Tecniche Lidar per lo studio del particolato atmosferico e dello strato mescolato

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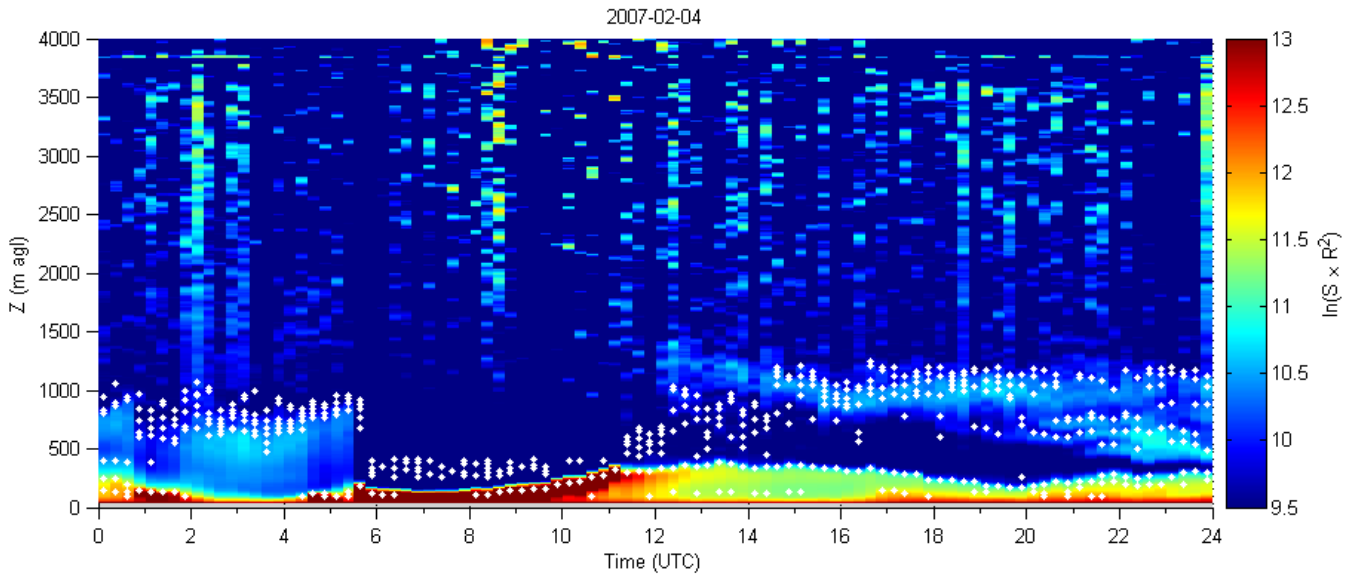


Corso ARPA Lazio – Roma - 16 Dicembre 2011

LIDAR

Il Lidar (acronimo di LIght Detection And Ranging) è uno strumento affine al RaDAR (RAdio Detection And Ranging) ma che, invece delle microonde, impiega come sorgente luce visibile, ultravioletta o infrarossa;

Grazie alla minore lunghezza d'onda il Lidar permette, rispetto ai Radar, il telerilevamento di corpi molto piccoli, tipicamente delle dimensioni del micron, quali gli aerosol atmosferici (TSP).

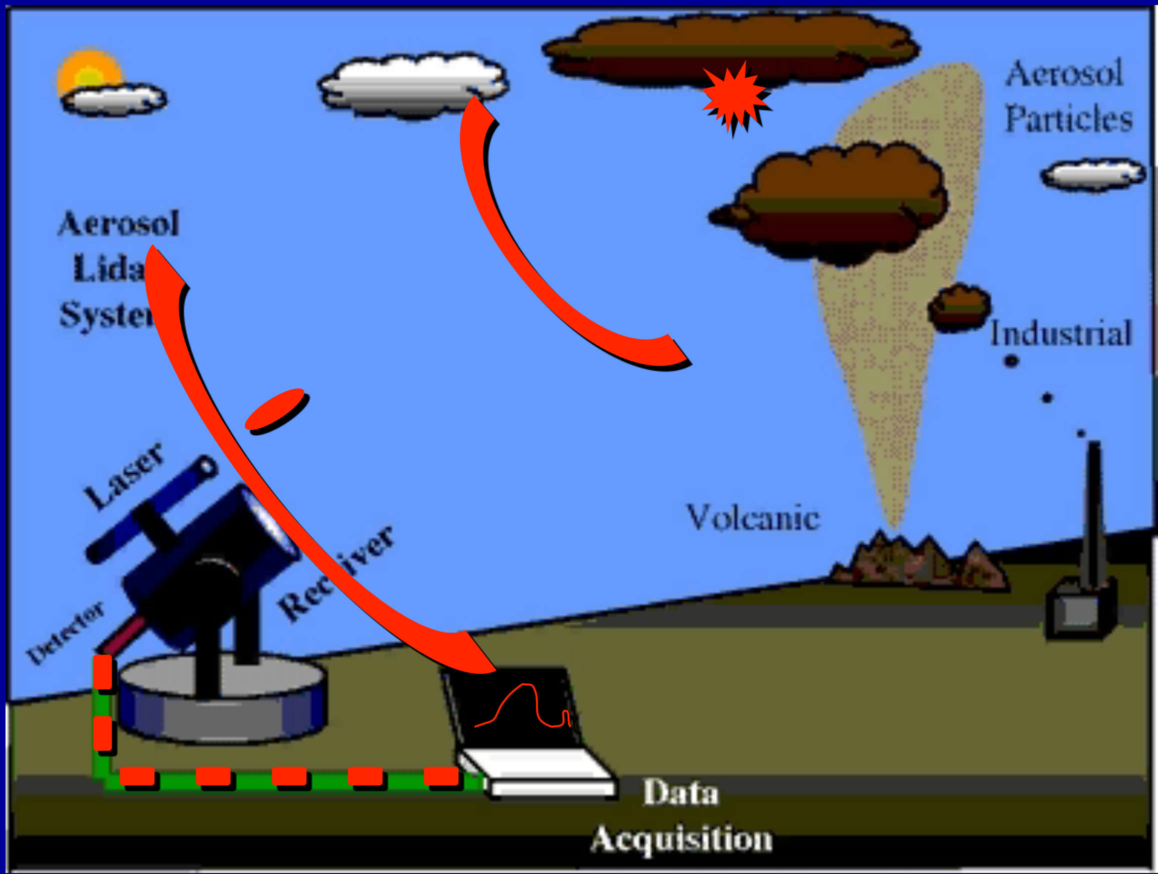
What is LIDAR?

•A pulse laser source provides range (distance) information from the time delay between the transmitted and received pulse.

•The light scattered from the aerosols and molecules by a telescope and focus on an optical detector.

•The detector convents this light into an electronics signal.

•The signal is digitized, processed and displayed by a computer.



Principal components of a Lidar system:

Emitter: Pulsed lasers (from UV to IR). Nd-YAG, Ruby, Alexandrite, Ti-Sa, Diode, etc.;

Receiver: Optical telescopes. From single lens (0.01 m^2) to multiple-mirror (10 m^2);

Bandpass: Interference filters ($\Delta\lambda$ 0.1-10 nm), monocromators, interferometers, etc.;

Detector: Photomultipliers (UV-NIR), Avalanche photodiodes (IR) (10^5-10^7 current gain);

Signal acquisition: A/D conversion, Photon counting (10-100 Mhz sampling rate);

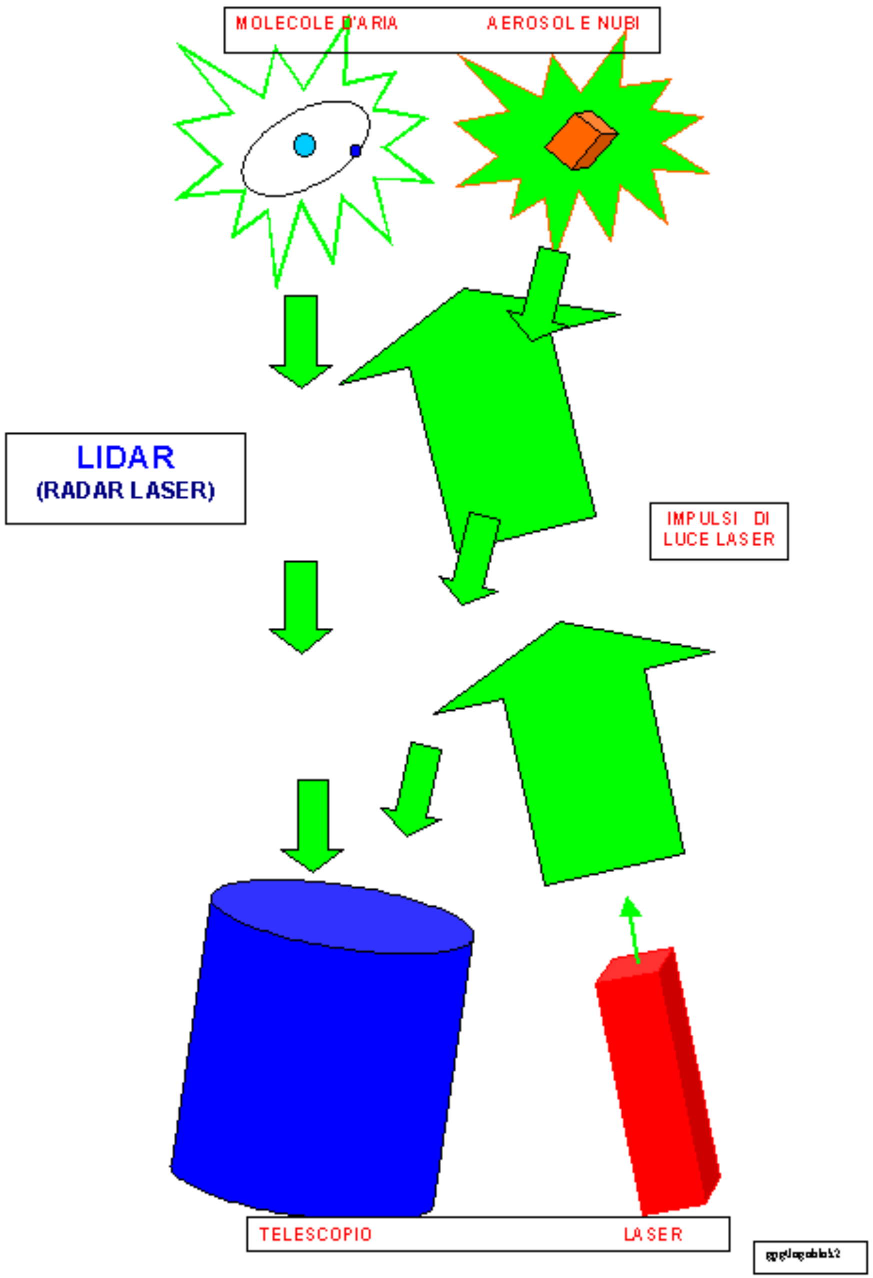
General properties:

Typical laser beam divergence of 1 mrad generates spots of 1 m at 1 km and of 10 m at 10 km.

Considering that typical range resolution is 10-100 m the resulting lidar sampling volume is very small;

High laser repetition rates (10-5000 Hz) can allow for short term averaging (seconds);

These characteristics allow to study atmospheric processes ranging from the micro to the macro scale.



LIDAR
Light Detection And Ranging

In atmosfera rivela la luce retrodiffusa da molecole, aerosol e nubi;

Impulsi laser UV-VIS-NIR (ns)

Ranging: Tempo di volo (1μs=150m)

Back-scatter elastico: aerosol, densità

Back-scatter anelastico (Raman, DIAL, fluorescenza): aerosol, specie chimiche

Parametri Tipici della Misura:

Risoluzione in quota: metri
Risoluzione temporale: secondi-minuti
Quota minima 10-500m

Applicazioni LIDAR

I Lidar rilevano dal suolo alla stratosfera profili di:

- **Aerosol**
- **Nubi**
- **Nebbie**
- **Altezza dello strato mescolato**
- **Nubi vulcaniche**
- **Polveri desertiche**
- **Pennacchi da incendi**
- **Temperatura (molecolare)**
- **Vapor Acqueo**
- **Gas minori (SO_2, O_3, CO_2)**

Trovando quindi applicazioni importanti negli studi di:
Meteorologia, Qualità dell'Aria, Clima e
in applicazioni per Protezione Civile, Traffico Aereo

Equazione Lidar (Backscatter Elastico):

L'energia E ricevuta dalla distanza R è:

$$E = C \cdot E_L \cdot \frac{A_0}{R^2} \cdot (\beta_m + \beta_a) \cdot e^{-2\int_0^R (\sigma_m + \sigma_a) dR}$$

dove:

E_L : Energia dell'impulso laser;

A_0 : Area del ricevitore (telescopio);

C : Costante lidar;

β : Coefficiente di backscatter (m=molecolare, a=aerosol)

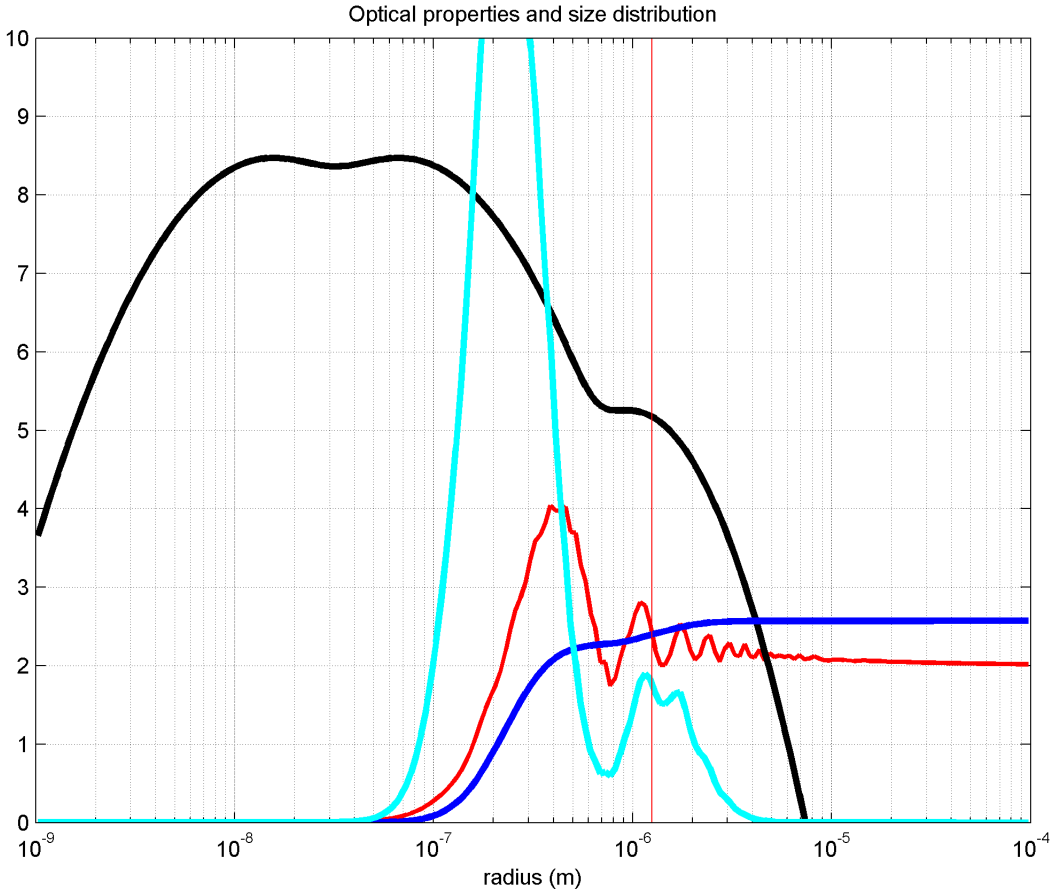
σ : Coefficiente di estinzione (m=molecolare, a=aerosol)

Per risolvere l'equazione rispetto β_a o σ_a:

β_m e σ_m e LR= σ_m / β_m sono misurati o modellati

Tutte le variabili sono funzione della lunghezza d'onda laser

Il massimo effetto ottico dell'aerosol atmosferico viene da particelle di raggio compreso tra 0.1 e 3 μm



