International Conference

**"Optical Turbulence
Astronomy meets Meteorology"**

Science Drivers

15-18 September 2008

'Optical Turbulence' (OT) is the term employed in astronomical field to refer to the turbulence affecting the spatial and angular resolution of images obtained at the ground-based telescopes foci. Fluctuations of temperature induce fluctuations of the refractive index and, finally, to fluctuations of the amplitude and phase of wavefronts (electromagnetic field) coming from astrophysical objects located in the faraway space. The origin of optical turbulence is therefore somehow different from the dynamic turbulence (having a mechanic origin) that is familiar to physicists of the atmosphere. On the other side, optical and dynamic turbulence are strictly physically related.

The optical turbulence is, by far, one of the main causes limiting the observational ground-based astronomy (OGBA) performances. The future and the success of the OGBA strongly depend on our ability **(1)** in characterizing the optical turbulence at the summit of the astronomical sites from a qualitative as well as quantitative point of view, **(2)** in improving our knowledge on the mechanisms producing and developing the optical turbulence **(3)** in predicting 3D maps of the optical turbulence to optimize the flexible-scheduling of scientific programs and instruments placed at the focus of telescopes and **(4)** in correcting wave-front perturbations produced by the atmospheric turbulence.

Several among the most challenging scientific programs to be carried out with ground-based telescopes and aiming to enhance our understanding of Universe require excellent turbulent conditions to be successfully performed. Competitiveness of ground-based astronomy with respect to the space-based one is strictly related to our ability in identifying and predicting such a temporal window in the most accurate way. On the front of the Adaptive Optics techniques, new sophisticated methods (MCAO, GLAO, LGS) conceived to optimize perturbed wave-fronts correction on different field of view and to optimize the efficiency of their employment require today a more detailed knowledge of the vertical distribution of the OT (not only integral values). This new generation AO requires a more detailed study of the Point Spread Function (PSF) morphology (for wide as well as narrow fields) and a comprehension of its connection with different parts of the turbulent spectrum. Some specific topics such as the precise nature and role played by the spatial coherence outer scale in the High Angular Resolution (HAR) techniques, the turbulence spectrum features in non-Kolmogorov regimes , are still theatre of discussion at present, and a more genuine scientific debate is suitable to better define the frontiers of the theory in this field.

The Operational Numerical Weather Prediction (NWP) systems at medium and mesoscale range might play an important role for the ground-based astronomy in the next decades. 4D-Var Assimilation Data employing satellites measurements recently strongly improved the quality of the Medium Range Weather Forecasts. A new challenge for the meteorology appeared at the horizon: the Mesoscale Data Assimilation. This consists on a network of surface stations and a mesoscale assimilation system with a resolution of a few kilometers. Such a system is mandatory to improve the ability of mesoscale models in reconstructing the unresolved physical parameters (such as the optical turbulence) evolving at spatial and temporal scales smaller than the model resolution and to improve the accuracy of meteorological weather forecasts extended on limited surfaces. *How this can be set up in remote regions of the earth such as those typically interesting for astronomers ?*

Aims of this International Conference is to join researchers (astronomers, physicists, meteorologists) to discuss about how to face the ground-based astronomy new era from the point of view of the TURBULENCE putting in evidence the main challenges and critical points. We exhort specialists in each field (instrumentation, modeling, theory, AO simulations and systems) in highlighting their new results as well as the open questions/problems/anomalies raised up in their researches. We wish to give to this meeting the framework of an experiment aiming to enforce new typologies of collaborations enhancing interdisciplinary and cross-field interactions. A special session will be dedicated to an open discussion with the participation of a few scientists who lead a few among the most powerful ground-based facilities from which the success of future ground-based astronomy will depend on and scientists leading operational forecasts systems.

Contributions on the following topics are welcome:

- Instruments, measurements, site testing survey of optical and dynamic turbulence
- Optical turbulence in the troposphere and stratosphere
- Optical Turbulence Data Base
- Inter-comparison measurements from different instruments, standardization of instruments
- Calibration: Instruments and Atmospheric Models
- Optical turbulence modeling and forecasts
- Turbulence closure schemes for night stable conditions
- Data Assimilation: GCM and mesoscale models
- Operational Models: GCM and mesoscale models
- AO and optical turbulence: simulations with analytic and Monte Carlo models
- PSF morphology (wide and narrow field) vs. turbulence
- MCAO, GLAO, LGS vs. turbulence
- Flexible-scheduling: strategies, present systems, lessons learnt, quantification of the scheduling efficiency

ABSTRACTS

Retrieving high layer atmospheric turbulence statistics on E-ELT scales

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In the framework of the Extremely Large Telescope design study, the Work Package (WP) 12000 is studying the Site Characterization for an European Extremely Large Telescope. In particular, INAF is in the WP 12300 group for the Large scale atmospheric properties study. Previous studies done in many astronomical sites have been optimized on spatial scales comparable with 3-4meter to 10meter class telescopes. The strong interest of the Astronomical Community in giant telescopes imposes a different site characterization opportune for 30-40meter class telescopes. One of the central point in the Adaptive Optics for Extremely Large Telescopes is given from the achievable sky coverage. Generally speaking, sky coverage is dominated by the high altitude layers correction. In other words ground layer adaptive optics has a sky coverage much larger than other kind of corrections. That means that ways to improve the sky coverage in the sensing of high altitude layers can be very effective in terms of overall performances. Moreover, there are good reasons to translate high coherence time of flowing layers, in a generalized Taylor assumption, into larger sky coverages. This poster presents the optical design of TOE, The Onduline Experiment, a WaveFront Sensor for sensing a Very Large Field of View on-board the VLT and possibly other telescopes as Gran TeCan in Canary islands. Such a WFS is to be intended as a tool to probe the atmospheric parameters in the free atmosphere (i.e. far from the ground layer) on a linear scale of the same order of magnitude of the diameter of the ELTs under consideration in this period.

LOLAS Results at Mauna Kea: Extreme Altitude-Resolution Monitoring of Turbulence-Profiles in the Boundary Layer

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The Low Layer Scidar (LOLAS) is an instrument aimed at the measurement of optical-turbulence profiles in the atmospheric boundary layer with high altitude-resolution. The method is based on the Generalized Scidar (GS) concept, but unlike the GS instruments which need a 1-m or larger telescope, LOLAS is implemented on a dedicated 40-cm telescope. The instrument was deployed in Mauna Kea for a seven-month period. In this contribution we will briefly present key instrumental aspects and report the results obtained during that campaign. Turbulence profiles with altitude-sampling interval as small as 12 m were obtained. This is the first statistical analysis of profiles with such an altitude resolution.

Turbulence in high angular resolution techniques in astronomy

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All astronomical observations are done best from space where the absorption by and turbulence in the Earth atmosphere are absent. One has access to the entire electro-magnetic radiation spectrum and the absence of seeing allows unlimited angular resolution. However, the cost of facilities in space is 2 to 3 orders of magnitude of similar sized facilities on Earth. Experimental astrophysicists have therefore in the past decades pursued the development of techniques to overcome the seeing limitations by the atmosphere. So far they have been very successful at this and much more is almost certain to come. Adaptive Optics (AO) will make very large (8-10 meters diameter) and extremely large (30-42 meters diameter) telescopes diffraction limited first in infrared wavelengths and eventually at visible wavelengths. The development of fast optical turbulence/seeing wavefront sensing using artificial sources (Laser Beacons) will enable doing that over the entire sky. Atmospheric Tomography (AT) needed for Multi-Conjugate Adaptive Optics (MCAO) will give 3D maps of the variable atmospheric turbulence. Large interferometers with baselines of hundreds of meters will further enhance the angular resolution using fringe tracking for both co-phasing and coherent operation. Ground based astronomy is therefore entering a new era in which milli-arcsecond observations and better are foreseen even of objects at the edge of the universe. Of course, those observations will be limited to the atmospheric spectral "windows". Where the atmosphere absorbs, space observations will be indispensable. The astronomical techniques will result in information of atmospheric optical turbulence which is likely to be of interest for meteorologists. I will give a broad review of these techniques with results to demonstrate the present state-of-the-art of the technology and resulting science.

