On the study of aerosol content for astronomical site characterization

A.M. Varela, C. Muñoz-Tuñón & J. Castro-Almazán

Institute of Astrophysics of Canary Islands

CIAI-AEMET, 19 de enero de 2017
Climatological parameters
(sky transparency and useful time/feasibility AO and T&D design)


Aerosols (mineral dust)
Size, density and vertical drainage/f_{dust} + PM10
Number of photometric/useful nights
Varela et al., MNRAS, 2008

Cloud Cover
distribution of photometric/useful nights

Precipitable Water Vapor
and local humidity

Ground level meteorological
Variables
Time evolution, climate trends

Tropospheric winds (image quality
and telescope & dome design)
...Sarazin & Tokovinin (2002)
vertical profiles, direction & gradients

Satellites
Telescopes for K_{V} and AOD
Airborne dust detectors
LIDARs, Cimel Phot., ...

Satellites
Visual (log book)
IR Radiometers, AllSky CCD

Satellites, GPS
Balloon
Radio Sounding
IR Photometers

AWS
(30 years)

Climate diagnostic
archives (NOAA-CIRES)
NCEP/NCAR (>25 years)
Support Telescope operation

Dust is detrimental for telescopes

Accumulated effects on sensitive parts can be very serious and heavily decrease operational quality. Examples of such sensitive parts are gears, bearings and optical surfaces (www.not.iac.es).

- Aluminising
- CO$_2$ Snow Cleaning (ING, SUBARU, GTC, TMT, etc.)
- Vapour Cleaning (Blanken et al, ING, 2003)

Dome completely close with $ws>12m/s$ and high humidity
CONTEXTUALISE EXTREME EVENTS

1959

Heidelberg Observatory expedition at Tenerife

testing Izaña for astronomy

1 dust storm rejected Izaña in favour of Calar Alto (south of Spain mainland)

Castro-Almazán et al., EWASS 2015
Visible Text:

1959

Heidelberg Observatory expedition at Tenerife

testing Izaña for astronomy

1 dust storm rejected Izaña in favour of Calar Alto (south of Spain mainland)

...what they lost:

~10% of useful nights

~20% of seeing quality

Castro-Almazán et al. (CUPS, 01-2015)

García-Gil et al. (PASP, 122; 2010)

Sánchez et al. (PASP, 119; 2007)

Varela et al. (ASP Conf. Ser. 226; 2002)
The Carlsberg Meridian Telescope (CAMC or CMT) is continuously working at the ORM since 1984 till 2014 (http://www.ast.cam.ac.uk) providing nightly values of atmospheric extinction coefficient in V and more recently in r’ Sloan filters http://www.ast.cam.ac.uk/dwe/SRF/camc_extinction.html. This dataset is ideal to explore the usefulness of data provided by satellites.

\[ A(\lambda) = A_{\text{Ray}}(\lambda, h) + A_{\text{oz}}(\lambda) + A_{\text{wv}}(\lambda) + A_{\text{aer}} \]
Atmospheric extinction-Clear Time

Seasonal Trend (trade wind regime)
Summer: (June-September)- Rest of the year.

Weather down-time (%)

20.7% weather downtime
SUMMER: 75% dust free nights
REST of the YEAR: 90%

Guerrero et al., 1998, García-Gil et al., 2010

Atmospheric Extinction at the ORM on La Palma: a 20yr statistical database from CMT
Atmospheric extinction-Clear Time

Limit for dusty nights = 0.15 mag/airmass.

Atmospheric Extinction at the ORM on La Palma: a 20yr statistical database from CMT García-Gil, Muñoz-Tuñón & Varela, PASP 122, 1109 (2010)
Mark-I telescope

- Operating at the OT since 1976 (transmitted light from 1984).
- Intensity of sunlight at blue and red wings of the Potassium KI 769.9 nm (Pallé et al. 1986).
- AOD is calculated as the linear coefficient of airmass vs magnitude.

