An astroclimatological study of candidate sites to host an imaging atmospheric Cherenkov telescope in Romania

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ABSTRACT
This paper presents an astroclimatological study of meteorological data on relative humidity, dew-point temperature, air temperature, wind speed and barometric air pressure recorded at four Romanian locations (Baisoara, Rosia Montana, Semenic, Ceahlau) and the Nordic Optical Telescope (NOT) located at the Observatorio del Roque de Los Muchachos (ORM), on the island of La Palma, Canary Islands, Spain.

Long-term trends of microclimates are compared in order to identify site-to-site variations. We performed this analysis as part of a site testing campaign aimed at finding the best location for the establishment of a small Cherenkov telescope in Romania. The conditions at the Romanian sites are compared with those of the Canary Islands considered as a reference.

A statistical approach is used for data analysis. Monthly and annual samples are extracted from series of raw data for night-time, day-time and entire-day intervals. For each of these samples, the median values, the standard deviations and the percentages of time when the weather conditions were suitable for the safe operation of a Cherenkov telescope are computed. The distributions of these medians, standard deviations and percentages are analysed in this paper.

Significant differences are found between the Romanian sites and the NOT site. The comparison of the Romanian locations indicates Baisoara to be the best site for the establishment of the telescope, closely followed by Rosia Montana. As these two sites are both located in the Apuseni Mountains, we consider this area to be the optimal place for performing astronomical observations in Romania.

Key words: site testing – telescopes – Earth.

1 INTRODUCTION
Very high-energy (VHE) gamma-rays (100 GeV < E < 100 TeV) of cosmic origin are best detected by ground-based imaging atmospheric Cherenkov telescopes (IACTs) (Buckley et al. 2008), MAGIC (Baixeras et al. 2003), VERITAS (Weekes et al. 2002), HESS (Hinton et al. 2004) and CANGAROO-III (Kubo et al. 2004), the most important IACT facilities currently in operation, have reported scientific results that have had a huge impact on astrophysics, cosmology and particle physics. The future Cherenkov Telescope Array (CTA) (Hofmann et al. 2010), with its next-generation, highly automated IACTs, will herald a new era of outstanding precision for gamma-ray astrophysics.

All major IACT experiments perform observations at their sensitivity limit or in multi-wavelength campaigns for most of their operation time. If monitoring observations take place, the amount of time assigned is, by a considerable margin, not sufficient. Under these circumstances, and considering the importance of the observational data, a global network of several small Cherenkov telescopes has been proposed, to be operated in a coordinated way for the long-term monitoring of the brightest blazars – the Dedicated Worldwide AGN Research Facility (DWARF) (Bretz et al. 2009). FACT (First G-APD Cherenkov Telescope) (Backes et al. 2011), the prototype telescope of this network, has been prepared for operation at the Observatorio del Roque de Los Muchachos (ORM).

To join the international efforts to understand the physics of VHE gamma-rays, a small, ground-based, IACT of the last generation will be installed and operated in Romania as a component of the DWARF network.
A site assessment campaign has been initiated to identify the best location in which to establish the telescope. Technical, economic and social selection criteria were applied for a list of possible sites, and four candidate locations (Baisoara, Rosia Montana, Semenic, Ceahlau) were selected (Radu et al. 2010). An astroclimatological study based on a statistical data analysis of local meteorological parameters was performed for these locations, and the results are presented in this paper. The local microclimates at the Romanian candidate sites are compared with that of the Nordic Optical Telescope (NOT) operated at ORM (Djupvik & Andersen 2009).

The international scientific community has sustained great efforts over the years to find the best sites for the operation of astronomical telescopes, but this is the first time that an analysis concerned with the operation of a ground-based Cherenkov telescope has been performed in Romania.

The layout of the paper is as follows: in Section 2 we discuss the influence of atmospheric conditions on the operation of Cherenkov telescopes; in Section 3 the statistical characteristics of the data used for analysis are presented; in Section 4 we present the astroclimatological results of this study.

2 Influence of Atmospheric Conditions on the Operation of Cherenkov Telescopes

As for most other types of astronomy, good atmospheric conditions are extremely important for studies performed on VHE gamma-rays with Cherenkov telescopes. The atmospheric conditions generally affect the quality of astronomical observations as well as the safety of the instruments and are quantitatively evaluated by meteorological parameters.

