The Cherenkov Telescope Array at the “Observatorio del Teide”

Tenerife as a candidate site for CTA-North

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The present document has been written by the CTA-Spain Consortium, which is

currently composed of the following research groups and institutions:

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- Institut de Ciències del Cosmos (ICC-UB), Universitat de Barcelona (IEEC-UB).
- Instituto de Ciencias del Espacio (ICE), Consejo Superior de Investigaciones Científicas (IEEC-CSIC).
- Institut de Física d'Altes Energies (IFAE).
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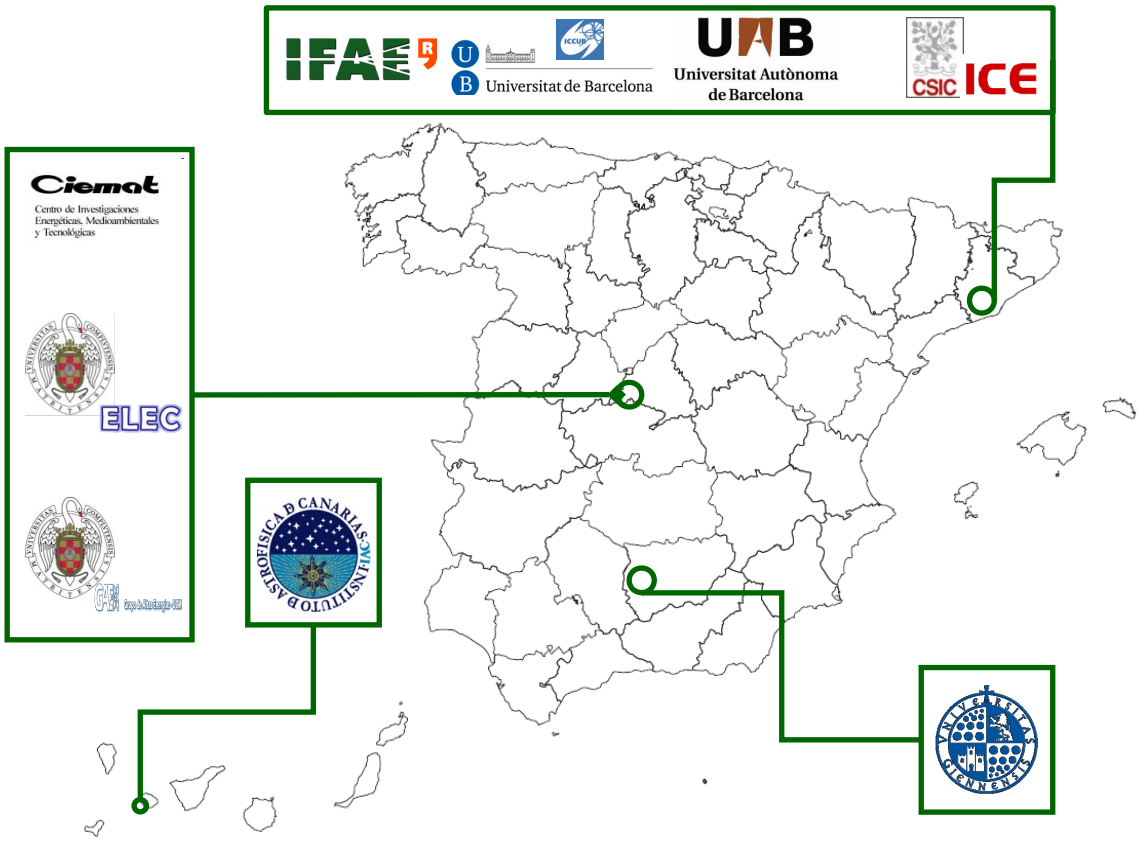

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Executive Summary

In this document we, the CTA-Spain collaboration, present the Spanish candidacy to host CTA-North. Our candidacy is supported by our long-term involvement in Very High Energy Astrophysics projects, from the former HEGRA experiment to the present MAGIC telescopes and the future CTA facilities.

We propose to host CTA-North in the Canary Islands, where the sky conditions, available infrastructures, legal and administrative regulations, local support and the proximity of the Instituto de Astrofísica de Canarias constitute a unique ensemble of advantages that will result in an enormous benefit for the operation and scientific return of CTA-North.

In the following, we offer an abridgement of the contents of the present document that summarizes the main points supporting our proposal. At the very end of this document, the fully completed site characterization matrix can be found.

The proposing group: CTA-Spain and the Spanish Scientific Community and Industry interested in CTA (Chapter 1).

The Spanish involvement in Ground based Very High Energy Astrophysics dates back to more than 20 years ago. Spanish researchers have been for many years important members of MAGIC, and previously the HEGRA experiment. They are among the **founding members of CTA** and have been deeply involved and very active since its very early conception. They currently represent around 12% of the total workforce of the collaboration.

CTA-Spain is a stable collaboration within CTA. It holds a solid participation from three of the most important Spanish universities: UCM, UB and UAB. On the other hand, IFAE, CIEMAT, CSIC and IAC are very well known research centres with stable support from both national and international agencies. UJA has recently joined CTA-Spain, and is in the process of being admitted to the CTA-Consortium. CTA-Spain agreed on a **Memorandum of Understanding** (MoU) and regularly applies for **funds in coordinated projects**, with a very high rate of success. It has excellent potential to guarantee long-term economic support from the Spanish funding agencies and is a **recognized consortium by the Spanish government**.

The Spanish Ministry in charge of Research has received this document and given authorization to CTA-Spain for submitting it to the CTA Consortium. A new Spanish Administration in which the former Ministry of Science and Innovation (MICINN) has been replaced by the new Ministry of Economy and Competitiveness taking over its functions concerning Research, Development and Innovation is still being deployed at this moment and, as a consequence, an official Government letter of support could not yet be issued before the deadline of this candidature.

Additionally a few **Spanish firms** have been playing an important role in the development of CTA concepts, in close collaboration with the research groups of CTA-Spain.

Spain as a host country for CTA-North (Chapter 2).

Spain is a highly industrialized country with **very high living standards**, counting with an excellent health-care system, an extensive network of roads, railways, high-speed rail, air routes, ports and pipelines. It is a **member of the European Union since 1986** and a **member of the euro zone since** its very start in **1999**. The country is also a full member of ESA, the ESO and CERN. Spain has developed into a **stable democracy** over the last 30 years and has shown stable governments since then.

A CTA-North site on Spanish territory would entail that **exchange rate or inflation risks** can almost completely be **excluded** for the lifetime of CTA.

Spain is one of the **safest countries** in the world. In an extensive study comparing victimization rates among EU countries in 2004, Spain came out as the country with the **lowest rate of common crimes** among the investigated 18 countries. Since then, crime rates have **further diminished** in Spain.

Strategic location of CTA-North in the Canary Islands (Chapter 3).

The Canaries have two islands with **world-class skies for astronomy, comprehensively characterized and protected by the Sky Law**. These islands host two international observatories which together constitute the most important optical, infrared and gamma ray observatories in Europe: the "Observatorio del Teide" (OT) on Tenerife and the "Observatorio del Roque de los Muchachos" (ORM) on La Palma.

Having CTA-North in the Canaries brings many **logistic, economic** and **social benefits**:

The Canaries are part of Europe. As a **EU territory**, the Canaries are a **safe, socially** and **economically stable environment**. This facilitates enormously **personnel movement** and **accreditations of qualifications**. A European citizen can use the **health system** of the country he or she is in. Moreover, the importation of materials and merchandise for the construction, operation and maintenance of CTA are **completely exempt of any (Spanish or Canarian) VAT and customs**.

Most European capitals are **less than 4-hour non-stop flying time** from Tenerife. Direct flights from continental Europe are available on a daily basis from almost any country of the European Union – most of them operated by low-cost airlines.

The **time difference** between the Canaries and most of the countries of continental Europe is **just one hour**, making it easier for work groups at different locations to cooperate and communicate.

Excellent site synergies are expected due to the proximity of the "Instituto de Astrofísica de Canarias" (**IAC**), excellence centre in astronomy which moreover has a great experience in research and engineering, the University of La Laguna, the two **optical/infrared** and **VHE** observatories **OT** and **ORM** and several additional Spanish ground facilities for **radio** (Yebes, IRAM, Robledo), **optical/infrared** (CAHA) observations. In addition, Spain participates in the ESA missions XMM-Newton and

INTEGRAL, and is involved in future **X-ray missions of ESA** such as ATHENA or LOFT, as well as hosting the **European Space Astronomy Centre** (ESAC).

The Canary Islands benefit, inside the legal framework of the European Union, from a special status as **Outermost Region (OR), guaranteed by the Lisbon Treaty**. The European Commission and the European Council are currently developing the new strategic development plan for the ORs for the period from 2014-2020, with the aim to increase their competitiveness, **guaranteeing dedicated funds for them**. The EU focuses on financing **large research infrastructures in the ORs.**

Therefore, the installation of the CTA-North observatory in the Canary Islands guarantees optimum fund opportunities from the European Union and minimum cost in terms of construction, operation and maintenance.

The Canary Island of Tenerife (Chapter 4).

The island territory is shared by desert landscapes on the coast, subtropical forests on the mid-slopes and summits, and volcanic areas, in particular in the **Teide National Park**, which receives **3 million yearly visits**.

There are no dangerous or poisonous animals living on the island and there is no threat by any dangerous disease.

The **University of La Laguna**, founded in 1792 is located there and receives students from all over the archipelago and even from the mainland, **especially for Astrophysics studies.**

Expenditure by OT and ORM user institutions demonstrate that **local enterprises** have the **capacity to deliver at least 70%** of the services, materials and supplies needed for building and operating CTA-North.

The **population** of Tenerife **supports the OT** and its present and future facilities. It sees in them and in the quality of the sky the **differentiating factor** that allows both La Palma and Tenerife to attract quality tourism based on activities for observing the sky.

The “Observatorio del Teide” (OT) as a candidate site for CTA-North (Chapter 5).

The observatories of the “Instituto de Astrofísica de Canarias” (IAC) have been **open to the international scientific community since 1979**, as a result of the Agreements for Cooperation in Astrophysics.

With time, the **IAC** has become the **largest research centre** of **Astronomy in Spain**, and also a **major reference in Europe and the world**. Most of the scientific disciplines related to Astronomy and Astrophysics are covered at IAC. Its scientific production exceeds 25% of the total scientific production of Spanish astronomy, in line with the number of researchers it hosts.

The **ORM and OT** are the **most important observatories for optical, infrared and VHE gamma astrophysics within the territory of the EU**.

The **OT** is located at an altitude of 2,400 m in the Izaña region of the island of Tenerife. It covers a surface area of 50 hectares and houses around fifteen telescope installations and other specialized astrophysical instruments.

The **pre-selected site** in Tenerife is a **plateau at an altitude of 2260 meters** a.s.l. with the geographic coordinates 28º16'36'' N and 16º32'08'' W. It has the great advantage of being located at only **3 km from the OT** and only 5 km from the Izaña Atmospheric Observatory (IZO), where the **atmosphere** has been extensively **characterized over 100 years**.

The site is public land and meets all the requirements established by the CTA-Consortium.

The site is **excellently communicated**: **30 km paved road** (except for the last two kilometres) **to the next town**. **Two international airports**, the largest **harbour** of Tenerife, the closest **hospital** and **gasoline station**, and the **IAC headquarters** are all **accessible within less than one hour drive**.

Characterization of the atmosphere at the candidate site (Chapter 6).

The region around the candidate site for CTA-North is one of the best, if not the best characterized astronomical site of the world. Several atmospheric parameters have a **record of 100 years**.

The Canary Islands have excellent conditions for astronomy because they are close to the Equator and out of the range of tropical storms. The Observatories are at an altitude of 2400 m, **above the "Alisio" thermal inversion layer** (located at around 1000–1600 m), which separates the moist marine layer below it from the free troposphere above. This ensures that the installations are in the free troposphere, above what is known as the "sea of clouds", where the atmosphere is usually clear, clean and free from turbulence.

The **average** annual **temperature** lies around **10ºC** and **average annual minima and maxima around 6ºC and 13ºC**. The lowest temperature ever measured during the last 92 years was -9.8ºC and the highest ever 30.4ºC.

The median humidity is 27%, both for day and night, and **in 75% of the night time, the relative humidity is lower than 56%**.

Due to the **abrupt orography** of the island, no reliable wind speed measurements are available for the candidate site so far. The site is better shielded against the predominant wind direction than IZO, 5 km from the site, where 78 years of wind measurements are recorded. For **over 90%** of the values, the **average wind speed**

was lower than 9 m/s (32.4 km/h) at that place**.** The average value lies at 6.8 m/s (24.6 km/h).

The site shows about **44 precipitation days a year, out of which 11 days are of snow** precipitation. Considering only the **days with precipitation ≥ 10 mm**, the annual number of days goes down to **11 precipitation days per year**.

Several authors have studied the **use of satellite data** for the **monitoring of cloud coverage and aerosol content** and found out that **spatial and temporal resolution is simply too poor** in order to obtain any valid data for the two Canarian observatories. Unfortunately, so far **there are no specific and well-calibrated instruments for ground measurements of cloud coverage**. We therefore present here a **compendium with the most relevant data found**: an average of 77.0% of insolation at IZO, and a fraction of useful observation time, obtained from telescope records, ranging from 72.5% to 83.7%.

The quality of the atmosphere results absolutely exceptional: Monthly averages of PM10 percentile 75% are below 10 $\mu g/m^3$ (extremely clean environments) throughout the year, except in summertime, where dust-loaded Saharan air mass intrusions (calima) may occur during 1-3 days typically. **During 50% of the time, the atmosphere is even cleaner than the ultra-clean Antarctic environment. Because of the exceptional atmospheric quality, the largest optical telescope in the world, the GTC, has been built in the Canaries.**

Atmospheric extinction has been measured to K_u = 0.557, K_B = 0.25 and K_V = 0.158 mag/airmass at the OT. **A detailed study, covering 20 years, from the ORM obtained a median coefficient K_V = 0.13**. **Ninety per cent of the time during the winter months resulted dust-free. For the summer months the percentage is around 75%.**

The **Aerosol Optical Depth** was measured at IZO, showing that **most of the year** the average remains **well below the AOD=0.1**, corresponding to non-absorbing particles.

Current night sky background measurements show **better than 21.6 mag/arcsec^2 in V** after midnight. Before midnight, the value is slightly worse. One can also see a **trend towards less NSB with the years** for the data obtained after midnight, when the sky protection law is strongest.

Sky protection in the Canaries (Chapter 7)

Lighting restrictions in Tenerife are in force across three quarters of the island and restrictions on all other potential sources of pollution are in force across the whole island.

A **power flow density limit** has also been set, calculated from the e.i.r.p. (equivalent isotropic radiated power) in the direction of the observatories.

An "**Ecological Protection Zone**" is declared covering **airspace over the observatories**.

No industry, activity or service that could cause **atmospheric pollution** is permitted to operate above an altitude of 1,500 meters.

To support the **enforcement of the law**, the IAC created the **Sky Quality Protection Technical Office (OTPC)**.

Geological risk assessment (Chapter 8)

The Canary Islands' astronomical observatories, the OT on Tenerife and the ORM on La Palma, are in volcanically active areas, but **show very small seismic activity**, almost an order of magnitude smaller than several ESO observatories in Chile or the observatory at Mauna Kea, and a factor 5 smaller than San Pedro Mártir. The entire island is classified as **"low seismic hazard"**.

Lava flow risks and risks of changes in the ground (tectonic faults) are negligible. The risk of pyroclastic flows is inexistent and the risk for being covered by 10 cm of ash from a VEI=4 eruption to happen once in 50 years is $10^{-2.2}$. Risks of changes in the earth (magma chamber) are very low and the risk of changes in the ground (dyke injection) is $10^{-4.3}$ to happen once in 50 years.

Basic and advanced infrastructure available for CTA-North at Tenerife (Chapter 9)

The OT can be accessed with **any type of vehicle**. Both main airports and ports are within less than an hour of reach. No special requirements are anticipated for the construction and operation of CTA, meaning that only routine maintenance and upgrades will be needed for everyday vehicle traffic.

As Tenerife is an international touristic resort, there are **many rental car agencies** and a well-developed **public transit service** (including taxi, bus and tram). Prices of these services are moderate compared with, for example, those in Continental Europe.

Internet transmission capacities of 200-300 Gbps are possible by 2012 from the OT to central Europe.

There is **mobile phone connection** from the three main Spanish providers at the OT. The **electric power** available at the OT is 1 MW although current demand does not exceed 0.3 MW.

The OT has **ten water tanks** with a total capacity 150 m^3.

The **OT Residence** has 14 double rooms for visiting scientific and technical staff. It also has 6 rooms in annex buildings and rooms for its own staff. The residence is **open 24 hours a day, seven days a week**. The OT also has general use facilities including a **fax, photocopier, computer room, meeting and videoconference rooms** and entertainment facilities including television rooms and a small library.

There is **storage space** at the observatory. Depending on the needs, the storage capabilities can be enlarged using the facilities at the IAC's headquarters in La Laguna, which are at less than an hour of driving. The observatory provides **limited workshop facilities** intended to serve small and urgent repairs.

Given that the IAC's headquarters are located close to the observatory, it is more cost-effective to use its facilities instead of having large workshops at the observatory. This has been the case in more than three decades of operating the OT.

There is **ample parking space** at the observatory to satisfy the needs of CTA.

There are **first-aid facilities** at the observatory and the personnel are trained to attend at the first moment. Ambulances and helicopters can easily arrive at it in a very short period of time.

The OT has further support facilities and services such as **refuse collection, stores, garages, ambulance and vehicles for users**. The **fire service** manages fire risk at the observatory to ensure that it is minimal.

The headquarters building in La Laguna is the main workplace for most IAC staff, a meeting point for the international astronomical community, a technological research and development institute and a training centre for researchers, engineers and technicians. It is also a dynamic centre for public education.

The **IAC** has the **most advanced equipment**, state-of-the-art facilities and **highly skilled personnel**, enabling it to design and develop in-house much of the technology required for its activities in astrophysical research. The IAC makes these skills and resources available to external organizations like other research centres and private bodies. **CTA-North would benefit from this infrastructure.**

The CALP, an office of the IAC at La Palma, is equipped with a **high capacity supercomputer**. It is connected to the Spanish Supercomputing Network (SSN) and will be connected in the future to the large European Supercomputer Network PRACE. Once a new upgrade of the MareNostrum computer has been completed the power of the La Palma computer is due to double, to 9 TFlops. The presence of an **on-site supercomputer** (interconnected with IAC headquarters and with the OT through a 200 Gbps circuit) is enormously useful for CTA for pre-processing their data as well as handling and distributing it.

1 The Proposing Group: CTA-Spain, and the Spanish Scientific Community and Industry Interested in CTA

1.1 Spanish Institutions in CTA

All the members of the CTA-Spain Consortium adhere to the present proposal and are regular parties of CTA[1]. As such they count with representatives in the CTA Consortium Board. Their participation in the different Work Packages, is given in the following figure 1.1:

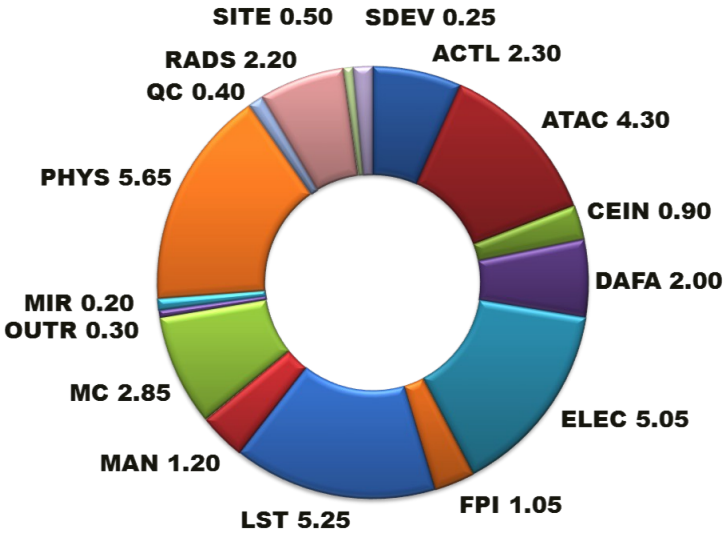

Figure 1.1: CTA-Spain weighted FTE, November 2011.

The total manpower invested by the Spanish groups in CTA is accurately reflected in the CTA regular parties FTE personnel investment, which regularly publishes the Consortium Board Chair. **CTA-Spain currently offers a total FTE of 34.4**, with a weighted FTE of 31.7, as indicated in the spread sheet published on November 18th, 2011.

CTA-Spain has been a founding member of the CTA Consortium. Currently, we represent around 12% of the total workforce of the collaboration.

The kick-off meeting of the CTA Design Study took place in 2008 at Universitat de Barcelona organized by the Spanish groups. Before the starting of the Design Study Phase, for instance, Manel Martínez was convener of the Camera Working group together with Pascal Vincent from France (the responsible of the construction of the H.E.S.S. cameras) for the first definition of the project (Letter of Intent).

[1] except for the University of Jaen, which has been accepted as a member of CTA-Spain and is currently in the process of application to become a regular member of CTA.

1.1.1 Internal coordination

The Spanish institutions participating in the CTA Consortium maintain an internal coordination and common frontend, through a series of mechanisms:

- Coordinated proposals for project funding, which led to joint participation in research and outreach activities.
- Periodical meetings: both in person and virtual.
- Mailing lists.
- A common web page: http://www.observatorio-cta.es.

CTA-Spain is a stable collaboration with excellent potential to guarantee long-term economic support from the Spanish funding agencies. It agreed on a Memorandum of Understanding (MoU), presently under formalization process, and regularly applies for funds in coordinated projects. CTA-Spain also holds a solid participation from three of the most important Spanish universities: UCM, UB and UAB, as well as a young university with a strong potential (UJA). On the other hand, IFAE, CIEMAT, CSIC and IAC are very well known research centres with stable support from both national and international agencies.

1.1.2 Spanish researchers in CTA governing boards and committees

In addition to these activities, CTA-Spain members play an important role in CTA governing boards and committees: Manel Martinez is presently co-spokesperson of CTA, the current physics and science coordinator is Diego Torres (IEEC-CSIC, Barcelona) and Oscar Blanch Bigas (IFAE, Barcelona) is the convener of the Camera for Large Size Telescopes Work Package. We note that Manel Martinez was convener of the ATAC Work Package until he was appointed co-spokesperson.

Within the Physics Work Package some working groups were defined to cover the different physics subjects and four of them are coordinated by scientists from Spanish Institutions, namely: Josep Maria Paredes, from ICC-UB, Barcelona, who coordinates the group on Binary Systems, Daniel Mazin, from IFAE, Barcelona, who coordinates the group on Extragalactic Background Light and Cosmology, Michele Doro from UAB who coordinates the group on Dark Matter searches and Giovanna Pedaletti from IEEC-CSIC who coordinates the PHYS-MC interface.

At the same time Michele Doro from UAB has been co-convening the Mirror work package since the Design Study phase and Jose Miguel Miranda from UCM-ELEC is convening the Risk, Dependability and Safety work package while Lamberto Fresnillo from FIDIAS is convening the Quality Control work package.

1.1.3 Funding received

Apart from the resources belonging to the institutions composing CTA-Spain, the funds

for additional personnel and execution costs have come basically from the former MICINN (Ministerio de Ciencia e Innovación) through the National Research, Development and Innovation (RDI) program, subprograms FPA (Particle Physics and Accelerators) and AyA (Astronomy and Astrophysics). Up to December 2011 the program was under the responsibility of MICINN, since then it belongs to the newly created "Ministerio de Economía y Competitividad".

The first activities related to the CTA conception and design studies were funded by the ministry under two Actions ("Acciones Complementarias"), submitted jointly by all the Spanish groups in 2007. This served to launch the activities and begin the coordination of the groups.

In the 2009 call for applications in the FPA program, five groups (IFAE, UCM-GAE, UCM-ELEC, UAB and CIEMAT) obtained one-year funding for the CTA activities through a coordinated project. In the 2010 call for applications in the FPA program, six groups (the ones above plus part of ICC-UB) obtained three-year funding for the CTA activities through a coordinated project in place up to the end of 2013. In addition the IAC group is being funded in a separate project of the FPA program, while the IEEC-CSIC and the rest of the ICC-UB group have been funded along these years by the AyA program.

In addition, the ministry is also supporting the detailed design and establishment of CTA through independent calls:

- The Spanish participation in the first ASPERA call for applications in 2009. The project received funds that are being used basically to contract post-docs and engineers full-time devoted to the CTA Design Study and Preparatory Phases.

- A line to promote collaboration between industries and research bodies called "Industria de la Ciencia" (Industry of Science), where two CTA related projects are active. One of them, the IEEC-CSIC and the enterprise GTD, are devoted to create scheduling tools for the future observatory. The other one is led by the enterprise INSA, in collaboration with UCM-GAE, IAC and the Universidad Carlos III, centred mainly in Data processing and communication issues. The projects extend from 2010 to 2012. Both enterprises are among the leaders in the Spanish Aerospace sector.

- A highly competitive subprogram especially devoted to international large-scale infrastructures called "Actuaciones Relativas a Infraestructuras Científicas Internacionales", among them those included in the ESFRI roadmap. An application to this subprogram was submitted by the whole CTA-Spain Consortium (73 researchers), and was granted financial support until mid 2014.

CTA-Spain has obtained a very high rate of success when requesting economic support from the national funding agencies in competitive programs.

1.1.4 Institutional support

The importance of the Spanish VHE gamma-ray community and of the CTA project for Spain was recognized in 2010 by the creation of a specific Working Group in the "Red de Infraestructuras de Astronomia" (Network of Astronomical Infrastructure RIA, www.riastronomia.es) which is a top-down organization depending on the ministry and whose goal is to coordinate the work in astronomical infrastructures in Spain. The first meeting of the "Cherenkov Telescope Array" RIA group took place in Tenerife in February 2011.

CTA has been officially chosen as one of the priority ESFRI infrastructures for Spain.

1.2 VHE Astronomy in Spain

1.2.1 Brief history

The Spanish involvement in Ground based Very High Energy (VHE) Astrophysics dates from more than 20 years ago.

In 1987 Spanish investigators from Universidad Complutense de Madrid (UCM) began their activities in the HEGRA experiment. HEGRA was the progenitor of VHE Astronomy in Europe and the "Observatorio del Roque de los Muchachos" (ORM) its birth place. HEGRA became the European counterpart of the US-based Whipple telescope, spearheaded the stereo technique and contributed to consolidate the field.

In the mid nineties members of the Cherenkov community became conscious of the need to decrease the energy threshold and increase the sensitivity of the instruments, so that members of the HEGRA Collaboration were the nuclei of the next generation of European IACT installations: H.E.S.S. in Namibia and MAGIC at the HEGRA site at ORM.

In the mid nineties, the MAGIC collaboration was created and a group from IFAE joined it. Starting in 1998 new Spanish groups gradually joined MAGIC, many of them from the Astrophysics field. This fact and the growth of the original groups contributed to raise the number to about 50 persons, i.e. one third of the whole MAGIC collaboration.

The MAGIC collaboration has published over seventy papers in international journals with high impact (Science, Astrophysical Journal, Astronomy and Astrophysics, Astroparticle Physics, Physics Letters, etc.). MAGIC detected to date more than twenty new sources of gamma rays and has substantially improved the existing measurements of virtually all previously known gamma-ray emitters in the northern hemisphere.

Spain has given so far a firm and determined support to ground-based gamma-ray astronomy, as evidenced by the high relevance attained by most of these groups not only within the MAGIC Collaboration but also on the worldwide international scene. For example the IFAE group was responsible, among other things, for the construction of the camera of the first MAGIC telescope, of the DAQ for the second telescope, and is the host institution of the coordinator of a major upgrade of the electronics in both

MAGIC telescopes.

All the Spanish groups have been very active also in the exploitation of scientific observations with MAGIC.

Moreover, several Spaniards had and have prime responsibilities in the MAGIC Collaboration like Manel Martínez ("Spokesperson" and later "Chair of the Collaboration Board"), Juan Cortina (current "Spokesperson" and previously "Co-Spokesperson" and "Technical Coordinator") or Abelardo Moralejo (former "Software Coordinator"). Manel Martínez is also a member of the Peer Review Committee of ApPEC (Astroparticle Physics European Coordination) and has participated prominently in the drafting of the "Roadmap for European Astroparticle Physics", as editor of the section on Gamma Ray Astronomy.

CTA has attracted other important Spanish groups towards VHE gamma astronomy, as is the case of CIEMAT, one of the main High Energy Physics Groups in Spain, the particle physics group at ICC-UB or the electronics and applied physics department at UCM.

Inside CTA the Spanish groups are working in a variety of subjects, with a clear focus on the Large Size Telescopes, mainly at Camera level. They collaborate in the FPI/ELEC work package being mainly involved in trigger issues, lead the PHYS, QC and RADS work packages and participate in ATAC, SITE, DAFA, CEIN, MIR and ACTL work Packages.

In addition Spanish groups are very active in other areas of RDI for CTA such as solid-state photo-sensor development, advanced technologies for atmospheric monitoring and calibration, GRID technologies for data handling and GPS and radio links, which have impact and may produce spin-offs in other fields of science and technology, as will be discussed later.

Concerning gamma-ray astronomy from satellites, the IEEC-CSIC is a member of the Fermi-LAT Collaboration where it has played a leading role in many results.

1.2.2 Training of human resources

There are well-established degrees in Physics, in Tenerife, Barcelona and Madrid. The three Universities, which host some of the signing groups offer Masters in Astrophysics and Particle Physics.

It is worth noting here that 20 PhD thesis involving MAGIC data have been defended in Spanish institutions from 2006 to 2011 (included). The average, of around 3,5 PhD thesis per year, represents about 10% of the total number of PhD thesis defended in Astronomy and Astrophysics every year in Spain.

1.3 CTA-Spain and the Spanish Industry

The CTA project features a significant strength of resource commitments from industry, both at international and Spanish levels. As a consequence the Centre for the development of Industrial Technology (CDTI) has shown interest in following the CTA activities and in bridging the communication between Spanish firms with experience in astronomy and large scientific facilities, and the CTA consortium.

Additionally a few Spanish firms have been playing an important role in the development of CTA concepts.

These are the following, some of them well known for their contribution to large scientific projects:

- **BCB Informática y control:** BCB (www.bcb.es), connected to CTA through the UCM-GAE group, offers products for the solar industry, both thermal and photovoltaic, and other fields as the control of industrial production using computer vision.

- **CDEI:** CDEI (www.cdei.upc.edu) is providing support on technological innovations. It can handle projects from the conceptual until the prototyping and testing phase. This company is working on the design for the buggies and undercarriage of the LSTs.

- **FIDIAS**. FIDIAS Consulting SL (www.fidias.es) has expertise in quality control and reliability analysis. FIDIAS activities include quality management solutions, consultancy, training, energy auditing and calibration services for International Quality Certification. It has experience in ISO9001 standards, CE mark and software development for failure analysis in mass production electronic boards and other industrial processes. The manager of FIDIAS is European auditor and has co-authored the CTA quality plan.

- **GMV**. GMV (www.gmv.com/es) offers its services and products in Aeronautics, Banking and Finances, Space, Defence, Health, Security, Transportation, Telecommunications, and Information Technology for Public Administration and large corporations. GMV is presently cooperating with CTA-Spain in the RADS work package. Three engineers of this company are the main authors of the first integral plan of CTA Reliability, Availability, Maintainability and Safety (RAMS plan). All of them are currently developing a proposal for the first integral plan of CTA Risk Assessment.

