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/feasibilty AO and T&D design)

Varela et at., Chap. 8, Aerosols: Properties, Sources and Mangement Practices, Nova Science Pub., NY, 2012

Aerosols (mineral dust)

Size, density and vertical drainage//f_{dust} + PM10

Number of photometric/useful nights

Varela et al., MNRAS, 2008

→ **Satellites**

Telescopes for K_V and AOD

Airborne dust detectors

LIDARs, Cimel Phot., …

Cloud Cover

distribution of photometric/useful nights

→ **Satellites**

Visual (log book)

IR Radiometers, AllSky CCD

Precipitable Water Vapor

and local humidity

→ **Satellites, GPS**

Balloon

Radio Sounding

IR Photometers

Ground level meteorological Variables

Time evolution, climate trends

→ **AWS**

(30 years)

Tropospheric winds (image quality and telescope & dome design)

...Sarazin & Tokovinin (2002)

vertical profiles, direction & gradients

→ **Climate diagnostic archives (NOAA-CIRES)**

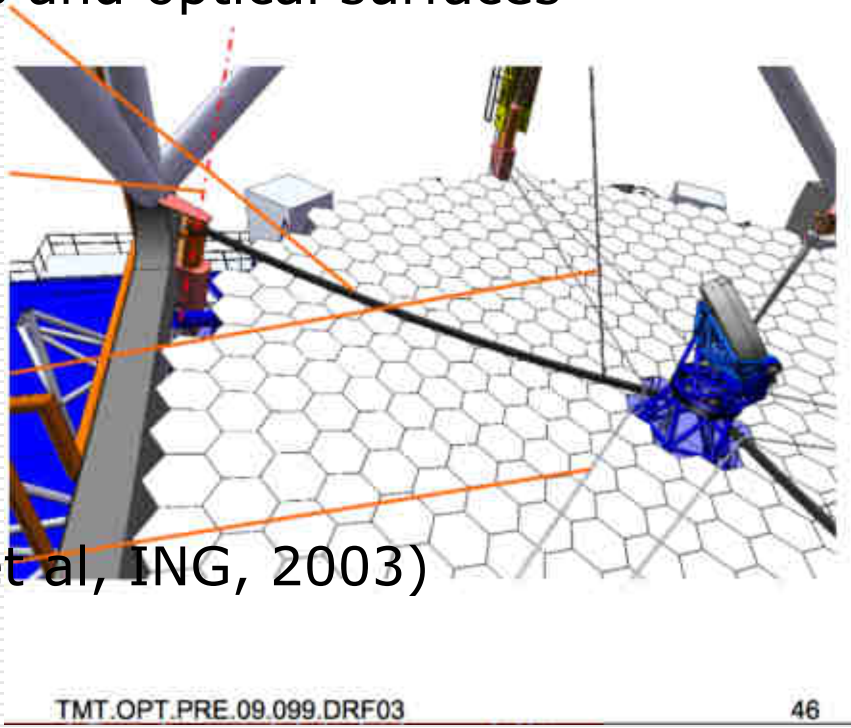
NCEP/NCAR (> 25 years)

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

CONTEXTUALISE EXTREME EVENTS

Castro-Almazán et al., EWASS 2015

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

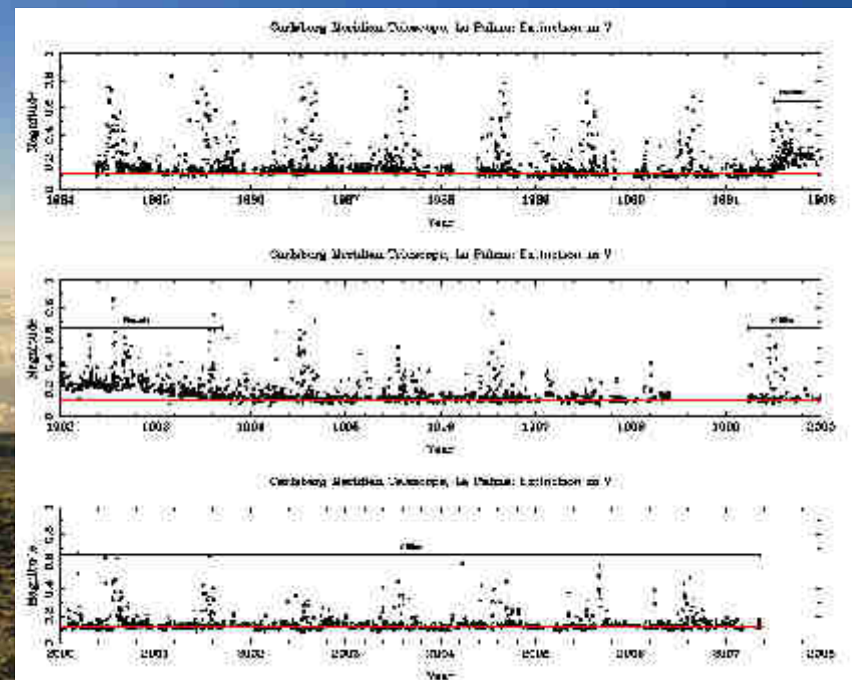
~20% of seeing quality

- *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)***

AIRBORNE AEROSOLS, DUST PROPERTIES AND DISTRIBUTION

The Carlsberg Meridian Telescope (CAMC or CMT) is continously 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.

$$A(\lambda)=A_{Ray}(\lambda,h)+A_{oz}(\lambda)+A_{wv}(\lambda)+A_{aer}$$

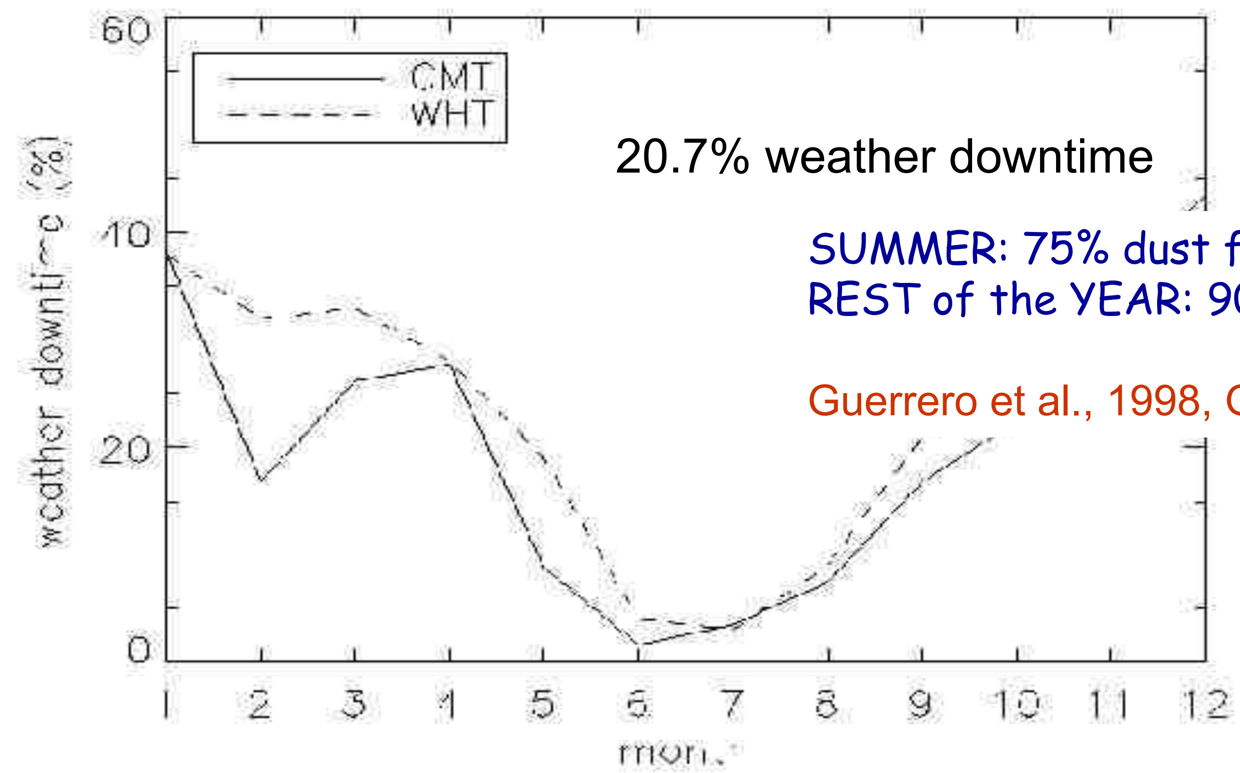


Acknowledgements: Evans provided CMT data, operated by ROA S. Fernando, Copenhagen University Observatory and Royal Greenwich Observatory

Atmospheric extinction-Clear Time

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

Weather down-time (%)



20.7% weather downtime

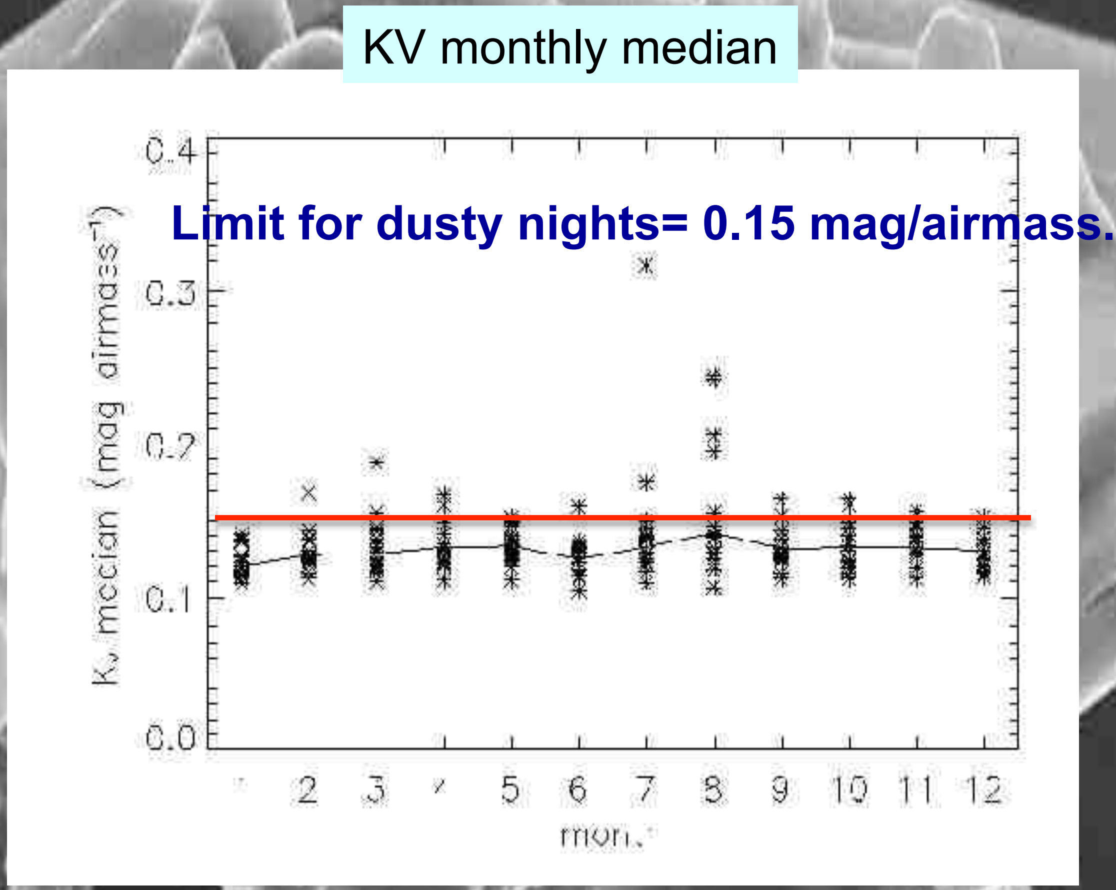
rmass.

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
García-Gil, Muñoz-Tuñón & Varela, PASP 122, 1109 (2010)

Atmospheric extinction-Clear Time



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

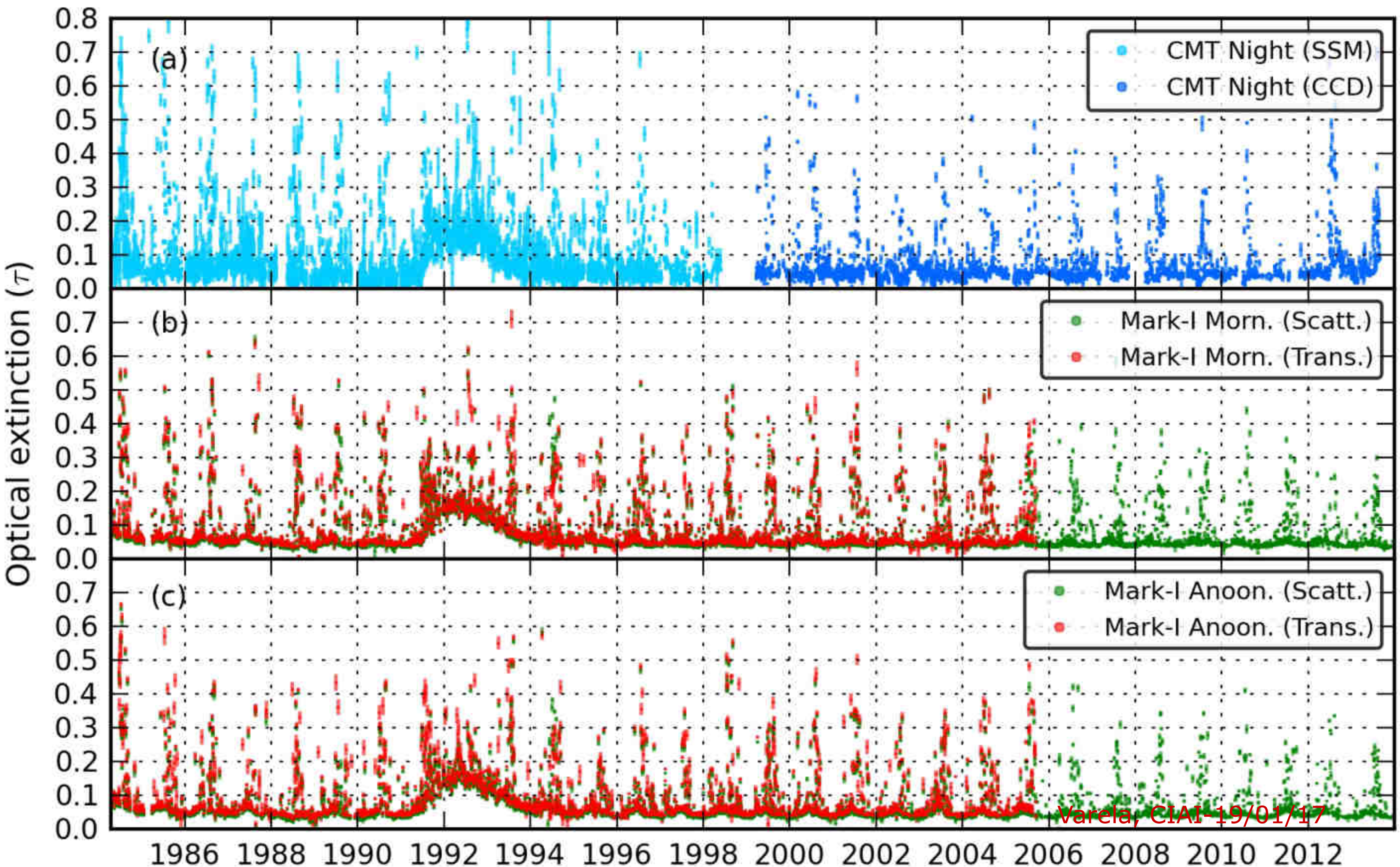
Mark-I telescope

- 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.

