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# The Cherenkov Telescope Array site search campaign

TOMASZ BULIK[1], FOR THE CTA COLLABORATION.

[1] *Astronomical Observatory, The University of Warsaw, Aleje Ujazdowskie 4, 00-478 Warsaw, Poland*

*tb@astrouw.edu.pl*

**Abstract:** The Cherenkov Telescope Array (CTA) project aims at building two observatories, one in the Northern and one in the Southern hemisphere. To this end a site search campaign was launched. I will describe the current status of the campaign and present the candidate sites. The site testing relies on three sources of information: 1) weather stations equipped with all sky cameras and night sky background sensors at sites, 2) satellite data, and 3) numerical weather simulations. I will describe all related methods.

**Keywords:** icrc2013, latex, template, example.

## 1 Introduction

The Cerenkov Telescope Array (CTA) is the next generation very high energy gamma-ray telescope [1, 2]. CTA aims at improving the sensitivity by an order of magnitude with respect to the existing observatories like HESS, MAGIC, and VERITAS. It is also planned to extend the spectral coverage and increase the spatial and spectral resolutions. CTA will consist of two observatories, one in the Southern and one in the Northern hemisphere, to ensure the coverage of the entire sky. In order to find the best location for the construction of CTA a comprehensive site search campaign was conducted, followed by a thorough site characterization study.

The basic requirements for the site were defined in 2010. They were:

- A flat area of 10 $km^2$ in the South and 1$km^2$ in the North
- Site elevation between 1500 and 3800 m.a.s.l.
- The flatness must be less than 8%
- More than 70% of nights good for observations
- Winds not to exceed 36km/h for observations
- Seismic acceleration below 5 $m\,s^{-2}$
- Medical rescue available within 2 hours.

This list has been extended and specified in much more detail later. With these requirements an internal call for site proposals was launched. The proposals for the Southern sites arrived in mid 2011, and for the Northern sites in January 2012. The Southern sites included two locations in Argentina, two in Namibia and one in South Africa. The South African site bid was later withdrawn and the South African team now supports the Namibian proposal. Later in 2012 a site in Chile was added at the request of the CTA Internal Site Review. The Northern proposals included a site in Mexico, two sites in Arizona in the USA, a site on the island of Tenerife in Spain, two sites in India, and site in Tibet in China. CTA has decided to assign a second priority to the Asian sites due to the logistical difficulties. The list of sites taken into consideration is presented in Table 1. There are several contributions in this volume that describe the site search and related analysis in more detail. The Argentinian sites are described in [4], the US sites are presented by [6], and for the Spanish site see [9].

## 2 Site quality evaluation

Given the short time that is given for the CTA site decision, a special strategy had to be applied for the site characterization process. Data were gathered from three main sources:

- Instrumentation at sites: developed by CTA and locally
- Numerical weather simulations
- Satellite data

The amount of data gathered by our instruments varies from site to site and the aim is to gather at least one year of data from each site. We can can compare these data with the weather simulations and with the simultaneous satellite data. Such a comparison in principle should allow one to extend the one year measurements taken by ground based instruments to several-year baseline from simulations and from satellites. Some sites are already extensively characterized and hence serve rather for the validation of the instruments and methods.

## 3 Instrumentation

The ATMOSCOPE (Autonomous Tool for Measuring Site COnditions PrEcisely) is a sensor station designed and build at the MPI for Physics in Munich, CPPM in Marseilles, and the Physics Institute in Olomouc. The station is made to be deployed and operated in a remote candidate site, without power and Ethernet connection. The device is capable of measuring site parameters as the brightness of the night sky (Light of Night Sky (LoNS)), the cloudiness - via temperature estimated cloud altitude - and other general weather data. The measurements are managed by a small single board computer (SBC) running Linux, while the power is provided by photo-voltaic solar cells. In addition to that they have been equipped with the All Sky Cameras developed in Olomouc [3] and Sky Quality Meters (SQMs) made by Unihedron. The hardware consists of the following subsystems:

| Name | Country | Latitude | Longitude | Elevation |
|---|---|---|---|---|
| Leoncito | Argentina | 31.7S | 69.3W | 2600 |
| San Antonio de los Cobres | Argentina | 24.0S | 66.2W | 3600 |
| Armazones | Chile | 24.6S | 70.2W | 2400 |
| HESS | Namibia | 23.2S | 16.5E | 1850 |
| Aar | Namibia | 26.7S | 16.4E | 1650 |
| Tenerife | Spain | 28.3N | 16.5 W | 2200 |
| Meteor Crater | USA | 35.0N | 111.0 W | 1700 |
| Yavapai | USA | 35.1N | 112.9W | 1670 |
| San Pedro Martir | SMexico | 31.0N | 115.5W | 2500 |

**Table 1**: A list of the sites under consideration for the construction of CTA.

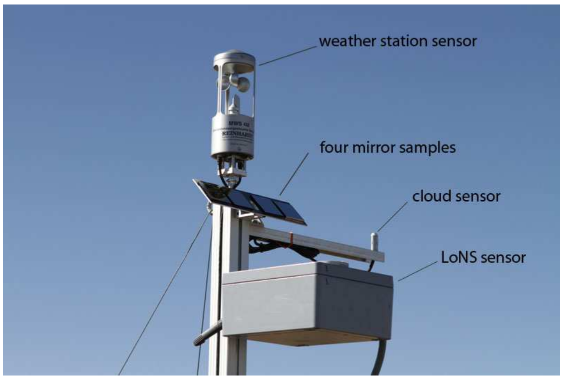


**Fig. 1**: The sensors of an ATMOSCOPE station

- SBC for control, readout and data storage,
- LoNS measuring device with a PIN-diode and a filter wheel,
- commercial weather station with radiation thermometer as cloud altitude sensor,
- solar cells, charger and battery.

The key element of the LoNS sensor is a Hamamatsu 3584 PIN-photodiode with an active area of $28 \times 28\,\mathrm{mm}^2$. The diode is put behind a 50 mm-lens of 60-mm focal length. The box also includes a filter wheel with a total of 5 positions: one closed slot for daylight protection and dark frame reference measurements, one astronomical V-band filter and one self made 'B' filter, which is a combination of the Schott BG25 and Schott BG39 filters, reproducing roughly the wavelength response of an photomultiplier. The two remaining filter slots are left empty. The diode current is amplified in three stages and digitized by an ADC with $I^2C$ interface. The temperature and humidity inside the sensor box is controlled with a digital high-precision sensor with $I^2C$ port. The analysis of the night sky background is presented in detail in [7].

For the weather station and the cloud monitor, the commercially available Reinhardt MWS M4 was chosen. The station records temperature, humidity, air pressure, wind speed and wind direction. The cloud sensor is an external module that allows to measure the sky temperature and thus estimate the cloud altitude.

The calibration of the Atmoscope was initially performed after their construction. While at sites the calibration of the LONS is regularly performed with a standard light source for several light levels. The devices to do the calibration have been designed at build at CPPM in Marseilles.

All Atmoscope stations are connected to the internet. At the remote sites this has been achieved by using GPRS connection through the local cell phone network. The routers are bought and registered locally. For several sites lying close to existing telescopes we are using the local network. The connection to the local observatory has been achieved through microwave link in Mexico, Tenerife and in Chile.

The All Sky Cameras are described in a separate paper in this volume [3].

## 4 Weather simulations

The weather simulations have been done through a contract with an external company (SENES, Canada). The approach used was a state-of-the-science weather forecast model run using historical data to develop climatology of clear nights and adverse environmental conditions for the candidate locations. Historical climatological data were validated by comparing the model predictions against observations made as close to the proposed locations as possible.

