ASTRI Mini-Array
Environmental Conditions at Teide

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Issue	**Date**	**Modification**
1.0	19/11/2020	First release
1.1	21/12/2020	Second release
1.2	13/04/2021	Third release

1 Introduction

The **ASTRI Mini-Array** (MA) is an INAF project aimed to construct, deploy and operate a set of nine identical dual-mirrors Cherenkov gamma-ray telescopes.

The ASTRI Mini-Array will exploit the imaging atmospheric Cherenkov technique to measure the energy, direction and arrival time of gamma-ray photons arriving at the Earth from astrophysical sources. In the almost unexplored energy range 1-300 TeV this technique requires an array of optical telescopes (~ 4 m in diameter) at a site located at an altitude of > 2000m. The telescope shall have UV-optical reflecting mirrors focusing the Cherenkov light produced by atmospheric particle cascades (air-showers) onto ultra-fast (nanosecond timescale) cameras. Most of the collected data will come from the large number of charged cosmic-ray initiated air-showers, that shall also be recorded, then appropriate data analysis methods shall be employed to reduce the level of this background and allow an efficient detection of gamma-ray coming from astronomical sources.

Besides gamma-ray scientific program, the ASTRI Mini-Array will also perform

- Stellar Hambury-Brown intensity interferometry: each of the telescopes of the ASTRI Mini-Array will be equipped with an intensity interferometry module. The Mini-Array layout with its very long baselines (hundreds of meters), will allow, in principle, to obtain angular resolutions as good as 50 micro-arcsec. With this level of resolution, it will be possible to reveal details on the surface and of the environment surrounding bright stars on the sky opening unprecedented frontiers in some of the major topics in stellar astrophysics.
- Direct measurements of cosmic rays: 99% of the observable component of the Cherenkov light is hadronic in nature. Even if the main challenge in detecting gamma-rays is to distinguish them from the much wider background of hadronic Cosmic Rays, this background, recorded during normal gamma-ray observations, will be used to perform direct measurements and detailed studies on the Cosmic Rays. To exploit the cosmic-ray science the ASTRI Array telescope shall be able to be pointed at large (>70°) zenith angles.

The site selected for the installation and operation of the ASTRI Mini-Array is the Observatorio del Teide in Tenerife, operated by the Instituto de Astrofisica de Canarias (IAC) and located on Mount Teide (~2400 m a.s.l.) in Tenerife (Canary Islands, Spain).

1.1 Purpose

This is the environmental requirement document of the ASTRI Mini-Array.

1.2 Scope

This document summarises the environmental conditions at the ASTRI Mini array site at the site of Tenerife-Observatorio del Teide (OT).

The Environmental Requirements presented here are intended for the purpose of setting the criteria to which the telescopes must be designed.

The products of the ASTRI MA system shall operate within the defined operational conditions and survive, as defined below, within the survival and damage limitation conditions.

These Environmental Requirements represent a compromise between cost and practicality.

1.3 Content

Section 3 describes the environmental requirements

Section 4 contains the compliance matrix for the environmental requirements and a summary of the environmental conditions in the various conditions in which the ASTRI Mini-Array can be.

1.4 Definitions and Conventions

1.4.1 Abbreviations and acronyms

The following abbreviations and acronyms are used in this document:

AIT	Assembly Integration and Testing
AIV	Assembly Integration and Verification
ASIC	Application Specific Integrated Circuits
ASTRI	Astrofisica con Specchi a Tecnologia Replicante Italiana
AR	Camera Acceptance Review
ATRR	Acceptance Test Readiness Review
BEE	Back End Electronics
CDR	Critical Design Review
CFI	Customer Furnished Item
CITIROC	Cherenkov Image Telescope Integrated Read Out Chip
COTS	Commercial Off The Shelf
EMC	Electro Magnetic Compatibility
FEE	Front End Electronics
FEM	Finite Element Analysis
FPGA	Field Programmable Gate Array
FMECA	Failure Mode Effects and Criticality Analysis
HW	Hardware
IAC	Instituto de Astrofísica de Canarias
INAF	Istituto Nazionale di Astrofisica

ITW	Integration Time Window
IZO	Izaña Atmospheric Observatory
KOM	Kick Off Meeting
LLI	Long Lead Items
MA	Mini Array
MIUR	Ministero dell'Istruzione, dell'Università e della Ricerca
OT	Observatorio el Teide
PA	Product Assurance
PBS	Product Breakdown Structure
PCB	Printed Circuit Board
PDM	Photon Detection Module
PDR	Preliminary Design Review
PR	Cameras Production Review
QA	Quality Assurance
QR	Qualification Review
QTRR	Qualification Test Readiness Review
RAM	Reliability, Availability and Maintainability
RR	Camera Requirements Review
SCADA	Supervisory Control And Data Acquisition system
SE	System Engineering
SI^3	Stellar Intensity Interferometry Instrument
SiPM	Silicon Photo-Multiplier
SLN	Serra La Nave
SMM	Structural Mathematical Model
SOW	Statement of Work
SW	Software
TCS	Telescope Control Software
TE	Test Equipment
TMM	Thermal Mathematical Model
VCD	Verification Control Document
VDB	Voltage Distribution Box

VHE	Very High Energy
WR	White Rabbit

1.4.2 Definitions

1.4.2.1 Shall, Should, May

In this document:

Shall – Shall is used to designate a mandatory requirement.

Should – Should is used for requirements that are considered good and are recommended but are not absolutely mandatory.

May – May is used for requirements that are optional.

1.4.2.2 Definition of type of technical requirements

The definitions for the various categories of requirements listed in this document are the following:

Environmental. These are all the requirements related to a product or the system environment during its life cycle; this includes the natural environments and induced environments (e.g. radiation, electromagnetic, heat, vibration and contamination).
Functional and performances These are all the requirements that define what the product shall perform, in order to conform to the needs statement or requirements of the user. Performances define how well the system performs the required functions under specific conditions
Design. These are all the requirements related to the imposed design and construction standards such as design standards, selection list of components or materials, interchangeability, safety or margins.
Physical. These are all the requirements that establish the boundary conditions to ensure physical compatibility and that are not defined by the interface requirements, design and construction requirements, or referenced drawings.
Interface. These are all the requirements related to the interconnection or relationship characteristics between the product and other items.
Product assurance. These are all the requirements related to the relevant activities covered by the product assurance.
Verification. These are all the requirements related to the Verification methods requested by the project.
Packaging, Transportation and Handling. These are all the requirements related to the relevant activities to the final delivery of the products.

1.4.2.3 Definition of the requirements verification methods

Verification shall be accomplished by one or more of the following verification methods (*M*) :

1. test (including demonstration) (*T*);

    2. analysis (including similarity) (*A*);
    3. review-of-design (*D*);
    4. inspection (*I*).

a. All safety critical functions shall be verified by test.
b. Verification of software shall include testing in the target hardware environment.

