THEME 1

NEW TECHNICAL DEVELOPMENTS IN THE FIELD OF AWS (SENSORS, NETWORKS, APPLICATION SOFTWARE, ETC.; MANUAL ENTRY OF OBSERVATIONS; EXPERIENCES WITH SOPHISTICATED SENSOR EQUIPMENT)

SWISSMETNET: RENEWAL OF THE SWISS METEOROLOGICAL NETWORKS

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Abstract

The Swiss Federal Office for Meteorology and Climatology (MeteoSwiss) has launched the SwissMetNet project for the renewal of its presently operational meteorological networks (subproject SDM) consisting of ANETZ (72 stations), ENET (44 stations) and KLIMA (25 stations). Furthermore, a new camera network (subproject CAM) will be installed consisting of 25 stations distributed around Switzerland to provide on-line information for now-casting information as well as for increasing the information potential concerning the aeronautical flight corridors over the Alps. Finally, an upgrade of the visual observation network (subproject OBS: 70 stations) will be performed by making use of modern computer techniques in order to increase the user-friendliness and therefore the quality of the observations.

Key words: Meteorological Camera Observation Network

1. HISTORY

The first automatic station of the ANETZ network was installed in Switzerland in 1975 and the last one in 1989. This means that the oldest station reaches today an operational period of more than 27 years.

For various reasons such as the difficulties in guaranteeing the renewal of the spare parts, a increasing old technology (field stations and central data acquisition station), a wear of the material, the lack of flexibility, an aging system of transmission of the data, etc, it was decided in 1998 to carry out an inquiry of the future requirements of the users and of the operators responsible for maintenance and correct operation of these networks. During the resulting numerous discussions, the need for a general concept became progressively obvious to work out a global strategy for MeteoSwiss concerning all the ground-based measurements for terrestrial and atmospheric meteorological information. This analysis was called "Messkonzept 2010" and was carried on in parallel of the project of renewal of the meteorological networks. Very quickly, it was recognized that:

- in the long term, all the networks of MeteoSwiss were to be renewed together with a total cleansing of the sites;
- only an integral and standardized renewal of the networks would make it possible to optimize the operational aspects, and to decrease the operational costs;
- MeteoSwiss had the possibility to offer its competences in this field to other institutions in charge of meteorological networks.

The direct consequence of these findings was an extension of the preliminary project (which took then the name of SwissMetNet) to all the existing meteorological networks. Moreover, the following decisions were made concerning the field of responsibility of this project:

- the visual observations were to be physically separated from the measuring sites, leading to the creation of a sub-project OBS;

- a new network of cameras for monitoring the atmospheric state was to be created, mainly to facilitate the task of the forecasters (sub-project CAM);
- a participation in the project EUMETNET/SWS " Severe Weather Sensors " would provide the necessary bases to proceed to the choice of the weather instruments installed on sites under very harsh conditions (sub-project SWS).

2. GOALS OF SWISSMETNET

The definitive goals of SwissMetNet were defined as following:

- Renewal of the automatic and conventional meteorological networks in Switzerland that are placed under the responsibility of MeteoSwiss (automatic backbone network ANETZ: 72 stations, automatic extended network ENET: 44 stations, “manual” climatic network KLIMA: 25 stations).
- In the future, and when suitable, take in charge other meteorological networks of the Confederation, Cantons, Communes and other partners to ensure their maintenance and operation (“Service provider”).
- Develop and put in operation a new network of 25 camera stations (either fixed or mobile).
- Separate the visual observations from the existing networks and develop a new stand-alone network for visual observations (70 stations) making use of the most modern technologies.
- Participate to the EUMETRNET/SWS experiment together with Finland and France.

3. INITIAL CONDIONS

3.1 General

The initial requirements for the project SwissMetNet were defined as following:

- Take into account the requirements of all the existing and potential users such as they were defined within the framework of Concept MK2010 ("Messkonzept 2010").
- Take into account the needs for modernization of the infrastructures and the operational processes according to requirements of the operators while carrying out the following objectives:
    - eliminate the recognized problems concerning the instruments and the operating procedures;
    - adapt the networks to modern technologies of the XXI century;
    - reduce the operational costs.

3.2 Configuration of the network

Following the recommendations yielded by the Concept MK2010, the following configuration of SwissMetNet was defined:

3.2.1. Stations

- 45 stations of type WEeather STAtion Westa B (basic climatological stations, high quality standards),
- 49 stations complementary stations of type WESTA S1 (identical WESTA B with reduced instruments’ configuration),
- 35 complementary stations of type WESTA S2 (simplified stations, reduced instrumentation),

- 70 visual observation stations of type WESTA O,
- 25 camera stations of type WESTA K.

3.2.2. Instruments

According to the Concept MK2010, the following criteria have to be applied:

- Preserve the instruments that give satisfaction.
- Replace the problematic instruments while preserving the quality of the existing long series of measurements by performing parallel measurements as far as possible.Prepare as far as possible the extension to new types of sensors in the future.

With regards to these requirements, the decision was made to partially renew the weather sensors equipping the automatic weather stations.

3.2.3. Data Acquisition Systems

Concerning the data acquisition systems, the following requirements of performances were selected, such as:

- Record and digitalize the signals produced by the instruments.
- Format and transmit the data to the Central stationPerform the needed computation to deliver physical values for local useStore locally the measurements (in the event of breakdown of transmission)Perform measurements concerning the state of the sensors and the station
- Initialize and transmit of meteorological or technical alarms.
- Guarantee the flexibility of the system and its user friendlinessWith regards to these requirements, the decision was made to completely renew the data acquisition systems of the automatic weather stations. In view of the volume of the task, the immediate consequence was that an international Call for Tenders following the rules of the World Trade Organization WTO would be mandatory.

3.2.4. Measurement fields

Concerning the stations' field facilities, the following recommendations were defined:

- The local data acquisition systems has to be installed on the field (unlike the setup of the old ANETZ where the loggers were installed in a nearby building).The infrastructure for the installation of the instruments has to be renewed (masts, towers, measurement bridges, etc.).
- A complete renewal of the cables and wirings is mandatory.
- An enhancement of the maintenance procedures is to be planed.

With regards to these requirements, the decision was made to proceed to the general cleansing of all the measurement fields of the automatic weather stations.

3.2.5. Transmission of the data

From the 1.1.2001, the Federal Office for Informatic and Telecommunications (FOITT) is responsible for all the transmissions within the Swiss Confederation. This new situation makes it possible to make use of the advanced technologies established and operationally used by the FOITT. For SwissMetNet, the following conditions were defined:

- Use of the BVnet ("BundesVerwaltungs Netz") network of the Confederation (FOITT).Installation of Cisco " routers " on the field facility in the Data Acquisition enclosure.
- TCP/IP Sessions between the measuring site and the Central station
- Availability and reliability of about 100%.

3.2.6. Central Server

The basic requirement for a standardization of the meteorological networks lead to the obvious conclusion that the WTO Call for Tenders should include the delivery of the central server, which would fulfill the existing requirements and make full use of the major improvements in the field of software and telecommunications.

4. CURRENT STATE OF THE SWISSMETNET PROJECT

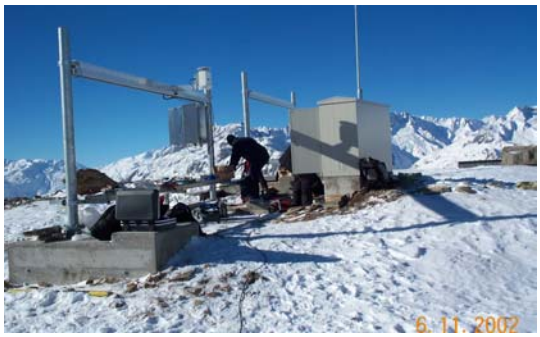
4.1 New automatic meteorological network (SDM)

At the end of year 2002, the SwissMetNet project has reached the following state.
A Preliminary Analysis phase was first launched in order to analyze the prevailing situation and to submit the different possibilities for the future network. A tentative budget planning was performed as well as the determination of the human resources needed. This preliminary phase ended in December 2000.
It was followed by a "Concept" phase where the specifications and requirements for the new network were defined, in order to launch the international WTO Call for Tenders (4.2.2002). The result of this action was then evaluated and a reduced number of potential manufacturers selected, whose offers went through a second detailed evaluation. The final decision was made on the 27.5.2002 with the selection of Almos Systems as supplier for the SwissMetNet. This ended the Concept Phase.

It was then possible to initialize the Realization phase that is dedicated to the testing of the offered hardware and software. This is presently being performed by proceeding to the installation of two pilot stations in plain (types WESTA B & S2 at Payerne) and of one pilot station in mountain (Guetsch, altitude 2300 m a.s.l.). This test period will give enough information to meet a final decision based on the results yielded by this pilot network, opening the way for the Introduction phase in July 2003.

Fig. 1 displays the installation of the Guetsch pilot station. As this site will be used in the future as a MeteoSwiss test station for harsh environment, the design has been extended in comparison with a "standard" B station. This may be seen with the installation of 2 measurement bridges to allow for the testing of numerous instruments and their references. A new type of mast, which can be kipped for the anemometer installation, can be spotted at the back of the picture. Furthermore, a new model of enclosure has been selected, which contains in separate compartments the power supplies, the data acquisition system (double units for the test station), the router, and the modem. A dedicated heating and ventilation system has also been designed to protect the latter sensitive elements. Finally, a full set of "house-keeping" measurement has been integrated in the system, allowing for an advanced remote diagnostic capability.

Fig. 1: Pilot station on the Guetsch, 2300 m a.s.l.



At the same time, the new central server has been installed at Zürich (standard version), so that the Acceptance Test procedures for the pilot network (2 pilot stations with a reduced set of measurements connected through the BVnet to the central server) could be performed at the end of November 2002, with full success.

4.2 New network of camera (CAM)

A preliminary analysis was concluded in January 2002, based on the evaluation by the clients (MeteoSwiss forecasters) of the pictures yielded by a test station installed at the International airport of Geneva and equipped with 3 types of cameras (fix, mobile and a "Total Sky Imager"). It was followed by a Concept phase where the definitive layout of the future network was defined as well as the procedures to be applied for the installation of totally new techniques for the MeteoSwiss staff. It was then decided that the Realization (pilot) phase had to deal with the following tasks:

- Installation of 5 pilot stations.
- Tests of the use of mobile cameras for the reconstruction of panoramic sights.
- Tests of the quality of transmission of multiple pictures through the BVnet.
- Installation of a Central Picture Acquisition server.Dissemination / Storing of the pictures (Internet, Data Base).

At present time, the installation of 3 pilot sites has been performed at Martigny (mobile camera), San Chrischona (mobile camera) and Murtel (fix camera), the latter being also used for the World Ski Championships that will take place in February 2003 at St. Moritz. The time resolution of the pictures is 10 minutes with the first set of 6 pictures for 360 degrees azimuth and a camera-elevation of 0 degree and the second set of 6 pictures for 360 degrees azimuth and a camera-elevation of 45 degrees. The detailed specifications for the central server are being presently prepared.

From the available sites, the following preliminary conclusions can be drawn:

- The use of mobile cameras is possible even under harsh conditions. The problem concerning the degradation of the pictures' quality due to rain or snow can be avoided by integrating the cameras in a dedicated heated enclosure. Furthermore, as the time resolution of the pictures is 10 minutes, the camera (mobile) is positioned in between in such a way that the protective window is oriented towards the ground. This seems to give very good results, taking into account that the use of wipers under harsh meteorological conditions induces more problems than solutions.

- The use of mobile cameras for reconstructing panoramic views gives good results, though the orientation dependence of the luminosity remains problematic.
- The use of the BVnet for the data transmission has proved very reliable.

4.3 Visual observations (OBS)

A Preliminary Phase was conducted in November 2001 based on the evaluation by the clients and the experiences gathered with the current system. It was followed by a Concept phase ending in July 2002 that took into account the following goals:

- Physical separation of the visual observations of the automatic weather stations.
- User-friendly tool for the observers.
- Use of available and implemented IT-structure (database, plausibility checks, etc.).
- Lowering the operational costs.

Based on these requirements, the following tasks are to be achieved during the ongoing Realization phase:

- The OBS-Clients are developed based on browser technology without a local intelligence. The whole intelligence is located on the central system (measuring program, plausibility checks, context-data, etc.). Information like stored pictures of clouds is available locally.
- The GUIs for the observers are set up dynamically, based on information provided by the central system.
- The data transmission is performed via modem and ISDN-terminal, based on a Remote Access Server, to reach a high security standard.
- The observations are collected online. Tests on limits are made immediately while tests on consistency and variability are performed at the end of each session.
- The dedicated software is developed in-house.
- The Realization phase is split into a “Proof of Concept” (detail-specification, performance, user guidance, security aspects, availability, etc.) and a pilot phase to implement the new tool at several pilot sites.

4.4 EUMETNET/Severe Weather Sensors (SWS)

The EUMETNET[1] project "Specification of Severe Weather Sensors 1997-1998" summarized the icing effects on different types of meteorological sensors. Following the first SWS project, the SWS II project was started by the EUMETNET in July 2000 in order to test a number of ice-free sensors, as well as other measurement arrangements designed for cold climate conditions. Three different sites in Finland, France, and Switzerland were selected for this purpose. For more details see ICEAWS-2003 paper of Tammelin et al.. The final report of the project is expected to be ready by the end of the year 2002.

The objective of the project is to systematically test and analyze ice-free instruments (humidity, temperature, wind speed, wind direction, ventilation/heating of solar radiation instruments) under harsh icing conditions to produce representative data for scientific studies:

- for inter-comparison of ice-free sensors used or preferred by EUMETNET members;
- for information on errors and the amount of heat needed for sensors to be ice-free;

[1] EUMETNET is a network of 18 National Meteorological Services: those of the EU plus Iceland, Norway and Switzerland; www.eumetnet.eu.or

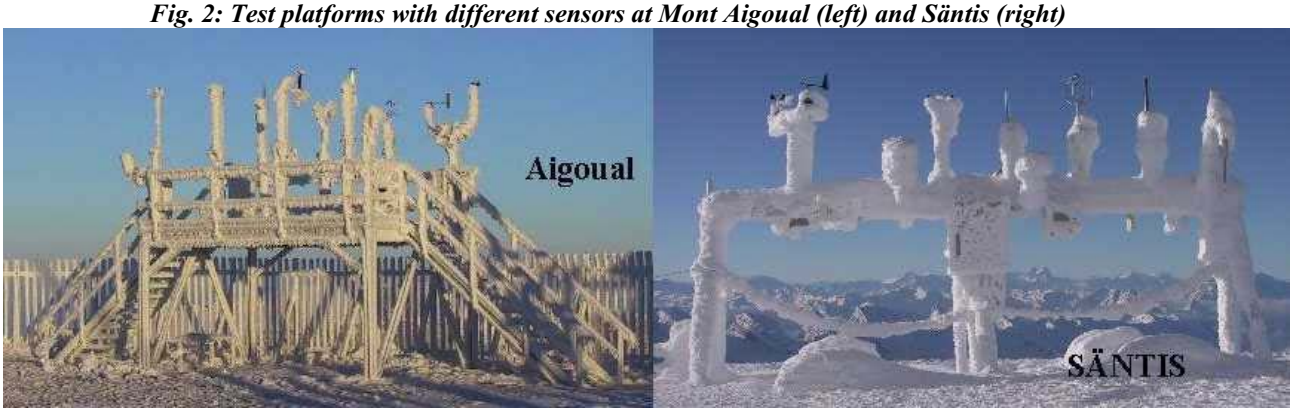
- for establishing the basic procedures to develop a network providing certification for sensors that are free of icing problems.

Test sites

The three test sites are located in different parts of Europe under various types of cold climate and icing conditions. All these sites are within areas of heavy or strong atmospheric icing (with number of icing days more than 15 d/y and high wind speeds). However, in the far north the winter days are short with very little solar radiation to melt the ice, while closer to the Mediterranean daily solar energy significantly reduces the amount of ice upon sensors (depending e.g. on the size, shape and color of the sensors) but also affects the structure of ice. One reason to have the test sites at such places is to have enough events with atmospheric icing for representative analyses of icing effects upon sensors and measurements under different climatic conditions.

The Mont Aigoual station, which is part of the basic network of MétéoFrance, is located on the top of Mont Aigoual (altitude 1567 m a.s.l., 44º07´N, 03º35´E). The MeteoSwiss test station at Säntis is close to a standard MeteoSwiss weather station and is located at an altitude of 2490 m a.s.l. (47º15´N, 9º20´E). The FMI test station is located in northern Finland north of the Polar circle on the top of Luosto fell at 515 m a.s.l. (68º08´N, 26º54´E). At each site a platform for sensors was built (see following picture). Each station is equipped with automatic data acquisition system providing 10 minutes averages and standard deviations. Mont Aigoual and Säntis are manned stations where the observers also frequently take photos of the status of the sensors (Fig. 2). Luosto is a fully automatic station where the status of sensors is monitored by three properly heated (ice-free) video cameras.

Fig. 2: Test platforms with different sensors at Mont Aigoual (left) and Säntis (right)



Sensors tested

The sensors to be tested during the winter 2001/02 at various sites were chosen according to the interest of the EUMETNET members. They were finally selected at the SWS II workshop held in Paris in June 2001. Thus some wind sensors known to be ice-free but not able to meet the WMO required accuracy of measurements especially at mountainous sites (where the vertical wind component affects strongly the measurements) were excluded from the experiment.

Measurement of icing is not actually included in the SWS II project, but as information of rime/ice accretion is required for other analyses, some ice-detectors and observation methods were also tested. According to results from the test period 2000/2001 it was decided that

ice/rime upon sensors was not to be removed by observers during the test period. Thus, apart from special cases, all sensors were performing as if located at an automatic weather station.

Number of icing days, intensity of ice accretion and type of icing varies between the three sites. In South solar radiation helps to remove the ice, but also turns rime to clear ice due to melting and icing, while in North solar radiation has no effect in November-February.

According to the amount of ice upon sensors (body, shaft, cups etc.) the severity of icing upon each sensor is divided into four classes: 0 = totally clear, 1 = presence of icing, not affecting the measurements, 2 = presence of icing, probably affecting the measurements, 3 = totally blocked. At Luosto, these analyses were based on continuous video monitoring. At Säntis the observer performed the classification 7 times a day, and at Mont Aigoual, it was based on photos taken by the observer during icing events.

The reference sensors at all three sites were chosen to be Rosemount Model 1774W for wind speed and wind direction, and the Thermo-hygrometer THYGAN for temperature and humidity measurements: these “relative” reference instruments were seen to operate most correctly at all three sites also during heavy icing. All other sensors were compared to these reference sensors, using data measured during the non-icing periods as reference “calibratio”.

COMPARISON OF VISIBILITY MEASUREMENTS WITH ROUTINE VISUAL OBSERVATIONS IN THE NETHERLANDS

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Abstract

Since November 2002 KNMI uses sensors in combination with algorithms to generate fully automatically the visual observations of hourly synoptic and climatological reports. KNMI uses a forward scatterometer to measure visibility. These sensors have been operated at several synoptic stations and airports throughout the Netherlands since early 2000. This paper gives a comparison of observed routine visibility reports with corresponding measurements using data of several stations for the years 2000 and 2001. The comparison generally shows good overall agreement. However, differences occur that are mainly the result of differences in location or reporting rules. This paper also focuses on fog events and investigates the effects of precipitation and darkness.

Key words: *visibility, observations, measurements, automation*

1. INTRODUCTION

The meteorological information on the present state of the atmosphere is described by routine hourly synoptic reports, so-called SYNOPs, and climatological reports (KLIMs). The observations of wind speed and direction, temperature, humidity, pressure, and precipitation amount are performed fully automatic at KNMI stations for more than a decade and hence the reports show (processed) sensor values. At some locations, an observer adds the so-called visual observations consisting of visibility, cloud amount and height and a description of the present and past weather to the report. Sensors can be used in combination with algorithms to generate automated visual observations. Since the beginning of 2000 KNMI operates cloud ceilometers and so-called present weather sensors at several stations throughout the Netherlands. In combination with a lightning detection system the sensor information is processed and used to generate fully automated reports including the visual observations. For about 2-years the automated system has been operated parallel to a manned station. The performance of the automated system was also monitored off-line at several other stations. The comparison has resulted in some improvements to the automated system. Since 2001 an existing station was upgraded to an automated visual station and in 2002 the manned station at De Bilt was automated. Since the introduction of the new measurement network of KNMI (including 2 Naval airbases) in November 2002 ALL synoptic and climatological reports are generated fully automatically. KNMI employs observers/forecasters only at airports, but they only make visual observations for aeronautical reports. In 2003 the meteorological systems of the Dutch Royal Airforce will be upgraded. This will result in a fully automated synoptic measurement network in the Netherlands.

A description of the new meteorological measurement network of the Netherlands is available elsewhere (Wauben et al., 2002). Details on the sensors and algorithms that KNMI uses for the automated visual observations can also be found in the literature (Wauben, 2001) as well

as information on the performance regarding cloud and weather observations (Wauben 2002a and b). Visibility is considered in more detail in this paper.

2. VISIBILITY OBSERVATIONS

The observer performs the routine visual observations at about 5 to 10 minutes before the hour. For that purpose, he (or she) goes outside and has a look around. The visibility is defined as the maximum distance that a black object of suitable dimensions can be seen near the horizon. During daylight an observer can determine this using visibility markers at know distances. In situation with low light levels, i.e. during twilight and at night, lights are used as reference points by the observer. The reported value is the lowest visibility in any direction. The hourly synoptic values of the visibility are reported in the VV-code. The VV-code reports the visibility in steps of 100m for values up to 5km (VV=0 to 49), steps of 1000m for values between 5 and 35 km (VV=50, 56 to 80), steps of 5000m between 35 and 70km (VV=81 to 88), and all values equal to and larger than 70km are reported as VV=89. The visibility is always rounded down to the nearest VV value. The reported visibility depends on the availability of markers, the contrast between the object and the background, the intensity of the lamp and also depends on the sensitivity of the observers' eye. In practice, the observation is mostly performed from a tower or building, although the WMO regulations state that it should be performed from the observation field. At most locations the observer has access to the sensor readings of visibility.

The visibility is related to the amount of extinction of the light between object and observer. The amount of extinction, which is directly related to the so-called meteorological optical range (MOR), can be obtained by measuring the reduction of the intensity of a light beam over a known distance. Such a measurement is performed by so-called transmissometers (TMM). KNMI operates TMMs only along runways at most airports. The TMMs give accurate MOR values, but they are sensitive to contamination and their visibility range is limited. The first problem can be overcome by contamination compensation algorithms or by regular maintenance. The latter disadvantage can be solved be using several TMMs with different baselines. For synoptic purposes, and recently also for aeronautical use, KNMI employs so-called scatterometers to measure MOR. The amount of radiation scattered by a volume of air is assumed to be proportional to amount of extinction of a light caused by the same volume of air. The accuracy of scatterometers is less than that of the TMMs, but they are within the WMO and ICAO requirements. Concerning the range and the sensitivity to contamination scatterometers have better characteristics than transmissometers. KNMI uses the Vaisala FD12P Present Weather Sensor (PWS), which apart from MOR also gives precipitation type and amount. The PWS is also equipped with a background luminance unit facing North. The PWS is generally located at the synoptic observation field of the station. The PWS sampling volume is only $0.1dm^3$ and is at a height of about 1.5m. For synoptic purposes KNMI decided to use MOR, although MOR in combination with the background luminance and assuming a lamp of 100cd can be used to calculate the background luminance corrected visibility. The 1-minute sensor values of MOR are averaged over 10 minutes. The averaged MOR value between 10 and 0 minutes before the hour is considered the sensor value of the visibility.

3. COMPARISON FOR DE BILT 2000

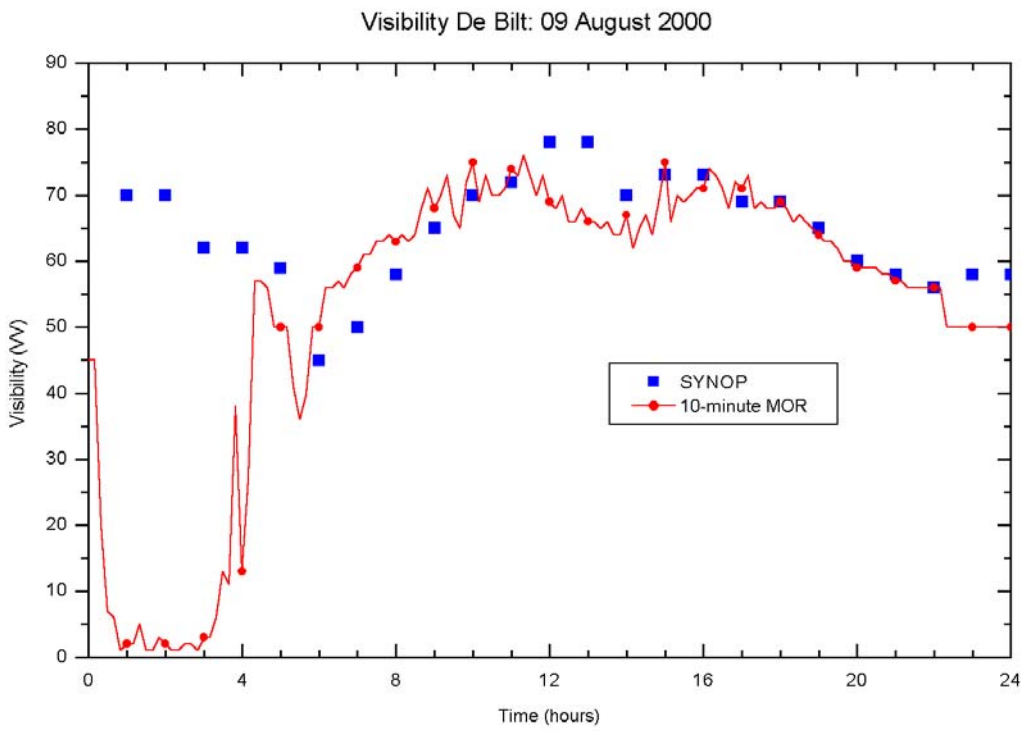
In this section the observed and measured visibility at De Bilt for 2000 is discussed in detail. The observer at De Bilt is situated on the third floor of the main building of KNMI. During

the visual observations the observer can go on the roof one floor above at a height of about 15m. The sensor is located at the observation field about 200m from the main KNMI building. The visibility of the observer (OBS) and sensor (PWS) is either given in the WMO code (VV) or in meters (VIS). Unless mentioned otherwise the 10-minute averaged MOR value of the sensor from 10 minutes before to the full hour is considered the PWS value.

