THEME 2

EXPERIENCES OF USERS FROM DIFFERENT FIELDS (SUCH AS SYNOPTIC FORECASTS, CLIMATOLOGY, AGROMETEOROLOGY, HYDROLOGY, MARITIME, AERIAL AND TERRESTRIAL TRANSPORT) WITH AWS DATA
SOME ASPECTS ON THE OPERATIVE USE OF THE AUTOMATIC STATIONS NETWORK OF THE BASQUE COUNTRY.

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Abstract

This communication presents the experiences accumulated during the development and the implementation of the Hidrometeorological Monitoring and Forecast Office (HMFO). The HMFO performs tasks of hidrometeorological surveillance and forecast within the Basque Country community. These activities depend to a large extent on the data received from the Automatic Weather Stations (AWS) network of the Basque Country. HMFO makes an intense use of the AWS, in real as well as in deferred time.

The first topics presented are related with the development of the different systems that allow us to control the correct operation of the net. They are commented the experiences derived from the design, development and pre-operative use of the different elements that conform the hidrometeorological systems of surveillance and alert.

Also we will try on the improvements that provides the AWS data assimilation in the operative numerical forecast, the use of data in validation of numerical models results and the use of the data in time deferred for the statistics calculation and the meteorological reports elaboration.

In this way we will check the most relevant aspects corresponding to the period of development of the office and in the pre-operative period, focusing on the use of the AWS mesoscale net present in our territory.

Keys words: operative use, validation, assimilation.

1. The automatic network, a description.

Since the creation of de Basque Meteorological Service (SVM) in 1990, Basque Government and other public institutions are working in the development and maintenance of an automatic surface hidrometeorological network oriented initially to supply data in the context of flood prevention.

The initial configuration, sensors, communication systems of the hidrometeorological Basque Country network, have evolved since those years [1], due to scientific, technical and new social requests.

Throughout these last years, Transportation and Civil Engineering Department of Basque Government has accomplished an effort by maintaining and improving the data acquisition systems and by promoting the knowledge of the present, past and future weather in the Basque country. In this context, the Direction of Meteorology and Climatology was created in 2002 assuming the subjects related to meteorology and climatology.

Currently the Basque Country mesonet is a combined automatic high density measuring network for meteorology, hydrology, oceanography and water quality. This automatic network provides meteorological measures in nearly 100 different sites in the area of Basque
Country, combined with river level and water quality measures in 27 locations, with river level measures in 15 locations, and with oceanographical measures in 7 coastal locations.

In figure 1 we can see the spatial distribution of the automatic network. The stations in the network are classified according to major use and configuration. They are divided into four subgroups: meteorological or type 1 (50), hydrological or type 2 (20), quality or type 3 (22) and oceanographical or type 4 (7). In the table I we refer sensors distribution in each type of automatic station, although really there exist different configurations even in each type.

The information offered by the surface network is complemented with the data originated from a Wind Profiler. Located in Punta Galea (near Bilbao harbour) it permits to register, with a temporary resolution of 30 minutes, profiles of wind and virtual temperature until 5000 m and 1500 m respectively, with a vertical resolution of up to 45 m.

In figure 2 a meteorological station and a hydrological one are shown. In figure 3 we can see the wind profiler and the oceanometeorological structure of Pasajes (Gipuzkoa).

In table II we can see principal sensors in Basque Country network. Additional sensors are temporarily or permanently connected to some stations where different new types of sensors are tested.

Direction of Meteorology and Climatology receives data registered in the stations in real time through computer equipment (concentrators) that communicated with AWSs by radio, with a periodicity of 10 minutes and in time deferred through the backup system disk of the station, task accomplished by the maintenance personnel. The process related to the receipt of data generates in the server a series of files, with various formats, stored in a specific directories structure. Once the data are found in the binary file server, they are introduced in an Oracle Database.

**2. The Hidrometeorological Monitoring and Forecast Office.**

In the context of increasingly needs of meteorological information is hold the Hidrometeorological Monitoring and Forecast Office (HMFO). This project began in 2001
year developing different systems and working in a preoperative way until 2003 year when it is supposed to be operative.

The main objective of the HMFO is to give forecast and monitoring capabilities to the Direction of Meteorology and Climatology, helping towards the full development of the Basque Meteorological Service. In that way, the HFMO has realized and realizes pre-operative and development works focused on surveillance and weather forecast, software development and management of meteorological information.

- AWSs network monitoring.
- Hidrometeorological Surveillance.
- Elaboration of analysis and forecast.
- Meteorological alerts pursuit.
- Data Quality Control.
- Climatological and hidrological data base generation.
- Data management and storage.
- Web design and support.
- Elaboration of climatic yearbook.
- Reports and technical assessments for the Basque Meteorological Service.
- Meteorological models.
- Hydrological models.
- Oceanographical models.
- Software Development for the Basque Meteorological Service.

In most cases, an intensive use of Basque Country mesonet data is made. The HMFO has got a dedicated circuit that joins, through microwave, the Office with the Basque Government seat. This circuit permits to obtain the meteorological data every ten minutes at the same time than in the Direction of Meteorology and Climatology.

In next sections, different aspects of the operative use of the AWSs registered data will be explained. We will show the systems that make an intensive use of the registered data: meteorological surveillance, elaboration of analysis and forecast validation, data assimilation, and numerical weather prediction validation. Some applications developed to handle warnings about the network working are shown too.

3. Data quality and network control systems.

Every failure detected on the AWS network is logged and notified to be fixed. All this process is handled by a warning management system implemented for this purpose. This failure warning management system of the AWS network, developed in Access, allows to send the different warnings to the different involved parts, as well as to proceed the tracking of the failure during all its life period, from its reading confirmation, until its correction by the relevant party, on a quick and easy way. This supervised system allows the correct management of peculiar situations of malfunctioning of the AWS network. It also incorporates a link between several charts (stations, sensors, processes, and so on.) and the possibility that a warning could have several addressees.

The system requires the notification by the warning addressee of acknowledgement of receipt. If this does not happen, the warnings are re-sent until they are logged properly. When a problem is notified to have been fixed, this is verified and the maintenance code is registered.

In order to track the communication among the different stations within the AWS network, the system can be queried about all the communications that happened in all the stations.
during the week, or about the communications with one particular station during the time period you specify. Finally, the system allows for the automatic generation of various reports, as well as the listing of the still pending warnings for their reparation, fixed warnings, and sporadic problems.

This initial proposed system is opened to further development that might be required due to new needs (SMS or the notification and registration of aspects not consider at the moment).

In 2002 (preoperative use), 160 warnings were registered that are broken down as follows (the general system failures that affect data reception at the HFMO are excluded):

- 5% failure communications (concentrator).
- 5% failure of the booster station.
- 20% general failure of the station.
- 70% detected errors on the measurement of meteorological variables: 15% precipitation, 9% wind direction, 11% wind speed, 8% sun irradiation, 17% temperature, 25% HR, 15% levels.

We dispose of redundant data; data coming from real time transmission and picked up periodically from the station’s data logger (at least once a month). The Basque Country’s meteorological service performs an automatic real time quality control on the real time transmission data prior to its storage [3].

The data from the data-logger, called backup data, is picked up by the maintenance personnel and sent to the HFMO. Through a supervised procedure, we select the best available set of data for each period of time and station. Once this control is passed, the data is storage as definitive or final data. In the future, the Office will avail of the appropriate tools to achieve the data cleansing and unification, generating a unique data set that will be managed through an Oracle Database.

The difficulty to obtain reliable measurements of rainfall data makes necessary to register them using different methods. The Basque Service of Meteorology has got some instruments connected to the rain gauges registering rainfall data and time (Data-rains). This data storage system allows carrying out a rainfall data quality control. Software has been developed using Visual Basic to achieve this goal. The datarain’s files are storaged in monthly files. Before this storage, some characteristics of these files are tested. Once the original Data-rain’s and AWS’s no real time data are saved, they are compared each other. This comparison allows us to validate the data measured by the AWSs, and sometimes to recuperate them. Also it is possible to calculate the precipitation intensity with better resolution [4].

4. Hydrometeorological monitoring and warning systems.

The hidrometeorologic surveillance is based on the continuous exam of the coming data from the mesonet of the Basque Country, as well as of other sources (especially coming information from the Radar of Jata, property of the Spanish National Institute of Meteorology and METEOSAT information).

Surveillance personnel have diverse tools that facilitate their work, that is a set of applications that permit, under request or in an automatic way, to examine rapidly the data that net is registering in real time (each 10 minutes). These tools are:

- Specific software that allows to examine the temporary evolution of any meteorological variable registered in each one of the EMAs, some statistical
information as well as combined graphics for different stations, variable and time periods.

- An application that permits the representation of water levels, the calculation of flows and its visualization in real time.
- An application that makes possible the spatial distributions of different variable presentation in real time, using maps with icons that show through a colours code the situation in each EMA with respect to the adverse meteorology classification established in the HMFO.

All this information is available in a visualization panel; this panel act as a video wall with 6 meters broad by 3 meters high, in this panel we have 3 plasma screens 50" combined with 6 20"monitors. This panel is supported by 6 SGI Octanes (Irix) and 1 PC (Windows) that take charge of updating map and graphics and load different applications (figure 5).

The HMFO has developed an specific software (using IDL) for surveillance rivers state in the Basque Country. This application allows warning and alarm levels visualization in the quality and hidrological stations (figure 6). The water level measure is represented in a geographical map, where we have different icons that allow to distinguish when and where the level is normal, a warning level or a alarm level. In the same applications there is an interface that presents the temporal evolution of precipitation, level and rivers flow. The application has been developed in IDL[6]. We can represent the stations water level in a given 10 minutes register or represent the maximun level in a selected period. The temporal evolution of water levels flows (calculated) with the correspondent alert and alarm river levels and the precipitation is also allowed.

The HMFO has developed a specific software (using IDL) for meteorological data visualization and representation. This application, each 10 minutes, takes real time data, changes formats, applies basic filters, makes a geostatistical analysis calculating experimental semivariogram and adjusting it to a theoretical model and interpolates the surface data using kriging, generating temperature, RH, rainfall, solar radiation and wind fields maps in real time (10 minutes after measured). Another derived quantities are also generated such as accumulated rainfall in 1 hour, maximum in 10 min, daily maxima and minima temperatures, etc. This software generates icon maps to show the situation registered in each station for each variable according to a colours code. All this graphical information stored in image format is the basis of different movies that are updated and shown in an automatic way in the surveillance panel. This graphical information is included in the HFMO intranet, and part of it will be of public use in the coming web of the Direction of Climatology and Meteorology.

When the HMFO is in alert period, an intense monitorization is required. It is necessary to pay attention to 3 types of information that it is monitored continuously in the surveillance panel:

- Satellite images, that permit to visualize the arrival disturbances to our territory, and to analyse clouds characteristics.
- Radar images, that permit to estimate the affected areas, the intensity of the rainfall, as well as estimate trajectories of rainy structures.
- AWSs data, at last those which provide the surface conditions.

The consideration of this type of information together with the available information coming from the mesoscale models and others permit to detect potentially dangerous situations, and to prevent the intensity of the adverse phenomenon, the areas that are affected and their possible evolution. Alert situations are, in fact, intense and continued surveillance situations. In these situations the involved personnel works covering all the adverse weather period.
5. Forecast validation and analysis systems.

The Hidrometeorological Monitoring and Forecast Office (HMFO) has developed a supervised analysis and forecast validation and management system, with the purpose of facilitating daily labour of analyst and forecasters, and to facilitate management and supervision of the daily generated information [7].

The HFMO produces daily different forecast and analysis products for internal and external use. The daily forecast bulletin with relevant meteorological information in the area for 4 days, the daily analysis, as well as a description of the synoptic situation and special and extended forecasts. All this information is managed in a unique application developed in Visual Basic and a Data Base in Access. This application allows the management of the different forecasts and analysis, and the validation of the forecast in the most objective way that is possible that is bases in the data registered from the AWS net. The elaboration of the analysis is carried out in a way supervised with a high degree of automation in function of the data registered in AWSs. In the same application the analyst or forecaster has access to all the HFMO available information referred to the meteorological characteristics of the particular day subject of analysis or forecast.

This application collects the analysis and forecast protocols established in the HFMO as a guidance for the annalist and predictor, facilitates the access of various types of information, permits the calculation of evaluation statistics for the objective validation and the automatic generation of several reports.

For the forecasts as well as for the analysis, each daily report has been divided in 12 parts: four temporary (awoken, morning, evening and night) and three spatial (sea zone, centre zone and south zone). The meteorologist elaborates the analysis or forecast through the landfill of a series of index cards related to the values of the different forecast or diagnose variables. The system makes possible to establish the quality of the forecast by comparison with the analysis. This comparison is carried out in an automatic way in function of a series of contingency tables that establish in a quantitative way the correspondent penalty to each type of meteor in function of the deviation between predicted and analysed value. The analysis is carried out in a semiautomatic way based on automatic calculations that are accomplished in function of the data registered in the AWS net. The registered data are grouped by zones and by parts of the day so that are compared for the different space-temporal portions. The evaluated variables are the same that conforms the forecast bulletin, that is to say temperatures (values and trends), cloudiness (fogs, height clouds and cover), rainfall (intensity, persistence, distribution, accumulated by zone), snow level, wind (intensity, peak gust, wind direction) and synoptic situation.

6. Data assimilation systems.

We are implementing and testing different data assimilation systems. This system allows to improve numerical forecast (specially in short range) and to have realistic numerical analysis for high resolution domains. At present we are developing and using in a preoperative way assimilation systems based in ADAS and little_R. In both systems used, several methods of quality control are applied to the observations.

ADAS (ARPS Data Assimilation System) is a 3-dimensional analysis program that allows, at present, the assimilation of registered data in the Basque Country and surroundings, coming from the AWSs network and the Wind Profiler, including RAOBs and METAR data in the
bigger domains. This system includes a few quality-control steps. Data are pre-analysed to compare with neighbouring observations and rejected if differs significantly, compared with the background field interpolated to the observation site.

We have developed a system that takes data in their original format and puts them in LAPS format. Those files are ingested by ADAS that works with a successive correction scheme analysis method known as the Bratseth method. This method allows interpolating data registered into the numeric ARP’s grid (in sigma-z coordinates) with background meteorological fields. We are testing multiple resolutions in the horizontal and vertical to determine the best approach to our needs.

Little_R is the assimilation module in MM5. This program performs an objective analysis which blends first guess (a meteorological grided file on pressure level) with observations (radiosonde and surface reports), and outputs data on a meteorological file pressure levels. This program use two types of objective analysis the Cressmann-type scheme and the multiquadratic method. The Cressman scheme uses an anisotropic radius of influence to modify grid points in the vicinity of each observation. The multiquadratic scheme relates the influence of each observation to every grid point in the domain based upon distance, and similarly correlates each observation to every other observation through an inverse distance metric.

The HFMO has developed a system (scripts programs) that takes meteorological data from the mesonet and from RAOBS and based in little_R program enhance the pressure-level, grided first guess meteorological data. This allows to consider observations of wind speed and direction, temperature, dew point, or sea level pressure coming for the mesonet and other sources. Before the assimilation process, the system reorders the observations into the required format for program input.

Previous to the assimilation process the system make a Gross Error Checks (Observation that exceed the limits values predefined are not considered) a Maximum Error Checks (comparison between each observation and the value interpolated from the first-guess), a Buddy Check (error check comparing observation with neighbouring data) and Vertical Consistency and convective adjustment checks (applied to vertical observations).

