The Bumba Project

validation of Belgian high resolution NO2 maps based on APEX hyperspectral data

RIO-IFDM NO2 annual mean

BUMBA

***B**elgian **U**rban NO2 **M**onitoring **B**ased on **A**PEX hyperspectral data*

Koen Meuleman and the BUMBA team
(special thanks to F. Tack BIRA/ISAB)

BUMBAir.be

PROJECT SETUP

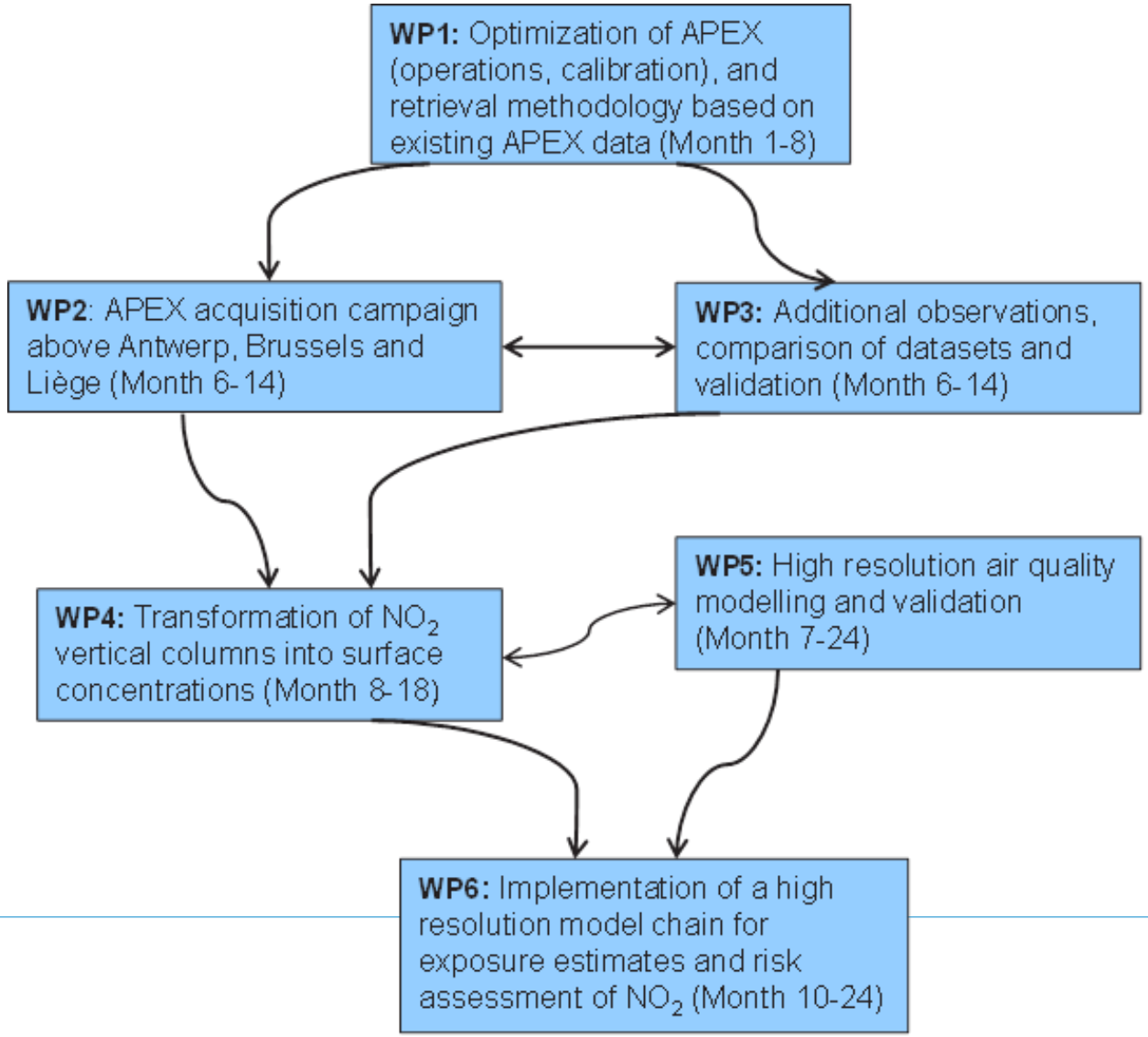
- STEREO III Application project
- Two years project – extended with 8 months (aug 2017)

- ***End-user*** irCELine
- Goal: produce hourly accurate exposure NO2 maps
- Project team:

F. Tack [1], A. Merlaud [1], T. Danckaert [1], Y. Huan [1], C. Fayt [1], M. Van Roozendael [1], M.-D. Iordache [2], K. Meuleman [2], F. Deutsch[2], H. Hooyberghs[2], W. Lefebre[2], S. Quidé[3], O. Peeters[3], C. Vanpoucke[3], F. Fierens[3]

[1]BIRA-IASB, Belgian Institute for Space Aeronomy, Brussels, Belgium
[2]VITO, Flemish Institute for Technological Research, Mol, Belgium
[3]irCELine, Belgian Interregional Environment Agency, Brussels, Belgium

PROJECT SETUP/SCHEDULE



vito

CONTENT

- Introduction:
- 1) NO_2 2) APEX sensor 3) DOAS
- Airborne NO_2 mapping campaigns
  - BUMBA (Brussels, Antwerp, Liège)
- APEX NO_2 VCD retrieval algorithm
- Results: NO_2 retrievals and horizontal distribution maps
  - BUMBA
  - AROMAPEX (Berlin)
- Comparison with correlative data sets
- Conclusion

NO_2: A KEY POLLUTANT IN THE ATMOSPHERE

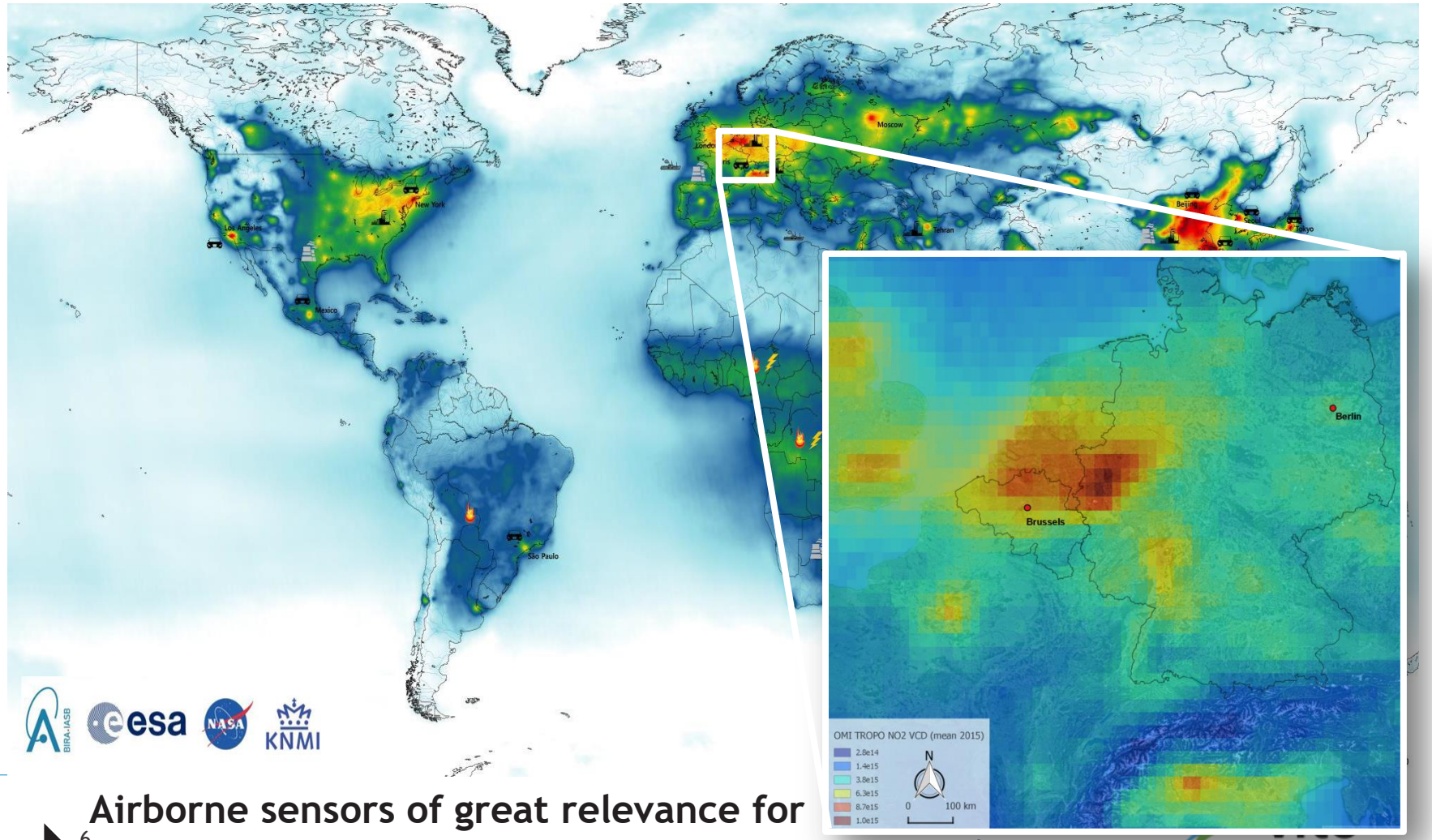
- Proxy for air pollution
- Direct health impact
- Indirectly affects the climate system

