Scientific Requirements to a

VLT OBSERVING CONDITIONS MONITOR

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Note: This document has been prepared at the invitation of M.Sarazin, in response to my expressed concern (September 9th, 1998) that no instrumental cloud detector has been proposed for the VLT.

1 Introduction

Although Paranal was carefully selected for its beneficial meteorological qualities, all nights are not equally cloudless. During partially clouded nights, the Very Large Telescope (VLT) observers want to know where is the clear sky, and on fully clear nights, they want just that assurance. Checking for themselves remains an obvious possibility, but in the era of large-format CCDs, and considering the cost of operations, ESO might provide a more quantitative assessment.

While *cloudiness* (Figure 1 and 2) is obviously the most important factor relevant to optical/near-IR astronomy, there are indeed a number of further quantities, knowledge of which can either help the observer do last-minute planning, or assist in the subsequent interpretation of data. Some of these are already being monitored, most notorious the *seeing* and *meteorological data* [1], but others such as *sky brightness*, *emission-line strength*, multiwavelength *extinction coefficients*, *lightning (+sprites, +elves), fireballs* and *seismic activity* could also be measured with reasonable effort. Some anthropogenic activities may influence astronomy: *aircraft*, jet-*contrails*, *spacecraft*, local and distant *light pollution*, *dust*-, *gas*-, and *heat*-emission, and possibly other.

The statistical analysis of all such data may be of use for the long term planning of observing proposals, and for the construction of new equipment.

The term *extinction* implies the zenith-distance dependent dimming of starlight during essentially cloudless nights. Conceptually, this measurement can be thought of as a refinement of the cloud-detection aspect, but requirements to accuracy and multiwavelength coverage are much different. Extinction coefficients are traditionally measured by smaller telescopes, equipped with photoelectric photometers, and one such measurement, in the R-band, is indeed provided as a by-product of the VLT seeing monitor [1]. It is, however, not guaranteed that extinction is a simple function of zenith distance only, even under seemingly perfect conditions. The mapping of multiwavelength extinction over the sky, and as a function of time, is a very meritable project, which surely will assist interpretation of many kinds of observations. The topic will be fully dealt with by other interested parties [2], so I shall not elaborate further.

2 Natural quantities, events

2.1 Cloudiness

Assessment of cloud cover is traditionally performed by the observer leaving the control room. However, dark adaption times may be so long, that valuable observing time is lost, before any disturbing clouds are perceived. At La Silla, a thin veil of cirrus is often noted at dawn only. Remote observers using the VLT must anyhow rely on other persons' verbal interpretation, which with the best of wills, cannot convey very detailed information.

Some instrumental impression on the cloud-cover can be gleaned from weather satellite data. This is particular useful for observation planning over time intervals of hours to days. Such planning will usually also take advantage of public-service or dedicated weather forecasts. However, the spatial resolution of satellite images is poor, typically 4 km, which, jointly with the lack of height information inhibits the very specific use in the observing moment.

The required accuracy, time-resolution, and spatial resolution of a VLT All Sky Monitor (ASM) will be dealt with below.

2.2 Sky brightness

Sky brightness is taken to mean the combined effect of continuum background and line radiation; the night-time sky-brightness during Moon-less nights is referred to as *airglow*.

The mere onset and end of the observing night can of course be looked up in almanacs or calculated on-line. In addition to this, the observer will often give a glance to the sky, to check that all is ok, before opening for light to the detector and acquisition cameras.

But for a given observatory site, sky brightness is a complex function of the sun's position below the horizon, the Moon's position above, the solar cycle, zodiacal light, presence of haze, volcanic activity, and time of night (evening skies red, mornings' blue!). Any very precise knowledge of the sky brightness therefore requires an instrumental measurement.

As examples of observing modes, which would benefit from such data one could mention the very time-critical acquisition of twilight-flat-field exposures and night-time observations in directions close to the Moon. Remotely observing astronomers would likely depend very much on instrumental measurements, be it a simple integrated measurement for the full sky, or a spatially resolved one.

Spatially resolved maps of sky brightness can be deduced from analysis of wide field CCD images.

