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# RECENT RESULTS AT THE CANARIAN OBSERVATORIES

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RESUMEN

Durante las últimas décadas, los Observatorios en Canarias, Observatorio del Roque de los Muchachos (ORM) y Observatorio del Teide (OT) han servido de banco de pruebas y desarrollo de nuevas técnicas y herramientas para *site testing*. Se ha realizado un gran esfuerzo, tanto en la definición de los parámetros claves para caracterizar Observatorios Astronómicos como en el diseño de instrumentos y herramientas capaces de medir y comparar diferentes sitios. En esta contribución revisamos algunos de los parámetros que se consideran relevantes para la evaluación de la calidad y también se describen brevemente los instrumentos y técnicas capaces de medirlos correctamente. Se presentan algunos resultados estadísticos, haciendo énfasis especial en aquellos más recientes obtenidos en el marco del programa FP6 de selección del emplazamiento para el futuro ELT Europeo.

ABSTRACT

During the last years a mayor effort has been carried out both, in defining key parameters to quantify the quality of a site for astronomical observations, and to design reliable techniques and tools to compare different sites. Here, we will revise some of the parameters relevant for astronomical site evaluation, and we will also brief on the instruments currently available for their measurements. The Observatories at the Canaries, Observatorio del Roque de los Muchachos (ORM) and Observatorio del Teide (OT) have been used as test bench for the development of new techniques and tools for more than three decades. Results on statistical measurements and techniques, emphasizing the most recent ones in the framework of the FP6 site selection program at the Canarian Observatories are given.

*Key Words:* **ATMOSPHERIC EFFECTS — SITE TESTING**

## 1. GENERAL BACKGROUND

Two of the seven islands that constitute the Canarian archipelago, Tenerife and La Palma, host the Observatorio del Teide (OT) (see `http://www.iac.es/eno.php?op1=3`) and the Observatorio del Roque de los Muchachos (ORM) (see `http://www.iac.es/eno.php?op1=2`), see Figure 1. Since the early seventies when the first telescopes were installed there, site testing studies have been carried out in order to get the most from the observations. As a result the database of atmospheric parameters related to the astronomical observations is very extensive and includes updated measurements and techniques that were implemented as new experiments or telescopes were planned. One of the last campaigns took place before the construction of GranTeCan (Gran Telescopio Canarias), a 10-m segmented telescope which had its first light on May 2007 (see `http://www.gtc.iac.es/`). More recently the ORM was preselected among five other places in the world to boost the Advanced Technology Solar Telescope (ATST, `http://atst.nso.edu/site/`), a 4-m mirror to observe the sun with the most advanced technology, developed by the ATST (National Solar Observatory, NSO). The final decision took place among the two sites best classified, Mauna Kea and ORM (see `http://atst.nso.edu/site/reports_final.shtml`).

Since the late eighties and been aware of the importance of continuous and updated site measurements for astronomical observations, a Site characterization team was created at the IAC[2]. The Sky Quality Group has been growing since then and nowadays a dedicated staff of about three EDPs, work on studies related to the characterization of the atmosphere for astronomical observations. In addition, the Sky Quality Group collaborates with other teams from the IAC and from outside, which develop programmes related to the physics of the atmosphere (see `http://www.inm.es/`), or atmospheric optics (see `http://www.iac.es/project/gare/esp/index.html`).

At the OT and the ORM a large number of user institutions (countries and Institutions) oper-

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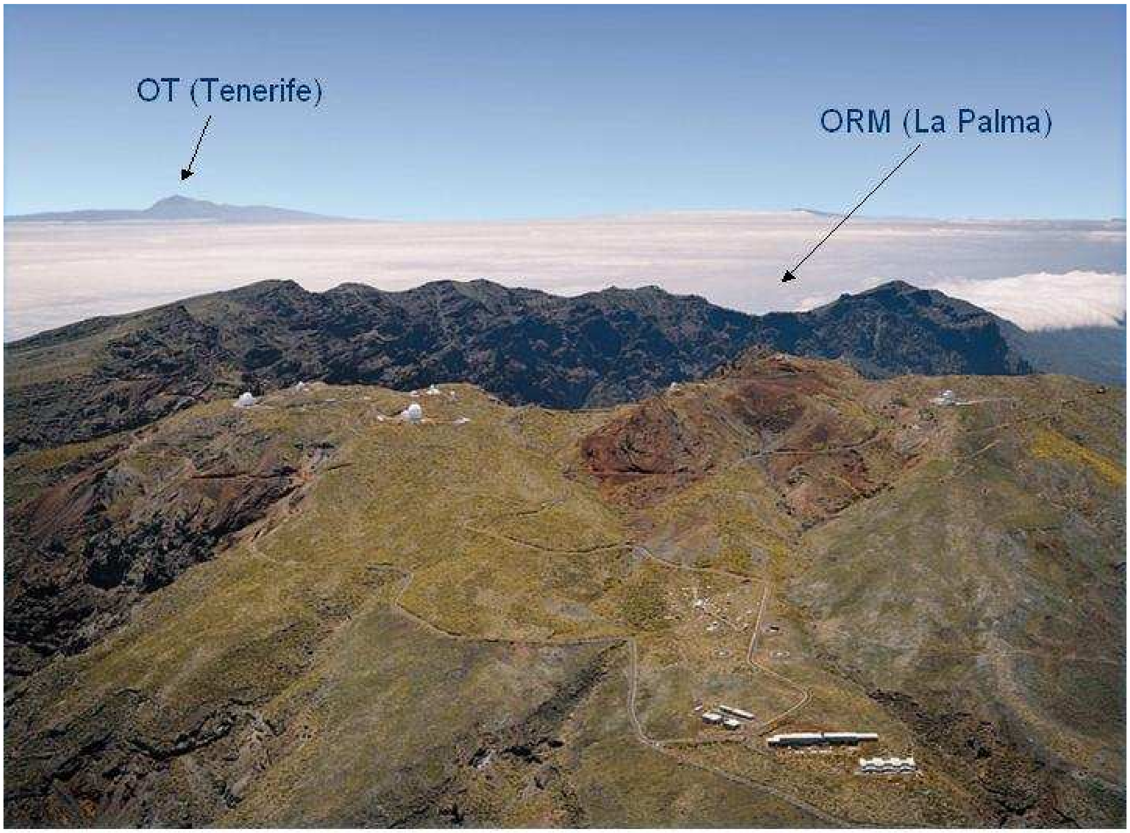