For the specific case of Cherenkov telescopes, it has been pointed out that atmospheric changes in relative humidity, air temperature and sky cloudiness as well as the influence of haze and sand storms, usually not taken into account in simulations, may lead to a systematic underestimation of the shower energy by \( \sim 15 \) per cent during data analysis (Mazin 2007).

As a function of the type of observations performed and the specific design of each telescope, the staff enforce safety-limit values for the relevant meteorological parameters beyond which the telescope can no longer be operated. The observers monitor the meteorological parameters on a continual basis in order to ensure a correct treatment of the astronomical data and the safe operation of the telescope (Cogan 2006).

In the following subsections we review the influence of the most significant meteorological parameters on the operation of Cherenkov telescopes. The influence of the clouds and the results of the sky cloudiness data analysis will be presented in a future paper.

2.1 Relative humidity and dew-point temperature

The relative humidity and the dew-point temperature affect the occurrence of moisture and water condensation on the coldest parts of the astronomical instrumentation. If the dew-point temperature is equal to the air temperature and the air cools, condensation appears. However, observing is dangerous for the instrumentation even if condensation has not actually occurred but there is a high risk that it will. This is the case if the difference between the air temperature and the dew-point temperature is smaller than a variable upper limit (1° C or 5° C, Lombardi, Zitelli & Ortolani 2009).

As a result of condensation, the light sensors and the electronic equipment become wet and can be damaged. If the condensation occurs on the optical surfaces, which include the upper surface of the telescope reflector and the interior surfaces of the light concentrators, the image of the observed astronomical object degrades. Regarding the relative humidity, a value of 90 per cent was used by the NOT collaboration, by Lombardi et al. (2007), and by Murdin (1985) as a threshold beyond which the observations should be stopped and the telescopes turned off. Mazin (2007) and Jabiri et al. (2000) also considered that a relative humidity level higher than 90 per cent means that observing is not feasible. However, 90 per cent is not an absolute rule. Limit values of 80 or 85 per cent are reported in Lombardi et al. (2009) for the Paranal Observatory (Atacama Desert, Chile).

High levels of relative humidity also result in an increase of air conductivity. This is important for the light detectors located in the camera of a Cherenkov telescope. In particular, the photomultiplier tubes (PMTs) and their voltage supplies, subjected to very high voltages during normal operation, can experience electrical discharges that cause irreversible damage to the circuits (Cogan 2006; Çelik 2008; Theiling 2009).

2.2 Wind speed

Astronomical observations are not undertaken in windy weather owing to dangers associated with the wind load on the optical reflector of the telescope, on its support structure, and on the drive subsystem (Cogan 2006). In order to ensure that none of the subsystems of the telescope are in danger, the telescope should be turned off and brought to the parking position if the wind speed exceeds an upper safety limit. This limit is telescope-dependent. A survival wind speed limit is also defined for the parking position.

The telescopes of VERITAS have positioners (devices responsible for telescope pointing) designed to operate safely at wind speeds up to 20 mph (8.9 m s\(^{-1}\)/32.2 km h\(^{-1}\)) and to survive in the parking position to wind speeds of 100 mph (44.7 m s\(^{-1}\)/161.0 km h\(^{-1}\)) (Cogan 2006; Çelik 2008). For MAGIC, it is considered that the subsystems of the telescopes are not in danger as long as the wind speed is lower than 40 km h\(^{-1}\) (11.1 m s\(^{-1}\)) (Mazin 2007).

Various other safety wind-speed limits are discussed in the literature. The telescopes in operation at ORM are closed if the wind speed exceeds 15 m s\(^{-1}\), whereas those at the site of Paranal Observatory are closed for wind speeds in excess of 18 m s\(^{-1}\) (Lombardi et al. 2009). In a meteorological study performed for the Oukaimeden site in Morocco, 15 m s\(^{-1}\) was also indicated as a typical maximum safe operating value for the wind speed (Murdin 1985; Jabiri et al. 2000).

If high-speed winds carry large amounts of dust the negative impact on the various hardware subsystems of a telescope is even worse. Moreover, dust is also a serious cause of decreasing transparency. The quantity of dust in the air depends on the altitude of the observing site, its proximity to a dust source, and the prevailing wind direction. From this point of view the Romanian sites, located in areas covered with vegetation and away from dust sources, have an advantage.