Acknowledgements: HIROS of the Birmingham Solar Oscillation Network (BiSON)

Barreto et al., AMTD, 2014 (since 1976 to 2012)
AERONET & PFR vs MarkI.
AERONET & CMT vs Mark-I.
Long-term database optical extinction from telescopes @ORM vs OT (Laken et al., 2016)
Remote Sensing:

- **Ground-based** that includes structure at ground, vehicle and tower up to an height of 50 meters
- **Airborne** that includes planes, high quote aircrafts and balloons up to an altitude of 50 Km
- **Spaceborne** that includes shuttles, satellites from an altitude of 100 Km up to 36000 Km.
  - Space shuttle: 250-300 Km
  - Space station: 300-400 Km
  - Low-level satellites: 700-1500 Km
  - High-level satellites: about 36000 Km

**In situ** techniques: automatic weather stations, telescopes, airborne particle counters.

**Areas and sites observed can be reliably compared.**
**Satellite data archives permit a comparison over reasonably long time period (> 10 years).**

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REMOTE SENSING: AEROSOL INDEX 
FROM TOMS (L1-free and easy to download)

Spatial Resolution: 1.25° x 1° (139 x 111 km²)
30 years.
No good resolution at lower atmosphere.

Aerosol Index = A.I. = -100 \left\{ \log \left( \frac{I_{331}}{I_{360}} \right)_{\text{meas}} - \log \left( \frac{I_{331}}{I_{360}} \right)_{\text{mod}} \right\}

A.I. > 0 absorbing aerosols (smoke, industrial activity, mineral dust, volcanic aerosol and soot)
A.I. = 0±0.2 clouds or large non-absorbing particles
A.I. < 0 non-absorbing aerosols (sulphates, marine aerosols)
Herman et al., 1997; Torres et al., 1998.

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The plume arrived at the Canary Islands but it did not reach the level of the Observatories!

\[ Kv < 0.15 \text{mag/airmass} \]
\[ AI = 2.7 \]
The AI is averaged over areas whose size covers the entire island.

The TOMS uses channels centred on the UV, and the measurements could be particularly contaminated by the presence of high reflective clouds and incorporating absorbing particles in ranges that do not affect atmospheric transparency in the visible range.
THIS DUST DRAINAGE PRODUCES THE EFFECT KNOWN AS SEA OF DUST OR ANTICYCLONIC GLOOM
AIRMASS INTRUSIONS IN THE CANARY ISLANDS

Thermal Inversion Layer separates the maritime mixing layer (MML) and the upper troposphere layer (TL)

Torres, Cuevas & Guerra, 2003

1. NAM; 2. NAT; 3. SAT; 4. EU; 5. LO; 6. AF

- There exist a seasonal dependent aerosol vertical drainage.
- Summer intrusions are almost absent in the MML and more intense in the TL. In winter the intrusions into the TL are less frequent.
AEROSOL INDEX (TOMS) vs
ATMOSPHERIC EXTINCTION COEFFICIENT (CAMC)

THE USE OF EXCLUSIVELY TOMS DATA IS NOT A VALID TOOL FOR THE ASTRONOMICAL SITE CHARACTERIZATION

Figure 2: Correlation of TOMS/Nimbus7 AI with ORM AE during summertime dusty events (AI > 0.7 and AE > 0.2)

Varela, Fuensalida, Muñoz-Tuñón, Rguez. Espinosa, García-Lorenzo & Cuevas SPIE 5489, 2004
Siher, Ortolani, Sarazin & Benkheldoun, SPIE 5489, 2004

Siher, Ortolani, Sarazin & Benkheldoun, SPIE 5489, 2004
Siher et al. 2014
Theoretical Extinction Coefficient from $K_V$ and AI correlation ... disagreement

Median = 0.13 mag/arcsec$^2$
Spatial resolution and geolocation

Varela et al., Nova Science, 2012
Kurlandczyk & Sarazin, SPIE, 2007

1km x 1km pixelsize

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On the use of satellites and climate diagnostic archives

- **Parameters:**
  - **Aerosols** (atmospheric extinction)
  - **Cloudiness** (useful time)
  - **Precipitable water vapor** (IR absorption)
  - **Tropospheric winds** (turbulence)