Fig. 1. Aerial view of the two islands: La Palma and ORM (front) and the silhouette of Tenerife in the background. Volcano Teide is the Peak were the OT is sited. Note the sea of clouds above the sea.



ate different installations. All the activities at the Observatories with are common are coordinated by the Comité Científico Internacional (CCI) (see `http://www.iac.es/eno.php?op1=5`). For practical reasons the different issues been handled by the CCI are organized by specific ad hoc subcommittees. In the early nineties a subcommittee on site properties (SUCOSIP) was created. Our mission was to promote and pursue studies related to site characterization and to advise the CCI on decisions which could affect the quality of the observing site, as for example the installation of new equipments or telescopes. The last action promoted by SUCOSIP was organizing networking activities related to the study of the Canarian Observatories. Networking Activity (Co-ordination and Integration of ENO facilities) is carried out under the framework of the Optical Infrared Coordination Network for Astronomy (OPTICON `http://www.otri.iac.es/na2/`). Network N2 will assist in the coordination and integration of the observing facilities at the Canarian Teide and Roque de los Muchachos observatories, described as the European Northern Observatory.

As a result of the large number of years of measurements with the most updated techniques, the day and night time database of optical turbulence is excellent and shows a very good and stable behavior along several years. All the information has been compiled at the Web `http://www.iac.es/project/sitesting/site.html`, which also has been managed as a data base with allows to retrieve atmospheric parameters as required (see Figure 2).

## 2. MORE RECENT WORK

Since 2005 we participate in the FP6 ELT design Study-WP on Site Selection (see Muñoz-Tuñón, Sarazin, & Vernin 2007). We have contributed to the design of the general guidelines of the WP, and the IAC is responsible among other things to carry out the measurements at ORM and OT. Besides we are deeply involved in the design and manufacturing of instruments for the ELT-WP. We have developed the two SCIDAR instruments for ORM and Paranal, and the DIMM interface of the MASS-DIMM (MASS is developed by ESO). As all other WP participants


Site 1 (Near the Not)

12-10-1995

| time | wind speed (km/h) | wind gusts (km/h) | wind direction | air temperature | relative humidity | barometric pressure | soil temperature | subsoil temperature | solar flux (W/m2) |
|---|---|---|---|---|---|---|---|---|---|
| 00:01:01 | 31.30 | 32.40 | 34.00 | 7.20 | 3.60 | 770.00 | 5.50 | 6.80 | 0.00 |
| 00:01:58 | 35.60 | 36.30 | 22.00 | 7.30 | 3.40 | 770.00 | 5.50 | 6.80 | 0.60 |
| 00:03:00 | 35.60 | 36.30 | 22.00 | 7.30 | 3.40 | 770.00 | 5.50 | 6.80 | 1.10 |
| 00:04:01 | 35.30 | 36.10 | 23.00 | 7.40 | 3.30 | 770.00 | 5.60 | 6.80 | 1.40 |
| 00:04:58 | 34.70 | 36.10 | 23.00 | 7.40 | 3.30 | 770.00 | 5.60 | 6.80 | 1.40 |
| 00:06:00 | 34.70 | 36.10 | 23.00 | 7.40 | 3.30 | 770.00 | 5.60 | 6.80 | 1.40 |
| 00:07:01 | 31.90 | 34.20 | 16.00 | 7.40 | 3.30 | 770.00 | 5.60 | 6.80 | 1.10 |
| 00:07:58 | 30.50 | 33.80 | 16.00 | 7.40 | 3.40 | 770.00 | 5.60 | 6.80 | 0.80 |
| 00:09:00 | 29.40 | 31.00 | 16.00 | 7.40 | 3.50 | 769.90 | 5.60 | 6.80 | 0.70 |
| 00:10:01 | 29.40 | 31.00 | 19.00 | 7.30 | 3.50 | 770.00 | 5.60 | 6.80 | 0.30 |

Fig. 2. Web page project of the Sky Quality Group of the IAC (left) - `http://www.iac.es/project/sitesting/site.html`) which has been managed as a seeing and meterorological database (right).



we will also be involved in the data analysis of the whole data set when it becomes available.

The guidelines of our present and near future work aim at designing and implementing new techniques and methods for site characterization. Besides we take care to update the site testing instruments pool at the Observatories, selected among those which are —to a reasonable extent— standarized. All of them are been installed, tested and applied at the Canarian Observatories. We are also exploring the use of satellite data and of the Climate Diagnostic Archives for site characterization. The large database existing at ORM and OT is excellent for comparing and cross-correlate remote sensing parameters with *in situ* measurements.

The list of items to be addressed in this paper are:

- Seeing or Atmospheric Coherence Length
- Long-term Meteorological Parameters
- Vertical Structure of the Atmospheric Turbulence
- Wind Speed, Direction, and Vertical Profile in the BL
- Sodium Layer Density and Height
- Ground Deformations and Seismicity
- Airborne Aerosols, Cloudiness and Atmospheric Extinction-Useful Time

For a more extended review see Muñoz-Tuñón, García-Lorenzo, & Varela (2006). The contents of this paper are complemented with other contributions included also in these proceedings (see Muñoz-Tuñón et al. 2007; Varela et al. 2007; Fuensalida et al. 2007).

## 3. SEEING OR ATMOSPHERIC COHERENCE LENGTH

The image degradation at the focus of the telescope is a key parameter for which there are nowadays sound techniques and instruments which provide reliable measurements. The instruments able to provide seeing values are: DIMM, MASS and SCIDAR. Alternative to classical SCIDAR, as Single Star SCIDAR (SSS) or SLODAR are been developed and their future use is still unknown. For details and references of the above mentioned instruments and techniques we refer to Muñoz-Tuñón, Sarazin, & Vernin (2007).

At La Silla, Paranal and ORM seeing is continuously been monitored using DIMMs. For further information see `http://www.iac.es/project/sitesting/site.html`, `http://www.ing.iac.es/ds/robodimm/`, and `http://www.eso.org.com`.

At ORM accurate seeing measurements (using a DIMM) are available since the early nineties. DIMMs are been operated at the observatory in routine mode. Very soon a DIMMA (DIMM-A) will start operation also at OT, to provide continuously night-time seeing values.

