Part I

Boundary-layer **A**ir **Q**uality-analysis **U**sing **N**etwork of **IN**struments

BAQUNIN

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- **Atmospheric Physics Laboratory Sapienza**: M. Cacciani, A.M. Siani, A. di Bernardino
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- **Sardegna Clima Onlus**: A. Murgia
- **ESA Technical Officer**: P. Goryl

The BAQUNIN mandate

- Sustain the **maintenance** and **operation** of ground based remote sensing instruments for Satellite Cal/Val and Atmospheric Monitoring/Research purposes, operating in the Rome area
- Acquire, homogenise and distribute **high quality data**
- Perform inter-calibration and validation **campaigns**
- Stimulate research in Urban Atmospheric Boundary Layer physics/chemistry by facilitating **inter-connections** between research institutes
- **Attract/engage** other Space/Research/Health Agencies/Institutions

BAQUNIN Project Structure

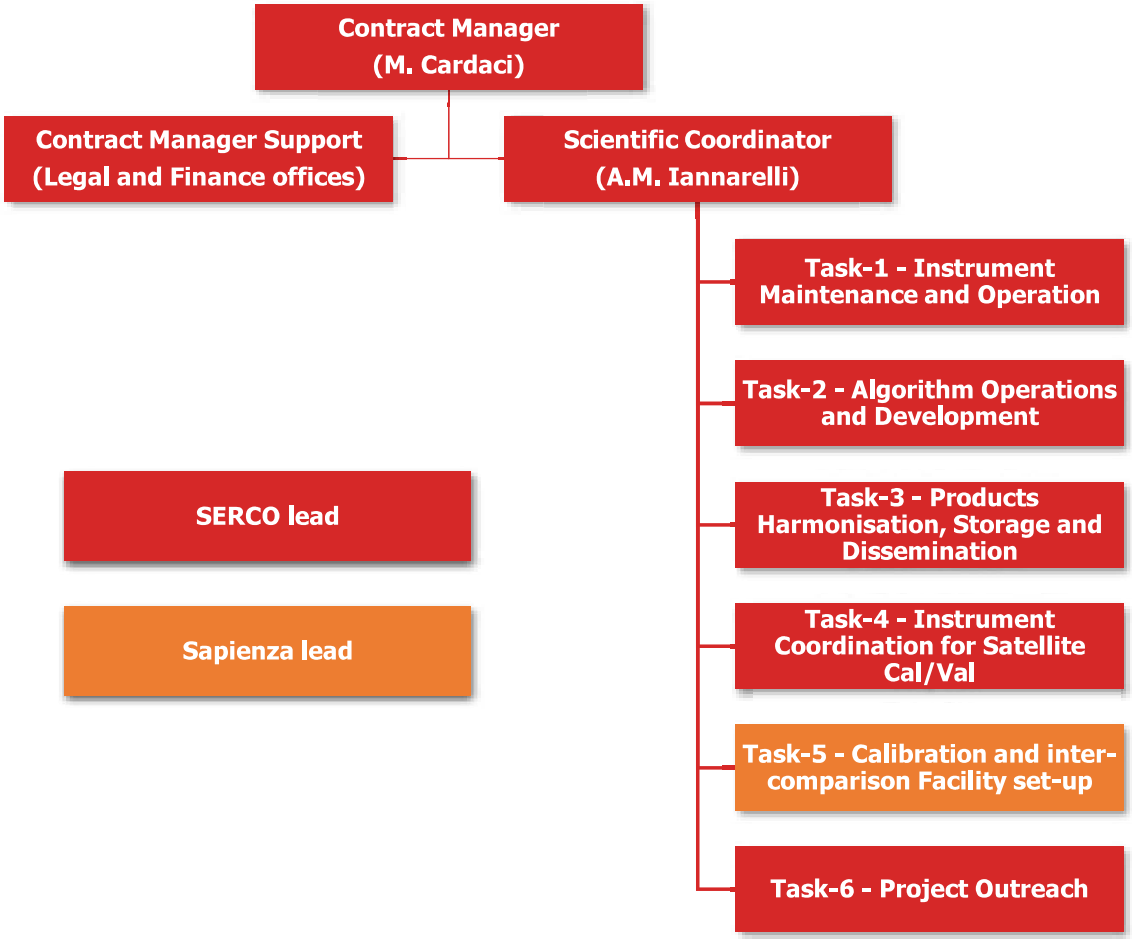
The project activities are structured into two phases, **Phase-1** and **Phase-2**.

The time duration of the phases is:

- **Phase-1**: from Mar-2019 to Feb-2020
- **Phase-2**: from Mar-2020 to Feb-2022

During **Phase-1**, only a subset of all potential activities will be activated, as this start-up period will be considered as a pilot and demonstrator.

The full activity realisation will be achieved during **Phase-2** of the project.



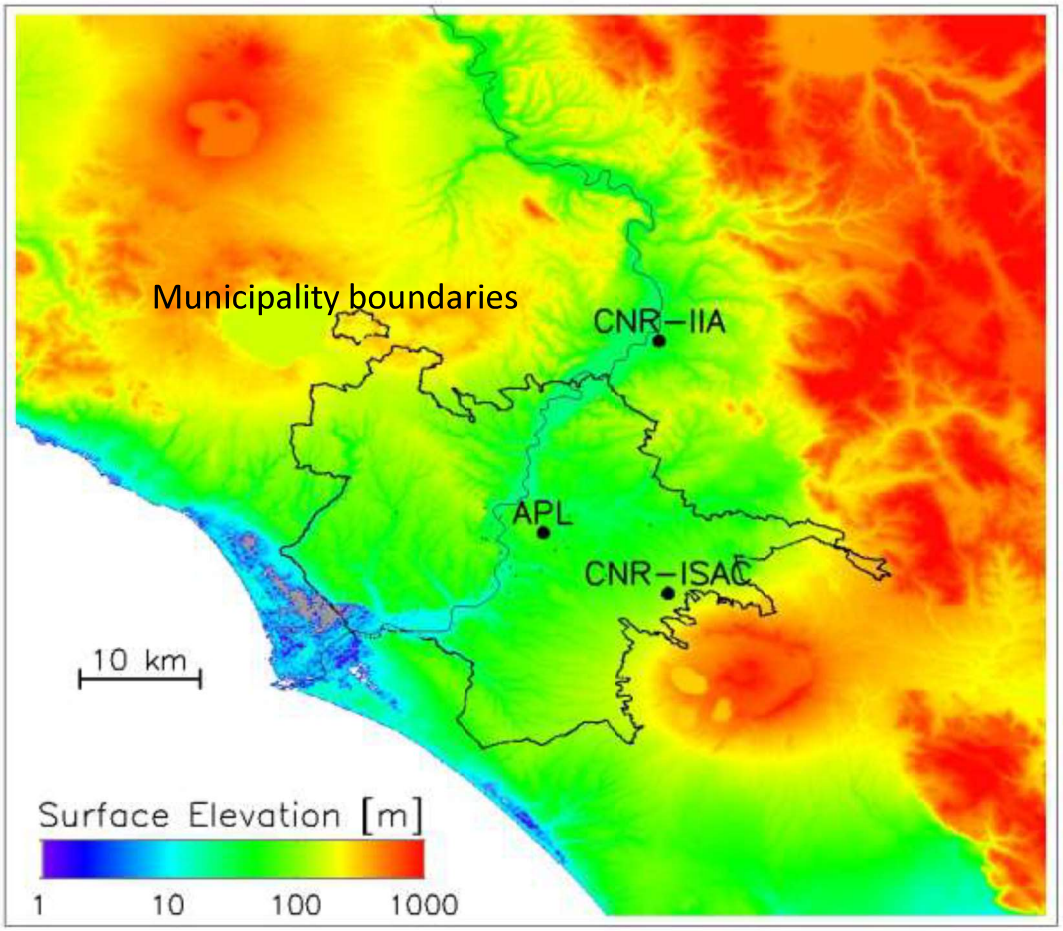
BAQUNIN Super-site Structure

BAQUNIN super site components:

- **Urban** (APL – Phys. Dep. Sapienza, Rome)
- **Semi-rural** (CNR-ISAC, Tor Vergata)
- **Rural** (CNR-IIA, Montelibretti)

Each component is hosting at least one **Pandora**(1) instrument and, as for APL, a large number of other atmospheric remote sensing devices.

The position of the three components, shown in the figure, allows for an effective monitoring of the atmosphere in Tiber Valley and over the city of Rome.



(1) Pandonia Global Network (PGN)
https://pandonia-global-network.org/

BAQUNIN Instrumental Suite (currently available)

Instrument	Owner	Site	Operation Conditions	Range (m.a.s.l.)	Dz (m)	Spectral Range / wavelengths	Observables	Since
SODAR	APL	**APL**	Day/Night	100 – 900	15	4450.75, 4650.75, 4840.75 Hz	**PBL winds and turbulence**	**1990**
Brewer MKIV	APL	**APL**	Day	Column	N/A	286.5 – 363 nm	**Radiance, trace gases**	**1992**
MFRSR	APL	**APL**	Day	Column	N/A	940, 870, 673, 615, 500, 415 nm	**Radiance, aerosols, trace gases**	**2004**
POM-PREDE	CNR-ISAC	**APL** **CNR-IIA**	Day	Column	N/A	1600, 940, 870, 670, 500, 440, 380, 340 nm	**Radiance, aerosols, water vapour**	**2010**
Meteo station	Climate Consulting	**APL**	Day/Night	In situ	N/A	N/A	**Air temperature and humidity**	**2014**
LIDAR	APL ESA	**APL**	Day/Night	300 – 20000	7.5	Elastic: 1064, 532, 355 nm Polarised: 532 nm Raman: 407, 386 nm	**Aerosols, water vapour, clouds**	**2015**
WRF	Sard. Clim.	**ESRIN**	Day/Night	0-20000	39 levels	N/A	**Meteorological variables**	**2015**
Pandora-2S	ESA	**APL** **CNR-ISAC** **CNR-IIA**	Day/Night (Moon)	Column	N/A	290-520 and 400-900 nm	**Radiance, trace gases, aerosols**	**2016**
Sun-photometer	Univ. Lille	**APL**	Day	Column	N/A	1640, 1020, 870, 675, 500, 440, 388, 340 nm	**Aerosols, water vapour**	**2016**
All Sky Camera	ESA	**APL**	Day/Night	N/A	N/A	RGB	**Clouds**	**2018**
Pyranometer	ESA	**APL**	Day	Column	N/A	285 – 3000 nm	**Radiance, clouds**	**2018**
Ceilometer	APL	**APL**	Day/Night	100 – 6000	N/A	Elastic: 904 nm	**Clouds, aerosols**	**2019**
Disdrometer	APL	**APL**	Day/Night	In situ	N/A	N/A	**Rain**	**2019**
FTIR EM-27	CNR-ISAC	**APL**	Day/Night	Slant Column	N/A	700 – 2200 cm^{-1} (4.5 – 14 mm)	**PBL GHG**	**2019**

BAQUNIN link to FRM Concept - I

Fiducial Reference Measurements (**FRM**):

"the suite of independent ground measurements that provide the maximum Scientific Utility and Return On Investment for a satellite mission by delivering, to users, the required confidence in data products, in the form of independent validation results and satellite measurement uncertainty estimation, over the duration of the mission."