Curva Nera: Concentrazione particolato Log10 N /dLog r

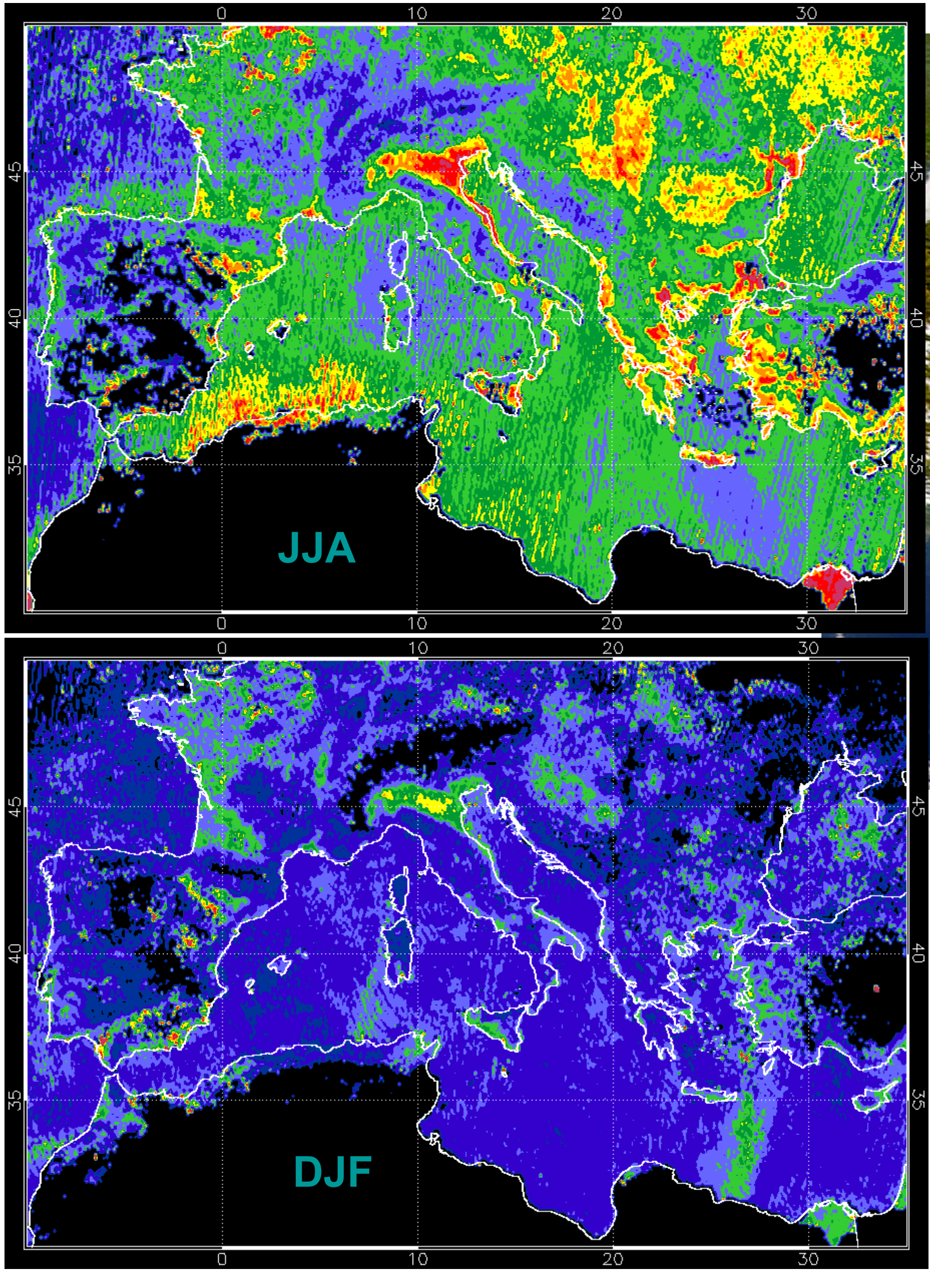
Curva rossa: Efficienza di estinzione Mie Q_{ext} a 532 nm

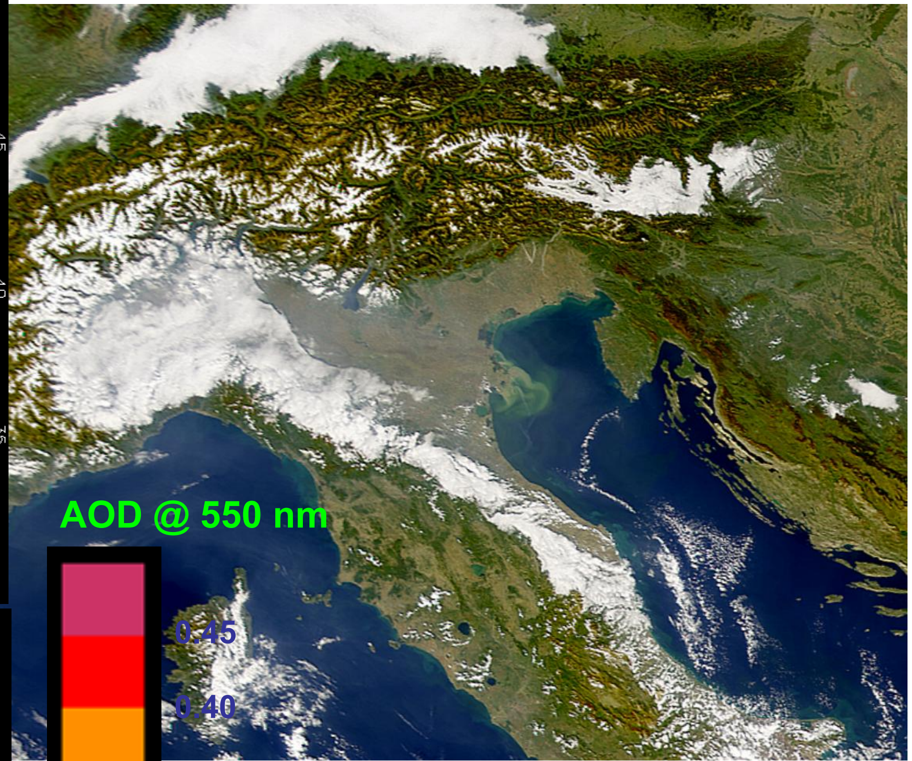
Curva ciano: Coeff. di estinzione $C_{ext}= N*Q_{ext}*r^2$

Curva blu: estinzione cumulativa x10 (km-1)

- **Coefficiente di estinzione a 532 nm: 0.25696 (km-1)**
- **Massa totale con densità 1.5 g/cm3: 107.489 (μg/m3)**
- **Concentrazione di particelle: 14300 (cm-3)**

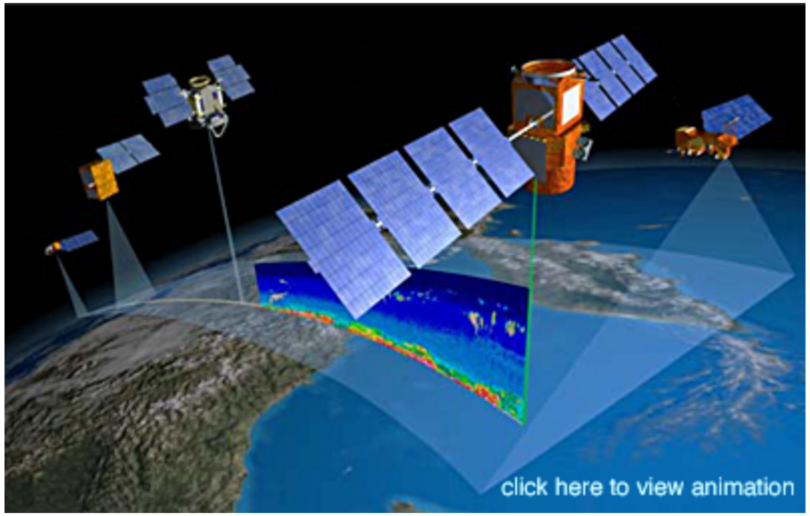
Aerosol Optical Depth (AOD) in 2001 (MODIS data)





Barnaba e Gobbi, Atmos.Chem. Phys. 2004

La complessità (ed il costo) dei sistemi e dei codici di analisi dati variano con le prestazioni



NASA/CNES CALIPSO
Polarization Lidar, 2006-

VELIS Polarization Lidar

Leosphere Polarization Lidar

ARM Raman Lidar, Boulder, USA

Vaisala Lidar-Ceilometer

The Lidar (Market) World

400k					2λRam Polar
200k				2λRam	
100k		1λRam	Polar. or 2λ		
50k	El.Bsc				
	Estim. EXT ±40%	EXT ±10%	EXT (± 30%) +shape or mode	EXT ±10% +mode	EXT + Mode + shape

Complexity,
Costs,
Faults

Information Retrieved

Further retrievals as volume (mass) require further processing….

La scelta di un sistema Lidar dipende quindi dalla tipologia della misura:

- Sistemi semplici: monitoraggio
- Sistemi complessi: ricerca

Le prossime trasparenze mostreranno esempi di osservazioni Lidar aerosol di interesse ambientale:

1. Distribuzione in quota;

2. Climatologia;

3. Rilevamento di polveri sahariane;

4. Altezza dello strato mescolato;

Profili Lidar VELIS (elastico-polarizzazione) Roma

Rapporto Depolarizzazione

$D = S_{\perp} / S_{//}$

Rapporto di Backscatter

$R = \beta_{a+m} / \beta_m$

AOD = ∫Ext

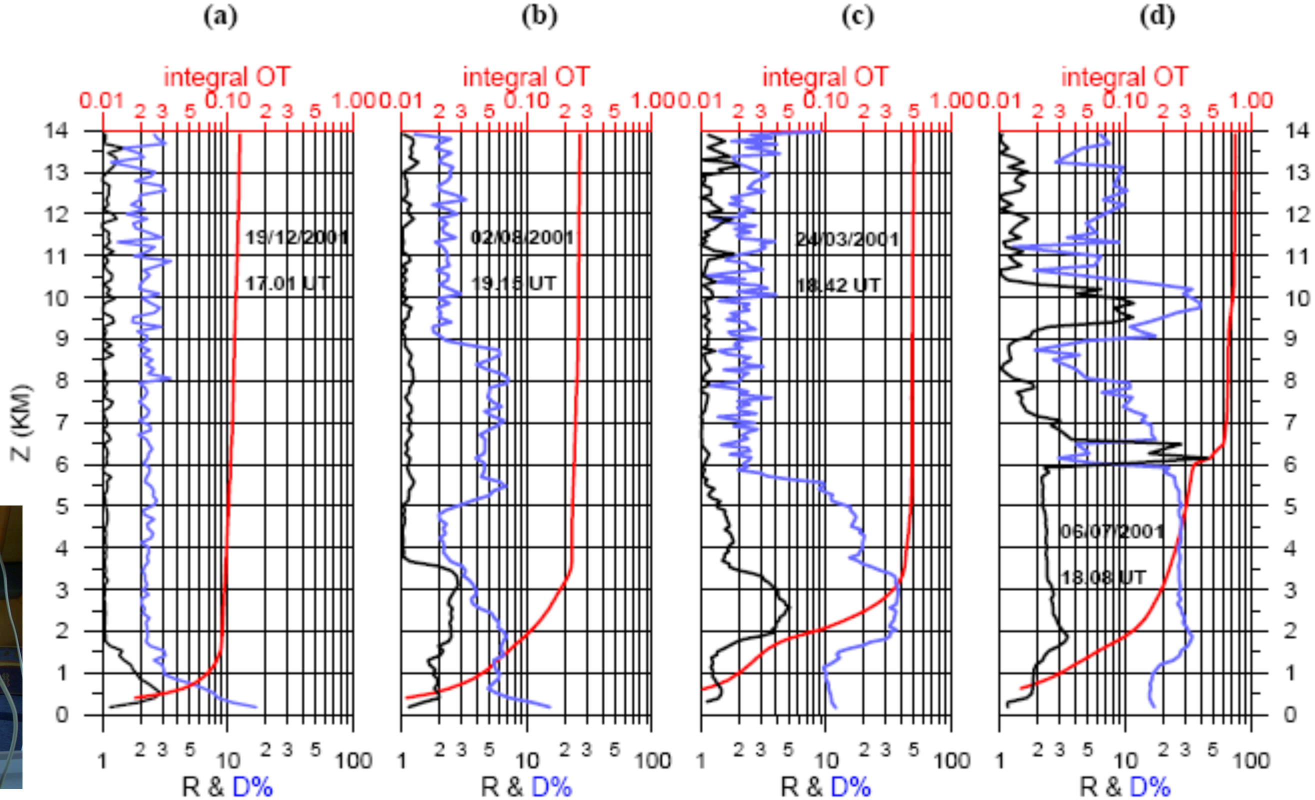


Fig. 1. Typical lidar profiles (at 532 nm) representative of: **(a)** clear winter conditions; **(b)** summer PBL aerosol and pre-dust conditions; **(c)** spring dust conditions, and **(d)** summer dust, liquid cloud and cirrus cloud conditions. The three curves reported in each plot represent vertical profiles of backscatter ratio R (black line), depolarization ratio D(%) (blue line), and (red line) the integral (from ground) of the extinction coefficient, i.e. OT(z), respectively.

Gobbi et al., ACP, 2004

VELIS Lidar PRODUCTS

Day & Night-time Profiling of: **NIGHT (DAY)**

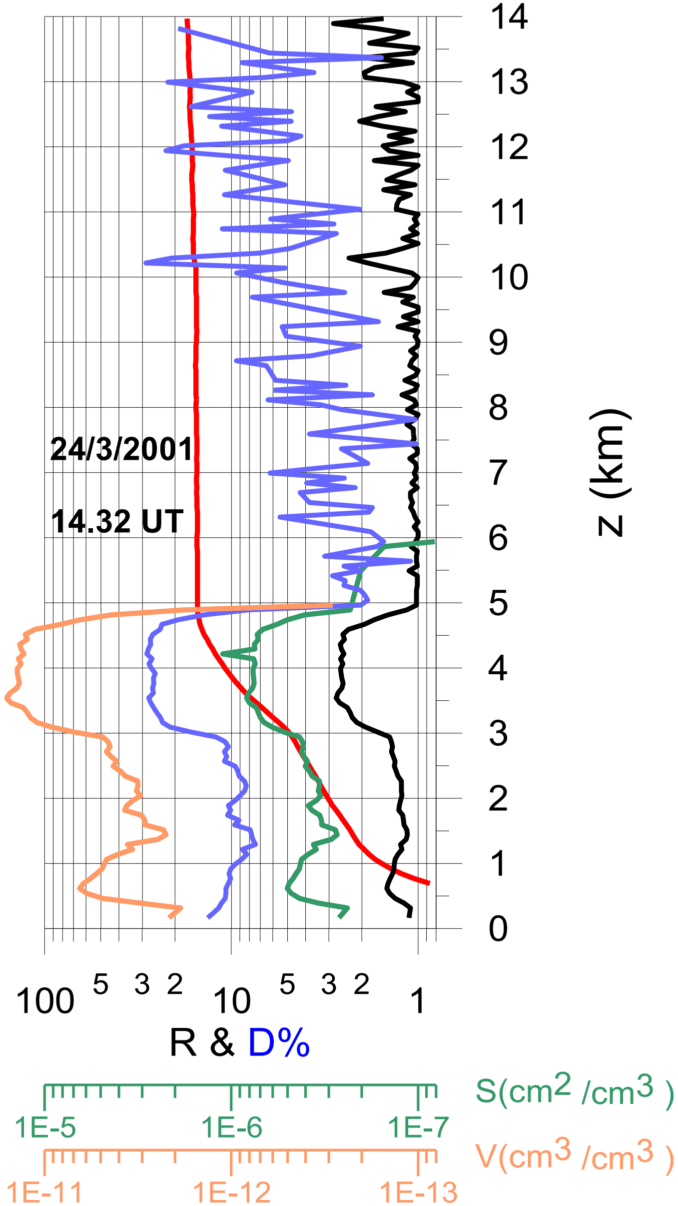
- Backscatter Coeff. 0-4000 m (Stat. Error 1% (2%))
- Backscatter Coeff. 4000-6000 m (Stat. Error 4% (8%))
- Backscatter Coeff. 6000-8000 m (Stat. Error 7% (30%))

- Extinction Coefficient (Typ. Error 25% [3])
- Aerosol Surface Area (Typ. Error 40% [1, 2, 4])
- Aerosol Volume (Typ. Error 40% [1, 4])

(6-minute averages)

