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Meteorological monitoring and climatological trends in Italian forest ecosystems

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ABSTRACT

In the framework of long term ecological research on Italian forests, this paper describes meteorological monitoring in Italy, analysing meteorological trends in the CONECOFOR areas, paying particular attention to temperature, solar radiation, precipitation and windiness. The correlation between geomorphologic and climatic conditions is also examined and the areas characterised climatically through the Thornthwaite model. The analysis is based on measurements performed for the last five years at Open Field and In the Plot stations. This study may help to understand the effects of a microclimate, taking into account its possible impact on crown condition and forest growth.

Key words: microclimate, meteorological trend, Thornthwaite classification

1. INTRODUCTION

The climate of a small area within a territory results from the interaction of a mixture of causes, such as astronomical and geomorphological conditions, which determine the air and soil temperature, air humidity and windiness.

A study of the possible natural causes of forest damage requires accurate data on the climatology of the sites of interest. Such data are necessary to calculate, for example, the environmental stress factors that depend especially on temperatures, high radiation and availability of water.

The meteorological sampling was not included in the EU/ICP Forest Level I Monitoring Programme (EC-UN/ECE 1997). All the meteorological information was obtained by the interpolation of parameters measured on sites near the area under consideration. However, there are often wide differences between measured and estimated data, especially on a day to day basis. This may be due either to inaccurate interpolations or because the considered sites do not have the same geographical configurations as the plots which are actually of interest. Due to these limitations, forest climate monitoring has been included in the Level II intensive monitoring network since 1996.

The Experimental Institute for Plant Nutrition is responsible for the climate survey, and co-ordinates analysis, data collection and evaluation at national level. Plot management and field work are organised by the National Forest service or Regional Administrations.

The main difficulty in climate classification is the identification of suitable factors to characterise different climatic types. Any "single climate" is actually a synthesis of all the climatic elements in a unique combination. Of all the climatic elements, temperature and precipitation are the most important and the most used in defining climatic types, although all the elements are significant in describing a climate. Furthermore, the limited extent of the areas and the insufficient experimental data available can make classification difficult. In this study we attempted a first classification of the areas of interest by applying the Thornthwaite model, which uses some indexes to identify climates.

Among ecological factors, the microclimate generally plays an important role. Ecological processes (evapotranspiration, photosynthesis, etc.) are often related to meteorological conditions, which can limit the life cycle of forest trees. Plants growing in natural environments may encounter various stresses, for example from high radiation, water, or high and low temperatures, during their growth and development. These stresses reduce plant growth and cause a series of morphological and biochemical alterations together with a reduction in the efficiency of key processes including protein synthesis, photosynthesis, respiration, etc. The relationship between plant growth and climate can be expressed by several empirical indices, such as those related to temperature stress (Klap *et al*. 1997; Calleart *et al*. 1997) and drought stress. Results of research on environmental stresses have been reported and discussed in detail in a previous paper (Amoriello & Costantini 2002).

The aim of this work is to describe the meteorological trends and climatic characterisation of forest areas over the past five years, using heliothermic diagrams, windiness analysis and the Thornthwaite climatic classification. Some concluding remarks on future activities close the paper.

2. MATERIAL AND METHODS

2.1. Technical equipment and software procedures

In many cases the measurements are carried out at two stations, one In the Plot (IP, under the canopy) and

