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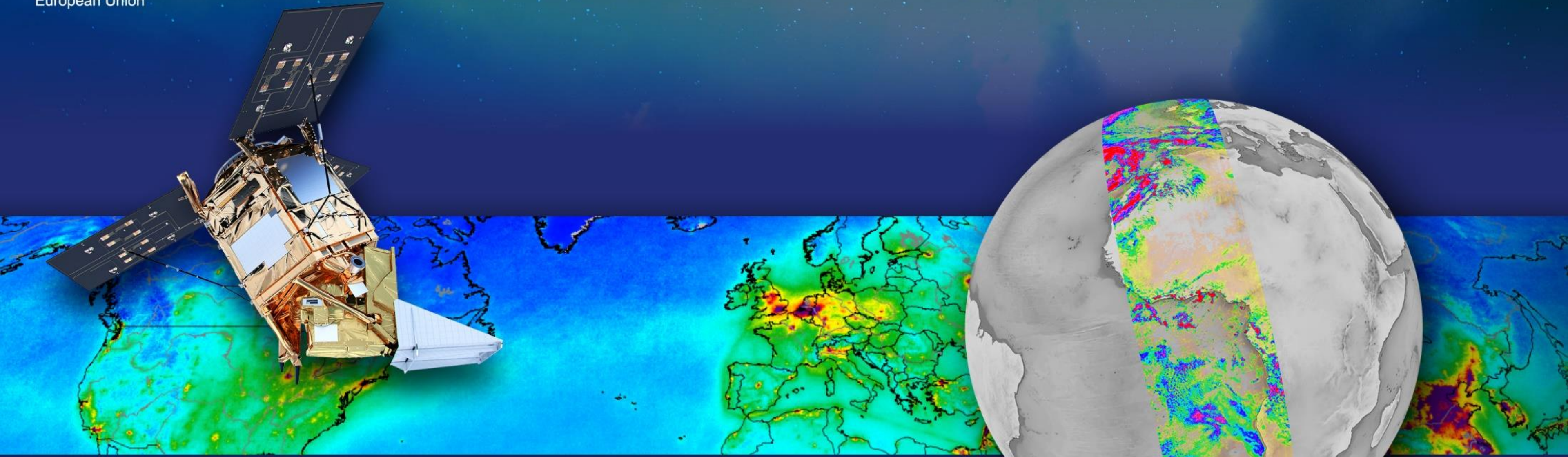

→ COPERNICUS SENTINEL-5 PRECURSOR VALIDATION TEAM WORKSHOP

11–14 November 2019 | ESA–ESRIN | Frascati (Rome), Italy

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Effect of Urban Boundary-layer turbulence on NO_2 concentrations retrieved from Pandora-2S: implications for TROPOMI validation

Boundary-layer **A**ir **Q**uality analysis **U**sing **N**etwork of **IN**struments (**BAQUNIN**) team:

- **SERCO**: A.M. Iannarelli, G. Mevi, E. De Grandis, E. Cadau, **S. Casadio**, M. Cardaci
- **Atmospheric Physics Laboratory, Sapienza Univ.**: M. Cacciani, A.M. Siani, A. di Bernardino
- **CNR-ISAC**: M. Campanelli
- **CNR-IIA**: C. Bassani, A. Fino
- **Sardegna Clima Onlus**: A. Murgia
- **ESA Technical Officer**: P. Goryl, A. Dehn

BAQUNIN Super-site Structure

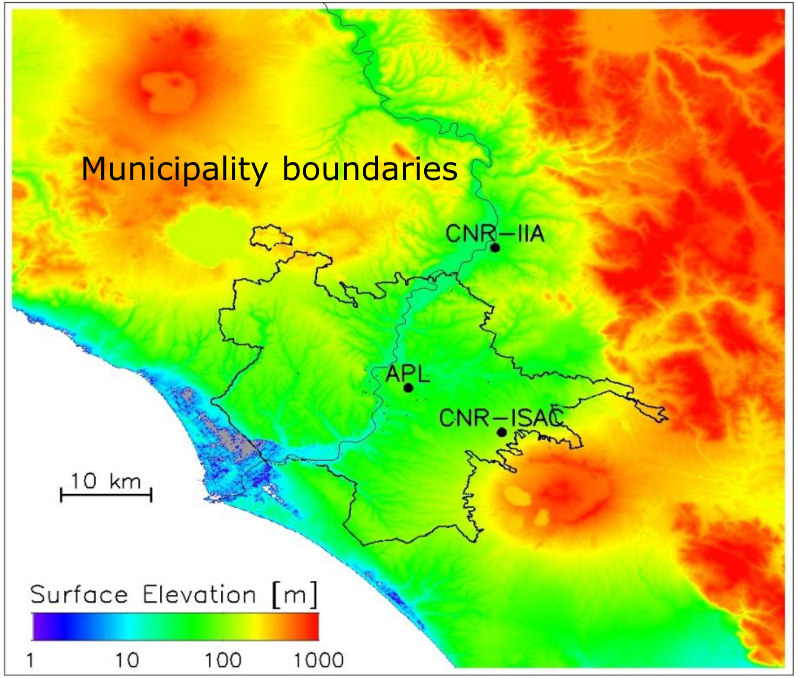
BAQUNIN super site components:

- **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/



Thanks to LuftBlick Team for invaluable support!

