"Atmospheric Characterization of Sites"

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The evolution of the astronomical sites selection and characterization

Walker (1984) introduced the main parameters and standard site evaluation criteria (for example for the seeing, the “Walker telescope”). He fixed the criteria for clear/mixed nights.

Recent evolution of the criteria and their relative weights: cloud coverage, atmospheric optical turbulence, precipitable water vapour, sky brightness, sky coverage, aerosols (dust), wind and humidity, ozone layer thickness, contrails...

Up to 20 parameters considered for the ELT site selection (2011-2013).

Very long investigations: the study for the LEST site (JOSO) took more than one decade.

Cerenkov light detectors (for example CTA) require “unusual” site conditions if compared to standard astronomical observatories.
Cerenkov light detection (CTA) site requirements

- Optical turbulence? **Irrelevant**
- Sky background? **Relatively high threshold**...
- Altitude? **A complicate issue**...
- Clear sky (photometric? Not really, non photometric conditions are acceptable)
- Contrails? Irrelevant?
- Temperature gradients? Not very important (only for the structure)
- Sky coverage: yes
- Aerosols (dust): yes  ... 
- Technical parameters: wind, earthquakes, (temperatures)

There is some overlap with standard astronomical sites, but there are also some relevant differences

Very tight schedule!
Site selection

Pre-selection of the sites: usually on the base of wide scale investigations (Sarazin, 2002), mainly based on satellite archives (TOMS, GOES, METEOSAT, MODIS...).

CTA: candidates based on proposals from countries/institutions

Analysis and detailed selection: standard meteorological instrumentation on site, plus night sky coverage detectors, night sky brightness photometers, dust detectors.

Current meteorological archives and models can support the analysis, but in principle they are not suitable for astronomy because they have different goals and targets.
Number of potential dark hours (Sun at h=-18) per year as a function of the latitude (disregarding Moon light and clouds): 
maximum 3400 (equator), minimum 1700 (l=84.5) 
(Sadibekova, 2005, PHD thesis)
ELT early investigation Sarazin, 2008,

Cloud coverage

Possible Sites for Optical Astronomy

- Sites often located on high desert areas
- The reason is that deep cold water comes to the surface and cools the air temperature. The first Inversion Layer is therefore lower than 600m. The observatories are located on top of the clouds.
- At the poles there is the possibility to do longer continuous observations during night time.
Sea level seasonal pressure: subtropical sites
The monsoon rainfall
Seasonal (summer) rainfall: the shift of the equatorial rain
Rainfall as a cloud proxy: Namibia, Hess-Isabis site: seasonal effects, local variations
The use of satellites: polar or geostationary
Example GOES (Cavazzani, 2014, PHD thesis)
B3, B4 and B6 bands (6.7, 10.7 and 13.3 µm; h=8000, 4000, 3000m)

Are some data “wrong”?
Does it make “mistakes”?
Bands of GOES12
An alternative, very simple approach: Mt. Graham, Sun radiation year distribution, winter storms and summer monsoon (Culombine data, 2008)
Mt Graham: year to year changes, 2008 is the best
A check of the Sun radiation and rainfall at Mt. Graham (della Valle et al., 2009)

Figure 18. Composite yearly mean distribution of clear nights at Mt. Graham
Counting stars (Dome C, Crouzet et al., 2010)
Other examples, all sky cameras, by Shamir and Nemiroff (2005)
All sky cameras (Martinis et al., 2013)

Figure 2: Left: Image of clear night sky. Right: Partly cloudy night skies. Moon and clouds are visible close to horizon.

Figure 3: Left: Example of the scattering in the data leading to the formation of a ‘clear sky band’ using 1 month worth of data for two stars, Sirius (blue crosses) and Fomalhaut (green crosses). Values have been normalized to a data number of 1000 at 45° ZA; Right: Similar to the left panel, but now using data from 3 months. See the online edition of the PASP for a color version of this figure.
The SQM data for the cloud coverage? (Vedovato, thesis 2013; Garstang, 2007)

Fig. 3 Brightness of clouds due to full moon (Moon near zenith at $\theta = 0$°): curve 1 as seen in the direction from the ground, curve 2 as seen from a satellite looking vertically downwards. For comparison with the brightness of a city without moonlight, curve 3 shows the brightness of a city with position 100 km and radius 36 km at the zenith from the centre of the city and curve 4 as seen from a satellite looking vertically downwards at the city centre. An observer at the centre of this city on a night of full moon would see a brightness given by adding curves 1 and 3, an observer looking downwards would see a brightness given by adding curves 2 and 4.
Mean extinction components: Rayleigh scattering dominates in the blue, but the aerosols (from 1 to 10 µ) are the short time variable component.