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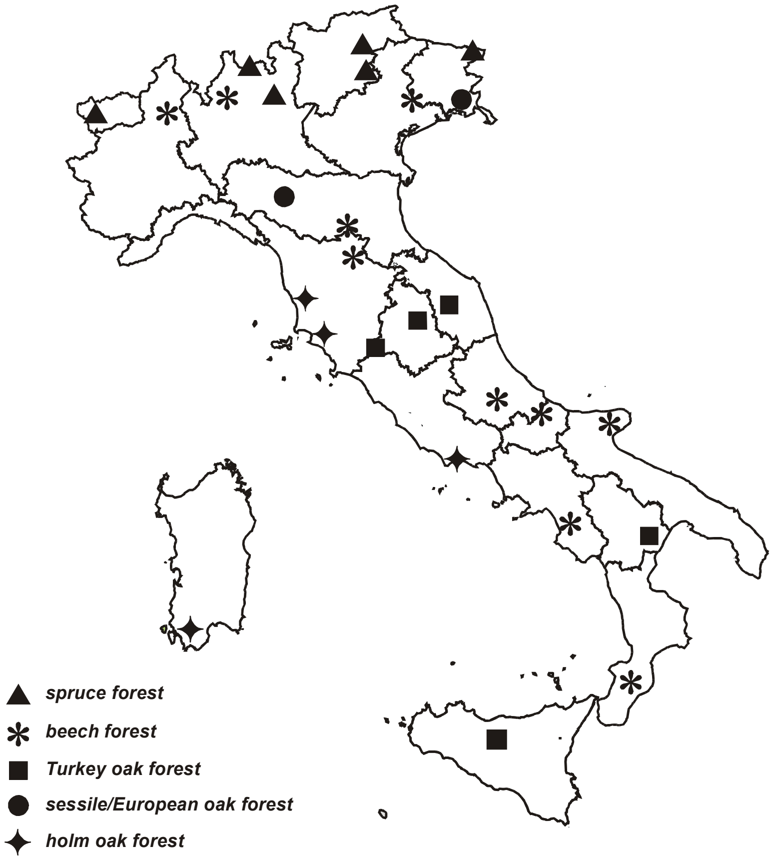

Fig. 1. Geographical location of the permanent plots of the Italian Network CONECOFOR The meteorological network consists of 13 areas, with 12 Open Field and 10 In the Plot stations.

one Open Field (OF), in close proximity (generally no more than 2 km) from the monitoring plot. This procedure is designed to record the specific conditions of woodlands and avoid errors due to wide spatial variability of meteorological data, especially as regards precipitation amounts. The technical equipment, the sensor and how they are placed are in accordance with the World Meteorological Organisation Standards (W.M.O. 1969).

Figure 1 shows the Italian meteorological network, which consists of 13 areas, with 12 Open Field and 10 In the Plot stations; table 1 gives the measured parameters for each station.

Precipitation measurements are carried out within 3 m from ground level, generally at 2 m. Air temperature and relative humidity are measured at 2 m (mandatory parameters), 10 m and 0.1 m (optional parameters); solar radiation at 2 m; soil temperature at a depth of 0.2 m; wind speed and wind direction at 10 m; snow depth at 5 m. The optional parameters are measured because they may offer extra meteorological information, useful for additional evaluations (Amoriello *et al*. 1999).

Data are recorded by means of a CR10 Campbell Data-Logger, which is installed in a locker to protect the electronics from high humidity. Functionality is guaranteed even at extremely low temperatures. Solar or wind generators are used as power supply.

Once a week, the data are collected from the field and loaded into a database, in daily and hourly values (sum or average/mean, min and max). The database also contains all relevant supporting information on the measurements, and background information on the geographical characteristics of the areas and on the technical characteristics of the sensors.

After loading each batch of data, we run an application that retrieves the measurements of the week, checks if data are within plausible ranges, and displays a graph of the data for selected sensors. This allows us to quickly spot possible problems with the newly acquired data. If an anomalous value occurs, the operator can modify or reject the input. However, it may be better to accept all the data and weed them out later, when more is known about sensor functionality or meteorological trends. Comparisons among related parameters can help in discerning between technical problems or extraordinary weather events. Quality and completeness of the data are controlled by cross-checking all parameters and historical series analysis.

An important element of quality assurance is provided by local foresters, who point out possible prob-

Tab. 1. AT= air temperature, ST= soil temperature, RH= relative humidity, PR= precipitation, SR= solar radiation, WS= wind speed, WD= wind direction, SD= snow depth.

Area		measured parameters							
		AT	ST	RH	PR	SR	WS	WD	SD
01-ABR1	OF	x	x	x	x	x	x	x	x
	IP	x	x	x	x				x
03-CAL1	OF	x	x	x	x	x	x	x	x
	IP	x	x	x	x				x
05-EMI1 OF	OF	x	x	x	x	x	x	x	x
	IP	x	x	x	x				x
06-EMI2	OF	x	x	x	x	x	x	x	x
	IP	x	x	x	x				x
08-FRI2	OF	x	x	x	x	x	x	x	x
	IP	x	x	x	x				x
09-LAZ1	OF	x	x	x	x	x	x	x	x
	IP	x	x	x	x				x
10-LOM1	OF	x		x	x	x	x	x	
12-PIE1	OF	x	x	x	x	x	x	x	x
	IP	x	x	x	x				x
16-TOS1	OF	x		x	x	x	x		
17-TRE1	OF	x		x	x	x			
	IP	x	x	x	x				x
19-VAL1	OF	x	x	x	x	x	x	x	
20-VEN1	IP	x	x	x	x				x
27-BOL1	OF	x		x	x	x		x	x
	IP	x	x						