BAQUNIN Instrumental Suite (currently available)

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Instrument red => active	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-EUBREWNET	APL	**APL**	Day	Column	N/A	O3: 310.1-320.0 nm NO2: 426-453 nm UV: 290-325 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- SKYRAD	CNR-ISAC	**APL** **CNR-ISAC**	Day	Column	N/A	1020, 940, 870, 670, 500, 440, 340 nm	**Radiance, aerosols, water vapour**	**2010**
Meteo station	Clim. Cons.	**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 levs	N/A	**Meteorological variables**	**2015**
Pandora- PGN	ESA	**APL** **CNR-ISAC** **CNR-IIA**	Day/Night (Moon)	Column	N/A	290-520 and 400-900 nm	**Radiance, trace gases, aerosols**	**2016**
CIMEL- AERONET	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**	**2020**
Disdrometer	APL	**APL**	Day/Night	In situ	N/A	N/A	**Rain**	**2020**
FTIR EM-27	CNR-ISAC	**APL**	Day/Night	Slant Column	N/A	700 – 2200 cm^{-1} (4.5 – 14 mm)	**PBL GHG**	**2020**

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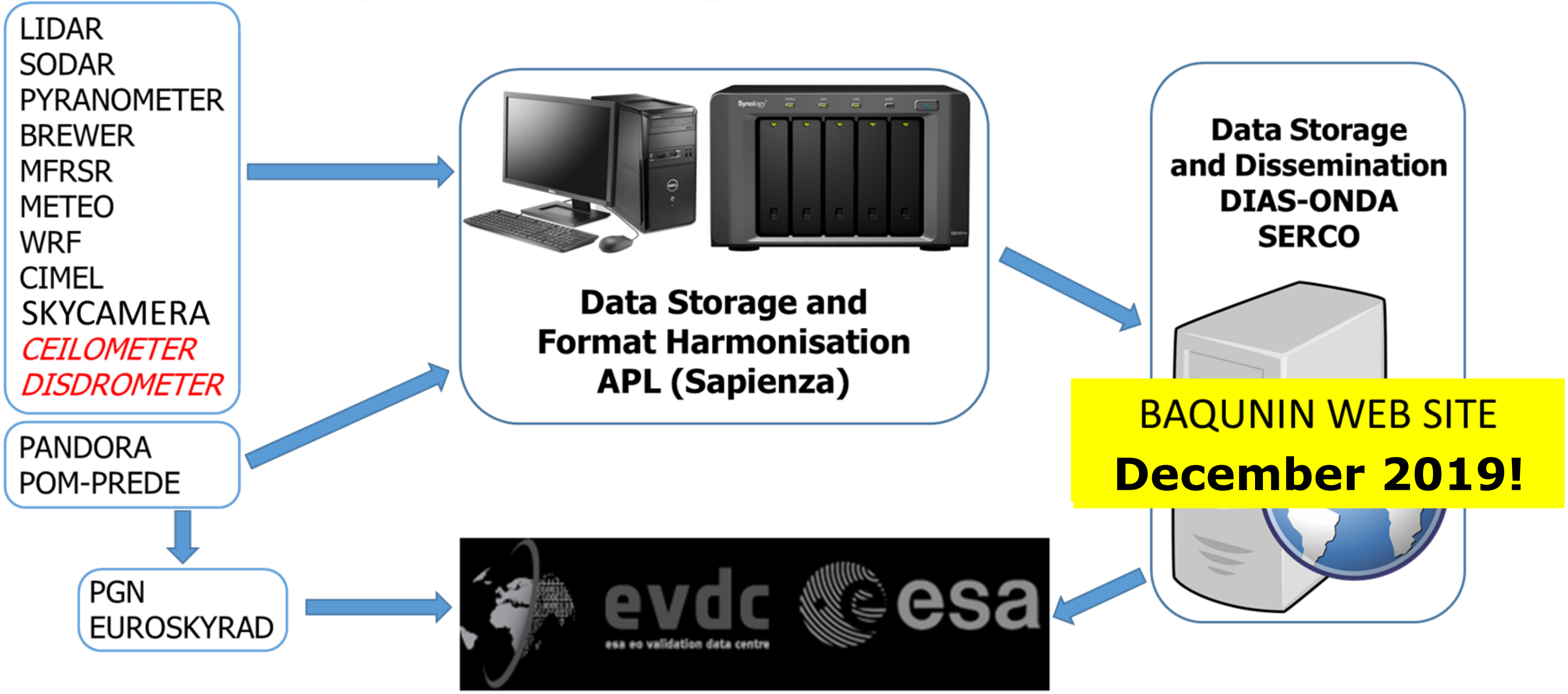
BAQUNIN Data Flow