7. Validation system of numerical results.

In this part of the document we consider the validation or verification of numerical results, coming from limited area models (MM5, ARPS) running in the HFMO in a preoperative way, with AWS data coming form the Basque Country Mesonet. Verification data should comprise a reliable estimate of the true value of a quantity, against which a forecast may be verified or validated. In the case of grided numerical weather prediction (NWP) forecasts. There is no unique procedure which allows validate numerical results by comparison with surface observations.

We distinguish two great groups of validation techniques, referred as punctual and areal techniques. The first ones consist in the estimation of the meteorological variable value subject of validation in the same place we measure, that is to estimate the predicted value over the station where the real value is registered. The second one takes the measured values and estimates the observed values distribution (the values in the numerical model grid nodes) that allows some kind of comparison with the estimate values distribution in the model. So in practical view in both cases we compare punctual values, observed values against forecast value in the same place or forecast values against observed estimated values over one point of
the numerical grid. There exists another kind of complex and limited use techniques for distribution analysis and similarity especially if we refer to spatial distribution of precipitation.

Verification of NWP can be done using either a grided analysis of the observations, or directly against the observations themselves. Each type of verification presents pros and cons depending on the variable characteristics to be validated. By instance, for temperature we consider comparison against station value, for precipitation it is more appropriate to verify against a grided analysis.

In any case we need to quantify the ability of the numerical forecast to correctly predict the situation observed, which means that we need some kind of verification statistics. In the OVPH we are implementing an automatic validation system that uses categorical statistics and continuous statistics. Categorical, or conditional, statistics quantify skill in the prediction of the occurrence of a particular event (such as rainfall). Some familiar examples of categorical statistics are the Probability of Detection and the False Alarm Ratio. Continuous statistics quantify the ability of the forecast to correctly predict the spatial and temporal distribution of a variable (for example the location and amount of rain). Some familiar continuous statistics are the root-mean-square error and the correlation coefficient.

8. Daily statistical calculation and bulletins elaboration.

The HFMO has between theirs functions to serve different requests, that often include some type of statistical data, the elaboration of monthly bulletins and the meteorological yearbook published by the Department of Transports and Civil Engineering.

In this context, the load of a daily database is carried out, that contains various statistics calculated in first instance with real time data and in no real time later. This information, different daily statistical data calculated for the different meteorological AWSs records, is the base for the quick and efficient resolution of good part of the demands posed, the elaboration of the monthly bulletins and the meteorological yearbook.

The whole process takes place from semiautomatic into an application developed by the HFMO in Visual Basic against Access database. This application takes the 10-minutes information of the stations, applies certain logical-physical range filters, and calculates the daily statistic data for each station: mean RH, maximum and minimum, mean temperature, maximum and minimum, accumulated precipitation, maximum, maximum 1-hour, wind prevailing direction, mean, maximum, peak gust, mean gust, total irradiation, maximum, mean levels, maxima and minima, mean pressure, maximum and minimum. Once calculated, they are introduced in the database.

The system’s interfaces are implemented in Visual Basic and take advantage of different Access queries. Prefixed queries allow us to obtain much information coming from de Database in a rapid way. These statistical data are calculated in first stage starting from the data via radio and later on completed or modified from the backup data.

The application developed has a validation module, so that the expert, depending on the available information (values in nearby stations, maintenance reports, surveillance reports, percentage data, visualization daily series,), can modify the considered wrong data, remaining labelled as modified. The intervention of the expert is mainly focused on considering deviations in the daily register amount of precipitation versus totals and extreme temperature values modifications.
These daily Database are the base of the monthly statistical data calculations that are presented in the monthly meteorological bulletins and in the annual meteorological report. Also, they are the bases of tables and maps elaboration, employing the most adequate interpolation to each meteor (ordinary kriging, kriging, co-kriging...) that is employed in the figures presented in the bulletins.

Figure 1. Surface distribution of Basque Country’s mesonet.

Figure 2. AWS in Navarrete and hydrological station of Gardea.

Figure 3. Wind profiler in Pta Galea and oceanographic station in Pasajes.
Figure 4. Some interfaces in the warnings program developed in the HMFO.

Figure 5. Monitoring Panel and examples of graphic information.

Figure 6. Some interfaces in the hydrological monitoring program.
References


AUTOMATIC WEATHER STATIONS NETWORK OF THE DEPARTMENT OF ENVIRONMENT OF GALICIA: DATA ACQUISITION, VALIDATION AND QUALITY CONTROL

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Abstract

The automatic weather stations (AWS) network of the Department of Environment of Xunta de Galicia consists of stations with standard meteorological measurements in real-time, saving 10-minute average data. The communication system for data acquisition is based on GPRS technology. Along the year 2003 a new topology with different locations and new stations added to the network will be done. Conventional climate stations that provide standard climate data will be converted to automatic stations so that these stations will be included in the AWS network.

About the data acquisition and quality control, specific software was developed for data real-time acquisition and validation. Data are stored in a SQLServer2000 database and metainformation in an Access2000 database.

Key words: AWS, database, quality control.

1.- INTRODUCTION

The Department of Environment of Xunta de Galicia has developed in the last years a permanent automatic weather stations network, which is centralised in the Lourizan Forestry and Environment Research Centre (Pontevedra). This centre is integrated in the Sustainable Development Centre. Currently, the network operates 24 stations and complements another network of 43 conventional climate stations, which started to collect data in 1955. Data from both networks are available on the Internet (real time data from AWS and off-line data from the classical network) through the Environmental Information System of Galicia (SIAM – www.siam-cma.org).

The automatic network started to record data at the end of 1999. Along the year 2003, the conventional climate network will be restructured and the stations will be transformed to automatic weather stations. In a first stage these new stations will record temperature, relative humidity and rainfall.

2.- NETWORK DESCRIPTION

Figure 1 shows a map with the position and altitude of 24 automatic weather stations belonging to the Department of Environment as well as the Coron station belonging to the Department of Fishing, also integrated in the network. This is the layout for the year 2002. In the first quarter of 2003 five stations will be moved to new locations and two new stations will be added to the network.
As it was mentioned in the introduction, another 30 stations, coming from the restructuring of the conventional network, will be added to the automatic network.

The area covered by the automatic network is 29.434 squared kilometres.

Figure 1. Map of site locations and altitudes.

Currently, all the automatic weather stations register temperature, relative humidity, pressure, rainfall, wind velocity and wind direction (10 m). Eight of them also measure global solar radiation and ultraviolet radiation in the erythemal range is recorded in five stations.

In relation to the instrumentation, there are sensors from several manufacturers and based on different technologies, like Thies, Casella, Geonica, Lufft, Ph-Schenk and Solar Light among others.

Regarding dataloggers, currently, most of them are Casella (DAU 16) and Geonica (Meteodata-1256). The last dataloggers installed in the network are Lufft (Opus 200), which allow a greater flexibility configuring each station.

With regard to power supply, approximately fifty percent of the stations are connected to the mains (there is also a small battery in case a cut in the supply) and fifty percent are powered by solar radiation.
3.- DATA ACQUISITION, VALIDATION AND QUALITY CONTROL

3.1.- Data Acquisition

Data are sent from the stations to the central office by using mobile phone technology (GSM). There are two exceptions: Lourizan and Coron stations. Both AWS are connected (by Internet Protocol) through Galicia Science and Technology Network.

*Figure 2. Data transmission system of AWS network.*

At the beginning of 2003, most of the stations will send data to the central office through GPRS modems. The use of GPRS reduces the operating costs a lot. But to operate with GPRS technology, it is not enough to change the modem, it is also necessary to install a computer at the AWS. This computer gets the data from the datalogger and after doing some calculations, compresses the data and sends them (on Internet) to the main computer, which is located in Lourizan. On the other hand, the computer installed at the AWS allows to do other tasks, like send messages (SMS or e-mail) when something happens in the station: meteorological alerts or, for instance, if there is a trespasser.

Figure 2 shows a diagram with the data transmission system of the AWS of the Department of Environment of Xunta de Galicia.

For the data-collection process, specific software has been developed. This software gets the data from the datalogger and sends them to the central office.

The computer in charge of picking up the data, every half an hour, asks the computers in the stations to send data. Data are stored in the AWS every minute. After arriving to the main computer, data are validated and finally inserted in the database.

Before putting data in the Internet, observations are transferred automatically to a web server where they are processed and displayed.
3.2.- Validation and quality control

Data are averaged in the datalogger every minute. When data are stored in the computer at the central office, a program validates and averages them. In this way, the database contains 10-minute data.

Several tests are applied in the validation process. These tests are commonly used (Shafer et al. 2000, Rissanen et al. 2000, Grüter et al. 2001) when data from AWS are checked for quality:

a) Firstly, it is verified that every observation falls within the range specified by the sensor manufacturer or within the physical limits indicated for each type of variable (it is took the most restrictive).

b) Secondly, it is checked that every observation falls within the limits obtained from historical datasets. In those stations where there is not available historical data, suitable values from the experience are considered.

c) Finally, it is applied a temporal consistency check to assure reasonable temporal changes among observations measured at a single station.

During the year 2003, new tests will be added to the validation process:

a) Test to check the persistency of a data set from a single station.

b) Consistency check among values registered at the same station.

c) Spatial consistency. To do that, interpolation techniques will be used. Also, diagnostics from the ARPS (a weather numerical model that run twice a day in MeteoGalicia) will be considered.

Once the datum has been analysed, it is stored in the database. Each datum is associated with a label that indicates its quality. The value of this label informs what level of quality has been reached to.

The engine of the database is MS-SQLServer®2000 (Frohock et al. 2000). This software is installed in a server (the operative system is Windows®2000 Server). The main purpose of this server is run MS-SQLServer®2000 and store data. This computer has two processors (Pentium®III), two hard disks (34GB in RAID 0) and 2 GB of RAM. However, the server will be improved because the AWS network will be extended.

In relation to the validation process off-line, from 10-minutes data stored in the database, it is obtained aggregated data (24 hour data), extremes, averages... Then maps and graphs are generated in order to make easier to detect new inconsistencies or to decide whether a suspect value is valid or invalid. This procedure runs daily.

Figure 3 shows an example of these kinds of maps.

In addition, at the end of each month summary reports with aggregated and averaged values are printed. This type of reports sometimes allows highlighting subtle errors that, in a shorter period of time, are much more difficult to identify.

Figure 4 shows an example of one of these monthly reports.
Through the analysis of data it is possible to identify factors that produce errors or systematic deviations. In this latter case, along with the hardware maintenance it is necessary to take into account the location of the weather station (WMO, 1996). If the location is not the right one,
data from that station never reach acceptable quality levels despite the sensors are well calibrated. That is why, in the restructuring of the AWS network, the recommendations from the World Meteorological Organization (WMO, 1993) and others agencies have been specially considered.

On the other hand, each site is visited at least three times annually for general maintenance and on-site sensor intercomparisons. This routine maintenance helps to prevent faults, which usually means lost of data.

All the information about the AWS network is stored in a MS-Access2000® database. This database contains general information about each station, problems with sensors, photographs, results of sensor intercomparisons, stock management, etc. An example of this database is shown in Figure 5.

**Figure 5. Access database screen containing metainformation.**

4.- CONCLUSIONS

When a threshold is reached in relation to the number of AWS in a network, it is essential that all the information flow (from the datalogger to the final user) is as much automated as possible. To do that, specific software has been developed. This software consists of two modules: one module is in charge of all the work related to acquisition and transmission of data. The other module copes with the validation process and, finally, inserts data in the database. In this way, it is guaranteed that all data in the database have been tested and labelled.
In the near future, it is planned to apply more tests and improve them. Moreover, it is necessary a special effort in homogenisation of the data series because of the changes in the network topology and type of sensors.

Last but not least, national and international quality standards for sensor calibration and maintenance should be incorporated.

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USE OF AWS AT METEOSWISS: EXPERIENCES AND PERSPECTIVES

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Abstract

According to the data users’ needs MeteoSwiss is on the way to introduce the 2nd generation of automatic weather stations. Whereas the 1st generation network of automatic weather stations required a lot of research and proprietary development the 2nd generation of AWS is a solution usual in the market. All in all the new ground-based automatic weather stations network will contain 130 stations and will be built up until 2008.

Contrary to the 1st generation network which it now in operation for 25 years, the 2nd generation of AWS is not planned to be operated for more than ten years because of its sophisticated IT hard- and software. Therefore, it is inevitable to find a solution to guarantee consistency of data. On the other hand it will be possible to measure new parameters according to the data user’s needs without big additional costs.

Key words: 2nd generation of automatic weather stations, data users’ need

Text

MeteoSwiss is responsible for the operation of a meteorological and climatological network in order to guarantee continuous measurements covering the whole area of Switzerland. MeteoSwiss delivers basic and extended services and products. The basic services and products deal with the supply of national and international weather and climate data, the warnings and predictions for the population, the flight weather information for the air-traffic control centers, the climatological information and the services for defence and population protection. Customer’s special needs can be fulfilled within MeteoSwiss’ extended services. For example, due to the good quality of weather forecasts, customers can win important additional information for design purposes, risk management or other applications.

The 1st generation network of automatic weather stations, the so-called ANETZ, was introduced in the late 70ties and the early 80ties and consists of 72 stations today. In addition, 25 conventional climatological stations and 350 conventional precipitation stations generate meteorological data.

During the past years, new demands for additional meteorological information arised from several data users: Much more meteorological data are required and used in different applications like road maintenance or air quality control. Since the density of the network cannot be augmented due to financial restrictions, it is necessary to check the present network and to find new solutions to fulfil the needs of the data users. Also the quality of the measuring units (WMO 1996) has to be in agreement with the different demands of the customers. Additionally, it becomes more and more difficult to find people for manual weather observations and hence new technology must be evaluated and tested to reduce human ressources.
The national weather service of Switzerland is now on the way to introduce the 2nd generation of automatic weather stations. For knowing and understanding the users needs, it was decided to group the known data users in four categories (governmental organisations, universities, private meteo agencies and the national weather service with the climatological unit), and to ask them for their present and future data needs. By doing more than 30 interviews, the needs and wishes of the data users for the network configuration were collected and summarised. The main results and consequences for the future organisation and structure of the network are as follows (Frei 2002):

- Manual climatological stations must be automated;
- The different ground based networks must be unified; Definition of three types of weather stations (basic, small 1 and small 2);
- Conventional precipitation stations will be reduced and concentrated on the alpine region;
- Additional meteorological networks that are run by other governmental organisations should be integrated;

For the ground-based network three different types of stations have been defined:

Type B: A large number of high quality sensors connected to an automatic data acquisition system (ADAS) with a large number of interfaces and highly sophisticated functionalities.

Type S1: Station identical to type B, but with reduced number of sensors

Type S2: A small number of sensors connected to an automated data acquisition system with smaller number of interfaces, less sophisticated functionalities but fully compatible with the ADAS of types B and S1.

The realisation of the data users’ needs will lead to the implementation of the 2nd generation of automatic weather stations in Switzerland. The data acquisition systems (ADAS) and the central data acquisition system (CDAS) were chosen by doing a WTO offer. Two pilot stations, one in the midland, one in the Alps, are now established. It is planned to build up a total of 130 automatic stations distributed all over the country between 2004 and 2008. In order to guarantee consistency from the 1st to the 2nd generation of AWS, some important sensors will be kept (like THYGAN), whereas others which are not available on the market anymore must be exchanged.