2.3 Lightning

No information appears readily available on groundbased detections of *lightning* at latitudes near Paranal. However, some recent satellite imaging shows a very strong activity over Argentina [3]. Experience from La Silla is that regions to the east of the observatory experience heavy lightning during many summer nights. Most flares are seen before local midnight, and some light up most of the sky. Many are composed of several pulses each lasting less than one ms, and separated by a few milliseconds,

It is well possible that some of the diffuse lightning strokes seen from La Silla are actually *sprites* [4] and even *elves*. Sprites are the result of conductivity break-down in the ionospheric D layer; they are spawned by positive cloud-to-ground lightning bolts, and occur over thunderstorms, mostly between 40 and

90 km above ground, and they last typically less than 10 ms. It is not known if they exclusively occur over large thunderstorms (100 km diameter), or also over smaller orographic thunderstorms. Sprites show emissions from N_2 first positive [5]. Elves are radially expanding pancake-like N_2 emissions at high altitude (90 km) triggered by powerful electromagnetic pulses; they precede the formation of sprites by a few milliseconds. While most sprites have been detected over the North American continent, some have been reported from Peru [6].

Sprites and elves over the high Andes will reach altitudes well within the fovs of the VLT. The VLT observers will probably not benefit much from the detailed knowledge of spectra, but be satisfied by a list of the moments of occurrence, and the approximate brightness in magnitudes per steradian (averaged over some specific time-interval).

2.4 Fireballs and fainter meteors

Fireballs typically last one second, and can contaminate spectra with a set of well-known emission lines. For one particular magnitude -9 fireball Borovicka [7] identified 305 lines in the 360-660 nm range, mostly due to Fe I, Na I, Mg I, Al I, Ca I, Ti I, Cr I, Mn I, Ni I, Mg II, Si II, Ca II, Fe II, FeO. For another fireball, Borovicka and Zamorano [8] detected six lines in the 660 - 715 nm interval, one of which is the Lithium line at 670.8 nm.

A few times per year, Paranal will experience fireballs some as bright as magnitude -15; this is sufficient to significantly rise the sky background level to spectroscopically detectable levels.

It is fairly straightforward to design a high-speed photometer, which can detect all fireballs brighter than mag -2, and provide a list of events for subsequent use with VLT data reduction. One such instrument was in intermittent use at La Silla during the 1980-ies, as part of the Gamma Ray Burst Monitoring System (Figure 3). It detected several fireballs, some of which were confirmed by visual observers, and/or using high-time resolution photometry at other telescopes (the ESO-50 cm, the Dutch 90-cm).

Again, the specific spectrum may not be warranted by the observer, only the moment and brightness. The photometric detection of a fireball may be used to command the (permanent) storage of the corresponding image from a spatially resolved All Sky Monitor; this would reveal if the event occurred near the VLT fovs (the ASM may detect the fireball independently).

2.5 Telluric emission-lines

These can be the green [OI] line at 557.7 nm, the red [OI] lines at 630.023, 636.388, and 864.5 nm, the NaD lines at 589.0 and 589.6 nm (which are also in terrestrial light sources), and Hydroxyl (OH) bands in the range 680 - 2400 nm [9]. Emission lines are due to atoms and molecules exited during day time irradiation with the solar UV flux. The green [OI] line is caused by the collision between energetic electrons with oxygen atoms at about 90-140 km altitude, the red [OI] lines arise at 150 - 300 km [10]. The OH vibration-rotation bands are exited in $\sim$90 km altitude.

The "OH clouds" are variable on time scales as short as seconds, and on angular scales as small as arcminutes; any detailed description is virtually impossible. For some particularly illustrating sequences of imaging data see [11].

A plot of the La Silla night-sky spectrum, 647.6 - 941.0 nm should be retrievable from [12]. For the 1.15 - 2.4 μm night-sky spectrum (Mauna Kea), see [13].

During the first years of CCD operation at La Silla, many observers noted strong fringing in V-band exposures; usually this effect decayed two to three hours into the night. The fringing was caused by the green oxygen line and has now been suppressed through a change in CCD manufacturing techniques. Red imaging remains prone to fringing, from [OI] and OH lines.

2.6 Telluric absorption bands

Absorption bands due to O_2 and H_2O are seen throughout the spectral range 600 - 1000 nm [14]. While standard observing techniques will compensate for the influence on science data, some form of monitoring might be applied, to warn when the level for e.g. the 950 nm H_2O band exceeds a given limit. This could be done spectroscopically, as for night-sky emission line measurements.

2.7 Seismic activity

The experience from La Silla is that some earthquakes cause vibrations in the telescope, which momentarily move stars out of photometer diaphragms.

The remotely observing VLT astronomer would undoubtedly appreciate instrumental detection of the disturbing event. A correlation between VLT astronomical observations and seismic activity can be done either using public-service data, which may not be sensitive enough, or a dedicated seismometer at Paranal.

