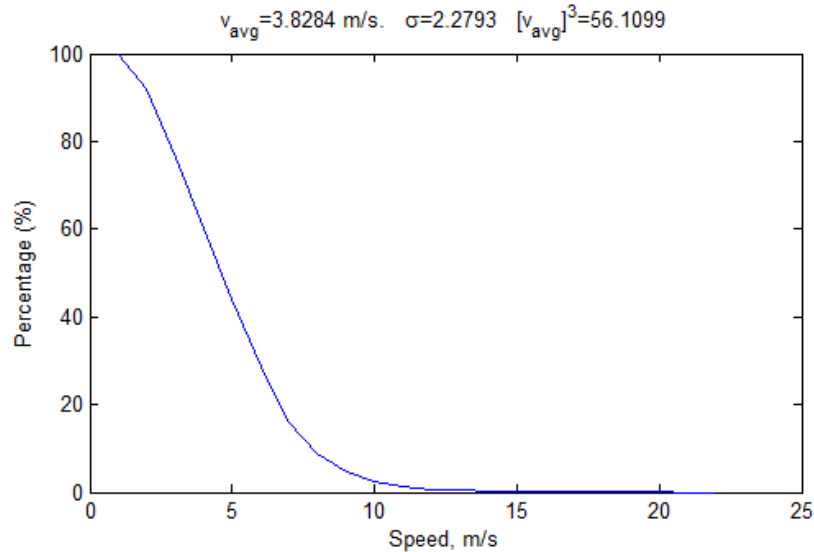


FIGURE 68: WIND SPEED DURATION CURVE, MKAHAL

### WIND ROSE

In Mkahal the wind direction was mainly southwest (28% of the time) and west (25% of the time), and in the range of 2 to 4 m/s (10% of the values) and 4 to 6 m/s (10%) in both directions.

An important part of the time, about 14% the wind direction was east, and around 10 % of the time the direction of the wind was south and northeast, but all the cases the wind speed varied from 2 to 6 m/ s mainly.

Location: MKAHAL. Sensor height: 10 m. 32°25.132' N, 35°7.657' E. Altitude: m.  
10 minutes data resolution. From 0:0 24/5/2011 to 13:20 5/3/2013

$v_{avg}=3.8284$  m/s.  $\sigma=2.2793$   $[v_{avg}]^3=56.1099$

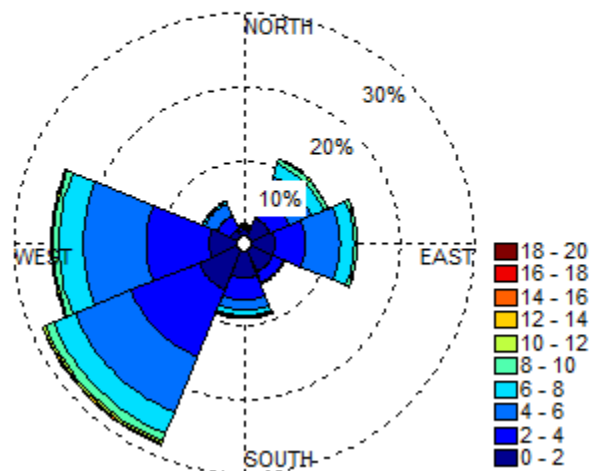


FIGURE 69: WIND ROSE, MKAHAL



## MONTHLY MEAN WIND SPEED

As it happened in Salfleet and Hebron, the monthly mean wind speed graph of Mkahal (Figure 70) shows that the windiest months of the year took place in winter, but the maximum values are lower than in the precedent stations, about 4.5 m/s. The lowest monthly mean speed was found in October, about 2.75 m/s. It is remarkable that in August the mean speed was increased and it reach around 4 m/s.

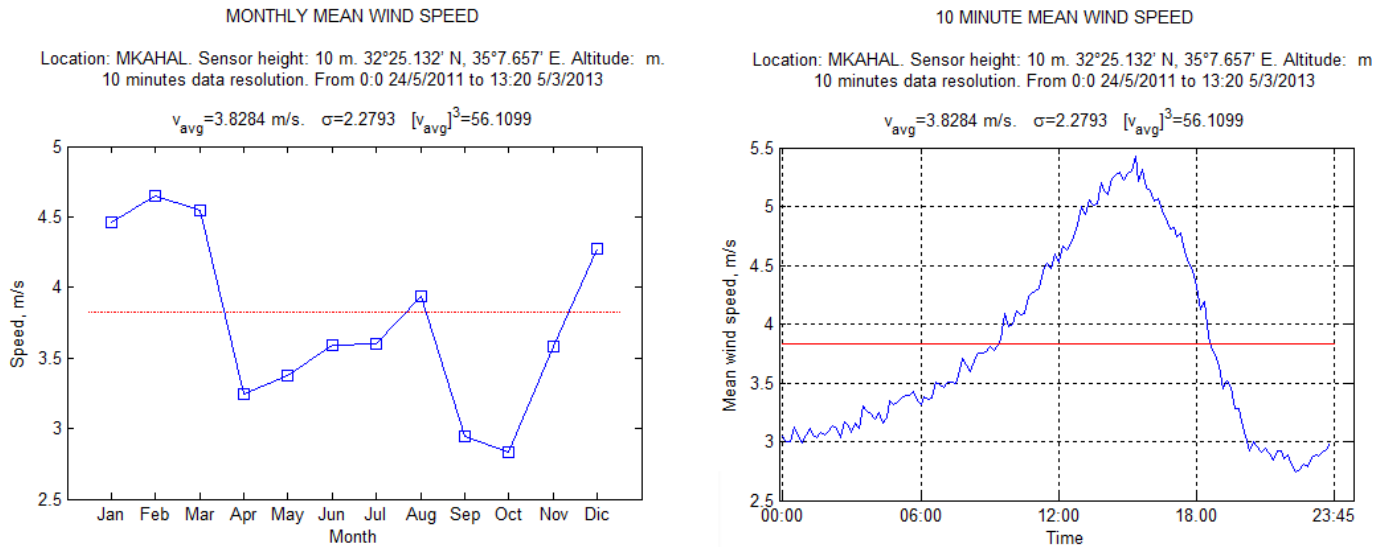


FIGURE 70: MONTHLY AND 10 MINUTES MEAN WIND SPEED, MKAHAL

## 10 MINUTE MEAN WIND SPEED

The results found in Mkahal differ with the other station under study because the minimum period took place at about 23h (the minimum value was 2.8 m/s) and from that moment the wind speed increased until the maximum moment (5.4 m/s), which happened at about 15h. After that moment it started to decrease again.

## DAILY MEAN WIND SPEED

In the Figure 71 the daily mean wind speed graph is shown. The lack of data is evident, and even if the data series started in May 2011 and finished in March 2013, there are some a few periods of the year where there are not data available in any of the years under study, and this especially prominent in April, where the is data missing along more than half of the month.

In winter, spring and the last part of the autumn the wind speed varied from 3 to 6 m/s and in summer it decreased and the maximum values were around 5 m/s, and finally in the beginning of the autumn it was ranged between 2 and 4 m/s.

### DAILY MEAN WIND SPEED

Location: MKAHAL. Sensor height: 10 m. 32°25.132' N, 35°7.657' E. Altitude: m.  
10 minutes data resolution. From 0:0 24/5/2011 to 13:20 5/3/2013

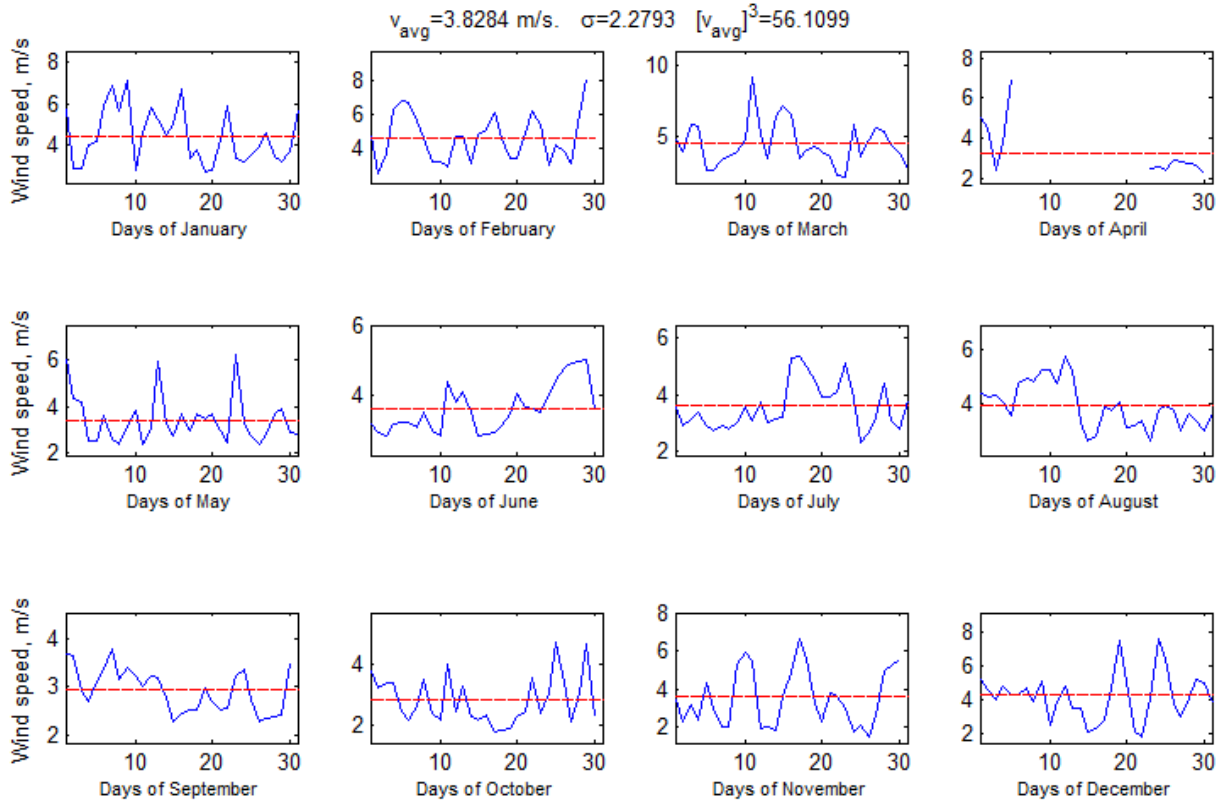


FIGURE 71: DAILY MEAN WIND SPEED

## 5.2 QUALITY CONTROL AND ANALYSIS FOR 2011

### 5.2.1 QUALITY CONTROL TESTS RESULTS OBTAINED FOR THE YEAR 2011

In this section, the quality of the data of 2011 from the stations in Hebron, Salfeet and Tubas will be tested. The data from Mkahal was not used due to the big amount of irregularities and missing data in 2011. Then, the obtained results will be compared with the results in the precedent subsection, and between the different stations. As the anemograms were already explained in the precedent section, they will be omitted in this part.

In the table below the results of the first part of the quality control process for the stations in Hebron, Salfeet and Tubas in 2011 are shown. First the length of the file is shown, and compared with the theoretical one, after the amount and percentage of missing and repeated values is summarized, then the results of the outliers test are presented, the double-zeros test in particular, and the anomalous patterns test. Finally in the last two columns the number and percentage of accepted data is shown.

Station	Initial length	Theor. length	Time series' length is	Missing values (date)		Repeated date values		Outliers	Double-zeros		Anom. patterns	Final length	Accepted data
				Inc	%	Inc	%		%	Inc			
Hebron 2011	35040	35040	Ok	0	0	0	0	0	0	0	0	35040	100
Salfeet1 2011	52333	52560	Wrong	227	0.4338	0	0	0	6501	12.4224	0	45832	87.5776
Salfeet2 2011	52333	52560	Wrong	227	0.4338	0	0	0	610	1.1656	0	51723	98.8344
Tubas1 2011	52559	52560	Wrong	1	0.0019	0	0	0	172	0.3273	0	52387	99.6728
Tubas2 2011	52559	52560	Wrong	1	0.0019	0	0	0	237	0.4509	0	52322	99.5491

TABLE 19: RESULTS OF THE 1<sup>ST</sup> PART OF THE QC PROCESS

Only in Hebron the data series length was correct, no missing or repeated values were found, neither other incidences such as outliers, double-zeros or anomalous patterns. Therefore, the totality of the data was accepted.

In both data series from Tubas only 1 missing value was found (0.002%), and 172 (0.33%) and 237 (0.45%) double zeros were detected in Tubas 1 and Tubas 2 respectively. Hence, 99.67% and 99.55% of the data were used for the second part of the quality control process.

In Salfeet 227 values were missing, 0.4% of the data, and many double-zeros were found in both data series: 6501 (12.42%) in Salfeet 1 and 610 (1.17%) in Salfeet 2. Consequently, 87.58% and 98.83% of the initial data were accepted.

In the second part of the quality control procedure the range test, step check test and repetitions test were carried out, and each value in the data series got a final flag depending on the results obtained in each of the checks.

Thus, the estimated Weibull distribution's parameters  $k$  and  $c$ , the limit values (RS and RE for the range test, and SS and SE for the step check) and the type of repetitions (zeros or non-zeros) are shown in the Table 20.