2.3 Air temperature

The air temperature fluctuations impact the instrumentation of Cherenkov telescopes and the reconstruction of shower images.

The PMT noise increases with temperature owing to increased thermionic emission, whereas the PMT gain reduces with temperature. Cogan (2006) reported a gain decrease of \( \sim 1 \) per cent/° C for these sensors. The temperature inside the camera of the telescope...
can increase as a result of the exterior temperature or because of the heat dissipated by the electronic components located inside it (for example pre-amplifiers). This is especially dangerous during the performance of maintenance operations during day-time in warm seasons. As a safety precaution, exhaust fans and temperature sensors are usually installed inside the telescope camera (Çelik 2008; Theiling 2009).

At the other extreme, temperatures below 0°C generate freezing. In order to avoid dew and snow effects, the mirror tiles of the large-area reflector of MAGIC telescopes contain heating elements (White 2007).

For Cherenkov telescopes, the main contribution to atmospheric attenuation comes from Rayleigh scattering, which depends on the chemical composition and the density of air molecules. The density of air molecules depends, in turn, on air temperature and barometric air pressure (Fruck 2011). As atmospheric attenuation is included in the shower reconstruction algorithm, air temperature and barometric air pressure fluctuations have an impact on the flux and the energy estimates of primary gamma-rays.

2.4 Barometric air pressure

Generally, an air pressure analysis is performed by the astronomical community in order to see if a certain site is dominated by high pressure, which would imply prevailing stable good weather (Lombardi et al. 2007).

As one moves from sea level to higher altitudes, air pressure decreases. The theoretically expected barometric air pressure \( P_{\text{theo}} \) at a given altitude can be calculated according to the US Standard Atmosphere model (USSA 1976) with the following formula:

\[
P_{\text{theo}} = P_0 \left[ \frac{T_h}{T_0 + L_h (h - h_0)} \right]^\frac{M_0}{R} \text{mPa},
\]

(1)

where \( g_0 = 9.80665 \text{ m s}^{-2} \) represents the sea-level value of the acceleration due to gravity, \( M_0 = 0.0289644 \text{ kg mol}^{-1} \) is the molar mass of the Earth’s air, and \( R^* = 8.31447 \text{ J K}^{-1} \text{mol}^{-1} \) is the universal gas constant. For altitudes lower than 11 km (troposphere), the subscript \( b \) is replaced by zero and all quantities refer to sea-level values. Thus the geopotential height \( h_0 = 0 \), and the standard temperature lapse rate \( L_h = -0.0065 \text{ K m}^{-1} \). If we replace all these constants in equation (1), we obtain:

\[
P_{\text{theo}} = P_0 \left( 1 - 0.0065 \frac{h}{T_0} \right)^{5.256},
\]

(2)

where \( P_0 = 1013.25 \text{ hPa} \) is the sea-level standard atmospheric pressure, and \( T_0 = 288.15 \text{ K} \) (15°C) is the sea-level standard temperature. For each investigated location, we used equation (2) to compute \( P_{\text{theo}} \). The results are included in Table 1 together with the geographical positions and the altitudes. The mean pressure value for a certain location, determined from statistical analysis, is compared with the theoretically expected air pressure \( P_{\text{theo}} \) for that altitude. The frequency with which the mean pressure is higher than \( P_{\text{theo}} \) is an indirect indication of high atmospheric stability (Jabiri et al. 2000). In contrast, variations of barometric air pressure on a short time-scale (a few hours) can induce weather instabilities that seriously impact the operation of a telescope (Lombardi et al. 2009).

Regarding the Cherenkov telescopes, the barometric air pressure fluctuations affect the atmospheric attenuation and implicitly the shower reconstruction, as discussed at the end of Subsection 2.3.

3 STATISTICAL CHARACTERISTICS OF THE DATA

For the present study we sampled data from the archive of the National Meteorological Administration (NMA) of Romania. The meteorological data were collected in the period 2000 January 1 to 2009 December 31, by the NMA weather stations operated in Baisoara, Rosia Montana, Semenic and Ceahlau. The geographical positions and the altitudes of these locations are presented in Table 1, and more details can be found in Radu et al. (2010). The weather stations were located in areas where reliable measurements and observations could be performed in accordance with the requirements of the World Meteorological Organization (WMO) (WMO Guide 2008). During the considered 10-year period (2000–2009) no station was relocated.