3 Anthropogenic effects

3.1 Spacecraft

With more than 10,000 spacecraft, or pieces of spacecraft in low-earth orbit, many VLT observations will be affected, in particular at dusk and dawn. Some glints from the Iridium satellites can be as bright as magnitude -8, marginally raising sky-background. For these, as well as MIR and other satellites, software is available to calculate the celestial track, and moments of visibility, and predictions are offered at several web sites e.g. [15].

Any organized approach to the handling of satellite predictions should be developed in conjunction with other large observatories.

3.2 Aircraft

Perhaps the most obvious effect of air traffic over an astronomical observatory is the shortlasting (50 - 200 ms) dips in light flux, and the effect of fixed and stroboscopic lights on imaging data (ref. the well-known problems affecting Schmidt exposures from Palomar).

The volume of Chilean air transport has been steadily increasing during recent years. This has caused some concern for its possible influence on observational astronomy from La Silla and Paranal [16], which are close to important air routes. Since 1997, a programme has aimed at registering the frequency of aircraft approaches to Paranal, independently of information obtained from civil aviation authorities. One hour of continuous surveillance is being logged each clear night; this interval advancing by one hour from night to night. In this way, more than 400 aircraft were registered [17]. The maximum number of aircraft detected during the equivalent of one observing night was eighteen (18). Figure 4 shows the altitude dependence of the sightings, with most aircraft passing some 25 degrees over the horizon, to the west. This is probably to low to be of much immediate concern, but a few aircraft do indeed pass nearly overhead. The visual detection method does not allow jet contrails to be seen; neither is it known if the aircraft are exclusively jets.

3.3 Contrails

In spite of perfectly cloudlesss conditions, the possibility remains that water vapor clouds form in the wake of jet aircraft. For reason of their influence on world climate, such *contrails* are coming under increasing scrutiny, including spaceborne detections [18a]. The ambient temperature, humidity, as well as fuel composition and combustion temperature, which permit formation of contrails, form the basis for many investigations [e.g. 18b, 19] which, however (almost) exclusively refer to day-time; little or nothing is known about the formation (or persistence) of contrails at night.

Often driven by jet streams, contrails sweep quickly over the sky, and will momentarily (2 - 20 seconds) affect any telescope at Paranal. This may cause absorption of star-light, increased sky-background, excess seeing, and possibly spectroscopic effects [16].

It would be prudent to include this detection as part of a VLT All Sky Monitor. If contrails do occur at night, their movement over the sky can be detected automatically, and used to issue warnings to the observers [20]. Most likely the number will be much smaller than the abovementioned number 18, since some airplanes pass east of the observatory, and some too far west, to be of much concern.

3.4 Sky brightness, 100 Hz component

Sky brightness has a 100 Hz component, introduced through electric lighting over nearby centers of civilization. At La Silla this is apparent through FFT analysis of high time resolution photometry. Incandescent lamps, as well as fluorescent lamps show such variability. The latter lamps shine in several emission lines, in particular Hg-lines at 404.656, 435.834, 546.074, 576.960, 579.066 nm, and NaD lines at 589.0 and 589.6 nm.

At La Silla, the amplitude decreases noticeably during the night, and there are probably also effects of the weekday. At Paranal, it would be prudent to monitor the secular rise in this "light pollution".

3.5 Dust-, gas- and heat-sources

Being due to mines, smelters and power plants (including Paranal's own!), these are in all likelihood too far away to be of any concern, and the effects mostly remain below the level of the observatory (There might, however, be other good reasons to supplement the Paranal power plant with wind turbines.)

4 Realization

4.1 Products offered to the observers

These are my ideas for services to the Paranal observers:

1. The VLT Daily Bulletin

   Each day at 4 o'clock PM a bulletin is issued on observing conditions last night. The report will list the records made of zenithal sky brightness as function of time, average cloudiness as function of time, peak-to-peak sky transmission as function of time, moments of major fireballs, integrated brightness of same, moments of aircraft and jet-contrail visibility, flares from satellites, their proximity to VLT units, etc. The bulletin will also list foreseeable data for the next night, such as sunset, sunrise, start- and end of astronomical night, Moon up and down, weather forecast, expected satellite flashes, expected aircraft, probability of contrail formation (in dependence of upper troposphere dew point), etc.

2. The Paranal All Sky Display

   The VLT control cabin should have a display of *sky transparency*, updated every 10 s, accurate to 0.5 %, and spatially resolved to about 0.5 degrees. The display should be contoured at 99.5, 99, 95, 90, 50, 10, 5, 1, and 0.5 % levels. The observer should be able to replay the last n exposures quickly. Another option should be to display the similar celestial distribution of *sky brightness*. Sky transparency can be measured in any color, most likely red.