Using the scintillation of extended objects to probe the lower atmosphere

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The scintillation of point-like objects is primarily caused by thermal fluctuations in the upper atmosphere. For them the scintillation index (σ_I^2) is proportional to the height integral of C_n^2(h) weighted by a height dependent function F(h) = h^α where α = +5/3. For extended objects like the Sun or the Moon the height contribution to the (much smaller) scintillation is quite different. Because of their size the effects of the optical turbulence is averaged over an ever increasing area as the distance to the detector increases. Here I will assume vertical viewing where the area diameter increases like h*Ω where Ω is the angular diameter of the Sun or Moon. For Kolmogorov turbulence the function F(h) then still has the same shape, but α = -1/3 so that the lower layers contribute more to scintillation making it a good tool for the probing of the lower atmospheric layers. Using an array of scintillometers one can probe the C_n^2(h) distribution of those lower layers in a technique called SHABAR. SHABARs have been used in site testing for lower atmosphere probing for solar and nighttime telescopes. The aim is to establish the height to place telescopes, like the Advanced Technology Solar Telescope (ATST), to minimize boundary layer seeing effects. SHABAR site tests using the Moon are planned both for Arctic sites (Hickson's talk) and Antarctic sites (Storey's talk) where boundary layer heights are very site dependant reaching sometimes very small values. In this talk I will describe some of the solar results related to the ATST site testing. I will also discuss the scintillation of planets which have an F(h) function different in shape from that of the Sun or Moon. For low heights, where their beams still are narrow, F(h) has a α of +5/3 (as for stars); for large heights it is 1/3 (as for the Sun & Moon). For Mars the height contributions F(h) for seeing and scintillation are similar.

Pupil slicing adaptive optics: making extremely large telescopes diffraction limited at short wavelenghts

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Extremely Large Telescopes (ELTs) will have aperture diameters up to 42 meters. Adaptive Optics (AO) at short wavelengths (1 micron) will be very hard to implement at these wavelengths because of the limited number of actuators on state-of-the-art deformable mirrors and because of the limited brightness of Laser Guide Stars (LGSs). For 1 arcsec seeing at 500 nm wavelength deformable mirrors (DMs) with about 150000 actuators will be needed and LGSs of a brightness of V = 8 to 9. That exceeds our present capabilities by a factor of about 100 and 2 magnitudes respectively. One might expect both to improve with time. We propose to combine the techniques of "pupil slicing" and AO to sharpen the telescope images at short wavelengths to the size of Airy disk of the pupil slices. I refer to this technique as "Pupil Slicing Adaptive Optics" or PSAO. At 500 nm wavelength that would correspond to the Airy disk of an appr. 5 meter diameter aperture, or a FWHM of 0.02 arcsec. As DMs increase in their number of actuators, the size of the pupil slices increase thus improving the angular resolution. Ultimately the full angular resolution of, for example, a 42 meter aperture would be reached (0.0024 arcsec at 500 nm). Of course, this does not resolve the issue of the limited brightness of LGSs. In that case one has to wait for more powerful lasers and the development of perspective elongation correction techniques. Alternatively one would accept limited sky coverage (0.1%) when using natural guide stars (NGSs). Particularly interesting is the PSAO technique for high resolution spectroscopy where the smaller image sizes even for many slices results in a significant decrease in spectrograph dimensions. The work presented is the result of collaboration with Torben Andersen and Mette Owner-Petersen at the Lund Observatory.

SNODAR: a new instrument to measure the height of the atmospheric boundary layer on the Antarctic plateau.

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The height of the atmospheric boundary layer on the Antarctic plateau is of particular importance to designers of optical telescopes for Antarctica. SNODAR was developed at the University of New South Wales to measure the height of the atmospheric boundary layer at Dome A and Dome C on the Antarctic plateau. SNODAR, or Surface layer Non-Doppler Acoustic Radar, is a true monostatic high-frequency acoustic radar operating between 3kHz and 14kHz. Such high frequencies propagate relatively well in the low temperature Antarctic atmosphere. As the height of the boundary layer at Dome C is expected to be less then 30m, and unknown at Dome A, SNODAR was designed to have a minimum sampling height of 5m with a vertical resolution of 1m or better. The maximum sampling height is dependent on atmospheric conditions, but is expected to be greater then 300m at Dome C. SNODAR uses a PC/104 computer to perform signal processing in real time, and a USB sound card for low latency analogue IO. SNODAR was designed to run autonomously storing data on USB flash disks for retrieval the following summer, while uploading of data acquisition scripts and spot checking of data is possible via Iridium satellite through UNSW's PLATO facility. SNODAR also incorporates a unique in-situ calibration sphere, based on techniques borrowed from underwater acoustics. We present details of the design, calibration and results from the testing of SNODAR.

SNODAR: Measuring the atmospheric boundary layer on the high Antarctic plateau.

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The nature of the atmospheric boundary layer above the Antarctic plateau is of interest both to atmospheric scientists and to astronomers wishing to plan future optical telescopes. SNODAR, or Surface layer NOnDoppler Acoustic Radar, was designed at the University of New South Wales to measure the turbulence in the boundary layer at sites such as Dome C and Dome A. The first SNODAR was deployed to Dome A in January 2008 as part of the PANDA project by a 1300km Chinese traverse from Zhongshan station. A PC/104 computer performs the signal processing in real time. SNODAR runs autonomously, storing raw data on USB flash disks for retrieval the following summer, while uploading processed data via the Iridium satellite network through the University of New South Wales PLATO facility. The Iridium communication also allows SNODAR to be remotely controlled. We present initial profiles from February 2008.

Profilometry for the lower terrestrial atmosphere

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The concept of an optical turbulence profiler (theory and numerical simulations) well-adapted for the study of the terrestrial atmosphere boundary-layer has been already presented (Symposium on Seeing - Kona, March 2007). By observing the entrance telescope pupil through 2 diaphragms (thin slits) placed on the solar limb image this profiler, based on a triangulation method identical to the one used in the SLODAR experiment, allows to deduce vertical profiles of the optical turbulence energy C_n^2(h). It has been shown that the intensity fluctuations observed in the pupil images are, at the first order, proportional to the fluctuations of the angle-of-arrival component considered in the direction perpendicular to the solar limb. The large angular separation which may be chosen between the diaphragms provides a high altitude resolution. Here, the influence of the model used for the limb is firstly discussed. Then, some results of angle-of-arrival statistics are presented. The effects of the filtering performed by the diaphragms and of eventual telescope vibrations have been also studied. The results of additive studies (theory and/or numerical simulations) concerning the taking into account of the scintillation mainly due to turbulent layers at high altitudes, as well as the potentialities of the use of more than 2 diaphragms simultaneously (for example 4 diaphragms in non-redundant angular positions lead to 6 angular baselines and thus 6 different maximum sensing altitudes and 6 different altitude resolutions) are given. The altitude resolution which may be reached is widely discussed. Finally, the case of night-time observations is presented, the diaphragms being placed on the lunar limb image.

Aklim: a potential site for astronomical observations

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Morocco is a candidate among five ones in the European-Extremely Large Telescope Project Prospect. Aklim is the site that has been chosen by Moroccan astronomers as a potential site for astronomical observations.

In this paper, we present the meteorological study of this site as well as aerosol cover and wind characteristics at 200 mb, as they exert a great influence on seeing quality. The data for meteorological study include wind speed and direction, temperature, relative humidity, cloud cover and atmospheric precipitable water vapour content. These data come on the one hand from the National Center for Environmental Prediction/National Center for Atmospheric Research NCEP/NCAR Reanalysis, and on the other hand from the newly set up meteorological station at this site. Statistical analysis of meteorological data and tropospheric winds has been performed for more than ten years. Aerosol data come from Earth Observing satellites, Total Ozone Mapping Spectrometer (TOMS), Moderate Resolution Imaging Spectro-Radiometer (MODIS) and Multiangle Imaging Spectroradiometer (MISR). Comparisons with famous observatories have been performed.

Data assimilation and mesoscale modelisation for optical turbulence forecast

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Local Meso-scale modelisation provides informative forecast of optical turbulence compared to large scale models through precise simulation of atmospheric variables inside troposphere (cf Christine Lac's talk). From temperature profiles an accurate reflective index can be deduced. That information is valuable for optimal scheduling of scientific programs and instruments. Such limited-area simulations require initial conditions to be as good as possible. So far intial conditions were derived from a global atmospheric model through a process that adapts fields to finer grid resolution (so called "dynamical adaptation mode"). For global model, initial conditions for a given time is a subtle blend between the last short-term forecast and every observation available inside a specific time-window, that process being named "data assimilation". Nowodays initial conditions for local meso-scale models can also be obtained through mesoscale data assimilation, showing some improvement compared to the dynamical adaptation mode. The first part of the presentation will be devoted to a general and comprehensive introduction of data assimilation for meteolorogical models. Then we will review the different types of data focussing on specificities of local area models. The last part will show the improvements expected for data assimilation mode versus dynamical adaptation mode with the example of Météo-France's AROME project.