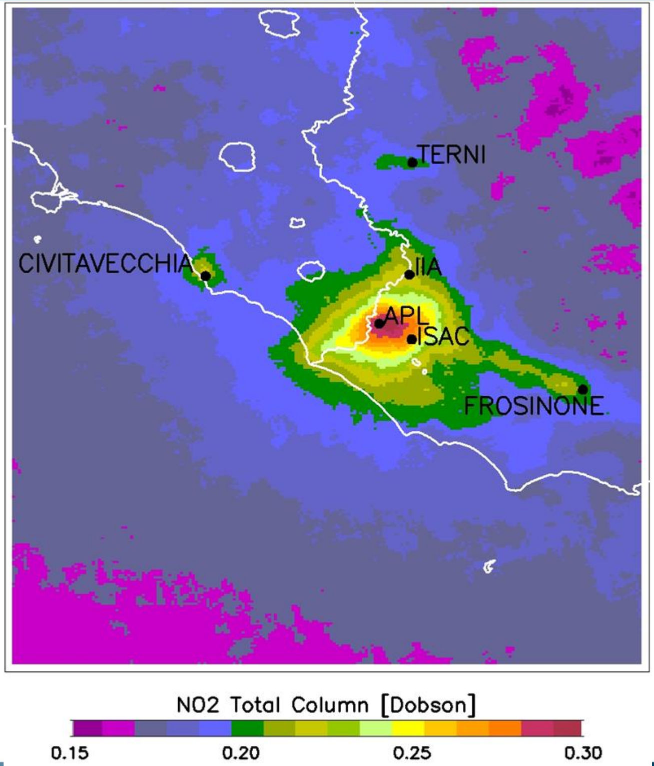
TROPOMI NO2 (offline) average field

TROPOMI NO2 concentration in the Tiber valley Nov18-Jun19

This map shows a **8** months average of NO2 Total Columns obtained from cloud-free/high-quality TROPOMI measurements (3.5 x 7 km^2, 13:30 UTC). The output grid resolution is 1x1 km^2.

The BAQUNIN "chemical" instruments (Pandora) are located at:
APL => Pan#117
CNR-ISAC => Pan#115
CNR-IIA => Pan#138

Apart from the **Rome** area, significant NO2 values are found in the **Sacco** Valley, where **Frosinone** is clearly detectable.
Civitavecchia is a significant source of NO2 (ships?).
Terni shows slightly enhanced NO2 values (steelworks?).



$DU = 2.6867 \times 10^{16}$ molec cm^{-2}

BAQUNIN-APL

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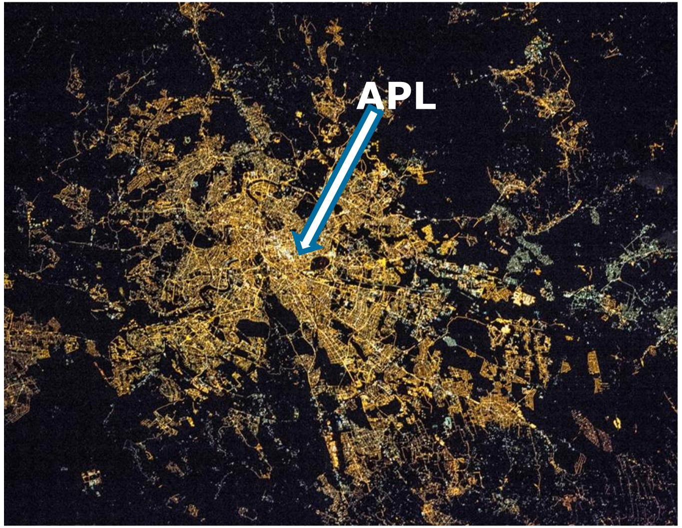
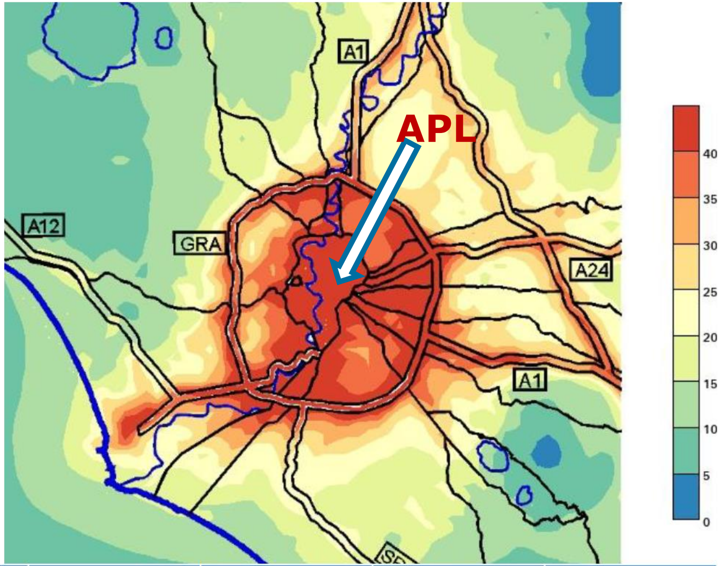
ARPA Lazio

Rome by night



RAMS/WRF + dispersion + photochemistry (1x1 km^2), **Surface NO2**

http://www.arpalazio.net/main/aria/doc/pubblicazioni.php



2016 statistics	Private cars	Motorcycles	Buses	Commercial	Special	Farm tractors	Total
Registered	1 759 601	394 871	7 404	141 165	36 324	3 965	**2 343 330**

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BAQUNIN (APL) SODAR: Sonic Detection and Ranging