1.4.2.3.1 Test

a. Verification by tests shall consist of a measure of the performance and functionality of the product under simulation conditions comparable to those of the destination environment.
b. The analysis of data derived from testing shall be an integral part of the test and the results shall be included in the test report.
c. When the test objectives include the demonstration of qualitative operational performance, the execution shall be observed, and results recorded.
d. A test programme shall be prepared for each product
e. The test programme shall be coordinated with the integration flow.
f. Tests performed as part of the integration flow to check quality and status of the in-progress configuration (including interfaces), having a formal verification purpose, shall be included in the test programme.
g. The test programme shall be defined in the Assembly, Integration and Test plan.

1.4.2.3.2 Analysis

a. Verification by analysis shall consist of performing theoretical or empirical evaluation using techniques agreed with the Customer.

   NOTE: Techniques comprise systematic, statistical and qualitative design analysis, modelling and computational simulation.

b. Verification by similarity shall be part of the verification by analysis.
c. Similarity analysis shall provide evidence that an already qualified product fulfils the following criteria:
   1. The already qualified product was not qualified by similarity.
   2. The product to be verified is an off-the-shelf item without modifications already subjected to qualification.
d. Similarity analysis shall define differences that can dictate complementary verification activities.
e. An analysis programme shall be defined in the Verification Plan (VP).

1.4.2.3.3 Review-of-design (ROD)

a. Verification by Review-of design (ROD) shall consist of using approved records or evidence that unambiguously show that the requirement is met.

   NOTE: Examples of such approved records are design documents and reports, technical descriptions, and engineering drawings.

b. A review-of-design programme shall be defined in the Verification Plan (VP).

1.4.2.3.4 Inspection

a. Verification by inspection shall consist of visual determination of physical characteristics.

NOTE: Physical characteristics include constructional features, hardware conformance to document drawing or workmanship requirements, physical conditions, software source code conformance with coding standards.

b. An inspection programme shall be defined in the Verification Plan (VP).

1.4.2.4 Definition of the codes of the requirements

The requirement code is defined as follow ASTRI-XXXX-YYYY.

The XXXX digits refer to the identification code of the element the requirement refers to as defined in the product tree [AD2].
The YYYY digits refers to the type of requirements and coding is reported in Table 1.

Table 1-1. Definition of code for type of requirement

Type of requirement	Code
Environmental	1000
Functional and performances	2000
Design	3000
Physical	4000
Interface	5000
Product Assurance	6000
Verification	7000
Package, Transportation and Handling	8000

For the requirements listed in this document the code will be **ASTRI-0000-YYYY**. In the tables that follow, only the code referring to the type of requirement is then shown.

1.4.2.5 Definitions of States

The **assembly states** are defined as follows:

- **Off State**: the assembly is entirely without electrical power.
- **On State**: with the following sub-states:
  - **Initialised State**: the state of the assembly after power on.
  - **Standby State**: a state that is still safe with respect to extreme conditions, but has all components activated, with preparations for observation

initiated. The assembly is prepared for rapid entry into the Operational State.
  - **Operational State**: a state associated with operations (e.g. data taking), with configuration dictated by performance requirements. This state might not be applicable to some site services and protection assemblies/devices.
  - **Safe State:** if dangerous conditions are present, the assembly goes into a configuration where the object is considered exposed to "normal" risk for damage or loss. This is also the configuration designed for survival in extreme conditions, minimising the use of power whilst still providing basic status monitoring, and maximizing instrument lifetime.
  - **Fault State**: the assembly has encountered a serious problem, which means it is currently unable to meet the requirements associated with one of the standard states. Alarm shall be generated.
  - **Engineering State**: a state designed to facilitate maintenance and engineering activities and is unavailable for routine operations.

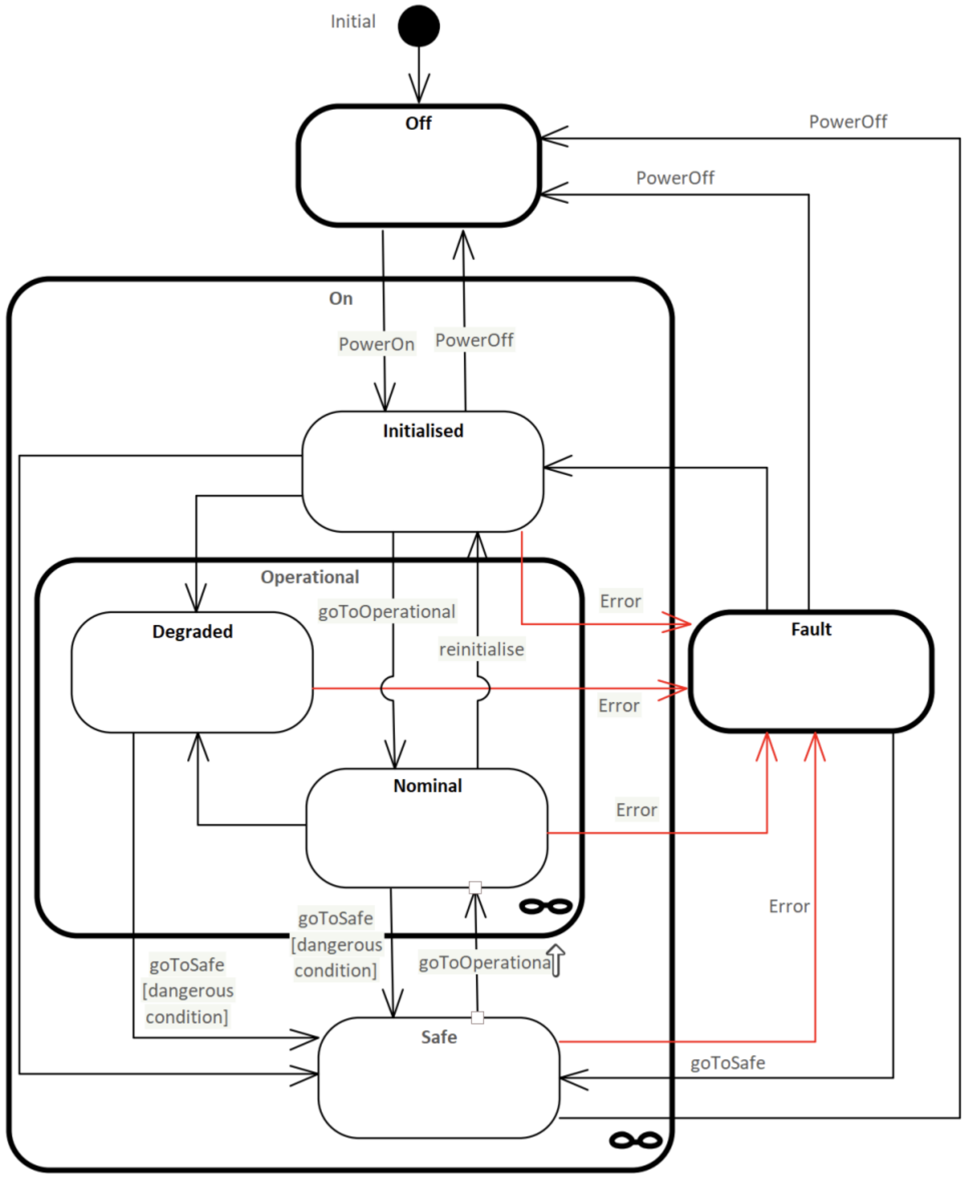
The assembly control system state machine is also applicable to composition of assemblies. In this case the overall states are defined by a composition of the states of its assemblies.