Barreto et al., AMTD, 2014 (since 1976 to 2012)
AERONET & PFR vs MarkI.
Laken et al., Journal of Climate, Vol..29, 227 (2016) (1984-2014)
AERONET & CMT vs Mark-I.

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

Long-term database optical extinction from telescopes @ORM vs OT (Laken et al., 2016)



In situ and remote sensing

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

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

Why?

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

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

TOMS: **T**otal **O**zone **M**apping **S**pectrometer, NASA; on board **Nimbus7: 1978-1993**; Meteor-3: 1991-1994; ADEOS,1996-1997; **Earth-Probe: 1996-2004**....

Spatial Resolution: 1.25^{o} x 1^{o} (139 x 111 km^2)

30 years.

No good resolution at lower atmosphere.

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

A.I. >0 absorbing aerosols (smoke, industrial activity, mineral dust, volcanic aerosol and soot)

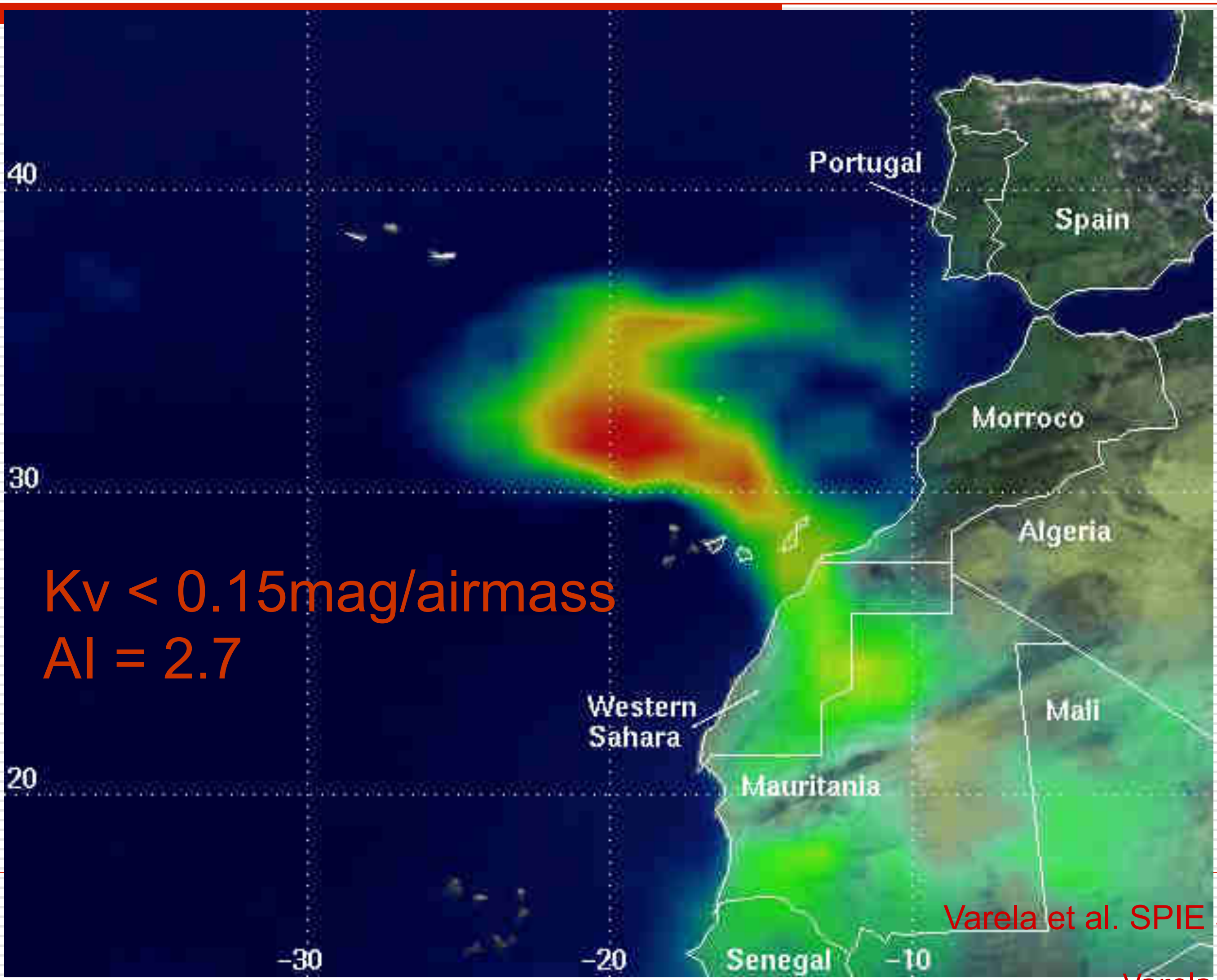
A.I.=0±0.2 clouds or large non-absorbing particles

A.I.<0 non-absorbing aerosols (sulphates, marine aerosols)

Herman et al., 1997; Torres et al., 1998.

FOR EXAMPLE: Western Sahara dust-February 26, 2000. TOMS/Earth Probe

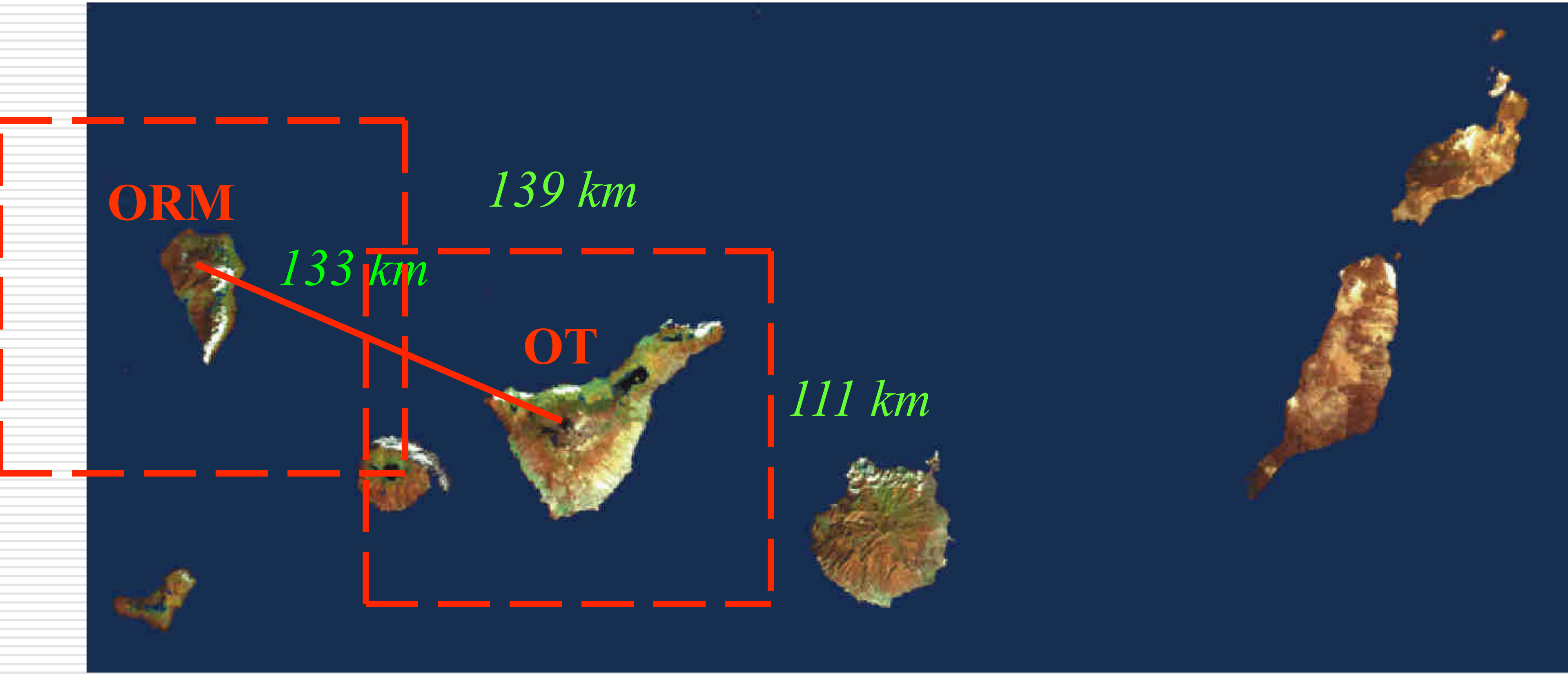
The plume arrived at the Canary Islands but it did not reach the level of the Observatories !



Varela et al. SPIE 5489 & 5571, 2004

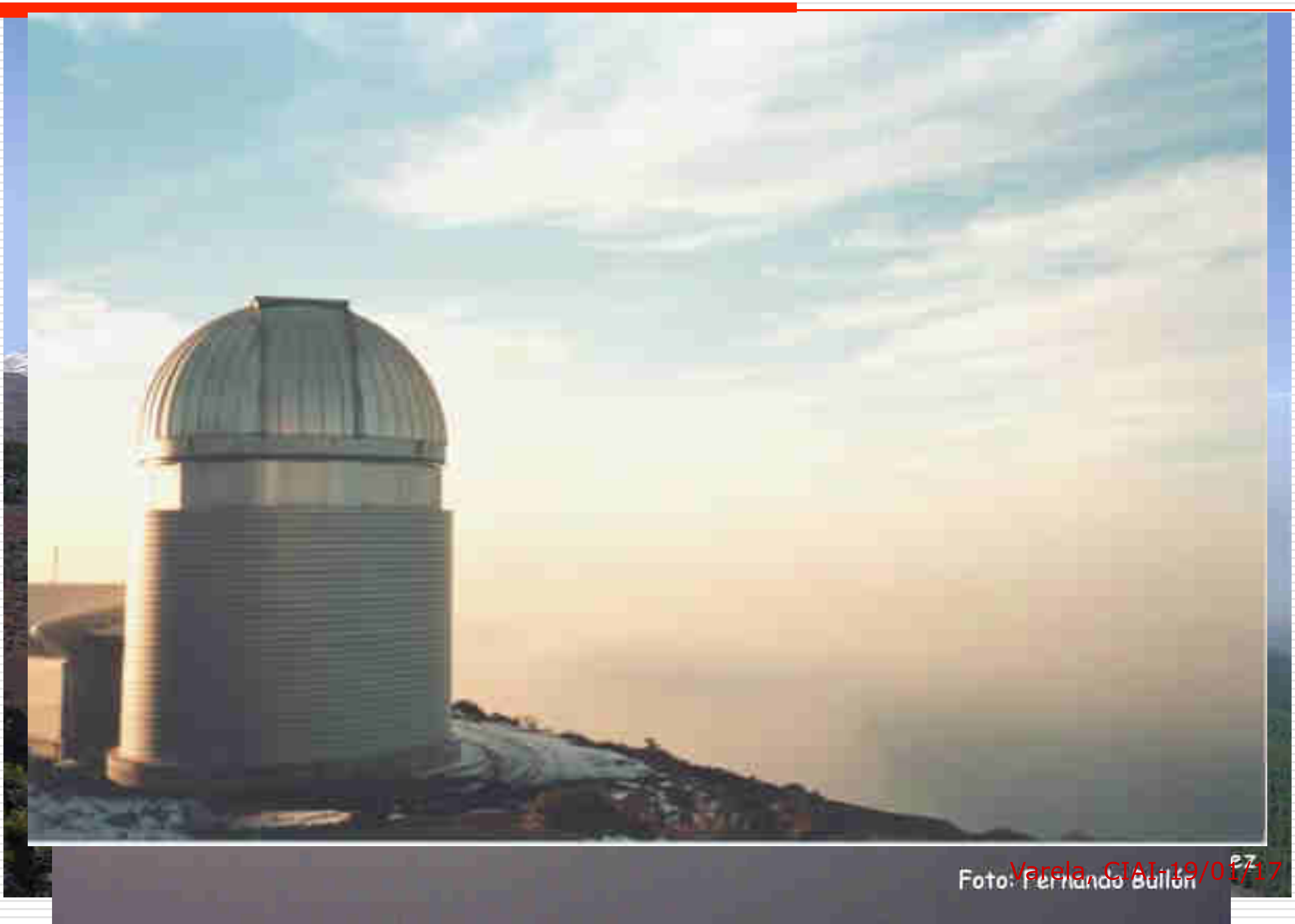
REASONS FOR THE LACK OF IN SITU AND SATELLITE CORRELATION

EP/TOMS spatial resolution: 1.25º x 1º



- 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

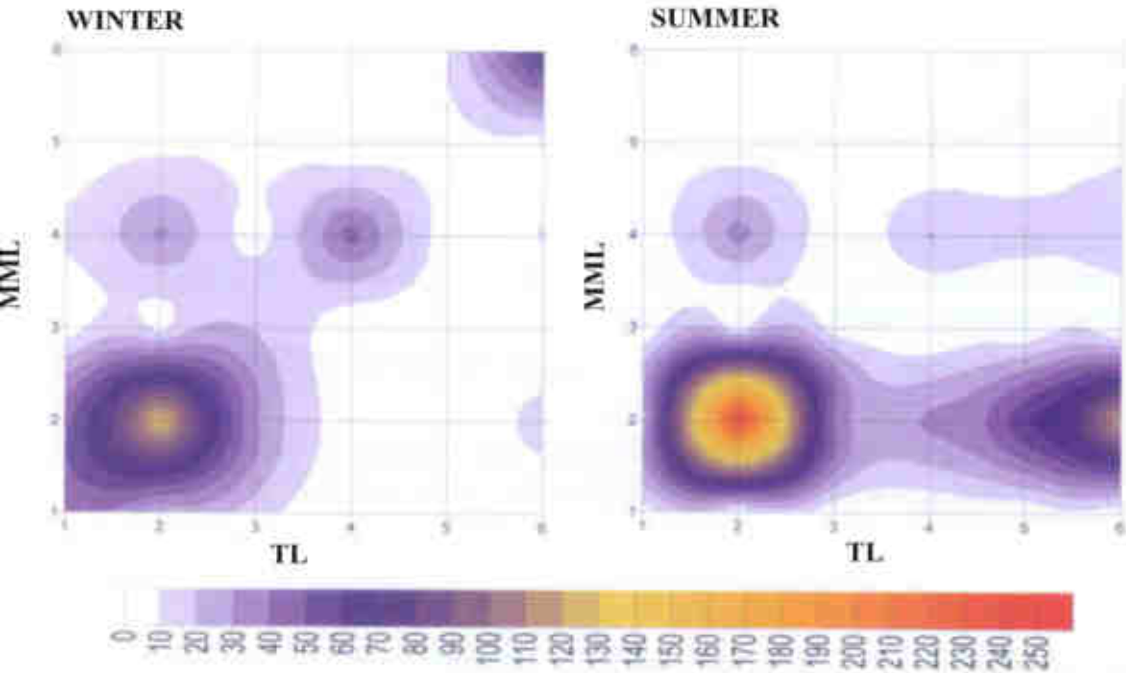


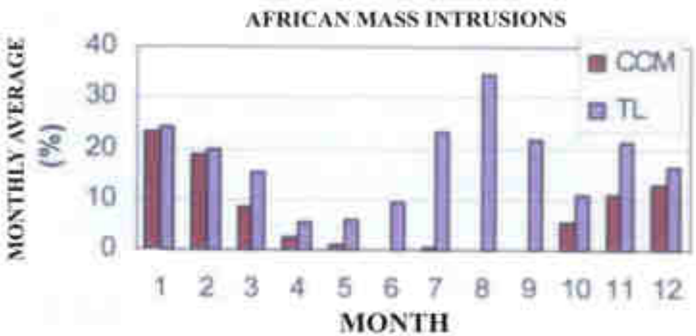
AIRMASS INTRUSIONS IN THE CANARY ISLANDS