- Concentrations are highly variable in space in time
- Main sources in urban areas are traffic and industry

- EU Directive 2008/50/EC: non compliance regularly reported in cities (e.g. Brussels)

→ **Monitoring the NO_2 variability at high spatial resolution is of great relevance**

NO_2 COLUMN FROM SPACE



Airborne sensors of great relevance for high resolution NO_2 mapping at scale of cities

AIRBORNE PRISM EXPERIMENT SENSOR (APEX)

Spatial performance (at 6000 m AGL)	
Spatial CCD	1000 detectors
FOV (across-track)	28°
Swath width	3000 m
IFOV (across-track)	0.028°
Spatial resolution (across-track)	3 m
Spatial resolution (along-track)	4 m
Other	
Plane speed	72 mps
Integration time	58 ms
APEX total mass	354 kg

Spectral performance for NO_2 calibration window	
Spectral interval	370 - 600 nm
Spectral detectors	249 (unbinned mode)
Nominal FWHM	1.5 nm
In-flight FWHM	> 2.8 and < 3.3 nm
Nominal spectral shift from CW	< 0.2 nm
In-flight spectral shift from CW	> 0.05 and < 0.8 nm
Spectral sampling interval (SSI)	0.9 nm
Sampling rate	3.1 to 3.6 pixels per FWHM

Dornier DO-228, operated by DLR

DOAS FOR TRACE GAS RETRIEVAL

- Trace gas retrieval based on spectral analysis of scattered sunlight
- DOAS remote sensing technique
  - **D**ifferential **O**ptical **A**bsorption **S**pectroscopy
  - Indirect measurement – scattered sunlight
  - Works in UV-Visible region
  - O_3, SO_2, HCHO, CHOCHO, BrO… but focus on NO_2
  - **DOAS equation based on Lambert-Beer's law:**

$$\ln \frac{I(\lambda)}{I_0(\lambda)} = Q_{(a)}(\lambda) + \sum_i \sigma_i(\lambda) SCD_i$$

  - Differential slant column (DSCD) as direct output: **integrated amount** of molecules **along the observed light path** relative to the same quantity in a reference spectrum

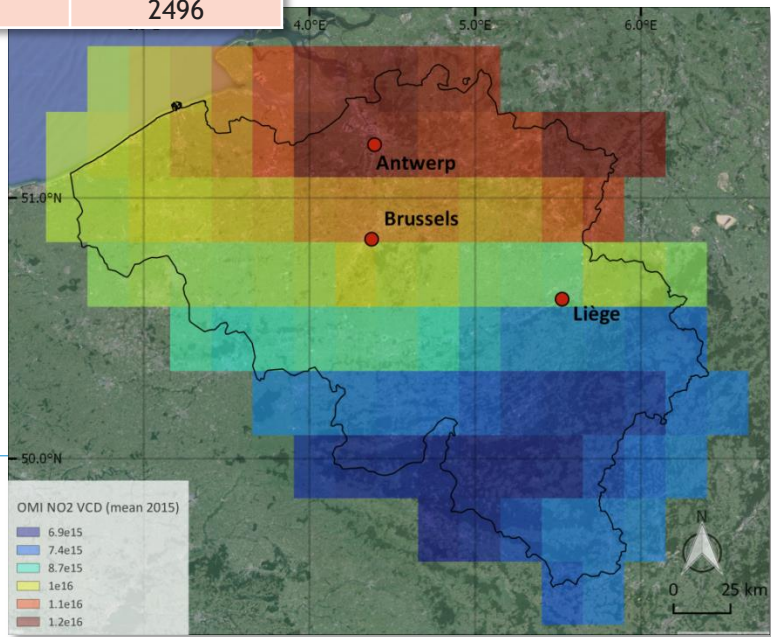
BUMBA CAMPAIGNS 2015 - 2016

	Brussels	Antwerp	Liège	Antwerp
Date	30-06-2015 (181)	15-04-2015 (105)	15-04-2015 (105)	19-07-2016 (201)
Flight time LT (UTC + 2)	14:43 - 16:04	10:06 - 11:30	11:55 - 12:18	15:33 – 18:03
# flightlines	8	9	3	14
Flight pattern (Heading °)	0 - 180	0 - 180	40 - 220	0 - 180
SZA (°)	29.7 - 38.6	60.4 - 49.6	46.0 - 44.1	36.7 – 57.3
Wind direction (°)	125	235	240	
Wind speed (Bft)	2	3	3	
Temperature (°C)	27.2	18.7	20.8	
PBL height (m)	1200	450	700	
Lat (°N) / Long (°E)	50.8 / 4.4	51.2 / 4.4	50.6 / 5.6	51.2 / 4.4
Terrain altitude (m ASL)	76	10	66	10
Total population	1.175.173	513.570	195.968	513.570
Population density (#/km^2)	6751	2496	2828	2496

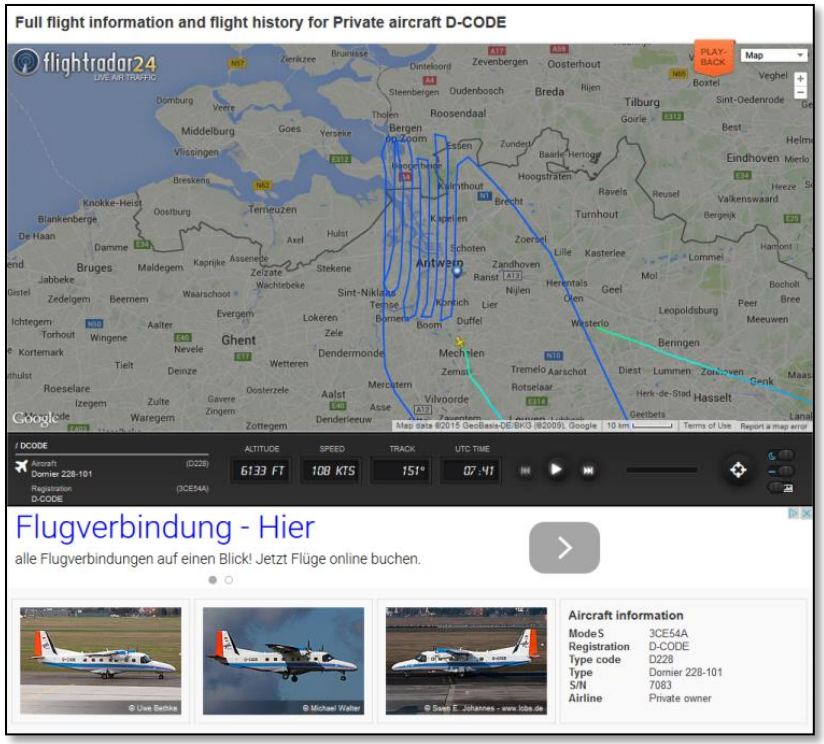
BUMBAir.be

belspo

- Airborne campaign
  - APEX
- Ground-based campaign
  - Mobile-DOAS x 2
  - Mini MAX-DOAS

