THEME 4

EXPERIENCES WITH HOMOGENEITY OF TIME SERIES

LINKING OF TRADITIONAL AND AUTOMATIC STATIONS DATA: OPERATIONAL EXPERIENCE OF UCEA

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Abstract

The main problems occurring in the operational replacement of mechanical weather stations (MWS) with automatic weather stations (AWS) are linked to data achievement and recording procedures. The different way to calculate daily meteorological statistics in the past (based on few available hourly data) regarding the present moment, could influence on the time series continuity, homogeneity and comparability between old and new data. For the same reason it could not be correct to use the same codes to identify daily statistics (e.g. daily mean temperature, daily total rainfall, etc.). With regard to those aspects, it is proposed an operational experience of the Italian National Agrometeorological Service (Ufficio Centrale di Ecologia Agraria). Some statistical analyses have been carried out on several data series collected in the same period and in the same site by automatic and mechanical devices.

Key words: time series, weather station, daily statistics

1. INTRODUCTION

The growing number of automatic stations adopted by meteorological services allows many advantages as for the quality and the storage of the data. However, when automatic weather stations (AWS) replace or are used together with traditional mechanical weather stations (MWS) in an observation network, it is possible for some problems to arise concerning homogeneity and comparability among their meteorological measures and/or their statistical elaborations. Most difficulties concern the uninterruption of time series because, if it is necessary to continue the oldest series, it is also useful to take advantage of the best performances of new measurement systems. Other problems can be met in the calculation, codification and storage of climatic statistics, like means, totals etc., when the data are calculated in different ways. For example, in the past, the available daily data of temperature were usually the extreme values (Tmin and Tmax), so it was possible to calculate daily average temperature only by these two measures. At present, as recommended by WMO, we must calculate daily average temperature at least with synoptical hours data or better with 24 hourly values. The question, then, is whether to give continuity to long time series (in some cases longer than a century) losing the opportunity to improve the information quality, or to interrupt the old series in order to give life to a new series. The main problems occurring in the operational shift from MWS to AWS are linked to data achievement and recording procedures. Changes in recording systems may create uncertainties referring to the following topics:

- Features of sensors and traditional instruments (sensibility, linearity, hysteresis, etc);
- Choice of recording intervals which may be very different from traditional stations (hours or sub-hours in automatic stations; at defined or synoptic hour in the traditional ones.)
- Modalities of processing recorded data for the calculation of averages and totals.

If the elaborations obtained from data recorded through hours or sub-hours intervals are compatible with the elaborations obtained through traditional observations, there can be a real correspondence between the two series. This correspondence has been supplied from the adjacent installation of a traditional station and of another automatic one. This test has been carried out at "Collegio Romano" the oldest weather observatory in Rome. Meteorological observations began in 1782 and have gone ahead until now. In July 1998, an automatic station (Campbell CR10) has been placed in according to a plane of modernization of the weather stations network of the Ufficio Centrale di Ecologia Agraria (UCEA). Technical and functional characteristics of the instruments are presented in the following tables:

Table 1 –technical characteristics of Mechanical Weather Station (MWS)

Instruments	Characteristics	Measure unit	Scale extention	Precision	Sensitivity
Screen	Larix wood				
Hygrothermograph	Bimetallic billows	°C %	-15+45°C 0-100°%	±1% ±3%	0.5°C 5%
MinimumThermometer	Alchoolic	°C	-30+50°C	±0.2°C	0.2°C
MaximumThermometer	Mercury	°C	-30+50°C	±0.2°C	0.2°C
AugustPsychrometer	artificial ventilation	%	-30+50°C	±0.2°C	0.2°C
Pluviograph	Gauge 10 dm	Mm	10mm	± 2%	0,2 mm
Fortin Barometer	Mercury	mmHg		±0,5%	0,1 mmHg
Barograph	Aneroid	mmHg	80mmHg	±0,5%	0,5 mmHg
Heliograph	Campbell-Stokes	Hours and			
Anemometer		Degrees° Km/h	0-360° 0-100 km/h	±5° 0,5-1,5m/s	0,5 m/s

Table 2 – Roma Collegio Romano: technical characteristics of Automatic Weather Station (mod.CR10 Campbell)

Parameter	Characteristics	Measure unit	Scale extention	Precision	Sensitivity
temperature	Ventilation resistance PT100	°C	-40 + 60°c	±0,3K	0.2°C
Humidity	Ventilation Resistance	%	0-100%	±1%(5-95%) ±2%	0,5%
Precipitation	Relay	mm		±0,2 mm	0,2 mm
Atmospheric Pressure	Potentiometer	hPa	0-690 bar	±0,3%±	
Insolation	Electric eye	Minutes	0,4-1,1µm	±3%	10uV/W/m^2
Wind direction	Potentiometer	Degrees	0-360°	±2%	0,6 m/s
Wind Speed	Magnetometer	m/s		±1% 10-5 m/s ±2% (>55m/s)	0,2 m/s

2. DATA AND METHODS

The period of experimentation begins 17 July 1998 (date of installation of AWS) and ends 31 December 2000, but the last date utilized to compare the two different kind of instrumentations refers to 31 December 1999 (date of release of the MWS). Meteorological measurements carried out from the two stations are recorded in a data bank through automatic transfer of data logger output files (AWS), or through manual type of information taken from paper recordings (MWS). MWS data recording is in compliance with the detailed notes established for UCEA traditional weather station: three daily observations (at 8:00 am, 2:00 pm, 7:00 pm local time) and some daily maximum and minimum values. AWS data refers to each daily hour and to some other daily measurements like maximum and minimum values with the relative occurring time. In order to carry out this work, all meteorological data have

been loaded on a worksheet to test the qualities and to effect elaborations. A specific statistical software has been used for elementary statistics, to carry out some statistical tests and some graphic representations. Meteorological parameters analysed are: Temperature (T), Rainfall (R), Relative humidity (RH) and Barometric pressure (P). Daily averages (for temperature, relative humidity and barometric pressure) and daily totals (for rainfall) have been calculated using two different procedures:

a) By traditional algorithms adopted by UCEA for data obtained from its observation mechanical weather stations network. To best compare AWS and MWS data series, the first data sets have been cut off at 31 december 1999. In this work those data have been marked as follow: (AWS)*.
b) By calculating modalities allowed for the newest automatic observations.

Two comparisons have been carried out:

a) Comparison between variables obtained through the same algorithm and referred to the two different meteorological stations.
b) Comparison between variables referred to a single station and calculated with different procedures.

Calculated daily values have regarded the following variables:

- Daily Mean Temperature T_{24} (only for AWS)

$$T_{24} = \frac{\sum_{i=1}^{24} t_i}{24} \qquad (1)$$

where:
t_i= hourly temperature

- Daily Mean Temperature T_{nx} (AWS and MWS)

$$T_{nx} = \frac{(t_{\max} + t_{\min})}{2} \qquad (2)$$

where:
t_{max}= daily maximum temperature
t_{min}= daily minimum temperature

- Daily Mean Temperature T_{ucea} (AWS and MWS)

$$T_{ucea} = \frac{(t_{8:00} + t_{19:00} + t_{\max} + t_{\min})}{4} \qquad (3)$$

where:
$t_{8:00}$= temperature at 8:00
$t_{19:00}$= temperature at 19:00
t_{max}= daily maximum temperature
t_{min}= daily minimum temperature

- Daily Total Rainfall R_{24} (AWS):

$$R_{24} = \sum_{i=1}^{24} r_i \tag{4}$$

where:
r_i= total hourly rainfall

- Daily Total Rainfall R_{ucea} (AWS and MWS):

$$R_{ucea} = r_{8:00} + r_{14:00} + r_{19:00} \tag{5}$$

where:
$r_{8:00}$= rainfall amount from 19:00 of previous day to 8:00 of present day
$r_{14:00}$= rainfall amount from 8:00 to 14:00 of present day
$r_{19:00}$= rainfall amount from 14:00 to 19:00 of present day

- Daily Mean Relative Humidity RH_{24} (AWS):

$$RH_{24} = \frac{\sum_{i=1}^{24} rh_i}{24} \tag{6}$$

where:
rh_i= hourly relative humidity

- Daily Mean Relative Humidity RH_{ucea} (AWS and MWS):

$$RH_{ucea} = \frac{(rh_{8:00} + rh_{14:00} + rh_{19:00})}{3} \tag{7}$$

where
$rh_{8:00}$= relative humidity at 8:00
$rh_{14:00}$= relative humidity at 14:00
$rh_{19:00}$= relative humidity at 19:00

- Daily Mean Barometric Pressure P_{24} (AWS):

$$P_{24} = \frac{\sum_{i=1}^{24} p_i}{24} \tag{8}$$

where:
p_i= hourly barometric pressure

- Daily Mean Barometric Pressure P_{24} (AWS and MWS):

$$P_{ucea} = \frac{(p_{8:00} + p_{14:00} + p_{19:00})}{3} \tag{9}$$

where:
$p_{8:00}$= barometric pressure at 8:00
$p_{14:00}$= barometric pressure at 14:00
$p_{19:00}$= barometric pressure at 19:00

Each variable has been well sorted to compare corresponding daily variables and excluding dates with incomplete or faulty values. Specifically for rainfall, the comparison has been effected only on rainy days, taking as reference values ($R \neq 0$) the AWS totals calculated with formula (4). Considering that analyzed data do not follow the normal distribution, comparative evaluations have been effected through nonparametric tests, as Kolmogorov-Smirnov test (KS-test) for two samples, fit to verify whether two distributions are identical or not. KS-test is even sensitive to differences among sample variances differing from parametric tests which only check differences between means or medians (WMO – 1986). Therefore the KS-test compares the couples of points that describe the curves of cumulated rank values. KS-test hypotheses:

$$H_0: \ F(x) = G(x) \qquad \text{for all x from } -\infty \text{ to } +\infty$$

$$H_1: \ F(x) \neq G(x) \qquad \text{for at least one value of x}$$

Other nonparametric tests have been realized with Kendall Coefficient of Concordance (W). This statistical method estimates the correlation between the rank cumulated curves in order to verify whether samples belong to the same population. The range for the W is between 0 and 1, reflecting a range from no association to perfect association among data. Small values for W do not permit rejecting the null hypothesis, but large values would support the conclusion of significant correlation among rankings (Siegel and Castellan – 1988).

2. RESULTS AND DISCUSSION

The main results of data analysis have been collected in Tables 3 and 4. Also, for each variable some graphics about distribution frequencies have been realized.

Table 3 – descriptive statistics of daily mean meteorological parameters

	Unit of measure	Number of values	Mean value	Standard deviation	25th percentile	50th percentile	75th percentile
T_{24} (AWS)	°C	847	17.1	6.9	11.0	17.2	23.2
T_{nx} (AWS)	°C	847	17.2	6.9	10.9	17.4	23.2
T_{ucea} (AWS)	°C	847	16.9	6.9	10.7	17.0	22.9
T_{nx} (MWS)	°C	507	17.4	7.3	10.8	17.9	24.0
T_{nx} (AWS)*	°C	507	17.1	7.1	10.6	17.4	23.5
T_{ucea} (MWS)	°C	507	17.1	7.3	10.6	17.5	23.8
T_{ucea} (AWS)*	°C	507	16.9	7.2	10.4	17.1	23.2
R_{24}(AWS)	mm	258	-	-	0.8	3.2	8.2
R_{ucea}(AWS)	mm	258	-	-	0.4	2.4	8.2
R_{24}(AWS)*	mm	166	-	-	0.6	3.1	9.3
R_{ucea}(AWS)*	mm	166	-	-	0.4	2.5	8.5
R_{ucea}(MWS)	mm	166	-	-	0.0	2.1	7.7
RH_{24}(AWS)	%	847	68	12	59	68	77
RH_{ucea}(AWS)	%	847	64	13	55	65	74
RH_{24}(AWS)*	%	509	67	11	59	67	76
RH_{ucea}(AWS)*	%	509	64	13	54	64	73
RH_{ucea}(MWS)	%	509	58	13	48	58	67
P_{24}(AWS)	hPa	849	1013.0	6.5	1008.7	1012.7	1017.1
P_{ucea}(AWS)	hPa	849	1012.9	6.5	1008.5	1012.6	1017.1
P_{24}(AWS)*	hPa	509	1012.5	6.3	1008.4	1011.9	1016.5
P_{ucea}(AWS)*	hPa	509	1012.4	6.4	1008.1	1011.8	1016.4
P_{ucea}(MWS)	hPa	509	1012.1	6.3	1007.8	1011.8	1015.8

* adapted AWS sample in order to well compare the shortest MWS data series

Table 4 - Nonparametric Tests. Kendall Coefficiente of Concordance (W) and Kolmogorov-Smirnov two samples tests

Variables	N. of cases	Simple Correlation	Kendall coeff. of concord. (W)	KS-test two sample test		
				Maximum difference (D_{max})	Critical difference (**)	Significative difference
T_{24} (AWS) / T_{nx} (AWS)	847	0.998	0.210	0.09091	0.06608	Yes
T_{24} (AWS) / T_{ucea} (AWS)	847	0.999	0.276	0.05313	0.06608	No
T_{nx} (AWS) / T_{ucea} (AWS)	847	0.999	0.322	0.06021	0.06608	No
T_{nx} (MWS) / T_{nx} (AWS)*	507	0.998	0.078	0.49507	0.08542	Yes
T_{ucea} (MWS) / T_{ucea} (AWS)*	507	0.999	0.206	0.33531	0.08542	Yes
R_{24} (AWS) / R_{ucea} (AWS)	258	0.904	0.026	0.05426	0.11974	No
R_{ucea} (AWS)* / R_{ucea} (MWS)	166	0.924	0.478	0.13855	0.14928	No
R_{24} (AWS)* / R_{ucea} (MWS)	166	0.814	0.272	0.18675	0.14928	Yes
RH_{24} (AWS) / RH_{ucea} (AWS)	847	0.972	0.598	0.15112	0.07921	Yes
RH_{ucea} (MWS) / RH_{ucea} (AWS)*	509	0.944	0.687	0.71120	0.10217	Yes
RH_{ucea} (MWS) / RH_{24} (AWS)*	509	0.926	0.877	0.75442	0.10217	Yes
P_{24} (AWS) / P_{ucea} (AWS)	849	0.971	0.122	0.02356	0.07911	No
P_{ucea} (MWS) / P_{ucea} (AWS)*	509	0.990	0.167	0.29077	0.10217	Yes
P_{ucea} (MWS) / P_{24} (AWS)*	509	0.988	0.160	0.31434	0.10217	Yes

* adapted AWS sample in order to well compare the shortest MWS data series
** level of significancy 0.95

2.1 Temperature

In the calculated series of daily mean temperature, mean values and variance indices differ but remain coherent with eachother. T_{nx} calculated with AWS and MWS data, tends to overestimate daily mean temperature demonstrating that more values are needed to adequately describe daily thermal course curve. All comparisons have shown high correlation close to 1. The brief length of the series and the seasonality affecting the examined period have produced bimodal distributions (Fig. 1), excluding consequently the possibility to use means and standard deviations for valid comparisons. KS-test, used to verify correctly the similarity of each variable, has shown non homogeneity among the series of daily mean temperatures, most of all for T_{nx}(AWS) vs T_{nx}(MWS) and T_{ucea}(AWS) vs T_{ucea}(MWS): the D_{max} obtained is very high, at least 4 times higher than the admitted limit value. The comparisons between AWS data series, to test differences among the various algorithms, have underlined a significative difference only in T_{24}(AWS) vs T_{nx}(AWS).

2.2 Rainfall

Daily rainfall series R_{24}(AWS), R_{ucea}(AWS) and R_{ucea}(MWS) show a typical alfamodal distribution (Fig. 2) and statistics (25°, 50° and 75° percentile) rather dissimilar from one another and smaller correlation levels than daily mean temperatures. As an example, for R_{24}(AWS) vs R_{ucea}(MWS), the correlation coefficient is 0.814, while in the other comparisons it is lightly more than 0.9. Kendall coefficient W expresses a very low concordance among variables, expecially between R_{24}(AWS) and R_{ucea}(AWS), where it reaches the minimal value of 0.026. However, the KS-test referred to R_{24}(AWS) vs R_{ucea}(AWS) and R_{ucea}(AWS) vs R_{ucea}(MWS) has supplied results of non significative differences, while a significative difference is proved in R_{24}(AWS) vs R_{ucea}(MWS). It is important to stress that KS-test for R_{ucea}(AWS) and R_{ucea}(MWS) has supplied a D_{max} value = 0,13855 very close to the critical value of 0.14928.

2.3 Relative Humidity

Daily mean relative humidity RH_{24}(AWS), RH_{ucea}(AWS) and RH_{ucea}(MWS), in spite of the brevity of the examined period, show frequency distributions quite similar to the normal curve (fig.3). Each variable highlights dissimilar mean values and variance indices but the correlation appears quite strong and includes values between a minimum of 0.926 (RH_{24}(AWS) vs RH_{ucea}(MWS)) to a maximum of 0.972 (RH_{24}(AWS) vs RH_{uce}a(AWS)). Nonparametric tests, in order to verify the homogeneity level, have supplied discording responses. Infact, KS-test has checked significative differences in every comparison, while the Kendall coefficient W has assumed values between 0.6 and 0.9, higher than results obtained in temperature and in rainfall.

2.4 Barometric Pressure

Daily mean barometric values have frequency distributions approaching to normality (fig. 4). Mean and standard deviation values are quite similar from one another and correlation coefficients are included between a minimum of 0.971 to a maximum of 0.99. Nonparametric tests have shown a non significative difference only in the comparison between P_{24}(AWS) vs P_{ucea}(AWS). Kendall coefficient W has generally assumed low values, never higher than 0.2.