The DIMM provides the full atmospheric seeing with an accuracy better than $0''.1$ with a sampling rate better than 1 data $\mathrm{min}^{-1}$. The DIMM is the ideal instrument for long term monitoring of the image quality (e.g., see statistics at ORM in Muñoz-Tuñón et al. 1997).

In Figure 3 (left panel) the statistics of seeing gathered at four sites (Maidanak, Paranal, La Silla and ORM) compiled by Ehgamberdiev et al. (2000)

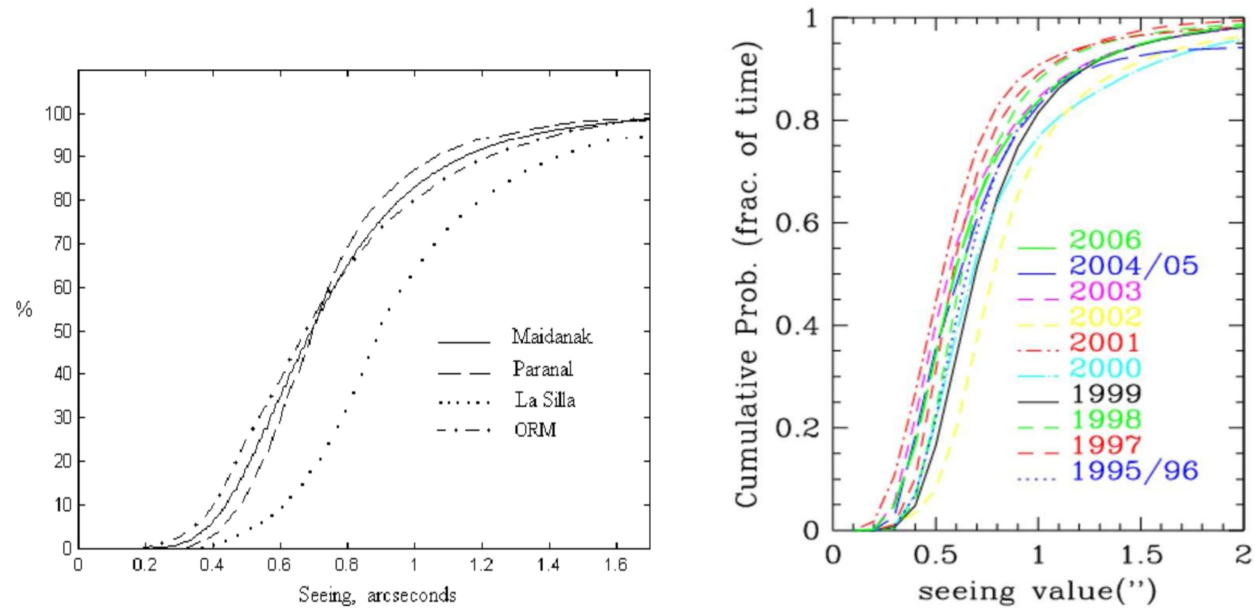


Fig. 3. Statistics of seeing gathered at four sites (Maidanak, Paranal, La Silla and ORM) (left) compiled by Ehgamberdiev et al. (2000). Right figure shows the yearly seeing cumulative function at ORM compiled by our team (`http://www.otri.iac.es/sitesting/index.php?flash=1&pag=9-73`).

are presented. While in Figure 3 (right panel) a compendium of yearly seeing cumulative function at ORM compiled by our team is presented (available also at `http://www.otri.iac.es/sitesting/index.php?flash=1&pag=9-73`).

A hybrid instrument, MASS-DIMM is to be used in the near future. The instrument measures the full atmospheric seeing with a resolution better than $0''.1$, providing also information of the turbulence profile in 5 atmospheric slabs (from 1–16 km). Monitoring campaigns are currently in progress at different astronomical sites (e.g. for the ELT, or TMT campaigns) and in particular, four units are been constructed for the European ELT contract (see Muñoz-Tuñón, Sarazin, & Vernin 2007). More information about MASS-DIMM can be found in Tokovinin (2004) and `http://mass.ctio.noao.edu`.

## 4. LONG TERM METEOROLOGICAL PARAMETERS

Meteorological parameters can be obtained in situ or through remote sensing techniques, such as those provided by climate diagnostic archives. Ground (in situ) measurements, are provided by equipped meteorological masts, e.g. Automatic Weather Stations (AWS). Typical parameters provided by AWS are: Air temperature, Soil and Subsoil Temperature, Barometric Pressure, Vapour Pressure, Relative Humidity, Wind Speed, Wind Gusts, Wind Direction and Rainfall. For references and use in astronomy see Mahoney, Muñoz-Tuñón, & Varela (1998).

The parameters obtained with standard AWS (see above) are important for getting statistics on the suitability of a particular site for astronomical observations. AWS can be considered the standard first equipment to be installed when a site is to be tested for the first time. Besides the above mentioned, meteorological parameters obtained via the standard sensors (AWS) attached to a mast are of most interest for the design of telescopes and enclosures. Wind and wind gust statistics *in situ* (say on a mast of 15 m height) are crucial for engineering design work and operation; most telescopes have an AWS installed next to them (see right panel of Figure 2).

Wind gust statistics are also very important and define a number of design parameter as well as feasibility studies (e.g., for the ELT). In Figure 4 we present the wind and wind gusts statistics at ORM.

The tropospheric winds at 200 mbar (about 12 km) has been also proposed as a parameter for site characterization.

## 5. VERTICAL STRUCTURE OF THE ATMOSPHERIC TURBULENCE

The relative contribution of turbulence at different scale heights is very important when evalu-

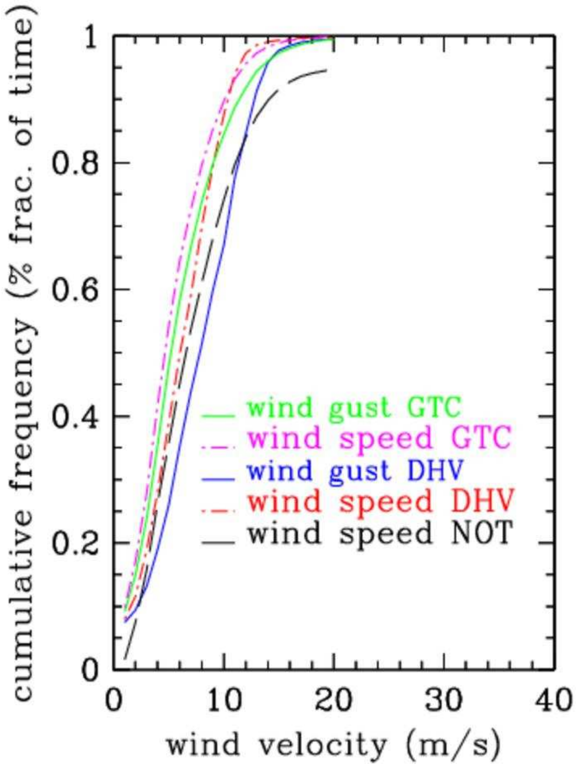


Fig. 4. Statistics of the wind speed and wind gust at the ORM compiled by the Sky Quality Group (http://www.otri.iac.es/sitesting/index.php?flash=1&pag=7-121.)