It cannot be helped that changes in data quality occur after the introduction of new weather stations. However, since the new IT-technology depending AWS will need to be exchanged much more frequently than the previous systems, it is inevitable to find solutions to minimize these changes. It is not foreseen that the second generation of AWS at MeteoSwiss will be operational as long as the first generation (25 years). Also the increasing amount of data is a challenge for data processing and quality assurance. As a consequence, MeteoSwiss started to develop a new quality control system which will be integrated into the corporate data warehouse system.
### Table 1: List of parameters that are measured at the different station-types

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Weather station B</th>
<th>Weather station S1</th>
<th>Weather Station S2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground temperature</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Luminosity</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pressure</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Air temperature: 2m</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Air temperature: 5cm</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Precipitation</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Rain detection</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radioactivity</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short-wave incoming radiation</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Short-wave reflected radiation</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long-wave incoming radiation</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snow height</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Snow temperature</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Sunshine duration</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wind speed</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Wind direction</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Wind gusts</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Redundant temperature</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Redundant precipitation</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: Chart of the 130 planned automatic weather stations in Switzerland
MHS = Message Handling System

Figure 2: General data flow from sensors to the database system (Data Warehouse)

Acknowledgements

The help of Catherine Stocker and the documents of Thomas Konzelmann and Alain Heimo are highly appreciated.

References

AUTOMATIC WEATHER STATION DATA MANAGEMENT
AT THE I.N.M. METEOROLOGICAL CENTER IN
THE BALEARIC ISLANDS

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Abstract

Automatic weather stations yield a huge amount of useful data, that are not fully exploited by the software provided with the stations. Therefore, as new needs emerged, a set of computer programs has been developed, allowing us to: a) store the data in a more efficient way, keeping all records on line for different climatological applications; b) apply additional quality controls on the data, with tools to correct or delete the errors; c) automatically generate e-mail messages with warnings to the Civil Protection services or data summaries for different customers; d) Generate web pages with data summaries and graphic displays in real time; e) generate graphs, data listings and other climatological products for different purposes. As these programs have been developed locally, they can be easily modified to accomplish new tasks with quite a short response time.

Keywords: automatic weather station, data management, Balearic islands.

1. INTRODUCTION

The automatic weather stations (AWS from now on) of the Spanish Instituto Nacional de Meteorología provide data of wind, air temperature and humidity, precipitation and atmospheric pressure every ten minutes. These data are available to our regional forecasters in real time, as a monitoring tool to watch the weather evolution in the Balearic Islands, and past data (from a pair of years) can be retrieve from the workstation dedicated to the AWS data management, both as tables and as graphic presentations.

However, the provided climatological applications are limited to the mere printing of standard monthly summaries, with no other utilities implemented by default. Therefore, a set of computer programs and routine procedures had to be developed at our Meteorological Centre to be able to obtain a variety of products from the vast amount of useful data generated by the AWS.

The first task to undertake was to design new and better manageable data archives, since data are organized in the dialing computer in daily files, located in a monthly tree directory (with literal names!). This daily files are updated every hour through a dialing process, and then imported to yearly binary files located in another computer (which acts as a server for all our climatological processes), with a size of 37% of the original files. This storage efficiency is of little relevance today, but was crucial in the late eighties to allow all data to be kept in line in a single PC hard disk (of about 100 MB those days).

The programs were first developed in GW-BASIC, running on a PC-MsDOS, but advantage was taken from the need to adapt them to the 2000 year, and they were re-written in C.
Therefore, they are now implemented in a SUN server running Solaris, and are also mirrored in a cheaper PC-Linux that acts as a supplementary and backup system. (Binary files are not fully compatible between these systems, due to the different byte order of their internal number representation, but this is easily solved through a conversion program).

Our experiences with this data and a brief description of the applications developed for them (both real-time and climatological) will be discussed in the following sections.

2. REAL-TIME APPLICATIONS

This section groups applications that are updated in real-time (hourly at present times), but may have either a meteorological or climatological character. Users of these products must be aware of the possible errors of the data, since their quality control is subject to a non real-time process.

2.1. Severe weather warnings to Civil Protection services

Civil Protection services are provided with heavy precipitation and/or strong wind gusts warnings through automatically generated e-mails, when prescribed thresholds of these elements are over-stepped. In addition, warnings of temperatures equal or under 0°C at the main town, Palma de Mallorca, are also included in the mails, allowing to take actions to provide shelter to eventual indigent people sleeping in open places.

Example of warning mail (translated to English):

From:
Sent: Monday, November 25, 2002 7:20 PM

INSTITUTO NACIONAL DE METEOROLOGIA
CENTRO METEOROLOGICO EN ILLES BALEARS


Heavy precipitations (2.5 mm in 10 minutes, or more) in:
Port de Pollença B.A. at 19.50 (2.7 mm), 20.00 (2.6 mm)

Strong wind gusts (50 km/h or more) in:
Port de Pollença B.A. at 19.10 (53 km/h), 19.20 (57 km/h),
19.40 (58 km/h), 19.50 (70 km/h)
Porreres at 19.40 (53 km/h), 20.00 (50 km/h)
Far de Portocolom at 19.30 (55 km/h)
Far de Capdepera at 19.10 (99 km/h), 19.20 (97 km/h),
19.30 (90 km/h), 19.40 (90 km/h), 19.50 (86 km/h), 20.00 (91 km/h)
Aeroport de Menorca at 19.30 (55 km/h)

This information is not subject to quality control and may contain errors.

2.2. Real-time weather updates for internal use

Real-time AWS information is available only at two dedicated terminals, while many of our staff may be eventually interested in their data. Particularly, the spokesperson of our Met. Centre often needs an easy access to both past (recent) and real time meteorological data
when providing information to local radio stations, newspapers and other media. The solution was to build an HTML page to our intranet Web server with AWS data summaries. This way, anybody of the INM staff (not only in our Centre, but in the Central Services in Madrid or in any other regional Centre or airport) may instantly access the data in their computer with just a Web browser.

**Example of HTML data summary:**

**Summary of AWS data from 26-11-2002**

<table>
<thead>
<tr>
<th>Station</th>
<th>Dir</th>
<th>km/h</th>
<th>time</th>
<th>Max. Wind gust</th>
<th>Temps.</th>
<th>Humidity</th>
<th>Precipitation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Max. hora</td>
<td>Min.</td>
<td>Max.</td>
<td>Min.</td>
</tr>
<tr>
<td>Palma Portopi</td>
<td>NW</td>
<td>43</td>
<td>0120</td>
<td>17.3</td>
<td>1050</td>
<td>12.4</td>
<td>0700</td>
</tr>
<tr>
<td>Palma Dic d.l'oest</td>
<td>WNW</td>
<td>44</td>
<td>1410</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Serra d'Alfàbia</td>
<td>NNW</td>
<td>127</td>
<td>0000</td>
<td>7.7</td>
<td>1000</td>
<td>3.8</td>
<td>0000</td>
</tr>
<tr>
<td>Lluc</td>
<td>SE</td>
<td>45</td>
<td>0030</td>
<td>14.1</td>
<td>1100</td>
<td>7.8</td>
<td>0000</td>
</tr>
<tr>
<td>Port de Pollença</td>
<td>N</td>
<td>67</td>
<td>0050</td>
<td>18.1</td>
<td>1110</td>
<td>12.0</td>
<td>0000</td>
</tr>
<tr>
<td>Porreres</td>
<td>SW</td>
<td>40</td>
<td>0030</td>
<td>18.3</td>
<td>1120</td>
<td>10.5</td>
<td>0710</td>
</tr>
<tr>
<td>Far de Portocolom</td>
<td>N</td>
<td>58</td>
<td>0000</td>
<td>18.8</td>
<td>1300</td>
<td>12.4</td>
<td>0000</td>
</tr>
<tr>
<td>Far de Capdepera</td>
<td>NNW</td>
<td>97</td>
<td>0200</td>
<td>17.2</td>
<td>1140</td>
<td>13.4</td>
<td>0210</td>
</tr>
<tr>
<td>Aero. de Menorca</td>
<td>NNE</td>
<td>76</td>
<td>0120</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aeroport d'Eivissa</td>
<td>WSW</td>
<td>32</td>
<td>1110</td>
<td>16.9</td>
<td>1040</td>
<td>11.8</td>
<td>0200</td>
</tr>
</tbody>
</table>

**Latest AWS data from 26-11-2002** (At specified time or in the previous 10 minutes)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(m/s) (kts)</td>
<td>(km/h)</td>
<td>(m/s)</td>
<td>(%)</td>
<td>(mm)</td>
</tr>
<tr>
<td>Palma Port.</td>
<td>1700</td>
<td>ESE 1.8 3</td>
<td>6</td>
<td>SE</td>
<td>3.9</td>
<td>8</td>
</tr>
<tr>
<td>Palma Dic</td>
<td>1700</td>
<td>SE 1.7 3</td>
<td>6</td>
<td>SSE</td>
<td>3.2</td>
<td>6</td>
</tr>
<tr>
<td>Serra d'Alf.</td>
<td>1700</td>
<td>NW 9.6 19</td>
<td>35</td>
<td>NW</td>
<td>12.3</td>
<td>24</td>
</tr>
<tr>
<td>Lluc</td>
<td>1700</td>
<td>S 0.8 2</td>
<td>3</td>
<td>SSE</td>
<td>3.1</td>
<td>6</td>
</tr>
<tr>
<td>Port Pollen</td>
<td>1700</td>
<td>NW 1.5 3</td>
<td>5</td>
<td>NNE</td>
<td>4.7</td>
<td>9</td>
</tr>
<tr>
<td>Porreres</td>
<td>1700</td>
<td>NW 1.8 3</td>
<td>6</td>
<td>NW</td>
<td>2.9</td>
<td>6</td>
</tr>
<tr>
<td>Portocolom</td>
<td>1700</td>
<td>WNW 1.9 4</td>
<td>7</td>
<td>WNW</td>
<td>3.5</td>
<td>7</td>
</tr>
<tr>
<td>Capdepera</td>
<td>1700</td>
<td>NNW 4.0 8</td>
<td>14</td>
<td>NNW</td>
<td>9.9</td>
<td>19</td>
</tr>
<tr>
<td>A.Menorca</td>
<td>1700</td>
<td>NNW 4.6 9</td>
<td>17</td>
<td>NNW</td>
<td>9.9</td>
<td>19</td>
</tr>
<tr>
<td>A.d'Eivissa</td>
<td>1700</td>
<td>WNW 1.3 3</td>
<td>5</td>
<td>W</td>
<td>3.0</td>
<td>6</td>
</tr>
</tbody>
</table>
2.3. Recent weather summaries for costumers

Some newspapers and other communication media, and other types of costumers such as insurance companies, are interested in receiving a daily summary of the weather of the past 24 hours. These are provided under contract through an automated procedure that compiles the summary with the AWS data and sends it by e-mail at scheduled times. This summaries include maximum wind gusts, extreme temperatures and total precipitation:

INSTITUTO NACIONAL DE METEOROLOGÍA
CENTRO METEOROLÓGICO EN ILLES BALEARS

Data summary from Automatic Weather Stations
Day 28-11-2002 at 21.00 official time.

<table>
<thead>
<tr>
<th>Station</th>
<th>Today temperatures (°C)</th>
<th>Precipit.(mm)</th>
<th>Max. gusts (km/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Now</td>
<td>Maxima</td>
<td>Minima</td>
</tr>
<tr>
<td>-----------------------</td>
<td>------------</td>
<td>------------</td>
<td>--------</td>
</tr>
<tr>
<td>Palma Portopí</td>
<td>15.5</td>
<td>20.6</td>
<td>12.7</td>
</tr>
<tr>
<td>Palma Dic de l'oest</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Aeroport de Palma</td>
<td>-</td>
<td>19.9</td>
<td>8.9</td>
</tr>
<tr>
<td>Serra d’Alfàbia</td>
<td>9.5</td>
<td>16.7</td>
<td>8.8</td>
</tr>
<tr>
<td>Lluc</td>
<td>11.5</td>
<td>20.8</td>
<td>2.5</td>
</tr>
<tr>
<td>Port de Pollença B.A.</td>
<td>16.0</td>
<td>21.2</td>
<td>8.7</td>
</tr>
<tr>
<td>Porreres</td>
<td>14.2</td>
<td>20.9</td>
<td>10.0</td>
</tr>
<tr>
<td>Far de Portocolom</td>
<td>16.5</td>
<td>19.9</td>
<td>14.5</td>
</tr>
<tr>
<td>Far de Capdepera</td>
<td>16.6</td>
<td>21.3</td>
<td>14.7</td>
</tr>
<tr>
<td>Aeroport de Menorca</td>
<td>14.9</td>
<td>17.9</td>
<td>12.1</td>
</tr>
<tr>
<td>Aeroport d'Eivissa</td>
<td>18.4</td>
<td>21.8</td>
<td>14.9</td>
</tr>
</tbody>
</table>

2.4. Sea breeze setting monitoring

Sea breeze circulations are a common feature of the Majorcan wind systems. (The other Balearic islands have also sea breeze circulations, but of a much more reduced scale). With a weak general pressure gradient the air at midday enters from sea to land through the two main bays, the Palma bay at the southwest and the Alcudia bay at the northeast, and converge to the centre of the island, where it rises, typically producing convective cumulus clouds. But many times there is a definite general wind that combines with the thermal effects, reinforcing the wind in one of the bays, restraining it in the other, and displacing the convergence zone wind-wards. In this situations diagnosing the sea breeze is not an easy task (not all the midday south-westerlies at the Palma bay are a sea breezes), yet it is of great importance because it affects the operational aviation procedures of the Palma international airport, located in the central coast of the bay.

This problem was addressed studying the convergence of the wind in Majorca, with the data of three AWS around the island depicting a triangle. The study showed that the sea breeze can be diagnosed when the wind convergence is greater than \( 5 \times 10^{-5} \) s\(^{-1}\) (GONZÁLEZ et al., 1998). Therefore, the graph of the wind convergence in Majorca (see example in figure 1) becomes a valuable tool for our regional forecasters. An intranet web page is then updated hourly with this graph, and the graphs of the previous two days are also presented, as an aid to forecasting the setting and ending times and the strength of the sea breeze.
2.5. Daily updates of climatological summaries

Many communication media phone us inquiring thinks like: What have been the highest (lowest) temperatures in this month? Has any of them become a new record? Have the precipitations been much lower than usual? How strong is the drought we are suffering?

To answer these questions, climatological summaries of the current month are updated daily, based mainly on AWS data, though manually complemented with data from conventional observatories. This reports, presented also in a HTML web page, consist in tables with daily values of extreme temperatures, total precipitation and sunshine hours, plus the summary table of the month (from the first day to yesterday), that bears cumulated precipitation values for the month and from 1-January (civil year), 1-September (hydrologic year), and for the last 365 days (moving year), with departures from the normal values. Monthly and daily extreme temperatures are also related and compared with their averages.