The development of Mauna Kea Weather Center: Forecasting planetary-scale to the turbulent-scale circulations for astronomy.

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This paper will provide an overview of the history of the Mauna Kea Weather Center and the multidisciplinary challenges faced in providing accurate custom nowcasts and forecasts of summit operating and viewing conditions. A prerequisite to formulating accurate forecasts that target the summit of Mauna Kea is an ability to collect in near real time a varied set of observations that range in time and space from planetary scale to molecular turbulence. Once collected, the diverse data streams must be synthesized and ingested/assimilated into numerical weather prediction models that are customized to provide guidance specific to the needs of the astronomy community. The forecast meteorologist must be intimately familiar not only with meteorological phenomena that span the same range in time and space, but in addition he/she must be able to grasp the special needs of the client community and effectively translate and communicate the perishable information.

High-resolution SLODAR measurements on Mauna Kea

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We have made high order (32x32 subaperture) Shack-Hartmann wavefront sensor observations of binary stars with separations of approximately 30 arcseconds using the University of Hawaii 2.2m telescope. We present results of a Slope Detection and Ranging (SLODAR) analysis of the data yielding measurements of turbulence strength, wind velocity and velocity dispersion as a function of altitude, with approximately 500m vertical resolution. We also place constraints on the validity of the Taylor frozen flow approximation and explore the implications for layer-oriented predictive AO reconstruction algorithms.

Sierra Negra characterization: an update

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Located at about 19 degrees North latitude, 97 degrees West longitude and at an altitude of 4580m, Sierra Negra is the site of the Large Millimeter Telescope (LMT), a 50-m antenna to work between 1-3 millimeters. The development of the LMT site led to the installation of further scientific facilities benefiting from its strategic location, as a 5m radio telescope and solar neutron telescope. More recently the base of Sierra Negra, about 500m below the summit, was chosen as the site for the High Altitude Water Cerenkov gamma-ray observatory (HAWC). The site is in the boundary between Puebla and Veracruz states, at the edge of the Mexican central plateau which drops East to reach the Gulf of Mexico at a distance of about 100 km. The weather of the site is influenced by the dry weather of the high altitude plateau and humid conditions coming from the Gulf. Opacity data has been collected since 1997 and weather data since 2000. Here we present an overview of the climate conditions measured by different teams.

Evaluation of GFS and MM5 meteorological models for Paranal, Pachón and Macón zones

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Paranal is located in the North zone of Chile (2Â°region), which is considered a privileged zones for the astronomical observations for his desert condition, not much cloudiness and low light contamination. These same conditions are repeated in the pachón summit (4th region) where is the GEMINI south telescope. The same features has the zone of Macon in Salta region in Argentina. This place is one of the sites preselected for the construction of the ELT. The behavior of the atmosphere is important within the astronomical observation because knowing his future state it would be possible to be programmed the nights of observation. For this models of weather forecast that are used they simulate the behavior of the atmosphere. The period in study was year 2005, where the atmosphere conditions were simulated GFS and MM5 with models. GFS is a global model and serves like condition of edge for the MM5 because is a mesoescalar model . In order to realise the analysis of the simulations in Macon and Paranal the geographic data were interpolated using coordendas of each station to realise the comparison of the meteorological variables. Statistical parameters like the correlation, quadratic error mean and bias were used. In this evaluation we verified 5 variables, the temperature at 2 meters, humidity regarding 2 meters, atmospheric pressure, direction and intensity of the wind at 10 meters. In the first part of the analysis we found that the prognosis of MM5 model is better than GFS model, reflected in the correlations. This improvement is around a 20% when comparing the correlations obtained by MM5 model over GFS model that inclusively reaches to 50%, in some hours. In the second part of the analysis the filter of Kalman will be implemented to erase the systematic errors of the simulations of GFS and MM5. Their excellent results are discussed.

Modeling Optical Turbulence using the Weather Research Forecasting System, WRF. Sensitivity analysis to horizontal and vertical resolution.

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In 2004 staff at the Mauna Kea Weather Center implemented an optical turbulence algorithm within the operational runs of MM5, thus providing predictions of C_n^2 and seeing as guidance for a community of astronomers associated with Mauna Kea Observatories. The Mauna Kea Weather Center recently transitioned from using MM5 to the Weather Research and forecast (WRF) model for its operational runs. The WRF model was constructed from the ground up by a team of researchers from the university and operational communities in the U.S. WRF's architecture allows atmospheric modeling at higher resolution than previously possible with MM5, while taking full advantage of the parallel computing architecture provided by modern cluster computers. WRF's modeling capabilities range from global scale to cloud/eddy resolving scale. This paper describes the adaptation of our optical turbulence algorithm to the WRF framework. Preliminary results from a sensitivity analysis to changes in horizontal and vertical will also be presented.

The ground and boundary layer at Mauna Kea and its implications for GLAO

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We present the results of the an extensive study of the ground layer optical turbulence at the summit of Mauna Kea using a SLODAR/LOLAS instrument. The optical turbulence in the boundary layer is a significant contribution to the total seeing and generally equal in strength to the free atmospheric turbulence. However, the optical turbulence within the boundary layer is confined within the first hundred meters above the site. The implications for GLAO on Mauna Kea are dramatic. GLAO can provide extremely wide corrected fields (a degree) at the free seeing limit at visible wavelengths with a moderate number of guide stars (laser or natural).

Planning operations for the European Extremely Large Telescope

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The advent of the giant telescopes such as the 42-m European Extremely Large Telescope (E-ELT), expected before the end of the next decade, is bound to produce new paradigms in the operations of astronomical observatories. It will also produce further evolution of many novel concepts that have been successfully introduced in the operation of the current generation of 8/10m-class telescopes. The integration of adaptive optics capabilities in the design of the E-ELT and the high performance enabled by new technologies in astronomical instrumentation have enabled very ambitious science cases that push the capabilities of the telescope and its instruments to the limits. However, the exploitation of such capabilities will require a careful planning of science operations aiming to fully optimize the use of the available observing time and the way in which scientists will interact with the facility. We review the most important features of science operations foreseen at the E-ELT, some requirements linked to the variety of adaptive optics modalities that will be available at the telescope and its instruments, and how the current design of the E-ELT facility and its operations model intends to respond to these needs.

Meteorological study of an event of turbulence in TMT sites: case 13 of August of 2006

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In the north of Chile exists three preselected sites for the construction of TMT (Thirty Meters Telescope) telescope, Tolar (21.964° S, 70.099° W, 2290 m.a.s.l.), Tolonchar (23.933° S, 67.975° W, 4477 m.a.s.l) amd Armazones (24.58° S, 70.189° W, 3064 m.a.s.l.). In these sites measurements of meteorological standard variables, turbulence (C_n^2) and seeing data by MASS are collected. Analysis of the C_n^2 data shows a special case of turbulence on the night of August 13th, 2006. The turbulence appeared on Tolonchar between 3-4 UTC and 2 at 16 km, and in Tolar appeared between 5-8 UTC and 1 at 2 km. In Armazones turbulence was not registered. Synoptic analysis for this day show anticyclonic predominance (AP) and Jet Stream (JS) in high levels of atmosphere. Simulations with MM5 mesoscale model are performed and compared with in situ real meteorological data. Turbulence in Tolonchar is associate to Jet Stream, but the turbulence in Tolar is not clear by synoptic conditions. Also trajectories were calculated for each site on the vertical levels of the MASS to 0.5, 1, 2, 4 and 8 km of height. The low levels trajectories in Tolar show the origin of air in this night from south-east on the central valley and follow the orography. For Armazones the low level trajectories were from north-east, similarly to Tolar. The flow that affects the Tolonchar is influenced by the circulation of the West near to the middle atmosphere (500 hPa). Simulations with MM5 model show clear signs of the local circulation for eac site, but to improve the results it is necessary to increase the vertical resolution of the mode in order to catch the turbulent processes and their evolution and the relation with good and bad seeing.

The impact of seismicity on high angular resolution astronomy: the case of the Canaries Observatories

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Seismicity induces ground vertical and horizontal displacements that could affect the image quality obtained by telescopes in a similar fashion than atmospheric turbulence. In this work, we study the effect of local seismicity relative to atmospheric turbulence upon the image quality of astronomical observations at the Canary Island observatories (El Teide observatory on the island of Tenerife and Roque de los Muchachos observatory on the island of La Palma, both being separated about 150 km). Three different aspects of seismicity are studied, namely regional seismicity (that is compared with other astronomical sites), seismic noise and possible resonances between seismic noise and the structure of telescopes.