Station	RANGE TEST				STEP CHECK TEST				REPETITIONS TEST	
	k	c	RS (95 <sup>th</sup> )	RE (99.9 <sup>th</sup> )	k	c	SS (95 <sup>th</sup> )	SE (99.9 <sup>th</sup> )	Zeros (%)	Non-zeros (%)
Hebron 2011	2.3961	4.8222	7.6227	10.8028	1.0909	0.4681	1.2797	2.7522	0	1.7437
Salfeet1 2011	1.8845	4.8899	8.7529	13.6359	0.9344	0.4761	1.5406	3.7672	0	1.9833
Salfeet2 2011	2.0714	5.4869	9.3189	13.9485	1.0717	0.4343	1.2090	2.6364	0	2.1693
Tubas1 2011	1.9576	5.4878	9.6118	14.73	1.0720	0.4678	1.3017	2.8377	0	2.1647
Tubas2 2011	1.9428	6.0999	10.7299	16.4953	1.0583	0.5042	1.4218	3.1310	0	2.4445

TABLE 20: SPECIFIC RESULTS OF EACH TEST FOR 2011.

For the range test the Weibull coefficients of the data series were estimated. A comparison of them is shown graphically in the figure below:

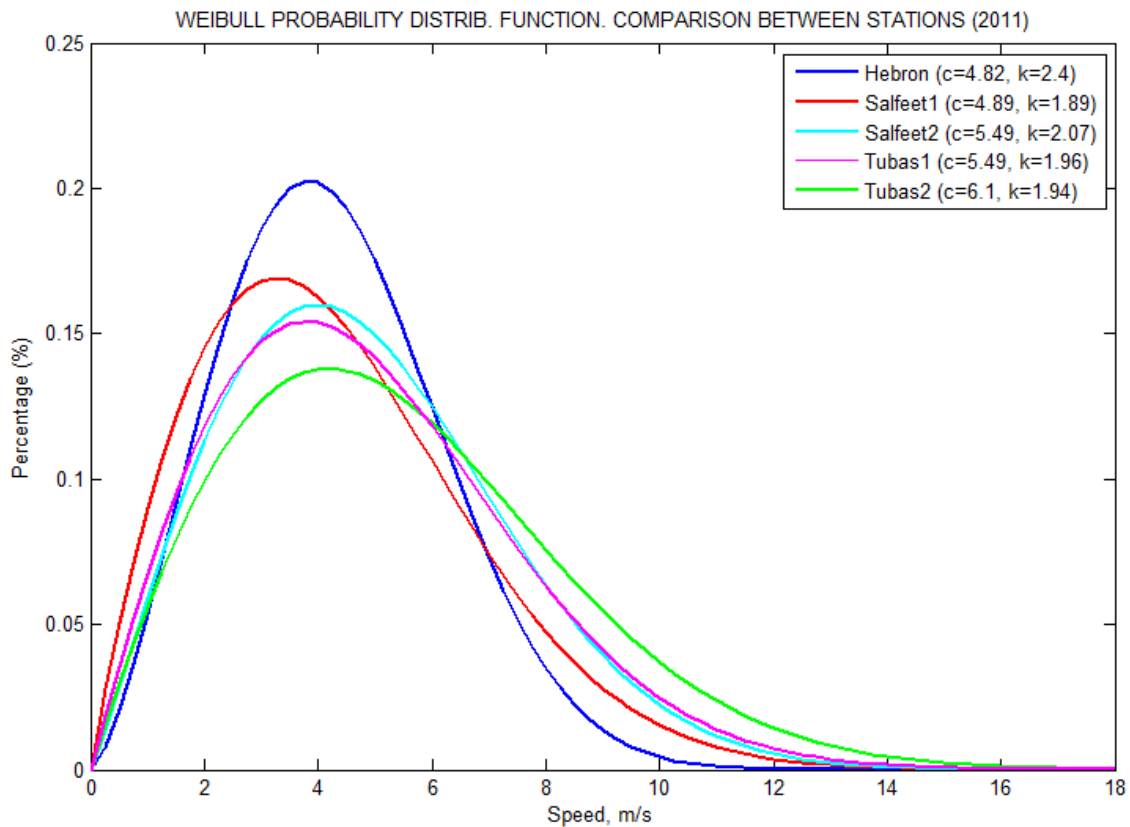


FIGURE 72: WEIBULL PDF COMPARISON BETWEEN STATIONS FOR 2011

There is a big difference between the curve from Hebron and the others. This is due to the shape coefficient of the distribution (k), which is higher than in other cases, and the scale coefficient (c), which is the lowest, so the slope of the distribution is steeper and most of the values are concentrated in the central period between 2 and 6 m/s, and the limit values are lower. The probability density function of Salfeet 2 and Tubas 1 was very similar to the one from Salfeet 1. In the case of Tubas 2, the slope was the least steep, which means that the limit values for the range test will be higher for this station.

RS varied from 7.62 to 10.73 m/s and RE from 10.80 to 16.50 m/s. As it was mentioned before, the most restrictive station (the one who had lower limit values) was Hebron, and the least restrictive was Salfeet 2.

Regarding the step check test, the shape coefficient k was around 1 for all the stations, and the shape coefficient was in the range from 0.43 to 0.50. The limit values varied from 1.21 to 1.54 for SS, and from 2.64 to 3.76. In none of the stations repeated zeros were detected. However, the repeated non-zeros percentage was around 2% in all the stations, excepting Hebron, where was lower, 1.74%, and Tubas 2, where the highest percentage was found, 2.44%.

Using these limit values the classification was carried out for each value, and of them has a 'Correct', 'Suspicious', 'Incorrect' flag, abbreviated as '0', '1', '2' respectively in the Table 20. From these results, the global assessment was done.

Station	RANGE TEST			STEP CHECK TEST			REPETITIONS TEST		GLOBAL ASSESSMENT					
	'0'	'1'	'2'	'0'	'1'	'2'	'0'	'2'	'0'		'1'		'2'	
									Am	%	Am	%	Am	%
Hebron 2011	95.16	4.27	0.58	91.46	8.10	0.44	98.26	1.74	33809	96.49	292	0.83	939	2.68
Salfeet 1 2011	94.79	4.77	0.44	91.96	6.73	1.30	98.02	1.98	43884	95.75	278	0.61	1670	3.64
Salfeet 2 2011	94.57	4.78	0.65	91.34	8.22	0.43	97.83	2.17	49513	95.73	579	1.12	1631	3.15
Tubas1 2011	95.28	4.62	0.10	91.62	7.89	0.49	97.84	2.16	50669	96.72	286	0.55	1432	2.73
Tubas2 2011	95.33	4.56	0.11	91.84	7.65	0.51	97.56	2.44	50464	96.45	268	0.51	1590	3.04

TABLE 21: QUALITY CONTROL RESULTS FOR 2011

In the range test around 95% of the values were considered correct, and about 0.5% were erroneous, excepting Tubas, where 0.1% of the data were flagged as incorrect. In all the cases over 4.2% of the values were suspicious.

In the second test carried out, the step check test, about 0.5% of the data was erroneous, excepting Salfeet, where the percentage was 1.30%. Nevertheless, in this test only around 91.6% of the data was flagged as correct, owing to the important percentage of suspicious data found: about 7.5%.

In the repetitions test the results were similar for all the stations, and about 2% of the values were incorrect. The best result was found in Hebron, where only 1.74% of the values were flagged as incorrect, and the worst occurred in Tubas, where 2.44% of the values were repetitions and considered erroneous.

Finally, in the global assessment about 96% of the data was accepted and around 2.7% was flagged as erroneous in Hebron and Tubas 1 (both had the best global results), and over 3% in the other stations. The range for suspicious data varied from 0.51% to 1.12%. The worst quality data was found in Salfeet, where 3.64% of the data were erroneous.

In the next lines a comparison of the classification anemograms obtained on each test will be carried out in order to determine if there are any similarities because the measures took place in the same period.

### 5.2.1.1 RANGE TEST

The classification anemograms are shown in the figures below:

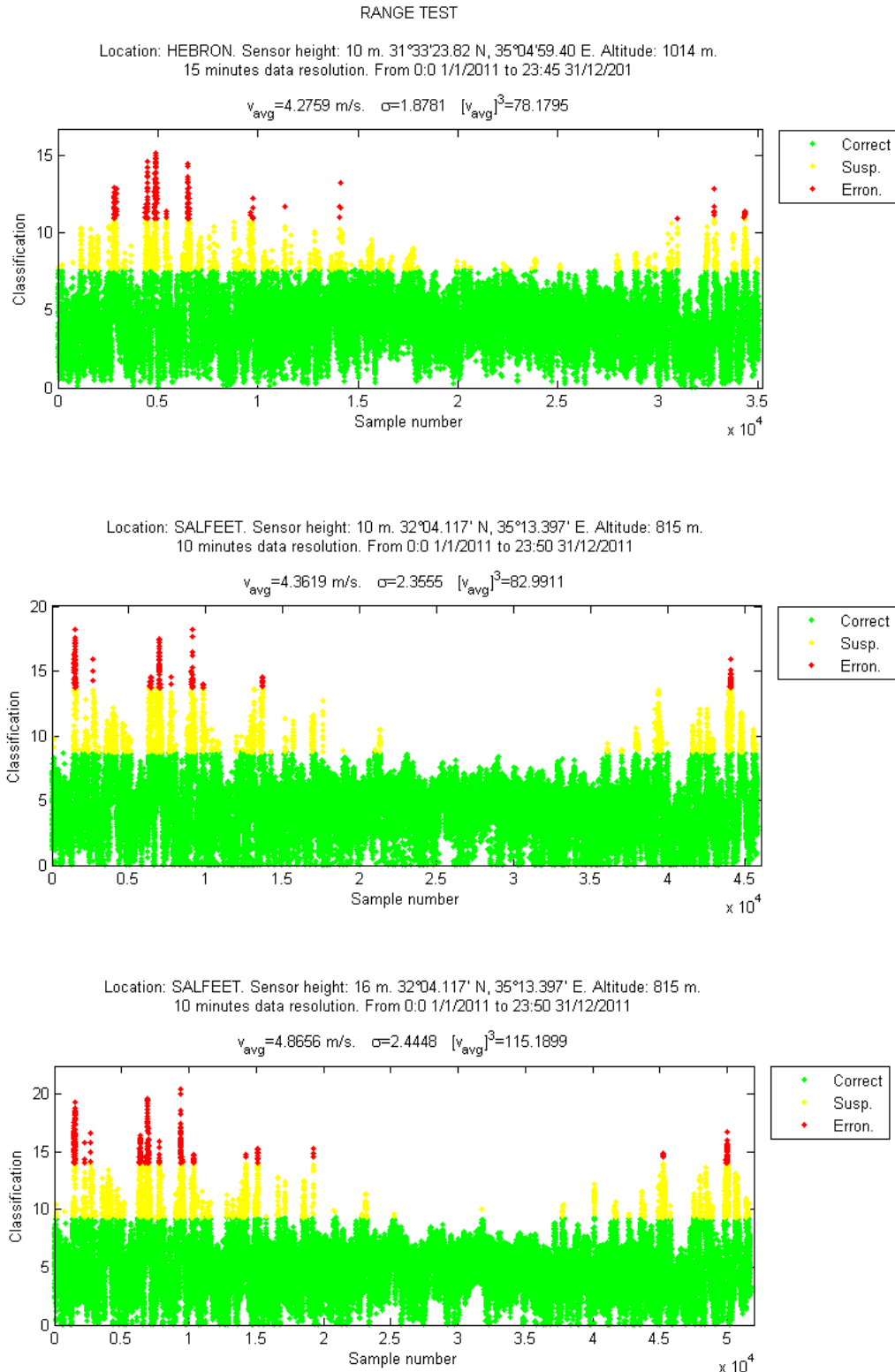
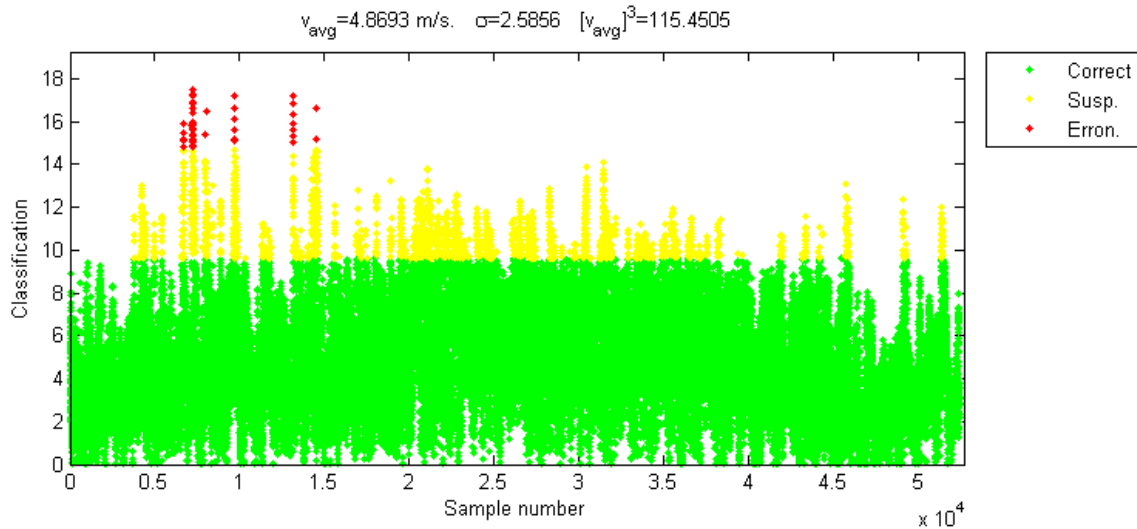


FIGURE 73: RANGE TEST RESULTS FOR HEBRON AND SALFEET IN 2011

### RANGE TEST

Location: TUBAS. Sensor height: 10 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
10 minutes data resolution. From 0:0 1/1/2011 to 23:50 31/12/2011