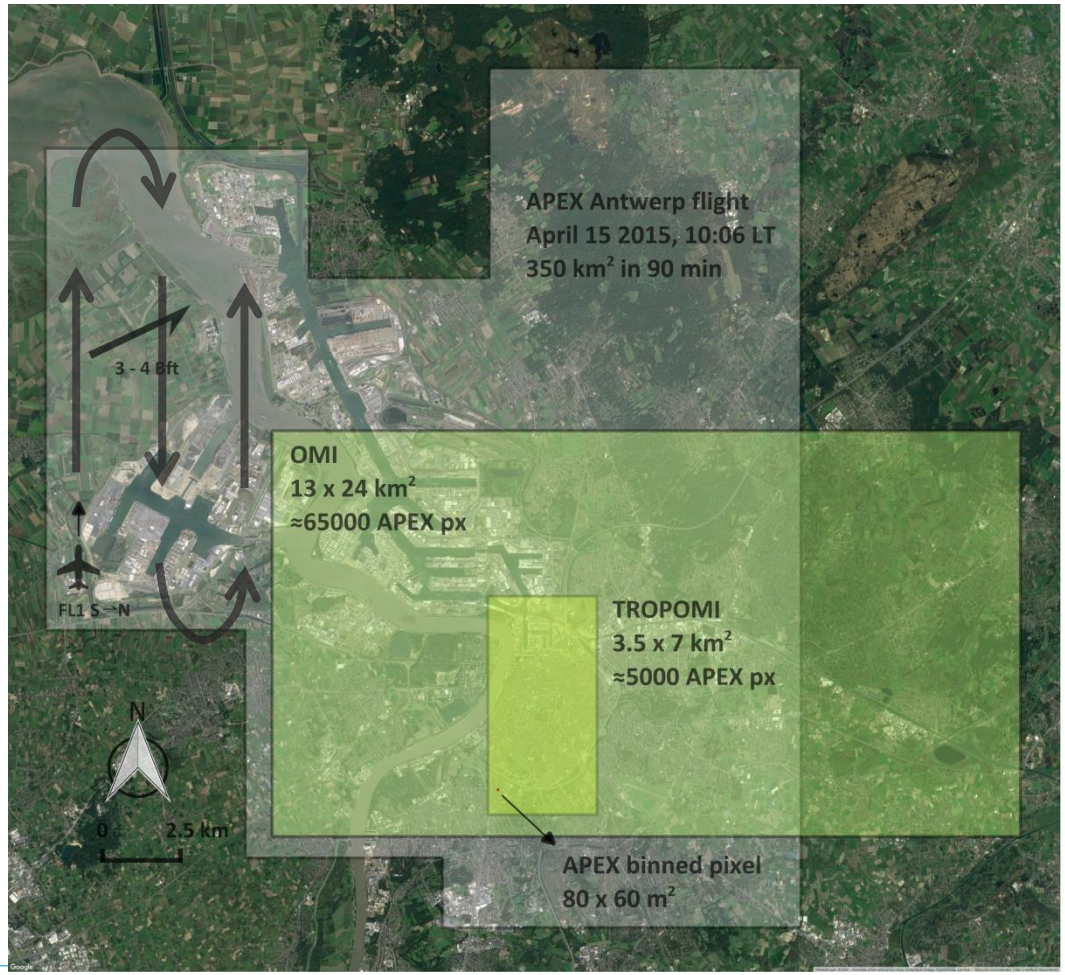


BUMBA CAMPAIGNS 2015 - 2016



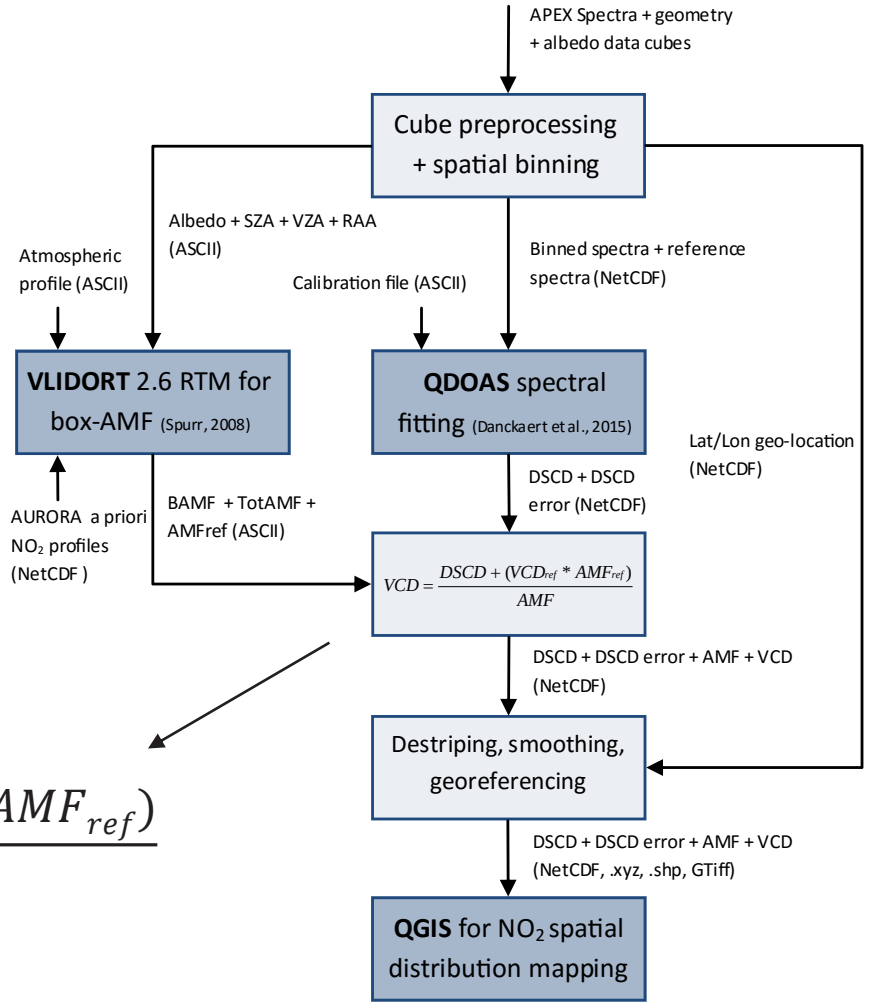
vito

APEX ANTWERP FLIGHTPLAN (DAY 105)



vito

APEX NO_2 VCD RETRIEVAL ALGORITHM



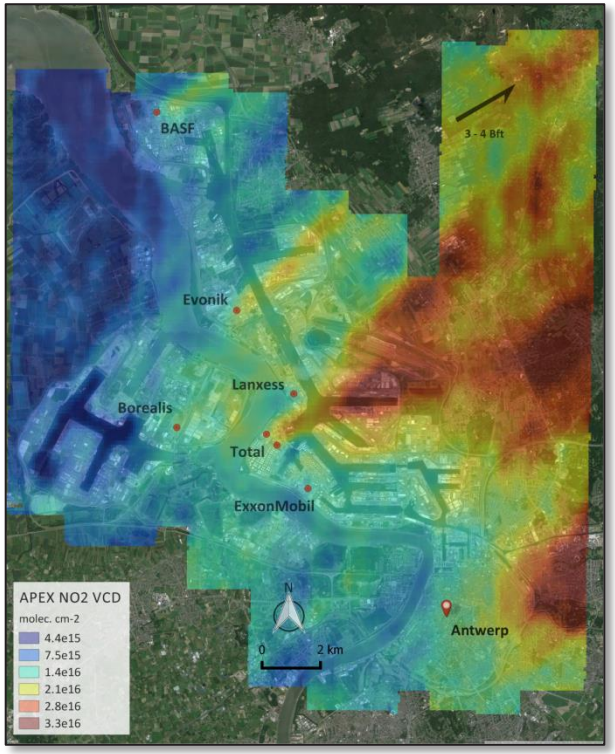
$$VCD_i = \frac{DSCD_i + (VCD_{ref} * AMF_{ref})}{AMF_i}$$

NO_2 retrieval from APEX

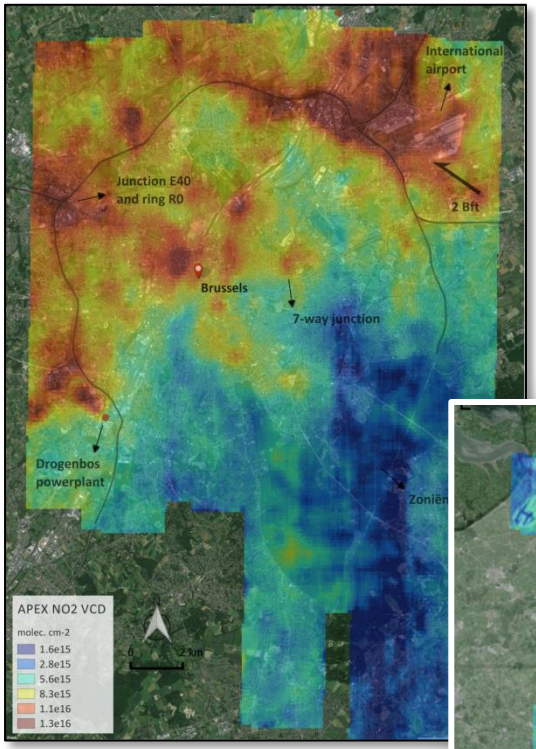
vito

NO_2 DISTRIBUTION MAPS (BUMBA 2015)