TOTAL DEPOLARIZATION $D = Signal_{\perp} / Signal_{//}$

AEROSOL DEPOLARIZATION $D_a = \beta_{a\perp} / \beta_{a//}$



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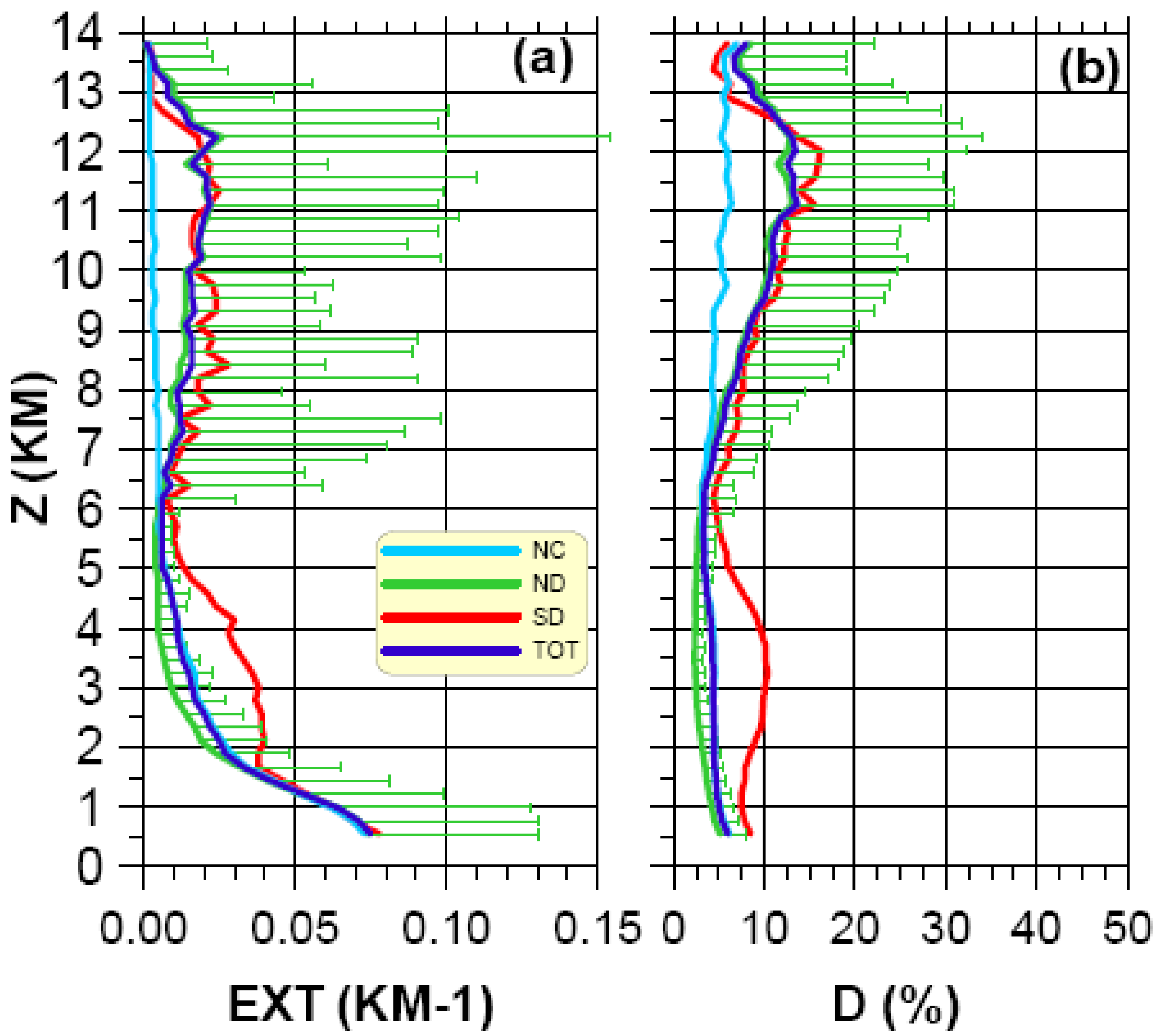
1) Barnaba & Gobbi, *J. Geophys. Res.*, 106, 3005-3018, 2001
2) Barnaba & Gobbi, *J. Atmos. Ocean. Tech.*, 21, 428 – 442, 2004
3) Gobbi, Barnaba, Blumthaler, Labow & Herman, *Atmos. Res.*, 61, 1-14, 2002
4) Gobbi, Barnaba, Van Dingenen, Putaud, Mircea & Facchini, *Atmos. Chem. Phys.*, 3, 2161-2172, 2003
5) Gobbi, Barnaba & Ammannato, *Atmos. Chem. Phys.*, 4, 351-359, 2004

In the year 2001, VELIS Lidar observations at Rome revealed Saharan dust on 27% of the measurement days.

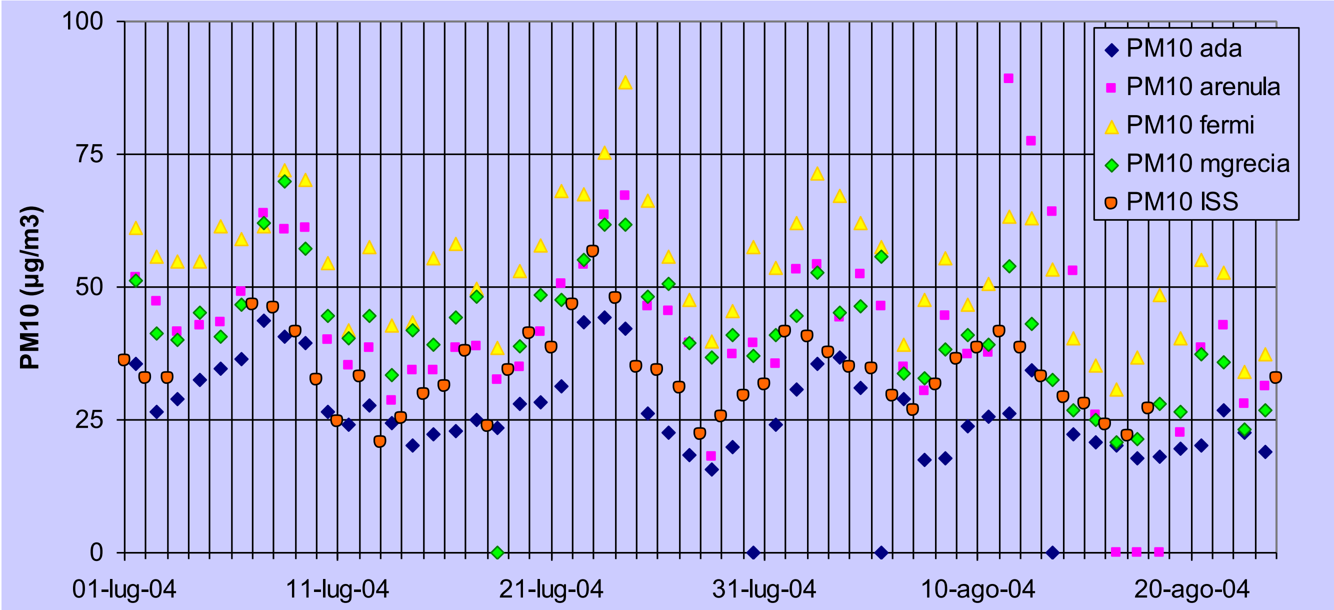


Green Line: Excluding Saharan dust events.
Red Line: In Saharan dust conditions.

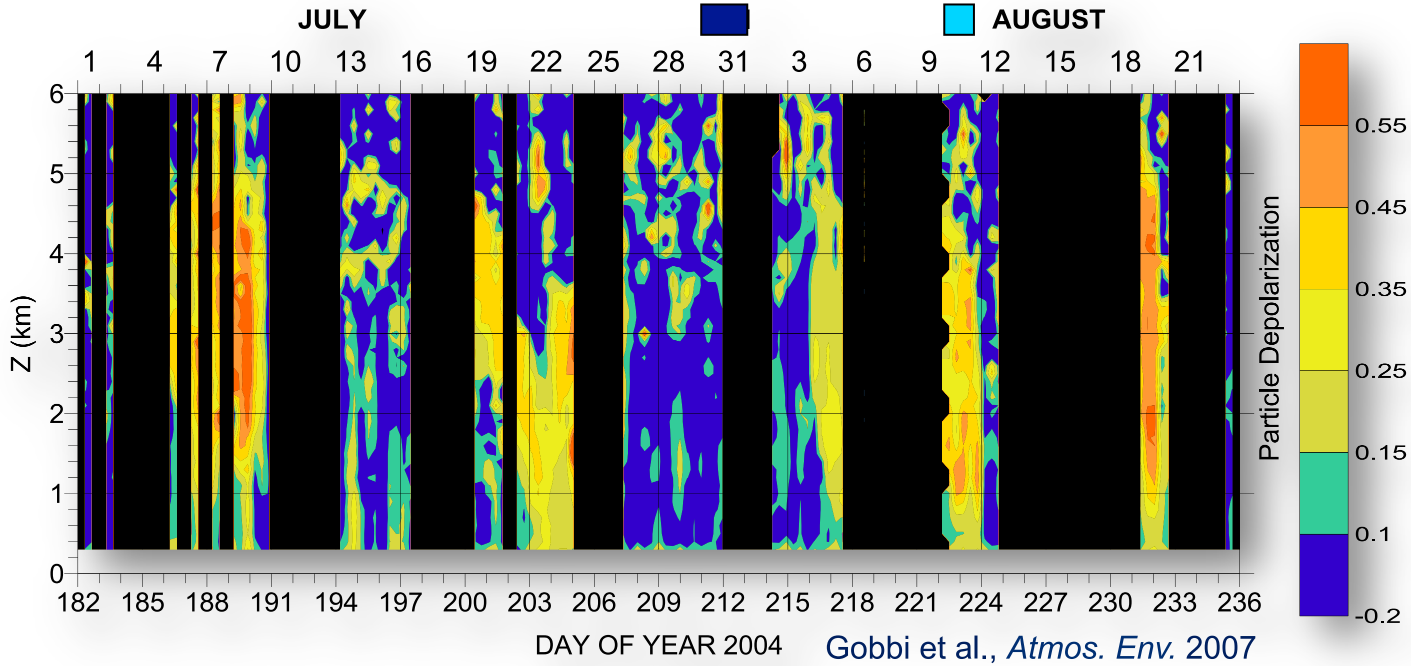
Gobbi et al., Atmos.Chem. Phys. 2004

ROME, July-August 2004 Saharan advections

PM10



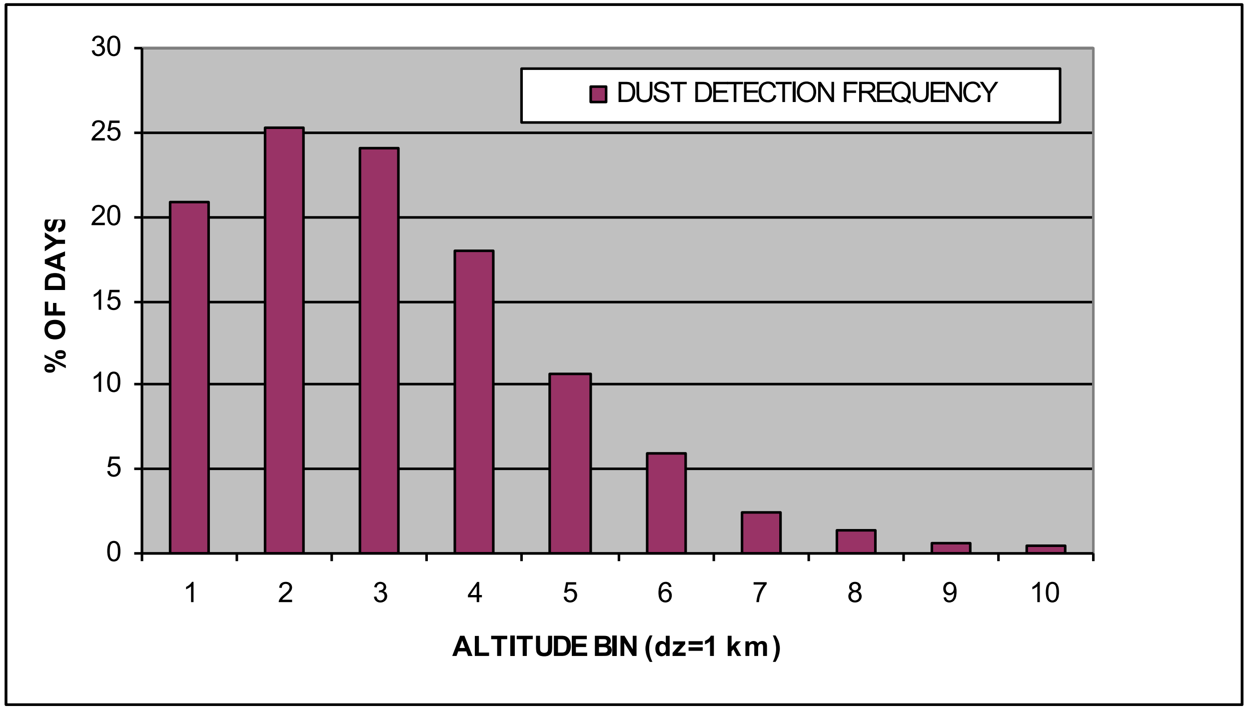
LIDAR (DEPO)



Gobbi et al., *Atmos. Env.* 2007

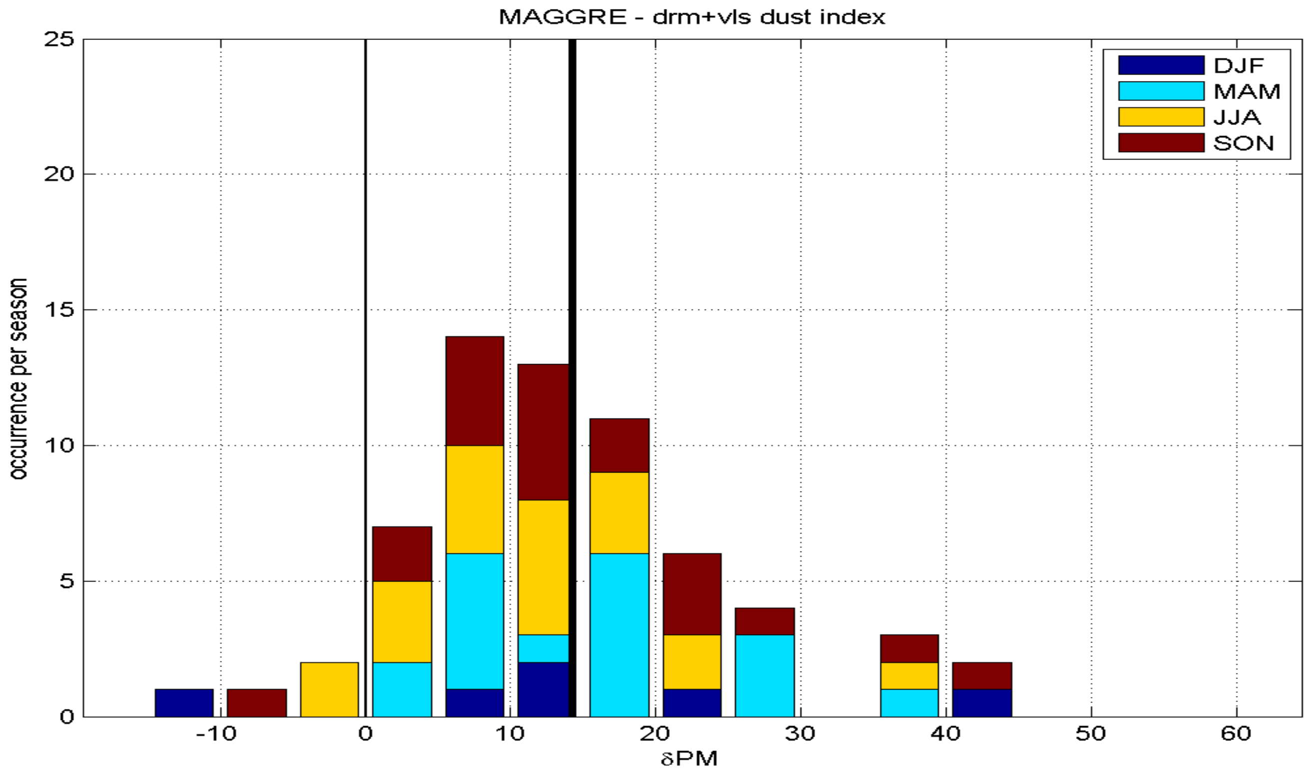
ISAC Rome Polarization Lidar Climatology

ISAC Rome has been running polarization lidar observations since 2001, collecting profiles on about 50% of the days of this period.