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

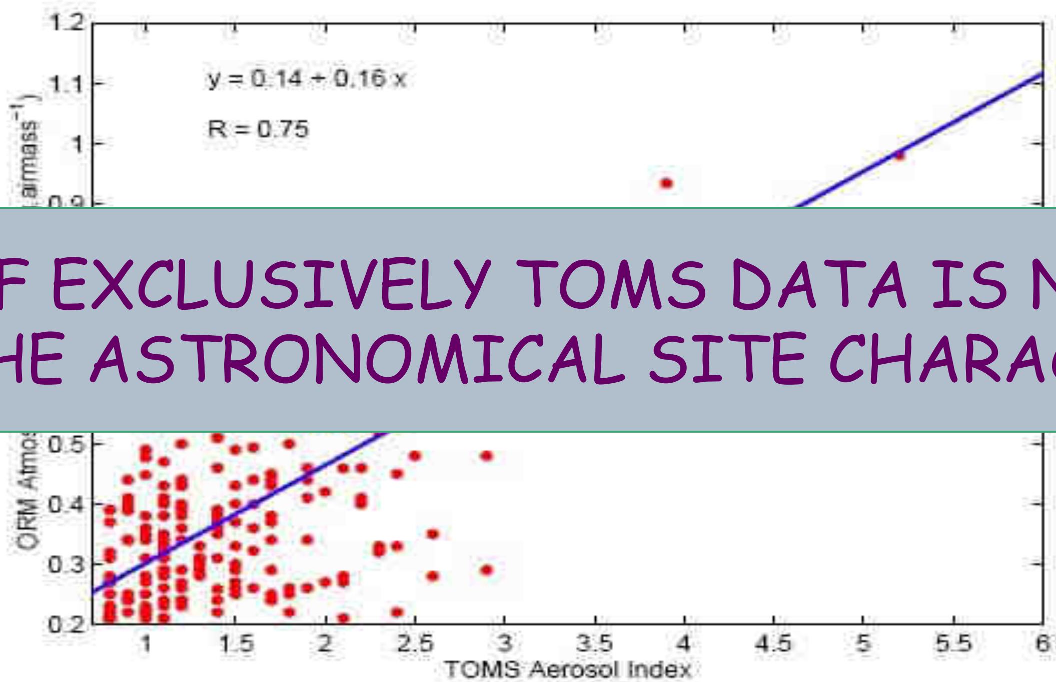




- There exist a seasonal dependent aerosol vertical drainage.
- Summer intrusions are almost absent in the MML and more intense in the TL. In winter the intrusions into the TL are less frequent.

Varela, CIAI-19/01/17

AEROSOL INDEX (TOMS) vs
ATMOSPHERIC EXTINCTION COEFFICIENT (CAMC)



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

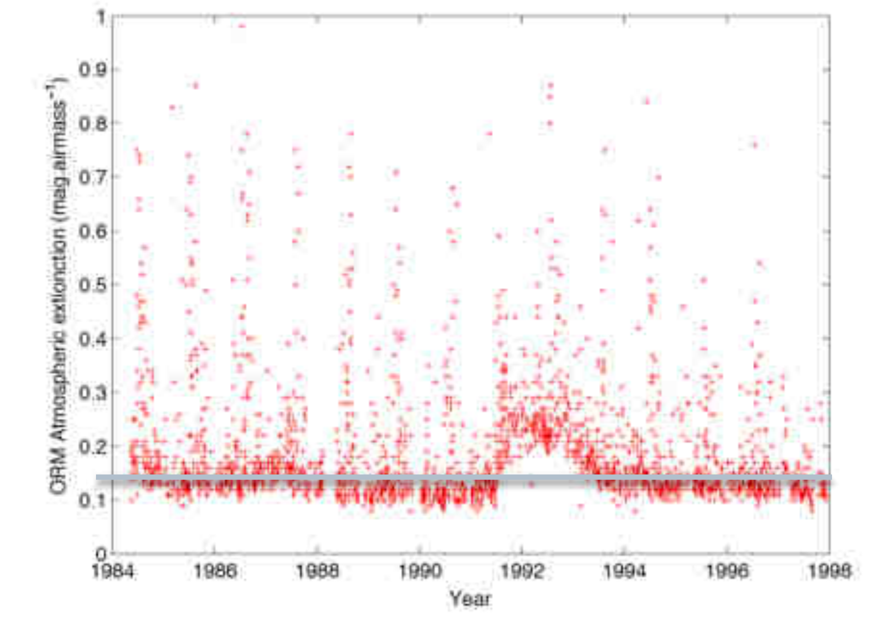
Figure 2: Correlation of TOMS/Nimbus7 AI with ORM AE during summertime dusty events (AI>0.7 and AE >0.2)

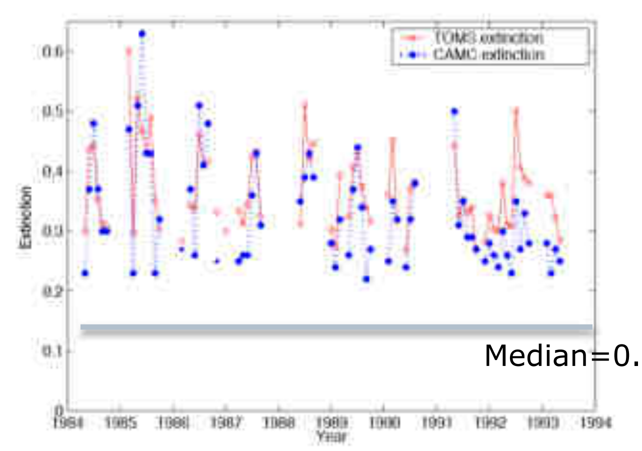
Varela, Fuensalida, Muñoz-Tuñón, Rguez. Espinosa, García-Lorenzo & Cuevas SPIE 5489, 2004
SPIE 5571, 2004

Siher, Ortolani, Sarazin & Benkhaldoun, SPIE 5489, 2004

Siher et al. 2014

Theorical Extinction Coefficient from K_V and AI correlation … disagreement





Median=0.13mag/arcsec^2

Spatial resolution and geolocation

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

1km x 1km pixelsize

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. Pixelsize and centered
  2. Spectral resolution
  3. Temporal sampling /Day and night dependence
  4. Others

- *In situ* calibration

Varela et al., Ch.8, Aerosols: Properties, Sources and Practices, Nova Science Pub., NY, 2012.

Geostationary Operational Environmental Satellite

NASA/NOAA

GOES East US

GOES West US

MTSAT (Pacific)

ESA

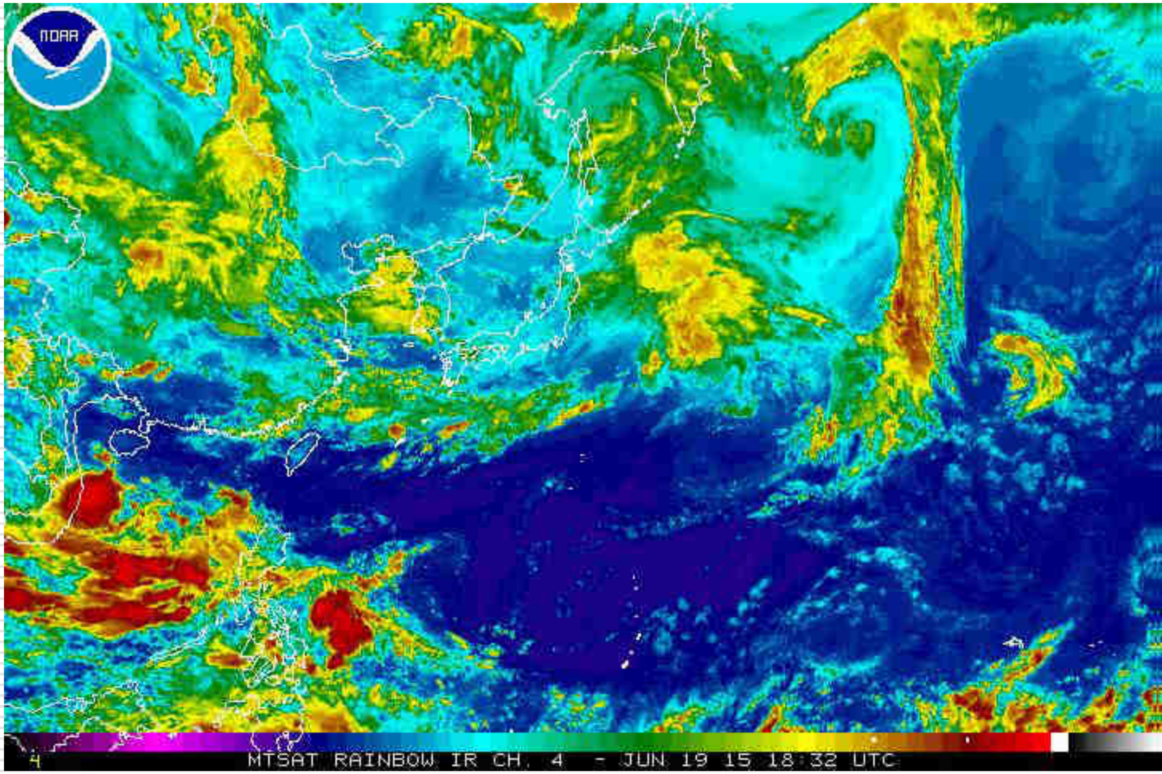
Meteosat (MFG & MSG)

(Europe & Africa)

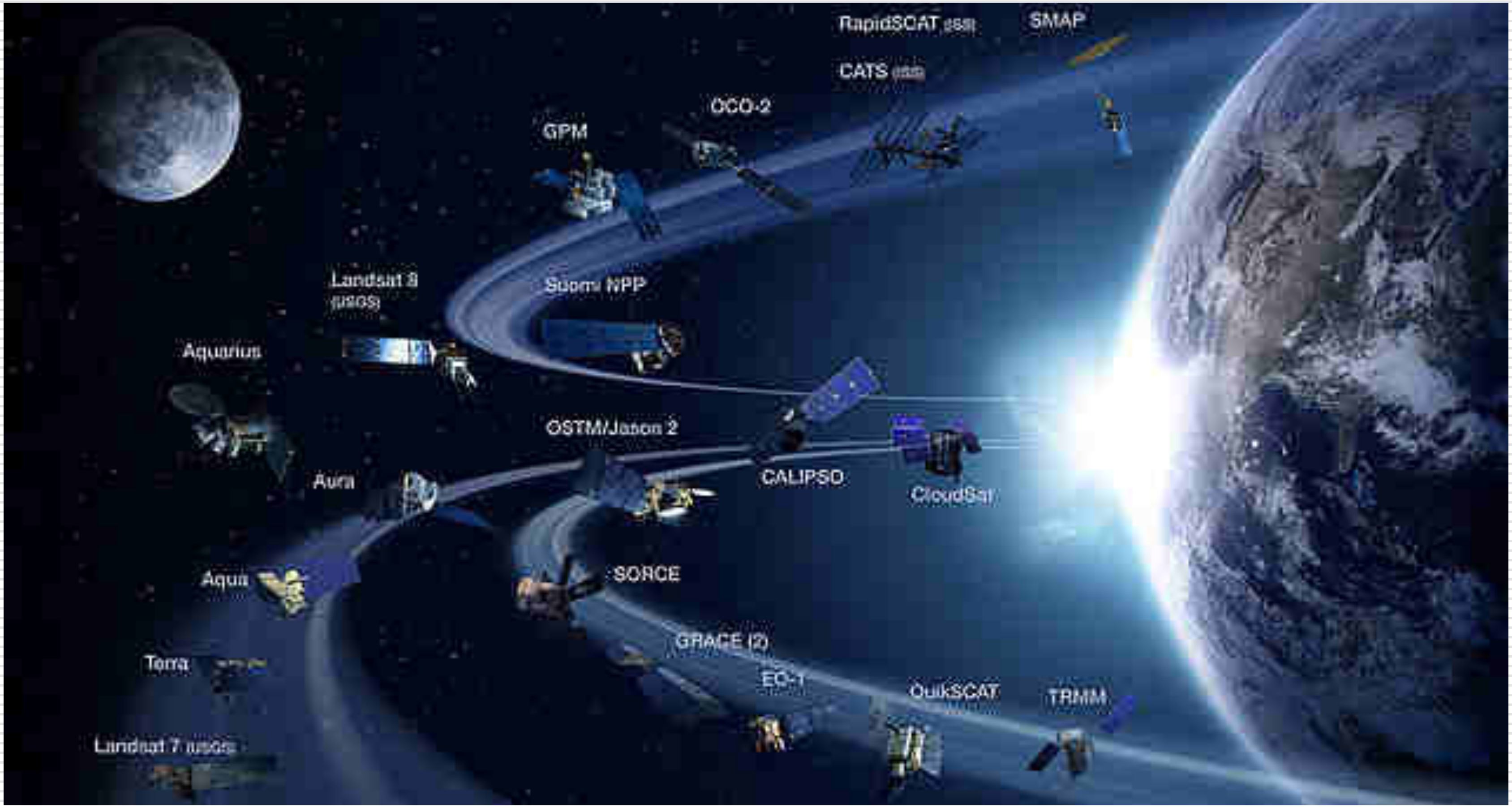
Meteosat Indian Ocean

ENVISAT (planet)

ERS (planet)



EOS satellites / NASA (Terra, Aqua, Aura, Calipso)