For comparison purposes, we have included in the present study meteorological data recorded by weather stations deployed at the NOT site. NOT is located at ORM, in the proximity of MAGIC, in a region considered a reference for very good astronomical conditions. The NOT meteorological data have kindly been made available to the public at http://www.not.iacc.es/weather/.

In order to check for regional variations and long-term trends we analysed meteorological data on relative humidity, dew-point temperature, air temperature, wind speed and barometric air pressure.

The data records are available in the NMA data base at regular intervals of one hour, similar to the case presented in Jabiri et al. (2000). As the NOT data are available at a higher frequency, we first computed hourly averages to enable a proper comparison.

Night-time (20:00–06:00), day-time (06:00–20:00) and entire-day (00:00–24:00) intervals were defined, and all the data series were considered in local time. Monthly and annual samples were extracted from these series of raw data according to the procedure described below.

For a particular meteorological parameter (e.g. relative humidity), location (e.g. Baisoara), month (e.g. January) and time interval (e.g. night-time) we extracted data from the NMA data base hour-by-hour, over the 10-year period. The relevant statistics (median, standard deviation, skewness) were computed for the obtained sample distribution. We then repeated the procedure for each of the 12 months, and the obtained statistics were used to produce a monthly distribution of medians. The procedure employed for the generation of the annual distributions of medians is similar, but instead of considering a certain month, data from a particular year (e.g. 2000) were used. For the case of NOT, we followed the same procedure, but hourly averages were computed first.

In addition to monthly and annual distributions of medians, we also derived monthly and annual distributions of percentages. This time, for a particular parameter, location, month and time interval, we computed the percentage of data records whose values exceeded certain limits (e.g. relative humidity > 90 per cent). The procedure was repeated for each month, with the 12 resulting values providing a monthly distribution of percentages. Annual distributions of percentages were obtained in a similar way.
Within the univariate analysis performed, two statistical characteristics of each sample were examined: central tendency and dispersion.

As measures of central tendency, the arithmetic mean and median are usually reported. The arithmetic mean is a useful statistic only if the investigated distribution is symmetrical (not too much skew), there are no outliers, and the analysed data are measured at interval or ratio level. The median (the middle score in a set of scores) is useful when data are not symmetrically distributed or they are measured at an ordinal level. For the meteorological parameters analysed we had to decide what the best statistic would be as a measure of central tendency. The amount of skewness was computed, for each sample, using the formula

\[ G_1 = \frac{\sqrt{n(n-1)}}{n-2} \frac{m_3}{m_3^{3/2}}, \]  

where \( m_3 = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^3 \) is the sample third central moment, \( m_2 = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2 \) is the sample variance, and \( \bar{x} \) is the sample arithmetic mean (Joanes & Gill 1998). However, the sample skewness tends to differ from the population skewness by a systematic amount that depends on the size of the sample. In order to be able to tell, from the samples that we have, if the populations are likely skewed (positively/negatively) or if they are nearly symmetrical, a test statistic is needed:

\[ Z = \frac{G_1}{SES}, \]  

where \( SES = \sqrt{\frac{6n(n-1)}{(n-2)(n+1)(n+3)}}. \)

A population is considered to be very likely skewed if \( |Z| > 2 \) (Cramer 1997). Otherwise, no conclusion can be reached about the skewness of that population. It might be symmetrical or skewed in either direction.

We computed this test statistic for all the samples used in the analysis. For most cases it turned out that the populations were very likely skewed. Therefore, we chose to use the median statistic as a measure of central tendency for all the distributions involved in our analysis. This option has no negative impact on those cases for which the test statistic given by equation (4) did not provide a clear conclusion. If the skewness is small, the difference between the median and the arithmetic mean is also small. For a symmetrical distribution, the arithmetic mean and the median are equal.

As an indicator for the dispersion of data, we used the standard deviation, defined as the square root of the sample variance \( m_2 \).

Following these considerations, the relevant statistics for all the data samples used in our analysis were the median and the standard deviation. Whenever a plot in the present paper includes error bars, the points represent the median values of the data samples for those specific months or years, while the error bars illustrate the standard deviation of the samples. As the error bars frequently overlap, we have included bottom plots of the standard deviation values in order to have a clearer image of the variability in the data.