The defining ***mandatory*** characteristics of an FRM are:

a) Have **documented** evidence of SI (International System of Units => metrology) traceability via inter-comparison of instruments under operational like conditions.
b) An **uncertainty budget** for all FRM instruments and derived measurements is available and maintained, traceable where appropriate to SI.
c) Are collected using measurement **protocols** and community-wide management practices (measurement, processing, archive, documents etc.).
d) Are independent from the satellite retrieval process.

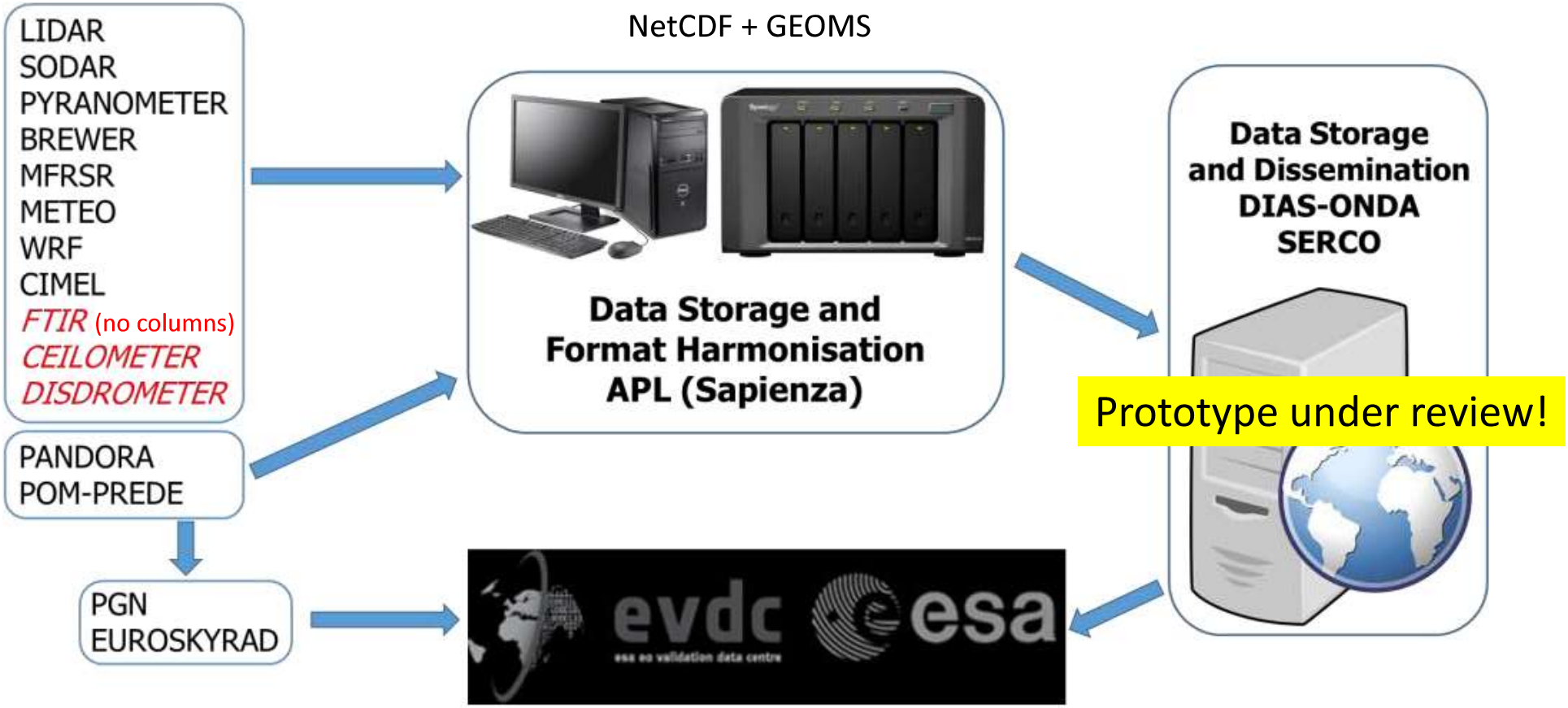
FRM are as close to the "Truth" for a given variable as we can get.

No uncertainties => No measurements: "observations"!

BAQUNIN link to FRM Concept - II

Instrument	Calibration/characterisation protocols/procedures	Data Processing
Spectrophotometer (Pandora)	Pandonia Global Network - PGN (ESA/NASA joint activity)	PGN
Sun-photometer (CIMEL)	AERONET – PHOTONS University of Lille	AERONET
Sun-Photometer (POM-PREDE)	EUROSKYRAD	EUROSKYRAD
Spectrophotometer (Brewer)	EUBREWNET (EC Cost Action project)	EUBREWNET
Pyranometer	PMOD/WRC Physical Meteorological Observatory Davos / World Radiation Centre	In house
MFRSR	PMOD/WRC	In house
LIDAR	EARLINET procedures fully applied (not member yet)	In house
SODAR	CNR-ISAC + Sapienza	In house
Sky-Camera	Under development	In house
Ceilometer	Under development	In house
FTIR EM-27	Under development	In house
Meteo Stations	Under development	In house

BAQUNIN Data Flow



BAQUNIN products (available/planned) and current/planned Atmospheric Composition Satellite Missions

Product	Related Mission/Instrument (Cal/Val)
O3, NO2, SO2, HCHO, O2 (col., surf., trop.)	**S5p**, **S4***, **S5***, **GOME-2**, **OMI**, **TanSat**, **GOSAT-2**
H2O (col., surf. and trop., profile)	**S5p**, **S3**, **Aeolus**, **EarthCare***, **S4***, **S5***, **GOME-2**, **IASI**, **MTG**, **OMI**, **TanSat**, **GOSAT-2**
Aerosol Optical Depth	**S2**, **S3**, **S5p**, **Aeolus**, **EarthCare***, **S4***, **S5***, **GOME-2**, **IASI**, **3MI***, **OMI**
Aerosol Bck/Ext profile, AE, SSA, RI, PF, VSD	**Aeolus**, **EarthCare***, **3MI***
UV Dose, UV Index, Radiance	**S5p**, **S4***, **S5***, **GOME-2**, **MTG**, **OMI**
Clouds	**S5p**, **Aeolus**, **EarthCare***, **S4***, **S5***, **GOME-2**, **3MI***, **OMI**, **TanSat**, **GOSAT-2**
Wind Speed and Direction, Turbulence	**Aeolus**, **EarthCare***, **3MI***
GHG (surf. and trop)	**S5p**, **S4***, **S5***, **TanSat**, **GOSAT-2**
Meteorological Simulations	**All**

* => future mission

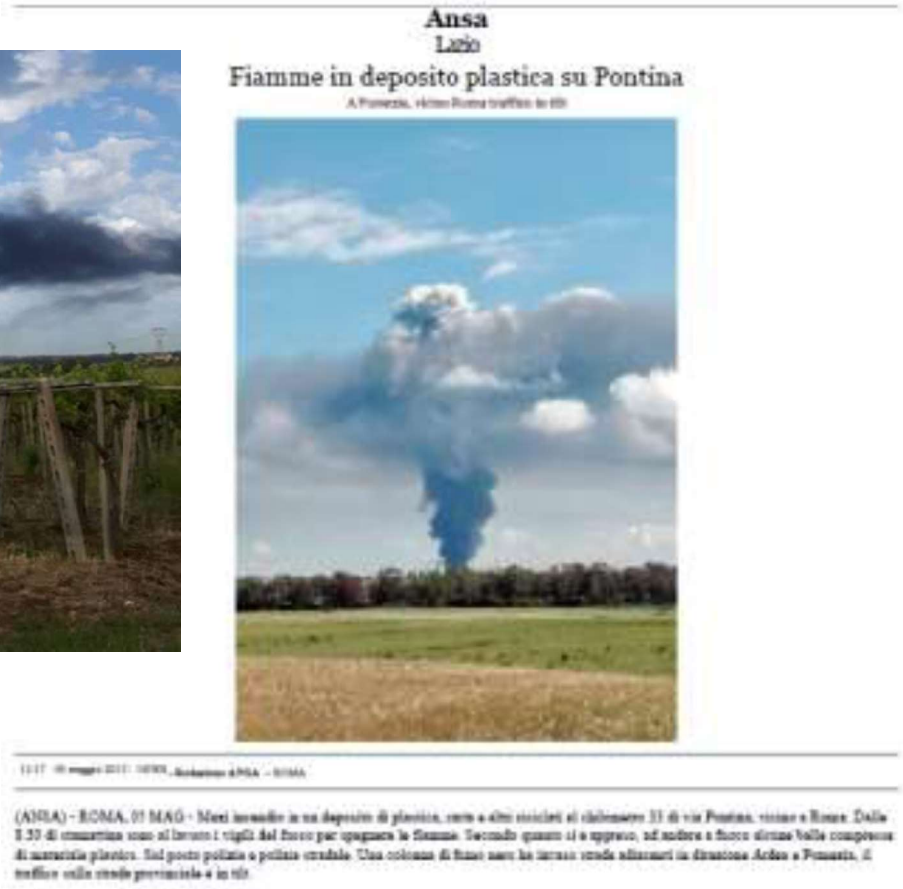
ESA, **EUMETSAT**, **Third Party Mission (TPM, ESA associated)**

Part II

Extreme air pollution episodes: remote sensing and in situ air quality (preliminary) data analysis

ECO-X fire (Pomezia, May 5, 2017)

The fire started on May 5, 2017 at around 6am UTC and lasted for the whole day
Burnt material: plastic and paper packaging (as far as we know)

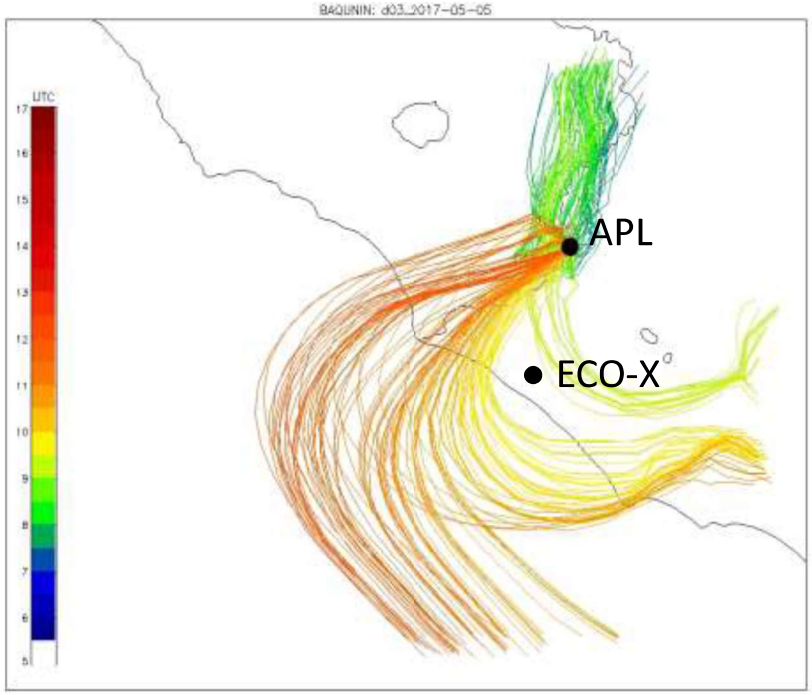


Ansa
Lazio
Fiamme in deposito plastica su Pontina

(ANSA) - ROMA, 05 MAG - Mezzi incendio in un deposito di plastica, carta e altri rifiuti al chilometro 31 di via Pontina, vicino a Roma. Dalle 8.30 di stamattina sono al lavoro i vigili del fuoco per spegnere le fiamme. Secondo quanto si è appreso, nel vedere a fuoco diverse balle compresse di materiale plastico. Sul posto polizia e polizia stradale. Una colonna di fumo nero ha invaso strade adiacenti in direzione Ardea e Pomezia. Il traffico sulla strada provinciale è in tilt.