3.1 Example of a selected day

The observed and measured visibility values can be compared directly. The results for a selected day are shown in Fig 1. The figure shows the observed hourly visibility value in the VV-code (blue squares) and the 10-minute averaged values of the sensor (red line). A red dot indicates the 10-minute sensor value at the full hour that is compared to the observed value. Figure 1 shows an example of a day were the results are close, except for some hours during the night, where the observer missed the fog detected by the sensor. The differences are mostly the results of differences in the observing practices. An observer is located at a tower and reports the lowest visibility around. The area of the lowest visibility may not include the location of the sensor. Because of the higher position of the observer will generally have a better visibility than close to the surface. The reported values are based on visibility marks and during darkness the observation can be restricted to the regions with sufficient lighting and/or marks. The sensor is situated at a fixed location and only reports the value at that location. The sensor has no bias between day/night situations.

Figure 1. Comparison of observed and measured visibility for De Bilt on August 9, 2000.



A general overview of the comparison between observer and sensor can be given in various ways. Each presentation method has its own merits and the best choice depends on the purpose. The presentations considered in this paper are given in the following sub-sections. In all cases the comparison is restricted to the cases that both observed and measured visibility

are available. The sensor values are sometimes missing because of problems with the acquisition of the results or periods when the sensor was not in use.

3.2 VV contingency matrix

The visibility values in VV-code can be grouped in order to get a reasonable size of a contingency matrix. Such a table is given for De Bilt 2000 in Table 1. The table gives the number of hours with observed and sensor values in the indicated range. Note that the indicated range is the upper visibility boundary of the bin, the lower boundary is the given be the entry above (to the left). The selected boundaries 100m, 200m, 500m, 1km, 2km, 5km, 10km and 20km form more a less a logarithmic scale. Table 1 shows that most entries are near the diagonal of the matrix. However, situations do occur where observer and sensor visibility give considerable differences. Situations where the sensor reports much lower values than the observer occur more often than vice versa. The reason for the differences has been mentioned above. In fact, the situation on 9 August 2000 accounts for 3 of the 5 entries with observed value between 10-20km and sensor value between 200 and 500m. A general measure of the agreement between observer and sensor visibility can be given by the fraction of entries were both agree, i.e. the fraction of entries on the diagonal. In Table 1 the percentage of events on the diagonal (DIAG) is 67%. However, this number strongly depends on the choice of the visibility ranges. Also, 2 values close to one another, but just at opposite sides of a boundary would be counted as wrong. Calculating the average difference between the observed and sensor in the original VV-code table gives a better measure of the quality. In that calculation the non-existence of VV-codes 51 to 55 is taken into account. The averaged value of the differences (VVobs-VVpws) is 3.5, i.e. the observer on average gives a VV-value that is about 3 VV-units higher. The averaged value of the absolute values of the differences abs(VVobs-VVpws) is 5.4 and indicates the average difference in the original VV table with 90 bins.

Table 1. Measured versus observed visibility contingency matrix for De Bilt 2000.

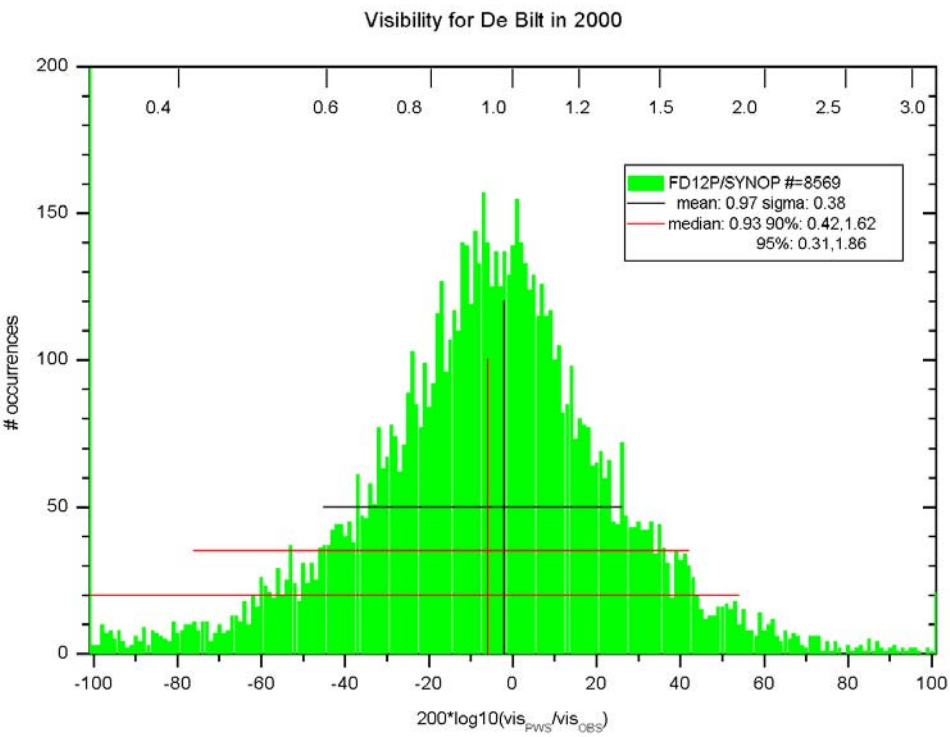
	Visibility at De Bilt in 2000, PWS										
OBS	*NA*	*<100m*	*<200m*	*<500m*	*<1km*	*<2km*	*<5km*	*<10km*	*<20km*	*≥20km*	*all*
NA	0	0	0	0	0	0	0	0	0	0	0
<100m	0	4	4	1	0	0	0	0	0	0	9
<200m	1	1	13	5	0	1	0	0	0	0	21
<500m	1	0	7	19	16	5	0	0	0	0	48
<1km	1	0	8	9	26	12	3	0	0	0	59
<2km	3	0	2	7	15	119	32	1	0	0	179
<5km	42	1	9	19	25	111	711	127	8	1	1054
<10km	45	0	3	7	8	27	295	1098	140	5	1628
<20km	39	0	3	3	15	14	84	622	1425	178	2383
≥20km	83	0	0	8	3	6	24	105	1012	2162	3403
all	215	6	49	78	108	295	1149	1953	2585	2346	8784

3.3 Distribution of visibility ratio

The differences between the observed and measured visibility can also be studied by considering their ratio VISpws/VISobs. By considering the ratio, the effect of the varying VV bin size is eliminated. Figure 2 gives the frequency distribution of the relative differences.

The vertical axis shows the number of events in a relative difference bin. The horizontal axis shows the relative difference bins. Note that the relative difference is plotted as 200*log(VISpws/VISobs) to get a more or less symmetric shape of the differences around zero and a good view of the details. In order to get an indication of the corresponding relative differences the position of some specific ratios is given at the top of the figure. The bins -101 and 101 contain the entries with differences outside the range. The frequency distribution has more or less a symmetric shape around zero. However, large negative values occur more often than positive value. Also note the 271 entries at –101 compared to 21 entries at 101. The results of this figure can be summarised by a mean difference of the ratio VISpws/VISobs of 0.97 with a standard deviation of 0.38. Since the distribution is not exactly Gaussian the summary can better be given as a median of 0.93 and 90% level between 0.41 and 1.62 (thus 5% of the events are below a ratio of 0.41and 5% above 1.62). The 95% levels are at ratios 0.31 and 1.86. The mean and median and their widths are gives by the vertical and horizontal lines in Fig. 2.

Figure 2. Distribution of measured versus observed visibility ratio for De Bilt 2000.

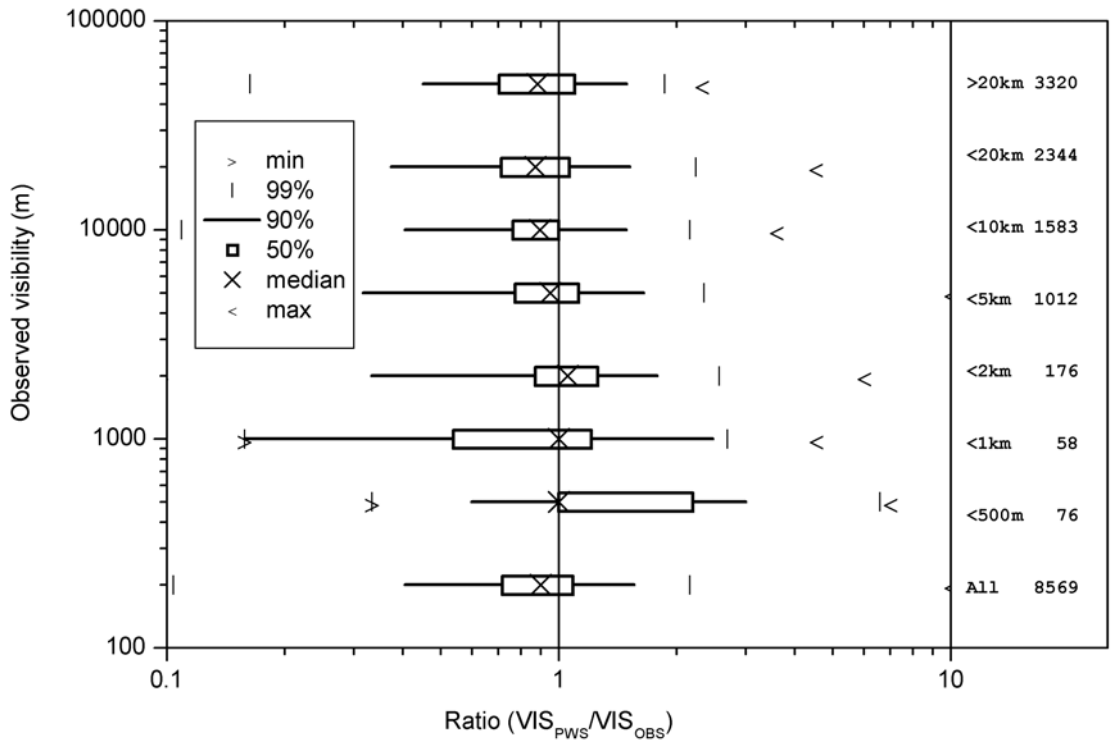


3.4 Box plot

A scatter plot does not give an elegant overview due to the large number of VV bins. Therefore, the VV bins are grouped like in the contingency matrix and the results are presented in a so-called box plot (see Fig. 3). The box plot shows the position of several parameters for the ratio PWS/OBS in each interval in a logarithmic scale. The results for the different observed visibility intervals are plotted at the corresponding log(VIS) level of the upper boundary. Since the statistics below 500m is rather poor these bins are combined in one. The lowest entry shows the parameters for the full visibility range. The upper boundaries and number of entries in each visibility range are indicated on the right hand side of the

figure. For each interval the box plot shows (if within the ratio range): the minimum ratio (denoted by “>”); the range containing 99% of the entries (first and second “|” denote ratio with 0.5% of the entries below and above, respectively); the range containing 90% of the entries (denoted by “-”); the range containing 50% of the entries (denoted by “ ”); and the median value (denoted by “X”).

Figure 3. Box plot of measured versus observed visibility ratio for De Bilt 2000.



3.5 Fog contingency matrix

The comparison of a specific event, such as the report of fog (VIS<1km), between observer and sensor can be given by a 2-by-2 contingency matrix denoted by the yellow squares in Table 1. The 4 regions of the table are (H) a hit if OBS and PWS agree that fog is present, (N) no fog reported by OBS and PWS, (M) a miss if OBS gives fog but PWS not, and (F) a fault when OBS gives no fog but PWS does. These regions are given in Table 2. The agreement can then be expressed in scores defined in Table 2. The fog cases of De Bilt 2000 have a probability of detection (POD) of 78.8%, the false alarm rate (FAR) is 50.6%, and the critical success index (CSI) is 43.6%. The rather poor score of fog is mainly a result of the differences in observing practices. An observer reports fog if the visibility is below 1km anywhere in the surroundings, the sensor only report fog if the 10-minute averaged value is below the limit. On the other hand the observer does not report fog close to the ground. The bias in the fog contingency matrix is 1.60 and the correlation coefficient is 0.62.

Table 2. Measured versus observed fog contingency matrix.

2-by-2 contingency matrix

		PWS	
	Event	*yes*	*no*
OBS	*yes*	H	M
	no	F	N

Scores

Probability Of Detection (POD) = 100*H/(H+M)
Fals Alarm Rate (FAR) = 100*F/(F+H)
Critical Succes Index (CSI) = 100*H/(H+M+F)
Bias = (H+F)/(H+M)
Correlation coefficient (CC) = (HN-MF)/sqrt[(H+M)(H+F)(N+M)(N+F)]

3.6 Overview and performance under specific situations

Table 3 shows an overview of the results of the various comparison between measured and observed visibility discussed in the previous sections for De Bilt 2000. The previous results are summarised in the column marked MOR. The column Vis gives the scores for the background luminance corrected MOR. The difference between MOR and Vis is generally very small except in situations with a low MOR and low background luminance. In those situations Vis is larger than MOR. Table 3 shows that the overall performance of MOR and Vis is nearly the same, but the number of fog cases reported is 10% less fr Vis. The 10% reduction is equally distributed between correctly and falsely reported fog events. The bias between measured and observed fog cases is less for Vis compared to MOR.

Table 3 also shows the performance of measured MOR versus observed visibility for day and night situations separately. Daytime cases are defined as situations where the background luminance measured by the PWS is above 10cd/m^2. During daytime the overall agreement is much better than at night. The detection of fog is better at night than during daytime, but at the expense of a large increase in false alarms. The CSI and the bias for fog detection are better during daytime than at night. The ratio of measured and observed visibility is generally less than one, meaning that the PWS reports on average smaller values. During daytime this ratio is closer to unity.

Finally, Table 3 contains in the last 2 columns the scores for dry and wet events. The precipitation events, denoted by wet, are the cases where the precipitation intensity reported by the PWS is larger than 0mm/h. able 3 shows that in dry situations the PWS in general reports lower visibilities than the observer, whereas in wet cases the PWS reports higher visibilities. In case of precipitation the PWS subtracts the precipitation signal from the scattered signal. The effect of precipitation on extinction and scattering is different and furthermore depends on the type and size distribution of the precipitation particles. The correction to be applied by the PWS is therefore not straightforward.

Table 3. Overview of performance of measured versus observed visibility for De Bilt 2000.

Parameter	MOR	Vis	Day	Night	Dry	Wet
Total # cases	8569	8569	4606	3963	7155	1414
DIAG	65%	65%	71%	58%	65%	65%
(VVobs-VVpws)	3.5	3.2	1.4	5.8	3.9	1.2
abs(VVobs-VVpws)	5.4	5.3	4.4	6.6	5.5	5.0
Mean/Std ratio	0.94/0.40	0.95/0.45	1.01/0.42	0.85/0.38	0.91/0.37	1.06/0.53
Median ratio	0.90	0.91	0.95	0.84	0.88	1.00
50% ratio	0.72/1.09	0.73/1.11	0.78/1.15	0.64/1.00	0.71/1.07	0.78/1.20
90% ratio	0.41/1.56	0.42/1.58	0.56/1.67	0.27/1.46	0.37/1.49	0.52/1.83
Number fog hits	113	96	43	70	107	6
POD fog	84.3%	71.6%	72.9%	93.3%	87.7%	50.0%
FAR fog	53.1%	45.5%	31.7%	60.7%	53.1%	53.8%
CSI fog	43.1%	44.9%	54.4%	38.3%	44.0%	31.6%
BIAS fog	1.80	1.31	1.07	2.37	1.87	1.08
CC fog	0.62	0.62	0.70	0.60	0.63	0.48

4. COMPARISON FOR OTHER STATIONS

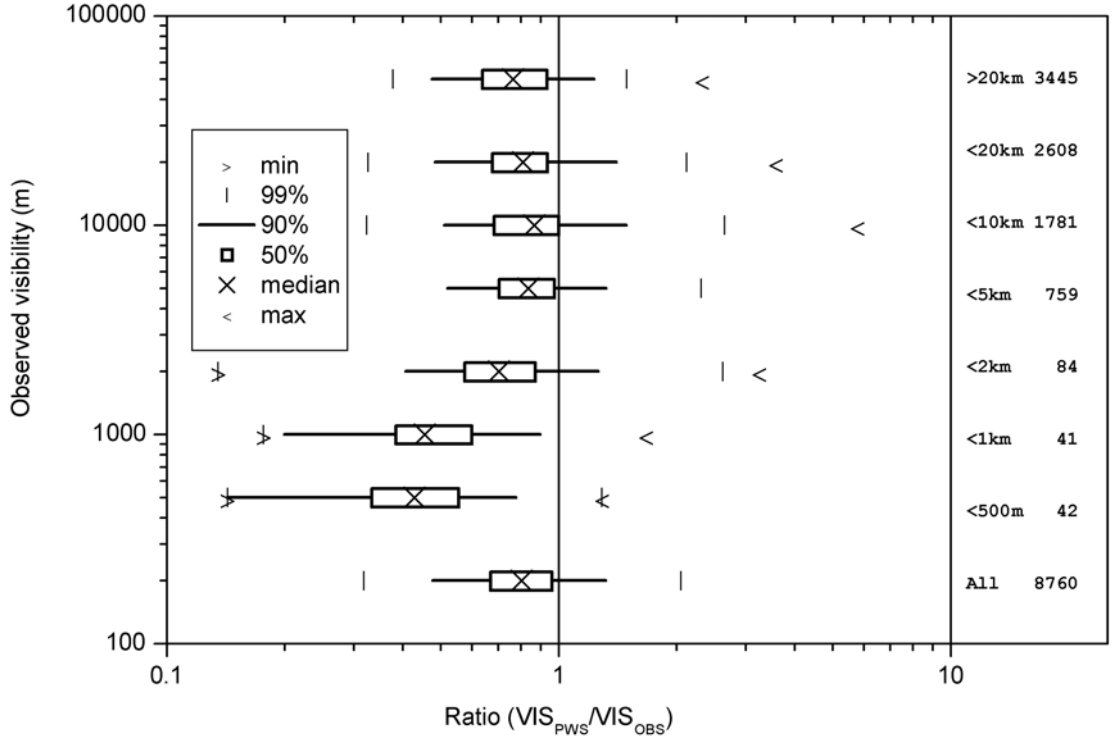
4.1 Results for Amsterdam Airport Schiphol 2000

In this section the results for observed and measured visibility at Amsterdam Airport Schiphol for 2000 are given. Schiphol is a 5-runway airport where the observer is situated in a tower at an altitude of about 40m and the observation field is located at a distance of about 4km. Furthermore, the observer has access to 15 TMM readings situated along the runways in an area with a radius of about 5km around the observer.

Table 4. Measured versus observed visibility contingency matrix for Schiphol in 2000.

	Visibility at Schiphol in 2000, PWS										
OBS	NA	<100m	<200m	<500m	<1km	<2km	<5km	<10km	<20km	≥20km	all
NA	0	0	0	0	0	0	0	0	0	0	0
<100m	0	0	0	0	0	0	0	0	0	0	0
<200m	0	0	0	0	0	0	0	0	0	0	0
<500m	0	9	22	11	0	0	0	0	0	0	42
<1km	0	0	3	27	10	1	0	0	0	0	41
<2km	0	0	0	4	29	43	8	0	0	0	84
<5km	2	0	4	3	2	109	590	41	8	2	761
<10km	10	0	4	1	2	6	420	1203	119	26	1791
<20km	7	0	3	2	0	2	28	881	1532	160	2615
≥20km	5	0	0	1	0	1	8	45	1378	2012	3450
all	24	9	36	49	43	162	1054	2170	3037	2200	8784

Figure 4. Box plot of measured versus observed visibility ratio for Schiphol 2000.



The visibility contingency matrix and the box plot for Schiphol 2000 are given in Table 4 and Fig. 4, respectively. Compared to the results for De Bilt, the PWS visibilities are even lower compared to the observed values. This is particularly the case for visibility values for below 2km. The deviation around 1km visibility, which is characteristic for all airports compared to other stations, disappears if the box-plot is made using background luminance corrected visibility of the PWS. The reason is probably twofold. First, the illumination levels at airports during night will generally be higher compared to other stations. Secondly, for airport practices the background illumination corrected visibility is used whereas for synoptical purposes MOR is prescribed. This difference is also reflected on the presentation screens. Moreover, the availability/use of TMM readings at airports, especially for the low visibility range, might play a role.

An overview of the performance for Schiphol 2000 is given in Table 5. It shows the same behaviour when a distinction between day/night and dry/precipitation situations is made as for De Bilt. A noticeable difference between De Bilt and Schiphol are the scores for fog events. These are generally better for Schiphol compared to the scores for De Bilt (cf. Table 3).

Table 5. Overview of performance of measured versus observed visibility for Schiphol 2000.

Parameter	MOR	Vis	Day	Night	Dry	Wet
Total # cases	8760	8760	4730	4030	7380	1380
DIAG	62%	63%	69%	53%	61%	67%
(VVobs-VVpws)	4.4	4.2	3.0	6.1	4.8	2.1
abs(VVobs-VVpws)	5.0	4.9	4.3	5.9	5.2	4.3
Mean/Std ratio	0.84/0.34	0.85/0.34	0.89/0.37	0.78/0.30	0.81/0.31	1.00/0.45
Median ratio	0.80	0.81	0.84	0.75	0.78	0.91
50% ratio	0.67/0.96	0.68/0.97	0.71/1.00	0.61/0.91	0.65/0.93	0.77/1.11
90% ratio	0.48/1.32	0.49/1.32	0.55/1.39	0.43/1.24	0.47/1.23	0.56/1.77
Number fog hits	82	80	30	52	78	4
POD fog	98.8%	96.4%	100.0%	98.1%	98.7%	100.0%
FAR fog	40.1%	27.3%	28.6%	45.3%	39.5%	50.0%
CSI fog	59.4%	70.8%	71.4%	54.2%	60.0%	50.0%
BIAS fog	1.65	1.33	1.40	1.79	1.63	2.00
CC fog	0.77	0.84	0.84	0.73	0.77	0.71

4.2 Results for other stations in 2000 and 2001

Table 6. Overview of visibility performance for several stations in the Netherlands in 2000.

Parameter	De Bilt	Schiphol	Rotterdam	Eelde	Beek	De Kooij*	Vlissingen**
Total # cases	8569	8760	8185	7989	7987	5641	2173
DIAG	65%	62%	64%	80%	80%	68%	42%
(VVobs-VVpws)	3.5	4.4	3.3	1.4	1.9	1.2	6.0
abs(VVobs-VVpws)	5.4	5.0	4.5	2.9	2.6	4.7	6.6
Mean/Std ratio	0.94/0.41	0.84/0.34	0.89/0.38	0.96/0.35	0.92/0.20	1.03/0.43	0.77/0.40
Median ratio	0.90	0.80	0.87	0.95	0.93	1.00	0.69
50% ratio	0.72/1.09	0.67/0.96	0.71/1.00	0.83/1.00	0.81/1.00	0.78/1.19	0.56/0.88
90% ratio	0.41/1.56	0.48/1.32	0.46/1.39	0.60/1.32	0.62/1.20	0.53/1.77	0.42/1.32
Number fog hits	113	82	163	148	59	42	18
POD fog	84.3%	98.8%	95.9%	91.4%	90.9%	100%	94.7%
FAR fog	53.1%	40.1%	34.0%	31.8%	41.2%	44.7%	5.3%
CSI fog	43.1%	59.4%	64.2%	64.1%	55.6%	55.3%	90.0%
BIAS fog	1.80	1.65	1.45	1.34	1.55	1.81	1.00
CC fog	0.62	0.77	0.79	0.78	0.73	0.74	0.95

* PWS De Kooij was installed in May 2000. ** PWS Vlissingen was installed in September 2000.

The overview of the performance for several stations throughout the Netherlands are given in Tables 6 and 7 for the years 2000 and 2001, respectively. De Bilt is the central location of KNMI in the centre of the Netherlands; Schipol is a large airport and Rotterdam a regional airport both in the Western part of the Netherlands; Eelde and Beek are regional airports in respectively the SE and NE; Vlissingen and the naval airbase De Kooij are coastal stations in respectively the SW and NW of the Netherlands. The overview shows: the regional airports Eelde and Beek have the narrowest distributions; the airports show the best agreement for fog detection; De Kooij, an airbase with one PWS and no TMM, more resembles the synoptic stations; De Kooij is the only station where the PWS reports on average larger visibility values than the observer.

Table 7. Overview of visibility performance for several stations in the Netherlands in 2001.

Parameter	De Bilt	Schiphol	Rotterdam	Eelde	Beek	De Kooij	Vlissingen
Total number	8671	8745	8626	8714	8717	8731	8727
DIAG	68%	61%	60%	79%	81%	67%	54%
(VVobs-VVpws)	2.8	4.3	4.7	1.2	1.6	0.9	4.1
abs(VVobs-VVpws)	5.1	5.4	5.6	3.1	2.6	4.8	5.8
Mean/Std ratio	0.98/0.45	0.86/0.43	0.85/0.36	0.97/0.34	0.94/0.22	1.06/0.57	0.88/0.48
Median ratio	0.93	0.78	0.83	0.96	0.93	1.00	0.81
50% ratio	0.76/1.12	0.65/0.97	0.65/1.00	0.83/1.04	0.84/1.00	0.77/1.19	0.61/1.00
90% ratio	0.41/1.59	0.47/1.40	0.41/1.40	0.57/1.39	0.62/1.24	0.53/1.86	0.41/1.52
Number fog hits	204	117	151	296	194	195	107
POD fog	81.6%	92.1%	96.2%	95.2%	98.0%	87.1%	85.6%
FAR fog	34.0%	32.8%	49.0%	28.0%	26.2%	22.9%	13.7%
CSI fog	57.5%	63.6%	50.0%	69.5%	72.7%	69.1%	75.4%
BIAS fog	1.24	1.37	1.89	1.32	1.33	1.13	0.99
CC fog	0.73	0.78	0.69	0.82	0.85	0.81	0.86

5. CONCLUSIONS

Measured and observed MOR values generally show good overall agreement. However, differences occur that are mainly the result of differences in location (sensor at typically measures at a height of 1.5m and the observer at 15m) or reporting rules (sensor reports 10-minute averaged value, an observer the lowest observed value around). The results for 2000 and 2001 are generally the same, but show some differences that are the result of different weather conditions between 2000 and 2001. The differences between the stations are the result of local conditions, the set-up, and practises. Table 8 shows the results for Lelystad Airport where 2 PWS' are located along the runway. The results give an indication of the differences that occur for 2 identical sensors separated by about 1km. It should be noted that in addition to the hourly reports, KNMI also provides every 10minutes sensor data of all stations to the users.