lems. The foresters are trained to perform simple maintenance and make weekly technical checks of the performance of the stations. A technical manager visits each station about every six months, optimising the calibration of all the sensors.

2.2. Heliothermic diagrams

Heliothermic diagrams have been used to emphasise the correlations between microclimate temperature trends and solar radiation. These diagrams represent the phase displacement of air temperature in comparison with radiation, and therefore show the thermic inertia typical of the environment. A heliothermic diagram displays the value of air temperature as a function of solar radiation, where the data are averaged over one month's observations.

2.3. Windiness analysis

Windiness classification (Seemann *et al.* 1979), based on the average wind speed values at 10 m and 2 m, is expressed with the Beaufort scale; wind direction distributions on 8 sectors (N, NE, E, SE, S, SO, O, NO) have been analysed at 10 m only.

2.4. Climatic classification

The Thornthwaite model (Thornthwaite 1948) was used for climatic classification. This model is based on precipitation and the concept of potential evapotranspiration, i.e. the amount of moisture that would evaporate from the soil and transpire from vegetation, if it were available.

The global humidity index (IG), the annual potential evapotranspiration (EV), the summer aridity index (IA) and the summer EV percentage (RS= summer/annual evapotranspiration in %) were calculated for each area.

Once defined, these indexes for each area are associated to letters that symbolize the different climatic characterizations: one letter (A, B, C, D, E) is assigned to the global humidity index, describing the climate type from humid to arid; one (r, d, s, w) to aridity (for damp climates) or humidity (for arid climates) indexes, for a sub-classification based respectively on water shortage or water excess; one (A', B', C', D', E') to the annual evapotranspiration, to distinguish types of climate from megathermal to frost; and finally, a letter (a', b', c', d') is assigned to a sub-classification based on summer EV percentage. The various climates are represented by combinations of these letters in a given order .

3. RESULTS AND DISCUSSION

3.1. Heliothermic diagrams

The heliothermic diagrams referring to the 10 Open Field stations are given in figure 2. The areas differ in shape, dimension (especially in the abscissas) and position. Particularly important are the differences in the slope of the curves and in the course of the hysteresis values (between the temperatures during July-December and January-June measured under equal solar radiation).