- **GTD:** GTD (www.gtd.es) is one of the main European companies for system engineering applied to space transport and services for commercial space launcher operations, as well as software control in general. It is contributing to the development and prototyping of Observation Scheduler software and utilities of CTA in direct collaboration with the IEEC-CSIC group.

- **INSA**. INSA – Ingeniería y Servicios Aeroespaciales (www.insa.es) operates in the field of aerospace engineering services and has experience in the design, construction and exploitation of complex scientific installations, like participation in the NASA Deep Space Network and support of many ESA missions. Since 2003, INSA has been involved in the introduction of GRID facilities in ESA's centre ESAC (European Space Astronomy Centre, Villafranca del Castillo, Madrid) and since 2007 operates and maintains the EGEE node at this centre. As part of the RDI investment of the company, INSA supports current activities related to site testing of the CTA-North Observatory and participates in the project outreach work package.

- **SolEner** (www.solener.com) is an awarded, renewable energy company with a deep experience in mid-size and large-size photovoltaic installations. This company collaborates with the UCM-ELEC group by giving assistance in its activities connected to CTA energy issues, including designs for clean energy supply and storage systems for CTA telescopes and data centres.

2 The Host Country: Spain

Spain is the proposed host country for CTA-North and, within Spain, the autonomous region of the **Canary Islands**. Spain counts with more than 47 million inhabitants, out of which approx. 2 million live in the Canaries.

The CTA observatory is going to be a large scientific infrastructure with an estimated lifetime of at least 30 years. For such a long exploitation period, it is worth exploring to which extent it is assured that the host country can provide optimum working conditions. In this sense, the political and economic stability and safety are relevant. The goal of the next sections is to address these questions.

2.1 Political Stability of Spain

After the death of General Franco in 1975, Spain succeeded in having an outstanding and peaceful transition (1975-1977) to democracy, being considered as an example to follow in many countries with similar problems. The Spanish constitution of 1978[2] heralded a radical transformation from a dictatorship to a democratic government, devolving power to the regions, which were given their own governments, regional assemblies and supreme legal authorities. The central government retains exclusive responsibility for foreign affairs, external trade, defence, justice, law (criminal, commercial and labour), merchant shipping and civil aviation. Although King Juan Carlos I is the chief of state, the prime minister is head of government. There is a bicameral legislature (Cortes Generales), consisting of a 255-seat Senate and a 350-seat Congress of Deputies. The Constitutional Court is responsible for ensuring that laws passed by parliament comply with the constitution and international agreements to which Spain is party. The Judiciary is independent of the government, with the highest legal body being the General Council of Judicial Power (Consejo General del Poder Judicial)[3].

Spain has been a member of the United Nations (UN) since 1955, the North Atlantic Treaty Organisation (NATO) since 1982 and the European Union (EU) since 1986, and is also a permanent observer member of the Organisation of American States (OAS). It is a member of the euro zone since its very start in 1999.

Spain has 17 autonomous regions (Comunidades Autónomas), each with its own president, government (Gobierno or Junta), administration and Supreme Court. One of these autonomous regions is the Canary Islands, which additionally enjoys separate governments for each island (the Cabildos).

The political stability of the country is guaranteed by belonging to the EU. A further

[2] available at http://www.boe.es/aeboe/consultas/enlaces/documentos/ConstitucionCASTELLANO.pdf
[3] For more information, see Paloma Román Marrugán, "Sistema Político Español", McGraw-Hill Interamericana de España, 1995, ISBN: 84-481-1790-5.

indicator is the fact that the frequency of government changes is low, legislative periods typically last the full mandate of 4 years until the next ordinary elections take place. What is more, the governing political party usually covers more than one mandate, as it can be seen in the following figure 2.1.

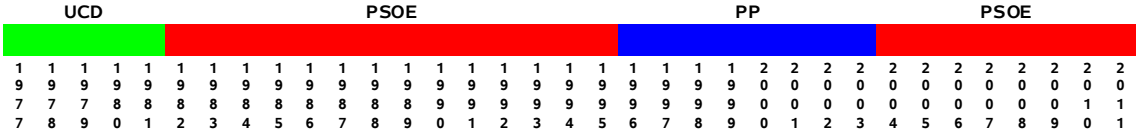

Figure 2.1: Political parties governing Spain since the transition to democracy.

Past November 2011, the most recent elections were held in Spain, as an outcome of which the conservative popular party (PP) led by Mr Mariano Rajoy won an absolute majority in both legislation chambers.

One can say that in Spain, there is an alternating government of the two main parties (PSOE and PP) with a typical change rate every 8 years (two 4-year mandates), very similar to what happens in old, stable democracies like Great Britain, United States and France.

2.2 Economic Stability of Spain

Spain is a highly industrialized country with high living standards.

The country is ranked nr. 20 by the 2010 UN Human Development Index[4]. About two thirds of the economy belongs to the tertiary sector, while its industry is based on metal manufacturers, chemicals, shipbuilding, automobiles, aeronautics, machine tools, textiles, food and beverages. It exports goods for a counter-value of approx. 250 billion euros[5] and annually imports for 270 billion euros[6]. Spain has a strong middle class, the national wealth being more or less equally distributed[7].

Spain counts with an excellent health-care system giving rise to a life expectancy of 81.8 years, one of the highest among OECD countries[8], an extensive network of roads, railways, high-speed rail, air routes, ports and pipelines.

Its geographic location makes it an important link between Europe, Africa and America. Spain is one of the world's leading countries in the development and production of renewable energy, which covered 33% of the demand in 2011[9]. Spain has become

[4] PNUD "The Real Wealth of Nations: Pathways to Human Development", http://hdr.undp.org/en/reports/global/hdr2010/chapters/en/

[5] Machinery, motor vehicles, chemicals, shipbuilding, foodstuffs, electronic devices, pharmaceuticals and medicines and other consumer goods.

[6] Fuels, chemicals, semifinished goods, machinery and equipment, foodstuffs, consumer goods, measuring and medical control instruments.

[7] Spain's Gini index, with around 31% lies in the upper average of OECD countries.

[8] "OECD Health Data 2008: How Does Spain Compare", OECD, available at http://www.oecd.org/dataoecd/46/7/38980294.pdf

[9] CHP 26%, nuclear power 21%, carbon 8%., see also http://www.ree.es/sistema_electrico/informeSEE-

solar power world leader and is Europe's main producer of wind energy. Water supply and sanitation in Spain is characterized by universal access and generally good service quality, while tariffs are among the lowest in the EU[10].

The CTA construction and operation periods will last several decades. In this scenario, it is relevant that the costs of operation and maintenance can be reasonably predicted and hence the evolution of the Consumer Price Index (CPI) is relevant. Of second order of importance are the parameters that indicate the trends in the host country with respect to the evolution of the Gross Domestic Product (GDP) and investment in Research, Development and Innovation (RDI).

2.2.1 Stability of the CPI

Belonging to the EU, together with the economic policies of the different governments in Spain, has been determinant to control the CPI, even in the case of the economic crisis from which the whole EU is currently suffering. Therefore, it is quite reasonable to expect that the CPI in Spain will not present high fluctuations in the next decades. Having the CTA observatory in a country in which monetary inflation could pick up significantly and in an unforeseen way could have a large impact on maintenance costs. In figure 2.2, the evolution of the CPI in the last years in Spain is shown.

It can be seen that inflation has been kept almost constant at around 3%, except in the year 2009, when the impact of the world-wide financial crisis brought the country close to a deflation which, however, could be successfully prevented. Exchange rate or inflation risks can almost completely be excluded for the lifetime of CTA.

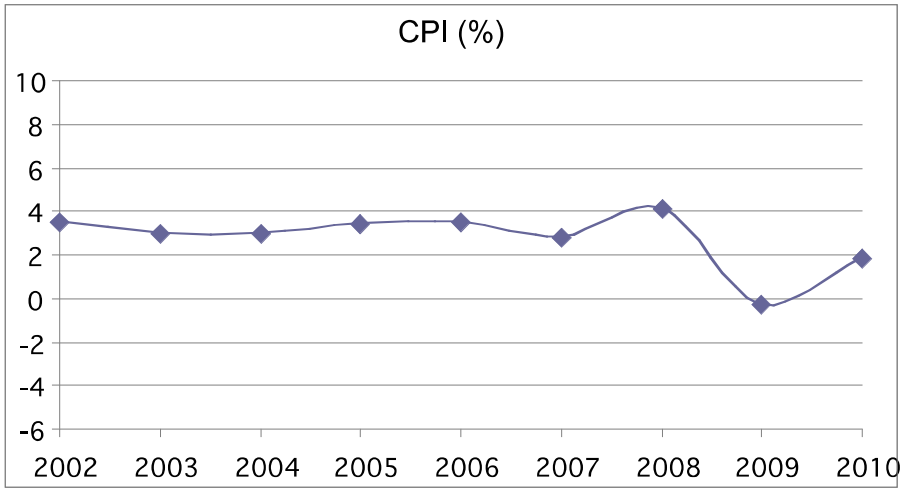

Figure 2.2: Evolution of Spanish CPI during the last 8 years [11].

avance2011.asp

[10] "International Statistics for Water Services", International Water Association http://www.iwahq.org/contentsuite/upload/iwa/document/iwa_internationalstats_montreal_2010.pdf

[11] Source: Instituto Nacional de Estadística (INE): http://www.ine.es/jaxiBD/tabla.do?per=12&type=db&divi=IPC&idtab=93

2.2.2 Evolution of the GDP

Figure 2.3 shows the evolution of the GDP per capita in absolute numbers for the same period of time. It can be clearly seen that the Spanish wealth has grown rapidly in the first decade of the new century, although impacted by the financial crisis in 2009.

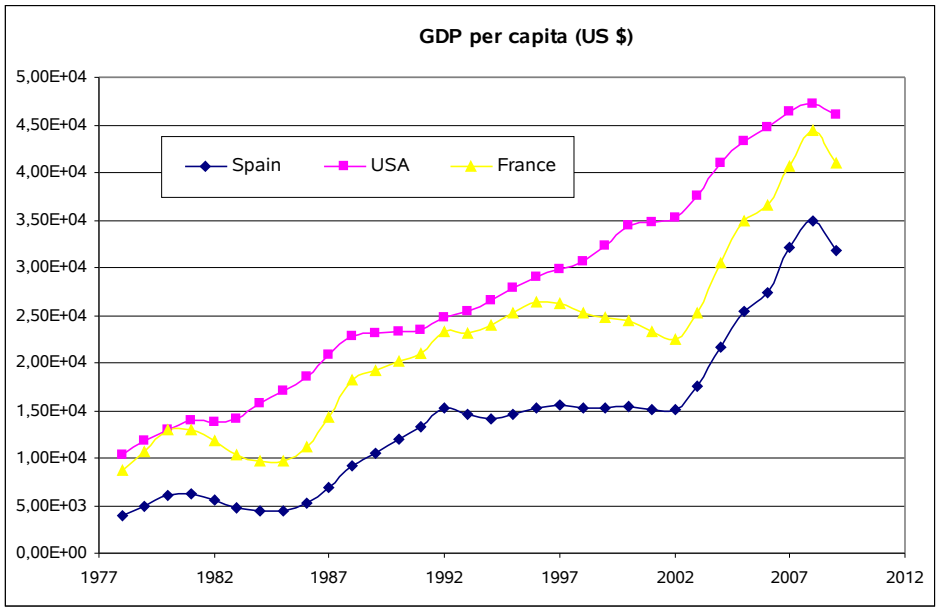

Figure 2.3: Evolution of Spanish GDP per capita, since transition to democracy. For comparison, the numbers from its direct neighbour, France, and the US are also shown.

The absolute GDP in Spain has increased very significantly in the last 25 years; from 111 billion US$ in 1975 to 1,407 billion in 2010. Spain was ranked the 12th world economy and the 5th economy of the European Union in 2010[12].

2.2.3 Public spending on RDI

In figure 2.4 the evolution of the Spanish government investment on RDI (in % of the GDP) is shown for the last 32 years, together with the same data available for the average of the EU, constituted by 27 countries.

It can be seen that spending on RDI in Spain is increasing and approaching the European average.

On the other side, capital contributions from the EU, which contributed significantly to the Spanish economic empowerment since joining the EU, decreased considerably in recent 20 years due to economic standardization in relation to other countries and the effects of EU enlargement. However in this respect, the Canary Islands continue enjoying a privileged status as Outermost Region of the EU (see also chapter 3.7).

[12] The World Bank GDP ranking http://data.worldbank.org/indicator/NY.GDP.MKTP.CD/countries/1W?order=wbapi_data_value_2010%20wbapi_data_value%20wbapi_data_value-last&sort=desc&display=default

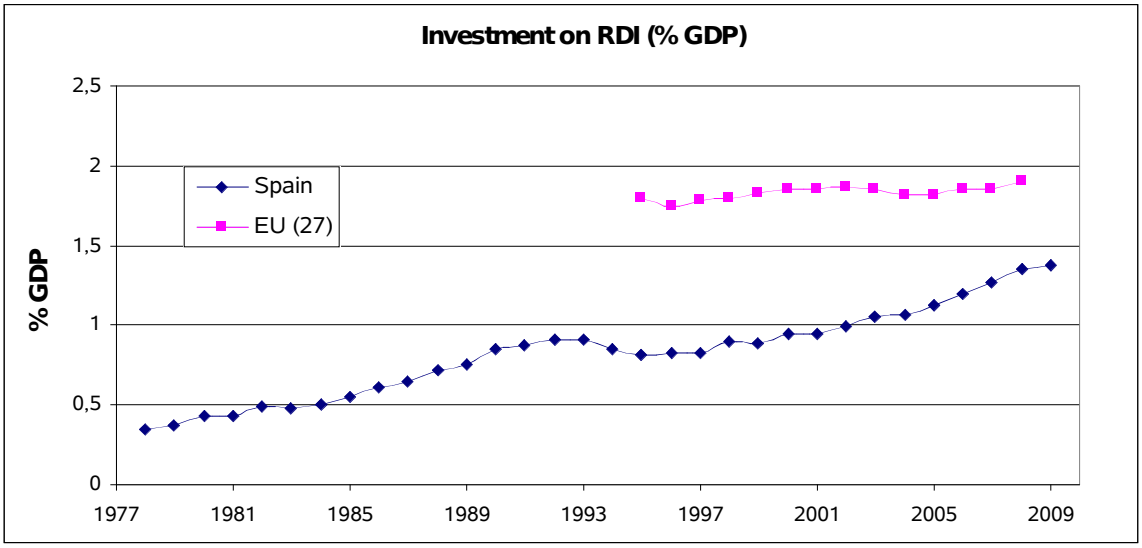

Figure 2.4: Spanish Investment on RDI, in percentage of its GDP, since transition to democracy. For comparison, the European Union average is also shown.[13]

[13] Source: Instituto Nacional de Estadística (INE), http://www.ine.es/jaxi/tabla.do?path=/t14/p057/2010/l0/&file=01002.px&type=pcaxis&L=0
and http://www.ine.es/jaxi/tabla.do?path=/t14/p057/e01/l0/&file=01001.px&type=pcaxis&L=0.

2.2.4 Recent developments

Although Spain is currently suffering from the implosion of a homemade housing bubble, in a similar way as the one affecting the US, it has so far successfully understood to maintain its national debt well below the European average[14] and has not been intervened by the EU or the IMF.

2.3 Safety in Spain and the Canary Islands

2.3.1 Situation of common crime

Crime is generally difficult to measure, especially when comparing different countries and cultures. Police statistics are known to be strongly biased, as only a fraction of all offences actually committed are reported to the police and other criminal justice agencies. The lack of uniform definitions of offences, of common measuring instruments and of common methodology makes comparisons between countries extremely hazardous.

To fill this gap, many countries have conducted **crime victimization surveys**. Such surveys collect data from households on crimes experienced as victims, on their reactions (including reporting the incident to the police), their opinion about police performance and fear of crime and related attitudes. The International Crime Victims Survey (ICVS), initiated in 1987 by a group of European criminologists with expertise in national crime surveys, was designed to produce data that allows valid cross-country comparisons[15].

There have been so far four main rounds of the ICVS at the European Union level. After the first round in 1989, the surveys were repeated in 1992, 1996 and 2000. In 2005, the EU ICS[16] conducted a sample survey among inhabitants of the European Union carried out in the 15 old member states of the European Union plus Poland, Hungary and Estonia.

The results of the 2005 report show that levels of crime were most elevated in Ireland, the United Kingdom, Estonia, The Netherlands and Denmark and **lowest in Spain (see figure 2.5)**.

Risks of crime victimization varied by the type of crime. Risks of being assaulted were found to be highest in the United Kingdom, Ireland, the Netherlands, Belgium, Sweden and Denmark. Risks were lowest in Italy, Portugal, Hungary, Spain and France. Women in Ireland, Sweden, Germany and Austria and least often in Hungary, Spain, France and Portugal reported experiences with sexual violence most often. Only in the

[14] 60.1% of GDP in 2010, compared to 85% for the Euro area average, see e.g. http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&language=en&pcode=tsieb090&plugin=1 or http://www.economist.com/content/global_debt_clock

[15] van Dijk, J.M., P. Mayhew, M. Killias (1990), "Experiences of Crime across the World, Key Findings of the 1989 International Crime Survey", Kluwer Law and Taxation.

[16] EUICS report, "The Burden of Crime in the EU, A Comparative Analysis of the European Survey of Crime and Safety (EU ICS) 2005", available at http://www.europeansafetyobservatory.eu/euics_rp.htm

case of robbery without weapon, Spain is found at place 4 among the EU countries. However, the authors stress that robbery rates are in general very low such that it is difficult to draw fair conclusions comparing the different countries.

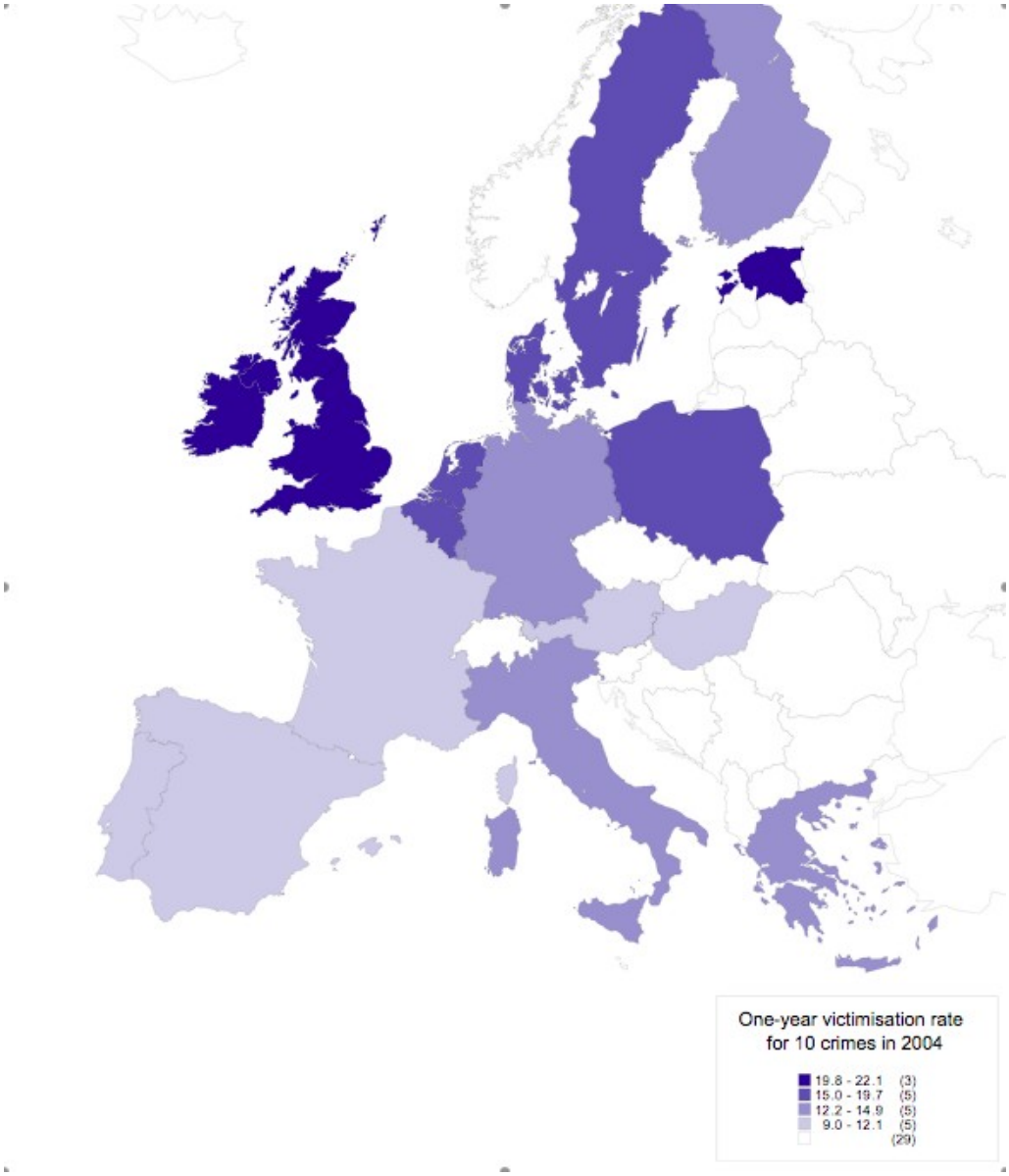

Figure 2.5: Level of common crime across the Member States of the EU in 2004.

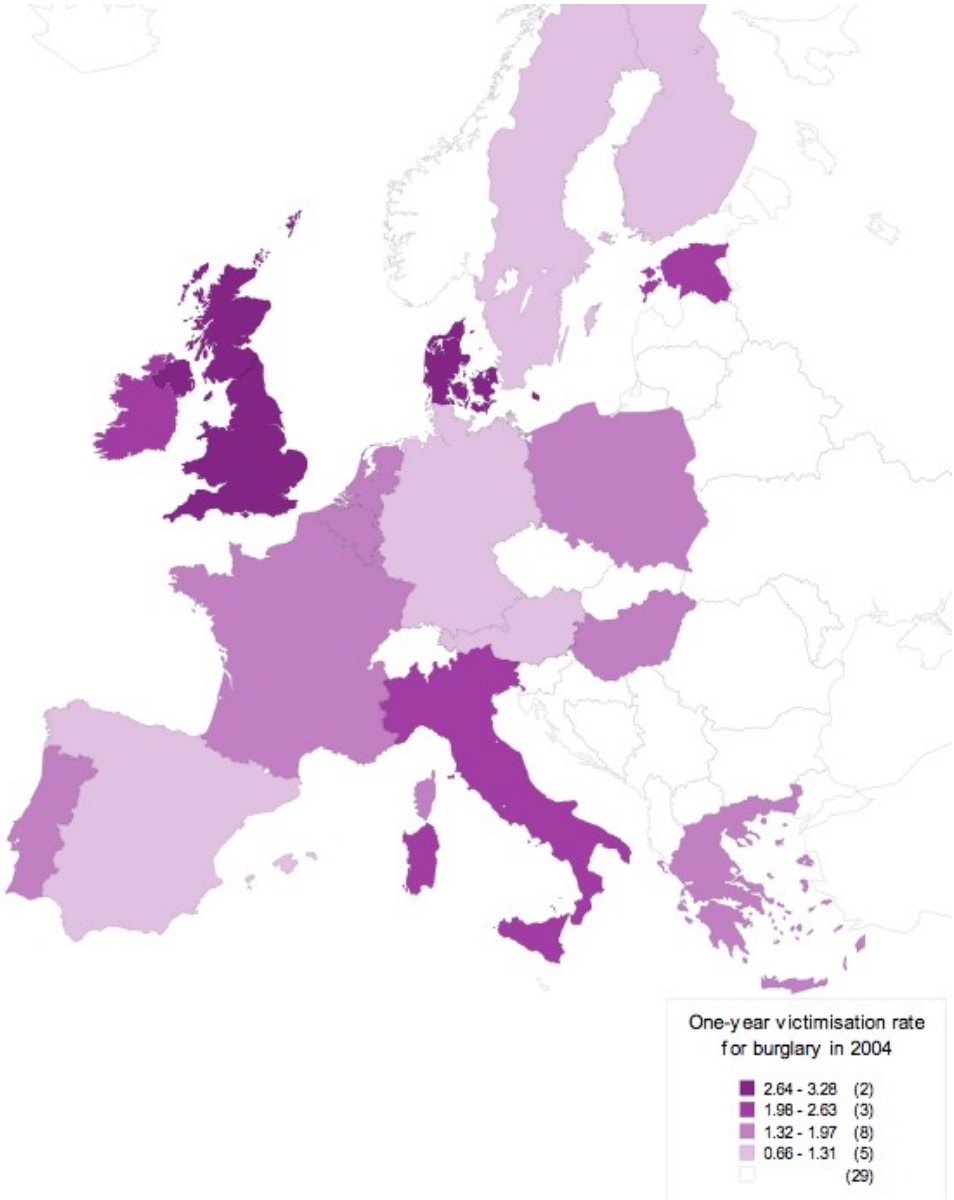

Figure 2.6: Level of burglary across the Member States of the EU in 2004.

Figure 2.7 shows the ranking of the EU countries with respect to corruption in 2004. Again, Spain is found among the countries with the lowest corruption index, a trend roughly consistent with the Corruption Perception Index of Transparency International, where Spain was found at place 22, together with France, out of 145 investigated states in 2004[17].

[17] see http://www.transparency.org/policy_research/surveys_indices/cpi/2004

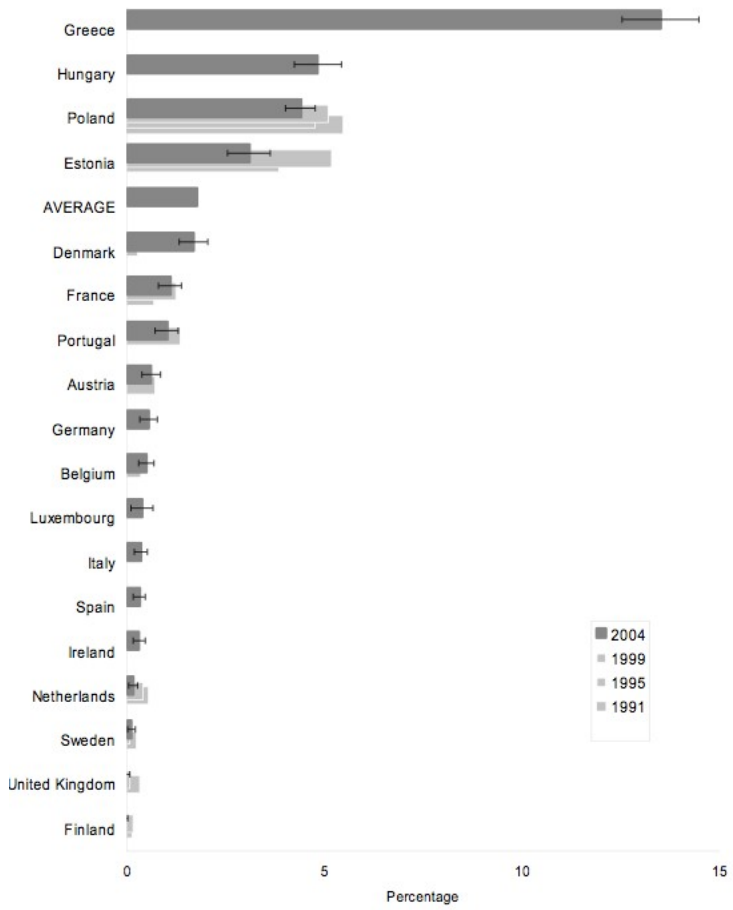

Figure 2.7: One-year prevalence rates for corruption in 2004, and results from earlier ICVS surveys.

Since 2004, there have no new Europe-wide ICVS surveys been carried out, however a longitudinal Spanish study was recently published, covering the period from 1989 to 2009[18].

This study could assess the evolution of crime in Spain in the last two decades and found that the general victimization rate has diminished even further (by 10%), when compared to the levels of 2005.

Concerning the most recent Corruption Perception Index of Transparency International[19], Spain occupied, in 2010, place 30 out of 178 investigated countries, lying at the European Union average.

Figure 2.8 resumes the overall burden of crime in an 2003/2004 international ICVS comparison campaign, **leaving again Spain as the country with the lowest crime rate at an international level.**

[18] Elisa García España, José Luis Díez Ripollés, Fátima Pérez Jiménez, María José Benítez Jiménez & Ana Isabel Cerezo Domínguez, "Evolución de la delincuencia en España: Análisis longitudinal con encuestas de victimización", Revista Española de Investigación Criminológica, 12 de abril de 2010.
[19] see http://www.transparency.org/content/download/55725/890310

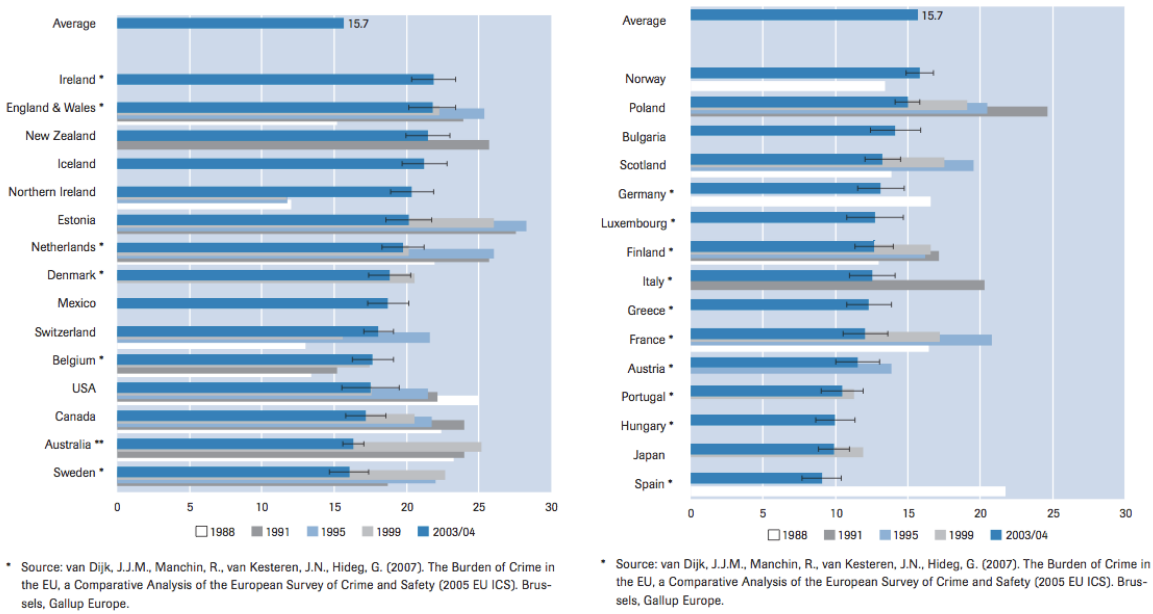

Figure 2.8: Overall victimization for 10 common crimes: shown are one-year prevalence rates in 2003/04 (as percentages) of the top 15 countries (left, highest crime rates) and bottom 15 countries (right, lowest crime rates) and results from earlier surveys[20].

Inside Spain, crime rate is slightly lower in the Canary Islands, when compared to the rest of Spain[21].

2.3.2 Terrorism

The Basque Country and Navarre in the North of Spain, and to a lesser degree Madrid, Barcelona and tourist areas of the Mediterranean coast were suffering from the terror organization ETA, mainly during the late 70s and 80s. With ever-increasing frequency, Spanish security forces have frustrated attempted ETA actions.