Table 8. Overview for 2 PWS sensors at Lelystad 2001.

Parameter	PWS 1 vs. 2
Total # cases	8083
DIAG	89%
(VVobs-VVpws)	-0.4
abs(VVobs-VVpws)	1.7
Mean/Std ratio	1.05/0.49
Median ratio	1.00
50% ratio	0.96/1.11
90% ratio	0.81/1.29
Number fog hits	301
POD fog	89.1%
FAR fog	3.8%
CSI fog	86.0%
BIAS fog	0.93
CC fog	0.92

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ICE-FREE WIND SENSORS

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ABSTRACT

The EUMETNET SWSS II project studied 13 ice-free anemometers at three European test sites prone to strong in-cloud icing. The heavily heated (700 W) Rosemount Pitot tube sensor remained ice-free at all sites. Also the Thies 2D (70W) and Metek 3D (125 W and 55 W) acoustic anemometers functioned well under these harsh environments. Among traditional cup anemometers, the Vaisala WAA25 (50+22 W) and at less extend, Degréane Deolia (70 to 140 W) proved to be quite usable even at heavy icing sites. The hot film anemometers tested remained well ice-free, but suffered of super-cooled cloud droplets associated with vertical winds. The test showed that ice-free sensors with relatively low heating power for harsh conditions are available. On the other side some sensors proved to have inadequate heating design/power, at least for such sites.

Key words*: anemometers, icing, ice-free wind sensors*

1. INTRODUCTION

As the use of automatic weather stations is increasing, the demand on reliable function of the sensors, e.g. reliability of measurements, becomes even more essential than at traditional manned weather stations.

Accurate wind measurements need to be performed for meteorological purposes as well as for many applications in cold environments prone to low air temperatures and atmospheric icing. Low air temperature typically makes the lubricants and bearings numb, which usually increases the starting velocity of the anemometer. Ice accretion upon cups decreases the rotation speed of the cups significantly. Many of the conventional wind sensors operated by national weather services are equipped with axial heating, which may be enough with respect to low air temperature but usually not enough to prevent measurements from being seriously erroneous at sites affected by icing.

The severity of icing of anemometers depends on requirements set on accuracy and availability of wind measurements: at synoptic meteorological stations the requirement on accuracy is typically ± 10 %, while at research stations (vertical profiles etc.) it could be around ± 1-2 %. Requirements on availability of data are seldom defined.

Icing of wind sensors, e.g. ice-free anemometers, have been an important issue especially within the wind power industry, where high accuracy in wind measurements and reliability of data is required.

Previous research has shown that ice-accretion upon sensors cannot be fully prevented by the coating of the structure of the sensor: internal heating is required. A number of “new generation” ice-free sensors of different types (cups, sonics, vanes, etc) equipped with internal heating systems are now available on the market. Most of them are very reliable under less

severe icing conditions, while some of them may suffer seriously of severe icing. Some of the sensors again may be ice-free under practically any icing conditions but less accurate in respect to the WMO requirements. Some acoustic wind sensors even provide usable air temperature values, a promising possibility for remote automatic weather stations.

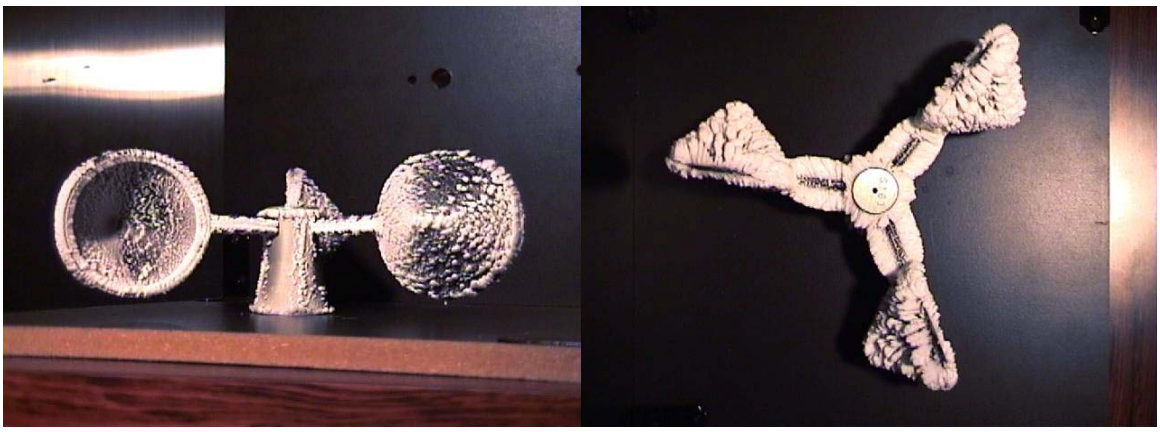
Within the EUMETNET SWS II project, 13 ice-free wind sensors were tested during the winter 2001-2002 at three sites with heavy icing located in Finland, Switzerland and France.

2. EFFECT OF ICING UPON CUP ANEMOMETERS

Cup anemometers are widely used to measure wind speed for meteorological purposes and other applications. Many cup anemometers are equipped with axis heating allowing for some rotation during an icing event, but not preventing the icing of cups and thus erroneous wind speed measurements. Icing of cups always reduces the rotation of the cups and leads to underestimation of wind speed.

For a cup anemometer the relation between the amount of ice on cups and the reduction in wind speed is quite well known thanks to several experiments (e.g. Tammelin et al., 1996; 2000), theoretical studies and wind tunnel simulations (Kimura et al., 2000; 2001). Wet ice typically forms a transparent smooth ice cover on both sides of the cup. This increases the weight of the cup, which mainly affects the time constant but not the rotation velocity of a cup. Dry ice upon the cups again has an alteration in the aerodynamic characteristics of the cups that leads to decreased rotation velocity of the cups. According to wind tunnel tests, 2 mm of dry ice upon cups causes a 30 % reduction in the rotation speed, and 5 mm would cause a measurement error of 40 % in wind speed (fig.2). At mountainous and other heavy icing sites the amount of ice on unheated cups may be several centimetres.

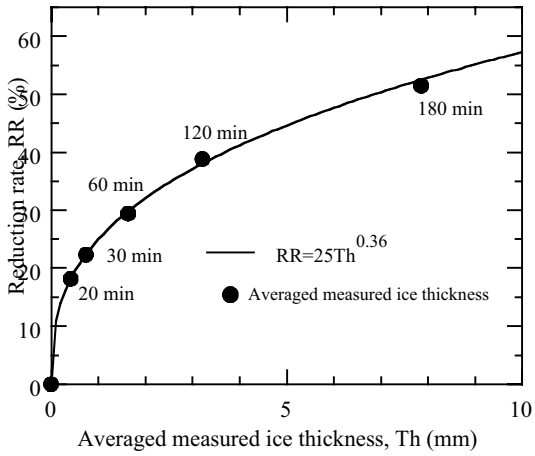
Fig.1. Two examples of ice accretion on a non-heated cup anemometer in dry-icing conditions in cold climate wind tunnel simulations (from Kimura et al., 2000; 2001).



(a) 60 min (b) 120 min

However, the cup anemometer is not only affected by the amount of ice upon cups and frozen axis, but also by the amount of ice upon the body of the sensor (and even by ice upon the booms or poles where the anemometer is mounted).

Fig. 2. The relation between the reduction rate and the averaged thickness of ice on the outer surface of the cup in dry-icing conditions. The amount of ice at 60 min and 120 min are shown in the previous figure. (from Kimura et al., 2000;2001)



3. THE WIND SENSORS TESTED AT THE EUMETNET SWS II PROJECT

All together, 13 wind sensors were tested at the three sites in Finland, Switzerland and France. At each site, the ice/rime load upon sensors may reach several centimetres or even several decimetres. However, the duration of icing, type of ice upon the sensors and effect of icing upon measurements varies between these three sites. At Luosto in northern Finland winter days are short and cold without solar radiation. At Mont Aigoual in southern France and Säntis in Switzerland, solar radiation melts efficiently snow, which, together with the effect of cold nights, produces modifications in the structure and the nature of the ice. The sites are described in more details in the EUMETNET SWS II reports (Tammelin et al., 2001; 2003).

The operation of sensors was monitored manually and by video control. The sensors tested differ in the needed heating power and in the heating architecture. They also differ strongly in operation under icing conditions: some sensors really provide highly reliable wind data under most harsh conditions, while some sensors cannot actually be called ice-free. On the other hand some sensors function better at one site than at the others: it must be kept in mind that the three sites differ in type, duration and rate of rime accretion.

Within this project it was not possible to study icing on wind sensors with the same accuracy as in a wind tunnel (Fig. 1). Thus it was agreed that the sensors would be tested as a part of a typical automatic weather station with no manual operations, e.g. removing the ice form the sensors, during the winter months.

Based on the results of test measurements during the previous winter, the Rosemount 1774W was chosen to be a relative reference. All sensors were compared to ROS during the non-icing periods to get the relationship between the instruments under normal conditions. Another alternative would had been the use of the heavily heated and modified Hydro-Tech WS-3, but due to the high vertical wind component at test sites Luosto and Säntis , the representativity of the wind speed measurements would have been affected.

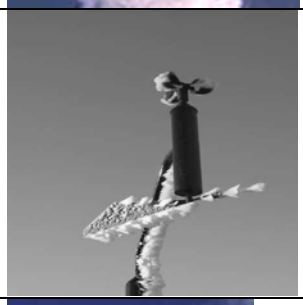
To study the correlation between each sensor and ROS wind directions with no obstacles and effect of the other sensors and their installation poles were selected at each site.

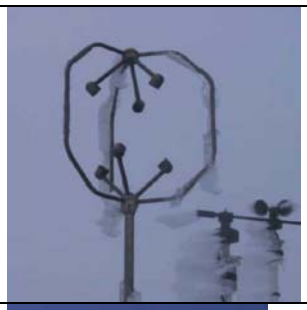
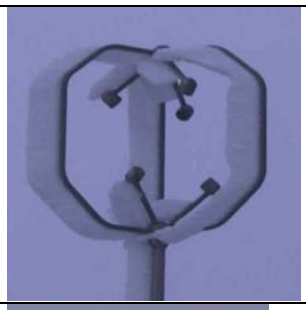
To study the effect of the type of icing upon wind speed measurements for each sensor, a classification of icing was used. This classification does not give a rate of icing similar to the one shown in Fig. 1, but rather tells if the sensor is only partly affected by ice accretion or if it is totally blocked by ice. The sensors' classification of icing and some of their characteristics are shown in figure 3. As seen in the following frames the classification does not take the icing of cups into account at the same accuracy as shown in Fig. 1. Thus class 2 includes cases with light icing (Fig. 1, left frame) to cases with heavily iced cups (cases 120 and 180 min shown by Kimura et al. 2001). Icing class 3 represents the situation where the sensor is totally blocked by ice and it is difficult to distinguish the structure of the sensor.

The classification of icing and the duration of ice upon sensors was based on manual and photo observations at Aigoual and on continuous video monitoring at Luosto. The Luosto video data was analysed manually.

Fig. 3. Classification of icing upon different wind speed sensors used at Luosto and Mont Aigoual during the winter 2001/2002. Class 0 = totally free of ice, 1= ice on body and pole but not on the measurement elements, 2 = ice also on measurement elements, 3 = sensor totally blocked by ice. Examples of class 3 are missing for some sensors due to that class 3 never existed at those sensors.

sensor	Class 1	Class 2	Class 3
Young **Wind monit. 05103** * mechanical *not heated * at A YOU			
Theodor Friedrichs *Mechanical * 60 W for shaft and body Abbreviation: THE			
Vaisala **WAA252** * mechanical * Cups 50 W * Shaft 12 W * body 10 W * at L, A, S Abbreviation: VAI			NOT OBSERVED

Thiess * 2D sonic * each arm 15-17 W * at L Abbreviation: THI			NOT OBSERVED
Kroneis **263PRH** * mechanical * axes 30 W * at A KRO			
Degréane, DEOLIA * mechanical * 70 to 140 W for shaft, cups and vane * at A DEO			
Rosemount **1774W** *2D Pitot tube * 700 W * at L, A, S Abbreviation: ROS		NOT OBSERVED	NOT OBSERVED
Vaisala **WAS425A** * 2D sonic *30 W at the arm tips * at L, A, S HAN			

Metek **USA-1** * arms 125 W at A and S * arms 55 W at L Abbreviation: MET			NOT OBSERVED
Irdam SA **WST7000 HS** * 2D hot film * 400 W * body heated to the lower screen * at A & L IRD			NOT OBSERVED
Lambrecht **QuattroMetH** *2 D hot film * 80 W; body and cap in 2 min intervals * at L and A LAM			NOT OBSERVED

4. SOME RESULTS

In the following some results from the most southern site (Mont Aigoual) and most northern site (Luosto) are shown.

As it may be seen from the frames in Fig. 4 the number of icing classes, and also the effect of icing, vary between the sensors. For KRO class 2 icing may lead to an measurement error (underestimation) of 60-70 %, while for YOU the error remains generally below 25 %. The acoustic anemometer HAN was part of the time iced (class 2 and 3). According to the measurements partial icing of the sensor (class 2) caused underestimation of 30 % at wind speeds below 15 m/s, but some overestimation at very high wind speeds. MET again seem to measure correct values also during class 1 icing. At Aigoual MET, IRD and ROS were practically always ice free (class 1 or class 0).

At Luosto the total load of ice upon sensors is bigger and the duration of perturbation due to ice is longer than at Aigoual, especially during the mid winter. At icing conditions represented by Luosto the sensors ROS, IRD and THI remained practically ice free under all icing conditions. LAM, MET and VAI were never totally blocked by ice, and suffered only few times of class 2 icing. HAN class 3 icing is easy to detect as the sensor in this case gives invalid data (showed as -1 m/s in the first frame in Fig. 5.

Fig. 4 . Correlation between 10 minute average wind speed measured by each sensor (DEO, HAN, IRD, KRO, LAM, MET and YOU) in icing classes 0-3 and ROS at Mont Aigoual, France. Only cases in the open sector 320-40 degrees with relative flat back ground terrain are used. The regression line is calculated from the verification under non-icing conditions. The frame in the right corner below shows the relative distribution of duration of different icing classes at each sensor.

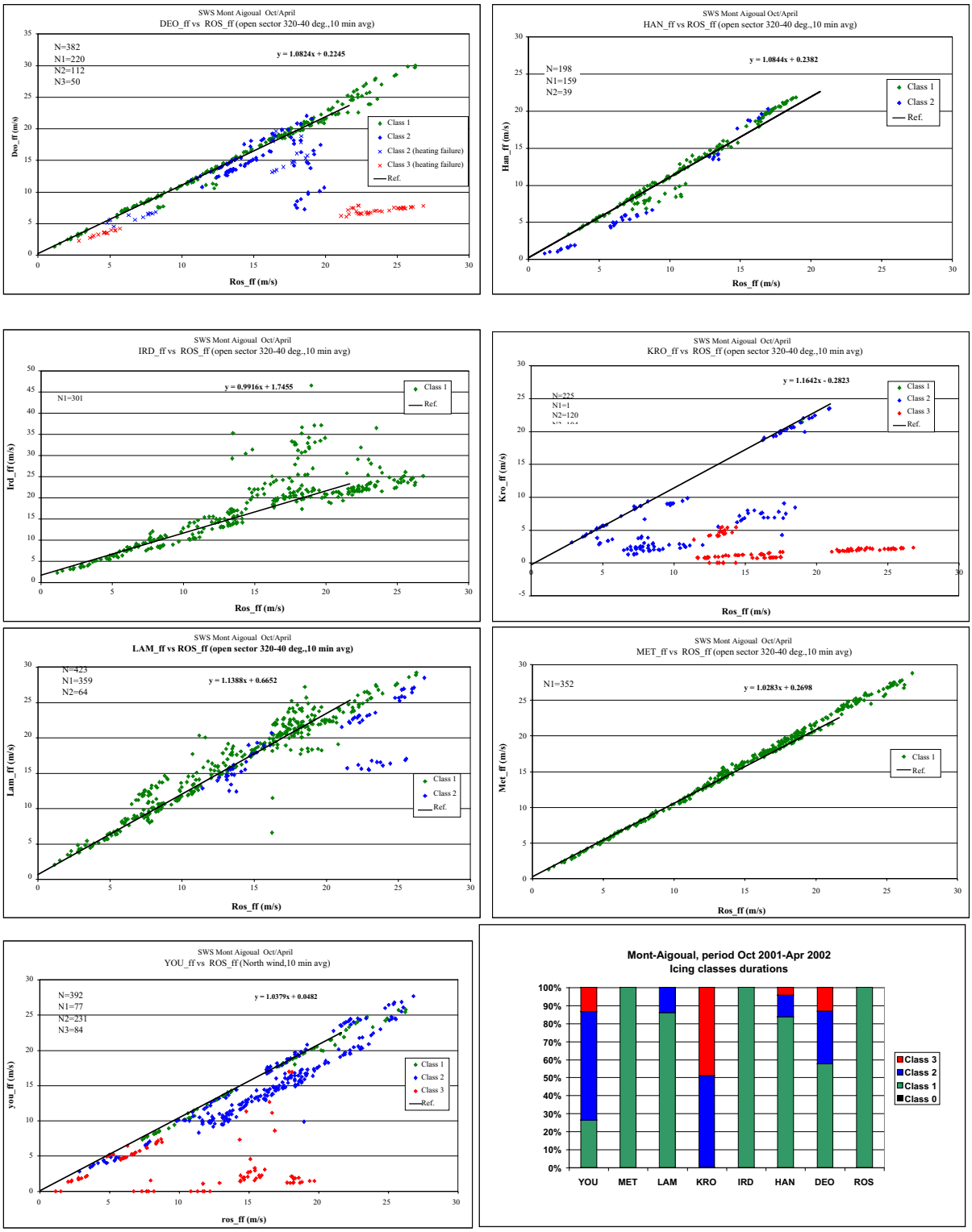
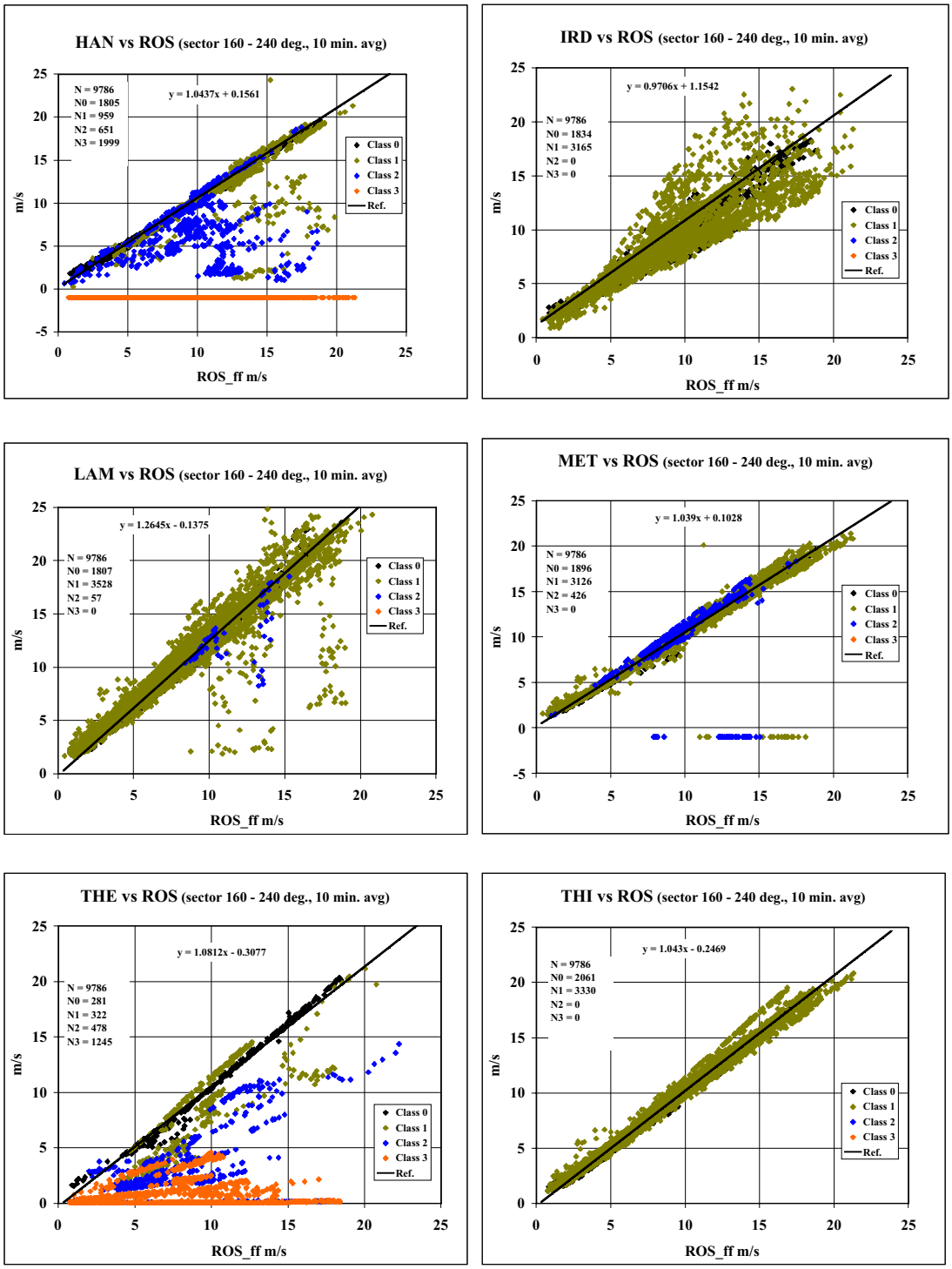
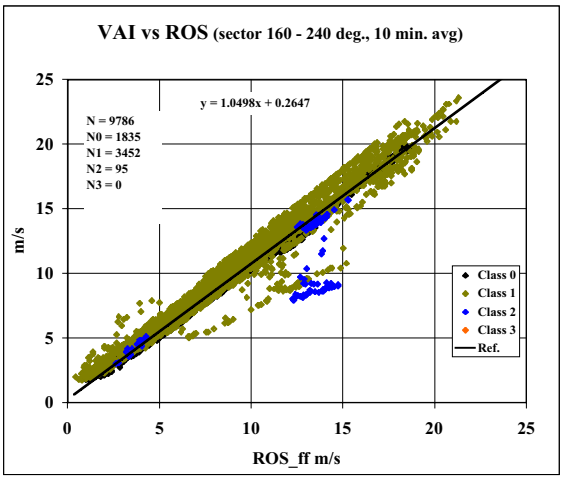
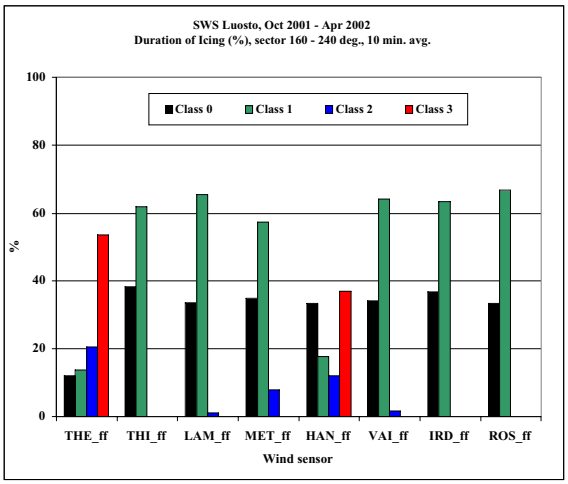


Fig. 5. Correlation between 10 minutes average wind speed measured by each sensor and ROS at Luosto during the period from October 2001 to April 2002. Only cases from the open sector are used. The last frame gives the proportional (%) duration of different icing classes for different sensors. For MET and HAN the measurement value -1 m/s is used for invalid data observed by the sensor.







These figures and more detailed research in the behaviour of different wind sensors at the three EUMETNET SWS II sites show that:

- perturbation on wind measurements due to icing is in general smaller at Mont Aigoual than at Luosto
- icing of the sensor and/or of the installation poles does not only produce an underestimation in the measurements but may also lead to overestimation of wind speed
- proper wind speed sensors which also fulfil the WMO requirements on accuracy of measurements also during icing conditions are available on the market
- some 100 W heating power with proper design of the sensor is required at harsh sites - Rosemount Pitot tube remains ice-free (the sensor tube but not the sensor body) under all icing conditions, but is not a very accurate wind sensor at low wind speeds (linearity)
- the acoustic sensors Thies and Metek provide good measurements, even if Metek 55 W seem to have too low heating power for the most heavy icing conditions
- the Vaisala heated cup anemometer suffers from too low heating power at cases with strong ice accretion, but experienced even class 2 icing only for few times
- the Irdam and Lambrecht hot film anemometers are fairly ice-free even under harsh conditions, but they both suffer from water droplets carried by wind upon the hot film
- design of heating for the Vaisala sonic anemometer is poor for heavy icing conditions (high number of icing class 3 at Luosto), but the sensor functions better at less harsh environments
- the Theodor Friedrichs cup anemometer with only heated body and shaft but non-heated cups is not sufficient for sites with heavy icing
- mechanical cup anemometers from Kroneiss (with 30 E heating for axis) and Degréane (70-140 W external heating for cups) were tested at Mont Aigoual, where both suffered from iced cups with reduction in wind speed, and partially also from icing class 3 with severe measurement errors
- the non-heated propeller anemometer from Young was tested at Mont Aigoual where the measurements were more reliable than for some of the partially heated cup anemometers
- the behaviour of wind sensors under icing conditions can be improved by improved design of sensors and heating.