The moving year precipitation and its relative anomaly (in percent) were implemented amidst the severe drought suffered from 1998 to 2001, which arose great concern in the water resource managers and the public in general. The inter-annual precipitation relative anomaly became a useful monitoring index of the state of the water resources, and a table with the values for Majorca (an average of the five more representative stations), Minorca and Ibiza (from their airports only) is updated daily and published in the Internet. The background colors of the table cells are computed in accordance with the values of the indexes.
Summary of the 27 first days of November, 2002

<table>
<thead>
<tr>
<th>Location</th>
<th>Total Precipitation (mm)</th>
<th>Anomaly (%)</th>
<th>Max Daily Precipitation (mm)</th>
<th>Day from 1-Jan (mm)</th>
<th>Anomaly (%)</th>
<th>Id. Relative (%)</th>
<th>Total from 1-Sep (mm)</th>
<th>Anomaly (%)</th>
<th>Id. Relative (%)</th>
<th>Running Annual (mm)</th>
<th>Anomaly (%)</th>
<th>Id. Relative (%)</th>
<th>Temp. Maxima</th>
<th>Anomaly (%)</th>
<th>Id. Relative (%)</th>
<th>Min. Average</th>
<th>Anomaly (%)</th>
<th>Id. Relative (%)</th>
<th>Average Temp.</th>
<th>Anomaly (%)</th>
<th>Id. Relative (%)</th>
<th>Sunshine Hours</th>
<th>Number of Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Menorca</td>
<td>110.6</td>
<td>30.9</td>
<td>47.3</td>
<td>620.0</td>
<td>18.4</td>
<td>20</td>
<td>60.8</td>
<td>101.4</td>
<td>8</td>
<td>664.1</td>
<td>60.8</td>
<td>10</td>
<td>22.5</td>
<td>0.8</td>
<td>4.1</td>
<td>19.0</td>
<td>1.4</td>
<td>13.6</td>
<td>16.3</td>
<td>1.4</td>
<td>2.3</td>
<td>137.3</td>
<td>27</td>
</tr>
<tr>
<td>Pera</td>
<td>103.0</td>
<td>54.3</td>
<td>46.0</td>
<td>590.7</td>
<td>-13.3</td>
<td>-8</td>
<td>1041.6</td>
<td>149.1</td>
<td>-36</td>
<td>531.6</td>
<td>-8</td>
<td>28</td>
<td>25.2</td>
<td>3.5</td>
<td>6.4</td>
<td>19.7</td>
<td>2.1</td>
<td>14.6</td>
<td>17.2</td>
<td>2.4</td>
<td>1.5</td>
<td>26</td>
<td>24</td>
</tr>
<tr>
<td>Pollensa</td>
<td>159.5</td>
<td>53.3</td>
<td>59.0</td>
<td>1041.6</td>
<td>-13.3</td>
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In the following example they are green and blue, due to a precipitation surplus situation, but during the drought they were yellow to red:
3. CLIMATOLOGICAL APPLICATIONS

The applications presented in this section do not need real-time updates, since recent data are not the most relevant. Therefore, they apply to past data, and the first task to undertake is to perform a thorough quality control. Once corrected, the data files will be able to provide a variety of climatological products. This products are not disseminated as intranet web pages, but generated on demand through a telnet connection to the server. (For graphic outputs, the client machine will need to have an X server running).

3.1. Data quality control

To perform the data quality control, the first step is to obtain a listing with suspect values. These are values with impossible (relative humidity of more than 100%) or too extreme values (78°C temperature), or inconsistent with others (average wind higher than the gust value).

Afterwards, errors are corrected in an interactive process where visual inspection of the data plays a major role. All variables of one day are represented simultaneously (figure 2), allowing meteorological judgment on the plausibility of the displayed values. Point errors are replaced by the interpolated value between the previous and following 10' observations. Otherwise, the data are simply deleted. This method was developed to control the quality of the Spanish AWS data for the PYREX project (GUIJARRO, 1992 y 1998), with enhanced possibilities in the correction (point interpolation) and deletion of data (individual variables, all wind, all variables, ...)

Fig. 2: Graph of the Palma AWS data from 15-11-2001. D: wind direction (degrees); Vx and V: gust and average wind speed (m/s); T: temperature (°C); HR: relative humidity (%); Ps: pressure (hPa); P: precipitation (mm).
3.2. Access to historical data

Once corrected, historical AWS data may be accessed in different ways: listings of row data (every hour or every 10 minutes), maximum daily wind gusts (for insurance companies), etc. Historical graphs of the data or even the aforementioned wind convergence can also be retrieved.

3.3. Climatological products

More elaborate climatological products can also be generated from the historical, quality controlled data. Examples are monthly mean and extreme values of the measured variables, monthly, seasonal and annual bi-dimensional tables (by direction and velocity intervals) of frequencies of average or gust winds, or mean monthly/hourly values of temperature and humidity (GUIJARRO, 2003).

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4. CONCLUSIONS

Data from AWS are an invaluable source for both real-time and climatological products. The logical developed at our Meteorological Centre has helped in serving the demands of a variety of customers, from insurance companies to Civil Protection services, and have also enhanced the internal use of the AWS data.

As the programs have been developed locally, they can be easily modified to accomplish new tasks in quite a short response time.

REFERENCES


GUIJARRO JA, 2002.- Valores horarios medios de temperatura y humedad relativa en Baleares.- Boletín Mensual Climatológico (I. Baleares), 57:121-134.
AN AUTOMATIC SNOW AND WEATHER STATIONS NETWORK FOR THE AVALANCHE PREDICTION IN THE CATALAN PYRENEES

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Abstract

The Institut Cartogràfic de Catalunya (ICC), belonging to the Catalan Government, began to install in 1997 an automatic snow and weather stations network (AWS) in the Catalan Pyrenees in order to elaborate the avalanche prediction.

On the basis of the experience of these five years, the aim of the paper is to show the effectiveness and problems presented by some sensors, mainly in those used for monitoring the evolution of the snow cover conditions. On the other hand, solutions adopted to guarantee a reliable data communication system will be shown.

Key words: Data transmission, snow gradient temperature, snow depth.

1. AN AUTOMATIC SNOW-WEATHER STATIONS NETWORK FOR SNOW AVALANCHE PREDICTION

The Institut Cartogràfic de Catalunya (ICC) started the implementation of a Network of Automatic Snow-Weather Stations in the Catalan Pyrenees in 1996. It was due to the necessity of specialized information to elaborate the Avalanche Warning Bulletin. Some stations belonging to the Instituto Nacional de Meteorología (INM) exist over 2000 m high, but their low density and nature of measurements are not adequate for avalanche prediction.

The implementation of the automatic network has to complement the measurements coming from the observers network, which is on active in the Catalan Pyrenees since 1991. In the frame of a good collaboration, data are daily sent to the INM, and to the Servei Meteorològic de Catalunya (SMC) and to Meteo-France.

1.1. Conditions for location

Spots for location must accomplish certain conditions:

- **Altitude over 2200 m.** Snow cover presence it is needing from the beginning to the end of the season. Moreover, avalanches use to depart above 2200 m

- **Homogeneous distribution of the snow cover.** The snow pack has to be representative of the surrounding area and not to be affected for local conditions. However, local
conditions sometimes can be looked for in order to monitor special spots (drift snow, slabs formation…).

- **Hazardous zones.** Mountain ranges frequently visited for skiers and climbers, roads affected for avalanches, ski resorts…).

- **High level of SGM coverage.** The fittest option from an economical point of view for transmission data.

*Figure 1. Network location.*

1.2. Network structure

1.2.1 **Automatic snow-weather stations.**

Campbell Scientific is the manufacturer. Nonetheless, some sensors and components are made by different manufacturers.

Sensors installed are: anemometer, global radiation piranometer, sonic sensor for snow depth, temperature and humidity sensor, temperature probes for snow cover and rain-snow gauge.
Sensors are attached at 6 m high aluminium tower. Datalogger, batteries, solar panels and communication equipment are held at the tower too.

1.2.2 Database.

ADQMSI 3.1 database software is supplied by PentaMSI manufacturer. It lets consult registers and calculations, generate reports and products to Internet.

2. COMMUNICATION SYSTEMS

The stations of the ICC meteorological network use three different communication systems: GSM, Radio-GSM and satellite. Following we can see a diagram with these tree systems interconnected at the same network been transparent for the users.
From the central data processing, storage and reception computer all stations are available. The software for network managing is the interface between the users and the different data communication systems. The communication system used by each station depends on the particular characteristics of the place selected to install the station.

2.1. GSM System

The GSM system is the most common system, because of its low acquisition, installation, maintenance and operation cost.

The system basically is built by a GSM modem, which communicates with the datalogger via a RS232 port using the asynchronous V.32 protocol (9.600 bps, 8N1, full duplex). At the central station a GSM modem array is available to communicate with the remotes and collect data.

This system allows us to establish an interactive connection with the remote stations, so in addition of data collection, we also can do software updates and real time data view.

The power consumption of this equipment is very low. With the electrical line not available at the stations the power supply systems are solar power system, and if consumption was high we should have to install very big batteries and extensive solar panel arrays.

The major problem of this system is that the coverage of the GSM network at high mountain (common place for installing the stations) is very limited and the dependency with the operation and relocation of the GSM repeaters is very high.

2.2 Radio-GSM System

This system is a variety of the GSM system and it has been developed to be applied to stations without, or with not enough GSM coverage, but near of them is a place with enough coverage to use a GSM modem like the previous system. So, with this system we have more freedom to decide where to install a station taking advantage of the low operation cost of the GSM system.

The link is done via radio between the station and an intermediate point where there is the interface that receives the data from the radio link, and sends them over the GSM network; been transparent for the users.

As consequence of using a single frequency radio system, the communication is bi-directional half duplex, making more complicated the handshaking and reducing the efficiency of the system.

This system mainly has three problems: complicated installation and maintenance, high power consumption and high sensitivity to radio interferences. So, this system is only useful for places where the distance between the stations and de radio-GSM repeater was not more than 1 Km.
Table I. Comparison of operative communication systems.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GSM</th>
<th>Radio-GSM</th>
<th>Satellite (Iridium)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition cost</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Installation cost</td>
<td>Low</td>
<td>High</td>
<td>low</td>
</tr>
<tr>
<td>Maintenance cost</td>
<td>Low</td>
<td>High</td>
<td>*</td>
</tr>
<tr>
<td>Operation cost</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>Coverage</td>
<td>Limited</td>
<td>Limited</td>
<td>Full</td>
</tr>
<tr>
<td>Interactivity</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Power consumption</td>
<td>Low</td>
<td>High</td>
<td>Medium-Low</td>
</tr>
<tr>
<td>Reliability</td>
<td>High</td>
<td>Medium</td>
<td>*</td>
</tr>
<tr>
<td>Robustness</td>
<td>High</td>
<td>Medium</td>
<td>*</td>
</tr>
<tr>
<td>Transmission</td>
<td>9600 bps</td>
<td>Full</td>
<td>9600 bps half duplex</td>
</tr>
<tr>
<td>velocity</td>
<td>duplex</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Information not available at the moment of the elaboration of this article (because of the pilot station has not enough operation time). Information will be available at the presentation of this article.

2.3 Satellite system

As consequence of the dependence of the previous systems with the GSM coverage has been necessary the have available any system that eludes this dependence and, in our case we have betted on the Iridium system. Iridium is satellite communication system that provides of coverage at all the de world including the poles.

The tests done with meteorological stations have been satisfactory and one pilot station is working with this system actually. This system has some advantages of the GSM system (low installation cost, easily installation and low power consumption); and includes one very important advantage: full coverage.

The mainly problem of the Iridium system is the economical one, because of the acquisition cost is much higher than the GSM (even thought similar to the radio-GSM system) and the operation cost is higher than both previous systems.

2.4 Comparison between 3 systems

Table I shows a summary of the comparison between the tree systems.

3. MEASUREMENT OF SNOW TEMPERATURE GRADIENT AND VALIDITY

In avalanche prediction is highly important to know the snow temperature, not only surface snow temperature but the different temperature of the snow layers. Specifically gradient temperature between snow surface and soil is calculated.

Temperature gradient controls the type and magnitude of snow metamorphism. Each snow grain evoles and changes its characteristics and properties, which define its stability level.
Avalanche danger depends on the snow stability level. So, temperature profiles are highly significant for grains bonding (Mingo, 1998). Temperature profile is weekly measured by the observers network.

The implementation of the automatic network let us measure the snow temperature gradient in a continuously way. Nevertheless, from the experience of the other colleagues it is known the difficulty in obtaining registers with good adjustment to the handle profiles. Troubles come from the fact of modifying the original snow structure when temperature probes and components are placed.

For these reasons, some countries have decided not to incorporate these observations in their automatic stations. Other countries have developed systems to measure the surface temperature of the snow cover by means of an infra-red thermometer (Gubler, 1998). Another countries even have placed vertical poles with probes at different heights on the soil.

The ICC has designed his own system for different reasons. It consists on a pipe of white colour placed in diagonal position. 8 probes are inserted in the pipe at different heights in parallel position respect to the soil. The first 4 lower ones are distanced 20 cm among them and the 4 upper probes are separated 30 cm among them. Snow temperature is measured with the model 107 temperature probe, manufactured by Campbell Scientific. The pipe are fixed at ground and at the tower. In advance, probes position seems not to interfere with vertical water vapour flow into the snow cover. Experience has demonstrated that shadows in snow drift situations are not generated. On the other hand, the structure is easy to install and to remove.

However, erroneous registers are observed in specific meteorological conditions as freezing rain and riming. Sensors will get isolated from the snow, during the snow cover formation.

In despite of the problems pointed out, a test has been carried out from 1997 to 2001 in order to know the validity of the automatic data to calculate temperature gradient. Test consists on the comparison of handle and automatic snow temperature profiles simultaneously performed.

3.1. Results

From 16 profiles couples and 148 sets of variables couples, the correlation coefficient \((r)\) of handle and automatic profiles reaches 0.71. As it was expected, a high proportionality factor exists.

Respect to the adjustment of values couples, covariance has been calculated to each couple of profiles. Covariance estimates deviations of each values couple. It is observed that events of low covariance values corresponds with situations of low temperature gradient (covariance values lower than 0.1). Covariance values close to 1.0 are observed in metamorphism of medium temperature gradient. Finally, covariance value upper 1.5 is obtained in high gradient temperature situation. Nevertheless, events with high gradient temperature are very scarce in our set of data and results are for guidance only.

Snow gradient temperature thresholds are established to identify different snow grains metamorphism processes (McClung, 1993):

- **Low gradient**: \(G<0.05^\circ C/cm\)
- **Medium gradient**: \(0.05^\circ C/cm<G<0.2^\circ C/cm\)
- **High gradient:** $G > 0.2^\circ\text{C/cm}$

As very low covariance values are detected in profile couples with low temperature gradient, it indicates that automatic measurements can be considered more reliable in low temperature gradient situations than in medium and high temperature gradient conditions. Automatic measurements are so highly reliable in snow isotherm conditions close to $0^\circ\text{C}$, when melt snow avalanches are more probable. They are useful to foresee rounded grain forms too. Contrary, automatic data are less reliable to detect faceted grain forms and depth hoar grains, unstable grains.

*Figure 4. Relation between covariance and temperature gradient measured in handle profiles.*

So, once profiles have been classified in the above thresholds the differences of temperature gradient between handle and automatic profiles are shown for the different metamorphism processes:

- **Low gradient metamorphism:** $0.008^\circ\text{C}$
- **Medium gradient metamorphism:** $0.047^\circ\text{C}$
- **High gradient metamorphism:** $0.049^\circ\text{C}$

*Figure 5. Differences of temperature observed in handle and automatic gradient profiles.*
As observed, temperature differences in low gradient metamorphism and melting situations are minimum and it corroborates the validity of the automatic measurements. Even for medium and high gradient metamorphism differences are not exaggerated.

4. ERRONEOUS DATA IN SNOW DEPTH MEASUREMENTS

The snow depth is measured with the SR50 acoustic snow depth sensor, manufactured by Campbell Scientific. Sometimes, notorious erroneous data are detected. Fortunately, this kind of mistake is easily filtered. Mistaken data consists on registering the height where sensor is placed.

Error frequencies distribution has been calculated respect to different meteorological parameters (humidity, temperature, precipitation), in order to know in which atmospheric conditions dysfunctions are registered.

Hourly registers from 2 stations of different climatic domains have been analysed: Ulldeter, mediterranean conditions, and Bonaigua, atlantic influence. Data correspond to years 2001-2002.

Respect to Ulldeter, from 7508 snow depth registers, 1.5% are erroneous. Distribution of frequencies in relationship with relative air humidity shows the modal interval in the class 90-100% with a highly significant frequency of 72%. About temperature, 64% of the cases have been recorded with air temperatures of -5°C to -1°C. Regarding to precipitation, it is interesting to remark that 74% of the erroneous data were registered while snowing or raining.

