FriOWL: A Site Selection Tool for the European Extremely Large Telescope (E-ELT) Project

Marc Sarazin[1]
Eddie Graham[2]
Hervé Kurlandczyk[1]

[1] ESO
[2] University of Fribourg/University of Berne, Switzerland

A systematic approach to site characterisation has been undertaken by ESO with the development of a geographical information tool dedicated to astroclimatology at the Department of Geography, University of Fribourg (Switzerland).

FriOWL for Global Analysis

FriOWL is a tool dedicated to tracking climatic trends and has been developed for ESO by the Department of Geography of the University of Fribourg, Switzerland (Graham et al. 2005). This tool has the primary function of helping to locate the most promising areas worldwide on the basis of the long-term average of various climate parameters. It also allows the estimation of the seasonal variability of these climate parameters at a given location, as well as their sensitivity to long-term climate change. FriOWL also allows the calculation of the anomaly coefficient of each climatic parameter with respect to the long-term average.

FriOWL (*http://archive.eso.org/friowl*) is a geographical information system with a spatial resolution of 2.5 degrees (ca. 300 km), It is composed of many different climatic layers containing a minimum of 15 years of data stored as monthly averages (the final goal is to have 45 years of data of all variables). The study of the temporal variability of the different layers gives new information on the seasonal and long-term climatology of the areas with selected sites. The nature of each of the layers has been chosen according to the expected sensitivity of ELT science to the different atmospheric parameters.

FriOWL Version 2.1 deals mainly with global climatological data, known as *reanalyses*. Reanalyses are the best available consensus of the global atmospheric system at any one time. They consist of reconstructions of the daily weather patterns from the 1950s to the present, using the latest numerical weather prediction and assimilation models. Reanalyses data come from two main centres, namely the joint National Centers for Environmental Prediction/National Center for Atmospheric Research in the USA (henceforth known as NCEP/NCAR) and the European Reanalysis products from the European Centre for Medium Range Weather Forecasting (henceforth known as ERA). Additional data, such as Outgoing Longwave Radiation (OLR) from NOAA, and the Aerosol Index from the Total Ozone Mapping Spectrometer (TOMS) satellite, are also included in the FriOWL database.

The FriOWL (latest version 2.1) database uses a temporal resolution of monthly means, with the total database ranging in length from 15 to 55 years, depending on the variable in question. Later, it will be possible to include higher temporal resolutions (e.g. daily, or possibly up to six-hourly). Most of the NCEP/NCAR parameters start in 1948, running through to the present, giving over 50 years of good quality data. The ERA dataset used in FriOWL Version 2.1 consists of data mostly from the ERA-15 project, a reanalysis covering the fifteen years between 1979 and 1993. A new, much longer 44-year reanalysis product, known as ERA-40, has been recently released and spans the period from September 1957 to August 2002. We hope to include ERA-40 in a later version of FriOWL.

Climatological analysis: the VLT site survey revisited

Identifying potential candidates for major ground-based astronomical projects is hardly a simple process and many factors other than science performance may sometimes blur the picture. But how can we be sure that no areas with strong potential have been ignored? Also the time schedules for project completion are often shortened because of the competition for funding and science delivery. Thus the site characterisation period which precedes the site selection process is often reduced to a minimum, typically 12 to 24 months. Therefore, how can we know whether the relatively short testing period is representative of the long-term history of the areas studied?

Within the next three years, more than 10 sites will be fully characterised by the various ELT groups in the world. And because much care was taken to use instruments which, if not always identical, are very similar and in any case repeatedly cross-calibrated, the data accumulated can easily be merged and the sites cross-compared for the benefit of all institutions. FriOWL will allow the assessment of the sensitivity of the candidate sites to climate change.