The measurement is not intended to be a high-precision extinction device. The requirement to time resolution is set by the air-plane and contrail detection routines.

The instantaneous pointing of the individual VLT units, the seeing monitor, other auxiliary telescopes, moon and major planets should be indicated.

3. The Zenithal Sky-Brightness and Flare Display

   A progressing plot (display) of *zenith sky brightness*, on a logarithmic scale. To be tagged with moments and clickable hyperlinks when bright flares (fireballs, man-made light pollution, etc.) were detected by a triggering algorithm. This in turn should allow the corresponding All Sky Monitor images to be recalled.

4. The Telluric Line Display

   Similar plots of [OI], NaD, selected OH lines, telluric H_2O line strengths. To be measured by a zenith-viewing spectrophotometer.

5. Airplane Alerts

   Detection of the progressing flight of *airplanes* should be done, based on data collected by the All Sky Monitor; post fact warnings should be issued to the observers, if an aircraft has passed close to the field-of-view.

6. Contrail Alerts

   Short-term prediction of *jet contrail* crossings, for the specific VLT unit.

7. Statistical Analysis

   All summary records are to be kept for future reference, and for statistical analysis.

8. Spin-off Science

   If practically possible, the original data from the All Sky Monitor should be kept, for investigations of variable stars and the discovery of unknown solar system objects [21].

4.2 Detection techniques available

A discussion of the scientific requirements to a VLT Observing Conditions Monitor would not be complete without a short review of the technical possibilities. However, the below list is certainly not exhaustive.

1. All Sky Camera, CCD based

   This could be based on an integrating CCD, viewing the sky through a wide-field lens, or an all-sky mirror. To be mounted in a fixed position. While a true 180 deg FOV is desirable, for viewing cloud systems very low over the horizon, this leaves a poor pixel scale for measuring the photometric effect of clouds in the zenith-distance range of usual interest to the observer. All sky-mirrors give strong image aberrations near the edge of the field. A computer controlled shadowing finger may have to be employed, for observations in strong moon-light.

A system consisting of four specially designed 100-degree lenses, imaging onto four 4k by 4k CCD detectors would appear desirable. Provisional studies indicate that the lenses can be made with a fast focal ratio 3.5 (effective), and very high and uniform resolution (proximity focussing, distorsion, back-focal distance and some other usual lens design criteria disregarded). However, four 'triangles' at the horizon will not be covered. Exposure times will be short enough, to allow Peltier-cooling. Depending on the operational mode of the CCDs, the mechanical shutter can be avoided, whereby the system has no moving parts, except for the exterior weather shelter. MIDAS (or IRAF, IDL) photometry can be used to detect the brightness of some 100,000 stars visible in each set of exposures, correct for extinction, divide by reference brightness, and display contour diagrams, sky-brightness diagrams, etc. Difference imaging and suitable high-level programming would allow the identification of airplanes, contrails, satellites, meteors, etc.

2. .. or video-detection

   Video imaging, intensified or direct. Lens/mirror system as for the integrating CCD. VHS LP mode registration will allow 8 hours data to be recorded onto a single tape, which may be recycled. For some applications (e.g. meteors) the higher time resolution of the video (50 Hz half-frames) would supplement those of the integrating CCD.

3. High-speed-photometer

   This would consist of (one or) several photomultipliers or light sensitive diodes, sampled at 1 kHz. The detectors should be organized in a very low resolution fly-eye fashion. Data should normally only be kept at very low time resolution, mostly for the detection of sun and moon, but shorter time spans could be kept at 1 ms time resolution around trigger instances (fireballs, lightning, local man-made light-pollution).

   Detection of lightning may be confirmed through their VLF radio signature. Such instruments are commercially available, and claimed to operate at distance of several hundred miles; they may allow distinction between normal lightning and sprites [22].

4. Emission/absorption-line Spectrophotometer

   A zenith-viewing spectrophotometer should be employed for telluric line measurements. Some outphased spectrograph from La Silla may serve well, if modified to Peltier-cooling.

5. Lidar

   Lidar techniques can be useful for precise evaluation of cloud heights, including the detection of jet contrails on otherwise clear nights.

5 Conclusion

It appears desirable that cloud-cover and sky-brightness, and perhaps also some other quantities, are measured by instrumental means, and put to the disposition of the VLT observer.