The ground layer as seen by MASS and DIMM and its relation to micrometeorology

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A study of the ground layer turbulence as seen by the combined measurements by MASS and DIMM during the TMT site survey is presented. The TMT site survey data include also the necessary meteorological parameters to infer important micrometeorological quantities. Several cases are being presented demonstrating the regime in which small scale local effects dominate the seeing within the first few hundred meters of the atmosphere. Some preliminary results of a specific DIMM campaign are presented as well.

Comparing TMT site testing results to climate indeces

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The five TMT site testing stations located in the central and eastern part of the Pacific area, formed during their time of simultaneous operation a turbulence monitoring network. These stations obtained during their lifetime of at least 2.5 years concise data of the atmospheric turbulence strength and other meteorological parameters. Here, these data will be analysed in view of their correlation with a number of climate indices, indicative of effects on the global scale.

Turbulence structure and meteorological conditions at Teide and Roque de los Muchachos observatories (Canary Islands)

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The proper characterization of the turbulence structure in an astronomical site requires a statistical study of the refractive-index structure constant (C_n^2(h)). Our team is monitoring since 2004 the C_n^2(h) profiles at the Teide and Roque de los Muchachos observatories on the islands of Tenerife and La Palma (Canary Islands, Spain), both sites being separated about 160 km. In this poster, we compare the seasonal behaviour of the turbulence structure at these two astronomical sites. We also discuss the night-to-night turbulence behaviour at these sites in comparison to meteorological conditions.

Vertical turbulence profiles at the Canary Islands Astronomical Sites

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We present the results of the monitoring of the optical turbulence profiles at the Canary Islands astronomical sites (Roque de los Muchachos observatory (ORM) and Teide observatory (OT), Spain) since February 2004. The data has been obtained using the generalized-SCIDAR technique at the 1m Jacobous Kaptein telescope at the ORM and 1.5m Carlos Sánchez telescope at the OT. We present the monthly and seasonal more probable vertical structure of the turbulence from 2004 at these sites, and the centiles in height of the C_n^2. The consistence of the behaviour of the turbulence in different time scales is crucial for AO/MCAO systems. We study how the position of hypothetic conjugated planes of a MCAO system affects to the improvement of the isoplanatic angle caused by the temporal evolution of the turbulence.

Studing the relationship between the average velocity of the turbulence (V0) and high altitude winds (V200) at the Teide Observatory (poster)

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The requirements for excellent image quality of current large and future very large telescopes demand a proper knowledge of atmospheric turbulence, and several projects are already pursuing this aim. The precise characterization of the turbulence above a particular site requires long-term monitoring, and in order to counter the lack of long-term information on turbulence, high-altitude winds (in particular winds at the 200-mbar pressure level, V200) have been proposed (Sarazin & Tokovinin 2002) as a parameter for estimating the total turbulence at a particular site, because records of this parameter exist from several sources. This proposal is based on the idea that the greatest source for turbulence generation is related to the highest peak in the vertical wind profile, which is located at the 200-mbar pressure level globally. Moreover, Sarazin & Tokovinin (2002) find a good correlation between the average velocity of the turbulence, V0, and V200 of the form V0= 0.4*V200 at the Cerro Pachon and Paranal Observatories in Chile. Although the V0-V200 relationship has not been tested at other sites, its validity would simplify the calculation of key parameters for adaptive optics, such as the coherence time. In this poster, we present the study of the possible connection between V0 and V200 at the Teide Observatory, defining the possible linear relationship between these two parameters and determinig the constant of proportionality for this site.

A new differentiation wavefront sensor for open-loop laser tomography on ELTs

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We present a new concept for an optical differentiation wavefront sensor, featuring a very high number of phase measurements across the pupil, with a linear response versus the phase gradient. This sensor is dedicated to open-loop phase measurements, for adaptive optics of wavefront characterisation. Its noise behavior and sensitivity gain are insensitive to changes in the LGS spot shape. We show lab measurements we have acquired with this sensor, obtained though turbulence on a elongated laser spot.

Future-Look Science Operations for the LBT

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The reconfigurable optics of LBT provides considerable versatility for observers to choose instruments and modes in near real time. Current values and predictions about both cloud cover and turbulence will become a critical factor in those choices, as the suite of available instruments expands with time. Two modes of operation are envisioned, both of which involve changes of focal station in response to conditions. One is partner-observer queue mode for facility instruments, which includes natural guide star adaptive optics. In that case, queue planning will use predictions and actual seeing to accommodate those programs requiring the best conditions. The other is a block-scheduling mode for new or complex capabilities, such as interferometry and early days of laser guide star operations. In that mode, site information will be essential for shifting to backup programs on nights that prove to be unsuitable for stable fringe tracking or reliable laser projection.

Preliminary results of the Optical Atmosphere Turbulence monitoring during Laser Guide Star Commisioning

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A combinaded MASS and DIMM instrument has been used to quantify the effects of the optical atmospheric turbulence on the Rayleigh Laser Guide Star commissioning during different turbulent scenarios. The importance to know the vertical distribution of the refraction index parameter C_n^2 along the LGS path and relationship of ground layers and free atmosphere seeing make the use of a turbulence monitor an important key in the performances and improvement of the LGS Observing system and in the development of new Adaptative Optics Instruments. We report preliminary statistical figures of the atmosphere turbulence profiles during the ING Ground Laser Guide Star (GLAS) commissioning.

Comparison of the atmosphere above the South Pole, Dome C and Dome A: first attempt

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In this contribution we present and discuss the results recently published in Hagelin et al. 2008 (MNRAS 387(4), 1499).

Using the analysis-data from the ECMWF (European Centre for Medium-Range Weather Forecasts) for an entire year (2005), the monthly median of several meteorological parameters, such as wind speed and potential temperature, are used to investigate three sites on the Internal Antarctic Plateau (Dome A, Dome C and the South Pole) for astronomical applications. Radiosoundings from Dome C and the South Pole are used to verify the reliability of the analyses and to study the wind speed in the first 100 m as the analysis-data are not optimized for this altitude-range. The wind speed in the free atmosphere is obtained from the ECMWF-analyses for all three sites. In this context a fourth site, Dome F, is also discussed. In the free atmosphere the stability is studied using the Richardson number, which is an indicator of the probability to trigger thermodynamical instabilities. We find that, in the large majority of the cases, the free atmosphere over the Internal Antarctic Plateau is more stable than at mid-latitude sites. Dome C shows worse thermodynamic instability conditions than those predicted above the South Pole and Dome A in the same vertical slab. Finally we provide a ranking of the three sites with respect to wind speed, in the free atmosphere (ECMWF analyses) as well as in the surface layer (radiosoundings).

Optical turbulence profiles at CTIO from a 12-element lunar scintillometer

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The spatial covariance of intensity fluctuations of moonlight can be used to infer the vertical distribution of atmospheric turbulence. Our lunar scintillometer employs 12 silicon photodiodes to measure the intensity covariance over baselines of up to 1.5 m. By inverting the data one obtains a measure of the turbulence profile in the lower 0.5 km of the atmosphere. I will summarize the theory, describe our instrument and inversion technique, and show some representative results from a year of turbulence measurements at Cerro Tololo Inter-American Observatory.

Preparing for Interferometry with the LBT

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The Large Binocular Telescope Interferometer (LBTI) is being built to carry out coherent imaging and nulling interferometry in the thermal infrared. In preparation for this we are carrying out test observations using the single aperture 6.5 m MMT as a pseudo-interferometer. I will present results from these observations, showing phase sensing and stabilization using interference at 2 microns. We have found that the use of average tip-tilt information over the subapertures provides useful additional information in tracking phase errors and have developed an algorithm that uses both error signals to stabilize the phase for deep nulling interferometric observations. The observational experience being developed at the MMT is important in simulating expected results and ranges of usable conditions for operation of the LBTI.

The impact of refractive index dispersion and water vapor based optical turbulence on AO system performance in the mid infrared.