### 4 Astroclimatological Results

#### 4.1 Relative Humidity

The relative humidity \((RH)\) has been measured at the Romanian locations to an accuracy of \(\pm 2\) per cent by sensors placed 2 m above the soil surface. At NOT, the relative humidity sensors placed 2 m above the ground provided data to accuracy better than \(\pm 2\) per cent (Lombardi et al. 2007).

In Fig. 1, we present the monthly and annual night-time distributions of medians for relative humidity at the assessed sites. The bottom plots include the values of standard deviations for each month and for each year.

The medians derived for the Romanian locations are clustered together and have values more than 40 per cent higher in comparison to NOT. The driest Romanian site is Baisoara, while Ceahlau is an extreme, unfavourable case displaying relative humidity

![Figure 1](http://example.com/figure1.png)
median values of 100 per cent throughout the year (Fig. 1, top-left and right).

A seasonal dependence can be observed for the NOT data (Fig. 1, top-left), and the lowest RH levels are recorded in July and August. A much fainter seasonal variation can be observed for Rosia Montana and for Semenic. Baisoara exhibits an almost flat trend over the year, but from January to March, increased levels of RH can be observed.

The analysis of the annual distributions of medians shows that all sites exhibit flat trends over the years, with fluctuations within the statistical errors (Fig. 1, top-right). For all the Romanian locations but Ceahlau, 2000 is the driest year from the available data.

The spread of data recorded at NOT exhibits a clear seasonal behaviour (Fig. 1, bottom-left), with minimum values observed in July and August when the RH levels also reach a minimum (Fig. 1, top-left). The spread of Romanian data shows a less visible seasonal variation, with a minimum also observed during summer.

On the other hand, both the monthly and the annual standard deviations of NOT samples exhibit systematically larger values with respect to the Romanian sites (Fig. 1, bottom-left and right). As the standard deviation measures the spread of data about their average, this result is an indication that the NOT RH data fluctuate more than the Romanian data, which are well clustered around their median values. This is not a seasonal effect, but a particular characteristic of the investigated locations (Romania vs. the Canary Islands).

In Fig. 2, we display monthly and annual night-time distributions of percentages for relative humidity data records whose values are larger than 90 per cent. Considering this value as a safety operational limit, the points in this figure indicate the percentage of time that a telescope built at the considered locations would have been unusable because of high levels of RH. The larger these percentages are, the worse the observing conditions. A seasonal variation is visible for all locations (Fig. 2, left), and the summer months appear to be best suited for observations everywhere except Ceahlau, where a small improvement can be observed only from October to December. The smallest computed values belong to NOT and confirm that its site is excellent for astronomical observations. Among the investigated Romanian locations, Baisoara offers the closest conditions to those of NOT, especially during October, November and December.

Regarding the annual night-time distributions of percentages for RH (Fig. 2, right), Baisoara shows values close to those of NOT, but an increasing trend can be observed since 2006. This raises the question whether we are in the presence of a change in the local microclimate or whether the data reflect a typical oscillating behaviour of the relative humidity over the years. More data are necessary to settle the issue.

Fig. 3 presents the monthly and the annual night-time, day-time and entire-day distributions of medians for relative humidity at Baisoara, Rosia Montana, Semenic and NOT. The median values of data recorded at Ceahlau are constantly equal to 100 per cent and not included in this figure. The night-time median values are higher than the day-time ones (Fig. 3, top and bottom), and night–day variations of ∼20 per cent can be observed especially during summer (Fig. 3, top) at the three Romanian locations. The lower levels of RH during day-time can be exploited for maintenance operations. At the NOT site, the night–day variations are very small, and sometimes the night-time median values are smaller than those of day-time data. This is especially favourable for astronomical observations.

### 4.2 Dew-point temperature

In order to evaluate the risk of condensation, we analysed the monthly and the annual night-time distributions of percentages for the differences between dew-point temperature and air temperature data records whose values are smaller than an upper limit. The larger the values of these percentages for a certain site, the higher the risk of condensation for that site. Two values were considered in our study for the upper limit: 1°C and 5°C. For the analysed meteorological data of all five locations, the cases where this difference is smaller than 1°C imply relative humidity values larger than 90 per cent. As this situation has been analysed in Subsection 4.1, we present here only the case when the upper limit is set to 5°C (Fig. 4).
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This can be regarded as an extension of the analysis performed in Subsection 4.1 for values of RH lower than 90 per cent.

