PROCEEDINGS OF SCIENCE

SWGO site environment characterisation activities

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The Southern Wide-field Gamma-ray Observatory (SWGO) project aims to build an array of air-shower detectors in the Southern hemisphere. Intensive site search activities are ongoing. We developed an Autonomous Environmental and Scientific SWGO Site Characterization Instrument (AEROSITE) to measure environmental characteristics of the proposed sites and deployed four of them in Argentina, Bolivia, Chile and Peru. The instruments are located at very high altitudes of more than 4500 m.a.s.l. We completed an intensive cross-calibration campaign to validate the performance and sensitivity of all AEROSITEs in 2020 and installed the instruments at the sites between October 2021 and April 2022. The instruments are gathering important data without any major issues. At some candidate sites, non-SWGO environmental monitoring systems are also available. In this case, the AEROSITE serves as a cross-calibration instrument to allow a possible extension of the data points to the past using the available data sources. On the other hand, the AEROSITE data are important for designing the SWGO detectors using the real conditions at the sites such as temperatures, wind, electric field and seismic activity.

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1. Introduction

The Southern Wide-field Gamma-ray Observatory (SWGO)[1] is a project of a future gamma-ray observatory to be built in the Southern Hemisphere. It is aimed to be installed at a minimum altitude of 4.4 km a.s.l. in order to reach a low energy range, down to hundreds of GeV, in addition to detecting gamma-rays all the way up to several hundreds of TeV. It will complement Northern Hemisphere observatories like HAWC [1] or LHAASO [2], utilizing an array of water Cherenkov detectors arranged in a high-fill-factor core with area considerably larger than HAWC and significantly better sensitivity, and a low-density outer array. [3]. An illustration of SWGO gamma-ray measurement is shown in Fig. 1. Candidate sites are located in South America: Argentina, Bolivia, Chile and Peru.

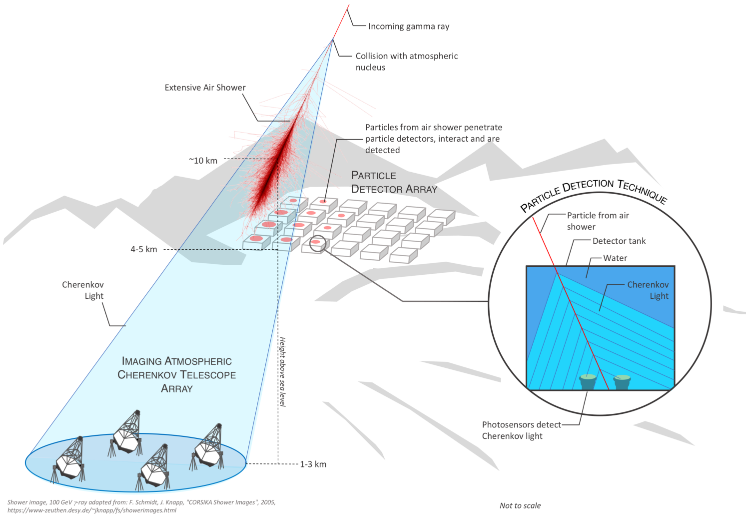

Figure 1: Gamma-ray detection illustration (courtesy of SWGO).

SWGO is still in an R&D phase – detector design and optimal site are being selected, simulation and analysis tools are being developed and science benchmark cases are being defined. One of the key aspects of optimal site selection is a detailed characterization of pre-selected sites. We present an instrument for a medium-term site evaluation – Autonomous EnviROnmental and Scientific SWGO site characterization InsTrumEnt (AEROSITE).

2. AEROSITE instrument

AEROSITE is an off-grid environmental monitoring device deployed on four SWGO candidate sites and providing on-site measurements of temperature, humidity, atmospheric pressure, solar irradiation, wind speed and direction, electric field (E field) intensity and seismic activity.

The mechanical setup of the station consists of a steel IP 65 box to accommodate and protect a battery, charger and electronics. The weight of the battery and the box itself (≈90 kg total) ensures the stability of the station position. The box is fixed to a support frame to increase the distance between the ground and protect the electronics against water leaking in case of heavy rain. The support frame is made of Bosch-type aluminum profiles. The profiles are rigid, light, easily