Satellite resolution

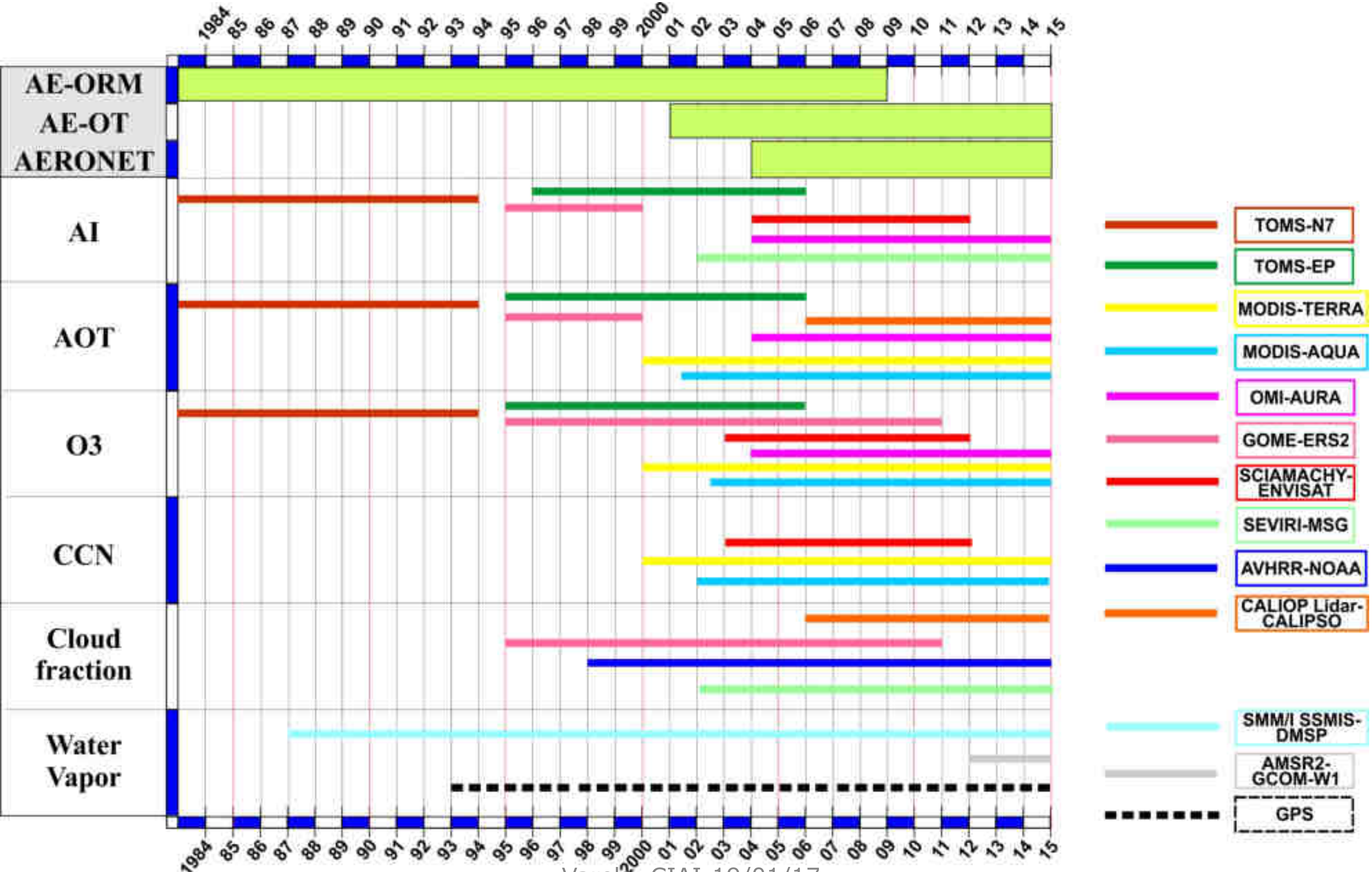
- **Spatial Resolution**
  - Field Of View (FOV), height, sensor viewing angle.
  - Pixel size that gives a lower limit for the spatial resolution. The measure of the pixel dimension is given from the Instantaneous Field Of View (IFOV) that is a solid angle through which the probe is sensitive at the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

Parameters / Instruments-Satellites



Varela, CIAI-19/01/17

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

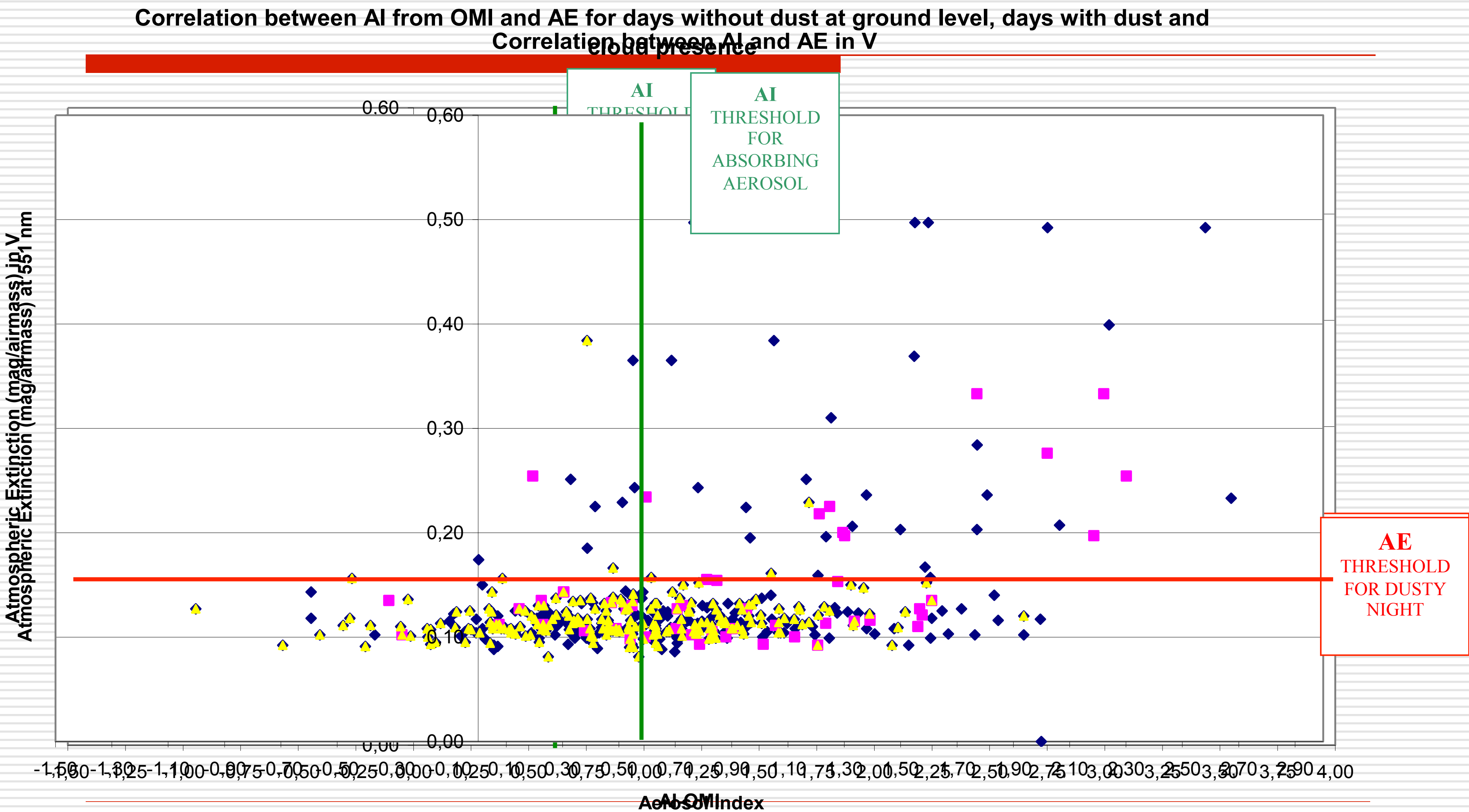
In order to respect these pressing ties, we have decided to work only with Level data 2 which have the same resolution as the IFOV Satellite.

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

	Instrument-Satellite	Horizontal Resolution	Parameter	Period
NASA	**TERRA and AQUA-MODIS**	10 × 10 Km	Aerosol Optical Thikness (AOT)	TERRA (2000-Now) AQUA (2002-Now)
	OMI-AURA	From 13 × 24 Km	Aerosol Index (AI)	2004-Now
ESA	**SEVIRI-MSG1 (Met8)**	4,8 × 4,8 Km	Aerosol Parameter	2004-Now

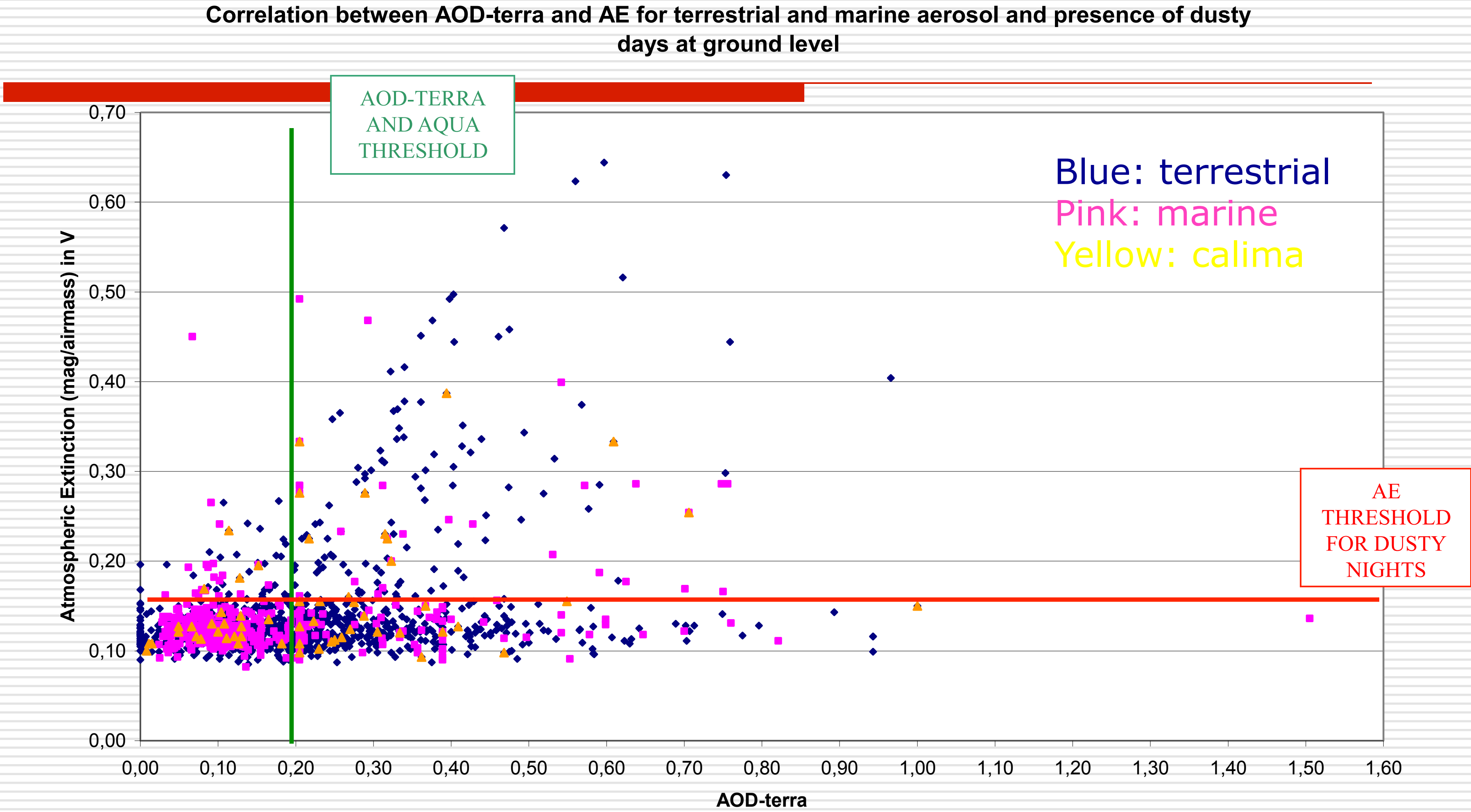
Correlation between AI from OMI-AURA and Atmospheric Extinction in V over ORM

Varela, Bertolin, Muñoz-Tuñón, Ortolani & Fuensalida, MNRAS 2008



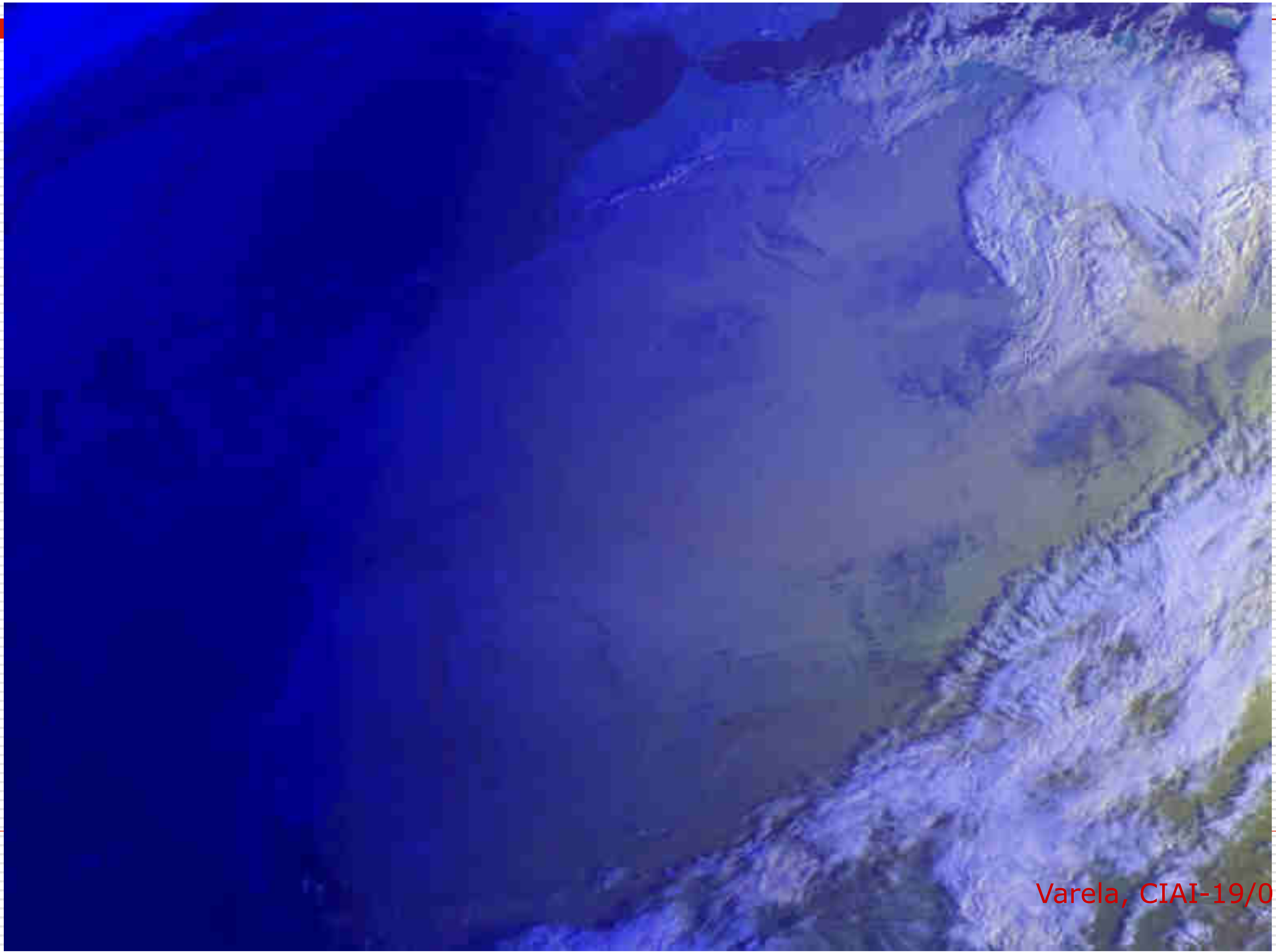
@CALIMA: pink points 'Datos suministrados como fruto del convenio de colaboración para el estudio y evaluación de la contaminación atmosférica por material particulado en suspensión en España entre la D.G. de Calidad y Evaluación ambiental del Ministerio de Medio Ambiente, el Consejo Superior de Investigaciones Científicas y el Instituto Nacional de Meteorología del Ministerio de Medio Ambiente'