3. CONCLUSIONS

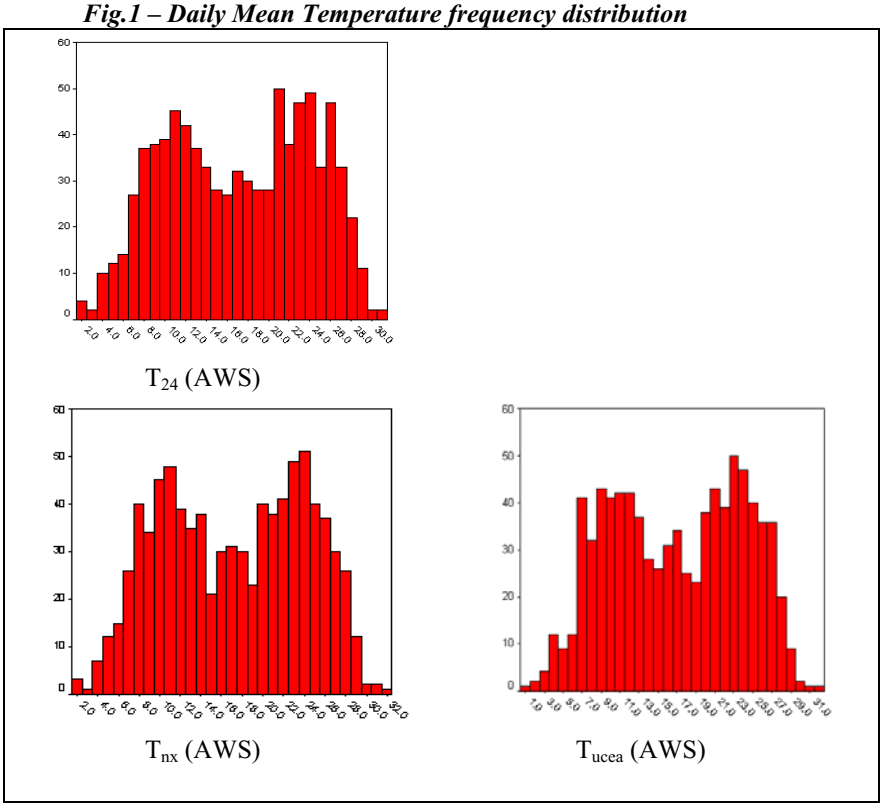
The replacement of MWS with a newer AWS, needs a period of simultaneus measurements for preliminary calibration of new sensors. Subsequently, with the start of AWS operating phase, some problems may arise in calculating methods (algorithm choice) and in meteorological statistics recording (for example, use of old or new codes in daily mean temperature identification). The consequences of these problems may concern the correct prosecution of the old historical series. In this work, daily statistics obtained through different algorithms and through AWS and MWS data have been examined and compared. Such data refer to a period of about 1.5 year in which the two meteorological stations have worked simultaneously at the Observatory of Rome “Collegio Romano”. Data analysis and statistics have shown strong correlations between compared values and some statistical significative differences. For example, in the calculation of daily mean temperature, the use of only minimum and maximum temperature cannot be considered homogenous with the average obtained by 24 hour measurements. Even the comparison between the T_{nx} calculated with the AWS and MWS data have shown a non similarity. Daily mean temperatures obtained with UCEA traditional system and through 24 hours daily measurements have been compared

using only AWS data and statistical tests have proved homogeneity between the two variables. On the other hand, the comparison between T_{24}(AWS) and T_{ucea}(MWS) has stressed such a non homogeneity as to advise against the hypothesis of old series prosecution. Similar results have been obtained in daily total rainfall. The comparison between R_{24} and R_{ucea}, using only AWS data, has not shown significative differences, although UCEA traditional method involves a 5 hours shift (infact, rainfall totals is calculated from the 19:00 of the previous day to the 19:00 of the present day) respect to the total calculated from the 00:00 to 24:00. The comparison between R_{24}(AWS) and R_{ucea}(MWS) has underlined a significative non homogeneity. So, in this case too, continuing old series with new daily statistics may be considered a wrong hypothesis. For relative humidity and barometric pressure the same previous conclusions have been noticed. In the end, different algorithms used with data of the same station have not always supplied statistically different values, while daily statistics series calculated with AWS and MWS data have always been significatively non homogeneous. In the operational field, stopping an ancient historical sequence or renouncing to AWS best performances would not be convenient, therefore informative notes (metadata) are needed to describe any weather station changements.

4. REFERENCES

- Siegel S., Castellan NJ. Jr., *Nonparametric Statistics for the Behavioral Sciences*. New York: McGraw-Hill; 1988
- WMO, *Guidlines on the quality control of surface climatological data.* World Climate Programme WMO/TD-No.111 – May 1986

Fig.1 – Daily Mean Temperature frequency distribution



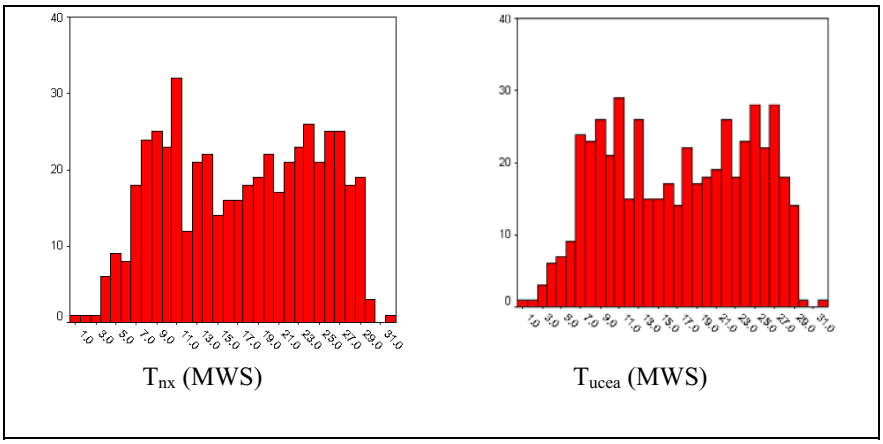


Fig. 2 – Daily total rainfall frequency distribution

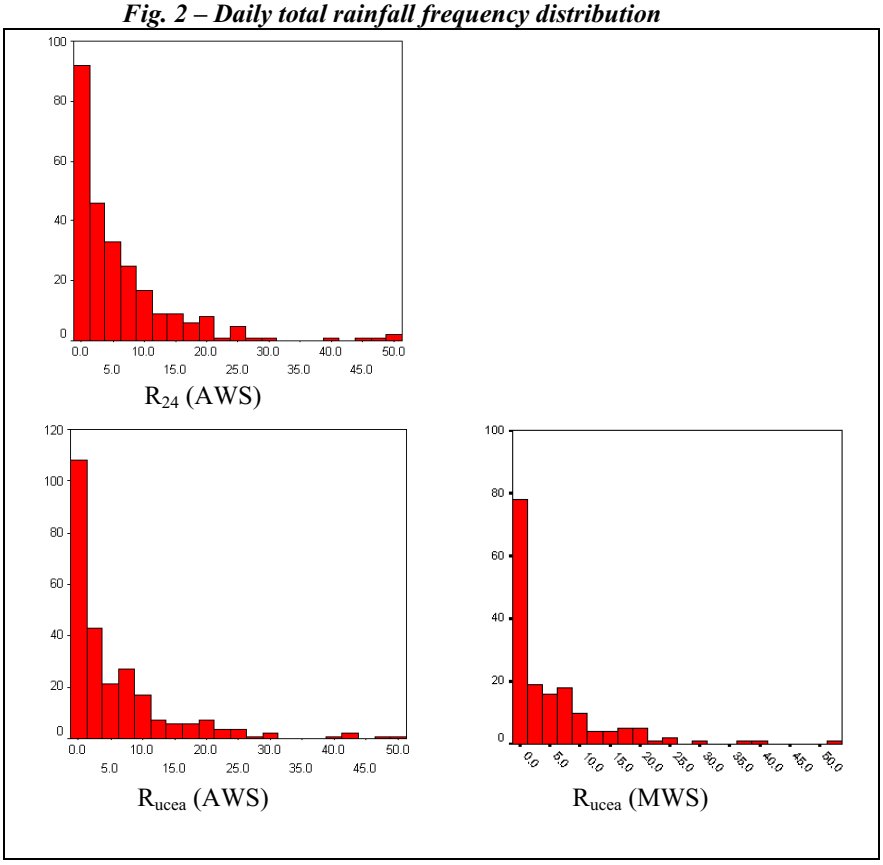
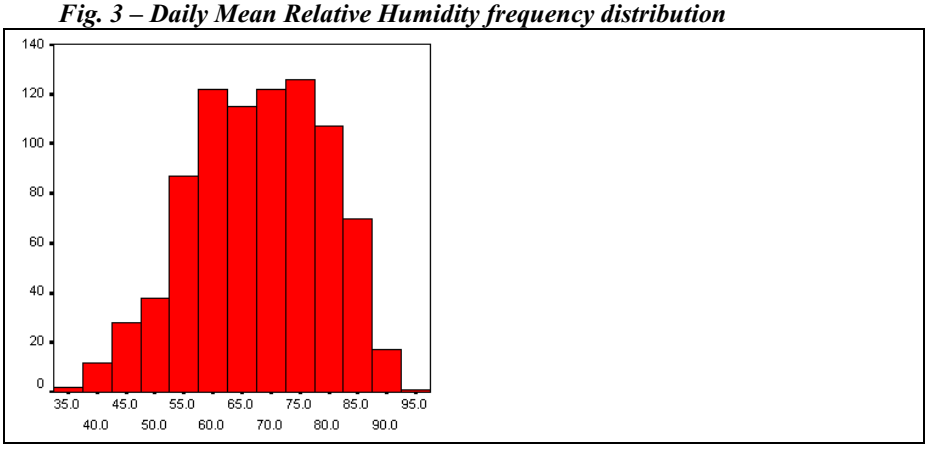


Fig. 3 – Daily Mean Relative Humidity frequency distribution



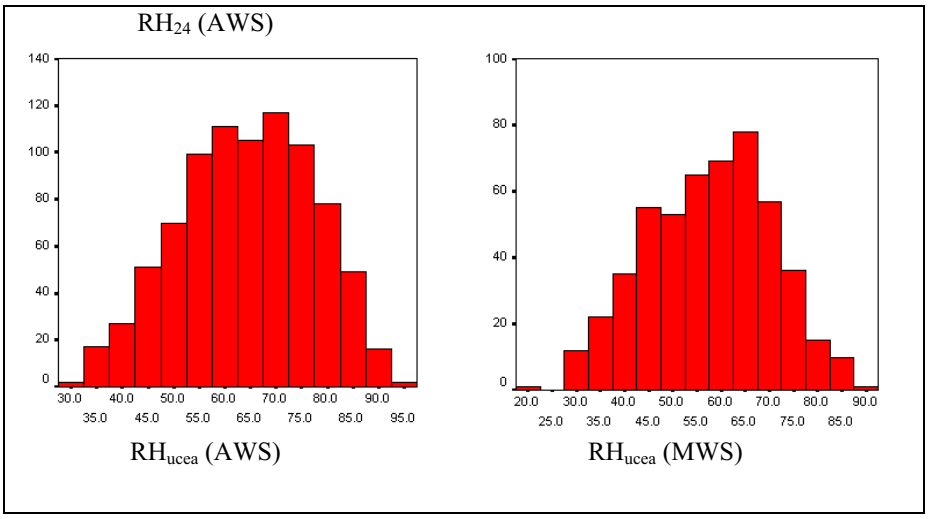
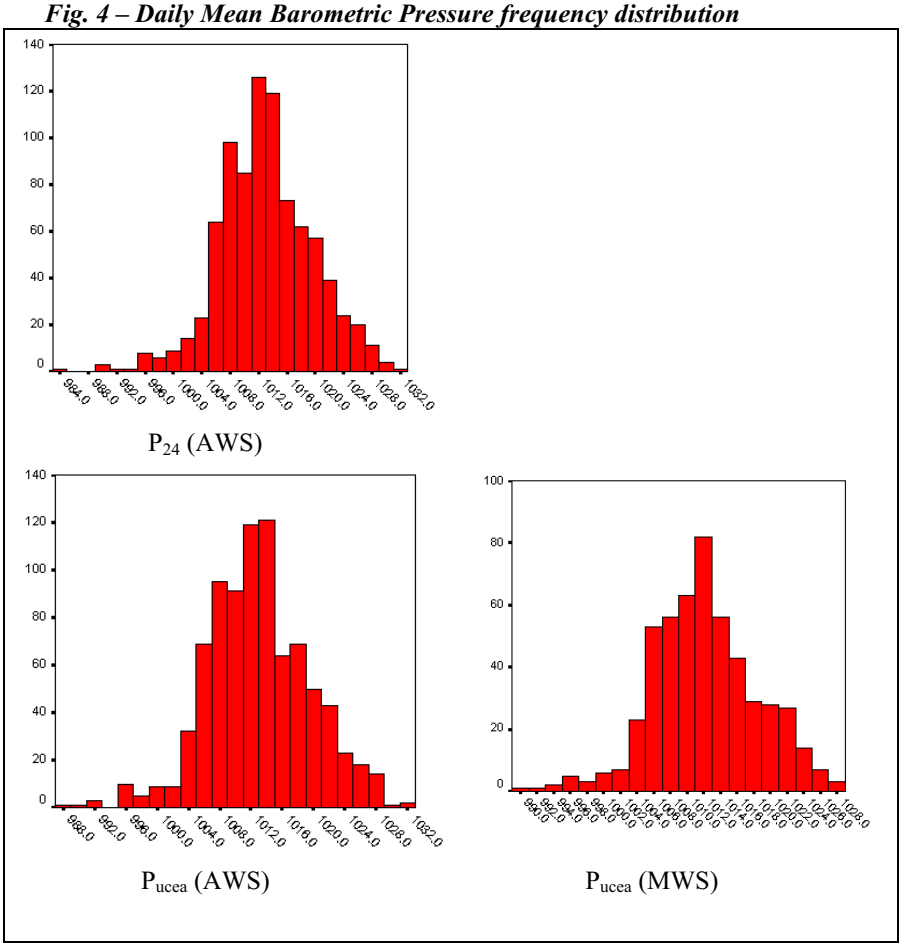


Fig. 4 – Daily Mean Barometric Pressure frequency distribution



CLIMATE DATA CONTINUITY USING AUTOMATIC WEATHER STATIONS?

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Abstract
There was a lot of progress in recent times on measuring and observing meteorological variables by the application of Automatic Weather Stations. Various types of sensors and software applied for these observations are already operated in automatic networks either on national or regional levels. The net of Automatic Weather Stations is increasing worldwide.

This paper intends to give an overview summary of the advantages and disadvantages of the new technology. It is written not only for the climate community but also to build an increased awareness within the instrument departments of the NMWS's of the importance of data continuity assessments into the inevitable instrument upgrade process.

Key words: AWS's advantages –disadvantages, data homogeneity, opportunities

1. INTRODUCTION

In this contribution I try to give a comprehensive summary of all accomplishments of some of data comparisons which were performed and some of the findings from a point of view as a WMO Rapporteur of the Technical commission for Climatology.

In most of the NWS's climatologists begin to hear about the plans for replacing their network of climate stations at a time as the new generation of measurements is already implemented. Usually this implementation of new and modern systems is developed for other stakeholder groups like e.g. the synoptical meteorology. Many years later the climate community realizes what impacts on data resources for monitoring the climate these instruments have. When reports of large biases and gross mis-measurements of basic climate elements begin to have an effect on climate continuity the warnings bells begin to toll.

The technical departments or instrument developing centers, however, do not welcome criticism or open discussions about the apparent problems with the new technology and usually the climate community has to launch a kind of climate continuity programme which can eventually contribute to several improvements of AWS and which can make public the changes and differences in AWS climate data with previous conventional observation data.

Climatologists should be quite aware that new instruments and especially AWS's cause many changes in sensor design, in observation techniques, in the interrogation time and data processing algorithms. This will inevitably introduce inhomogeneities into the climatic record of sites with a long history of conventional observations. Therefore the climate interested community should have more than a passive interest in the development of AWS's. As well as making clear what "historical" observations are required to maintain continuity and homogeneity of the climate record, AWS-data gives an opportunity for obtaining more

relevant data to the needs of climatologists. It is acknowledged that the needs of climate are generally more stringent than the demands of other branches of the meteorological community like e.g. the synoptical meteorology or the modelers group, but they are also generally less complex in the view that the priority surface climate data needs have changed little over the century.

2. APPLICATION OF PRINCIPLES

That is the reason why climatologists should apply some principles dealing with new observing systems like AWS:

1) **Assessment of Change:** How and the extent to which will influence a proposed change of the observing system the existing and future climatology, particularly with respect to climate variability and change. Most of the time series breaks caused by changed observing times and averaging methods proved to be not tolerable compared with the magnitude of the climate signal itself. Therefore it is crucial to develop from the beginning special algorithms for the AWS to guarantee a comparison with the old conventional registrations and to preserve homogeneity in the time series.
2) **Climate requirements:** Talk with the technical department, instrument engineers, network designers, operators and tell them about the climate monitoring requirements at the outset of the network design
3) **Ensure the functional requirements of the new system:** Standardizing the AWS sensor specifications (accuracy, data sampling frequencies, etc.), observation/measurement methodologies and data preprocessing methods/algorithms is crucial. The operational accuracy requirements and the typical instrument performance must be in accordance with the WMO regulations. (CIMO – Guide) The biases oft the instrument outputs must be sufficiently small to resolve climate variations and changes.
4) **Parallel testing:** Overlapping measurements to derive transfer functions for converting between climatic data taken before and after a change in an existing observing system are crucial. The period of overlapping measurements should be sufficiently long to observe the behaviour of the new system over the full range of variation of the climate variable observed. The preferred minimum period of overlap is two consecutive years
5) **Data Quality and Continuity:** Assess data quality and homogeneity as a part of routine operating procedures. This assessment should focus on the requirements for measuring climate variability and change, including routine evaluation of the long-term, high resolution data capable of revealing and documenting important extreme weather events.
6) **Complementary data:** tell the network designers that there is high priority in the implementation of new sites of instrumentation to data-poor regions, poorly observed variables, regions sensitive to climate change, and key measurements with inadequate temporal resolution

3. SUMMARY OF ANALYSES AND RESULTS

In climatology, especially in the study of climatic changes, the homogeneity of the data is important. Long- term changes due to real causative factors have been and will be small and slow and are hidden under large year-to-year variability. Climatic records, at least those which are readily available, are normally mixtures of both apparent and real variations. Factors

causing long-term climatic changes which may be influenced by changing the system from a conventional to an automated are the following:

- Changes in observing times
- Changes in averaging methods
- Stations relocation
- Change in design (e.g. screen, aspiration)
- Changes in location height
- Changes in calibration method

The deviations can be divided into systematic and stochastic ones. If the systematic differences are not corrected, inhomogeneities in the climatological series are the consequence. Several statistical methods are available, which can show whether any bias is included in the data records. Some methods provide also an indication of its location, but the causes cannot be revealed by any statistical methods.

Air Temperature: AWS ambient temperatures are in many countries where they made comparisons lower than conventional. (e.g. in US-Network the results show a bias of about 0,3 °C) However this value can vary greatly from station to station and from network to network. Sometimes the bias is only due to changes in station location and exposure.

_ *Continuity of time series has to be carefully handled*

Pressure: Biases are usually very small but show systematic error depending strongly on the used sensor type and the calibration method.

_ *Continuity of time series has to be carefully handled*

Precipitation: In many countries comparisons of precipitation data indicate the AWS are recording less precipitation than conventional systems. The reason is the use of heated tipping bucket rain gauges where the evaporation loss is very high. The better performance of weighting gauges is usually not used because of the expensiveness and inaccuracy.

_ *Discontinuity of time series is in all likelihood*

Dewpoint, Humidity: Measurements have been and are with AWS's not very accurate. Measurements with the chilled-mirror technique have a very erratic behavior.

_ *No change in time series*

Wind: Data of AWS are often incomparable with conventional registrations. The reason is that the algorithms used could not be evaluated from analogous registrations. (For instance vector mean.) But using e.g. arithmetic means wind direction and speed are quite similar. Wind gust information is strongly depended on the interrogation and average time A three second wind average is quite compatible to the older registration-instruments. Very important is the metadata information.

_ *Discontinuity of time series could be avoided using specially algorithms*

Ceiling, Cloudiness (height, amount, etc.) and Visibility: The derived data from AWS are not comparable with those of human observers. But of course there are only small differences if you use the same sensors and only different logger systems.