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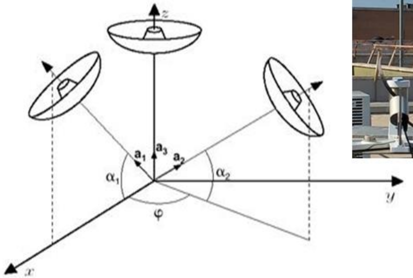
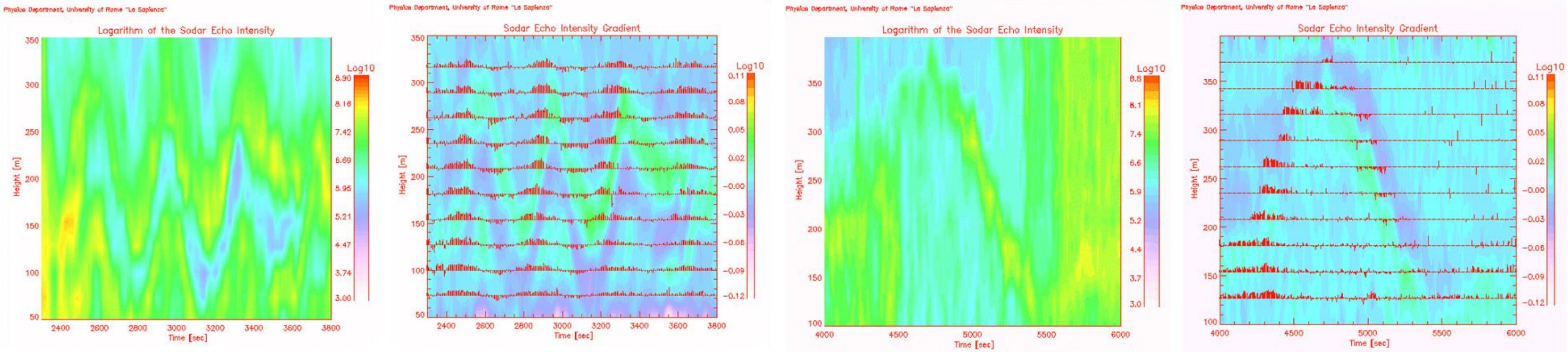
APL-SODAR data since 1990

Reflection of Sound Signals in the Troposphere

G. W. Gilman, H. B. Coxhead, and F. H. Willis
Bell Telephone Laboratories, Inc., New York, New York

(Received July 16, 1946)





Courtesy P. Castracane

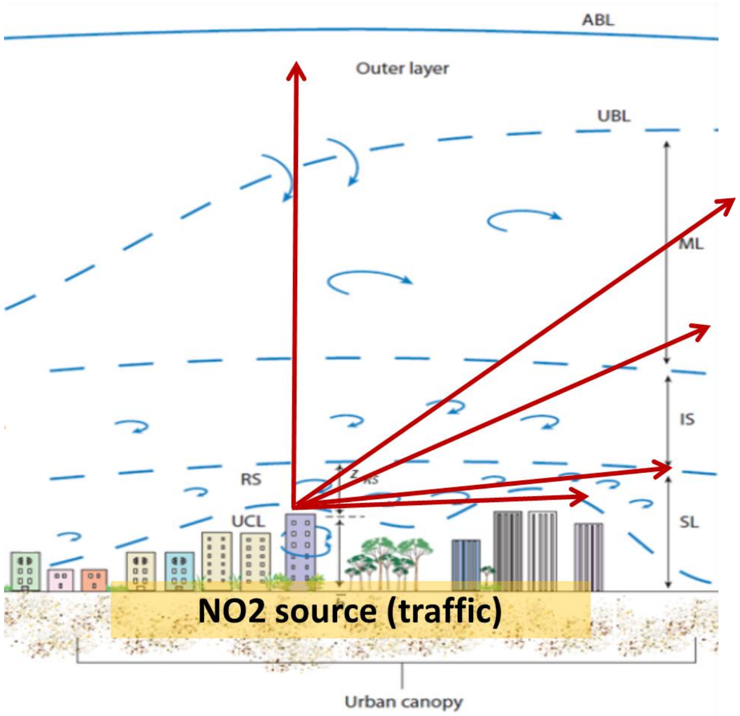
BAQUNIN-APL Pandora and SODAR operation mode

Between November 2018 and June 2019, PAN#117 performed sequences of Max-DOAS (Sky) measurement scans at 6 fixed pointing azimuth angles, i.e.
0, **60**, **120**, **180**, **240** and **300** degrees North.

For each scan, Surface (**SC**) and Troposphere (**TC**) concentrations of NO2 and H2O are estimated (+uncertainties).
The time required to complete the six sky measurements and two Direct Sun measurements is about 40 minutes.

The SODAR horizontal wind speed profiles are vertically averaged over the first 100 m (above the instrument) to estimate a Urban Surface Layer wind speed (U).
SODAR data are time-collocated with PAN#117 MaxDOAS scans ($\Delta t<1$min).

Pandora #117 Sky (MaxDOAS) setup



MaxDOAS (Sky) zenith angles:
0, 60, 75, 88, 89 deg

Retrieved quantities:
H2O and NO2
Surface Concentration (SC)
Tropospheric Column (TC)

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

Pandora NO2 vs. SODAR wind speed (1)