Along the four-year period 2001-2004, lidar measurements (703 days) detected Saharan plumes transiting over the city on ~28% of the time, with minimum occurrence in wintertime. Dust was observed to reach the ground on ~20% of the time. Average duration of events was ~ 2.7 days

PM10 levels measured at air quality monitoring stations in the period 2001-2004 have been analysed against concurrent Saharan dust advection events to infer the impact of these natural conditions. Saharan events were either detected by the ISAC-CNR VELIS polarization - lidar observations (703 days) or forecasted by web-available numerical models.



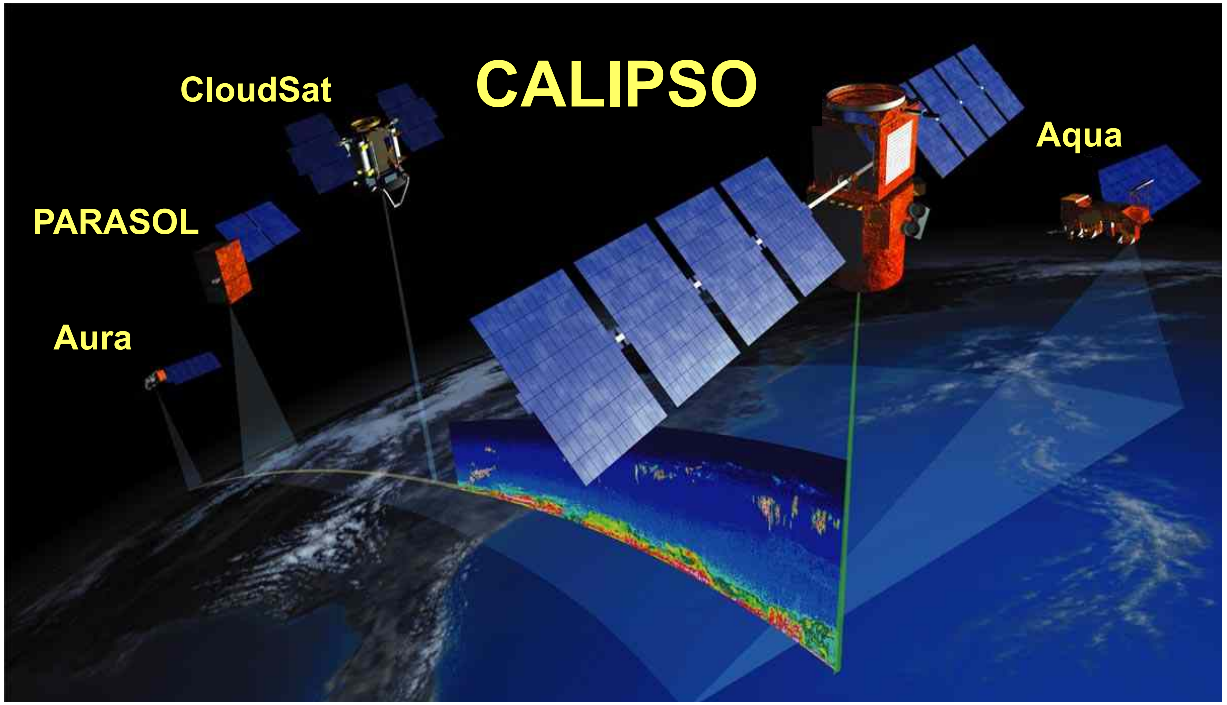
Seasonal distribution of PM10 changes associated to dust advections at the Rome heavy traffic station of Magna Grecia

Outcomes:

The analysis of Rome PM10 datasets based on the differential between the five-day average PM10 before dust events and average PM10 during the events (timing determined on the basis of both lidar and model records) showed Saharan dust advections to exert a meaningful impact on the PM10 records, with average increases of the order of 15±10 µg/m3 (Gobbi et al., 2011, in preparation).

This analysis led to conclude that exceedances of the 50 µg/m^3 PM10 limit occurring in the city in this four-year period had a Saharan (i.e., natural) origin: on 26% of the cases, at the heavy traffic station of Magna Grecia, on 32% of the cases at the urban background station of Villa Ada, and on 43% of the cases, at the regional background station of Fontechiari.

CALIPSO: mission concept



- **Orbit:** 705 km, 98° inclination, in formation with Aqua, CloudSat and Parasol
- **Launch 2006**
- **Mission duration: >3 years**
- **Three co-aligned instruments:**
  - 3-channel lidar
    - 532 nm ||
    - 532 nm ⊥
    - 1064 nm

Vertical distribution of aerosols and clouds

  - Imaging IR radiometer
- Wide-field camera

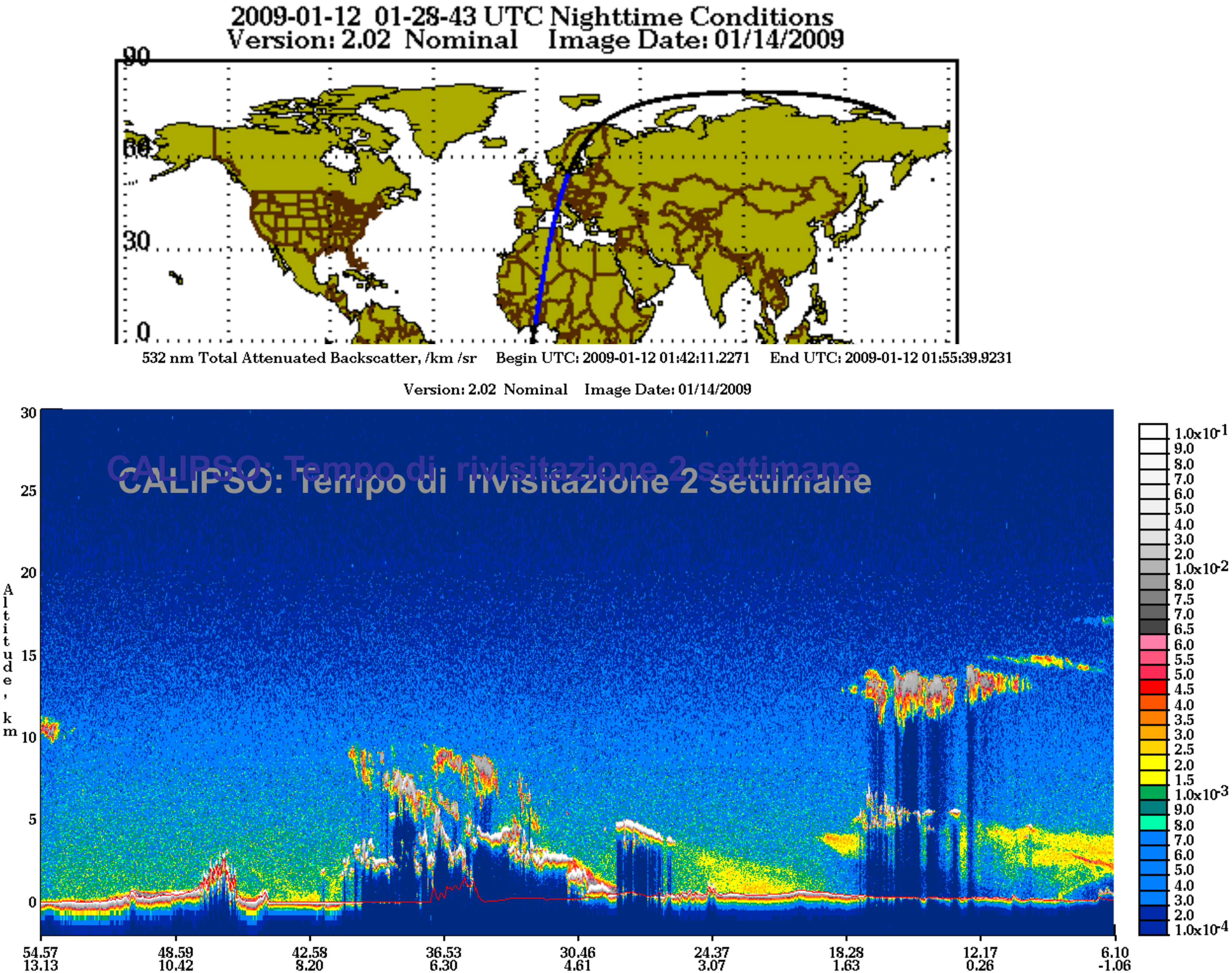
Aerosol / cloud properties

Complementary Instruments

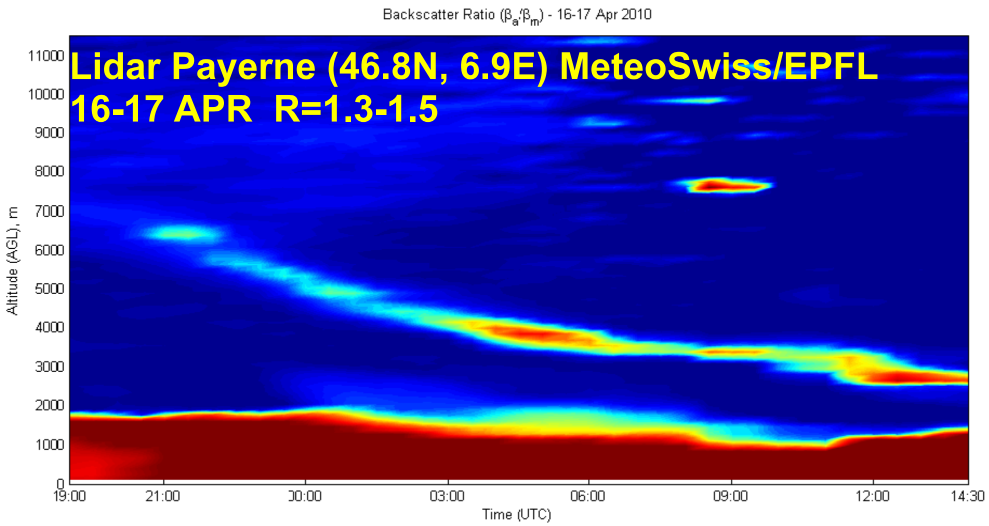
- CloudSat radar (cloud profiles)
- Aqua CERES (top-of-the-atmosphere radiation)
- Aqua AIRS / AMSU-A / HSB (atmospheric state)
- Aqua MODIS (aerosol / cloud properties)
- PARASOL (aerosol / cloud properties)
- Aura OMI (aerosol absorption)

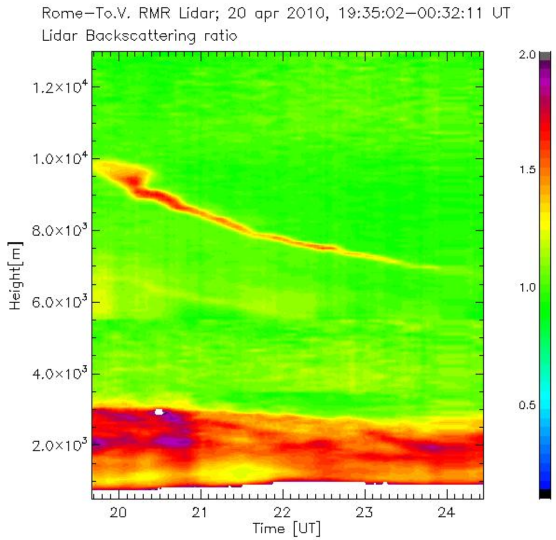
Adapted from J. Pelon: Active remote sensing of aerosol and clouds from space in the CALIPSO mission

CALIPSO: Tempo di rivisitazione 2 settimane

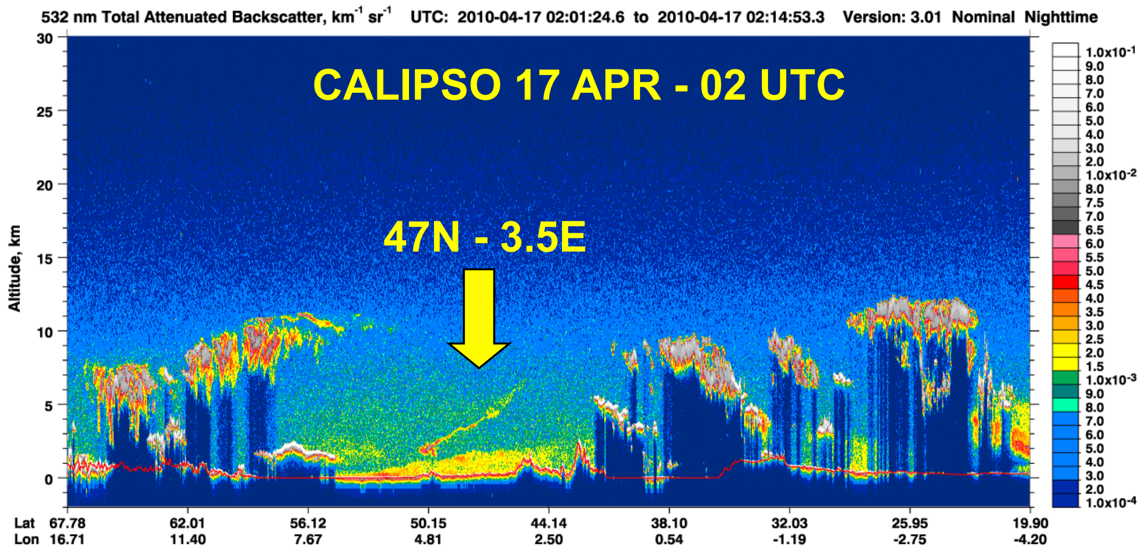


Isolated vs. Mixed Volcanic Clouds: Aloft





Raman Lidar ISAC Rome (41.8 N, 12.6 E, 120 m asl) 20 APR - 21UTC Backscatter Ratio 532nm R ~1.3-1.5



At Mace Head and Hohenpeissemberg ~10 times more?

$BksCoeff_{532}$= 1-1.5E^{-3} km^{-1}sr^{-1}
Ext_{532} ~ 0.05-0.075 km-1

Aerosol e Strato Mescolato

- Il LIDAR può fornire l'evoluzione nel tempo e in quota di traccianti quali l'aerosol ed il vapor acqueo.

- Le stratificazioni di questi traccianti (noi osserviamo l'aerosol) rivelano l'altezza dello strato mescolato (e.g., Eresmaa et al., ACP, 2005).

