The Boundary-layer Air Quality-analysis Using Network of Instruments (BAQUNIN) supersite for atmospheric research and satellite validation over Rome area

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109° Congresso Nazionale SIF
Sezione IV: *Geofisica e fisica dell'ambiente*
Salerno, 11-15 Settembre 2023

Società Italiana di Fisica

MOTIVATION

Ten years ago…

*"The requirements for a good validation strategy are simple: continue acquiring new data, go to the **right places**, take the **right measurements** at the **right time**, accumulate enough data, include **validation of ancillary data** and facilitate **data access**."*

Richter et al., "*Validation strategy for satellite observations of tropospheric reactive gases*"
ANNALS OF GEOPHYSICS, 56, FAST TRACK-1, 2013; 10.4401/AG-6335
ACVE, 13-15 March 2013

*"A clear need to **develop validation activities for AQ products** in "**challenging**" conditions has been identified during the ACVE2013 to be documented in an "Air Quality Validation Plan". In particular, areas with strong pollution gradients, different cloud conditions, variable terrain types and slopes, and high aerosol loads **should be considered for the installation of validation tools** "*

Casadio et al., "*The Atmospheric Composition Validation and Evolution Workshop (ACVE2013) - Recommendations*"
ANNALS OF GEOPHYSICS, 56, FAST TRACK-1, 2013; 10.4401/AG-6335
ACVE, 13-15 March 2013

MISSIONS

In response to these needs, since 2015 the European Space Research Institute (ESRIN)–Sensor Performance, Products and Algorithms (SPPA) section has promoted and supported an activity called:

Boundary-layer Air Quality-analysis Using Network of INstruments
BAQUNIN

aimed at the creation of a "Satellite Calibration/Validation and Urban Environment Monitoring Super-Site"

In the framework of BAQUNIN IDEAS+ Work Package, a number of instruments have been purchased by ESA or provided by other research institutes, and installed/operated at:

- ESRIN (Frascati, Rome): 2015-2016
- Physics Department of Sapienza University of Rome (Rome): 2016 - today
- CNR-ISAC (Tor Vergata, Rome): 2016 - today
- CNR-IIA (Montelibretti, Rome): 2018 - today

MISSIONS

- Sustain the **maintenance** and **operation** of various ground based remote sensing instruments for Satellite Cal/Val and Atmospheric Monitoring/Research purposes
- Acquire, homogenise and distribute high quality **data**
- Updating & application of **improved measuring techniques**
- Data analysis and **interpretation**
- Perform inter-calibration/comparison 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 (e.g., EUMETSAT, ASI, TPMs)

STAKEHOLDERS

- ✓ National/International Space Agencies
- ✓ National/International Research Institutes
- ✓ Universities
- ✓ National and Local Administrations
- ✓ Local and National Health Departments
- ✓ Citizen Associations
- ✓ Atmospheric Instrument Manufacturers
- ✓ Private Sector Services

IMPLEMENTATION: SCIENTIFIC STRATEGY

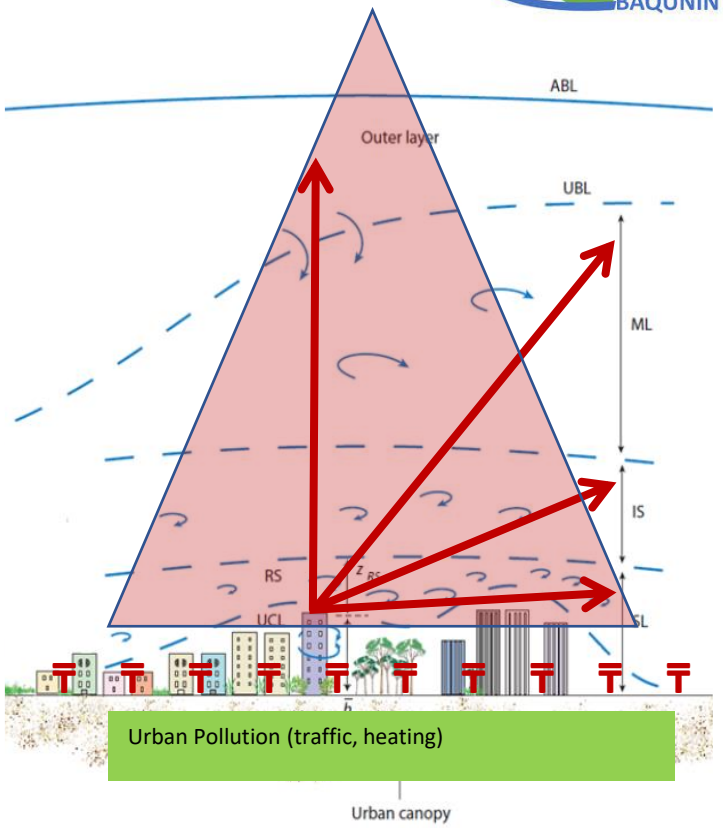
a) *Ground based remote sensing instruments* "see" **upper SL and above**. Good time resolution, large air volumes. However, the pollution production layer (**UCL**) **is not probed**. **Clouds can be** a limiting factor, **some** instruments **need sunlight**.

