Site Surveys, from Pioneering Times to the VLT Era

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On December 4, 1990, ESO selected Cerro Paranal as the site for its future European Very Large Telescope, the VLT. The choice of this isolated summit in the Chilean Atacama desert, 700 km from the La Silla Observatory, followed one of the longest and most comprehensive site study campaigns ever undertaken in the history of astronomy.

The VLT concept was subjected to considerable modification from the moment the project received its funds in December 1987 and throughout the subsequent years. 1992 saw the finalized design, adapted to the orographic constraints of the site and aimed at preserving the intrinsic imaging quality. Albeit somewhat late in the day, it had become clear that the amplitude of the distortions of astronomical images introduced by the atmosphere was much smaller than those registered so far by classical telescopes. An innovative programme had been launched at the CFHT as early as 1981 involving the systematic monitoring of image quality at the telescope to understand better the reasons for local degradation of observing conditions. The enormous potential gain from such efforts was revealed at the La Silla Observatory on the night of 22/23 March 1989 when engineers began first tests on the newest ESO telescope, the NTT (New Technology Telescope). The images (*The Messenger* No. 56) surpassed all those ever obtained. So much so that the astronomical community had to admit that most existing large telescopes were simply not able to take advantage of the atmosphere during its best moments. Consequently, the operation of the NTT initiated vast improvement programmes for existing telescopes, both for the analysis of spherical aberrations of the primary/secondary mirrors and for the monitoring of thermal equilibrium and dome ventilation. The site study for the VLT also orientated itself towards research on the frequency and duration of prime conditions on the various listed sites.

The age of preconceived ideas attributing comparable image quality to all sites was past. Work by specialists in atmospheric optics was suddenly in great demand. For a decade they had been explaining how variable the atmosphere was and what the mechanisms were that made it so. With the help of these researchers who formed the first working group for the VLT site selection, special instruments were selected and installed on candidate sites. They also helped to carry out an intensive measuring campaign on La Silla and later on at Paranal (*The Messenger* Nos. 44 and 68). The aim was not only to formulate the definitive characterization of an astronomical site but also to demonstrate the coherence of results from different measuring techniques using a single theory.

Over the centuries experimental astronomy has seen a gradual evolution both with regard to the observer's place in society and to scientific objectives. As far as the location of observatories was concerned, the majority were located, in the distant past, according to non-scientific criteria. The most important criterion was to be in the vicinity of religious, cultural or power centres. The Maya Observatory of Chichen Itza (Mexico) is one such example, as well as those found in most European capitals. It was only at the end of the last century when astronomers were encouraged by the improvements in photographic quality and the discovery of spectroscopy that they made resources available for site selection. The minimization of spectral absorption was one of the first priorities and this, of course, led to the selection of sites at a higher altitude. In France the Observatory of the Pic du Midi is a case in point; built in 1878 at an altitude of 2,877 m, it is still in use today. Then came the short-lived Janssen Observatory on the summit of Mont-Blanc (4,808 m) which was in operation from 1893 to 1909. 1926 saw the first attempt at characterizing the effects of atmospheric turbulence with the introduction by Danjon of a scale allowing the estimation of image quality from the visual observations of diffraction rings in small 25-cm diameter telescopes. Nevertheless, up until the middle of the century, sites which were economical and located near research centres were still preferable, regardless of the inevitable pollution induced by human activity. A prime example is the dramatic increase in sky luminosity above the 5-m Hale telescope on Mount Palomar (1,706 m) which was put into operation in 1948.

It was probably in the southern hemisphere that site studies were first carried out solely for science. In the 1960s several observatories were constructed there with the aim of receiving a new generation of telescopes 3 to 4 m diameter 10 years later. In 1962, the International Astronomical Union dedicated a symposium on the selection of observatory sites and assembled all experts (IAU Symp. No. 19). The study by J. Stock which lasted from 1960 to 1963 in Chile resulted in the choice by AURA (Association of Universities for Research in Astronomy, USA) of Cerro Tololo (2,399 m), 600 km north of the capital Santiago, and Cerro La Silla (2,428 m), 100 km further north by ESO in May 1964, after an extensive search lasting seven years in South Africa (*The Messenger* No. 55). Then, some years later, the site Cerro Las Campanas (2,280 m) was chosen, 30 km north of La Silla, by CARSO (Carnegie Institution of Washington, USA). At about the same time Australia carried out its site selection for the Anglo-Australian Observatory which was built in May 1962 on Siding Spring Mountain (1,164 m), 500 km from Sidney.

The main criteria during these campaigns were cloud coverage, air humidity and the image quality or "seeing". Instruments dedicated exclusively to the optical measurements of the effects of atmospheric turbulence were used in the 60s, proposed by J. Stock (1960), H.W. Babcock (1963), M.F. Walker (1965). The same instruments were used by the Max-Planck-Institut für Astronomie in the early 70s for a comparative study of the Gamsberg mountain in Namibia (then South-West Africa) and La Silla. However, while ESO's choice of La Silla in 1964 instead of South African sites was prompted mainly by scientific considerations, the 1982 decision of MPI to install the 2.2-m telescope at La Silla was taken more on political grounds (Namibia obtained independence in 1990). The two sites were found to be of quite comparable interest for astronomy.