The location characterized by the lowest risk of condensation is that of NOT. The statistical distribution of data taken at its site shows a clear seasonal dependence (Fig. 4, left), with a minimum reached in July and August. A seasonal dependence is also visible for Rosia Montana and Semenic, with lower values reached during summer. Baisoara exhibits the lowest risk of condensation during April and May, while high values are observed from January to March. Ceahlau is again the worst case, despite a decrease for the risk of condensation in the interval October–December.

The analysis of the annual distributions (Fig. 4, right) shows a dry climate at NOT and confirms Baisoara as the driest Romanian location. The Romanian sites exhibit an oscillating behaviour over the years, and 2000 is the least humid year.

4.3 Wind speed

At the Romanian locations, wind speed was measured by sensors placed 10 m above the soil surface, to an accuracy of ±1 m s^{-1} for wind speeds in the range 0–8 m s^{-1}, of ±2 m s^{-1} for wind speeds in the range 8–20 m s^{-1}, and of ±4 m s^{-1} for wind speeds in the range 20–40 m s^{-1}. The NOT wind sensor recorded data to an accuracy of better than 2 per cent (Lombardi et al. 2007).

In Fig. 5, we show the monthly and the annual night-time distributions of medians for wind speed at the assessed sites. A clear dependence on altitude (see also Table 1) is apparent for the median values and for the spread of data. The higher the altitude of a location, the stronger the wind speeds and the larger the variations of data. Baisoara is a favourable exception, as its site has the lowest wind speeds even though it is not located at the lowest altitude. This effect is probably a result of the local orography. The unfavourable exception is Ceahlau, which has similar wind conditions to NOT and a larger spread in data, even though it is situated at a lower altitude.

Faint seasonal variations can be observed for the distributions derived at NOT, Ceahlau and Semenic (Fig. 5, top-left), and the lowest wind speeds are measured during summer. A seasonal variation is also visible for the spread of all Romanian data (Fig. 5, bottom-left). This dependence is clearly observable at Ceahlau, but is weaker for the other Romanian locations.

The analysis of the annual distributions (Fig. 5, top-right) shows that all sites exhibit almost flat trends over the years, with fluctuations within the statistical errors.
Figure 4. The monthly (left) and the annual (right) night-time distributions of percentages for the difference between dew-point temperature and air temperature data records where values are smaller than 5°C.

Figure 5. The monthly (top-left) and the annual (top-right) night-time distributions of medians for wind speed. The bottom plots (left and right) show the values of standard deviations.

Considering 15 m s\(^{-1}\) as the wind speed limit beyond which a telescope should be turned off and brought to the parking position (Subsection 2.2), we have plotted in Fig. 6 the monthly and the annual night-time distributions of percentages for wind speed data records larger than this limit. The larger these values are for a certain site, the higher the percentages of time when a telescope operated there should be turned off because of high winds. All the Romanian locations except Ceahlau show values lower than the NOT site and almost flat trends. The distribution of Ceahlau data shows a seasonal dependence (Fig. 6, left), with the lowest values from April to September when its conditions are closer to those at NOT.

A good picture of the wind speed distributions at the analysed locations can be obtained from Table 2. Over the 10-year range, it reports the percentages of night-time wind speed data records that fall into given intervals for the period April–October. The period
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April–October was chosen as the interval with the best observing conditions at the Romanian sites, from the point of view of all meteorological parameters analysed. Astronomical observations can be performed outside this interval, but the amount of lost observational time owing to bad weather would be much larger. Baisoara has a predominance of wind speeds smaller than 3 m s\(^{-1}\) (71.5 per cent), whereas the other locations fare worse. However, this parameter exceeds 10 m s\(^{-1}\) only in 0.4 per cent of cases at Rosia Montana, and in 5.8 per cent at Semenic, so these locations also preserve good wind speed conditions.

If 15 m s\(^{-1}\) is considered as a safety operational limit, a telescope installed at Baisoara, Rosia Montana or Semenic will almost never have to be turned off because of strong winds.

If, in addition to this wind speed limit, we also consider that the relative humidity values should not exceed 90 per cent, a duty-cycle can be computed for each analysed location. We calculated this parameter only with night-time data recorded from April to October over the 10-year period; the results are presented in Table 3.