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



A.M. Varela, C. Bertolin, C. Muñoz-Tuñón, S. Ortolani & J.J. Fuensalida, MNRAS 2008

MODIS



In situ measurements

AIRBORNE AEROSOLS, DUST PROPERTIES AND DISTRIBUTION

<u>Vertical structure of aerosols (backscattering coefficient and optical aerosol depth)</u>

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

<u>Size and density (local)</u>

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 campaing 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

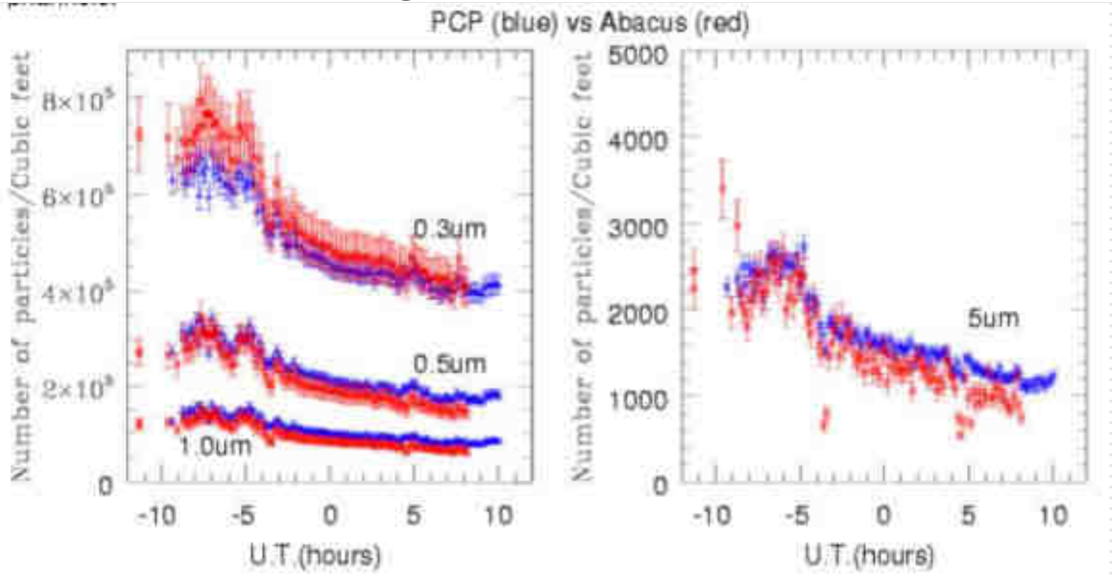
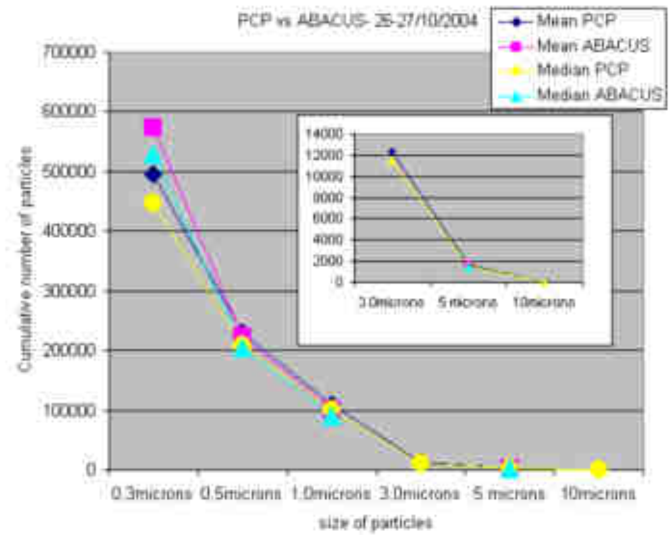


Figure 1. Cumulative number of particles measured in the cross-calibration campaign between the PCP IAC and Abacus TNG particle counters at the TNG dome at the channels: 0.3, 0.5 and 1.0 microns (left figure) and 5microns (right figure). U.T.=0.0 hours corresponds to midnight.



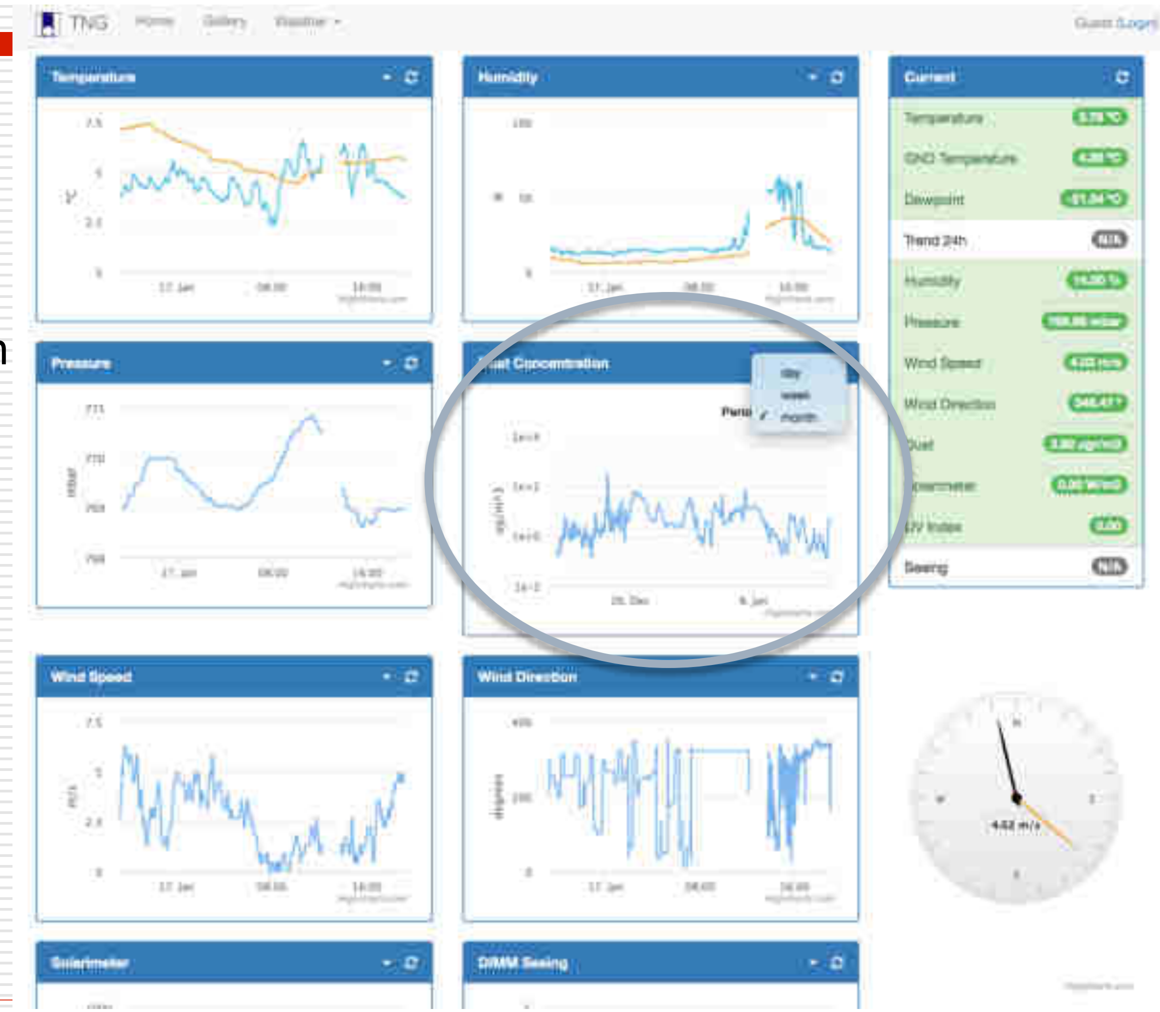
- Limit for dust N(PM5) > 35 10^3 counts/m3 (from correlation with Kv)

Monitoring local dust at the **ORM** & OT

www.tng.iac.es

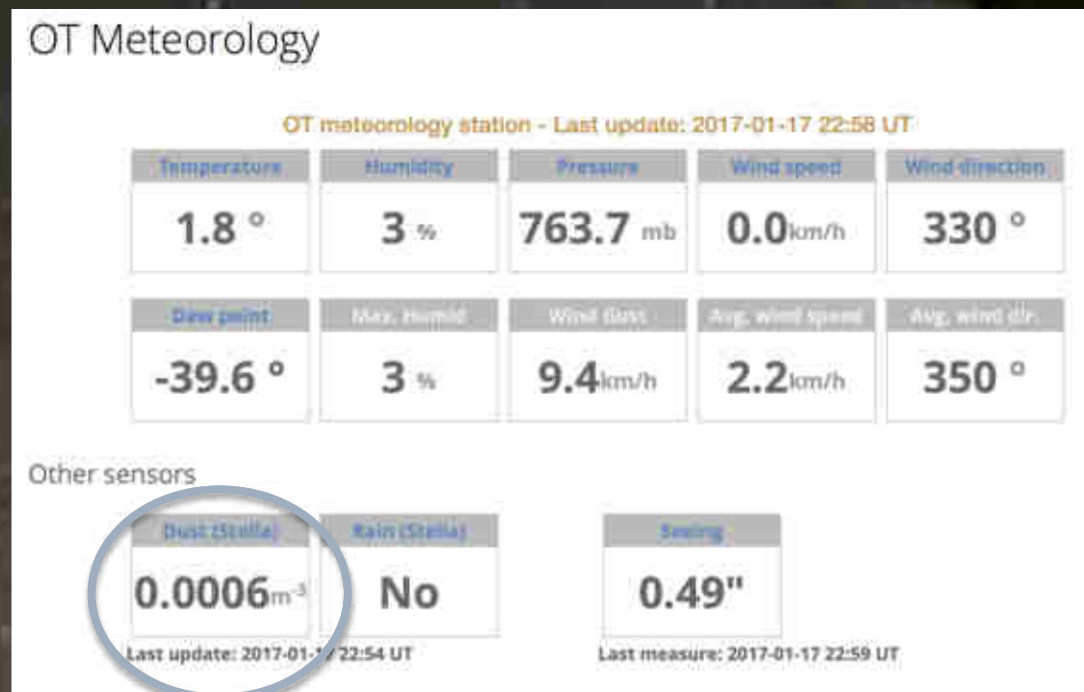
Lasair II, model 310B
Particle Measurin System Inc.
Opearting @ TNG since 2007 (ORM)

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



Monitoring local dust at the ORM & **OT**

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



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

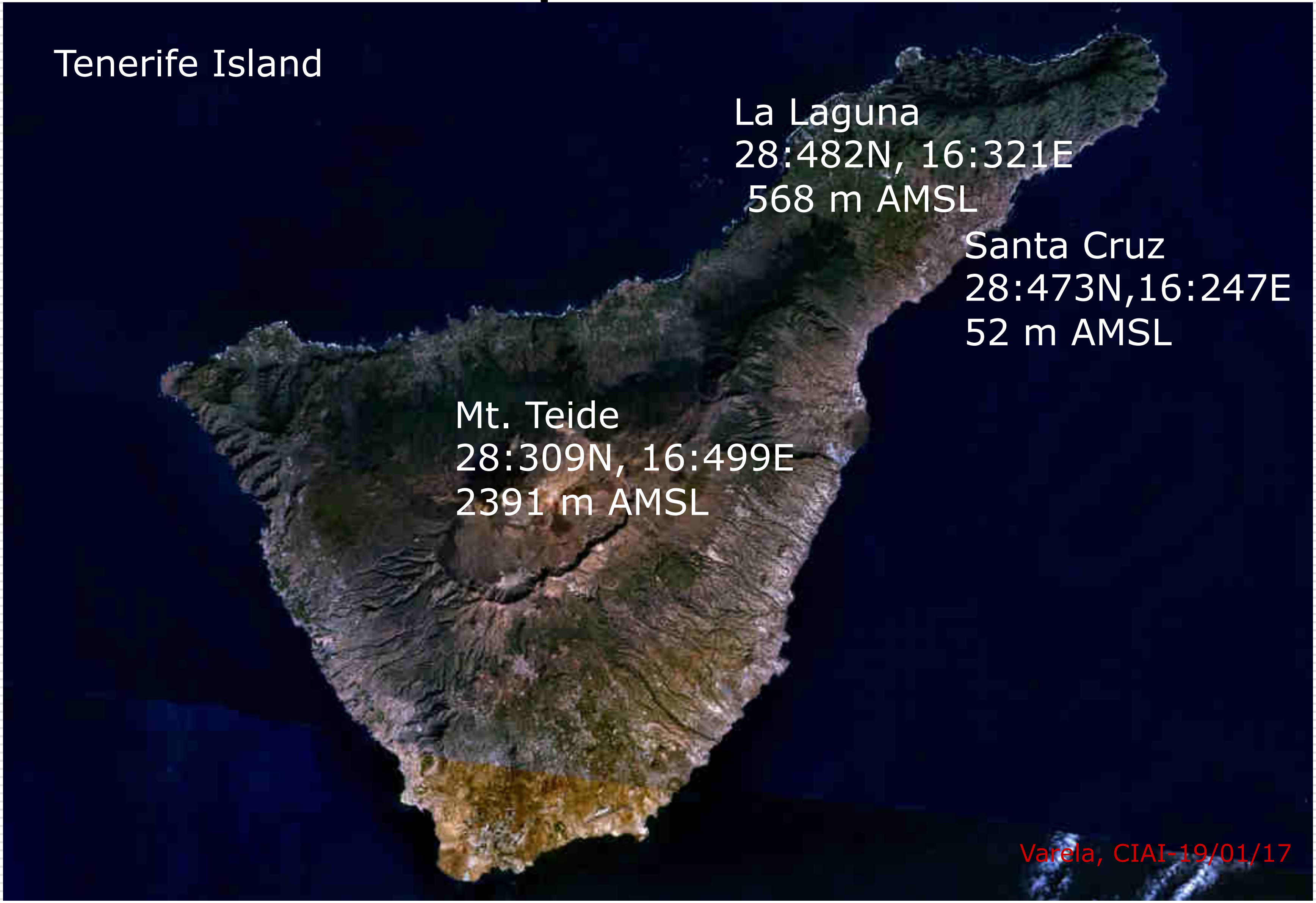
Directiva Europea PM10/PST=0.8; PST>28.5µg/m³…PM10=22.8 (S. Alonso P., 2007)