_ *Discontinuity of time series is sure if you change from manned stations to AWS -reporting.*

Sunshine Duration: The results of the intercomparison regarding sunshine duration data recorded by the conventional systems with CAMPELL-STOKES sunshine recorder and electronic sensors at AWS's point out two systematic differences that are caused by the different technical features that have different response to some types of cloud formation. During periods of rapidly changing cloud conditions the conventional recorder indicates more sunshine than the AWS. Due to lower time resolution of CAMPELL-STOKES sunshine duration seem to be overestimated by the classical instrument. In situation of small sun elevation the higher sensitivity of the electronic sensor causes more sunshine in respect with the conventional type. In average AWS measures 1% to 4% more sunshine at low-land stations, but 5% less at the mountain areas.

_ *Continuity of time series has to be carefully handled*

4. COMMENTS AND REFLECTIONS

In many countries the introduction of AWS was a great frustration to many climatologists, because many important elements of long-term climate monitoring were interrupted or at least compromised but one has to look in summary on the advantages and disadvantages of the new instrument generation:

Advantages:

- Location of AWS in rural areas to avoid anthropogenic factors is much easier than with conventional manned stations
- After an AWS makes an observation the recorded value undergoes a data sampling and processing procedure and enhance the data quality.
- Real time data quality control of data has important effects on climate application products.
- A great variety of climate data products may be derived directly online from the basic measurements or could be very quickly computed at the regional centers.
- Integrating remote sensing products like e.g. weather radar or satellite information is possible
- Growing meteorological databases are the supposition of a better detection of climate variability and change
- AWS data supports the growing demands on meteorological information from new clientele groups like lawyers, environmental consultants, urban water planners, etc.
- Climate modeling and theoretical studies are excellently supported by AWS data especially in regard of spatial and temporal resolution requirements
- Increase in number of stations nation- and worldwide
- The automation of visual and subjective observations has to be reconsidered within the light that automated systems perform differently than human observers (i.e. it has to be based on a more objective and well defined basis). If this can be done, widely homogeneous observations can be achieved globally both within and outside of NMHSs.

Disadvantages:

- Maintaining and servicing of sophisticated devices is difficult and cost intensive and therefore might be minimized and lead thus to disrupted data
- Discontinuities in long-term records have crippled research efforts and complicated various climatic applications
- Changes in several parameters like cloud cover, visibility, thunderstorm activity, etc.
- Complete loss of quantitative data of cloud types, snowfall, hail
- The loss of information on frequency and duration of various weather phenomena if the AWS measurements are not supported by sensors which are usually very expensive like (PWS, ice pellets, freezing precipitation, etc.) or the AWS is not assisted by a human observer. But due to this possible combination of observations performed by various types of instruments, the continued need for some visual or subjective observations traditionally done by human observers needs to be reconsidered. These observations were urgently needed in the past for obtaining, as far as possible, a complete picture of the atmosphere. Such parameters as cloud cover, cloud type, but probably also to the intensity of precipitation and thunderstorms, etc. could in several cases, now or in the near future, be obtained or derived either directly from sophisticated instruments, combinations of them, or by remote measurements, such as surface based remote observations (weather radars, windprofilers, etc.) or space based platforms (satellites).
- However, the direct or remotely generated data and the combination of these measurements by sophisticated algorithms are no longer anymore available as "point observations" as obtained from observing stations. The advantage of these "new" data is that they might be more representative for users than traditional point measurements since they provide a more integral picture of the area of concern and may make obsolete some of the traditionally needed visual observations. This approach could replace, and perhaps extend, in the near future or in a longer-term, several traditional point measurements and, especially, visual observations.
- However, it is clear that especially for the application of indirect or remote observing methods, such as weather radars when applied for precipitation amount and intensity measurements, and for satellite observations, surface observations are still crucial for now and the foreseeable future, for in situ calibration purposes and "ground truth". The need for a higher quality of this kind of observations and real-time availability will increase. These expected needs call for a clear statement of requirements of observations to be done automatically by AWSs

Future opportunities:

AWS- networks provide an opportunity for international cooperation and leveraging of resources that is unprecedented in the history of national and global climate monitoring. But to be successful a coordinated effort is crucial. WMO and especially their technical commissions as CIMO and CBS are right on the way to face the needs of the climate community.

REFERENCES

1. Höhne, W., 1986: Automatische meteorologische Stationen; Entwicklungstendenzen, Systemaspekte und Einsatzprobleme. Zeitschrift für Meteorologie, 36 1, 1-14
2. Karl T. R., Derr, V. E., Easterling, D. R., Folland, C. K., Hofmann, D. J., Levitus, S., Nicholls, N., Parker, D. E. and Withee, G.W.1995: Critical issues for long-term climate monitoring. Climate Change, 31.185-221
3. Plummer, N., Collins, D., Trewin, B. and Della-Marta, P. 1999: Automatic Weather Stations in Australia – A Climate Perspective. Proceedings of the ICEAWS99, in Vienna, 27-29 September 99, Austria
4. Rudel, E.1997: Report and review about data processing and quality control procedures involved in the conversion of manually operated stations to automatically operated stations. World Climate Programme: Data and Monitoring No.31, WMO-TD No.833
5. RUDEL, E. 1995: More than 10 years of experience with the automatic meteorological observation network in Austria. Proceedings of the International Workshop on Experiences with Automatic Weather Stations in operational use within National Weather Services Vienna, Austria , 15-17 May 1995. WMO Instruments and Observing Methods Report N0 58, WMO/TD-No.670
6. RUDEL, E. 2001: What we have learned about Climate Data Continuity using new Measurements Technologies, Proceedings of the Fourth European Conference on Applied Climatology (ECAC 2002), RIMB, Brussels, 12.- 15.November 2001
7. WMO, 1995: Guidance Specification (functional) for a general purpose Automatic Weather Station, Prepared by the CIMO Rapporteur on Functional Specifications for Automatic Weather Stations,
8. WMO, 1997: Final Report of the Expert Meeting on Automation of Visual and Subjective Observations, held in Trappes/Paris, France, from 14 - 16 May 1997.
9. WMO, 1999: Report of the Expert Meeting on Requirements and Representation of Data from Automatic Weather Stations, held in De Bilt, Netherlands, from 19-23 April 1999
10. WMO 2001: Automated Weather Stations for Applications in Agriculture and Water Resources Management: Current Use and future Perspectives. Proceedings of an International Workshop, 6-10 March 2000, Lincoln , Nebraska, USA, WMO/TD No. 1074

STUDY OF THE ERRORS OF RAINFALL RECORDED AT THE BALEARIC A.W.S. THROUGH COMPARISON WITH TRADITIONAL RAIN GAUGES

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Abstract

The automatic weather stations ruled by the Spanish Instituto Nacional de Meteorología at the Balearic Islands are located at conventional pluviometric stations, provided with a Hellmann gauge whose measures have been used to assess the reliability of the AWS tipping bucket records over the observational period of each station. The study has been carried out with the eight Balearic AWS with more than 200 days with at least 1 mm rainfall. Taking the conventional measures as the reference, the average correction factors to the different AWS range from 0.96 to 1.22. The influence of the rainfall intensity on these errors has also been considered. It is statistically significant in most of AWS, though its contribution to the errors is generally little and varied in nature.

Keywords: tipping bucket, rainfall, errors, Balearic islands.

1. INTRODUCTION

The tipping bucket rain gauge is widely used as the precipitation sensor in the Automatic Weather Stations (AWS) for its simplicity and easy maintenance. However, its measures can be affected by errors of different origin, most of them common to other types of rain gauges, but others specific, as the tendency of the bucket to tip before it is filled when the rainfall intensity is high.

Many studies have been devoted to these errors (for example: SEVRUK, 1996; FANKHAUSER, 1998; HABIB *et al.*, 2001; etc). In this work, advantage is taken from the fact that the Balearic AWS are located at conventional pluviometric stations, provided with a Hellmann gauge. These measures will act as references to assess the reliability of the tipping bucket records in different rainfall intensities, once overcome the difficulty of having different time resolutions (24 hours and 10 minutes, respectively).

2. METHODOLOGY

The rainfall measure comparisons have been carried out on eight AWS of the Balearic Islands, with data extending from 1989 to 2002 (table 1 and figure 1).

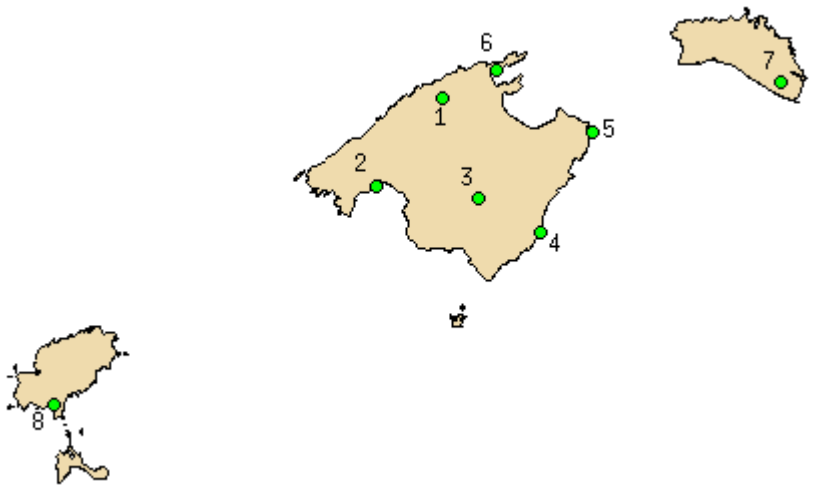
A first approximation to the relationship between the *true* precipitation (y) and that measured by a tipping-bucket gauge in 10 minute intervals (x) can be the linear expression: $y = b\,x$. The hypothesis to test is that b, rather than a constant, is also dependent on the intensity of the precipitation. If this dependence is linear: $b = c + d\,x$, and hence: $y = c\,x + d\,x^2$. Other polynomial expressions can be tried in search for a better adjustment.

But while the AWS tipping-bucket has a time resolution of 10 minutes, our best estimator of the true precipitation, the conventional rain gauge measures, are taken once a day (four times per day only in the principal observatories, stations 2, 7 and 8 of table 1). Therefore, Y, the 24 hours precipitation at conventional stations (measured from 7 to 7 hours UTC at the principal observatories and from 8 to 8 at the secondary ones), can only be related with summatories of different powers of the 10' data: $X_1 = \quad x_i$, $X_2 = \quad x_i^2$, and so on.

Table 1: Names, coordinates and observing periods of the studied Automatic Weather Stations.

N	Indic.	Name	Coordinates North Lat.	Coordinates East Lon.	Altitude Z(m)	Period	Selected days
1	B013	Lluc	39°49'26"	2°53'08"	490	1993-02	269
2	B228	Palma Portopí	39°33'18"	2°37'35"	3	1989-02	329
3	B346A	Porreres Poliesportiu	39°31'10"	3°01'24"	120	1989-02	258
4	B434	Far de Portocolom	39°24'53"	3°16'19"	17	1993-02	230
5	B569	Far de Capdepera	39°43'00"	3°28'42"	66	1989-02	253
6	B780	Port de Pollença A.M.	39°54'38"	3°06'02"	2	1989-02	360
7	B893	Aeroport de Menorca	39°52'01"	4°13'35"	85	1993-02	230
8	B954	Aeroport d'Eivissa	38°52'38"	1°22'12"	11	1994-02	205

Fig. 1: Location of the eight AWS used in this study



Due to the different observation hours, together with some uncertainty in the time of the observation made by a human observer, the study has been made only on the rainy days with at least 1 mm precipitation in the conventional rain gauge, and with no more than 0.1 mm tipping-bucket precipitation between 7 and 8 hours in the same and the following days. This yielded a number of selected days ranging from 205 at Ibiza Airport to 360 at Port de Pollença. The method used to explore the relationships was multiple linear regression, performed with the R statistical package, running under Linux.

3. RESULTS AND DISCUSSION

An exploratory study made with the data from Palma Portopí tested the linear simple dependence $Y = b\,X$ and the binomial $Y = c\,X_1 + d\,X_2$, with powers in the vicinity of 2 ($X_2 = \Sigma\, x^q$, with q=1.6, 1.8, 2.0, 2.2 and 2.4). The fitting R-squared values obtained were 0.9917 for the linear equation and 0.9921 for all the binomial expressions, irrespective of their power value. The improvement of the binomial equation seems negligible, but the p-value is highly and increasingly significant, suggesting that, though the different powers give quite similar results, values greater than 2.4 might offer even better adjustments.

Therefore, a much wider range of powers were tried. 24 hours summatories of the 10' precipitations raised to powers 2 to 5 were computed, and multiple regression analysis were performed to fit the general model:

$$Y = b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5$$

Stepwise backwards elimination of the variables which were not significant at α= 0.05 resulted in different polynomial models been adjusted to each of the AWS. A summary of the results is offered in table 2.

Table 2: Results of the simple and multiple regression analysis. Only variables significant at α = 0.05 were retained in a backwards stepwise procedure.

Ind.	b	r^2	b_1	b_2	b_3	b_4	b_5	R^2
B013	1.0105	0.9832	1.063	-1.959e-1	-	-	-	0.9838
B228	1.2174	0.9917	1.198	-	1.347e-3	-	-	0.9921
B346a	1.1444	0.9589	-	-	-	-	-	-
B434	1.0237	0.9647	1.067	-1.750e-1	4.957e-2	-3.995e-3	9.679e-5	0.9765
B569	1.0752	0.9146	1.266	-4.691e-1	1.817e-1	-1.961e-2	5.842e-4	0.9232
B780	1.0284	0.9678	1.080	-	-8.411e-3	6.081e-4	-	0.9697
B893	0.9607	0.9780	0.970	-	-	-1.996e-5	-	0.9784
B954	1.0384	0.9947	1.031	-	-	-1.723e-4	1.344e-5	0.9964

The regression coefficients of the simple linear model are all but one greater than one, showing a general tendency of the tipping bucket rain gauge to underestimate rainfall (as compared to the Hellmann gauge). Five of the eight gauges studied keep their average errors under the 5% threshold, while two of them are greater than 10%, the maximum been as high as 21.7% (B228, Palma Portopí). The coefficients of determination report explained variances over 95%, except for B569, which only explains 91.5%.

Figures 2 and 3 show the fitted lines for the data of the stations that gave the best and worse results. In both of them, most of the points lay in the vicinity of the fitted line, while several outliers appear generally on the upper side of the line (tipping bucket underestimation). A dashed identity line (Y=X) acts as a visual reference to show the magnitude of the average correction to apply to the AWS precipitations.

The multiple correlation analysis yielded a variety of results, from the null improvement of one station (B346a - Porreres) to the significance of all the five terms of the polynomial model in other two (B434 and B569). The multiple coefficients of determination (adjusted to account for the different freedom degrees) make only slight improvements on the percentage of variance explained by the simple linear model.

Figure 4 presents the residuals of both the simple and polynomial models plotted against the fitted values, for the station B434 (Far de Portocolom), which is the site with greater fitting improvement (from r^2=0.9647 to R^2=0.9765). But this difference is still quite small, and only a pair of simple model residuals are greater than the polynomial ones.

According to these results, the influence of rainfall intensity on the tipping bucket records are different between the stations, but little enough to consider them as negligible. This is supported by the different degrees of the fitted polynomials, that resulted from establishing a significant level of acceptance of $\alpha = 0.05$. Moreover, this kind of significance assessment is only of relative value in our case, since the precipitation data are quite far from having a normal frequency distribution.

Fig. 2: Best fitted simple linear regression

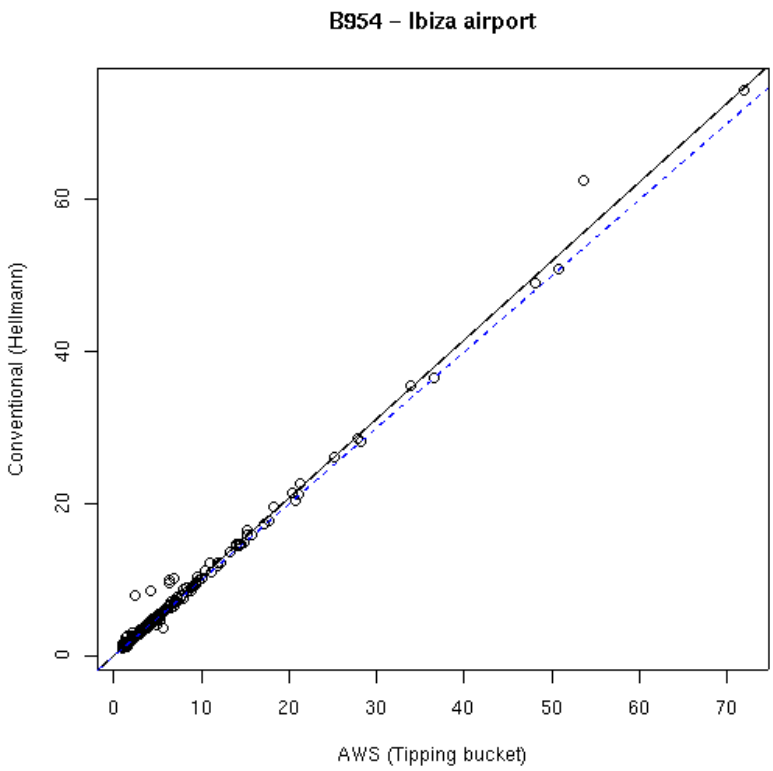


Fig. 3: Worse fitted simple linear regression

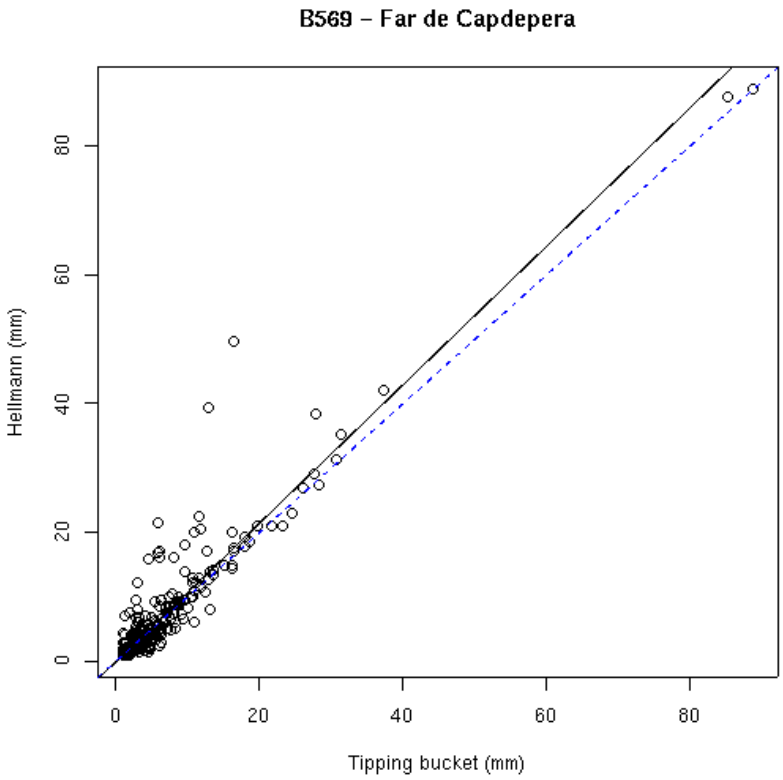
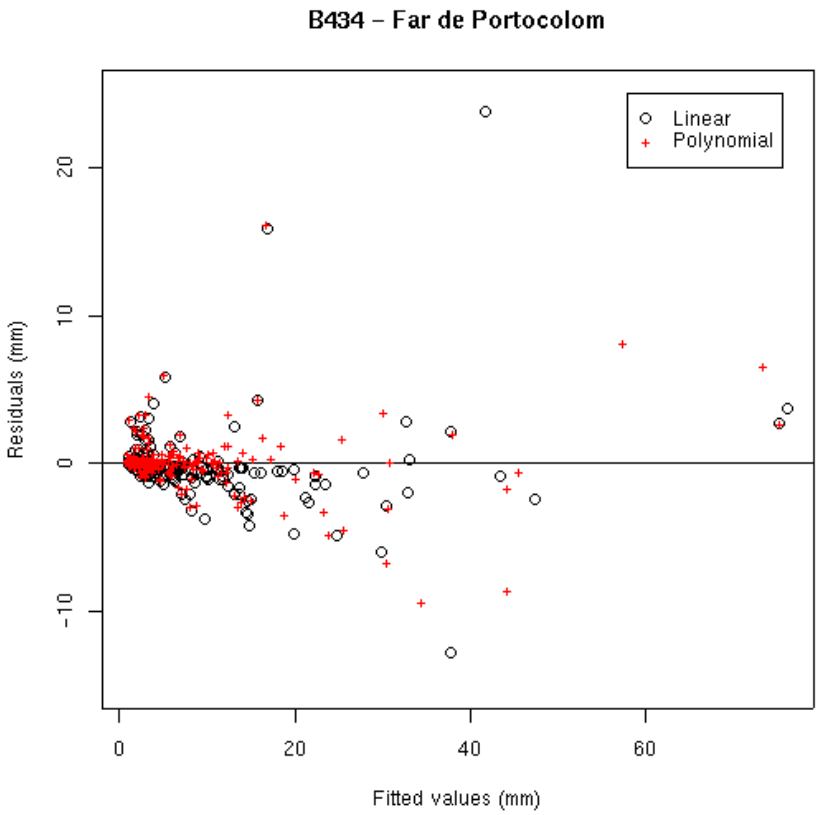


Fig. 4: Residuals vs. fitted values for the simple and polynomial models, at the station with greater difference in explained variance.