ECO-X fire (Pomezia, May 5, 2017)

The diameter of the black plume at 10am is about 4 km. However, what we see here is the optically thick part of the smoke (flagged as “cloud” in the L2 product). The optically thin portion of the plume cannot be easily detected from space.



WRF back-trajectory calculations for APL

PROBA-V image (10:04 UTC)
Product and image analysis by F. Niro (SERCO)

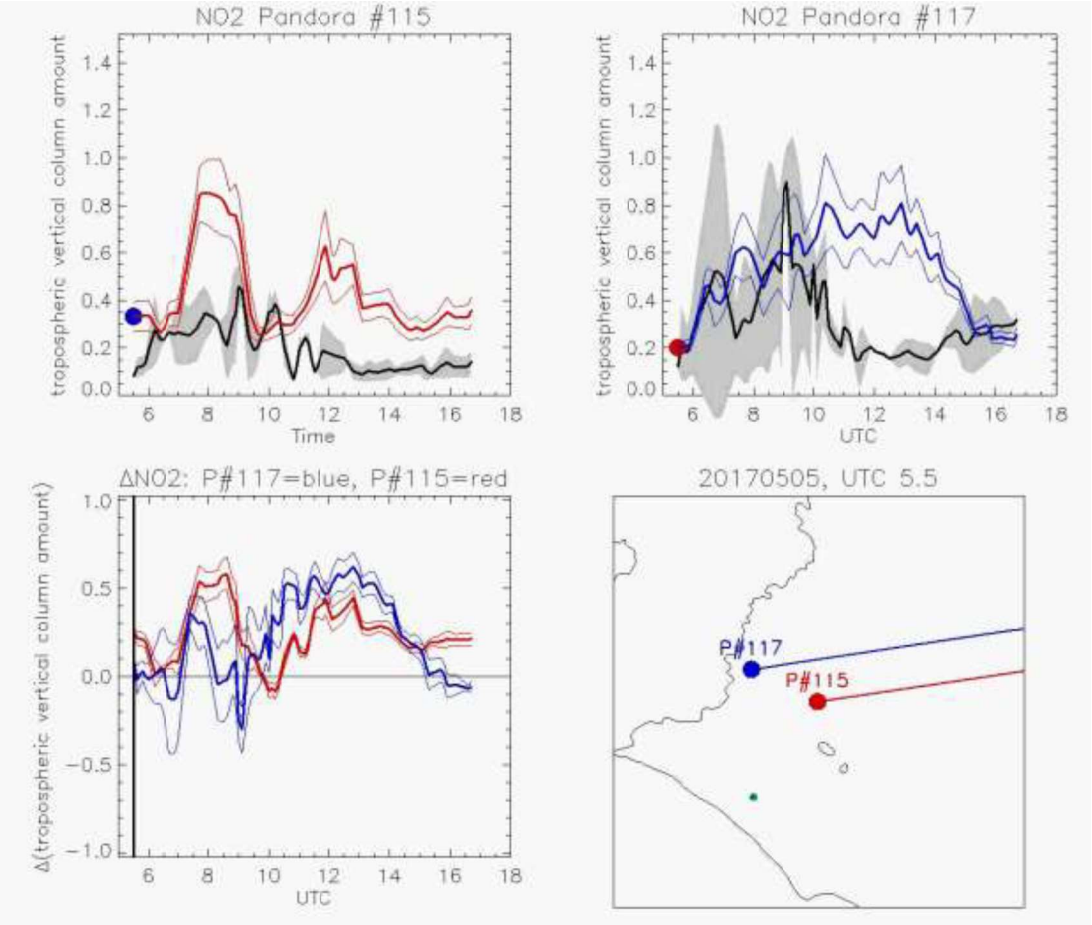
ECO-X fire (Pomezia, May 5, 2017)

Instrument: **Pandora** spectrophotometer
Measurement mode: **MaxDOAS**
Molecule: Nitrogen Dioxide (**NO2**)

Upper panels
Black = avg ± std (day-2 to day+2)
Red (ISAC), Blue (APL) = data ± unc (day)

Lower Left panel
Data - avg ± combined **uncertainties**
Red (ISAC), Blue (APL)

Lower Right panel
Position of air parcels injected in the atmosphere from ECO-X at **6am** (green dots, WRF trajectories)



https://www.earthstartsbeating.com/2017/06/28/the-may-5th-2017-eco-x-fire-event-as-seen-by-pandora-instruments/

ECO-X fire (Pomezia, May 5, 2017)

The analysis of the **ARPA** chemistry data have been performed as follows:

1) Stations containing valid data (4): Bufalotta, Magna Grecia, Fosso del Cavaliere, Malagrotta
2) For each station, extract the **NO2** and **NOx** (generic Nitrogen oxides) time series
   I. Select the data relative to the event date **± 2 days**
   II. Calculate the hourly average of previous and subsequent days
   III. Upper panel: 5 days time series (**red line**)
   IV. Lower Panel: hourly average (**blue dots**) and hourly data for 2018-05-05 (**red dots**)

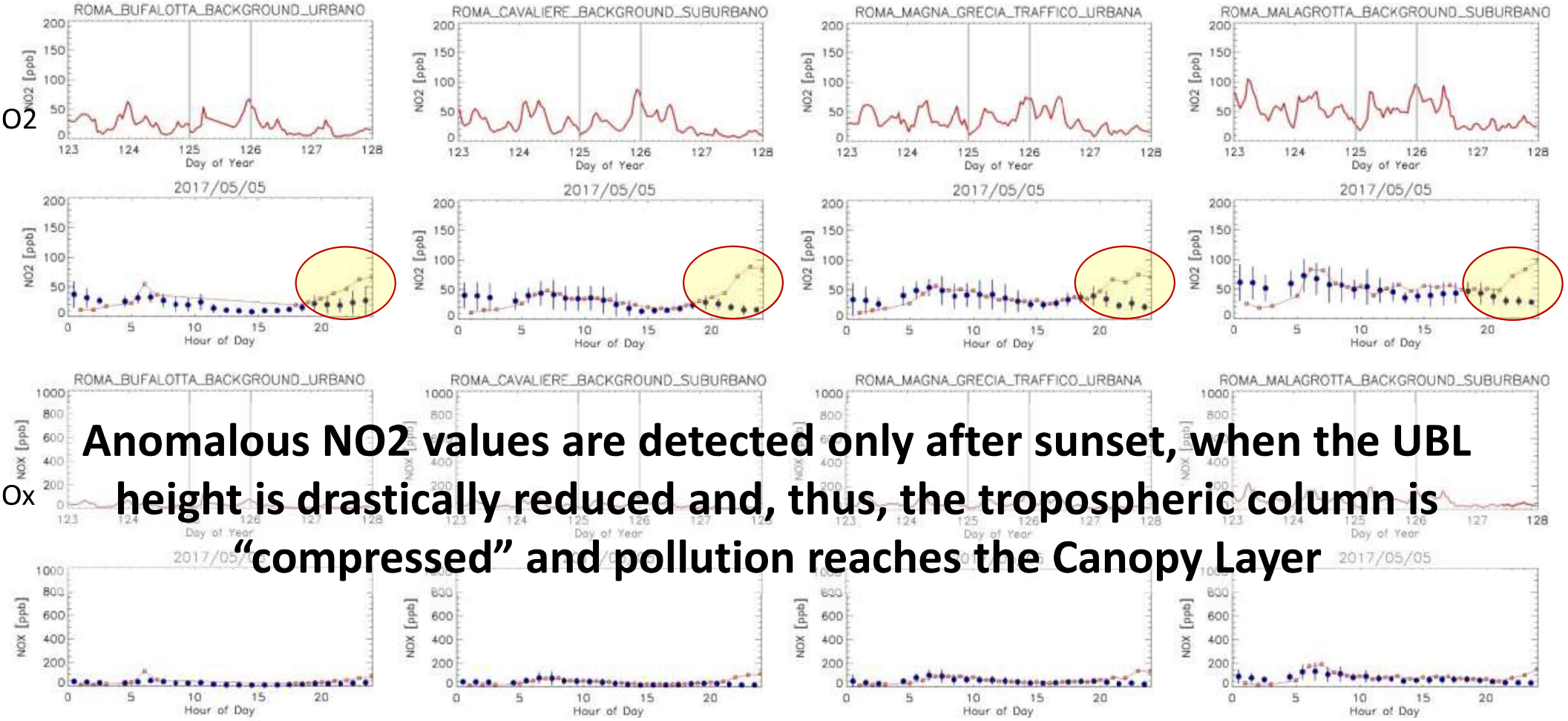
The aim of this exercise is to detect changes in species concentration amounts with respect to what is estimated during "clean days".
We did not analyse ARPA aerosol products, as no hourly data are available (daily means).

The **ARPA Lazio** data can be freely downloaded here
http://www.arpalazio.net/main/aria/sci/basedati/chimici/chimici.php

ECO-X fire (Pomezia, May 5, 2017)

NO2

NOx



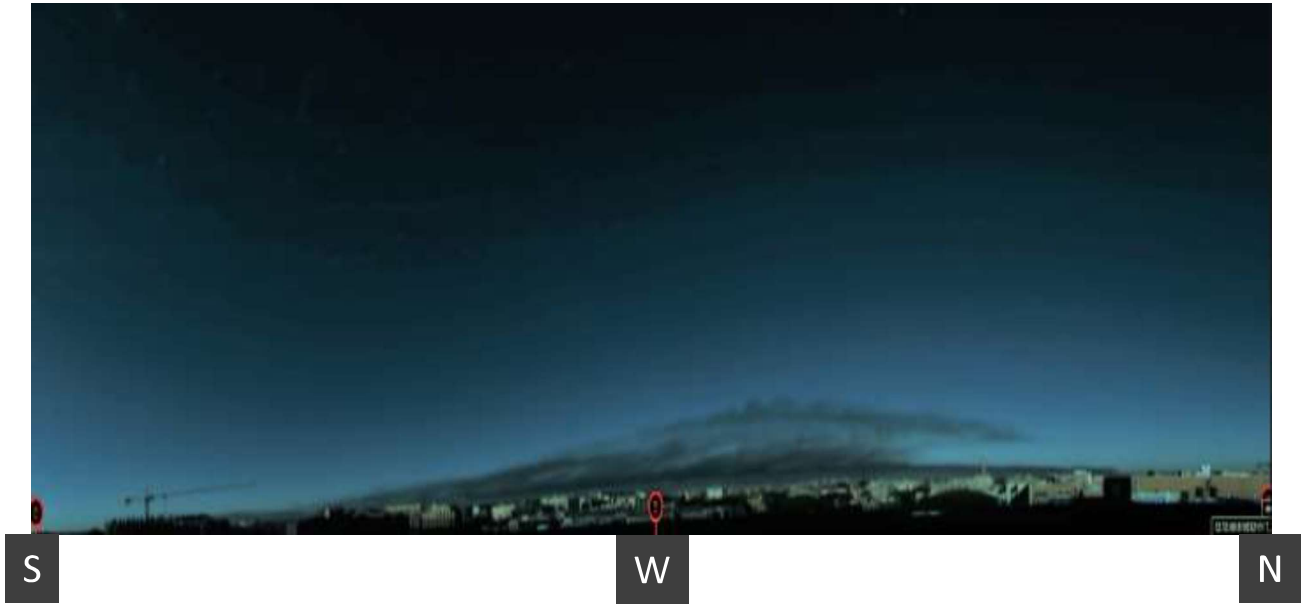
Anomalous NO2 values are detected only after sunset, when the UBL height is drastically reduced and, thus, the tropospheric column is "compressed" and pollution reaches the Canopy Layer

