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The *ideal* site revisited for future ground based telescope projects

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Abstract. Extremely Large Telescopes, the next generation of ground based astronomical facilities, are in the planning phase in various institutes worldwide. Despite their massive appearance, these glassy mastodons might be much more demanding than their predecessors from the environmental point of view, thereby excluding from the race some of the world's most famous observatories. The particularities of ELTs relevant to site selection are reviewed and alternative strategies for global site surveys are discussed.

1. Introduction

The earth atmosphere has always been a real nuisance for astronomy and the general trend is naturally to escape to space as often as possible. However, despite the steady development of space industry in the last 20 years, we are still currently, like in the 80's with HST at a point where space and ground based projects remain both concurrent and complementary. But to stay in the race, ground based projects are pushing the technical requirements to new extremes in terms of collecting area and resolving power. The family of extremely large telescopes (ELTs) currently on the drawing board intend to use adaptive optics (AO) techniques for compensating atmospheric image distorsions which, if successful, shall reveal in turn residual optical figuring errors or wind load effects which were until now considered as negligible. In addition, AO techniques are extremely demanding in computing power, related both to site seeing by the required number of actuator for avhieving full compensation and to site tropospheric winds which determine the available lag between the wavefront analysis and its correction in closed loop operation.

Also because of the concurrence with space observations, ground based astronomy has evolved towards more flexible scheduling modes which allow to use at the best the intrinsic qualities of the various sites. For instance one can switch instruments in a matter of minutes on all modern facilities. Because of this and of the shortening of science exposures due to the increase of collecting area, the quality of science data has become for instance increasingly sensitive to the short term stability of observing conditions (Rigaut, 1999).

Finally, because of their extreme size and weight, it is more complex to protect ELTs from their environment, in particular with respect to severe weather and earthquakes. A number of existing observatories might not be able to fulfill

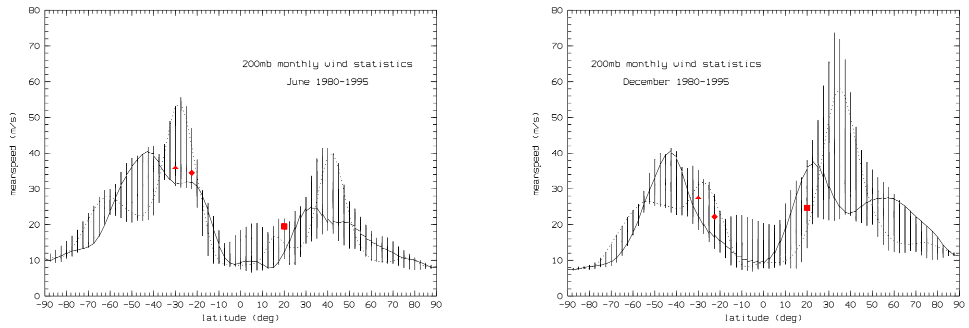

Figure 1. 200 mb mean wind velocity during the months of June (left) and December (right) from 1980 to 1995 as a function of latitude for all longitudes (vertical bars) and for 0° (full line) and 180° (dashed line) longitudes. The observatories of Mauna Kea, Paranal and La Silla are indicated, respectively, by a filled square, diamond, and triangle.

such requirements, thus opening the way for a new global search for potential sites.

2. New Parameters for ELT sites

2.1. Tropospheric flow

It was noted above that adaptive optics techniques are sensitive to the rate of change of the optical wavefront high spatial frequency structures due to atmospheric turbulence. The sub-tropical jet stream acts as circulation engine which drags lower layers of the atmosphere in its infernal rotation around the earth. It is thus realistic to assume that whatever their altitude, the velocity of all turbulence layers is somehow linked the 200 mb global circulation.

The graphs of Figure 1 were built from the 2.5 degree resolution NOAA Global Gridded Upper Air database using the 16-year (1980-1995) statistics of climatic summaries produced by the model of the European Center for Medium Range Weather Forecasts (ECMWF). The data summarized in Table 1 show that the ratio between existing observatories and a site belonging the intertropical belt (no jet stream) is about 2 on average and up to 5 on some months.

Month	Costa Rica	Mauna Kea	Namibia	Paranal	La Palma	Maidanak
June	17.8	19.5	32.0	34.5	24.0	27.1
December	10.3	24.7	20.0	22.2	42.6	49.6
Mean	14.1	22.1	26.0	28.4	33.3	36.4

Table 1. Comparison of the mean 1980-1995 200 mb wind velocity in m/s at various sites for the months of June, December and the average of both.