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Since the beginning of the history of astronomical adaptive optics (AO) in the late 80', the effect of refractive index dispersion was considered completely negligible by the AO community, with reason, as it can be demonstrated that for medium size telescope apertures, in the near infrared regime, and low to moderate order AO systems, optical turbulence can be considered achromatic. Nowadays, though, with the event of extremely large telescopes and their very high angular resolution, the planning of extremely high order AO systems (Strehl ratios in the range 0.9 to 1), and AO system for the mid-infrared, we start to be in regimes where the variation of the refractive index with the wavelength, and with meteorological conditions becomes noticeable and can have a significant impact on AO performance, therefore cannot be neglected anymore. Now, solutions have been devised to compensate or at least mitigate some of the effects generated by dispersion, but these techniques critically depend on models of the air refractivity which in turn depend on the accuracy of the measurement of local weather conditions. On top of that, it is known that towards the far end of the mid-infrared regime ($\sim$10 microns and beyond), optical turbulence due to the water vapor becomes significant, and dry air models of turbulent profile measured in the visible cannot be used anymore to assess system's performance. As a consequence, it is becoming urgent, today, first to find reliable techniques to determine the refractive index fluctuation models parameters during AO observations, and second to find ways to assess the real impact of water vapor optical turbulence, and if needed, devise methods to measure the associated optical turbulence vertical profile, as seen in the mid-infrared regime. In this paper, we first review the knowledge on wet air refractivity, its impact on optical turbulence, then discuss the consequences for AO-based observations, emphasizing the need for accurate measurement of meteorological conditions, and optical turbulence in the mid to far infrared regime.

The meso-scale meteorological models Meso-NH and AROME

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It is well known that optical turbulence is triggered by phenomena such as lee waves, gravity waves, jet stream or wind shear and convection. Furthermore, most of the optical turbulence is concentrated in the Atmospheric Boundary Layer (ABL, first two kilometres), consecutively affected by convective processes during the day and stable nightly conditions. Therefore these phenomena are better simulated by using meteorological models based on non hydrostatic equations, fine horizontal and vertical resolutions and a sophisticated physics to better understand and represent the optical turbulence. The first part of the presentation will be dedicated to a description of the Meso-NH atmospheric model and its recent results with possible astronomical applications (Masciadri et al., 2004, see Masciadri's talk). A more stable advection scheme has been recently implemented, that is able to maintain the sharp gradients of the fields to be better transported. The benefit of the algorithm will be shown on idealized trapped orographic waves occurring downstream of a mountain flow and increasing the turbulence. Examples of Meso-NH used on a broad range of resolution will be shown, from the meso-scale (e.g. 1-2 km horizontal resolution) to Large Eddy simulations (LES, 100m resolution or finer). LES are a frequent way to study different regimes in the ABL, and recent investigations of stably stratified ABL (Cuxart et al., 2007) or convective ABL (Couvreux et al., 2005) will be shown. For meso-scale simulations with a grid box of a few kilometers, a recent improvement is a new Eddy-Diffusivity-Mass-Flux scheme, a parameterization of the contribution of larger vorticies and plumes in dry and cloudy convective boundary layers (Pergaud et al., 2008). The second part will focus on AROME, the new weather forecast mesoscale system of Météo-France, first applied on France, which comprises a data assimilation system (see P.Brousseau's talk) and a numerical model. The latter is based on a spectral non hydrostatic dynamics, at 2.5km horizontal resolution and a physical package coming from Meso-NH. Arome is planned to become operational at the end of 2008. Objective scores and some real test cases will be presented with a special focus on turbulent processes.

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Cuxart, J., and M. A. Jiménez, Mixing processes in an nocturnal low-level jet: An LES study, Mon. Weather Rev., 64, 1666-1679, 2007.

Masciadri E. , Avila R., Sanchez L.J., 2004 : Statistic reliability of the Meso-Nh atmospherical model for 3D, simulations. RMxAA, 40, 3.

Pergaud, J., V.Masson, S.Malardel and F.Couvreux 2008: A Parameterization of Dry Thermals and Shallow Cumuli for Mesoscale Numerical Weather Prediction. Submitted to Bound. Lay. Meteor.

IMAKA: Imaging from MaunA KeA

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The Canada France Hawaii Telescope has a long history of wide-field imaging, and this is reflected in its users community. Many projects are competing in the A.omega race but so far, all are limited by atmospheric turbulence. The characteristics of the turbulence of Mauna Kea are perfectly matched to such an instrument: a very thin ground layer with excellent free seeing (Chun etal, Gemini site study) would allow very wide fields to be corrected by a GLAO system, making the site an integral part of the instrument design.

The goal of this project is to achieve exquisite image quality over the largest possible field of view, with a goal of a FWHM of not more than 0.3" over a square degree field in the optical domain. This goal depends crucially on the thickness of the ground layer and its prevalence. But over such large fields the probability of finding sufficiently numerous and bright natural guide sources is high, although a constellation of laser beacons could be considered to ensure homogeneous and uniform image quality.

The image is then limited by the free atmosphere seeing (0.2" to 0.4"). This can be further improved by an Orthogonal Transfer CCD camera (Tonry etal, PASP 1997) which can correct local image motion on isokinetic scales from residual high altitude tip-tilt. Knowing the vertical turbulence profile, the outer scale and the isokinetic patch can help at the design level, but potentially also in real time operations.

The Antarctica polar vortex: study of winter 2005

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During winter and springtime, the flow above Antarctica at high altitude (upper troposphere and statosphere) is dominated by the presence of a vortex centered above the continent. It lasts typically from August to November. This vortex is characterized by a strong cyclonic jet centered above the polar high.

In a recent study of four different sites in the Antarctic internal plateau (South Pole, Dome C, Dome A and Dome F), Hagelin et al. (2008) made the hypothesis that the wind speed strength in the upper atmosphere should be related to the distance of the site to the center of the Antarctic polar vortex. This high altitude wind is very important from an astronomical point of view since it can influence strongly some optical turbulence parameters. What we are interested in here is to localize the position of the minimum wind in altitude. For that we studied the analyses from the ECMWF for winter 2005 at different levels. We deduced a prefered position of this minimum, tilted with altitude, in a zone between South Pole and Dome A, for the year 2005. This extensive study over one entire winter confirms the "position space" of the polar high deduced by Hagelin et al. (2008).

Numerical simulations of the wintertime optical turbulence in Antarctica with the mesoscale model MESO-NH

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Mesoscale model such as Meso-NH have proven to be highly reliable in reproducing 3D maps of optical turbulence (Masciadri et al (1999), Masciadri and Jabouille (2001), Masciadri et al (2004)). These last years ground-based astronomy has been looking towards Antarctica, especially its summits and the continental plateau where the optical turbulence appears to be confined in a shallow layer close to the icy surface. Preliminary measurements have so far indicated pretty good value for the seeing: 0.27", Lawrence et al. (2004), 0.36", Agabi et al. (2006) and 0.4", Trinquet et al. (2008) at Dome C, for examples. However some uncertainties remain. That's why our group is focusing on a detailed study of the atmospheric flow and turbulence in the internal Antarctic Plateau. A study among others (Hagelin et al., 2008) has shown that the analyses from the ECMWF global model do not describe sufficiently the antarctic boundary layer in the plateau. A better description could be obtained with a mesoscale meteorological model. Our intention in this study is to use the Meso-NH model to do predictions of the atmospheric flow in the internal plateau. The use of this model has another advantage: we have access to informations inside an entire 3D volume, which is not the case with observations only.

Two different configurations of the model have been used: one with a low horizontal resolution (ΔX = 100 km) and another one with higher horizontal resolution with the help of the grid-nesting interactive technique (ΔX = 1 km in the innermost domain). The impact of the different configuration induced on the simulated meteorological parameters has already been studied (Lascaux et al. 2007). We present here the first forecasted C_n^2 profiles extended on the whole 20 km obtained with a mesoscale model (Meso-Nh), surface layer thickness and seeing values above Concordia Station at Dome C in winter time. Turbulence distribution reconstructed by Meso-Nh will be compared to the measured one (Trinquet et al. (2008)) for all the 16 nights monitored in winter time 2005.

A new Meso-Nh surface scheme optimized for polar conditions: first validation tests for astronomical applications

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In the frame of AROME*, a new project of Météo-France in terms of numerical weather prediction, joint efforts of CNRM (Centre National de Recherches Météorologiques, Toulouse, France) research departments, Laboratoire d'Aérologie (Université Paul Sabatier, Toulouse, France) will contribute to the development of a new meso-scale weather prediction model for research activities, operational data assimilation and forecast (2008). In the development of AROME, the modelisation of surface processes has been externalised in order to have a full compatibility between the surface representation in research and operational models. One of the objectives of the externalisation is to better take into account the heterogeneity of the surface with specific physical parameterisations over town, vegetation, lake and open water.