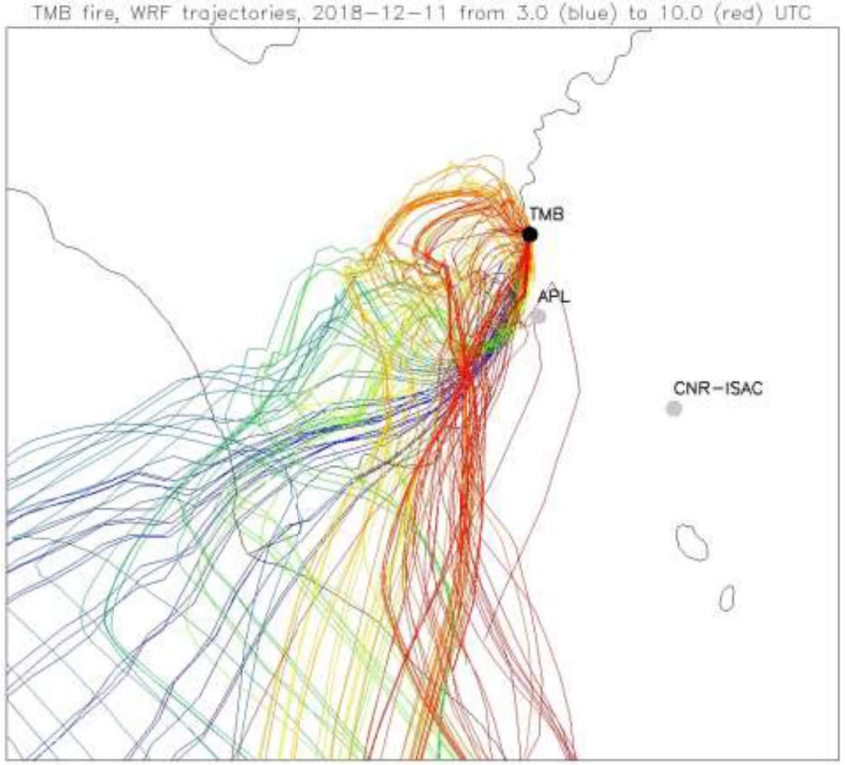
TMB (waste facility) fire, 11 Dec 2018

(ANSA) - Rome, December 11 2018 - A large fire broke overnight at a waste facility managed by Rome municipal trash company AMA. The fire at the 2,000-square-metre rubbish centre produced thick smoke on via Salaria, in the north of the historic capital, and the smell of smoke reached the centre. The city council has advised people in the area to keep their windows closed and refrain from outdoor activities. The local authority said Lazio's ARPA environmental agency had not registered air-pollution levels outside the permitted parameters.

TMB (waste facility) fire, 11 Dec 2018

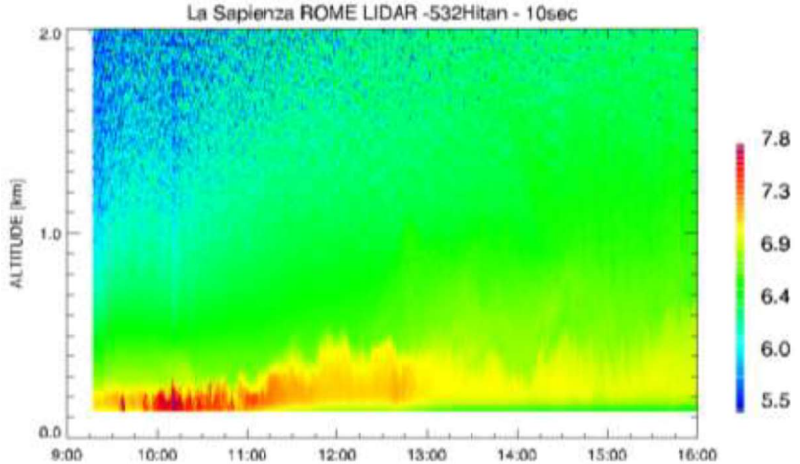
Sky-Camera Image
09:40 UTC



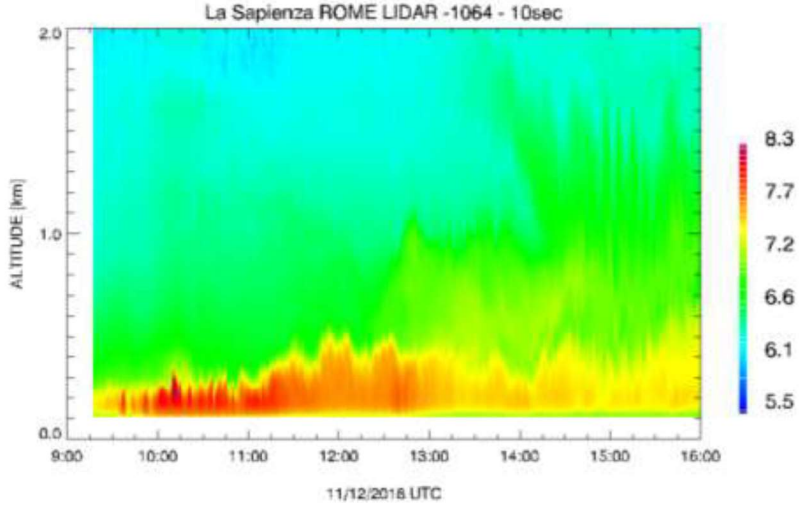


TMB (waste facility) fire, 11 Dec 2018

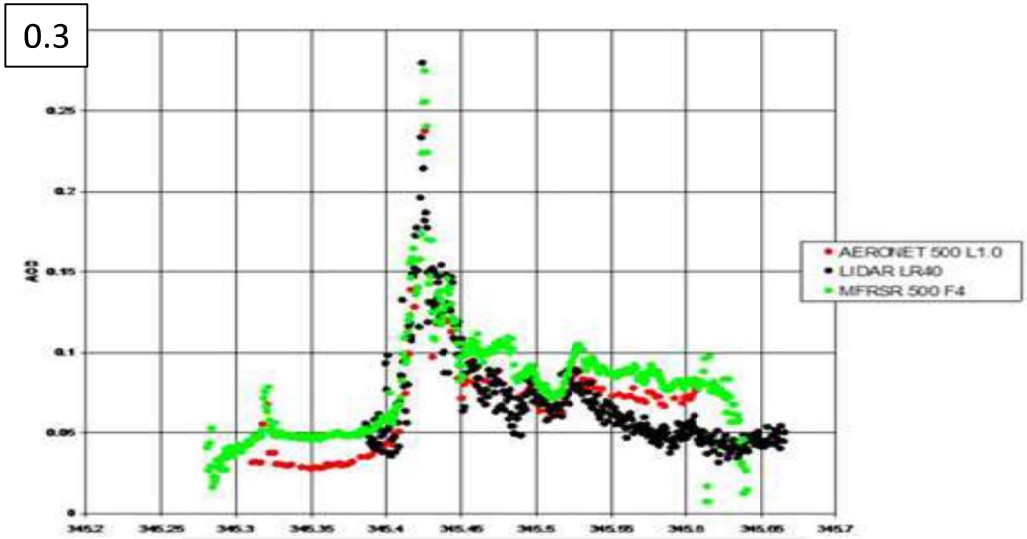
532 nm



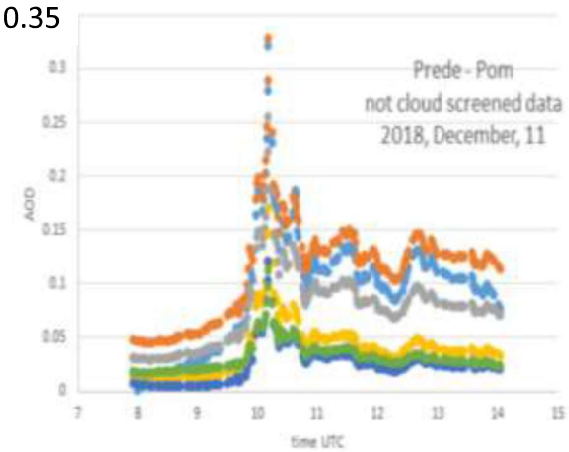
1064 nm



0.3



0.35



wvl (nm)