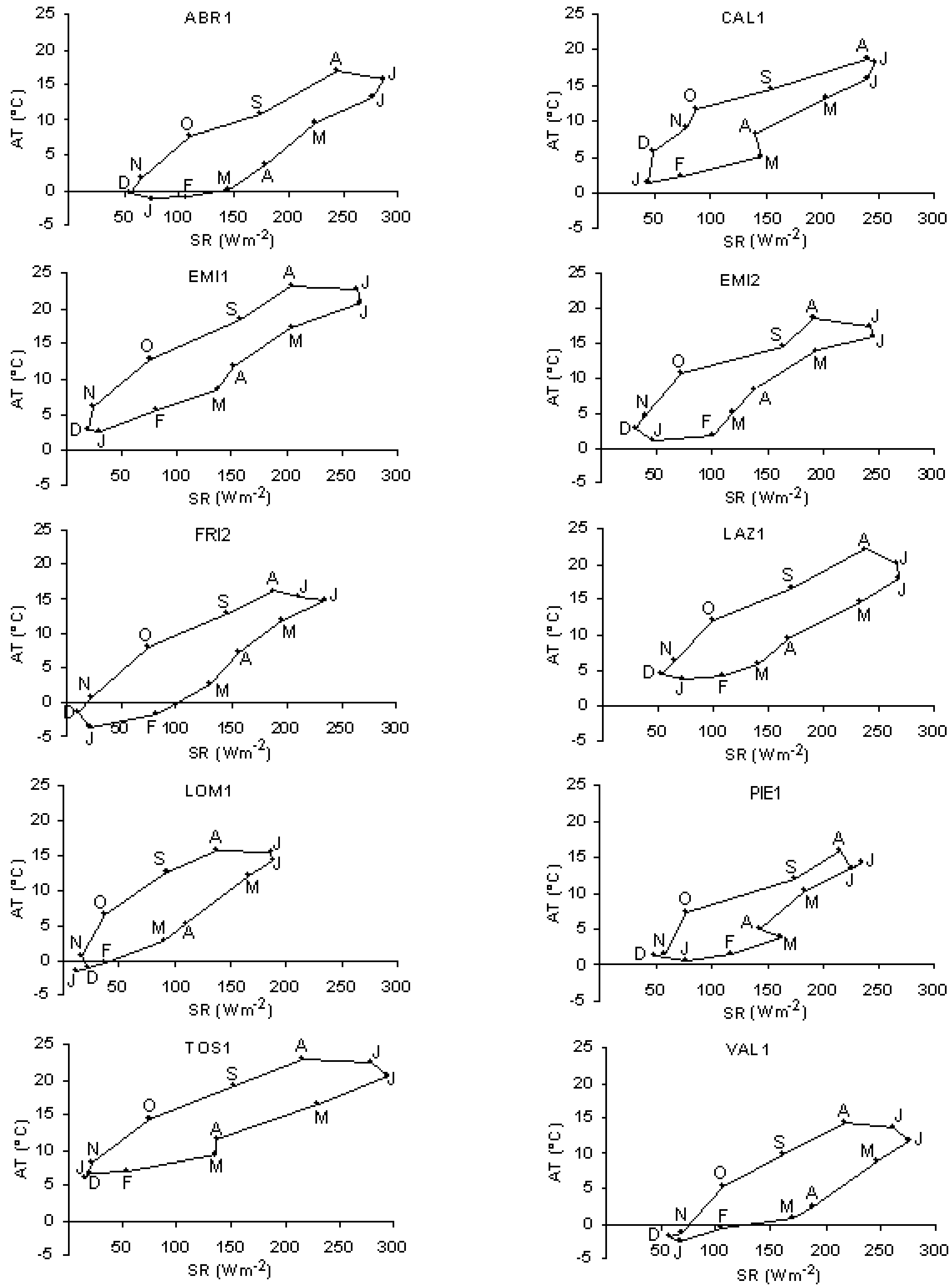

Fig. 2. Heliothermic diagrams referring to the 10 Open Field stations.

Tab. 2. Mean and max wind speed values at 10 m and 2 m for the 10 Open Field stations.

Area	WS at 10 m (m s^{-1})				WS at 2 m (m s^{-1})		
	mean	max	calm (%)	definition	mean	max	definition
01-ABR1	4.7	37.8	6	Gentle breeze	3.8	32.6	Gentle breeze
03-CAL1	1.7	16.7	8	Light breeze	1.0	10.4	Light air
05-EMI1	1.3	14.4	10	Light air	1.0	12.0	Light air
06-EMI2	1.9	29.1	5	Light breeze	0.6	22.1	Light air
08-FRI2	1.1	14.1	17	Light air	0.8	11.1	Light air
09-LAZ1	1.8	16.2	6	Light breeze	1.3	12.6	Light air
10-LOM1	-	-	-	-	0.5	33.6	Light air
12-PIE1	1.4	21.6	12	Light breeze	1.3	17.8	Light air
16-TOS1	-	-	-	-	0.8	-	Light air
19-VAL1	4.7	23.6	-	Gentle breeze	-	-	-

The extreme values (June-July and December-January) of solar radiation and temperature are correlated to latitude and altitude respectively, if topographical exposure is also considered. Sometimes these values have shifting that cannot be analytically justified on account of other factors, such as cloudiness for the solar radiation, distance from the sea or water bodies, the slope of the ground, and windiness (intensity and direction) for the temperature.

3.2. Windiness analysis

The anemometric data show that, although the effects of wind are moderate for most areas, some areas are particularly sensitive to wind action.

The classification according to the Beaufort scale for the 10 Open Field stations is given in table 2. Average wind speed values are fairly low; the highest values, both at 10 m and 2 m, were 4.7 and 3.8 ms^{-1} respectively, measured at ABR1 OF: winds of this speed are considered as breezes.