Location: TUBAS. Sensor height: 16 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
10 minutes data resolution. From 0:0 1/1/2011 to 23:50 31/12/2011

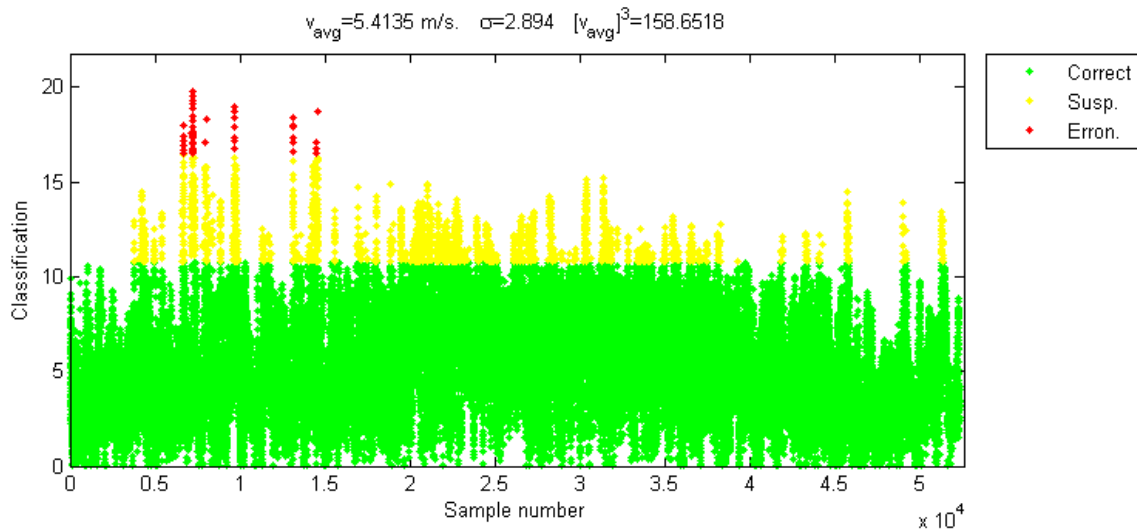


FIGURE 74: RANGE TEST RESULTS FOR TUBAS IN 2011

The obtained results were analogous for Salfleet 1 and Salfleet 2, which is logic, due to the fact that the values were taken in the same location, the only difference was the height, and the same occurred in Tubas. Regarding Hebron, the distribution of the incidences found was similar to Salfleet, and the erroneous data were found in the same periods, which are the windiest months of the year (winter and spring).

In Salfleet there are fewer samples than in the other stations because more erroneous data were already dismissed in the precedent stages.

### 5.2.1.2 STEP CHECK TEST

The obtained classification anemograms are:

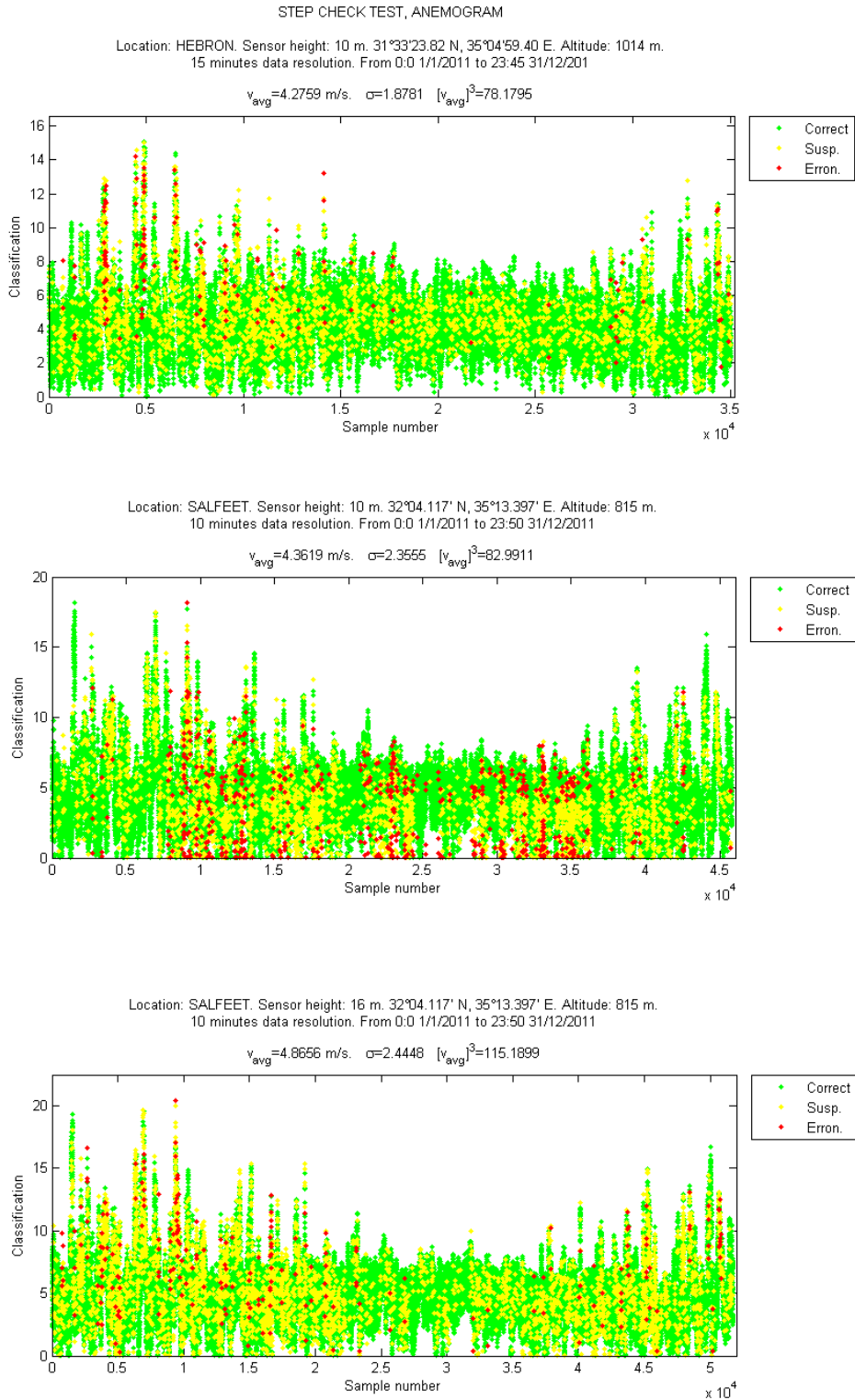
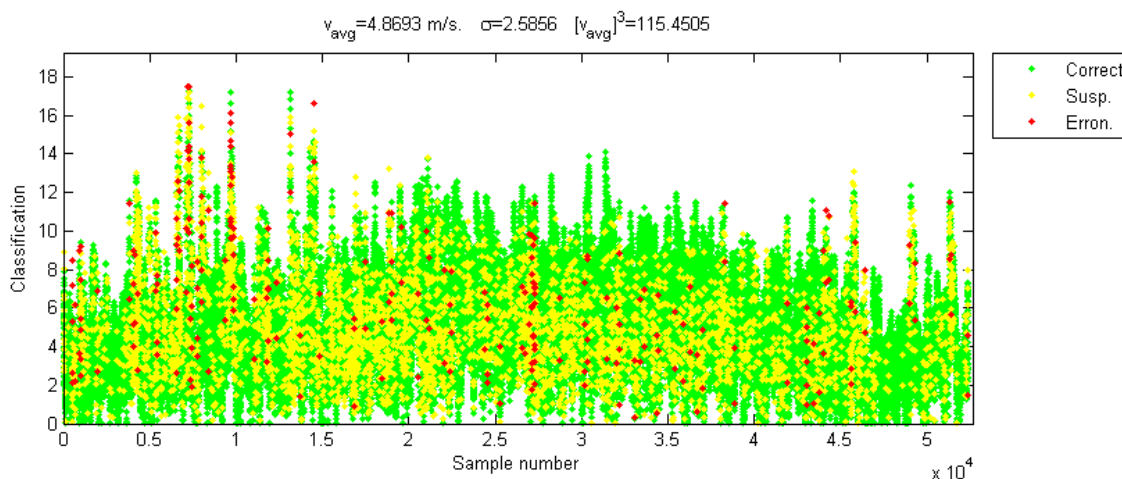


FIGURE 75: STEP CHECK TEST RESULTS FOR HEBRON AND SALFEET IN 2011



STEP CHECK TEST, ANEMOGRAM

Location: TUBAS. Sensor height: 10 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
10 minutes data resolution. From 0:0 1/1/2011 to 23:50 31/12/2011



Location: TUBAS. Sensor height: 16 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
10 minutes data resolution. From 0:0 1/1/2011 to 23:50 31/12/2011

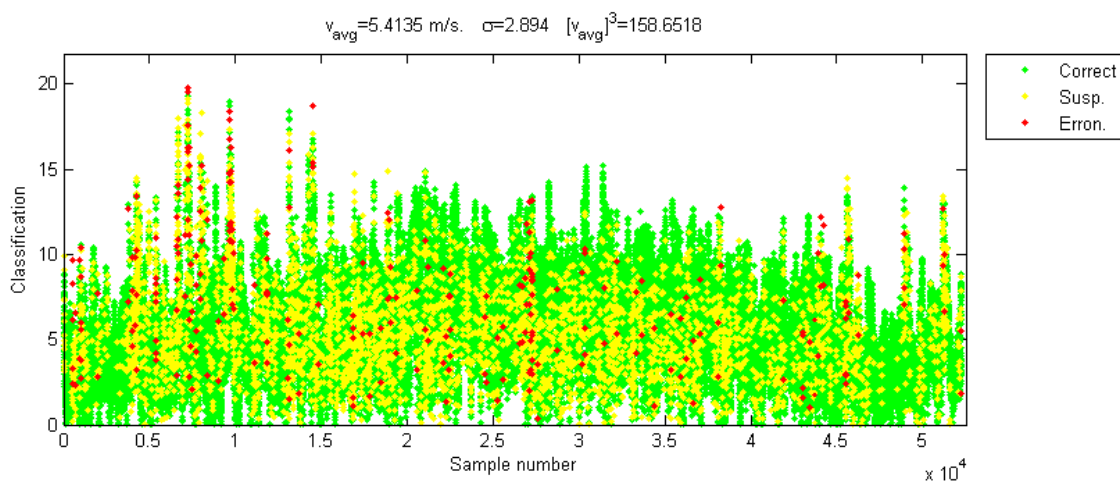


FIGURE 76: STEP CHECK TEST RESULTS FOR TUBAS IN 2011

The distribution of the incidences is very similar in Tubas1 and Tubas 2. However, there is not any similarity with other stations. On this test the results between Salfet 1 and Salfet 2 were completely different, because the erroneous data was particularly numerous in Salfet 1. Nonetheless, the distribution of the incorrect data in Hebron was similar to Salfet 2, even if it was not as numerous as in the second station.

### 5.2.1.3 REPETITIONS TEST

Regarding to the repetitions test, the classification anemograms are shown below:

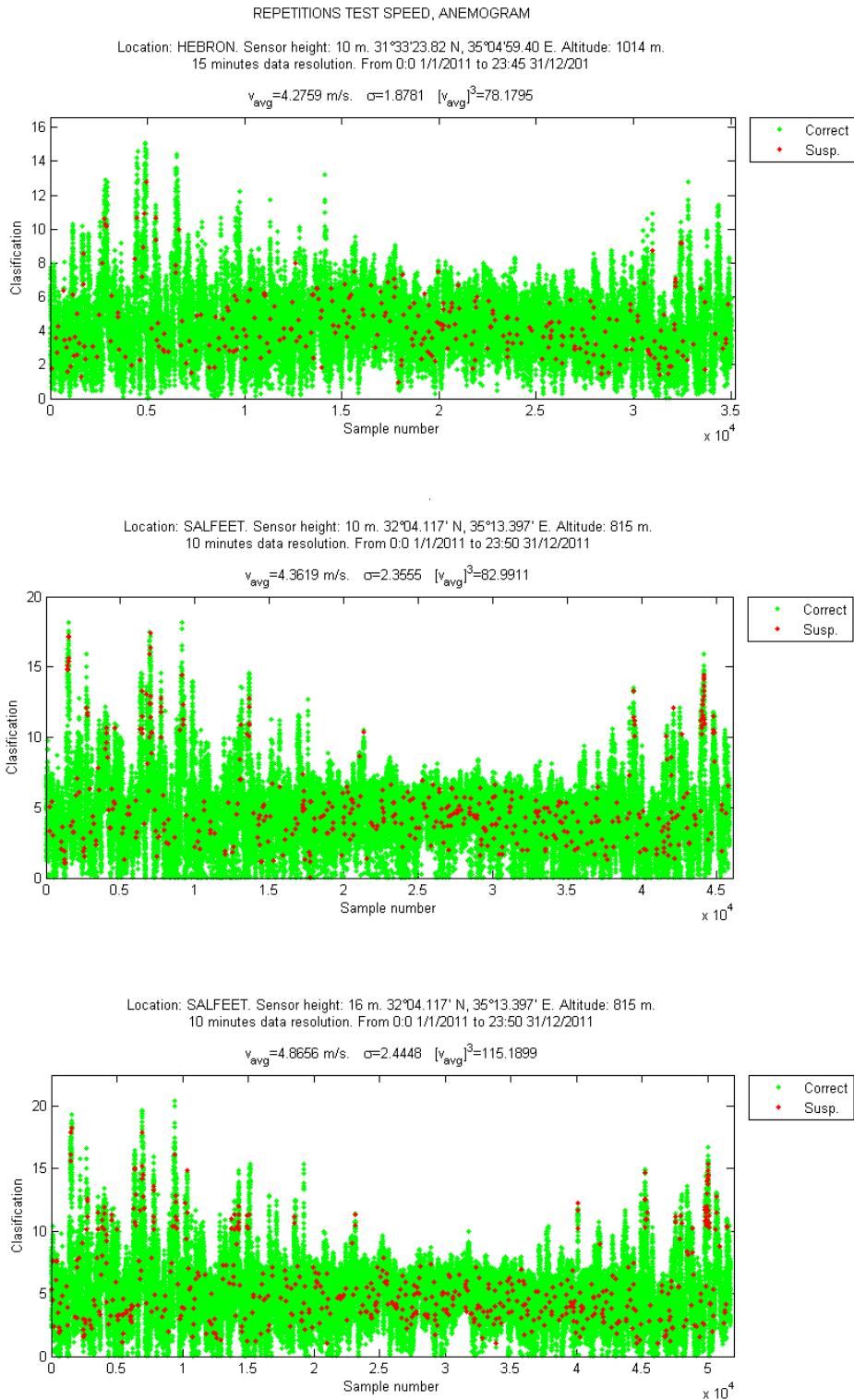
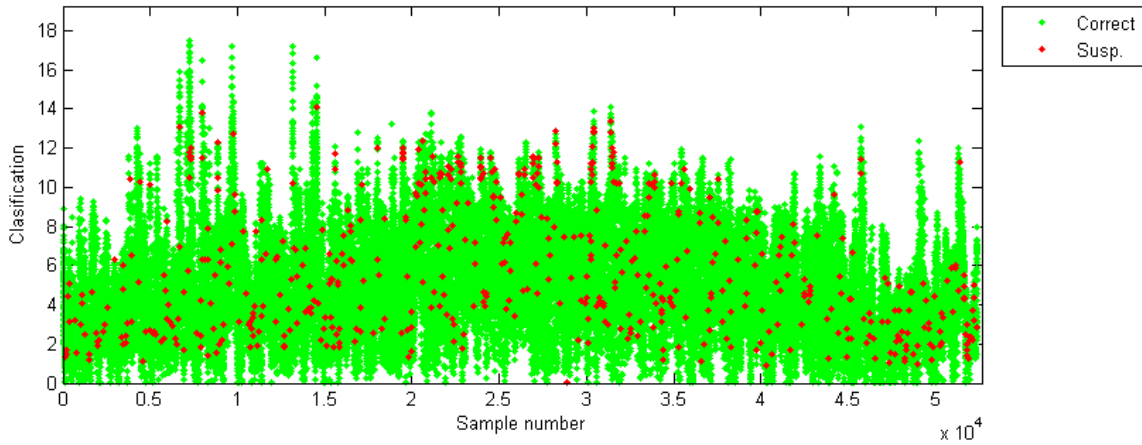


FIGURE 77: REPETITIONS TEST RESULTS FOR HEBRON AND SALFEET IN 2011

REPETITIONS TEST SPEED, ANEMOGRAM

Location: TUBAS. Sensor height: 10 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
10 minutes data resolution. From 0:0 1/1/2011 to 23:50 31/12/2011

$$v_{avg}=4.8693 \text{ m/s. } \sigma=2.5856 \quad [v_{avg}]^3=115.4505$$



Location: TUBAS. Sensor height: 16 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
10 minutes data resolution. From 0:0 1/1/2011 to 23:50 31/12/2011

$$v_{avg}=5.4135 \text{ m/s. } \sigma=2.894 \quad [v_{avg}]^3=158.6518$$

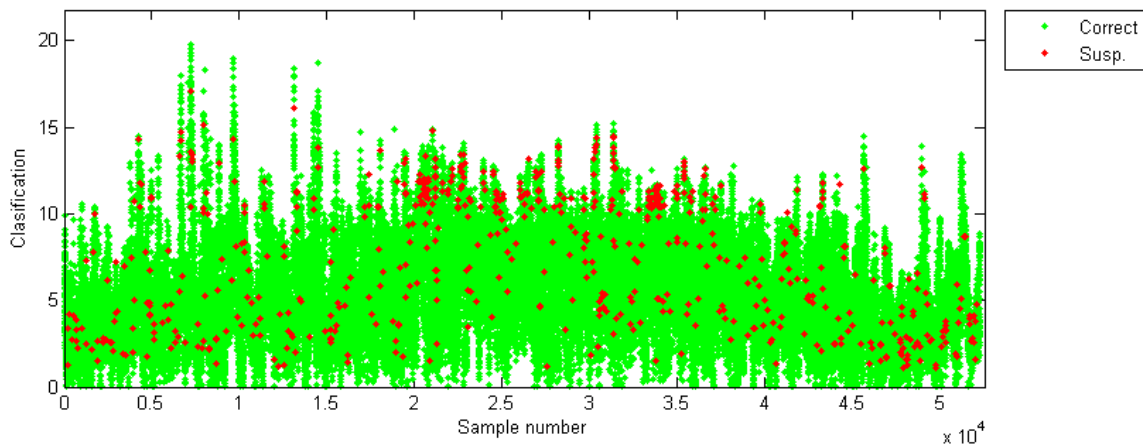


FIGURE 78: REPETITIONS TEST RESULT FOR TUBAS IN 2011

As it happened before, the results in both heights in Tubas and in Salfet were very similar. However there were not remarkable similarities between stations located in different points.

### 5.2.1.4 GLOBAL CLASSIFICATION

The global classification anemograms are shown in the two following figures.

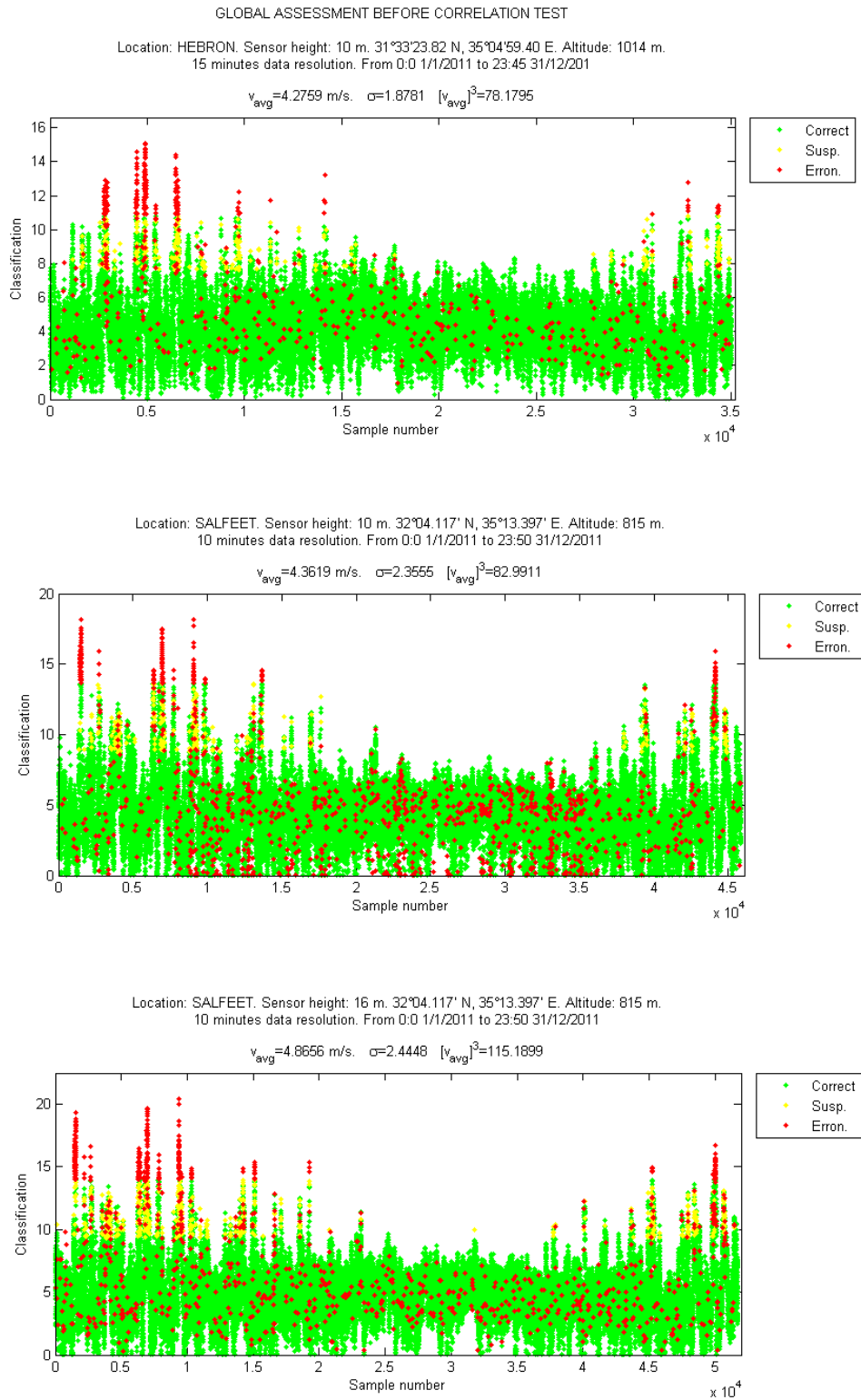
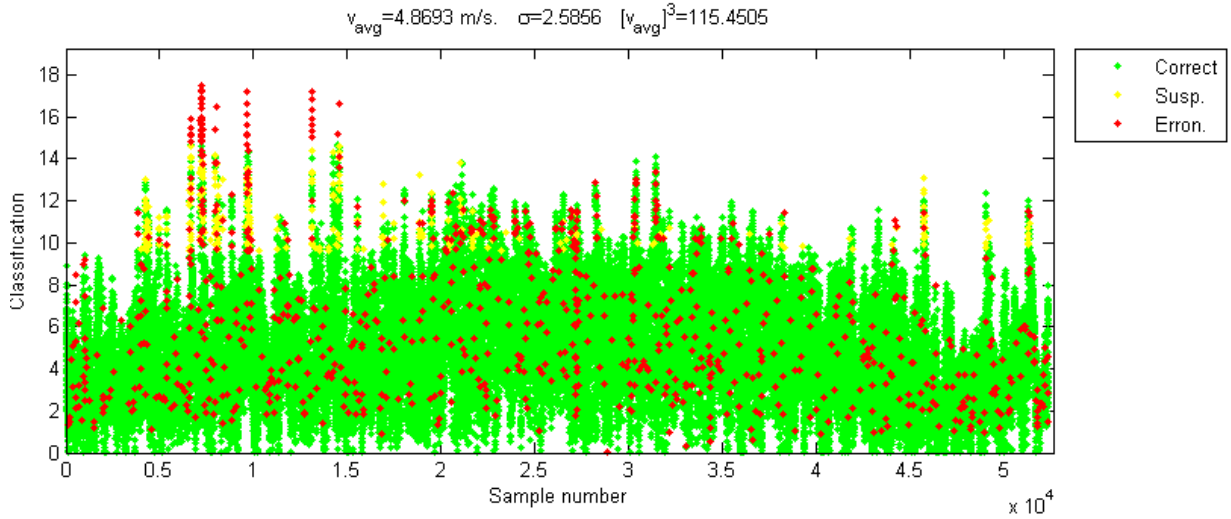


FIGURE 79: GLOBAL RESULTS FOR HEBRON AND SALFEET IN 2011

GLOBAL ASSESSMENT BEFORE CORRELATION TEST

Location: TUBAS. Sensor height: 10 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
10 minutes data resolution. From 0:0 1/1/2011 to 23:50 31/12/2011



Location: TUBAS. Sensor height: 16 m. 32°19.160' N, 35°21.373' E. Altitude: 570 m.  
10 minutes data resolution. From 0:0 1/1/2011 to 23:50 31/12/2011

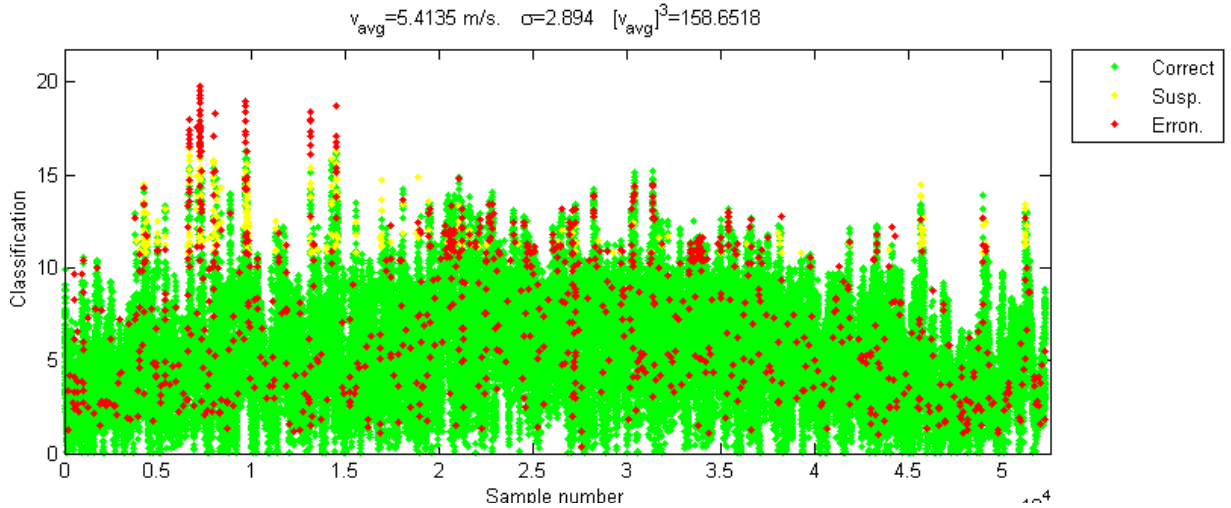


FIGURE 80: GLOBAL RESULTS FOR TUBAS IN 2011

The suspicious values are found roughly in the same part of the year (from winter to early spring, the windiest period of the year), and the same happened to some of the erroneous data (due to the incorrect data found in the range test). The rest of the erroneous data were distributed along the year, but in different extent: Visually, Salfect 1 was the station where more incorrect data was found and Hebron the one where less incorrect data was detected.