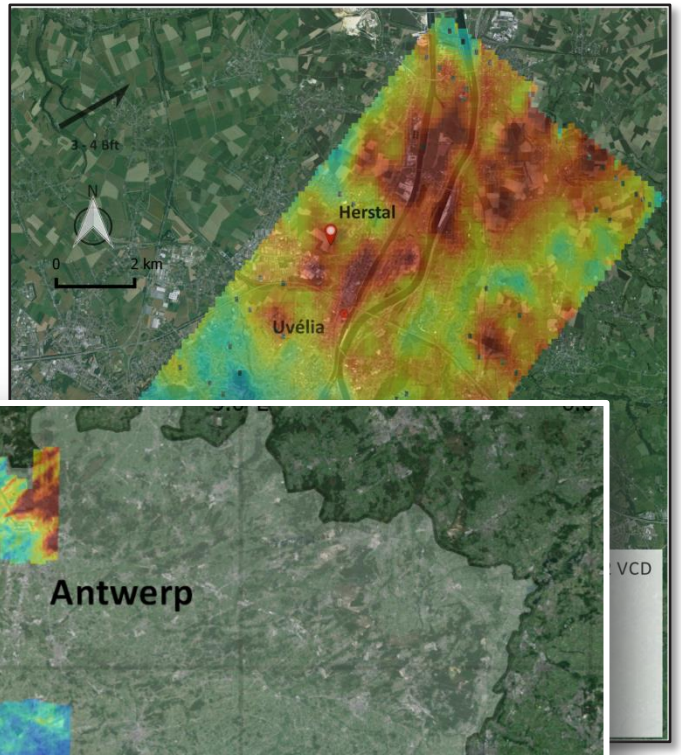
Antwerp: 15-04-2015

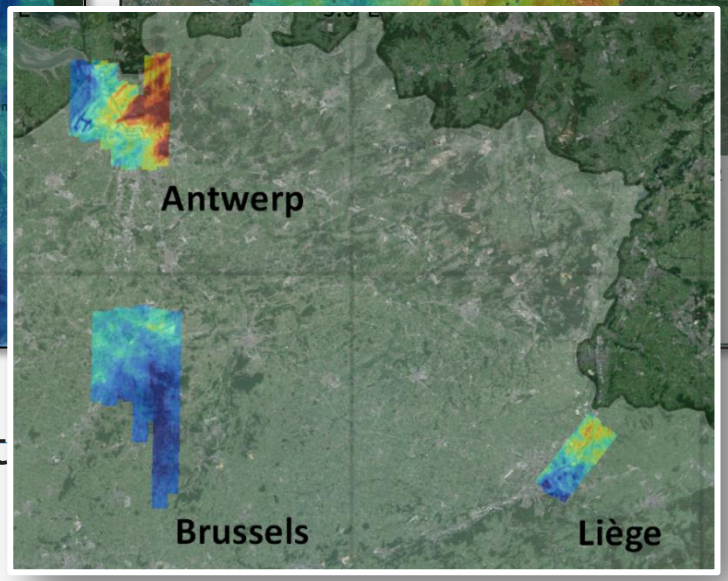


Brussels: 30-06-2015

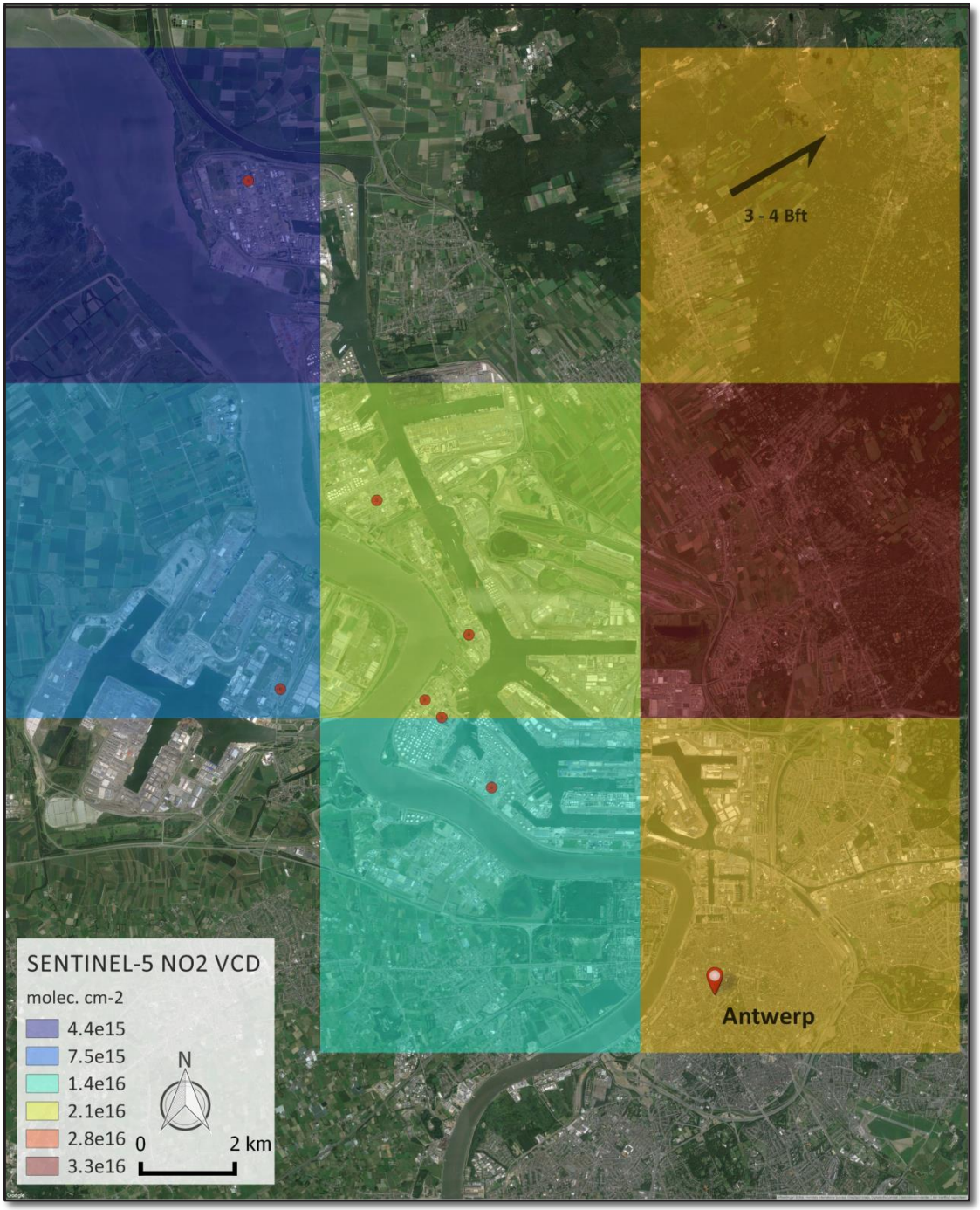


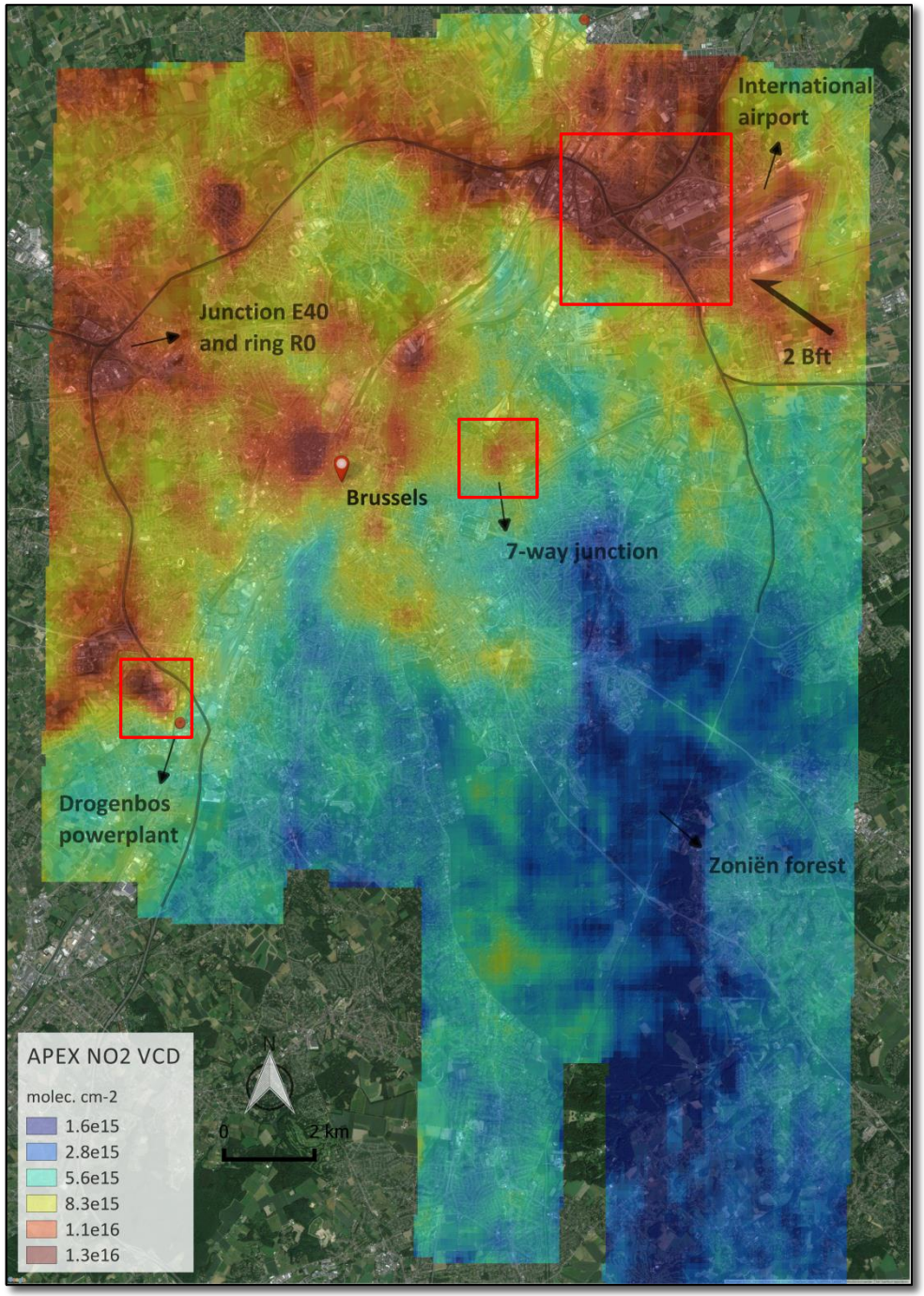
Liège: 15-04-2015

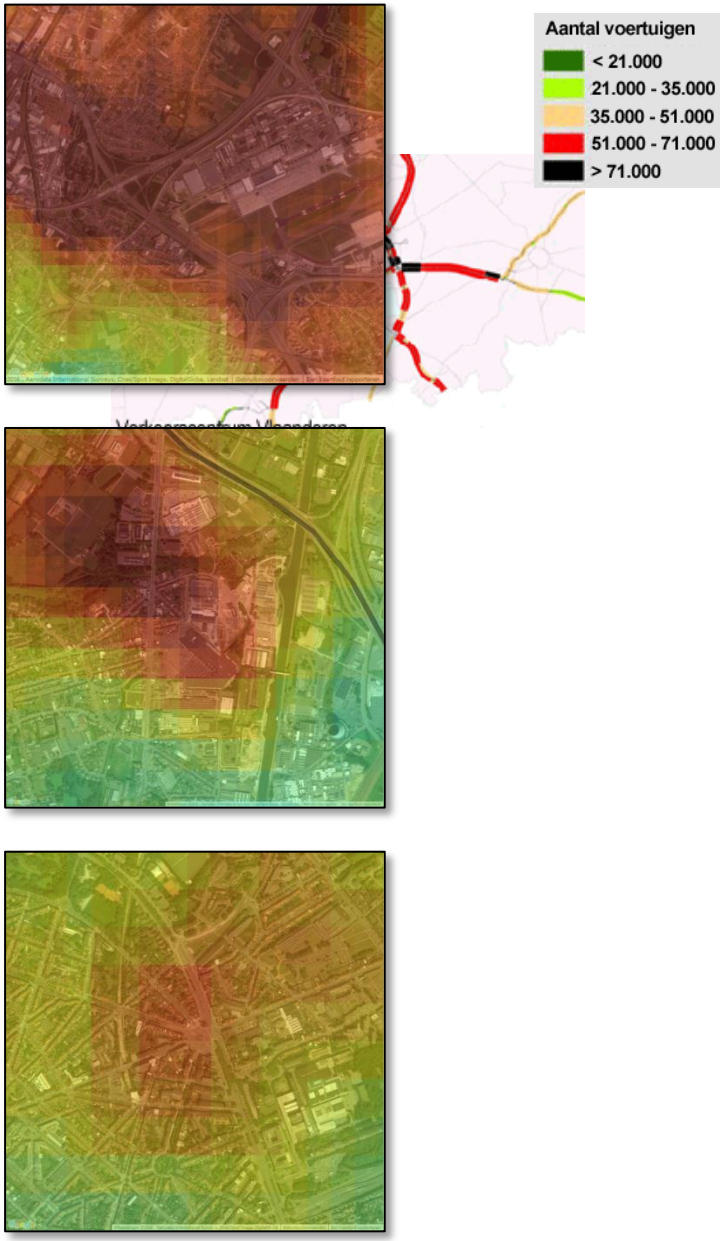




Note: color scales optimized for each flight


3 - 4 Bft
SENTINEL-5 NO2 VCD
molec. cm-2
4.4e15
7.5e15
1.4e16
2.1e16
2.8e16
3.3e16
N
0
2 km
Antwerp


International airport
Junction E40 and ring R0
2 Bft
Brussels
7-way junction