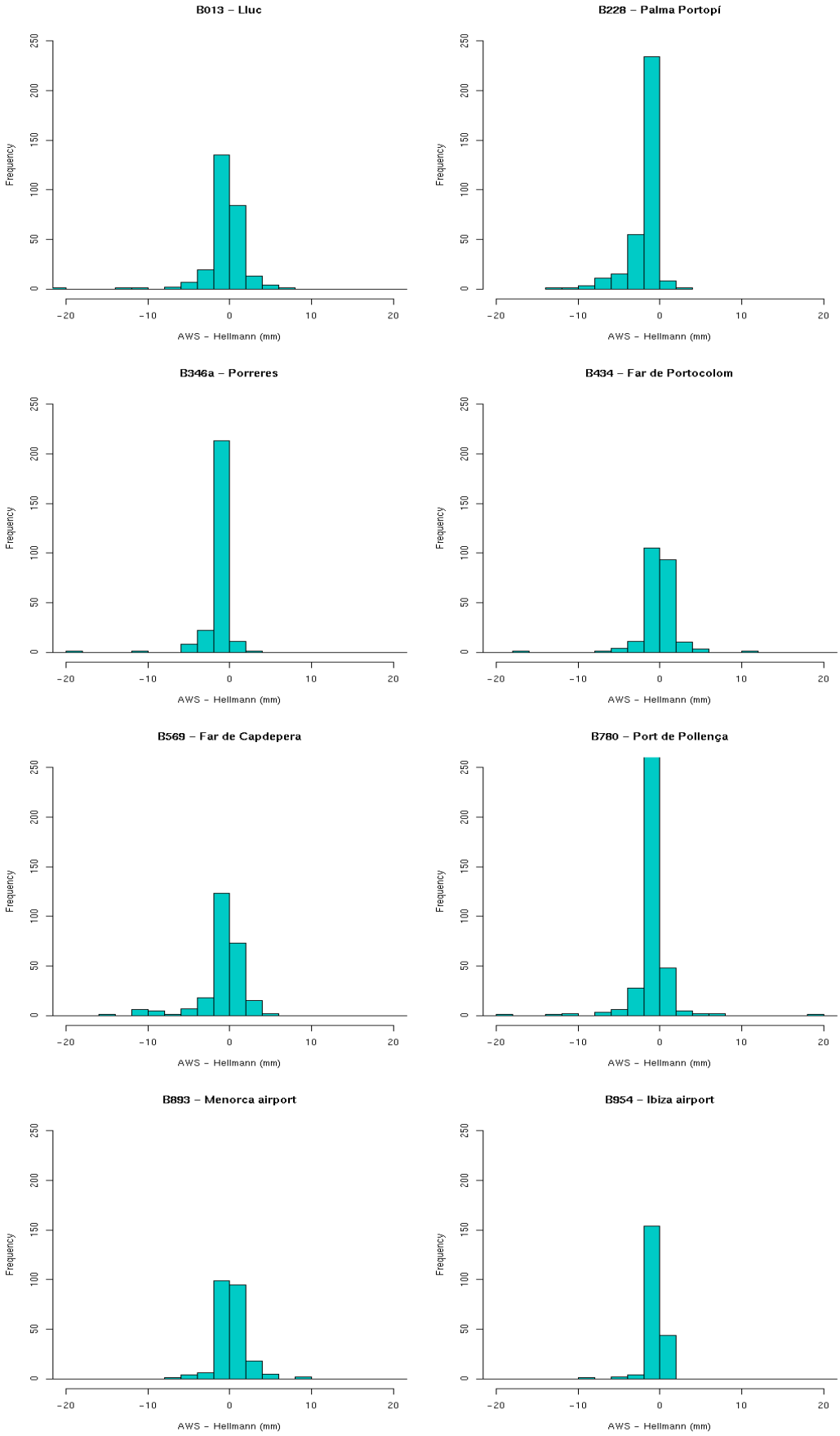


But the regression results discussed so far only give us information on the average errors of the data. Individual errors, or rather, deviations from the Hellmann measures, are greater, as shown in table 3 and figure 5. All the stations but one (B893 - Menorca airport) show left biased deviation distributions. Most of the deviations are of little absolute value (74 to 97% equal or under 2 mm), but there are outliers with deviations as large as +18.1 and –33.2 mm. These must be due to other kind of errors, either human or instrumental (obstruction of the gauge funnel, etc).

Table 3: Tipping bucket record deviations from the Hellmann rain gauge measures. Some statistics, and percentage of deviations with absolute value equal or under 2 mm.

Ind.	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	|D|<=2mm(%)
B013	-22.8	-0.6	-0.1	-0.40	0.3	7.0	81.8
B228	-12.4	-2.1	-0.7	-1.50	-0.3	3.3	74.2
B346a	-41.7	-1.1	-0.4	-1.08	-0.1	2.9	87.2
B434	-24.8	0.0	0.0	-0.03	0.4	11.9	87.0
B569	-33.2	-1.0	0.0	-0.90	0.5	5.2	77.9
B780	-18.0	-0.8	-0.2	-0.56	0.0	18.1	85.8
B893	-6.3	-0.5	0.1	0.21	0.6	9.7	84.3
B954	-8.8	-0.2	-0.1	-0.25	0.0	2.0	96.6

Fig. 5: Histograms of the AWS-Hellmann deviations in the eight studied stations



4. CONCLUSIONS

The tipping bucket rain gauges of the Balearic Automatic Weather Stations tend to underestimate rainfall, when compared to the traditional Hellmann rain gauges.

The intensity of the precipitation has a statistically significance on the errors of the tipping bucket, but the improvements of fitting polynomial models to take it in account are quite small, and the elimination of the non significant terms yield a variety of different models for the studied stations.

Therefore, rainfall intensity has a negligible effect on the differences between the Balearic AWS and the Hellmann precipitation measures.

REFERENCES

FANKHAUSER R., 1998.- Influence of systematic errors from tipping bucket rain gauges on recorded rainfall data.- *Water Science and Technology*, 37:121-129.

HABIB E., KRAJEWSKI W.F., and KRUGER A., 2001.- Sampling errors of tipping-bucket rain gauge measurements.- *Journal of Hydrologic Engineering*, 6:159-166.

SEVRUK B., 1996.- Adjustment of tipping-bucket precipitation gauge measurements.- *Atmospheric Research*, 42:237-246.

STATISTICAL ANALYSIS OF TIME-SERIES. GENERAL REMARKS AND APPLICATIONS LAND AIR AND SEA SURFACE TEMPERATURE. CORRECTED JOINT REDUCED VALUES AND ORIGINAL ONES

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Abstract

Basically, in the study of the climate evolution, the main research concerns the meteorological conditions existing over the land air and sea surfaces. The scale of the study of these observations extends from the local to the regional, hemispheric and global research. The Hadley Center has undertaken their determination, followed by their correction. The values are the differences with the normals 1961-1990.

In our research, two types of problems have been considered: 1) the search for the random component in the global or hemispheric series; 2) the importance of the corrections applied on the data. From this search, the analysis process allowing the rigorous selection of the random part in each series and the measure, at the global scale, of the difference degree between old and new series values, has been settled.

In the first case, compared with the division of the global series into homogeneous sequences, only the combinational analysis leads to the determination of random groupings of close values bound to an unstable cahotic distribution. In the second case, the differentiation between ranks derived from the association of reduced land air and sea surface temperatures and the corresponding sum of ranks of original observations, keeps in the dark the correction effect, leaving the place to the difference between the forms of evolution appearing in each series. In each case, the value reduction of the variance to the unit 1 allows their joint, which is impossible with original values.

1. The factors of the climate evolution. General properties

At the local scale, the weather evolution and, consequently, the resulting variable values, depend on the physics of the phenomenon producing these values. These physics concern the general circulation of the air masses over the land and sea surfaces and, with a varying importance, the turbulence of this circulation resulting from internal effects or from its interaction with the form or the orography of the continents.

Concerning the Earth rotation on itself, or around the Sun, the periodic effects are eather attenuated or eliminated in the daily, monthly or annual means. On the other hand, if, the non-linearity of equations determines a physical evolution of the weather involving a natural instability, turbulence and cloudiness lead to random differences between the observations made at separate stations, differences which go over from an unlimited unbroken space to a limited discrete set.

Finally, the climate characterization depending on the frequency of the weather types, it follows that the problem has to be reduced to a probability one, leaving to values the determination, in a finite and discrete form, of the physical answer to the evolution phenomenon.

For the remainder, it has been demonstrated (Gumbel) that, for a set of n observations x_i ranked in increasing order, the mean values E of the function $F(x_i) = \text{Prob}\,(x < x_i)$ are, for i = 1, 2,.. ., n:

$$E[F(x_i)] = i/(n+1).$$

It follows that, replacing the values with their rank i, keeps unchanged the order of the probabilities, which simplifies in a considerable way, the method of time-series analysis.

This being done, the random character of a series being defined by the stability and the independence of the rank values, appropriate tests put forward eventual trends or correlations. In this case, these tests are respectively the Mann trend test and the serial correlation one. In addition, for a complete information, trend analysis has to be applied in a progressive and reciprocal way.

In case of rejection, the correct answer is given, eather with separating eventually succeeding random sequences or with applying combinational analysis. In this last case, the determination of random groups is made with selecting in size order, close values put together in chronological order.

2.Examples. Joint values of land air and sea surface temperatures.

2.1 Globe corrected annual values with variance reduced to 1. Met. Office, Hadley Center for climate prediction and research, United Kingdom, Bracknell, Berkshire

2.1.1 Test of the random character of the complete series

With the mean and standard deviation, m_v and s_v, table 1 gives the results of the series analysis involving the standardized values of the trend and of the serial correlation test u(t) and u(r) for the complete series, as well as $u_d(t)$ and $u_d(r)$, for its dispersion. For intermediate values, u_x, u'_x, u_{dx} and u'_{dx} are extremes, while u and u' are values derived from the direct and reverse analysis of the series and its dispersion.

Table 1. Globe annual values. Trend analysis of the complete series.

	n	m_v	s_v	u(t)	$u_x(t);u'_x(t)$	u(r)	$u_d(t)$	$u_{dx}(t);u'_{dx}(t)$	$u_d(r)$
1870-1999	130	-.123	.213	10.26	-2.10;10.26	9.65	.78	-3.89;5.88	7.92
					1913;1870			1976;1965	

A minimum occurring in 1913, significant at the .018 level, the direct trend analysis suggests the existence between 1870 and 1927 of a compensating oscillation between groups of high or low mean values. After 1927, though the continuation of oscillating means, the trend statistic u(t) increases steadily up to the end of the series. From the reverse analysis, a compensating instability appears in the sequences 1870-1895 and 1930-1973, while the slight trend appearing in the ending sequence 1987-1999, is simply due, in the complete series, to the 1998 occurrence of the highest value. Concerning the dispersion, with mean value of .78 the compensating trend appears in the direct and reverse extremes of 1976 and 1965 leading to a very significant serial correlation value of 7.92. It follows that trend t and serial correlation r appear to be significant, practically with probability 1, for the existence of a persistent trend. In addition, the intermediate values given by each statistic $u_x(t)$, $u'_x(t)$, $u_{dx}(t)$ and $u'_{dx}(t)$ reveal, for both the mean and dispersion, the unstable character of their evolution.

For characterizing the unstable evolution of the mean, using the progressive trend analysis, sequences involving only non significant progressive u(t) values have been successively withdrawn from the original series.
Similarly to those of Table 1, the trend analysis of the selected partial series leads to the results of Table 2.

Table 2. Globe annual values. Trend analysis for stable sequences selection

n	m_v	s_v	u(t)	u, $u'_x(t)$	u(r)	$u_d(t)$	u, $u'_{dx}(t)$	$u_d(r)$
1870-1902	33	-.288	.090	.57	-	2.40	.88	2.61; 2.18 1.89
1903-1918	16	-.368	.088	1.04	; 2.40	2.19	-.23	- .90
1919-1930	12	-.232	.073	1.10	-	.08	1.37	- -.93
1931-1979	49	-.045	.099	.26	2.87 ;	2.34	.43	- -.20
1980-1986	7	.091	.079	-.45	-	-1.00	.75	- 1.40
1987-1999	13	.283	.114	1.59	; 2.23	1.72	1.22	- .36

It appears in this way that if the values of the mean m_v reveal a systematic variation, for the standard deviation s_v, values are close to .0934. In addition, for only three cases, for both direct and reverse analysis, significant intermediate trend statistic values u(t) and u'(t) are absent. Accounting for the serial correlation u(r) for each of three series, among them, only two are randomly disributed.

For the dispersion, with the exception of the first sequence, stability and independence make the random assumption acceptable.

As a first conclusion derived from this selection of approximate homogeneous sequences, compared to the standard deviation of the complete series, the variance of the selected sequences represents 19% of the total variance, the remaining 81% representing the non random unstable part of these sequences.

2.1.2 The change-point account in combinational analysis

The physics of the evolution of the weather involving the existence of situations of indetermination, at all scales, in climatological time-series, change-points have to be expected.

Actually, for the series of seasonal temperature averages, such change-points were derived for the first time in 1958 for Brussels and Paris-St-Maur using a trend analysis. Moreover, its meteorological justification was given by Lorenz only in 1963, this justification being issued from the mathematical properties of non linear differential equations established by Henri Poincaré.

As seen above, trend analysis seems not leading to exhaustive results, in spite of the non-parametric character of the used methodology. Actually, in the case of a time-series, with considering the n! possibilities, combinational analysis gives the possibility of determining the closeness to randomness of any time-series.

Using ranks, the methodology reduces here to detect first contiguous groups with respectively high or low values and to select groups homogeneous in the mean with a trend analysis of their arrangement in increasing order of the rank means.

In particular, the selection has grouped successively, in chronological order, the ranks in number of approximately ten values from 1 to 10, 11 to 20, up to 50, followed by about twenty values up to 110 and finally, by about ten values up to 130.

Table 3. Globe annual rank values. Homogeneous rank groups selection.

Nb	n	m	s	u(t)	u(r)	$u_d(t)$	$u_d(r)$	m_v	s_v	$u_D(t)$
1	10	5.50	2.97	-.72	-.25	-.27	.42	-.436	.0151	
2	10	15.50	2.92	.98	.45	-.63	-1.51	-.374	.0165	3.34
3	11	26.00	3.01	1.32	.25	.47	.06	-.320	.0089	4.17
4	8	35.50	2.24	-.12	-.56	.37	1.21	-.287	.0149	3.64
5	10	44.50	2.83	.89	-.45	-.54	-.53	-.246	.0143	3.37
6	21	60.00	6.13	.03	-.34	-.69	-.96	-.175	.0271	3.76
7	19	80.00	5.56	1.22	-.26	.31	3.01	-.071	.0274	5.07
8	20	99.50	5.84	.88	-.97	-.71	-.09	.032	.0241	5.35
9	10	114.50	2.99	1.70	.15	-.80	1.05	.130	.0368	4.39
10	11	125.00	3.30	1.79	-.24	1.17	.93	.310	.1030	4.59

Type-number Nb, size n of groups, mean m, standard deviation s, standardized trend statistic u(t), serial correlation coefficient u(r), corresponding values $u_d(t)$ and $u_d(r)$ for the dispersion from the mean, mean and standard deviation m_v and s_v for each group; standardized trend statistic $u_D(t)$ derived from the joined contiguous groups.

From the results given in table 3, stability and independence may be accepted for all the sequences. In particular, for the sequences 9 and 10, the significance of the trend statistic u(t) is due only to the place occupied by the smallest or by the highest value at the beginning or at the end of the series. In addition, this significance is still poorer due to existing tied values in the groups of the two series.

On the other hand, the trend analysis applied on the contiguous series, joined two by two, leads, for the lowest value of the trend statistic $u_D(t)$ reduced at the scale of the complete series, to a result significant at the 2.5%0 level. The significance may thus be extended to the complete set of results in table 3.

Carrying back the type-number for each value to the date of its year in the original time-series, the selection of years bound by consecutive type-numbers have been reported in table 4.

It appears first, in this way, that exception made of the type-number 7, between 1870 and 1918, the type-numbers 1 to 6 are the single appearing ones. After 1918, an increase of the annual means appears regularly, with, on one side, the reappearance of number 7 since 1925, followed by the new type-numbers 8 and 9 from 1937 and 10 from 1983 and, on the other side, the disappearance of the type-numbers 1 and 2 since 1919, 3 and 4 since 1930, 5 since 1967 and 6, 7 and 8 respectively since 1977, 1980 and 1986. In parallel, it follows that, for the global temperatures, the variation interval was reduced to the one of the ranks of the group 10 during the six last years. With the last warming, the climate diversity was thus progressively decreasing.

Coming back from the ranks of table 4 to the corresponding values, the synthesis given in table 5 concerns the chronological evolution of the derived sequence values. For each of these sequences, it concerns respectively the type-numbers, the size n, the corresponding mean m and set interval itl with, in addition for the consecutive sequences, the mean difference dm and the corresponding trend statistic $u_D(t)$ derived from contiguities.