ating the feasibility of AO programmes. Intensive campaigns, although expensive and complicated to carry out, are the only way to obtain a comprehensive knowledge of the atmosphere. For this purpose, simultaneous techniques such as balloon soundings ($C_{\rm N}^2$ profiles, water vapor, wind velocity and direction), SCIDAR, DIMMs and meteorological towers equipped with microthermal sensors are used. For a general description see Vernin & Muñoz-Tuñón (1992, 1994, and references therein). Similar campaigns have been carried out at Paranal, La Silla, Mauna Kea, and S. Pedro Mártir.

Some comparisons can be make by using results from intensive campaigns. The ORM, La Silla and Mauna Kea have been compared in this way. The *free atmosphere* at the ORM has a very low contribution ($0\farcs4$), which is comparable to the values measured at La Silla ($0\farcs34$) and Mauna Kea ($0\farcs46$). The contribution from the surface layer (from 6 to 12 m) is $0\farcs08$, which is almost negligible (Vernin & Muñoz-Tuñón 1994). However, in most places, our knowledge of turbulent layer stratification is very poor and still lacks a firm statistical basis.

The need of knowing both the relative contribution from the free atmosphere and the boundary layer to the integrated seeing, needs a new technique. Intensive campaigns cannot provide data with the required long term statistical basis. For achieving a statistical database with the relative contribution to the turbulence from the different atmospheric layers in the candidate sites we propose the use of a G-SCIDAR or a MASS.

Different remote sensing techniques have been implemented to monitor the vertical structure of the atmospheric turbulence. The instruments suitable for achieving the $C_{\rm N}^2$profiles are: SCIDAR, SLODAR and MASS. SCIDAR is the one which provides the best vertical resolution, covering the whole vertical scale, from the ground layer. MASS samples the vertical profiles in several slices (about 5) and therefore gives a low resolution sampling of the turbulence vertical profile. However, it is the one which is nowadays automatized thereby allowing long term measurements, with the limitation of being "blind" in the first km.

Techniques measuring the refractive index *in situ* are also standard and have also been successfully proven, using equipped balloons. However, the resources required make them useful for intensive campaigns only and they become inadequate for systematic, prolonged measurements.

### 5.1. *SCIntillation Detection and Ranging (SCIDAR)*

SCIDAR (Vernin) has proved to be the best contrasted, efficient and extended technique from ground level for atmospheric turbulence measurements. Several teams are using the SCIDAR technique nowadays: http://www.iac.es/project/gare/esp/index.html, http://www.astrosmo.unam.mx/~r.avila/Scidar/, http://www.eso.org/gen-fac/pubs/astclim/lasilla/asm/scidar/.

Intensive campaigns of SCIDAR observations have taken place in some astronomical sites such as San Pedro Mártir (Mexico), La Silla (Chile) or Mauna Kea (Hawaii, USA).

Long-term monitoring observations started during 2003 at the Observatorio del Roque de los Muchachos (ORM) on the Island of La Palma, Spain and Observatorio del Teide (OT) on Tenerife, Spain.

An updated version of SCIDAR (Cute-SCIDAR), which aims at being more flexible and user friendly, is been developed at the IAC (Instituto de Astrofísica de Canarias), in collaboration with LUAN (Laboratoire Universitaire d'Astrophysique de Nice). The

SCIDAR technique is explained in different papers and measurements of the vertical turbulence profiles using this technique have also been published. We list here some references: Avila et al. (2004); Coburn et al. (2005); Fuensalida et al. (2004); Klueckers et al. (1998); Vernin & Roddier (1973).

For extensive information about cute-SCIDAR (updated instrument and data —turbulence profiles— at ORM and OT, see Fuensalida et al. (2007).

### 5.2. *SLOpe Detection and Ranging (SLODAR) and Multi-Aperture Scintillation Sensor (MASS)*

SLODAR (Wilson 2002) is, so far, the less extended technique for the vertical turbulence profile measurement of the listed techniques in this document, but it is becoming more popular thanks to its portability and possible automatism. Information about SLODAR can be found at: `http://www.cfai.dur.ac.uk/fix/projects/slodar/`.

Intensive campaigns of SLODAR have taken place at some astronomical sites such as ORM (La Palma, Spain), Cerro Tololo (Chile) and Cerro Paranal (Chile). The main references about SLODAR are the following: Wilson (2002), Wilson & Saunter (2003), and Wilson et al. 2004.

MASS (Tokovinin) is an instrument to measure the vertical distribution of turbulence in the atmosphere by analyzing the scintillation (twinkling) of bright stars. Most information about this technique can be found at `http://www.ctio.noao.edu/~atokovin/profiler/`.

Intensive campaigns using MASS have been carried out at: Mt. Maidanak (Republic of Uzbekistan), Cerro Pachón and Cerro Tololo (Chile), Mauna Kea and Dome-C (Hawaii, USA).

We list here some papers about MASS and its measurements: Tokovinin (1998); Tokovinin & Kornilov (2001); Tokovinin (2004); Kornilov et al. (2003).

## 6. WIND SPEED AND DIRECTION; VERTICAL PROFILE IN THE BOUNDARY LAYER

Information about the wind's vertical profile can be obtained from SCIDAR and SLODAR measurements, as well as from climate diagnostic archives. SCIDARs team is already developing procedures to gather the wind profiles. The algorithms are ready and suitable to be implemented along this year.

The vertical profile in the boundary layer (BL) can be obtained from SODAR measurements.