### 5.2.1.5 CORRELATION TEST

The data flagged as correct or suspicious was analyzed in the correlation test.

The correlation between each station was calculated, and the correlation coefficients are in Table 21.

Stations	Hebron	Salfeet 1	Salfeet 2	Tubas 1	Tubas 2
Hebron	1	0.5793	0.5988	0.4459	0.4448
Salfeet 1	0.5793	1	0.9561	0.4373	0.4281
Salfeet 2	0.5988	0.9561	1	0.4311	0.4222
Tubas 1	0.4459	0.4373	0.4311	1	0.9948
Tubas 2	0.4448	0.4281	0.4222	0.9948	1

TABLE 22: CORRELATION COEFFICIENTS, 2011

Only in the stations which have two levels the coefficient was higher than 0.8, in the rest of calculations it was much lower, so the stations are not correlated, and the quality control process is finished.

The next step is analyze the data series in order to know the main features of the wind, but only the correct and suspicious data were used for that stage.

## 5.2.2 WIND ANALYSIS

### 5.2.2.1 STATISTICAL RESULTS

Some statistical parameters were calculated for each station, and they will be presented in this section. First of all the measures of central tendency and of dispersion were found, then the wind power density were calculated and the coefficients of the correspondent Weibull distribution. Finally, a comparison between these results and the ones obtained for the complete data series in 5.1 section will be carried out.

#### MEASURES OF CENTRAL TENDENCY AND OF DISPERSION

The measures of central tendency and of dispersion calculated are presented in the Table 22. The highest wind speed was found in Tubas 2, over 5.3 m/s, and the lowest occurred in Hebron, 4.22 m/s. The intermediate values were found in Salfeet 1, 4.30 m/s and Salfeet 2 and Tubas 1, around 4.8 m/s. It is observed that the wind speed from the lowest level is 10% less than the mean wind speed in the higher level in Tubas and Salfeet.

The median was around 4.08 in Hebron and Salfeet 1, 4.5 in Salfeet 2 and Tubas 1, and 4.9 in Tubas 2.

The mode of the speed was around 4 m/s in all the stations excepting Tubas 2, where was 10.2 m/s, and the mode of the directions had different values depending on the station. Only in Tubas was similar in the two sensors, around 285°. In Hebron it was 357.4°, in Salfeet 1 it was 314°, and in Salfeet 2, 271.8°.

The lowest values were 0.011 m/s in Hebron and 0.002 m/s in the rest of stations. About the highest values, the maximum speed value was 16.4 m/s, found in Tubas 2, and the station which had the smaller value was Hebron, 10.8 m/s.

The mean absolute deviation shows the average distance between the values and the wind speed, so that means that the closest values were recorded in Hebron, and the values were the most separated between each other in Tubas 2. This will be shown again in the following lines.

The highest standard deviation was found in Tubas 2; that means that this was the station where the values fluctuated more from the mean value, so the values are more dispersed. In Hebron the variance was much lower, 1.78, so the values are less dispersed from the mean wind speed. This fact will be show graphically as well in the next sections.

About the coefficient of variation, which measures the ratio of the standard deviation to the mean, the highest variation was found in Tubas (in both levels) and in Salfeet 1, where the coefficient was over 51%. The lowest variation was detected in Hebron, 42%, and in Salfeet 2 as well, 47%.

Station	Measures of central tendency				Measures of dispersion					
	Mean	Median	Mode (Speed)	Mode (Directions)	Lowest value	Highest value	Mean deviation	Variance ( $\sigma^2$ )	$\sigma$	Coeff. of variat.
Hebron	4.22060	4.08	4.13	357.4	0.011	10.8	1.4097	3.1547	1.7762	42.0831
Salfeet1	4.3045	4.07	3.94	314	0.002	13.6	1.69307	4.1924	2.2164	51.4902
Salfeet2	4.7698	4.52	3.92	271.8	0.002	13.9	1.7326	5.0974	2.2576	47.3343
Tubas 1	4.8270	4.45	3.94	289.6	0.002	14.7	2.0740	6.4043	2.5307	52.4278
Tubas 2	5.3353	4.94	10.2	283.8	0.002	16.4	2.3056	7.8844	2.8079	52.6286

TABLE 23: MEASURES OF CENTRAL TENDENCY AND DISPERSION, 2011

## WIND POWER DENSITY

Regarding the wind power density, shown in the Table 23, the highest values took place in Tubas, 177.79 W/m<sup>2</sup> in Tubas 2 and 131.27 W/m<sup>2</sup> Tubas 1, then in Salfeet, 117.14 W/m<sup>2</sup> in Salfeet 2 and Salfeet 1 93.49 W/m<sup>2</sup>, and finally, the station where least wind power density was found was Hebron, with 73.35 W/m<sup>2</sup>.

Station	Wind power density [W/m <sup>2</sup> ]
Hebron	73.3452
Salfeet1	93.4904
Salfeet2	117.141
Tubas 1	131.268
Tubas 2	177.79

TABLE 24: WIND POWER DENSITY, 2011

The highest density was found in Tubas 2, 177.8 W/ m<sup>2</sup>, and the lowest in Hebron, 73.34 W/m<sup>2</sup>.

## WEIBULL COEFFICIENTS

As it was done before, the Weibull coefficients were estimated using the maximum likelihood method, and the results are presented in Table 24.

Station	Shape coefficient, k [dimens]	Scale coefficient, c [m/s]
Hebron	2.5275	4.7549
Salfeet1	1.9789	4.8307
Salfeet2	2.1996	5.375
Tubas 1	1.983	5.4403
Tubas 2	1.9734	6.0121

TABLE 25: WEIBULL COEFFICIENTS IN 2011



The best result for the shape parameter was found in Hebron 2.53. In Salfeet it was 2.2 and other cases it was about 2. This means that the most constant wind during the 2011 was measured in Hebron, and in the other stations the wind was more variable, and this will be displayed graphically in the next subsections.

About the scale parameter, the highest value was found in Salfeet 2, 6.01 m/s, in Tubas 1 and Salfeet 2 it was about 5.4 m/s, and about 4.8 m/s in Hebron and Salfeet 1, so this means that the highest values will be found in Salfeet 2. This coefficient is related and is proportional to the wind speed, and the values which have similar scale parameter have similar mean wind speed as well.

The graphical comparison of all the stations is shown in the figure below. The Weibull of Tubas 2 has the least steep slope, and the curve of Hebron has the steeper slope, due to the fact that the slope is inversely proportional to the scale parameter.

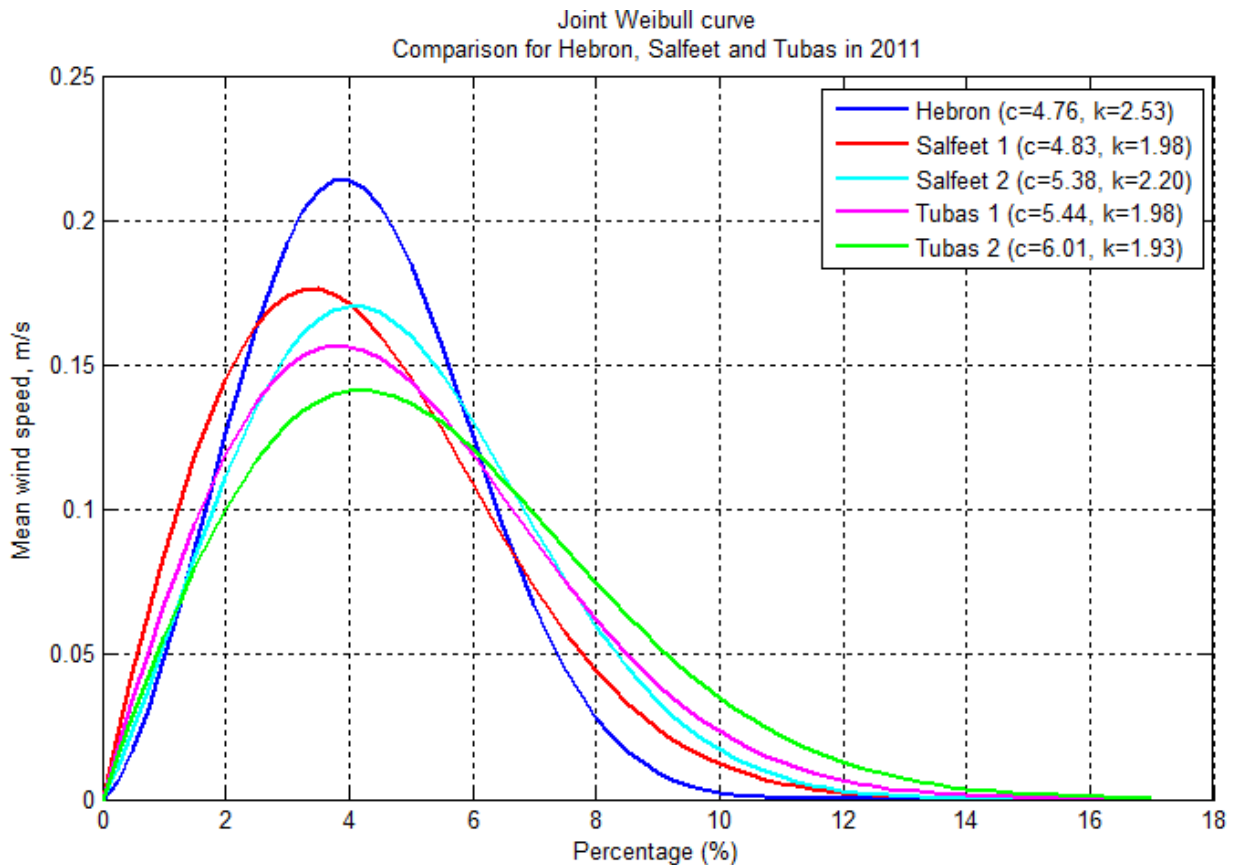


FIGURE 81: JOINT WEIBULL CURVE IN 2011

### 5.2.2.2 GRAPHICAL RESULTS

#### WIND SPEED DURATION CURVE

First of all, the wind speed duration curve was created for each of the stations, and the curves were superimposed in the Figure 81.



The station where higher speeds were measured was Tubas 2, where 50% of the time the wind speed exceeded 6 m/s, 30% of the time exceeded 7.8 m/s, and 10% of the time exceeded 10 m/s. In Tubas 1 the results were similar, but the percentage of the time was about 5% lower.

In Salfeet 2 the results are close to Tubas 2 until 4.3 m/s, and 70% of the time the wind exceeded this value. However, for higher wind speeds the results deteriorated and the wind was superior to 6 m/s in 40% of the time, and only 14% of the values were greater than 8 m/s.

The worst results were found in Hebron and Salfeet 1, where half of the time the wind speed was superior to 5 m/s, 30% of the time was greater than 6 m/s, and it exceeded 8 m/s about 10% and 7% of the time respectively for each station.

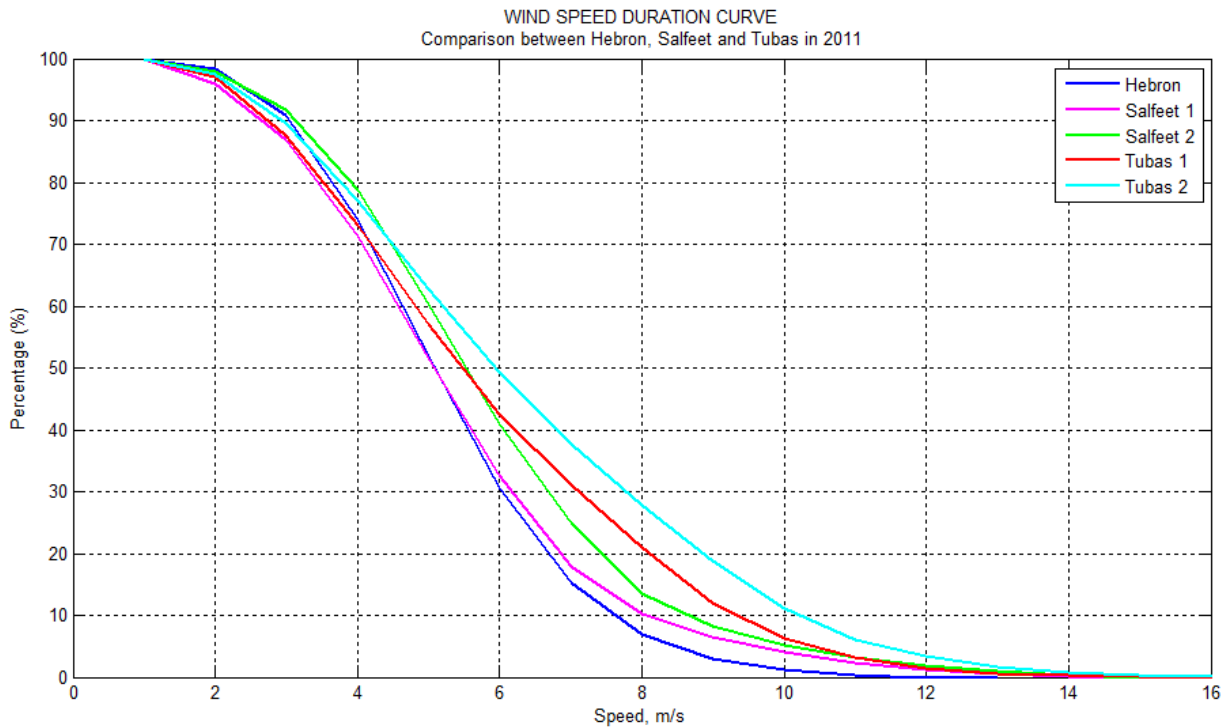


FIGURE 82: JOINT WIND SPEED DURATION CURVE IN 2011

## WIND ROSE

A wind rose was generated for each of the stations, and they are shown in the figure below.