On 20 October 2011, ETA announced a cessation of armed activity. It has not carried out any attacks since more than two years now.

In 2004, the commuter train system of Madrid was victim of an Al-Qaida inspired terrorist attack. In a 2007 trial, 21 defendants were found guilty for that attack and charged in Madrid.

[20] Data from 1989-2005 ICVS and 2005 EU ICS combined, see also references inside the figure.
[21] "Evolución de la criminalidad 2010", Gabinete de Estudios de la Criminalidad, Gobierno de España, Ministerio del Interior, available at http://www.mir.es/file/11/11180/11180.pdf

3 Strategic Location of CTA-North in the Canary Islands

3.1 The Canary Islands as a part of Europe

It is estimated that more than 80%[22] of the number of astronomers and technicians likely to work on CTA-North in some way during the operating phase, either as an employee or a visiting user, will come from a European Union country. The remainder will be mainly visiting researchers from the American continent and from Asia. This makes a strategic location for CTA-North in Europe very important for most of the personnel who will be involved in the project. The proximity of the Canary Islands to continental Europe, with the excellent air links that largely result from tourism in the Islands and the fact that they are a EU territory, would make it easy for technical and research staff to travel to CTA-North in Tenerife.

In 1992 the EU created a "single market" for all of its members (allowing the free movement of people, goods, services and money). This means that people can travel and do business across the whole of Europe on exactly the same footing as they do in their own country.

This market has reduced bureaucracy, simplified trade, cut prices and generally made Europeans better off. Everyone benefits from increased competition within the EU, for example through cheaper flights, lower telecommunications costs and lower energy prices. In 2007 the Schengen area was created, covering 29 countries[23]. This Agreement allows nationals and legal residents of any of the "Schengen area" member countries to travel freely between them. This means that a citizen of any of the countries mentioned can travel to Spain with a valid national identity document. Nationals of non-Schengen countries must obtain a transit visa or temporary resident's permit if this is required for citizens of their country of origin. Countries whose nationals do not require a visa for visits to the Schengen area include Australia, Canada, United Kingdom and the United States; countries that have an important place in astronomy.

Having CTA-North in the Canaries will therefore benefit citizens covered by the Schengen Agreement, whether they are visiting the installations or contracted to work on them during the construction or operating phases. In fact the Canaries, which are in EU territory, provide cast iron legal assurance for research and technical

[22] This number is obtained when comparing the current FTEs dedicated to CTA from European institutions with those from the rest of the world.

[23] Germany, Austria, Belgium, Bulgaria, Czech Republic, Cyprus, Denmark, Slovakia, Slovenia, Spain, Estonia, Finland, France, Greece, Hungary, Iceland, Italy, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Norway, Netherlands, Poland, Portugal, Romania, Sweden, Switzerland.

personnel.

In the field of health, a pan-European strategy for removing even more barriers to the circulation of patients and professionals, simplifying procedures and improving the quality of access to treatment across borders, is being drawn up.

At the present time, a European citizen can use the health system of the country he or she is in, thanks to the agreements that already exist between Member States.

In education, the European Space for Higher Education, which was set up with the 1999 Bologna Declaration[24] and officially launched in 2010, also relies on the harmonization of university systems across the Member States, so that there are no barriers to the movement of persons across the EU for this purpose. This is a particular benefit in terms of being able to employ the best professionals without being caught up in the endless process of accrediting qualifications.

Similar considerations apply to the import and export of materials for the construction, operation and maintenance of CTA. Building this array of telescopes in the Canaries will simplify the process of transporting the different installation components to the site.

3.2 The Canaries as a secure and stable environment

The European Union has brought many benefits for its Member States (amongst them Spain and with it the Canaries), which can be summarized as a stable and peaceful Europe, the creation of the "single market" and the continuity of a united Europe.

As well as providing and protecting a stable and peaceful environment, the EU has played an important role in safeguarding peace and security in the European regions and extending it to neighbouring countries.

A free, safe and lawful area like this is the most desirable environment for housing and operating a large and complex installation like the CTA.

From the safety perspective, a safe environment is as important as a safe workplace.

- Safe environment: The Canary Islands offer a calm and peaceful environment and a relaxed atmosphere to promote a sense of safety and well-being (see also chapter 2.3). There are no dangerous animals nor diseases found over the entire archipelago.
- The seismic risk in the Canaries is very small, almost an order of magnitude smaller than several ESO observatories in Chile or the observatory at Mauna

[24] "The Bologna Declaration of 19 June 1999 – Joint declaration of the European Ministers of Education", available at http://www.ond.vlaanderen.be/hogeronderwijs/bologna/documents/MDC/BOLOGNA_DECLARATION1.pdf

Kea, and a factor 5 smaller than San Pedro Mártir. The entire island is classified as “low seismic hazard”.

- Safety in the workplace: Spanish labour law provides a secure working environment with an emphasis on worker protection. Any person contracted to work within Spanish territory is protected by the law governing contract working and is entitled to the benefits it confers: social security, unemployment benefit, severance pay relative to length of service, a maximum limit on working hours, right to take paid holiday etc.

  In addition, employers must comply with the relevant health and safety at work regulations for its business and provide a safe working environment for all employees.

In conclusion, the Canary Islands, as a EU territory, offer a very safe, stable environment for research and technical staff both socially and economically.

3.3 Proximity of the Canary Islands to mainland Europe

The Canary Islands can be reached from any European location within a day.

For example, most European capitals are **less than 4 hours non-stop flying time** from Tenerife. Direct flights from continental Europe are tourist flights and are available on a daily basis from almost any country of the European Union – most of them operated by low-cost airlines. Whenever it is necessary, there are also 9 daily connections from Madrid and five from Barcelona to Tenerife. The average length of an indirect flight from Europe to Tenerife is around 6 hours. Flights between Spain and the Canary Islands are subsidized for island residents (there is a 50% discount)[25].

People working with the CTA would benefit personally and professionally in the following ways:

- It is easy for personnel from abroad to relocate to the island.
- It is easy for personnel from abroad who are working on the island to stay in contact with their families and friends in their home countries. This normally leads to higher levels of satisfaction amongst staff working abroad and thus helps to create a stable workforce.
- Work trips (for technical or scientific purposes) for CTA personnel or visitors to the CTA from continental Europe would be more straightforward and cheaper.

3.4 Time difference between the Canaries and Continental Europe

There is just one hour’s difference between local time in the Canaries and most of

[25] In order to obtain a resident card, a rental housing contract in a Canarian municipality is required.

continental Europe (see Figure 2.1). Working hours would therefore be practically the same at the CTA and the various European organizations involved in its construction, operation and maintenance.

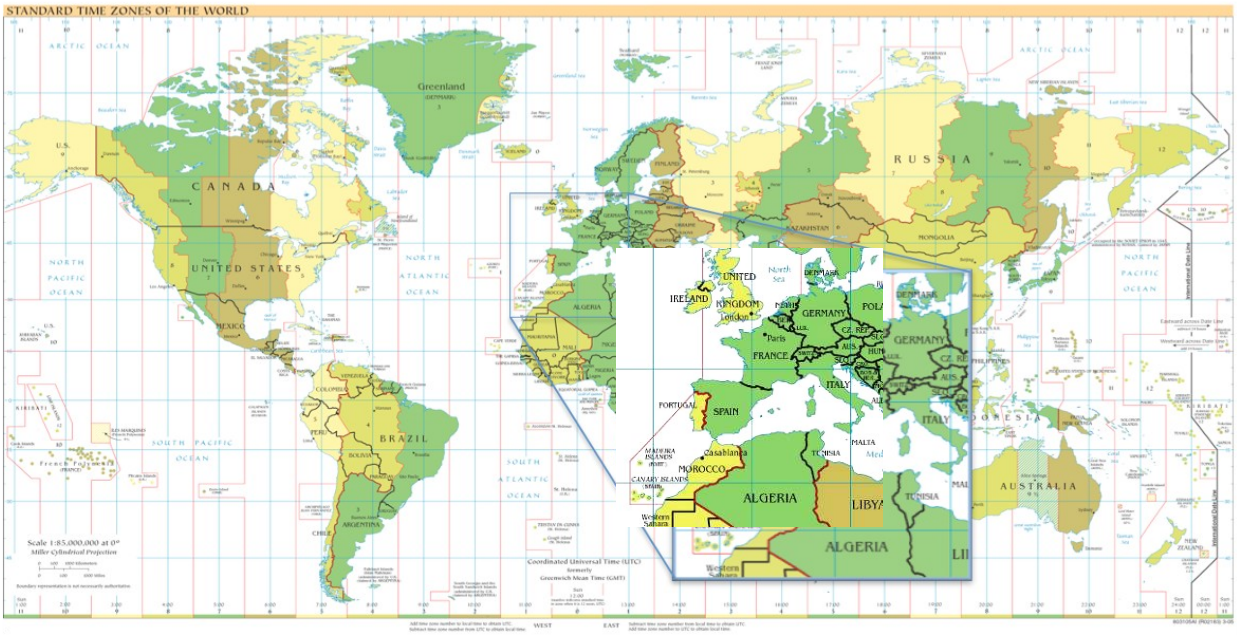

Figure 3.1: World time zones.

Sharing the same working day has the following benefits:

- Any work-related consultations or queries that arise between personnel located at the CTA and at other European organizations can easily be resolved without the delays that occur across different time zones. This is likely to impact positively on the hours of availability of the installation.
- It will make it easier to organize remote meetings (video conferences, conference calls, etc.).
- It will improve the ergonomics of travel between the CTA and other organizations in continental Europe (there will be no jet-lag from traveling across time zones).

3.5 Infrastructures for an Observatory is Readily Available

The Canaries count with two world-leading astronomical observatories, the "Observatorio del Roque de los Muchachos (ORM)" and the "Observatorio del Teide (OT)". Apart from being among the best, and best-characterized astronomical sites in the world, any infrastructure needed for the construction and maintenance of CTA-North is already available. A detailed description can be found in the separate chapter 9.

3.6 Exemption of Taxes

The Canary Islands Economic and Fiscal Regime (REF) Law of 1991 establishes a different taxation system in the Canaries from the rest of Spain. Especially the Spanish 18% VAT is not applied in the Canaries, instead the "Impuesto General Indirecto Canario (IGIC)", of only 5%. For this reason, products and services are usually cheaper in the Canaries than in the rest of Spain.

Moreover imported goods have to pay customs, the "tax on imports and deliveries of goods in the Canary Islands (AIEM)"[26].

The importation of materials and merchandise necessary for the functioning of the Observatories and telescopic installations of the IAC are exempt of the IGIC and the AIEM[27].

3.7 Site Synergies with Other Scientific Projects

In Spain there are now several ground facilities that allow to carry out radio (Yebes, IRAM, Robledo), optical/infrared (ORM, OT, CAHA) and VHE (MAGIC at ORM) observations. In addition, Spain is a member of ESA participating in several missions, such as the space observatories XMM-Newton and INTEGRAL, and is involved in future X-ray missions of ESA such as ATHENA or LOFT, as well as hosting the European Space Astronomy Centre (ESAC). Spain is also a full member of the European Southern Observatory (ESO), and participates in the VLT, ELT and ALMA observatories. Finally, Spain is full member of the CERN.

At present, there is an important feedback between research activities carried out in Spanish facilities and the Cherenkov telescope MAGIC. There are programs that monitor AGNs in the optical and infrared bands (for example, the Whole Earth Blazar Telescope (WEBT)[28] at the OT and the KVA telescope at the ORM) and alert MAGIC to observe blazars when there are strong flares. There are also similar programs that apply to different objects/phenomena, such as flares of transient objects and Gamma Ray Bursts (GRB). In some cases, some of these sources are followed by in-depth observations in the ORM and/or CAHA observatories. A clear example of the complementarities between instruments working at different wavelengths is the recent discovery in M87 that gamma rays and radio waves, both, often arise from the same regions. This was shown clearly when M87's most energetic gamma-ray flares, observed by MAGIC, were accompanied by the largest flare of radio waves seen from that galaxy by the radio interferometer VLBA. In a near future, the Spanish radio

[26] European Council Decision of 20 June 2002 on the AIEM tax applicable in the Canary Islands

[27] articles 14.10 and 6.7 of the Law 20/1991, from the 7 of June 1991

[28] see http://www.oato.inaf.it/blazars/webt/

astronomers will contribute to these kinds of discoveries through the use of the Spanish Yebes 40 meters antenna and the Robledo-NASA 70 meters antenna working together in the European VLBI Network (EVN), the most sensitive VLBI network in the world.

Moreover, on the nearby “Observatorio del Roque de los Muchachos” (ORM) on La Palma, 140 km from the OT, the “Gran Telescopio Canarias” (GTC), a 10,4 m segmented primary mirror telescope is found. The GTC project is a Spanish initiative, led by the IAC. An outstanding installation at the ORM is also the 4.2 m “William Herschel Telescope” (WHT), one of the most competitive of the world. With the WHT, the first evidence for the existence of a super massive black hole in the centre of the Galaxy was found. The WHT belongs to the “Isaac Newton Group”, a group of telescopes in which participate the UK, the Netherlands, Ireland and also Spain, through the IAC. The group operates also the “Isaac Newton Telescope” (INT), with which, in 1990, the most distant object until then was discovered, a quasar situated at 12,000 million light years from the Earth.

Sweden, Norway, Finland and Denmark built and operate the 2,56 m “Nordic Optical Telescope” (NOT), optimized to obtain very neat images in the optical and infrared. It is an ideal instrument to study the central zones of our Galaxy, occulted by interstellar dust clouds. This telescope also uses to follow-up GRBs, often being the first to yield a redshift measurement of their host galaxies.

Moreover, the “Telescopio Círculo Meridiano” is found at the ORM. This telescope is the most efficient worldwide to measure the position of celestial objects with high precision.

Italy has installed at the ORM its 3,58 m “Telescopio Nazionale Galileo” (TNG), a “new technology” telescope, which permits to obtain higher quality images than those from conventional telescopes.

The ORM hosts also the world-wide biggest robotic telescope, the “Liverpool Telescope” (LT) with a diameter of 2 m, belonging to the University John Moores, Liverpool, and MERCATOR, a 1,2 m telescope operated by the Catholic University of Lovaine, Belgium and dedicated to projects which require long-term observations of a same celestial object, like astroseismology, or flexibility in the assignment of observation time, like supernova explosions. Finally, the SUPERWASP, a small robotic telescope, is specialized for the search of extra-solar planets.

In the Very-High-Energy gamma-ray domain, the pioneering HEGRA telescopes operated at the ORM, until the arrival of the MAGIC telescopes, operative since 2003, and completed in 2009 by a second telescope for stereoscopic observations. The MAGIC collaboration also operates the 35 cm KVA telescope, mainly for optical monitoring of AGNs. Since this year, the smaller FACT telescope, equipped with a G-APD camera, has started observations aside the MAGIC telescopes.

3.8 Status of Outermost Region (OR) of the EU

The Canary Islands benefit, inside the legal framework of the European Union, from a special status as Outermost Region (OR).

Almost 4.3 million people live in the ORs, representing 0.9% of the total EU population. Among the 9 recognized ORs[29] of the UE, the Canaries count with the largest population and the highest economic value.

The EU recognizes the existence, inside the ORs, of geographic and economic realities different from the rest of Europe: remoteness, insularity, reduced surface, economic dependency on certain products, etc.

The article 349 of the Lisbon Treaty[30] provides a special recognition of the ORs. These areas are covered by EU law and the other rights and duties associated with EU membership, however there is a legal basis to adjust policy to their needs when necessary. The European Commission found[31] that the economies of ORs underperformed compared to the EU average: the level of the Gross Domestic Product (GDP) per head ranges from 92% of EU-27 in the Canaries to 49% of EU average in French Guyana, unemployment being significantly higher than in the EU-27. Despite of this, the policy of the European Union towards the ORs has taken into account a strategy of considering them as "opportunity regions" with a great development potential.

Since the "Programmes of Specific Measures for Remote and Insular Areas (POSEI)"[32] were launched in 1989, ORs have increasingly benefited from EU special treatments through targeted additional funds and instruments.

In the past, the main priorities were to improve access, competitiveness, and regional ties. The recent European Commission communication[33] "The outermost regions: an asset for Europe" however, advocates for an alternative approach, to turn the handicaps of ORs into assets. **For example, the ORs have geographical and geological characteristics that make them excellent laboratories for research in a number of fields**.

Many rules of EU law already take into consideration the special situations of ORs: An additional allocation, amounting to 35 euros per inhabitant per year, has been launched in order to compensate for the handicaps and constraints of the ORs, which cause additional production costs (such as transport, storage, maintenance, etc.).

Although investment in Research, Development and Innovation (RDI) in the Canaries remains below the national standard, it is considered a priority in order to guarantee competitive medium-term development, strengthened by the potential of the Canary

[29] Guadeloupe, French Guiana, Martinique, Réunion, Saint-Barthélemy, Saint-Martin, the Azores, Madeira, and the Canary Islands.
[30] available at http://europa.eu/lisbon_treaty/full_text/index_en.htm
[31] Monfort, P. "Territories with specific geographical features. Europan Commission, Regional Policy Working Papers no. 2009:02", 2009, available at http://ec.europa.eu/regional_policy/sources/docgener/work/2009_02_geographical.pdf
[32] see http://europa.eu/legislation_summaries/agriculture/general_framework/l13026_en.htm
[33] COM (2008) 642, available at http://ec.europa.eu/regional_policy/sources/docoffic/official/communic/rup2008/rup_com2008642_en.pdf

Islands in areas like maritime research, renewable energies, biotechnology and astrophysics.

The actual policy of the Autonomous Government of the Canaries with respect to the promotion of RDI activities focuses on an important increase in these areas, mainly in the private sector, and a diversification of the market, which nowadays depends strongly on the services sector, and there principally on tourism.

Open calls for RDI projects with predominant participation of the private companies, being this sector the possible beneficiary of the grants; grants for the incorporation of scientific and technical staff into the productive sector; technology grants; etc., are all examples of the new public measures in the Canaries to bring fourth RDI activities inside their own environment.

Although implementation of the initiatives in favour of the ORs concerning RDI forms mainly part of the FP7 program, the European Commission and the European Council are currently developing the new strategic development plan for the ORs for the period from 2014-2020, with the aim to increase their competitiveness and to favour a cohesion policy with the rest of the European region, **guaranteeing dedicated funds for them**.

It is also worth to mention that the European Commission will adopt, in 2012, a communicate in which it will explicitly outline the new strategy that the European Union will apply in favour of the ORs for the period from 2014-2020. For this reason, there will be a clear opportunity for the Canarian government to influence the priorities of the funds dedicated to large scientific infrastructures.

3.8.1 Synergies between the FP7 program and the status of OR

Although the Programme of Community Action on RDI is being implemented since 1984, it is only now, with the FP7 call that a priorization towards the ORs has been obtained, including a specific action, inside the FP7 programme, named "**Capacities**".

This programme has the aim to turn on the scientific potential of these regions and to improve their integration into the European Research Area (ERA). The achievement translates into a budget item of **340 million euros**[34] centred, among other priorities, **on transnational cooperation of research staff, recruitment of experienced researchers, acquisition and development of scientific equipment and the organization of conferences and promotion activities to ameliorate the visibility of OR research centres**.

Complementary to that, the **FP7 programme foresees special actions to finance the construction phase of large research infrastructures, under the programme**

[34] see http://cordis.europa.eu/fp7/capacities/convergence-regions_en.html

“Capacities”. In this sense, the construction phase of large infrastructures will be financially supported using, among other measures, the complementarity of the national and communitarian instruments (like the structural funds or the European Investment Bank). In addition, the scientific excellence potential of the ORs will be taken into account, if installed there, in order to facilitate economic support to those priority projects whose borrowing need is considered critical (e.g. direct subsidy, loan from the European Investment Bank, use of the Risk-Sharing Finance Facility, etc.).

CTA-North would benefit directly from these mechanisms if installed in the Canary Islands.

4 The Canary Island of Tenerife

Tenerife is the largest island of the Canarian Archipelago. It has a surface area of 2,034 square kilometres and lies in a central position between the islands of Gran Canaria, La Gomera and La Palma. It is located over 1000 kilometres from the Spanish mainland.

4.1 History and Demography

The Canary Islands have always been present in myths and legends. Classical writers have placed Paradise, the Elysian Fields and the Garden of the Hesperides here.

When the Spanish conquistadors arrived in Tenerife, the island was divided into nine small kingdoms with a king, or mencey, in charge of each, advised by his council of elders, or tagoror. Tenerife was the last island of the archipelago to be conquered in 1495.

Tenerife has always been close to America, being an obligatory stopover for ships traveling to the New World. The people of Tenerife have played an active role, as colonists, in the birth of new cities and nations. It was island families, for example, who founded the cities of Montevideo and San Antonio, Texas. Venezuela and Cuba were the traditional destinations for emigrants from Tenerife.

Owing to their geographical location, Tenerife and the other Canary Islands have always maintained certain economic and administrative peculiarities compared to the rest of Spain. These differences were set down in the Law of Free Ports at the end of the 19th century (1872); and recognized in the creation of the Island Councils, similar to a sort of government for each island (1912), and the Canary Islands Economic and Fiscal Regime (REF) Law of 1991.

In 1982, the Canary Islands became an Autonomous Region and in 1986, the islands were integrated into the European Union, along with the rest of Spain. Today, the archipelago's position in Europe is defined as an Outermost Region (OR) in the Maastricht Treaty (1992) and the Amsterdam Treaty (1997) and is recognized by the project for a European Constitution, in the Lisbon Treaty (2004), and the ORs Statute.

Today, the territory provides a home for more than 800,000 inhabitants, and boasts two of the three cities of the Canary Islands with more than 100,000 inhabitants, Santa Cruz and La Laguna. Tenerife has population density of about 400 inh/km^2 (see figure 4.1). Each year several thousand new residents relocate to the island, mainly coming from Great Britain, Venezuela and Germany[35].

The shape of the island looks like an irregular triangle. Its three corners are formed by the Anaga, Teno and Adeje Massifs and at its centre, rising above the Cañadas Caldera is Mount Teide, the highest mountain in Spain at 3,718 metres above sea

[35] Canarias en Cifras 2007-2008, Instituto Canario de Estadística, available at www.planculturacanarias.net/uploads/Canarias-en-cifras-2008.pdf

level.

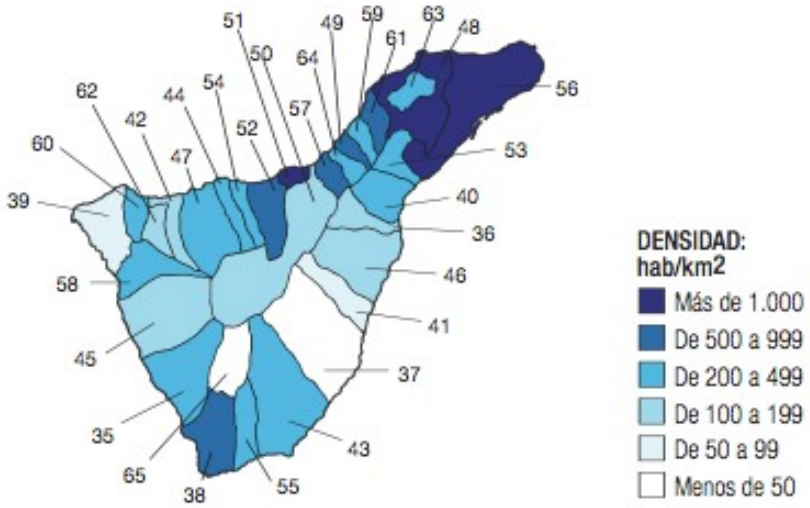

Figure 4.1 Population density of Tenerife in 2007.

4.2 Climate and Vegetation

Tenerife is an island of contrasts, marked by the fact that it has grown up around the volcano of El Teide and the mountain range that begins at its summit and forms an elevated crest running from east to west. This geographical feature gives the island abrupt changes in altitude and temperature, as well as a changing, diverse climate, which can differ from one street to another, and is known under the term of microclimate. The coast, the mid-slopes and the summit represent the island's three natural ecosystems.

The island territory is shared by desert landscapes on the coast, subtropical forests on the mid-slopes and summits, and volcanic areas, in particular in the Teide National Park and its volcanic cone.

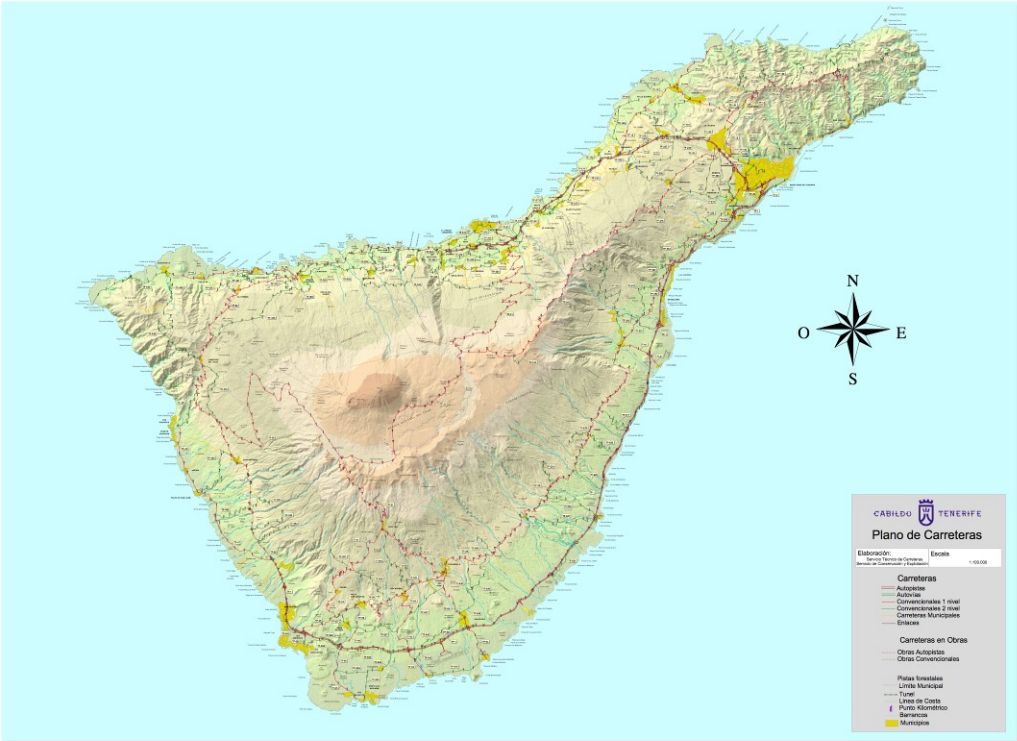

Figure 4.2 Official map of Tenerife[36]

Out of the seven Canary Islands, Tenerife is the biggest one and hosts most of the biological diversity. The efforts to conserve it by the island's institutions and citizens are increasing every day. Today over half of its territory is protected and there are almost 50 sites of ecological interest listed. The most famous is the Teide National Park, one of the four national parks in the Canaries, and the most visited in Spain. The exceptional ecological value of Tenerife includes over 1000 species of flora and fauna with up to 140 species being endemic to this island only. It also has a growing number that are in severe danger of becoming extinct.

In the high-mountain area, above 2000 m, arid climate and strong sunlight prevail. Flora well adapted to the conditions give rise to unique ecosystems such as the alpine broom, the Vipers bugloss, the Teide white broom, the Teide violet and the endemic cedar (Juniperus cedrus). There are a total of 139 known species of vascular flora in the park, a third of which are native to the Canary Islands. The mountain's fauna is dominated by invertebrates, with over 400 species, of which nearly 70% are native to the area, insects being the most abundant group.

There are no dangerous or poisonous animals living on the island.

4.2.1 The Teide National Park[37]

[36] see http://www.tenerife.es/wps/portal/tenerifees
[37] C/ Emilio Calzadilla, nº 5. 4º piso, 38002 S/C de Tenerife, Tel. 922 290 129, pnteide@teleline.es

The area was declared National Park in 1954 and its protected status strengthened further in 1981 and 1984[38]. It prohibits all type of construction inside the National Park, except for signposting and scientific use, previously authorized. The area consists of a large oval-shaped caldera of 14-kilometer diameter and covers and area of 18,990 ha. It is surrounded by a "pre-parque" zone, designed to protect the National Park from detrimental influences from the direct surroundings, e.g. wood fires, etc. In 2007, the UNESCO declared the Teide National Park a World Heritage Site.

The Teide National Park receives 3 million visitors each year during the day. It is the most visited national park in Europe[39], an enormous benefit for the divulgation of the CTA project.

Figure 4.3 The Teide National Park[40]

4.2.2 San Cristóbal de La Laguna

San Cristóbal de La Laguna is a municipality located in northeastern Tenerife, only 10 km from the current capital Santa Cruz de Tenerife. It is declared a UNESCO World Heritage City, has an exceptional, universal value due to the concept of its town plan. This historical site is the archetype of city-territory. It is the first example of a non-fortified town, conceived and built according to a plan inspired by navigation, the science of the time by 1500 AD. It was the capital of the islands until the 19th century.

The town map can actually be read as a "stellar map" in which the dots indicate particular points in the city and the links between these points and the town as a whole. It has a symbolic meaning and should be interpreted as a marine map or a map of the stellar constellations. The characteristics of the city of La Laguna set the tone for the

[38] Law on Reclassification of 1981 Real Decreto 2423/1984, de 14 de noviembre. (B.O.E. 39, 14 de febrero de 1984) and Use and Management Master Plan (PRUG) Decreto 153/2002, de 24 de octubre. (B.O.C. no 164, 11 diciembre 2002).
[39] Diario de Avisos, 30 July 2010.
[40] Picture from http://www.webtenerife.com/Destinos-y-lugares/Parque-nacional-del-Teide/PARQUE+NACIONAL+DEL+TEIDE.htm?Lang=es

new cities in America. The city is home to approximately six hundred well-preserved original Mudejar buildings and is a living example of the exchange between European and American culture, a culture the city has maintained strong ties with over the centuries.

Figure 4.4: A photo of La Laguna's centre at night[41].

The **University of La Laguna[42], founded in 1792 is located in La Laguna** and its various campuses (Central, Geneto, Guajara and Ofra) receive students from all over the archipelago and even from the mainland, especially for Astrophysics studies.

This University continues to educate thousands of students every year in all kinds of university studies: it offers over 50 different degree subjects and over 30 master studies. As of the academic year 2009/2010, the university had 25,000 students, 1,764 professors and 843 administrative and services employees. Among the master studies, the master on Astrophysics has an outstanding quality award: "Mención de Calidad".

La Laguna also hosts the main headquarters of the Instituto de Astrofísica de Canarias (IAC)[43] as well as some institutes of the Consejo Superior de Investigaciones Científicas (CSIC, the Spanish National Research Centre).

La Laguna is only 40 km from the "Observatorio del Teide", less than 1-hour drive on a paved road.

4.2.3 The North of the Island

The north of the island, from Tacoronte to Buenavista del Norte, enjoys a pleasant subtropical climate, wetter and cooler than the rest of Tenerife. After the conquest, the north was the most important area in terms of population and industry. Although they are not as important today, the towns still preserve their rich heritage based on trade with Europe. Puerto de la Cruz, Valle de la Orotava and the Isla Baja are the main tourist areas in this part of the island[44].

[41] Picture from: http://www.visitlalaguna.es/en/localizacion_laguna.jsp
[42] see http://www.ull.es/view/institucional/ull/Inicio/en
[43] see http://www.iac.es/index.php?lang=en
[44] Source: http://www.webtenerifeuk.co.uk/Sobre-Tenerife/La-isla/islas-canarias/TENERIFE.htm?Lang=en

Figure 4.5 Caserío de Masca[45].