It is tempting of course to use FriOWL to verify that the previous astronomical projects have been well sited. In Figure 1, the cloud cover during the VLT site survey period (1984–1990) has been resituated within the twice longer time span available in FriOWL (1979–1993) as an illustration of the power of FriOWL to detect climatological anomalies. In this figure, the pixels surrounding Paranal show a very low anomaly while the Amazon basin was 10 % clearer than usual and the north-west of the continent was up to 10 % cloudier. Note that the current spatial resolution of FriOWL is sufficient for the analysis of climatological fluctuations which are linked to large-scale synoptic patterns (i.e. the 'highs' and 'lows' on a weather chart). On the other hand, the longer time coverage provided by ERA-40 is required for a better variability assessment.

Site short-listing

Most existing observatories housing international facilities have high standards and are natural candidates for future projects, unless they suffer from a lack of space or environmental restriction, such as Mauna Kea (Hawaii), providing only second-choice areas compared to the summit ridge (e.g. TMT). Several ELT sites surveys are currently conducted on well-known places such as La Campanas in Chile (GMT), San Pedro Martir in Mexico (TMT) and Roque de los Muchachos in Canary Islands (E-ELT). With the perspective of a lower weather downtime than in the Canary Islands during winter, the anti-Atlas mountain ridge is also considered for the siting of the Euro-

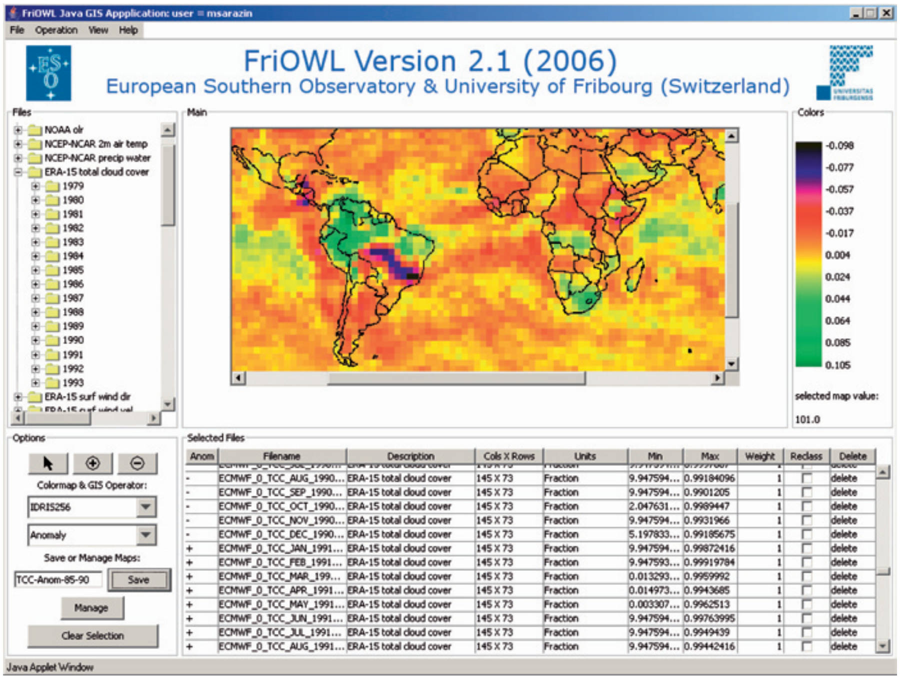


Figure 1: Total cloud cover anomaly of the VLT site testing period (1984–1990) with respect to the longer term average (1979–1993). The Paranal pixel shows a very low anomaly while the Amazon basin was 10 % clearer than usual and the north-west of the continent was up to 10 % cloudier.

pean ELT. In the 'photon valley' where the VLT Observatory of Paranal (Chile) resides, ESO plans to characterise a summit ~ 20 km to the north (La Chira) for the E-ELT, while TMT is studying an earlier candidate of the VLT site survey (Armazones) ~ 20 km further to the east.