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

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

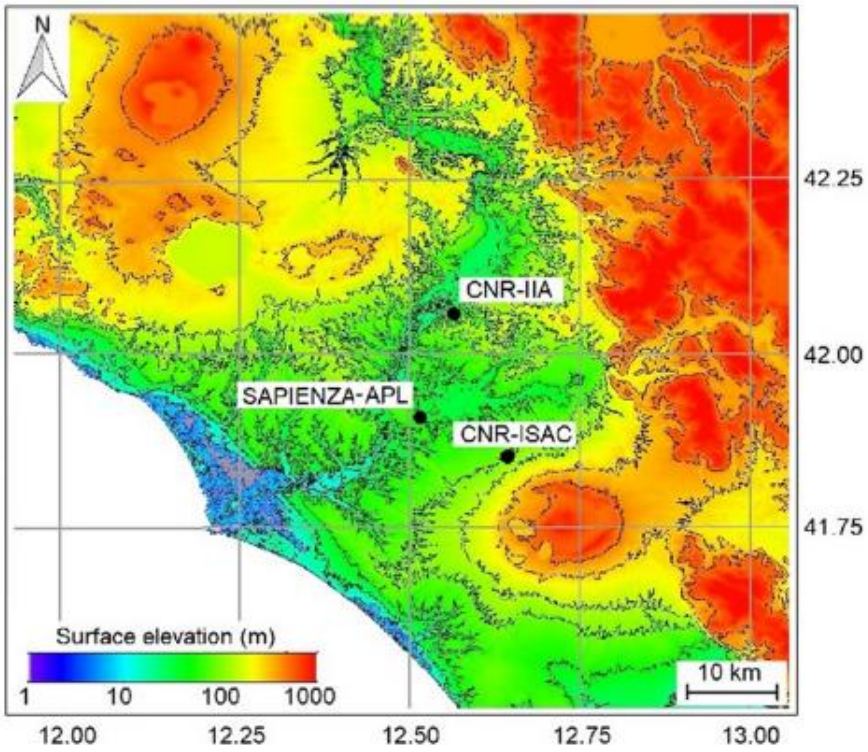
d) Modelling provides a good **4D description**, knowledge of **emission sources** is a limitation, UBL physics/chemistry **too complex**, **no unpredictable events** (e.g., industrial/wildfires).

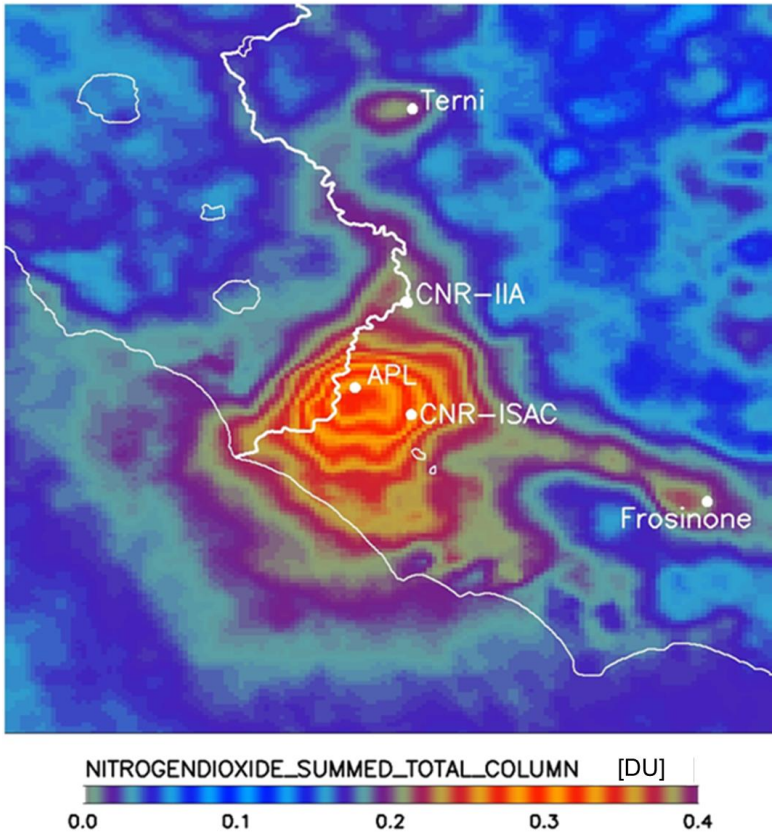
These techniques are ***fully complementary.***
Accurate information on urban atmosphere is obtained
from their physically consistent combination.



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

GEOGRAPHIC AND ATMOSPHERIC POLLUTION CONTEXT





URBAN ENVIRONMENT

SEMI-RURAL ENVIRONMENT

RURAL ENVIRONMENT

INSTRUMENTAL SUITE

Instrument	Network	Site
POM-PREDE #11	SKYNET	Sapienza
POM-PREDE #22	SKYNET	CNR-ISAC
POM-PREDE Lunar	SKYNET	Sapienza
Air Quality Low Cost		Sapienza
PANDORA #115	PGN	CNR-ISAC
PANDORA #117	PGN	Sapienza
PANDORA #138	PGN	CNR-IIA
Pyranometer		Sapienza
EM27-Sun FTIR	COCCON	Sapienza
All Sky Camera		Sapienza
MWL-LIDAR		Sapienza
SODAR		Sapienza
MFRSR		Sapienza
BREWER	EUBREWNET	Sapienza
WRF model		ALL
CIMEL	AERONET	Sapienza
Microbarometer		Sapienza
Meteo Station		Sapienza
All Sky Camera "stereo view"	NASA "CloudMask"	Sapienza
Ceilometer RAP		Sapienza
Ceilometer IIA		CNR-IIA