4.2.4 The South of the Island

In the south, from Candelaria to Santiago del Teide, the climate is the warmest and driest on the island. Here you have the main tourist resorts and the largest farming areas, inside greenhouses. The south, for years the least populated and most isolated area of the island, is now experiencing the fastest growth and development.

More about Tenerife can be found on the official website of the Canary Islands:

http://www.turismodecanarias.com/canary-islands-spain/tourism-office/tenerife-island/index.html

Figure 4.6 Malpaís de Güímar[46] in the South of Tenerife.

[45] Picture from: http://www.webtenerife.com/Destinos-y-lugares/Pueblos-y-caserios/Masca.htm?Lang=es
[46] Picture from: http://www.webtenerife.com/Destinos-y-lugares/Otros-espacios-naturales/MALPAIS+DE+G%C3%9CIMAR.htm?Lang=es

4.4 Economic Issues of the Island

Tenerife is divided into 31 administrative districts grouped together in three different zones.

The city of Santa Cruz de Tenerife, the capital, and the adjoining districts of La Laguna, Tegueste and El Rosario make up the metropolitan area of the island creating an important business, commercial and cultural centre.

The predominant economic sector in the Canary Islands is the services sector (see figure 3.2) and specifically tourism, which is still the main engine of the Canary Islands' economy. The primary sector has been gradually reduced over the last decades.

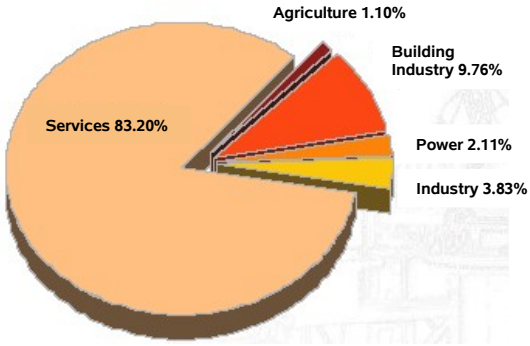

Figure 4.7: The Canary Island's economy by sector

Industry in the Canaries relevant for CTA include RDI companies, chemical companies including nitrogen and helium supplies, industrial oil, liquid coolants and diesel, metallurgy industry, electrical installation, climate control, shops and hotels, transport and communications, building rental, maintenances, fire protection, security equipment, conference venues, events organization, courses and water transportation.

Expenditure by OT and ORM user institutions demonstrate that local enterprises in the Canary Islands have the capacity to deliver at least 70% of the services, materials and supplies needed for building and operating CTA-North. Main shortages were only found in goods and services provided by specialist sectors including electronics and optical components, new technology development and large industrial contracts.

Tenerife produces and consumes about 8 million MWh electric energy each year, out of which about 93 per cent were produced by petrol in 2011. It is foreseen[47] to reduce the dependency on petrol via diversification of the energy provision. The aim is to create 28% of the energy demand by 2015 with natural gas and renewable energies, especially wind and solar energy.

[47] Plan Energético de Canarias 2006 (PECAN2006), elaborado por la Consejería de Industria, Comercio y Nuevas Tecnologías del Gobierno de Canarias, available at http://www.agenergia.org/files/resourcesmodule/%40random499e7c461536b/1235126986_Resumen_PECAN_2006.pdf

About 80% of the islands water supplies come from collected subterranean waters, the rest from salt-water desalination plants. The island also has wastewater treatment plants that enables treated water to be re-used for different types of consumption. On the other hand, Tenerife also has plants that improve the quality of the subterranean waters by reducing the excessive mineral and salt content[48].

Average yearly housing prices in Tenerife are currently 1,500 euros/m^2, about 25% less than the Spanish average[49]. The monthly labour cost (ULC) lies at 2,077 euros, about 16 euros per effective working hour. Tenerife counts with a 29% unemployment rate.

Average electricity costs were 0.16 euros/kWh during day and 0.068 euros/kWh during night in 2011 for individuals[50]. Big consumers may obtain additional significant reductions. The biggest electricity company in Tenerife is "Unelco Endesa"[51], followed by "Iberdrola"[52].

4.5 History of Astrophysics in Tenerife

"When night falls and our last glimpse of the peak still remains high in the sky, we wondered how long the enlightened world delay the installation there of a station that promises much for the better advancement of the most sublime of Sciences"[53].

The quality of the sky over the Canaries has long been recognised. As far back as 1856 the Royal Scottish Astronomy Association performed a series of experiments at mountain tops on the island of Tenerife which led them to conclude that the sky over the Canary Islands were perfect for astronomical observations.

Astrophysics in the Canaries began in the early sixties with the first telescope to study zodiacal light in 1964. In 1968, a number of European institutions worked together on a joint campaign to gather data for characterising a number of sites for solar observation. They compared 40 different sites and ultimately concluded that the best conditions were to be found in Tenerife and La Palma[54].

In 1979, Spain signed the "Agreement and Protocol for Cooperation in Astrophysics" with several other European countries, which led to the creation of the OT and the ORM. One of the most emblematic telescopic installations at the OT was the "Telescopio Solar VTT", a classic solar telescope based on a coelostat (two mirrors), which, on the other side of the tower, introduce the light into a telescope, guiding the light through 10 floors of the tower.

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[48] from "Tenerife island wáter board", see http://www.aguastenerife.org/
[49] Instituto Canario de Estadística (ISTAC) 2011 http://www2.gobiernodecanarias.org/istac/dw/indicadores/coyunturaeconomica/lstIndicadores.jsp?codAplicacion=32
[50] less than 10 kW yearly, see http://www.minetur.gob.es/energia/electricidad/Tarifas/Tarifas2008/Paginas/precios.aspx
[51] see www.endesaonline.es
[52] see www.iberdrola.es
[53] "Tenerife: An Astronomer's Experiment", Charles Piazzi Smyth, 1858.
[54] Vistas in Astronomy, 28, 437,1985.

In the mid-seventies, the “Instituto de Astrofísica de Canarias” (IAC) was created. This institute under public consortium management since 1982, currently shared by the Ministry of Economy and Competitiveness, the “Consejo Superior de Investigaciones Científicas” (CSIC), the University of La Laguna (ULL) and the Autonomous Government of the Canary Islands. Its headquarters are situated at La Laguna, engaging professors of the named university, researchers from the CSIC, now officials of the Canary Islands, and finally researchers from the ministry to form an own stable workforce.

The creation of the IAC in the Canary Islands certainly responded to the possibility of exploiting their high-quality sky for astronomical purposes. The signature of the “International Agreements on Cooperation in Astrophysics, 1979” provided the framework for consolidating the presence of instruments of the highest quality for the observation of the sky in the Canaries. The signatories of these agreements were, initially, United Kingdom, Denmark, Sweden and Spain, which have been joined later by Germany, Belgium, France, Holland and Italy. A highlight at that time was the transfer of the 2.5-meter “Isaac Newton” Telescope from Herstmonceux, in the southeast of England, to the ORM, where the conditions of observation, due to the sky quality, make it a highly productive instrument.

With the time, the IAC has happened to become the largest research centre in virtually all disciplines of Astronomy in Spain, and also a major reference in Europe and the world. Its scientific production exceeds 25% of the total scientific production of Spanish astronomy, in line with the number of researchers it hosts.

The IAC is a research centre in almost all subjects of astronomy, but it dominates the Spanish scene in solar physics, the search and characterization of exoplanets and everything related to the design and development of telescopes and optical and infrared instrumentation. Stellar physics, extragalactic astronomy and cosmology are also part of the broad spectrum of topics in which the IAC retains an important activity.

In 1988, the Law 31/1988 “sobre Protección de la Calidad Astronómica de los Observatorios del Instituto de Astrofísica de Canarias”, commonly known as the “Sky Law”, was published, with the aim of creating an “Astronomy reserve” on the islands by protecting the darkness of the sky, limiting radio frequency emissions, air routes and controlling light pollution.

Since 1990 the IAC has operated the “Sky Quality Group”, whose mission is to continuously characterize the observatories, using instruments and techniques to gather data for a long-term database that can be contrasted and compared with other high level observatories. The “Site Properties Sub-Committee” (SUCOSIP) was created at the same time, under the auspices of the International Science Council, to advice on infrastructure project sites at the Observatories. Its main purpose is to ensure that no new installation has an adverse effect on observing conditions for existing telescopes.

4.6 Social Perception and Valuation of Astronomy

The population of Tenerife is steeped in the importance of the observatory and its present and future facilities. It sees in them and in the quality of the sky the differentiating factor that allows both La Palma as Tenerife to attract quality tourism based on activities for observing the sky.

The spread of the Sky Law especially has raised awareness to the inhabitants of La Palma, who not only appreciate and value the sky but also have assumed the importance of preserving it.

On the other hand, from the headquarters of the IAC, in La Laguna, a major effort has been made to raise awareness among residents and visitors to the island of Tenerife, bringing them closer the science performed at both observatories, stressing at the same time the importance of caring for the night sky and minimizing all possible negative impacts on it.

No doubt many of the inhabitants of the Canary Islands are conscious of living in a unique place, where you can observe the sky like only in a few places in the world and hence astrophysics as an experimental science has arisen wider interest in the Canarian society.

5 The “Observatorio del Teide” (OT) as a Candidate Site for CTA-North

The basic requirements for the installation of CTA are quite restrictive as they include not only good meteorological conditions and clear skies for astronomy, but also suitable geographical conditions, among them a flat area of about 1 km^2 above 1500 meters.

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

A specific National Law protects the quality of the sky in these observatories[55]. Whereas night pollution at the ORM at La Palma is slightly lower than at the OT at Tenerife, **the island of La Palma does not fulfil the CTA requirement of having a flat land of 1 km^2 above 1500 meters. Tenerife, on the other hand, has this area available** at a place located near the OT, which fulfils all the requirements established by the CTA Consortium. Furthermore, contrary to what one would naively expect, night light pollution in Tenerife is constantly decreasing with time, due to the fact that local authorities are gradually changing the classical streetlamps for new ones that do not shed light into the upper sky.

5.1 The Canary Islands’ astrophysics observatories

The excellent astronomical quality of the sky over the Canaries, which has been comprehensively characterized and is protected by Law, makes the two observatories of the “Instituto de Astrofísica de Canarias” (IAC) an “astronomy reserve” which has been open to the international scientific community since 1979, as a result of the Agreements for Cooperation in Astrophysics[56].

Currently, the OT at Tenerife and the ORM at La Palma are home to more than 25 telescopes and instruments belonging to some 60 institutions from 20 countries.

The ORM and OT are the most important observatories for optical, infrared and VHE gamma astrophysics within the territory of the European Union. Other first-class facilities for high energies, microwave, training, etc., are also present at these sites.

The International Scientific Committee (CCI) coordinates the activity of those Institutions

[55] “Ley 31/1988 del 31 de Octubre, sobre Protección de la Calidad Astronómica de los Observatorios del Instituto de Astrofísica de Canarias”.
[56] BOE 6 July 1979 and BOE 14 October 1983.

operating at the IAC Observatories.

The observatories have been considered and remain in consideration by the EU as Large-Scale Research Facilities under the successive Framework Programmes for Research and Technology Development. On a national level, the observatories are considered Singular Scientific and Technological Infrastructures (SSTI), alongside some fifty facilities for other scientific disciplines across Spanish territory. Together they form the SSTI map, a vital resource for improving and increasing the competitiveness of science, technology and innovation in Spain. The SSTI infrastructures are all unique in their field and extremely costly to build and maintain. They are designed to deliver progress in experimental science and technological development, and they also stimulate business and the local economy in the areas where they are located.

5.2 General description of the OT

The OT is located at an altitude of 2,400 m in the Izaña region of the island of Tenerife. It covers a surface area of 50 hectares and houses around fifteen telescope installations and other specialized astrophysical instruments.

Astrophysics in the Canary Islands began in the early 1970s at this Observatory.

The OT's geographical position (between the eastern and western solar observatories), together with the transparency and excellent astronomical quality of its sky, means that it is generally dedicated to work on solar physics and is home to the best European solar telescopes. Foremost among them are THEMIS and the German GREGOR and VTT, as well as instruments for studying solar seismology.

In addition to these instruments for solar observations, the OT has a number of other telescopes, such as the "Carlos Sánchez Telescope" (TCS), a very productive instrument that introduced many Spanish astronomers to the specialty of infrared astronomy. The latest generation of robotic telescopes is represented by STELLA, which consists of "twin" telescopes with complementary instrumentation. The European Space Agency's Optical Ground Station (OGS), which was built for laser communication with orbiting satellites, is also used for tracking space debris. The IAC80 telescope, which was designed and built at the IAC, is used for observing objects with long-term variability and as a test-bed for new instruments as well as for teaching astronomy to graduate students and young researchers.

There are also other highly specialized telescopes, like STARE, which is used as an "exoplanet hunter", and the QUIJOTE, which is used to study the polarization of the

cosmic microwave background (CMB) radiation. In fact, since 1984 the OT has been the location and determining its angular power spectrum at scales ranging from just a few degrees to several arc minutes.

The OT also houses several robotic telescopes like the UK's Bradford Robotic Telescope (BRT); and the Optical Telescope Array (OTA), which has two automatic domes with a meteorological station, two Schmidt Cassegrain reflecting telescopes, two robotic telescope mounts and an All Sky camera.

Other telescopes and instruments are continuously being located at the OT.

5.4 The Pre-selected Candidate Site for CTA-North

The pre-selected site in Tenerife is a plateau at an altitude of 2260 meters a.s.l. with the geographic coordinates 28º16'36'' N and 16º32'08'' W. It has the great advantage of being located at only 3 km from the OT, which has all kind of infrastructure for an observatory available, and only 5 km away from the Izaña Atmospheric Observatory, where the atmosphere is extensively characterized.

Figures 5.1 and 5.2 show the exact location of the pre-selected Spanish candidate site for CTA-North (green circle of 1 km^2) near the OT.

Figure 5.1: The Tenerife Island with the OT pinpointed in yellow and the location of the pre-selected Spanish candidate site for CTA-North, represented by a green circle[57].

Figures 5.2 and 5.3 show close-up views of the site, together with bottom panels that measure the altitude around or across the CTA green circle. The figures show that this plateau has always a slope of less than 5% and is flat enough to fulfil the CTA requirements.

[57] Figures from Google Earth

Figure 5.2: Close-up of the CTA-North Spanish candidate site (green circle) and the OT. The Teide peak (white, left) is also visible[58].

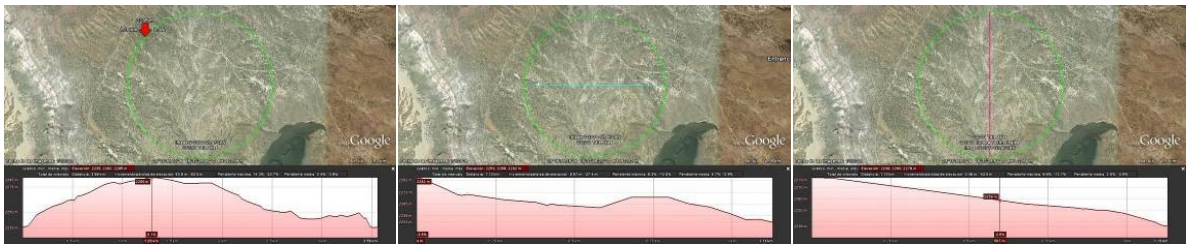


Figure 5.3: Left: altitude along the circle inside which CTA-North would be built. The maximum elevation is found at 2285 m (NW of the circle) and the minimum one at 2235 m, showing a maximum difference of 50 meters. Centre: altitude along the E-W diameter (in blue). The minimum elevation is 2251 m and the maximum one is 2280 m, showing a maximum difference of 30 meters. Right: altitude along the N-S diameter (in pink). The maximum elevation is 2279 m and the minimum one is 2236 m, showing a maximum difference of 45 meters[59].

Figure 5.4 shows two pictures taken from a hill next to the pre-selected candidate site for CTA-North: the first one taken by day and the second one during the night.

[58] Figures from GoogleEarth
[59] Figures from GoogleEarth

Figure 5.4: Picture of the pre-selected location for CTA, taken from a hill next to the pre-selected candidate site for CTA-North**:** By day (top) and by night (bottom). Note the good visibility, as you can see the island of Gran Canaria, about 100 km away. Some clouds below the altitude of the site can also be seen, just over the ocean. The night picture exhibits the exceptional quality of the sky.

5.4.1 Type of soil

The type of soil is strong, since the Canaries are volcanic islands emerged in the Atlantic Ocean, where strong basaltic layers can be found few meters below the organic soil.

5.4.2 Ownership

The proposed site is public land. All authorities (at local and national levels) related to the development and use of the site have already been contacted and are aware of this candidacy.

5.4.3 Electricity

The OT has currently 0.7 MW free capacity, which can serve the CTA installations (see also chapter 9.1). A power line for the last 3 km to the site will be built in case CTA-North is located in Tenerife.

5.4.4 Communication

The site is **excellently communicated**: 30 km paved road (except for the last two kilometres) to the next town – La Orotava. The closest airports, the largest harbour of Tenerife, the closest hospital and gasoline station, and finally La Laguna, where the IAC headquarters are found, are all accessible within less than one hour of drive. One can even take a cab, at a very convenient price, to get there.

Please have a look at chapter 9 to get a closer look at all the facilities and infrastructure available for this site.

5.4.5 Geomagnetic Field

We have computed the geomagnetic field at that location using the service provided by the US National Geographic Data System[60], using the model IGRF11 and the first of January of 2015 as reference date, although the value of the Geomagnetic field has a very weak dependence on these values. The result we get for the module of the field and its horizontal component are:

$$|B| = 38{,}5\ \mu T \quad |B_{horiz}| = 30{,}8\ \mu T$$

In the latitude band around 30° where the candidate sites for CTA-North will likely be located, differences in Geomagnetic field are small and their effects for CTA performance, although still not completely understood, do not seem to be determinant. The more relevant quantity, i.e. the component of the magnetic field orthogonal to the shower axis direction, depends strongly on the observation direction. This dependency is certainly stronger than the variations resulting from placing the observatory in different locations within the latitude band considered for the CTA-North site. Therefore, conclusions about the instrument performance in different sites should consider the whole range of observation directions and be very carefully assessed.

[60] http://www.ngdc.noaa.gov/geomagmodels/IGRFWMM.jsp

6 Climate, Weather Conditions and Atmospheric Quality in the Region of Izaña

A big part of the information in this section has been obtained from the Meteorological State Agency of Spain (AEMET) webpage[61], as well as from one of its research centres', the Izaña Atmospheric Research Centre (IARC), webpage[62]. Several of the paragraphs are word-for-word citations. We are very grateful to these institutions for the fruitful public information provided.

We are also very grateful to the Sky Quality Group (SQG) of the IAC[63] for their collaboration as well as to the Sky Quality Protection Technical Office (OTPC)[64] for supplying information on the night sky background.

Access to the best possible scientific quality for observations is the key factor that ultimately decides the site for major research installations. Given this, it is evident that the quality of the sky in the Canary Islands puts the "Observatorio del Teide" on the island of Tenerife at the forefront of the worlds leading observatories. The excellent conditions at the Observatory result from the Canary Islands' geographical location and their orography, the continuous characterization of their skies and the legal measures in place to protect sky quality.

The astronomical quality of an observatory is largely determined by the **transparency of the sky** above it and the number of useful hours of observation it offers each year (**useful time**). These two constraints are intimately bound up with the site's climate and geography.

The Canary Islands have **excellent conditions for astronomy** for the following reasons:

- They are close to the Equator and **out of the range of tropical storms**.
- The Observatories are at an altitude of 2,400 m, **above the thermal inversion layer** located around 1,000 – 1,600 m a.s.l.) which separates the moist marine layer below it from the free troposphere above. This ensures that the installations are in the free troposphere, above what is known as the "sea of clouds", where the **atmosphere is frequently clear, clean and free from turbulence**.

[61] http://www.aemet.es/es/portada
[62] http://www.izana.org/
[63] http://www.iac.es/site-testing
[64] http://www.iac.es/servicios.php?op1=28

6.1 The Izaña Atmospheric Research Centre and the Izaña Atmospheric Observatory

Tenerife hosts an important centre for research of the atmosphere, the **Izaña Atmospheric Research Centre (IARC)** and a high-altitude atmospheric observatory in the Izaña region, the **Izaña Atmospheric Observatory (IZO)**, both belonging to the **Meteorological State Agency of Spain (AEMET)**. The Izaña Atmospheric Observatory is located **only 5 km from the candidate site for CTA-North**.

The IARC, which is part of the Department of Planning, Strategy and Business Development of the AEMET, carries out, among other activities, environmental developments and international research projects. The IARC conducts monitoring and research related to the atmospheric constituents that are capable of forcing changes in the climate of the Earth (green-house gases and aerosols) and of those that play key roles in the air quality from local to global scale. The IARC contributes to the World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) system with the high altitude IZO and to the GURME program, with the Santa Cruz de Tenerife Observatory (SCO)[65].

IZO is not only a GAW station. It is also an observing site for the Network for the Detection of Atmospheric Composition Change (NDACC), as well as a Baseline Surface Radiation Network (BSRN) station. Moreover, it is one of the two platforms worldwide for calibration of the Cimel sun photometers of AERONET (Aerosol Robotic Network), a worldwide program of NASA for atmospheric studies.

Most of the data presented in this report (meteorological data as well as the data related to atmospheric quality) stem from the IZO, which is located at 28º18' N, 16º29' W, at 2373 m a.s.l. about 2 km from the OT and 5 km from the candidate site for CTA-North. It was inaugurated in 1916, being almost 100 years old now. The observatory is located on the top of a mountain plateau in the pre-national park area of the Teide National Park and is environmentally protected by the "Sky Law" (see Chapter 7). IZO lies normally above the quasi-permanent temperature inversion layer and is hence free of local anthropogenic influences and clouds.

Figure 6.1 shows the IZO's relative location to the OT and the candidate site for CTA-North.

[65] Specific research and monitoring programs such as aerosol programs can be found here: *http://www.izana.org/index.php?option=com_content&view=article&id=91&Itemid=24&lang=en*

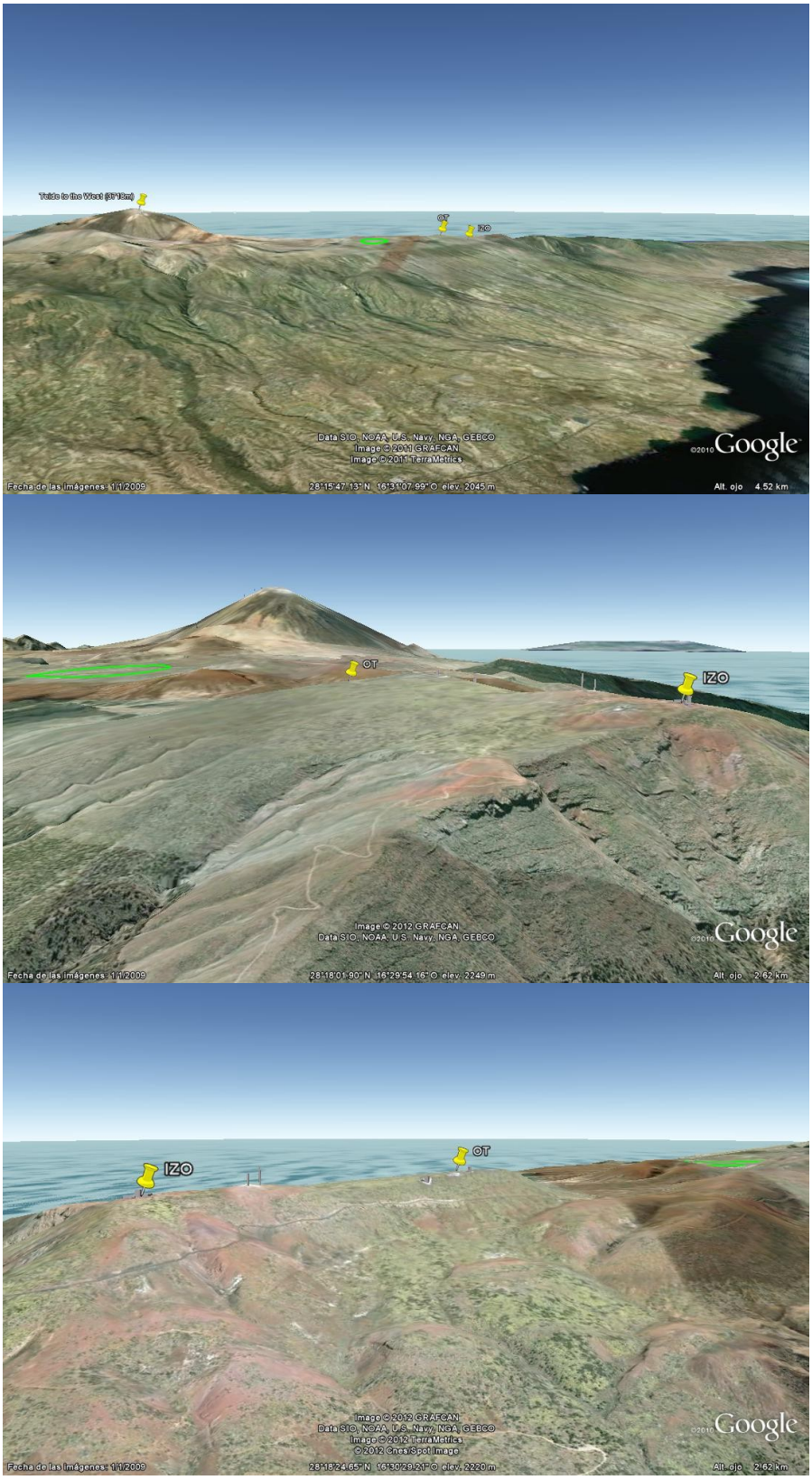


Figure 6.1 The IZO's relative position to the OT and the CTA-North candidate site (green circle of 1 km^2)[66].

6.2 Climate in the Region of Izaña

[66] Figures from GoogleEarth.

The atmosphere in the subtropical region of the Canary Islands is characterized by its great stability throughout the year. This is due to the combination of two processes of the atmospheric circulation at large scale[67]. One of them is the descending branch of the Hadley cell around 30º N and the other one the Trade or Alisios Winds coming from the Azores high area that blow in the low troposphere above an ocean which is relatively cold. As a result of these two processes, a temperature inversion layer appears around 1300 m a.s.l. on average, called the "**Alisio inversion**", which can be usually well identified by the "sea of stratocumulus" on the northern coasts of the islands. 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 has a seasonal dependence, being higher and thinner during the winter (when it is located between 1350 and 1850 m 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)[68].

Figure 6.2 Picture from the Space Shuttle Atlantis, STS 101.

At the Izaña region, above 2000 m a.s.l., clean air and clear sky conditions are prevailing all around the year.

The reason is two-fold: it is located above the stable inversion layer, in the free troposphere, and it is situated on an island far away from any significant industrial activities (and protected by the "Sky Law", see chapter 7). Consequently, it offers excellent conditions for in-situ measurements of trace gases and aerosols under free troposphere conditions, for atmospheric observations by remote sensing techniques (like the IZO) and for astronomical observations (like the OT). The environmental conditions and pristine skies are also optimal for calibration and validation activities[69].

6.3 Temperature, Humidity, Wind and Precipitation Measurements

[67] see e.g. Palmén E. and Newton C.W "Atmospheric circulation systems" International Geographic series, vol 13, Academic Press Ed., 1969.
[68] see e.g. Torres C. et all "Characterization of the marine boundary layer and the free troposphere in the subtropical region over Canary Islands", 3rd Hispanic-Portuguese Assembly of Geodesics and Geophysics, 2002.
[69] Izaña is one of the two places in the World for calibration of the Cimel sun photometers inside the AERONET NASA program.

Most of the data presented in this section are **public**[70]. They have been measured at the IZO, located at 5 km from the pre-selected site for CTA, and processed by the Meteorological State Agency of Spain (AEMET). The database **spans almost 100 years** from 1915 (or later on, depending on the parameter) to present. Daily averages correspond to 24-hour averages, not only daylight time.

6.3.1 Temperature measurements

The average temperature at the OT is 9.8ºC, with average minimum and maximum averages being 5.9ºC and 13.6ºC respectively[71]. These agree with the temperatures measured at the nearby IZO observatory, yielding an **average annual temperature around 10ºC**, for the period from 1915 to 2000, and average minima and maxima around 6ºC and 13ºC, respectively (see figure 6.3).

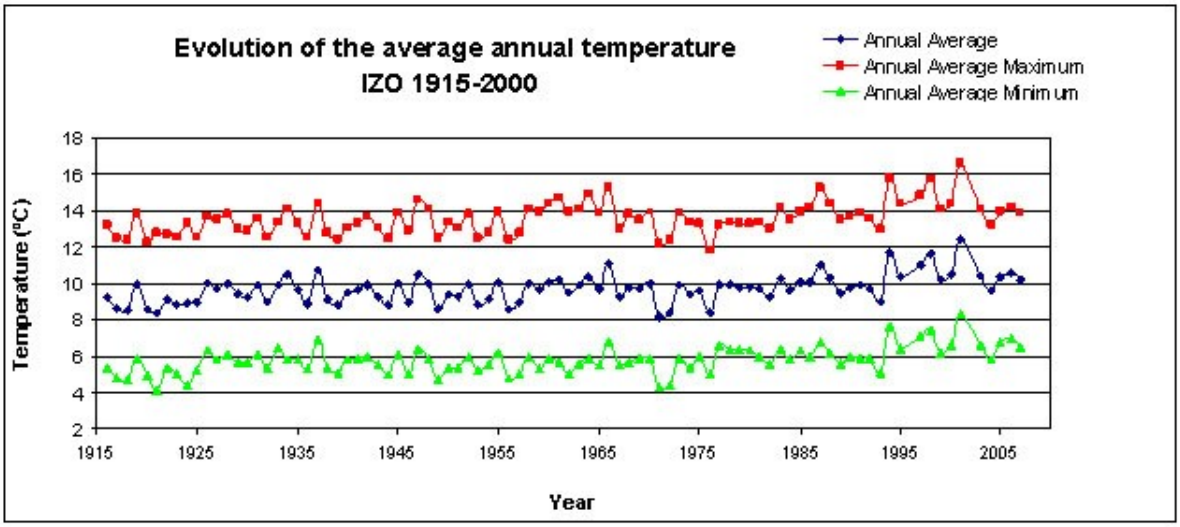


Figure 6.3: The evolution of the average annual temperature, average annual minima and average annual maxima at IZO[72].