2.2. Surface winds

The ELTs shall be very sensitive to wind load if they have to operate in open air. The yearly average surface wind velocity varies about by a factor of 2 between unprotected summits (Paranal, Mauna Kea, 6 to 7 m/s) and the foothills of a major mountain chain (Maidanak, 3 m/s). It is not possible to retrieve accurate values of surface wind intensity in mountain areas using global models alone, of 30 to 60 km horizontal resolution. It is thus not possible to foresee to use this parameter as one of the input variables of the initial global search. As discussed later in this paper, 1 km resolution mesoscale models can be run on several specific preselected locations to document the short-listed candidates, but in any case local measurements shall be needed before the decision making process can take place. The short term (eg. 20 mn) stability of wind direction is also a good indicator of overall stability of observing conditions.

2.3. Seismicity

A global survey of seismic hazard (Giardini 1999) led to the production of a world map depicting the level of ground motion (PGA: peak ground acceleration) that has less than 10 % probability to be exceeded during an exposure time of 50 years. The PGA is a short period ground motion parameter which affects short period structures like one- to two story buildings.

Table 2 shows the large diversity in the seismological environment of existing observatories. All these sites are nevertheless suitable for 10 m class telescopes because appropriate engineering solutions could be developed. It is not yet known how much seismicity will matter for ELTs: an ELT mechanical design allowing a survival maximum horizontal ground peak acceleration of 0.1 g would remove entire continents from the competition, including more than 50 % of existing astronomical sites. Even the current design goal of 0.2 g set for OWL would still exclude many high quality areas like northern Chile.

Site	Acceleration
Paranal	0.34
La Silla	0.30
Chajnantor	0.28
Maidanak	0.20
La Palma	0.06
Mauna Kea	0.04
Namibia	0.05

Table 2. Maximum 50-years horizontal ground peak acceleration in units of g (source: Giardini 1999 and M. Quattri, ESO).

2.4. Climate change

As shown on Figure 2 and as stated in the Intergovernmental Panel on Climate Change (IPCC) third report (2001), *the rate and duration of warming of the surface temperature of the northern hemisphere during the twentieth century is likely to have been much greater than in any of the previous nine centuries.*

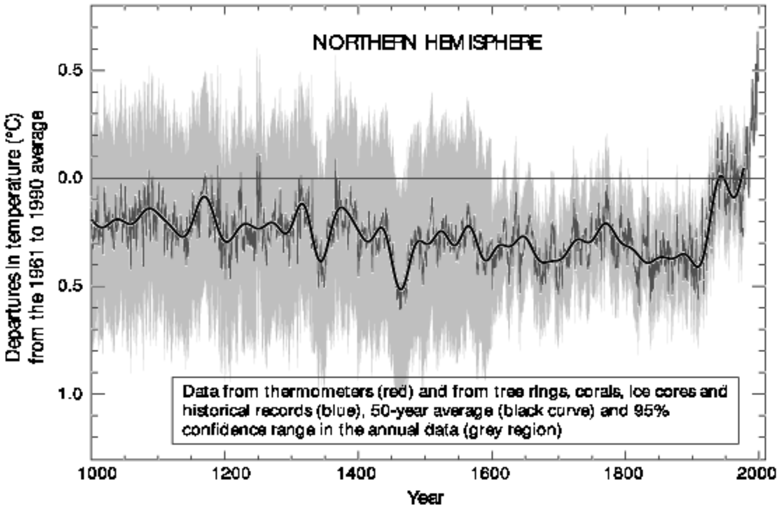

Figure 2. Departure in temperature from the 1961 to 1990 average (source: World Meteorological Organization, Weather and Climate, their variability and change).

It is not possible to go through a site selection process without contemplating the value of accumulated data in front of climatic unstabilities, whether long term trends as global warming or of oscillatory nature like el niño (ENSO). In case of short term field measurement campaigns, the past history of the site has to be analyzed so as to assess the representativity of the local data collection period.

2.5. Seeing

Seeing requirements for ELTs are similar to those of the 8 meter class facilities and field measurements with portable monitors are certainly needed in the final stage of the site survey. However some ideas are proposed below to be implemented at the early stage of a global survey in view of reducing the number of candidates. There is still no analytic relationship between orography, meteorology and seeing but the increase of the number of tested sites has improved our understanding in several areas:

1. Height (above sea level): very high altitude sites (> 5000 m) do not show significantly better seeing than good quality observatories located around 2500 m. Indeed at this level of excellence, it takes a small amount of local effects (wake of nearby summits, katabatic flows, local ground layer) to cancel out the gain of a thinner atmosphere.