CNR-ISAC "CIRAS"

- MaxDOAS
- CIMEL
- SODAR

CNR-IIA "Liberti"

- MaxDOAS
- Meteo Station
- Air Quality in situ

Sapienza => Urban
CNR-ISAC => Semi-rural
CNR-IIA => Rural

Radiation

Trace/GHG

Aerosol

Clouds

Meteorology

INSTRUMENTAL SUITE - SAPIENZA

COCCON (GHG)

DWL*(wind, turbulence)

NASA Sky-Cam (stereo clouds)

*incoming

Meteo Station (p, T, RH, rain, UV, wind)

AERONET, SKYRAD (aerosol)
PGN (trace gases, aerosol)
Air-Quality (T, RH, trace gases, aerosol)

MWL-LIDAR (cloud, aerosol, H_2O)

SODAR (wind, turbulence)

Pyranometer (solar irradiance)
MFRSR (aerosol, trace gases)
SkyCamera (cloud)

RAP-LIDAR (cloud, aerosol)

EUBREWNET (trace gases, aerosol)

Meteo Station (T, RH, wind)

INTERNATIONAL NETWORKS

The BAQUNIN supersite is the cross-point of the following international networks.

This requires rigorous application of procedures/protocols, from instrument calibration to retrieval algorithms, ensuring highest quality of reference datasets.

- EVDC (https://evdc.esa.int)
- AERONET (https://aeronet.gsfc.nasa.gov)
- SKYNET (https://www.skynet-isdc.org/index.php)
- EUBREWNET (http://www.eubrewnet.org/eubrewnet)
- PGN (https://www.pandonia-global-network.org)
- COCCON (https://www.imk-asf.kit.edu/english/COCCON.php)

Moreover, the Sapienza site is an "*ACTRIS-Italy facility for scientific and inter-calibration and inter-comparison campaigns*".

CAL/VAL ACTIVITY

Product	Mission/Instrument
Trace gases	S5p, S4*, S5*, GOME-2, OMI, GOSAT, GOSAT-2, NewSpace
Water Vapour	S5p, EarthCare*, S4*, S5*, GOME-2, IASI, MTG, OMI, GOSAT, GOSAT-2
Aerosol	S2, S5p, EarthCare*, S4*, S5*, GOME-2, IASI, 3MI*, OMI, GOSAT-2, NewSpace
UV Dose/Index, Radiance	S5p, S4*, S5*, GOME-2, MTG, OMI
Clouds	All
Wind and Turbulence	EarthCare*, 3MI*
Green-house Gases	S5p, S5*, GOSAR, GOSAT-2, NewSpace
Meteorological Simulations	All

*future mission/instrument

ESA

EUMETSAT

TPM (including atmospheric "NewSpace" missions)

KEY SCIENTIFIC PUBLICATIONS (1)

BAMS Article

The Boundary Layer Air Quality-Analysis Using Network of Instruments (BAQUNIN) Supersite for Atmospheric Research and Satellite Validation over Rome Area

Anna Maria Iannarelli, Annalisa Di Bernardino, Stefano Casadio, Cristiana Bassani, Marco Cacciani, Monica Campanelli, Giampietro Casasanta, Enrico Cadau, Henri Diémoz, Gabriele Mevi, Anna Maria Siani, Massimo Cardaci, Angelika Dehn, and Philippe Goryl

Iannarelli et al. (2022)
DOI: 10.1175/BAMS-D-21-0099.1

This article describes all aspects of the BAQUNIN project, from the organisation of the activities through the scientific relevance of the instrumental suite to the data dissemination.

It is the BAQUNIN "reference" article, to be cited in all our scientific and technical documents.