Respect to Bonaigua, from 8382 snow depth registers, 17% are erroneous. Distribution results are similar to Ulldeter data. Regarding to air humidity, there is agreement with the high frequency value of the modal interval; 81% of the errors were recorded in extreme conditions of relative humidity (90-100%). Contrary, results with temperature distribution seems not to be too outstanding, since frequency distribution has a platycurtical behaviour, where 73% of the errors are equally distributed in several intervals (between 6.5°C and -2.5°C). Respect to occurrence of precipitation, 45% of the errors were measured when precipitating.

Results seem to indicate that atmospheric conditions close to saturation produces mistakes in the snow depth sensor measurements. On these cases, the radiation emitted by the device works detects erroneous snow height because of the opaque air conditions.

\[ Figure \ 6. \ \text{The \ majority \ of \ the \ errors \ were \ recorded \ in \ humidity \ close \ to \ 100\%.} \]
ACKNOWLEDGEMENTS

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REFERENCES


THE VALENCIA ANCHOR STATION, A CAL/VAL REFERENCE AREA FOR LARGE-SCALE LOW SPATIAL RESOLUTION REMOTE SENSING MISSIONS

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Abstract

New and forthcoming Earth Observation satellite missions include in their payloads remote sensing instruments of very low spatial resolution. Data and product validation from these sensors introduces a set of specific scientific issues that make it necessary to carry out specific measurements over large extended areas. The main objective of the VALENCIA Anchor Station is to define a reference area (Utiel-Requena Plateau, at about 80 km from the city of Valencia, Spain) robustly equipped with suitable automatic meteorological instruments and to provide a methodology to characterise significant geophysical parameters, representative of sufficiently large zones in relation to the pixel size of the remote sensing sensor under consideration. The region (about 50x50 km²) is highly convenient thanks to its large-scale reasonable homogeneity from different viewpoints (climatology, land use, topography, etc.). The station has also available complementary mobile instrumentation to produce reliable parameters representative of relatively large areas defined around the Anchor Station.

Key words

Anchor Station, Calibration/Validation, Low spatial resolution sensors, Remote Sensing

1 INTRODUCTION

The requirements for data records and information products derived from Earth Observation technology are consistent quality, precision and accuracy. Besides, in order to produce reliable measurements as input to the geophysical parameter retrieval, a basic requirement is that the spaceborne instruments are properly calibrated. This ensures that the retrieval algorithms are independent of instrument errors and establishes confidence in the geophysical parameter estimates. For climate measurements, for example, changes of only a few percent in geophysical parameters are of critical interest.

The activity that endeavours to ensure that remote sensing products are highly consistent and reproducible is known as calibration and validation, or simply "cal/val". This is an evolving discipline that is becoming increasingly important as more long-term studies on global change are undertaken, and new satellite missions are launched. Calibration is the process of quantitatively defining the system responses to known, controlled signal inputs. Validation is the process of assessing, by independent means, the quality of the data products derived from the system outputs. These definitions are internationally accepted and are most
often used in the remote sensing context to refer specifically to sensor radiometric calibration and geophysical data product validation. Agencies usually undertake the calibration of their respective mission satellite systems; however to extend this beyond the commissioning phase is potentially very difficult. Therefore, well-instrumented benchmark test sites and data sets for calibration should be supported, in particular for terrestrial applications, to provide calibration information to supplement or substitute for on-board calibration, in a coordinated way, and ensuring continuity and reliability to access to their data with minimal delay. These sites could well receive rotating support from agencies with the agency (or company) with the most recent satellite launch funding the site during the commissioning phase.

Besides a history of long data records, the ideal requirements for these test sites include that they are large, flat homogenous areas, with nearly Lambertian and nearly flat spectral reflectance, and with high percentage of clear skies and dry conditions. They should primarily be bright targets, including a few low reflectance targets as well. Besides having year-round availability, the test site should somehow have “controlled” human disturbance as well.

The primary objective of validation is to assess the quality, and as far as possible to quantify the accuracy of remote sensing data products. Ideally, validation activities seek to compare the data products with more accurate independent measurements of the same quantity over a statistically significant number of samples and wide variety of situations. The problem is that the space and time scales of the in-situ data and the satellite data are rarely directly comparable. Typically, there are insufficient in-situ measurements to cover a satellite field of view, whether the field of view is some meters (high resolution imagers, for example), or several km (broadband radiometers, L-band radiometers, etc). Thus, even a perfect remote sensing measurement will be expected to differ from an in-situ verification measurement because of the inability to match the observations in time or space. In-situ measurements are invariably taken at small space and time scales, while a satellite overpass is a few second snapshot of a large area. For broadband radiometers, a common example is the comparison of a surface flux radiometer to a satellite based estimate for the radiometer field of view. The matching error can be reduced (but not eliminated) by increasing the number of surface observations within the field of view (level 2 data) or grid box (level 3 data). This error can also be minimized by using very large ensembles of matched data.

Field campaigns are best for process studies and hypothesis formation. They provide the most complete case study data, but usually provide very limited statistical significance. Dedicated sites, BSRN (Baseline Surface Radiation Network), surface sites, and other long-term sites are considered the best strategy for validation, in this case, of cloud and radiation data.

In many geophysical fields, the region of the earth viewed by a satellite observation rarely matches exactly that viewed by the surface radiometer. Recourse must be made to statistical intercomparisons in order to reduce the sampling noise induced by the different space and time sampling characteristics of satellite and surface data. The special character of remote sensing measurements to correspond to area integrated values, obliges independent in situ measurements to be representative of zones of a minimum number of pixels of the sensor under consideration. The large pixel size of some satellite missions such as GERB, EarthCARE (Earth Clouds, Aerosols and Radiation Explorer), CERES (Clouds and the Earth’s Radiant Energy System), SMOS (Soil Moisture and Ocean Salinity), etc., introduces a number of scientific issues that make it relevant and even necessary to develop a specific methodology and carry out specific measurements over large extended areas. These regions
should be well controlled from the viewpoint of other complementary measurements, also at a large scale.

The University of Valencia has recently set up a robust automatic meteorological station located towards the North-West part of the Valencia region, in the Utiel-Requena Plateau, at about 80 km from the city of Valencia. The main objective of the VALENCIA Anchor Station is to define and characterise a large, reasonably homogeneous and flat area, mainly dedicated to vineyards, as reference for Cal/Val activities in low-resolution large-scale pixel size satellite sensors, as those corresponding to the missions mentioned above. The area is well documented and has previously been used in other projects. It is desirable that the VALENCIA Anchor Station area, together with the Central Spain area where the University of Castilla-La Mancha has three other twin stations operational, could define a still larger and reasonably homogeneous region of about 300 x 200 km², in order to be able to count with a minimum number of large size pixels of the order of 50 x 50 km² (Figure 1).

2 SCIENTIFIC OBJECTIVES OF THE VALENCIA ANCHOR STATION

The specific scientific objectives of the tasks to be carried out at the zone mainly in relation to the missions mentioned above are (Lopez-Baeza et al., 2001, 2002):

2.1 Definition of a large scale validation area for low spatial resolution missions

Valuable requirements for a test site are the information on the area, basic documentation, availability of retrospective measurements and maintenance and attention to the site. These conditions are especially accomplished in this case, both for the University of
Valencia site, that is, the VALENCIA Anchor Station, and for the University of Castilla-La Mancha sites, that is the Tomelloso, El Bonillo and Barrax Anchor Stations.

On the one hand, the Regional Ministry for Public Works, Land Planning and Transports of the Regional Government of Valencia scientifically documented the territory from the viewpoint of soil as a natural resource, and provided physiography maps, maps of soils, land capability, potential erosion and actual erosion (Antolin, 1998). These maps may be obtained in a Geographical Information System environment, perfectly documented.

On the other hand, the Castilla-La Mancha region has thoroughly been studied in previous well-known international projects such as:

- EFEDA (*ECHIVAL Field Experiment in a Desertification-Threatened Area*)
- ECHIVAL-EFEDA PHASE II Project no. 5: Remote Sensing and Radiometric Properties of the Surface: Assessment of Desertification From Space
- RISMOPE (*Radiometric Impact of Surface Moisture on Precipitation*)
- RESMEDES (*Remote Sensing of Mediterranean Desertification and Environmental Stability*)
- RESYSMED (*RESMEDES Synthesis of Change Detection Parameters Into a Land-Surface Change Indicator for Long-Term Desertification Studies*)

Besides, the area has currently been used as the vicarious validation area for METEOSAT. The University of Castilla-La Mancha holds information on soils, vegetation, land use classifications, etc.

The overall area proposed may be defined from the available information mentioned above, taking into account the characteristics of soils, climate, physiography, etc. It does then result in total a large extended area, more than 300 km wide, reasonably homogeneous taking into account the low spatial resolution of the remote sensing instruments under consideration. The first principal task to be undertaken should be to homogenize the large quantity of information available and complete intermediate zones by means of interpolation methods based on spatial statistical techniques (kriging and co-kriging) and by using remote sensing techniques. It may be stated that there does not exist in Europe an area of similar characteristics, especially as large and homogeneous, and located in a climatic area of so much scientific interest from many different viewpoints.

### 2.2 Definition and characterisation of a large scale reference pixel

Complementarily to the previous objective, it is also planned to carry out specific tasks to facilitate the preparation of future Cal/Val activities of the missions mentioned earlier. This is a valuable objective that both the GIST (*GERB International Science Team*) and the SMOS Science Team have positively valued by accepting the VALENCIA Anchor Station site as one of the basic areas to carry out this kind of activities. This objective includes several planned tasks starting from the classification of different homogeneous environmental units in the large pixel area. The plan is to select an area about 50 km wide around the actual Anchor Station site, approximately of the size of a GERB or a SMOS pixel where to design and carry out a number of distributed measurements of soil moisture content, soil temperature, surface temperature, reflectance, albedo, and net radiation together with some other meteorological parameters (Figure 2).
Non-homogeneities within every unit will be characterised by defining transects and using mobile instrumentation. As far as surface reflectance is concerned, the Climatology from Satellites Group will count on the collaboration of the Field Radiometry Group, both included in the Remote Sensing Research Unit of the University of Valencia. It would be desirable to be able to also count on the collaboration of other groups to carry out angular measurements by using L-band radiometers as well (Figure 3).

It is planned that this characterisation be made firstly in an area of about 5 km diameter, and then scaling up to 10 km, 20 km, etc, until covering the whole zone. It will also be carried out under different meteorological and climatological conditions along the year, minimally during a dry period and immediately after a significant rain event, accounting for spatial variability and topographic effects as well.
2.3 Study of scaling issues. Criteria for aggregation and disaggregation. Time Interpolation and Spatial Averaging

With no doubt, the large size, not only of the whole area, but also of the reference pixel, makes it necessary to study in detail the change of scale processes in order to be able to compare measurements proceeding from so different sources at different scales, namely point measurements, aircraft observations, different spatial resolution acquisitions from different satellite platforms, etc., and establish criteria for aggregation and disaggregation to get different area averages and validate large scale pixels.

Similarly, time interpolation, that is, handling the time dependent diurnal cycles or getting monthly averages of surface temperature, solar zenith angle albedo dependence, and cloud property diurnal cycles, to name a few examples is also a difficult task except for geostationary satellites.

3 VALENCIA ANCHOR STATION DESCRIPTION

The VALENCIA Anchor Station (39°34'15"N, 1°17'18"W, 813 m) is placed in the Requena-Utiel Plateau. This is an extensive undulated plain formed by quaternary sediments surrounded by mountainous regions at the Northern and Eastern sides and the Gabriel River Basin at the Western and Southern sides. The landform shows erosion and depositional footslopes and topography characterised by flat regions (slope <2%) and undulated areas (8-15%). The major soils of the region - Calcareous Cambisol and Haplic Calcisol - are deep soils with carbonate accumulations and equilibrated textures, and low organic matter amounts. The dominant land use in the plateau is dedicated to vineyards, however, the Anchor Station surrounding area contains representative ecosystems of the Mediterranean arch, typical of semi-arid regions, including Alepo pine forests and Mediterranean shrubs.

In principle, the VALENCIA Anchor Station as such is a robust meteorological station where measurements are made at different levels both in the atmosphere and in the soil in order to be able to derive surface energy balance fluxes. Table 1 shows the parameters that are operationally measured at different levels together with the characteristics of those measurements (instrument, resolution, range, model and maker). Brand names are given just for information and do not mean any special endorsement from the authors. The station is composed of two masts. One holds conventional meteorological instruments at the atmospheric levels of 2 and 15 m, and –10, -20 and –40 cm in the soil. Air temperature is also measured at 0.5 m. The second mast is dedicated to the measurement of the four radiation components at 2 m above the ground.

Table 2 shows the mobile instruments that can be used to measure specific parameters and some meteorological quantities in the whole Anchor Station area by means of transects performed with the vehicles shown in figure 4. There are two mobile meteorological stations that measure air temperature and humidity, global irradiance, surface albedo and net radiation at 2 m above the ground and soil temperature profile and soil heat flux at different levels within the soil. The specific parameters mentioned earlier refer mainly to surface reflectance and brightness temperature and some vegetation parameters, together with other soil characteristics such as soil moisture content and soil dielectric characteristics. Atmospheric transmissivity may also be measured. There are other instruments planned to be acquired in the short future to improve atmospheric and cloud measurements, as well as a singular and unique instrument to determine atmospheric radiation divergence.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Instrument</th>
<th>Resolution</th>
<th>Range</th>
<th>Model</th>
<th>Maker</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Speed at 2 and 15 m</td>
<td>Anemometer</td>
<td>0.1 m s⁻¹</td>
<td>0 - 50 m s⁻¹</td>
<td>VV-200</td>
<td>Geónica</td>
</tr>
<tr>
<td>Wind Direction at 15 m</td>
<td>Weather Vane</td>
<td>1°</td>
<td>0 – 360°</td>
<td>DV-200</td>
<td>Geónica</td>
</tr>
<tr>
<td>Air Temperature at 0.5 m</td>
<td>Temperature Sonde</td>
<td>0.1°C</td>
<td>-50 °C - +50 °C</td>
<td>STA-212-PVC</td>
<td>Geónica</td>
</tr>
<tr>
<td>Air Temperature and Humidity at 2 and 15 m (tbc)</td>
<td>Integrated T and H Transmitter</td>
<td>T: 0.1°C</td>
<td>-50 °C - +50 °C</td>
<td>44212/50-U</td>
<td>Vaisala</td>
</tr>
<tr>
<td>Atmospheric Pressure</td>
<td>Barometer</td>
<td>1 mb</td>
<td>600 – 1100 mb</td>
<td>SPA-900</td>
<td>Druck Limited</td>
</tr>
<tr>
<td>Downwelling, Reflected and Net SW Radiation</td>
<td>Albedometer</td>
<td>1 W m⁻²</td>
<td>0 – 1500 W m⁻²</td>
<td>CM 14</td>
<td>Kipp &amp; Zonen</td>
</tr>
<tr>
<td>Downwelling, Emitted and Net LW Radiation</td>
<td>Pyrgeometer</td>
<td>1 W m⁻²</td>
<td>0 – 1500 W m⁻²</td>
<td>CG 1/2</td>
<td>Kipp &amp; Zonen</td>
</tr>
<tr>
<td>Soil Temperature</td>
<td>Temperature Sonde</td>
<td>0.1°C</td>
<td>-50 °C - +50 °C</td>
<td>STS-212-PVC</td>
<td>Geónica</td>
</tr>
<tr>
<td>Soil Heat Flux</td>
<td>Soil Heat Plate</td>
<td>1 W m⁻²</td>
<td>0 – 1500 W m⁻²</td>
<td>RIMCO</td>
<td>RIMCO Middleton Synchotac</td>
</tr>
<tr>
<td>Soil Moisture Content</td>
<td>Delta-T Profile Probe (tbc)</td>
<td>±0.5 m³ m⁻³</td>
<td>0-10 m³ m⁻³</td>
<td>PR 1/4 – 1/6</td>
<td>Hoskin Scientific LTD</td>
</tr>
<tr>
<td>Evaporation</td>
<td>Evaporimeter</td>
<td>0.76 mm</td>
<td>0 – 254 mm</td>
<td>255-100</td>
<td>Nova Lynx Corp.</td>
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<tr>
<td>Precipitation</td>
<td>Pluviometer</td>
<td>0.1 mm</td>
<td>0 – 26 cm</td>
<td>52202/52203</td>
<td>Young</td>
</tr>
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</table>