340

400

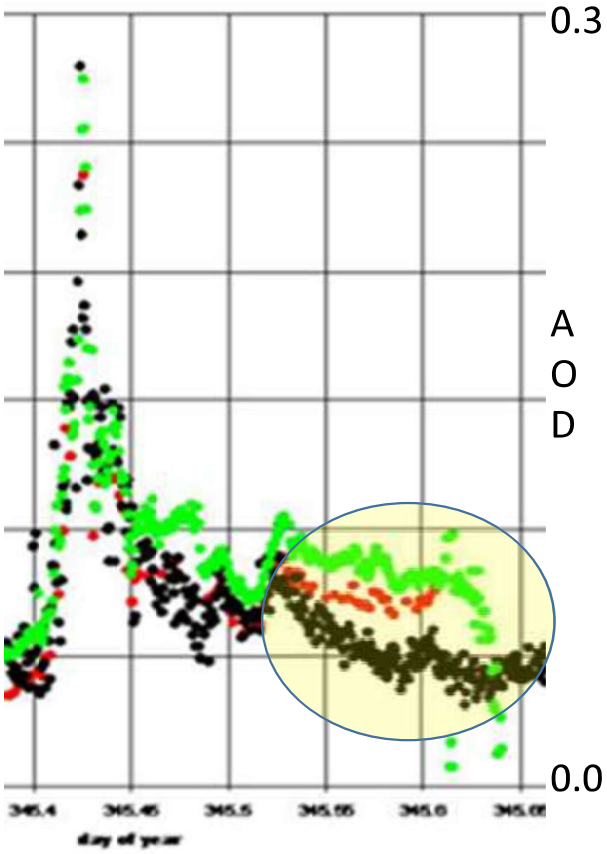
500

675

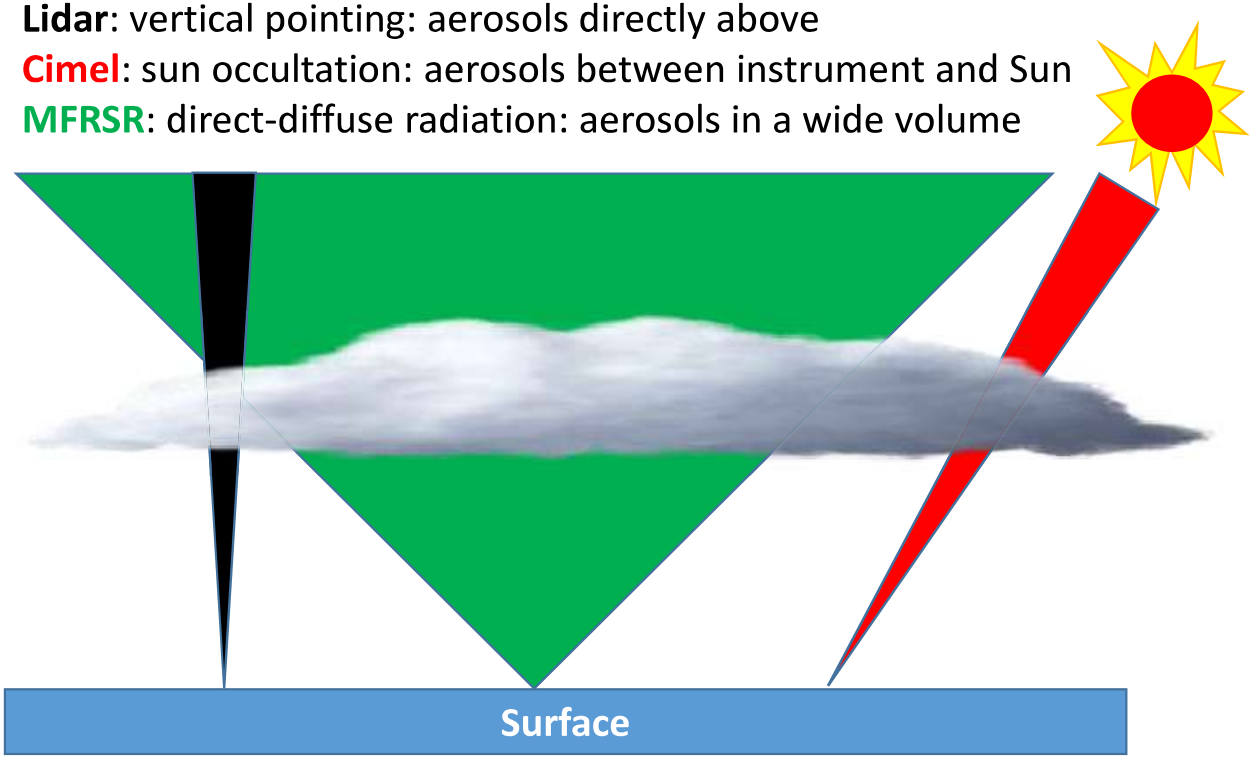
870

1020

TMB (waste facility) fire, 11 Dec 2018



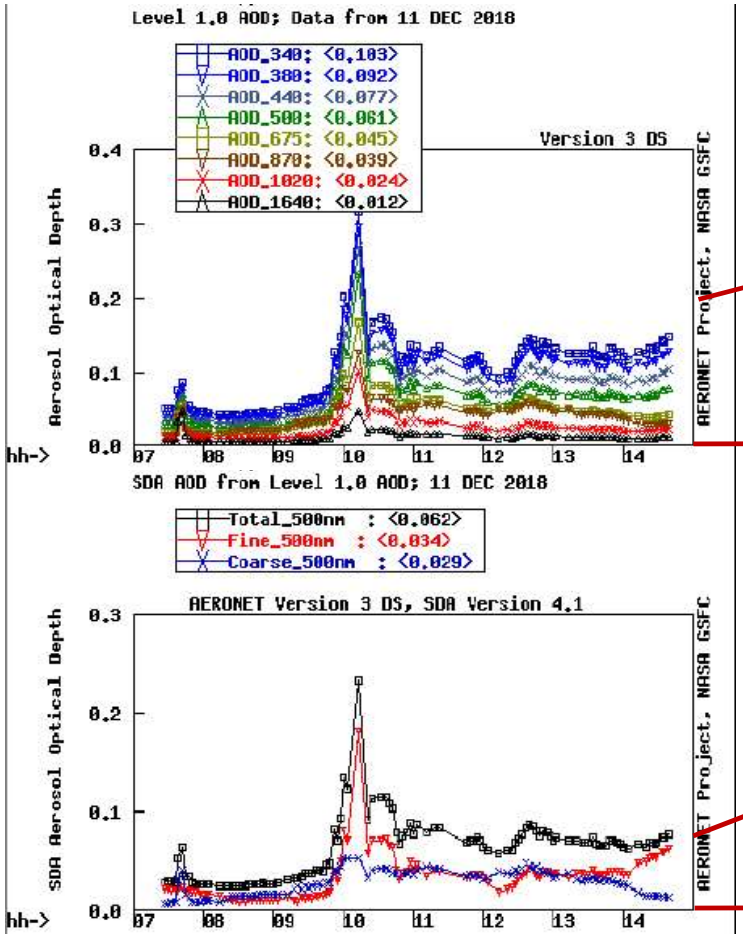
Lidar: vertical pointing: aerosols directly above
Cimel: sun occultation: aerosols between instrument and Sun
MFRSR: direct-diffuse radiation: aerosols in a wide volume



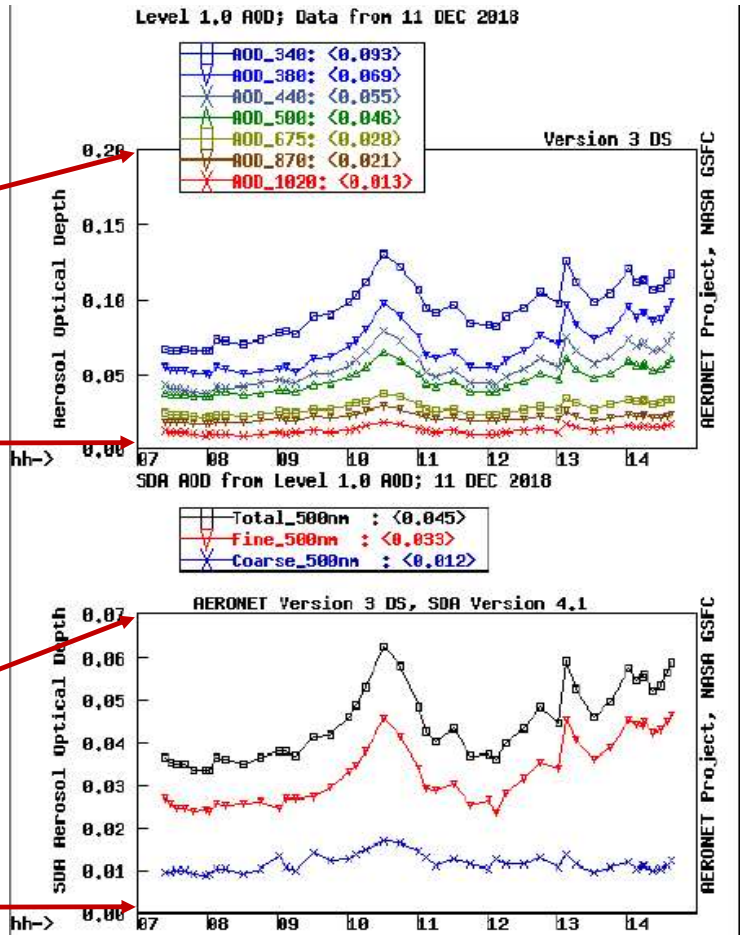
Nothing wrong here, just different points of view.
Interpretation of results depends on instrument type!

TMB (waste facility) fire, 11 Dec 2018

URBAN (BAQUNIN)



SEMI-RURAL (CNR-ISAC, G.P. Gobbi)



TMB (waste facility) fire, 11 Dec 2018

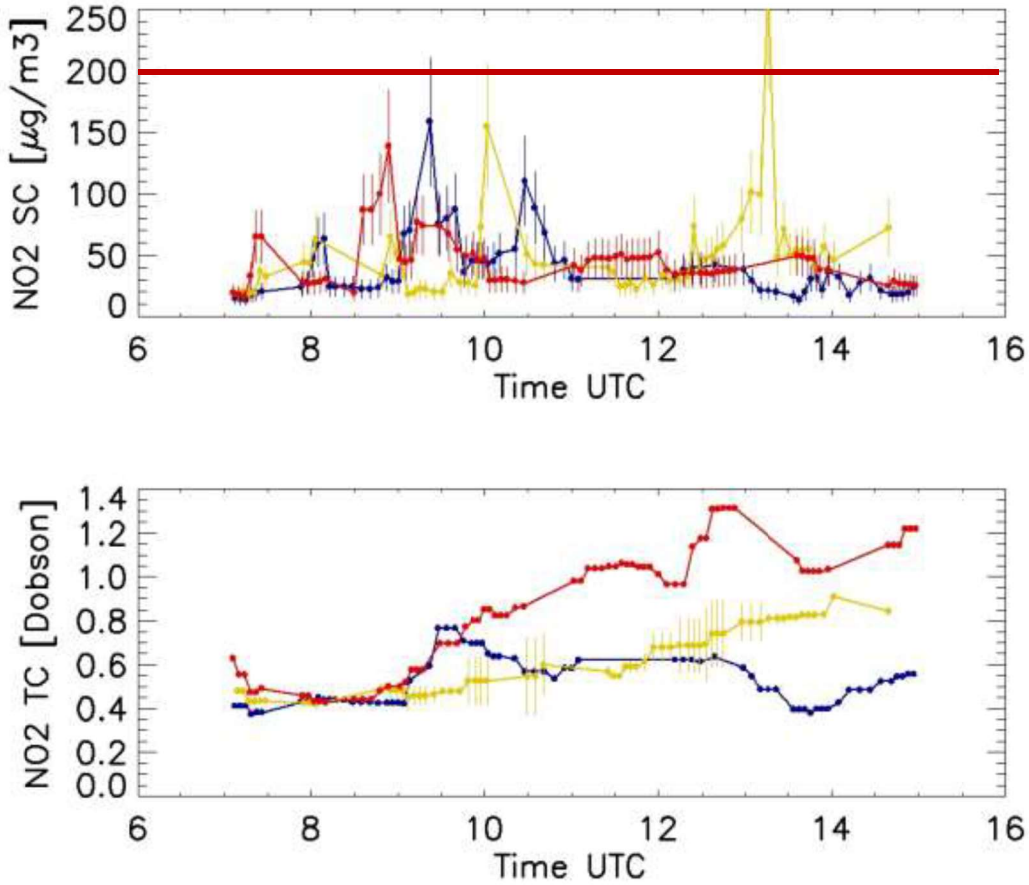
Analysis Pandora #117 NO2 (Sapienza)

Blue = 20181210
Red = 20181211
Yellow = 20181212
Vertical bars: estimated uncertainties