Table 4. Globe. Temperature evolution following type numbers 1 to 10 (table 3)

Type number	1	2	3	4	5	6	7	8	9	10
Year										
1870-71				---						
1872					---					
1873-76		---	----	----						
77-78						---	----			
79-80				---	---					
81-84				---	---					
85			---							
86					---					
87		---								
88				---						
89						---				
90-95	---	---	---							
96-97						---				
98			---							
99-1901						---	---			
1902-03		---	---	---						
05-06			---	---						
07-13	---	---								
14-15					---	---				
16-18	---	---								
19-21				---	---	---				
22-24			---	---						
25-28						---	---			
29			---							
30-32						---	---			

33	---					
34-36		---	---			
37-49			---	---	---	
50-53		---	---	---		
54-56	---	---				
57-63				---	---	
64-72		---	---	---		
73					---	
74-76		---	---			
77-79			---	---		
80-82				---	---	
83						---
84-85				---		
86-99					---	---

Table 5. Sequences defined by the involved type-numbers, the size n, the mean m, the interval itl, the difference dm and the trend statistic $u_D(t)$.

Period	Type-numbers	n	m	itl	dm	u_D
1870-1978	(1-7)	9	-.292	.38		
1879-1889	(2-6)	11	-.276	.14	.016	.81
1890-1895	(1-3)	6	-.382	.12	-.106	-2.84
1896-1901	(3-6)	6	-.202	.16	.180	2.26
1902-1906	(1-4)	5	-.342	.14	-.140	-2.26
1907-1913	(1-2)	7	-.421	.09	-.079	-.27
1914-1918	(1-6)	5	-.310	.30	.111	2.40
1919-1936	(3-7)	18	-.197	.26	.113	3.01
1937-1945	(7-9)	9	.044	.22	.241	4.88
1946-1964	(5-9)	19	-.051	.34	-.095	-.69
1964-1976	(6-9)	12	-.081	.27	-.030	-.12
1977-1982	(7-9)	6	.058	.17	.139	2.08
1983-1985	(8-10)	3	.090	.22	.032	.21
1986-1993	(9-10)	8	.209	.21	.119	1.17
1994-1999	(10)	6	.353	.34	.144	2.14

The first derived result is the division of the complete series into three sequences: 1870-1936, 1937-1985 and 1986-1999.

For the first sequence, the means in ◦C of the sequences vary from -.197 to -.421, which leads to an interval of .224 with a mean of -.282. For the second one, the interval is reduced to .171 with a mean of -.019, while for the last sequence, a trend test divides it into two parts, the interval of which is reduced to .144 with a mean of .271.

It follows that from 1870 to 1999, the abrupt warmings of 1937 and 1986 reached respectively .263◦C and .290◦C, which leads to a total increase of .553◦C. Finally, coming back to the extreme temperatures in the shortest sequences, the respective means for the sequences 1907-1911 and 1997-1999 being -.442◦C and .430◦C, the largest difference reaches .872◦C. However, the values of the Hadley center being sums established by the empirical method, on the point of view of the physics of the phenomenon, these results remain purely indicative.

Concerning the natural instability of the climate temperature, following table 3, the variance of the random component of the complete series reaches only 2.84% of the total variance, which leaves 97.16% of this variance for its non random part.

2.2 Comparison between corrected reduced land air and sea surface joint temperatures with the corresponding original P.D. Jones (1994) series. NH observations 1870-1995

2.2.1 Trend analysis of the complete series

The existence of some dubious data found in the P.D. Jones series of observations for both land air and sea surface temperatures made their correction necessary. The first result of this correction being new global and regional series of annual averages, the opportunity has been given for determining the degree of deviations encountered when analysing the Jones series. This search has been made for the Jones NH land air and sea surface temperature series.

Similarly to the corrected new temperature series, for this purpose, the elements used for the Jones series are the sums of the corresponding land air and sea surface observations. Moreover, the first property to be acceptable being the identity of the probabilities assigned to each value, in each time-series, the elements have been replaced by their corresponding rank.

Table 6. Trend analysis of the rank values and of their difference, in complete series.

	$u(t)$	$u_x(t)$	$u'_x(t)$	m	s	$u(r)$	$u_d(t)$	$u_{dx}(t)$	$u'_{dx}(t)$	$u_d(r)$	
P.Jones(1994)	8.43	-1.85;-1.60	2.04;	4.52	63.5	36.514	7.84	.18	-2.50	4.57	4.24
Corrected	8.52	-2.03;-2.48	1.58;	4.26	63.5	36.507	8.70	.66	-1.93	4.31	5.14
Years	1895;	1913	1937;	1964	1975	1964					
Difference	-.91	-2.21;2.99	2.44;	-3.47	0	6.75	2.14	-3.93	-3.80	-3.95	1.03
Years	1885	1925	1949;	1900				1909	1921		

Having applied the Mann trend test to each of the two series, the results show (table 6), for the two complete series and for the corresponding dispersion, very close values for the standardized trend statistics $u(t)$ and $u_d(t)$ as for the standardized serial correlation statistic $u(r)$ and $u_d(r)$.

The same is true for the intermediate values of the trend statistics $u_x(t)$ and $u'_x(t)$ as well as $u_{dx}(t)$ and $u'_{dx}(t)$ derived from the direct and reverse progressive analysis, with, in addition, identical years of occurrence. Moreover, among all these standardized trend statistics, as for all the dispersion series, the trend statistics $u_d(t)$ are the single ones having a non significant value.

For the complete difference series and its dispersion, internal decreasing trend statistics reach values close to the ones for the two complete series, while for these two first series, the u(t) statistics values reveal a very significant increasing trend. For the difference, moderate for the u(t) statistic, the decreasing trend is very significant for the $u_d(t)$ statistic.

For the remaining, the set of ranks being indentical for each of the two series, means m and standard deviations s are identical. For the difference, if the mean is obviously zero, the standard deviation of the rank differences allows the derivation of the correlation between the two series. With the standard deviations respectively equal to 36.51 for the two series, and to 6.75 for their difference, with var x = var y and the correlation coefficient [cov(x,y)]/var x = r, we have:

$$\text{var}(x-y) = \text{var}\,x + \text{var}\,y - 2\,\text{cov}(x,y) = 2[\text{var}\,x - \text{cov}(x,y)] = 2\,(1 - r)\,\text{var}\,x,$$

from which follow the results:

$$(1 - r) = (6.75/36.51)^2/2 = .01709 \quad \text{and} \quad r = .98291.$$
(1)

Thus, in probability, for the rank values in each series, the correlation coefficient r shows that their common part amounts to 98,29%, while the independent part reaches 1,71%.

2.2.2 Internal instability of the series of rank differences

Having determined the importance of the rank differences between the corrected and the P.D. Jones series, the remaining question is the degree of randomness for the difference series. For this purpose, replacing the rank differences by their own rank in this series, a first selection of the values belonging to the intervals $0 < x < 10$, $10 \leq x < 20$,... , $120 \leq x \leq 125$, has been made and repeated with new groupings of contiguous intervals up to appearing non random trends. Actually, the numerous equal values being unequally distributed, assembling homogeneous values has been operated whith small groups of values in table 7. In addition, for the series of rank (3) of this Table, 1978 appears to divide the series of the corresponding dispersion into two random series.

Table 7. Random groupings derived from close rank values of the complete difference series

Type numbers	n	u(t)	m	s(m)	s	u(r)	$u_d(t)$	$u_d(t)$
(1)	19	-.59	10.0	1.28	5.60	-1.64	.63	-1.44
(2)	14	1.26	26.5	1.04	3.90	.97	-.16	-.83
(3)	33	.17	50.0	1.67	9.58	-.22	1.94(1978)	.82
(4)	14	-1.31	73.5	0.88	3.28	.11	1.31	.11
(5)	20	-.39	90.5	1.31	5.86	-1.81	1.33	-.67
(6)	26	.26	113.5	1.49	7.60	-.20	-.84	-.24

Table 8. Difference between NH annual means corrected and original. Evolution given in type numbers of table 7.

Type numbers	1	2	3	4	5	6	
1870-74		---		---			---
75-78		---				---	
79-82	---				---		
83-87	---	---			---		
88-90		---	---				---
91-94			---			---	
95-99	---	---	---	---			
1900-07						---	---
08-14				---	---	---	
15-16			---				
17-27				---	---	---	
28-33	---				---		
34-36				---	---	---	
37-43	---		---		---	---	
44-47	---		---	---			
48-53	---	---	---		---	---	
54-60	---	---	---	---			
61-64			---	---	---		
65-70	---	---	---				
71-74	---		---		---		
75-88			---	---	---	---	
89-95			---	---			

Referring the ranks of the complete series to the type numbers of table 7 leads to the evolution of the difference values given in table 8. In particular, it shows that if up to 1894 a strong alternation of short groupings of relative high, moderate or low values appear, an alternating grouping of low or high values follows up to 1988, after which the last type-numbers are placed at the centre of the complete group.

Comparing these results to the one of table 4, the given picture is the one of a residual independent of the climate evolution, the reduction of the variability during the very last years being due to the last progress in the methods of observation.

On the other hand, referring to the random residual of the total variance of the corrected NH series, the random component of the Jones series and the one of the corrected series may be considered as being of the same size. It follows that for the two rank series, their difference results from differing determinations. Actually, the first one is simply the sum of ranks each derived from the corresponding probabilities, while for the other one, the sum is calculated on the original values, simply reduced by the corresponding standard deviation remaining, in this way, dependent of the original distribution laws. The different physical significances behind each rank series explains, in this way, the non random character of their rank difference.

However, though the significant difference existing between the ranking of each series, compared to the naturel effects of the climate evolution, it appears to be negligible. Recalling that for the Jones NH series, the common part between the evolution of the land air and sea surface temperature reaches only 59% of the total variance, the estimate of the variance of the independent part (41%) remains strongly significant. This being true at all time or space scale, is being reinforced in a considerable way.

Concluding remarks

(1) The basic property characterizing the climate evolution is the probability with which the climatological observations are distributed. For an optimal determination, elements have been replaced by their rank in the complete series. It is remarkable that, though the absence of ties for only one third of the rank values, the evolution in probability of the difference between the Jones and the corrected series, leads this evolution to a quite acceptable characterization.

(2) If, for the time-series analysis, the combinational analysis is the most efficient way for determining the departure from randomness, progressive trend and serial correlation analysis remain the logical way for selecting random sequences of finalizing groups of close values placed in chronological order. Noting that in this case, parametric tests, involving the assumption of a given distribution function, would introduce in this way a bias in the test, distribution free determination remains the clearest rigorous picture of the evolution of the considered variable.

(3) In the case of a continuous variable, in a finite series of observations, the probability of identical values is zero. Ties are thus due to an insufficient accuracy of the estimation of the elements of the series. In particular, when occurred for averages, it results from an insufficiency of the number of (decimal) digits determined when operating their calculation.

Finally, if for a space distribution, the elimination of erring outlyers has a high priority for further developments of an appropriate research, in the case of synthetic large scale averages, methodology and results may only be rejected if the resulting perturbation affects obviously the picture of the natural climate evolution at the considered scale. Any systematic rejection may be an important loss for the knowledge process.

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References

Gumbel, E.J., 1968. Statistics of Extremes. Columbia University Press, New York 1958, 375pp.
Jones, P. D., 1994. Hemispheric surface air temperature variations: a reanalysis and update to 1993, Journal of Climate, 7, 1794-1802.
Easterling, D.R. and T.C. Peterson, 1995. A new method for detecting undocumented discontinuities in Climatological series, Int. J. Climatology, 15, 369-377.

Lorenz, E.N., 1963. Deterministic non-periodic flow, Journal of Atmospheric Science, 20, 130-141.
Mann, H.B., 1945. Non parametric test against trend. Econometrika, 13, 245-259.
Petitt, A.N. 1979. A non-parametric approach to the change-point problem. Appl. Statist. 28, 126-135.
Sneyers, R., 1958. Connexions thermiques entre saisons consécutives à Bruxelles-Uccle. Institut R. Météorologique de Belgique, Pub. B, No 23, 23 pp.
Sneyers, R., 1975. Sur l'analyse statistique des séries d'observations. O.M.M., N.T. 143, Genève, Suisse, 210pp. Spanish version, W.M.O. 1975, English version, W.M.O. 1990.
Sneyers, R., 1999. The data homogeneity problem as alternative search to randomness. Theoretical justification of the methodology and example of temperature extremes in the case of traditional and automatic themometer readings. ICEAWS 1999, Vienna, Austria, 2nd International Conference on Experiences with Automatic Weather Sations, 27 to 29 September 1999, Vienna, Austria. Österreichische Beiträge zu Meteorologie und Geophysik, Nr 20, (Cd-Rom), 6pp.
Sneyers, R., 2000, 1. Temperature Differences between Highlands and Plain Meteorological Stations. The case of Sonnblick and Vienna. 26th International Conference on Alpine Meteorology, 11-15 September 2000, Innsbruck, Austria. Österreichische Beiträge zu Meteorologie und Geophysik, Nr 23/ Publ. Nr 392. Central Institute for Meteorology and Geodynamics, Vienna, Austria, 5pp.
Sneyers, R., 2000, 2. Testing Homogeneity of Time Series: a Rank Problem. The example of the NH sea surface and land air temperatures. Third Seminar on homogenization and reliability of climatological data. Meteorological Service, Budapest, Hungary, September 2000, 8pp.
Sneyers, R., 2001, La Climatologie. Science ou Littérature. Un historique du développement de la recherche en climatologie. La Météorologie, Revue de la Société météorologique de France, 8e série-N◦36-février 2002, 54-61.
Sneyers, R., H. Tuomenvirta and R. Heino. Observation Inhomogeneities and Detection of Climate Change. Geophysuca, 1998, 34(3), 159-178.
Sneyers, R. and L. Alvarez, 2000. The change-point instability of climatological time-series as alternative to randomness. The example of annual temperature averages 1908-1995 at Casablanca (Cuba. Bulletin of the Cuban Meteorological Society, 6(1): electronic publication (http://www.met.inf.cu/v06_n01/english/paper_61.htm).

THE ENVIRONMENTAL CLIMATOLOGY INFORMATION SUBSYSTEM OF THE REGIONAL MINISTRY OF THE ENVIRONMENT, JUNTA DE ANDALUCÍA

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Abstract

The Environmental Climatology Information Subsystem (Subsistema de Información de Climatología Ambiental, S.I.C.A.) consists of a set of meteorological observation networks related by an informatic system that allows its use for diferent organisations. Manual and automatic weather stations data are converted to an unique format and, after being tested and completed, they are transfered to a definitive and homogeneus climatic database. The S.I.C.A., which is one of the basic tools of the Climate Change Regional Strategy, aims to answer to the increasing need of quality climate data which allow to carry out climate evolution studies and anticipate possible consequences of the climate change in Andalusia.

Key words: *Environmental Climatology Geographic Information System, Automatic Weather Stations, Andalusia.*

1. INTRODUCTION

The Environmental Climatology Information Subsystem (Subsistema de Información de Climatología Ambiental, S.I.C.A.) consists of a set of meteorological observation networks which belongs to diferent public and private organisations and the informatic system that integrates data, carry out data quality control and allows the use of final data by diferent users, scientifics as well as planners.

The S.I.C.A. was designed and created by the Planning General Direction of the Regional Ministry of the Environment of the Regional Government of Andalusia (Spain) in order to giving answers to the new needs created as result of the Climate Change Regional Strategy and besides, because of the establishment of the Environmental Information Network (Red de Información Ambiental, R.I.A.) in Andalusia. The R.I.A. tries to unite the efforts of different centers, information users and producters, from universities to other scientific centers.

The S.I.C.A. main aim is the homogeneisation of meteorological data in order to get a trustworthy information source to study different meteorological variables and to elaborate other climatic studies in Andalusia, such as the calculation of environmental indicators and, the most important, the evaluation of the possible climate change impacts and consequences. Figure 1 shows the situation of Andalusia in the european and the mediterranean context.

The S.I.C.A. is also related to the international interest in establishing informatic aplications and systems that systematize the processes related to the homogeneisation and use of climatic information. Some examples of this trend is the European Comission project to investigate and establish comun criteria about the use of

geographic information systems in Climatology and Meteorology (European Comission, 2001), and the method established by the National Institute of Meteorology to study the evolution of the rainfall structure in Spain (Almarza y Gutierrez – Marco, 2001).

Figure 1: Andalusia in the european and mediterranean context.

2. METEOROLOGICAL OBSERVATION NETWORKS INTEGRATED IN THE S.I.C.A.

The different meteorological observation networks included in the S.I.C.A. were created by three different public organisations:

- National Institute of Meteorology (I.N.M.).
    - Automatic Weather Station Network (E.M.A.S.).
    - Complete weather station network.
    - Daily weather station network.
- Regional Ministry of Agriculture and Fisheries (C.A.P.).
    - Agroclimatic Information Network (R.I.A.C.).
    - Plague Alert and Information Network (R.A.I.F.S.).
- Regional Ministry of the Environment (C.M.A.).
    - Air Quality Network (SIVA).
    - Forest Fire Fight Network (INFOCA).
    -

Table I: Different meteorological networks included in the S.I.C.A.

ORGANISATION	NETWORK	TYPE	AMOUNT OF STATIONS
I.N.M.	AUTOMATICS	Automatics	42
	COMPLETES	Semi-automatics	28
	DAYLYS	Manuals	1914
C.M.A.	INFOCA	Automatics	32
	SIVA	Automatics	43
C.A.P.	RAIFS	Automatics	81
	RIAC	Automatics	89
TOTAL	Automatics		315
	Manuals		1914

These networks sum a total of 2,300 stations, in which more than 300 are automatic weather stations. The main characteristics of these weather stations are summarized in the table I. Besides, in the figures 2 and 3 stations are showed their distribution maps: automatic and semi-automatic weather stations are showed in figure 2 (different colours has been assigned depending on the organisations which manage them), while manual stations can be observed in figure 3 (all of them belong to the I.N.M.).

Figure 2: Automatic weather stations included in the S.I.C.A.