### 6.1. *Velocity of Turbulence Layers Measured using SCIDAR and SLODAR Observations*

The wind speed and direction of turbulence layers can be measured from SCIDAR and SLODAR observations. The following references describe the different methods developed to derive the velocity of turbulence layers from SCIDAR observation: García-Lorenzo & Fuensalida (2006); Prieur et al. (2004).

SODAR (sonic detection and ranging) systems are used to remotely measure the vertical turbulence structure and the wind profile of the lower layer of the atmosphere (boundary layer). Note that a SODAR is operating at OT since 2007.

### 6.2. *Climate Diagnostic Archives*

Climate Diagnostic Archives maintain a large collection of data sets that support climate research. Climate diagnostic databases make such data freely accessible to the world, within the limits of their resources. The most popular is the Climate Diagnostic Center which combines data from different sources and climate sophisticated models (`http://www.cdc.noaa.gov/index.html`).

Climate Diagnostic Archives have proven to be very useful to obtain winds vertical profiles and several works have already been published concerning their use to analyze the wind profiles at different sites. In Figure 5 we show, as an example, the seasonal variation at ORM taken from García-Lorenzo et al. (2005). In a previous paper the cross-calibration of this data set and local parameters using balloons was established (Chueca et al. 2004).

## 7. MESOSPHERIC SODIUM LAYER DENSITY AND HEIGHT

The sodium layer's density and altitude can be measured through laser experiments from telescopes or from LIDAR measurements. There is no need to say the importance of the knowledge of the strength, height and stability of the Na layer for AO using laser guide stars.

### 7.1. *Laser Experiments fromTelescopes*

Several measurements of the mesospheric sodium layer, using laser beacons launched from telescopes, have been already carried out. For references consult the following Web pages and papers: `http://op.ph.ic.ac.uk/jkt_lgs/`; `http://www.iac.es/project/gare/esp/index.html`; Michaille et al. (2000); Michaille et al. (2001); Chueca et al. (2004).

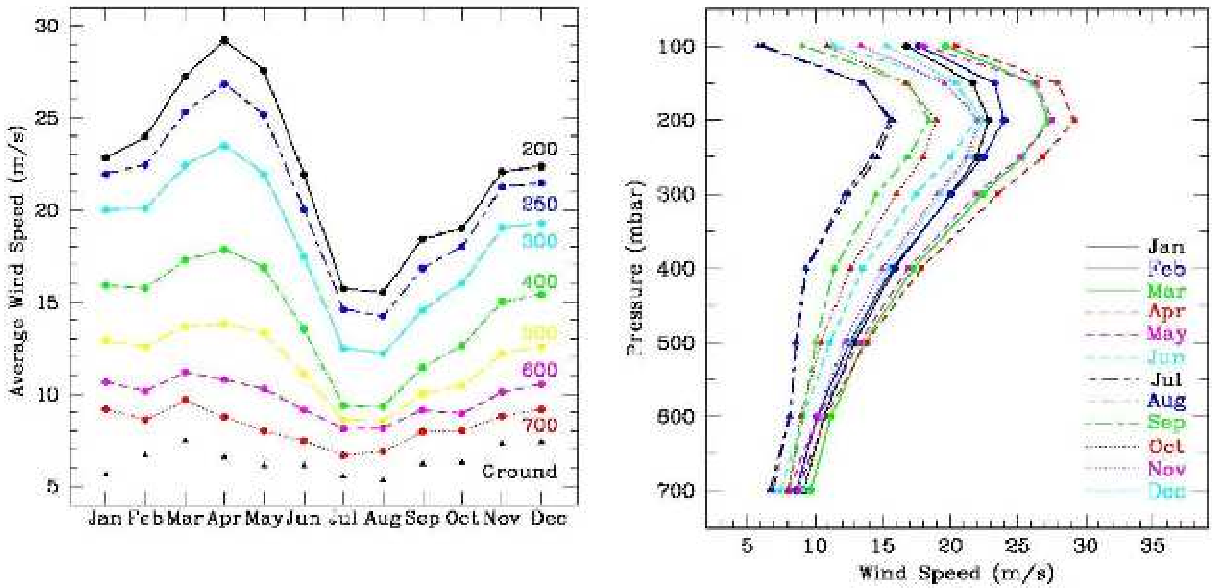


Fig. 5. The monthly averaged wind velocity for the period 1980–2002 at the pressure levels indicated in the figure at ORM (from García-Lorenzo et al. 2005). The paper also compiles results for La Silla, Mauna Kea, Paranal and S. Pedro Mártir.

### 7.2. *Light Detection and Ranging (LIDAR)*

LIDAR systems are "laser radar systems". The time for the light to travel out to the target (mesospheric Na layer) and back to the LIDAR is used to determine the height of the layer. Usually LIDAR's are used in a monostatic configuration: a laser beam is projected through the receiving telescope or is parallel to the optical axis. Typically, a pulsed dye laser is tuned to the Na D2 resonant absorption line (589 nm, orange). Backscattered photons are collected in a telescope and focused onto a photomultiplier tube. Typical plots from a LIDAR systems show the signal received vs. the altitude where the photons come from. The altitude is directly determined from the photon's "time of flight": as the detected light is recorded in sample bins the detector records the time since the laser was fired. Typical resolution may be 0.5 km, or better. The density of Na may be determined from the ratio of the photon counts in the mesosphere region to those in the high stratosphere (30 km), where Rayleigh scattering occurs with air molecules, while no Mie scattering with aerosols is present. The Na column abundance ranges from a summer minimum of $\sim 3\times10^{9}$ cm$^{-2}$ to a winter maximum of $\sim 10^{10}$ cm$^{-2}$.

LIDAR campaigns are been carried out at ORM and Paranal within the Site Selection-FP6 framework (see Muñoz-Tuñón, Sarazin, & Vernin, 2007).

## 8. GROUND DEFORMATIONS AND SEISMICITY

Ground deformations are induced by (a) barometric pressure loading and hydrologic loading: rain and snow, (b) deformations induced by temperature changes, and (c) magma motion at great depths that can produce landslides.

Ground deformations can be measured with: Tiltmeters (low cost, very high accuracy), GPS and Radar Interferometers. Currently, continuous monitoring of ground deformations with enough precision are not yet available.

Seismicity is induced by regional tectonics, oceanic effects, volcanic and/or anthropogenic activity. Several different types can be found: Regional Seismicity >1 mb (very low), Microseismicity, and Low frequency Seismicity (volcanic tremors, oceanic effects).