- Abbiamo impiegato un Lidar-Ceilometer Vaisala LD-40 per osservare il ML e la concentrazione di aerosol in varie condizioni atmosferiche e località:

Innsbruck: mountain site (~600 m ASL)

Winter and summer campaigns

Milano Bicocca: urban site

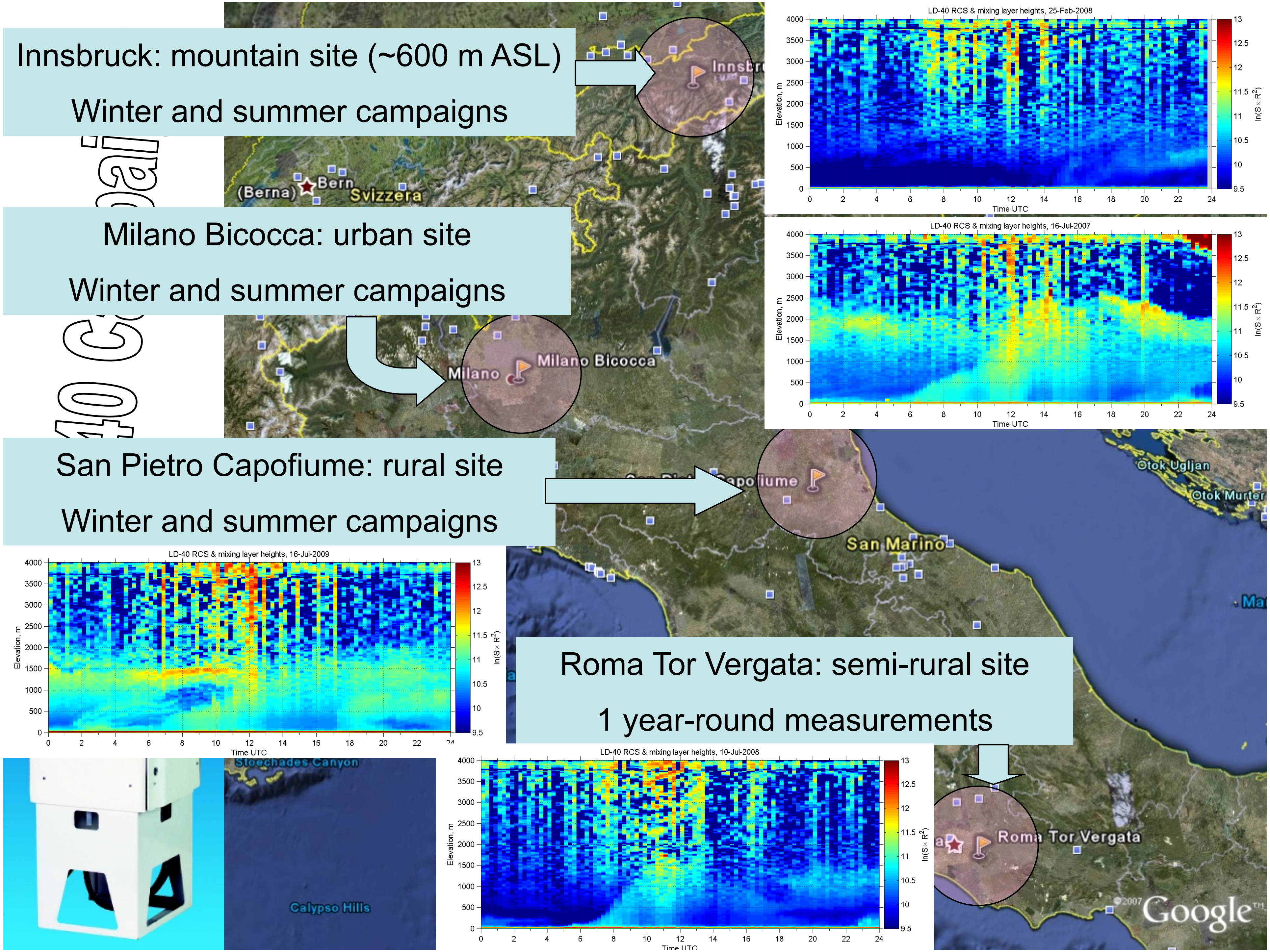
Winter and summer campaigns

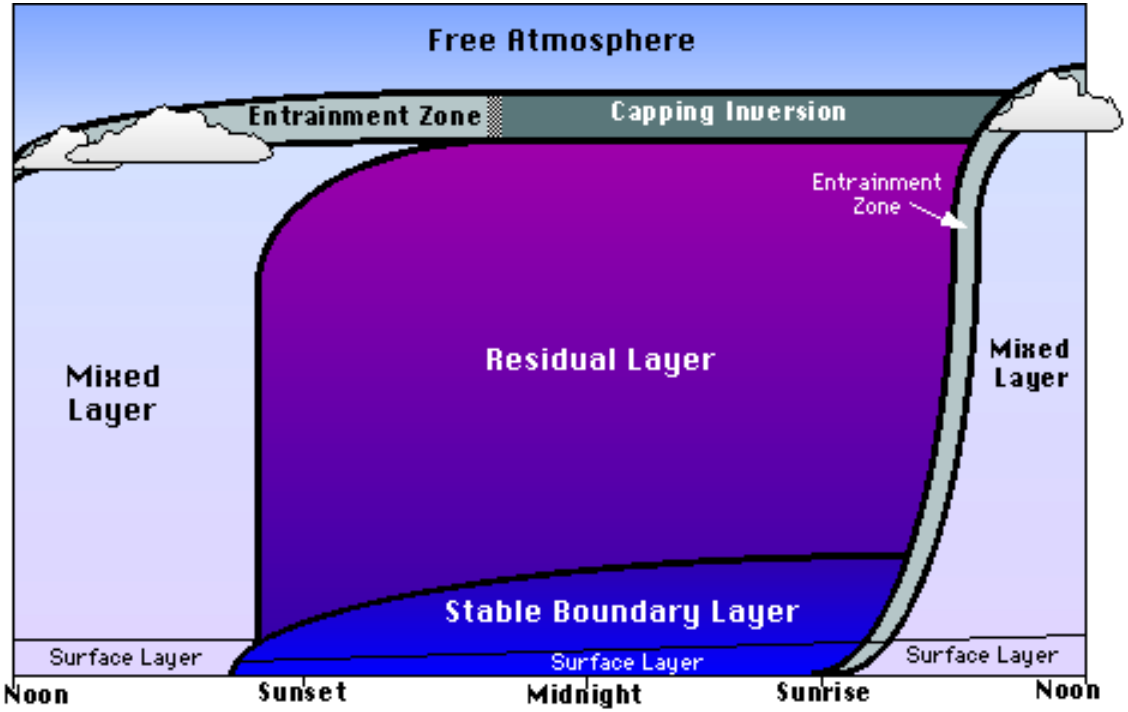
San Pietro Capofiume: rural site

Winter and summer campaigns

Roma Tor Vergata: semi-rural site

1 year-round measurements





Structure of Planetary Boundary Layer
adapted from Stull, 1988.

"The mixing height is the height of the layer adjacent to the ground over which pollutants or any constituents emitted within this layer or entrained into it become vertically dispersed by convection or mechanical turbulence within a time scale of about an hour" (Seibert, Atm. Env. 2000).

PBL Determination by Lidar

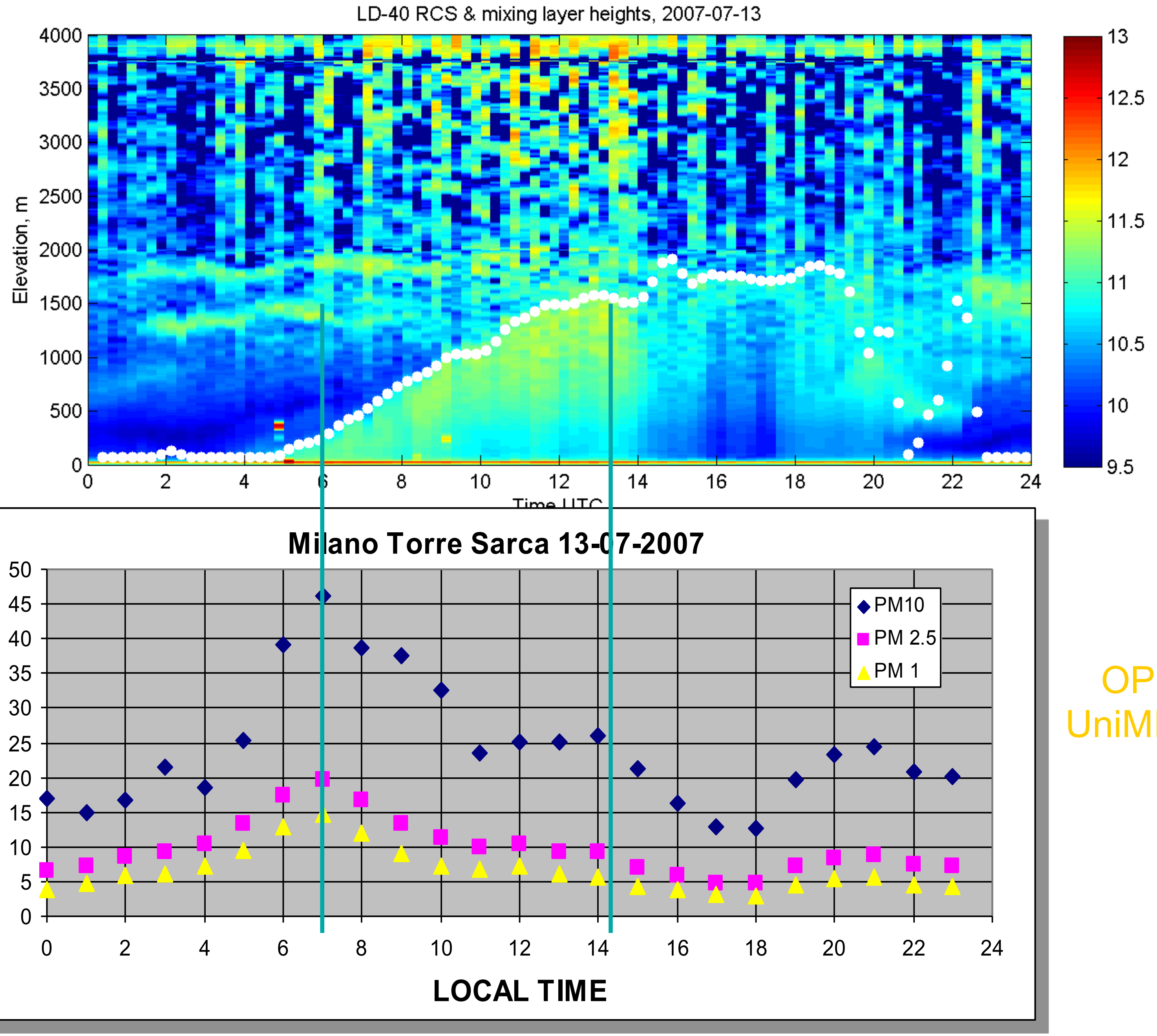
- **In general, the automated MLH retrieval algorithms belong to three categories:**

1) **Threshold methods: determination of the lowest height for which the range-corrected signal (RCS) falls under a threshold value** (*e.g. Melfi, 1985*);

2) **Variance methods: the spatial-temporal variance of the RCS is higher in high turbulence layers, and a threshold in the RCS variance shows the top of the ML** *(e.g.: Hennemuth et al, 2006);*

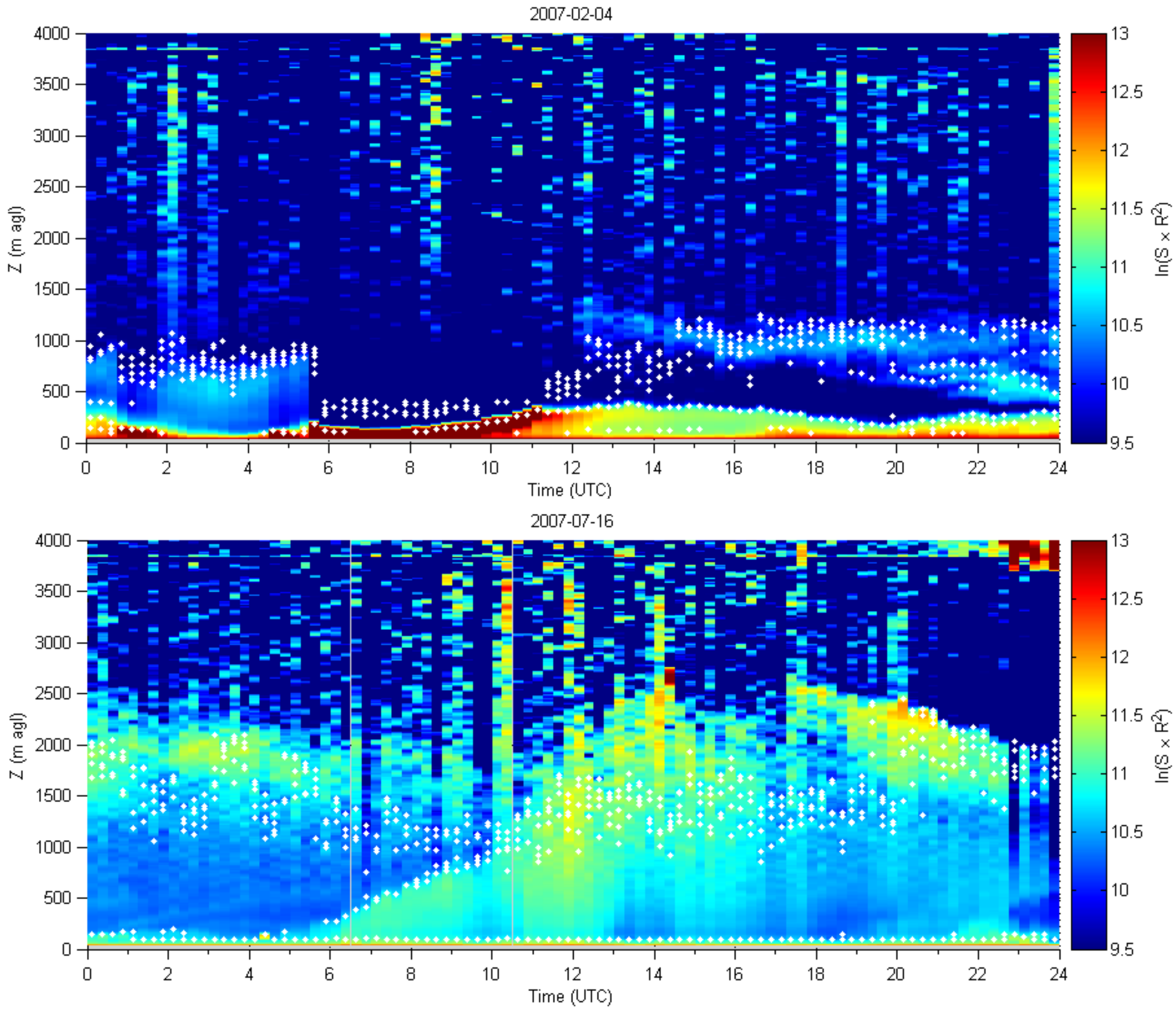
3) **Gradient methods: the inflection points of the lidar signal are used to locate the top of the ML (e.g: Endlich, 1979), using numerical differentiation, or discrete wavelet transforms. However, the results are quite similar (***de Haij et al, 2007***).**

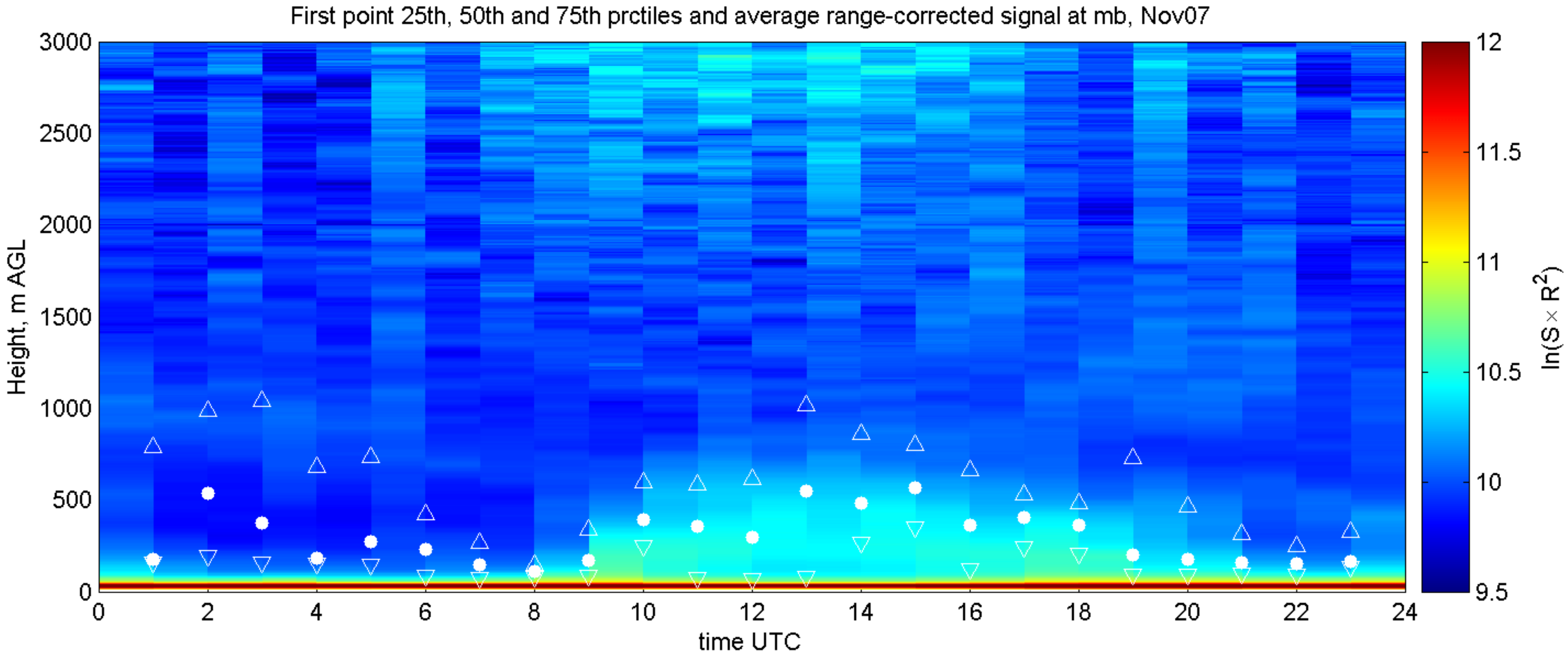
Avg. Range Corrected Signal - Mixing Height – PM - MI 13 JUL 07



OPC from
UniMI Bicocca

Milano 2007 LD-40 ISAC





2007/08 Climatology of avg. RCS & median Mixing Height at MI Bicocca

I Lidar-Ceilometer di nuova generazione permettono di misurare continuativamente (ogni 10 min, H24) i seguenti parametri:

1. Distribuzione in quota del particolato (50-6000 m agl);
2. Distribuzione in quota di nubi e cirri (50-10000 m agl);
3. Rilevamento di polveri sahariane e/o avvezioni in quota;
4. Evoluzione dello strato "mescolato";
5. Presenza ed evoluzione di nebbie.