Representativity of measurements produced by various wind speed sensors under different types of cold climate conditions depends on the requirements set by the user. It makes a big difference if the demand is to have accurate (± 5 %) wind measurements with 95 % monthly availability or if less accurate with a low availability can be accepted during winter times.

5. CONCLUSIONS

Measurement errors due to ice accretion upon sensors is a significant problem especially at automatic weather stations located at mountain sites or at high latitudes with cold climate and icing conditions. Icing may be a severe issue also for measurements made at less critical icing sites, especially when the requirements for accuracy and for availability of data are high.

At sites prone to strong icing proper fully heated wind sensors have to be used to be able to provide with reliable wind measurements. Also the installation poles and other structures close to the wind sensors have to be kept free of ice to avoid serious measurement errors.

Video monitoring have proved to be a powerful tool to control the status of different types of sensors at automatic weather stations. However, there is a big need for sensors to measure the rate and the duration of atmospheric icing.

Fully ice-free sensors even for most demanding icing climates are available at the market. In order to help the operators and manufacturers of wind sensors, a classification for sensors taking into account the accuracy of measurements the severity of climatic conditions and the reliability of data required for different applications should be promoted. Test sites located at heavily icing climates can be used for testing and development of ice-free sensors. The market for reliable ice-free sensors is growing not only within the meteorological community but also within different areas of applications

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MAINTENANCE PROBLEMS RELATED TO SUSTAINING A NETWORK OF AUTOMATIC STATIONS UNDER COASTAL CONDITIONS

SPEECH BY FRANCISCO JOSÉ RODRÍGUEZ HURTADO, CHIEF OF BASIC SYSTEMS FOR THE TERRITORIAL METEOROLOGICAL CENTRE FOR EASTERN ANDALUSIA AND MELILLA

ABSTRACT

The average service life of the installations required for an Automatic Weather Station, specifically those exposed to weather elements, has proven to be very short. Wind gauges are installed on metal towers exposed to the wind. Rain gauges are likewise installed on metal posts. Temperatures and humidity sensors are located in the wooden housings. Data is transmitted through cables that have to pass through connection devices. All these elements are quite sensitive to environmental conditions over the course of time.

Various problems can arise due to these conditions: the difficulty or impossibility of preventive or corrective maintenance, the sticking or tightening up of sensors, erroneous data, data missing for considerable periods of time, and large amounts of time lost in the replacement of damaged elements.

Some measures have been put into practice at this Meteorological Centre that have significantly increased the average service life of these installations and will be explained below.

Key words: automatic stations, coastal corrosion

In this work we are going to explain the main problems caused by environmental conditions for stations installed in Spain's Southern Coastal region as well as some solutions that have been adopted. No doubt, if the measuring units had been made, or would be made in the future, or had been purchased at the time, using some other types of materials, there were be no need to adopt any of these proposed solutions, which naturally imply the loss of time, materials and data.

In several sections of this work false data readings are mentioned which are due to environmental effects on the electrical connections to the units. One of these consequences, but not the only one, is shown by the "peaks" that may appear on the graphs of affected stations.

A temperature peak appears in Figure 1 at 07:00 AM, caused by the effects marine corrosion at connection points and exposed automatic station circuits. These peaks are treated later on in fact, but there is no guarantee that this purification treatment is exhaustive, nor that the less significant peaks falsify the measurements.

Figure 1

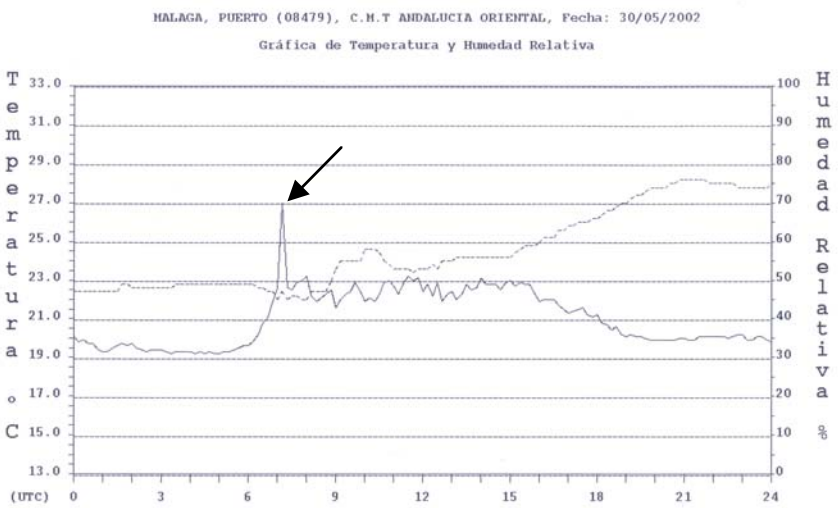
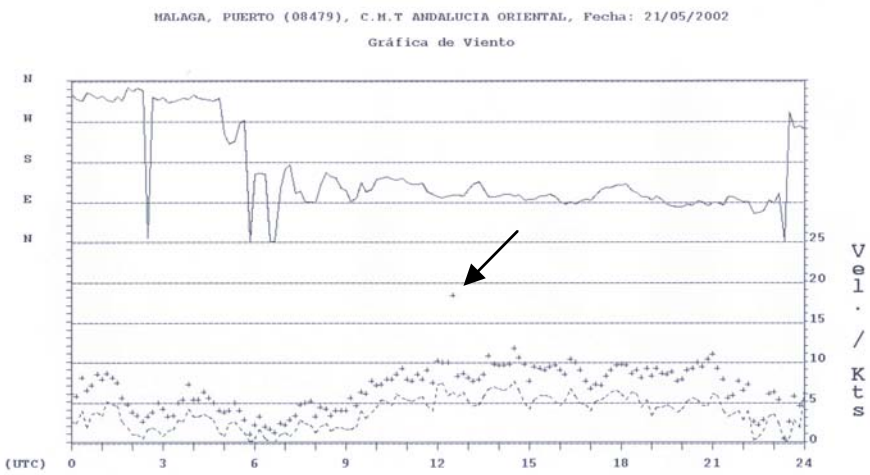


Figure 2 shows a peak in wind velocity at 12:00 AM.

Figure 2



Some pictures have been taken of the Automatic Station at the Cape of Torrox (Malaga).

As shown, the effects of corrosion on the entrance gate to the station are quite strong.

1. WIND MEASURING UNITS

As shown in Table I, several weather measuring units have had to be replaced with stainless steel components. The material first used was galvanised steel, which has proven to have an average service life of less than six months in some locations.

The wind tower could also be made of stainless steel, but this is hard to find. A good result can be obtained by applying a coat of marine anti-oxidizing paint to the components.

On the inside where the sensors are housed, a healthy application of Vaseline on the gears and silicone on the electronic components is required. On the outside, a large dose of silicone must be applied to all joints where the sensors are connected to the crosstree.

Table I

Problem	Solution
Cables, dogs, tensors, nuts, bolts. These corrode and become unusable in less than six months.	These should all be stainless steel components.
The Wind Tower. Due to deterioration it becomes impossible to climb in a period of about a year.	A dual-component anti-oxidizing paint must be applied, similar to the products us for maritime navigation.
The mast supporting the wind crosstree. It rusts and doesn't allow lowering for maintenance tasks.	This should be a stainless steel component.

The Wind Crosstree: data cable connections and sensor fixtures to the crosstree. They corrode and at first, give false data readings and later, data fails.	Vaseline must be applied on the inside at connection points and on the direction and speed sensors. Silicone must be applied to all joints where the sensors connect to the crosstree.
Crosstree clamps. They corrode making maintenance impossible.	These should be stainless steel components.

2. PRECIPITATION MEASURING UNITS

As shown in Table II, connection points are the most vulnerable spots of the installation, which in this case, can be eliminated all together. In fact, it is better to eliminate them and protect the data cables going to the sensor with silicone.

Table II

Problem	Solution
Connections to the Rain Gauge: It corrodes and at first, gives false data readings and later, data fails.	These connection points should be eliminated. Connections should be made directly to the sensor.

3. TEMPERATURE AND HUMIDITY MEASURING UNITS

The fact that temperature and humidity sensors are industrially designed as one unit means that the entire device must be replaced when the hair bundles that measure relative humidity deteriorate. This occurs in our area in period of less than a year.

Table III

Problem	Solution
Relative humidity hair bundle measuring unit: corrodes and delivers false data.	Since the temperature and relative humidity measuring sensors are made as one unit, both devices must be replaced.

4. PRESSURE MEASURING UNITS

Apart from the repetitive problem with the connection points, the pressure measuring unit has a more difficult problem to resolve. The grill itself, which acts as a protection for the air intake needed to make the pressure measurement, deteriorates due to the environment it is in.

Table IV

Problem	Solution
Connection point: It corrodes and at first, gives false data readings and later, data fails.	Vaseline should be applied on the inside of the connection.
Air Intake Grill. It becomes useless due to the salt deposits on the grill. This hinders air intake, thus giving a false pressure reading.	There is no other solution except to occasionally clean the grill.

5. INTERFACES

As can be seen in Table V, the connection problem is reproduced here but there is also a new corrosion problem which appears on the sheet metal supporting the interface.

Table V

Problem	Solution
Connection points: They corrode and at first, give false data readings and later, data fails.	Vaseline should be applied on the inside of the connection. The connection should then be sheathed with an appropriate plastic tube.
Sheet metal fixture for connecting field interface to the support element: It corrodes.	This should be a stainless steel component.

ACKNOWLEDGEMENTS

The Public Entity, Puertos del Estado, for offering to allow us to photograph the meteorological installations at the Faro de Torrox.

Mr. Miguel Sánchez Sánchez, Maintenance and Calibration Specialist for the Territorial Meteorological Centre for Eastern Andalusia and Melilla.

Mr. Francisco José Castejón de la Cuesta, Expert Engineer for the Territorial Meteorological Centre for Eastern Andalusia and Melilla.

Mr. Vicente Albero Molina, Expert Engineer for the Territorial Meteorological Centre for Eastern Andalusia and Melilla.

THE INTERCOMPARISON OF THE ULTRASONIC ANEMOMETERS IN REAL CONDITIONS AT THE LJUBLJANA AIRPORT

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ABSTRACT
In the Environmental Agency of the Republic of Slovenia (former the Hydrometeorological Institute) we use only cups anemometers in our meteorological, hydrological and ecological measuring network. We intend to change some of them with the ultrasonic anemometers in the next few years. Because we had no experiences with them we made the intercomparison between different ultrasonic sensors and two cups anemometers in real conditions at the Ljubljana Airport. The results are presented.

KEY WORDS: *ultrasonic anemometers, intercomparison*

INTRODUCTION
The ultrasonic anemometers intercomparison was carried out at the Ljubljana Airport from February to May 2002 by the Environmental Agency of the Republic of Slovenia. The main objective was to determine, in a field test, the operational applicability of the ultrasonic anemometers for measuring wind speed and direction in different conditions in our meteorological network. At that time we used only the cup anemometers for the wind speed measuring. Because of icing conditions, we had several problems with the wind measuring during the winter. We also had no calibration facilities for the cup anemometers; therefore we could not periodically check the quality of bearings. For this reason we decided to think about changing them with the ultrasonic anemometers.

DESCRIPTION OF THE SITE AND THE EQUIPMENT

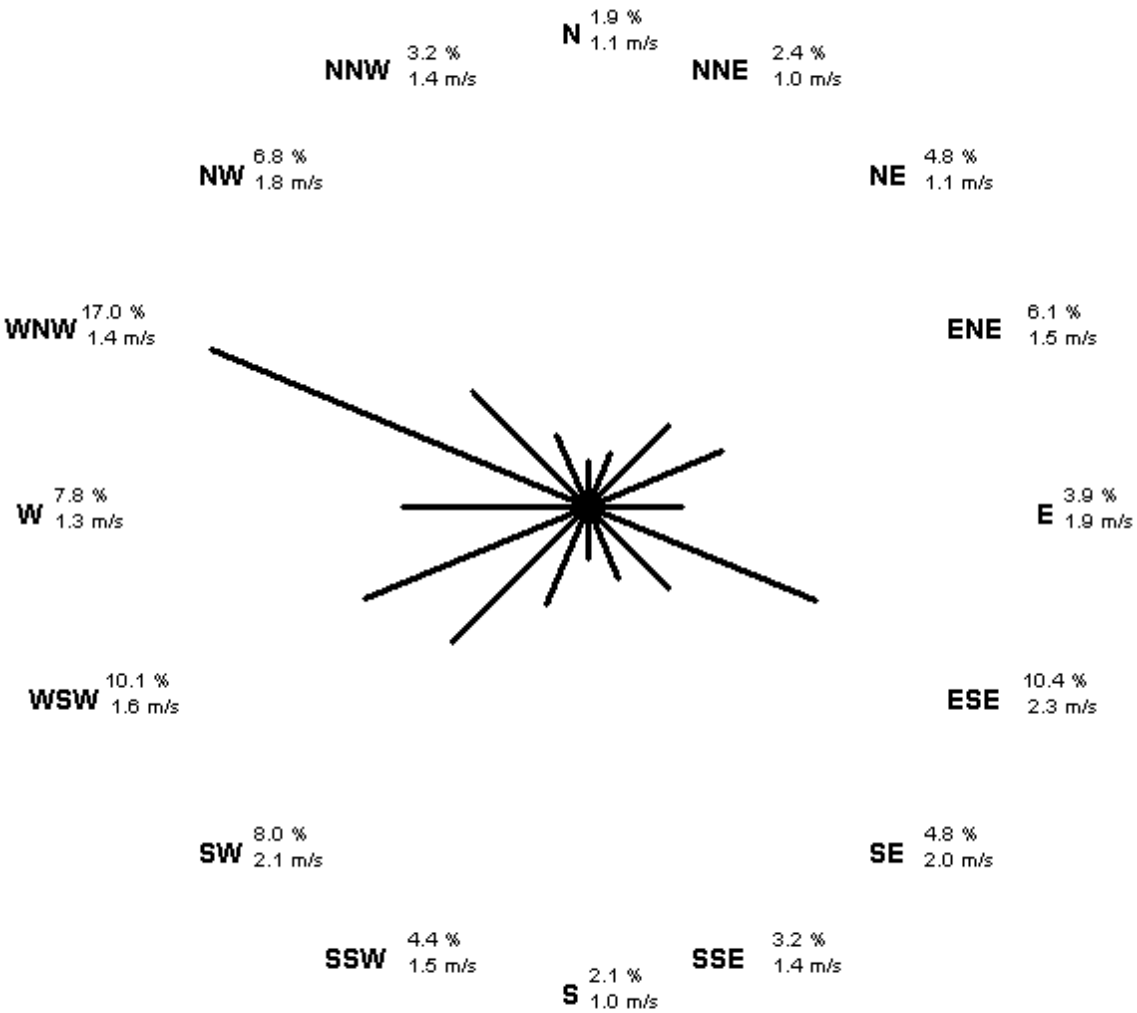
The meteorological observations site at the Ljubljana Airport is situated on a grass plain near the runway. The ultrasonic anemometers were installed on the existing pylon. On the top of the 10 m high pylon, there were two operative cup anemometers. Approximately at the 9 m height a rail was oriented to the north. The ultrasonic anemometers were placed on the rail at about the same height and at a distance between them which is large enough to avoid any mutual interference.

There were four ultrasonic anemometers participating in the intercomparison. A description of them is in the table:

Manufacturer	**Gill Instruments Ltd, England**	**G. Lufft Mess- und Regeltechnik GmbH, Germany**	**Adolf Thies GmbH, Germany**	**Vaisala Oyj, Finland**
Identifier	GILL	LUFFT	THIES	VAISALA
Type	Wind Observer II	Usonic	US 2D	WAS425 AH
Measuring range	0 .. 65 m/s 0 .. 359˚	0 .. 60 m/s 0 .. 360˚ -30 .. +60˚C	0 .. 65 m/s 0 .. 360˚ -40 .. +70˚C	0 .. 65 m/s 0 .. 360˚
Resolution	0.01 m/s 1˚		< 0.1 m/s 1˚ 0,1 K	0.1 m/s 1˚
Accuracy ***speed*** ***direction*** ***temperature***	 ± 2 % at 12m/s ± 2˚ (< 25 m/s) ± 4˚ (> 25 m/s)	 ± 0.1 m/s (< 5 m/s) < 1.5 % (> 5 m/s) ± 3˚ ± 1 K	 ± 0,1 m/s rms (< 5 m/s); 2 % rms (> 5 m/s) ± 1˚ ± 0,5 K	 ± 0.135 m/s or ± 3 % ± 2˚
Power	9-30 V DC	9-28 V DC	12-24 V AC/DC	10-15 V DC
Heating power	24 V AC/DC	20-24 V DC	24 V AC/DC	36 V DC
Output ***RS 232*** ***RS 422*** ***RS 485*** ***Analog***	 * *	 * * *	 * * * *	 * * *
Max. output rate	10/s	1/s	10/s	1/s
Sampling	39/s	1/s	10/s	1/s
Operating temperature	-55˚ to +70˚	-30˚ to +60˚	-40˚ to +70˚	-55˚ to +55˚
Protection	IP66	IP67	IP65	
Weight	1,5 kg	1,2 kg	2,5 kg	1,32 kg
Heating	*	*	*	*

THE METEOROLOGICAL CONDITIONS IN THE TESTING PERIOD

The wind rose of the measuring site in the intercomparison period is presented below:



DATA ACQUISITION AND PROCESSING

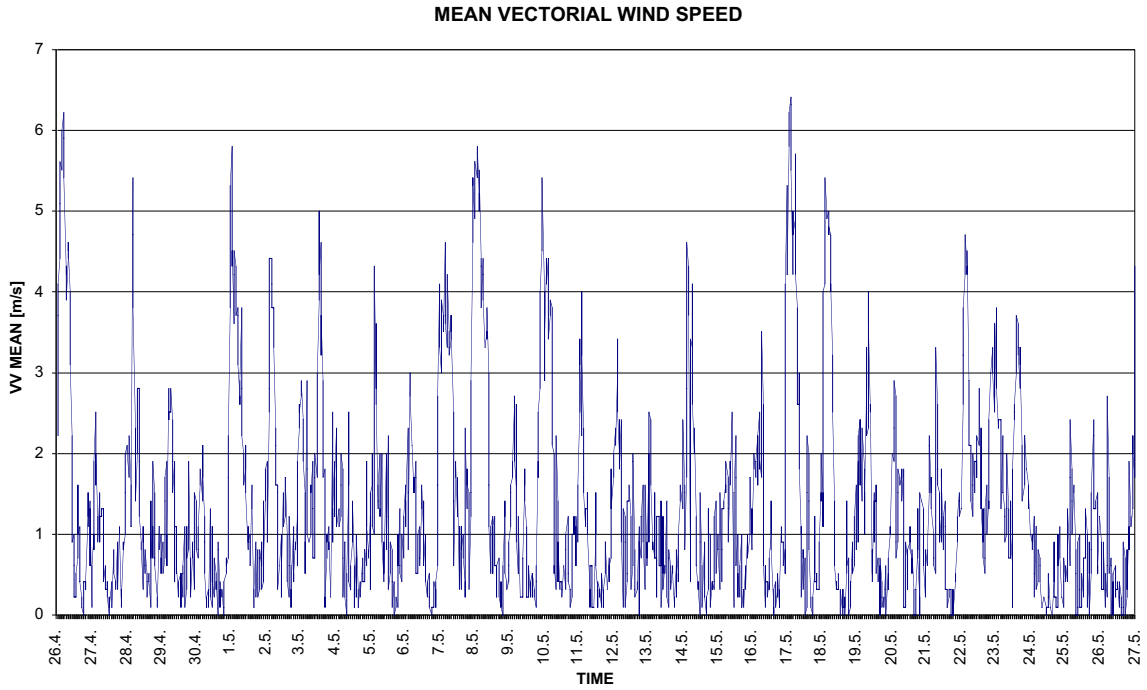
We used RS422/485 serial interface for the data acquisition. The sensors were connected directly to PC. The output rate of the sensors was 1 per second. The average data value of all ultrasonic sensors was a working reference.

We calculated the following average parameters (1 min, 10 min, 30 min, and 60 min): the mean scalar wind speed, the mean vectorial wind speed, the mean wind direction, the standard deviation of the wind direction, the standard deviation of the scalar wind.

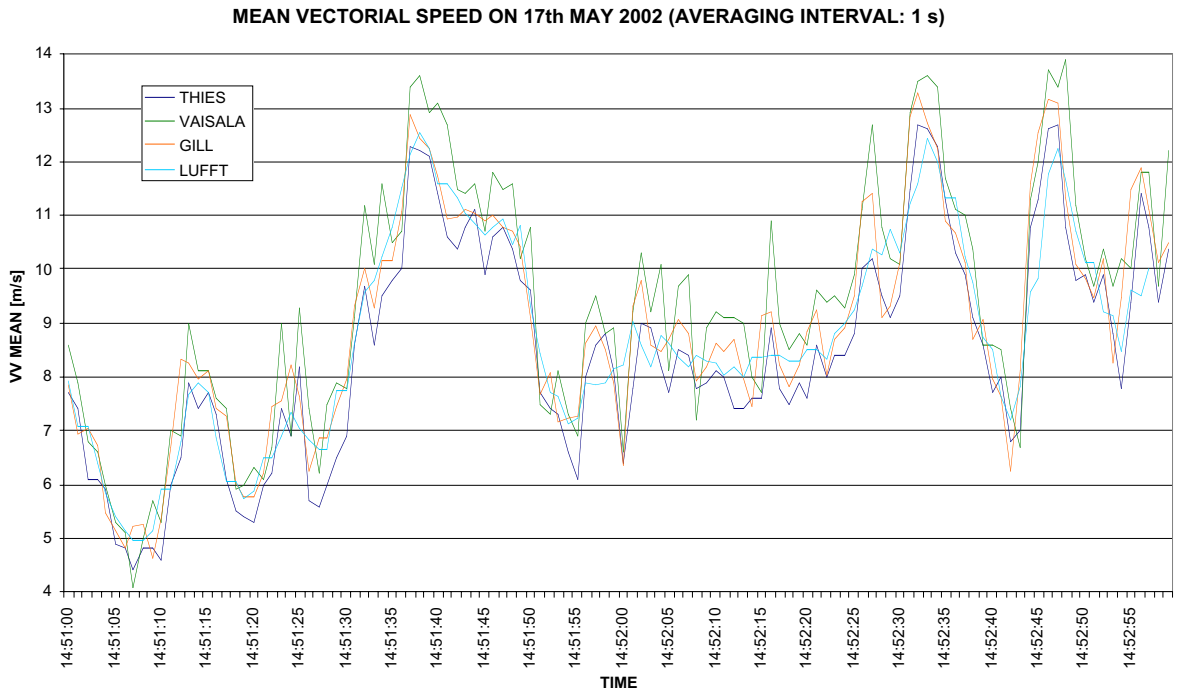
One meter above the ultrasonic sensors there were two operative cup anemometers. The first is a part of the automatic meteorological station (identifier: AWS). The second is connected directly to the Aviation Meteorology Service at the Ljubljana Airport (identifier: UAM). They both are manufactured by AMES (DHV39, DSV39A). We compared the cup anemometers data with the data measured by the ultrasonic anemometers.