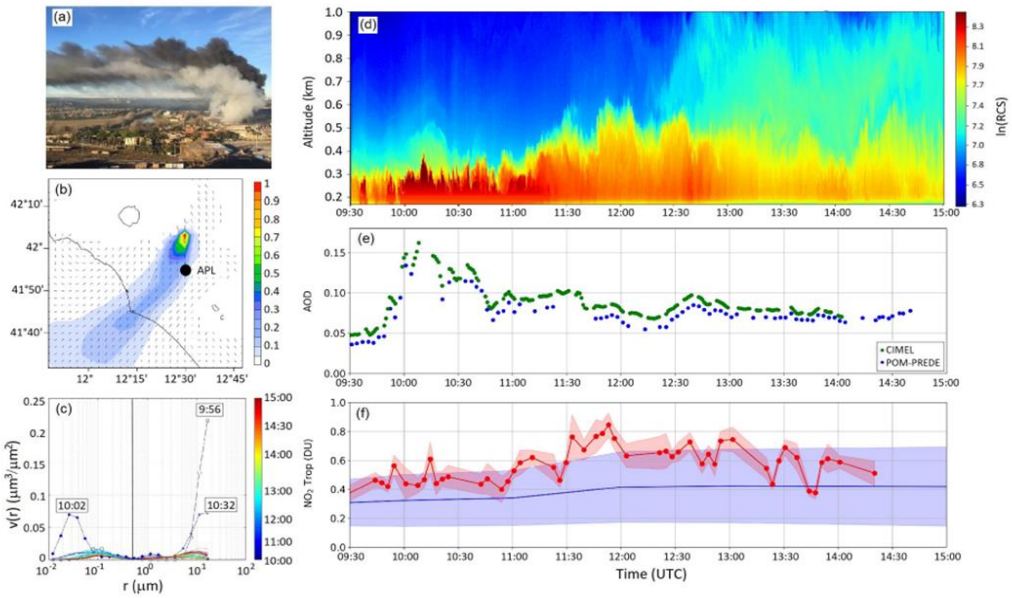
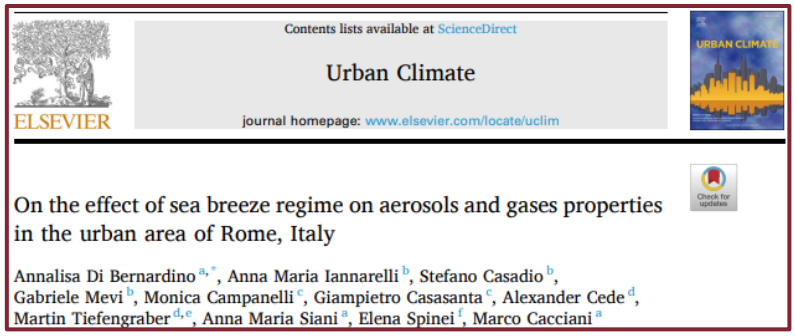


Fig. 5. (a) Plume generated by the fire at the TMB plant on 11 Dec 2018, (b) WRF dimensionless smoke concentration and wind field (150 m MSL) at 1000 UTC, (c) volume size distribution from Prede-POM, (d) logarithm of the range- and overlap-corrected backscatter at 1,064 nm from the lidar, (e) AOD at 500 nm retrieved from Cimel-CE318 (green dots) and Prede-POM (blue dots), (f) NO_2 tropospheric amount (red dotted line) with its standard deviation (red shaded area) compared to the 2016–19 reference period (blue line) with its standard deviation (shaded blue area).

The figure shows the complexity of the analysis of a fire plume event that can be performed adopting the BAQUNIN strategy.

KEY SCIENTIFIC PUBLICATIONS (2)



Di Bernardino et al. (2021)
DOI: 10.1016/j.uclim.2021.100842

Ground-based remote sensing and in-situ instruments are used to investigate the development of the sea-breeze front and its effect on both the optical and physical aerosol
properties, the particulate matter content and the tropospheric and near-surface NO2 concentrations in the urban area of Rome.
Two sea-breeze patterns are identified: the front days, in which the sea-breeze front develops in a few minutes, and the gentle breeze days, in which the onset of the front is gradual.