The part of the numerical code concerning the interaction between soil, biosphere and atmosphere (ISBA), that characterizes the exchanges of energy between the atmosphere and the vegetation, has been adapted to Polar conditions in order to be used at Dome C (Antarctica). This specific study has been conceived in the context of a collaboration set-up between the GMME-CNRM and the ForOT Team - INAF-Osservatorio Astrofisico di Arcetri, Firenze, Italy. The latter are, at present, involved in researches aiming to characterize and quantify the optical turbulence developed above potential astronomical sites in the Internal Antarctic Plateau. The study uses a meteorological dataset related to Dome C for the year 2005 (Osservatorio Meteo-Climatologico at Dome C, PNRA, Italy) and also the measurements of temperature done at -5cm, -15cm and -30cm in the snow and the atmsopheric fluxes (ISAC/CNR, Rome, Italy). A simple version of the surface scheme, with only 2 layers to represent the heat transfer in the snow column, is used to simulate the surface temperature representative of the first centimeters and a deep temperature that corresponds to the daily average of the surface. On top of that, a climatological temperature is used to avoid a thermal drift of the system.

The calibration of the climatological temperature and its relaxation time have been done on a monthly basis by minimizing the root mean square error between the simulated deep temperature and the temperature observed at -30cm. The results show an improvement of the annual simulation of deep and surface temperatures. Besides we show preliminary validation tests done with Meso-Nh (a French meso-scale research model) by the ForOt Team and aiming to quantify the impact of the surface scheme on other meteorological parameters characterizing the atmsopehric flow near the surface. Further tests are planned to evaluate the impact in the computation of the turbulent surface fluxes, and more generally in the representation of the boundary layer included the effects on the optical turbulence.
(*) Operational French meso-scale model. The physical package comes from the Meso-Nh model.

Astroclimatological analysis of ground-based observatories

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We present an analysis of possible correlations between synoptical parameters relevant for astronomical observations, and the properties of atmospheric optical turbulence, in short and long time scale. The analysis gets started using the meteorological data of Observatorio del Roque de Los Muchachos (Canary Islands) where a homogeneous long term database is available. We are extending this work to the most important astronomical sites, including those located in Northern Chile and Antarctica. This analysis is aimed to optimize the use of the telescopes and to give data useful for the selection of new astronomical sites.

HVR-GS at Mt. Graham: Optical turbulence vertical distribution at standard and high resolution

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Since a few years measurements of the optical turbulence vertical distribution have been done at Mt. Graham with a Generalized Scidar (GS) located at the focus of the 1.75 m Vatican Advance Technological Telescope (VATT). Such a telescope is placed on the summit of Mt. Graham (Arizona) at around 250 m far away from the Large Binocular Telescope (LBT). Thanks to a recently proposed new technique (Egner & Masciadri, 2006) based on the observation of wide-binaries (30-35 arcsec) with a GS we could also collected measurements of C_n^2 profiles characterized by a vertical resolution as high as 20-30 m in the first 600 m. The statistic sample of measurements consists, at present, of 43 nights distributed in different periods of the year. In this contribution we present the main scientific motivations of this extended survey as well as the analysis and new insights into the turbulence characterization achieved so far by this on-going activity.

ForOT: a new approach for the optical turbulence forecasts studies applied to the ground-based astronomy

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The characterization of the optical turbulence (OT) done with meso-scale models for astronomical applications is an alternative approach to this science that intrinsically presents some interesting and complementary features/advantages with respect to the characterization done with measurements.

The most important advantages are namely: (1) the possibility to describe a 3D map of the C_N^2 in a region around a telescope, (2) the possibility to forecast the optical turbulence i.e. to know with some hours in advance the state of the turbulence conditions above an astronomical site and (3) the possibility to perform a climatology of the optical turbulence extended over decades. No other tool of investigation with comparable potentialities can be figured out at present to achieve these 3 scientific goals.

The forecast of the optical turbulence is a fundamental requirement for the optimization of the management of the scientific programs to be carried out at ground-based telescopes foci. Ground-based astronomy will remain an appealing option for astronomers with respect to the spaced-based one only if the telescopes management will be performed taking advantage of the best turbulence conditions. The future of new ground-based telescopes generation relies therefore upon the success of these studies.

ForOT is a scientific project but even more, it identifies a philosophy of approach to the studies and researches related to the characterization of the optical turbulence in an astronomical context. In this contribution we will deal about the main success obtained so far in this discipline in the past, the new goals predetermined by ForOT and the main results we obtained so far. To conclude, we will trace a perspective at long time scale showing where our research is addressed and how the scientific community and the managers who lead the ground-based astronomical facilities can support our researchers to progress in these studies.

Detailed analysis of the turbulence in the surface layer above Paranal

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The image quality delivered by the VLT Unit Telescopes (UT's) is always better, and often much better, than the seeing measured by the Paranal DIMM. This rather inconvenient discrepancy is thought to be due to the presence of a thin (dh$<$20m) layer of turbulent air that is seen by the DIMM but not by the UT's (Sarazin et al. 2008). The presence of this Surface Layer on Paranal has led some pundits to question the long term stability of the exceptional atmospheric conditions of Paranal, which would suggest that other sites in the area may not be valid alternatives for the E-ELT. The fact of the matter, however, is that while the seeing measured by the DIMM has degraded over the past 10 years, the image quality delivered by the UT's has at worst remained constant, and at best improved over the same period of time. So the real question we need to answer is what determines the height of the surface layer, and how sensitive is this mechanism to the effects of climate change. In this presentation we address these fundamental questions on the basis of a detailed analysis of the meteorological data recorded at Paranal over the past 8 years.

Site Selection of Iranian National Observatory

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The Astronomical Society of Iran decided in 2001 to make plans for a National Observatory housing a 2m size telescope. A workshop was organized on instrumentation and observatory site selection by inviting the experts from ESO, Nice University and Midi-Pyrenees Observatory in France, Indian Institute of Astronomy as well as from Iranian astronomical community. The INO proposal was prepared by IASBS on 2003 and finally approved by the Ministry of Science, Research and Technology on March 2004. In this respect the preliminary studies concerning the long -term meteorological parameters was started in Institute for Advanced Studies in Basic Sciences (IASBS) in Zanjan. The candidate regions, namely, Kashan, Kerman, Marzi in Qom and Birjand in South of Khorasan were selected among more than 30 potential sites around the country (Nasiri & Abedini, 2003, Nasiri, 2003). Four candidate sites have been selected considering the long-term meteorological parameters. The meteorological studies on long-term data collected by the local Synoptic stations exist in or near the regions of interest as well as by METEOSAT. To find the final site we had to measure the local atmospheric turbulence, as an important parameter, for these regions. We constructed four set of Differential Image Motion Monitor (DIMM) (Rodier, 1981, Sarazin & Rodier, 1990), using 11" Celestron telescope, ST2000 CCD camera, PC and masks with 2 sub-apertures that were able to measure the statistics of the perturbations on the incoming wave front caused by the atmospheric turbulence (Darudi & Nasiri, 2005, Nasiri, 2005). To produce a twin image the telescope was set slightly out of focus instead of using a wedge in front of one of the apertures. The technique is known as the defocused DIMM (Tokovinin, 2002). All four DIMM were calibrated simultaneously and were taken to the four mentioned regions. We developed software which made it possible to find the on site seeing value by calculating the statistical variance of the centeroid relative motion. By September 2004 our instruments were complete. During one week intense course on site selection for training about 40 young astronomers in IASBS, we selected 8 people and arranged them in four teams, one for each site. We started to find the best site in each aforementioned region and to make road, building and preparing the living and transportation facilities. The simultaneous night time seeing data started from April 2005 in a continuous manner throughout the whole year. After 11 months the Birjand site was rejected compared to the other 3 sites. 6 months later the Kerman site was also rejected (Nasiri & Darudi, 2006). By March 2007 we stopped Data collection and by considering the other astroclimate parameters for Kashan (Kolahbarfi) and the Marzi sites, it seems that, there is not a crucial difference between their seeing condition. We selected new location which is located at higher altitude but nearby the old ones. For final selection, our site selection team will do some measurement of light pollution, seeing, sky brightness, perceptible water, inversion layer and dust condition from May up to August 2008 for new candidate sites.

SLODAR profiling of the surface layer of optical turbulence

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A prototype of a new SLODAR instrument has been developed at Durham CfAI and tested at the Paranal observatory. The instrument targets very wide double star targets, with separations of several arc-minutes, to achieve profiling of the surface layer of turbulence with very high resolution in altitude (10m or less). We describe the instrument and the results of preliminary observations made at Paranal.