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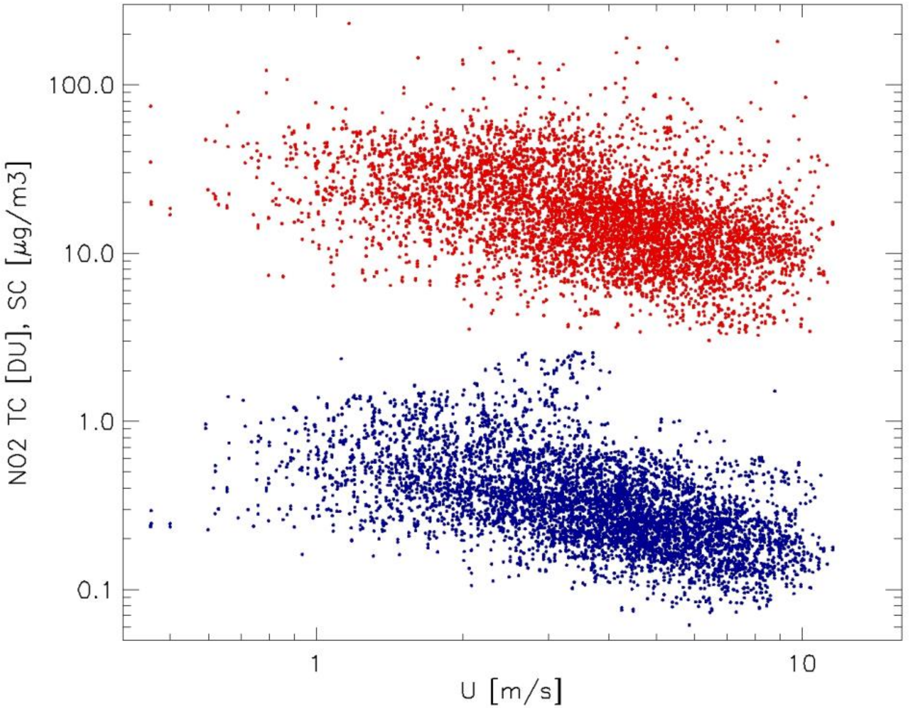
Data selection criteria

SZA < **70** deg
NO2 random unc < **50%** (SC&TC)
SODAR profiles up to **200** m asl

All valid data are used (no seasonal analysis)



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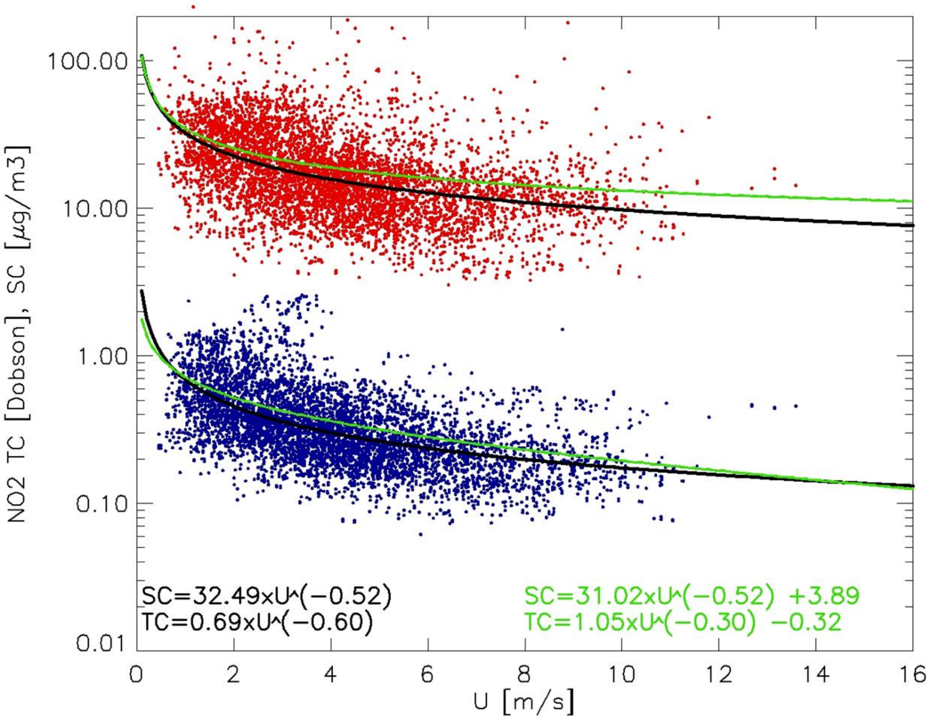
DU = 2.6867 x 10^{16} molec cm^{-2}

Pandora NO2 vs. SODAR wind speed (2)

$$C = C_0 \cdot U^{\alpha}$$

$$C = C_0 \cdot U^{\alpha} + C_{\infty}$$

C = TC [Dobson] or SC [μg m^{-3}]
U = wind speed
C_0 = ***C***(U=1)
C_{∞} = ***C***(U→∞) (background)



DU = 2.6867 x 10^{16} molec cm^{-2}

Summary GEOMETRIC function parameters

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NO2	C_0	α	C_∞	Measurements
$C = C_0 \cdot U^\alpha$				
SC	32 [μg m^{-3}]	-0.52	-	Pandora + Sodar
TC	0.7 [Db]	-0.60	-	Pandora + Sodar
$C = C_0 \cdot U^\alpha + C_\infty$				
SC	31 [μg m^{-3}]	-0.52	3.9	Pandora + Sodar
SC (Grundstrom, 2015)	47 [μg m^{-3}]	-0.76	2.3	Chemilum. + ultrasonic anem.
TC	1.1 [Db]	-0.30	**-0.3**	Pandora + Sodar

M. Grundstrom et al., Atmospheric Environment 120 (2015) 317-327, http://dx.doi.org/10.1016/j.atmosenv.2015.08.057

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Upward transport efficiency vs. wind speed