The **system/subsystem state machine** (e .g., a telescope) is represented in Fig. 1-1. The main states are:
- **Off :** the subsystem is entirely without electrical power.
- **On** : the system is switched-on and with the following sub-states
  - **Initialised**: the state after the power is turned on. The system is also configured and in standby, i .e. the subsystem is prepared for rapid entry into the Operational State.
  - **Operational State:** a state associated with data taking.
    - **Nominal** : a state in which the system can be operated with full performance.
    - **Degraded state**: a state in which the system can be operated with reduced performance.
  - **Safe State:** if dangerous conditions are present, the system goes into a configuration suitable for survival i n extreme conditions, minimising use of power whilst still providing status and vital monitoring information. The safe state configuration shall be defined for each system installed at the site
  - **Fault State**: the subsystem has encountered a serious problem, which means it is currently unable to meet its functional and performance requirements. The transition to Fault State shall generate an alarm signal for the Operator

1.4.2.6 Definitions of Modes

- **Local Mode**: mode of operation of a field-deployed Controllable System activated and deactivated by a person physically present at the Interface Cabinet associated with the system. Whilst in Local Mode all remote actions that could endanger the safety of a local person are prevented. Local Mode supports engineering and maintenance activities.

- **Remote Mode**: Mode of operation of a Controllable System to allow control by a person not present at the Array Element Location, available when not disabled at the Interface Cabinet. Remote mode supports observatory science operation and system/array-



level engineering activities.

Figure 1-1. System-subsystem (e g. Array/Telescope) *ASTRI State Machine*

1.4.3 Definitions of Conditions and Limits

- **Observation Conditions**. Environmental conditions under which full operation of the ASTRI mini-array must be possible without incurring damage.
- **Normal Conditions**. Environmental conditions under which standard operation, engineering and maintenance activities may be undertaken, during day or night.
- **Transition Conditions**. Environmental conditions under which environmental parameters may exceed those of the observing state, whilst the system transitions into a safe state.
- **Survival Conditions**. Environmental conditions expected to occur with a probability of roughly 2% per annum at the array site. The level of damage incurred under survival conditions must not exceed the serviceability limit state.
- **Serviceability Limit**. Damage can be repaired in-situ using available spare parts and a normal level of on-site manpower.
- **Collapse Prevention Limit**. The structure is heavily damaged, with very limited residual strength and stiffness, yet retains structural integrity and resists collapse. Repairs may require additional resources beyond those usually available on-site.

1.4.4 System Related Definitions

- **Imaging Atmospheric Cherenkov Telescopes (IACTs):** are telescopes designed to detect the nanosecond-timescale flashes produced within extended air showers induced by very high energy gamma-ray photos or cosmic-ray.

- **Dew Point** (DWPT) - A measure of atmospheric moisture. It is the temperature to which air must be cooled in order to reach saturation (assuming air pressure and moisture content are constant). A higher dew point indicates more moisture present in the air. It is sometimes referred to as Dew Point Temperature, and sometimes written as one word (Dewpoint).

2 Related Documents

2.1 Applicable Documents

[AD1] ASTRI Mini-Array Product Breakdown Structure ASTRI-INAF-DES-2000-001

[AD2] ASTRI Quality Plan ASTRI-INAF-PLA-3000-001

[AD3] ASTRI Mini-Array Technical standard list ASTRI-INAF-SPE-2000-003

2.2 Reference Documents

[RD1] Bechtel B. (2016). The climate of the Canary Islands by annual cycle parameters. In the International Archives of the Photogrammetry, volume XLI-B8 of Remote Sensing and Spatial Information Sciences, pp. 243–250. XXIII ISPRS Congress, 12–19 July 2016, Prague, Czech Republic

[RD2] Beck H.E., Zimmermann N.E., McVicar T.R., Vergopolan N., Berg A., Wood E.F. (2018) Present and future Köppen-Geiger climate classification maps at 1-km resolution. Scientific Data 5:180214, doi:10.1038/sdata.2018.214.

[RD3] AEMET site http://www.aemet.es/en/serviciosclimaticos

[RD4] IAC site http://research.iac.es/proyecto/site-testing/

[RD5] European Extremely Large Telescope Site Characterization III: Ground Meteorology. Varela A. M. et al., 2011.

[RD6] The Spanish Institutions in CTA (2014). The Cherenkov Telescope Array at “Observatorio del Roque de los Muchachos" - La Palma as a candidate site for CTA-North. Technical report, CTA

[RD7] González de Vallejo L. I., García-Mayordomo J. and Insua J. M., “Probabilistic Seismic-Hazard Assessment of the Canary Islands”, Bulletin of the Seismological Society of America, Vol. 96, No. 6 (2006) 2040-2049.

[RD8] Observatorio del Teide Common Weather site http://cww.ot-admin.net/

3 Environmental Requirements

The Canaries have two islands with world-class skies for astronomy that host two international observatories which together constitute the most important optical, infrared and gamma ray observatories in Europe: the “Observatorio del Teide” (OT) at Tenerife and the “Observatorio del Roque de los Muchachos” at La Palma (ORM).

The ASTRI Mini-Array site is located in the island of Tenerife (Canarias, Spain) at about 5 km from the Izaña Atmospheric Observatory (IZO) (Latitude: 28°18'32'' N – Longitude: 16°29'58'' W).

The MA site is located at coordinates 28°17'60.00" N -16°30'20.99" W, at an altitude of approximately 2370 m. Figure 2 shows the OT site, the position IZO observatory and the positions of the nine telescopes.

In Table 1 the coordinates of the nine telescopes of the ASTRI Mini-Array are listed.