Drogenbos powerplant
Zoniën forest
APEX NO2 VCD
molec. cm-2
1.6e15
2.8e15
5.6e15
8.3e15
1.1e16
1.3e16
N
0
2 km

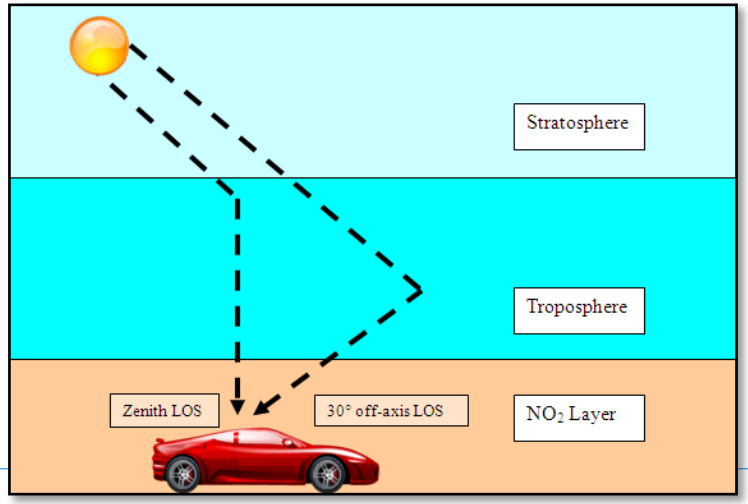

Aantal voertuigen
< 21.000
21.000 - 35.000
35.000 - 51.000
51.000 - 71.000
> 71.000

BIRA MOBILE-DOAS → VALIDATION

- 2 AVANTES spectrometers 200 – 750 nm, 1.15 nm resolution

- Optical head mounted on the car window and/or roof

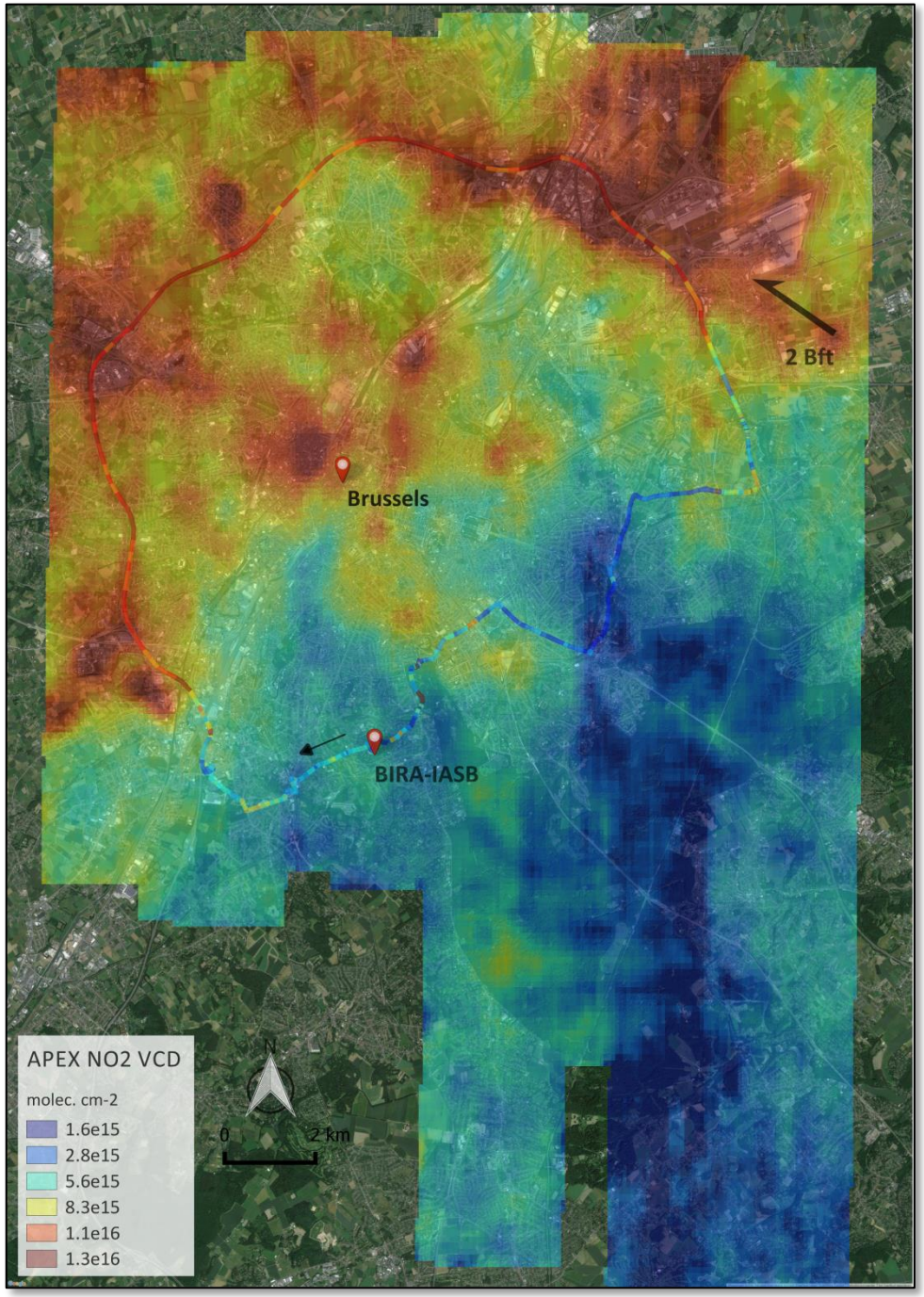
- 2 viewing directions : zenith and 30° elevation, 2.5 ° F.O.V