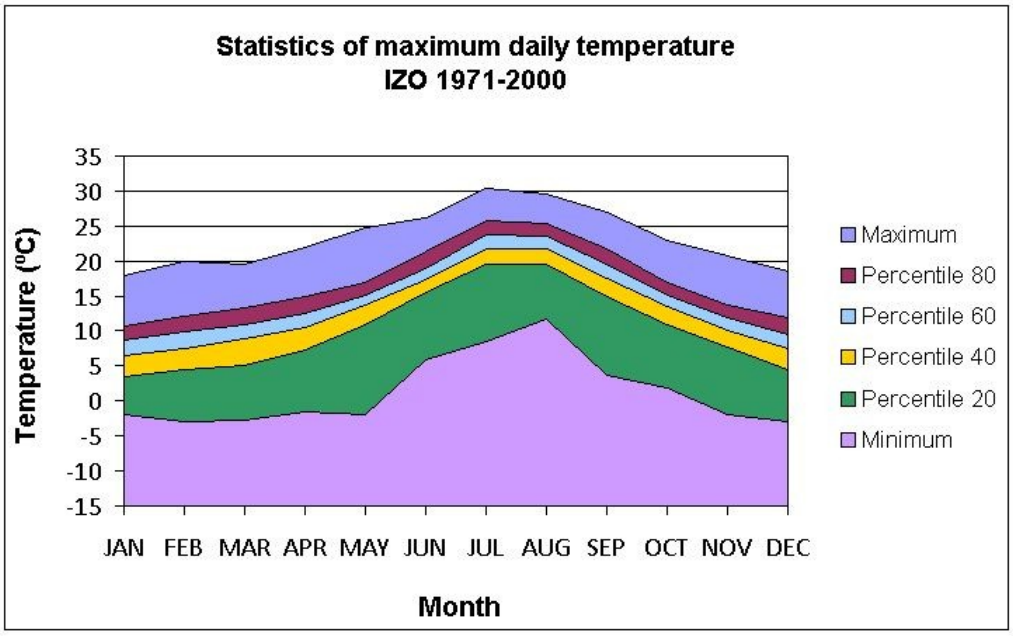
In the Canary Islands there is a stable pattern of temperatures showing a seasonal variation with warmer summers and colder winters that is also present at the Izaña region.

In figure 6.4, statistics in the form of percentiles of the daily maximum and minimum temperatures are given for each month for the period from 1971 to 2000. As expected, the highest temperatures occur in summer and the lowest in winter.

In the 92 years from 1920 to present, the highest temperature was recorded on July 19th 1995, reaching a value of 30.4ºC and the minimum being –9.8ºC, recorded on

[70] to be accessed from the AEMET webpage: http://www.aemet.es/es/servidor-datos/acceso-datos/listado-contenidos/detalles/series_climatologicas
[71] see http://www.iac.es/proyecto/site-testing/index.php?option=com_content&task=view&id=90
[72] graph from the IARC webpage on climatology http://www.izana.org/index.php?option=com_content&view=article&id=23&Itemid=23&lang=en

February 26th 1971.



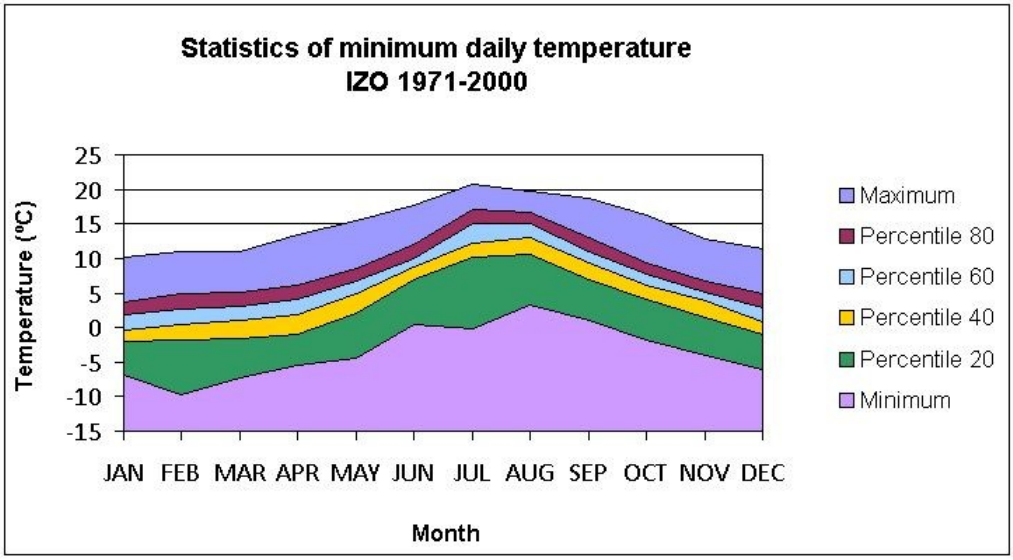


Figure 6.4 Statistics of the daily temperature maxima (top) and minima (bottom) from 1971 to 2011, measured at IZO[73].

[73] graph from the IARC webpage on climatology http://www.izana.org/index.php?option=com_content&view=article&id=23&Itemid=23&lang=en

6.3.2 Humidity measurements

Unfortunately, humidity is not one of the parameters measured at IZO. The values presented here correspond to the European Extremely Large Telescope (E-ELT) campaign carried out from May 2008 to May 2009[74]. The median, mean and percentiles (5%, 25%, 75% and 95%) are given for day-time and night-time, separately (see figure 6.5).

The median is found at 27% humidity, both for day and night, and in 75% of the night-time, the relative humidity is lower than 56%.

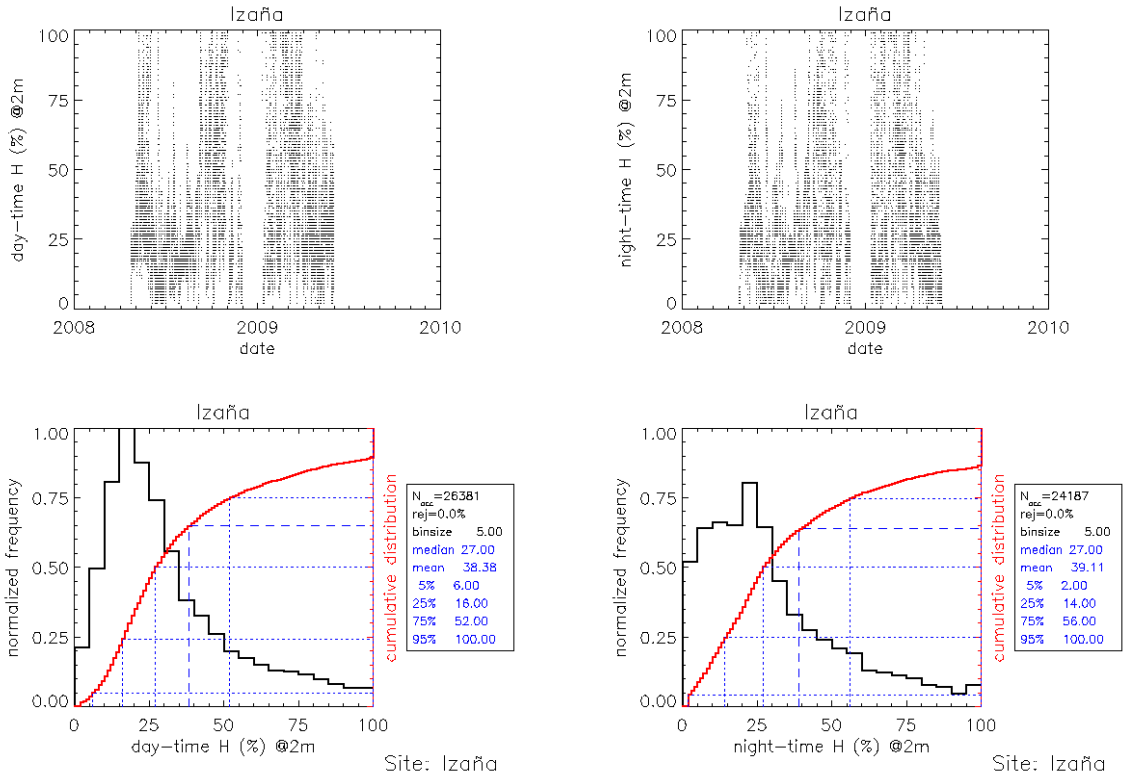


Figure 6.5 Frequency of daytime (left) and night-time (right) humidity, as observed at the OT during one year. In black, the normalized frequency, while in red the cumulative distribution is shown. The sensor used for this campaign saturates at values around 90%, this is what causes the abrupt change for the highest humidity values. These correspond to days with overspill of clouds, being the observatory inside the clouds.

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. However, the **highest humidity values are less frequent in this long database**[75].

[74] see European Extremely Large Telescope Site Characterization III: Ground Meteorology. Varela A. M. et al., 2011, submitted to PASP.

[75] Private Communication of the Sky Quality Group (SQG) of the IAC.

6.3.3 Wind Speed Measurements

Due to the abrupt orography of the island, wind speed and direction greatly vary from place to place. These two parameters can also vary considerably from day to night.

For instance, comparing the wind speed roses at IZO[76] and OT[74], 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 (for the same location).

The wind speed data presented here were measured at IZO, at 5 km from the CTA candidate site. As orography plays a key role in local winds on the island[76], **these measurements must only be taken as a rough reference, and local measurements at the pre-selected place for CTA-North must be carried out.**

Wind speed measurements are carried out at IZO since January 1933. The data are public and can be accessed from the AEMET webpage[77]. The wind speed measurements were taken every second or every 0.25 seconds (depending on the anemometer which has changed over the years). The average wind speed values have been averaged every 10 minutes. The anemometer has been placed at different altitudes: from January 1933 to February 1984 it was located at 12 meters altitude, since then until February 2000 at 16 meters and after this date to present at 10 meters altitude.

Figure 6.6 presents the monthly average wind speed cumulative frequency from 1933 to present: for over 90% of the values, the average wind speed is lower than 9 m/s (32,4 km/h). The average value lies at 6,8 m/s (24,6 km/h).

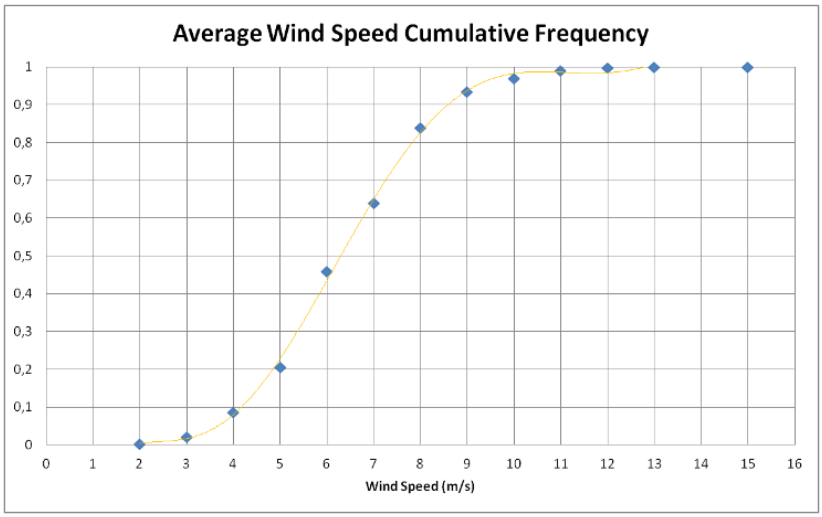


Figure 6.6: The cumulative monthly average wind speed frequency, as observed at IZO[78] from January 1933 to August 2011.

It is however expected that the wind speeds are smaller at the CTA candidate site,

[76] A. M. Varela et al "Site-testing results at the Teide Observatory", ASP Conference Series, Vol. 266, 2002.
[77] http://www.aemet.es/es/servidor-datos/acceso-datos/listado-contenidos/detalles/series_climatologicas
[78] Data obtained from AEMET database http://www.aemet.es/es/servidor-datos/acceso-datos/listado-contenidos/detalles/series_climatologicas

since IZO is located at the top of the most exposed peak in the area, whereas the CTA candidate site is more shielded (see figure 6.1).

As for wind gusts at IZO (defined as the wind speed average over 3 seconds, whereby the time difference between two measurements lasts 1 second), it was found that over the 73 years of data (from May 1938 to August 2011) the wind gusts exceeded 200 km/h seven times, the lower value being 201 km/h and the highest 248 km/h. The worst case by far happened on 28th November 2005. Although there were minor damages recorded at sea level, it is worth mentioning that the observatories at an altitude of 2400 meters did not experience problems. In fact, MAGIC I was standing at the ORM at the time and could take regular observations right on the next day.

One more thing to notice is that these wind gusts are all coming from the W-NW region where the CTA site is more shielded (see picture 6.7).

Date	Wind gust speed (km/h)	Wind gust direction (º)
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

Table 6.1: A compilation of the highest wind gusts recorded by IZO during 73 years.

Figure 6.7 The CTA-North candidate site is expected to be more shielded from the wind in the W and NW directions (facing the Teide peak and two nearby hills) than IZO, located at the top of a prominent peak totally exposed (see Fig. 6.1).

6.3.4 Precipitation Measurements

The climate at the Izaña region is extremely dry most of the year, as it lies above the quasi-permanent temperature inversion layer, in the dry free troposphere.

Already in figure 6.7, it can be appreciated that the landscape is typical for a dry, but moderate climate.

Precipitation is mainly recorded in winter time when Atlantic low areas pass over the Canary Islands: in winter, 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 6.8 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.

The annual average during this period is about 44 precipitation days. Out of these, about 11 days are of snow precipitation, mainly from November to April and, less frequently, from May to October.

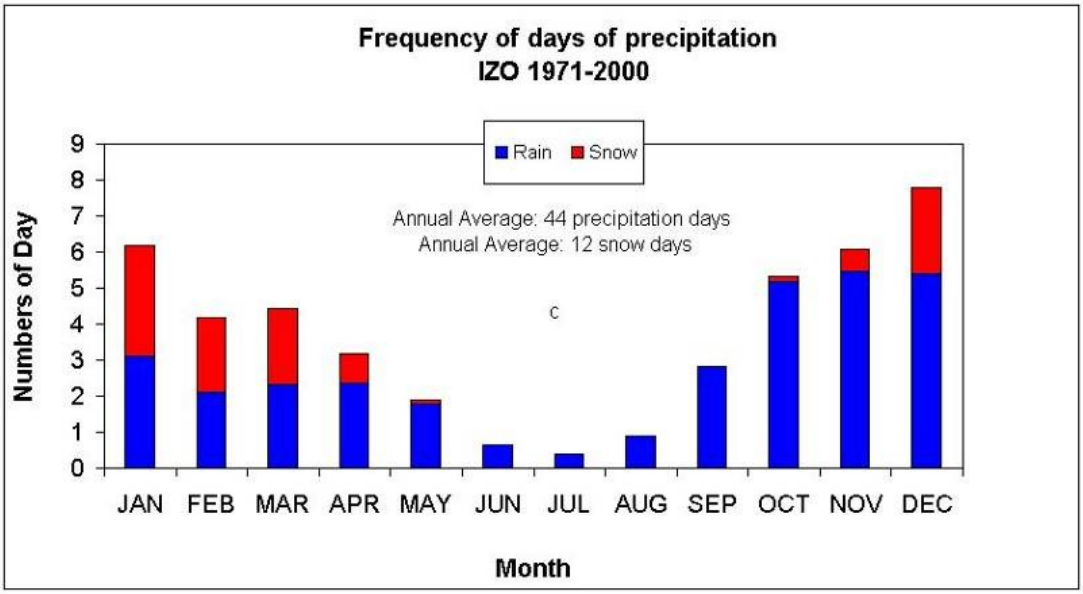


Figure 6.8 Frequency of precipitation days per month, measured at IZO and averaged over 29 years[79].

Using the entire AEMET public database[80] from 1920 to 2011, the annual average of appreciable precipitation agrees with the one already given, as expected.

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

[79] graph from the IARC webpage on climatology http://www.izana.org/index.php?option=com_content&view=article&id=23&Itemid=23&lang=en

[80] from http://www.aemet.es/es/servidor-datos/acceso-datos/listado-contenidos/detalles/series_climatologicas

Figure 6.9 shows the evolution of the average annual total precipitation at IZO, for the period from 1915 to 2008.

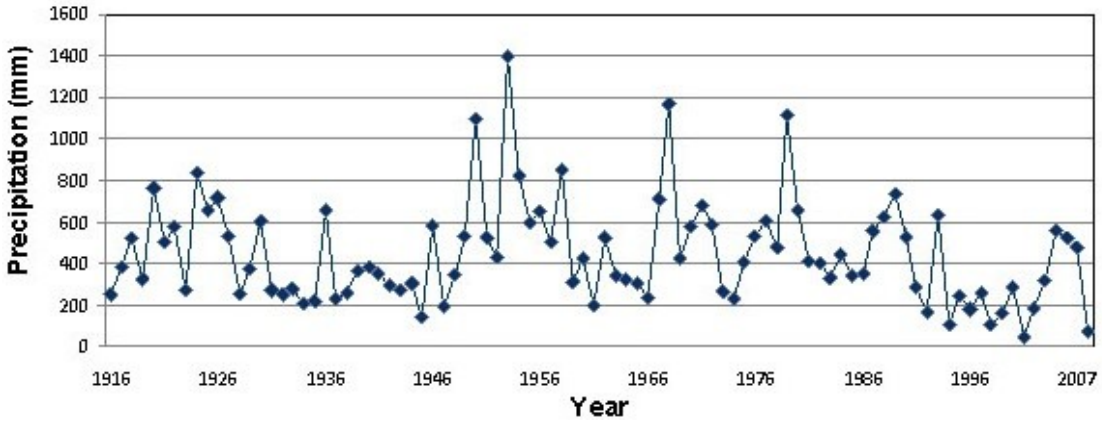


Figure 6.9 Evolution of the annual total precipitation, measured at IZO over 93 years[81].

The AEMET public database also gives the number of days with hail per month from 1920 to 2011. The annual average for this period amounts to 1.5 days of hail per year.

It is worth mentioning that in the 8-years lifetime of MAGIC the mirrors did not loose any reflectivity, as could recently be verified.

[81] graph from the IARC webpage on climatology http://www.izana.org/index.php?option=com_content&view=article&id=23&Itemid=23&lang=en

6.4 Atmospheric Quality

"The peak of the Teide is much more suited to physical and astrophysical investigations than the high mountains of Switzerland or the Monte Rosa, Italy, due to the scarce content of dust and of water condensation…" (Dember H., Buckheim W., Uibe M., Works carried out on the island of Tenerife during the year 1914 to 1917).

The Cherenkov light that arrives to the telescopes from the particle showers in the high atmosphere is highly dependent on the quality of the atmosphere that it traverses. In fact different density profiles lead to differences in Cherenkov light density of up to 60%[82].

6.4.1 On the use of satellite data for studies of cloud coverage and aerosol content at the observatories of the Canary Islands

In the Western Canary Islands Tenerife and La Palma, the very abrupt orography and the presence of the stable inversion layer (at an altitude from 750 m to 1850 m a.s.l. where the "sea of clouds" is usually present), together with the different nature of the two air masses above and below this layer render useless most satellite studies of cloud coverage and aerosol content at the observatories[83].

The use of satellite data for studies of the Izaña region is confronted with the following problem: as this region (above 2000 m a.s.l.) lies above the temperature inversion layer, in the dry free troposphere and as the island is very abrupt, locations just 2 km away in horizontal direction can be hundreds of meters lower in vertical direction, ending up lying in the moist marine layer (i.e. under the "sea of clouds").

For the study of clouds, for instance, when a pixel size bigger that 1 km is taken, one integrates the clouds lying below the observatories. Figure 6.10 shows a picture of Tenerife, with the 1 km^2 CTA candidate site as a green circle, surrounded by a red pixel of 5 km size. It is clear that a study of cloud coverage with a resolution of only 5 km will be useless. In order to make a coherent satellite study of the cloud coverage, a resolution of at least 1 km^2 is needed.

Varela et al.[84],[85] show the comparison of satellite data of 3-km^2 space resolution with ground data for the DHV site (candidate site for the European Extremely Large Telescope (E-ELT) at the ORM). Because of abrupt orography, the coincidence of the data is only of 64% for a pixel centred at the ORM.

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[82] Konrad Bernlöhr, "Impact of atmospheric parameters on the atmospheric Cherenkov technique" Astropart.Phys.12: 255-268, 2000.

[83] A. M. Varela, C. Bertolin, C. Muñoz-Tuñón, S. Ortolani and J. J. Fuensalida "Astronomical site selection: On the use of satellite data for aerosol content monitoring", MNRAS, Volume 391, Issue 2, pp. 507-520, 2008.

[84] A. M. Varela, C. Muñoz-Tuñón, B. García-Lorenzo, J. J. Fuensalida and J. Castro-Almazán, "On the Use of Remotely Sensed Data for Astronomical Site Characterization", Editor(s): Yakov Alekseyev and Klavdiy Plisetskaya, Series: Environmental Science, Engineering and Technology, Pub. Date: 2012 1st Quarter, ISBN: 978-1-61942-182-0.

[85] A. M. Varela, C. Bertolin, C. Muñoz-Tuñón, S. Ortolani and J. J. Fuensalida "Astronomical site selection: On the use of satellite data for aerosol content monitoring", MNRAS, Volume 391, Issue 2, pp. 507-520, 2008.

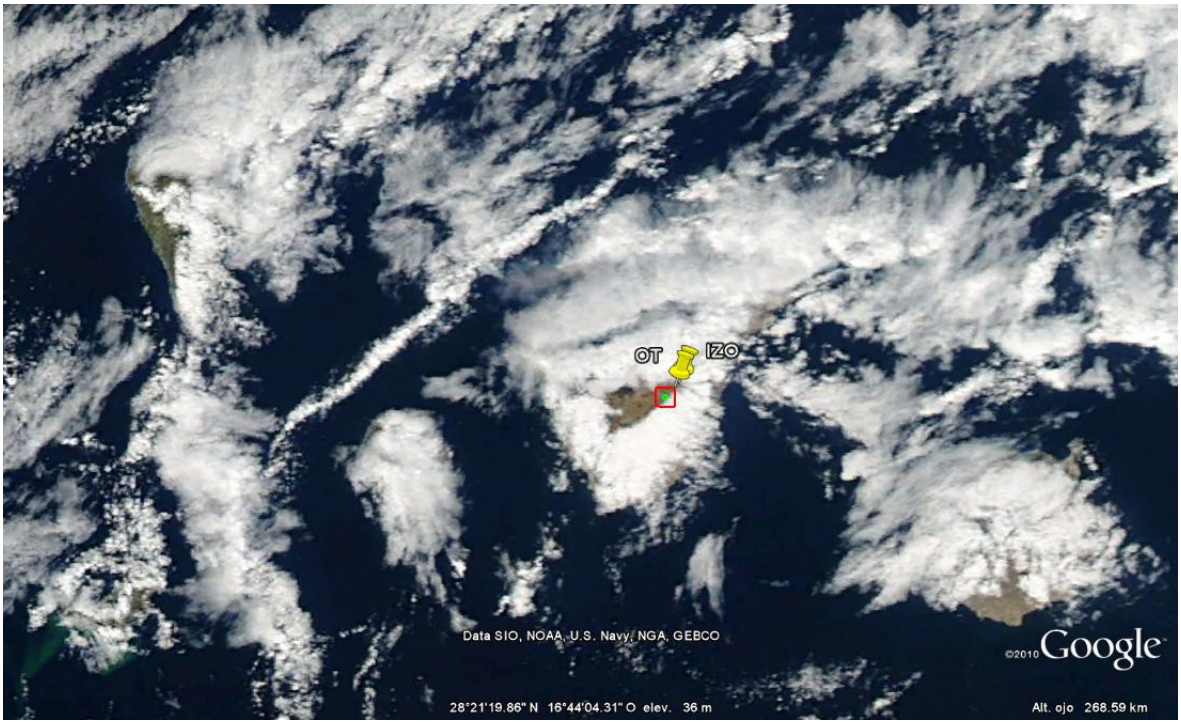


Figure 6.10: A MODIS satellite picture of Tenerife, superimposed on a Google-Earth image of Tenerife, showing the CTA candidate site (green circle, 1 km^2 area, found entirely above the cloud layer) and for comparison a pixel size of 5x5 km (red square). On the left side, the island of La Palma (where the effect is even more dramatic at the location of the ORM) is seen and right below the island of Gran Canaria. It is clear that the red square integrates a good part of the clouds found below the candidate site and hence results to be a bad indicator for the CTA candidate site[86].

Concerning the aerosol content, several studies (see again Varela et al. (2008) and references therein), explore satellite measurements with high spatial and temporal resolution concluding that aerosol data provided by satellites up to now are not reliable enough for aerosol site characterization and that in-situ data are required, particularly at those astronomical sites with abrupt orography. Either the Aerosol Index (AI), provided by the Total Ozone Mapping Spectrometer (TOMS), as the Aerosol Optical Depth (AOD), provided by the MODIS instruments on the satellites TERRA and AQUA, lack correlation with direct measurements of the atmospheric extinction coefficients at the ORM. The lack of correlation between Aerosol Index (AI) satellite remote sensing data and in-situ AOD data has also been reported by Romero et al.[87]

[86] Picture extracted from A. M. Varela, C. Bertolin, C. Muñoz-Tuñón, S. Ortolani and J. J. Fuensalida "Astronomical site selection: On the use of satellite data for aerosol content monitoring", MNRAS, Vol.391, Issue 2, pp. 507-520, 2008.

[87] P. M. Romero and E. Cuevas, Proc. of 3ª Asamblea Hispano Portuguesa de Geodesia y Geofísica, Feb 3-8, Valencia, 2002.

Figure 6.11: Plumes of dust over the Canary Islands from the west coast of Africa, observed by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's AQUA satellite on March 10, 2007. The easternmost island is just over 100 km from the African coast. The peaks of La Palma and Tenerife remain clear of dust. Picture extracted from Varela et al.[88], full image available at[89]

In spite of the great difficulties explained here, authors like Cavazzani, Zitelli, Ortolani and others are working on very sophisticated satellite analyses, including for instance better spatial and temporal resolution, as well as considering several channels.

6.4.2 Cloud Coverage and Useful Nights

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. Studies have been carried out in the island of Tenerife[90] with data from over 10 years of radiosondes, sent twice a day and data from two atmospheric observatories, one at sea level (PHO, Punta del Hidalgo Observatory) and the other at 2400 m a.s.l. (IZO), finding that the circulation systems for the marine boundary layer and the free troposphere (below and above the inversion layer) are different and un-coupled. It was also confirmed that the inversion layer is very stable throughout the year. It is present during 78% of the year on average, being most frequent in summer (when it is also lower and thicker). The air above the inversion layer usually comes from the North Atlantic region, being clean and dry (there is a difference in relative humidity between the bottom and top of the inversion layer of 51% on average, being the top part the drier).

Unfortunately, so far there are no specific and well-calibrated instruments for ground measurements of cloud coverage. We present here a compendium with the most relevant data found: sunshine measurements at IZO and useful time at the ORM

[88] A. M. Varela, C. Bertolin, C. Muñoz-Tuñón, S. Ortolani and J. J. Fuensalida "Astronomical site selection: On the use of satellite data for aerosol content monitoring", Mon. Not. R. Astron. Soc., Volume 391, Issue 2, pp. 507-520, 2008.

[89] http://earthobservatory.nasa.gov/Newsroom/NewImages/Images/canary amo 2007069 lrg.jpg

[90] C. Torres, E. Cuevas and J. C. Guerra, "Characterization of the marine boundary layer and the free troposphere in the subtropical region over Canary Islands", 3rd Hispanic-Portuguese Assembly of Geodesics and Geophysics, 2002.

observatory on La Palma, 140 km away and also located at 2400 m a.s.l., i.e. also above the inversion layer, and cloud coverage at the ORM calculated with satellites.

The insolation, defined as the period of time during which the sun shines, at Izaña is very high, especially in summer, recording the highest average annual insolation duration of Spain with 3448.5 hours/year. Figure 6.11 shows the monthly insolation in percentage taken with a heliograph at IZO from January 1933 to August 2011. The average is **77% of sunshine**, slightly increasing during the last 10 years.

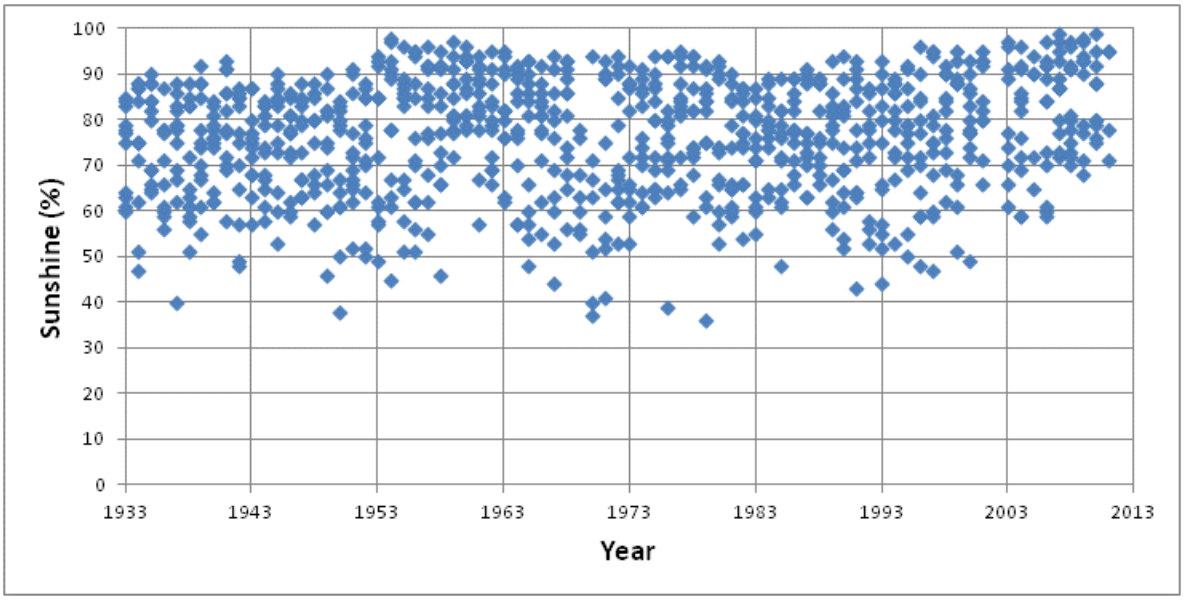


Figure 6.11 Monthly insolation, as observed at IZO[91].

Detailed satellite studies have been carried out by the certified consulting meteorologist Dr. André Erasmus for the ORM on La Palma, showing that the **photometric time** at this observatory is **83.7%** (for the 7-year period 1996-2002).

Cross-calibration with ground measurements using the Carlsberg Meridian Telescope (CMT) at the ORM shows a good agreement of the data[92], with only 1.2% differences[93]. Cavazzani et al.[94] use GOES satellite data for the time interval from 2007 to 2008 and find that the percentage of clear nights is 72.5% at the ORM at La Palma.

The weather downtime has been calculated[95] for the period 1999-2003 using the logs

[91] Data obtained from the AEMET database http://www.aemet.es/es/servidor-datos/acceso-datos/listado-contenidos/detalles/series_climatologicas

[92] D.A. Erasmus, & van R. Rooyen, "A satellite survey of cloud cover and water vapour in Morocco and Southern Spain and a verification using la Palma ground-based observations". *Final Report to ESO* 2006, Purchase Order 73526/TSD/04/6179/GW/LET

[93] C. Muñoz-Tuñón, A. M. Varela and J. J. Fuensalida, "Recent results at the Canarian observatories", RevMexAA, vol. 31, 36-46, 2007.

[94] S. Cavazzani, S. Ortolani, V. Zitelli and Y. Maruccia, "Fraction of clear skies above astronomical sites: a new analysis from the GOES12 satellite", MNRAS, Vol 411, 1271-1283, 2011.

[95] A. García-Gil, C. Muñoz-Tuñón, and A. M. Varela "Atmosphere Extinction at the ORM on La Palma: A 20 yr Statistical Database Gathered at the Carlsberg Meridian Telescope".
PASP, vol. **122**, 1109–1121, 2010.

of the CMT telescope. This procedure obtained an average of **20.7% weather downtime** (defined as the period when there were no recorded observations during a whole night).

The monthly average of weather downtime was also calculated and compared with the one obtained at the William Herschel telescope for the 18-years period from 1989 to 2006 are in good agreement with the previous numbers, see figure 6.12.