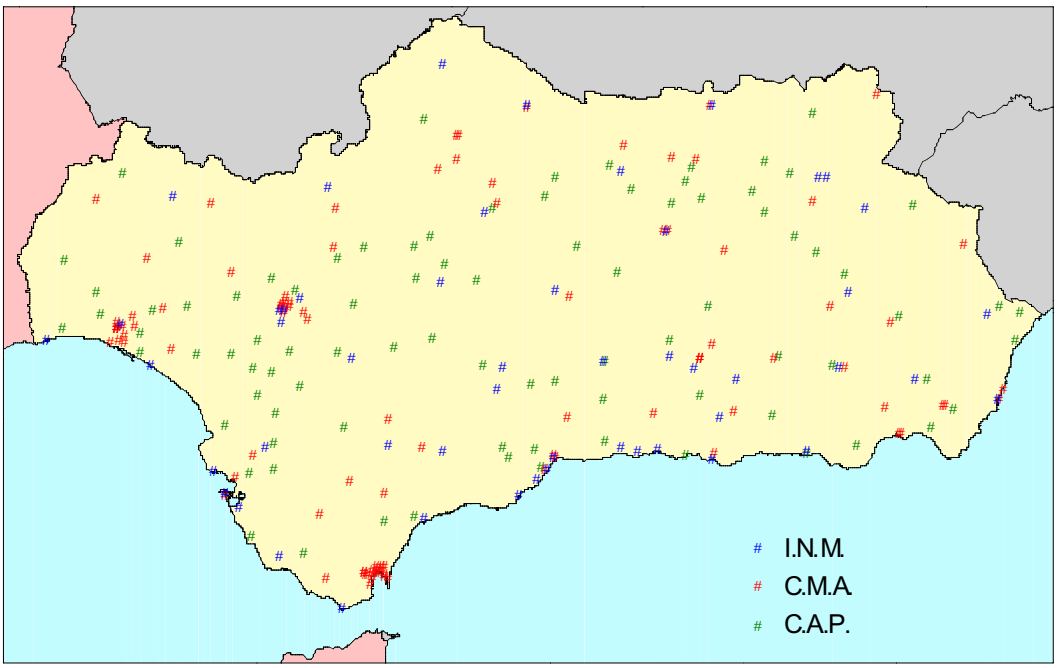
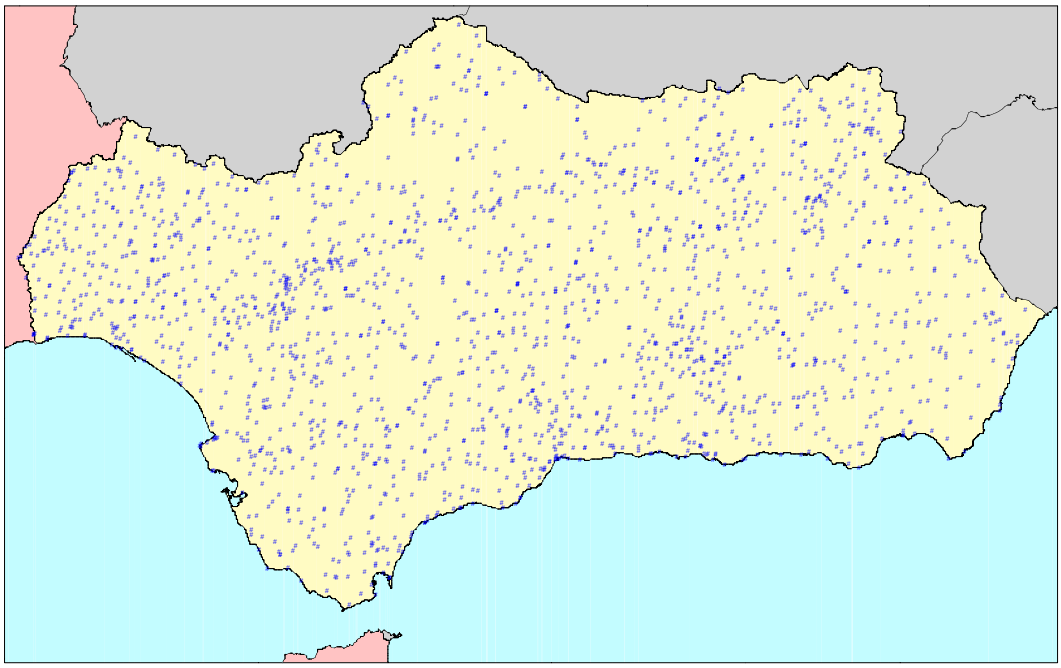


Figure 3: Manual weather stations included in the S.I.C.A.

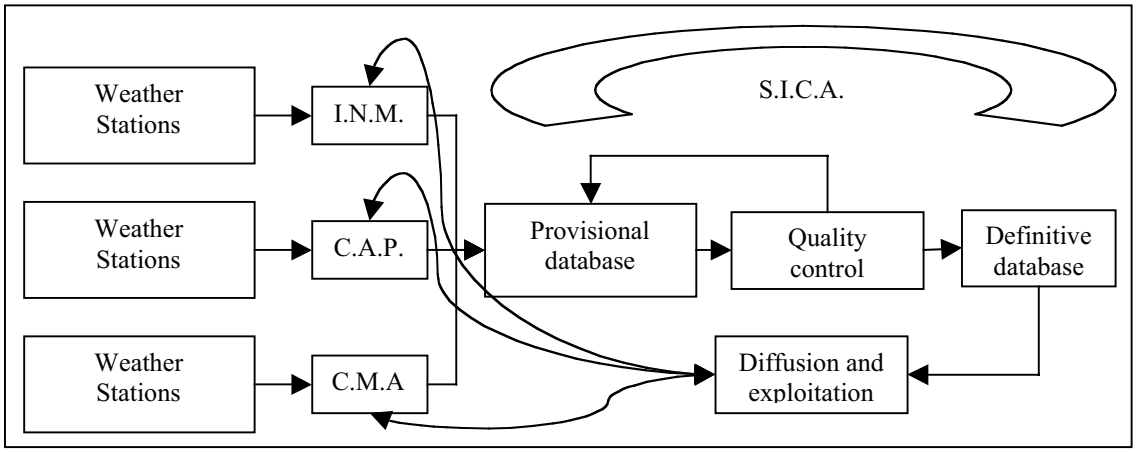


3. MAIN PROCESSES AND INFORMATION FLOWS IN THE S.I.C.A.

Once data have been acquired in the stations, they are transfered to different data concentrators depending on the organisation and, from these places to the S.I.C.A. data concentrator, where data are converted to an homogeneus and comun format. After overcoming a whole set of validation criteria, being corrected erroneous data and being filled no data records, the information is integrated in a definitive climatic database. Now, data can be extracted as tables, graphics or maps. Therefore, three different processes can be distinguished:

- Data introduction to the system. This process would include the acquistion, consultation and transmission of meteorological data from the stations to the data concentrators of the different networks as well as to the S.I.C.A. data concentrator.
- Analysis of received data. It involves data conversion from different formats to the S.I.C.A. format and the validation and correction of these data. Database is managed by using ORACLE.
- Utilisation of original and calculated data. It includes several products: the automatic creation of statistics, graphics and tables and the interpolation of spatial data in maps. Besides, data can be exported in different formats.
  These processes are expressed in the information flows showed in the figure 4.

Figure 4: Information flows in the S.I.C.A.



4. DATA ACQUISITION AND LOAD

There are several organisations and networks included in the S.I.C.A., so there are multiple types of weather stations depending on their needs and each one meassures different metorological variables and in different temporary scales (see table II). Therefore, nowadays, the S.I.C.A. has a great value as a management tool in climatology given that integrates heterogeneous information in an homogeneus database.

Because each network has been designed separately, each one saves data in a different format. Several processes allow to capture data stored in each data concentrator by the S.I.C.A. and convert these data to an unique and comun format.

Table II: Magnitudes and temporary scales in the different networks.

NETWORK NAME	TEMPORARY SCALES	MAGNITUDES (see table III)										
		P	T	V	H	N	I	R	E	A	S	O
E.M.A.S. (I.N.M.)	INTRA – DAY	X	X	X	X							X
COMPLETE STS. (I.N.M.)	INTRA – DAY	X	X	X		X	X	X	X		X	X
DAYLY STS. (I.N.M.)	DAYLY	X	X									
INFOCA (C.M.A.)	INTRA – DAY	X	X	X	X			X				X
SIVA (C.M.A.)	INTRA – DAY	X	X	X	X			X				X
R.A.I.F.S. (C.A.P.)	INTRA – DAY											
R.I.A.C. (C.A.P.)	INTRA – DAY	X	X	X	X			X				

Meteorological data are captured periodically according to their temporary scales. Dayly data from manual weather stations are loaded annually, once there have been processed in the I.N.M. However intra – day data, in spite of they can be obtained at any time, it has been established that they are captured at 0:00 every day, in order to avoid interferences in the works of the other organisations. So, at first, data are loaded in a temporary database until they have been validated, aggregated and no data records have been filled. In that moment, data are transfered to a definitive database where data are consolidated.

5. DATABASE STRUCTURE AND AGGREGATION PROCESSES

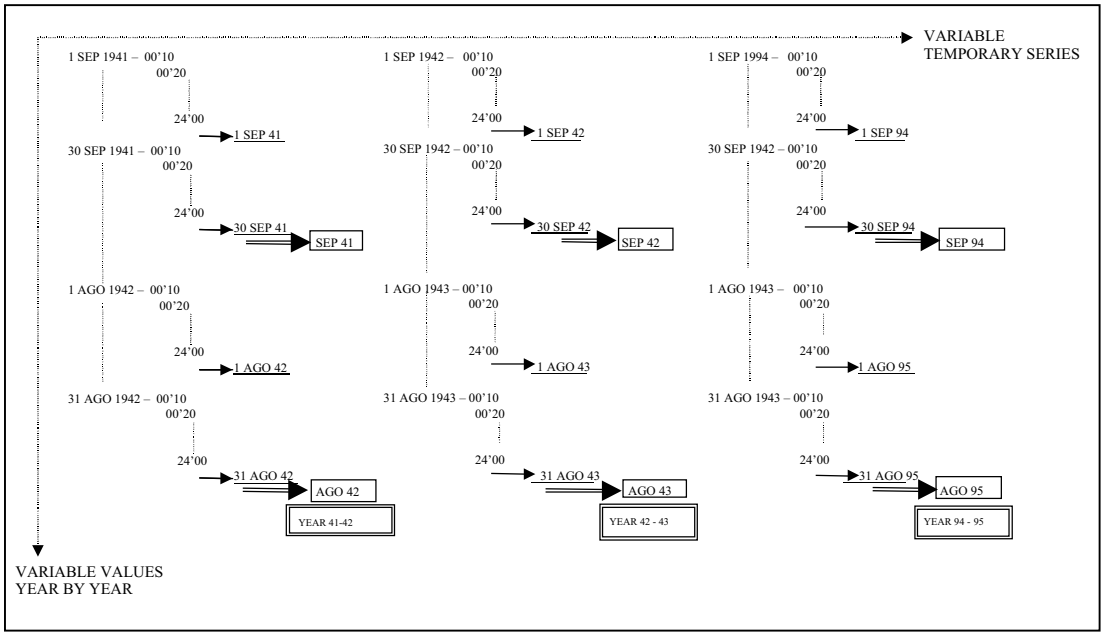
5.1 Database structure

The design of the database structure is based on the design of the data formats included in the System. The format is inspired, basicly, in the format used by the National Institute of Meteorology in its complete weather stations network, given that this organisation is the one that produces the major part of meteorological data. However, there are considered elements from other networks, such as automatic weather station formats, which will be the protagonists of the meteorlogycal information in the future.

In the database there are included 11 magnitudes and almost 700 meteorological variables (see table III); besides, each variable is included in four temporary scales; intra – day, dayly, monthly and annual. The intra – day scale was thought to include data from automatic weather stations, which usually acquire data every ten minutes. Thereby, although the format was basicly designed to include these data, it allows to include other temporay scales, such as data from complete stations which acquire data several times a day (mainly hourly).

In dayly and monthly scale, there are two possibilities: data can be original or they can be processed by the System from their lower temporary scales. Therefore, in the intra – day scale, data always are originals, while in the annual scale, data always come from the monthly scale. The figure 5 shows graphicly the database structure and the way in which data are obtained from the low temporary scales.

Figure 5: Database structure.



5.2 Aggregation data processes

Those variables, which are not original, have associated different processes to aggregate them according to obtained data in the their lower temporary scales. Data aggregation is carried out once that at least 80% of data have been validated. However in some excepcional cases, in spite of data have more than a 20% of no data records, data are aggregated, or also they are obtained from other variables of the same or the lower temporary scales.

Table III: Magnitudes and variables included in the S.I.C.A.

MAGNITUDES		VARIABLES
T	TEMPERATURE	Dry thermometer temperature
P	RAINFALL	Total amount of rainfall
		Existence of rainfall
		Existence of snow
		Existence of hail
		Existence of storm
		Existence of fog
		Existence of dew
		Existence of hoar – frost
		Existence of snow covering the soil
H	HUMIDITY	Air relative humidity
		Vapour pressure
		Wet themometer temperature
		Dew point temperature
N	CLOUDINESS	Class 1st of low clouds
		Class2nd of low clouds
		Amount of low clouds
		Class of middle clouds
		Class of high clouds
		Total cloudiness
I	INSOLATION	Total insolation
V	WIND	Wind direction
		Wind velocity
		Wind run

R	RADIATION	Horizontal plane global radiation
		45 degrees plane global radiation and south orientation
		Direct solar radiation
		Diffuse solar radiation
		Ultraviolet radiation
		Net radiation
E	EVAPORATION	Piche evaporimeter evaporation
		Evaporation in tank
A	EVAPOTRANSPIRATION	Potencial evapotranspiration in lisimeter
S	SOIL TEMPERATURE	Soil temperature at 0,05 depth
		Soil temperature at 0,10 depth
		Soil temperature at 0,15 depth
		Soil temperature at 0,20 depth
		Soil temperature at 0,15 height
P	ATMOSPHERIC PRESSURE	Atmospheric pressure at sea level

6 . METEOROLOGICAL DATA QUALITY CONTROL: DATA VALIDATION AND INTERPOLATION OF EMPTY RECORDS

Data quality control in the S.I.C.A. can be divided in two parts: firstly, there are validations based on ranges and logical filters; secondly, empty or no data records are interpolated by using values of the same weather station or values from other surrounding stations.

6.1 Data series validation

The first validation process applied on data is the use of ranges of values established for every meteorlogical variable; any value out of these ranges will not be admitted by the System. The climatological diversity of Andalusia obligate to the establishment of wide ranges in order to include every circunstance all over the region. Besides, there were avoided exact ranges given that they could lose extreme but valid data. Therefore, there are wide ranges to include all real data but, at the same time, there are some limitations to locate erroneous data. In spite of this, the system allows to adjust specific ranges for every meteorological variable in every weather station; thereby, little by little, there will be made concrete the logical intervals for every station improving the efficiency of the validation method (PITA LÓPEZ, 1999).

Besides the ranges, in some cases there have been established logical filters to alert if erroneous data are located. These filters compare two or more than two variable values to validate the whole set.

Finally, there were established some sophisticated methods, based on the succesion of intra – day values, the monitoring of the variation of meteorological variables according to the measurement periodicities, and the verification of any value that exceeded some dayly, monthly or annual maximum values.

Data which has not overcomed the quality control are conisdered as erroneous and there are marked to avoid that any of them be used in aggregation or interpolation processes. Therefore, erroneous data are only marked but not eliminated in order to conserve the original values.

6.2 Interpolation of empty records

Methodologies to interpolate no data or empty records are different depending on the temporary scale of the variables and their spatial and temporal behavior. These values are only obtained when there are guarentees of reliability. Monthly and annual variables are interpolated by using values of the nearest weather stations, in the case of intra – day variables, polinominal function adjusted to the dayly cycle are used and, in dayly variables (and also in some intra – day variables), arithmetic means are carried out based on previous and later values. The used methods are showed in the table IV.

Table IV: Temporary scales and interpolation methods.

TEMPORARY SCALE	INTERPOLATION METHOD
INTRA – DAY	Arithmetic mean of the values in previous and later days at the same time
	4th order polinominal function
DAYLY	Arithmetic mean of values in the previous and later days at the same time
MONTHLY	Correlation by using values of surrounding stations
ANNUAL	Correlation by using values of surrounding stations

7. DATABASE DIFFUSSION AND USE

Given that one of the main aims of the S.I.C.A. is the improvement of the quality of climatological and meteorological studies and, especially, climatic change studies, this System is at the disposal of the scientific and technical community, who want to investigate climatic related topics in Andalusia. Data can be obtained in threee different ways:

- Data extraction in tables and graphics for specific stations and variables in different dates (see figure 6). If necessary, these data can be obtained in real time in order to manage environmental problems, such as fire forests or atmospheric pollution.
-

Figura 6: Tabular data extraction.