However, the maximum speeds measured have to be looked at to understand if windiness could have caused damage. Areas ABR1, EMI2, VAL1 and PIE1 were undoubtedly at risk of damage: wind intensity often reached high values (37.8, 29.1, 23.6 and 21.6 m s^{-1} respectively). During the year 2000, at ABR1, the wind seriously damaged the instrumentation, so it can argued that the vegetation also suffered ill-effects.

The effects of windiness on vegetation are due both to the speed of the wind and the duration of the event, even at limited speed. When the speed increases beyond certain limits, there is visible mechanical damage, with parts of plants (e.g. branches) being broken and leaves damaged or separated, etc. Even if windiness (i.e. duration of the wind in a period) of values around those indicated as "breeze" in the Beaufort description does not cause obvious damage, it can still determine a series of negative effects at metabolic, physiological, and photosynthetic level.

The effects of wind also depend on its direction: for example, the Sirocco increases the risk of summer fires. Figure 3 shows the wind direction distribution for the 7 Open Field stations. This distribution depends especially on the topographical configuration of the areas, so that the distribution of previous years was similar to that of the year 2000, with differences of only a few percent, both for stays on sectors and calm.

Windiness was recorded as high at ABR1 in sector S (due to its particular topographical exposure: the area is completely open to the south), low in the NE, SW and N sectors, and practically negligible in the other sectors (i.e. in directions parallel to the Apennine chain). CAL1 windiness was recorded especially in the N-NW sectors and was absent in the other sectors, as the area is protected by the Aspromonte chain. EMI1 is characterized by moderate windiness in the W-SW sectors, while this was absent in the N-S direction, as it is protected by the woods. EMI2 has moderate windiness in the SE, S and NW sectors: in fact, there is a lake in the NW and there are no obstacles in the S. The distribution of windiness in FRI2 and LAZ1 is fairly uniform, but with some attenuation in the W-NW-N sectors, which are characterised respectively by presence of vegetation and mountains. PIE1 windiness is concentrated in the N and S sectors and is absent in other directions, as the area is protected by the Alpine chain.

3.3. Climatic classification

Table 3 shows the Thornthwaite climate classification for 11 areas. The letter A, referring to the global humidity index, indicates rain forest for all areas.

The letters B' and C', which refer to the annual evapotranspiration, indicate respectively mesothermal and microthermal climates. Six areas (ABR1, FRI2, PIE1, TRE1, VAL1, VEN1) emerged as having microthermal climates. In areas with microthermal climates, there is a prevalence of more or less extended cold periods; the average temperature of the hottest month is more than 10 °C, while that of the coldest month is lower than 2 °C. Precipitation occurs especially in summer and is generally not very plentiful (300-1000 mm y^{-1}); in FRI2, VEN1 and PIE1 this range