2. Proximity of the sea: continental sites can present as good seeing conditions as coastal or island sites. The study of Maidanak observatory in Uzbekistan (Ehgamberdiev 2000) has shown than outstanding quality was possible in Central Asia, along with very low surface wind intensity.

3. Wind direction: seeing conditions at a good site can deteriorate in a matter of a few minutes when the wind in the first 1000 m changes direction: at the VLT site for instance, there is a narrow ($\pm$15 degree) area of the wind rose pointing inland which is unvariably linked to bad ($>$ 1.5 ") seeing.

It is easy to conclude that if current outstanding astronomical sites present good nighttime seeing conditions when the atmosphere aloft moves from an area of low perturbation like the sea surface or a flat desert, further candidates sites for ELTs should at least present similar characteristics. We need to define a space variable representing the potential for good seeing, for example minimizing the *upwind roughness* (uR). An analytic expression for uR should involve the mean synoptic flow in the surrounding area of the site up to about 100 km radius. Using synoptic flow maps at the closest pressure level, each pixel is given a weight proportional to the probability that the flow passed over them before reaching the site. The upwind roughness uR is the weighed rms elevation of these neighboring pixels. Additional features to be introduced are a damping factor proportional to the distance of each pixel to the site, as well as a relative height index to account for turbulence borne by aerodynamical wakes (upwind pixel higher than the site). The empirical expression of uR can be tuned on existing sites for which exists a consistent database of seeing and wind data.

3. New tools for ELT site surveys

3.1. Geographical information systems

As put by Berry 1995, *what began in the 1960s as a cartographer's tool has evolved into a revolution in many disciplines... A geographical information system (GIS) can store tremendous volumes of descriptive data and overlay myriad maps for their coincidence.*

A GIS is a special-purpose digital database in which a common spatial coordinate system is the primary means of reference. Among the many types and characteristics of available GIS models, one should prefer a general **relational** model of **conceptual, perception-based** type, ie. incorporating both fact interpretation and value weights. The GIS model itself should be of **spatial** type, being able to produce a map of suitability based on mathematical relationships among mapped variables. The model should present the following characteristics according to the generalized classification guide for GIS models (Berry 1995):

SCALE	Macro
EXTENT	Complete
PURPOSE	Prescriptive
APPROACH	Theoretical
TECHNIQUE	Deterministic
ASSOCIATION	Linked
AGGREGATION	Disaggregated
TEMPORAL	Static

The **prescriptive purpose** serves the characterization of direct and indirect factors related to system response (eg: ELT project cost/performance related to surface wind and seismicity).The **theoretical approach** is based on the linkage of proven or postulated relationship among variables (eg suitability for adaptive optics as a function of seeing and tropospheric wind; or seeing quality as a function of up-wind terrain roughness). The **linked association** indicates that the state of an individual location is dependent on other map locations (eg. upwind roughness). Finally the model is said **disaggregated** because the suitability map is based on spatially evaluating a regression equation in which each input map identifies an independent variable, each location a case and each value a measurement. The GIS is static in that sense that time is not one of the variables but preferably there will be separate collections of input maps for the various seasons or for yearly averages giving separate outputs. However, a static GIS can easily become dynamic when addressing *what if* questions, actively involving decision makers and interested parties.

Two groups of field variables or layers can be envisaged to compose an ELT GIS database, which can be classified as scientific and logistic, a non exhaustive list follows:

- Scientific variables: digital elevation model (DEM), cloudiness, precipitable water vapour, aerosol, surface (700 mb or 500 mb) wind, tropospheric wind, upwind roughness, sky background, outgoing longwave radiation
- Logistic variables: consumer cost index, bnp, political stability, road network

While some variables are readily available in data format, others have to be computed for example by combining the information from two or more layers as illustrated on Figure 3. In the case of upwind roughness which, when reaching low values, is supposed to be an indicator of good seeing, one can for example combine the 700 mb wind flow with the DEM slope analysis in a way similar to the example of Figure 4.