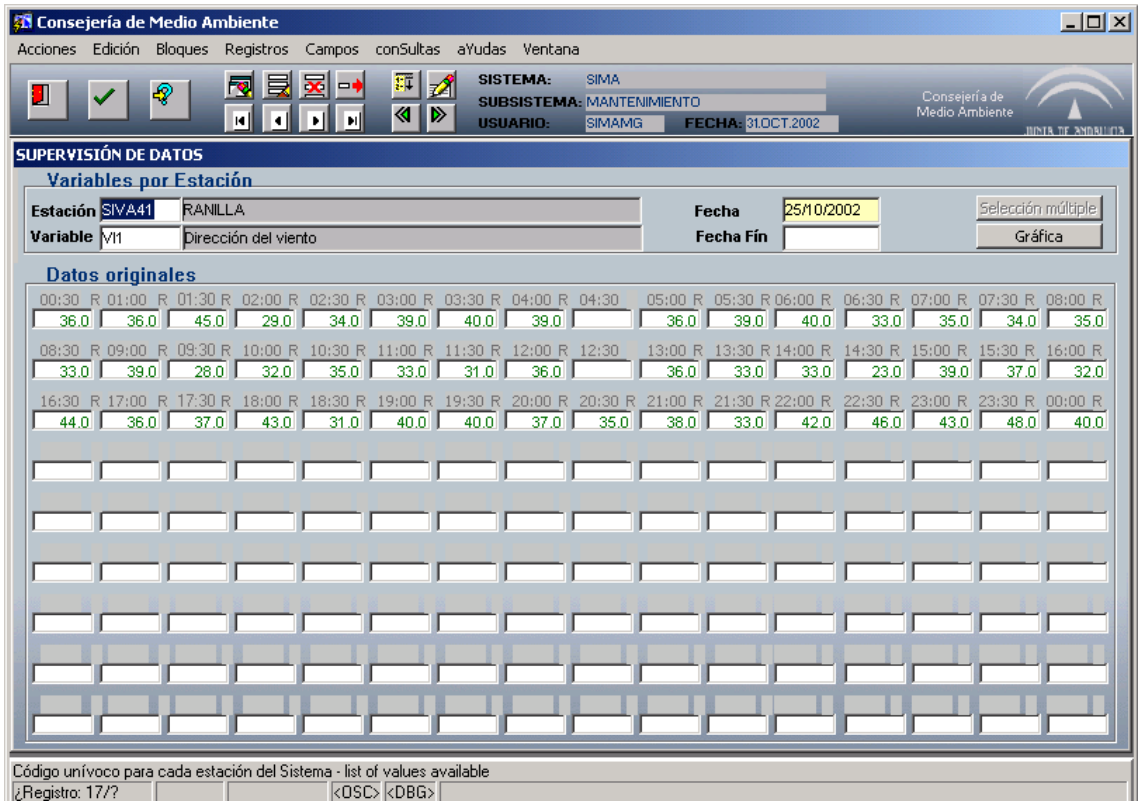
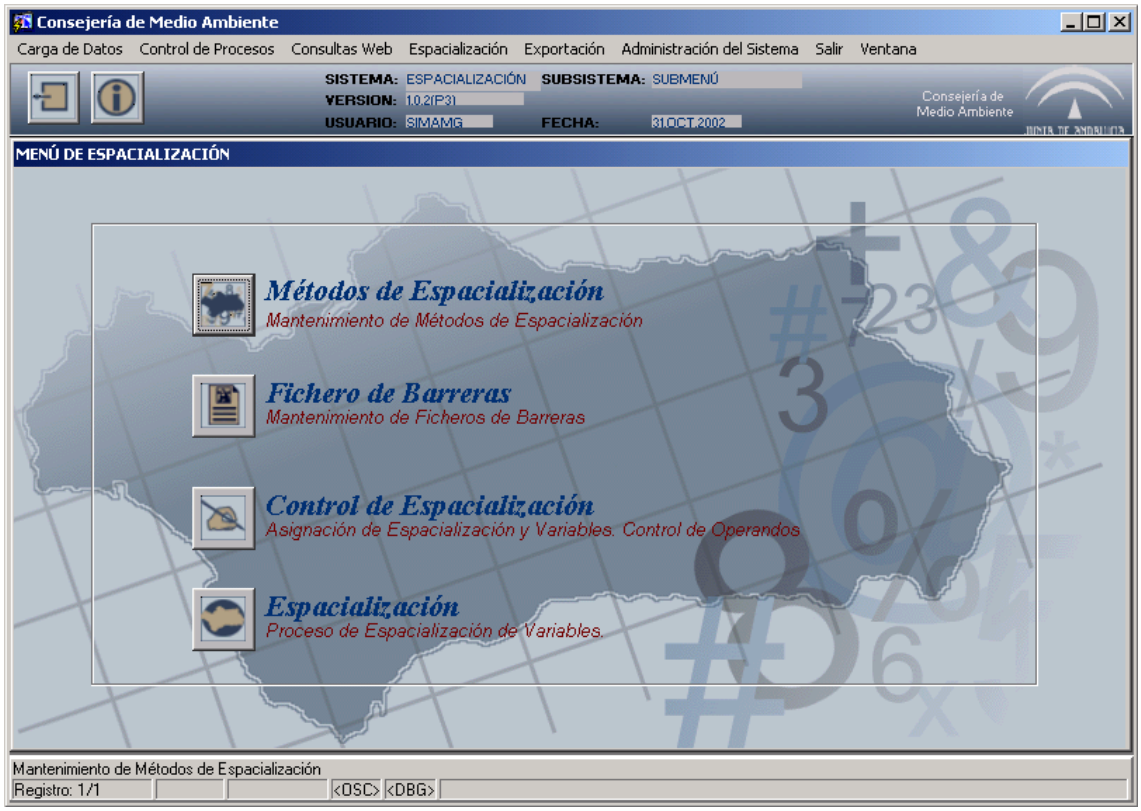
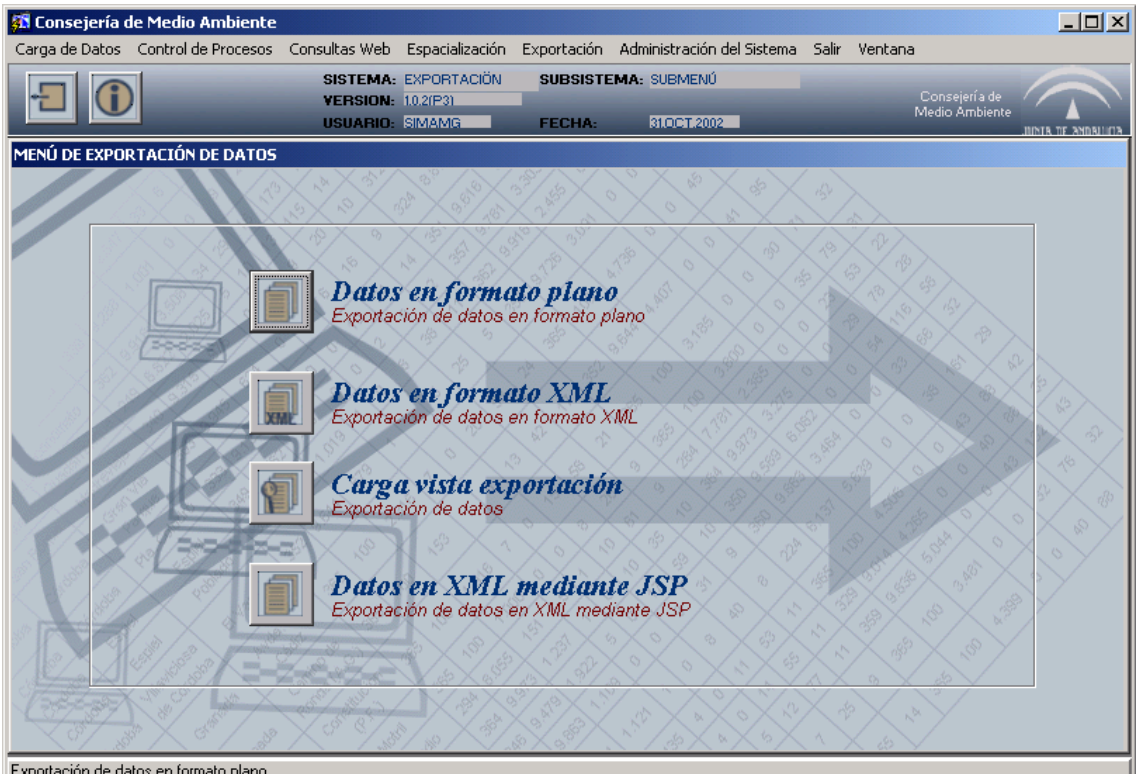


Figura 7: Spatial interpolation main menu.



- Spatial interpolation of meteorological variables by using personalized or pre-designed methods (see figure 7). For these tasks a geographical information system is used (ARC-INFO). Also, data can be used in simulation models to get knowledge about the atmospheric behaviour and for weather forecasting.
- Massive exports of meteorological data in different formats to analyse them by using other specific softwares (see figure 8).

Figura 8: Data export main menu.



Besides, although there are some restrictions, the S.I.C.A. can be consulted through the Internet (www.cma.junta-andalucia.es) (see figure 9).

8. CONCLUSIONS.

The S.I.C.A. is an effective tool to integrate meteorological data from the different observation networks in Andalusia. The load and aggregation processes as well as the validation and interpolation methods allow to give homogeneity to the acquired meteorological information and it can be used as a whole set in a study.

The S.I.C.A. integrates almost 2,300 stations that belong to seven different meteorological observation networks what depend on three organisations. The System works with information about 11 magnitudes and almost 700 meteorological variables. Therefore, an enormous work to establish comun criteria and coordinate efforts has been made. It can allow to face with more success guarantees the recently established "Regional Climate Change Strategy".

Likewise, there has to be stood out that the S.I.C.A. has been designed to be reformed at any time by including new meteorological variables or new processes. Therefore the System is opened to future needs.

The S.I.C.A., which will be operative in some months, can be the most important and reliable source of meteorological information to study the climate and evaluate and manage natural resources in Andalusia.

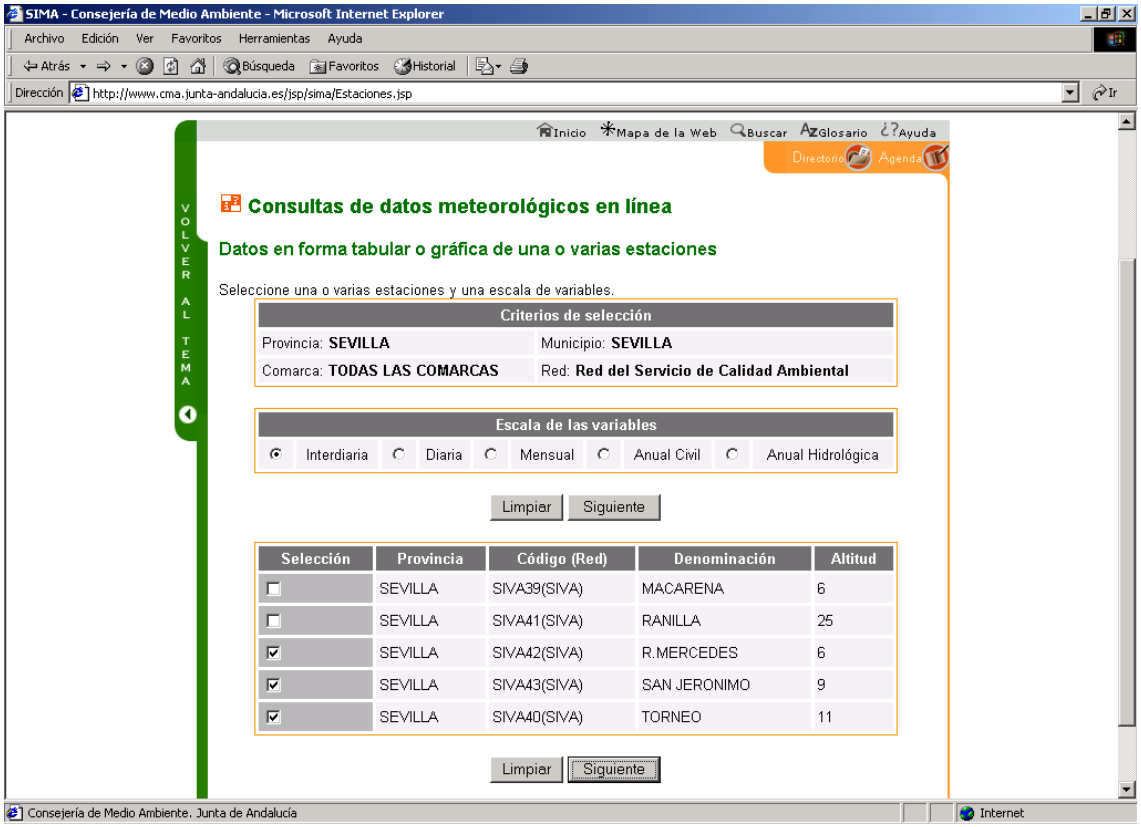


Figure 9: The S.I.C.A. through the Internet.

REFERENCES

- ALMARZA, C. and GUTIERRREZ – MARCO, E. (2001). "El sistema de información geográfica con fines climatológicos del Instituto Nacional de Meteorología", in PITA et al: Actas del XIV Congreso de la Asociación Internacional de Climatología, Seville.

- EUROPEAN COMISSION (2001): COST 719. The use of geographical information systems in Climatology and Meteorology, Memorandum, Bruxeles.

- PITA LÓPEZ, M.F. (1999): Diseño de una metodología de espacialización de variables climáticas, estructuración de bases de datos de clima y obtención de indicadores ambientales. Report elaborated by the Geography Department of the University of Seville for the Regional Ministry of the Environment.

COMPARISON OF RECORDING PRECIPITATION GAUGES: WEIGHING, TIPPING-BUCKET AND FLOAT TYPES

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Abstract: *The parallel occurrence of three types of recording precipitation gauges at meteorological station in Liesek in Slovakia has been a good opportunity for comparison of their records. The analysis of one minute records was made in the warm half-year during two years. The next comparison of tipping-bucket and float types at 20 stations was made during 3 years period in operational seasons (May - September) to the float type rain gauge - Pluviograph. Minute records have been analyzed. They have been received with different methods in some categories of rain intensity. In the evaluation, the occurrence of meteorological events has been taken into account. They influenced errors in precipitation gauges. The results can be used in preparation of intensity analysis from different sources of data.*

Key words: *recording precipitation gauges, pluviograph, measuring methods comparison*

1. INTRODUCTION

The analysis of the minute data gives new possibilities in quality control procedures and in application of evaluating the intensity of rain.

Twenty automatic weather stations (AWS) of SHMI simultaneously measure with three methods in warm period of the year. The first method realized by Tipping-Bucket Gauge is one part of AWS sensors. The second, Standard Rain Gauge is common instrument in Slovak precipitation network (697 stations). The third method is pluviograph, operating in warm half-year. This instrument composition gives a good opportunity for comparison of daily precipitation totals.

2. THE PRINCIPLE

Standard Rain Gauge METRA is used for manual observation of daily rainfalls at 7. a.m. each day. The area of orifice of the collector is 500 cm^2 and is located at the height of 100 cm above the ground level. Rain gauges are unshielded against the wind.

Recording Rain Gauge - Pluviograph METRA type 890 is used for continues liquid precipitation measurement in the Slovak Hydrometeorological Institute network. Operational season is from April to October. The area of the orifice is 250 cm^2 and is located at the height of 118 cm above ground level. It operates by means of a float which is raised by the rain water accumulated in a container. The rate of rise of the float matches the rate of rainfall and this is recorded on a chart, assembled on a cylinder which rotates at a constant rate once per 26 hours. The height of the line plotted on the chart corresponds to the amount of rain accumulated up to a upper limit of 30 mm of precipitation. The paper chart is 150 mm wide i.e. the amount of 1 mm of rain corresponds to 5 mm on the chart. After 30 mm has been accumulated, the container is siphoned off. On the time scale 1 hour of record corresponds to 20 mm on the chart, i.e. 3 minutes is equal 1 mm on the chart. The siphoning period takes about 30 seconds and no additional force is used. A heating device is not installed so care must be taken to prevent the float from freezing. Pluviographs are unshielded.

Tipping - Bucket Gauge - this type of rain gauge is used in connection with AWS. The principle of its operation is simple. A light plastic or metal bucket divided into complements is balanced in unstable equilibrium around a horizontal axis. In its normal position, the bucket stays against one of two stops, which prevents it from tipping. After a pre-determinate amount of water has entered into the compartment, the bucket becomes unstable and tips over to its alternative rest position. The movement of the bucket operates a reed switch contact which activates the electronic part. A tipping - bucket gauge used in SHMI network has area of orifice 500 cm^2 (PAAR and Meteoservis) and 200 cm^2 (Lambrecht) and resolution of 0.1 mm of rainfall per one tip. The orifice is located at the height of 100 cm above the ground. Gauges are heated in the winter season. Tipping - bucket gauges are also unshielded against the wind.

The next type of rain gauge used for the comparison is conventional Hellmann gauge with area of orifice of 200 cm^2. A pair of the gauges is installed at the station Liesek (the pit and elevated gauge at 1m height). The gauge is checked and measured three times per day. From these three values a daily sum was calculated.

The last compared rain gauge is the weighing-recording gauge Pluvio (manufactured by OTT). There were installed two pieces of this type of rain gauge for experimental field intercomparison purpose. One of them is installed at standard height of 1m above ground level and second one at ground level. The weight of precipitation gathered in the collecting container (capacity of 250 mm) is measured by an electronic weighing cell with resolution 0.01 mm. By the defining ring of the measuring surface, the precipitation gets directly into the collecting container. Thus precipitation can be immediately measured, because there is no time delay. The high accuracy is obtained by an automatic self-calibration by means of a calibration weight. The processor-controlled evaluation unit supplies a temperature-compensated and linearized output signal, which is available directly as a pulse output. A specific mechanical balance construction is used to achieve high accuracy of measurement.

Table I: List of meteorological stations with automatic weather station (AWS) in Slovakia

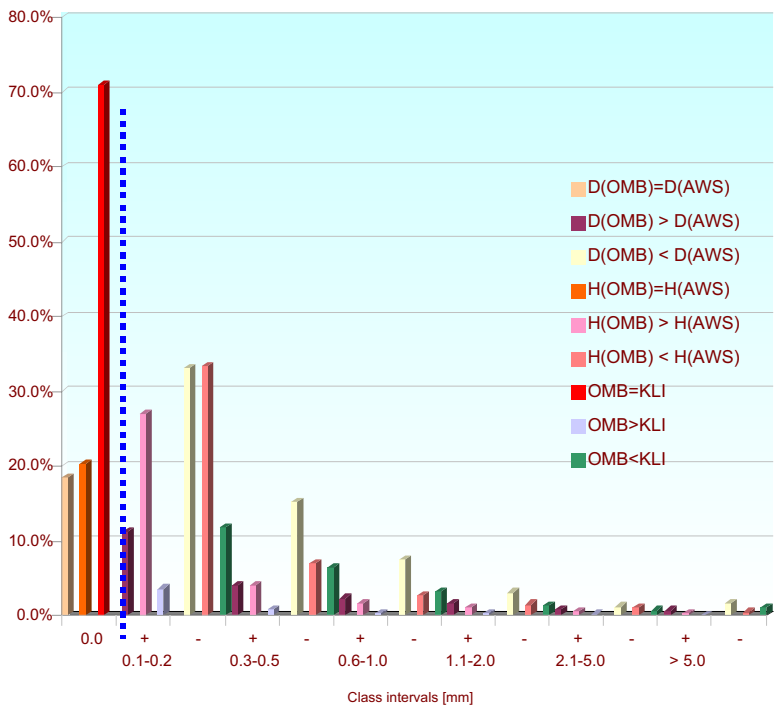
IND	STATION	H.A.S.L. [m]	LATITUDE	LONGITUDE	TYPE OF RAIN GAUGE
11813	Bratislava-Koliba	286	48°10´07´´	17°06´38´´	PAAR
11816	Bratislava-letisko	131	48°10´18´´	17°12´00´´	PAAR
11819	Jaslovské Bohunice	176	48°29´12´´	17°40´15´´	PAAR/Meteoservis
11826	Pies?any	163	48°36´47´´	17°49´58´´	Lambrecht / Meteoserv
11841	Doln? Hrièov	309	49°13´55´´	18°37´04´´	Lambrecht
11855	Nitra	135	48°16´44´´	18°08´18´´	PAAR
11856	Mochovce	261	48°17´22´´	18°27´22´´	Meteoservis
11858	Hurbanovo	115	47°52´23´´	18°11´39´´	PAAR/Meteoservis
11867	Prievidza	260	48°46´11´´	18°35´38´´	Meteoservis
11880	Dudince	139	48°10´09´´	18°52´34´´	Lambrecht
11903	Sliaè	313	48°38´33´´	19°08´31´´	Lambrecht
11918	Liesek	692	49°22´10´´	19°40´46´´	Meteoservis
11927	Luèenec	214	48°20´20´´	19°44´11´´	Lambrecht
11933	Strbské Pleso	1354	49°07´26´´	20°04´09´´	Lambrecht
11934	Poprad	694	49°04´08´´	20°14´44´´	Lambrecht
11938	Telgárt	901	48°50´55´´	20°11´21´´	PAAR
11968	Kosice	230	48°40´20´´	21°13´21´´	Lambrecht / Meteoserv
11976	Stropkov	216	49°12´56´´	21°39´00´´	Lambrecht
11978	Milhostov	105	48°39´47´´	21°43´26´´	PAAR
11993	Kamenica nad Cirochou	176	48°56´20´´	22°00´22´´	Lambrecht / Meteoserv

3. METHODS AND RESULTS

3.1. Intercomparison results for twenty stations in precipitation network

The differences of daily precipitation sums, measured by Standard Rain Gauge (KLI), Pluviograph (OMB) and Tipping - Bucket Gauge, connected with AWS (AWS) from 20 stations for period 1999 – 2001 and months May – October were analysed. At the Figure 1 there are graphically depicted the mean differences of daily sums from all stations (OMB – KLI and OMB – AWS) and differences of hourly sums (OMB – AWS), divided with respect to amount of precipitation. It is seen, that the agreement of precipitation sums OMB and KLI in the days with precipitation occurs makes 70% from all evaluated cases. The agreement of daily sums OMB and AWS is about 20 % of cases. The KLI sums are higher than OMB sums in 20% and lower in 5 % days with precipitation. Into the interval ± 0.5 mm belongs 94% of OMB – KLI values. The daily sums measured by AWS are higher than sums measured by KLI (60%), lower (20 %). Whereby, around 65% of difference values OMB – AWS are in interval ± 0.2 mm and the difference higher than ±1 mm is in 9 % of days with precipitation.