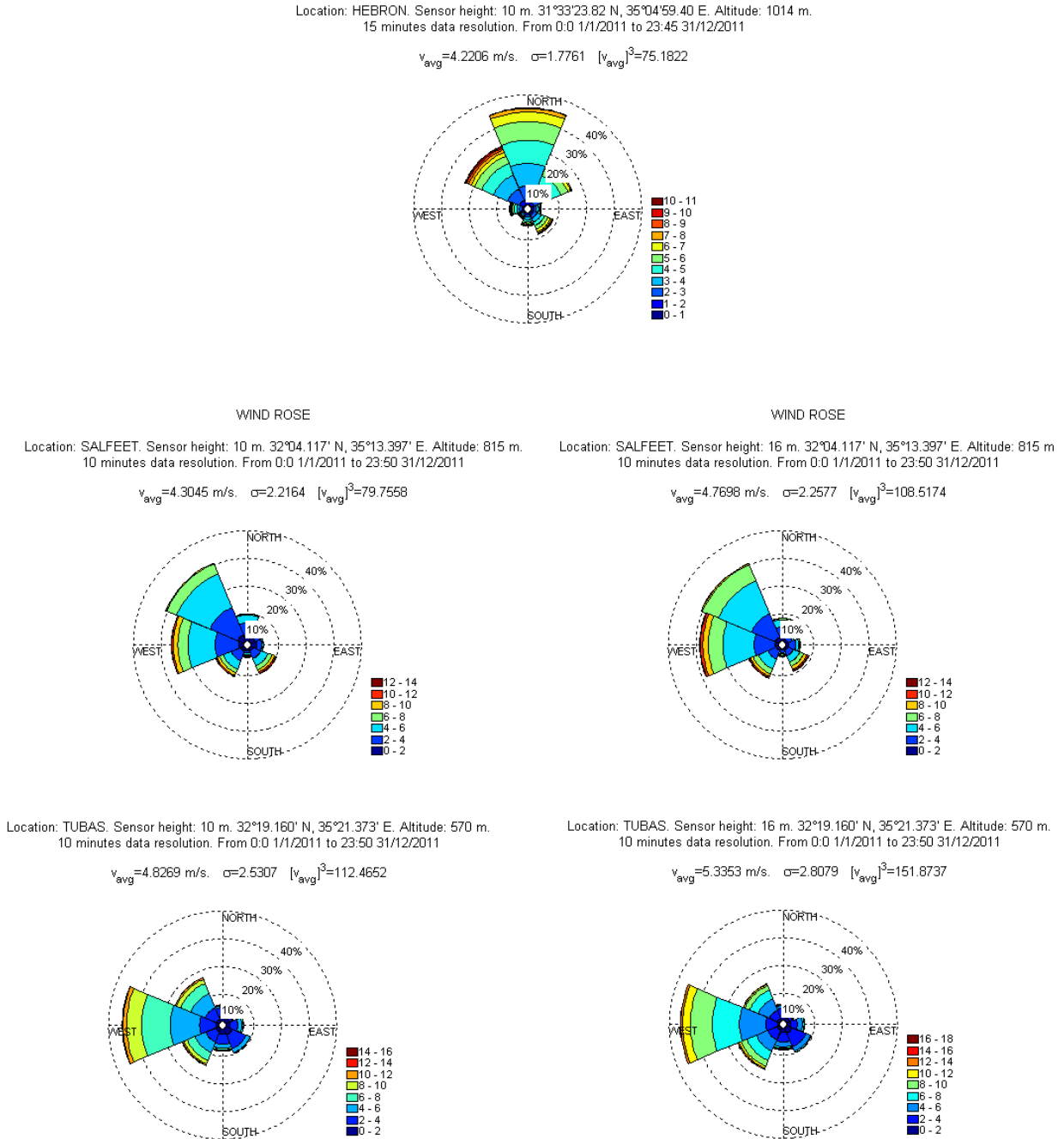


FIGURE 83: WIND ROSE FOR EACH STATION IN 2011

In the first line the wind rose of Hebron is shown, in the second the ones of both sensors in Salfeet, and in the last line the graphics of Salfeet 1 and 2 are presented. The wind roses of both couple of sensors (Salfeet 1 and Salfeet 2, Tubas 1 and Tubas 2) were very similar to each other, the wind directions are almost the same, which makes sense because both sensors are in the same location, but the wind speed proportions are different, and they are always higher in the sensors that are in the second level (Salfeet 2 and Tubas2).

About the wind direction, it varied from the west to the north in about 50 % of the time in all the stations. In Hebron, it was mainly from the north (35%), from the northwest (24%) and from the northeast as well (16%). In Salfeet 30% of the time the wind was from the northwest, 26% was from the west, and only 10% of the time was from the southwest. Finally, in Tubas more than 30% of the time the wind was from the west, 18% was from the northwest and 15% from the southwest.

It is remarkable that in all the stations about 10% of the wind was from the southeast.

### MONTHLY MEAN WIND SPEED

In the Figure 84 the mean speed for each month in 2011 for each station is presented.

The lowest wind speed values were found in Hebron, where the speed was around 4.4 m/s during all the year with very small variations, and in Salfeet 1, where the mean value was the same, but the variations were more prominent in the different months.

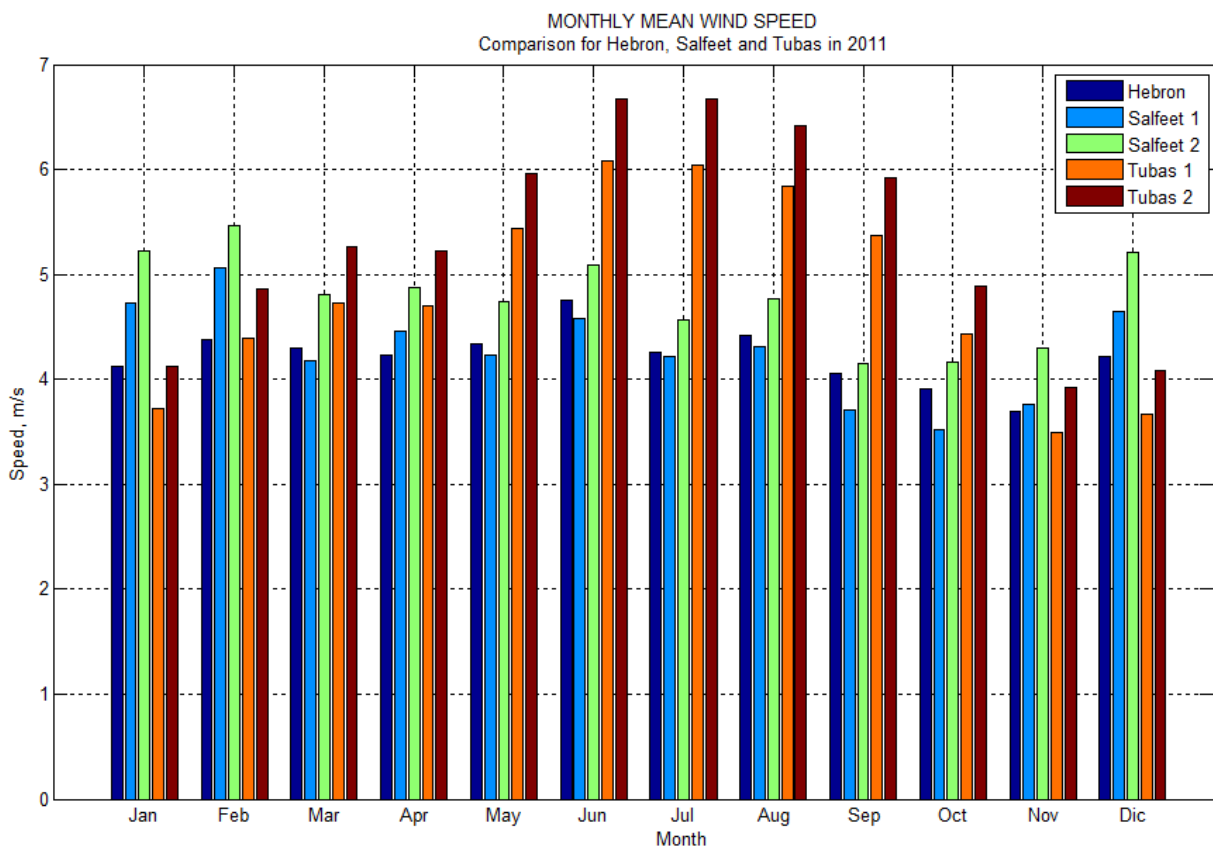


FIGURE 84: JOINT MONTHLY MEAN WIND SPEED IN 2011

As it was said before in the first analysis, Tubas has the highest wind speed values in summer, around 6 m/s in Tubas 2 and 5.5 m/s in Tubas during this period. In the rest of the year the means values were lower, and at the beginning and end of the year (January, February, November and December) the wind speed measured in this station and in Hebron was very similar.

The highest wind speed in winter was found in Salfeet 2, about 5 m/s, but during the rest of the year this value was lower and varied around 4.5 m/s.

### MEAN WIND SPEED

The graph of the Figure 85 the evolution of the wind during a mean day is shown.

In all the stations the windiest moment of the day was in the afternoon, between 16h and 18h, and the least windy moment took place in the morning, around 9h. The maximum values varied from 5 m/s in Hebron to 7 m/s in Tubas 2, but the variation of the minimum values was lower, about 0.5 m/s, from 3.5 m/s in Tubas 1 to 4 m/s in Salfeet 2.

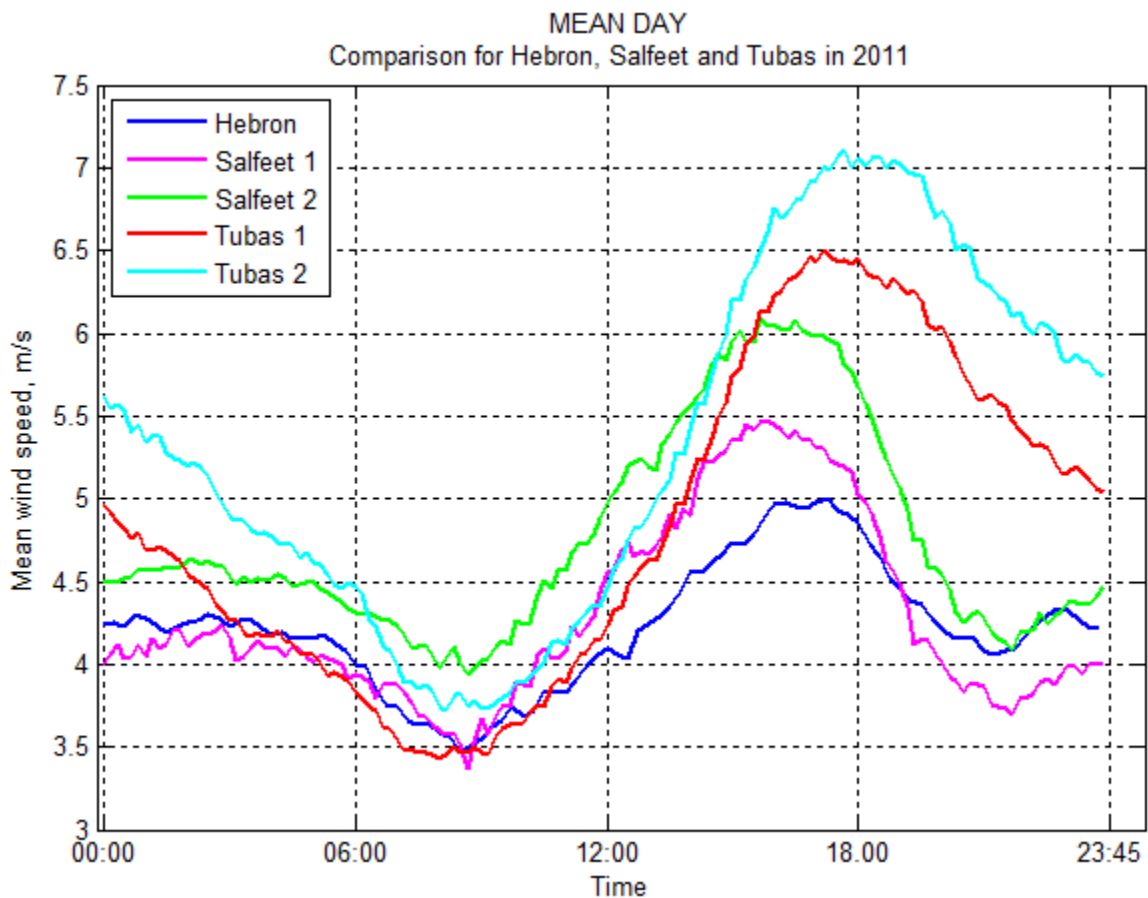


FIGURE 85: JOINT MEAN DAY IN 2011

### 5.3 COMPARISON BETWEEN THE COMPLETE DATA SERIES AND THE YEAR 2011

---

First of all, the statistical parameters between the two groups of data are compared:

- The mean and the median were very similar in 2011 (Table 14 and Table 21) and in the general study carried out before, the difference was less than 3% in all the cases, and it was shown that the windiest place is Tubas 2, and the lowest is Hebron. In all the stations the mean value was higher than in 2011 excepting Tubas 2.
- About the variation of the data from the mean, the variance, mean deviation and coefficient of variation show that in general the data varied more in the general data series than in 2011.
- Even if the standard deviation was not very similar, the coefficient of variation was almost analogous in the two periods under study, and the difference was around 3.5% in the worst case.