[1]http://www.swgo.org

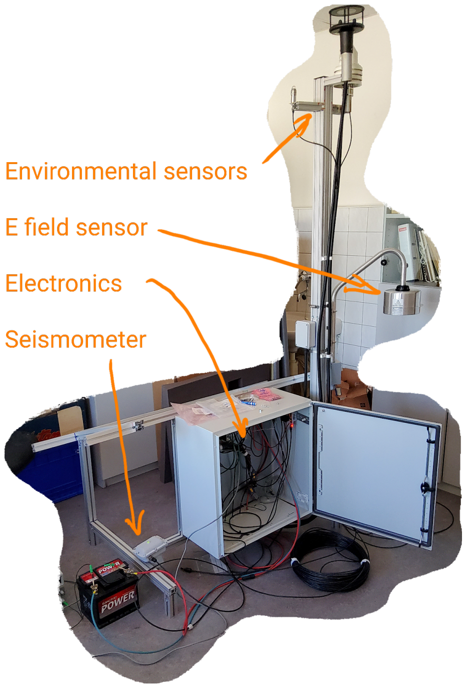

Figure 2: AEROSITE assembly.

adaptable and easy to assemble without welding. Weather and wind sensors are installed on a rigid mast with 2 m height. The sensor location is selected so that there is no shadowing of the wind or irradiation sensor. In the default configuration, there is a 150 W solar panel attached to the frame providing power for the entire station. A photograph of the AEROSITE assembly is in Fig. 2.

Barometric pressure, humidity and temperature are measured by Reinhardt DFT 55V. The temperature range is −40 °C to 60 °C with 0.01 °C resolution and 0.3 °C accuracy. The relative humidity range is 10 % to 100 % with 0.03 % resolution and ±2 % accuracy. The range of the barometric pressure is 300 hPa to 1200 hPa with 0.01 hPa resolution and ±0.8 hPa accuracy [4].

Gill WindSonic [5] is utilized as the anemometer. It is a 2D ultrasonic anemometer with measurement range of the wind speed $0\,\mathrm{m\,s^{-1}}$ to $60\,\mathrm{m\,s^{-1}}$ with resolution of $0.01\,\mathrm{m\,s^{-1}}$ and accuracy of ±2 %. The wind direction measurement ranges from 0° to 359°, with resolution of 1° and accuracy of ±3°.

The solar irradiation is an important input into thermal simulations of water Cherenkov detectors and is affected by the local cloudiness. The sensor from Reinhardt company was selected and allows to measure the light of wavelengths in the range from 300 nm to 2800 nm. The measured range of solar irradiation is $0\,\mathrm{W/m^2}$ to $1500\,\mathrm{W/m^2}$ with 0.3 W resolution and ±40 W precision.

Strong electric fields can adversely affect measurement of water Cherenkov detectors, as observed by HAWC colleagues [6], hence the E field is measured by a Boltek EFM-100C [7] electric field mill with measurement range of −20 kV/m to 20 kV/m and 5 % accuracy.

Seismic activity measurements are provided by a seismometer designed by the group of T. Bulik from the Polish Academy of Sciences [8].

Additionally, the AEROSITE deployed in Peru is equipped with a remote string of 14 temperature sensors (DS18B20, 2 of-the-shelf waterproof, 12 epoxy-potted) to monitor temperatures inside a prototype water tank. These readings will be used for validation of thermal modeling of tanks.

Data acquisition of all sensors except for the seismometer is handled by Balena Fin computer [9], an industrial standard single board computer utilizing Raspberry Pi 3 compute module and equipped with 16 GB eMMC memory.

Four sets of environmental sensors were thoroughly tested and cross-calibrated before the AEROSITE stations assembly and shipping. The sensors were installed on the roof of the Joint Laboratory of Optics in Olomouc (CZ) from Oct 2020 until beginning of 2021 with a two-week break for climate chamber tests. The climate chamber cycling constituted temperature and humidity cycling in the ranges of −20 °C to 35 °C and 5 % to 100 % [10].

3. Site characterization

Site candidates were proposed by interested institutions meeting the criteria:

- altitude of 4.4 km or higher to provide the lower energy threshold of the hundreds of GeV,
- latitude between 10° and 30° South to ensure the view of the Galactic Center,
- surface area of $\sim$1 km^2 to accomodate the SWGO reference configuration [3] and allow for a potential future extensions.

The three conditions represent the hard constraints, while more parameters are evaluated to determine the performance, cost and risks of SWGO at a given site [11].

The following locations are being considered by SWGO as candidate observatory sites:

- **Argentina:** Cerro Vecar, Alto Tocomar (close-by)
- **Bolivia:** ALPACA site (Chacaltaya plateau)
- **Chile:** Pampa la Bola, Pajonales (close-by)
- **Peru:** Imata, Yanque, lakes Sibinacocha, Pasto Grande, Suches

The underlined sites were or still are equipped by AEROSITE. The underlined close-by sites are equipped by one AEROSITE near both of them. The AEROSITE station at Imata was collecting data for a year and it was moved to Yanque site in Oct 2022. The locations of AEROSITEs placement were selected by the local site representatives.