The Seismicity is measured with broadband seismometers. In general, all countries monitor the regional Seismicity (e.g., in Spain `http://www.ign.es`). However, a devoted network for very local Seismicity is needed. At Paranal there are instruments installed to measure it (Gilmozzy, private communication) and at ORM some equipment has been used in the past (for references see Muñoz-Tuñón (2002) and `http://www.iac.es/project/sitesting/site.html`, once there do a search for the keyword seismicity).

## 9. USEFUL TIME, ATMOSPHERIC EXTINCTION, SATELLITES FOR AIRBORNE AEROSOLS AND CLOUDINESS

### 9.1. *Useful Time*

The use of TOMS has been explored to retrieve the aerosols and clouds via remote sensing techniques. The determination of clouds coverage and related parameters (useful time) has been the subject of study of Andre Erasmus for quite a large number of years. As result, A. Erasmus[3] and collaborators have carried out specific studies for determining the useful time for a large number of regions on the world, making use of satellites and defining very precisely the technique for the appropriate data interpretation. Erasmus reports have been promoted and purchased from different institutions. Below find a summary made by us, by making used of Andre's reports on Paranal and ORM and OT.

**At the ORM**

From Satellite Survey of Cloud Cover and Water Vapour in Morocco and Southern Spain and verification using La Palma Ground-based Observatories, Erasmus & van Rooyen (2006) study was conducted for ESO. They used data from EUMETSAT (European Organization for the International Exploitation of Meteorological Satellites) and ISCCP (International Satellite Cloud Climatology Project) over a 7 years period (1996 to 2002) with spatial resolution 5 km×5 km and temporal resolution 3 hr for two data channels: 6.4 $\mu$m (water vapor) and 11.5 $\mu$m (IR), i.e. cloud cover in the middle-upper troposphere and PWV. **They conclude that the photometric time at the ORM (also named clear) is 83.7%.** Cross-calibration at ground with Carlsberg Automatic Meridian Circle (CAMC) Atmospheric Extinction Coefficient in V (KV) has been verified to be accurate within 1.2%.

**At Paranal**

From a satellite Survey of Cloud Cover and Water Vapor in Northern Chile by Erasmus & van Staden (2001) and conducted for CTIO & University of Tokyo, by using satellite data from ISCCP data set: Meteosat-3 (1993 – 1994) and GOES-8 (1995 – 1999), with spatial resolution 9.1 km×8.0 km and temporal resolution 3 hr, using data at 6.7 $\mu$m (water vapor) and 10.7 $\mu$m (IR window). **They conclude that the percentage of photometric (clear) nights at Paranal is 84.6%.** Cross-calibrated at ground with LOSSAM (Line of Sight Sky Absorption Monitor) which provides Extinction (E) the "clear fraction" has been verified to be accurate within 1%. See also `http://www.otri.iac.es/sitesting/index.php/`.

[3]At the time this workshop took place Andre Erasmus passed away. We owe him a lot for his pionereing work in meteorology-astronomy. We miss him here at San Pedro Mártir and we will remember and respect him always.

### 9.2. *Atmospheric Extinction in the Visible and Near-Infrared*

For the optical, near-infrared (NIR), and mid-infrared (MIR) regimes, a dedicated telescope is required to determine properly the atmospheric extinction (e.g., Carlsberg Automatic Meridian Circle (CAMC) or Mercator at the ORM). One of the largest database available can be obtained at `http://www.ast.cam.ac.uk/dwe/SRF/camc_extinction.html`. There the extinction values at ORM are given daily since 1984.

### 9.3. *On the Use of Satellites*

For an extensive review on the subject see Varela et al. (2007). More references: Varela et al. (2004a,b); Siher et al. (2004); Erasmus & van Rooyen (2006). For cloudiness, fog and dust, it is now been explored the use of other detectors on board different satellites (MET-9, MODIS) that operate in bands of astronomical interest (visible and near-infrared) and with higher spatial resolution (1 km×1 km or better). Also useful are NCEP-NCAR data (see also Erasmus & van Rooyen 2006).

## 10. LAST REMARKS

The importance of good statistics is obvious nowadays. Some years before, sites were decided based on several intensive campaigns lasting a few years —in the best cases. We now know that there are local climatic cycles which need to be known in order to define the temporal extent needed for correctly sampling a particular site. Pacific decadal oscillation, El Niño, for example define the sampling period for sites like Paranal. This is something that we have learned after tracking the evolution of meteorological and optical parameters for a number of years after the site testing campaigns for the VLT took place.

At the Canaries, it is well known since the early fifties that there is a seasonal cycle, defined by the variations of the trade winds, which affects directly the strength and height of the inversion layer. More recently, we have demonstrated also that the atmospheric turbulence indeed follows the same trend, with two seasons, winter and summer, in which the statistics of seeing are different. In Figure 6 we illustrate these results (from Muñoz-Tuñón et al. 1997).