Questa capacità sta avviando verso l'implementazione di reti di monitoraggio basate sui Lidar-Ceilometers (COST 702)

Eyjafjoll Ash cloud

17. April 2010

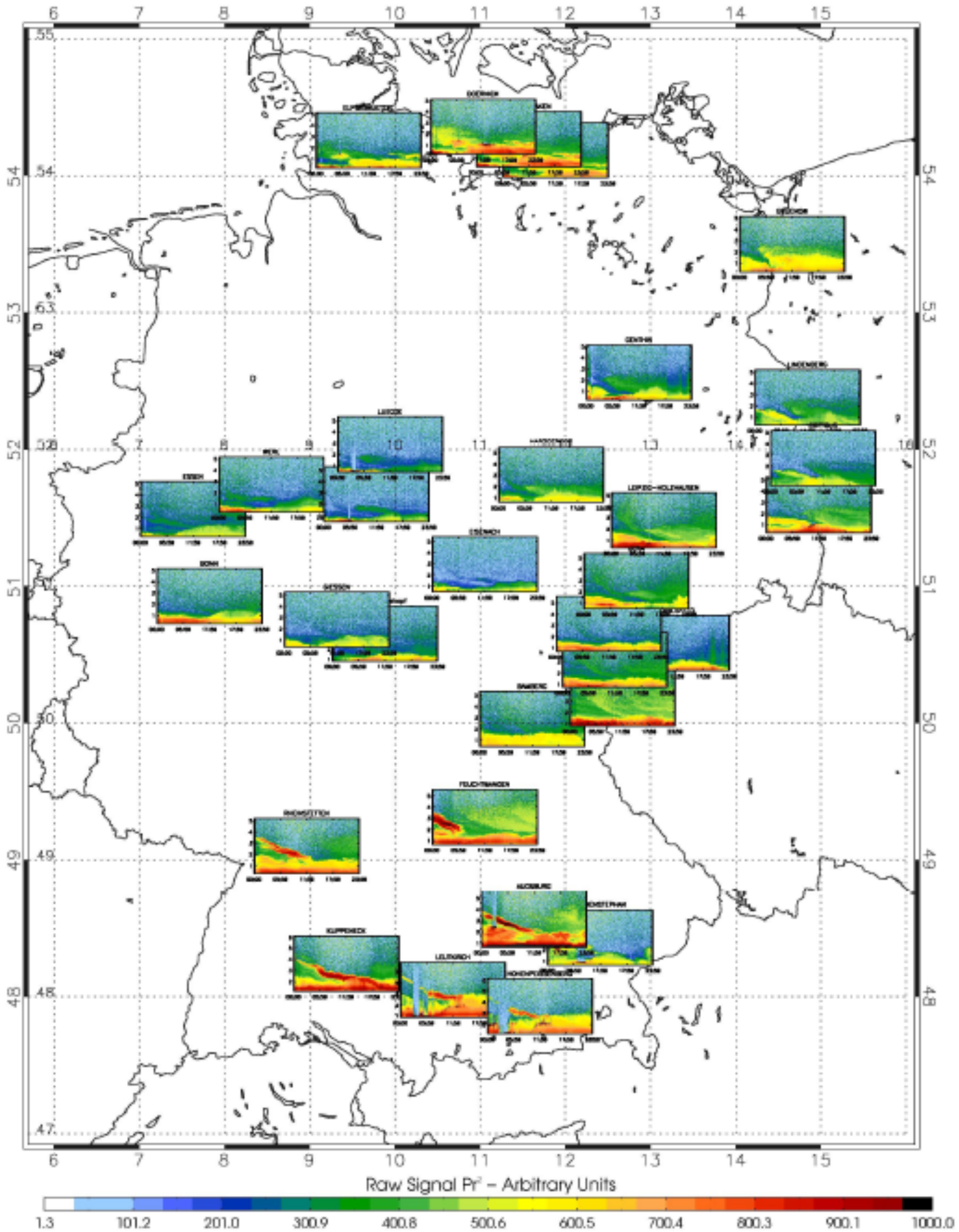
Deutscher Wetterdienst

Meteorologisches Observatorium Hohenpeißenberg

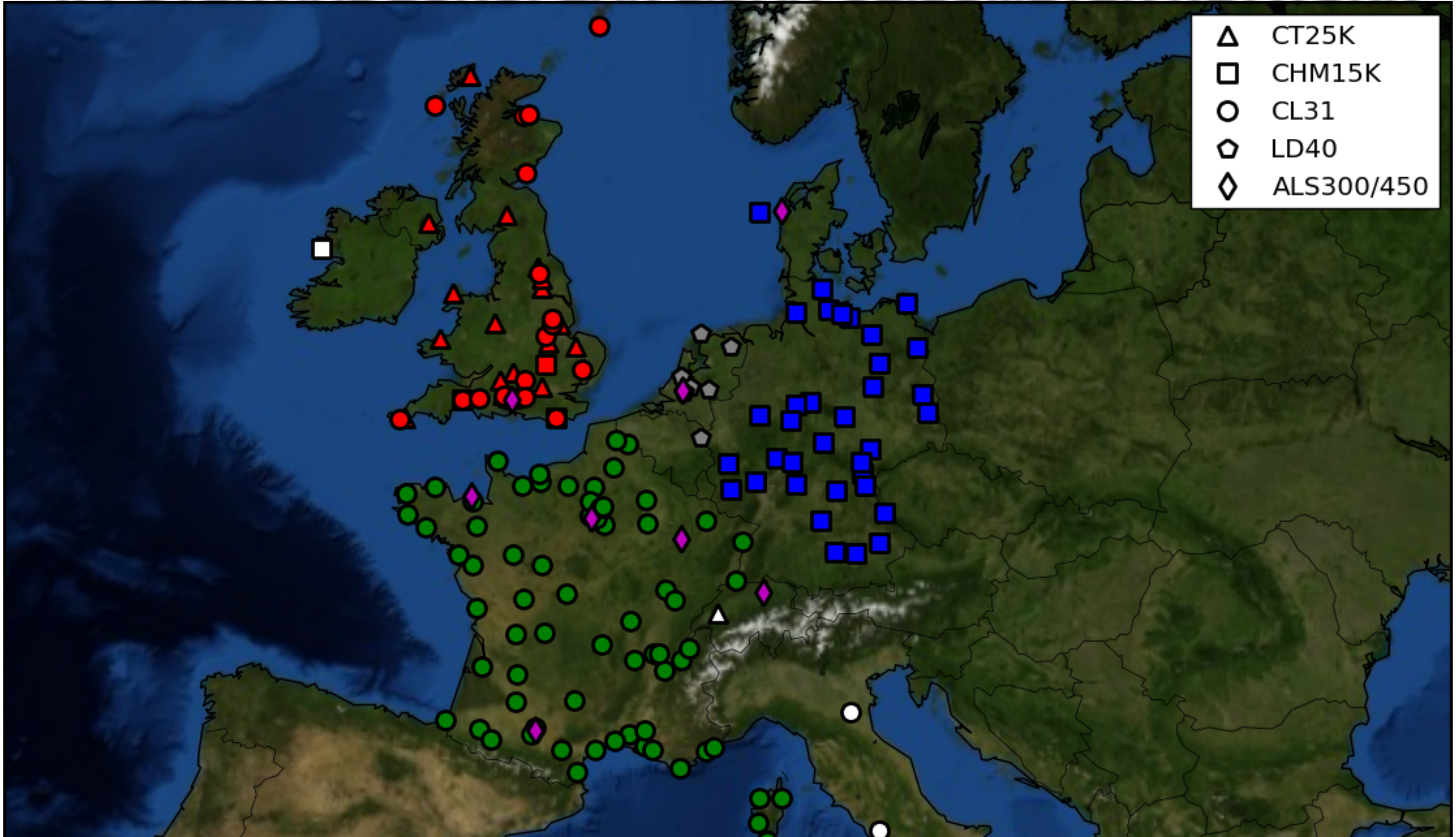
Descent from 5 to 2 km or

advection of tilted layer?

Entrainment into BL after noon



1. POTENTIAL EUROPEAN LIDAR-CEILOMETER NETWORK



Dense networks of profilers: motivation to improve retrievals

Geographical distribution of continuously operating profiling lidars and ceilometers over France, Germany, the Netherlands, and the United Kingdom. The type of lidar or ceilometer is shown in the Figure legend. Blue, red and grey signs correspond to systems currently operated by DWD, UKMO, and KNMI, respectively. Green signs correspond to profiling ceilometers to be deployed by Meteo-France in 2011-2013. Magenta diamonds correspond to ALS lidars operated within LEONET. White signs are profiling systems operated by other organizations.

The Impact of Saharan Advections on PM Levels and the LIFE+ "DIAPASON" Project

DIAPASON

Desert-dust Impact on Air quality through model-Predictions and Advanced Sensors ObservatioNs

1) Institute of Atmospheric Sciences and Climate, ISAC-CNR, Rome, Italy

2) Jenoptik ESW GmbH, Jena, Germany

3) Latium Agency for Environmental Protection, ARPA Lazio, Rieti, Italy

Project Coordinator: g.gobbi@isac.cnr.it

An Outline of the Project

DIAPASON Project

PROBLEM

How to securely implement EU Air quality Policy and Legislation allowing to assess and subtract contributions to PM levels due to natural particles

MAJOR OBJECTIVE

Starting from EC 2010 Guidelines* to build an upgraded desert dust detection Methodology to assess and quantify PM levels due to Saharan dust

MEANS

Detection and description of Saharan dust clouds through advanced atmospheric observations (prototypes of Polarization Lidar-Ceilometers), particle counters, supported by satellite maps, and model forecasts

EXPECTED RESULTS

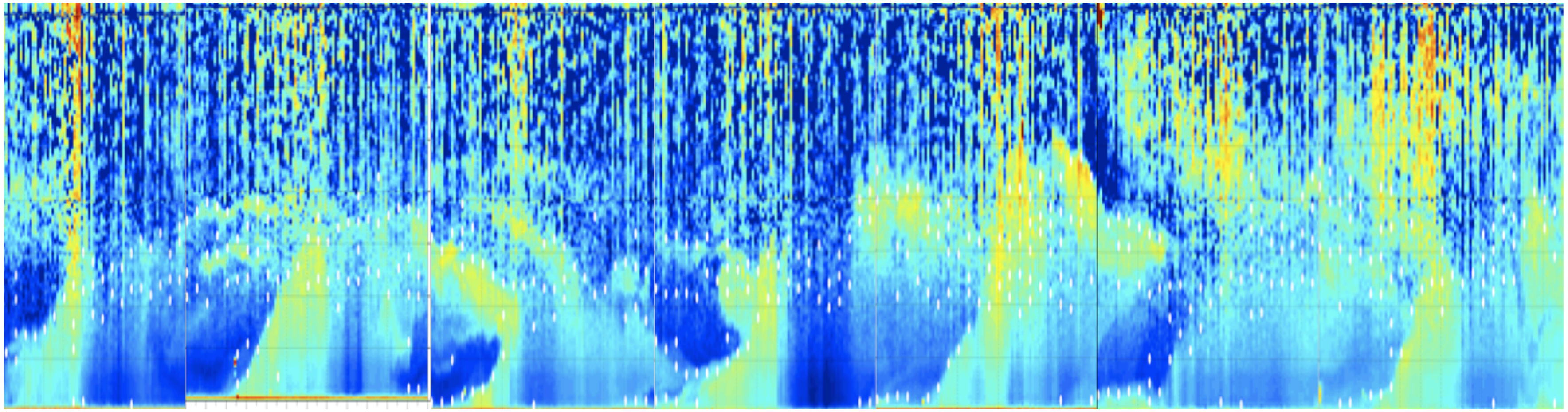
Guidelines & Recommendations for a secure and affordable detection and assessment of the contribution of Saharan dust to PM under the EU Air Quality Directive 2008/50/EC

La Roadmap di DIAPASON

Il progetto DIAPASON: Desert-dust Impact on Air quality through model Predictions and Advanced Sensors ObservatioNs….

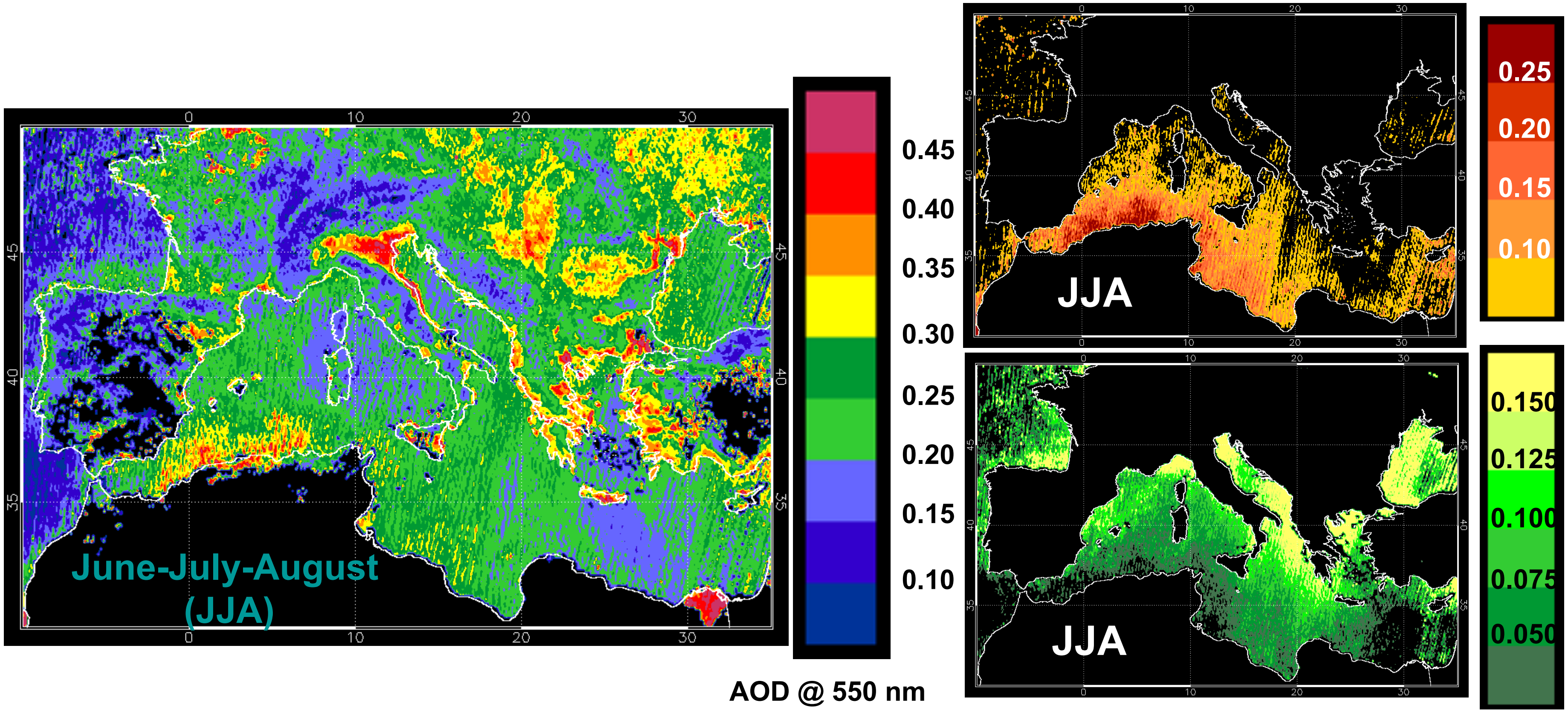
- è stato approvato nell'ambito del programma europeo LIFE+ 2010 (DG Ambiente) ed è iniziato il 30 Settembre 2011. Durerà 3 anni;
- svilupperà tecnologie innovative, economiche e *user-friendly* come i Ceilometers-Polarimetrici per integrarle nelle reti di monitoraggio della qualità dell'aria;
- Implementerà e dimostrerà metodologie osservative e di analisi mirate al miglioramento delle attuali linee guida europee sul rilevamento del particolato di origine naturale (direttiva 2008/50/EC);
- sarà dimostrato inizialmente nell'area di Roma sul caso delle avvezioni sahariane ma sarà facilmente estendibile al rilevamento di *plume* vulcanici o da incendi;
- Tra un mese sarà attivo il sito: www.diapason-life.eu

Grazie per l’Attenzione



Queste attività di ricerca sono state in parte condotte nell’ambito dei progetti QUITSAT (Agenzia Spaziale Italiana), AEROCLOUDS (MIUR) e DIAPASON (EU-Life+).