Table 2.- VALENCIA Anchor Station’s mobile instruments

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td>Net Radiation</td>
<td>2 Middleton pyrradiometers</td>
</tr>
<tr>
<td>Global Irradiance</td>
<td>2 Kipp and Zonen pyranometers</td>
</tr>
<tr>
<td>Surface Albedo</td>
<td>2 Kipp and Zonen albedometers</td>
</tr>
<tr>
<td>Soil Heat Flux</td>
<td>4 Middleton heat flux plates</td>
</tr>
<tr>
<td>Soil Temperature Profile</td>
<td>Campbell Pt-100 Temperature probes</td>
</tr>
<tr>
<td>Surface Radiometric Temperature</td>
<td>Raynger MX4 HowholsIt</td>
</tr>
<tr>
<td>Atmospheric Transmissivity</td>
<td>EKO Sunphotometer MS-110</td>
</tr>
<tr>
<td>Soil Dielectric Constant</td>
<td>Tektronic TDR 1502C</td>
</tr>
<tr>
<td>Soil Moisture Content</td>
<td>ThetaProbe type ML2X</td>
</tr>
<tr>
<td>Surface Spectral Reflectance (Field Radiometry Group)</td>
<td>GER-SIRIS and GER-3700 Spectroradiometers</td>
</tr>
<tr>
<td>Band Reflectance (Field Radiometry Group)</td>
<td>EXOTECH Radiometer</td>
</tr>
<tr>
<td>LAI (Field Radiometry Group)</td>
<td>LICOR-2000 Plant Canopy Analyser</td>
</tr>
<tr>
<td>Chlorophyll (Field Radiometry Group)</td>
<td>Minolta SPAD-502</td>
</tr>
</tbody>
</table>

The Valencia Anchor Station is operative 24 hours a day since it has several batteries which are fed by solar panels. The panels provide the necessary power for the operation of the METEODATA/HIDRODATA data acquisition systems. So, the automatic weather station (AWS) works in a continue way. This system storages the measured data and the microprocesator calculations from each input channel values. The AWS has 3
METEODATA/HIDRODATA systems in order that each sensor can be connected to the data acquisition system by a single channel.

The unit is sampling all the signals with a resolution of 13 bits and in a sequential way, measuring its instantaneous values and periodically calculating maxima, minima, means, accumulated values, etc.; at programmable time intervals. The sampling rate chosen is of 2 seconds, whereas the reading rate is of one signal every 10 minutes. It thus constitutes 144 readings per day and parameter.

The data processing is carried out with the TELETRANS_W software orvided by the supplier company. This tool allows the data coming from the station to be downloaded in a simple and intuitive form. This software allows having a window for each station from which one is able to select the data requested. The correspondent channels for each station, the parameters related to each channel, the measured values (only visible in the instantaneous mode) and their physical units can be seen in this window as well.

The station-computer communication system is based on the GSM communication protocol or directly by connecting the data acquisition system to a laptop computer through the series RS-232 port. The measurements are downloaded and saved in ASCII and MatLab format monthly. The communication process is the main energy expense in the station.

The sensors spatial distribution follows the classic scheme as seen in other stations (figure 4):

![Figure 4: Valencia Anchor Station Scheme](image-url)
Figure 5 shows a sample of different direct and derived products of the station.

4 ACKNOWLEDGEMENTS

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There are presently two Spanish Research Programme on Space Research Projects that are being developed in the framework of the VALENCIA Anchor Station, namely MIDAS, in the context of the SMOS Mission (Lopez-Baeza, 2001), and SCALES in the context of the GERB Mission on board MSG (Lopez-Baeza, 2002). Both include tasks addressed to the characterisation of the whole VALENCIA Anchor Station area, respectively with respect to soil moisture content and to radiation and cloud studies.
We also acknowledge the confidence and scientific support from the GIST (GERB International Science Team) and the SMOS Science Team who count on the VALENCIA Anchor Station as a reference station for their validation activities.

5 REFERENCES


SUMMARY: The Agroclimatology Network of Catalonia (XAC), managed by the Catalonia Meteorological Service, was founded in 1987 and is made up of a total of 91 automatic weather stations. These are based in Catalonia, and are located preferably in places where agrarian activity makes up a significant part of the economic wealth of an area, or where agrarian activity occupies a high percentage of land surface. The XAC’s unique features are its location, the variables that it measures and the agroforestry applications derived from it.

Key words: The Agroclimatology Network of Catalonia; XAC; Agroclimatology

1. INTRODUCTION

The Agroclimatology Network of Catalonia, (hereinafter referred to as XAC), was set up in 1987 as a result of the requirements of the Department of Agriculture, Livestock and Fisheries of the Catalan Autonomous Government, (the Departament d’Agricultura, Ramaderia i Pesca de la Generalitat de Catalunya: hereinafter referred to as DARP), to have continuous measurement data available. The data required regarded a high number of meteorological variables to be used as an auxiliary, but essential, tool for various agricultural applications.

The DARP used to run the XAC until the beginning of 2001, when it was handed over to the Catalonia Meteorological Service.

At first, an accurate inventory was made of the weather observation stations in Catalonia in order to use the data of most interest. The inventory showed that there were several networks, making up more than 600 stations, providing data. Despite this high number, there were two fundamental, generalised problems that proved intractable when attempting to meet the needs of the agrarian sector (LLASAT, 1997):

- **Time restraints and the physical location of the data.** Many conventional weather stations were located in urban areas, or near them. Thus they were not very representative for agrarian purposes. Furthermore the density and distribution of the other meteorological networks were far from what would be acceptable for agrarian requirements.

As for the time restraints, it should be noted firstly that the majority of stations are of the manual observation type and only collect data a maximum of four times per day. For fire prevention purposes, or for pest and disease control, measurements should be virtually continuous. Secondly, these meteorological data sequences are often unfortunately presented with blank periods which include no measurement data.

In conclusion, it should be pointed out that the availability of real time information was very scarce; - in the conventional networks, information is not made available until weekends.

- **The variables measured and the location of sensors.** The majority of places where meteorological observations were made only collected data on daily rainfall levels, or at
most average and maximum daily temperatures. There was a total lack of data on specific variables such as: net global solar radiation, wind speed and direction at 2m, temperature of subsoil or humidity of vegetation covers, all of which is information essential for any type of agronomic application.

Once these shortcomings were analysed, the conclusion was arrived at that there were not enough stations that complied with the required conditions, and that a specific network was needed to manage agrarian resources in the best way and optimise the use of meteorological information. This information provides an auxiliary tool of great importance in many agricultural applications, (fundamentally in the protection of irrigated land and irrigation water control), and in the management of forest resources. Furthermore a stock of meteorological data of different variables is required which will be continually expanded upon.

It was decided to adopt the XAC solution so that the weather stations would comply with a series of requirements:

- Equipment was installed from scratch enabling the choice of the sites most representative to locate stations so that they can comply with the requirements previously mentioned.
- As stations would be automatic, they would operate continuously and generate a quantity of data that visual observation methods could not guarantee.
- Site locations would fulfil some minimal requirements, such as the fact that there should be no nearby obstacle that might affect the data
- Records of all the meteorological variables that might be of use to the agricultural sector would be obtained.
- Each station would have an exclusive phone line that would allow data to be centralised in one place and to be available in real time.
- Data should be available to interested institutions and individuals in a format that is easily accessible and easy to use.
- As the computer system’s software includes the appropriate calculus programmes, data should be automatically available, not only from sensor recordings but also from other indirect sources, regarding for example reference crop evapotranspiration. (ETo) and the water balance.

To continue with the review of its fifteen years of activity it should also be mentioned that the XAC comprises, at present, not only the weather stations that belong to the Catalonia Meteorological Service, but also those acquired from other institutions. This is how it has been able to achieve the integration of nearly all of the automatic agroclimatology stations operating in Catalonia into one network.

2. LOCATION OF THE WEATHER STATIONS

Initially, the weather stations were sited in the most economically profitable areas of the country: the fruit growing zone of the flat regions of Ponent, Empordà and Ribera d’Ebre areas; the vineyards of Raimat, the olive and nut growing zones of the regions next to the Reus and Tarragona areas, and the vegetable growing zones of the Maresme and Baix Llobregat areas.

This initial stage of development takes us up to 1995 when several stations located in the middle of the Mediterranean forest areas were then set up. These stations were to serve as
forest fire prevention aids. This investment was a result of the state of maximum alert imposed after the devastation caused by numerous forest fires all over Catalonia in the summer of 1994.

The period between 1995 and 1998 is characterised by the incorporation of lots of stations previously belonging to other owners. The new stations were made by the same manufacturer and were located in areas of forestry or agricultural interest. With these latest incorporations, nearly all of the agricultural zones of Catalonia (CUNILLERA, 1995) had at least one representative XAC station.

From the end of 1998 onwards, the majority of new stations were designed specifically for the battle waged against pests (insects) and disease (bacteria and fungi) in areas under cultivation. These stations cover a smaller area than the others, and criteria regarding installation were influenced by the experiences of those areas most susceptible to disease. In this regard, more new agroclimatological stations may be needed in Catalonia in the future.

3. VARIABLES MEASURED

The majority of the XAC’s agroclimatological stations have sensors to measure the following meteorological elements:

- air temperature (at 1.5m)
- relative humidity (at 1.5m)
- rainfall (at 1-1.5m)
- global radiation (at 2m)
- wind speed and direction (at 2m)
All of these measurements are taken at standard altitudes for any climatological purpose, except for the wind recordings that are made at 2m (not at 10m which is the altitude recommended by the WMO). This is so because in agronomy wind at 2m is what affects crops, as they do not usually grow beyond this height.

In many of these weather stations the following measurement sensors have also been installed:

- net global solar radiation (at 1 m)
- subsoil temperature at 5 to 50cm
- humidity of vegetation cover

Stations used for forestry purposes also have:

- a second wind speed and direction sensor, located at an altitude of 6m as that is the height used by all of the fire spreading risk forecast models
- some forest stations also have sensors to measure the humidity of forest fuels and the temperature and humidity of the soil (TDR)

The stations designed for the battle against pest and disease only have the following sensors:

- air temperature
- relative humidity
- rainfall
- humidity of vegetation cover

These stations are installed in the middle of irrigated fields and, as they have no wind sensors there are no screening problems.

Finally on this subject, it only remains to say that a few stations do have wind sensors at altitude of 10m, due to local conditions governing the site, or because their owners had decided on that altitude. There are also some stations with atmospheric pressure gauges previously acquired by their owners. None of the Catalonia Meteorological Service’s stations have been equipped with these.

4. APPLYING THE DATA

In addition to the weather stations, the XAC has a whole series of agricultural and forestry applications at its disposal, and meteorological records are a basic part of what it can offer its users. Current applications are:

4.1. Calculations on crop irrigation water

It has become more evident over the last few years that water is a very scarce resource and that it will become even more scarce in the years to come.

If one considers that the major consumer of water is the agrarian sector where it is used principally as it always has been, i.e. for crop irrigation, water usage will need to be rationalised more and more.

From its beginnings, the XAC was conceived to improve water management and for this reason the weather stations located in those places that covered irrigation areas were given
priority and equipped with all resources, sensors and means available to carry out the appropriate calculations. The most important calculation is for evapotranspiration (ETo) which is the water consumed (m$^3$/ha per day) by the reference crop (lawn). This computation of the ETo is done using the Penmann formula, revised in recent years (ALLEN, et al., 1998).

Once the ETo and the real time rainfall data of the major agricultural areas in Catalonia data are available, it is obvious that all necessary means should be employed to use this data as a basis for programming irrigation so that crop areas have the necessary water available for their optimum development, whilst maintaining the productive potential of the land (i.e. not salinising it).

The PAC REG (SIÓ et al. 2002) computer programme was developed in order to facilitate the calculations required to determine the crop irrigation water needed over a period of time, for a specific crop, on a specific parcel of land.

The PAC REG system facilitates real time irrigation programming for both surface irrigation (furrow irrigation, surface) and localised irrigation (dropping, microsprinkling) by using the ETo and the rainfall data from the XAC. It also uses data from other sources (evaporimeter tanks, manual rainfall gauges etc) and the data which is easily observable from a specific parcel of land, such as the characteristics of the irrigation system, the soil and water as well as the crops

The PAC REG programmings can be compared with direct measures of watering the land (tensiometers, TDR etc) and in any case the experience of the technician or farmer himself will allow for adjustments according to different real scenarios.

4.2. Fire risk prevention

Meteorological variables play a strong role in setting off and fuelling forest fires. For this reason it is essential to have the most significant records of meteorological variables available such as relative humidity, radiation or wind direction. The XAC allows for hour-by-hour surveillance, and when required at even smaller intervals.

Aside from these variables, the XAC is becoming more specialised and has equipped itself with other sensors which are not just meteorological, such as sensors to measure humidity in combustibles and Time Domain Reflectometry (TDR) sensors. The sensors for humidity in combustibles measure the water content in a brushwood type of fuel. It is a direct, integral measure of all of the variables of the surrounding area which act upon the dead vegetation which would feed a fire. And the TDRs are sensors which measure water levels in the soil at the depth at which they are placed. This datum is normally calculated using water balance.

4.3. Frost risk prevention

Temperatures below zero outside the normal season can be very damaging to crop areas, causing losses of entire harvests, especially if they take place in the spring when plants are no longer in their winter latency phase (ELÍAS, et. al 1996). Prediction of these frosts would thus be a very important tool in saving these harvests.

Of the three types of frost —the radiation type, the advection type and the evaporation type— the first two are the most easily forecastable using just the meteorological data of the site in question. Radiation frosts occur during clear, cloudless nights with low relative humidity and light or no winds. During these nights the earth’s irradiation into the atmosphere is very high and so the temperature drops at a continuous significant rate. This loss of heat is a well-recognised phenomenon and is therefore measurable. So using the temperature records before
sunset, temperature drops over the following night can be predicted and temperature drops to below or barely above zero can be highlighted. Bearing all of this in mind, the XAC has a temperature prediction option available at those weather stations located in the main agricultural areas, these also have a longer series of data available. This option can be implemented using data from the previous 18 hours (T.U.).

4.4. Rainfall Intensity

Throughout the entire Mediterranean region one of the most definitive phenomena of the climate is the irregularity of its rainfall, not just its overall annual levels, but also the distribution over the year—essentially long periods without rain followed by rainfall of short duration but extreme intensity. This feature is very important for the part these flash floods play on soil loss, on erosion, and the on fact that we have not been able to harness the downpours as the land cannot absorb such great quantities of water, the majority of it often being wasted due to the surface drain-off effect.

The XAC has a computer application which can supply data for 10-minute periods of rainfall to improve our knowledge on the data available on short downpours. The time length of the application can be shortened even further, however this is not done as the records of other manual stations do not allow for the discrimination of periods of less than 10 minutes, and one of the main aims of the XAC is to provide information which can be freely compared with all other stations.