The differences between the wind power density in the complete data series, shown in Table 16, and in 2011, Table 22, were important in Hebron and Salfeet, the variation was around the 13%. In Tubas, however, the results were very similar and the variation was around 3%. In all the cases this value was higher in the complete data series.

The estimated Weibull coefficients for the 2011 and for the complete data series, shown in Table 17 and Table 23, were very similar in all the cases, and in any case the difference was greater than 3%.

About the wind direction, the wind roses obtained in Tubas and Salfeet were almost the same (it is noteworthy that in the first part data from July 2010 to June 2012 was used, and in the second part data for the whole 2011 was analyzed).

However some differences were found in Hebron: Even if the main directions were the same, west and northwest, in 2011 the most common was north, and in the three years data series was northwest. In 2011 more than 15% of the time the direction was northeast, but in the complete data series this did not occurred and about 10% of the time it was west.

Anyway, in 2011 and in the complete data series about 10% of the time the direction was southeast in all the stations.

The monthly mean wind speed was very similar for the two groups of data in general, but in Salfeet the values were higher in 2011 in winter, and in Tubas in the same period the values were higher in the complete data series.

Regarding the mean day, the same tendency was found in the two groups of data: the windiest moment took place in the afternoon and the least windy period happened in the morning. In general the results were very similar, but small variations were found:

- In Hebron the maximum and minimum values were lower in 2011: The highest value in the afternoon was 2% lower and the lowest was 8% lower.
- In Salfeet 1 the highest value in the afternoon was the same, but in the morning it increased a 10% in 2010.
- In Salfeet 2 mean wind speed was lower in 2011: the maximum value was a 3% lower and the minimum value was 5 % lower than the complete data series.
- In Tubas 1 the results were exactly the same.
- In Tubas 2 the maximum value was the same but the minimum value was lower in 2011.

## 6 CONCLUSIONS

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A software for the quality control and analysis of the wind data was developed using Matlab. This tool can be used to analyze data from any weather station because it is a general software.

The results after the quality control process of the complete data set show that over 95% of the data was correct in Salfeet, and over 96% was correct in Hebron and Tubas. In Mkahal the percentage of correct data was around 89%. In this station a 10% of the data was incorrect, but this percentage was lower in the other stations under study and it varied from 2.87% in Hebron to 3.60% in Salfeet 1. Finally, the suspicious data was not lower than 0.59% (Tubas 2), and not higher than 1.23% (in Salfeet 2). The stations were not correlated.

Regarding the results obtained in the first analysis, where the complete data series of all the stations were evaluated, we have observed:

- The highest mean wind speed took place in Tubas 2, 5.4 m/s and the lowest in Mkahal, 3.8 m/s.
- Once all the measures of dispersion were calculated it was discovered that the values were closer between each other in Hebron, and the most dispersed in Tubas 2.
- About the wind power density, very different values were found depending on the station, the highest was found in Tubas 2, 184.3 W/ m<sup>2</sup>, and the lowest was found in Mhahal, 76.8 W/ m<sup>2</sup>.

Some conclusions about the comparison after and before the quality control tests for the complete group of data are:

- The variation of the mean after and before the tests was around 0.8% and 2.1%. However, this value was higher in Mkahal, 5%, and in Salfeet 7.6%, where the rate of erroneous data was the highest. The same happened for the median, the percentage was around 0.13% to 0.7% excepting Salfeet, 5.29%, and Mkahal, 6.6%.
- In the majority of the stations the mode in speed and direction changed, due to incidences mainly in the double zeros check.
- The wind power density depends on the cube of the wind speed, and therefore the percentage of variation before and after the quality control tests was important: in all the cases it was around 10%, excepting Salfeet 1, where it was just 3% and Mkahal, over 5%.

The conclusions obtained in the analysis of the stations of Hebron, Salfeet and Tubas in 2011 are:

- The mean wind speed varied from 4.4 m/s to 5.4 m/s. The best results were found in Salfeet 2, and the worst in Hebron. In all the cases the difference between the two levels in the same station (in Tubas and Salfeet) was 10%. This occurred in the general data series as well.
- The data series from Salfeet had the highest variation between the available values. Nevertheless, the station which measured the most constant values was Hebron.
- The highest wind power density was found in Tubas 2, 177.8 W/ m<sup>2</sup>, and the lowest in Hebron, 73.34 W/m<sup>2</sup>.
- Regarding the wind direction values obtained in all the stations, the wind direction in the region varied from the west to the north in half of the time. In Hebron it was mainly from the north, in Salfeet from the northwest and in Tubas from the west. The fact that 10% of the time the direction of the wind in all the stations was from the southeast is striking.
- The highest mean monthly wind speed was found in Tubas 2 in summer months (around 6 m/s) and in Salfeet 2 in winter months (around 5 m/s).

- The windiest moment of the day took place in the afternoon, between 16h and 18h, and the least windy happened in the morning, at around 9h. The variation of the maximum values measured in each station was important, about 2 m/s, from 5 m/s in Hebron to 7 m/s in Tubas 2, but it was lower in the minimum values, just 0.5 m/s, from 3.5 m/s in Tubas 1 to 4 m/s in Salfeet 2.

Although small differences were found between the complete data series and 2011, and in general the mean values were higher in the second data set, the data of 2011 is a good example of the complete data because obtained results in both analyses are very similar. Nonetheless, more complete years would be needed to state this with certainty.

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# 03002 and 03101

## R. M. Young Wind Sentry Set and Anemometer

R. M. Young's 03002 Wind Sentry Set accurately measures wind speed and direction. The 03101 provides just the anemometer for customers who only want wind speed measurements. These sensors interface directly with our dataloggers; no signal conditioning is required. All of our contemporary dataloggers and many of our retired dataloggers (e.g., CR510, CR10X, CR23X) are compatible with the Wind Sentry.

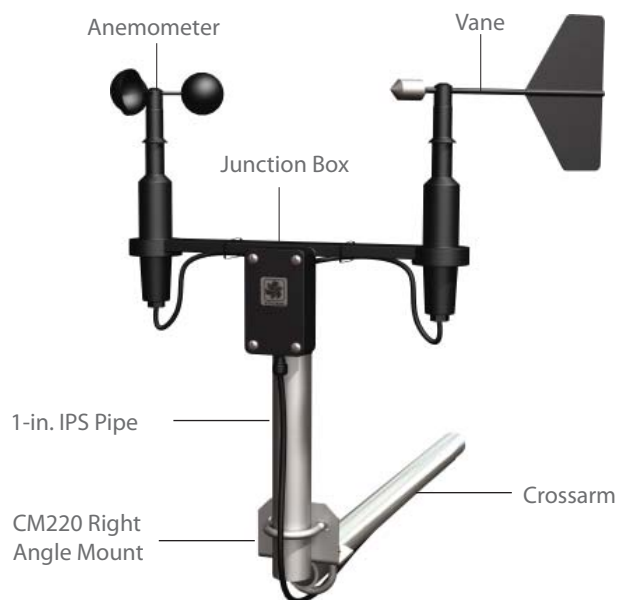
The Wind Sentry uses a three-cup anemometer to measure wind speed. Rotation of the cup wheel produces an ac sine wave that is directly proportional to wind speed. The frequency of the ac signal is measured by a datalogger pulse count channel, then converted to engineering units (mph, m/s, knots). Campbell Scientific's version of the Wind Sentry uses shielded bearings which lowers the anemometer's threshold.

Wind direction is sensed by a potentiometer. With the precision excitation voltage from the datalogger applied to the potentiometer element, the output signal is an analog voltage that is directly proportional to the azimuth angle of the wind direction.

An ideal application for the Wind Sentry is wind profile studies. For this application, the LLAC4 4-channel Low Level AC Conversion Module can be used to increase the number of Wind Sentry Sets measured by one datalogger. The LLAC4 allows datalogger control ports to read the anemometer's ac signals instead of using pulse channels. Dataloggers compatible with the LLAC4 are the CR200(X)-series (ac signal  $\leq 1$  kHz only), CR800, CR850, CR1000, CR3000, and CR5000.

### Mounting

The 03002 is supplied with a 12-in.-long x 1-in. IPS unthreaded aluminum pipe, which mounts to a crossarm via a CM220 Mount or 17953 NU-RAIL fitting. When purchased separately, the 03101 anemometer is supplied with a galvanized 10-in.-long x  $\frac{3}{4}$ -in. IPS threaded pipe, which mounts to a crossarm via a CM220 mount or 1049 NU-RAIL fitting. The 03002 or 03101 can also be mounted to the top of a CM110, CM115, or CM120 stainless-steel tripod via the CM216.



### Ordering Information

#### Wind Sensors

- 03002-L** Wind Sentry Set; enter lead length, in feet, after the -L. A cable termination option is required (see below).
- 03101-L** Wind Sentry Anemometer only; enter lead length, in feet, after the -L. A cable termination option is required (see below).

#### Cable Termination Options (choose one)

- PT** Cable terminates in stripped and tinned leads for direct connection to a datalogger's terminals.
- PW** Cable terminates in a connector for attachment to a prewired enclosure.
- CWS** 03002 cable terminates in a connector for attachment to a CWS900 interface. Connection to a CWS900 interface allows the 03002 to be used in a wireless sensor network. This option is only for the 03002.

#### Mounts

- CM220** Right Angle Mounting Bracket for attaching a 03002 or 03101 to a crossarm, such as a CM202, CM204, or CM206.
- 17953** 1-in. x 1-in. NU-RAIL Fitting for mounting the 03002 Wind Sentry Set to a crossarm, such as a CM202, CM204, or CM206. This mount is for only the 03002 Wind Sentry Set.
- 1049**  $\frac{3}{4}$ -in. x 1-in. NU-RAIL Fitting for mounting just the 03101 anemometer to a crossarm, such as a CM202, CM204, or CM206. This mount is for only the 03101 Wind Sentry Anemometer.
- CM216** Sensor Mounting Kit for attaching the 03002 or 03101 to the top of a CM110, CM115, or CM120 stainless-steel tripod.

### Recommended Cable Lengths

CM6	CM106	CM10	CM110	CM115	CM120	UT10	UT20	UT30
10 ft	13 ft	13 ft	13 ft	19 ft	24 ft	13 ft	24 ft	34 ft

*These cable lengths assume the sensor is mounted atop the tripod/tower via a CM202 crossarm.*

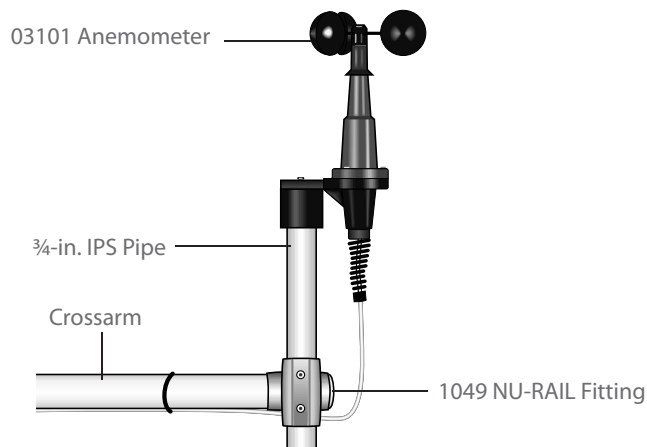
## Specifications

### Wind Sentry Assembly

<b>Operating Temperature:</b>	-50° to +50°C; assuming non-riming conditions
<b>Overall Height:</b>	32 cm (12.6 in.)
<b>Crossarm Length:</b>	40 cm (15.7 in.) between instruments (center-to-center)
<b>Mounting Diameter:</b>	34 mm (1.34 in.); mounts on standard 1-in. IPS pipe

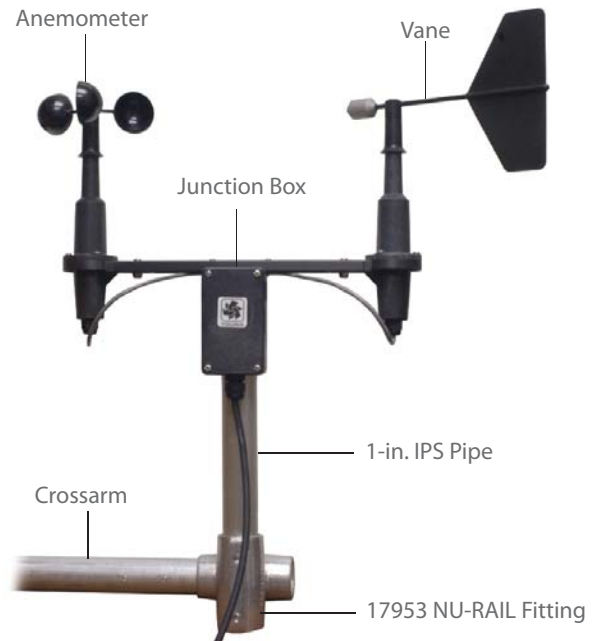
### Wind Speed (Anemometer)