Upper panel
Surface Concentration (**SC**) time evolution

Lower panel
Tropospheric Column (**TC**) time evolution

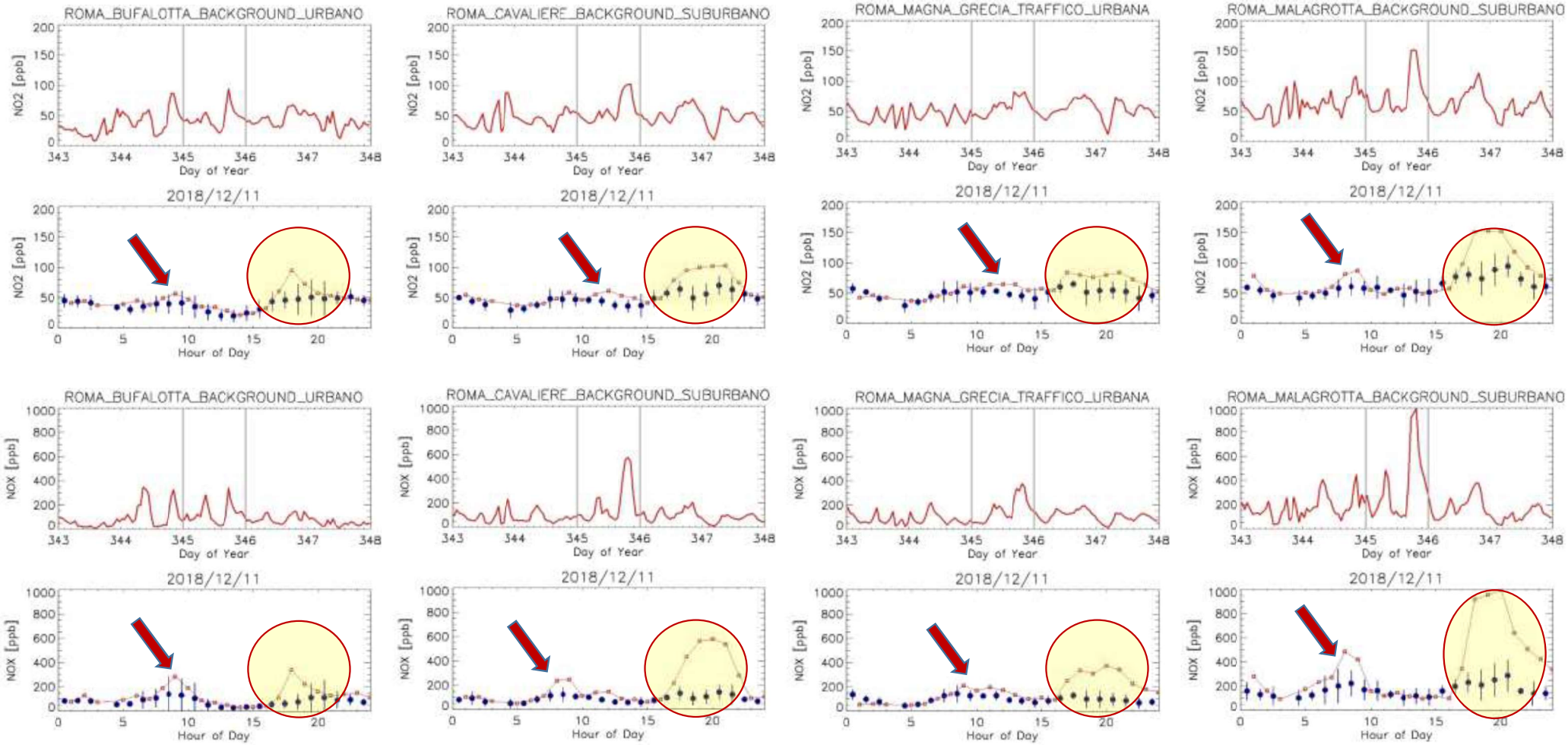
Comments
SC: **no clear conclusions can be drawn**
TC: **significant increase** (concentration doubled!)



TMB (waste facility) fire, 11 Dec 2018

NO2

NOx



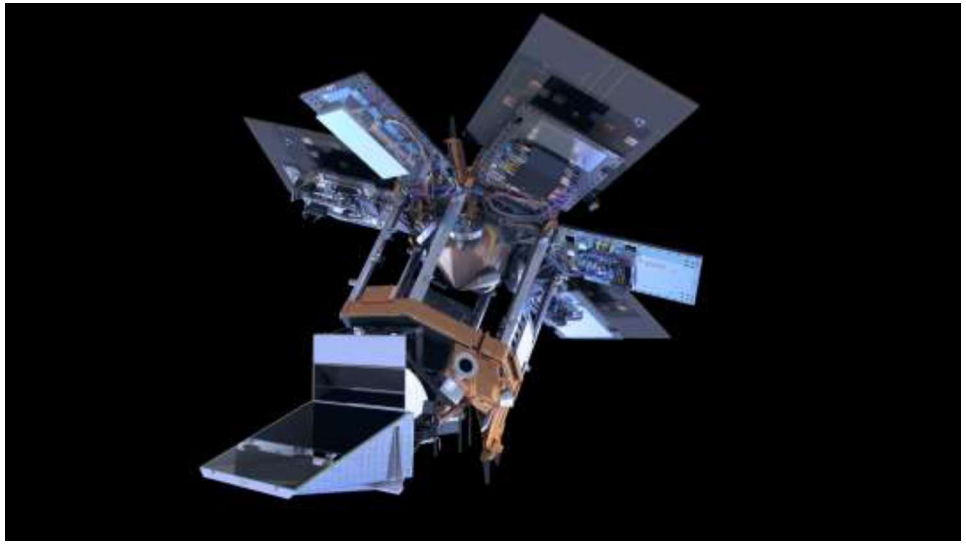
Lesson learnt:

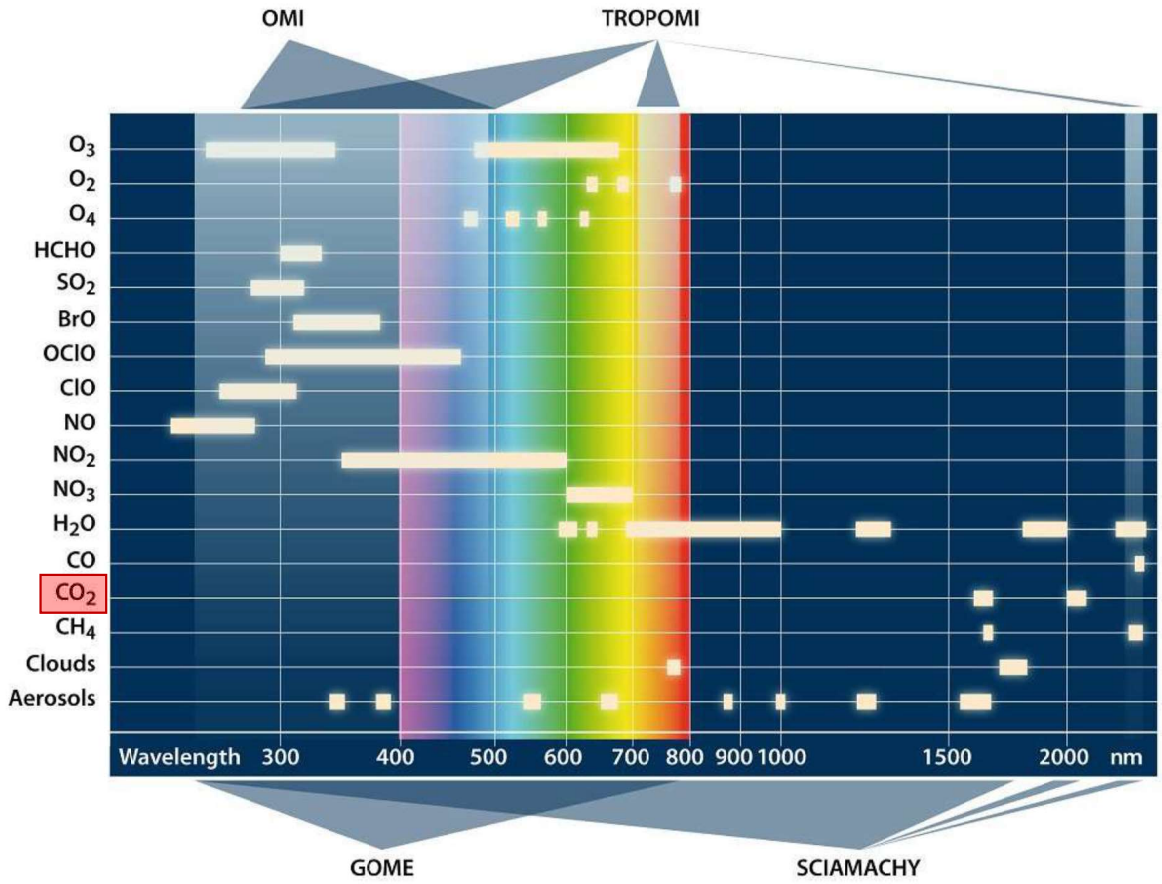
1) The Remote Sensing instruments can detect aerosol and trace gases plumes and/or layers if located above the surface layer (50-100 m)
2) The time resolution for any instrument should be of the order of minutes (or seconds)
3) The in situ instruments should provide uncertainties (or, at least standard deviation for the averaging period)
4) The analysis of the in situ data should include the analysis of the Urban Boundary Layer characteristics (height, stability, …)
5) The analysis of Remote Sensing Data is not straight forward.

Part III

Rome pollution seen from space: S5p-TROPOMI NO2

Copernicus Sentinel-5 Precursor: first Copernicus mission dedicated to monitoring Earth atmosphere.
Payload: TROPOspheric Monitoring Instrument (TROPOMI) instrument.
The satellite was launched on 13 October 2017 from the Plesetsk cosmodrome in Russia.
Local time ascending node crossing: 13.30
TROPOMI spatial resolution (ground pixel size): 3.5 x 7 km^2
https://sentinels.copernicus.eu/web/sentinel/missions/sentine
TROPOMI data access:
https://s5phub.copernicus.eu/dhus/#/home





BAQUNIN activities for TROPOMI Cal/Val

S5p ESA Validation Project ID 42807 (PI Stefano Casadio)

"An Italian coordinated contribution to the Validation of Sentinel-5p Level-2 products from four atmospheric observatories in the Central Mediterranean Sea"

SERCO: **3** scientists, **BAQUNIN**
ENEA: **7** scientists+**2** technicians, Lampedusa Observatory
CNR IIA: **5** scientists, Montelibretti
CNR ISAC: **3** scientists, CNR Isac Rome Atmospheric Supersite - CIRAS
Sapienza: **2** scientists (+master/PHD students), **BAQUNIN**
Sardegna Clima Onlus: **1** scientist, **BAQUNIN**