FReSH-4 is a SENES-developed weather forecasting system that includes 3 modules. The first module collects and formats the global base temperature and pressure observational data. The second module runs a state-of-the-science weather model Weather Research Forecast Non-hydrostatic Mesoscale Model Version 3.3 (WRF-NMM). WRF-NMM is currently the U.S. operational forecast model and the model that validates against observed data better than any other model in the world. The third module tailors outputs from the model to meet the clients needs. The system runs under the LINUX operating system on a desktop computer and typically has a 4-km grid resolution.

The WRF-NMM model was initialized using the U.S. National Center for Environmental Prediction (NCEP) 6 hrs analysis fields. For better accuracy, the model was run in a nested mode, first on a large modelling domain of approximately 900 km by 900 km with a 5 km grid spacing. The output from the large scale domain was used as input into a finer resolution run with a domain of 300 km by 300 km and a 1 km spacing.

Currently we have the results that span 10 years of data for each site. In addition to that we have ordered running simulations concurrent with Atmoscope data taking at sites. Such simulations are currently ordered up to June

**Fig. 2**: The ATMOSCOPE station installed in Chile. Note the 10 meter weather tower.

30th, 2013, and we are planning to continue for the rest of the year.

## 5 Satellite data

We are using data from several satellites for the weather analysis. This includes data from polar satellites like MODIS, and geostationary like METEOSAT and GOES.

Moderate Resolution Imaging Spectroradiometer is the main instrument of two satellites orbiting Earth: Terra and Aqua. Their 12h orbit allows to obtain 2 measurements (per satellite) one for day and one for the night for any place on the globe. One of their main purposes is to measure atmospheric conditions such as temperature, water vapor, cloudiness, etc. Due to the fact that the access to non-derived products (raw scientific data) is free, the MODIS data are an excellent low-cost tool for monitoring remote site with no previous measurements history. A more detailed description of the MODIS mission can be found at the official website[1].

The MODIS data are organized in several levels, and within each level, in separate products. Levels correspond to the amount of post-processing done to the raw measurements, whereas the term products refers to different scientific aspects. For our analysis we chose the second level data for two reasons:

- High resolution of data - 5 km at nadir of the satellite
- Easily accessible format - pixels with spatial coordinates (longitude, latitude) and scientific measurements.

The only drawback of the second level data are that it is still in the satellite based coordinates i.e. the analysis of the images has to take into account the orbit of the satellite.

We are also analyzing the geostationary satellite data. For this purpose we use the METEOSAT and GOES data. The METEOSAT data cover the Canary Islands and Namibian sites, and allow the analysis of the Argentinian sites. The latter is hampered by the fact that the two sites lie at the edge of the field of view of the satellite. GOES data covers the American sites and the Canary Islands are at the edge of its field of view. The satellite studies have been found to be more precise and reliable for flat areas than for sites with abrupt orography.

## 6 Summary

We have described the basic ideas used for the site search developed for CTA. The site characterization depends on three main sources of information. The ground based data has the smallest time line due to the fact that the decision must be taken quickly. For most sites we will gather a year of ground based data. As this is not sufficient to make a comprehensive comparison of the sites we must also use several long term data sources from sites. These long term data sources carry a much larger systematic error. In order to overcome this source of uncertainty we are conducting a massive comparison between the ground based data and the remote data, such as the numerical weather simulations and the satellite data. This allows to find uncertainties and systematic shifts in the remote data. The remote data are also verified for consistency at other nearby sites: at local astronomical observatories, or weather stations. In most cases the comparison between the ground based and the remote data is satisfactory, yet there are some cases when we only can rely on the limited ground based data.

1. http://modis.gsfc.nasa.gov/

There are several site related studies carried by the CTA. We are performing very long term weather change study for all the sites using the FriOwl data. The potential influence of the presence of the E-ELT lasers if the site is chosen in Chile is shown in [8]. There is a mirror testing facility in San Antonio de los Cobres in Argentina, and which is described in [10]. The aerosol study of Argentinian sites is presented in [5].

The CTA site decision process is currently under way. We expect to have a final recommendation at the end of 2013.

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