From the attempts made in the 1960s up to the beginning of the VLT site study, considerable progress was made by theoreticians on the understanding of the influence of the atmosphere on astronomical image quality. What astronomers lacked in the past was a tool to relate quantitatively the physical laws of atmospheric turbulence to those of optical propagation. This gap was then filled by the unified theory of V.I. Tatarskii in the USSR in 1966. At the same time in the USA D.L. Fried was pursuing similar work. We have to thank Fried for the parameter named after him which is used internationally to characterize the perturbation of astronomical images by the atmosphere.

Work of that nature never went outside specialist circles due to its theoretical character and in fact reached the astronomical community with a few years' delay. The latter, however, had already become aware of the increasing importance of spatiotemporals of the atmosphere by the discovery of interferometric speckle by A. Labeyrie in 1970 and by the limits imposed by the twinkling of stars in precision photometry. But engineers and instrument designers had to wait almost ten years to see work written in a more accessible style by e.g.: S.F. Clifford in 1978 or F. Roddier in 1981.

It was precisely during this period, the 1980's, that projects were introduced for the construction of large telescopes to become operational before the year 2000. They were to be equipped with sophisticated techniques to compensate, at least partially, for atmospheric effects on light waves. However, these techniques are only as effective and economical as the site quality is good. It was clear that the choice of a site was not just an unavoidable, rather administrative, formality but a decision with far-reaching consequences on the future performance of the observatory.

These were the favourable conditions in which a site study campaign for the VLT was launched. First there was a pre-selection of the candidate sites based on criteria such as logistics and large-scale meteorological analysis, followed in 1983 by inspection visits that led to the establishment of a team of observers on the summit of Cerro Paranal at the end of the same year (*The Messenger* Nr. 64). The chronology of a study of this kind was predetermined: first of all, the regions with the least cloud cover, in other words offering the highest number of photometric and spectroscopic nights, had to be located before looking at atmospheric turbulence. The observers, who worked in fortnightly shifts, had the task of observing the quality of the sky both night and day. They also had conventional meteorological instruments and infrared radiometers that enabled them to measure the emissivity of the sky to deduce the precipitable water vapour content. Similar work was carried out simultaneously at the La Silla Observatory and after a few months the exceptional quality of the summits of the Atacama desert became evident, both for cloud cover and for water vapour content.

There are three mountain ranges at this latitude (23–25 degrees south): a coastal range of which Cerro Paranal is one of the highest summits, an intermediary or pre-Cordillera range 100 km more to the east and rising above 5,000 m, and then the Cordillera of the Andes with its volcanoes, some of which are higher than 6,000 m. Sporadic measurements taken on many of these summits confirmed the tendency to an increase in cloud cover near the Cordillera as well as a more marked seasonal influence. Worth mentioning is the infamous Bolivian winter that manifests itself in several weeks of wintry conditions in the middle of the southern summer.

The aridity of the Atacama desert is due to the low temperature of the Pacific Ocean, driven along the coastline by the cold Humboldt current that maintains the inversion layer, and clouds, at an altitude of less than 1,000 m in the main. This phenomenon, in addition to the steep slope of the coastal range facing the ocean, guarantees Cerro Paranal's complete isolation which means no sea spray in the ambient air even though it is situated only 12 km from the sea. At the beginning of 1987 and in view of the first encouraging results, ESO decided, following agreement with the Chilean government, to make permanent changes to the landscape and constructed a rudimentary access road up to the summit. In April of the same year the first image quality measurements were available from a differential image motion monitor (DIMM). This instrument uses intensified CCD imaging. It was still being developed and became fully operational in October 1988. However, it was only one year later that the DIMM reached the required accuracy (better than 10 % down to 0.25 arcsec seeing). So it was on the basis of statistics on cloud cover and humidity collected over 7 years and 1 year of taking image quality measurements that ESO committed itself to the construction of a new observatory on Cerro Paranal. The same DIMMs are now in routine operation both at Paranal and La Silla and permit the estimation of the stability of ESO observatories with regard to the long-term climatic trends, as described in the next article.

(Part of this text was translated from the original French by S. Milligan.)

Seeing Update: La Silla Back on the Track

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The VLT at Paranal will be equipped with a new feature hitherto unknown at observatories: an Astronomical Site Monitor (ASM) whose function it is to deliver permanently and in real-time the status of the site parameters that affect astronomical observing and/or telescope performances. The ASM comprises several dedicated instruments locally controlled by a common unit and part of the observatory network. It will feed a database accessible by users, telescope subsystems and by the science archive management system.

Meteorological data and seeing have already been routinely monitored at Paranal, with one interruption period of 15 months during levelling work. A new 5-m-high tower based on a design for Galileo at La Palma by Capodimonte Astronomical Observatory (Italy) was erected last April for the differential image motion monitor (DIMM3). This tower has the advantage of being easily dis-

Figure 1: *This fully retractable enclosure (here shown half open) was entirely designed and built solely for the La Silla DIMM by the Department of Maintenance and Construction. It was installed on the 5-m-high concrete tower in April 1993 and can be remotely controlled by the DIMM itself.*