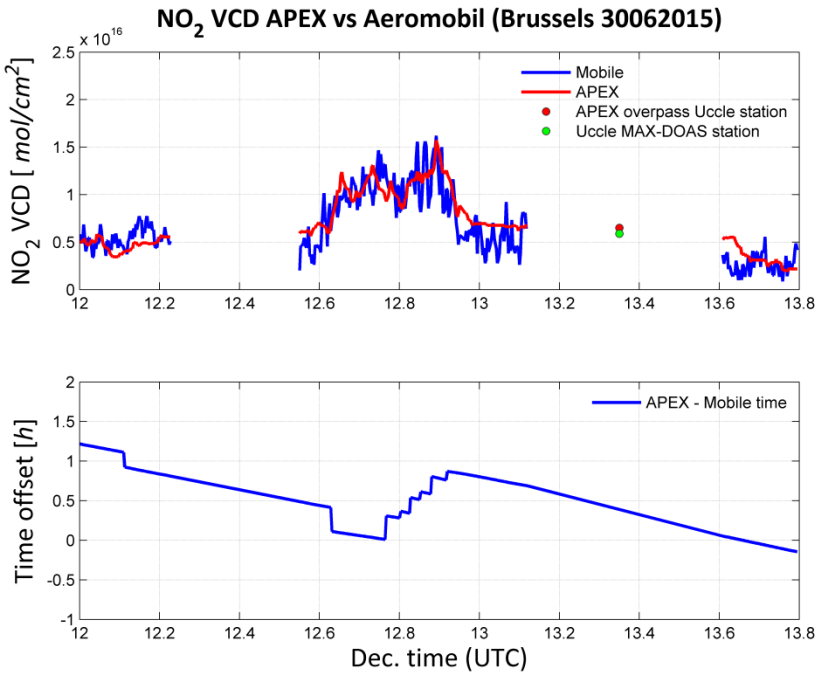


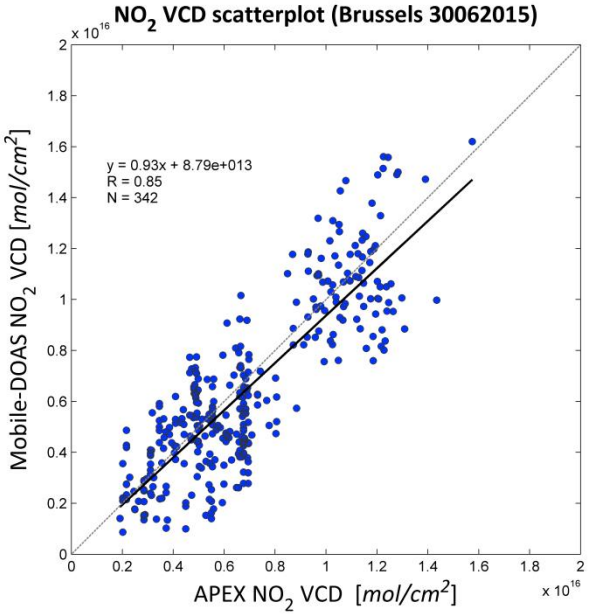
- For BUMBA GB campaign: 2 operational systems, each consisting of 1 driver & 1 operator

www.aeromobil.be

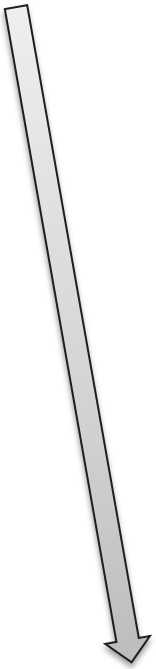
BUMBA GB campaign


2 Bft
Brussels
BIRA-IASB
APEX NO2 VCD
molec. cm-2
1.6e15
2.8e15
5.6e15
8.3e15
1.1e16
1.3e16
N
0
2 km


NO2 VCD APEX vs Aeromobil (Brussels 30062015)
x 10^16
NO2 VCD [mol/cm2]
Mobile
APEX
APEX overpass Uccle station
Uccle MAX-DOAS station
Time offset [h]
APEX - Mobile time
Dec. time (UTC)


NO2 VCD scatterplot (Brussels 30062015)
x 10^16
y = 0.93x + 8.79e+013
R = 0.85
N = 342
Mobile-DOAS NO2 VCD [mol/cm2]
APEX NO2 VCD [mol/cm2]
x 10^16

RIO - IFDM chain



Regional background

- Interpolation of measurements
- Make use of land use (CORINE)

Urban features

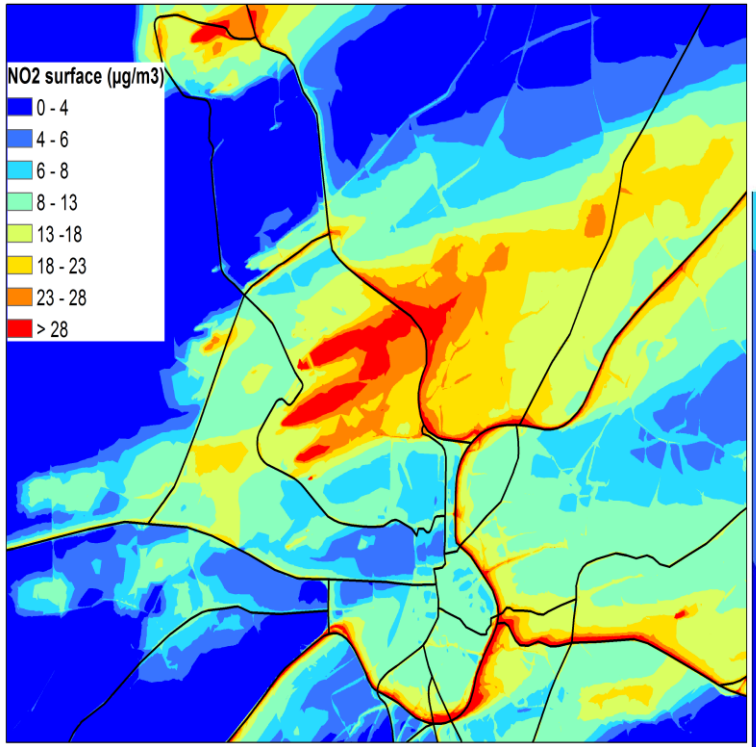
- Gaussian dispersion modelling of traffic and industrial emissions
- Including quick ozone-chemistry

- Intelligent coupling of regional and urban-scale model results
- Use of double-counting correction

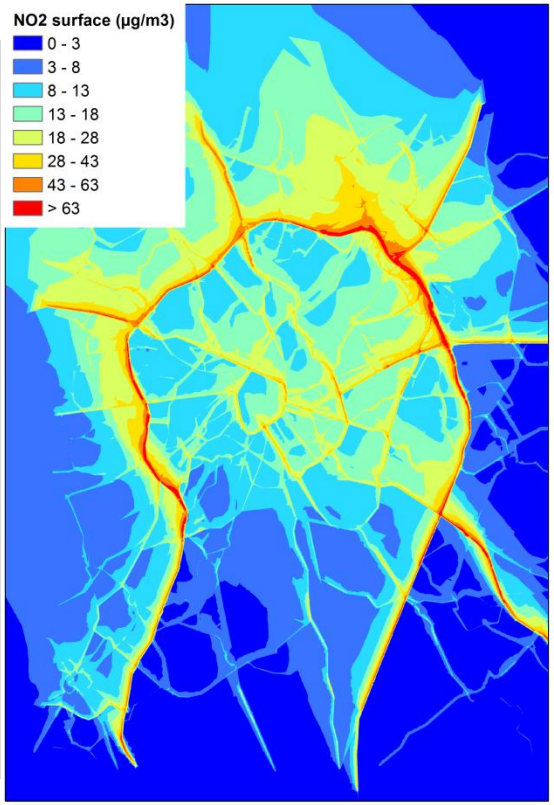
vito

MODELLING RESULTS (AURORA-RIO-IFDM)

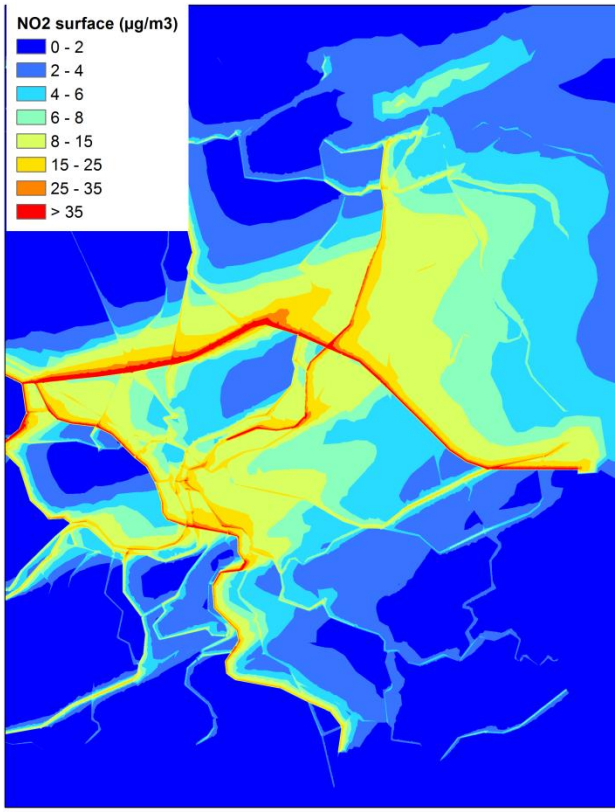
Surface concentrations *for the moments of the flights*