A literature survey has revealed no similar instrumentation in operation at other large observatories. The basic elements of the equipment needed are, however, already in use at ESO, so assembly of a provisional set-up should be possible for the start of regular VLT observations.

6 References and Notes

Hypertext references are available from http://www.astro.ku.dk/~holger/ASM/links.html

[1] For a general description of the Paranal Astronomical Site Monitor, see Sarazin, M. (1998): http://www.eso.org/gen-fac/pubs/astclim/paranal/asm/. The functioning of the Paranal seeing monitor and general meteorological data sampling can best be described by reference to the similar measurements from La Silla: http://www.eso.org/observing/asm/dimm/dimmplot.html
and http://www.ls.eso.org/lasilla/dimm/
[2] Sarazin, M. (1998): private communication
[3] http://wwwssl.msfc.nasa.gov/newhome/headlines/lis/y_djf.gif
and http://wwwssl.msfc.nasa.gov/newhome/headlines/essd19may98_2.htm
[4] Sprites are visible to the naked eye, but were discovered as late as 1989: Franz, R.C., Nemzek, R.J., and Winckler, J.R. (1990): "Television image of a large upward electrical discharge above a thunderstorm system", Science, 249, 48-51. See also http://sprg.ssl.berkeley.edu/atmos/sprite.html.
[5] http://sprite.gi.alaska.edu/html/sprites.htm
[6] http://umbra.nascom.nasa.gov/spd/pressrel_95-84.html
[7] Borovicka, J. (1994): Astron. Astrophys. Suppl. Ser. 103, 83-96.
[8] Borovicka, J. and Zamorano, J. (1995): Earth, Moon and Planets, 68, 217.
[9] Benn, C.R. and Ellison, S.L., (no date): "La Palma night-sky brightness", preprint. See also http://vizir.u-strasbg.fr:2001/manuals/redeye/chapter7.html
[10] http://sprg.ssl.berkeley.edu/atmos/aurora.html
[11] http://pegasus.phast.umass.edu/2mass/teaminfo/airglow.html
[12] Tinney, C.: http://www.aao.gov.au/local/www/cgt/cgthome/staging.html
[13] http://vizir.u-strasbg.fr:2001/manuals/redeye/chapter7.html
[14] http://msowww.anu.edu.au/~dhj/WWWimages/Stevenson.1.gif
[15] http://www2.gsoc.dlr.de/scripts/satvis/iridium.asp
[16] http://www.eso.org/gen-fac/pubs/astclim/contrails/contrail-070597.ps
[17] http://www.eso.org/gen-fac/pubs/astclim/contrails/contrail-021297.ps and Pedersen, H., in preparation.
[18a] http://cimss.ssec.wisc.edu/goes/misc/971108.html
[18b] http://atmos.uah.edu/~sundar/contrail.html
[19] http://www.giss.nasa.gov/research/intro/mishchenko.01/
[20] Neural networks have been trained to recognize contrails in satellite imagery, see http://www.obs.aip.de/~dieter/Cascais-Poster/Choice_clip.gif
and http://www.obs.aip.de/~dieter/Cascais-Poster/Cascais-Poster.html
[21] see e.g. Kroll, P., and Lehmann, T. (1993): "Working Group on Wide Field Imaging" under IAU's Commission 9', Newsletter No. 3, p. 30, and Nemiroff, R. (1998): astro-ph/9809404
[22] http://www.stormwise.com/striking.htm