NASA MPL-NET -AERONET

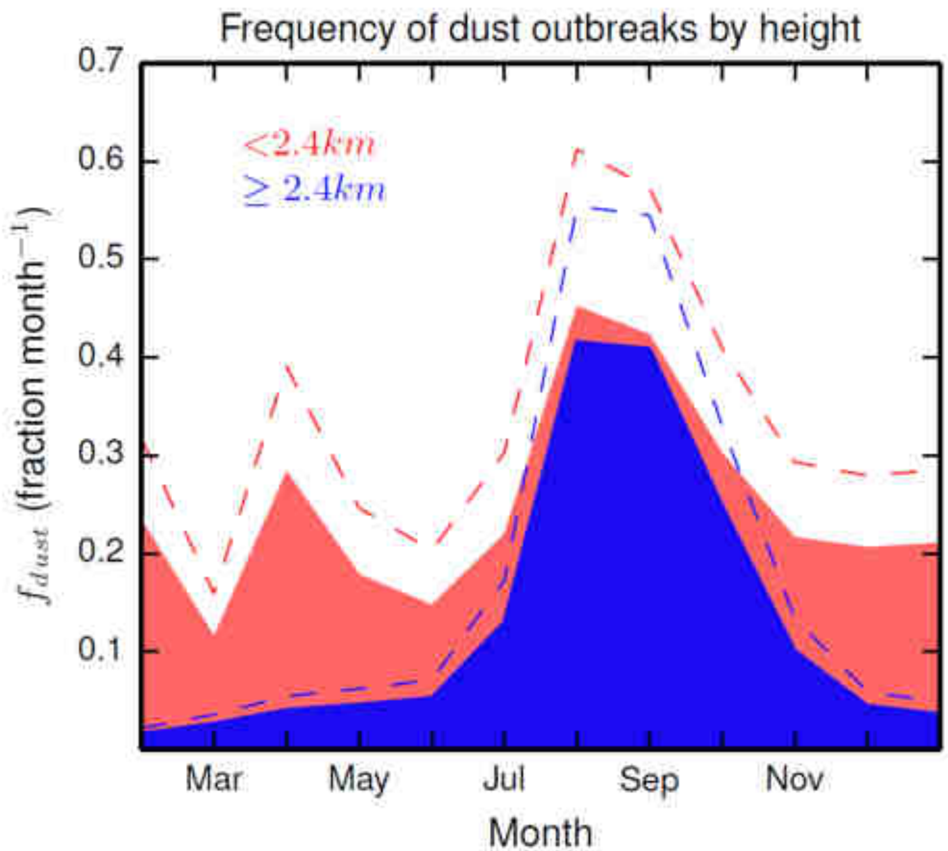
- The aerosol optical depth (τ) is calculated from the Sun-photometer in λ to be sensitive to mineral dust (Muller et al., 2003).
- Period 2004-2014. Level 2.0, daily summary at 679nm
- Due to the different altitudes of the AERONET stations: the altitude of mineral dust events—a factor known to be important 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)



Frequency of dust outbreaks at Canary Islands Observatories (from telecope and AERONET data 2004-2014)



July-September:
> 2.4km 94.3±1.6%

November-May:
< 2.4km 79.5±3.1%

Thirty years of atmospheric extinction from telescopes of the North Atlantic Canary Archipelago

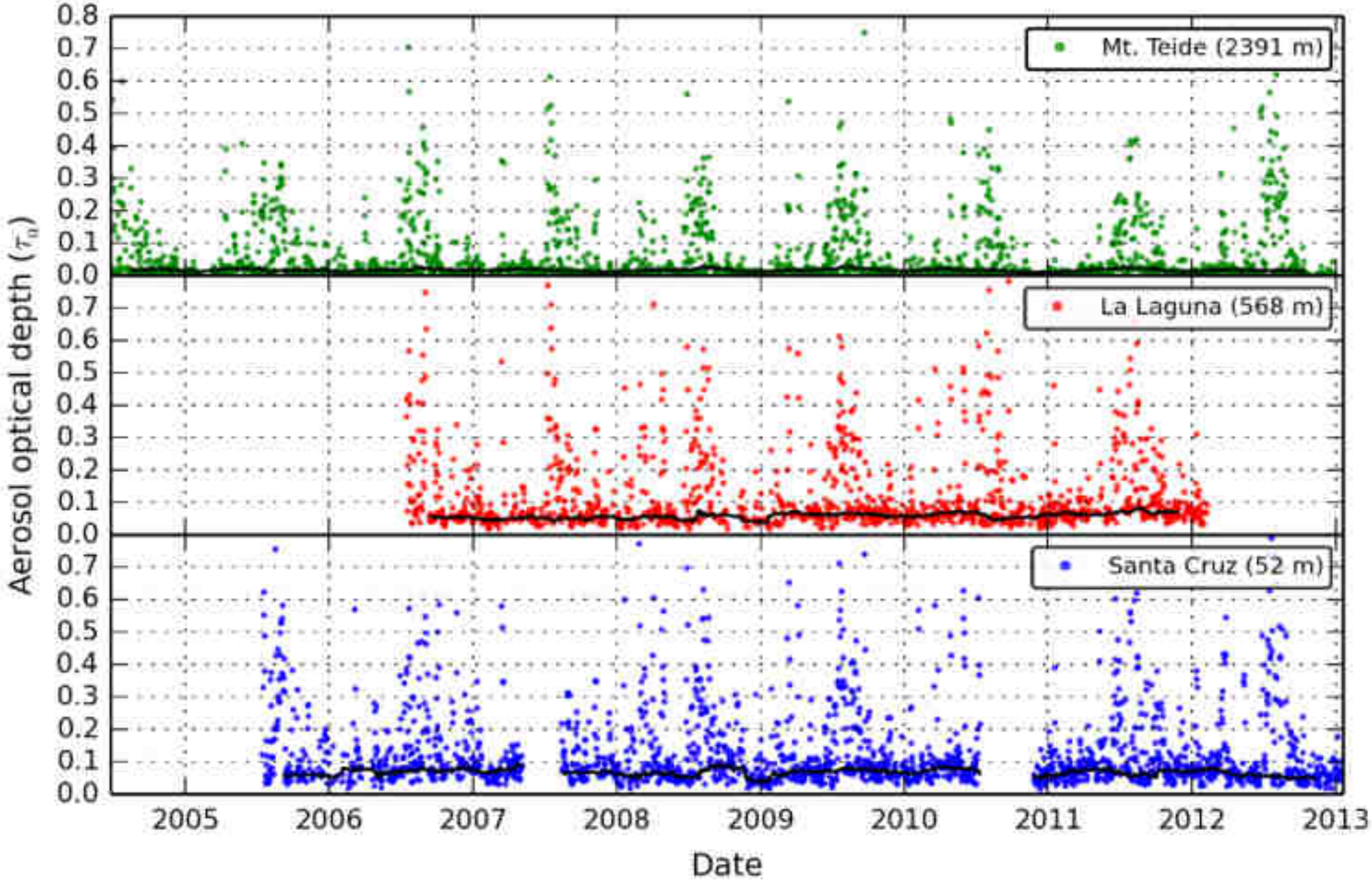
B. A. Laken[1], H. Parviainen[2], A. García-Gil[3,4], C. Muñoz-Tuñón[4,5], A. Varela-Pérez[4,5], and P. Pallé[4,5]

[1]Department of Geosciences, University of Oslo, Oslo, Norway
[2]Department of Physics, Oxford University, Keble Road, Oxford, OX13RH, England
[3]Agencia Estatal de Meteorología (AEMET), Spain
[4]Instituto de Astrofísica de Canarias, Vía Lactea s/n, E-38205, Tenerife, Spain
[5]Department of Astrophysics, Universidad de La Laguna, Tenerife, Spain

Correspondence to: Benjamin Laken
(benjamin.laken@geo.uio.no)

Laken et al. , JC, 2016

Evidence of dust settlement with altitude



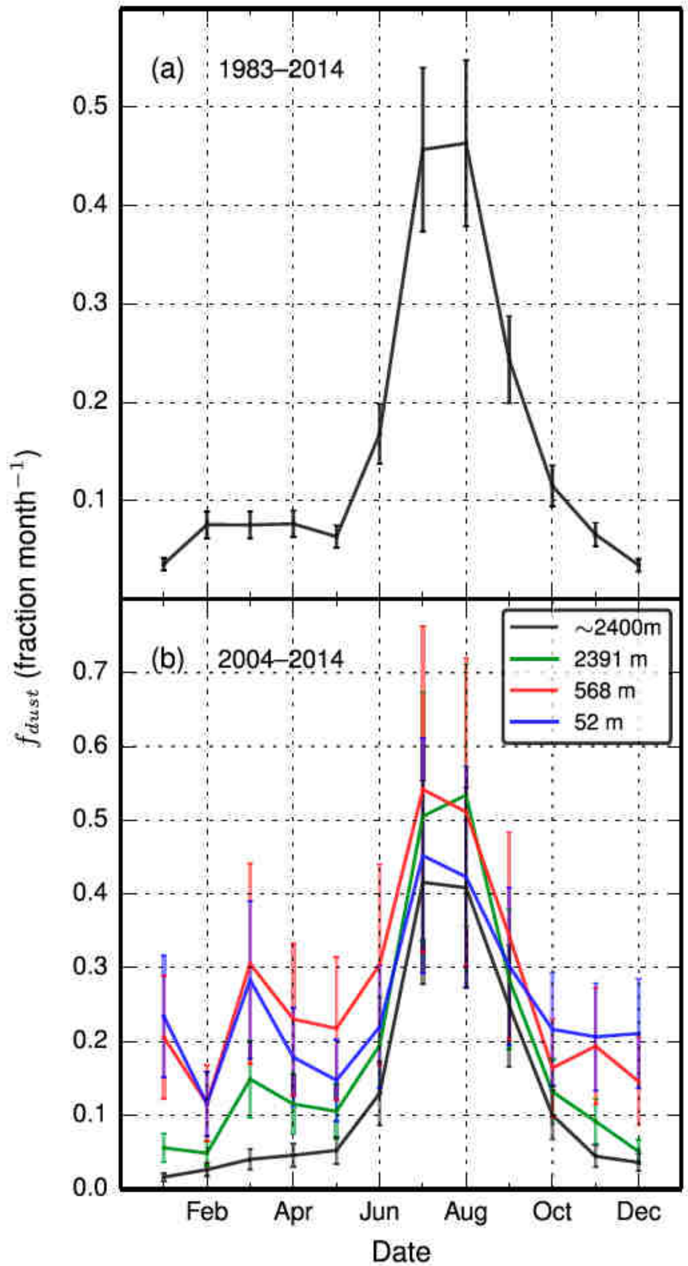
Clear-sky (days/month)

24.1± 0.6

18.9 ±0.8

21.6 ± 0.8

The f_{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

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
  - Meteorological data from NCEP-NCAR (UTH-cirrus thickness-AE relationship, Erasmus & Sarazin, 2000-2002)

- 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.

CANARIAN OBSERVATORIES UPDATES (CUps)

CUps 01-2015

Day time Cloud Cover at Teide Observatory

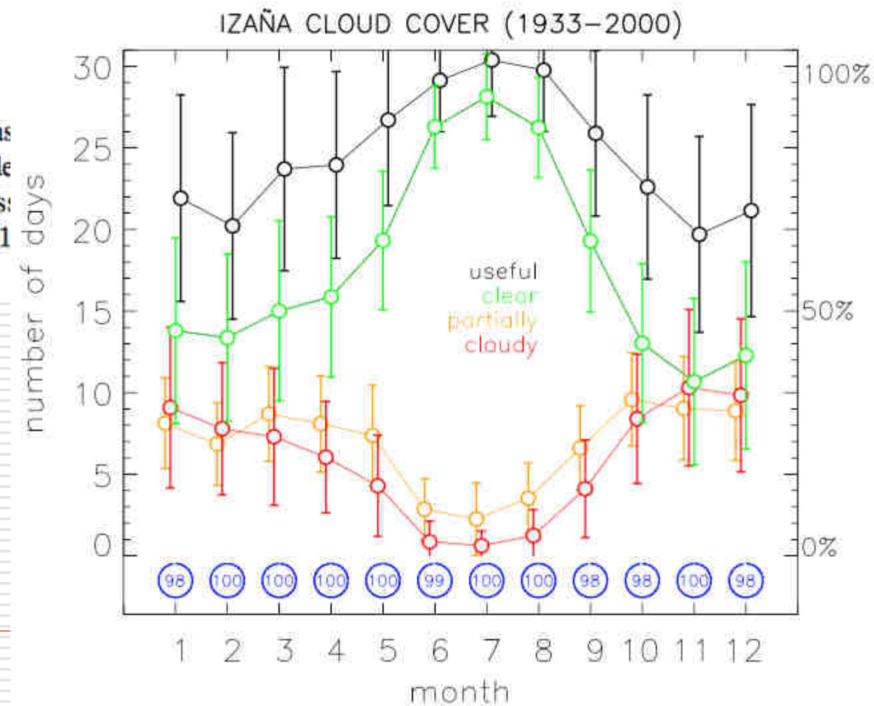
J.A. Castro-Almazán,[a,b*] A.M. Varela[a,b] and C. Muñoz-Tuñón[a,b]

[a] *Instituto de Astrofísica de Canarias, E-38200, La Laguna, Spain*

[b] *Dept. Astrofísica, Universidad de La Laguna, E-38200, La Laguna, Spain*

Abstract

We have exploited the European Climate Assessment & Datas
Observatory, Tenerife (Spain), to estimate the useful time at Teide
(1933–2000). The useful time, considered as the sum of days clas
94% in summer and 69% in autumn, with an average value of 81
November.



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%**.