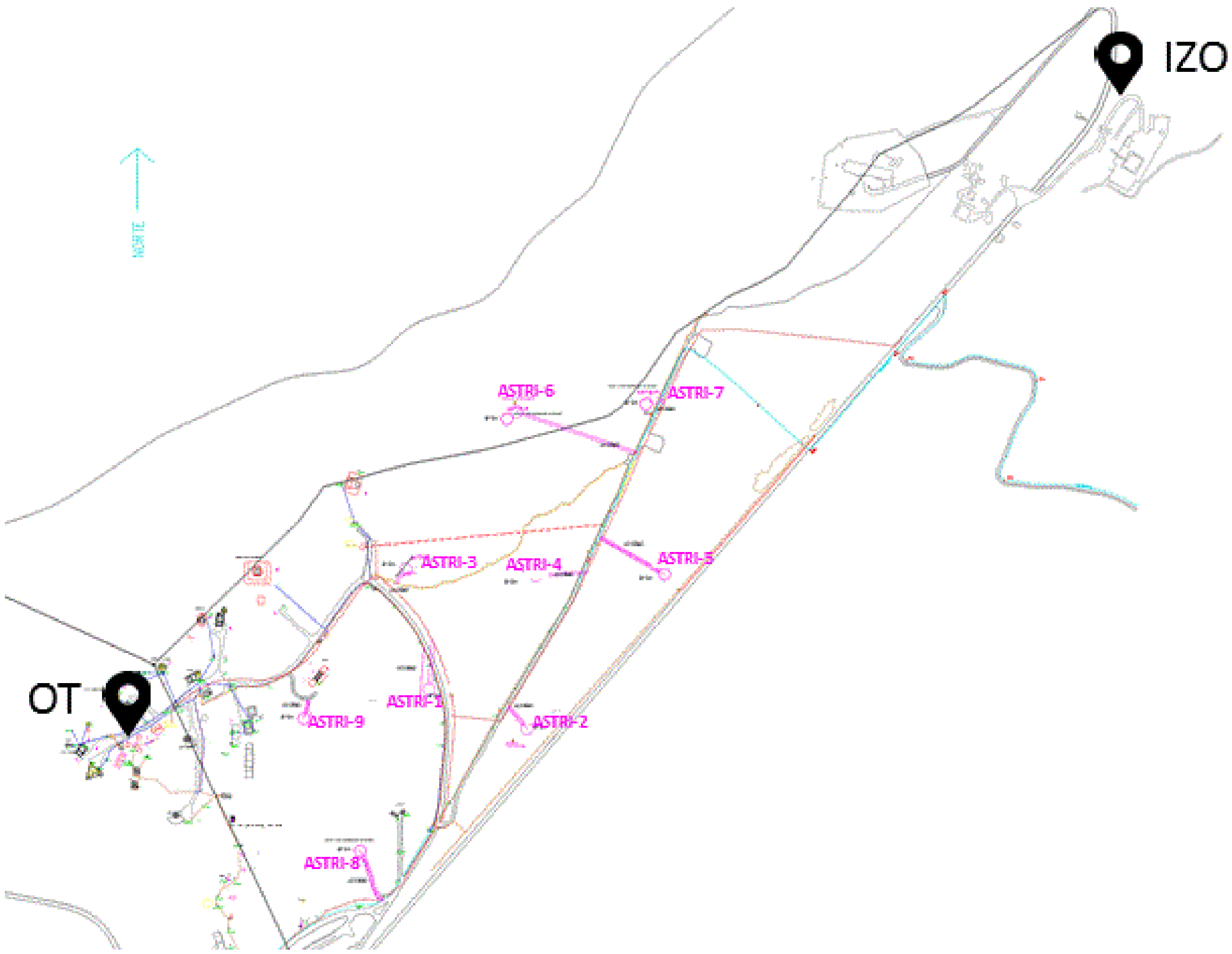


Figure 1. Map of OT site with the positions of the ASTRI Mini-Array telescopes

Table 1 Geographical locations of the ASTRI Telescope Array at Teide Observatory

	Latitude N	Longitude W	Altitude (m)
ASTRI-1	28°18'3.69"	16°30'28.69"	2359.00
ASTRI-2	28°18'2.43"	16°30'23.78"	2348.00
ASTRI-3	28°18'8.53"	16°30'29.82"	2364.00
ASTRI-4	28°18'8.31"	16°30'23.90"	2356.00
ASTRI-5	28°18'8.73"	16°30'17.63"	2358.00
ASTRI-6	28°18'14.91"	16°30'24.88"	2351.00
ASTRI-7	28°18'15.56"	16°30'18.56"	2342.00
ASTRI-8	28°17'57.45"	16°30'31.34"	2359.00
ASTRI-9	28°18'2.75"	16°30'33.98"	2376.15

The climate of Tenerife is generally dominated by the N-E trade winds and the relatively cool Canary Current [RD1]. The Canary Islands exhibit micro-climates ranging from hot desert to subtropical humid but the area containing Tenerife has a temperate dry/warm summer climate, Köppen-Geiger classification Csb [RD2]

The following environmental requirements are applicable to the following elements of the ASTRI Mini-Array:

- 7.0 Telescope
- 10.0 Monitoring, Characterization and Calibration System

The WEB site of the Agencia Estatal de Meteorología (AEMET) http://www.aemet.es has been consulted to obtain summary information about the meteorological conditions at ASTRI MA site and most of the data presented in this report (meteorological data as well as the data related to atmospheric quality) stem from the IZO [RD3].

The temperature inversion layer in Canarias appears around 1300 m of altitude on average, the so called *Alisio inversion*. This layer separates two well-defined regimes: below it, there is the moist marine boundary layer and above it, the dry free troposphere. The Alisio inversion is a quasi-permanent layer, being present 78% of the time throughout the year. Its altitude and thickness have a seasonal dependence, being higher and thinner during the winter (when it is located between 1350 and 1850 m above the sea level (a.s.l.), being only 350 m thick and lower and thicker during the summer (between 750 and 1400 m a.s.l., being about 550 m thick).

The ASTRI MA site is permanently above this inversion layer with clean air and clear sky conditions that prevail all around the year.

3.1 Temperature

The average temperature at the OT is 9.8°C, with average minimum and maximum averages being 5.9°C and 13.6°C respectively [RD4]. These agree with the temperatures measured at the nearby IZO observatory, yielding an average annual temperature around 10°C, for the period from 1981 to 2010, and average minima and maxima around 6°C and 14°C, respectively. Figure 2 shows the temperatures in the coldest months (December - February) [RD3].

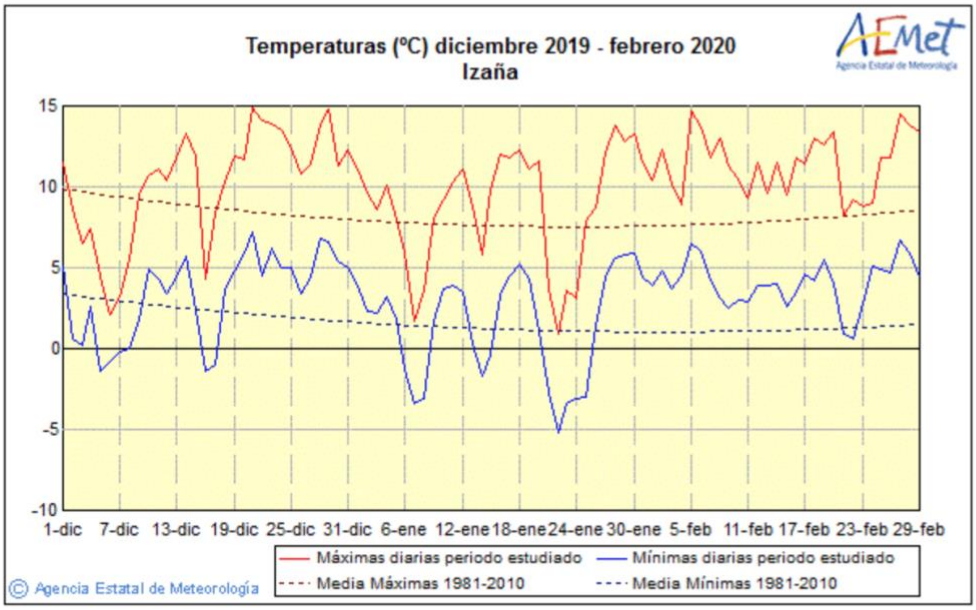


Figure 2. Temperatures (max and min) at IZO between December 2019 and February 2020 with median values reported as dotted lines