- Long-term variation (climate trends)

- Unknown sites

- **Error sources:**
  1. Pixel size and centered
  2. Spectral resolution
  3. **Temporal sampling /Day and night dependence**
  4. Others

- *In situ* calibration


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Geostationary Operational Environmental Satellite

NASA/NOAA
GOES East US
GOES West US
MTSAT (Pacific)

ESA
Meteosat (MFG & MSG) (Europe & Africa)
Meteosat Indian Ocean
ENVISAT (planet)
ERS (planet)

Varela, CIAI-19/01/17
EOS satellites / NASA (Terra, Aqua, Aura, Calipso)
Satellite resolution

- **Spatial Resolution**
  - **Field Of View** (FOV), height, sensor viewing angle.
  - **Pixel size** that gives a lower limit for the spatial resolution. The measure of the pixel dimension is given from the Instantaneous Field Of View (IFOV) that is a solid angle through which the probe is sensitive at the radiation...and centered.

- **Spectral Resolution** concerns with the dimensions and the number of wavelength bands in the electromagnetic field where the detector is sensitive, that means how many channels are sampled by one pixel.

- **Radiometric Resolution** is the measurement about the sensitivity of the detector at small variances in the retrieved intensity, so more refined is the radiometric resolution, more ability has the detector to discover little differences in the reflected and emitted energy.

- **Temporal Resolution** describes how many times the data are retrieved for a same area, it changes from some hours to several days, if the overpass satellite is daily or twice a day, the resolution is high. Recent satellites can provide 15’ data.
Selection of satellites for aerosols @ ORM & OT

1. Large spatial resolution
2. Good vertical resolution
3. Large temporal resolution
4. NearUV, Optical and NIR channels
5. Long-term database

In order to respect these pressing ties, we have decided to work only with Level data 2 which have the same resolution as the IFOV Satellite.

Problems in unloading data: privileges, file sizes, daily catalogues, lot of Gb, data reduction, etc.

<table>
<thead>
<tr>
<th>INSTRUMENT-SATELLITE</th>
<th>HORIZONTAL RESOLUTION</th>
<th>PARAMETER</th>
<th>PERIOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASA</td>
<td></td>
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<tr>
<td>TERRA and AQUA-MODIS</td>
<td>10 × 10 Km</td>
<td>Aerosol Optical Thikness (AOT)</td>
<td>TERRA (2000-Now)</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>AQUA (2002-Now)</td>
</tr>
<tr>
<td>OMI-AURA</td>
<td>From 13 × 24 Km</td>
<td>Aerosol Index (AI)</td>
<td>2004-Now</td>
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<tr>
<td>ESA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEVIRI-MSG1 (Met8)</td>
<td>4,8 × 4,8 Km</td>
<td>Aerosol Parameter</td>
<td>2004-Now</td>
</tr>
</tbody>
</table>

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Correlation between AI from OMI-AURA and Atmospheric Extinction in V over ORM

Correlation between AOD for MODIS-Terra and Atmospheric Extinction in V over ORM

Correlation between AOD-terra and AE for terrestrial and marine aerosol and presence of dusty days at ground level

Blue: terrestrial
Pink: marine
Yellow: calima

AOD-TERRA AND AQUA THRESHOLD

AE THRESHOLD FOR DUSTY NIGHTS

MODIS
**In situ measurements**

**AIRBORNE AEROSOLS, DUST PROPERTIES AND DISTRIBUTION**

Vertical structure of aerosols (backscattering coefficient and optical aerosol depth)

**LIDAR (INTA)** 30m resolution (NASA MPL-NET -AERONET).

**Size and density (local)**

- **Radiometers (MFRSR)**
- **Airborne Particle Counter (Pacific Scientific Instruments)**
  - 6 channels: 0,3 – 0,5 -1 –3 – 5- 10µm
  - Caudal: 1 c.f.m.
  - Light source: laser diode

1. Calibrated with the TNG dust counter at the ORM (Varela & Ghedina, Tech.Note TNG, 2005).
2. Calibration campaign at the OAT (S. Rodriguez et al., 2010, internal report)
Monitoring local dust at the ORM & OT