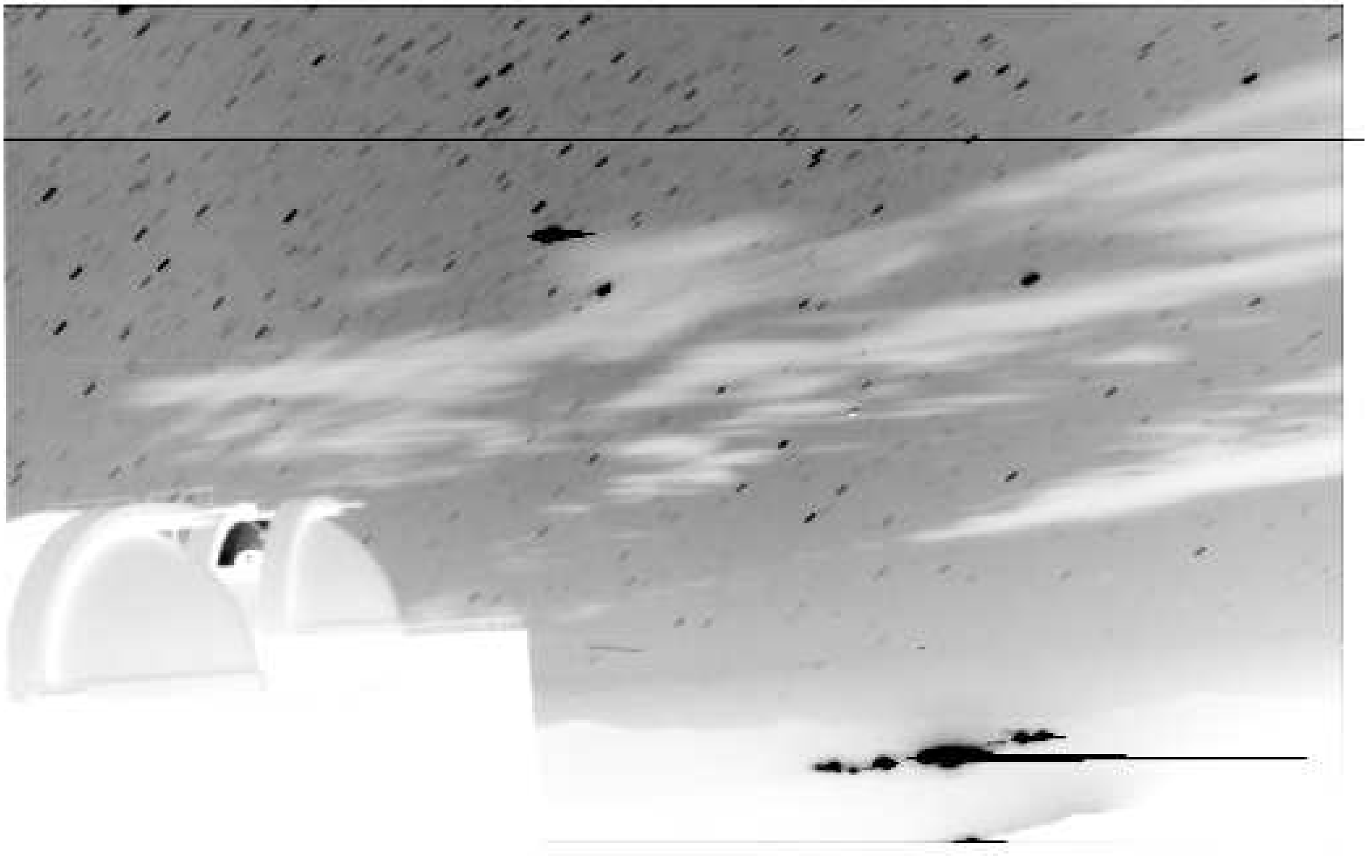

Figure 1. A wide-angle (11 * 18 degrees) CCD image (negative representation) obtained 1983 March 9 UT 02:34:19, through the balcony door at the 1.54-m Danish telescope at La Silla. The brightest star are β, π, and ψ Aurigae. The two telescope buildings are the 1.52-m (lights on) and the 1.0-m ESO telescopes. Bright lights in the lower part of the frame are mostly due to vehicles traveling on the Pan American Highway. Notice also the scattered light over the Pelicano gate (sic!). A band of altostratus covers parts of the sky. The image is part of a long series of 60 s and 10 s unfiltered images, obtained to prove the CCD as a potential optical gamma-ray burst detector. The chip was CCD #1 (312 x 520 pix), with a short-focus lens provided by the Optical Laboratory.