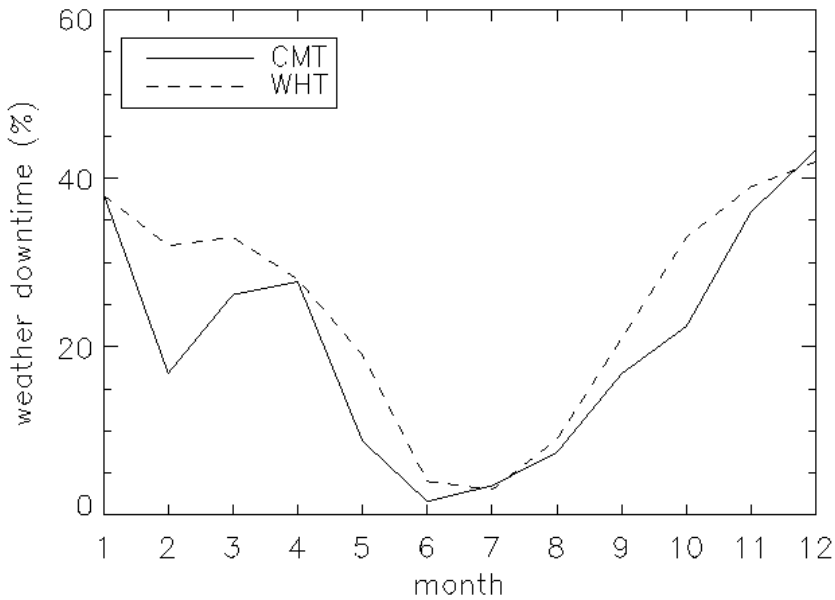


Figure 6.12 Relative monthly frequency of weather downtime at the CMT from the log files, averaged over 5 years, and compared with that of the WHT for an 18 years period[96].

Other in-situ measurements of useful time at the ORM yield the values: 78%[97], 75%[98] (11 years time interval) and 72.7%-77.5%[99] (4 years period). More detailed references and data can be found at the IAC site-testing webpage of the Sky Quality Group[100].

The quality of an observatory is clearly dependent on the number of useful hours it provides each year. Useful observation time is the amount of time during which observations can be undertaken without the restrictions imposed by adverse weather conditions. The definition of "adverse conditions" varies from one telescope to another but, in general, the criteria include: wind speed, humidity, clouds and aerosols in the atmosphere.

[96] Graph extracted from A. García-Gil,C. Muñoz-Tuñón, and A. M.Varela "Atmosphere Extinction at the ORM on La Palma: A 20 yr Statistical Database Gathered at the Carlsberg Meridian Telescope", PASP, vol **122**, 1109–1121, 2010.

[97] Paul Murdin, "Nighttime skies above the Canary Islands", Vistas in Astronomy, vol. 28, Issue 2, pp.449-465 1985.

[98] ING Annual Report 1999 of the PPARC-NWO ING Board and Rutten, R.G.M; ING Director's Report: operations and development, 9-10 April 2001.

[99] Lombardi, G.; Zitelli, V.; Ortolani, S.; Pedani, M., "El Roque de Los Muchachos Site Characteristics. I. Temperature Analysis", PASP, 118: 1198–1204, 2006.

[100] http://www.iac.es/proyecto/site-testing/index.php?option=com_content&task=view&id=89

At both observatories, the percentage of time lost per year due to adverse atmospheric conditions remains between 16.3% and 27.5%, depending on the methodology for calculations and the selected period of time.

6.4.3 Air quality and dust intrusions (calima)

The results presented here have been extracted from the "Report on the Incidence of African dust intrusions at the Astronomical Observatories of the Canary Islands: characterization and temporal analysis", a report released by the Izaña Atmospheric Research Centre of AEMET and the Earth Sciences Department (Barcelona Supercomputing Centre – Centro Nacional de Supercomputación BSC-CNS)[101].

6.4.3.1 In-situ particulate matter

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 are monitored since 2002 at IZO. The PM10 hourly-values frequency distribution at IZO for the period from 2002 to 2008 is shown in figure 6.13. In table 6.2, the percentile distribution of PM10 is indicated for the same period.

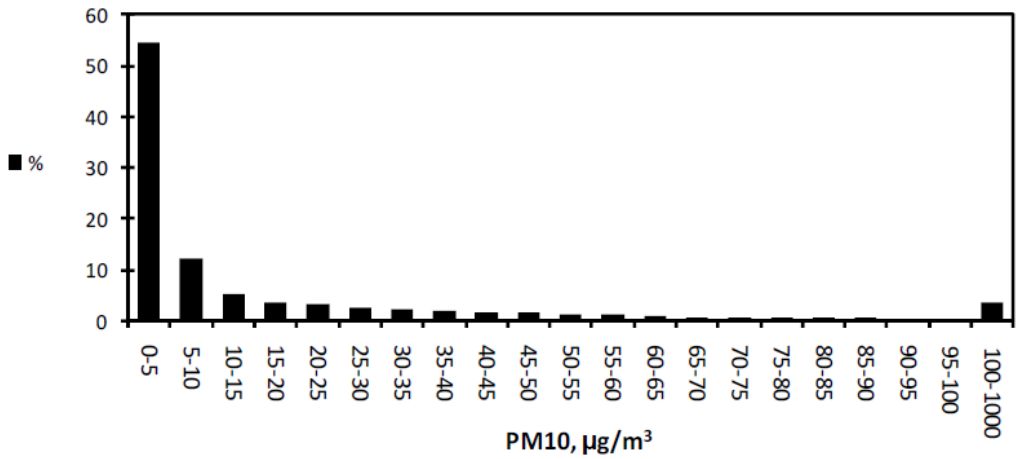


Figure 6.13: PM10 hourly-values frequency distribution at IZO for the 2002-2008 period. Figure taken from ref. [101].

Percentile	PM10, µg/m³
10	0.2
20	0.5
30	1.0
40	2.0
50	3.9
60	6.5
70	12.5
80	26.5
90	54.8
95	85.4

Table 6.2: Percentiles of PM10 hourly concentrations at IZO (Period: 2002-2008). Values taken from ref. [101].

[101] "Report on the Incidence of African dust intrusions at the Astronomical Observatories of the Canary Islands: characterization and temporal analysis" Emilio Cuevas (AEMET) and Jose María Baldasano (BSC-CNS), 2009.

PM10 concentrations lower than 10 µg/m^3 correspond to extremely clean environments.

For comparison, the ambient PM10 mass averages at the remote and ultra-clean McMurdo Antarctic base[102] range from 3.4-4.1 µg/m^3. Around 50% of the hourly PM10 values at IZO are observed below this mean value.

A 67% of the hourly records at IZO are lower than 10 µg/m^3. In figure 6.14, the seasonal variation of PM10 percentiles at IZO is shown.

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.

These show a marked seasonal distribution being predominantly observed in summer time (July-September)[103] The very low PM10 concentrations at the Izaña Observatory permit studies of nanoparticles and nucleation processes at this observatory[104].

The worldwide longest record of Total Suspended Particles (TSP) series in the free troposphere has been obtained at the Izaña Observatory (see figure 6.15).

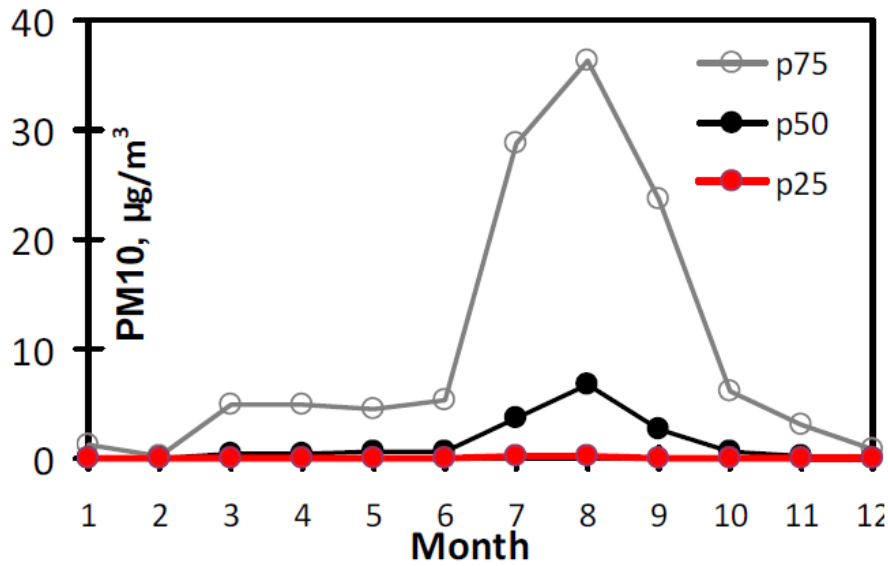


Figure 6.14: Seasonal variation of the 25th, 50th and 75th PM10 percentiles at IZO. Figure taken from ref. [101].

[102] Mazzera D. M., "PM(10) source apportionment at McMurdo Station, Antarctica"; PhD thesis, University Of Nevada, Reno, Source DAI-B 61/02, p. 757, Aug 2000, 323 pages.
[103] Chiapello I. et al., "Detection of mineral dust over the North Atlantic Ocean and Africa with Nimbus 7 TOMS", J. Geophys. Res., 104, 9277-9291, 1999.
[104] Rodríguez S. et al., "Atmospheric nanoparticle observations in the low free troposphere during upward orographic flows at Izaña Mountain Observatory", Atmos. Phys. Chem., 9, 6319–6335, 2009.

TSP's are all aerosol particles (sometimes even above sizes of 100 mm) suspended in the air. A detailed analysis of the TSP series shows no trend in the period from 1987 to 2008. We can thus confirm that the in-situ dust concentration at IZO has not increased over the last 21 years. It is worth to mention that in this period of time, dramatic changes in meteorological parameters (i.e. temperature increase) have been recorded worldwide.

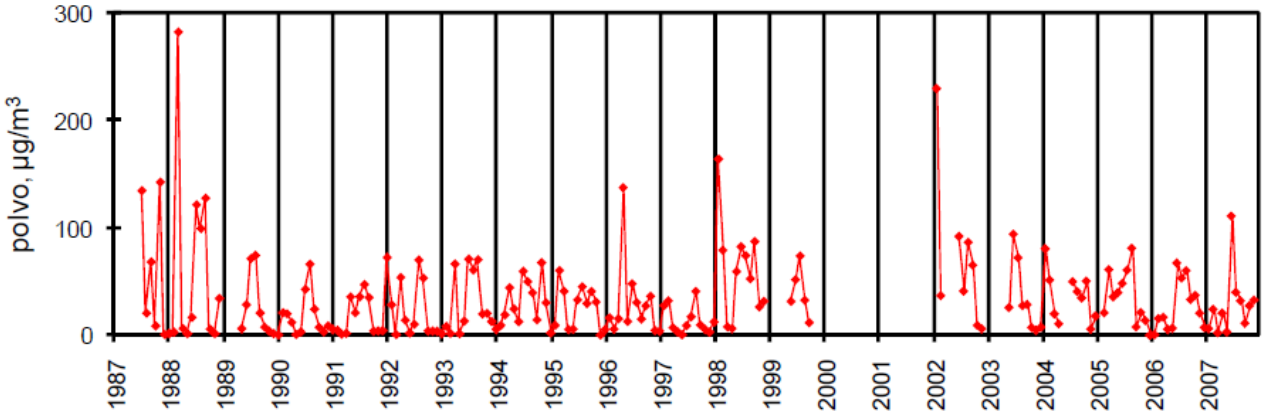


Figure 6.15: Monthly mean Total Suspended Particles (TSP) at IZO for the 1987-2008 period. Figure taken from ref. [101].

The conclusions are this report are that in-situ TSP, PM10 data, and Aerosol Optical Depth (AOD) observations performed at IZO demonstrate that the site **IZO-OT is characterized by extremely clean air and pristine skies**. IZO-OT is sometimes affected by dust loaded African air mass intrusions in the summer time (July-September). Since African air masses impact only in summer when nights are short, the annual percentage of nocturnal observing affected by dust-loaded air mass episodes is very low. **The fact that under calima intrusions, middle clouds are observed between 5 and 6 km altitude minimizes the negative impact of these intrusions on astronomical observations performed at the OT.**

It is important to realize that dust episodes are not accompanied by strong winds. There is no risk of damage of the telescopes (as it happens at other places). MAGIC mirrors are in use for 8 years now without loosing reflectivity, as was recently checked.

6.4.3.2 Atmospheric Extinction

The local extinction is measured with the help of comparison stars, although one must take into account that this procedure cannot

disentangle the vertical structure of the atmosphere, leading to differences of 5-10% in the amount of Cherenkov light at mountain altitudes[105].

Extinction coefficients for the OT, calculated on the night of September 9th 2010 with the telescope IAC80, are given in table 6.3. In order to perform these calibrations, the fields PG0220, PG2213, PG2331, SA109 and SA113 were observed with air masses between 1.0 and 1.9. The seeing during this night was 1.2 and the night was photometric[106].

Filter	Extinction (mag/airmass)	Uncertainty (mag/airmass)
K_U	0.557	0.014
K_B	0.250	0.004
K_V	0.158	0.004

Table 6.3: Extinction coefficients for the OT

Varela et al.[107] show that there is a similar tropospheric aerosol distribution at both observatories, the OT at Tenerife and the ORM at La Palma. Based on this result, we will present data for the ORM observatory, which has a much more extensive database on extinction, as the Automatic Transit Circle telescope (ATC, previously called the Carlsberg Telescope) has provided continuous automated measurements of atmospheric extinction since it started operations in May 1984. The ATC telescope can also be used on nights with aerosols (Saharan dust) to estimate the effect of dust on atmospheric extinction.

[105] Konrad Bernlöhr, "Impact of atmospheric parameters on the atmospheric Cherenkov technique" Astropart.Phys.12: 255-268, 2000.
[106] see http://www.iac.es/telescopes/pages/es/inicio/utilidades.php -> CAMELOT. Calibración fotométrica.
[107] A. M. Varela, C. Bertolin, C. Muñoz-Tuñón, S. Ortolani and J. J. Fuensalida "Astronomical site selection: On the use of satellite data for aerosol content monitoring", MNRAS, Vol. 391, Issue 2, pp. 507-520, 2008.

Figure 6.16: An impressive example of the Canary Islands' transparency of the sky. In these photographs, taken from the ORM (La Palma) in the evening, Mount Teide (Tenerife), 143 km away, can be seen clearly together with the National Park that it stands in.

The following information is extracted from García-Gil et al.[108] Using a database **covering 20 years**, from 1988 to 2009, excluding 1992 and 1993, at the ATC, they obtain the extinction coefficients from table 6.4:

[108] A. García-Gil, C. Muñoz-Tuñón, and A. M. Varela "Atmosphere Extinction at the ORM on La Palma: A 20-yr Statistical Database Gathered at the Carlsberg Meridian Telescope". PASP, vol 122, 1109–1121, 2010.

	Extinction (mag/airmass)	Uncertainty (mag/airmass)
Median K_V	0.130	0.002
Mode K_V	0.121	0.002
Mean K_V	0.161	0.002

Table 6.4: Extinction coefficients for the ORM

The median coefficient is much better than the one obtained at 2800 m a.s.l. at Mauna Kea in Hawaii (median K_V = 0.17 mag/airmass), and similar to the one obtained at the 4200 m a.s.l. at Mauna Kea (median K_V = 0.11 mag/airmass).

García-Gil et al. also provide an analysis including only dust-free and non-cloudy nights, obtaining a mean value of **K_V = 0.124 mag/airmass** in summer and **K_V = 0.132 mag/airmass** for the rest of the year. This value is similar (even better in summer) to the one obtained at La Silla (0.130 mag/airmass) using foreseeable good, stable and uninterrupted nights.

Figure 6.17 shows the results separately for winter (above) and summer (centre).

The lower part of the graphic shows that **90% of time during the winter months is dust-free. For the summer months the percentage is around 75%.**

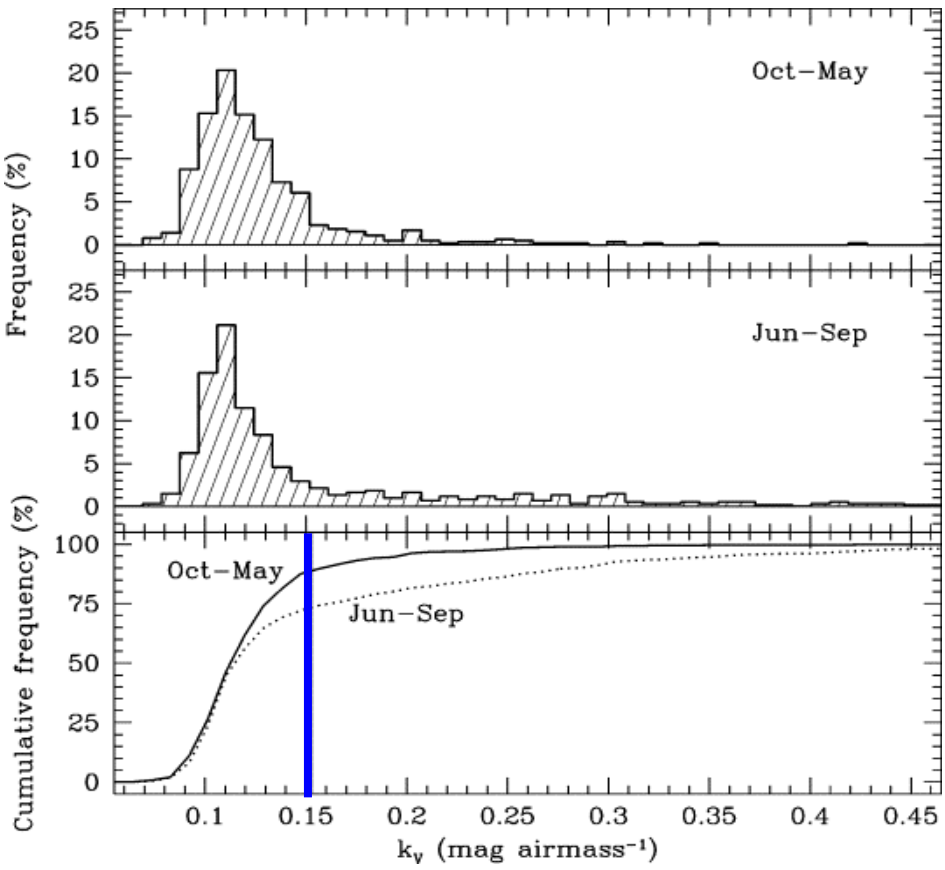


Figure 6.17: Extinction frequency over the ORM in winter (above) and summer (centre). The corresponding cumulative frequency is also shown (below). The vertical line indicates the limit from which dust can arise (K_V=0,153).

6.4.3.3 Aerosol Optical Depth and Precipitable Water– Ground data

The following data are from the AERONET sun photometer (see figure 6.18), installed at IZO since 2004, using Level 2.0 – Quality Assured Data[109]. It summarizes the statistics of aerosol optical depth (AOD) at 500 nm (tau_{a500}), the Ångstrom exponent ($alpha_{440-870}$) and precipitable water (PW), the associated standard deviations (sigma), the number of days (N) and months (Month) in the observation periods, shown in table 6.5.

Figure 6.18 The Cimel sun photometer is a multichannel, automatic sun-and-sky scanning radiometer that measures the direct solar irradiance and sky radiance at the Earth's surface. Spectral range: 340, 380, 440, 500, 675, 870, 936, 1020, (and 1640) nm. At IZO, there are about 6 Cimel master working simultaneously.

[109] see http://aeronet.gsfc.nasa.gov/new_web/V2/climo_new/Izana_500.html

Overall Averages of	tau_{a500}	sigma	$alpha_{440-870}$	sigma	PW	sigma	*N*	Month
JAN	0.02	0.02	1.09	0.31	0.25	0.14	114	6
FEB	0.03	0.04	1.35	0.65	0.25	0.14	74	6
MAR	0.05	0.08	1.17	0.53	0.29	0.17	134	6
APR	0.05	0.08	1.18	0.46	0.32	0.16	146	6
MAY	0.04	0.04	1.09	0.32	0.37	0.19	158	6
JUN	0.05	0.09	1.05	0.46	0.39	0.21	161	7
JUL	0.14	0.14	0.54	0.51	0.50	0.24	205	7
AUG	0.12	0.11	0.52	0.47	0.62	0.35	176	6
SEP	0.09	0.11	0.78	0.51	0.64	0.32	155	6
OCT	0.04	0.04	1.06	0.41	0.49	0.27	162	6
NOV	0.04	0.04	1.08	0.40	0.45	0.27	118	6
DEC	0.03	0.03	1.20	0.36	0.25	0.18	114	6
YEAR	0.06	0.04	1.01	0.26	0.40	0.14	1717	74

Table 6.25Results from the Cimel sun photometer (see text for explanations).

The annual average precipitable water (PW), obtained with the Cimel sun- photometer is 0.40 cm; moreover a seasonal variation is observed (see figure 6.19), being the PW higher in summer (when nights are shorter). Note that Schneider et al.[110] estimate a PWV precision for the Cimel sun photometers of 7%, for PWV > 7mm, and only about 25% under very dry conditions (PWV ≤ 2 mm).

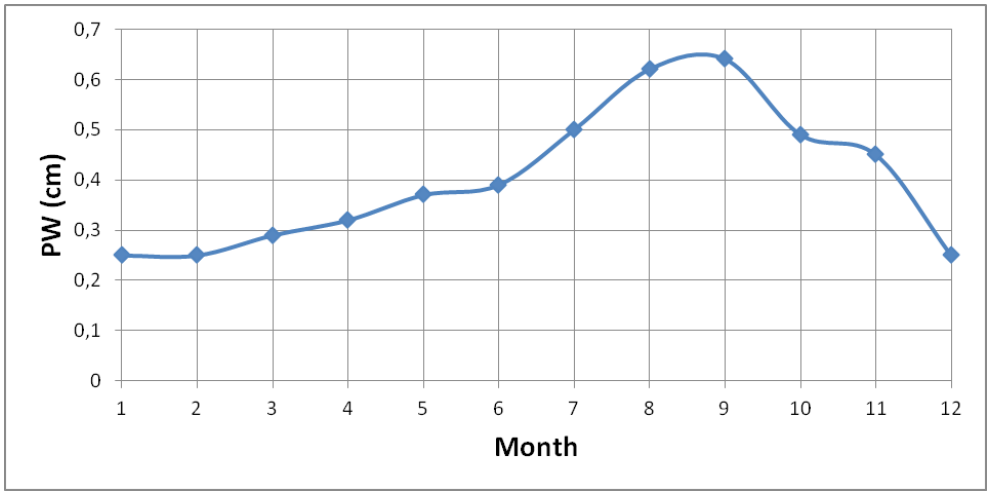


Figure 6.19 Monthly average PW, measured by the AERONET Cimel sun-photometer, located at IZO.[111]

The annual average AOD obtained with the Cimel at 500 nm is 0.06, the worst months being July to September, when intrusions of calima appear. All these AOD values were obtained during daytime, however the AOD during night is expected to be even lower,

[110] M. Schneider, P. M. Romero, F. Hase, T. Blumenstock, E. Cuevas and R. Ramos, "Continuous quality assessment of atmospheric water vapour measurement techniques: FTIR, Cimel, MFRSR, GPS, and Vaisala RS92", Atmos. Meas. Tech., Vol 3, 323–338, 2010.

[111] Data extracted from http://aeronet.gsfc.nasa.gov/new_web/V2/climo_new/Izana_500.html

due to the katabatic flow that is normally well established during the night[112]. Figure 6.20 shows the monthly averages, where the seasonal dependency of the AOD appears.

Most of the year the average remains well below the AOD=0.1 corresponding to non-absorbing particles[85].

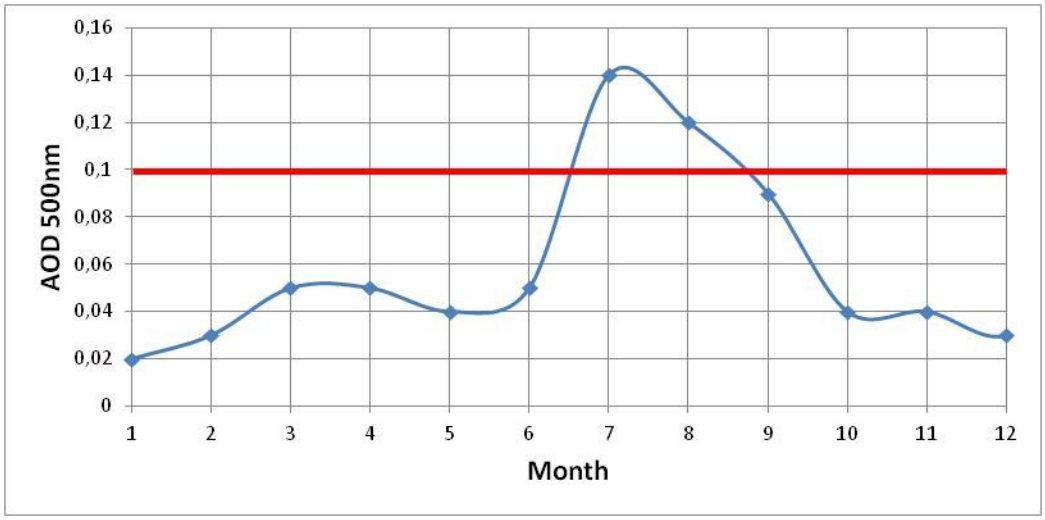


Figure 6.20 Monthly average AOD (550 nm), measured by the AERONET Cimel sun-photometer, located at IZO[113].

6.4.4 Night Sky Background (NSB)

Night Sky Background defines the magnitude limit of the observations in a certain wavelength that can be observed. It means the minimum brightness of an astronomical object that can be detected at that wavelength. A dark sky allows to operate to the maximum of large telescopes' capacity and to arrive thus at the observation of the most remote universe and, therefore, more early.

The data presented here have been supplied by the Sky Quality Protection Technical Office (OTPC). This office was set up by the IAC in January 1992 in order to provide advice on the application of the "Sky Law"[114] that protects the astronomical quality of observatories in the Canaries. Their official webpage is: http://www.iac.es/otpc.

For the NSB measurements, a **Sky Quality Meter (SQM)** was used, the technical details of which can be found in the SQM webpage[115]. Before mid- 2009, a version with 80º field-of-view was use and, since then, the one with a field-of-view of about 20º with a lens at the entrance. Figure 6.21 shows the NSB, measured with a V-filter of the SQM during the years **2006-2010**.

[112] "Report on the Incidence of African dust intrusions at the Astronomical Observatories of the Canary Islands: characterization and temporal analysis" Emilio Cuevas (AEMET) and Jose María Baldasano (BSC-CNS), 2009.
[113] Data extracted from http://aeronet.gsfc.nasa.gov/new_web/V2/climo_new/Izana_500.html
[114] "Ley 31/1988 del 31 de Octubre, sobre Protección de la Calidad Astronómica de los Observatorios del Instituto de Astrofísica de Canarias".
[115] http://unihedron.com/projects/darksky/

One can see a trend towards less NSB (greater magnitude!) with the years for the data obtained after midnight, when the sky protection law is strongest.

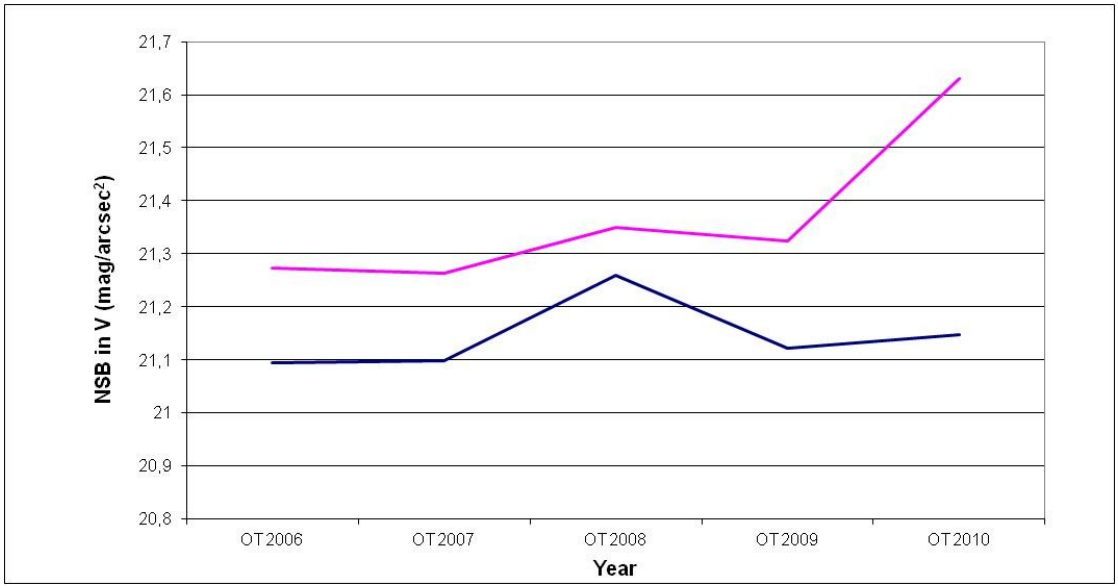


Figure 6.21 Measurements of the V-filter NSB at the OT from 2006 to 2010. In dark blue: before midnight, in pink: after midnight[116].

There was an earlier campaign (22 nights between **1995-2000**) for which the NSB was not only calculated for the zenith but also for several altitudes (15º, 30º, 45º, 60º and 75º) and all azimuths (in steps of 10º). The effect of the different cities can be seen for big zenith angles, see figure 6.22. The apparatus used was a photoelectric photometer model SSP-5A1 (OPTEC Inc.) R4457PMT with a 50 mm aperture telescope with 1-degree field.

[116] Graph provided by the OTPC

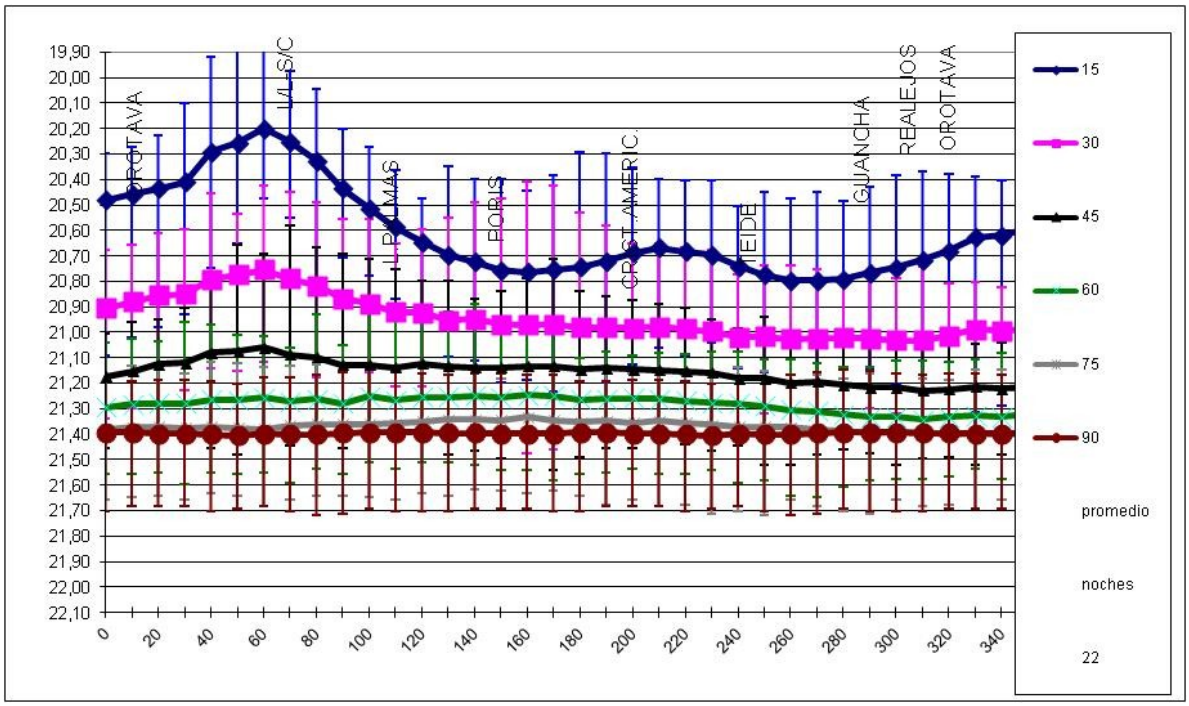


Figure 6.22 Measurements of the V-filter NSB at the OT, average of 22 nights from 1995 to 2000. Note the inverted scale in this figure, compared to figure 6.21[117].