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 measuremnts 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_{200hPa} and the velocity of the turbulence (Sarazin & Tokovinin , 2002)

High to low altitude wind correlation

$V^* \approx 0.4\ V_{200hPa}$ Sarazin & Tokovinin 2002
in Paranal and Cerro Pachón

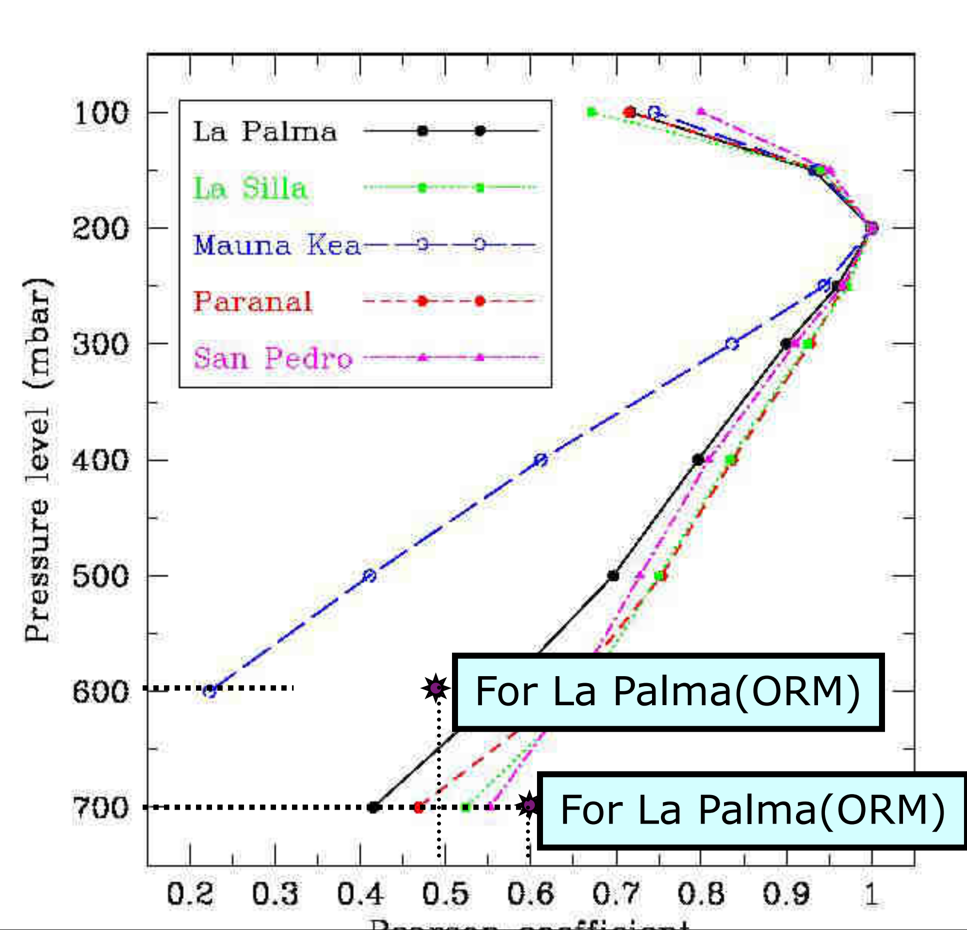
García-Lorenzo et al., 2005

- We have compared the 6-hourly any level with $V_{200\ hPa}$ (data from N archive)

- Similar high to low winds correlation except for Mauna Kea

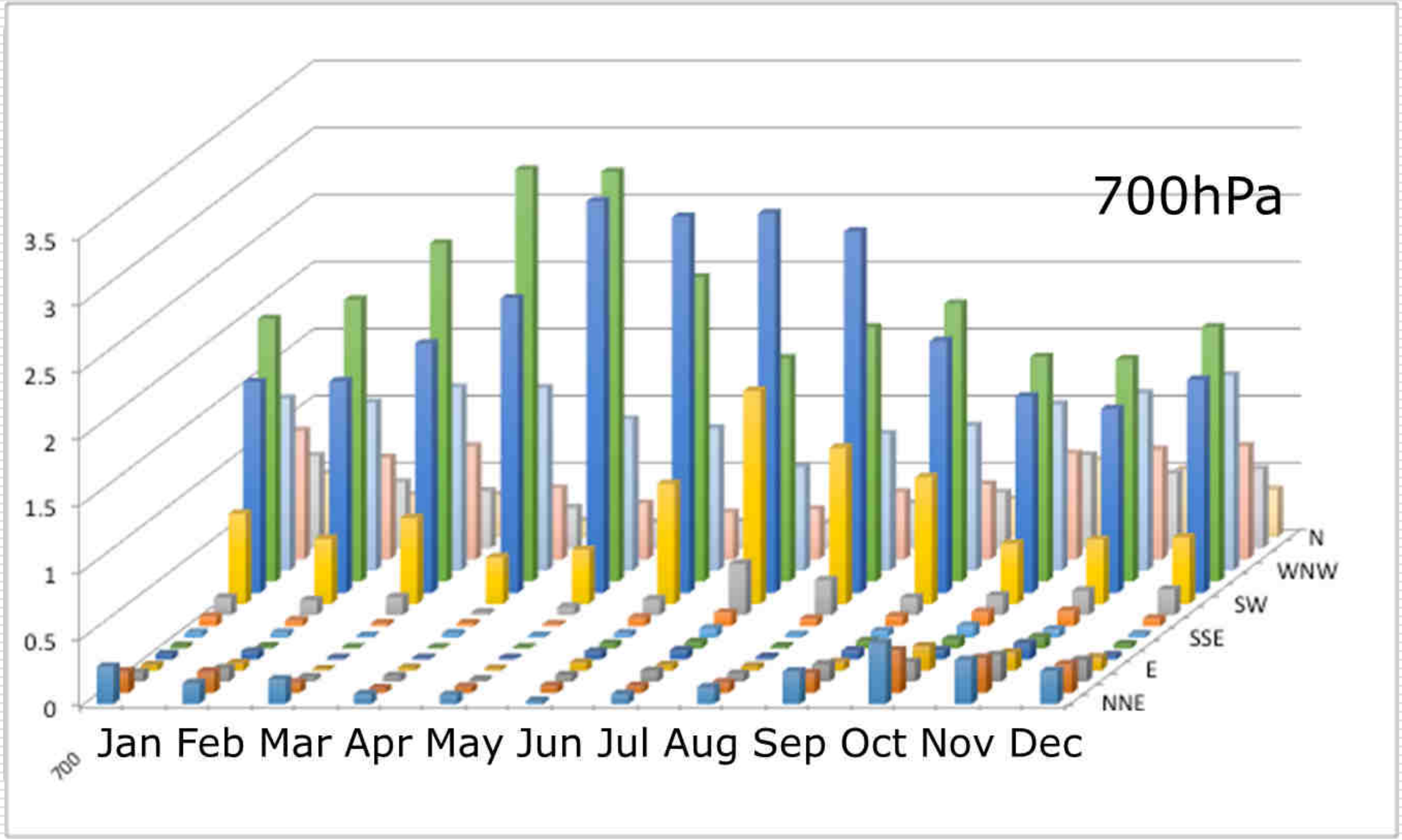
- Topography is affecting winds at the lowest levels

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

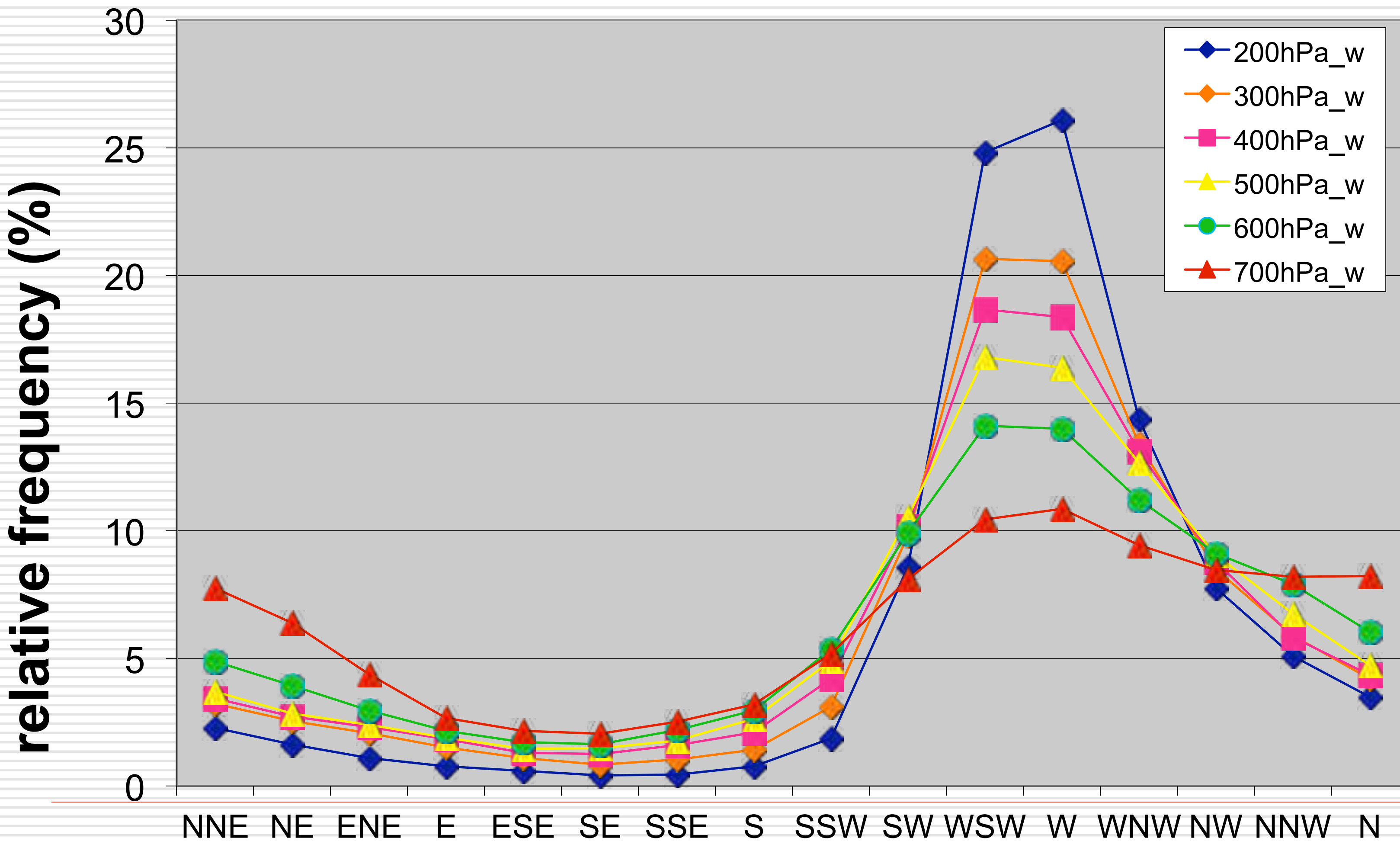


Ground level to low altitude winds connection studied at La Palma (Varela & Muñoz-Tuñón,2015)

Trade wind scenario at the ORM
Seasonal variation (NCEP/NCAR 22 years/24hrs)

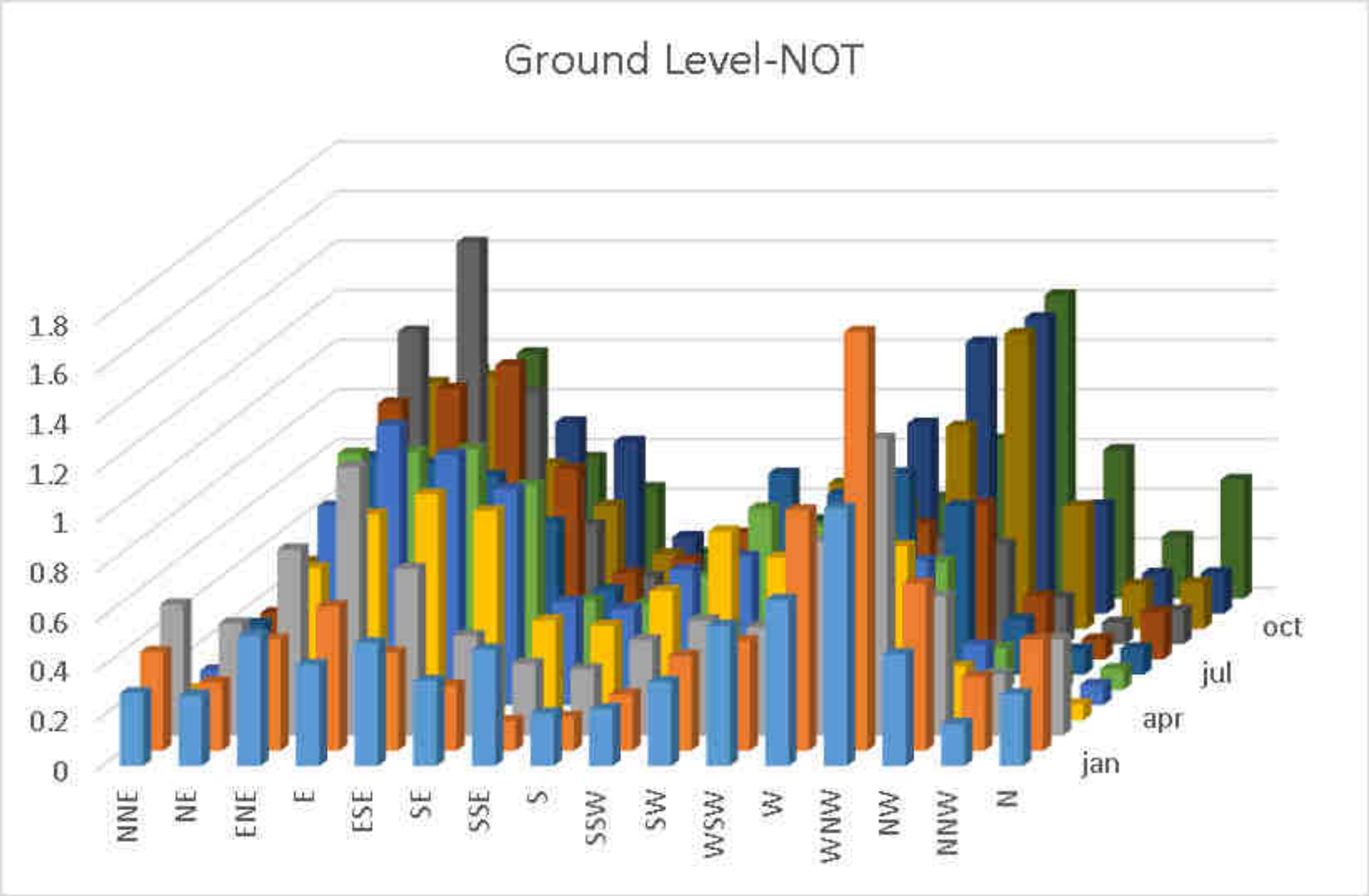


Trade wind scenario at the ORM (22 years)