<b>Range:</b>	0 to 50 m s <sup>-1</sup> (112 mph)
<b>Gust Survival:</b>	60 m s <sup>-1</sup> (134 mph)
<b>Sensor:</b>	12-cm diameter cup wheel assembly, 40-mm diameter hemispherical cups
<b>Accuracy:</b>	±0.5 m s <sup>-1</sup> (1.1 mph)
<b>Turning Factor:</b>	75 cm (2.5 ft)
<b>Distance Constant (63% recovery):</b>	2.3 m (7.5 ft)
<b>Threshold:</b>	0.5 m s <sup>-1</sup> (1.1 mph)
<b>Transducer:</b>	Stationary coil; 1300 ohm nominal resistance
<b>Transducer Output:</b>	AC sine-wave signal induced by rotating magnet on cup wheel shaft 100 mV peak-to-peak at 60 rpm; 6 V peak-to-peak at 3600 rpm
<b>Output Frequency:</b>	1 cycle per cup wheel revolution; 0.75 m s <sup>-1</sup> per Hz
<b>Cup Wheel Diameter:</b>	12 cm (4.7 in.)
<b>Weight:</b>	113 g (4 oz)



### Wind Direction (Vane)

<b>Range:</b>	360° mechanical; 352° electrical (8° open)
<b>Sensor:</b>	Balanced vane; 16 cm turning radius
<b>Accuracy:</b>	±5°
<b>Damping Ratio:</b>	0.2
<b>Delay Distance (50% recovery):</b>	0.5 m (1.6 ft)
<b>Threshold</b>	
<b>10° Displacement:</b>	0.8 m s <sup>-1</sup> (1.8 mph)
<b>5° Displacement:</b>	1.8 m s <sup>-1</sup> (4 mph)
<b>Transducer:</b>	Precision conductive plastic potentiometer; 10 kohm resistance; 1.0% linearity; life expectancy of 50 million revolutions. Rated 1 Watt at 40°C, 0 Watts at 125°C.
<b>Transducer Excitation:</b>	Requires regulated dc voltage, 15 Vdc maximum
<b>Transducer Output:</b>	Analog dc voltage proportional to wind direction angle with regulated excitation voltage supplied by the datalogger
<b>Vane Length:</b>	22 cm (8.7 inch)
<b>Weight:</b>	170 g (6 oz)





# CR1000 Specifications

Electrical specifications are valid over a -25° to +50°C, non-condensing environment, unless otherwise specified. Recalibration recommended every two years. Critical specifications and system configuration should be confirmed with Campbell Scientific before purchase.

## PROGRAM EXECUTION RATE

10 ms to one day @ 10 ms increments

## ANALOG INPUTS (SE1-SE16 or DIFF1-DIFF8)

8 differential (DF) or 16 single-ended (SE) individually configured. Channel expansion provided by multiplexers.

RANGES and RESOLUTION: Basic resolution (Basic Res) is the A/D resolution of a single conversion. Resolution of DF measurements with input reversal is half the Basic Res.

Range (mV) <sup>1</sup>	DF Res (µV) <sup>2</sup>	Basic Res (µV)
±5000	667	1333
±2500	333	667
±250	33.3	66.7
±25	3.33	6.7
±7.5	1.0	2.0
±2.5	0.33	0.67

<sup>1</sup>Range overhead of ~9% on all ranges guarantees that full-scale values will not cause over range.

<sup>2</sup>Resolution of DF measurements with input reversal.

## ACCURACY<sup>3</sup>:

±(0.06% of reading + offset), 0° to 40°C

±(0.12% of reading + offset), -25° to 50°C

±(0.18% of reading + offset), -55° to 85°C (-XT only)

<sup>3</sup>Accuracy does not include the sensor and measurement noise. Offsets are defined as:

Offset for DF w/input reversal = 1.5-Basic Res + 1.0 µV

Offset for DF w/o input reversal = 3-Basic Res + 2.0 µV

Offset for SE = 3-Basic Res + 3.0 µV

## ANALOG MEASUREMENT SPEED:

Integration Type/ Code	Integration Time	Settling Time	Total Time <sup>5</sup>	
			SE w/ No Rev	DF w/ Input Rev
250	250 µs	450 µs	~1 ms	~12 ms
60 Hz <sup>4</sup>	16.67 ms	3 ms	~20 ms	~40 ms
50 Hz <sup>4</sup>	20.00 ms	3 ms	~25 ms	~50 ms

<sup>4</sup>AC line noise filter.

<sup>5</sup>Includes 250 µs for conversion to engineering units.

INPUT NOISE VOLTAGE: For DF measurements with input reversal on ±2.5 mV input range; digital resolution dominates for higher ranges.

250 µs Integration: 0.34 µV RMS  
50/60 Hz Integration: 0.19 µV RMS

INPUT LIMITS: ±5 Vdc

DC COMMON MODE REJECTION: >100 dB

NORMAL MODE REJECTION: 70 dB @ 60 Hz when using 60 Hz rejection

SUSTAINED INPUT VOLTAGE W/O DAMAGE: ±16 Vdc max.

INPUT CURRENT: ±1 nA typical, ±6 nA max. @ 50°C; ±90 nA @ 85°C

INPUT RESISTANCE: 20 Gohms typical

ACCURACY OF BUILT-IN REFERENCE JUNCTION

THERMISTOR (for thermocouple measurements):

±0.3°C, -25° to 50°C

±0.8°C, -55° to 85°C (-XT only)

## ANALOG OUTPUTS (Vx1-Vx3)

3 switched voltage, sequentially active only during measurement.

RANGE AND RESOLUTION: Voltage outputs programmable between ±2.5 V with 0.67 mV resolution.

V<sub>x</sub> ACCURACY: ±(0.06% of setting + 0.8 mV), 0° to 40°C

±(0.12% of setting + 0.8 mV), -25° to 50°C

±(0.18% of setting + 0.8 mV), -55° to 85°C (-XT only)

V<sub>x</sub> FREQUENCY SWEEP FUNCTION: Switched outputs provide a programmable swept frequency, 0 to 2500 m square waves for exciting vibrating wire transducers.

CURRENT SOURCING/SINKING: ±25 mA

## RESISTANCE MEASUREMENTS

MEASUREMENT TYPES: Ratiometric measurements of 4- and 6-wire full bridges, and 2-, 3-, and 4-wire half bridges. Precise, dual polarity excitation for voltage excitations eliminates dc errors. Offset values are reduced by a factor of two when excitation reversal is used.

VOLTAGE RATIO ACCURACY<sup>6</sup>: Assuming excitation voltage of at least 1000 mV, not including bridge resistor error.

±(0.04% of voltage reading + offset)/V<sub>x</sub>

<sup>6</sup>Accuracy does not include the sensor and measurement noise. The offsets are defined as:

Offset for DF w/input reversal = 1.5-Basic Res + 1.0 µV

Offset for DF w/o input reversal = 3-Basic Res + 2.0 µV

Offset for SE = 3-Basic Res + 3.0 µV

## PERIOD AVERAGE

Any of the 16 SE analog inputs can be used for period averaging. Accuracy is ±(0.01% of reading + resolution), where resolution is 136 ns divided by the specified number of cycles to be measured.

## INPUT AMPLITUDE AND FREQUENCY:

Voltage Gain	Input Range (±mV)	Signal (peak to peak) <sup>7</sup>		Min Pulse Width (µV)	Max <sup>8</sup> Freq (kHz)
		Min. (mV)	Max (V)		
1	250	500	10	2.5	200
10	25	10	2	10	50
33	7.5	5	2	62	8
100	2.5	2	2	100	5

<sup>7</sup>With signal centered at the datalogger ground.

<sup>8</sup>The maximum frequency = 1/(twice minimum pulse width) for 50% of duty cycle signals.

## PULSE COUNTERS (P1-P2)

2 inputs individually selectable for switch closure, high frequency pulse, or low-level ac. Independent 24-bit counters for each input.

MAXIMUM COUNTS PER SCAN: 16.7x10<sup>6</sup>

## SWITCH CLOSURE MODE:

Minimum Switch Closed Time: 5 ms

Minimum Switch Open Time: 6 ms

Max. Bounce Time: 1 ms open w/o being counted

## HIGH-FREQUENCY PULSE MODE:

Maximum Input Frequency: 250 kHz

Maximum Input Voltage: ±20 V

Voltage Thresholds: Count upon transition from below 0.9 V to above 2.2 V after input filter with 1.2 µs time constant.

LOW-LEVEL AC MODE: Internal AC coupling removes AC offsets up to ±0.5 Vdc.

Input Hysteresis: 12 mV RMS @ 1 Hz

Maximum ac Input Voltage: ±20 V

Minimum ac Input Voltage:

Sine Wave (mV RMS)	Range(Hz)
20	1.0 to 20
200	0.5 to 200
2000	0.3 to 10,000
5000	0.3 to 20,000

## DIGITAL I/O PORTS (C1-C8)

8 ports software selectable, as binary inputs or control outputs. Provide edge timing, subroutine interrupts/wake up, switch closure pulse counting, high frequency pulse counting, asynchronous communications (UARTs), SDI-12 communications, and SDM communications.

HIGH-FREQUENCY MAX: 400 kHz

SWITCH CLOSURE FREQUENCY MAX: 150 Hz

EDGE TIMING RESOLUTION: 540 ns

OUTPUT VOLTAGES (no load): high 5.0 V ±0.1 V; low <0.1

OUTPUT RESISTANCE: 330 ohms

INPUT STATE: high 3.8 to 16 V; low -8.0 to 1.2 V

INPUT HYSTERESIS: 1.4 V

INPUT RESISTANCE: 100 kohm with inputs <6.2 Vdc  
220 ohm with inputs ≥6.2 Vdc

SERIAL DEVICE/RS-232 SUPPORT: 0 TO 5 Vdc UART

## SWITCHED 12 VDC (SW-12)

1 independent 12 Vdc unregulated source is switched on and off under program control. Thermal fuse hold current = 900 mA @ 20°C, 650 mA @ 50°C, 360 mA @ 85°C.

## CE COMPLIANCE

STANDARD(S) TO WHICH CONFORMITY IS DECLARED: IEC61326:2002

## COMMUNICATIONS

RS-232 PORTS:

9-pin: DCE (not electrically isolated) for battery-powered computer or non-CSI modem connection.

COM1 to COM4: Four independent Tx/Rx pairs on control ports (non-isolated); 0 to 5 Vdc UART

Baud Rates: selectable from 300 bps to 115.2 kbps.

Default Format: 8 data bits; 1 stop bits; no parity

Optional Formats: 7 data bits; 2 stop bits; odd, even parity

CS I/O PORT: Interface with CSI telecommunication peripherals

SDI-12: Digital control ports 1, 3, 5, and 7 are individually configured and meet SDI-12 Standard version 1.3 for datalogger mode. Up to ten SDI-12 sensors are supported per port.

PERIPHERAL PORT: 40-pin interface for attaching CompactFlash or Ethernet peripherals

PROTOCOLS SUPPORTED: PakBus, Modbus, DNP3, FTP, HTTP, XML, POP3, SMTP, Telnet, NTCIP, NTP, SDI-12, SDM

PROCESSOR: Renesas H8S 2322 (16-bit CPU with 32-bit internal core RUNNING AT 7.3 MHz)

MEMORY: 2 MB of Flash for operating system; 4 MB of battery-backed SRAM for CPU usage, program storage and final data storage.

RTC CLOCK ACCURACY: ±3 min. per year. Correction via GPS optional.

RTC CLOCK RESOLUTION: 10 ms

SYSTEM PROCESSOR: Renesas H8S 2322 (16-bit CPU with 32-bit internal core RUNNING AT 7.3 MHz)

MEMORY: 2 MB of Flash for operating system; 4 MB of battery-backed SRAM for CPU usage, program storage and final data storage.

RTC CLOCK ACCURACY: ±3 min. per year. Correction via GPS optional.

RTC CLOCK RESOLUTION: 10 ms

## SYSTEM POWER REQUIREMENTS

VOLTAGE: 9.6 to 16 Vdc

EXTERNAL BATTERIES: 12 Vdc nominal (power connection is reverse polarity protected)

INTERNAL BATTERIES: 1200 mAh lithium battery for clock and SRAM backup that typically provides three years of backup

TYPICAL CURRENT DRAIN:

Sleep Mode: 0.7 mA typical; 0.9 mA max.

1 Hz Sample Rate (1 fast SE meas.): 1 mA

100 Hz Sample Rate (1 fast SE meas.): 16.2 mA

100 Hz Sample Rate (1 fast SE meas. w/RS-232 communication): 27.6 mA

Optional Keyboard Display On (no backlight): add 7 mA to current drain

Optional Keyboard Display On (backlight on): add 100 mA to current drain

## PHYSICAL

DIMENSIONS: 23.9 x 10.2 x 6.1 cm (9.4 x 4 x 2.4 in.); additional clearance required for cables and leads.

WEIGHT (datalogger + base): 1 kg (2.1 lb)

## WARRANTY

3 years against defects in materials and workmanship.