Unfortunately up to now there are not NSB measurements in the U and B filter ranges. However a new automated permanent machine to measure the NSB with the Johnson filters U, B, V and R is currently being installed at the OT. It is called the AllSky Transmission MONitor (ASTMON)[118] which comprises a detector CCD (3500x2500 pixels and 5.5 microns pitch) and a fisheye that provides a full circular field-of-view of 180 degrees in any direction. The main purpose of this instrument is to characterize and measure the light pollution of the night skies at the OT, although it can also be used to measure the cloud coverage. It is expected to start operations in January 2012, after a period of alignment and calibration (see figure 6.23).

Figure 6.23 The ASTMON installed at the OT, on the left the ESA telescope OGS can be seen.

[117] Graph provided by the OTPC
[118] see http://astro-itec.com/pageID_10354571.html

The measurements show that the candidate site fulfils the requirements for the background light in the V-filter. It is assumed that the same holds for the U and B filters, to be measured with the ASTMON early this year.

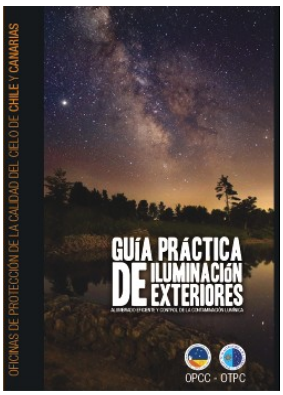
7 Sky Protection in the Canaries

The Spanish Government, at the request of the Canary Islands Parliament, passed the Law for the Protection of the Astronomical Quality of the IAC Observatories (Law 31/88)[119] on the 31st October 1988, and on the 13th March 1992 the Regulations enforcing it (R.D. 243/1992)[120].

The Law contained a range of measures designed to assure the outstanding quality of the observatories of the "Instituto de Astrofísica de Canarias", as recommended by the International Astronomical Union.

The legislation set out conditions and tolerances for all of the factors that adversely affect the quality of the sky over the observatories. These factors are light pollution, radio-electronic transmissions, atmospheric pollution, and aviation routes.

7.1 Light pollution



Light pollution is a generic term used to describe all of the undesirable effects of artificial light. One of the most damaging effects for astronomy is the glow or glare of light in the night sky. Artificial light reflecting on and being diffused by particles of gas and air cause it. It generally results from poorly designed streetlights, which shine light directly towards the sky or outside the area requiring illumination, and also by excessive illumination.

Any lighting installation within the area covered by the Sky Law must comply with some basic standards:

1. Outside lighting must not shine above the horizon and must use lamps that produce the least possible disruption to astronomical observations.
2. No more than 15% of the spectral range of light emitted by outside lights can be at wavelengths under 440 nm.
3. Only sodium vapour lights may be used for road lighting. Colour corrected mercury vapour and metallic halogen lights are prohibited.
4. Any type of lamp can be used for ornamental lighting on public buildings and at sports and recreation facilities, but they must be turned off after midnight.
5. Low-pressure discharge lamps and incandescent lighting can only be used for advertising if they are turned off after midnight. Projectors and lasers may not be used for advertising, or recreational or cultural activities.

[119] Law 31/1988 of 31st October, for Protection of the Astronomical Quality of the Observatories of the "Instituto de Astrofísica de Canarias".

[120] ROYAL DECREE 243/1992, of the 13th of March, giving approval to the Regulations of Law 31/1988, of 31st October, on protection of the astronomical quality of the Observatories of the "Instituto de Astrofísica de Canarias".

6. Finally, a total luminous flux limit is in force in certain areas of the island of La Palma.

7.2 Radio Electrical Pollution

Radio electrical pollution includes electromagnetic radiation emissions. The law also sets down limits for electromagnetic radiation to prevent interference with equipment and readings at the astronomical observatories.

A power flow density limit has also been set, calculated from the e.i.r.p. (equivalent isotropic radiated power) in the direction of the observatories, to ensure that levels within them are never higher than $2x10^{-6}$ W/m^2 for each frequency, equivalent to an electric field with an intensity of 88.8 dB μ V/m.

The combined impact of multiple interferences produced by the radio communication stations will also be monitored, using the quadratic sum method defined by the Consultative Committee on International Radio. The radio communication stations will take any necessary steps to reduce their power radiation emissions in the direction of the observatories to the lowest possible level.

In order to control radio electrical pollution, an agreement has been reached with the General Telecommunications Secretariat for periodic readings of the radio frequency background to be taken at both observatories.

7.3 Atmospheric Pollution

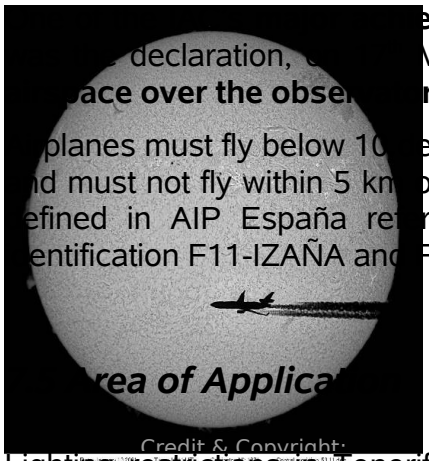
Atmospheric pollution is one of the fastest growing environmental problems. Gases released into the atmosphere as a result of human activity produce noxious effects on atmospheric patterns, with consequences for the health of people, animals and plants. Deterioration in the quality of the atmosphere brings with it deterioration in astronomical observations.

The Sky Law 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 1,500 meters.

As the area surrounding the observatories abuts a National Park it is governed by environmental regulations and so has a higher level of protection than normal (in the same way as natural protected spaces and national parks).

7.4 Air Routes

Air routes can cause interference and impact on sky transparency. The interference is in the form of clouds created by the condensation of airplane exhaust and combustion gases.



evements in its endeavours to protect the observatories declaration, May 1998, of an "Ecological Protection Zone" **covering ace over the obse ries**.

planes must fly below 10 egrees above the horizon as seen from the observatories nd must not fly within 5 km of them horizontally. The area with effective protection is efined in AIP España re rence ENR 5.6-6 of the 17th of May 1998, with the entification F11-IZAÑA and F12-ROQUE DE LOS MUCHACHOS.

Lighting restrictions in Tenerife are in force across three quarters of the island and restrictions on all other potential sources of pollution are in force across the whole island. The area where this law is in application includes also the whole of La Palma.

7.6 Enforcement of the Sky Law

To support the application of the law and to preserve the astronomical quality of the Canary Islands' Observatories, the IAC created the Sky Quality Protection Technical Office (OTPC) in 1992. The OTPC's work has served as an exemplar for other similar groups.

8 Geological Risk Assessment

The Canary Islands' astronomical observatories, the OT on Tenerife and the ORM on La Palma, are in volcanically active areas, but show very small seismic activity.

The last volcanic eruptions were in 1971 on La Palma and 1909 on Tenerife. The orography sculpted by this geological activity is, in large part, responsible for the excellent local atmospheric conditions and sky clarity at these sites.

Large telescopes, whether existing or planned, must be designed to not only withstand seismic and/or volcanic activity but also to minimize operating time lost to the mechanical and optical misalignment it can cause.

Seismic and volcanic activity poses a range of risks to an astronomy observatory but for the purposes of this report only those that pose a direct threat to telescopes like seismic risk, lava inundation, volcanic ash and geological changes in the landscape, are considered.

A risk assessment methodology has been developed for observatories, based on the probability of an event occurring in the forthcoming 50 years, the anticipated lifespan of a new telescope.

The figures and tables below give verified, comparable data for the two observatories. The tables use the most recent available information, which has been verified with the help of leading national groups in the field of geological risk.

8.1 Seismic Risk

In 2010, a detailed seismic risk assessment was carried out at the ORM/OT[121]. The study was undertaken on the recommendation of the "Global Seismic Hazard Assessment Program" (GSHAP)[122]. GSHAP employs a probability method that uses data about past seismic, tectonic, geological and volcanic activity to define the statistical laws that regulate seismic phenomena in an area. Results from the GSHAP give the peak ground acceleration rate (PGA) to be expected by the largest seismic event in the next 50 years, occurring with a probability of 10% (i.e. 90% chance of non-exceedance). This definition is equivalent to a worst-case scenario, which can occur (with a probability of 10%) during the estimated lifetime of big scientific or industrial installations. The PGA values obtained from GSHAP range from less than 0.02g to more than 0.5g (see figure 8.1 for the distribution of PGA hazards on a part of the world).

[121] Geological Hazards at the Astrophysical Observatories of El Roque de los Muchachos and El Teide, Canary Islands, Spain. See also the very instructive seminar given at http://www.iac.es/info.php?op1=23&op2=119&op3=41&y=2010&id=277

[122] Giardini D., Grünthal G., Shedlock K. M., Zhang P. "GHASP, The Global Seismic Hazard Map", Annali di Geofisica, Vol. 42, No. 6 (1999) 1225-1230, see also www.seismo.ethz.ch/GSHAP/global

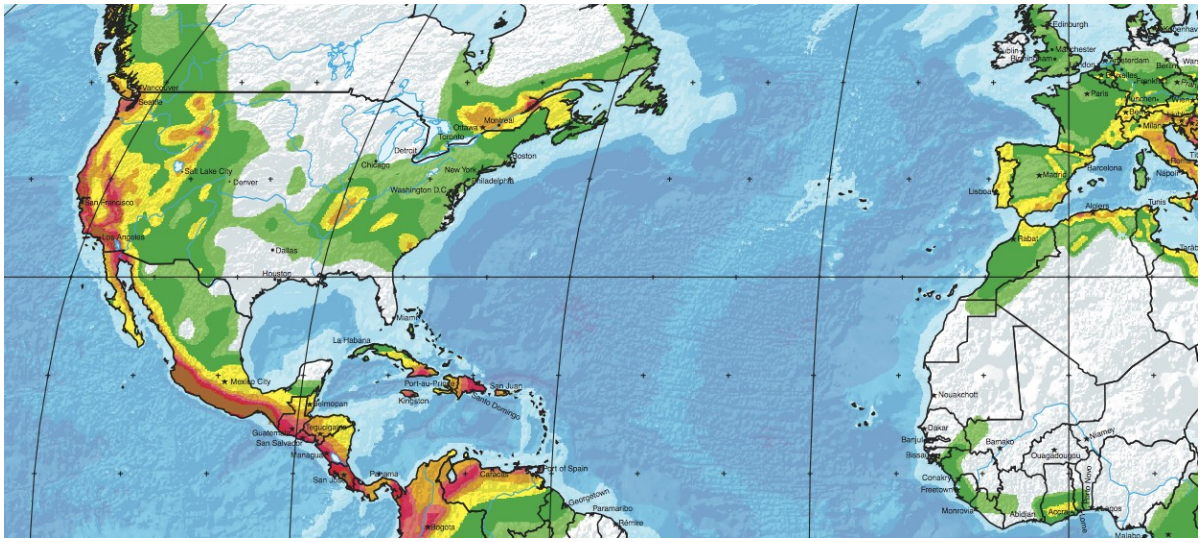


Figure 8.1: Distribution of seismic activity risk, obtained by the GSHAP survey[123]. The colours reflect the obtained PGA values and can be classified in "low hazard" (white and green, 0<PGA<0.08g), "moderate hazard" (yellow and orange, 0.08g<PGA<0.24g), "high hazard" (pink, 0.24g<PGA<0.4g) and "very high hazard" (dark red and brown, 0.4g<PGA<5.6g).

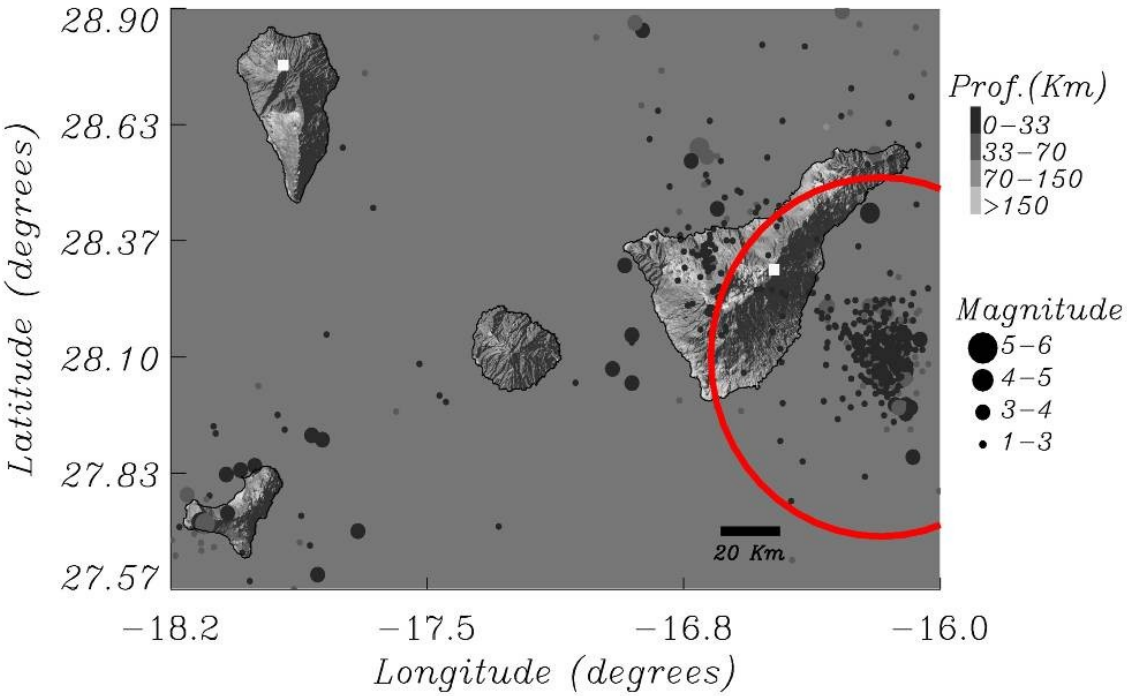


Figure 8.2: Distribution of seismic activity in the western Canary Islands from 1973 to 2010 obtained by the NEIC (US *GEOLOGICAL SURVEY*[124]). The depth and magnitude of earthquakes are shown as circles in different shades of grey and of different sizes, respectively. The red circle contains the area where the probable seismic risk is PGA=0.06g to occur with a probability of 10% within the next 50 years; for the remainder the PGA=0.05g.

Data for the Canaries were interpreted by González de Vallejo et al.[125] (2006) and the

[123] http://www.seismo.ethz.ch/GSHAP/static/GSHAP/global/

[124] see http://neic.usgs.gov

[125] 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. Full

results are shown in figure 8.2 and table 8.1.

Observatory	Anticipated magnitude at 100 km (Richter scale)	Peak Ground Acceleration (PGA)
La Palma	5.80	0.05g
Tenerife	6.00	0.06g
Mauna Kea	8.10	0.4g
Chile (Paranal)	8.35	0.34g

Table 8.1: Approximate estimate of the magnitude (with a 10% probability of being exceeded in the next 50 years) within 100 km from the observatories. Data based on the results shown in Figure 8.1. The values for Mauna Kea and Paranal are shown for comparison, the colours correspond to the ones used in figure 8.2.

8.2 Lava flow risk

Lava flow risk is the probability of an area being affected by lava flow following volcanic activity. For all volcanic risks, the research team liaised with the Alicia Felpeto group at the CSIC Natural Science Museum in Madrid, to map the areas susceptible to basaltic eruptions (mafics) and highly explosive eruptions (felsics) on the island of Tenerife. The resulting map is reproduced in figure 8.3 and shows the areas with the greatest risk of volcanic activity. The probability of lava invasion is given in figure 8.4 and shows that the risk at the Izaña Observatory is negligible as the last eruption in this area took place over 400,000 years ago.

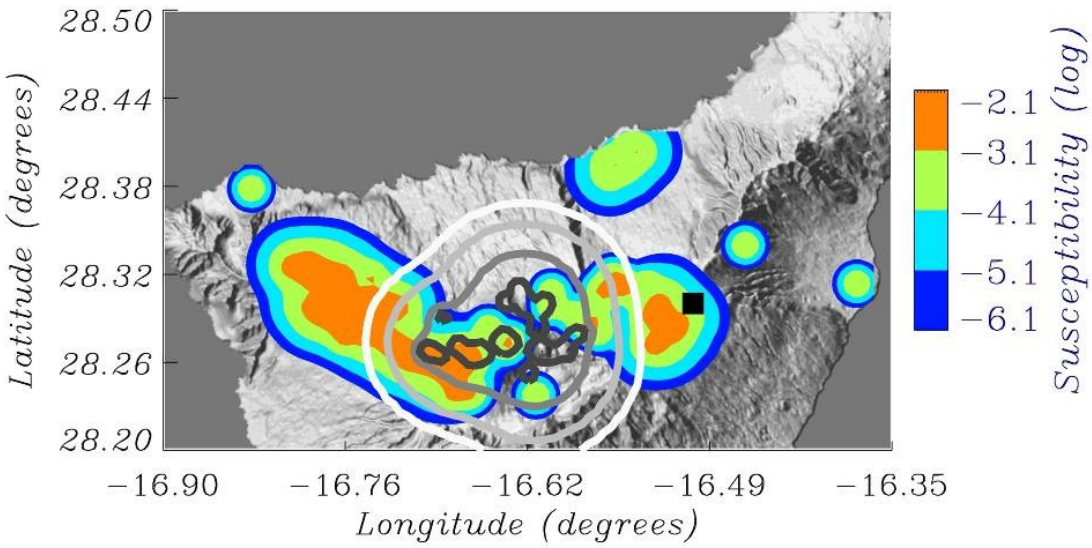


Figure 8.3: Logarithm of susceptibility to mafic (coloured areas) and felsic (grey contours) eruptions to occur once during the next 50 years. The four contour lines correspond to colour codes, with the dark

article available at http://www.ucm.es/info/geodina/curriculums/LGV/pdf_articulos/2006%20Probabilistic%20Seismic%20Hazard%20Canary.pdf

grey line equivalent to the orange colour of the mafic eruptions and the lightest contour line equivalent to the dark blue.

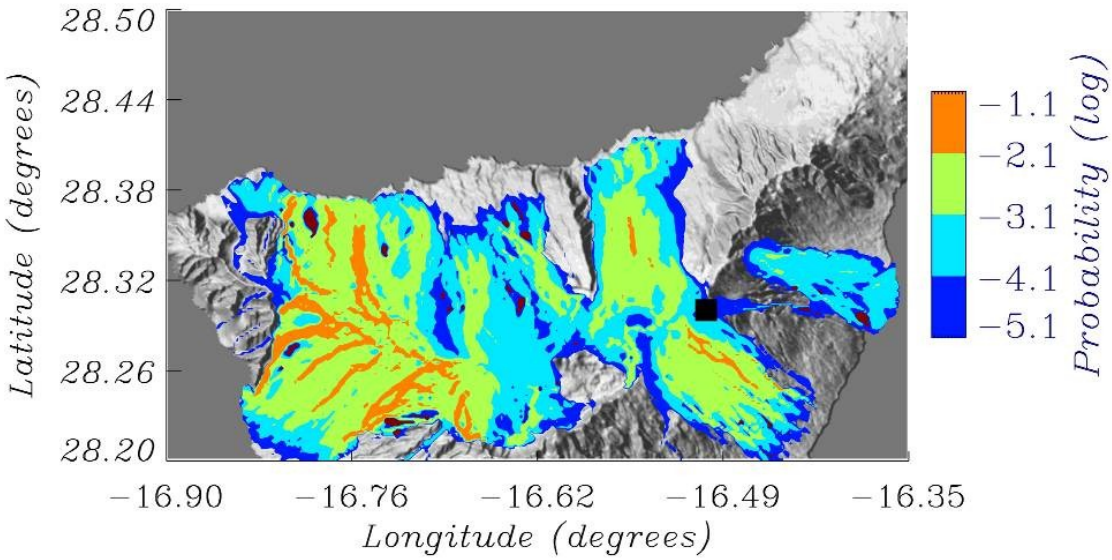


Figure 8.4: Probability (logarithm) of lava invasion to occur once during the next 50 years from the mafic areas shown in the previous figure.

8.3 Ash risk

Ash risk is the risk of an area being covered by ash from volcanic activity nearby. 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 VEI=2 for a small scale basaltic eruption to VEI=4 for a sub-plinian eruption. Since VEI=2 eruptions create eruptive columns of only low height, the ash deposits only locally. In Tenerife moreover, the Alisio winds blow towards the SW, while the areas with the highest risk of eruption are found towards the West of the OT. For this reason, the ash risk from VEI=2 eruptions is negligible. 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 (i.e. a recurrence time of 3000 years). Figure 8.5 summarizes the ash risk evaluation for Tenerife and La Palma.

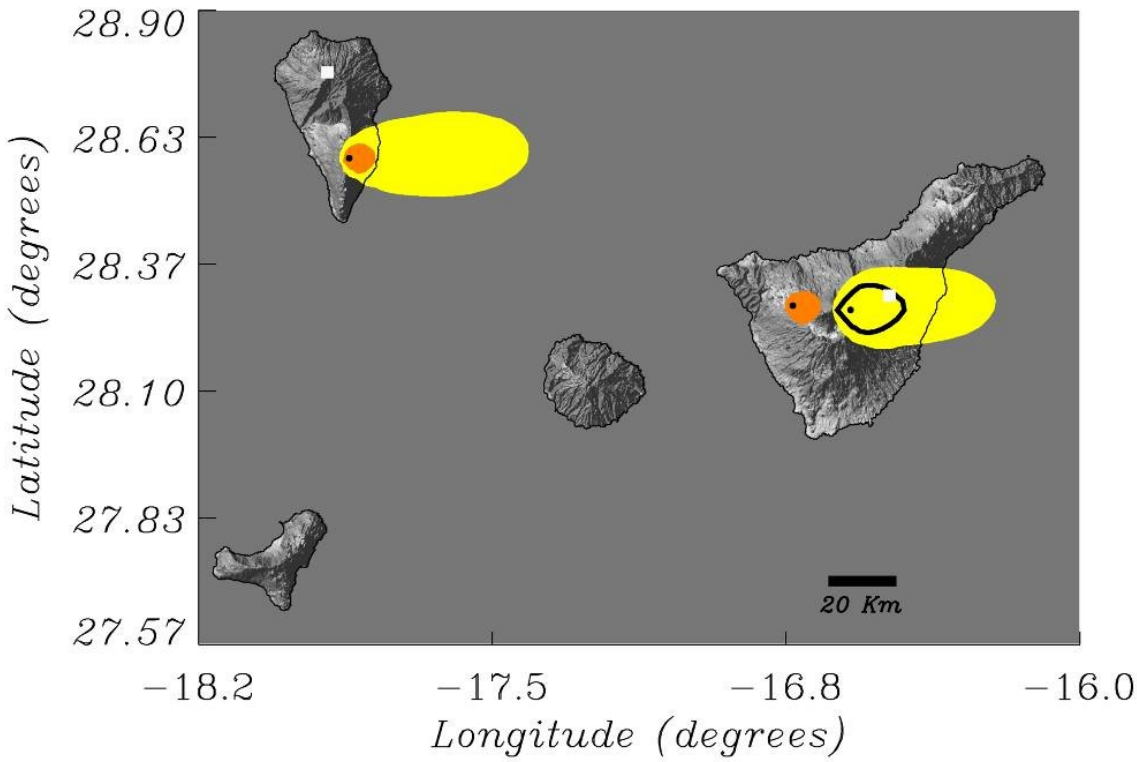


Figure 8.5: Spatial distribution of ash deposits (at least 1 cm thick) following an eruption of the eruptive centres (black circles). The observatories are represented by white squares. The orange and yellow areas in Tenerife represent the extent of the ash after VEI=2 and VEI=4 eruptions respectively. The black contour line represents the distribution of ash deposits at least 10 cm deep.

8.4 Risk of ground deformation

Risk of ground deformation is measured by the inclinations that could appear in the ground at the observatories if volcanoes became active, which would affect the alignment of mechanical and optical components and pointing and tracking systems in telescopes. The risk of changes in the ground caused by the presence of a magma chamber beneath Teide, or dyke injection or fault reactivation has also been assessed. It can be seen that the only potential risk is from reactivation of the magma chamber beneath Teide, although this is only possible in very superficial or high-pressure chambers (not the type present in Tenerife). Once again, the frequency of such events is unclear.

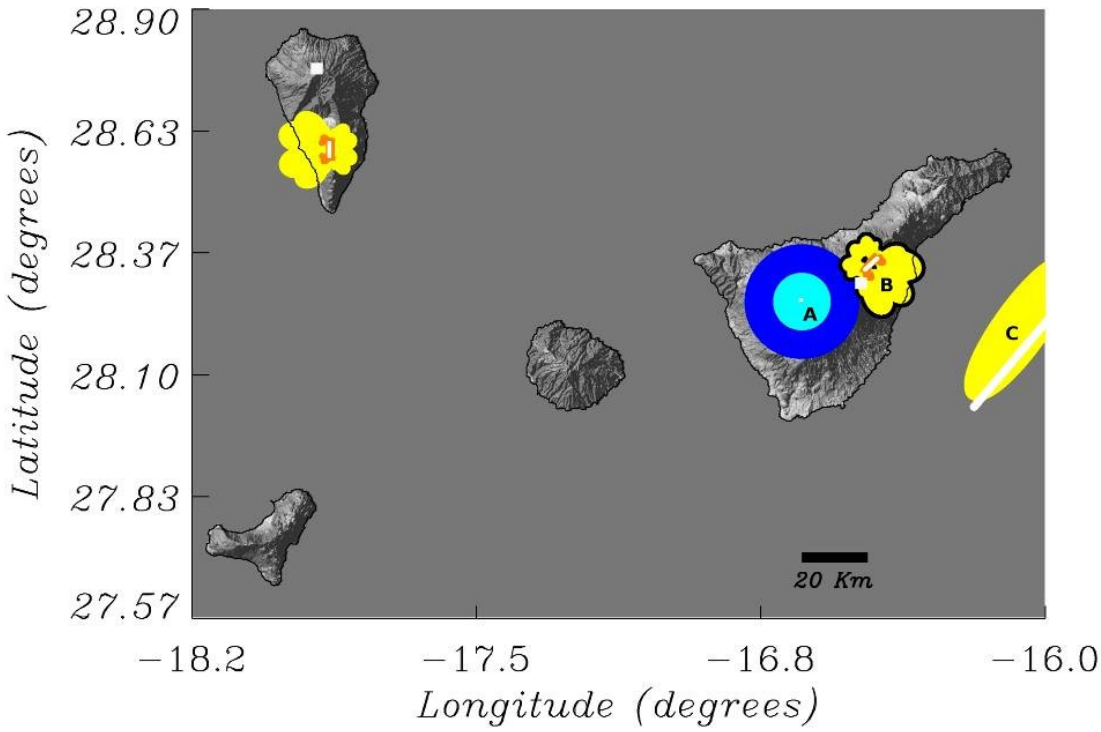


Figure 8.6: Spatial distribution of changes in the ground appearing as inclines caused by vertical rising. Areas with deformation of at least 20 arc seconds or 2 arc minutes are shown in yellow and orange, or dark and light blue. The observatories are shown as white squares, with the fault lines projected on the surface as white lines. Three types of subsidence are projected for Tenerife: subsidence due to activity in the magma chamber (A), dyke injection (B) and tectonic faults (C). For La Palma, subsidence caused by dyke injection at Cumbre Vieja is projected.

8.5 Pyroclastic Flows

Available records and studies show no evidences of pyroclastic flows in Tenerife within the last 150,000 years. The volcanic buildings responsible for this type of phenomena disappeared from the island about that time, to make way to the formation of the Teide.

Table 8.2 summarizes all of the most pertinent results of the geological risk study for the Canary Islands' Observatories.

	OT	ORM	Comments
Seismic Risk	PGA=0.06g	PGA=0.05g	PGA is the peak ground acceleration rate to be expected by the largest seismic event, expected during the next 50 years with a probability of 10%.
Lava Flow Risk	Negligible	Negligible	Probability of lava invasion in the next 50 years.
Ash risk (VEI=2)	$P_A=10^{-4.3}$	Negligible	Probability of at least 1 cm of ash. Frequency for Tenerife 10,000 years.
Ash risk (VEI=3)		Very low	There has never been a VEI=3 eruption in La Palma or Tenerife.
Ash risk (VEI=4)	$P_A=10^{-2.2}$		Probability of at least 10 cm of ash. Frequency for Tenerife 3,000 years.
Risk of changes in the earth (magma chamber)	Very low		Probability of inclinations of at least 20 arc seconds in the ground in the next 50 years due to reactivation of the magma chamber.
Risk of changes in the ground (dyke injection)	$P_A=10^{-4.3}$	Negligible	Probability of inclinations of at least 20 arc seconds in the ground in the next 50 years due to dyke injection. Frequency 10000 years.
Risk of changes in the ground (tectonic fault)	Negligible		Probability of inclinations of at least 20 arc seconds in the ground in the next 50 years due to fault activity.
Pyroclastic flows			No evidences of pyroclastic flows within the last 150,000 years in Tenerife

Table 8.2: Summary of risk factors at the Observatories examined. The blank fields correspond to situation, which have not been studied, due to the fact that these phenomena have not been detected in the geological registers so far and hence result highly improbable.

9 Basic and Advanced Infrastructure at the OT and the IAC

The Canary Islands' Observatories have virtually the entire infrastructure needed to support the construction and operation of CTA. This cannot be overstated as it means that the project would be logistically viable and avoid budget overspends for new support infrastructure.

The entire existing general-purpose infrastructure at the OT is maintained by IAC central services, simplifying logistics for the scientific institutions working at the observatory.

9.1 Infrastructure at the OT

9.1.1 Access

The roads leading to the OT and the access roads within it are all medalled, in good condition and properly signposted. The Canary Islands' Observatories can be accessed with any type of vehicle whereas entry to other leading observatories requires special vehicles (all terrain, etc.). Both main airports and ports are within less than one hour of reach.

The local authorities maintain the roads. No special requirements are anticipated for the construction and operation of CTA, meaning that only routine maintenance and upgrades will be needed for everyday vehicle traffic. However, the regional government is implementing a Private Land Transport Modernization and Restructure Plan and this could cover any specific work needed to support CTA.

As Tenerife is an international touristic resort, there are many rental car agencies and a well-developed public transit service (including taxi, bus and tram). Prices of these services are moderate compared with, for example, European ones due to the importance of the tourism industry in the island.

Very rarely (once per year) the access road to the observatory is closed due to bad atmospheric conditions (essentially snow). In any case, the local island government ("Cabildo") is committed to open it within 24 h.