From temperature values at IZO we can extrapolate the environmental requirements on operating and survival temperatures. Differential thermal expansion may cause structural damage, binding of moving parts, induce high strains in optical components, cause unstable operation or failure of electronic components due to high thermal gradients and degradation of polymers and composite materials resulting in a shortened operational lifetime. Temperature variations of mechanical properties, fracture toughness, fatigue resistance, as well as thermal expansion coefficients must be considered. The air temperature referred in the requirements below is that measured outside at 1.5 m height above ground level.

ASTRI-0000-1200 Operating Temperature: The ASTRI MA performances shall be met within the ambient temperature range -5°C to +25°C.

ASTRI-0000-1210 Survival Temperature: The extreme air temperature range where telescopes and auxiliary devices shall suffer no damage shall be -15ºC to 35ºC when the telescope is in the Safe State

ASTRI-0000-1220 Survival Temperature without Power: The extreme air temperature range where telescopes and auxiliary devices shall suffer no damage shall be -10ºC to 30ºC when no power is available.

ASTRI-0000-1230 Temperature Gradient: The ASTRI MA performances shall be met with an air temperature gradient less than 7.5ºC/h.

ASTRI-0000-1240 Survival Temperature Gradients: The ASTRI MA shall withstand continuous temperature gradients of at least 0.5ºC/min for 20 minutes when in the Safe State.

3.2 Relative Humidity

Humidity is not one of the parameters measured at IZO. The values presented here correspond to the European Extremely Large Telescope (E-ELT) [RD5] campaign carried out from May 2008 to May 2009. The median is found at 27% humidity, both for day and night. Moreover, in the 75% of the night-time, the relative humidity is lower than 56%.

The mean humidity value of 27%, found for this one year of data (from May 2008 to May 2009), coincides with the value obtained from a 5-years site characterization campaign for the European Solar Telescope (EST), carried out from 2003 to 2008 at the OT.

Low relative humidity can cause degradation of polymeric or rubber based compounds such as seals, couplings or drive belts and increase the possibility of electrostatic discharge, high relative humidity can cause condensation within enclosed spaces such as electrical enclosures. Should the ambient temperature fall below the dew point, condensation may form on optical components and metallic surfaces and the optical image quality be adversely affected. Dewing of optical surfaces may be mitigated by use of anti-dew heating elements embedded into the optics but these will considerably increase optical element complexity and electrical power requirements. One requirement should be imposed to avoid mirror misting by requiring that the ambient temperature is above the dew point.

ASTRI-0000-1250 Observation Humidity: Observation with the ASTRI MA shall be possible when the relative humidity is in the range from 2% to 90%.

ASTRI-0000-1255 Mirror misting: The ASTR MA Telescopes shall operate with un-misted mirrors when the dew point temperature is at least 2ºC lower than the ambient temperature.

This requirement is effectively an upper limit on relative humidity as a function of the ambient temperature.

ASTRI-0000-1260 **Survival Humidity**: The ASTRI MA telescopes shall survive in safe state or when no power is available when the relative himidity in the range 2% to 100%

3.3 Wind Speed Measurements

In Tenerife wind speed and direction greatly vary from place to place, with the possibility of a big variation from day to night. For instance, comparing the wind speed roses at IZO and OT, one finds that the average wind speeds at the OT are significantly lower than at IZO and that the night values at IZO are much lower than during daylight.

Wind speed measurements have been carried out at IZO since January 1933. The data are public and can be accessed from the AEMET webpage [RD3]. The wind speed measurements were taken every second or every 0.25 seconds. The average wind speed values have been averaged every 10 minutes. From 1933 to present for over 90% of the values, the average wind speed is lower than 32.4 km/h with an average value that lies at 24.6 km/h.

The wind gust at IZO is defined as the wind speed averaged over 3 seconds. It was found that over the 82 years of data (from May 1938 to September 2020) the wind gusts exceeded 200 km/h seven times, the lower value being 201 km/h and the highest 248 km/h as reported in Table 2.

Table 2 Events from 1938 to 2020 at IZO with wind gust speed > 200km/h

Date	Wind gust speed (km/h)	Wind gust direction (°)
23 January 1947	216	300
25 February 1947	216	270
15 February 1975	216	250
14 December 1975	216	270
18 January 1994	201	310
28 November 2005	248	300
18 February 2010	213	290

However, we expect that the wind speeds are smaller at the ASTRI MA site, since IZO is located at the top of the most exposed peak in the area, while the site is more shielded.

The operational wind speed will directly impact upon the operational slew torque and the telescope pointing and tracking ability. The transitional wind speeds will impact upon the slew torques required to drive the telescope to the safe stow position.

The survival wind speed will dictate the magnitude of the static and dynamic wind loads that must be resisted by the telescope and the magnitude of the overturning moments that must be resisted by the foundation.

ASTRI-0000-1700 Observation wind speed: The ASTRI MA Performance requirements for observations shall be met under 10 minute average wind speeds of up to 36 km/h

ASTRI-0000-1710 Transition wind speed: During transitions, damage of ASTRI MA elements shall not occur due to 10 minute average wind speeds of up to 50 km/h and damage beyond the Serviceability Limit State shall not occur due to 10 minute average wind speeds of up to 60 km/h.

ASTRI-0000-1720 Survival wind speed: Damage shall not occur at the ASTRI MA on-site elements due to 10 minute average wind speeds of up to 100 km/h. Damage beyond the Serviceability Limit State shall not occur due to 10 minute average wind speeds of up to 120 km/h when in the Safe State.

ASTRI-0000-1730 Survival wind gust: Damage beyond the Serviceability Limit State shall not occur on the ASTRI-MA on-site elements due to wind gusts (1s) of up to 248km/h.

The wind speeds referred to are at 10 metre height above ground (this corresponds to the Mean Wind Velocity as defined in Eurocode 1- part 4[AD3]).

3.4 Precipitation Measurements

Precipitation is mainly recorded in winter time when the thermal inversion layer is weaker and some days it may even disappear or is found above the IZO altitude, resulting sometimes in fog and hoarfrost events. Figure 3 presents the seasonal frequency of days of appreciable precipitation (i.e. precipitation > 0.1 mm), observed at IZO for the period from 1971 to 2000 [RD3].
The annual average during this period is about 44 precipitation days with about 11 days of snow precipitation, mainly from November to April and, less frequently, from May to October.