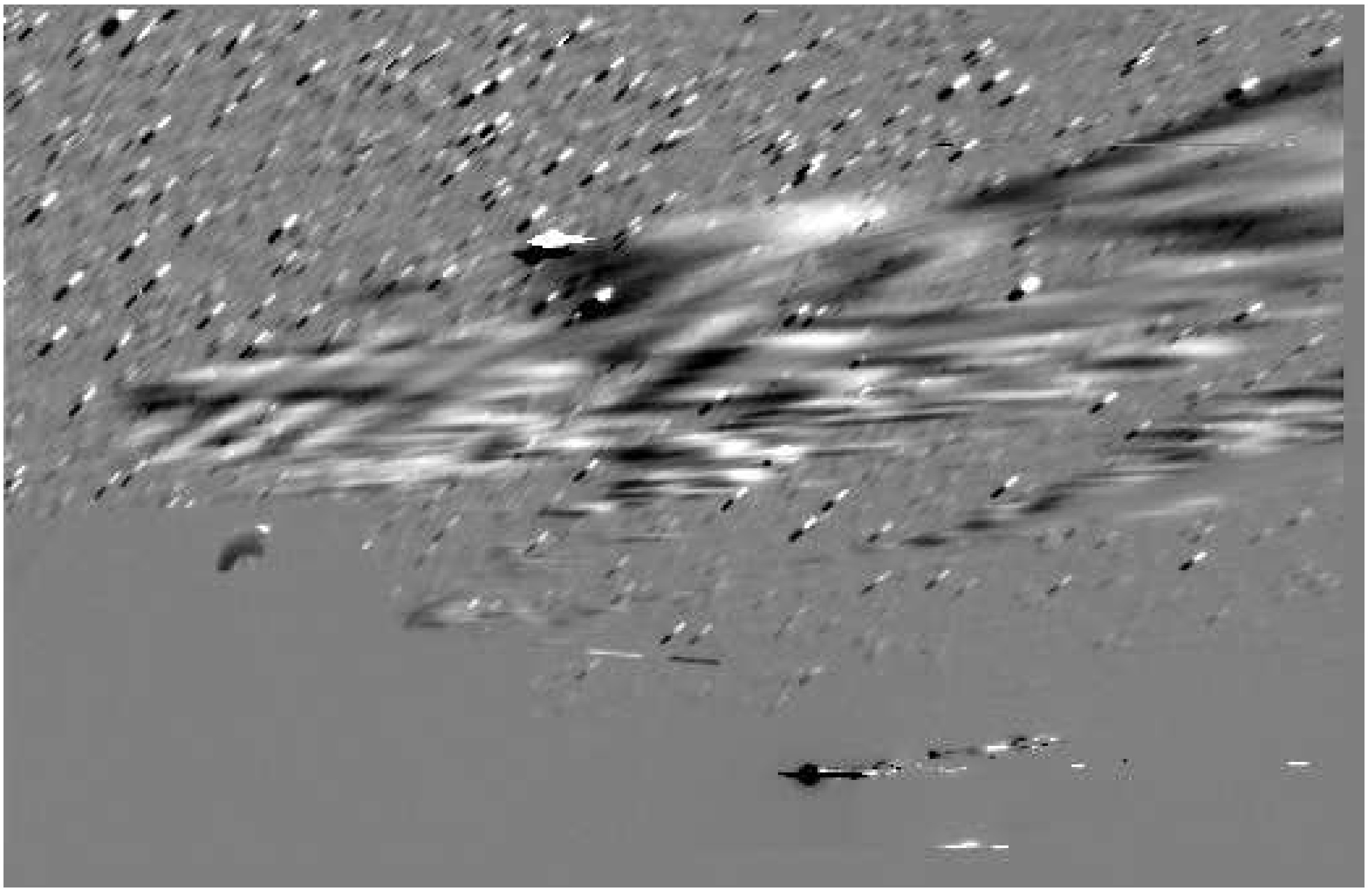

Figure 2. The difference between the picture shown in Figure 1, and the subsequent 60 s exposure. The clouds are seen moving westwards while they undergo morphological changes. An aircraft is seen moving north, close to the horizon.

For the "All Sky Monitor" considered by the author, the presence of clouds is detected through a photometric analysis of all stars in a suitable magnitude interval, which may be $m_R = 6 - 10$. Pattern recognition procedures should be able to pick up the aircraft signatures (the fixed and stroboscopic lights), and use these for prediction of contrail passage moments. Contrails may be identified independently of the aircraft lights.