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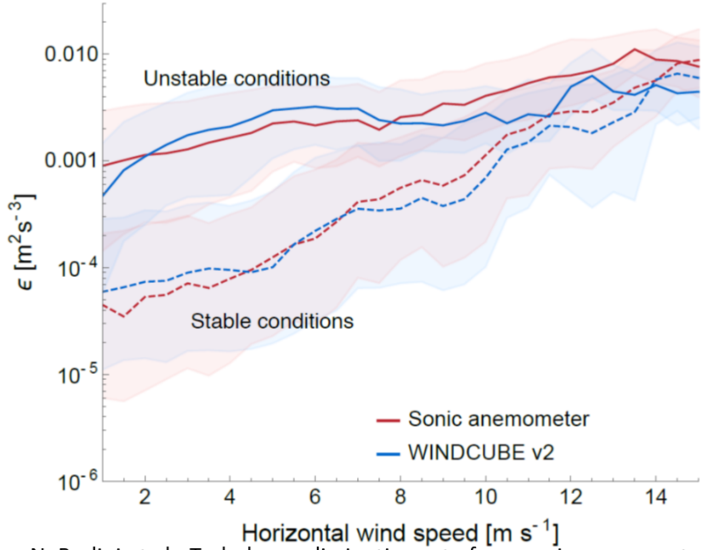
$$\frac{\partial TKE}{\partial t} = Ad + M + B + Tr - \epsilon$$



N. Bodini et al.: Turbulence dissipation rate from sonic anemometer and lidar during XPIA, Atmos. Meas. Tech., 11, 4291–4308, 2018

TKE = Turbulent Kinetic Energy (per unit mass, [m^2 s^{-2}])
Ad = advection of TKE by the mean wind
M = mechanical generation of turbulence (>0)
B = buoyant generation or consumption of turbulence
Tr = transport of turbulence energy by turbulence itself
ε = viscous dissipation rate (<0)

Strong wind => larger dissipation, smaller eddies, reduced upward convection

Weak wind => higher UBLH (increases faster) than with strong wind
Upward transport more efficient!

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PAN#117-TROPOMI-OFFL NO2 comparison

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V 10200 Nov18
V 10202 Nov18-Mar19
V 10300 Mar19-Apr19
V 10301 Apr19-Jun19

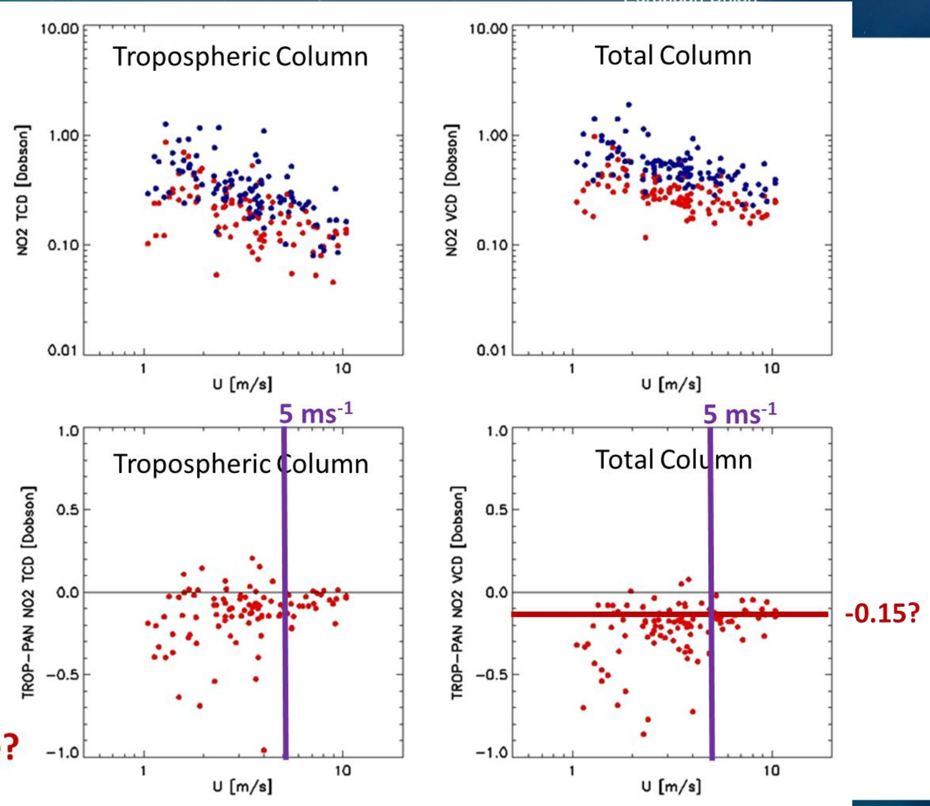
TROPOMI L2
VCD = SUMMED_TOTAL_COLUMN
TCD = TROPOSPHERIC_COLUMN

PANDORA #117
VCD = Direct Sun
TCD = MaxDOAS

Distance < 6 km (centre pixel)
CF < 0.2
Dt < 1 hour

U < 5 ms^{-1}: **PAN#117 » TROPOMI**
U > 5 ms^{-1}: **PAN#117 ≈TROPOMI**

VCD bias: Stratospheric Column issue?