- Calibration PCP vs Abacus (ORM) (Varela & Ghedina, 2005)
  Excellent agreement

- Limit for dust N(PM5) > 35 $10^3$ counts/m3 (from correlation with Kv)

Varela, CIAI-19/01/17
Monitoring local dust at the ORM & OT

Lasair II, model 310B
Particle Measurin System Inc.
Operating at TNG since 2007 (ORM)

0.3, 0.5, 1.0, 3.0, 5.0 and 10.0µm
Flow rate = 1 cubic feet

Varela, CIAI-19/01/17
Monitoring local dust at the ORM & OT

- Limit for dusty conditions from Stella is 25µg/m³

Directiva Europea PM10/PST=0.8; PST>28.5µg/m³...PM10=22.8 (S. Alonso P., 2007)

http://vivaldi.ll.iac.es/OOCC/observing-tools/

Varela, CIAI-19/01/17
The aerosol optical depth (τ) is calculated from the Sun-photometer in λ to be sensitive to mineral dust (Muller et al., 2003).


Due to the different altitudes of the AERONET stations: the altitude of mineral dust events—a factor known to be important in controlling the vertical heating of the local atmosphere (Westphal et al., 1987).

Acknowledgements: Cuevas, Expósito-González & Damarí established and maintain the Tenerife AERONET.
AERONET map (aeronet.gsfc.nasa.gov)

Tenerife Island

La Laguna
28:482N, 16:321E
568 m AMSL

Santa Cruz
28:473N, 16:247E
52 m AMSL

Mt. Teide
28:309N, 16:499E
2391 m AMSL
Frequency of dust outbreaks at Canary Islands Observatories
(from telescope and AERONET data 2004-2014)

July-September:
> 2.4km 94.3±1.6%

November-May:
< 2.4km 79.5±3.1%

Laken et al., JC, 2016
Evidence of dust settlement with altitude

Clear-sky (days/month)

24.1±0.6

18.9±0.8

21.6±0.8

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The $f_{\text{dust}}$ (and SEM range) per calendar month (fraction per month) for
(a) 1983–2014 accumulated telescope data
(b) accumulated telescope data and AERONET data during 2004–2014.
(Laken et al. 2016)
Ongoing issues for providing the atmospheric extinction at the CCOO

Collaboration with the CIAI-AEMET:

AOD-OT: Cimel Sunphotometers from IZO.....on-line data (soon)

AOD-ORM: Cimel Sun Sky Lunar photometer CE318-T (since 2004) ... ORM campaign? (AOD also nighttime)

Comparison Kv

$K_{V}$-ORM: Exploring SuperWASP (Wide Angle Search for Planets)

$K_{V}$-ORM: Exploring DIMM (since 1994)

Also interesting forecasting at free troposphere

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Cloudiness at the ORM

Satellite Survey of Cloud Cover and Water Vapour in Morocco and Southern Spain and verification using La Palma ground-based Observatories.
Erasmus and van Rooyen, 2006; A study conducted for ESO

- **EUMETSAT (European Organization for the International Exploitation of Meteorological Satellites)-ISCCP:**
  - 7 years period (1996 to 2002)
  - Spatial resolution 5km x 5km and temporal resolution 3 hours.
  - Data at: 6.4um (water vapour) and 11.5um (IR): cloud cover in the middle-upper troposphere and PWV

- **SATELLITE (definitions):**
  - Upper Tropospheric Humidity (UTH)
  - Photometric or clear: UTH ≤ 30%
  - Spectroscopic or usable: 30% < UTH < 100%

- Cross-calibrated at ground with Carlsberg Automatic Maridian Circle (CAMC)
  - Atmospheric Extinction Coefficient in V (KV):
  - Photometric time: KV < 0.15
  - Non-photometric: KV > 0.15
  - Cross-cal (ground) has been verified to be accurate within 1.2%

- **RESULTS:**
  - **SATELLITE:** Photometric time (also named “clear”) is 83.7%
  - Spectroscopic time (also named “usable”) not provided in the report.
The plots also show the probability of useful (clear+partially cloudy) time. The diurnal useful time at IZO ranges between 94% in summer and 69% in autumn, with an average value of 81%.