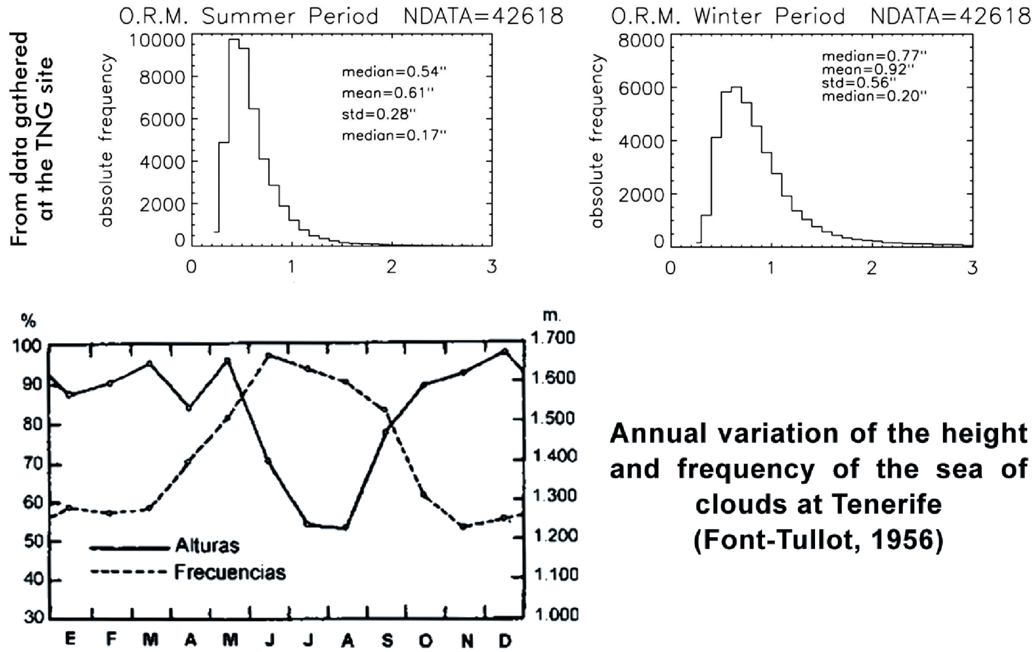


Fig. 6. Seasonal seeing variations at ORM (top and central panel) and annual variations of the scale height and frequency ofthe sea clouds in Tenerife (bottom) (see Muñoz-Tuñón et al. 1997).

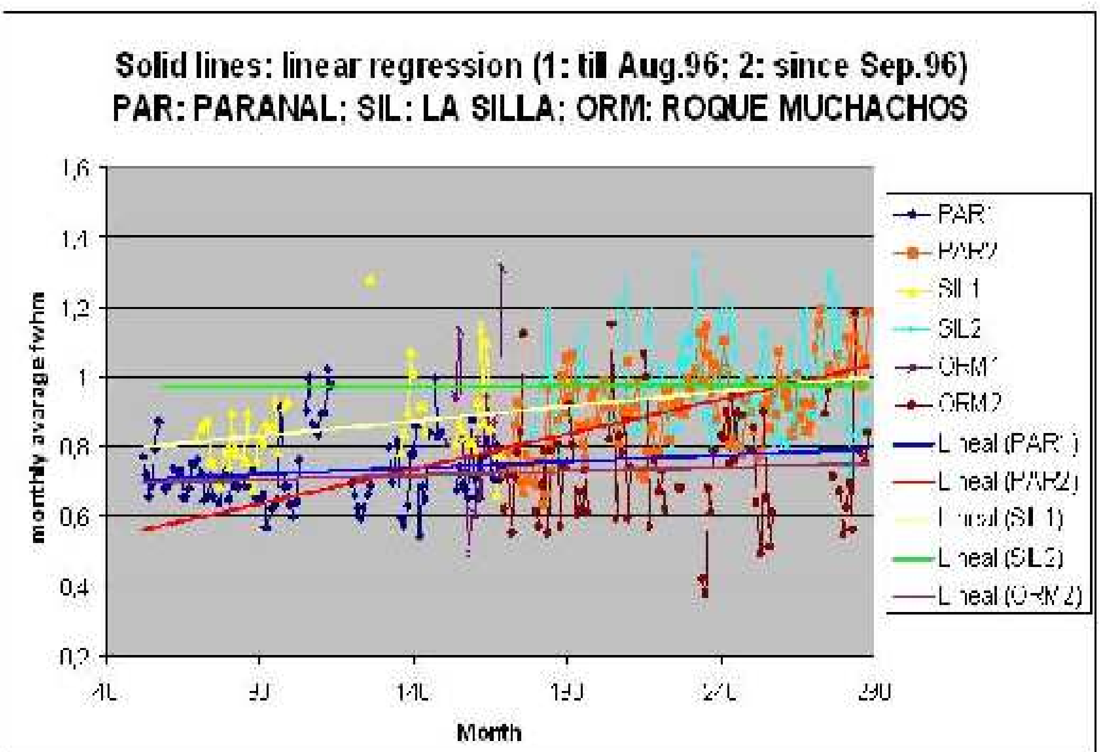


Fig. 7. Seeing evolution at Paranal and La Silla (from `http://www.eso.org/gen-fac/pubs/astclim/paranal/seeing/statseeing.lis`). See overlap values at ORM (from `http://www.iac.es/project/sitesting/site.html`).

| | G-SCIDAR | SLODAR | MASS | DIMM | LIDAR | SODAR | GSM | Equiped Balloons | AWS | DustMeter | Climate D.Arch. | GOME | TOMS | MET9 | MODIS | satellites | "Ad hoc"Telescopes | International Networks | BB seismographs (in situ) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Integrated Seeing | X | X | X (1) | X | | X (1) | X | X | | | | | | | | | | | |
| Seeing (Long term) | | | X (1) | X | | X(1) | | | | | | | | | | | | | |
| tauo | X | | | | | | X | X | | | | | | | | | | | |
| theta | X | X | X | | | | X | X | | | | | | | | | | | |
| Scintillation | X | X | X | X | | | X | | | | | | | | | | | | |
| CN2(h) | X | | | | | | | X | | | | | | | | | | | |
| Cn2 para Deltah | | X | X | | | X(1) | | | | | | | | | | | | | |
| V(h) | X | | | | | | | X | | | | | | | | | | | |
| V(h) (in the BL) | X | | | | (2) | X | | | | | | | | | | | | | |
| V200mbar | | | | | | | | X | | | X | | | | | | | | |
| Na (content) | | | | | X | | | | | | | TBE | | | | TBE | X | | |
| Na (height, t) | | | | | X | | | | | | | TBE | | | | | X | | |
| PWV | | | | | | | | | | | X | | | X | X | X | | | |
| Ozone (content) | | | | | | | | | | | | X | X | | | | | | |
| Temporal variation(Ozone) | | | | | | | | | | | | X | X | | | | | | |
| Ground meteo | | | | | | | | | X | | | | | | | | | | |
| Local aerosols | | | | | X | | | | | X | | | | | | | | | |
| Aerosols (h) | | | | | X | | | | | | | | | | | | | | |
| Integrated aerosols | | | | | | | | | | | | | | TBE | TBE | | | | |
| Sky Background | | | | | | | | | | | | | | | | | X | | |
| Extinction | | | | | | | | | | | | | | TBE | TBE | | X | | |
| Cloudiness and fog | | | | | | | | | | | | | | X | TBE | | X | | |
| Seismicity | | | | | | | | | | | | | | | | | | X | X |
| Microseismicity | | | | | | | | | | | | | | | | | | | |
| Ground tilmeter | | | | | | | | | | | | | | | | | | X | X |

(1) Parcial. Mass does not SEE below 1Km y SODAR is "blind "above several kms.
(2) LIDAR Doppler
GOME= Global Ozone Monitoring Experiment
TBE= To Be Explored

Fig. 8. Compendium of parameters and instruments and tools for site testing.