DU = 2.6867 x 10^{16} molec cm^{-2}

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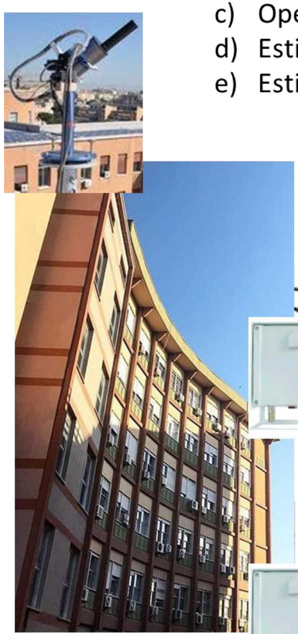
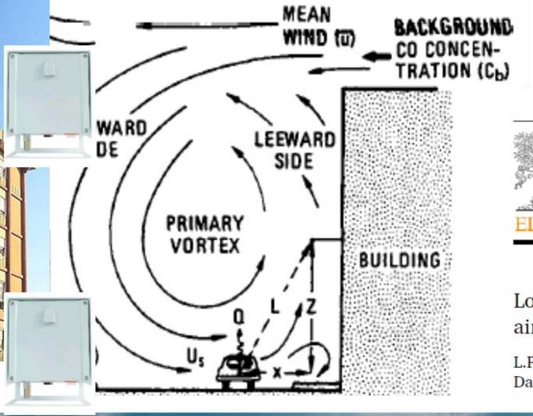
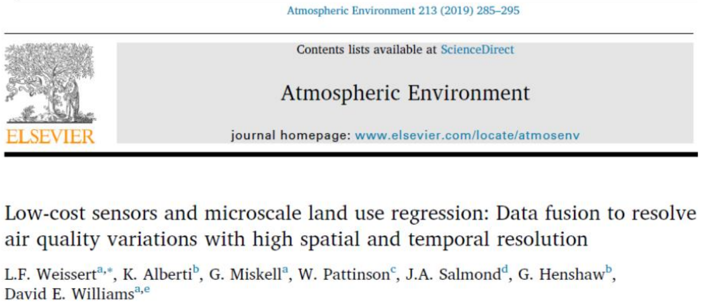
Next step: NO2 from canopy to surface and mixed layers

a) Operate in situ sensors (O2, NO2, PM2.5, T, RH) at street level and top of building (30m)
b) Pandora to perform MaxDOAS scans at fixed azimuth (probe atmosphere above in situ sensors)
c) Operate SODAR as usual (time resolution = 1s, max altitude = 200 m above top of building)
d) Estimate UBL similarity parameters (u*, w*, Zi) from SODAR
e) Estimate MLH from LIDAR

In addition, depending on available resources:
d) Operate ceilometer at street level (instrument refurbishment)
e) Operate sonic anemometer (top of building, TBD)






Atmospheric Environment 213 (2019) 285–295

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journal homepage: www.elsevier.com/locate/atmosenv

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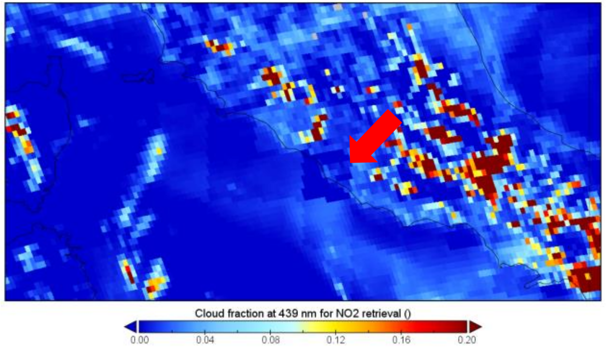
Low-cost sensors and microscale land use regression: Data fusion to resolve air quality variations with high spatial and temporal resolution

L.F. Weissert[a,*], K. Alberti[b], G. Miskell[a], W. Pattinson[c], J.A. Salmond[d], G. Henshaw[b], David E. Williams[a,e]

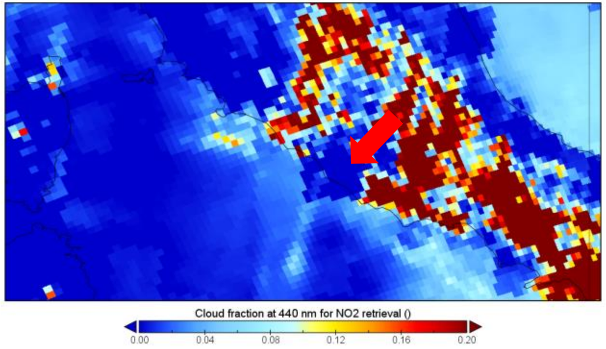
TROPOMI NO2 CF and AMF

20190821

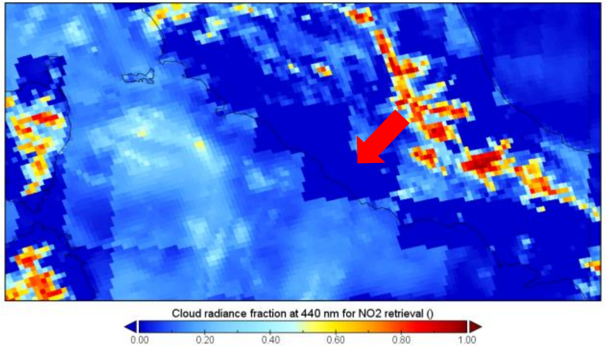
Cloud fraction at 439 nm for NO2 retrieval 20190303



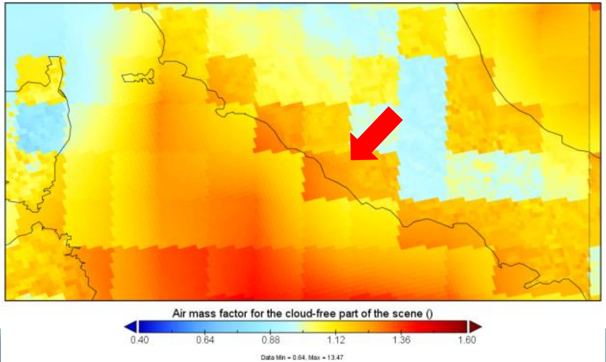
Cloud fraction at 440 nm for NO2 retrieval 20190603