Considering only the days with precipitation ≥ 10 mm, the annual number of days goes down to 11 precipitation days per year.

For the snow accumulation, there are no written records for IZO but it is usually very low.

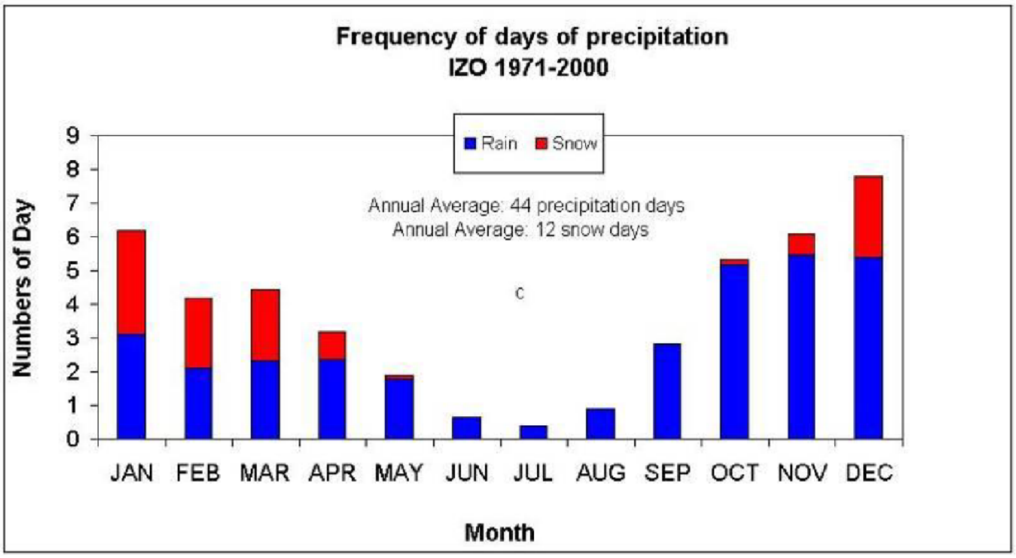


Figure 3. Frequency of precipitation days per month, measured at IZO and averaged over 29 years

Structural and other elements of the telescopes must be designed such that water cannot accumulate, either by appropriate sealing or by providing drainage. Accumulation of trapped or standing water will lead to corrosion and may also lead to structural damage as a result of ice formation at low temperatures. Water tightness of enclosures containing electrical equipment is extremely important. Ice accretion or snow accumulation on the telescope will increase static loads on the telescope due to self-weight and increase static and dynamic loads due to wind resistance.

ASTRI-0000-1600 Rain in 24 hours Damage on telescopes and on-site elements shall not occur due to rain precipitation of up to 200mm in 24 hours

ASTRI-0000-1610 Rain in 1 hour Damage on telescopes and on-site elements shall not occur due to rain precipitation of up to 70mm in 1 hour.

ASTRI-0000-1620 Rain wind speed Damage beyond the Serviceability Limit State on telescopes and on-site elements shall not occur due to precipitation in the form of rain, snow or hail for (10 minute average) wind speeds of up to 90km/h.

ASTRI-0000-1630 Rain during transitions During transitions, damage on telescopes and on-site elements shall not occur due to rainfall of up to 2 mm/hour.

ASTRI-0000-1800 Hailstone damage Damage on telescopes and on-site elements shall not occur due to the impact of 5 mm diameter hailstones with kinetic energy of 0.2 Joule.

ASTRI-0000-1810 Survival ice load Damage beyond the Serviceability Limit State on telescopes and on-site elements shall not occur due to an ice thickness (on all surfaces) of up to 20 mm

ASTRI-0000-1820 **Survival snow load** Damage beyond the Serviceability Limit State on telescopes and on-site elements shall not occur on the ASTRI-MA site whilst in the Safe state due to snow loads of up to 200kg/m^2 on horizontal surface of < 50cm

3.5 Atmospheric Quality

The Sky Law in Tenerife imposes controls on activities that could damage the atmosphere in the area surrounding the observatories. No industry, activity or service that could cause atmospheric pollution is permitted to operate above an altitude of 1500 meters.

The climate in the upper region of the Canary Islands (above 2000 m a.s.l.) is characterized by the free troposphere, above the persistent inversion layer where clouds usually lie. The result is a clear sky with an average of 77% of sunshine, in the last 10 years. The ASTRI MA site is characterised by having a generally very low level of dust concentration with episodes of high dust levels resulting from intrusions of wind-blown material from the Sahara, locally known as *La Calima*. These episodes typically last from 2 to 5 days and occur predominantly in the summer months of July and August with ~46±8% of time affected but can occur throughout the year (<15% of time affected) as determined from sky opacity measurements. PM10 is a notation used to describe particulate matter with an aerodynamic diameter of 10 microns or less. In our case, PM10 is basically constituted by mineral dust. PM10 particulate concentrations have been monitored since 2002 at IZO. PM10 concentrations lower than 10 μg/m^3 correspond to extremely clean environments and the 67% of the hourly records at IZO are lower than 10 μg/m^3.

Monthly means of PM10 percentile 75% are below 10 μg/m^3 throughout the year, except in summertime. Significant PM10 concentrations are observed only above the 80% percentile (26 μg/m^3). PM10 concentrations above 36 μg/m^3 are recorded in the 85% percentile, due to the presence of dust-loaded Saharan air mass intrusions [RD3].

Items of electrical or mechanical equipment that are designed to operate at sea level may be derated for operation at the site altitude.

Ultraviolet radiation increases with altitude due to decreasing atmosphere thickness, ozone, cloud cover and aerosols. Cooling efficiency of items such as motors and fans will be impaired; hence these must be oversized for operation at altitude. As a general guideline ultraviolet solar radiation increases by approximately 10% for every 1000 metres increase in altitude.

Materials such as thermoplastics and polymers are particularly susceptible to photo-degradation due to ultraviolet exposure and increased UV levels can cause embrittlement and loss of extensibility, tensile strength and impact resistance.

A lightning protection system must be installed consisting of air termination points, down conductors, test points and earthing points. The lightning protection system must be designed in accordance with national standards.

ASTRI-0000-1100 **Atmospheric Pressure:** The ASTRI MA performances shall be met at the atmospheric pressure range of 750±50 mbar.

ASTRI-0000-1350 **Solar radiation level** : Damage on telescopes and on-site elements shall not occur due to solar radiation of up to 1200 W/m^2 (averaged over 1 hour) at a maximum ambient temperature of 35ºC when in the Safe state.

ASTRI-0000-1360 **UV resistance** All components present at the ASTRI MA site exposed to direct solar radiation shall be UV resistant

ASTRI-0000-1370 **Survival illumination** Damage on telescopes and on-site elements shall not occur due to illumination levels of up to 106 photons ns−1 cm−2 in any state.