Aerosol Optical Depth (AOD) in the period June-August 2001 (MODIS data)

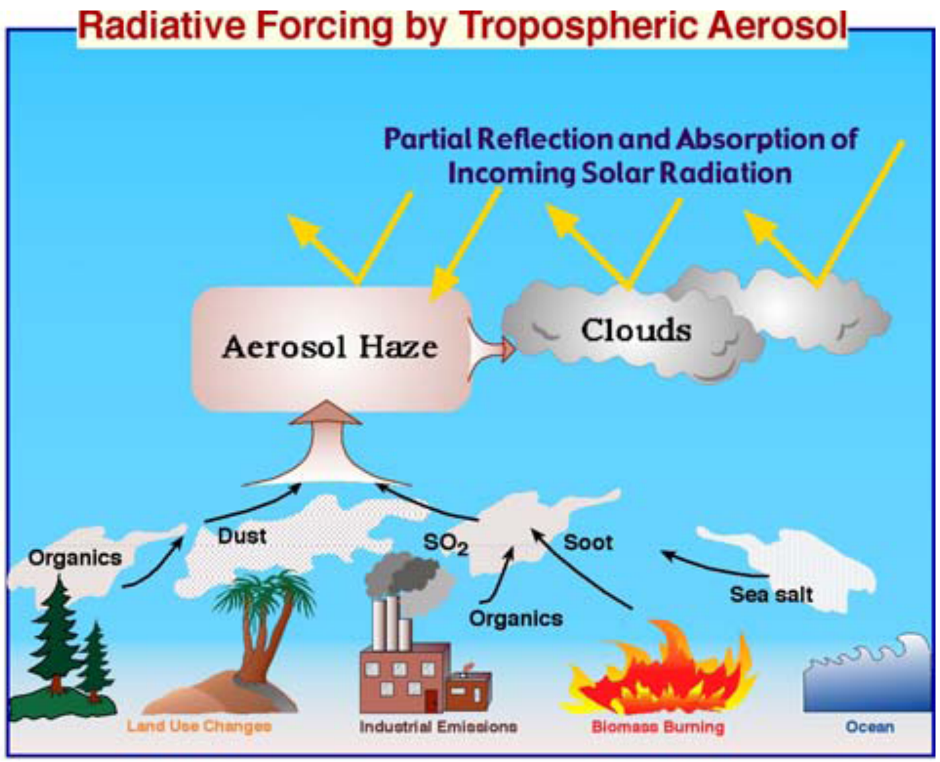


- On average, 26% of the central Mediterranean surface was covered by Saharan dust in the year 2001

Barnaba et al., Atmos.Chem. Phys. 2004

Global aerosol sources (Tg/yr)

- **Natural 3060**
  - *Primary*
    - **Soil mobilization 1500**
    - **Sea salt 13**
    - **Volcanic aerosol 30**
    - **Biological particles (?) 50**
  - *Secondary*
    - **Sulphate (conv. SO2) 100**
    - **Nitrate (conv. NOX) 20**
    - **Organic aerosol (conv. BVOC) 6**



- **Anthropogenic 395**
  - *Primary*
    - **Industrial aerosol 100**
    - **Fossil fuel combustion 25**
    - **Biomass burning 80**

    Secondary

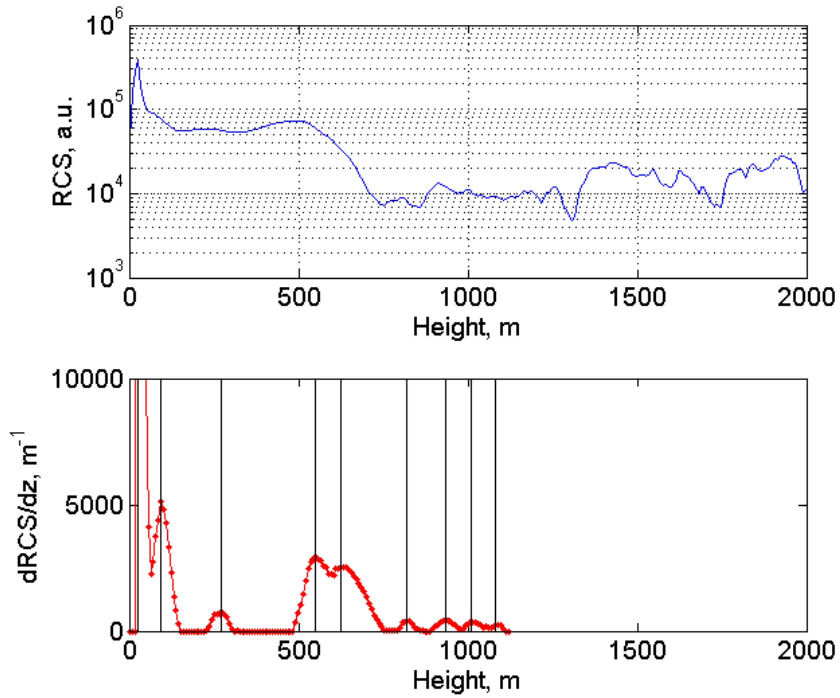
    Sulphate (conv. SO2) 140
    - **Nitrate (conv. NOX) 40**
    - **Organic aerosol (conv. AVOC) 10**

In terms of extinction of solar radiation, anthropogenic aerosols are responsible of 20-25% of the total (from satellite observations) 10-50% from models !!!.

Wavelet algorithms

- The wavelet algorithm is an alternative way to calculate the inflection points. It can also be used to separate the high and low frequency components of a serie (e.g.: image compression)
- It works better for noisy signals, because it finds the correlation between the given function and a step function (zero-order wavelet), so it is based on integral calculation rather than numerical differentiation.
- The main hindrance is that the step function has a finite size, so that the search for inflection points has 'dead zones' at the boundings. These zones are large the half of the wavelet size.
- Anyway, a threshold is required to determine the lowest inflection point. We chose the first maximum above the threshold exceeding.
- In order to lower the dead zone at the bottom, a shorter wavelet is nested in such zone if the inflection point is found at the first usable height.

Spatial gradient algorithms used for LD-40 data analysis



- LD-40 data is averaged over 15-min periods
- Identify stratifications as heights where RCS signal derivatives minimize

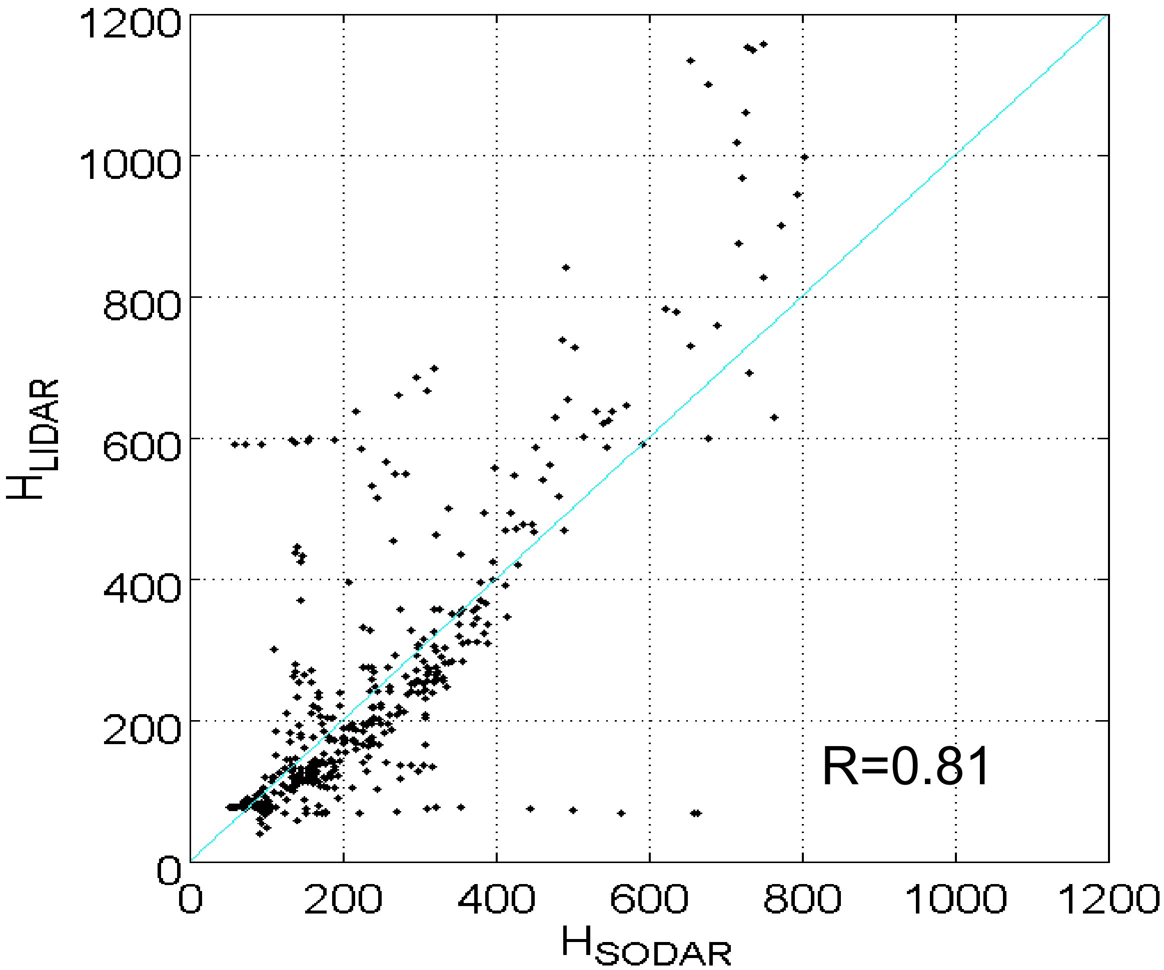
- Filter to reject noise-induced minima

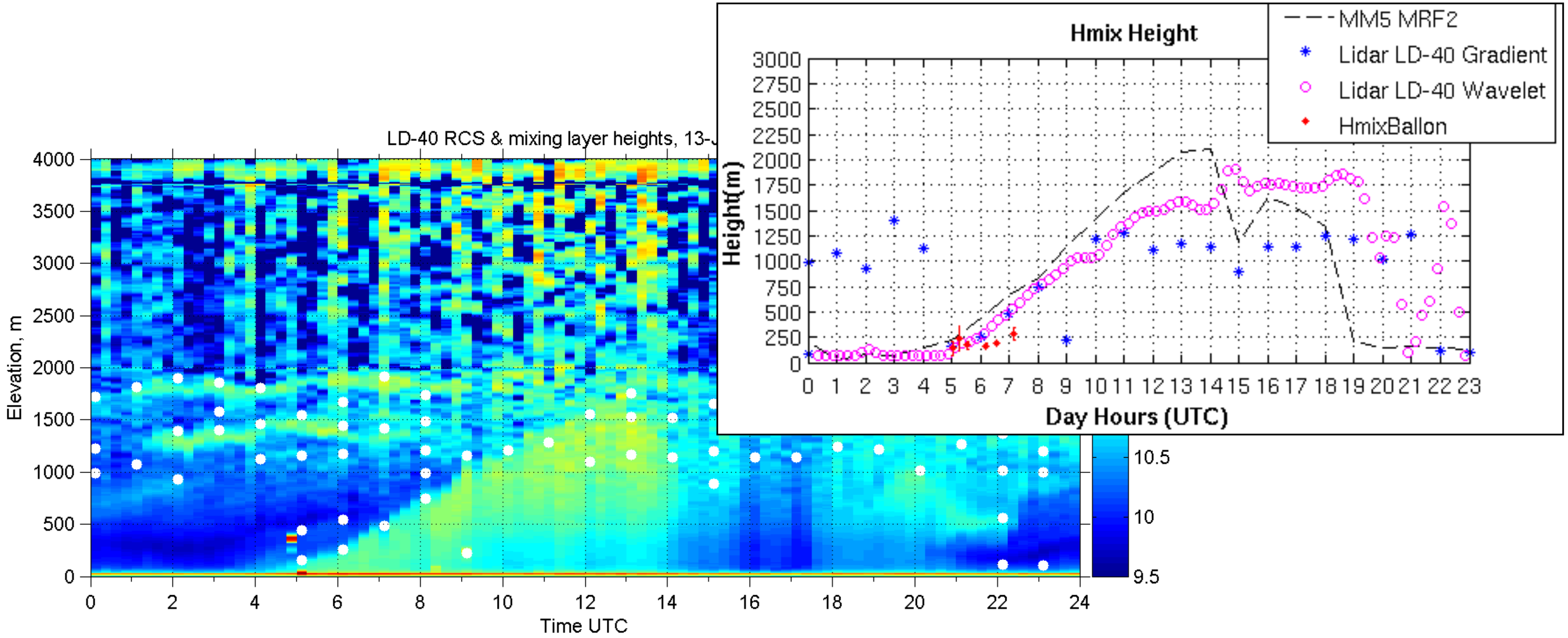
- MLH defined as first minimum

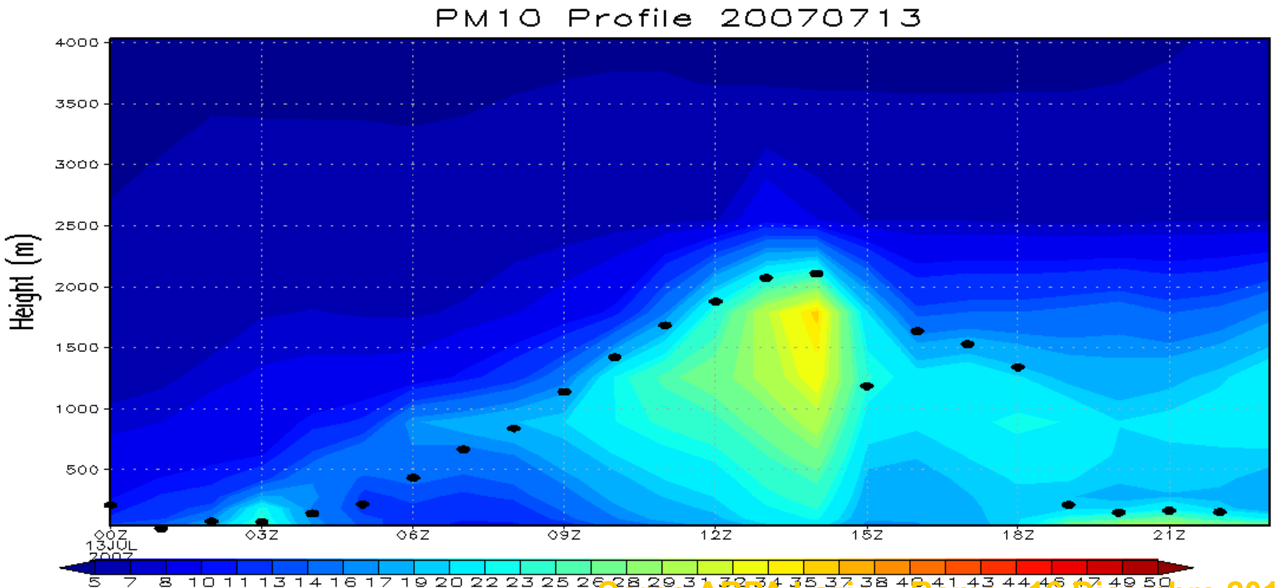
- PBL height determined by wavelet-analysis