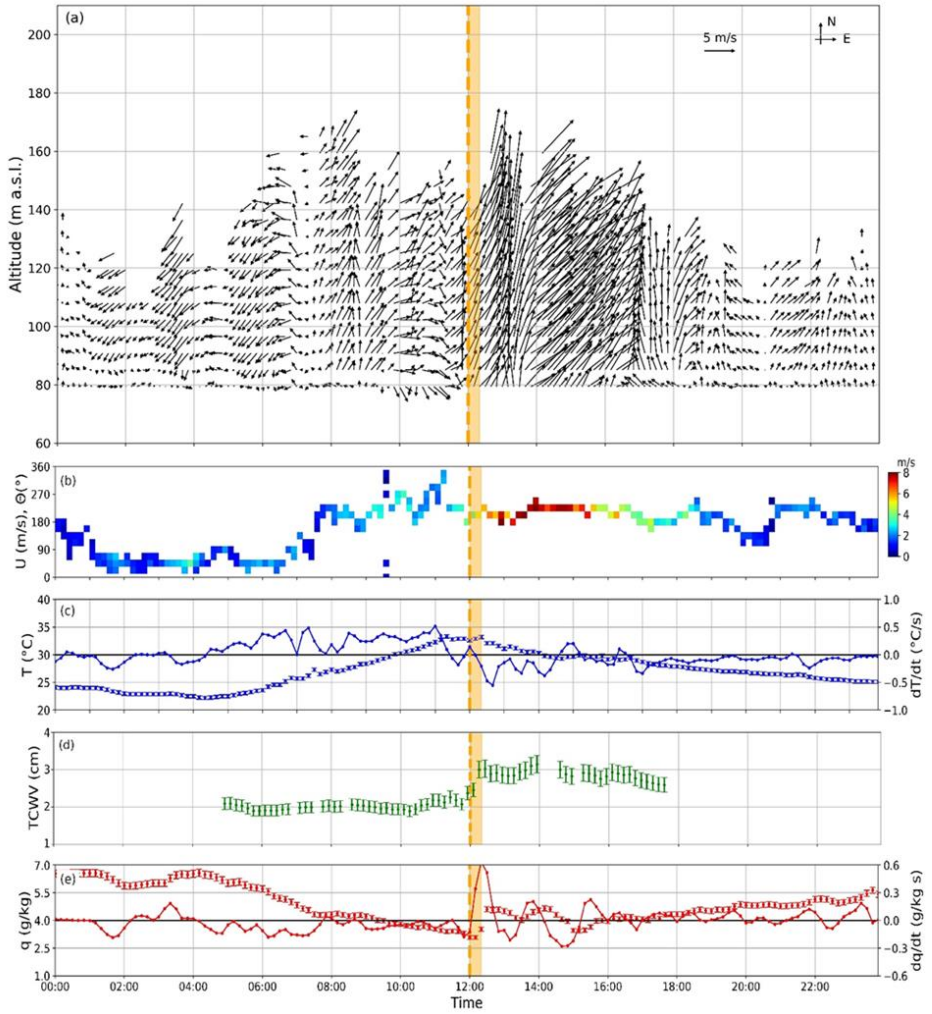


Fig. 3. Temporal variation of meteorological parameters for 1 August 2019. (a) 10-min averaged vertical profiles of horizontal wind velocity, (b) wind velocity U (colours) and direction θ as measured by SODAR at 84 m.a.s.l, (c) hemispherical solar radiation, (d) ground air temperature T, (e) total column water vapour TCWV, (f) specific humidity q. Continuous lines in panels (d) and (f) refer to the gradient of T and q, respectively. The orange dashed line represents the arrival of the SB front. The orange-filled area depicts the time interval required for the complete development of the SB. The black dotted lines show the sunrise and the sunset.

KEY SCIENTIFIC PUBLICATIONS (3)

Boundary-Layer Meteorology (2022) 185:333–363
https://doi.org/10.1007/s10546-022-00734-5

RESEARCH ARTICLE

Interaction of the Sea Breeze with the Urban Area of Rome: WRF Mesoscale and WRF Large-Eddy Simulations Compared to Ground-Based Observations

Annalisa Di Bernardino[1] · Vincenzo Mazzarella[2,3] · Mattia Pecci[4,5] · Giampietro Casasanta[6] · Marco Cacciani[1] · Rossella Ferretti[2]

Di Bernardino et al. (2022)
DOI: 10.1007/s10546-022-00734-5

WRF model is used to test the ability to reproduce the local circulation, and the onset and propagation of the sea breeze in Rome.
Several simulations are carried out modifying the land use and the thermal and physical properties of the surfaces.
Hence, the best simulations are used to initialize a large-eddy simulation at high spatial resolution to analyze the interaction between the sea breeze and the urban heat island and to investigate the interaction of the sea breeze front with orography and surface roughness.

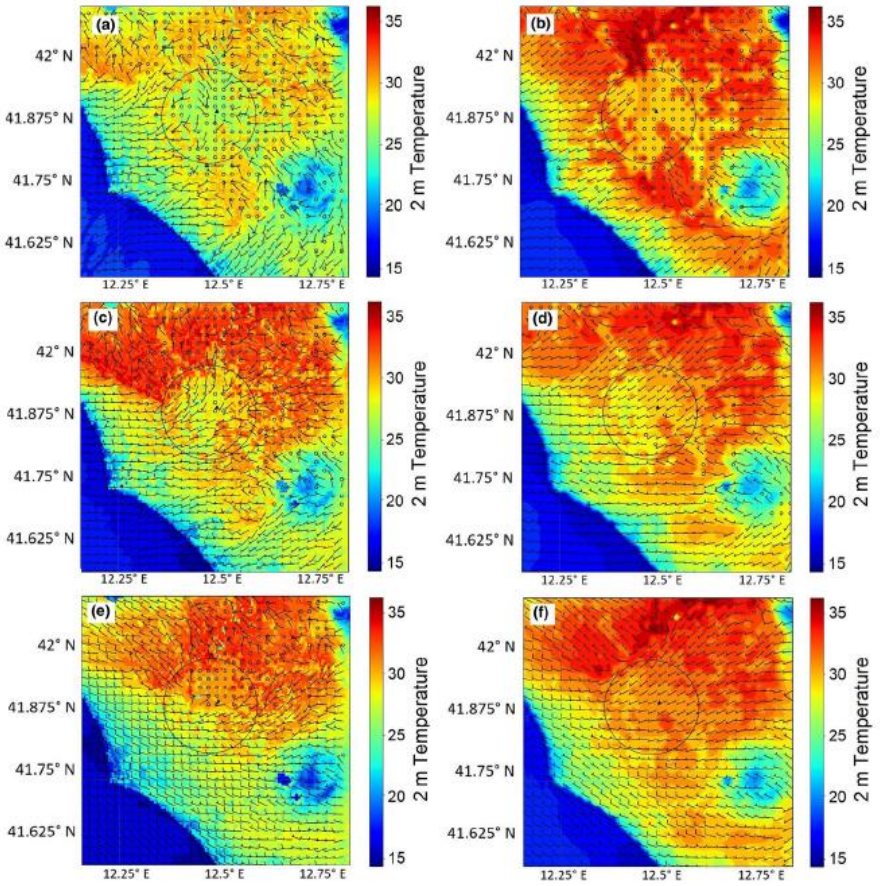


Fig. 12 Air temperature (colors) at 2 m a.g.l. and horizontal velocity (barbs) at 10 m a.g.l. for 28 June 2011 at 1000 UTC (a) and (b), 1200 UTC (c) and (d), and 1400 UTC (e) and (f). Left column: LES. Right column: NO-LES WRF_CAP2

KEY SCIENTIFIC PUBLICATIONS (4)