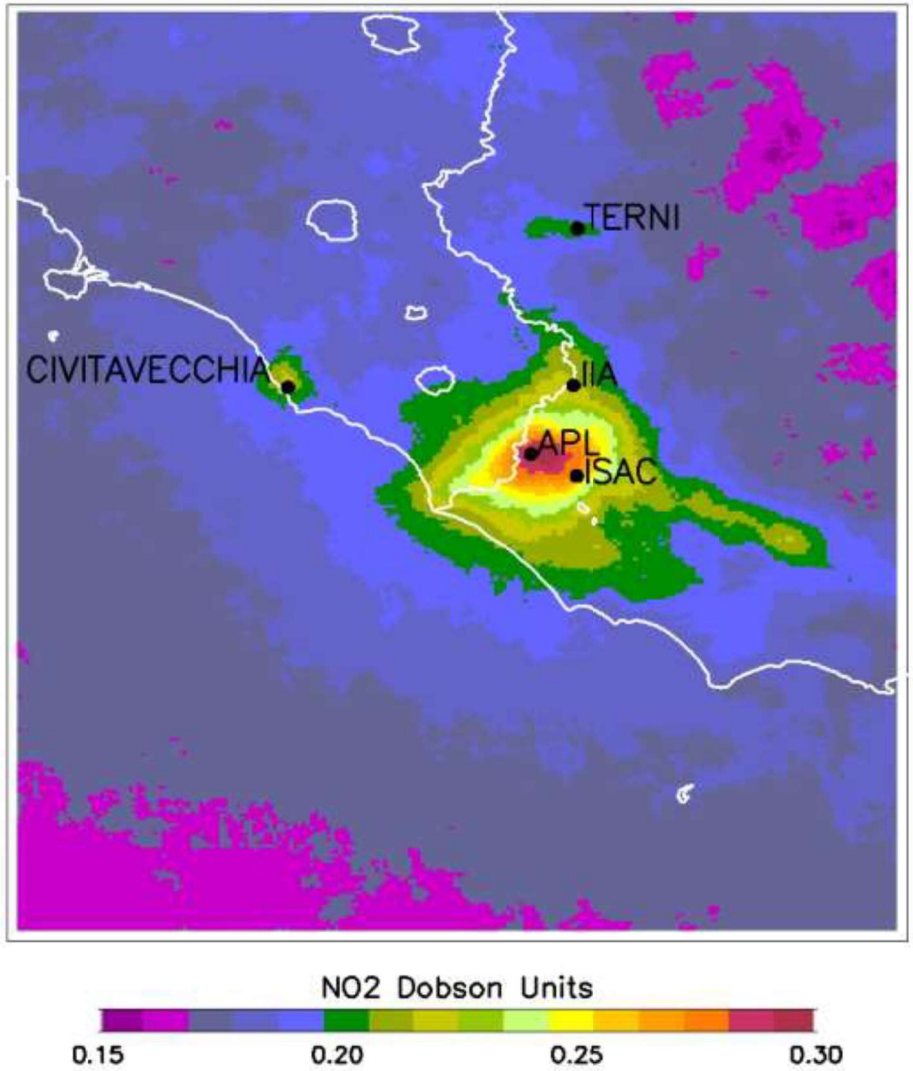
- Direct validation of **O3**, **NO2**, **HCOH**, **SO2**, **H2O** tropospheric and/or vertical column densities
- Impact of different **aerosol types and loads** in TROPOMI trace gases retrieval algorithm
- Impact of the **urban environment** and of its spatial inhomogeneity in terms of both surface and atmospheric properties

TROPOMI NO2 concentration in the Tiber valley

This map shows a 6 months average of NO2 Total Column Concentration obtained from cloud-free/high-quality TROPOMI measurements (3.5x7 km2).
The sensing time is 13:30 UTC (14:30 local time)

The positions of the three BAQUNIN "chemical" instruments (Pandora) are also displayed:
APL (Sap) => Pan#117
CNR-ISAC => Pan#115
CNR-IIA => Pan#138

Apart from the **Rome** area, significant NO2 values are found in the **Sacco Valley** and along the **Tiber river bed**.
Civitavecchia is a detectable source of NO2 (ships?).
Terni shows slightly enhanced NO2 values (steelworks?).



TROPOMI NO2 concentration in the Tiber valley

The impact of Cloud Coverage and Quality Indicators (flags) on the analysis discussed in previous slide, is summarised in this figure, where the percentage of useful TROPOMI data is shown.

Useful TROPOMI data = 100 x (“good” data) / (total measurements) per grid cell

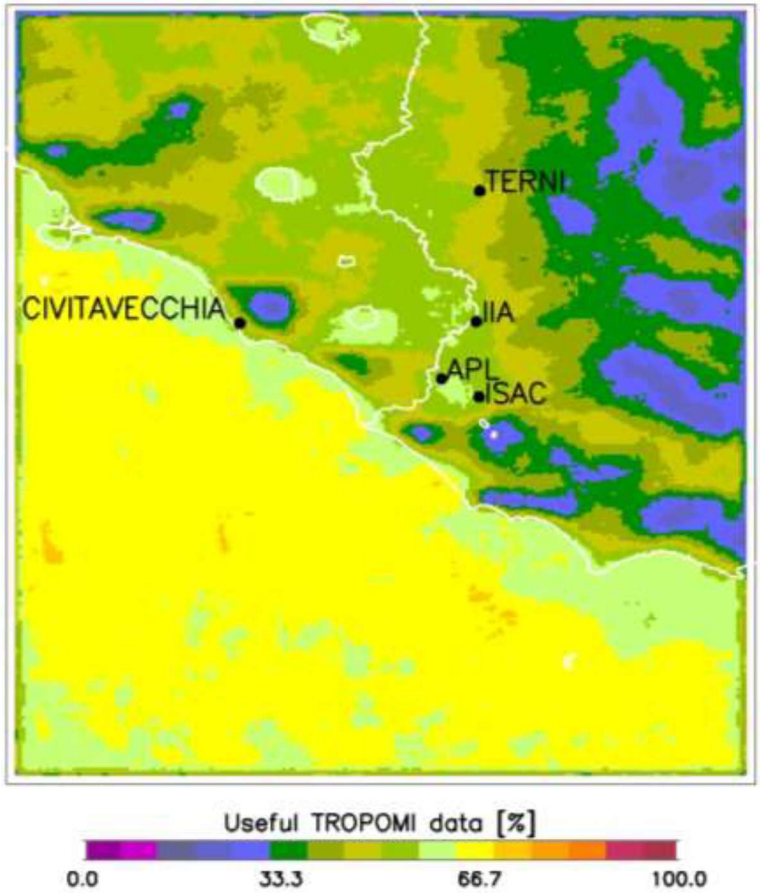
We can observe that:

- Over land, **~ 60%** of TROPOMI measurements are cloudy or low quality
- Over sea the situation is much more favourable (**~ 30%** discarded)

Possible explanations:

1) Temperate coastal hydrological cycle (more clouds over land around noon)
2) TROPOMI cloud algorithm sensitivity to underlying surface reflectance
3) NO2 Quality Indicators sensitivity to underlying surface reflectance

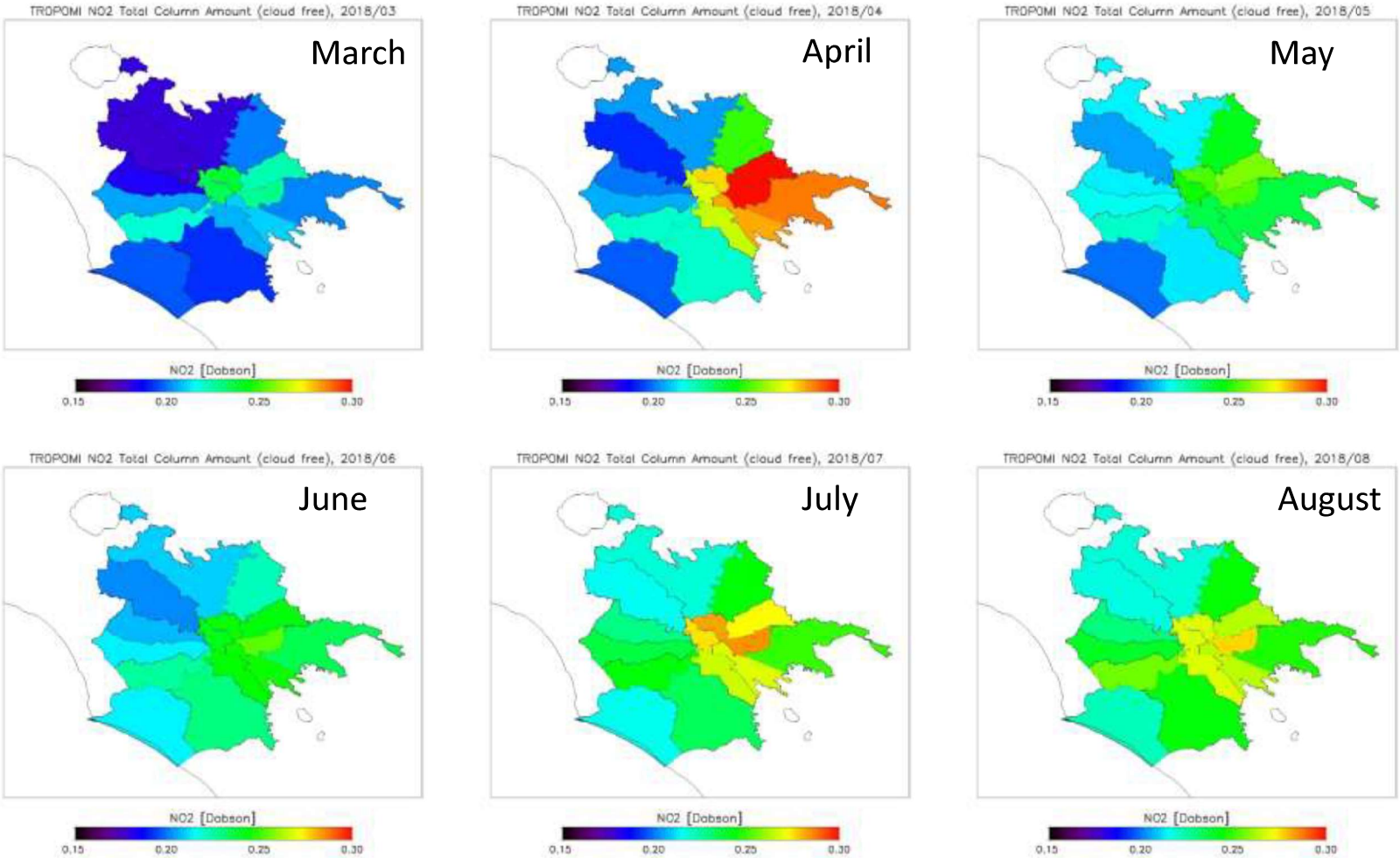
Thus, before drawing conclusions, it is necessary to evaluate all possible aspects of given dataset: from basic physics of the retrieval to geophysical nature of the species in question.



Interpretation of results is not straight forward!

TROPOMI data analysis: monthly NO2 concentrations per Municipality

Clouds play a significant role here (seasonal)!