DATA ANALYSIS

We analysed the data in the period from 26th April 2002 to 27th May 2002. The wind speed at that time is presented below:

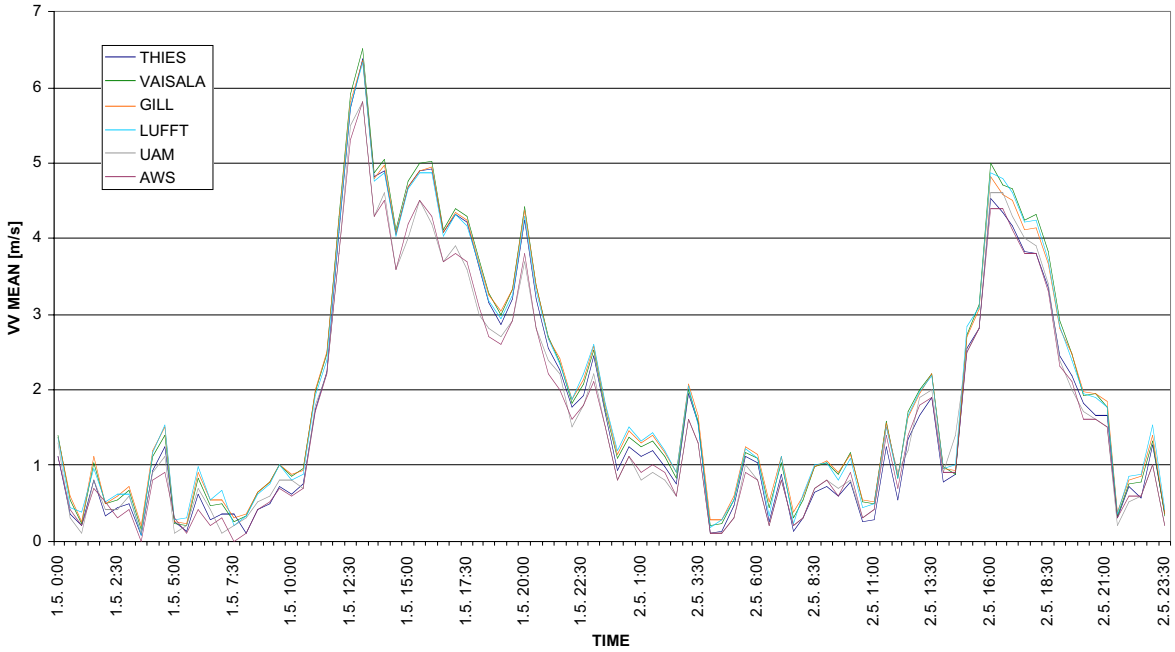


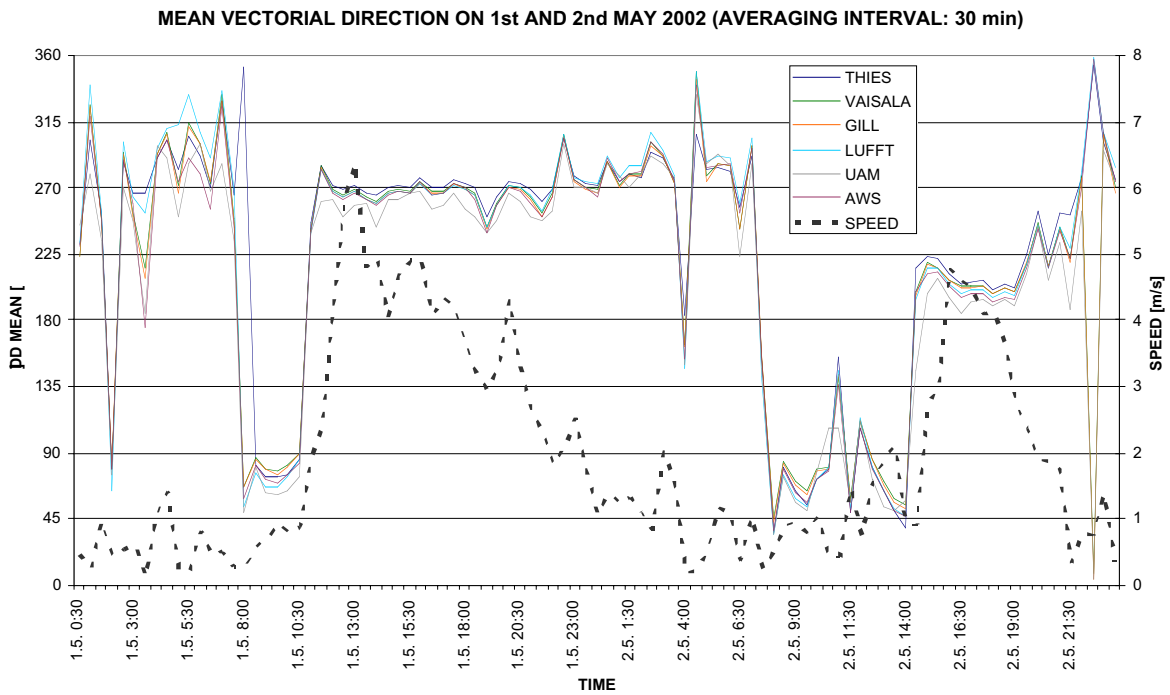
Some graphs hereafter show mean vectorial speed and direction at different averaging intervals:



MEAN VECTORIAL DIRECTION ON 17th MAY 2002 (AVERAGING INTERVAL: 1 s)

MEAN VECTORIAL SPEED ON 1st AND 2nd MAY 2002 (AVERAGING INTERVAL: 30 min)





CONCLUSIONS

Some conclusions of the intercomparison test are:

- The ultrasonic anemometers suit our requirements for measuring the wind speed and its direction for our meteorological needs. On the graphs above, there is presented how the measuring results of the cup and the ultrasonic anemometers are close to each other. Although we had some problems with data missing from some ultrasonic anemometers, all of them appear to be able to give reliable values.
- Although there were no icing conditions at the time of the intercomparison, we expect the heated ultrasonic anemometers will support moderate icing events.
- Because there is virtually no starting threshold and no delay distance in the case of measuring the wind speed and the direction with the ultrasonic instruments, it is possible to use them also for other purposes (turbulence, vertical component of the speed etc.).

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TESTING OF METEOROLOGICAL INSTRUMENTS TO BE USED AT AWS IN MARINE ENVIRONMENTS

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Abstract: *The Norwegian Meteorological Institute established a test field at Stavernsodden lighthouse in autumn 2002. The purpose is to test meteorological instruments to be used at AWS in marine environments. First of all wind sensors were installed to be tested for reliability requirements and a minimum of necessary maintenance without reducing the reliability of the measurements. A video camera was also installed to see if video technology can supply meteorological information which earlier has been observed visually by meteorological observers. Data from the test field is analysed at the Norwegian Meteorological Institute in Oslo.*

Key words: *Wind sensors, marine environment, video technology.*

1. INTRODUCTION

During summer 2002 a test field at Stavernsodden (south east coast of Norway) was established for meteorological measurements. Data collection from the test field started October 2002. The Norwegian Meteorological Institute is responsible for the project that at the moment is planned to last for five years.

2. OBJECTIVES

- To get experience regarding reliability of different sensors.
- Enable selection of sensor types that minimize maintenance, work and expenses.
- Evaluate the usefulness of video technology substituting observers.

At many lighthouses along the coast of Norway observations have been carried out by lighthouse keepers. Since most of the lighthouses now are unmanned, the Norwegian Meteorological Institute has to find other solutions for observations along the coast. AWS will be used instead. There can be bad weather conditions along the coast, so one of the objectives is to see how the instruments behave in such environment. This includes reliability of the measurements and maintenance. In addition the observers have informed about the condition of the sea. Therefore another objective will be to see if video technology can replace observers for this purpose.

3. THE TEST FIELD

Stavernsodden is at the south east coast of Norway, about two hours drive from Oslo. The test field is at a small island about 1 km from mainland. The climate is coastal, with relatively small temperature differences during the year.
Traditionally instruments that measure wind, temperature and air humidity are installed at the test field. These instruments will be tested for reliability requirements and a minimum of necessary maintenance without reducing the reliability of the measurements.

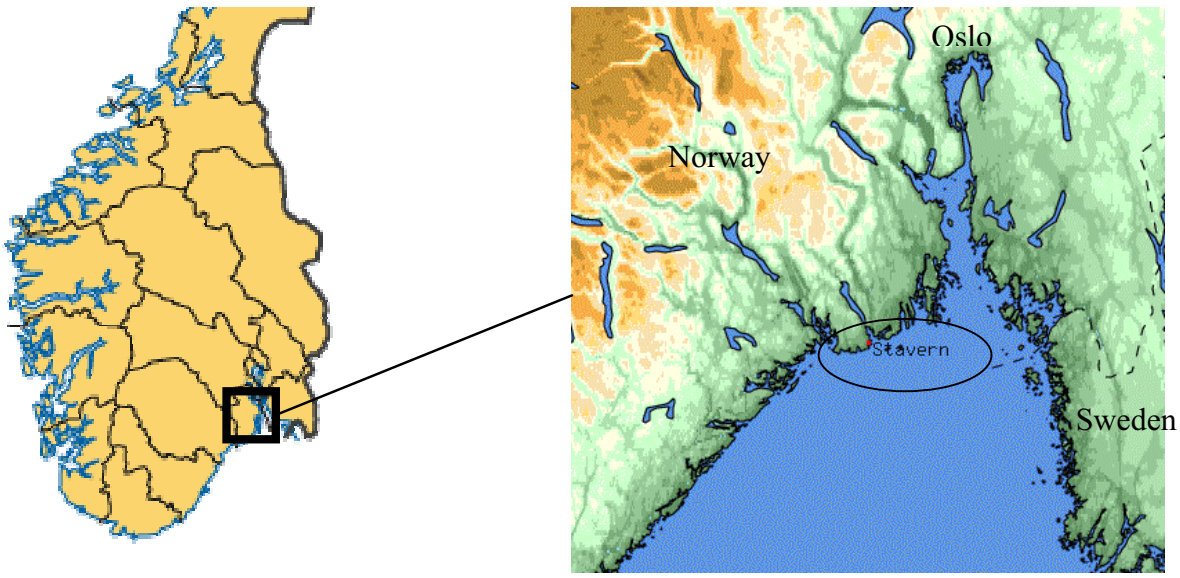


Figure 1. Stavernsodden lighthouse is in the south east coast of Norway.

3.1 Sensors

- Two Gill WindObserver sensors (speed and direction).
  This is an ultrasonic anemometer made of stainless steel and with a heated head to keep it free from ice and snow.
- One Gill WindSonic Anemometer (speed and direction).
  This is an ultrasonic anemometer.
- One Vaisala WAA151 Anemometer (speed).
  This is an optoelectronic anemometer. A heating element in the shaft tunnel keeps bearings above the freezing level in cold climates.
- One Vaisala WAV151 Wind vane (direction).
  This is a counter-balanced low-threshold wind vane with optoelectronic transducer. A heating element in the shaft tunnel keeps bearings above the freezing level in cold climates.
- One Vector A100R, maritime type (speed).
  This is a switching anemometer.

At the moment a new type of wind sensor (TMI) is planned to be installed as soon as possible. In addition the temperature sensor PT 100 and the humidity sensor Vaisala HMP45D are installed. Since the measurements are used for intercomparison of sensors and not as observation data, all wind sensors are installed at a 6 m high mast instead of normally 10 m above ground.

Figure 2. The mast with all the sensors.

Figure 3. The top of the mast. From the right is the Gill sensor, then the Vaisala sensor and the second Gill sensor and to the left, the Vector sensor.

3.2 Video camera

The test field also includes use of video technology to supply meteorological information which earlier has been observed visually by meteorological observers. At the top of the

lighthouse a camera is installed. One can steer the camera from Blindern. In this way we can watch the condition of the ocean at all hours. Some visibility points will be used to decide the visibility. The camera will be preprogrammed to move to the visibility points.

Figure 4. The lighthouse at Stavernsodden where the video camera is installed.

3.3 Data access

The test station has a data connection to The Norwegian Meteorological Institute at Blindern where the station is under surveillance. All incoming data is analysed at Blindern.

3.4 Data collection

Every minute data is logged in a file. For the Gill sensors and the Vaisala sensor the following parameters are logged:

- Wind speed (now value, 2 minutes average, 10 minutes average)
- Wind direction (now value, 2 minutes average, 10 minutes average).

For the Vector sensor only wind speed is logged as the same way as described above.

4. PRELIMINARY RESULTS

Since collection of data started in October 2002, there isn't so much data to analyse yet. In this section some preliminary results from a few days in November are presented.

4.1 Method

As reference we use the Vaisala sensor since that is the mostly used sensor at the Norwegian AWS. The results are presented as dispersion diagram and frequency distribution for each sensor.

4.2 Results wind speed

The figures below show that the two Gill sensors harmonize well with the Vaisala sensor. Especially for low wind speeds they harmonize very well. For higher wind speeds they scatter a bit more.

Figure 7 shows that the Vector sensor measure lower wind speeds than the Vaisala sensor for all wind speeds. It seems like the Vector sensor is a bit slow.

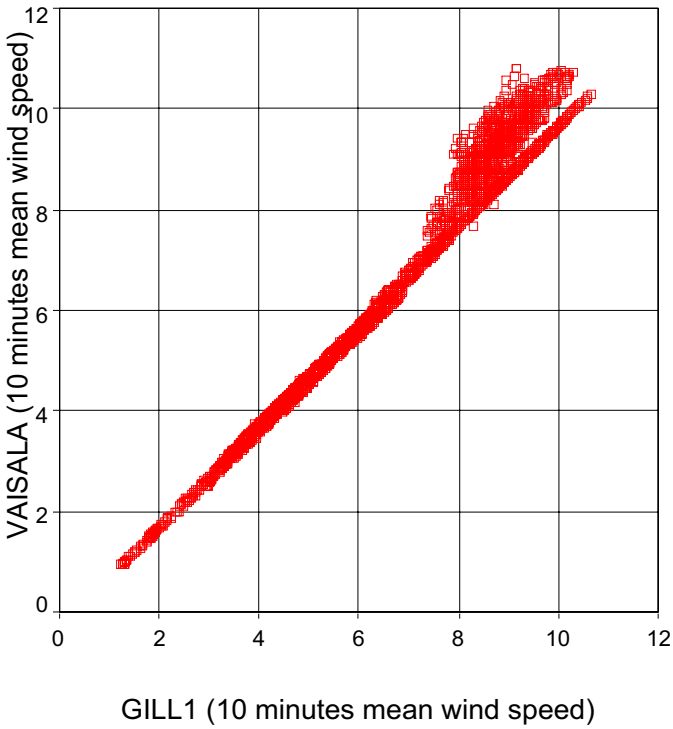
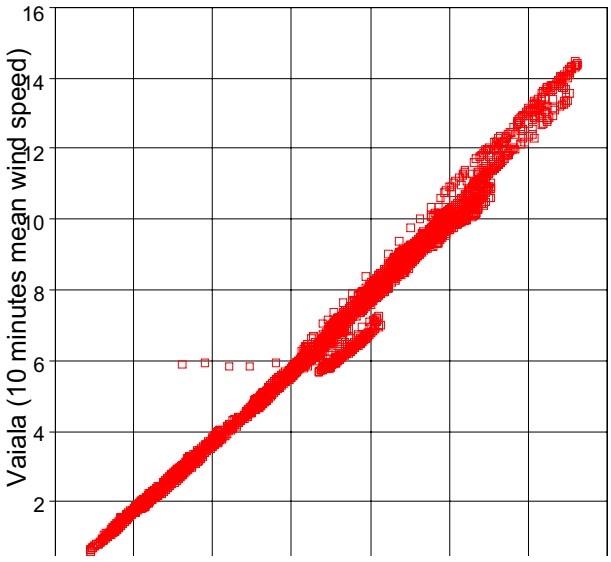


Figure 5. Comparison of the Vaisala sensor and the Gill1 sensor.



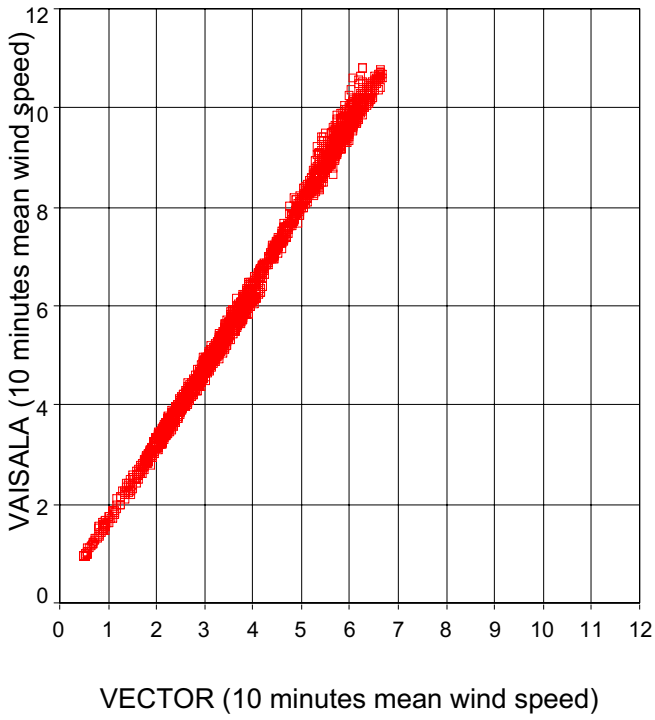


Figure 7. Comparison of the Vaisala sensor and the Vector sensor

4.3 Results wind direction

The figures below show the difference in wind direction between the Vaisala sensor and the two Gill sensors. The differences are for all wind directions. In the final report we will divide the wind directions into sectors, because for some wind directions the wind sensors are differently exposed. At the moment we have too little data to do that.
For both the Gill sensors there are two peaks, but the peaks are at different values. This can be explained by different exposure in particular wind directions. There are also about 2 degrees insecurity in the measurements caused by a small difference in the installations.

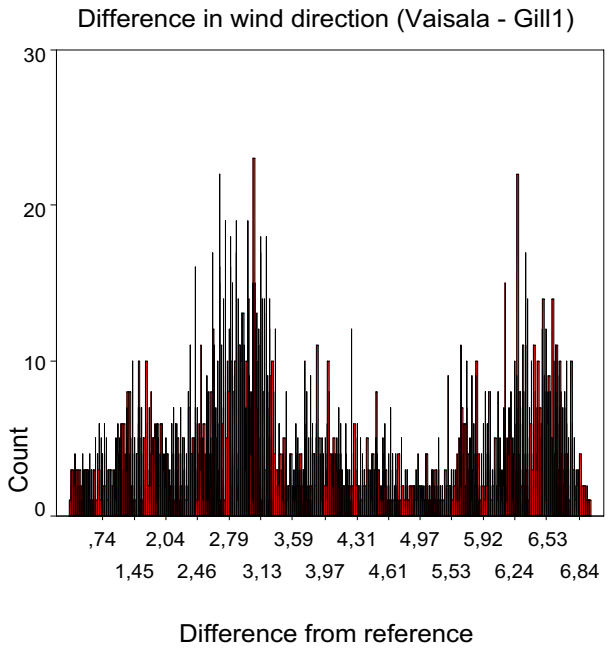


Figure 8. Difference in wind direction between the Vaisala and Gill1 sensors. 10 minutes mean wind direction.

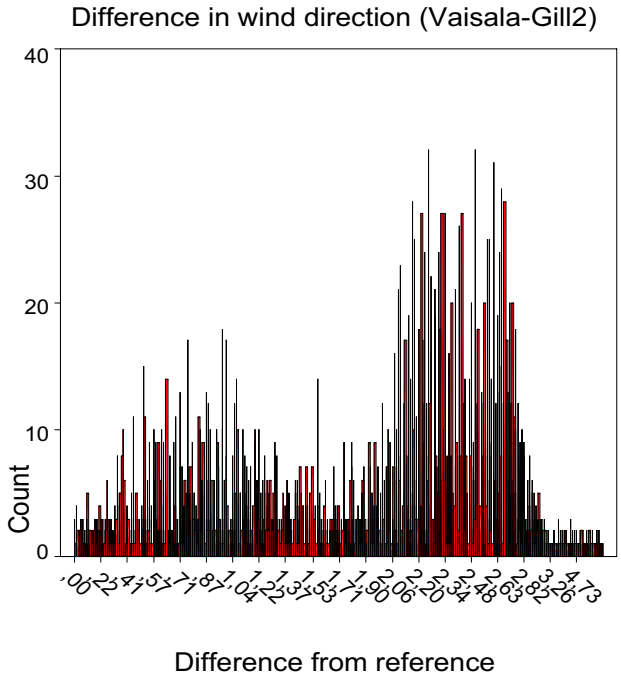


Figure 9. Difference in wind direction between the Vaisala ang Gill2 sensors. 10 minutes mean wind direction.

AN ANEMOMETER BASED ON POSITION SENSING DETECTOR

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Abstract

A Position Sensing Detector (PSD) is an electro-optic device (semiconductor chip) which converts an incident light spot into continuous position data (x, y). It provides outstanding resolution (nanometer), fast response and excellent linearity for a wide range of light intensities.

The PSD has been utilized as the main component in a new type of anemometer that has been tested out during a winter season in Norway.

The results from the prototypetesting of the anemometer reveal an outstanding dynamic response together with reliability during severe climatic conditions.

The instrument can be classified as a " no moving parts" anemometer and the commercial version will be available on the market from December 2002.

1. Introduction

Sponsored by the Norwegian research council in 1998, TMI (Trondheim Maritime Instrumentation) started the development of an anemometer based on the opto-electronic device called PSD (Position Sensing Detector).

The main purpose was to construct a robust sensor with practical no moving parts, a wide dynamic range and an instrument that gave reliable data during extreme climatic conditions. Ordinary cup anemometers suffer from wearing during severe weather conditions resulting in high maintenance costs. Damages caused by extreme wind are common. More modern anemometers based on sonic principles often fail to give valid data when strong winds occur together with heavy precipitation. Icing of this type of instruments is also a significant problem at many locations.

This paper deals with the technology and principle for the new sensor that has been given the conceptual name OptoWind-100, later referred to as OW-100. Analyzed results from the first prototype testing during a winter season are also presented. A standard cup anemometer together with a wind vane was used for the reference measurements.

From the first field tests of the prototype the following can be concluded:

- The sensor reveals an excellent dynamic response
- No influence from heavy precipitation has been detected
- The threshold level (sensitivity) is better than expected

2. Measuring principle

A Position Sensing Detector (PSD) is an opto-electronic device (semiconductor chip) which converts an incident light spot into continuous position data (x, y). It provides outstanding resolution (nanometer), fast response and excellent linearity for a wide range of light intensities.

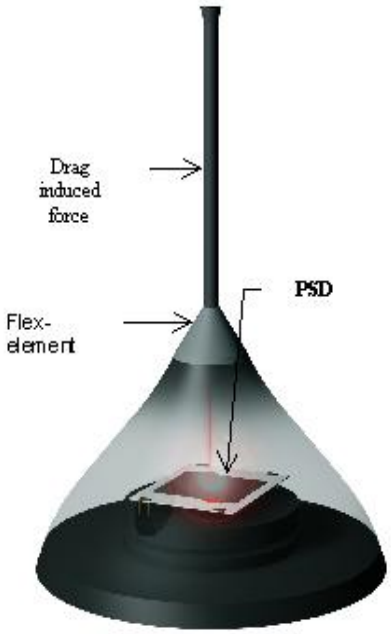


Figure 1 measuring principle

An illustration of the measuring principle is given in figure 1. The wind induced drag force tilts the stick slightly (in the order of 5° during hurricanes), and the x, y – position of the light spot emitted from the laser diode mounted on the lower end of the stick is detected by the PSD. The x, y – values are given as analog signals (voltages).

The signal conditioning electronics together with the microprocessor is housed inside the unit, and the output is a calculated wind speed and direction together raw data and some housekeeping parameters. The principle and design may seem simple, but the requirements with respect to material in the flex element and the optics of the sensor are strict.

Detailed technical specifications of the anemometer are given in chapter 5.

3. Theory of operation

Drag induced force

OptoWind is based on the drag induced force principle, and therefore can it be classified as a ***thrust anemometer***. The force exerted on a body in airflow depends in a complex way upon the velocity of the flow relative to the body, the viscosity and density of the medium, the shape of the body, and the roughness of its surface.

A cylinder (stick) which is exposed to a relative wind V_r experience a drag force F_D according the following formula:

$F_D = _ * _V_r^2 * A_s * C_D$ (1)

Where

V_r is the relative velocity
_ = density of air
A_s = cross sectional area of cylinder
C_D = the drag coefficient in air

The drag coefficient $\mathbf{C_D}$ is not constant. $\mathbf{C_D}$ depends upon the velocity of the body, viscosity of the medium, the shape of the body, and the roughness of the body's surface.

The **Reynolds number** has been found to be a useful dimensionless number that can characterize the drag coefficient's dependence upon the velocity. The Reynolds number is basically the ratio of the inertial force of the medium over its viscous force.

Re = r * L *V/h (2)
Re = Reynolds number (Dimensionless)
L = Characteristic length of the body along the direction of flow (m)
h = Dynamic Viscosity of the medium. (N s/$m^{2)}$
r = Density of the medium. (Kg/$m^{3)}$
v = Velocity of the body relative to the medium. (M/s)

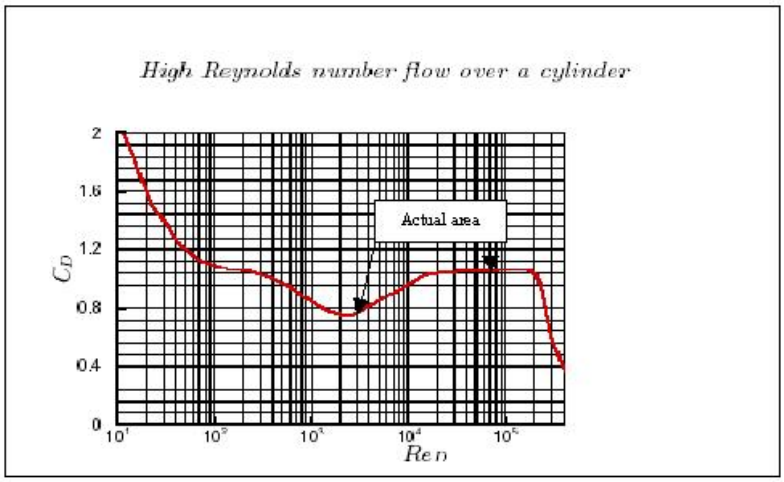


Figure 2 illustrates the drag coefficient as a function of the Reynolds number. Figure adapted from Cooper & Alley (1994)

For small values of the Reynolds number, called laminar flow since the flow is nonturbulant, the drag coefficient is inversely proportional to the velocity. This means that the drag force is only proportional to the body's velocity.

When the flow is turbulent the Reynolds number is large, and the drag coefficient $\mathbf{C_D}$ is approximately constant (see figure2). This is the quadratic model of fluid resistance, in that the drag force is dependent on the square of the velocity. In the design of the anemometer it has been important to strive for a constant C_D coefficient in order to simplify the calibration routines in the production. Preliminary test results indicate that we have succeeded in that respect.

The air density enters into the calibration of the anemometer, with the sensitivity to velocity being proportional to the square root of the density. The air density is inversely proportional to the absolute air temperature, and thus the speed calculations are subject to errors coupled to the temperature fluctuations, and in a similar way to, but to a lesser extent, to humidity variations. However, these errors are small enough to be neglected in most cases.

Sonic anemometers have a speed response which is proportional to the absolute temperature , while the thrust anemometers is proportional to the square root of the absolute temperature. Errors due to temperature fluctuations are therefore only half as large in thrust anemometers as in sonic anemometers.