Earth Syst. Sci. Data, 13, 4929–4950, 2021
https://doi.org/10.5194/essd-13-4929-2021

Open Access Earth System Science Data

Advanced NO_2 retrieval technique for the Brewer spectrophotometer applied to the 20-year record in Rome, Italy

Henri Diémoz[1], Anna Maria Siani[2], Stefano Casadio[3], Anna Maria Iannarelli[3], Giuseppe Rocco Casale[2,a], Vladimir Savastiouk[4], Alexander Cede[5,6], Martin Tiefengraber[5,7], and Moritz Müller[5]

Diémoz et al. (2021)
DOI: 10.5194/essd-13-4929-2021

This article describes a new product from Brewer: NO_2 vertical column density from direct Sun measurements.
The retrieval of NO_2 requires the most accurate calibration of the Brewer and must account for very subtle instrumental effects. Through this work, the longest time series of urban NO_2 column density has been created (1996-2017) in order to be used for climatic and long-term analyses.

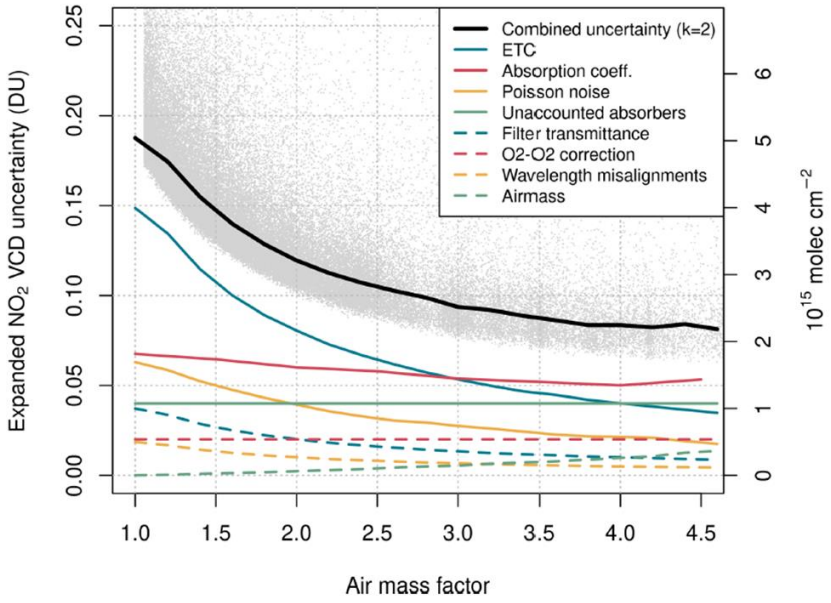


Figure 5. Total expanded uncertainty (black line) and its components, discussed in the text. The lines represent the median values for each air mass bin. Uncertainties are actually estimated for each individual measurement, here represented as grey dots.

KEY SCIENTIFIC PUBLICATIONS (5)

Atmos. Meas. Tech., 16, 2989–3014, 2023
https://doi.org/10.5194/amt-16-2989-2023

Atmospheric Measurement Techniques
Open Access
EGU

Evaluating the effects of columnar NO_2 on the accuracy of aerosol optical properties retrievals

Theano Drosoglou[1], Ioannis-Panagiotis Raptis[1,2], Massimo Valeri[3], Stefano Casadio[3], Francesca Barnaba[4], Marcos Herreras-Giralda[5], Anton Lopatin[5], Oleg Dubovik[6], Gabriele Brizzi[3], Fabrizio Niro[7], Monica Campanelli[4], and Stelios Kazadzis[8]

Drosoglou et al. (2023)
DOI: 10.5194/amt-16-2989-2023

This paper describes the rigorous analysis of a systematic error affecting one of the most popular aerosol dataset, AERONET, widely used in satellite Cal/Val. In the UV range, the AERONET inversion scheme does not account properly for NO_2 absorption, thus impacting the AOD and AE values in that spectral range. The BAQUNIN datasets have been used to demonstrate the effectiveness of the proposed correction which can reach 15% on AOD and even more for AE.