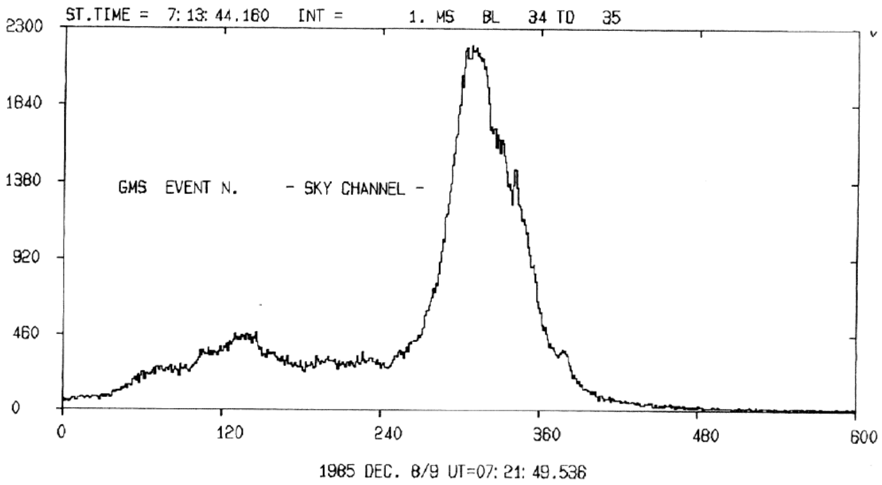

Figure 3a. A photometric record of a -14 magnitude fireball over La Silla. The fireball was seen visually by H.Lindgren and H.Brugger. The light curve was detected in "5-σ trigger-mode" by the All Sky Monitor of the Gamma Ray Burst Monitoring System at 1 ms time resolution. A similar set-up at Paranal would safeguard against misinterpretation of scattered light in VLT observations.

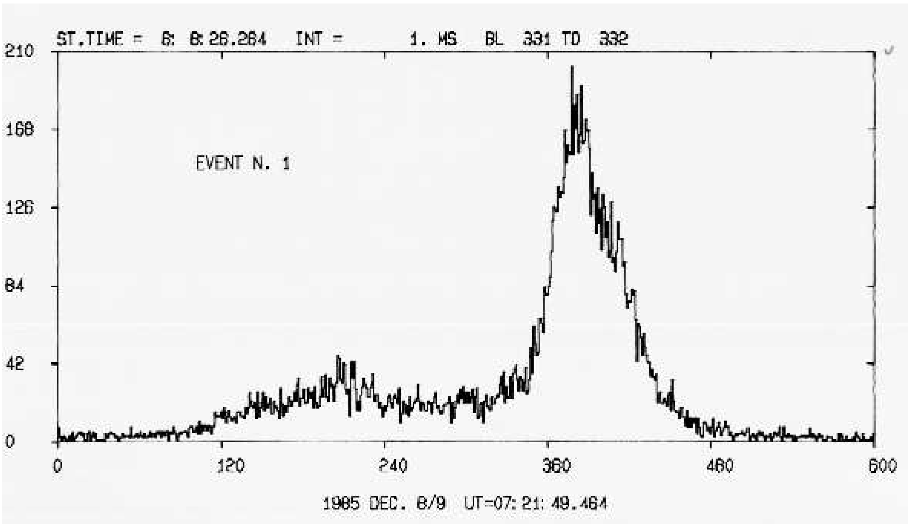

Figure 3b. The same event independently detected in *science data* at the ESO 50 cm telescope, likewise at 1 ms time resolution.

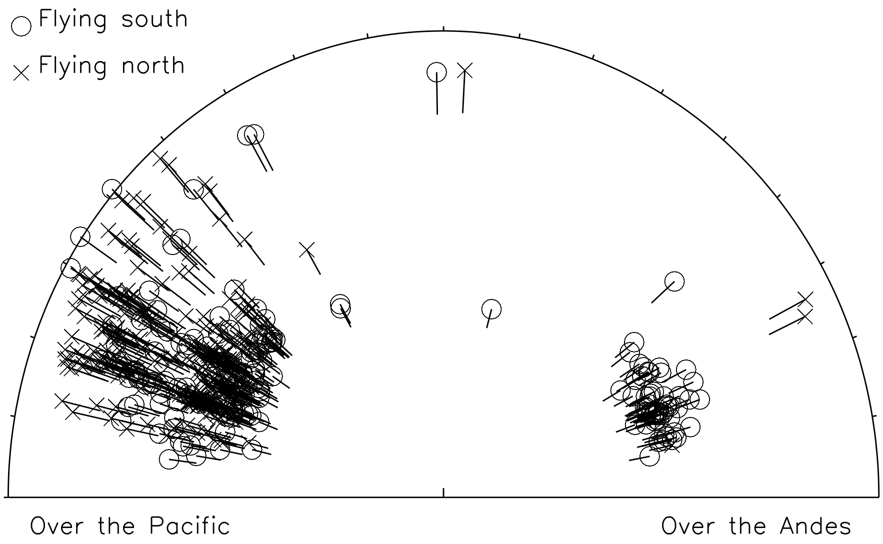

Figure 4. The altitude distribution of aircraft passing Paranal at night time. This data set covers the period May 23, 1997 to August 29, 1998 in a uniform fashion (covering some 7 percent of the available night time). 439 passages were recorded. For each cloudless night one hour of observations were logged visually, this hour-interval advancing by one hour from night to night. Symbols indicate direction of flights; the radial distance depends on time, innermost observations first, and the most recent ones at the edge. The data result from a long-term monitoring campaign, aimed at revealing the potential influence of aviation on observing conditions at Paranal.