3.2. Mesoscale meteorological modeling

The subject is reviewed in this conference by Masciadri 2000. Obviously in the perspective of a global survey, mesoscale meteorological models which are able to depict surface flows even in complex orography like mountain sites could help selecting the least windy sites in a given area. Feasibility tests have however to be conducted to determine whether the currently available global digital elevation model of 1 km resolution is sufficient to resolve local flows in typical astronomical environments. Moreover the sensitivity of candidate sites to climate change could be tested by running the model with varying initialisation conditions.

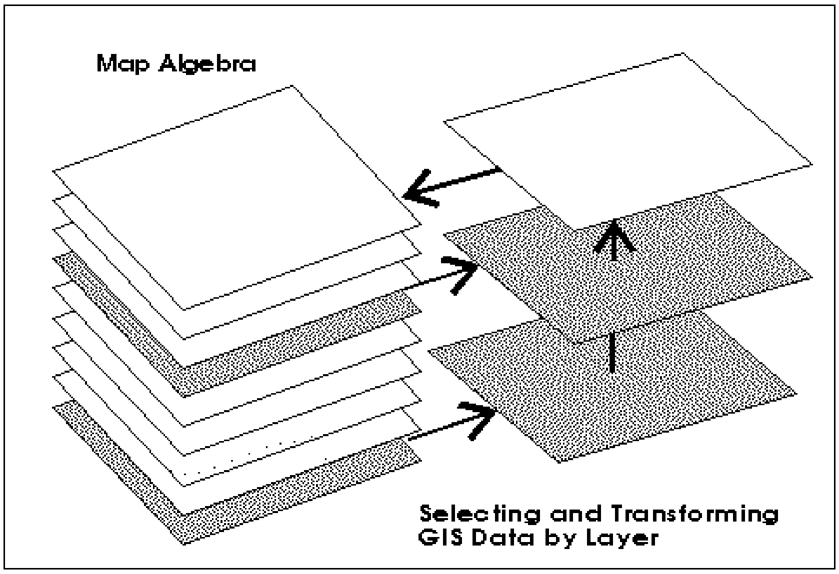

Figure 3. GIS algrebra: combining and transforming information from different layers (source: Kenneth E. Foote and Margaret Lynch, The Geographer's Craft Project, Department of Geography, The University of Colorado at Boulder).

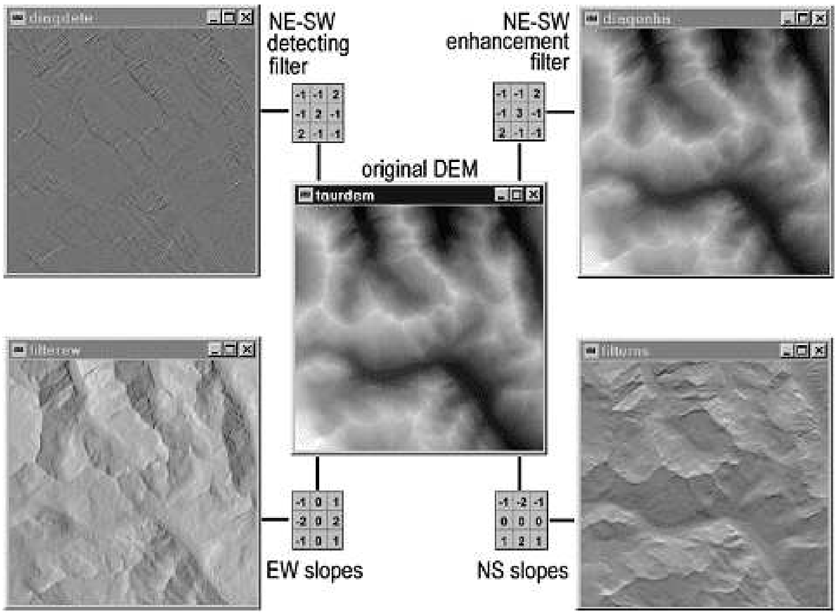

Figure 4. Example of directional filter (source Eric J. Lorup, IDRISI tutorial on WWW).

4. Conclusion

A new methodology is required for selecting ELT sites which makes intensive use of the recently available geophysical databases and now affordable powerful computer models. The suitability for adaptive optics operation and the low surface winds are new parameters to be taken into account even at the cost of a lesser number of photometric nights. The trade-off criteria are expected to evolve with the maturity of ELT engineering design, powerful software tools based on multi-layered geographical information systems have to be developed so as to assess in the course of the project the impact on site selection of technological choices and operational schemes.

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