For middle and far infrared observations, a lower external temperature reduces the thermal background. High elevation mountains also provide low precipitable water vapour (PWV) content. This is the case of the 4600-m site in the Macon ridge in NW Argentina studied by ESO and Cordoba Observatory which, in addition to low PWV, presents only half the seismic risk of Paranal. This is also the case of the new Franco-Italian Antarctic scientific station of Concordia at Dome C, whose proponents claim that it offers such favorable observing conditions that even a significantly smaller ELT would be highly competitive in some scientific areas.

In addition to topography, FriOWL is currently composed of 11 layers, among which are total cloud cover and precipitable water vapour (PWV). It is possible to combine the FriOWL layers with different weights so as to compose dedicated maps of suitability. An example is given in Figure 2 where topography, PWV and cloudiness have been used as reference parameters for infrared astronomy. It is easy to see that only a few regions on earth are suitable, but these still cover enough area to provide many possible candidate sites.

The wider the observation spectrum of the astronomical facility, the more layers must be added and the narrower the choice becomes. For instance, in UV and V photometry, despite their high number of clear nights, the central Saharan regions where the desert sand is blown upwards before travelling to Europe, Brazil or to the Middle East depending on the seasons, have to be discarded for they contain high aerosol contamination. Note that the aerosol index available in FriOWL (Figure 3) is believed to be related to atmospheric extinction, but this is still debated (Siher, 2004; Varela et al., 2004).

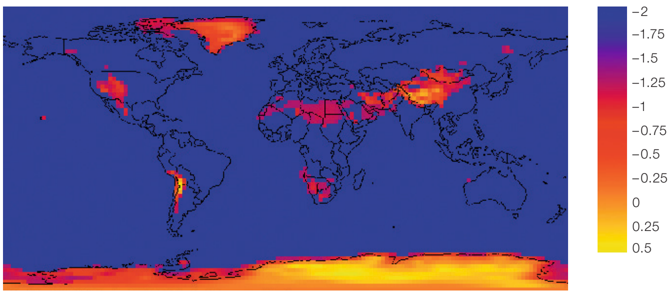


Figure 2: Overlay distinguishing areas providing high summits and low cloudiness as well as low PWV (arbitrary scale) 2.5 degree square pixels.

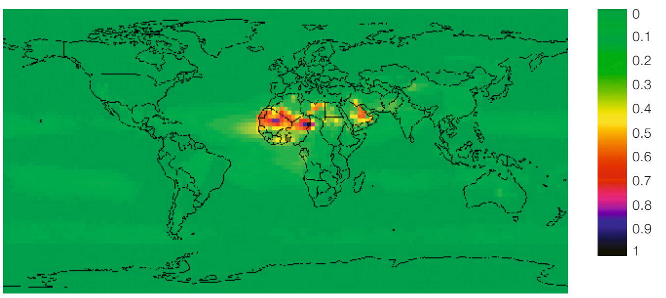


Figure 3: Mean aerosol index (arbitrary scale) as measured by TOMS UV satellite for the period 1980–2002, 2.5 degree square pixels.

Another layer specific to high-resolution observation with adaptive optics is the high-altitude wind speed. Based on radio-soundings performed at the VLT and Gemini sites in Chile by the LUAN (Nice), Sarazin and Tokovinin (2002) have shown that the wind speed at the jet stream level (12 km altitude asl, or 200 hPa pressure level) could be related to the temporal coherence of the wave front to be corrected by adaptive optics. Note that the numerical relation derived for Chilean sites was further confirmed at San Pedro Martir, but not on an island like La Palma (Varela et al., 2004). The experience accumulated at the VLT-NAOS facility shows that the performance of the wavefront correction decreases considerably when the coherence time is shorter than about 3 ms. At Paranal, the coherence time is longer than 3 ms about 80 % of the time in summer, but only 40 % of the time during the rest of the year (Figure 4). The large differences in the 200 hPa FriOWL wind layer for the first (Figure 5a) and the third (Figure 5b) trimester of the year imply that, rather than relying on yearly averages, estimating the efficiency of AO observing on a candidate site should take seasonal variations into consideration.