Mesoscale NWP over Antarctica: AMPS and Support for Ground-Based Astronomy

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The Antarctic Mesoscale Prediction System (AMPS) effort is one by the United States to provide real-time, high-resolution numerical weather prediction (NWP) over Antarctica and the high southern latitudes. AMPS is a mesoscale modeling system run at the U.S. National Center for Atmospheric Research (NCAR) that provides twice-daily forecasts for the U.S. Antarctic Program. AMPS, however, also supports a host of international logistic and scientific needs for atmospheric forecast output. As AMPS and its products have been adapted over the years to satisfy diverse needs for NWP guidance over Antarctica, supporting ground-based astronomy would be a natural extension of the system. Discussed will be an introduction to AMPS, its capabilities, and its potential for support of Antarctic forecasting needs of the ground-based astronomy community. Ideas for model products tailored for astronomy and for avenues of collaboration for serving the international astronomy community will be solicited.

Why is the VLT very efficient?

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Operating a large facility like the Very large Telescope requires a lot of planning and effort. But the final goal is not only to operate it, but to operate it efficiently.

VLT operations rely on a hybrid model that includes a large fraction of Service Mode observing, which was identified from the very beginning as one of the key features for an efficient use and successful scientific output of the facility.

After almost 10 years of operations, we have now gained a broad experience on the various features of this model and we can analyze its pros and cons. This presentation will focus on the analysis of different parameters that can measure the efficiency of our facilities and the user satisfaction.

An Astronomer's View of Optical Turbulence

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Some provocative declarations, generally supported by facts, will be made about the futility or utility of various types of OT modeling. The exercise has become futile for the purpose of site selection. Now-casting and forecasting of turbulence structure and of the resulting telescopic point spread function with a time resolution of a few minutes are primordial for the management of science programs, especially when adaptive optics are used. Understanding and mitigating the deleterious effects of "local" OT are also important. Challenges for meteorologists to meet are proposed to help astronomers who cannot forecast and, quite generally, do not really understand what spoils their telescopic images and attempt to improve them by largely empirical measures.

Dealing with turbulence: some MCAO experience and beyond

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Multi Conjugated Adaptive Optics, thanks to the Multi Conjugated Adaptive optics Demonstrator (MAD) of ESO, entered into the realm of producing astronomical science after more than a decade. I review our experience with the Layer Oriented Wavefront Sensor with an accent to the practical influence of the encountered atmospheric turbulence on the achieved science. A, maybe very personal, outcome of the perspective in the near and not so near future are outlined.

TMT site selection survey: Instruments, methods and operations

R. Riddle[1], S. Els[2], M. Schoeck[1], W. Skidmore[1] and T. Travouillon[1]

[1]Thirty Meter Telescope (Caltech), Pasadena, US
[2]CTIO, La Serena, Chile

The Thirty Meter Telescope Project has been testing several mountains in Chile, Mexico and Hawaii to determine the eventual placement of the telescope. The site testing project has operated for several years, and employed a variety of methods to measure the suitability of each of the sites. Here, we discuss the instruments, methods and operations of the site testing equipment, as well as future experiments planned for site characterization.

C_n^2 profile measurement from Shack-Hartmann data

C. Robert[1], N. Védrenne[1], V. Michau[1] and J.-M. Conan[1]

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C_n^2 profile monitoring usually relies on the exploitation of wavefront slope correlations or of scintillation pattern correlations. Scintillation is rather sensitive to high turbulence layers whereas wavefront slope correlations are mainly due to layers close to the receiving plane. Wavefront slope and scintillation correlations are therefore complementary. Shack-Hartmann wavefront sensor (SHWFS) is currently used to measure wavefront slopes only. But it could also be sensitive to scintillation as the average intensity in a given subaperture can be obtained by adding pixel intensities in the subaperture focal plane up. We propose here to exploit wavefront slope and scintillation correlations recorded with a SHWFS to retrieve the C_n^2 profile. Two measurement methods are exposed. In CO-SLIDAR (Coupled SLODAR SCIDAR), correlations of SHWFS data recorded on two separated stars are exploited. SCO-SLIDAR (Single CO-SLIDAR) relies on the same principle as CO-SLIDAR but SHWFS data are recorded on a single star. Results of C_n^2 estimation from simulated SHWFS data are presented.

Wavefront Characterization Campaign at Paranal: concurrent measurements with DIMM, MASS, GSM, MOSP, LuSci and SCIDAR

M. Sarazin[1], G. Lombardi[1], J. Navarette[1], A. Ziad[2], A. Berdja[2], J. Borgnino[2], W. Dali Ali[2], J. Maire[2], A. Tokovinin[3], E. Bustos[3], H. V. Ramió[4], M. Reyes[4], J. M. Delgado[4] and J. J. Fuensalida[4]

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In the frame of the EU funded ELT Design Study, a wavefront characterization campaign has been conducted at Paranal LT observatory in December 2007 involving concurrent measurements with DIMM, MASS, GSM, MOSP, LuSci and SCIDAR. The campaign goals and instrumentation suite will be described and preliminary results will be presented.

TMT site selection survey: Calibration and results

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[1]Thirty Meter Telescope (Caltech), Pasadena, US
[2]CTIO, La Serena, Chile

The Thirty Meter Telescope Project has been testing several mountains in Chile, Mexico and Hawaii to determine the eventual placement of the telescope. The site testing project has operated for several years, and employed a variety of methods to measure the suitability of each of the sites. Here, we discuss the calibration of instruments and methods and the results from the candidate sites.

Global study of the Nimbus7/AI and the visual CAMC/AE correlation

E. A. Siher[1]

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The use of the satellite data in astronomy is always possible, but its use depends on the needed problem. In previous studies, we showed that is a link between Aerosol Index (AI) satellite data and the ground Astronomical Extinction (AE). This link was possible using only the AE threshold 0.2 mag/airmass and the AE threshold 0.7. In this work, we will present a global study of this link by using the 2 days/one light and 2 nights/one day method to confirm if one can use the satellite for the sites qualification.

Reducing optical turbulence profiler data to a representative set for GLAO simulations

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A table of three profiles, often called *good, typical*, and *bad*, that represent the free-atmosphere together with another table of three to represent the ground-layer, is a popular and effective way of representing the variety of vertical distributions of C_n^2 (optical turbulence) in nine composite profiles. A small number of profiles for input to adaptive optics (AO) simulations should produce the same distribution of the PSF image quality metric as if the AO simulation was run on a very large, representative sample of C_n^2(h). In the context of ground-layer AO we expect the zones of uncorrected and partially corrected turbulence to be more important to the cumulative distribution of the AO corrected PSF metric of interest. We quantify this expectation by generalizing the composite profile concept to N tables each with M_N profiles for the zone that it will represent. The reference C_n^2 profile population will be a large number of Scidar measurements from Mt. Graham and the ground-layer AO simulation will be a fast filter on the power spectrum of the phase in order to compute the full population of PSF images in a reasonable amount of time. We find N and each set of M_N that sufficiently sample the vertical distribution to produce smooth and accurate cumulative distributions of ground-layer AO PSF image FWHM and radius of 50% encircled energy.

Modern instrumentation for measurement of atmospheric turbulence profiles

J. W. V. Storey[1], M. C. B. Ashley[1], J. S. Lawrence[1], C. S. Bonner[1] and D. M. Luong-Van[1]

[1]New South Wales University, Sydney, Australia

A number of techniques exist to extract turbulence profiles from the atmosphere, based on in-situ sensors, observations of scintillation, and acoustic radar. In this talk we will review these methods, their advantages, and their limitations. Atmospheric conditions above the Antarctic plateau are very different to those above temperate sites, particularly in the winter time when an intense temperature inversion is present through the lowest few tens of metres. The optimum techniques for studying Antarctic turbulence might therefore be expected to differ from those normally used. We will describe work currently being conducted at the University of New South Wales in the development of instrumentation that is specifically optimised for Antarctica.

Giant Magellan Telescope Site Testing and Characterization at Las Campanas Observatory

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[1]Giant Magellan Telescope/Las Campanas Observatory

Las Campanas Observatory has been designated as the location for the Giant Magellan Telescope (GMT). We report results obtained since the commencement, in 2005, of a systematic site testing campaign at LCO. Meteorological (cloud cover, temperature, pressure, wind, and humidity) and DIMM seeing data have been obtained at three potential sites, and are compared with identical data taken at the site of the twin Magellan 6.5m telescopes. In addition, measurements of the turbulence profile of the free-atmosphere above LCO have been collected with a MASS/DIMM. We examine the contribution to the seeing arising from turbulence in the ground layer (defined here as below an altitude of 500 m) through the difference between the turbulence integrals in the full atmosphere (as measured by DIMM) and in the free atmosphere (as measured by MASS). Additionally, we consider photometric quality, light pollution, and precipitable water vapor at LCO.