The site selection process is quite complex and environmental data are only one part of it. The environment is to be considered from the point of view of location (altitude, latitude), weather (storms, lightning, sun irradiance, freezing days, day/night temperature variation) and geology (rocks, terrain slope, earthquakes). Water source is crucial for water Cherenkov detectors, hence the distance, quality, supply rate, price of transport and possible environmental effect need to be considered. Another key variable is infrastructure, e.g. the power supply or internet connectivity. Also other site merits need to be evaluated, ranging from site accessibility to political and administrative aspects (site ownership, taxes, import of equipment, support from local research institutes and companies, labor rules, etc.).

The process has reached the shortlisting phase, in which primary and backup sites for each country were identified. All the primary and some of the backup sites were visited by a team of experts from the collaboration, to investigate and validate the proposed site characteristics [11].

The environment of the candidate sites is being evaluated based on:

- Public data – long-term historical data obtained from nearby observatories, meteostations, satellites etc.
- AEROSITE data – data from cross-calibrated instruments to provide a reliable reference.

The public data come from various sources with different uncertainty and possible offsets and are mostly collected by instruments located rather far from the candidate sites. Hence, the AEROSITEs provide a way to calibrate these data and calculate reliable uncertainties.

4. AEROSITE deployment

The deployment of the AEROSITE stations was affected by COVID pandemics, as the experts who prepared the stations were not able to travel to final destinations. Hence, AEROSITEs without solar panels and battery were shipped from Olomouc and instructions were given to personnel of local institutes. Power (solar panel and battery or grid/mains) was also provided by local institutes.

Figure 3: Locations and site photos of deployed AEROSITEs. The Peruvian AEROSITE deployed at Imata was moved to Yanque in Oct 2022.

The four stations were successfully assembled and deployed on selected sites at the end of 2021 or beginning of 2022. The Peruvian AEROSITE deployed at Imata was moved to Yanque in Oct 2022.

5. Data taking

AEROSITEs are gathering data on selected sites for 10–20 months now. Values were continuously stored over this period, with the exception of 2 issues that occurred on different stations. The first was caused by a storm that damaged meteorological sensors. The second was a power failure. As the sites are very remote, both issues caused a gap in data taking of the order of months.

Currently all the sites have internet access and the AEROSITE data can be directly uploaded to our server. The only exception are the seismometer data, which still have to be collected manually for some stations due to the amount of data being transferred and a limited connection.

Data from one of AEROSITEs are plotted in Fig. 4.

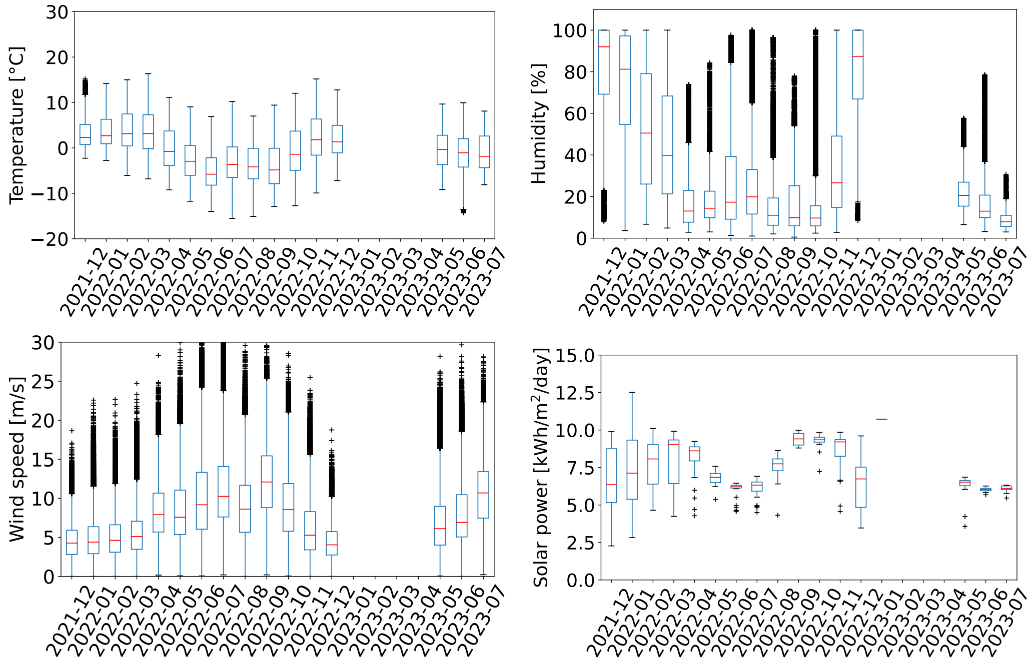

Figure 4: An example of AEROSITE data. The gap is due to a power failure.