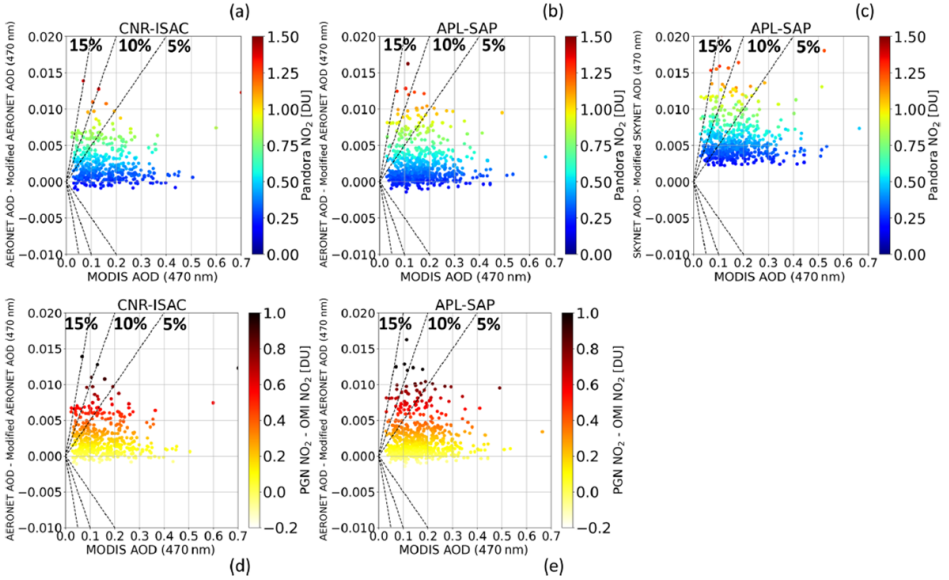


Figure 10. **(a–c)** Absolute correction as a function of the corresponding MODIS DB AOD data and PGN NO_2 data (color scale) for both CNR-ISAC and APL-SAP sites using AERONET and SKYNET AOD. The analysis was performed considering a maximum distance between the center of the MODIS DB pixel and the site location of 5 km and Δt_max of ±30 min. **(d, e)** Absolute correction of the MODIS DB AOD data for both CNR-ISAC and APL-SAP, using AERONET AOD as a function of the corresponding MODIS DB AOD data and the absolute difference between PGN and OMI climatological NO_2 (color scale).

FIELD CAMPAIGNS (1)

VIEPI (Integrated Evaluation of Indoor Particulate Matter, INAIL)
Date: February **2016** to December **2019**
Instruments involved: SODAR, MWL-Lidar, APL facility
Focus: evaluating indoor air quality and exposure to particulate matter (PM) of humans in workplaces

EMERGE (Effect of Megacities on Transport and Transformation of Pollutants on Regional to Global Scales, Univ. Bremen)
Date: July **2017**
Instruments involved: MWL-Lidar, SODAR, Pandora, PREDE-POM, Particle Counter
Focus: quantification of the emissions from targeted Major Population Centers and study their transport and transformation.

QUATRAM 1/2/3 (QUAlity and TRaceabiliy of Atmospheric aerosol Measurements, CNR)
Date: October **2017**; May to September **2019**; September **2021**
Instruments involved: PREDE-POM, CIMEL, MWL-Lidar
Focus: Calibration of a primary master sun-photometer and transfer of calibration to other instrumentation

FIELD CAMPAIGNS (2)

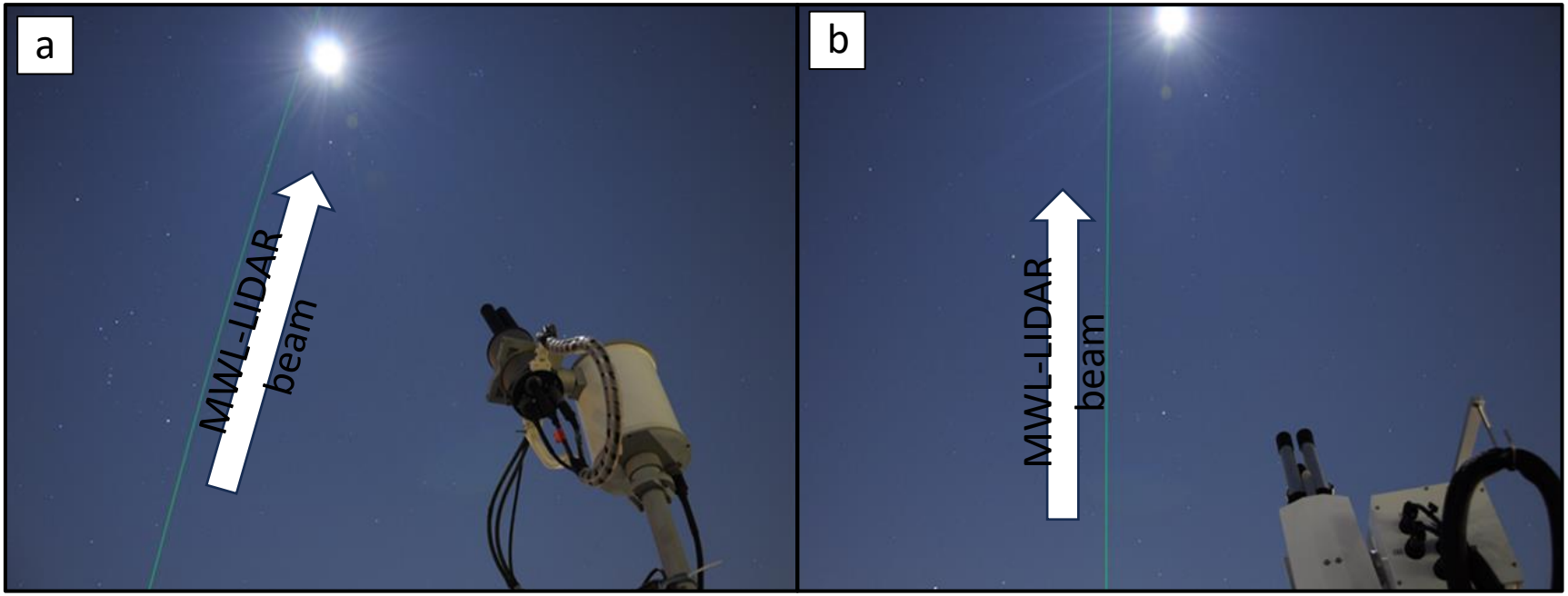
PGN-PGN (FRM4AQ, ESA project)
Date: September **2019**, September to October **2020**
Instruments involved: Pan#117 and Pan#138
Focus: Check instrument calibration, uncertainty, and stability

PGN-MaxDOAS (QA4EO WP, ESA)
Date: September **2021**
Instruments involved: Pan#117
Focus: New Max-DOAS NO2 total and tropospheric column quality assessment

MAPP (Metrology for Aerosol oPtical Properties, ESA)
Date: September **2021**
Instruments involved: PREDE-POM (x2), CIMEL, Pan#117
Focus: enable the SI-traceable measurement of column-integrated aerosol optical properties retrieved from the passive remote sensing of the atmosphere using solar and lunar radiation measurements.