In preparation to characterize the Giant Magellan Telescope site and guide the development of its AO system, two campaigns to systematically compare the turbulence profiles obtained independently with three different instruments were conducted at Las Campanas Observatory in September 2007 and January 2008. Slope detection and ranging (SLODAR) was used on the 2.5-m duPont telescope. SLODAR measures the C_n^2 profile as a function of height through observations of double stars. The separation of the observed double sets the maximum altitude and height resolution. Ground layer (altitudes $<$ 1 km) and free atmosphere turbulence profiles are compared to those obtained with a lunar scintillometer (LuSci) and a multi-aperture scintillation sensor (MASS), respectively. In addition, the total atmospheric seeing was measured by both SLODAR and a differential image motion monitor (DIMM).

Understanding the ground layer turbulence of the TMT sites

T. Travouillon[1]

[1]Thirty Meter Telescope (Caltech), Pasadena, US

The TMT candidate sites cover three kinds of observatory terrain: Island, coastal and inland. Their ground layer turbulence therefore differs both in terms of intensity and vertical extend. For the first time, a comparison between these terrain can be carried out thanks to the array of inter-calibrated instruments installed by TMT on these sites. The turbulence profiles obtained with SODARs will be reviewed and a physical interpretation of the results will be presented in conjunction with the thermal and topographic properties of the different sites.

Optical turbulence and atmospheric instabilities

H. Trinquet[1] and J. Vernin[1]

[1]Laboratoire Fizeau, Université de Nice-Sophia Antipolis, France

During the winter 2004, a 2 weeks campaign has been held at the Observatory of Haute Provence (OHP), in France, from the 21st November to the 5th December. The goals of this campaign were to study the conditions in which optical turbulence are generated and the role played by atmospheric gravity waves in this process. Two technics were used to sense the optical turbulence and meteorological parameters: meteorological balloons and Scidar. Several meteorological balloons equipped with micro thermal sensors were launched at different ascentional wind speed to detect the gravity waves. At the same time, the Generalized Scidar or the Single Star Scidar were used at the focus of the 152cm telescope to retrieve and study the temporal evolution of the optical turbulent layers. We will present some results particularly interesting obtained during one night where Kelvin-Helmholtz and gravity waves instabilities are clearly put in evidence and trigged the optical turbulent layers.

Climatology at the Roque de los Muchachos Observatory

A. M. Varela[1] and C. Muñoz-Tuñón[1]

[1]IAC, Tenerife, Canary Islands, Spain

The Roque de los Muchachos Observatory (ORM) at La Palma (Canary Islands) is one of the two top pre-selected sites for hosting the future European Extremely Large Telescope (E-ELT), the other one is Paranal. Meteorological and seeing conditions are crucial both for the site selection and for telescope design and feasibility studies for adaptive optics. The ELTs shall be very sensitive to wind behaviour when operating in open air. Therefore, ground level wind velocity and wind gust are also required for the feasibility of the telescope construction. Here we analyse the wind speed and wind direction, the air temperature, the relative humidity and the barometric pressure statistical results obtained from data recorded at different sites at the ORM by several Automatic Weather Stations (AWS) from 1985, day and night time separetely. Ground wind speed regimes are compared with those provided by satellites from 200mb to 700mb and compared with those obtained at other astronomical observatories. There exists also observational evidence of the correlation between the seeing and the wind speed and wind direction that will be discussed in this work. Apart from the expected small differences among the ORM sites due to the differences in altitude, there are local meteorological effects associated to the orographical profile and geophysical properties which are discussed in this work.

SLODAR site monitors for site characterization and real-time support of adaptive optics

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[1]Durham University, Department of Physics, UK

We describe the current status, recent enhancements and applications of the SLODAR optical turbulence monitors developed at Durham CfAI. SLODAR systems designed for real-time support of adaptive optics for astronomy have been installed at the Cerro Paranal and Mauna Kea observatories. Another system will be deployed at the South African Astronomical Observatory in 2008. The instruments provide real-time measurements of the strength, altitude and velocity of the atmospheric optical turbulence. Recent enhancements, including greater automation, will be described. We summarize the capabilities of the instruments, data obtained to date, and their implications for site characterization and support of astronomy with adaptive optics.

Adaptive Optics and Interferometry in the International Astronomical Community: Present and Future Systems and the Impact of Turbulence

P. Wizinowich[1]

[1]Keck Observatory, Hawaii, US

This presentation is intended to provide an overview of the astronomical capabilities provided by existing and future AO and interferometer facilities, and the limitations and design constraints imposed by atmospheric turbulence.

Turbulence outer scale for High Angular Resolution Techniques

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Wavefront outer scale is a relevant parameter for the experimental performance evaluation of large aperture telescopes. The actual size of the outer scale has long been controversial, with measured values ranging from less than 10 m to more than 2 km. What is not controversial is the conclusion that when the diameter of the telescope approaches or exceeds the size of the outer scale, the optical consequences of atmospheric turbulence are changed dramatically from their traditional Kolmogorov behavior. In particular, power in the lowest Zernike aberration modes, e.g., tip and tilt and the overall stroke r equired for an adaptive-optics system can be much reduced. A finite outer scale has implications for interferometry as well. With the current interest in the design of extremely large ground-based optical and infrared telescopes, reliable estimates of the outer scale profile have assumed considerable importance.

The GSM ("Generalized Seeing Monitor") is the only instrument dedicated to this outer scale measurement. Developped by our team TOMI at Fizeau Laboratory, since 1997 this instrument visited the major sites over the world (Paranal, La Silla, Cerro Pachon, Mauna Kea, La Palma, Dome C, San Pedro, Palomar, Maydanak...). A review of the outer scale collected during the GSM different campaigns will be presented and discussed. Outer scale measurements have been confirmed by processing data obtained with existent High Angular Resolution instruments like optical interferometers and adaptive optics systems. Correlations of measured outer scale with other optical turbulence parameters has been studied and will be discussed. Outer scale values provided by the GSM are model-dependent deduced in the case of the von Karman model and the use of another model would change the L_0 values. The validation of the atmospheric turbulence model by processing data obtained with 15 aligned baselines of the GSM instrument have been studied. The first results obtained with this new method at Calern Observatory and at Paranal will be presented and discussed as well as the implication of the model on the GSM measurements and on the HAR techniques.

A new instrument MOSP (Monitor of Outer Scale Profile) has been developed by our team for outer scale profile extraction. We retrieve the vertical distribution of wavefront outer scale by analysing angular correlation of wavefront Angle of Arrival fluctuations deduced from Moon's limb image motion. We use simulated annealing algorithm to deduce the height dependence of the wavefront outer scale with given C_n^2 profiles simultaneously measured with the SCIDAR instrument. We present results obtained during two campaigns of observation at the Mauna Kea Observatory (Hawaii) and the Observatoire de Haute Provence (France). Estimated outer scale profiles exhibit smaller values in the boundary layer than in the free atmosphere. Comparisons with GSM outer scale measurements are possible and give good agreement. During the winterover 2007, the MOSP has been deployed at the Dome C site in Antarctica. Some data have been collected and the first results will be probably presented. These results are of great importance due to the fact that the GSM at Dome C exhibits outer scale values two times smaller than the mid-latitude sites and that turbulence is dominated by a 30m surface layer. In addition, verification of theoretical relation between height-dependent outer scales and those related to wavefront perturbations incoming in telescope pupils has been performed.

Some implications on adaptive optics systems and long-baseline interferometry are considered such as wavefront tip-tilt correctors and fringe trackers which overcome the limitations imposed by the atmosphere. For ELTs, sky coverage limitations of an adaptive optics system due to anisoplanatism can be improved by techniques like turbulence tomography and multi-conjugate adaptive optics which retrieve 3-dimensional instantaneous wavefront perturbations. Air refractive-index fluctuations profile, give information on the contribution of the different heights to the wavefront distortions. Spatial correlations on wavefront fluctuations at large scale produced by turbulent layers and related wavefront outer scale profiles are needed for completing the evaluation of atmospheric components which intervene in ELT optimal design. For example, wavefront outer scale profiles are useful to define maximal stroke needed for mirrors optically conjugated at different altitudes of the atmosphere.