\[ K = K_{\text{ray}} + K_{\text{mie}} + K_{\text{O3}} \]

\[ \frac{I}{I_0} = \cos \theta \cdot \frac{(1 + \cos^2 \phi)}{\lambda^4} \]
The Sahara is the major source of dust on the Earth (200 x 10^6 t/year) (Murdin, 1986, see also Sicard et al., 2010)

Figure 3.3 Dust transport over the Atlantic (after Rapp, 1974)

3 K = Tenerife
2 = Jebel Marra Mountains, Sudan
1 = Cape Verde Islands
4 = Barbados

Figure 5.1 Saharan dust trajectories across West Africa
Aerosol typical distribution and transport of dust from Sahara (Bertolin thesis, 2005)
Size and settlement of the dust: typical height 6 km, settlement time (1 km) up to 50 days (1 μ). With an average speed of 10 m/s the dust can be transported up to a distance of 10.000 km before settlement. Most of subtropical sites are affected. Obviously higher sites are in a better position.
In the north the atmospheric dust content is maximum in summer: sources are Sahara, Arabian Peninsula, Tibet, other deserts affected before the summer peak (Arizona...).
Aerosols (dust) in June-July and September TOMS (Earth Probe) satellite data: in September there is the highest activity in the south.
La Palma extinction (CAMCT): sahara dust + Pinatubo eruption (1992)
The dust particle number increases at smaller sizes.

The optical effect is greater for bigger particles.

During dust storms bigger particles density increases.
Zodiacal light, La Silla – La Palma
Soardo, 2008; Cinzano, 2008
Hollan, J.; Cinzano, P., 2003
(2% upward lamp plus ground)

Why the sky over your town and even far from it glows so much?

When the light from lamps or illuminated surfaces goes:

@ 90 degrees upwards: 30% scatters, from 26% downwards, altogether it returns down just 8% of such light.

@ 15 degrees upwards: 76% scatters, from 40% downwards, altogether it returns down 31% of such light.

@ 5 degrees upwards: 97% scatters, from 45% downwards, altogether it returns down 45% of such light.

The light sent upward attenuated by scattering on gas and aerosols, before it escapes to space, and its scattered parts (schematically)

The curved Earth atmosphere: each its thickness scatters some 30% of the light.

Sum of the light scattered by the air and its true directions – mostly similar to the original direction.

just 0.24 of the light escapes unscattered.

Which of the cases given above contributes most to the skyglow, in your opinion?
A unique experiment at Asiago Observatory: about 5000 street lamps off in the night of March 28°, involving 15000 people in a 500 km² area. A limited gain (30%) on the sky brightness at Ekar observatory, still a factor 3 above the natural sky.

A wrong statement:

“No norm is better for observing the sky than the lack of lighting: observatories should be surrounded by dark zones (the so-called “star parks”), where lighting installations should not be allowed.”
Who is polluting the sky? Hg, Na, CFL and LED lamps. The dark night vs. a “normal” night. Street lights are actually dominated by Na and Hg (LED?):

[Graphs showing emission spectra for different elements.]
All the sites are affected by some light pollution: Cile (Paranal-Armazones), the darkest site, San Pedro Martir, North Arizona (Meteor Crater), Tenerife (Izana)
Contrails

Figure 1: Contrails over North America, as detected by NASA’s Terra satellite on January 29, 2004.
http://earthobservatory.nasa.gov/Newsroom/NewImages/Images/contrails_southeast_lg.gif

Figure 14-7: World map of jet aircraft contrails in 1992 (top), and predicted for 2050 (bottom), from [72]
Namibia, Hess (sinistra) e Aar. In basso la zona costiera
Argentina: S. Antonio de los Cobres (4000m) e El Leoncito (2500m)
Paranal sky
Cambiamenti climatici importanti in astronomia: andamento notti fotometriche a Paranal e a La Silla in 20 anni

Photometric Nights, 1984-2004
past 12-month running mean
black, Paranal 0.076%, trend: -0.5%/year
red, La Silla 0.061%, trend: +0.7%/year
green, El-nino SOI index, arbitrary