FIELD CAMPAIGNS (3)

Support to development of new products: night-time Aerosol Optical Depth from PGN and SKYNET sun-moon-photometers



Long-lasting campaign aimed at the development of new Night-time products, such as O_3, NO_2, NO_3 and AOD from Lunar observations.

The figure above shows (a) PGN and (b) SKYNET photometers pointing at Full Moon Disk (@Sapienza). The thin green line in both (a) and (b) panels is the MWL LIDAR laser beam. LIDAR data are used to characterise the aerosol vertical distribution to verify the quality of the AOD data estimated by the two passive instruments' lunar measurements.

EDUCATION (1)

- Introduction to Atmospheric Physics – Bachelor degree in Physics (Sapienza)
  PROGRAM CONTENT: atmospheric circulation, atmospheric thermodynamics, radiative transfer

- Laboratory of Remote Sensing – Master degree in Atmospheric Science and Technology for Meteorology & Climate (Sapienza & University of L'Aquila)
  PROGRAM CONTENT: remote sensing instruments, aerosol microphysics, radiative transfer, laboratory activities

- Honours Programmes – Bachelor degree in Physics (Sapienza)
  Observation and modeling techniques for the study of the atmosphere and climate
  PROGRAM CONTENT: Ozone and UV radiation, Atmospheric aerosol, wind and turbulence, air quality numerical modeling

- Bachelor/master degree thesis in Physics

- Master degree thesis in Atmospheric Science and Technology for Meteorology & Climate

- PhD thesis in Information And Communication Technology (Sapienza)

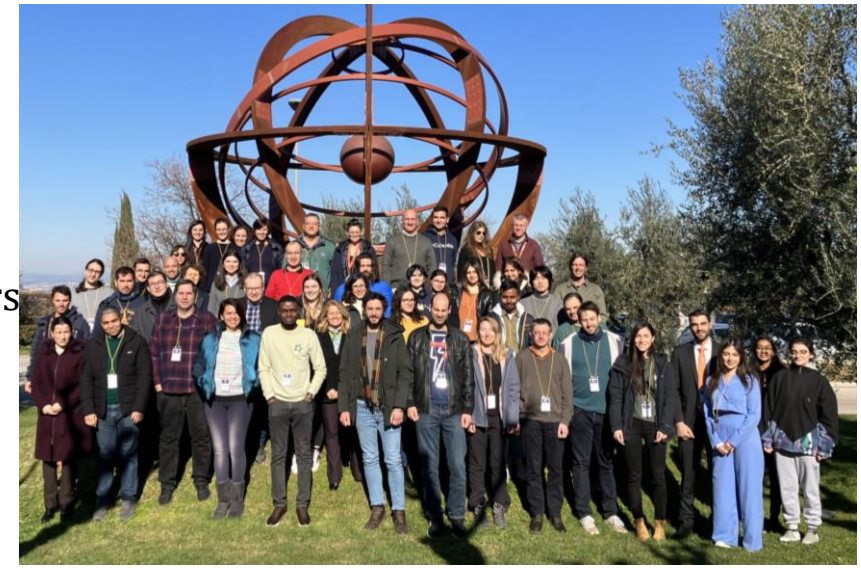
EDUCATION (2)

***SO**lar **R**adiation **B**ased **E**stablished **T**echniques for a**T**mospheric **O**bservations (SORBETTO) international school*

SORBETTO 1
Date: 2-6 July **2018**
33 students from 16 Nations, 18 international teachers
Web site: http://sorbetto2018.artov.isac.cnr.it/

SORBETTO 2
Date: 13-15 September **2021**
140 students from 43 Nations, 19 international teachers
Web site: http://sorbetto2.artov.isac.cnr.it/

SORBETTO 3
Date: 6-10 February **2023**
35 students from Europe, 18 international teachers
Web site: http://sorbetto2.artov.isac.cnr.it/



https://www.baqunin.eu

@BaquninProject

Supported by

esa EUMETSAT

Thank you for your attention!

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Stefano Casadio (Senior Scientist) stefano.casadio@ext.esa.int

Remembering Prof. Marco Cacciani

DATA STORAGE AND DISSEMINATION

LIDAR
SODAR
PYRANOMETER
MFRSR
METEO
WRF
SKYCAMERA(s)
RAP
CEILOMETER

PANDORA
POM-PREDE
CIMEL
BREWER
EM27-SUN

PGN
SKYNET
AERONET
EUBREWNET
COCCON

Data Storage and Format Harmonisation (@Sapienza)

Data Storage and Dissemination DIAS-ONDA SERCO

evdc esa
esa eo validation data centre