We shall use the definition: PBL= ML+EZ (in daytime)

Sodar & LD-40 MLH retrievals at Rome Tor Vergata 2008

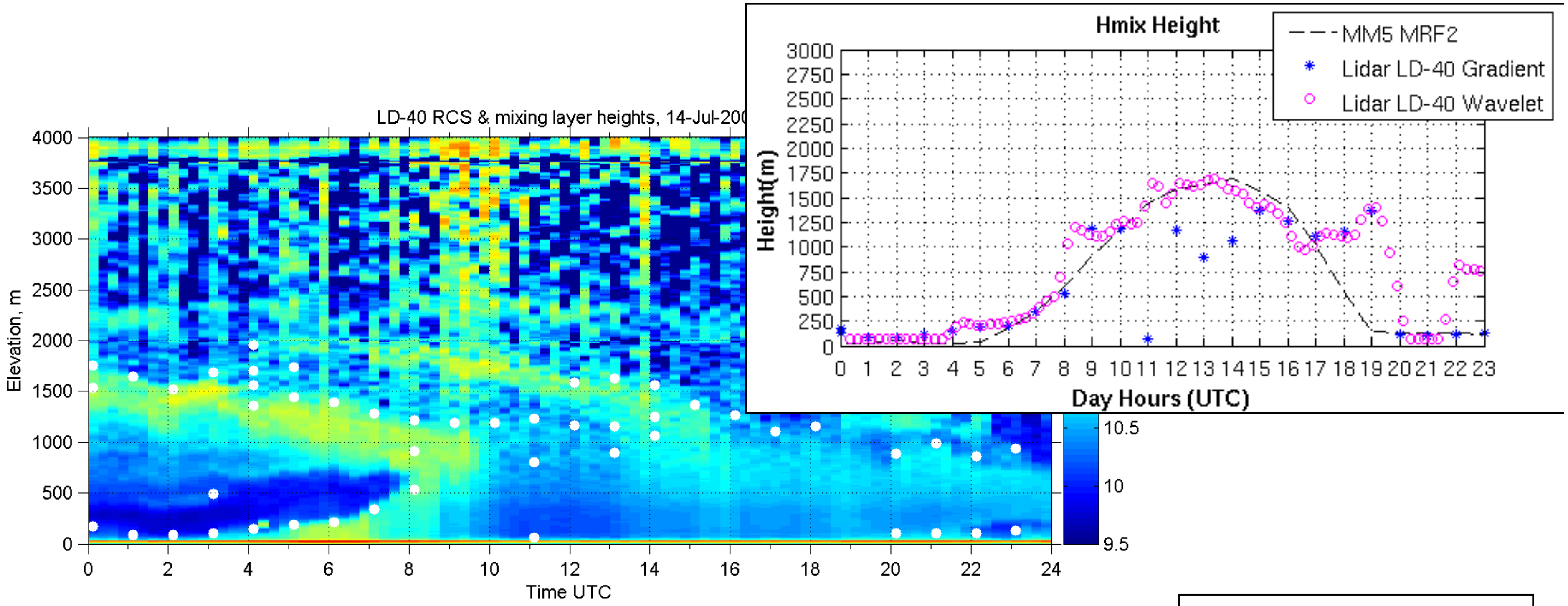


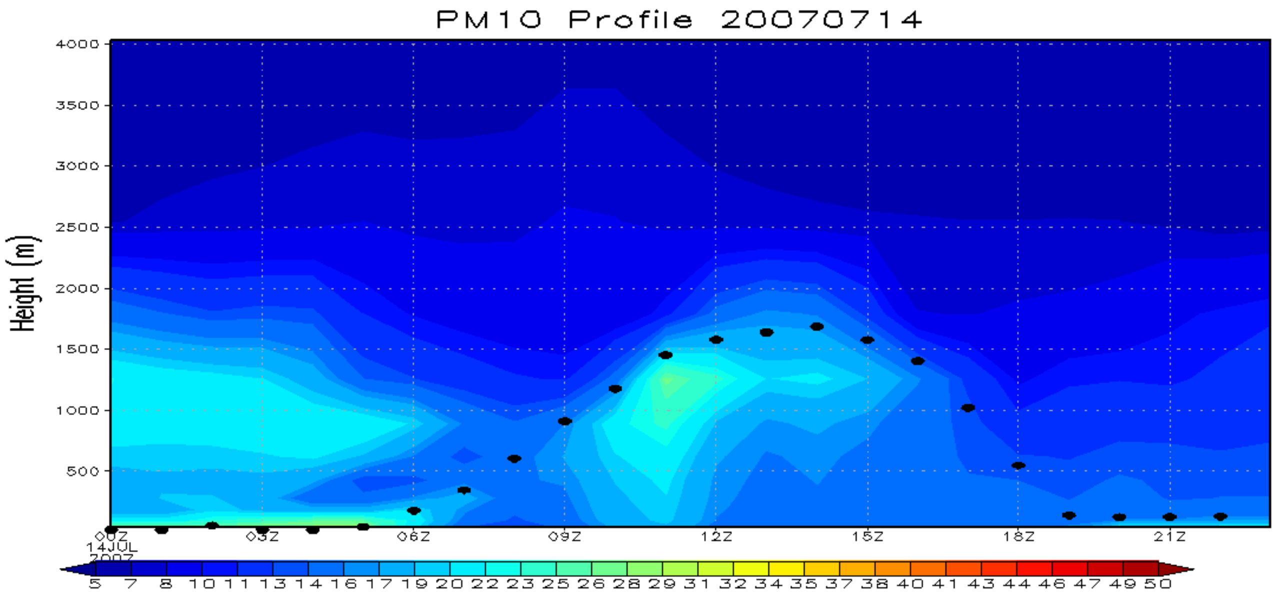




-The model well reproduces:
* Timing of events,
* PBL height,
* Aerosol field, in particular:
* Elevated PM maximum
* Formation of an evening 'residual layer'
•Breeze clean-up after 15 UTC.

Poor: ground PM levels



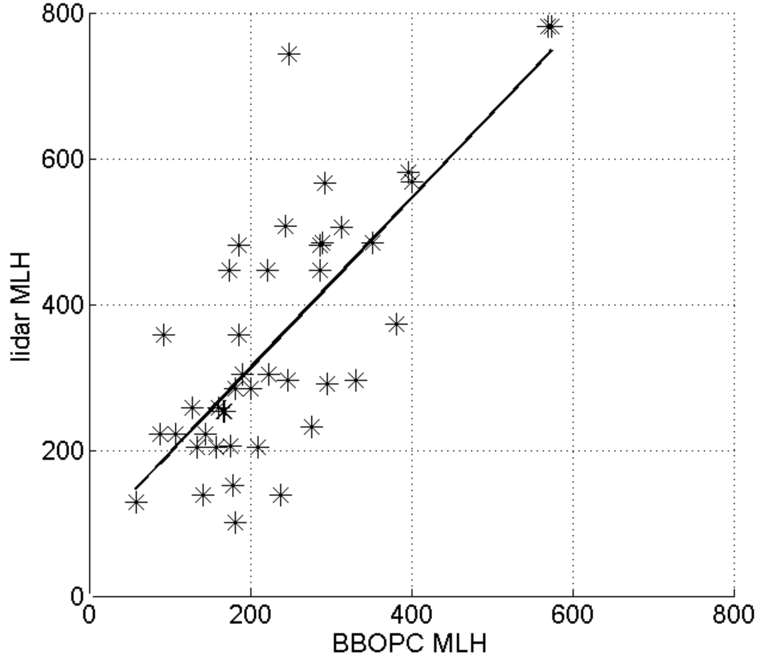


-The model reproduces quite well:

PBL height
Residual layer evolution

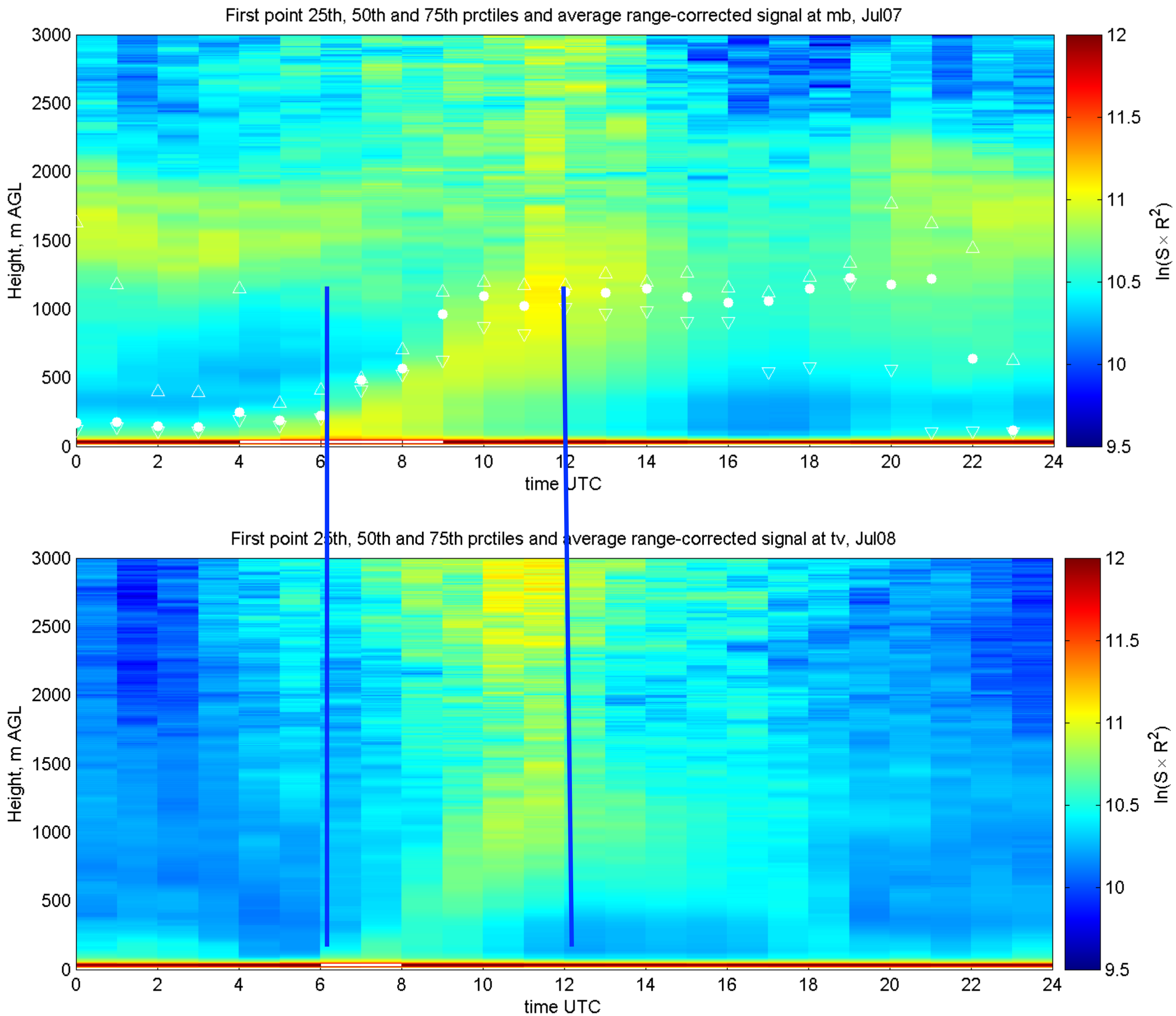
Characterizes as nitrate the aerosols aloft

Comparisons LD-40 vs. Balloon-Borne OPC retrievals of MLH at Milan (2007-2008)

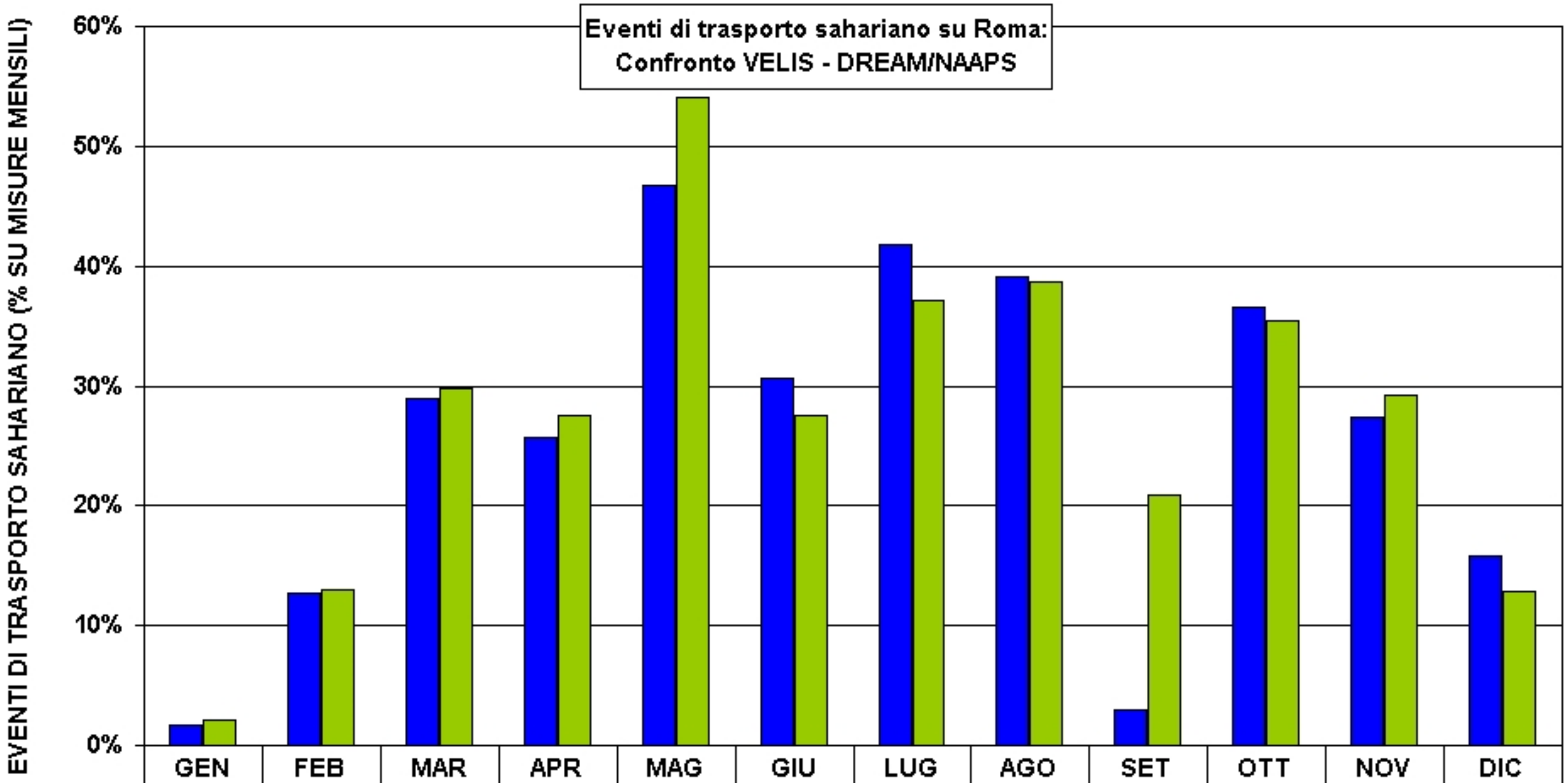


Comparison between the BBOPC-derived and the lidar-derived MLHs (gradient method). The line represents the best linear fit of the data (Y=a+bX), with a correlation coefficient of 0.75. The fit parameters are: a=79.44 and b=1.16 .

Avg. Range Corrected Signal MI JUL 07 RM JUL 08



Monthly percent of days with Saharan advection events in Rome (2001-04)



	GEN	FEB	MAR	APR	MAG	GIU	LUG	AGO	SET	OTT	NOV	DIC
VELIS	2%	13%	29%	26%	47%	31%	42%	39%	3%	37%	27%	16%
VELIS + Modello	2%	13%	30%	28%	54%	28%	37%	39%	21%	35%	29%	13%

Agreement between observations and models allows for the identification of Saharan advection days along the whole period 2001-2004.