The best result for a Romanian location was obtained for Baisoara, which would offer a duty-cycle of \(\sim 79\) per cent. This value is quite close to the one obtained for the reference site of NOT (\(\sim 88\) per cent) and suggests that Baisoara would be a good potential site for the establishment of a Cherenkov telescope in Romania.

### 4.4 Air temperature

The air temperature at the Romanian locations was measured by sensors placed 2 m above the soil surface to an accuracy of better than \(\pm 0.2\) °C. The same type of measurements was performed at NOT to an accuracy of \(\pm 0.1\) °C.

In Fig. 7, we display the monthly and the annual night-time distributions of medians for air temperature. A clear seasonal variation is noticeable for all investigated sites, but the difference between winter and summer months is higher for the Romanian locations (Fig. 7, top-left). Ceahlau is characterized by the lowest air temperatures throughout the year, while the other Romanian locations exhibit similar median values. From April to October the air temperature conditions at Baisoara, Rosia Montana and Semenic are very similar to those at NOT.

A greater spread characterizes air temperature data at the Romanian locations in comparison to NOT (Fig. 7 bottom-left and right), and a clear seasonal dependence can be observed from Fig. 7 (bottom-left). Less variability in the Romanian air temperature data occurs from April to September, when its values tend to get closer to those of the NOT site.

The analysis of the annual distributions (Fig. 7, top-right) shows for all sites almost flat trends with fluctuations within the statistical errors.
Fig. 7 (top-left and right) also depicts an altitude dependence (see also Table 1) for the median values of air temperature distributions. Ceahlau, which has the highest altitude of the investigated Romanian locations, is also the coldest one. As the altitude decreases, the temperature values increase. Rosia Montana and Baisoara exhibit the highest temperatures. Even though it is located at the highest altitude, NOT is also characterized by high temperatures. This effect can be explained by the much lower latitude at which NOT is positioned in comparison to the Romanian locations (Table 1). The increase in altitude is compensated by the decrease in latitude, and the median temperatures increase.

Various technical procedures can be employed to overcome the negative effect of freezing on the proper functioning of telescopes. However, an ideal site to host a telescope would have air temperatures below 0°C only very rarely. Fig. 8 shows the monthly and the annual night-time distributions of percentages for air temperature records whose values are below 0°C. The larger these values are for a certain site, the greater the periods of time when a telescope operated there would be affected by freezing. From the analysis of
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Figure 9. The monthly (top) and the annual (bottom) night-time, day-time and entire-day distributions of medians for air temperature.

these distribution results in Romania, the best period for observations is May–September (Fig. 8, left), when data are quite similar to those at NOT and there is practically no freezing. The annual distributions (Fig. 8, right) show larger year-to-year fluctuations at the Romanian sites in comparison to NOT (except for 2000 and 2001). Baisoara and Rosia Montana experience the least freezing among the Romanian sites.

The median values of the monthly and the annual night-time, day-time, and entire-day distributions of air temperature are presented in Fig. 9. For all locations, the largest day-time to night-time variations can be observed during summer (Fig. 9, top), and larger differences can be seen at the Romanian locations compared to NOT. The annual distributions (Fig. 9, bottom) show similar levels for the day-time temperatures at Baisoara, Rosia Montana and NOT, while the night-time temperatures are lower in Romania.

4.5 Barometric air pressure

The barometric air pressure was measured at the Romanian locations 1.20 m above the soil surface to an accuracy of ±0.1 hPa. The NOT air pressure sensor was placed 2 m above the ground and provided data to an accuracy of ±0.1 hPa (Lombardi et al. 2007). Fig. 10 shows the monthly and the annual night-time distributions of medians for barometric air pressure at the studied sites. A clear inverse correlation with altitude can be observed in the top-left and the top-right sections of the figure (see also Table 1). The highest-altitude site (NOT) exhibits the lowest air pressures, whereas the highest pressures are recorded at the lowest-altitude site (Rosia Montana).

A very faint seasonal variation can be observed from Fig. 10 (top-left) at all Romanian locations, with higher median values of barometric air pressure recorded during summer. The analysis of the annual distributions (Fig. 10, top-right) shows an almost constant flat trend over the years for all locations.