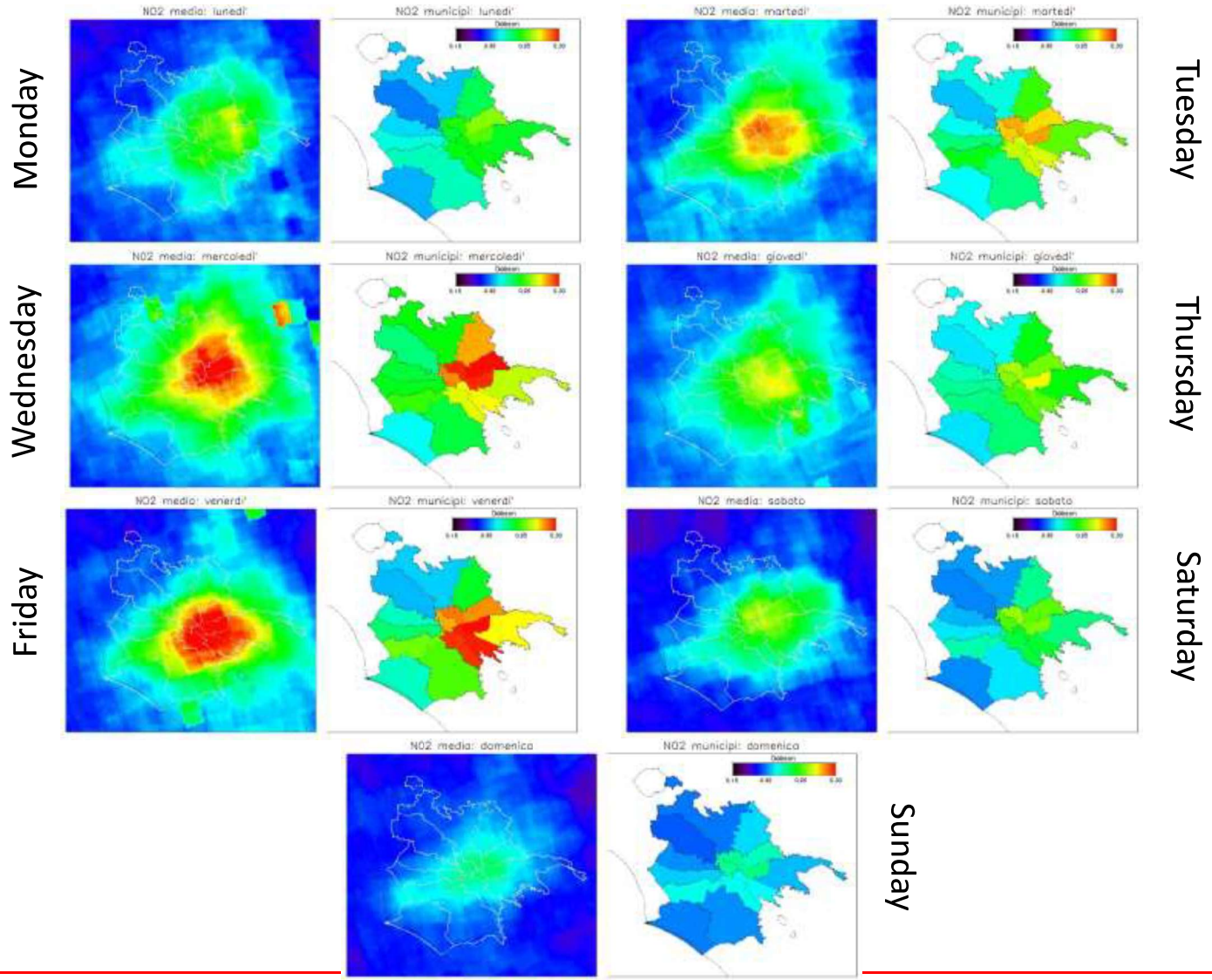
TROPOMI data analysis:
Day-of-week NO2 concentrations

These preliminary results show that the NO2 production is strictly related to traffic: Wednesday and Friday are by far the most polluted days.

As expected, Sunday is the cleanest day of the week.

Please note that highest NO2 values do not occur always in the same Municipalities.

Clouds do not play a role here!

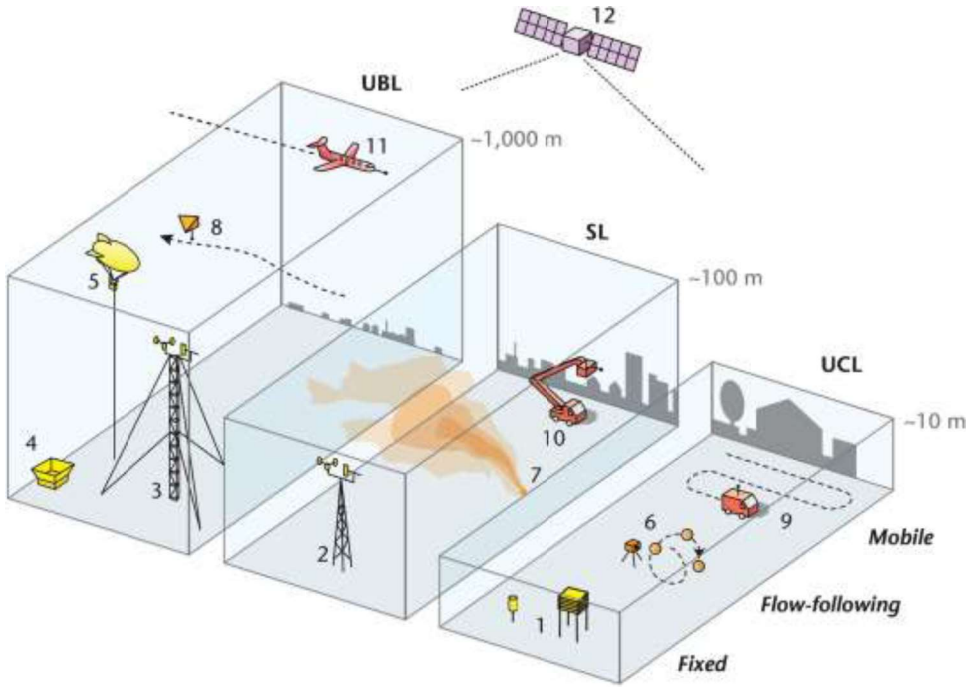


Part IV

On the satellite, ground based and in situ complementarity

Which devices can be used in a **urban environment** for air quality monitoring?

UBL = Urban Boundary Layer
SL = Surface Layer
UCL = Urban Canopy Layer



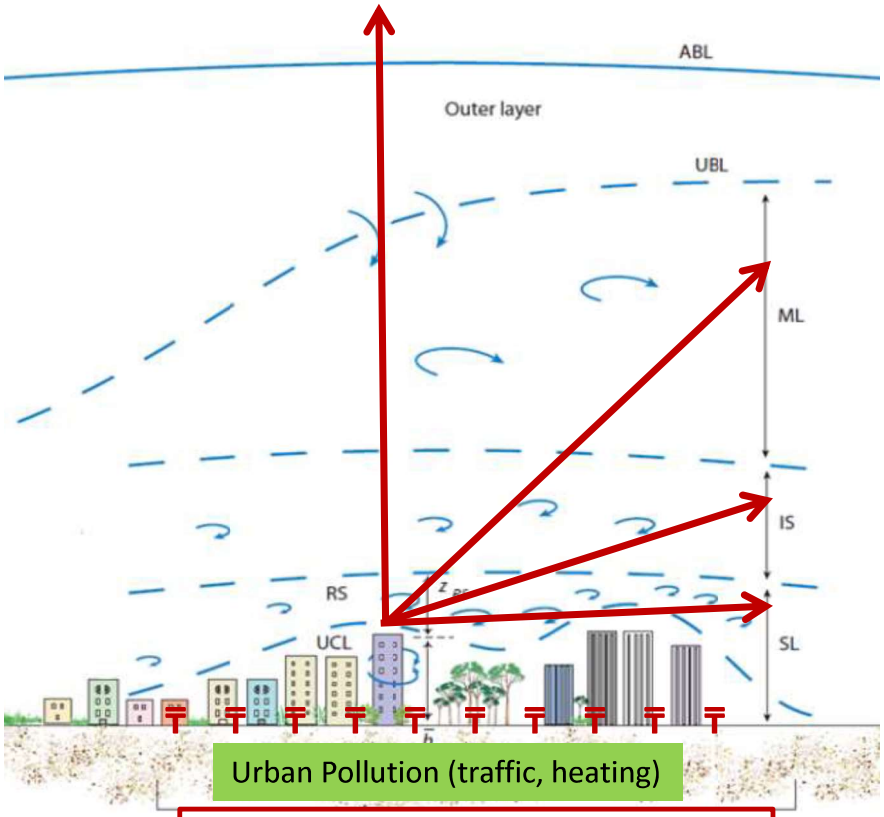
ID	Typology	Operations	Sampling	Provider
1	In situ	Automatic, 24/7	1 m	***ARPA***
2	In situ tower <30m	Automatic, 24/7	1 m	NA(?)
3	In situ tower <200m	Automatic, 24/7	1 m	NA
4	Remote sensing	Automatic, 24/7 Operator	0.1-10 km	**BAQUNIN**
5	Tethered balloon / kite	Operator	Not allowed	NA
6	Small balloon / drone	Operator	Not allowed	NA
7	Tracers	Operator	Not allowed	NA
8	Balloon	Operator	Not allowed	NA
9	In situ mobile	Operator	1 m	NA
10	In situ mobile <30m	Operator	1 m	NA
11	Airborne	Operator	1-5 km	NA
12	Satellite	Automatic	0.1 (optical) to 5 km (chemical)	**BAQUNIN?**

a) *Ground based remote sensing instruments* "see" **upper SL and above**. Good time resolution, large air volumes. However the pollution production layer (UCL) is **not probed**.
Clouds can be a limiting factor.

b) *In situ instruments* are **embedded in the UCL** but can only probe the atmosphere in their proximity. **Low** time resolution, **insufficient** coverage (**no uncertainties**).

C) *Atmospheric Composition Satellite instruments* provide a good **2D description**, but are almost insensitive to what happens below the ML (physical limitations).
Clouds are a limiting factor.

Thus, the three techniques are ***fully complementary***, and precise information on the quality of the urban atmosphere ***should result from their physically consistent combination***.



Urban Boundary Layer (UBL)
- Mixed Layer (ML)
- Inertial Sublayer (IS)
- Surface Layer (SL)
  - Roughness Sublayer (RS)
  - Urban Canopy Layer (UCL)

Conclusions

SERCO Italia, in collaboration with University Sapienza, CNR-ISAC, CNR-IIA and Sardegna Clima, is the prime contractor of the **BAQUNIN** ESA project (2019-2022).

Main **BAQUNIN** tasks for the next three years:

- **Operate/calibrate/characterise** remote sensing and in situ instruments
- **Collect, harmonise and distribute** high quality atmospheric products (aerosols, trace gases, wind/turbulence)
- **Support/perform validation** of Atmospheric Composition Satellite missions
- **Promote synergistic use** of active/passive atmospheric probes to improve data quality and information content
- Perform Urban Boundary Layer **research studies**
- Perform **inter-comparison** / **inter-calibration** campaigns
- **Attract** other scientific institutions operating in Rome area to "**facilitate**" research activities and, possibly, **new services for the Community**

Campaigns 2017/2018/2019

- Lidar&Radiometer Measurement Campaign (LRMC-2017 - ACTRIS)
- Effect of Megacities on the Transport and Transformation of Pollutants on the Regional to Global Scales (EMeRGe, http://www.iup.uni-bremen.de/emerge/home/home.html)
- QUAlity and TRaceabiliy of Atmospheric aerosol Measurements (QUATRAM, http://www.isac.cnr.it/en/tags/quatram)
- Valutazione Integrata dell'Esposizione a Particolato in ambiente indoor (VIEPI - INAIL)
- QUATRAM-2 (April-June 2019)

Projects 2018/2019

- DIVA ESA Project selected Lidar-CIMEL station
- PANDONIA ESA Project "POp" and "FRM4AQ"
- EarthCare ESA Validation Project ID 38811
- S5p ESA Validation Project ID 42807
- SORBETTO Summer School

Conferences/Symposia/Workshops:

- LPS (**2016**, **2019**)
- ACVE (**2017**)
- ILRC (**2017**)
- ESA/Task-3 (**2017**, **2018**, **2019**)
- S5p VT (**2018**)
- EGU (**2018**)
- CNR-IIA (**2018**)
- AISAM (**2018**)

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Thanks for your attention!!!