6. Public data comparison

There are currently 5 available weather station data sets with historical data from near the candidate sites, ranging from few meters to about 5 km in distance from AEROSITE. The data sets need to be compared to the AEROSITE data to estimate systematic offsets and uncertainties originating in use of different instruments on a different location.

An example of such a comparison from a nearby weather station (~50 m apart) is shown in Figs. 5 and 6.

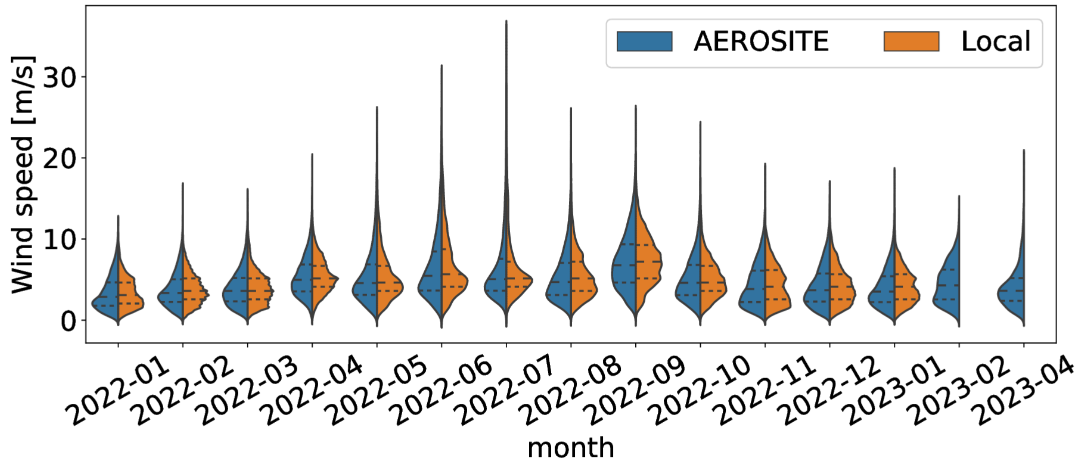

Figure 5: Monthly distributions of wind speed in the AEROSITE data and data from a local weather station.

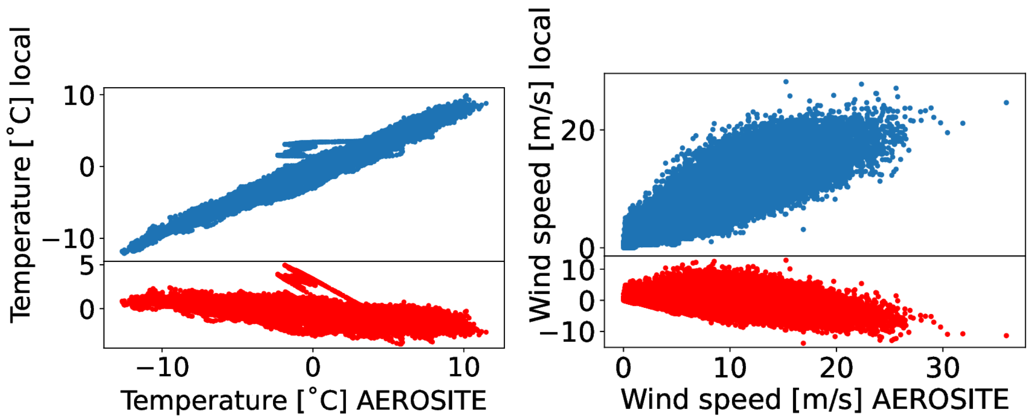

Figure 6: Correlation of the nearest measurements of temperatures (left) and wind speeds (right) in the AEROSITE data and data from a local weather station. The lower red subplot shows differences of individual values.

Such a close-by station provides very similar distributions of the measured quantities. The event-by-event comparison, using the values that are nearest in time to each other in both data sets, shows a larger spread. The spread can be attributed mainly to the different sampling and is more pronounced in the case of wind speed due to its larger temporal variance.

7. Outlook

AEROSITEs will continue taking data at least until the end of 2023, when the SWGO site should be selected. We plan to move one AEROSITE together with all-sky camera to the selected site to keep collecting data while detector design is being finalized.

Work is ongoing on evaluation of the data from local weather stations and E-field sensors. Prototype water tanks are being deployed together with in-water temperature sensors to improve the understanding of water behavior under given conditions.

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