4.5. Day-Degrees

It has long been recognised that each plant species requires a certain amount of heat during its growth stage in order to be able to grow correctly. This amount is fairly constant for each species and can be calculated using the sum of average hourly temperatures (when available) during the growth period of the plant in question, and is known as Day-Degrees. This calculation is carried out with manual instruments and thermographs and is extremely involved, however with the XAC weather station records it can be done automatically and immediately.

The calculation of Day-Degrees is done between the thresholds of recognised, previously specified temperature, above and below which growth is halted.

4.6. Hours of cold

For many crops (normally deciduous fruit trees) an annual period of winter hibernation is necessary with temperatures below a certain threshold. The total temperature below this known threshold, essential for the crop to ‘rest’ is known as hours of cold and is also more or less constant for each species. It has been proven that the harvest can be noticeably lower if a specific winter is too warm, or if periods of cold temperature alternate with warm periods. Also if the winter is too cold the plant’s productivity can be affected. This data is therefore of great importance. As with day-degrees, the XAC’s temperature records permit the instant calculation of this variable and avoid having to carry out never ending calculations manually.

So the programme calculates the number of hours when the ambient temperature is between the previously specified temperature thresholds. It also specifies the total number of hours of cold accumulated on the days previously outlined.
4.7. Pest and disease control

The ways that many pests and diseases can affect crops grown by man is significantly influenced by the behaviour of certain meteorological variables. Given that economic losses caused by these illnesses can be significant, knowing how to tackle them and what the influence on these pathological agents of temperature values, humidity, wind and rainfall is, are significant tools when treating plants correctly so that infection may be avoided.

Among the above-mentioned meteorological elements, humidity is very important because pathological agents need water to survive. But, this measure of humidity is an indirect way of knowing how much water there is available in plants for the development of insects, fungi and bacteria. To overcome this problem, a sensor capable of directly measuring the water in leaves and vegetation surfaces has been created, it is called the humidity sensor.

At the moment one can consult at the XAC about the risk of infection of the following pests and illnesses:

- vine mildew
- potato mildew
- apple and pear black spot
- peacock eye-spot disease of olive trees
- white peach scale
- pear brown spot (*Stemphylium vesicarium*)
- pyriculariosis of rice

This field offers great possibilities for new computer programmes, in fact, from the agroclimatology point of view this is the most virgin field.

5. CHARACTERISTICS AND THE OPERATING OF XAC WEATHER STATIONS

5.1. Features of the weather stations

5.1.1. Main features

All XAC weather stations are manufactured by Campbell Scientific, which is the company that makes the units that collect and treat data (data loggers) and some of the sensors, and has adapted the remaining sensors made by other manufacturers in order to enable them to work with the most important feature, the previously mentioned data logger.

Since it began working with the XAC, the manufacturer has been developing these features, central to the weather station operations. However the XAC stations have not been updated except in cases where there has been an irreparable breakdown. For this reason various different models of data loggers currently coexist, each with different storage capacity.

Either way, the majority of weather stations have units that can collect between 29,000 and 62,000 data values, which permits the warehousing of records for a period of between 3 and 7 weeks minimum in a standard XAC station, depending on the number of sensors and bearing in mind the number of different types of data collected and the current set up of the station.
5.1.2. Other features of the weather stations

As well as the central unit collecting and storing each station’s data, i.e. the data logger, the majority of XAC stations have an exclusive telephone line as well.

These are standard phone lines in those stations established before 1995. For this reason stations set up before this period needed to be located near existing telephone line networks in order to make a telephone connection feasible. Between 1995 and 1998, stations were equipped with radios that were linked to a local relay station. This technology, known as TRAC, allowed for a few kilometres distance from the receivers and enabled the establishment and connection of weather stations in the middle of forest areas.

From 1998 onwards, nearly all of the new stations have been equipped with mobile phones. This has granted a degree of autonomy to almost the entire Catalonia region and has avoided the installation of long cable lines, often detrimentally affected by electrical storms.

Telephone equipment (of all types) need equipment that can translate the data loggers’ signals and convert them into impulses recognisable by the XAC’s central server computer. This equipment is the interface.

Until 1992, the data logger and the telecommunications systems needed electricity supplies in order to function. This was another factor to be considered when searching for the right location to set up a station. Another problem was the high number of breakdowns caused by storms. The majority of stations are now run off solar panels.

5.1.3. Retrieval of data from the data logger

The data loggers are directly connected to each sensor and are programmed to retrieve data at the rate required.

Currently all of the data loggers programmes interrogate each sensor every second to retrieve data except in the cases of temperatures (air, or soil when applicable) relative humidity, water content of the soil, and temperature and humidity of forest combustibles. Each of these variables are measured every 10 minutes. This has always been done in this way so that the variation in between short time periods is small.

All of the data collected, whether it be every second or every ten minutes, are saved by the data logger in a part of its memory that can only be consulted in real time and directly from that data logger. Once the moment has passed, the data logger summarises the data. This part of the data logger’s memory is volatile and disappears over the following hour and new records are superimposed on the older ones. At the end of the day the data logger will create a summary of hourly data.

That part of the memory that can be consulted whilst the storage capacity of the data logger is not exhausted generates three types of record lines: 10-minute periods, hourly and daily. In each record line the data logger will first indicate the type of data that follows, the year and the Julian day, and the time, if applicable to the type of record.

It should be noted that the hourly and daily data are independent and are prepared by the data logger itself, for this reason any alteration of the records should be made to the hourly or daily data. However, in the case of the monthly records which are calculated at a later stage, based on daily data, any rectification of daily records will translate into changes on these monthly summaries.
6. RETRIEVAL AND CONSULTATION OF WEATHER STATION DATA

The Central Server is responsible for retrieving data from stations (every hour between 03.00 and 21.00, T.U.) and for making them available to users. It covers all of the IT structure, software and hardware, supports all of the automatic processes of data retrieval from the weather stations, programmes, data bases, communications, users connections and other central servers’ sub-units which supply data to the XAC.

- Consultations can be made via the web and consist of a series of programmes for the retrieval and transmission of data, a suite of agroclimatology and forestry applications and other additional programmes which are external (for example the PACREG programmes).

The ways in which XAC users have been able to consult data from weather stations has always been dependent on the technology available at the time.

- **AGROTEX CONSULTATIONS (1989-93).** The Ibertex system consisted of remote access to a computer which acted as central server and which used technology that required some terminals to be dedicated exclusively for this purpose. (Ibertex, not only the Agrotex service offered by the DARP-Department of Agriculture, Livestock and Fisheries). If we compare these to the current technology, the speed of the enquiry was a lot slower and the access system a lot less flexible. In order to increase the use of the XAC, the DARP installed Ibertex access systems in all of its units. Furthermore, some private users also had access to this system for other purposes and could thus consult the XAC also. In any case, the extension of use was, by its nature, limited.

- **Remote consultation via the ONLAN programme (1992-2001).** This programme permitted remote connection via a modem connected to any computer which used the MS-DOS operating system, i.e. the vast majority. This type of access represented a very significant qualitative leap in terms of allowing open access to the XAC data base system and its applications.

- **The WEB version of XAC (1999-2002).** The web version permits data to be used from a much more intuitive, agile and speedy platform. Furthermore, there is no limit on the number of users that can initiate enquiries, and anybody can work on their own spreadsheets at a later time more easily. Also one should bear in mind that the phone calls to the INTERNET are local and therefore the cost is much lower.

As at November 2002 there are more than 730 external XAC users, plus the internal ones. This is double what it was a year ago, which clearly demonstrates that the XAC’s usefulness is becoming more and more obvious over time. One of the most important objectives of the XAC management should be to respond to the needs of these users and of potential future users.

7. CONCLUSIONS

The XAC is a dynamic reality, and as such one should consider that over the coming years, new applications for pest prevention, updating of irrigation systems, frost prevention, and improvement in data quality control could be introduced. It seems obvious that the XAC should be a key instrument in several agrarian applications and that its records, and the applications derived from these, are becoming used more and more. However we should like to conclude with some points that we consider as requiring immediate action:

- The number of XAC stations is extremely significant and already covers nearly all of the agricultural areas of Catalonia. However, the number of applications covered
by these stations should be increased, adding, for example, new models for pest and disease forecasts.

- The continuous operation of these stations, adding hourly values of many variables, makes the XAC an increasingly important database for climate studies and statistical purposes.

- It should be remembered that the network comprises sensors specific for agrarian use, such as net radiation which enables ET0 calculations, soil temperature, humidity of forest combustibles, soil humidity etc. This is why the agroclimatology value of these records is almost unique in Spain.

- The optimisation of irrigation water use, finding the best time for preventative measures against disease, avoiding the use of excess amounts, are all aspects which help establish an agricultural sector which respects the environment without foregoing maximum yields.

- Automatic weather stations can often replace manual ones, providing more data and without the need for an on-site individual to make the recordings.

- The availability of data on the web allows for the simultaneous connection of many more users, more interactivity and more ways of finding information and using it at a later stage.

We should like to end by stating our view that the XAC is a fundamental tool for the future management of agriculture which must be based on the use of information, technology which can substitute manual input, and enables the optimisation of environmental management.

*Connection to the XAC is totally free and open to anybody in the agrarian sector and can be requested from the Catalonia Meteorological Service.*

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USE OF A NETWORK OF AUTOMATED WEATHER STATIONS FOR THE DETERMINATION AND DISSEMINATION OF REFERENCE EVAPOTRANSPIRATION

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ABSTRACT

This work reports the results of the comparison between the estimated and measured daily reference evapotranspiration (ET₀) by using the Penman-Monteith FAO-56 method and a weighing lysimeter, respectively. Weather data from a weather station from the Agrometeorological Information Network (Department of Agriculture of the Andalusia Government) site at Cordoba (Spain) were used. Data from the years 2001 and 2002 were analyzed. The behaviour of the Penman-Monteith-FAO equation was excellent. The method showed a tendency to underestimate ET₀ with high evaporation rates. Underprediction of net radiation could explain this behaviour.

Key words: Automated weather stations, Reference evapotranspiration, Penman-Monteith, Lysimeter.

1. INTRODUCTION

The estimation of reference evapotranspiration (ET₀) is of vital importance for the planning and irrigation scheduling, and also in hydrological studies (Jensen et al., 1989). In Andalusia there is a network of automated weather stations (AWSs) which permit the estimation of reference evapotranspiration by different methods, as well as the obtention and dissemination of mean daily values for agriculture of the most important weather records. Also, with the availability in the CIFA in Córdoba of two weighing lysimeters capable of accurate measurements of evapotranspiration (ET), it is possible to make evaluations of the estimations obtained by different methods of calculating the ET₀. This work presents values estimated by the Penman-Monteith, FAO-56 version, method (Allen et al., 1998), comparing them with lysimetric values measured during 2001 and 2002, for different evaporative demand conditions.

2. MATERIAL AND METHODS

The Agroclimatic Information Network was set up during 1999 and 2000 by the Ministry of Agriculture, Food and Fisheries and since then it has been exploited and maintained by the Department of Agriculture and Fisheries of the Autonomous Government of Andalusia. It comprises a total of 87 automated weather stations (AWSs) and a regional agroclimatic exploitation centre. One of these stations is located in the Centre of Research and Agricultural Training (CIFA) in "Alameda del Obispo", Córdoba. The stations were set up in order to give coverage to the irrigation areas of Andalusia and therefore to supply agroclimatic information to the irrigation districts.

The stations are equipped with a CR10X datalogger (Campbell Scientific Instruments, Logan, UT), a raingauge (ARG 100), an air temperature and relative humidity probe (HMP45C, Vaisala),
an wind monitor (Young) and a silicon photocell pyranometer (SP1110, Skye), and supply half-
hourly data and daily means of the main weather variables. The mean daily values are published
daily in Internet together with the mean daily $E_{To}$ calculated by the Penman-Monteith FAO-56
version method (Allen et al., 1998).

The work was carried out in the lysimetric station of the CIFA in Córdoba on a field of Festuca
arundinacea Schreber, in the geometric centre of which there is a weighing lysimeter with a tank
measuring 2 x 3 m$^2$ in surface and 1.5 m in depth (Colomer et al., 1986). This tank gravitates on
the platform of some counterweighted scales capable of detecting weight variations at around 100
g, so that the precision of the lysimeter is situated at approximately 0.02 mm of evapotranspired
water depth. In this lysimeter hourly and daily values of $E_{To}$ were recorded using a load cell (TSF
model, Epel Industrial S.A., Barcelona) and storing data in a CR510 (Campbell Scientific Inc.)
datalogger. The rainy, irrigation and grass clipping days were not considered for the analysis.
Also, the data recorded in the weather station were used to calculate the daily $E_{To}$ by the Penman-
Monteith FAO-56 method.

The regression of the $E_{To}$ estimated in comparison to the measurement with the lysimeter was
studied. Similarly, an analysis was made of the differences between the lysimetric values and
those estimated by calculating the root mean square error (RMSE) with its systematic and random
components (RMSEs and RMSEa respectively) and the index of agreement (IA) (Willmott, 1982).

3. RESULTS AND DISCUSSION

The Penman-Monteith FAO-56 method slightly underestimated the $E_{To}$ for high evaporative
demand (Figures 1 and 2). The underestimations were presented as from 6 mm/day of $E_{To}$. These
small underestimations might have proceeded from the underestimation of certain variables
entered in the equation, mainly the net radiation, estimated by the Brunt equation (1932). Indeed,
some estimations of reference evapotranspiration made under the same conditions, with values of
net radiation measured, were more accurate (Gavilán and Berengena, 2000; Gavilán, 2002). The
latter author found underestimations in the net radiation, with the method cited, of approximately
8%. At any rate, from a study of the accumulated values of measured and estimated $E_{To}$ it was
deduced that the results are acceptable for their use in the irrigation scheduling (Figure 3).

![Graph 1](image1.png)

*Figure 1. Comparison of the ET values measured and estimated by the Penman-Monteith FAO-56 method using the weather station data.*

![Graph 2](image2.png)

*Figure 2. Evolution of the ET values measured and estimated by the Penman-Monteith FAO-56 method.*
Figure 3. Evolution of the accumulated values of $ET_o$, measured and estimated by the Penman-Monteith FAO-56 method

Table I shows the results of the simple analysis of regression between the daily $ET_o$ measured and the $ET_o$ estimated by the Penman-Monteith FAO-56, as well as other statistical parameters of the model's behaviour. The coefficient of determination ($R^2$) was highly significant and the regression slope ($b$) and the intercept were not significantly different from 1 and 0, respectively, for a level of significance of 5%. The index of agreement (IA) was over 0.99, which indicates the high degree of agreement between the measured and the estimated values. The mean underestimation was 2% and the relative error (RE) (defined as the ratio between the $RMSE$ and the mean value of the evapotranspiration measured in the lysimeter) was 11%. The value of the root mean square error, slightly higher than that presented in other works, might originate, as previously mentioned, from the underestimation of the net radiation in the calculation of the $ET_o$.

Also, the influence of the strong advective conditions in the area where the study was conducted could also be another cause of the underestimations described. However, although some authors have shown the tendency of the Penman-Monteith equation to underestimate in sites with a high evaporative demand (Steduto et al., 1996), recent works have demonstrated the good prediction ability of the method cited, even under conditions of a strong sensible heat advection (Gavilán, 2002).

Table I. Analysis of regression between lysimetric values of daily $ET_o$ (independent variable) and values estimated by the Penman-Monteith FAO-56 method (P-M) and quantitative measurements of the model's behaviour (Wilmott, 1982).

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>$O_{med}$</th>
<th>$P_{med}$</th>
<th>b</th>
<th>$R^2$</th>
<th>RMSE</th>
<th>$RMSE_s$</th>
<th>$RMSE_a$</th>
<th>RE</th>
<th>IA</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-M</td>
<td>257</td>
<td>4.6</td>
<td>4.5</td>
<td>-</td>
<td>0.95</td>
<td>0.97</td>
<td>0.52</td>
<td>0.27</td>
<td>0.44</td>
<td>0.11</td>
</tr>
</tbody>
</table>

$^*$ Not significantly different from 1 ($α = 0.05$).