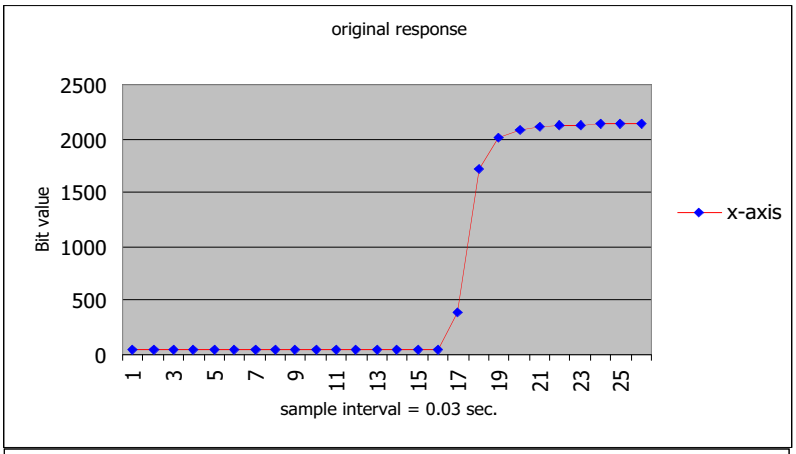
Response of anemometer

The response and sensitivity of OW-100 depends on various factors where the following are the most important:

- Damping and stiffness in the flex- element
- Weight and roughness of exposed stick
- Filtering in the electronics
- Size of light spot

During the laboratory tests various composite materials for the flex-element were investigated, and a priority list was made:

1. Material should keep the stiffness properties over a wide temperature range (-50 to +70° C)
2. Material should withstand UV radiation and other severe climatic conditions
3. The stiffness had to be within specified limits to fit actual measuring conditions



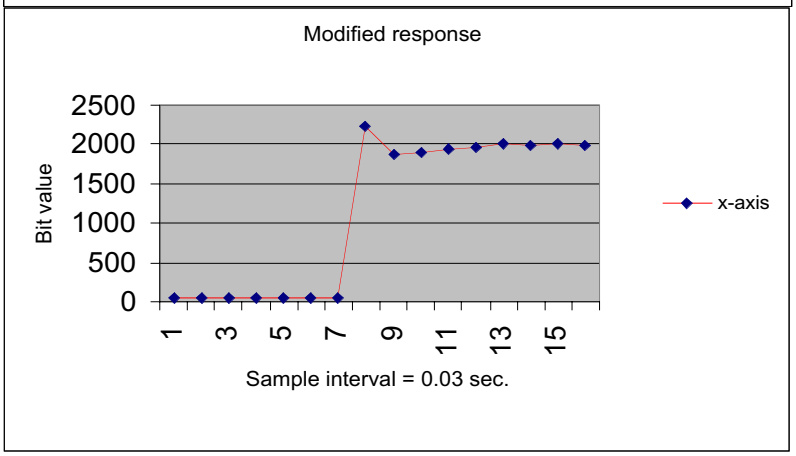


Figure 4 Noncritical damped response

OW-100 can be regarded as a second order oscillating system with a specific stiffness and damping constant. The analysis of the oscillating system is not outlined in this article, but a comprehensive study is given in a separate article.

Response time

Prior to final construction of the prototype instrument, the response of the sensor with various spring/damping constants and shapes of the flex-element was investigated thoroughly in the laboratory. The first tests revealed a critical damping with a time constant of approximately 0.06-sec. (63%). See figure 3. Modifications on the signal conditioning electronics gave a shorter time constant (0.017 sec.), but a small overshoot (appr. 10%). The modified response as presented in figure 4 was chosen for the first field measurements.

The response of the y –axis was the same as for the x-axis.

The initial laboratory tests comprised calibrations with respect to input force, threshold level (sensitivity), stability and repeatability. The results from these tests are given in chapter 5 (specifications).

Any change in the response of the sensor due to wearing or radiation was not seen after the field measurements (measuring period of 7 months). This indicates that the material in the flex-element is a proper choice.

As mentioned earlier, it is possible to adjust the response by varying different parameters. The only change that will be made on the first production series is the form and encapsulating of the flex-element. The test and final calibration of the first production units will be presented in a separate article when the wind tunnel testing has been completed.

4. Field measurements

Before the first production series of OW-100 are launched on the commercial market, the sensor must go through extensive field-testing. In order to reveal all weak points and malfunctions during harsh environmental conditions, the prototype was exposed to strong winds (hurricanes) together with heavy precipitation (snow and rain) last winter. This chapter deals with the results from the field tests. The sensor was mounted on the roof of Pirsenteret (located seaside in Trondheim) together with a reference station (cup anemometer). See picture to the left.

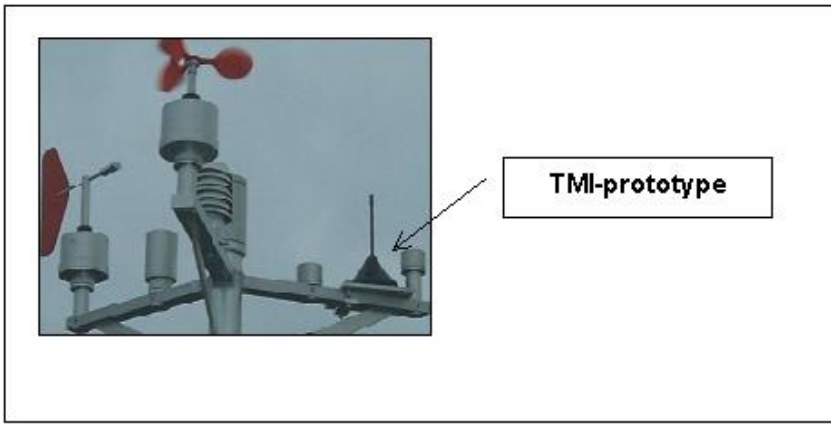


Figure 5 Installation of prototype and reference sensors

The results from the first field test are better than expected. While the reference station had to be replaced twice due to malfunction, the TMI-Sensor worked satisfactory throughout the 7 months test period. The analog output from the OW-100 was digitized with a sampling frequency of 1 Hz, and all data were stored on PC for later analysis and comparison with the reference data.

The reference station measured 1 minute averaged wind speed together with a 3-second wind speed gust. A wind vane detected the wind direction at the end of the averaging period.

In general it can be concluded that the both speed and direction correlated very good with the reference data during the test period.

The prototype instrument revealed an excellent dynamic response and sensitivity during the field tests. Any influence from heavy precipitation (snow and rain) was not seen during the test period.

The prototype sensor did not have any temperature compensation, which is needed for a correct calibration. The production units will be equipped with internal temperature sensor. However, the air temperature was recorded throughout the whole test period in order to reveal any unforeseen temperature effects.

The response of the prototype was measured prior to and after the field measurements. The instrument did not show any sign of degrading (aging) effects in the material of the flex-element.

In the following some characteristic samples from the recorded data are presented. Both analyzed data and raw data are presented.

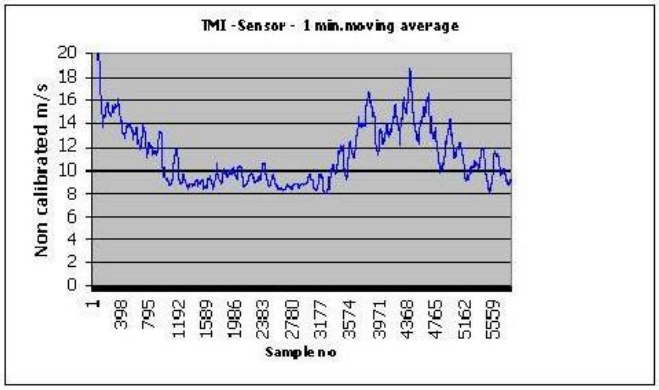
It is important to note that the results from the prototype anemometer are not calibrated values. The results are only used for a quality assessment of the sensor during different climatic conditions.

However, the non-calibrated values give a good indication of the performance with respect to sensitivity, dynamic range and repeatability

Data collected during periods with heavy precipitation

Totally 250 million samples of wind data from the prototype were collected during the first field-test.

The analog values from the prototype instrument (x- and y-component of the wind vector) were sampled at a rate of 1 Hz and stored on PC.



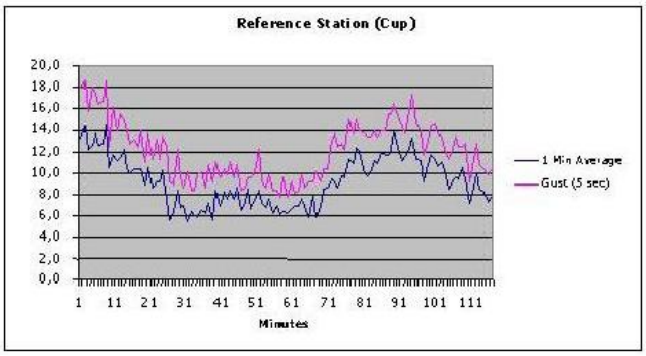


Figure 6 Heavy precipitation. Comparison with reference station.

Representative timeseries from a period with heavy precipitation is shown in figure 6 (left). A moving average with a window of 1 minute is applied on the data from the prototype. The averaged data correlate very good with the data from the reference station. Due to the squaring effect, the higher wind speeds are amplified, and apparently the prototype seems to have lower resolution at lower wind speeds. However, such effects will not be valid when the true calibration constants are established.

A detailed analysis of the collected raw data from the prototype instrument indicate that the maximum wind speeds during actual period (2 hours) is far higher than the values presented in figure 6. The low pass filtering effect caused by the averaging reduces the max. speeds by a factor of 70%.

However, any detailed analysis of the wind spectra by using measurements from the TMI-anemometer, will not be presented in this paper.

The preliminary results from the prototype indicate that the instrument performs satisfactory during conditions with heavy snow fall/rain, and no sign of degrading effects or skewness were seen during such conditions.

Acoustic anemometers based on the travel time difference principle would have failed to give any valid data during similar conditions.

Sensitivity and stability of sensor

In an early stage of the field test program it was clear that the prototype instrument gave reasonable wind data. An evaluation of the sensitivity and stability of the sensor was the main purpose with the first field tests. The prototype is designed to measure wind speeds up to 100 m/s and still be able to resolve speeds as low as 0.1 m/s. The averaged data presented in figure 8 confirm that the prototype is able to give reliable

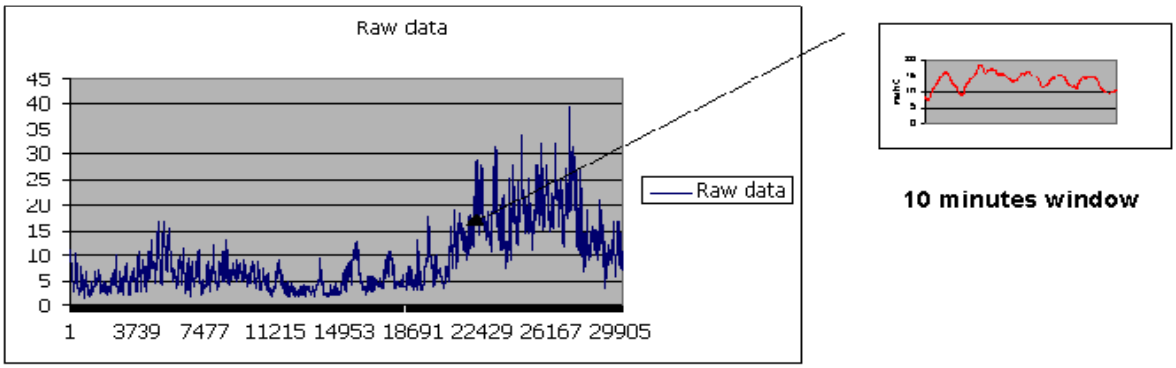


Figure 7 Structure of wind field (storm conditions)

and stable data within the aimed limits. As can be seen from the graphs, the sensor output is appr. 40 bits when wind reference speed is 4 m/s. This indicate that the sensor is accurate and stable in the lower end of the measuring range. Further laboratory tests (wind tunnel) are required to establish the correct and final resolution, but it is reasons to conclude that the sensor satisfies the specifications that were set in the design phase of the development project.

With respect to the maximum wind speed the sensor shall be able to measure, that is a question of mechanical design and electronics. As a first approach TMI will try 100 m/s. However, we have to remember the squaring effect (see chapter 3) when we reach high speeds. The squaring effect and the limited area of the PSD may reduce the maximum speed down to 90 m/s. Anyhow the new anemometer will be able to withstand wind speeds far above 100 m/s and still keep performance.

Calculation of wind direction

Wind direction is calculated by using unit vector summation. I.e. independent of wind speed .
Mean wind direction unit vector, θ_1 [1]:

$$\theta_1 = Arc\tan\left(U_x / U_y \right), \text{ Where } (3)$$

- $U_x = \dfrac{\sum \sin\theta_k}{N}$, and (4)
- $U_y = \dfrac{\sum \cos\theta_k}{N}$, and (5)

[1] This procedure will not give a unique solution for the wind direction, but will take care of the mean value around 0° / 360°. An additional test giving the quadrant of the angle is undertaken to find the exact direction.

- θ_k is a single measurement of wind direction (in degrees), and
- N is the number of measurements for the mean value calculation.

Comparison of wind direction data with reference station

The above method has been utilized to correlate the data from the prototype instrument with the wind directional data from the reference station.

While the direction from the reference wind vane is a momentary value at the end of the averaging period (1 minute), the direction obtained from the prototype instrument is a 1-minute smoothed value. Therefore it is not worthwhile to make any detailed correlation analysis, but the directional data are presented to give an impression of the stability of the x- and y-components measured by Optowind-100.

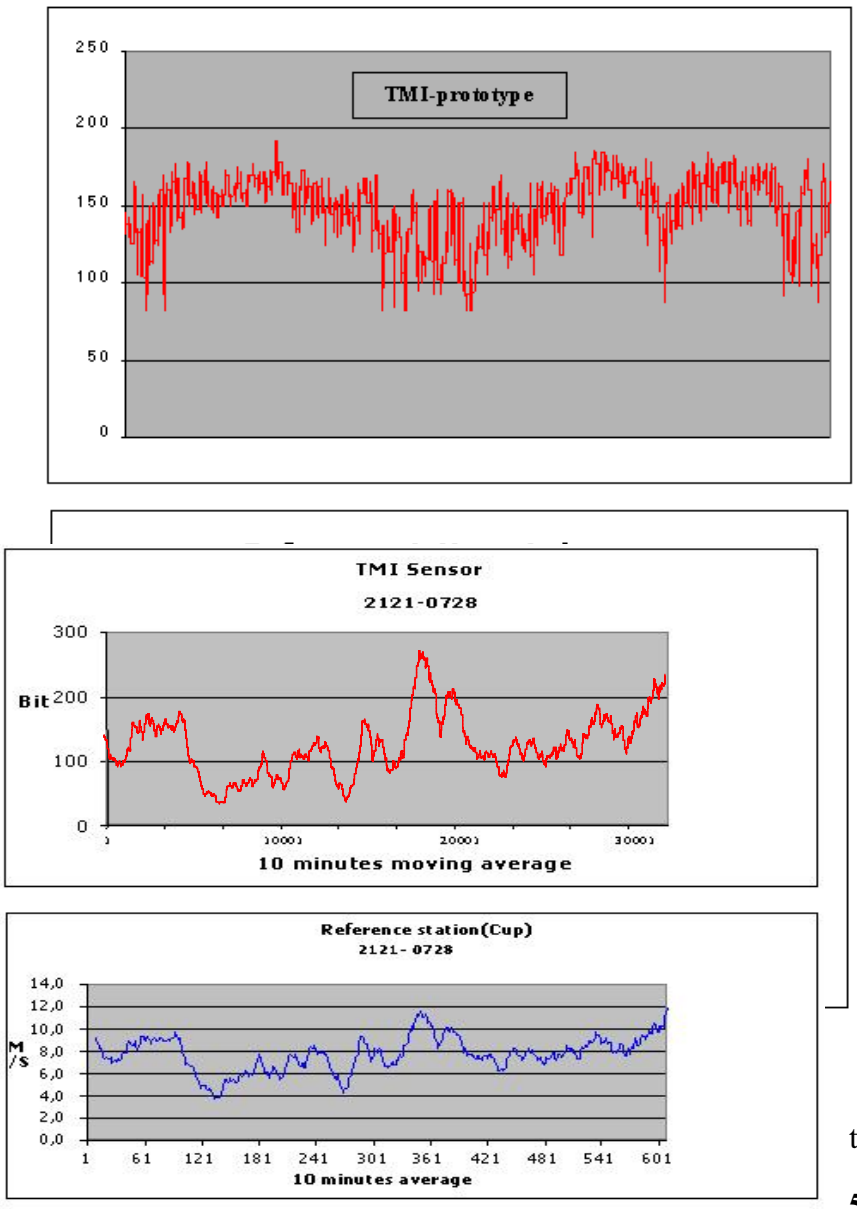


Figure 8 Comparison of 10 minutes averaged wind speed

Periods with strong wind have been chosen for presentation. The length of the timeseries presented in figure 9 (left) is approximately 10 hours.

The present prototype measures the x- and y-component of the wind vector, and the direction is calculated later from the recorded components.

The commercial version of OW-100 will calculate the direction for each sample based on above algorithms, and the direction is presented together with speed data using a standard protocol and telegram.

The specification of the standard protocol and data telegram is not finalized yet. However, TMI will design the first version on recommendations by the Meteorological Office in Norway.

5. Concluding remarks

OptoWind-100 represents a new commercial type of instruments for measuring wind speed and wind direction. The instrument can be regarded as a “no moving parts” type. The low weight and surface finishing of the housing makes deicing gear needless.

The preliminary results from the field tests indicate that this type of instrument will be a very good alternative to acoustic anemometers. While the sonic anemometers fail to give reliable data during conditions with heavy precipitation and also suffer from icing problems, the TMI-anemometer will provide valid wind data with a high time resolution. The new type of instrument will be available on the commercial market in autumn 2002.

MPS BUFR SOFTWARE FOR AWS

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The software developed by MPS system Ltd., Bratislava, Slovakia, is a software product for interactive processing of AWS data for encoding them into BUFR messages (WMO FM-94). It runs under 32-bit operating systems Microsoft Windows 95/98, NT4/2000. Main features of this encoding/decoding software are: generation and editing of BUFR templates (BUFR section 3) based on user requirements (Figure 1); automatic and/or manual data input into BUFR messages using BUFR templates (Figure 2), saving messages on a disk either in BUFR format or as a text file after decoding; sending BUFR messages into GTS (additional software module required). BUFR descriptors as well as code and flag tables are easily configurable. The software is very suitable for the implementation into PC connected with AWS to meet user requirements for new data from the AWS.

It is possible to connect BUFR Workshop to database (e.g. Microsoft Access, Microsoft SQL Server, MySQL etc.) and to insert data from database table into BUFR message. To read data from database following requirements have to be fulfilled:

- Proper ODBC driver has to be available and installed on local computer;
- ODBC data source has to be created on local computer using ODBC data source administrator.

The software is going to be used by SHMI for testing a new way of data transmission from AWS to the National Data Processing Centre.

Key words: *AWS data, BUFR code.*

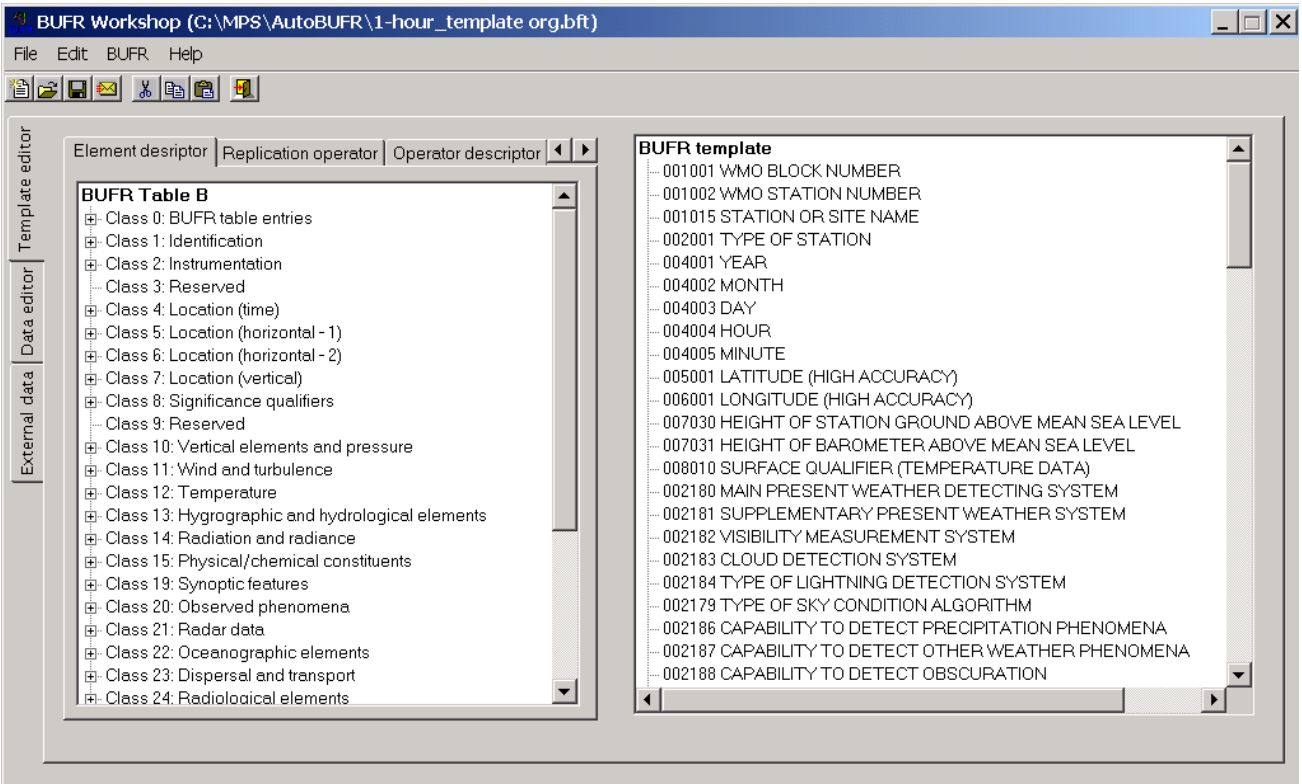
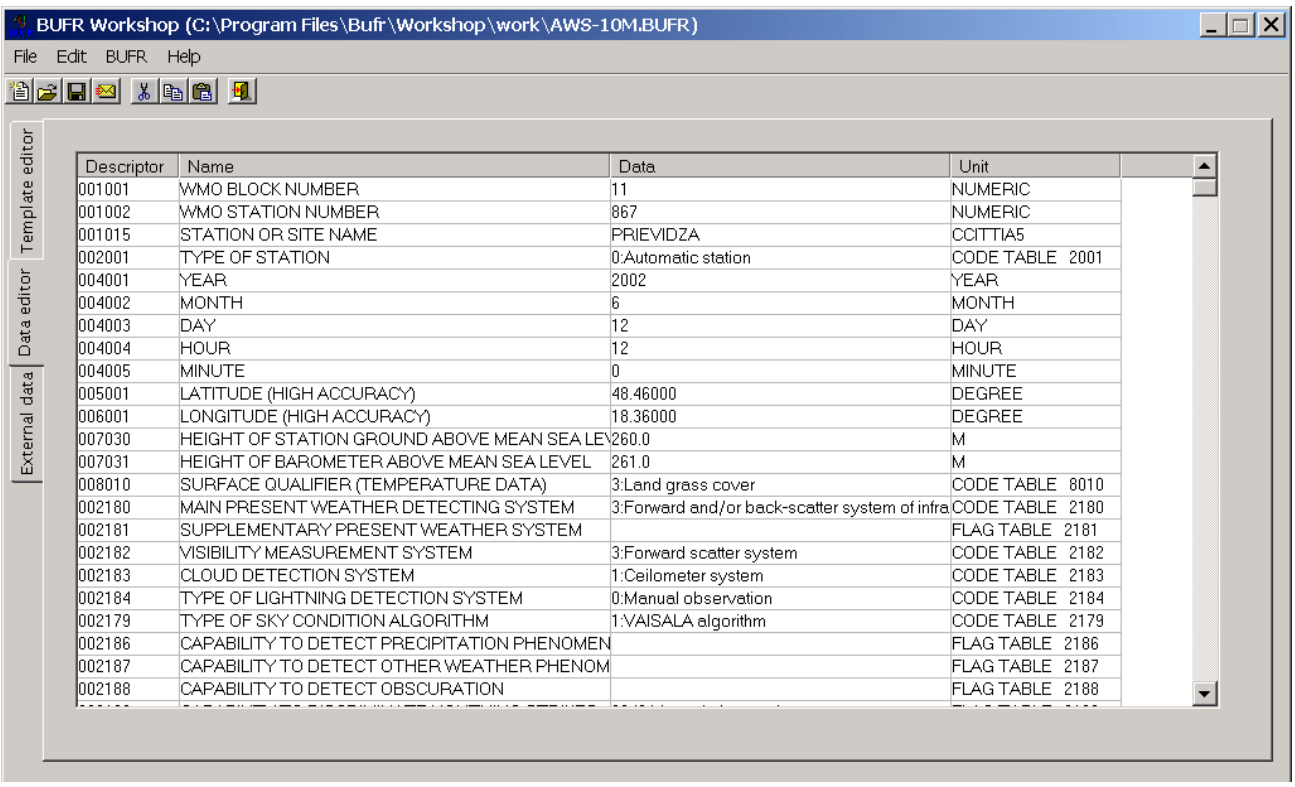


Figure 1: Template editor.



Descriptor	Name	Data	Unit
001001	WMO BLOCK NUMBER	11	NUMERIC
001002	WMO STATION NUMBER	867	NUMERIC
001015	STATION OR SITE NAME	PRIEVIDZA	CCITTIA5
002001	TYPE OF STATION	0:Automatic station	CODE TABLE 2001
004001	YEAR	2002	YEAR
004002	MONTH	6	MONTH
004003	DAY	12	DAY
004004	HOUR	12	HOUR
004005	MINUTE	0	MINUTE
005001	LATITUDE (HIGH ACCURACY)	48.46000	DEGREE
006001	LONGITUDE (HIGH ACCURACY)	18.36000	DEGREE
007030	HEIGHT OF STATION GROUND ABOVE MEAN SEA LE	260.0	M
007031	HEIGHT OF BAROMETER ABOVE MEAN SEA LEVEL	261.0	M
008010	SURFACE QUALIFIER (TEMPERATURE DATA)	3:Land grass cover	CODE TABLE 8010
002180	MAIN PRESENT WEATHER DETECTING SYSTEM	3:Forward and/or back-scatter system of infra	CODE TABLE 2180
002181	SUPPLEMENTARY PRESENT WEATHER SYSTEM		FLAG TABLE 2181
002182	VISIBILITY MEASUREMENT SYSTEM	3:Forward scatter system	CODE TABLE 2182
002183	CLOUD DETECTION SYSTEM	1:Ceilometer system	CODE TABLE 2183
002184	TYPE OF LIGHTNING DETECTION SYSTEM	0:Manual observation	CODE TABLE 2184
002179	TYPE OF SKY CONDITION ALGORITHM	1:VAISALA algorithm	CODE TABLE 2179
002186	CAPABILITY TO DETECT PRECIPITATION PHENOMEN		FLAG TABLE 2186
002187	CAPABILITY TO DETECT OTHER WEATHER PHENOM		FLAG TABLE 2187
002188	CAPABILITY TO DETECT OBSCURATION		FLAG TABLE 2188

Figure 2: Data editor.