In order to identify the best candidates within a FriOWL pixel area, the low spatial resolution information can be complemented by the direct use of geostationary satellite imagery. With a resolution better than the size of the observable sky of a ground-based facility, the technique developed by Erasmus (2006) for cloudiness and PWV assessment has proven its usefulness.

European astronomy managed to converge towards a single funding request to the European Commission FP6 framework programme. This gave birth to the 2005–2008 ELT Design Study, a technology development programme coordinated by ESO and conducted by research institutes and industrial companies in Europe. The study covers the development of enabling technologies and concepts required for the eventual design and construction of a European extremely large optical and infrared telescope, with a diameter in the 30- to 60-m range. Site characterisation, exploratory instrument designs, and an assessment of the performance of a segmented aperture

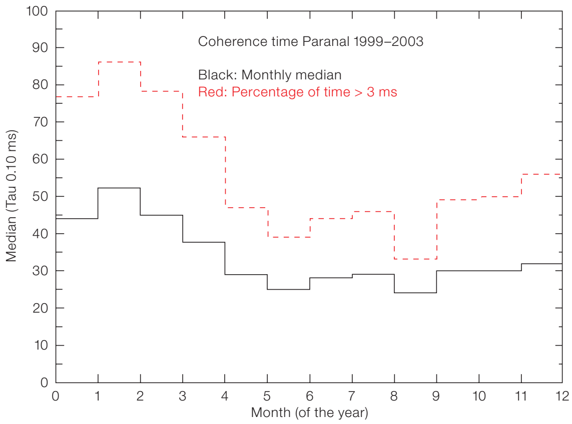


Figure 4: Statistics of the atmospheric coherence time at Paranal showing a strong seasonal trend.

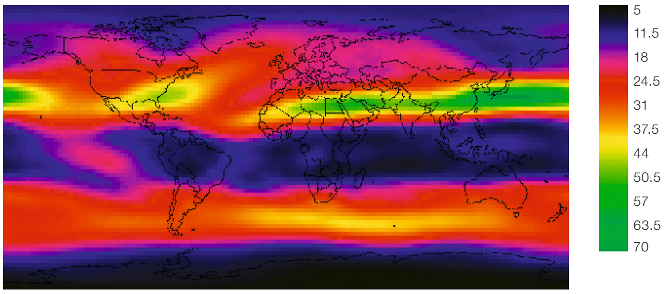


Figure 5a: Mean wind speed at 200 hPA (ca. 12 km above sea level) in m/s for the months of January, February and March during the period 1979–1993, 2.5 degree square pixels.

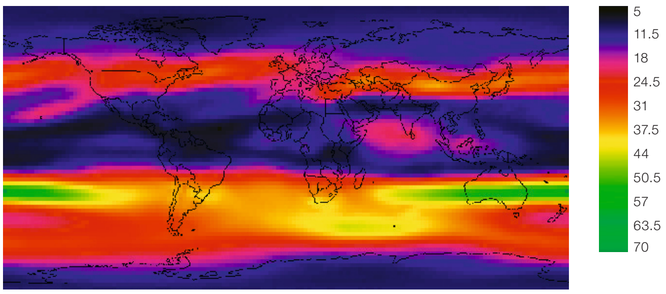


Figure 5b: Same as Figure 5a, but for the months of July, August and September.