Antwerp



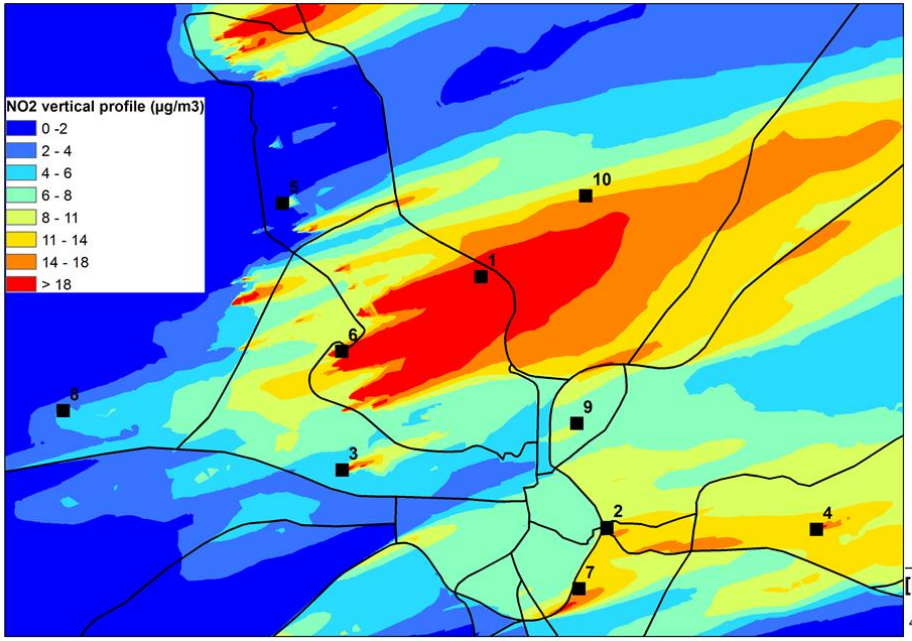
Brussels



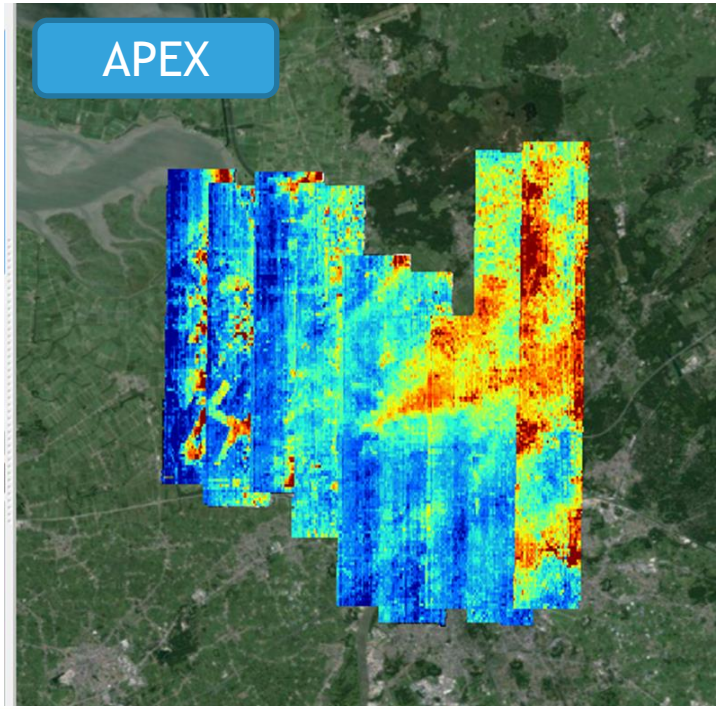
Liege

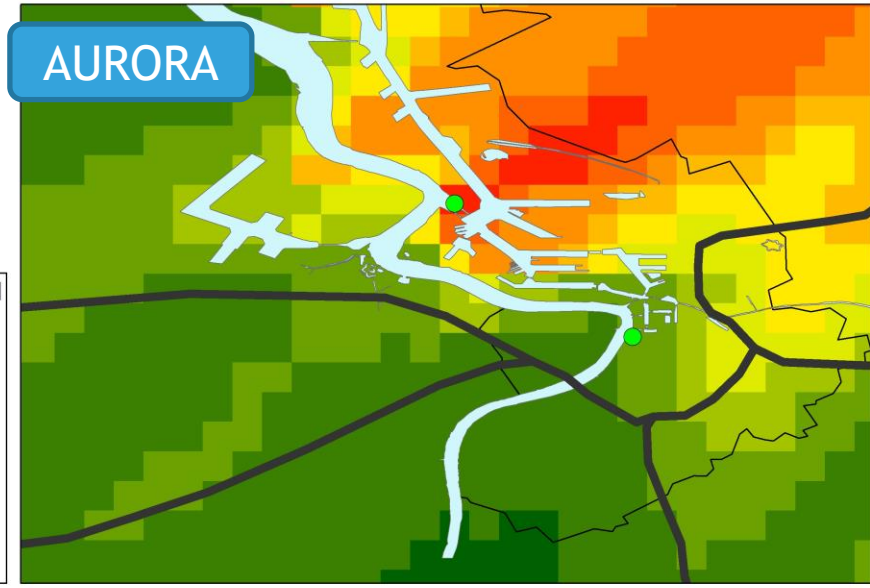
vito

VERTICAL COLUMNS: COMPARISON



IFDM





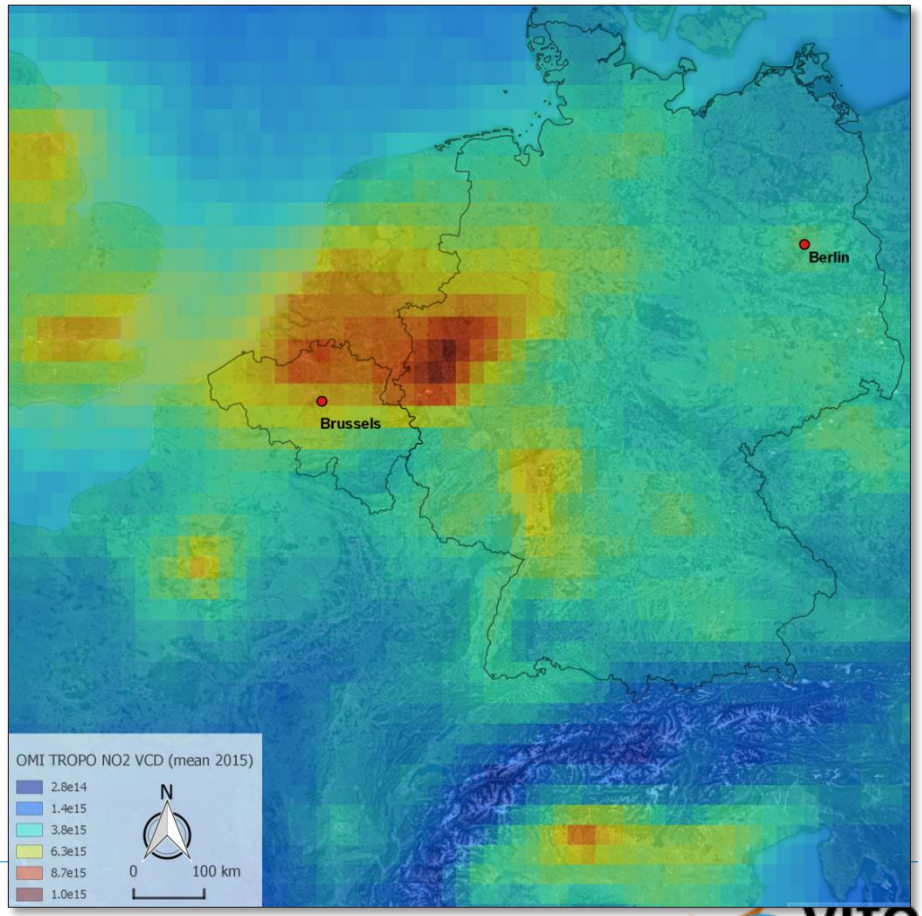
[mg/m2]
4.5 - 5
5 - 7
7 - 8
8 - 9
9 - 10
10 - 11
11 - 12
12 - 14
14 - 16
16 - 17.6

AROMAPEX CAMPAIGN 2016 (BERLIN)

- Airborne campaign
  - 4 imaging systems: **APEX, SWING, AirMAP, SpectroLite**

	Berlin AM	Berlin PM
Date	21-04-2016 (112)	21-04-2016 (112)
Flight time LT (UTC + 2)	09:34 - 12:01	14:24 - 16:39
# flightlines	15	14
Flight pattern (Heading °)	0 - 180	0 - 180
SZA (°)	58.3 - 42.4	43.3 - 58.7
Wind direction (°)	276	285
Wind speed (Bft)	3	4
Temperature (°C)	-	-
PBL height (m)	-	-
Lat (°N) / Long (°E)	52.28 / 13.18	52.28 / 13.18
Terrain altitude (m ASL)	70	70
Total population	3.500.000	3.500.000
Population density (#/km^2)	3994	3994