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Tropospheric winds: climate diagnostic archives

Combine world-wide long-term meteorological data + sophisticated models

The atmospheric BL is crucial to characterize the site and for telescope design.

Assessing the BL from the NCEP/NCAR database: calibration using SL measurements at the ORM, Varela & Muñoz-Tuñón, poster EWASS’15)

The propagation of the wind flux in height and its correlation with ground winds could explain the influence of trade winds on image quality.

Relationship between $V_{200\text{hPa}}$ and the velocity of the turbulence (Sarazin & Tokovinin, 2002)
We have compared the 6-hourly any level with $V_{200\text{ hPa}}$ (data from NCEP/NCAR climate diagnostic archive).

Similar high to low winds correlation except for Mauna Kea.

Topography is affecting winds at the lowest levels.

The continuity of wind profile allows to use a troposphere model to obtain atmospheric parameters (seeing). Sarazin & Tokovinin, 2002.

Ground level to low altitude winds connection studied at La Palma (Varela & Muñoz-Tuñón, 2015).

$V^* \approx 0.4 \ V_{200\text{ hPa}}$

Sarazin & Tokovinin 2002 in Paranal and Cerro Pachón.

García-Lorenzo et al., 2005
Trade wind scenario at the ORM
Seasonal variation (NCEP/NCAR 22 years/24hrs)

Varela, CIAI-19/01/17
Trade wind scenario at the ORM (22 years)

Varela, CIAI-19/01/17
Trade wind scenario at the ORM (ground level)
No strong differences in wind direction profiles except for Mauna Kea.

In this case the wind speed at 200hPa would be not sufficient to estimate the atmospheric turbulence and in situ measurements would be necessary.
Wind speed seasonal dependency

Varela & Muñoz-Tuñón, 2015
Wind speed continuity

![Graph showing wind speed continuity](image)

- Wind speed (m/s)
- Height (hPa)

Points:
- 22.15 at 100 hPa
- 18.25 at 200 hPa
- 14.2 at 300 hPa
- 11.65 at 400 hPa
- 9.77 at 500 hPa
- 6.5 at 600 hPa
- 2.41 at 800 hPa

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NCEP/NCAR database
Balloon Measurements

Adaptive Optics suitability ranking

<table>
<thead>
<tr>
<th>Site</th>
<th>Mean (m/s)</th>
<th>Median (m/s)</th>
<th>$\sigma$ (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>La Palma (ORM)</td>
<td>22.13</td>
<td>20.79</td>
<td>11.67</td>
</tr>
<tr>
<td>San Pedro Mártir</td>
<td>26.55</td>
<td>24.57</td>
<td>15.39</td>
</tr>
<tr>
<td>Paranal</td>
<td>30.05</td>
<td>28.63</td>
<td>13.01</td>
</tr>
<tr>
<td>La Silla</td>
<td>33.35</td>
<td>32.77</td>
<td>12.94</td>
</tr>
</tbody>
</table>

García Lorenzo et al., 2005
Chueca et al., 2004
Some remarks

- Aerosol Optical Depth provided by satellites should be regarded with caution in particular in those astronomical sites with abrupt orography (ORM, Mauna Kea or San Pedro Mártir). *In situ* measurements are always required.

  Reason: topographical dependent (vertical drainage).

- Clouds cover information provided by satellites and ground-based measurements seems to be in agree (Erasmus et al.).

  Reason: the satellites can distinguish between optically thin and thick cirrus, maritime stratocumulus, … Similar to PWV and O3

- The NCEP/NCAR archive are useful for sampling the wind profile at the ORM. The continuity of the wind profile allows us to use $V_{200\text{hPa}}$ to obtained other atmospheric parameters (seeing).

  Ongoing: updating WS and model T, RH, …

  local calibrations should be carried out at other sites before apply troposphere models.

Varela, CIAI-19/01/17
Thanks for your attention