There we present also how the seeing values correlate with more global meteorological conditions related to the climate at the Canary islands.

The man-made impact can also be important and we have to think about it for future actions. For instance, we know that different vegetation or soil are important to stabilize the temperature at the surface layer which obviously has an impact in the turbulence of a site a low level height (say 5 to 10). Nowadays we are also facing and developing big infrastructures (nothing to do with the small-cozy 1-m telescopes of the past) —future large telescopes— which, in some cases require important modification of the local orography for their construction.

Figure 7 presents a plot in which the seeing time evolution is shown for Paranal `http://www.eso.org/gen-fac/pubs/astclim/paranal/seeing/statseeing.lis`. We still do not understand the reasons for the trend. Climatic changes have been claimed as a possible explanation, but in the overplot we find values at La Silla or ORM for the same period where no such variations are found. The understanding of this puzzle is important and has been a key issue, we hope to be able to solve it in the near future.

Now, more that ever, the site characterization work is a multidiscipline in which meteorologist, astronomers and geophysicists have to work together.

To finish and going back to the need of having appropriate techniques and tools providing reliable measurements, we present a compendium in Figure 8 of parameters and instruments available which defines the state of the art at present.

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## REFERENCES

Avila, R., Masciadri, E., Vernin, J., & Sánchez, L. J. 2004, PASP, 116, 778

Carrasco, E., Avila, R., & Carramiñana, A. 2005, PASP, 117, 104

Chueca, S., et al. 2004, MNRAS, 349, 627

__________. 2004, Proc. SPIE, 5237, 261

Coburn, D., Garnier, D., & Dainty, J. C., 2005, Proc. SPIE, 5981, 105
Erasmus, D. A., & Sarazin, M. 2002, ASP Conf. Ser. 266, Astronomical Site Evaluation in the Visible and Radio Range, ed. J. Vernin, Z. Benkhaldoun, & C. Muñoz-Tuñón (San Francisco: ASP), 310
Erasmus D. A., & van Rooyen, R. 2006, Final Report to ESO
Ehgamberdiev, S., et al. 2000, A&AS, 145, 293
Fuensalida, J. J., et al. 2004, Proc. SPIE, 5572, 1
García-Lorenzo, B., & Fuensalida, J. J. 2006, MNRAS, 372, 1483
García-Lorenzo, B., et al. 2004, Proc. SPIE, 5572, 68
_________. 2005, MNRAS, 356, 849
Klueckers, V., et al. 1998, A&AS, 130, 141
Kornilov, V., et al. 2003, Proc. SPIE, 4839, 837
Mahoney, T., Muñoz-Tuñón, C., & Varela, A. M. 1998, New Astron. Rev., 42, 417
Michaille, L., et al. 2000, MNRAS, 318, 139
_________. 2001, MNRAS, 328, 993
Muñoz-Tuñón, C. 2002, ASP Conf. Ser. 266, Astronomical Site Evaluation in the Visible and Radio Range, ed. J. Vernin, Z. Benkhaldoun, & C. Muñoz-Tuñón (San Francisco: ASP), 498
Muñoz-Tuñón, C., García-Lorenzo, B., & Varela, A. M. 2006, Instruments and tools for site testing (prepared for GW3-ESO Site Evaluation)
Muñoz-Tuñón, C., et al. 1997, A&AS, 125, 183
Prieur, J.-L., Avila, R., Daigne, G., & Vernin, J. 2004, PASP, 116, 682
Sarazin, M., & Roddier, F. 1990, A&A, 227, 294
Siher, E. A., et al. 2004, Proc. SPIE, 5489, 138
Tokovinin, A. 1998, ESO Report VLT-TRE-UNI-17416-008
Tokovinin, A. 2004, NOAO-NSO Newsletter, 77, 32
Tokovinin, A., & Kornilov, 2002, ASP Conf. Ser. 266, Astronomical Site Evaluation in the Visible and Radio Range, ed. J. Vernin, Z. Benkhaldoun, & C. Muñoz-Tuñón (San Francisco: ASP), 104
Varela, A. M., et al. 2004, Proc. SPIE, 5489, 245
_________. 2004, Proc. SPIE, 5571, 105
_________. 2007, MNRAS, submitted
Vernin, J., & Roddier, F., 1973, J. Opt. Soc. Am., 63
Vernin, J., & Muñoz-Tuñón, C. 1995, PASP, 107, 265
Wilson, R. W. 2002, MNRAS, 337, 103
Wilson, R. W., & Saunter, C. D. 2003, Proc. SPIE, 4839, 466
Wilson, R. W., Saunter, C. D., & Guerra, J. C. 2004, Proc. SPIE, 5382, 661
http://www.astrosmo.unam.mx/~r.avila/Scidar/
http://www.eso.org/gen-fac/pubs/astclim/lasilla/asm/scidar/
http://www.cfai.dur.ac.uk/fix/projects/slodar/
http://www.ctio.noao.edu/~atokovin/profiler/
http://www.met.fsu.edu/explores/Guide/tirosindex.html
http://www.ozonelayer.noaa.gov/action/tovs.htm
http://www.ngdc.noaa.gov/dmsp/index.html
http://op.ph.ic.ac.uk/jkt_lgs/
http://www.iac.es/project/gare/esp/index.html
http://www.ign.es
http://www.iac.es/project/sitesting/site.html
http://www.gtc.iac.es/
http://www.ing.iac.es/ds/robodimm/
http://www.eso.org.com
http://www.ctio.noao.edu/atokovinin/profiler/principle.html
http://mass.ctio.noao.edu
http://www-luan.unice.fr/GSM/Bibliography.html
http://www.ast.cam.ac.uk/~dwe/SRF/images/vextinction.gif
http://www.iac.es/eno.php?op1=3
http://www.iac.es/eno.php?op1=2
http://atst.nso.edu/site/
http://atst.nso.edu/site/reports_final.shtml
http://www.inm.es/
http://www.iac.es/eno.php?op1=5
http://www.otri.iac.es/na2/
http://www.otri.iac.es/sitesting/index.php?flash=1&pag=13-86
http://www.eso.org/gen-fac/pubs/astclim/paranal/seeing/statseeing.lis