ASTRI-0000-1400 **Dust and sand** Damage on telescopes and on-site elements shall not occur due to an environment with up to 2.9 x 10^5 size per m^3 of air for 90% of the time at 2m above ground (not applicable to mirrors). Note: This limit corresponds to the definition of ISO-Class 9 of ISO14644-1 for particles of this size.

3.6 Geological Risk Assessment

The last volcanic eruptions in the Canarias were in 1971 on La Palma and 1909 on Tenerife. The probability of lava invasion at the Izaña Observatory is negligible as the last eruption in this area took place over 400.000 years ago.
The ash risk in Tenerife is very low as reported by [RD7]. Ash fall is determined by the direction and strength of the wind and the explosiveness of the volcano, measured using the Volcanic Explosivity Index (VEI), which gives values between 2 (small scale basaltic eruption) and 4 (sub-plinian eruption).
Eruption with VEI=3 has never been recorded in Tenerife or La Palma islands. The ash risk from VEI=2 eruptions in OT is negligible (the probability of at least 1 cm of ash has a frequency for Tenerife of 10.000 years). On the other hand, VEI=4 eruptions create eruptive columns of several kilometres height, possibly covering large areas with ash. At these heights, the predominant winds blow eastwards. This scenario would affect the OT, resulting in a risk of 10$^{-2.2}$ to occur once during the next 50 years (a recurrence time of 3000 years).
Concerning the risk of earthquake, the island has a low seismicity. The peak ground acceleration rate (PGA) to be expected by the largest seismic event, expected during the next 50 years with a probability of 10% for OT site is 0.06g [RD7].
Foundation and structure cost may be considerably affected by the seismic acceleration magnitudes. Acceleration of the telescope as a result of seismic activity will impose large overturning moments upon the foundation.

ASTRI-0000-1500 **Earthquake damage limitation** No damage on telescopes and on-site elements shall occur due to peak horizontal ground acceleration up to 0.06 g and peak vertical ground acceleration up to 0.06 g. (Anticipated magnitude at 100 km (Richter scale) = 6.0)

4 Compliance Matrix

Table 3 Environmental requirements with code, name of the requirements, description of the requirement and verification method (M) for the requirements (test (T), analysis (A), inspection (I), review of design (D)).

Code	Name	Description	M
1100	Atmospheric pressure	The ASTRI MA performances shall be met at the atmospheric pressure range of 750±50 mbar.	DA
1200	Operating temperature	The ASTRI MA performances shall be met within the ambient temperature range -5°C to +25°C.	AT
1210	Survival Temperature	The extreme air temperature range where telescopes and auxiliary devices shall suffer no damage, will be -15ºC to 35ºC when the telescope is in the Safe State	A
1220	Survival Temperature without Power	The extreme air temperature range where telescopes and auxiliary devices shall suffer no damage will be -10ºC to 30ºC when no power is available.	A
1230	Temperature Gradient	The ASTRI MA performances shall be met with an air temperature gradient less than 7.5ºC/h.	AT
1240	Survival temperature gradients	The ASTRI MA shall withstand continuous temperature gradients of at least 0.5ºC/min for 20 minutes when in the Safe State.	AT
1250	Observation Humidity	The relative humidity for observations of the telescopes is in the range 2% to 90%, that provided the condition for operation with un-misted mirrors	AT
1255	Mirror misting	Telescopes shall operate with un-misted mirrors when the dew point temperature is at least 2ºC lower than the ambient temperature. This requirement is effectively an upper limit on relative humidity as a function of the ambient temperature	AT
1260	Survival Humidity	The relative humidity, for survival of the telescopes in safe state or when no power is available, shall be in the range 2% to 100%	A
1350	Solar radiation level	Damage on telescopes and on-site elements shall not occur due to solar radiation of up to 1200 W/m^2 (averaged over 1 hour) at a maximum ambient temperature of 35ºC when in the Safe state.	T
1360	UV resistance	All components present at the ASTRI MA site exposed to direct solar radiation shall be UV resistant	DT

1370	Survival illumination	Damage on telescopes and on-site elements shall not occur due to illumination levels of up to 10^6 photons ns $^{-1}$ cm^{-2} in any state	T
1400	Dust and sand	Damage on telescopes and on-site elements shall not occur due to an environment with up to 2.9 x 10^5 particles of ≥5µm size per m³ of air for 90% of the time at 2m above ground. (not applicable to mirrors) Note: This limit corresponds to the definition of ISO-Class 9 of ISO14644-1 for particles of this size.	DT
1500	Earthquake damage limitation	No damage on telescopes and on-site elements shall occur due to peak horizontal ground acceleration up to 0.06 g and peak vertical ground acceleration up to 0.06 g. Anticipated magnitude at 100 km (Richter scale) = 6.0	A
1600	Rain in 24 hours	Damage on telescopes and on-site elements shall not occur due to rain precipitation of up to 200mm in 24 hours	T
1610	Rain in 1 hour	Damage on telescopes and on-site elements shall not occur due to rain precipitation of up to 70mm in 1 hour	T
1620	Rain wind speed	Damage beyond the Serviceability Limit State on telescopes and on-site elements shall not occur due to precipitation in the form of rain, snow or hail for (10 minute average) wind speeds of up to 90km/h.	A
1630	Rain during transitions	During transitions, damage on telescopes and on-site elements shall not occur due to rainfall of up to 2 mm/hour	A
1700	Observation wind speed	Performance requirements for observations shall be met under 10 minute average wind speeds of up to 36 km/h	A
1710	Transition wind speed	During transitions, damage shall not occur at the on-site elements due to 10 minute average wind speeds of up to 50 km/h and damage beyond the Serviceability Limit State shall not occur due to 10 minute average wind speeds of up to 60 km/h.	A
1720	Survival wind speed	Damage shall not occur at the ASTRI MA on-site elements due to 10 minute average wind speeds of up to 100 km/h. Damage beyond the Serviceability Limit State shall not occur due to 10 minute average wind speeds of up to 120 km/h when in the Safe State.	A
1730	Survival wind gust	Damage beyond the Serviceability Limit State shall not occur on the ASTRI-MA on-site elements due to wind gusts (1s) of up to 248 km/h	A

1800	Hailstone damage	Damage on telescopes and on-site elements shall not occur due to the impact of 5 mm diameter hailstones with kinetic energy of 0.2 Joule.	AT
1810	Survival ice load	Damage beyond the Serviceability Limit State on telescopes and on-site elements shall not occur due to an ice thickness (on all surfaces) of up to 20 mm	A
1820	Survival snow load	Damage beyond the Serviceability Limit State on telescopes and on-site elements shall not occur on the ASTRI-MA site whilst in the Safe state due to snow loads of up to 200kg/m^2 on horizontal surface of < 50cm	A

Environmental requirements are summarised in the following matrix. All requirements are associated with a specified State of the System or Product.