Varela, CIAI-19/01/17

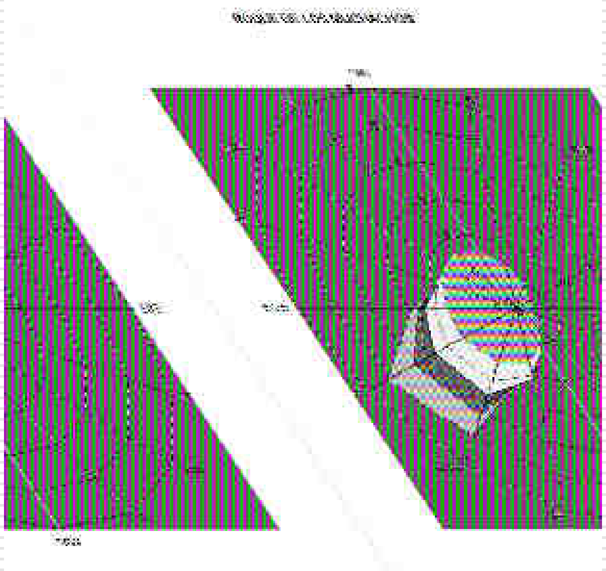
Trade wind scenario at the ORM (ground level)



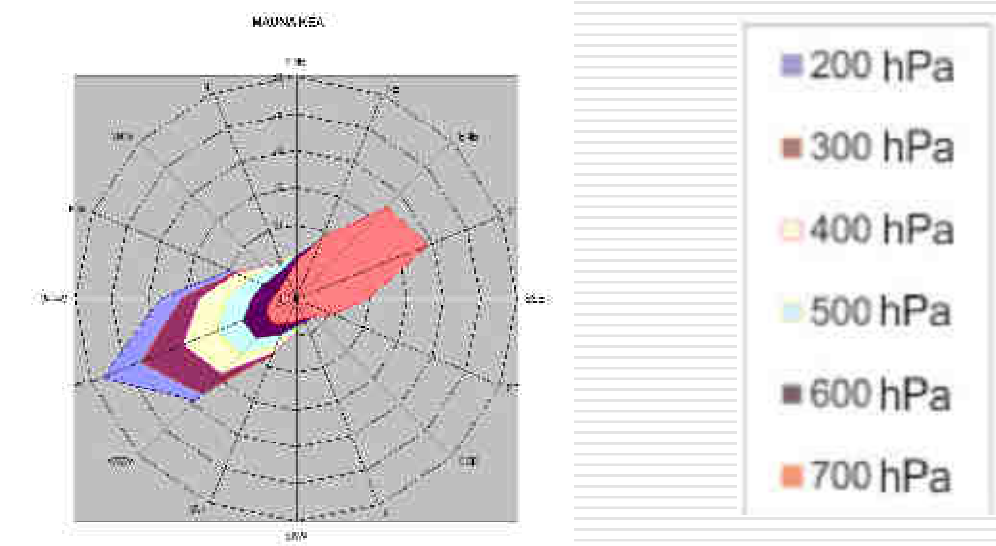
Troposperic wind rose at the ORM

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

La Palma



Mauna Kea

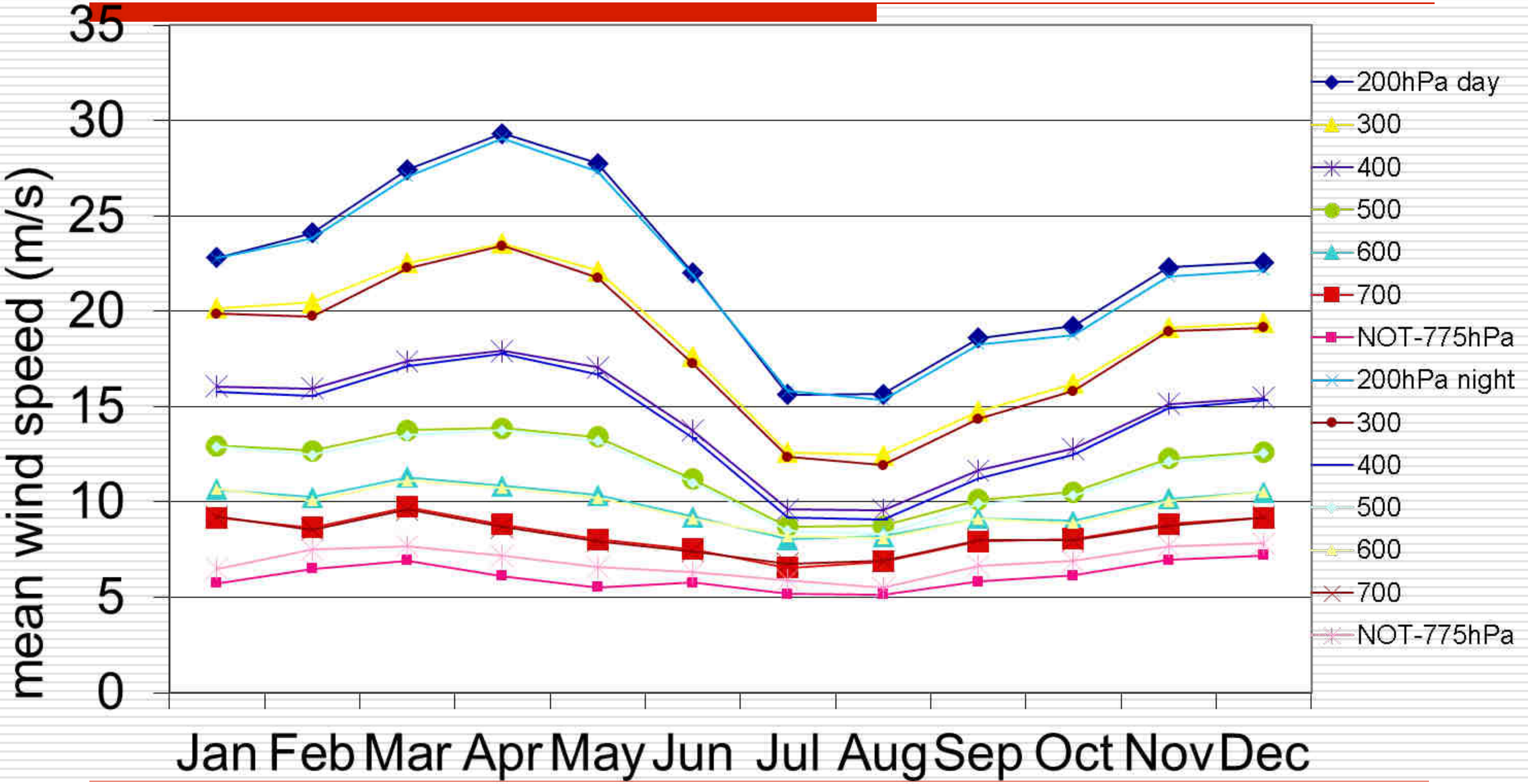


- No strong differences in wind direction profiles except for Mauna Kea.

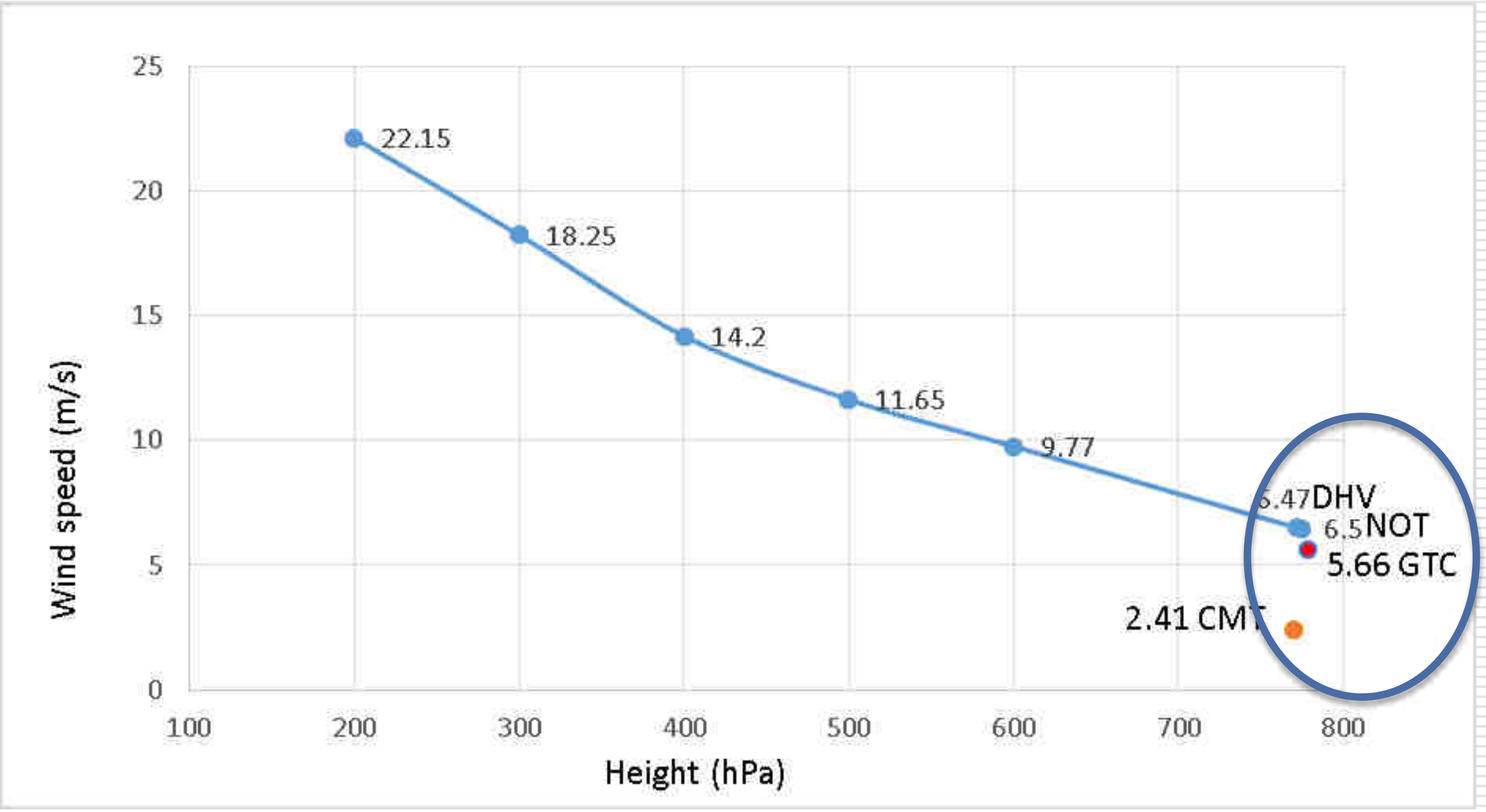
- In this case the wind speed at 200hPa would be not sufficient to estimate the atmospheric turbulence and in situ measurements would be necessary.

Wind speed seasonal dependency

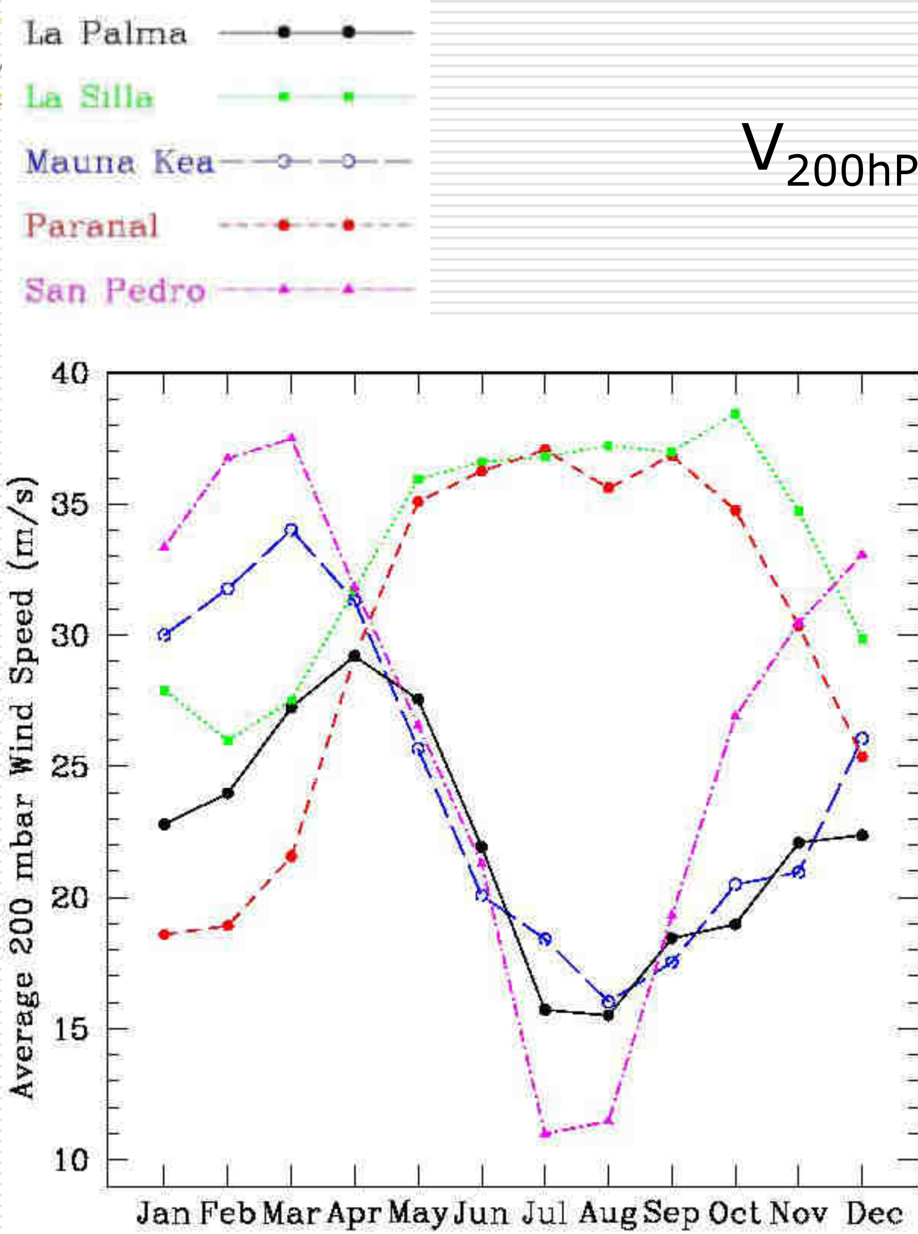
Varela & Muñoz-Tuñón, 2015



Wind speed continuity



V_{200hPa} comparison



***Tropospheric winds.* Period 1980-2002**

NCEP/NCAR database

Balloon Measurements

Adaptive Optics suitability ranking

Site	**Mean** (m/s)	**Median** (m/s)	σ (m/s)
La Palma (ORM)	22.13	20.79	11.67
San Pedro Mártir	26.55	24.57	15.39
Paranal	30.05	28.63	13.01
La Silla	33.35	32.77	12.94

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_{200hPa} 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.

Thanks for your attention