METEOROLOGICAL AND SOLAR RADIATION RECORDING DATA FOR RENEWABLE ENERGIES AT C.I.B.A. LABORATORY, VALLADOLID, SPAIN

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Abstract: *The Department of Applied Physics of the Faculty of Sciences of Valladolid has a Renewable Energies Investigation Group since 1989. This Group has installed a weather and radiometric station in the Low Atmosphere Research Center (C.I.B.A.). Solar radiation at different bands is recording and another meteorological variables like temperature and relative humidity, rainfall and wind direction and speed are registered. The data acquisition system consist on CR23X Campbell dataloggers.*

The objective of this work is to describe the characteristics of the meteorological and radiometric station and show the most interesting results concerning to solar energy studies. From the recording data, parameters evaluation of the tilted diffuse solar radiation Perez model has been made; parametrization studies of ultraviolet solar radiation and PAR and horizontal global solar radiation correlations are made; calculation of Ultraviolet Indices (UVI) to prevention of the effects that this radiation causes on the human health; modelling of the infrared radiation for cloudless and clear skies from the horizontal global solar radiation, temperature and relative humidity; design of solar radiation isolines maps from data of Castile and Leon, including solar radiation measured in C.I.B.A. were performed.

Key words: *meteorological sensors, data acquisition systems, energy applications.*

1.- INTRODUCTION

When different climatic variables are evaluated from a place or region it is necessary to have a good measurement station to the correct data taking. Also, to know the solar energy availability in a certain place is necessary to have radiometric recording. There are several measures used to evaluate the meteorology or the solar energy availability in a place. They can be radiometric variable, such as global, thermal, ultraviolet radiation, etc., or meteorological variables, as temperature, humidity, wind speed, etc.

The sensors used to measure solar radiation can be of two types: pyranometers and pyrheliometers. These sensors convert solar energy in another type of energy, mainly electrical energy, so this last one can be measured of a simple form. This energy will depend of the inclination and the direction of the sensor, it is different to recording solar radiation in a on horizontal surfaces than in a vertical one.

In this work, the solar experimental device installed in the weather station place in the Low Atmosphere Research Center, (CIBA) is described of a concise form. Solar radiation sensors will be described with more detail, although we will give the main characteristics of the meteorological sensors.

2. - LOCATION AND SET UP OF THE C.I.B.A. STATION

The C.I.B.A. weather station, C.I.B.A. (2001), (Low Atmosphere Research Center) depends on the Applied Physics Department of the University of Valladolid, it is located to 40 km

from Valladolid, next to La Mudarra (to about three kilometres). This research center is managed jointly by the Meteorological National Institute (INM) and the University of Valladolid. This center is located to latitude of 41.82N, longitude of 4.93W and 845 m.a.s.l, so the climatological characteristics of the measurements are dry and sunny summers and cold winters.

The station is placed free of any obstacle (trees or constructions) that could make erroneous the measures. The vegetation is low, so it is the ideal site to locate a station of these characteristics (where it needs that there are not shades, reflections or other elements that modify the measures).

Initially, the main radiometric sensors were placed on a metallic flat platform, sustained by posts, to a height of 0,5 m and with 2 x 5 m dimensions. Due the vegetation increased around this platform, the sensors have been changed of place to avoid shades on them.

Figure 1. Radiometric and meteorological station.

At the present time, a similar structure to the previous one, Figure 1, was installed but located to a height of 1.5 m on the level of the ground. This height will eliminate possible shades on sensors. The structure has 2 x 5 m dimensions. It is made in stainless steel, to avoid deteriorate in the time, and has a grid, in the superior part, to avoid that rainwater remains on the surface. The great part of the installed sensors is located in this platform except the wind vane, the anemometer and the humidity and temperature probe. These sensors are located in a 10 m meteorological tower, behind the metallic structure. In Table I can be seen the installed sensors.

3. - MEASUREMENTS

3.1. - Solar global radiation measurements.

Six CM-11 Kipp&Zonen sensors are installed at C.I.B.A. These sensors measure horizontal and 42º tilted global and diffuse solar radiation in the 0.3-2.8 μm spectral range. At C.I.B.A. station two types of shade bands are installed to eliminate direct solar radiation from the sun:

Eppley model SBS shade band, installed on the horizontal diffuse solar radiation sensor, and the Kipp&Zonen model CM-C11/121 shade band installed on diffuse 42º tilted solar radiation sensor.

Pyranometers CM-C6B of Kipp&Zonen are used to measure solar radiation on vertical surfaces, Figure 2. These sensors, like the previous ones, measure in the 0.3-2.8 µm spectral range. They are installed on a stainless steel structure constructed to avoid possible deterioration with the time. A horizon band is used to avoid reflected from the ground radiation.

Table I. Number of sensors, sensor, variable name, trade sensor and model sensor places on the platform.

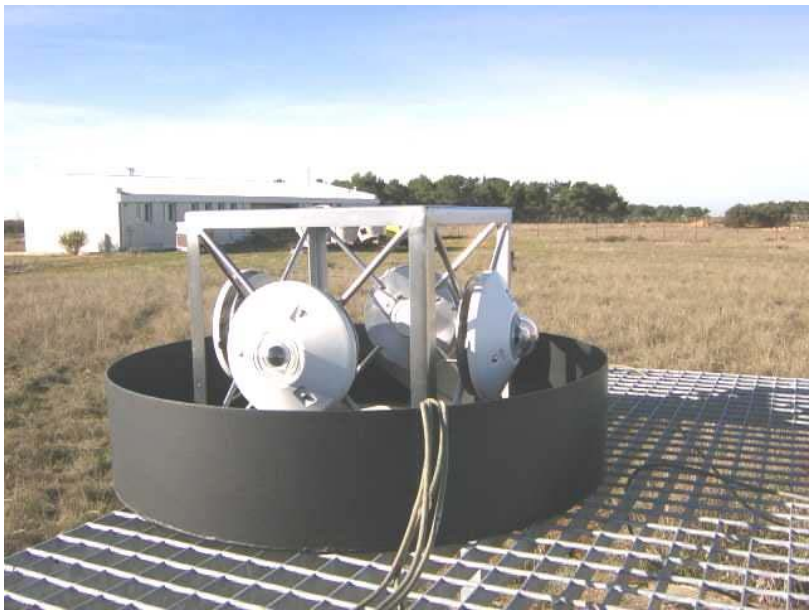
Number	Sensor	Variable	Brand name	Model
1	Pyranometer	Horizontal global radiation	Kipp&Zonen	CM-11
1	Pyranometer	Global radiation over 42º tilted surfaces	Kipp&Zonen	CM-11
1	Pyranometer	Horizontal diffuse radiation	Kipp&Zonen	CM-11 with shade band
1	Pyranometer	Diffuse radiation over 42º tilted surfaces	Kipp&Zonen	CM-11 with shade band
4	Pyranometer	Vertical global radiation	Kipp&Zonen	CM-6B
1	Albedometer	Ground reflectance	Kipp&Zonen	CM-14
6	Photometric sensor	Illumination	LICOR	Li-210SA
1	Pyrgeometer	Thermal radiation	Eppley	PIR
1	Quantum Sensor	Photosynthetic radiation	LICOR	190-SA
1	UV pyranometer	Total ultraviolet radiation	Eppley	TUVR
1	UV pyranometer	UV-B ultraviolet radiation	Yankee	UVB-1
1	Pyrheliometer	Direct radiation	Eppley	NIP
1	Temperature and relative humidity probe	Temperature and relative humidity	Campbell	HMP35AC

1	Rain gauge	Rain	Campbell	ARG100
1	Anemometer	Wind speed	Vector instruments	A100R
1	Potentiometer wind vane	Wind direction	Vector instruments	W200P

Validation and evaluation of diffuse solar radiation models on tilted surfaces has been made with data recording with these sensors. In addition, the coefficients of the tilted diffuse solar radiation Perez model, Perez et al., (1988), specific for Valladolid have been calculated.

The ground reflectance is registered with an albedometer CM-14 of Kipp&Zonen. The spectral range of this albedometer is 0.3-3.0 µm. The superior sensor measures global solar radiation from the sky, whereas the inferior sensor measures reflected from the ground solar radiation. With both sensors the ground reflection can be calculated as the ratio between the two values.

Figure 2. Vertical pyranometers facing north, south, east and west.



3.2. - Measurements in the Infrared Range

Another important measurement made in C.I.B.A. station, is the infrared radiation one, also denominated long wave radiation or infrared radiation. Two-sensor models PIR of Eppley are used for this kind of measures. The spectral band of these sensors is 3,5-50 µm. These sensors take built-in temperature compensating circuits to correct the emission of longwave radiation from the sensible cell. Instead of using these compensating circuits, the Albrecht and Cox (1977) correction is used, from the original measurement.

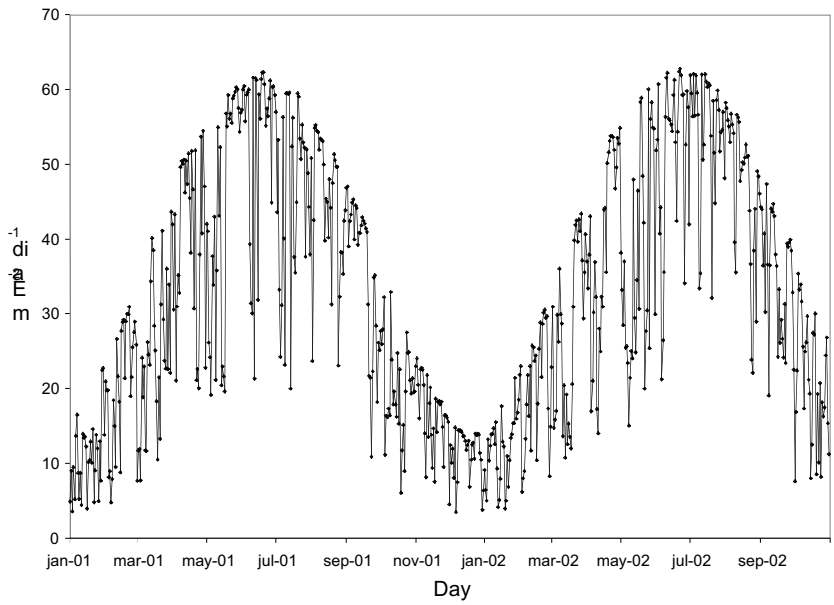
In C.I.B.A. station there are two pyrgeometers in order to measure downward (from the clouds) and upward (from the ground) longwave irradiance. Modelling infrared radiation for cloudless and overcast skies from global solar radiation, temperature and relative humidity, Niemelä et al., (2001), has been realized.

3.3. - Measurements in the Visible Range

A Li-190SA LICOR sensor is used to measure in the visible range (400-700 nm). This sensor is designed to measure photosynthetically active radiation (PAR) in places where the space distribution of the radiation is not uniform, mainly under plants and trees leaves. This sensor measures photosynthetic photon flux density (PPFD) in the visible range, and therefore contributes to the photosynthetically active radiation.

This sensor is used by ecological scientists, meteorologists, horticulturists, environmental groups and other scientists, to measure PPFD in the atmosphere and in greenhouses. Figure 3 shows the daily values of photosynthetically active radiation at C.I.B.A, Valladolid. Maximum values of 62 $Em^{-2}dia^{-1}$ are registered in July and minimum values of 4 $Em^{-2}dia^{-1}$ are observed in January.

Figure 3. Daily values of photosynthetically active radiation (PAR), 2001-2002.



Relations between photosynthetically active radiation (PAR) and the horizontal global solar radiation, Howell and Meek (1983) have been studied.

3.4. - Measurements in the Ultraviolet Range

The ultraviolet solar radiation can be divided in several zones of the spectrum, depending on the wavelength and the discipline considered. So, three principal subdivisions can be made: UVC radiation, 100-280 nm, totally absorbed by the stratospheric ozone (O_3) before arrive to the terrestrial surface; UVB radiation, 280-315 nm, partially absorbed by the atmosphere. The principal absorbents of this radiation are the nucleic and aromatic acids; finally, the UVA radiation, 315-400 nm. which is absorbed by proteins and ADN. Another classification, studied principally for doctors and biologists, would include the erythemal solar radiation range, 290-315 nm.

Two sensors for the measurement of the ultraviolet solar radiation are used on C.I.B.A. station, which can be seen in Figure 4. The TUVR sensor of Eppley measures in the spectral range 0.295-0.385 μm. This range includes UVB and UVA solar radiation.

Another used sensor is the ultraviolet solar radiation pyranometer model UVB-1 of Yankee, which measures in the range 280-315 nm. The stratospheric ozone absorbs in this part of the spectrum, for what any variation of this atmosphere component leads to increases the ultraviolet B solar radiation on the terrestrial surface. This spectrum is very similar to the erythemal action spectrum, so it is ideal for climatological and biological studies.

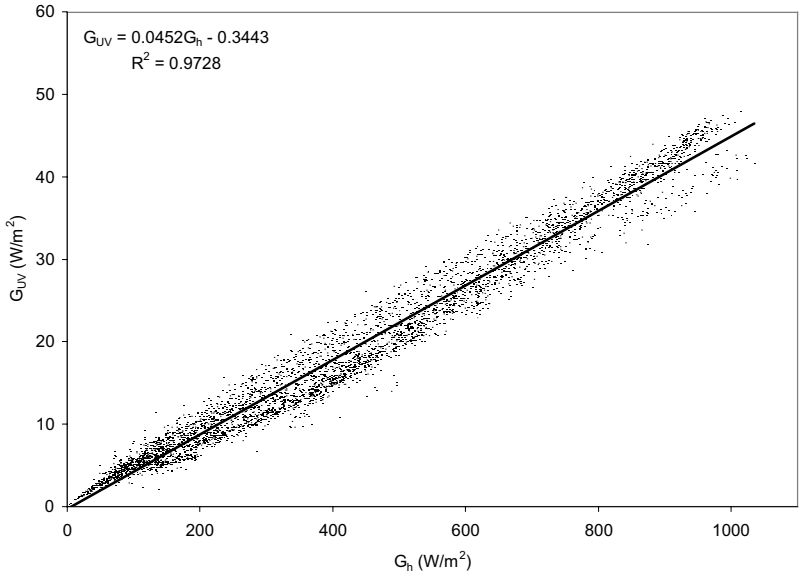
With these sensors data have been studied the relation between ultraviolet solar radiation (TUVR pyranometer) and the horizontal global solar radiation or the air optical mass, Martínez-Lozano et al., (1994); effects on the living creatures (UVB pyranometer), Diffey (1991); and information can be provided to the general public about the risks of UVB radiation from the Ultraviolet Indices (UVI), Martínez-Lozano et al., (2002).

Figure 4. (a) Total ultraviolet solar radiation pyranometer model TUVR of Eppley. (b) Ultraviolet B solar radiation pyranometer model UVB-1 of Yankee.

(a) ***(b)***

Figure 5 shows the scatterplot between ultraviolet solar radiation and the global solar radiation. It is observed that the ultraviolet solar radiation on the terrestrial surface represents 4.5 % of the horizontal global solar radiation. This study has been realised using data of 2001-2002 years recording on the C.I.B.A. station, Valladolid, dividing in clear and clouds days from the clearness index values.

Figure 5. Ultraviolet solar radiation in front of horizontal global solar radiation in C.I.B.A., Valladolid. The percentage between ultraviolet and global solar radiation is 4.5%.



3.5. - Illuminance Measurements

Illuminance measurements are realised by six Li-210SA sensors of LICOR. Four of these sensors are placed to measure vertical illuminance with a similar structure of the vertical pyranometers, but made of methacrylate. Another sensor measures horizontal solar illuminance, whereas the last one measures diffuse solar illuminance. A shade band is being made in order to eliminate the direct illuminance from the sun.

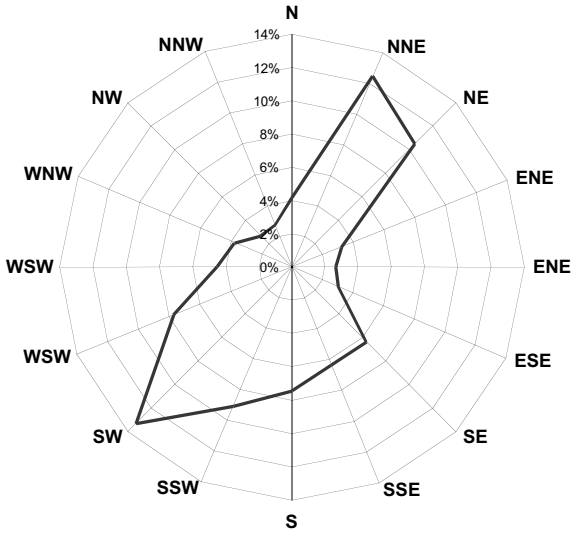
These sensors measure luxes (1 photocandle = 10.764 luxes). The spectral response curve of this sensor is similar to the human eye one. This sensor is used to realise studies of natural illuminance in architecture and has been used to calculate Perez's coefficients, Robledo and Soler (1998), adapted for illuminance, so illuminance in any surface can be evaluated.

3.6. - Another measurements

Besides measurements in different solar spectrum bands, measurements of rainfall, relative humidity, temperature, wind direction and wind speed are realised. The rainfall is measured with an ARG100 rain gauge of Campbell. The temperature and relative humidity is registered with a HMP35AC temperature and relative humidity probe of Campbell. This probe presents a precision termistor for the temperature measurement and another sensor for the relative humidity determination. This probe is placed inside a 41005-5 cover of Campbell. The wind speed measurement is realised by an A100R anemometer of Vector Instruments. To measure the wind direction a W200P wind vane of Vector Instruments is used. These two sensors, together the temperature and relative humidity probe are placed in the meteorological tower.

In Figure 6 can be seen that the predominant wind direction is the Southwest (SW). This annual wind rose has the typical form of arrow, indicating the privileged direction.

Figure 6. Annual wind rose in C.I.B.A., Valladolid. 2001-2002.

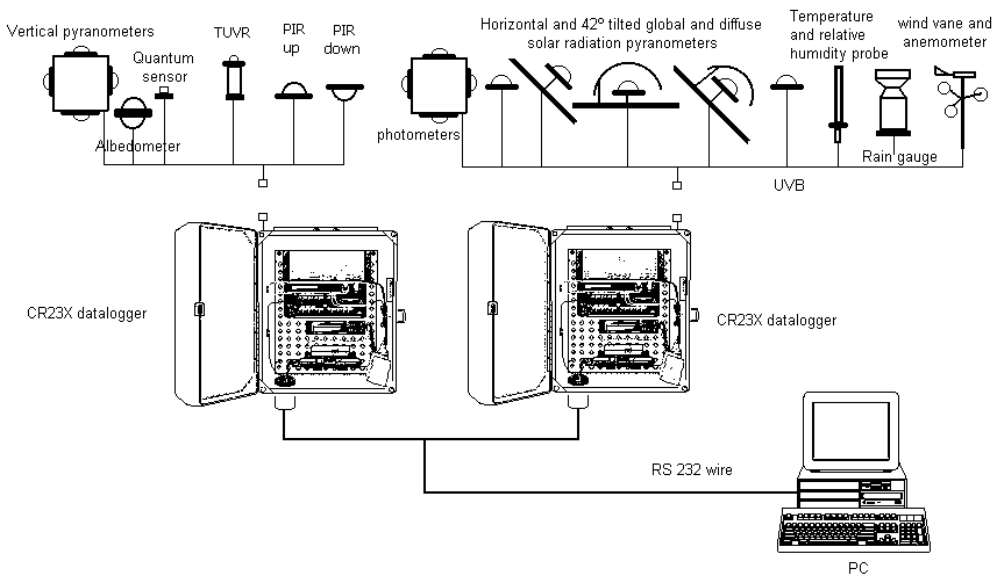


4. - DATA ACQUISITION SYSTEM

A data acquisition system is a device that program and control different sensors, and register and store the different measurements. The mayor part of the sensors generate an electrical sign when interact with a physical system that, translated into a tension sign, is registered by the datalogger. This tension, in general, is proportional to the magnitude that wants to be measured.

The data acquisition systems used in the C.I.B.A station are two CR23X Campbell dataloggers, Figure 8. A sketch of the sensors and the data acquisition system used in C.I.B.A can be observed in Figure 7. The information is registered every 30 s and averaged and stored every 10 min and every hour.

Figure 7. Experimental set-up of the C.I.B.A. station.



The CR23X Campbell datalogger, Campbell (2002), communicates via modems, reduces data, controls external devices, and stores both data and programs in memory. The 1 Mbytes memory stores 500,000 data points in two final storage areas. The CR23X's operating system includes a comprehensive set of measurement, processing, and output/program control instructions to create a datalogger program. Most signal sensors can be measured directly by the CR23X datalogger; Terminal Input Modules (TIMs) and other interfaces provide signal conditioning for specialised sensors.

Processing instructions support algebraic, statistical and transcendental functions allowing data reduction on-site. Output/program control instructions control external devices and process data over time (e.g., averages, maxima, minima, histograms, FFTs). The maximum rate the CR23X can execute its program is 100 times per second. A battery-backed clock assures accurate timekeeping. The multi-tasking operating system allows simultaneous communication and measurement functions.

Figure 8. CR23X Campbell datalogger.

5. - SENSOR MAINTENANCE

For the measurement sensors is not necessary a great maintenance. In fact, frequent dome sensor cleaning activities is sufficient to have in perfect conditions the sensors. The diffuse solar radiation sensor shade bands are adjusted continuously to cover all time the solar path.

Deposition of frost on the radiometric measurement sensors is a serious problem. In order to avoid spurious measurements, pyrgeometers and pyranometers domes have to be cleaned every morning. Especially in pyrgeometers, because a small ice layer on the dome can to perturbed the real measurements. Quantum and photometric sensors do not have domes, so in these sensors, water deposition are more likely that in pyranometers and pyrgeometers, resulting that small ice layers can blind these sensors in an easier way.

6. - DATA QUALITY CONTROL

To use the registers, a criterion has to be established to eliminate those registries that do not adjust to the reality. The criterion developed by Kambezidis (1997) has been followed in the C.I.B.A. station.

The radiation values follow the next criteria:

- Horizontal or tilted diffuse solar irradiance registries greater than 1.1 times the corresponding value of horizontal or inclined global solar radiation, respectively, has been rejected.
- Horizontal and tilted global solar irradiance values greater than 1.2 times the solar constant, also have been eliminated.
- In addition, diffuse solar irradiance values greater than 0.8 times the solar constant have been despised.

Another criterion that is applied to data is the Miskolczi et al., (1997) one, according to which irradiance data corresponding to angles of solar elevation, h, minors of 10º are eliminated.

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THE AGROCLIMATIC INFORMATION NETWORK OF ANDALUSIA

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ABSTRACT

The Agroclimatic *Information Network of Andalusia is composed* of *89 AWS spread* over *800000 has of irrigated area and show*s daily *information in the web of the Department of Agriculture and Fisheries of the Andalusian Government:*

http:// www.cap.junta -andalucia.es.

Set up *during 1999-2001,* it is at present keeping to *the protocols and procedures developed by the Dpto of Soil and Irrigation of CIFA "Alameda del Obispo"of the D.G:I.F.A of the Andalusian Government, with technical assistance* from the *Public Company for the development of Agriculture and Fishing in Andalusia, S. A. (D.a.p.)*

This paper describes the events and strategies followed *during these past two years* with regard to *environmental and sensor control, data* dissemination/leakage *and the us*age *level of the information* collected*,which is targeted to*wards the obtaining of *useful and reliable meteorological information and agroclimatic estimations.*

Key words: *Automated Weather Stations (AWS), Agroclimatic Information Network of Andalusia, Agroclimatic Information*

1. BACKGROUND

The agroclimatic information network of Andalusia is at present made up of 89 automated weather stations spread over 800,000 has. of irrigated area in the Andalusian community.

Set up during 1999-2001 with funds from the European Community and by the Ministry of Agriculture and Fisheries (Interreg IIC), it is part of a more extensive project which aims to provide several autonomous communities with this infrastructure.

The ultimate objective is to supply qualitied agroclimatic information permitting a more rational use of water by means of the adaptation of irrigation to the hydric needs of crops.

In our community, with an endemic deficiency in this resource, this optimization of the use of water is especially necessary since, also, in many areas sectors such as tourism and agriculture coincide, with activities which imply its consumption in large amounts.

The sustainable development of agriculture as a disseminating element of the population in respecting the natural environment has encouraged the Department of Agriculture and Fisheries of the Autonomous Government of Andalusia to initiate assessment policies for irrigators and to assign part of its budget in order for the agroclimatic information network to

fulfill the conditions necessary for it to be a basic tool in this process of modernization and optimization of agricultural activity.