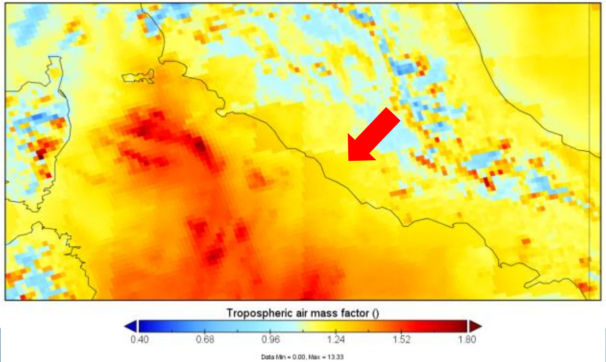
Cloud radiance fraction at 440 nm for NO2 retrieval 20190821



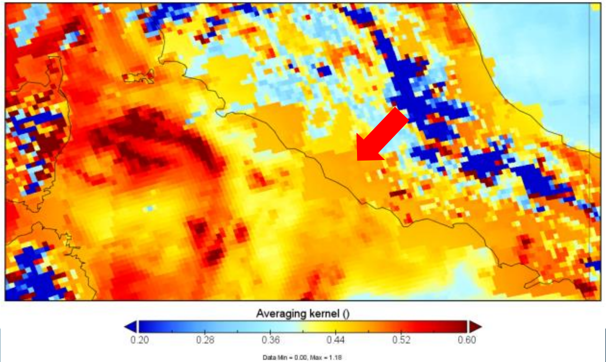
Air mass factor for the cloud-free part of the scene 20190821



Tropospheric air mass factor 20190821



Averaging kernel 20190821



Summary/Outlook

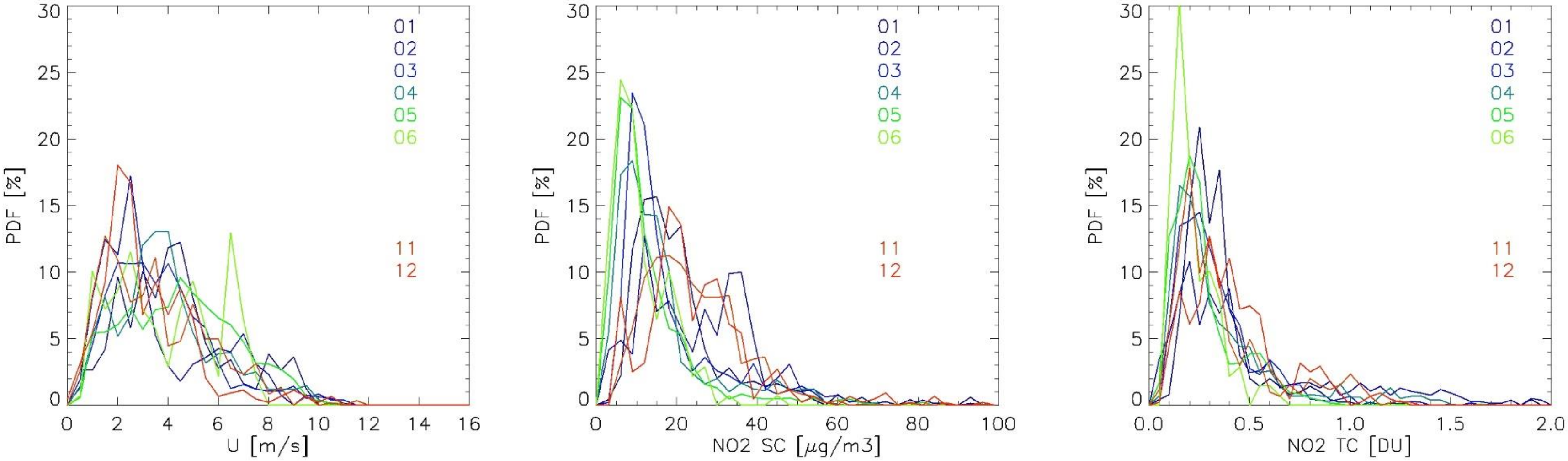
- Pan#117 operates in an urban environment (APL, Rome downtown), in synergy with a large number of other remote sensing and in situ devices (40m above traffic lane).
- Pandora Viewing geometry (zenith angles) do not include the urban canopy (NO2 source).
- The estimated NO2 values are tightly linked to the efficiency of the turbulent upward transport from the canopy layer, showing a significant dependence on wind intensity.
- TROPOMI NO2 TC and VCD show smaller (yet significant) dependency on wind speed.
- Results of the comparison between TROPOMI and PAN#117 NO2 concentrations are, by consequence, wind speed dependant:
  - $U < 5\ ms^{-1}$: **PAN#117 » TROPOMI**
  - $U > 5\ ms^{-1}$: **PAN#117 ≈TROPOMI**

In the next months we will:

1. Analyse seasonality of wind-NO2 correlation (including Jul-Aug-Sep 2019 data)
2. TROPOMI CF and AK Rome area, increased resolution
3. Set-up experiment to quantify the impact of boundary layer stability on upward transport of NO2 from urban canopy to upper layers (1 full year)

Thanks for your attention!

BAQUNIN Web site:
December 2019!



30
25
20
15
10
5
0
PDF [%]
0 2 4 6 8 10 12 14 16
U [m/s]
01
02
03
04
05
06
11
12
0 20 40 60 80 100
NO2 SC [μg/m3]
0.0 0.5 1.0 1.5 2.0
NO2 TC [DU]