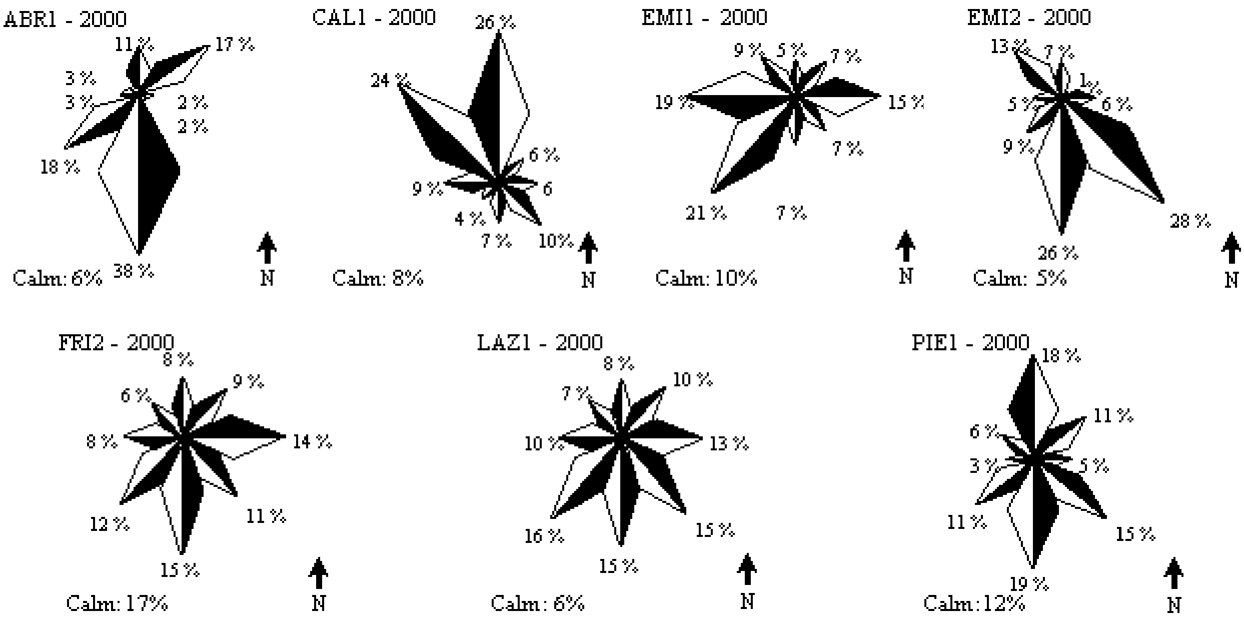

Fig. 3. Wind direction distribution referring to 7 Open Field stations.

Tab. 3. Precipitation and Thornthwaite climate classification for 11 areas. *Data available for one year. PR Range = max and min precipitation values, I_G = global humidity index, I_A = summer aridity index, EV = annual potential evapotranspiration, R_S = summer/annual evapotranspiration.

Area	Range PR (mm)	I_G (mm)	I_A (mm)	EV (mm)	R_S (%)	Classification	Description
ABR1	745 - 909	2683	74.1	523	58.7	$AC'_2s_2b'_2$	Microthermal
CAL1	1692*	10300	76.9	632	49.0	$AB'_1s_2b'_4$	Mesothermal
EMI1	613 - 918	2451	63.6	752	53.8	$AB'_2s_2b'_3$	Mesothermal
EMI2	1044 - 1262	8244	41.1	684	51.2	$AB'_1s_2b'_4$	Mesothermal
FRI2	1371 - 1667	13580	17.0	569	54.4	$AC'_2rb'_3$	Microthermal
LAZ1	782 - 1024	2763	63.1	696	52.6	$AB'_1s_2b'_3$	Mesothermal
PIE1	2466*	5942	0.0	560	52.8	$AC'_2rb'_3$	Microthermal
TOS1	615 - 1087	1500	75.2	747	50.8	$AB'_2s_2b'_4$	Mesothermal
TRE1	627*	341	16.0	437	60.4	$AC'_2s_2b'_2$	Microthermal
VAL1	649 - 1051	4614	38.3	493	58.3	$AC'_2s_2b'_2$	Microthermal
VEN1	2005*	7442	8.1	529	53.9	$AC'_2rb'_3$	Microthermal

was exceeded, with values of up to 2500 mm y^{-1} in PIE1.

Five areas (CAL1, EMI1, EMI2, LAZ1, TOS1) emerged as having a mesothermal climate. This is a moderate climate, with limited precipitation and not too severe winters. The average temperature of the coldest month is between 2 °C and 15 °C. The quantity of precipitation varies from zone to zone, and is generally between 700 and 1500 mm y^{-1}. There is very little snow, generally confined to the mountains.

The letters r and s refer to aridity in damp climates (such as rain forest): r means adequate rainfall in all seasons (FRI2, PIE1 and VEN1) and s means low rainfall in summer (ABR1, CAL1, EMI1, EMI2, LAZ1, TOS1, TRE1 and VAL1).

The letters b'_2, b'_3, b'_4 indicate, for all areas, a summer evapotranspiration which amounts to between 48% and 61.6% of the annual evapotranspiration. The lower values refer to CAL1, EMI2 and TOS1, the higher to ABR1, TRE1 and VAL1.

4. CONCLUSIONS

The climatic characterisation of all the areas cannot be considered definitive, because further years of meteorological monitoring will be required, especially for the areas (CAL1, PIE1, TRE1 and VEN1) for which we have data for only one complete year. However, the results obtained could be of use in the research conducted under the National Program for Forest Ecosystem Control, for an understanding of the influence of microclimate in other surveys.

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