9.1.2 Telecommunications

In 2009, the IAC completed an upgrade of telecommunications between its observatories and offices. The improvements led to a Gbps bandwidth increase.

At the end of 2009, both the ORM and the Centro de Astrofísica de La Palma (CALP)

were already connected to the IAC headquarters at La Laguna on the island of Tenerife by a 10 Gbps circuit providing a high speed digital communications network for scientific research activities. The same upgrade process has also been completed on Tenerife from the OT to the IAC.

In terms of connection to national and international networks, the Ministry of Science and Innovation is implementing an investment of 130 million euros, financed jointly with FEDER, for the fast implementation of a new fibre optic network ("dark fibre") connecting all of the country's universities, public research centres using RedIRIS and especially (the result of a commitment to Spain's Autonomous Regions) all of Spain's Singular Scientific and Technological Installations, including the OT and ORM. This new project, RedIRIS-Nova, will be a huge improvement compared to the existing communications infrastructure. **Transmission capacities of 20-30 lambda (200-300 Gbps) will be possible by 2012 from both observatories (OT y ORM) to central Europe**.

There is mobile phone connection from the three main Spanish providers at the OT.

9.1.3 Electricity

Red Eléctrica de España provides the electrical transport network throughout Spain, operating the electricity system that carries electricity from power stations to the consumer. The company that supplies power to the mountain sites of by the Canary Islands' Observatories is Unelco-Endesa.

At the OT, the main supply comes from a substation near the Izaña Military Detachment. The line originates in Güímar and is overhead until the limit of the Teide National Park, where it goes underground. The Observatory has three sub-stations near to the Themis telescope (ET1, Power 400KVA), the Carlos Sánchez Telescope (ET2, Power 250KVA) and the Residence (ET3, Power 100KVA). The power available at the OT is 1 MW although current demand does not exceed 0.3 MW.

When the power supply is interrupted generators at the telescopes are used. The telescopes are equipped with batteries (UPS) which provide sufficient energy to power them and their cooling, heating and other systems whilst the generators, which can run independently for up to two weeks, power up.

9.1.4 Water supply and sewerage

The OT has ten water tanks (total capacity 150 m^3) to meet the needs of its personnel and other users at its residence and telescopes. Annual consumption is currently around 2,100 m3 (Residence –1.000 m^3, Telescopes – 600 m^3). The annual cost is around 41 k€ (~20 € / m^3).

For wastewater and sewerage the observatories have purification plants to treat the water before it is discharged onto the land. Wastewater is only produced by personnel as no industrial or other activities are undertaken at the site.

9.1.5 Residence

The OT Residence has 14 double rooms for visiting scientific and technical staff. It also has 6 rooms in annex buildings and rooms for its own staff. Average annual occupancy is over 4,500 stays.

The residence is open 24 hours a day, seven days a week. The residence provides breakfast, lunch and dinner during the working hours of the institutions using the observatories.

The OT also has general use facilities including a **fax, photocopier, computer room, meeting and videoconference rooms and entertainment facilities including television rooms and a small library**.

9.1.6 Workshops and storage place

There is storage space at the observatory. Depending on the needs, the storage capabilities can be enlarged using the facilities at the IAC's headquarters in La Laguna, which are at less than an hour of driving (see also next chapter).

The observatory provides limited workshop facilities intended to serve small and urgent repairs.

Given that the IAC's headquarters are located close to the observatory, it is more cost-effective to use its facilities instead of having large workshops at the observatory. This has been the case in more than three decades of operating the OT.

In any case, there is permanent maintenance staff at the observatory and personnel from the IAC travels diary to the mountain.

9.1.7 Parking

There is ample parking space at the observatory to satisfy the needs of CTA.

9.1.8 Medical Support

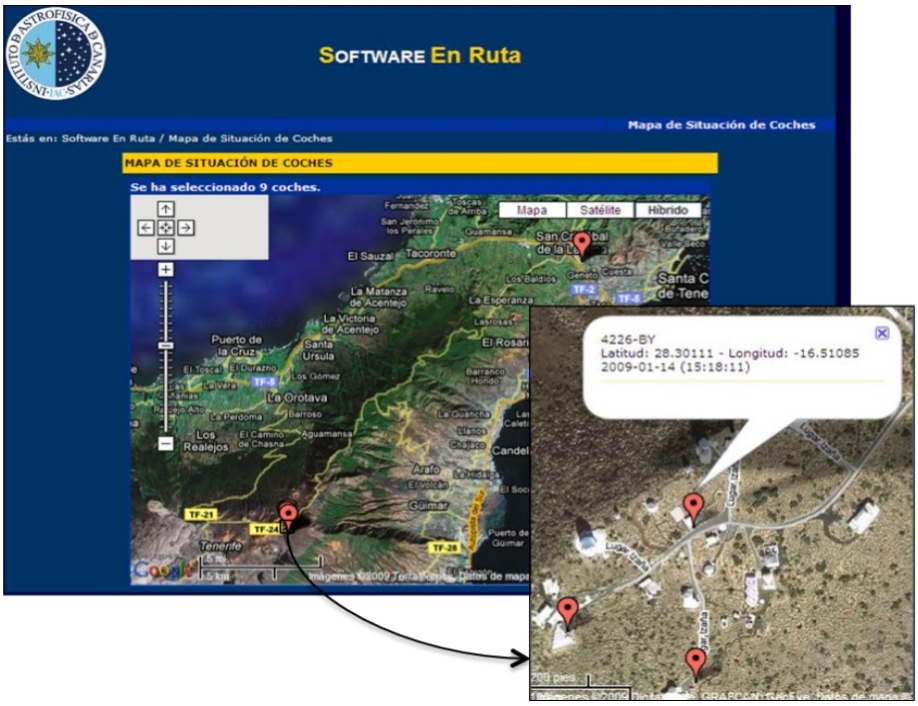
There are first-aid facilities at the observatory and the personnel is trained to attend at the first moment. Ambulances and helicopters can easily arrive at it in a very short period of time.

9.1.9 Further Support installations

The OT has further support facilities and services such as **refuse collection, stores, garages, ambulance and vehicles for users**.

The **fire service** manages fire risk at the observatory to ensure that it is minimal (in line with advice and directives from the local authorities). IAC central services maintain a fire tender in case of fire and provide fire training for the user institutions.

Additional controls are being considered to minimize the risk of injury from the movement of people and vehicles at these isolated locations. At the OT a **GPS vehicle monitoring and warning system** is being piloted (see Figure 9.1).



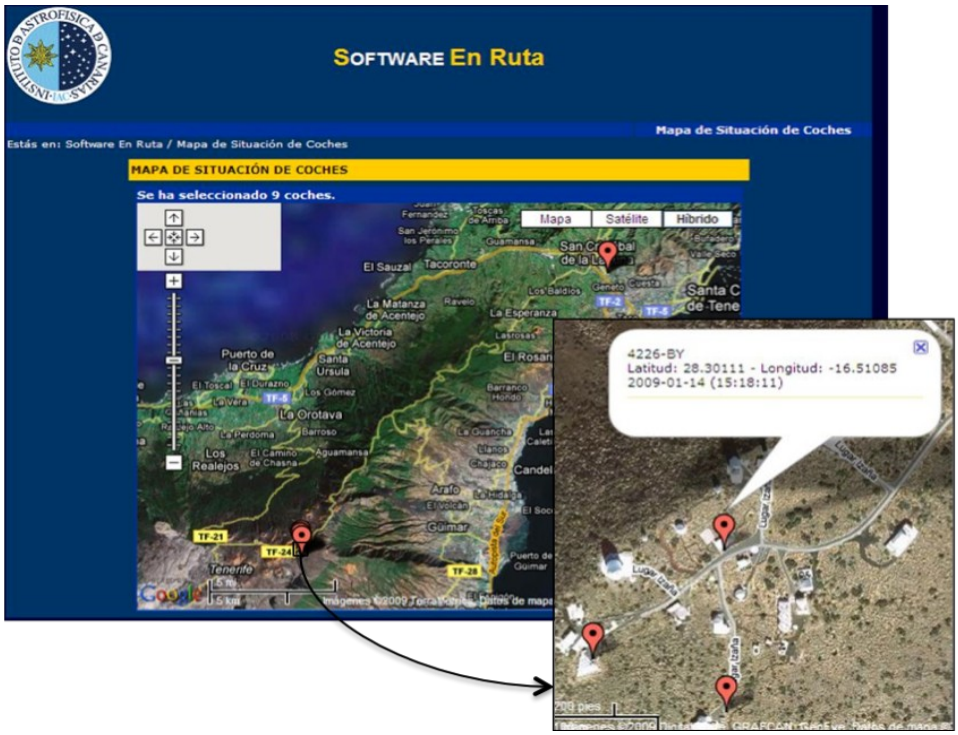

SOFTWARE En Ruta
Mapa de Situación de Coches
Estás en: Software En Ruta / Mapa de Situación de Coches
MAPA DE SITUACIÓN DE COCHES
Se ha seleccionado 9 coches.
Mapa
Satélite
Híbrido
4226-BY
Latitud: 28.30111 - Longitud: -16.51085
2009-01-14 (15:18:11)

Figure 9.1: Web page of the GPS vehicle monitoring system at the IAC in Tenerife.

9.2 Sea-level facilities

9.2.1 Headquarters of the IAC at La Laguna, Tenerife

The Astrophysics Institute in La Laguna is the IAC's headquarters. It houses most of the IAC's workshops, technical rooms and laboratories as well as offices and other observation and post-observation resources needed for its role as the administrative base of the International Observatories.

IAC Headquarters

The headquarters building in La Laguna is the main workplace for most IAC staff, a meeting point for the international astronomical community, a technological research and development institute and a training centre for researchers, engineers and technicians. It is also a dynamic centre for public education.

The IAC has recently obtained the Spanish government's "Severo Ochoa" excellence award in research (among 70 competing institutions), which has been granted by the Spanish ministry of Science to those eight Spanish research institutions with the biggest scientific impact in their field.

9.2.2 Technology Support at the IAC

The IAC has the most advanced equipment, state-of-the-art facilities and highly skilled personnel, enabling it to design and develop in-house much of the technology required for its activities in astrophysical research. The IAC makes these skills and resources available to external organizations like other research centres and private bodies. CTA-North would benefit from this infrastructure.

This is a summary of the services, capabilities and facilities available at the IAC's Technology Division:

9.2.2.1 Technology support services

- Engineering and Production
- Joint technology development projects
- Instrument maintenance
- "Sky Law" compliance monitoring

9.2.2.2 Technical capabilities

- Optical system design and testing
- Mechanical and opto-mechanical system design and development
- Cryogenic and vacuum system design and development
- Precision mechanics
- Adaptive optics
- Co-phasing
- Control systems
- Fibre optics
- Sensor characterization
- RTD project management
- Electronic system and software design and development
- Laser communications

9.2.2.3 Technical facilities and main equipment

- Optics Laboratory
- Optical Coating Laboratory
- Fibre Optics Laboratory
- Electronic Design Laboratory
- Electromagnetic Compatibility Laboratory
- Electronics Workshop
- Electric Calibration Laboratory
- Astronomical Image and Sensor Laboratory
- Mechanical Integration and Verification Laboratory
- CAD Studio
- Dimensional Metrology Laboratory
- Technical Delineation Workshop
- Instrument Maintenance Workshop
- Mechanics Workshop
- Large Instruments Assembly, Integration and Verification Room

The headquarters of the IAC (the city of San Cristóbal de La Laguna) is 9 km from the provincial capital, Santa Cruz de Tenerife, in the north of the island.

9.2.3 Supercomputing

The CALP (La Palma) is equipped with a high capacity supercomputer. It is connected to the Spanish Supercomputing Network (SSN) and will be connected in the future to the large European Supercomputer Network PRACE ("Partnership for Advanced Computing in Europe"), also an ESFRI priority project.

The current nodes in the network are at the Barcelona Supercomputing Centre (National Supercomputer Centre) as the principal node, CALP, CeSViMa (Supercomputing and Visualization Centre of Madrid)

and at the Universities of Cantabria, Málaga, Valencia, Zaragoza and Gran Canaria. Each of these supercomputers can exchange enormous quantities of information, distribute tasks and optimize resources at high speed. The SSN gives Spanish researchers access to massive computations, using unique, interconnected infrastructure, for the first time. The SSN is funded by the Ministry of Science and Innovation and coordinated by the National Supercomputer Centre.

The La Palma node currently comprises 512 processors giving a performance of 4.5 TFlops, putting it at number 413 on the list of the world's fastest computers in 2006. When its computing power is connected to the SSN, exceptionally complex-computing tasks will be shared across the whole network. It will also deliver other resources like massive storage capacity. Once a new upgrade of the MareNostrum computer has been completed the power of the La Palma computer is due to double, to 9 TFlops.

The power of this computer is a giant step forward for the astrophysics community, as its high-speed calculations will make research projects much quicker. The installation of the supercomputer on La Palma was a strategic decision to provide support for observations at the "Observatorio del Roque de los Muchachos", which was recently enhanced by the addition of the GTC, and to telecommunications development on the island.

PRACE will provide Europe with a cutting edge computer, one of the five most powerful in the world that, through regular upgrades, will give scientists permanent access to the most up to date technology available.

The CTA will generate more data than conventional computers can deal with. The presence of an on-site supercomputer (interconnected with IAC headquarters and with the OT through a 200 Gbps circuit as earlier described) is enormously useful for pre-processing this data as well as handling and distributing it. The direct link between this supercomputer, the other nodes of the SSN and PRACE will make massive processing of this information possible, together with comparisons between real and simulated data, and this will deliver new results for science.

9.3 Prevention of occupational accidents

The IAC, following the Spanish Law for Prevention of Occupational Accidents (Ley 31/95) and going beyond the rules and recommendations of that law, has adopted the following prevention policy in order to ensure the safety at work of its staff and any other person that could remain inside the installations of the IAC:

- To integrate prevention of occupational risks in all activities, actions, administrative procedures and the management of the IAC, as well as its command chain and the decisions taken, assuming that as common objective the prevention of occupational hazards is the responsibility of all levels of the Institute, from management to each of the people who make up the IAC.
- Ensure participation, information and consultation procedures for workers through effective communication channels, enhancing the relevant competence of the Committee on Safety and Health at the IAC.
- Achieve the highest possible level of health and safety, even above those established by law, making as many necessary risk assessments as necessary, and the implementation of preventive measures resulting therefrom.
- Allocate resources for the implementation and development of the Policy on Occupational Health and Safety and all the management system for the prevention of occupational risks.
- Provide the necessary training on the prevention of occupational risks to all staff, including it in the general IAC training plans so as to ensure active and responsible participation.
- Ensure the staff of the companies contracted by the IAC, including self-employed, for bearing the same level of safety and health.
- Review and update this policy so as to adapt to technological and legislative changes.
- Establish control mechanisms to verify compliance with both the management system of the prevention of occupational risks and the regulations derived therefrom.
- To implement the management system risk prevention model adapted to the Central Government, with a commitment to maintain a continuous improvement process.
- Review and update this policy so as to adapt to technological and legislative changes.
- Establish control mechanisms to verify compliance with both the management system for the prevention of occupational risks and the regulations derived therefrom.

9.3.1 Accidents from the period 2008-2011

As part of the IAC's security policy, it has established the investigation of all accidents, whether with or without sick leave.

Table 9.1 shows the number of accidents resulting in a sick leave for the last four years, out of around 300 workers employed by the IAC.

YEAR	ACCIDENTS with SICK LEAVE
2008	2
2009	2
2010	2
2011	1

Table 9.1: Number of accidents occurred during the last four years resulting in a sick leave.

9.3.2 Health Surveillance

Based on Risk Assessment and in accordance with paragraph c) of Art. 37.3 of the Regulations for Prevention Services, the IAC has developed health surveillance protocols specific to each job based on the risks they present. It has also identified those jobs, which, according to that stipulated in art. 22 of the law for the prevention of occupational risks, and after consultation with workers or their representatives, require mandatory health checks.

9.3.3 Health and Safety Committee

The IAC has a Health and Safety Committee with its own internal procedure of operation. This is a joint body of collegial involvement, aimed at regular and periodic consultation of the proceedings of the IAC in the prevention of occupational risks.

9.3.4 Risk Assessment

In order to obtain a proper knowledge of the information necessary for the management of the IAC to take appropriate decisions on the need for preventive measures and, if so, what kind of measures need to be taken (Art. 3.1 of the Regulation on Prevention Services) it has made an initial risk assessment and established periodic reviews of it.

9.3.5 Training

Depending on the needs identified each year, the training of workers is planned in terms of identified risks during the job evaluation as well as those the resulting from accidents, etc.

Acronyms

We include a list of acronyms used throughout this document:

Acronym	Meaning
1FGL	First Fermi Gamma-ray LAT catalogue
ACTL	Array ConTroL (a CTA work package)
AD	Anno Domini (After Christ)
AEMET	Agencia Estatal de METeorológica
AERONET	AERosol Robotic NETwork
AGN	Active Galactic Nucleus
AI	Aerosol Index
AIEM	Arbitrio sobre las Importaciones y Entregas de Mercancías en las Islas Canarias
ALMA	Atacama Large Millimetre/submillimetre Array
AOD	Aerosol Optical Depth
ApPEC	Astroparticle Physics European Coordination
ASPERA	AstroParticle ERAnet
ASIC	Application Specific Integrated Circuit
ASTMON	AllSky Transmission MONitor
ATAC	Atmospheric monitoring, Associated science and instrument Calibration (a CTA work package)
ATC	Automatic Transit Circle Telescope (previously CMT)
ATHENA	Advanced Telescope for High Energy Astrophysics
AyA	Astronomía y Astrofísica
BOC	Boletín Oficial de Canarias
BOE	Boletín Oficial de Estado
BRT	Bradford Robotic Telescope
BSC-CNS	Barcelona Supercomputing Centre – Centro Nacional de Supercomputación
BSRN	Baseline Surface Radiation Network
CAB	Centro de Astrobiología
CAD	Computer-Aided Design
CAHA	Calar Alto observatorio astronómico Hispano-Alemán
CALP	Centro de Astrofísica en La Palma
CMB	Cosmic Microwave Background
CCD	Charged Coupled Device
CCI	Comité Científico Internacional
CDEI	Centre de Disseny d'Equips Industrials
CDTI	Centro de Desarrollo de Tecnología Industrial
CEIN	CTA Computing and E-Infrastructure for data management (a CTA work package)
CENIT	Consorcios Estratégicos Nacionales de Investigación Tecnológica
CERN	Centre Européen de Recherche Nucléaire
CeSViMa	Centro de Supercomputación y Visualización de Madrid
CIEMAT	Centro de Investigaciones Medioambientales y Tecnológicas
CMT	Carlsberg Meridian Telescope

CSIC	Consejo Superior de Investigaciones Científicas
CPAN	Centro nacional de física de Partículas, Astropartículas y Nuclear
CPI	Consumer Price Index
DAFA	Data Format, Archiving and analysis
DAQ	Data AcQuisition
DOT	Dutch Open Telescope
E-ELT	European Extremely Large Telescope
EGEE	Enabling Grids for E-Science in Europe
ELEC	Electronics Group / Readout ELECtronics and trigger (a CTA work package)
ERA	European Research Area
ESA	European Space Agency
ESAC	European Space Astronomy Centre
ESFRI	European Strategy Forum on Research Infrastructures
ESO	European Southern Observatory
ESRF	European Synchrotron Radiation Facility
ESS	European Spallation Source
EST	European Solar Telescope
EU	European Union
EU ICS	European Crime and Safety Survey
EVN	European VLBI Network
FEDER	Fondo Europeo de Desarrollo Regional
FP5	5th Framework Program (1998-2002)
FP7	7th Framework Program (2007-2013)
FPA	Física de Partículas y Acceleradores
FPI	Focal Plane Instrumentation (a CTA work package)
FTE	Full Time Equivalent
GAE	Grupo de Altas Energías
G-APD	Geiger-mode Avalanche Photo Diode
GAW	Global Atmosphere Watch
GDP	Gross Domestic Product
GOES	Goestationary Operational Environmental Satellite
GSHAP	Global Seismic Hazard Assessment Program
GPS	Global Positioning System
GRAAL	Gamma Ray Astronomy at Almería
GRB	Gamma Ray Burst
GTC	Gran Telescopio Canarias
GURME	GAW Urban Research and Meteorological Environment
HEGRA	High Energy Gamma Ray Astronomy
H.E.S.S.	High Energy Stereoscopic System
IAA	Instituto de Astrofísica de Andalucía
IAC	Instituto de Astrofísica de Canarias
IACT	Imaging Atmospheric Cherenkov Telescope
IARC	Izaña Atmospheric Research Centre
ICC	Institut de Ciències del Cosmos
ICE	Institut de Ciències de l'Espai
ICVS	International Crime Victims Survey
IEEC	Institut d'Estudis Espacials de Catalunya

IFAE	Institut de Física d'Altes Energies
IFCA	Instituto de Física de Cantabria
IFIC	Instituto de Física Corpuscular
IGIC	Impuesto General Indirecto Canario (the Canarian VAT)
ILL	Insitut Laue Langevin
INAOE	Instituto Nacional de Astrofísica, Óptica y Eletrónica
INSA	Ingeniería y Servicios Aeroespaciales
INT	Isaac Newton Telescope
INTA	Instituto Nacional de Técnica Aeroespacial
INTEGRAL	INTErnational Gamma-Ray Astrophysics Laboratory
IRAM	Institute for Radio Astronomy in the Millimetre range
ISIS	Institute for Science and International Security
ISO9001	International Organization for Standards, quality management and quality assurance
ISS	International Space Station
ISTAC	Instituto Canario de Estadística
IVA	Impuesto al Valor Agregado (the Spanish VAT)
IZO	Izaña Observatorio
KVA	Kungliga VetenskapsAkademien (Royal Swedish Academy of Science)
LAT	Large Area Telescope
LEP	Large Electron Positron collider
LIDAR	Light Detection And Ranging
LHC	Large Hadron Collider
LOFT	Large Observatory for X-ray Timing
LST	Large Size Telescope
LT	Liverpool Telescope
MAGIC	Major Atmospheric Gamma-ray Imaging Cherenkov telescope
MAN	MANagement
MC	Optimization of array layout, performance studies and analysis algorithms (a CTA work package)
MICINN	Minsterio de Investigación, Ciencia e Innovación
MIR	MIRrors (a CTA work package)
MODIS	MODerate resolution Imaging Spectroradiometer
MoU	Memorandum of Understanding
MST	Mid Size Telescope
MWh	Mega-Watt hours
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NDACC	Network for the Detection of Atmospheric Composition Change
NECTAr	New Electronics for the Cherenkov Telescope Array
NEIC	National Earthquake Information Centre
NOAO	National Optical Astronomy Observatory
NOT	Nordic Optical Telescope
NSB	Night Sky Background
NSO	National Solar Observatory
NW	North-West
OAS	Organization of American States

OECD	Organization for Economic Cooperation and Development
OGS	Optical Ground Station
ONERA	Office Nationale d'Etudes et de Recherches Aérospatiales
OR	Outermost Region
ORM	Observatorio del Roque de los Muchachos
OT	Observatorio del Teide
OTA	Optical Telescope Array
OTPC	Oficina Técnica para la Protección de la Calidad del Cielo
OUTR	OUTReach (a CTA work package)
PECAN	Plan Energético de CANarias
PGA	Peak Ground Acceleration
PHO	Punta del Hidalgo Observatorio
PHYS	Astroparticle PHYSics (a CTA work package)
PM10	Particles of the order of 10 μ m or less
POSEI	Programmes of Specific Measures for Remote and Insular Areas
PP	Partido Popular
PRACE	Partnership for Advanced Computing in Europe
PSOE	Partido Socialista Obrero Español
PW	Precipitable Water
PWV	Precipitable Water Vapour
QC	Quality Control (a CTA work package)
QUIJOTE	Q U I Joint Tenerife
RDI	Research, Development and Innovation
RADS	Risk Assessment, Dependability and Safety (a CTA work package)
REF	Régimen Económico y Fiscal
RENATA	Red Nacional Temática de Astropartículas
RIA	Red de Infraestructuras de Astronomía
RIMA	Red Ibérica de Medida fotométrica de Aerosoles
RTD	Research and Technical Development
SCO	Santa Cruz de Tenerife Observatory
SDEV	Site DEVelopment
SITE	SITE selection and site infrastructure (a CTA work package)
SQM	Sky Quality Meter
SQR	Sky Quality Group
SSN	Spanish Supercomputing Network
SST	Small Size Telescope
SST	Swedish Solar Telescope
SSTI	Singular Scientific and Technological Infrastructures
STARE	Stellar Astrophysics and Research on Exoplanets
STELLA	STELLar Activity
SUCOSIP	SubCOmité de "Site Properties"
TAC	Time Allocation Committee
TCS	Telescopio Carlos Sánchez
THEMIS	Telescope Héliographe pour l'Etude du Magnétisme et des Instabilités du Soleil
TNG	Telescopio Nazionale Galileo
TOMS	Total Ozone Mapping Spectrometer

TSP	Total Suspended Particles
UA	Universitat d'Alacant
UAB	Universitat Autònoma de Barcelona
UAH	Universidad de Alcalá de Henares
UAM	Universidad Autónoma de Madrid
UB	Universitat de Barcelona
UCM	Universidad Complutense de Madrid
UG	Universidad de Granada
UIB	Universitat de les Illes Balears
UK	United Kingdom
ULC	Unitary Labour Cost
ULL	Universidad de La Laguna
UNAM	Universidad Nacional Autónoma de México
UNESCO	United Nations Educational, Scientific and Cultural Organization
UPS	Uninterrupted Power System
UV(eg)	Universitat de València (estudi general)
UPC	Universitat Politècnica de Catalunya
UPV	Universitat Politècnica de València
UCM	Universidad Complutense de Madrid
UN	United Nations
UZ	Universidad de Zaragoza
VAT	Value Added Tax
VEI	Volcanic Explosion Index
VERITAS	Very Energetic Radiation Imaging Telescope Array System
VHE	Very High Energy
VLBI	Very Long Baseline Interferometry
VLT	Very Large Telescope
VTT	Vacuum Tower Telescope
WASP	Wide Angle Search for Planets
WEBT	Whole Earth Blazar Telescope
WHT	William Herschel Telescope
WMO	World Meteorological Organization
WSO	Wilcox Solar Observatory
XMM	X-ray Multi Mirror satellite

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Site Characterization Matrix

	OBSERVATORIO DEL TEIDE
ACCESSIBILITY	
Distance to nearest town / city	30 km to La Orotava / 40 km to La Laguna
Size of nearest town / city	40.000 inh / 200.000 inh
Type of road to nearest town /city	Paved / paved
Access by rail	No
Access from nearby town / city (hours)	Less than 1 hour / less than 1 hour
Distance to nearest local airport	40 km
Air landing path on site	Heliport
Distance to nearest international airport	40 km
Distance to nearest international harbour	60 km
Travel time to EU & USA	4 hours to Germany and 7 to Florida (direct flights)
Maximum allowed width on access road	3 m in each direction, with hard shoulders of 1m
Maximum allowed height on access road	No serious limitations in height
Maximum allowed weight per axis on access road	10 tons per axis (50 tons in total)
Distance to nearest gasoline station	30 km
Distance to nearest medical emergency service or hospital	30 km
Distance to nearest fire station	5 km (El Portillo)
Accessibility by public transportation to nearest town	Yes
Distance to car rental	40 km
Distance to hotel	On site
Distance to restaurants and food provision	On site
Distance to workshops, supply stores	30 km
Distance to high bandwidth connection	On site
Nearby convention facilities	40 km
Local manpower availability	Yes
INFRASTRUCTURE	
Provision of electrical energy	Yes, 1MW
Distance of required power line	3 Km (from CTA to OT)
Alternative power supply	Electrical Generator
Power costs	0.11 euros/kWh
Internet access / bandwidth	200-300 Gbps to Central Europe
Cost of bandwidth	Free
Gas	No
Water supply	Yes
Drinking water supply	Yes
Office space	Yes

Covered storage space	Yes
Open storage space	Yes
Workshop space	Yes
Bedrooms – Dorms	17 double rooms
Computing rooms	Yes
Parking	Yes
Cell phone coverage	Yes
Telephone	Yes
Waste management	Yes
Drained and wastewater management	Yes
POLITICAL AND ECONOMIC CONDITIONS	
Political stability	Excellent
Landowners	Public
Land access conditions	Regulated by public authorities
Land access costs	Not applicable
Customs clearance	No customs for CTA at OT
Local political support	National and local authorities are aware of this candidacy
Local economic support	To be discussed at a later stage
Impact study requirements	Detailed socio-economic and environmental studies will be prepared if the site is selected.
Accessibility restrictions (National Parks, etc.)	No
Cost of manpower	2,077 euros ULC
Scientific support at regional & national levels	Excellent
Closest scientific facilities distance	OT (5 km), IAC (40 km)
Technical & industrial support at regional and national levels	Excellent
Living conditions of permanent staff	Excellent
Site synergy with other scientific projects	Excellent
Financial contribution by host country	To be discussed at a later stage
SAFETY	
Wild fires, animals, risk of regional diseases, criminality	No
Labour related accidents (international and national labour regulations)	0.003-0.006 / yr.

SITE GEOGRAPHYSICAL CONDITIONS	
Total available flat area [km^2]	50 ha.
Latitude	28º16'36'' N
Longitude	16º32'08'' W
Altitude [masl] (2500-4000 masl, preferred < 3500 masl)	2260 masl
Soil composition - Ground type	Strong basaltic layers few meters below the organic soil.
Clear horizons	Yes, observability from 10 deg. w/o restrictions
Terrestrial magnetic field	$\|B\|$ = 38,5 µT $\|B_{horiz}\|$ = 30,8 µT
NATURAL HAZARDS	
Seismicity	Very low, PGA=0.06g
Rigidity cutoff	12.4 GV at 20 km
Volcanic activity	Very low risks, see chapter 8 for details
Hail	1.5 days / yr. on average
Tornadoes-Hurricanes (last 10 years)	No
Thunderstorms	Very rarely
ATMOSPHERIC AND METEOROLOGICAL CONDITIONS	
Light pollution	V-Filter after midnight: 21.65 mag/$arcsec^2$ in 2010, improving trend. See chapter 6 for details
Average summer day/night temperature	20º C (24h period)
Average winter day/night temperature	6º C (24h period)
Maximum temperatures	30.4 º C (in 92 years)
Minimum temperatures	-9.8 º C (in 92 years)
Average wind velocity	Needs to be measured locally, see chapter 6 for details (6.8 m/s at IZO).
Number of days with wind velocity > 10 m/s	Needs to be measured locally, see chapter 6 for details.
Wind gusts	Needs to be measured locally, see chapter 6 for details.
Average summer humidity	The median (whole year) is 27%, see chapter 6 for details.
Average winter humidity	The median (whole year) is 27%, see chapter 6 for details.
Cloud coverage	The useful time lies between 82.7% and 72.5%, see chapter 6 for details.
Nightly cloud coverage	The useful time lies between 82.7% and 72.5%, see chapter 6 for details.
Fog	There are no records of fog.
Precipitations	11 days/yr. for precipitation > 10 mm 44 days/yr. for precipitation > 0.1 mm
Snow accumulation (maximum last 10 years)	There are no written records, but it is usually

	very low.
Nearby mining activity	No (forbidden by the Natural Park and the Sky Law).
Aerosols	Significant PM10 concentrations in 15% of the year, mainly in summer (and accompanied by cirrus), see chapter 6 for details.
Risk of nearby population growth	No risk (National Park area)