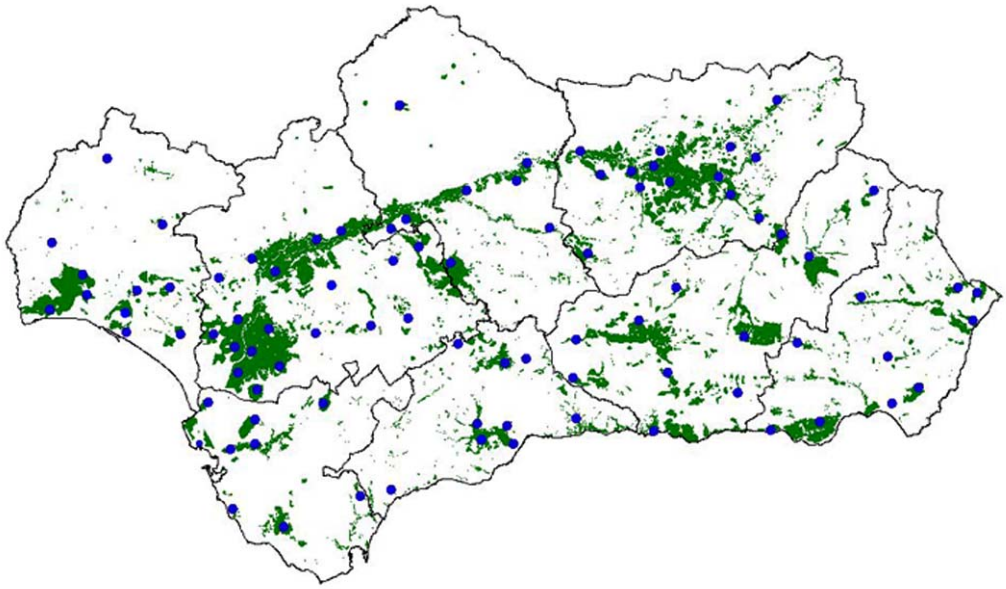
2. WORKING STRUCTURE

2.1 Location of the stations

Since the main objective of the network is to provide information permitting the optimization of the use of irrigation water, the orientation of the locations proposed was based on a preliminary work on the characterisation in our community of the different regions of ETO and its irrigation areas. These studies were made by the Department of Agriculture and Fisheries in collaboration with D.a.p. (Moreno F. 2001).

The final location of the stations can be seen on the map

Figure 1 Location of the 89 stations of the AIN of Andalusia.



2.2 Installations

All the network stations have the same installations and incorporate the same group of sensors. An enclosureof 10 x 10 m composed of a fence 1.5 m high with three rows of barbed wire. The tripod, in which the sensors are fixed, is situated in the centre of the fencing and is housed in a hut containing the battery, which is recharged by a solar panel.

The sensors installed are an wind monitor, a pyranometer, a moisture and temperature probe, and a pluviometer. The characteristics and precision are shown in the table.

Figure 2 Weather stations of Palma del Rio (Córdoba)

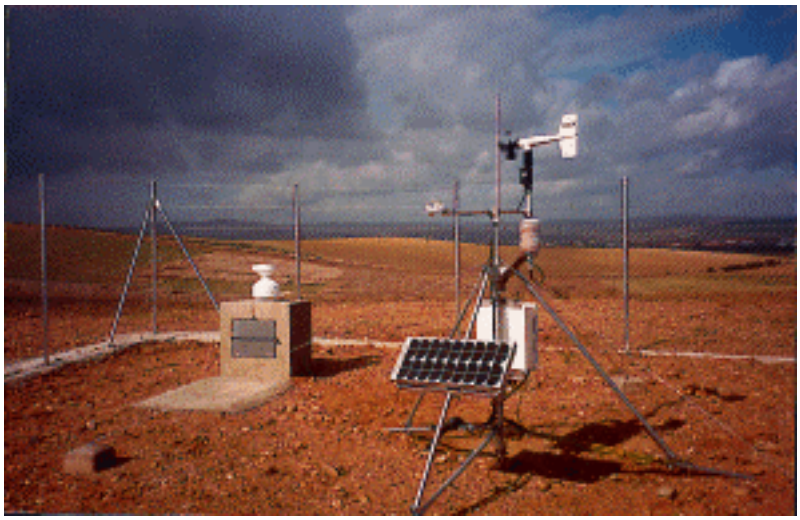


Table I Characteristics of the sensors installed.

Temperature and Relative Humidity Probe HPM45C Vaisala		
Sensor	Accuracy	Measurement range
PT1000 Vaisala HUMICAP 180	±0.2ºC ±2%0-90%; ± 3% 90-100%	-39ºC-60ºC 0.8-100%
Wind Monitor RM Young modelo 05103		
Wind speed		
	±0.3 $m.s^{-1}$ 1-60 $m.s^{-1}$ ±1 $m.s^{-1}$ 60-100 $m.s^{-1}$	0-60 $m.s^{-1}$
Wind direction		
	±3º	0-355
Solar Radiation Sensor SP1110 Skye		
	±5%	350-1100nm
Tipping Bucket Raingauge ARG100		
0.2 mm / tip		

The frequency of the sampling for the radiation, pluviometry, speed and direction of the wind is 10 seconds, and every 10 minutes a sample of the moisture and temperature is taken.

All the data are averaged every half hour and daily, and the variables described are stored in the table II

Table II Type of variables stored in the database.

Registros horarios	Registros diarios 1	Registros diarios 2
Province	Province	Province
Station	Station	Station
Year	Year	Year
Day of Year	Day of Year	Day of Year
Hour:Minute	Hora:Minuto	Calm(%); Vel < 0.5 $m.s^{-1}$
Mean Air Temperature ºC	Mean Air Temperature ºC	No Calm (%); Vel > 0.5 $m.s^{-1}$
Mean Relative Humidity %	Max Mean Air Temperature ºC	Temperature [-40,-30]
Mean Win Speed [ms^{-1}]	Max Temp Hour:Minute	Temperature [-30,-20]
Mean Win Direcction ºC	Min Air Temperature	Temperature [-20,-10]
Mean Radiation [wm^{-2}]	Min Temp Hour:Minute	Temperature [-10,0]
Total Rainfall [mm]	Mean Relative Humidity %	Temperature [0,10]
Mean box´s Temperature ºC	Max Relative Humidity % %	Temperature [10,20]
	Max Relative Humidity Hour:Minute	Temperature [20,30]
	Min Relative Humidity %	Temperature [30,40]
	Min Relative Humidity Hour:Minute	Temperature [40,50]
	Mean Win Speed [$m.s^{-1}$]	Temperature [50,60]
	Wind Direcction media º	
	Max Wind Speed [$m.s^{-1}$]	
	Max Speed Hour:Min	
	Vmax Wind Direction º	
	Rainfall [mm]	
	Total Radiation[$MJ.m^{-2}$]	
	BatteryV	

As well as the sensors and measurement elements, the stations are equipped to communicate the data stored to the receiving centre by cell phone.

2.3 Data receiving centre

Located in the Department of Information Technology of the Department of Agriculture and Fisheries of the Government of Andalusia in Seville, this comprises a server in charge of sequentially calling each of the stations and managing the download. The call is made during the night with three repetitions per station. If it is not possible to establish any communication the download is postponed until the next day.

Once the data from the 89 stations is downloaded this triggers a process for their incorporation into a database, which is the one supplying the climatic variables shown on the web page of the Department of Agriculture and Fisheries of the Andalusian government.

So that the ETo is calculated in such a way that any change or modification in the database is reflected in this calculation, a Java routine has been programmed and this is executed every time a user enters the page.

This data-receiving centre is responsible for making safety copies (weekly) of the database. Moreover, the Ministry of Agriculture and Fisheries, in collaboration with Tragsatec, is in charge of making new copies in the data-receiving centres of the different autonomous communities.

2.4 Zone Centre

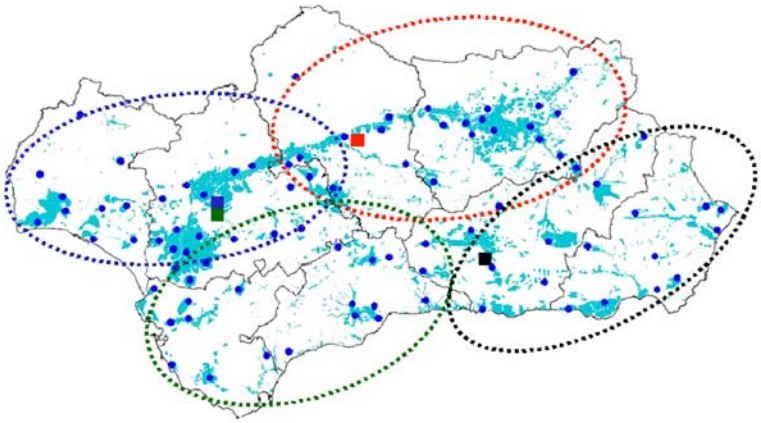
Situated in the Provincial Office of Córdoba of D.a.p., this is where the tasks of the coordination, exploitation and maintenance of the network are carried out, in collaboration with the Department of Soils and Irrigation of the CIFA, Alameda del Obispo, in Córdoba,

which belongs to the DGIFA of the Department of Agriculture and Fisheries of the Andalusian government.

2.5 Staff

The maintenance staff is made up of four experts who are in charge of controlling the areas and of the measurement elements. Each of them is responsible for an area which can be seen in the figure.

Figure Area of influence of the maintenance experts



Three work centres, Córdoba, Granada and Seville, have been established to accommodate the travelling times and the optimization of the frequency of visits.

As well as the maintenance staff, the team is completed with two graduate in engineering, in the tasks of coordination, and of exploitation and maintenance of the data, respectively.

3. WORK PLAN

3.1 Objectives

Although in Spain and in our community there are several weather networks which record meteorological information, the Agroclimatic Information Network of Andalusia has been especially conceived and installed to supply information of agricultural usefulness, which can be compatible with other initiatives developed by the Department of Agriculture and Fisheries of the government of Andalusia in collaboration with D.a.p. aimed at improving the use and management of water for irrigations.

The main objective proposed in this network is to supply information which is:

- Reliable, by means of the triggering of control mechanisms at different levels.
- Useful, by taking into consideration the contributions made by users.
- Easily accessible, using Internet as a medium and setting up pages which permit an access to information of interest in few steps.

3.2 Materials and Methods

It is a basic fact that the information supplied should have a sufficient degree of quality for it to be used with adequate confidence. For this purpose, a plan is under way which has the

specific objective of achieving an acceptable level of control of the different aspects influencing the quality of the data stored.

The levels established have been divided into three areas, including:

1- Control of the entry sensors and Calibration
2- Activity of maintaining the network and the zone centre
3- Agrometeorological exploitation and dissemination of the climatic information.

3.2.1 Control of the entry sensors and Calibration

By means of the comparison of the values of the sensors entering the Agroclimatic Information Network of Andalusia, with other reference sensors, calibrated and traced, with an annual periodicity.

These reference sensors permit us:

- To verify the values of the sensors entering the AIN of Andalusia
- To periodically control the portable sensors used by the maintenance experts for the specific control of the sensors and measurement elements of the stations in their periodical maintenance activities.
- To control the sensors calibrated before their re-installation.

Calibration is carried out annually. In the moisture sensors, the salt method is followed with at least three calibration points. In the rest of the sensors, the values obtained are compared with other reference sensors, calibrated and traced and the coefficient of calibration is modified.

3.2 2 Activity of maintaining the network and the zone centre

This is done at three levels:

- Periodical preventive conservation maintenance
- Annual maintenance
- Maintenance of incidents, attending to any contingency related to the correct working and conservation both of the instruments and of the enclosure.

This includes both the sensors and the environment. If these, on certain occasions and at different times of the year, do not receive adequate attention, they can have a great influence on the quality of the data.

A control of the vegetation and of invertebrates and their nesting are basic to prevent any deterioration of the sensors and to ensure acceptable conditions in the measurement surroundings.

The sensor control activities included in the maintenance tasks are carried out:

- Monthly. Comparison of the specific values of the sensors with other calibrated portable reference sensors. These sensors are verified every two months with others of more precision, calibrated and traced.

It is aimed to show any permanent failures in the sensors.

- Annually. Intalling in parallel sensors of the same characteristics as those installed but controlling them every two months with others, calibrated and traced. Data are collected in parallel with the same sampling frequency so that after two weeks any sporadic failures in the sensors or exhaustion phenomena can be seen. The analysis follows the methodology proposed in the FAO 56 manual (Allen et all. 1998).

Figure 4. Sensors installed in parallel in some of the locations of the AIN

3.2.3. Agrometeorological exploitation and dissemination of climatic information.

After the daily collection of climatic information by means of an automatic call to the stations, and its incorporation into a database management system, the following daily controls are made.

The stations which have not been able to connect up and the time that this situation persists are revised in order to establish priorities in the visits of the maintenance experts.

The values of all the stations are revised so that values above or below the threshold values can be shown. The maximum/minimum monthly historic value and the maximum detection limits for each sensor have been established as threshold values.

The values of each of the variables are represented in a GIS in order to study its geographical agreement. This is especially useful in rain records.

The data are disseminated/leaked following the recommendations of the guide for the world system of data processing(OMM,2001).

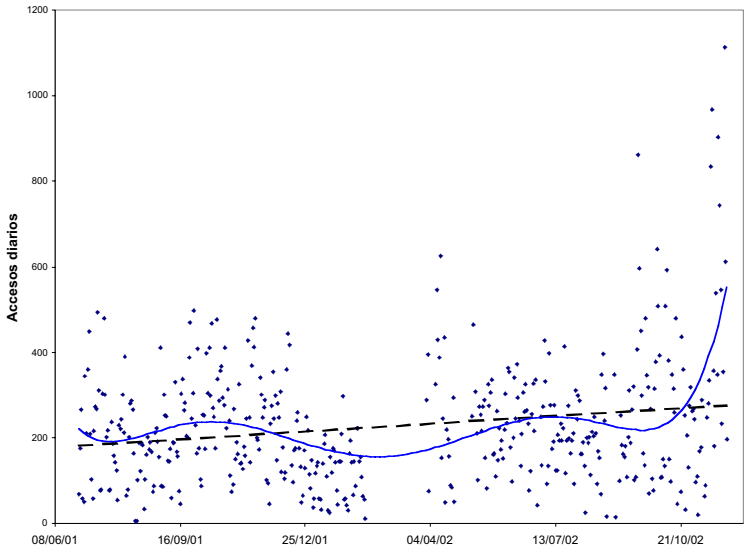
After this process of leaking/dissemination the data considered to be erroneous are eliminated and doubtful data marked. Every modification is recorded as a metadatum, including the reasons for its elimination or doubtfulness.

The calculation of the ETo is carried out following the Penman-Monteith FAO-56 equation by means of a routine in Java, which is triggered every time a user visits the page. In this way,

all the modifications and incorporations are immediately reflected in the calculation of the ETo.

Finally, and in order to establish a really useful service for farmers, a line of information is kept up of the preferences and needs of the sector through a suggestions e-mail address and a daily control of visits to the page.

Figure 5 Graphic of visits to the stations page.



Show a constant increase of access and a slight seasonal tendency with reference to the maximum values of annual visits. This seems to be related to rainfall periods and seasons with special hydric needs of crops in irrigation farming

4 CONCLUSIONS

During this two years the AIN of Andalusía is been a basic tool in process of modernization and optimization of agricultural activity and a more rational use of water. Provide agroclimatic information every day with a reliability upper to 90%, in the web of the web of the Department of Agriculture and Fisheries of the Andalusian Government.
Actually is been developing tools for improve the quality of data and a constant adaptation o the information showed to farmers requeriment.

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ON-LINE PSYCHROMETER SUITABLE FOR CONTINUOUS OPERATION AND DATA ACQUISITION

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Abstract

The psychrometric technique is still now a well appreciated calibration standard for humidity sensors. Its cumbersome use can be greatly simplified if it is used in the original configuration we have proposed time ago. Finally an on-line data acquisition system now under control of a LabView code allows real time and remote archiving of the data.

We will describe how to properly build the instrument in order to guarantee its intrinsic accuracy (typical uncertainty of 2%) and its integration in a general purpose ground based weather station. Over one month of unattended operation can be obtained in almost any climate, also if it is moderately below the freezing point.

The psychrometer development was found to be a very powerful tool as a "project work" for university students following the "Atmospheric Measurement Laboratory".

Key words: *humidity sensors, sensor calibration, data acquisition*

1. PSYCHROMETER VERSUS OTHER HUMIDITY SENSORS

Humidity is one of the most difficult parameters to be measured in the boundary layer.

Depending on the field of use, the physical quantity "humidity" is usually expressed with different units: *absolute humidity* (mass of water / unit of volume), *specific humidity* (mass of water / total mass of air), *relative humidity* (vapour pressure / vapour pressure in saturated air at the same temperature and pressure). Again different techniques are used to sense *mean humidity* and *humidity fluctuations* (1,2).

In the first category of measurements, the most classical one is the dew point hygrometer.

A mirror surface is cooled until it reaches the temperature when the moisture in the air begins to condense and the mirror gets misted. Then the mirror is heated until the water film starts to disappear. If the time response of the servo system controlling the temperature is properly adjusted, the temperature reaches equilibrium, called "dew point", typically within a few tens of seconds.

The implementation of this instrument is delicate, mainly for keeping clean the mirror, then it needs periodical re-calibration.

New transducers are cheaper and easier to use, particularly in on-line data acquisition systems. They respond to humidity variations with changes in resistance or capacitance, or both of them. Typically, they are assembled within an electronic microcircuit that provides a voltage proportional to relative humidity. These sensors have good spatial resolution, while their common limits are hysteresis, propensity to contamination, ageing, loss of accuracy at high relative humidity values (near 95%).

For monitoring humidity fluctuations, fast response sensors are needed. There are substantially three different types of instruments: the infrared hygrometer; the Lyman-alpha hygrometer and the microwave refractometer.

The *infrared hygrometer* measures humidity through differential measurements of infrared transmittance at two adjacent wavelengths, one in the region of high water vapour absorption, and the other where the absorption is negligible. Typical paths are 20 cm.

The *Lyman-alfa hygrometer* works by the same physical principle, but with ultraviolet radiation; in the atmosphere the only gases absorbing UV are oxygen, ozone and water, but at the Lyman-alfa wavelength (0.12156 μm), the oxygen and ozone absorption are negligible in the boundary layer, while the water absorption is very strong, making possible to sense water vapour fluctuations without contamination by oxygen and ozone. The strong water absorption allows to make measurements over shorter paths (around 1 cm).

The physical principle of the *microwave refractometer* relies on the fact that the air refractivity depends on temperature, humidity and pressure (3). The instrument sensing element is a microwave cavity (typical dimension is 5 cm) partially open to the outside air: its refractive index determines the resonance frequency of the cavity, which is measured by monitoring the reflected amplitude of an injected radio frequency signal, sweeping around the cavity resonance. In order to separate the humidity fluctuation contribution, simultaneous measurements of temperature and pressure in the cavity are needed

The *psychrometer* is a well known instrument for humidity measurements. It has been very widely used in the past as it accounts the real physical process involved in the humidity: the capacity of water to evaporate. It also joins the advantages of a good spatial resolution with an enough high frequency response and if it is properly realised, may be used as a reference standard for the calibration of other humidity sensors.

Its use in modern data acquisition systems has largely decayed, mainly because it requires an attended operation.

In its traditional version, the psychrometer uses two mercury thermometers, one exposed directly to the air (dry bulb) while the other is covered with a wick imbued with distilled water (wet bulb). Water evaporates, in a way inversely proportional to the relative humidity in the atmosphere. Evaporation removes heat so the wet bulb records a lower temperature. To operate the instrument correctly, fresh air is blown across the wet bulb, at a speed of 3-5 m/s, to avoid an increase of humidity in the measurement region.

The final result can be obtained or by reading it on the so called “psychrometric tables”, when the two previous temperatures are entered, or computed using the same algorithm on which those tables are constructed. This is a rather complicated, semi-empirical, relationship among

vapour pressure, saturated vapour pressure, dry temperature, wet temperature and atmospheric pressure.

A measurement uncertainty of a few percent is strictly related to the calibration of the temperature sensors: their absolute accuracy must be within ± 0.5 °C and their response matching lower than ± 0.1 °C, across the whole working range.

Some years ago, we built a new version of the psychrometer, suitable for very long continuous operation and remote data acquisition (4).

The use of a "watering place for birds", together with a one litre plastic bottle as the water reservoir, allows keeping wet the second thermometer for more than one month, under normal climate conditions. A fan is used to suck (not blow) air through the pipes containing the temperature sensors to prevent undesired heating. In place of the mercury thermometers, we have used two silicon diodes (1N914B), as parts of our meteorological station.

In order to preserve the measurement accuracy, we carefully checked that their self-heating was negligible; that their absolute calibration was within ± 0.5 °C and their relative discrepancy within ± 0.1°C, with a curve fitting based on a systematic data recording lasting all over a week. Finally we installed the new psychrometer in a suitable place, where it was possible to guarantee its intrinsic accuracy.

2. OUR RECENT IMPLEMENTATION OF PSYCHROMETER, UNDER CONTROL OF A LABVIEW CODE

New fast CPUs and extremely versatile high level programming languages like LabView allow nowadays to build rather easily still improved versions of old instruments.

In the case of our psychrometer we have decided to upgrade it in the data acquisition area and in the real time processing of the data.

As temperature sensors we chose the LM35 series precision integrated-circuits, (made by NI). Their output voltage is linearly proportional to the ambient °Celsius (Centigrade) temperature.

The LM35 are claimed not to require any external calibration or trimming in order to provide typical accuracies of ±_°C at room temperature and ±_°C over the operational temperature range (-40° to +110°C). Self heating is declared to be 0.08 °C in still air. The low cost is assured by trimming and calibration at the wafer level.

On the other hand, we have verified that these sensors have the disadvantage of a rather long time thermal response (a few seconds in still air, which may be worse for the wet sensor). This is not a problem for applications in a standard meteorological station, where the time constants of the environmental parameters to be measured are much slower.

For the interface circuit between the sensors and the PC we have selected a low cost card (DAQ series PCI-6024E, again by National Instruments) that features reliable data acquisition capabilities in a wide range of applications. Its main features are: 12 bit resolution; 200 kS/s sampling rate; 16 analog inputs (single ended) and two analog outputs; 8 digital input/output channels.

We have put care in the wiring between the two sensors and the DAQ card. While the metallic cup of the sensors is still in open air, the connection wires have been covered with plastic sealed-end tubes, in order to avoid leakage and corrosion when we calibrate the sensors, using melting ice and boiling water. This way, we avoid the same problems that may occur around the wet bulb.

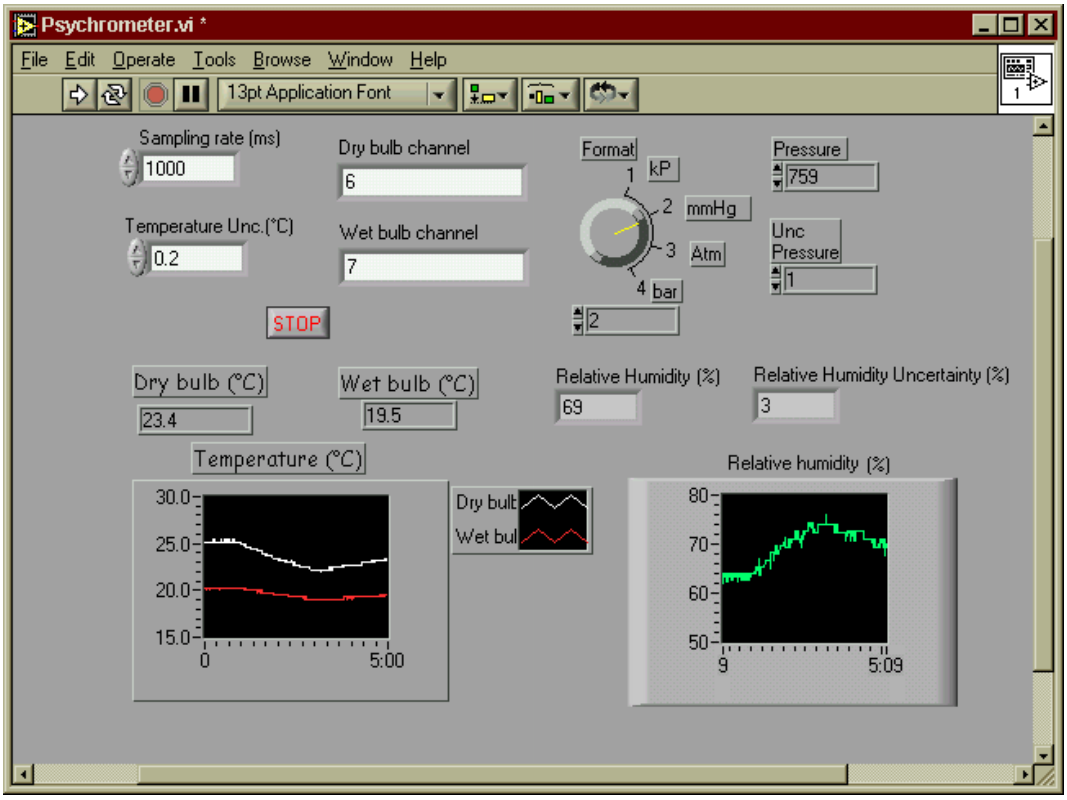
As a cross check, we have also tested in the lab, by proper calibration procedures, the features declared by the sensor manufacturer. In particular, when testing about ten units together, we have always found an absolute accuracy better than 0.2°C at both the melting ice and boiling water temperatures; moreover the relative discrepancies among the calibrated sensors, all over the whole working range and along a measurement campaign lasting for many days, never exceeded 0.2°C.

Two of these sensors have been installed inside in our version of the psychrometer.

For the data acquisition and the signal processing, we have developed a dedicated software code in the LabView (NI) environment, as it is well suited for data acquisition, instrument control, measurement analysis, and data presentation.

The *control panel,* or user interface we have developed, looks like the following picture. The *block diagram* instead contains the data flow from the acquisition to the final presentation of the results, according to the specific algorithms needed in this application.

Fig.1. The control panel of the Labview code developed to manage the psychrometer data acquisition.



As you can see from Figure 1 the user can specify, before running the data acquisition, the following parameters:

- sampling rate;
- temperature uncertainty of the sensors;
- channel number choice for the dry and the wet sensors;
- atmospheric pressure value and its uncertainty. (This last quantity will be soon measured directly with an appropriate sensor).

The results are displayed in real time by two chart recorders graphs: on the left are shown the dry and the wet temperatures measured by the two sensors, while on the right it is possible to follow the relative humidity variations calculated according the algorithm implemented in the block diagram. All the results are saved in a text file for later processing.

3. CONCLUSIONS

Our recent implementation of atmospheric temperature and humidity measurements is the first step in order to build up a complete meteorological station under LabView control. This effort has started as a project work for students following the new course of "Atmospheric Measurement Laboratory" at the Department of Physics of the Bologna University. It will give them the opportunity to learn the working principle of the main sensors (anemometer, rain gauge, radiometer…), to find procedures to test in the lab the particular features of each of them (time response, reliability…) and to check their calibration. Students will be allowed to modify the software according to their new ideas and then achieve new improved results.

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