N: number of observations; $O_{med}$: mean of values measured; $P_{med}$: mean of the values estimated; b: regression slope; $R^2$: coefficient of determination; RMSE: root mean square error with its systematic and random components ($RMSE_s$ y $RMSE_a$, respectively); RE: relative error; IA: index of agreement.
4. CONCLUSIONS

The possibility of disposing of a network of automated weather stations in Andalusia facilitates the daily obtention and dissemination of the $ET_o$ values needed for a rational irrigation scheduling.

The Penman-Monteith FAO-56 method gives an acceptable estimation of the daily reference evapotranspiration for different conditions of the evaporative demand in the valley of the Guadalquivir. The slight underestimations obtained for high evaporation demand conditions might be due, among other reasons, to an underestimation in the calculation of the net radiation with the Brunt equation (1932), as the stations do not have any sensors for measuring net radiation. However, these underestimations did not signify any notable differences, as can be deduced from the accumulated values of $ET_o$.

Although it would be recommendable to measure the radiation in the AWSs, the difficult maintenance of these sensors and their high cost would not justify any increase in precision obtained. Although some manufacturers have recently made available net radiometers with little maintenance, their precision should be contrasted with those used up to now. At any rate, the use of guaranteed meteorological records for the estimation of reference evapotranspiration is fundamental for the obtention of reliable values and the equations used in the calculation should always be calibrated.

REFERENCES.


THE HADA PROJECT: USE OF WEATHER STATION NETWORKS FOR DIAGNOSTICS OF INCENDENCES OF POLLUTION IN PORT AREAS

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Key words: Automatic Weather Stations, Particulates

1. INTRODUCTION

Uncontrolled emissions into the air coming from the decanting of solid bulk cargos at the port or from powdery substances due to from heaps of grain or from civil works being carried out in port areas, have made dust, fume emissions and noise to be considered as one of the most significant environmental aspects at the ports. In order to prevent and control any possible incidences of air pollution, a project has been put into action called HADA (Herramienta Automática de Diagnóstico Ambiental, Automatic Environmental Diagnostic Tool) financed by the European Commission’s LIFE Program.

Figure 1. LIFE Programme and HADA Project Logos.

HADA is a prototype that covers the control of air environmental impacts, a first integrated management phase on environmental impact of port activities and operations. It is structured on microscale networks of automatic weather stations installed within the premises of the ports from which the data received can be diagnosed concerning wind fields that move the particle dust clouds produced by the decanting of solid bulk cargos and the heaping of grain. The CALMET model is used for diagnostics at each port integrated in the Project by CIEMAT, in which a Dispersion model is nested. The data is updated every 10 minutes and informs the person in charge of the environment at the service control centre about the estimate of PM₁₀ concentrations in the port area, thus allowing, if the case may be, to change the decanting conditions, water the heaps of grain or take any other extenuating actions.
2. **BACKGROUND: PORT WEATHER NETWORK**

The Port Weather Network, *Red Meteorológica Portuaria* (REMPOR) was created in 1995, with the first weather station being installed at the La Estaca Port (on the El Hierro island), as part of the works covered by the Port Weather Support Plan, *Plan de Apoyo Meteorológico a Puertos*, (Guerra, 1996). The Plan attempted to respond to the need for specific information, local characteristics and statistical and numerical studies required by large commercial ports in order to improve their services, compliance to contingency plans, evaluations on the environmental impact of their activities and the design of structures from the so-called **Wind Project** and its dynamic feature (spectral description). The resolve to obtain data from at the port itself would improve statistical estimates previously carried out from data obtained through visual observations coming from boats and weather stations belonging to the different territorial centres of the Spanish National Meteorological Institute (INM) or the different Autonomous Communities.

The installation of at least one automatic weather station at all ports would allow local data on weather variables to be made available in real time and would respond to the needs required for operations and port scheduling.

Among these requirements are:

- Control of the operational limits for port installations and structures (Extreme and Exceptional Conditions).
- Control of wind speed limits for navigating within the port. Criteria for the use of tow boats.
- Determination of Environmental Loads. Wind Activity.
- Determination of Thermal Loads.
- Forecast of fog.
- Continuous weather control for certain types of decanting. Air pollution problems.
- Emergency and Contingency Plans.
- Determination of the source of marine pollution.
- Leakage of harmful agents.
- Forecast of coastal winds in high resolution for generating models for waves, currents, sediment movement, etc.
Since the wind is the most significant weather factor for port operation and varies greatly not only over time but also spatially (local effects), it was advisable that the AWSs be installed with strict port criteria.

<table>
<thead>
<tr>
<th>Anemómetro de Hélice</th>
<th>Bladed Wind Gauge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Piranómetro</td>
<td>Pyranometer</td>
</tr>
<tr>
<td>Termómetro</td>
<td>Thermometer</td>
</tr>
<tr>
<td>Higrómetro</td>
<td>Higrometer</td>
</tr>
<tr>
<td>Pluviómetro</td>
<td>Rain Gauge</td>
</tr>
<tr>
<td>Unidad de adquisición de datos</td>
<td>Data Logger</td>
</tr>
</tbody>
</table>

Among these criteria it was determined that the placement of the stations should be at the mouth of the port or at those points particularly sensitive to dock navigation. The treatment the registers should receive was established by the Maritime Works Recommendation: Wind Activity 04-95, Recomendación de Obra Marítima: Acciones de Viento 04-95, and should be the same for all port premises, with identical validation controls and identical statistical techniques. All of this led to the forming of the Port Weather Network, (REMPOR), which integrated all the ports with the exposed criteria and implied receiving both preventive and corrective maintenance since their incorporation into the Network. Currently, 30 weather stations installed on 27 port premises comprise the Network (Figures 2 and 3) (www.puertos.es).
2.2. **METEOROLOGICAL AND ENVIRONMENTAL INSTRUMENTATION PLAN**

The practical application of REMPOR ranges from its use for determining static or dynamic loads on ships or structures to the monitoring and control of incidences of air pollution. The Meteorological and Environmental Instrumentation Plan, *Plan de Instrumentación Meteorológica y Ambiental*, from the Valencia Port Authority set up a network of AWSs (Figure 4) on the port premises in order to have data available in real time on the evolution of the atmosphere (surface wind, stability and estimate of the height of the Mixture Layer), which allows clouds of suspended particles PM$_{10}$ coming from the decanting and storing of coal, clinkers and other solid bulk materials at their terminals to be monitored.

![AWSs at the nose of the Eastern Pier and at the Western Pier](image)

**Figure 4.** AWSs at the nose of the Eastern Pier and at the Western Pier. Meteorological and Environmental Instrumentation Plan. Port of Valencia.

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anemómetro Sónico</td>
<td>Sonic Wind Gauge</td>
</tr>
<tr>
<td>Termómetro con aspiración forzada</td>
<td>Forced air suction thermometer</td>
</tr>
<tr>
<td>Piranómetro</td>
<td>Pyranometer</td>
</tr>
<tr>
<td>Pluviómetro</td>
<td>Rain Gauge</td>
</tr>
</tbody>
</table>

3. **THE HADA PROJECT**

The installation of mesoscale AWS networks, such as the one at the Ports of Tenerife, with stations at the ports of Santa Cruz de Tenerife (Llanos and Este Piers), Los Cristianos, Granadilla, La Gomera, La Palma and La Estaca, aimed at obtaining knowledge of the navigational conditions in the archipelago, are supplemented therefore with the installation of the AWS networks on a local scale, installed within port premises, such as the networks at the Port of Valencia or the one operating at the Port of Barcelona. These local networks, even
though they maintain stations at port locations (junction of the mouths), have a markedly environmental function.

In order to attain the installation of this type of local network at eight large ports, which would allow weather data to be available in real time for feeding weather diagnostic and atmospheric dispersion models (Figure 5), Puertos del Estado requested a subsidy from the European Commission, within the LIFE Environment Programme. The HADA Project was configured as a first phase in the integrated management of the environmental impact of port activities and operations.

The aim of this first phase as mentioned, is the implantation of local networks at eight ports involved in the Air Monitoring and Quality Control System Project (Crespi et al. 2001), which takes into consideration weather variables, fume concentration, suspended and sedimentary particles in the port area, as well as a Noise Monitoring and Reduction System (Aspuru et al. 2002). It also will attempt to design a particulate emissions model depending on indicators such as merchandised handling technologies, weather, decanted materials and registered emissions.

![Figure 5. Particle Sensor and Wind Gauge. Output from the MELPUFF model. Port of Valencia.](image)

All the measurement and modelling data will feed a decision making system in real time (Bernardo et al. 2001) that will assess the most adequate measurements to reduce the environmental impact of noise and air coming from port activities for which the carrying out of a cost-benefit analysis of the particle pollution reduction systems will be undertaken.

### 3.2. MEASUREMENT NETWORKS

The implantation of the Port Air Pollutant Sampling Network, *Red de Muestreo de Contaminantes Atmosféricos Portuarios*, (REMCAP) at the eight ports involved in the Project and supplemented by the local AWS networks, will allow a concentration control tool to be available for PM$_{10}$, SO$_2$, NO$_x$, CO as well as BTX at the Port of Barcelona. The structure of
the portable cabins will allow the expansion of CO₂ and ozone sampling units, or any other air pollution elements characteristic to port areas such as Volatile Organic Compounds (VOCs).

The air monitoring and quality control system will be supplemented with a noise control system (Figure 6), also designed specifically for port areas, that will be implanted and validated at the Port of Bilbao, which meets the necessary conditions for complexity and variety of sources. This Pilot Project will be the seed of the Port Noise Network, *Red Acústica Portuaria*, (RAP).

![Figure 6. Microphone at the Port of Pasajes.](image)

These pollution sampling stations will be connected in real time with the port services control centre allowing the continual monitoring of the air quality indexes within port premises. Eventually, HADAs will integrate water and soil quality control systems.

### 3.3. Diagnostic Atmospheric Dispersion Models

One of the basic roles of AWS local networks is to provide continuous weather registers that will be used by the CALMET model (TVM in the case of the Port of Valencia) to carry out a wind field diagnosis and atmosphere stability within the physical domain of the port. The wind field will inform the MELPUFF model on pollution transport mechanisms, and the stability of its turbulent characteristics. Therefore the proper location of the AWSs is essential since they contribute to the real data model which can hardly be simulated.

Also considered in the Project is the reception of weather forecasts coming from different models (MASS, ARPS, HIRLAM) that will be coupled with the diagnostic model. The use of registers obtained by the AWSs for validation and statistical improvement of the forecasts received, another of the Project’s characteristics, would make their installation alone be worth it.
4. **CONCLUSIONS**

For any outdoor commercial or industrial activity, the control and forecast of weather conditions for this activity is essential. In the case of ports, weather processes take on a double importance, since these processes are responsible for the state of the sea which the ships and their approach and docking operations they must face. Therefore, in order to know these very high spatial and temporal variability processes, the installation and correct maintenance of the local AWS networks is crucial.

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THE U.S. CLIMATE REFERENCE NETWORK – VISIONS AND STATUS

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Abstract

The Climate Reference Network of the United States (USCRN) is now being deployed across the nation. The lifetime of this high-precision climate observations network is expected to be 50-100 years. Data from the 29 USCRN observing stations so far deployed are automatically reported to the NOAA-National Climatic Data Center archive once per hour. The underlying philosophy of the USCRN is adherence to the Ten Climate Monitoring Principle. This has resulted in deployment of the USCRN stations in areas unlikely to be developed in the near future, of redundant intercalibrated sensors, and of seeking co-locations where possible of USCRN stations with stations from other networks (e.g., U.S. Cooperative Network, Historical Climatology Network, etc.)

Key words: AWSs, climate data; data homogeneity; transfer functions

U.S. climatologists have yearned for a precision climate monitoring network for several decades. Until the U.S. National Research Council’s recommendations on the “Adequacy of Climate Observing Systems” in 1999, no long-term budgetary commitment was available for design, acquisition, and deployment of a state-of-the-art national climate monitoring system. This base need is being addressed by building a climate monitoring network capable of detecting and quantifying climate variations with high scientific confidence and over a period of at least 50 years. This goal would help national government and industry decision-makers to make policy and resource allocation decisions which might be driven by climate and its temporal variations.

The guiding principles in the design of the resulting U.S. Climate Reference Network (USCRN) are the “Ten Climate Monitoring Principles” specified by Thomas R. Karl, the Director of the NOAA National Climatic Data Center (NCDC):

1. Assess the impact of network changes on future climatology.
2. Make overlapping measurements to derive correct transfer functions.
3. Metadata should fully document the observing system and its operating procedures.
4. Routinely assess the quality and homogeneity of the current and historical data.
5. Integrate environmental assessments into the Global Observing System strategy.

6. Give priority to maintaining stations with a long (century-scale) homogeneous data record.

7. Improve monitoring coverage in data-poor regions, poorly observed variables, regions sensitive to climate change, and regions with inadequate temporal resolution.

8. Include climate monitoring at the outset of the network design.

9. Maintain a stable, long-term commitment to these observations and to climate change monitoring.

10. Provide low cost freedom of access to the data and metadata.

The vision of the USCRN program is to deploy and operate no fewer than 225 high-precision, reliable, intercalibrated, autonomous and automatic stations within the 50 States of the USA by 2007. Design philosophy emphasized the use of commercial, off-the-shelf equipment wherever possible, to enhance system reliability and modularity. Station instrumentation is calibrated annually against traceable standards by NOAA’s Atmospheric Turbulence and Diffusion Division (ATDD). Data are reported hourly by using the Data Collections Systems of the GOES-East and GOES-West satellites. Upon receipt of the data at the NCDC, the data are subjected to rigorous quality control checks, and then placed into the archive. Data are usually available for downloading and review via the Internet, usually about 70 minutes after each reporting period. The two primary high-precision measurements taken by each USCRN station are air temperature and precipitation. Triply redundant sensors for temperature are being used to bolster confidence in the data, and to provide a direct measure of precision. Individual secondary instruments provide measurements of wind run and absolute velocity, global solar radiation, and ground surface temperature. Testing is underway for possible future addition of relative humidity, soil moisture, and soil temperature measurements at all stations.

The level of precision of USCRN instrumentation will reduce average annual temperature error to 0.1 degree Celsius, and to 1.5% for precipitation accumulation. Decadal temperature trend errors will be reduced to about 0.05 degrees Celsius. These targets will allow USCRN to capture 95% of the U.S. national variance (excluding Alaska and Hawaii) in monthly temperature measurements, and 90-95% of the variance in annual precipitation.

After a critical two-year period of initial testing and calibration of sensors, sensor suites, configuration, and communications, deployment of the first 40 USCRN stations began in August, 2001, with the installation of a calibrated pair of stations in the Asheville, North Carolina region. By July 2003, 40 USCRN stations will be deployed and operating in 27 States. Additional deployments for 2004-2007 are planned at a rate of approximately 45 per year.

Densification of the USCRN is envisioned through inter-instrument, inter-station, and inter-network comparisons to establish data transfer functions. Candidates for transfer function
determinations include the US Historical Climatology Network (USHCN), the Cooperative Network, and others.

In order to leverage our common interests as climate scientists, it would be useful to work towards determinations of data transfer function values among actual and proposed national climate monitoring networks. This could be done in a number of ways. One of these might be the establishment of a number of international, joint-use megasites for co-location of instrument suites. Several sites in the USA are already being considered for such a potential future use; similar candidates elsewhere would be complementary and very welcome.