The spread of data recorded at the Romanian sites shows a more pronounced seasonal dependence and is larger in comparison to NOT (Fig. 10, bottom-left). The lowest spread of data is observed during summer, when the weather conditions are more stable and the air pressure values fluctuate less. The lower spread of NOT air pressure data is an indicator of more stable weather conditions.

When the local barometric air pressure is lower than the theoretical value ($P_{\text{theo}}$) at a given altitude, the weather conditions may become unstable (Subsection 2.4). In order to compare the stability of weather conditions, we computed the percentages of local
barometric air pressure data records whose values are lower than those theoretically expected for the investigated sites. The lower these percentages are for a certain site, the better the observational conditions offered by that particular site. The results are presented in Fig. 11.

The percentage values at NOT are roughly equal to 0 per cent. Almost always, the values of the local barometric air pressure are higher than those theoretically expected. The site is dominated by high-pressure values, and remarkably stable weather conditions characterize it. The situation is different at the Romanian sites, where the values of the local barometric air pressure often fall below those theoretically expected. Fig. 11 (left) shows a very clear seasonal dependence, with the most favourable weather conditions for astronomical observations from May to October.

The analysis of the annual distributions (Fig. 11, right) shows that for all Romanian sites these percentages fluctuate extensively. Large differences can be seen for the years 2000, 2001, 2002, 2004 and 2007, while smaller ones appeared in 2003, 2005, 2006, 2008 and 2009.
5 CONCLUSIONS

A site assessment campaign has been initiated for the identification of the best location to install and operate a small, imaging atmospheric Cherenkov telescope in Romania.

The results of an astroclimatological study based on the statistical analysis of local data of relative humidity, dew-point temperature, air temperature, wind speed and barometric air pressure have been presented in this paper.

Data over a 10-year period (2000–2009) were sampled from the archive of the National Meteorological Administration (NMA) of Romania, for four candidate locations (Baisoara, Rosia Montana, Semenic, Ceahlau). Meteorological data recorded at the NOT site were used as a reference for comparison purposes.

Prior to presenting the results of the analysis, the influence of atmospheric conditions on the operation of Cherenkov telescopes was reviewed, and the statistical characteristics of the available meteorological data were studied in order to choose the relevant statistics of distributions.

The analysis of relative humidity data revealed, as expected, that the weather in Romania is more humid than at NOT. However, among the Romanian investigated sites, the microclimate of Baisoara appears to be the driest, and it offers the conditions closest to those reported for NOT. During summer, the relative humidity night-time data exhibit the least spread and are clustered around low-level central values at all investigated locations except Ceahlau.

Night-day variations of up to ~20 per cent were observed between the medians of the statistical distributions at the Romanian sites, while at NOT these variations are very small.

In order to evaluate the risk of condensation, we analysed the night-time distributions of percentages for the difference between dew-point temperature and air temperature data records whose values are smaller than 5°C. The lowest risk of condensation is found for NOT, while in Romania, Baisoara offers the best conditions.

The wind speed analysis showed that the higher the altitude of a site, the stronger the winds and the larger the spread of data. Baisoara is the exception, being characterized by the lowest winds, even though it is not located at the lowest altitude. Speeds lower than 3 m s\(^{-1}\) were measured there 71.5 per cent of the time. Wind speed conditions are generally better in Romania than at NOT, in particular because of the lower altitudes.

A duty-cycle was computed considering that a telescope should be turned off in the case of wind speeds exceeding 15 m s\(^{-1}\). From the distributions depicted in Fig. 11, Semenic appears to have the most stable weather of the Romanian investigated sites.

The analysis of the barometric air pressure data revealed that the NOT site is dominated by high-pressure values and that remarkably stable weather conditions characterize it. At the Romanian sites the weather conditions are more stable from May to October, and Semenic is designated as the location with the most stable weather. An inverse correlation between the barometric air pressure and the altitude was observed for all locations.

The results of the present study have led us to select Baisoara as the best investigated site for the establishment of a Cherenkov telescope in Romania. Good meteorological conditions were also determined at Rosia Montana, and as these two sites are both located in the Apuseni Mountains, we consider this area as the optimal place for the location of the telescope. A suitable period, within a given year, for operating a Cherenkov telescope in Romania appears to be from April to October, but taking data is not restricted to this time-frame only. Outwith this period, however, the number of usable nights is lower.

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