Figure 1: Distribution of differences between different gauge types into given intervals



The differences of hourly sums OMB – AWS in the hours with precipitation are following. With regard to fact, that data were not synchronised in time, the accordance of hourly sums higher than 0 mm is in 20% of all hours. Similarly like in the case of daily sums, there is shown that AWS hourly sums are higher than OMB sums (in 45%) and lower in 34% of hour sums. About 80% of values OMB – AWS are in the interval ± 0.2 mm. Difference OMB – AWS higher than ±1.0 mm was in 5% of hour sums.

The relative distribution of differences (OMB – AWS)/OMB, with regard to daily sum was analysed (Table II). The daily sums up to 0.5 mm were in 20%, to 1.0 mm in 35% of days.

In occurrence of low daily sums is, with regard to accuracy of measurement the high amount of cases to the relative difference 50%, the occurrence of AWS = 0, when OMB is measurable

(relative differences 100% and more). The occurrence of higher relative differences with increasing of daily precipitation is decreasing for positive and negative differences and has the same distribution characters.

The example of positive (OMB-AWS)/OMB hourly differences is in the Figure 3. The sum of differences is high, when AWS = 0 and OMB > 0, simultaneously in category of hourly sum 0.1 - 0.5 mm. In another cases, the distribution of hourly differences up to the sum < 5.0 mm is similar to daily differences (Figures 2 and 3).

Figure 2: Number of cases of relative positive differences of daily precipitation sums divided in class intervals – D [(OMB-AWS/OMB)*100] %

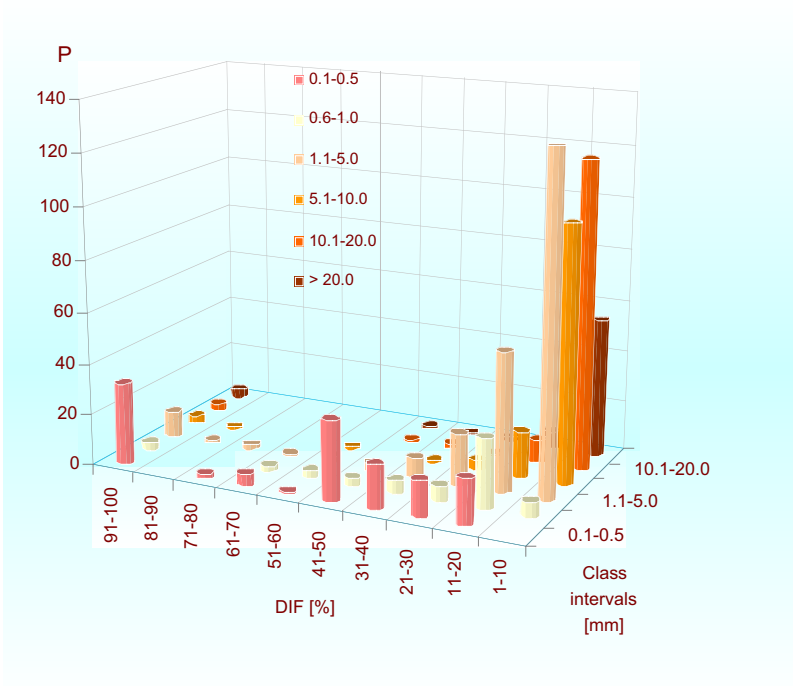
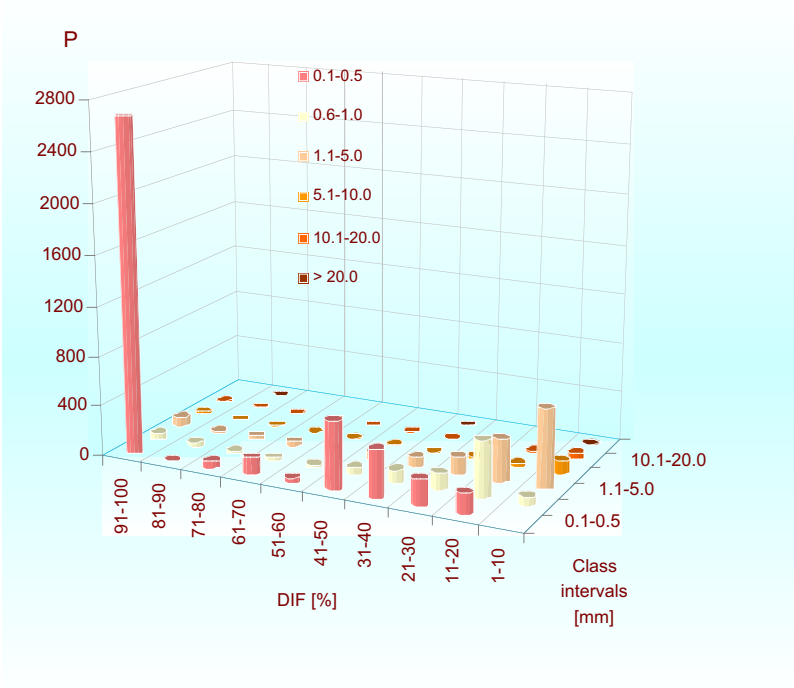


Table II: Distribution of differences in measurement of precipitation (OMB-AWS) divided into class intervals

Class intervals of 24 h precipit. [mm]	N_{eq}	1-10 %		11-20		21-30		31-40		41-50		51-60		61-70		81-90		91-100		SUM	
		+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-
0.1-0.5	299	0	0	18	28	14	36	14	35	31	53	1	5	5	5	0	0	32	45	115	207
0.6-1.0	98	6	12	27	74	6	27	6	20	3	16	3	3	2	1	0	2	3	3	56	158
1.1-5.0	204	130	417	54	212	20	58	20	18	3	3	3	1	1	1	1	0	10	2	242	712
5.1-10.0	51	99	291	18	54	4	5	4	0	0	1	1	0	0	0	1	2	3	0	130	353
10.1-20.0	22	119	262	9	20	1	1	1	1	1	0	0	0	0	0	0	0	3	0	134	284
> 20.0	14	54	84	7	7	2	1	2	0	1	0	0	0	0	0	0	0	4	0	70	92
SUM	688	408	1066	133	395	47	128	47	74	39	73	7	9	8	8	3	4	55	50	747	1807

*Figure 3: Number of cases of relative positive differences of hourly precipitation sums divided in class intervals – H [(OMB-AWS/OMB)*100] %*



3.2. The comparison methods and results in special precipitation measurements in Liesek

The Table III shows the cumulative sums of precipitation measured by each type of rain gauge over whole period at station Liesek. The smaller sums of precipitation which are recorded by automatic recording gauges are evoked not only by the real difference between the gauges, but big losses evokes current failure and therefore the measurement or connection failures that often occurred in heavy rains or thunderstorms. The great part of events must be excluded from data processing with tipping-bucket rain gauge. Only the convention gauges are measured through the whole period. The number of the usable days (N.U.D.) is the count of all days over the whole period which they are usable for our intercomparison. In fact, it shows the reliability of the different types of rain gauges. The highest reliability from all registration gauges has the weighing gauge (6 lost days) and the lowest the tipping-bucket gauge (13 lost days). The weighing gauges are not in operational use and the data are collected by GSM communication once in week or decade. Because of the problems by transferring the data from this type of gauge, some days lost of data since the memory of data logger is limited. The absolute and relative differences of precipitation totals DIF are calculated only from these days when measurements are available from both gauges respectively. It means that the total amount of precipitation to the reference Hellmann pit gauge is various with regard the compared gauge.

According to the precipitation totals compared to the pit gauge the difference of elevated gauges shows the effect of systematic errors of wind flow and therefore induced losses.

Significant is the loss of precipitation total measured by weighing pit gauge (6.5%). It can be caused by not enough representative exposure due to shadow of building and bushes. Up to 3-5% per cent of the loss however can be due to other systematic errors e.g. wetting loss. Ratio of this type of systematic loss will be explored in other study. In DIF comparison of between the elevated gauges, the difference of Hellmann and Metra 886 gauge is similar and not exceeds 4%. The separate inter comparison of the amounts of those gauges insignificant difference of 0.4% (of the Hellmann total). The major part of the small daily differences is caused by systematic and random errors in by human observing. Generally larger differences have the registration gauges. The DIF varied between 7.8% by tipping-bucket gauge and 9.2% by Pluviograph Metra. The signification of the difference is due to the known errors of the recording gauges – the wetting losses, evaporation losses, loss during the siphoning or tipping period.

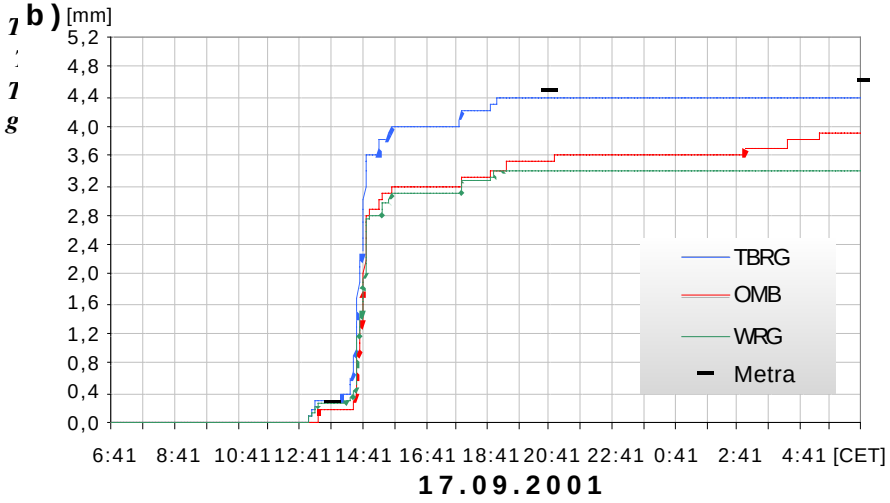
In the Table IV only the elevated rain gauges to one another are compared. Into the table only those days have been selected in which precipitation sums are available from all compared types of rain gauges. As reference gauge was selected our national standard gauge Metra 886. Compared were together 139 daily sums. The number of days with measurable precipitation (0.1 mm and more) fluctuate in range from 115 (Pluviograph) to 133 (Metra 886). As it was showed in the Table I the differences between differ conventional rain gauges are small and don't exceed 0.5%. The Hellmann gauge measured a little more precipitation than the Metra 886 gauge over the whole period. All other compared gauges measured less precipitation than manually measured conventional gauges. The difference is from about 3.2% in the tipping-bucket to about 5.0% of the weighing recording gauge.

The daily statistics show that the average difference is not larger than 0.3 mm. The largest DIF-s occurred during heavy rains, when the daily amounts exceed 15 mm. Nevertheless from data processing, there is no clear relation between the DIF and quantity of precipitation. The standard deviations vary between 0.3 and 0.4 mm. The percentage relative distribution of positive and negative DIF shows as a good advisable characteristic. It seems, that the DIF between two conventional gauges are due to random error in measurement whereas the registration gauges measure in more than one half to almost three quarter cases less precipitation than conventional gauges.

In next part we deal with details of arisen rainfall totals of registration gauges, but we have detected no unambiguous dependence. Primarily it was necessary to synchronise the series in time before the data processing. It is quite sophisticated work and never two or more time series (bring off) can be synchronised absolutely ideally. The smaller time interval is inputted, the more important the time synchronisation is. The time synchronisation is considerable not only when is raining by turn of our investigated intervals but especially when we want to explore source of big differences in rain amounts measured by several gauges. In case of light rain or drizzle or beginning of rain the resolution of the gauge plays important role. It is enough if some rain drops fall to one gauge sooner as to another and this gauge can register the first event (record) some minutes earlier than other one. The best synchronisation can be reached by comparison of maxima and minima (the peaks) or by short time heavy rains (from cumulus clouds). When we had the time series optimally synchronised it was possible to try to explain the reasons of big differences of the precipitation totals.

In the Figure 4a) one may see the big difference between pluviograph OMB (the red line) and the rest types of recording gauges in period from morning to about 1 p.m. local time. The big difference is due to fault of float rain gauge (red line).

Figure 4: The typical examples of intercomparison of cumulative sums of precipitation measured by three types of registration gauges at station Liesek, Slovakia



national s tandard conventional rain gauge Metra 886.

ph Metra, WRG – weighing recording gauge, Metra – national standard conventional

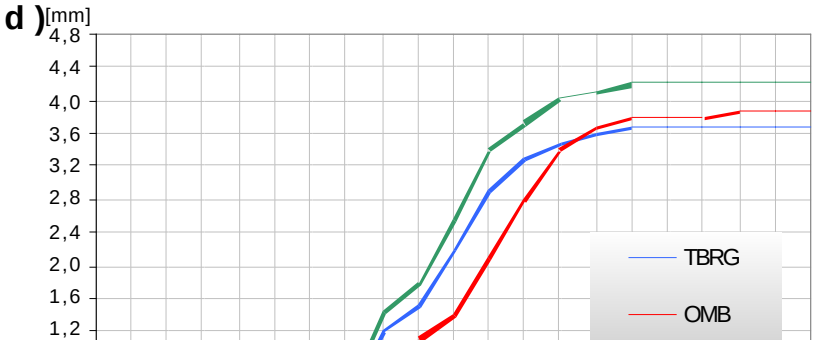


Table III: The cumulative sums (SUM) of precipitation measured by 7 types of conventional and recording gauges and absolute and relative differences (DIF) in relation to the totals measured by Hellmann pit gauge at station Liesek, Slovakia over the period from June 2001 to September 2001 and May 2002 to September 2002

N.U.D. – number of usable days for data evaluation, N.D.P. [0.1 mm] – number of days with precipitation of 0.1 mm and more.
HE0 – Hellmann pit gauge, HE1 – Hellmann elevated gauge, METRA – national standard conventional gauge, TBRG – tipping-bucket recording gauge, OMB – national pen-writing float recording gauge, WRG0 – weighing recording pit gauge, WRG1 – weighing recording elevated gauge.

	Type of rain gaug	N.U.D.	N.D.P. [0.1 mm	SUM [mm]	DIF [mm]	DIF [%]
1	HE0	258	153	1087.5	0	0
2	HE1	258	152	1050.1	37.4	3.44
3	METRA	258	157	1046.2	41.3	3.80
4	TBRG	245	136	829.1	70.2	7.81
5	OMB	248	126	850.4	85.6	9.15
6	WRG0	252	142	934.1	64.7	6.48
7	WRG1	252	137	911.9	86.9	8.70

Table IV: The evaluation of daily statistics of precipitation measurement by 5 types of elevated rain gauges at station Liesek, Slovakia over the period from June 2001 to September 2001 and May 2002 to September 2002

SUM – total of precipitation measured over the whole period, DIF absolute and relative difference of total precipitation in relation to the Metra 886 gauge, N.D.P. [0.1 mm] – number of days with precipitation of 0.1 mm and more, 0 [%] – relative ratio of occurrence when daily DIF = 0, P [%] – relative ratio of occurrence when daily DIF > 0, N [%] – relative ratio of occurrence when daily DIF < 0.
METRA – national standard gauge (here as reference gauge), HELL – elevated Hellmann gauge, TBRG – tipping-bucket recording gauge, OMB – pen-writing float recording gauge, WRG – elevated weighing recording gauge.

						DAILY DIF							
	Type of rain gauge	SUM [mm]	DIF [mm]	DIF [%]	N.D.P. [0.1 mm]	MEAN [mm]	MAX [mm]	MIN [mm]	STDEV [mm]	SKEW	0 [%]	P [%]	N]%]
1	METRA	705.5			133								
2	HELL	709.1	-3.6	-0.5	129	0.0	1.0	-1.5	0.3	-1.3	44	28	28
3	OMB	672.5	33.0	4.7	115	0.2	2.4	-0.8	0.4	2.2	20	69	11
4	TBRG	682.8	22.7	3.2	124	0.2	2.6	-0.5	0.4	3.5	30	51	19
5	WRG	670.5	35.0	5.0	120	0.3	1.7	-0.3	0.4	1.8	20	71	9

In this cases it probably concerns the jamming of the gearing or writing mechanism. Whereas from the graph 4b) it can be seen that the tipping-bucket gauge (TBRG) counted about 25% more precipitation than other gauges. Interesting is that this sum is the best approached to the sum of reference conventional rain gauge Metra. We do not explain why the float and weighing mechanism failed. On this figure is possible to see the registration of very slight rain or drizzling by float gauge in the morning hours. Vice versa it was not registered by weighing or tipping-bucket gauge. Such cases occurred many times.

The Figures 4c) and 4d) show events of occurrence of short rains with big intensities accompanied by hail. In these events reaction to register of rain should be delayed through the melting of hails resulting from principle of measurement of tipping and float gauges. You can see it partly in the Fig. 4c) where in addition on big intensity of rain was coming to loss of precipitation by each tipping. The hails must be melting so far that the strong delaying in minute sums can be visible. However this physics is clearly not confirmed by the event of the hail-fall you can see in the Fig. 4d). Though the time series were synchronised with the best correlation, for extremely big intensities (up to 1 $mm.min^{-1}$) are very important some seconds. From particular one-minute sums of precipitation is explicit (Fig. 4d) that pluviograph Metra (signed as OMB) would be preferably synchronised to smaller time units what was not possible by one minute data of course. This means when we want to compare the minute data it must be synchronised in seconds.

4. CONCLUSIONS

The comparison of daily and hourly precipitation totals shows the common properties of individual types of recording precipitation gauges. One of them is a tendency to underestimate the sums by the AWS instruments in the comparison to pluviographs.

The gained results are very important for users of precipitation data sets. Hourly and short-term data are asked by many customers, namely hydrologists. Its regular evaluations are the goal of our effort.

The cognition from our analysis gives new signals to quality control procedures in databases or rain intensities evaluation gained from the different sources of precipitation measurements.

A longer parallel precipitation measurement would precise conclusions outlined in this contribution.

5. REFERENCES

PLUVIO : The description manual, OTT Messtechnik, Kempten, 1990

Samaj, F., Lapin, M.: Results from the study of methodics for measuring precipitation and systematic errors of raingauges in Czechoslovakia. In: B. Sevruk (ed.). WMO/CIMO Instruments and Observing Methods Rep., No. 24, WMO/TD-No. 104, 179-186, 1985,288 pp., Geneva.

Stastny, P., Tekusova, M., Bjel., D.: Comparison of precipitation totals measured by AWS and conventional gauge in the warm half-year, 2 nd ICEAWS, 27-29.Sept.1999,Viena,Austria, p.21

WMO/CIMO: Correction of precipitation measurements, Instruments and Observing Methods Rep., No. 24, WMO/TD-No. 104, 1985, Geneva.

WMO/CIMO : Guide to Meteorological Instruments and Methods of Observation, 6th edition, WMO-No.8, 1996.

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