Table 4 Environmental requirements as function of conditions

Parameter	Normal	Observation	Transition	Survival
Air pressure	750±50 mbar **ASTRI-0000-1100**			
Air temperature	-5°C to +25 °C **ASTRI-0000-1200**		For T<-5°C or T>25°C to Safe State	-10°C to +30°C without power; **ASTRI-0000-1220** -15°C to +35°C in Safe State **ASTRI-0000-1210**
Temperature gradient	N/A	≤7.5°C/h **ASTRI-0000-1230**	> 7.5°C/h	0.5°C/min for 20 mins **ASTRI-0000-1240**
Relative humidity	2% to 90% **ASTRI-0000-1250**		>90%	2% to 100% **ASTRI-0000-1260**
Rain	none		≤2mm in 1h **ASTRI-0000-1630**	≤70mm in 1h; **ASTRI-0000-1610** ≤200mm in 24h; **ASTRI-0000-1600**
Snow	none		none	≤200 kg/m^2 on horizontal surface <50cm **ASTRI-0000-1820**
Ice	none		none	≤20 mm thickness **ASTRI-0000-1810**
Hailstone	none		none	∅ =5 mm, E = 0.2 J **ASTRI-0000-1800**
Wind	≤36km/h for 10 mins **ASTRI-0000-1700**		≤50 km/h for 10mins; serviceability limit state: <60km/h for 10mins **ASTRI-0000-1710**	≤100km/h for 10mins; serviceability limit state: ≤120km/h for 10 mins in safe state; serviceability limit state: ≤120km/h for 10 mins in safe state; **ASTRI-0000-1720**

			serviceability limit state: ≤248km/h for 1s (gust); **ASTRI-0000-1730** serviceability limit state: ≤90km/h for 10 mins (precipitations hail / snow/ rain); serviceability limit state: ≤248km/h for 1s (gust); **ASTRI-0000-1620**
Solar radiation	1200 W/m^2 (averaged over 1 hour) T≤ 35ºC in the safe state **ASTRI-0000-1350**		
Dust and sand	none	none	2.9 x 10^5 particles of ≥5μm size per m^3 of air for 90% of the time at 2m above ground **ASTRI-0000-1400**
Illumination	none	none	≤10^6 photons ns^{-1} cm^{-2} **ASTRI-0000-1370**
Earthquakes	none		horizontal ground acceleration ≤0.06g; peak vertical ground acceleration < 0.06g **ASTRI-0000-1500**

Annual report 2019-2020

Below the annual report (November 2019-November 2020) for temperature, humidity and wind speed recorded at the Common Weather website of the OT http://cww.ot-admin.net/ [RD8].

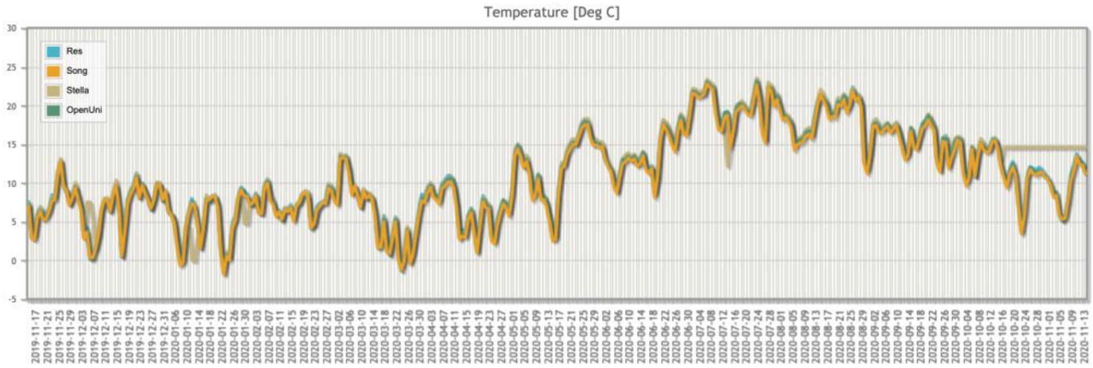


Figure 4. Temperature behaviour at OT site during last year

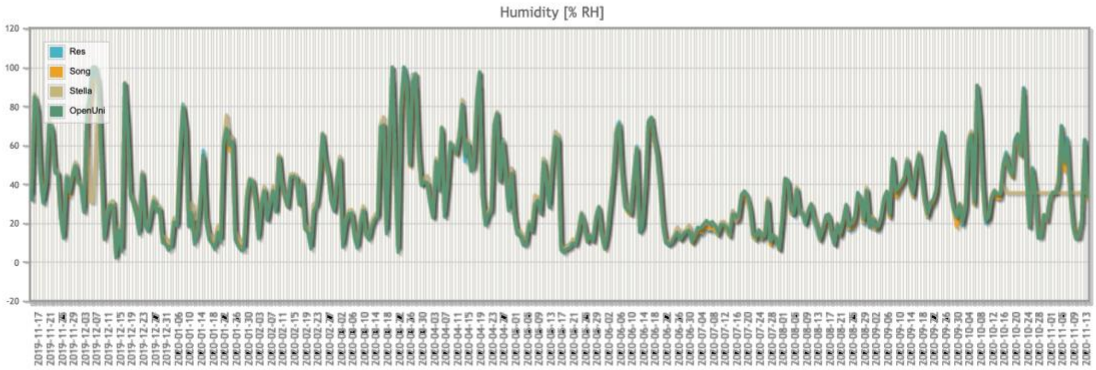


Figure 5. Humidity behaviour at OT site during last year

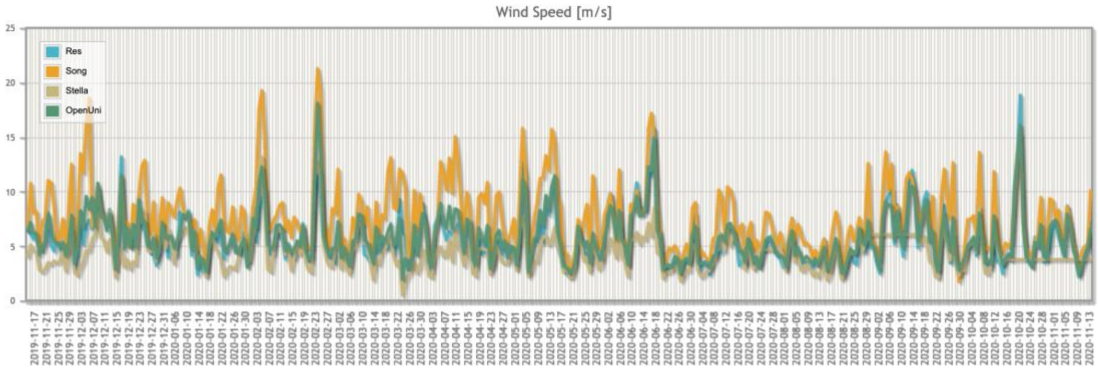


Figure 6. Wind speed behaviour at OT site during last year