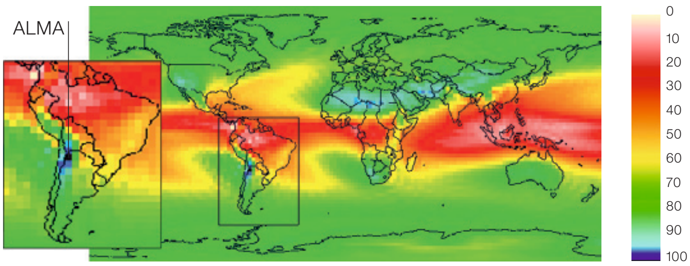
exposed to wind on a representative site are also included. Considering the available funds, the site characterisation work package under the responsibility of Nice University (IAC and ESO as deputies) has been limited to four sites (Chile, Canary Islands, Argentina, Morocco) and will be compared to Dome C in Antarctica. It also includes actions for a better understanding of the physics of the turbulence at large scales proposed by Arcetri Observatory, LUAN and ONERA. At the end of the site characterisation period, the E-ELT site selection process will start with the participation of the ESO community at large through the ELT Standing Review Committee (ESRC) in which site activities are covered by Roland Gredel.

Verification of the ALMA site

For the site selection of the ALMA telescope some specific climatic and meteorological requirements were necessary. In particular in order to achieve good observational conditions, Outgoing Longwave Radiation (OLR) and Precipitable Water Vapour (PWV) were identified as key parameters among others to determine suitable sites for millimetre and submillimetre wavelength radio astronomy.

OLR is inversely related to cloud cover and directly related to surface temperature (in the absence of clouds). Increased cloud cover will reduce OLR reaching the top of the atmosphere from the earth's

Figure 6: Sum overlay of Outgoing Longwave Radiation (OLR) measured from 1974–2001 and the Precipitable Water Vapour (PWV) measured from 1948–2001. The darkest pixel corresponds to the most appropriate place on the non-icy earth that combines both parameters. The ALMA site (Chajnantor) is included in that dark pixel.



surface and vice versa (Erasmus 2006). Typically the highest values of OLR indicate the high temperature of the earth – because hot regions radiate the greatest amounts of longwave radiation to space. However, thin cirrus clouds trap a significant amount of OLR – thus, lower values of OLR indicate higher than normal presence of cirrus clouds but may also indicate lower than normal surface temperatures (in the absence of clouds). Therefore the icy region such as the poles will not be considered here. The model used in this example has a 2.5° horizontal resolution for the period from June 1974 to December 2001. The units are watts per square metre (W/m^2).

Precipitable water vapour (PWV) is provided as a monthly mean of integrated total column precipitable water vapour in kg/m^2 (which is equivalent to millimetres). It is the mean total amount of water that could be precipitated from the atmosphere. Values typically range from a few mm in cold regions to over 50 mm in the tropics. In the Chajnantor pixel of FriOWL, the PWV is around 2,5 mm which is particularly low. Note that the real Chajnantor PWV value is lower (0.68 mm), because the climate model height at this pixel (approx. 4 000 m) is lower than the real height of Chajnantor (over 5 000 m).

As an example a qualitative composite map was made, by combining the mean Outgoing Longwave Radiation and Precipitable Water Vapour maps of FriOWL. Firstly, in order to have comparable values, the scales of the different units were adjusted and then the PWV values were inverted since we wanted to avoid high values of PWV. Finally, both maps were overlaid upon one another. The result (Figure 6) confirms the Chajnantor pixel as the best possible combination of both parameters on the whole non-icy earth.

References

Erasmus A. D. 2006, Proc. of the IAUS 232, 510
García-Lorenzo B. M. et al. 2004, SPIE Proc. 5489, 130
Graham E. et al. 2005, Meteorological Applications, Vol. 12, Issue 1, 77
Sarazin M. and Tokovinin A. 2002, Proc. to ESO Conference and Workshops 58, 321
Siher E. A. et al. 2004, SPIE Proc. 5489, 138
Varela A. M. et al. 2004, SPIE Proc. 5571, 105

Image of the Robert's Quartet group of galaxies, from *B*, *V*, *R* and *I* observations made with FORS2 on the VLT. Image processing by Henri Boffin, Kristina Boneva and Hans Hermann Heyer (all ESO). See ESO Press Photo 34a/05 for more details.