  - ZS-DOAS
  - CAPS in-situ analyzer

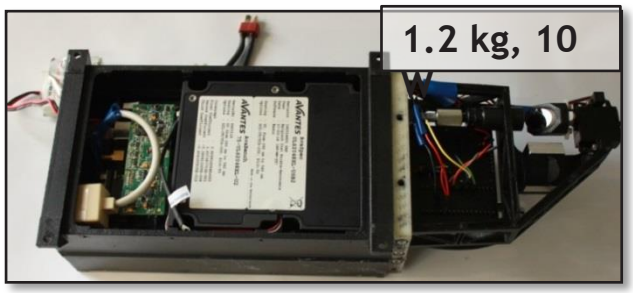


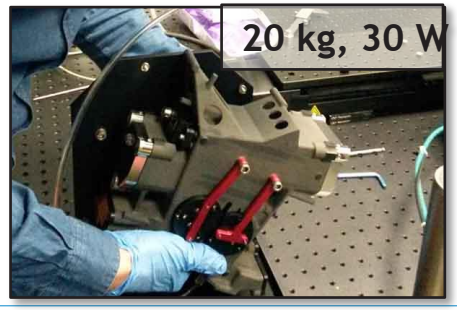
AROMAPEX campaign

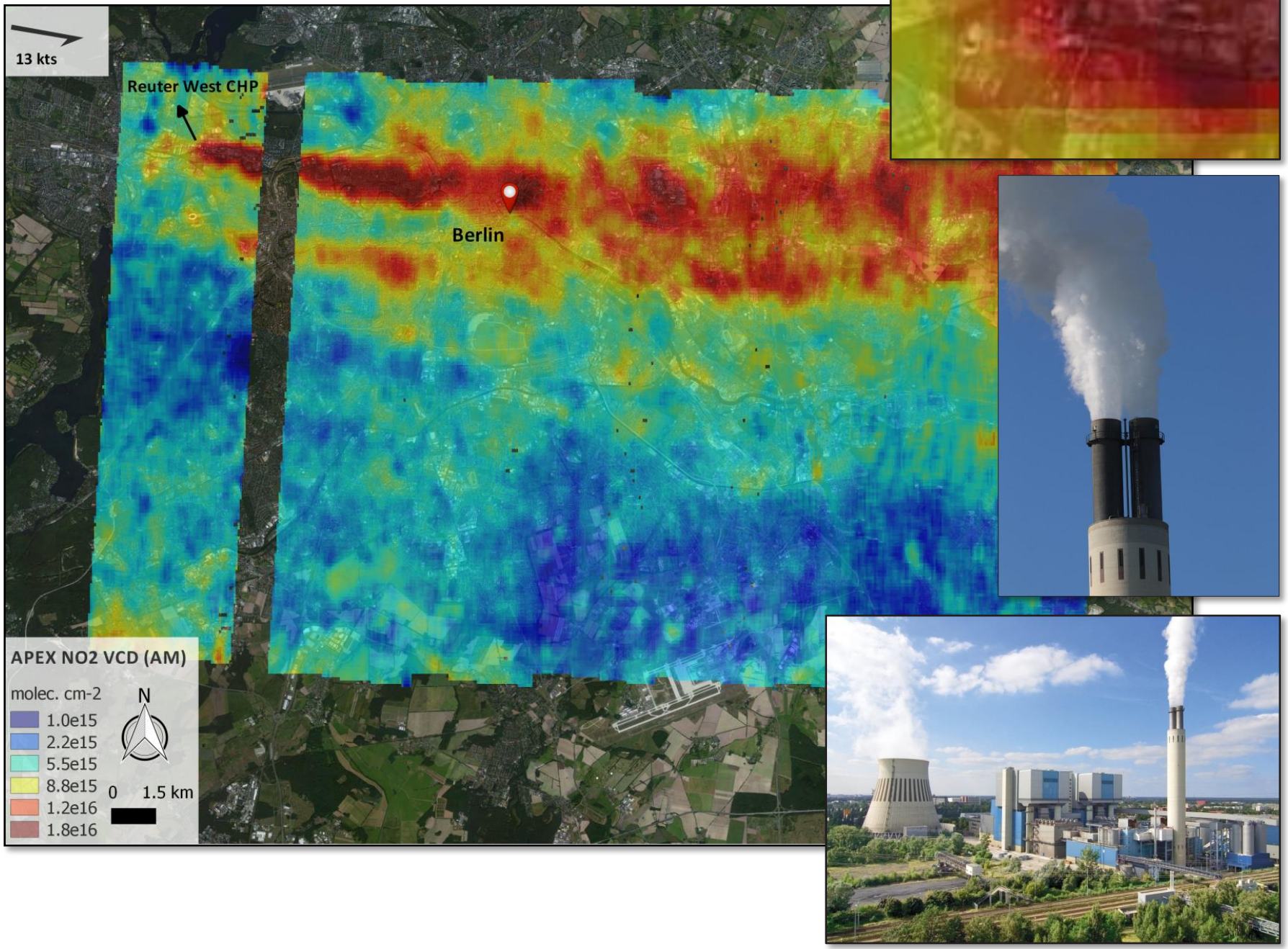
NO_2 DISTRIBUTION MAPS (AROMAPEX 2016)

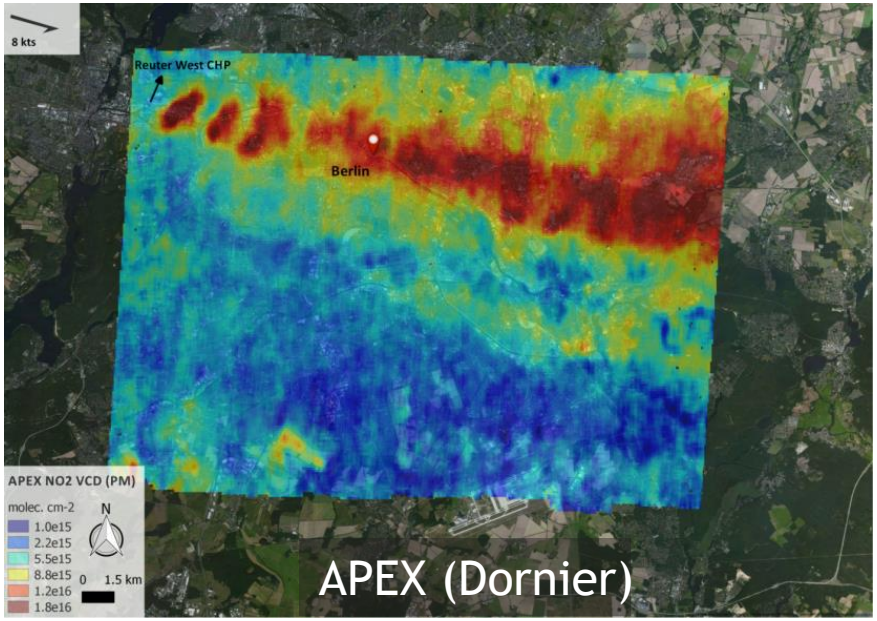
- Golden day: 21-04-2016
- 2 times 2 synchronized flights (AM & PM)
- 4 imaging sensors simultaneously operated
  - APEX (VITO/BIRA) } DLR Dornier (6 km AGL)

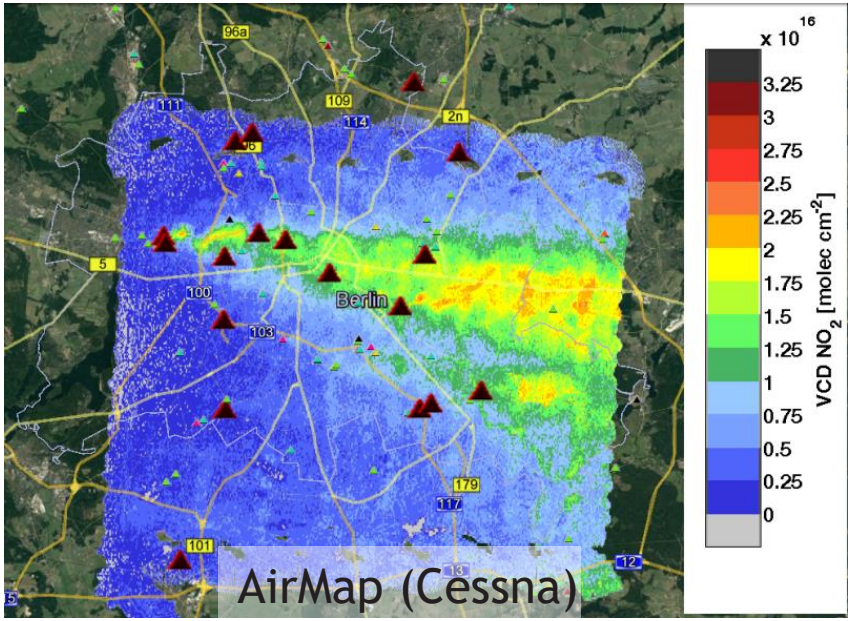
  - AirMAP (IUP Bremen/FU Berlin)
  - SWING (BIRA)
  - SpectroLite (TNO/TU Delft) } FUB Cessna (3 km AGL)

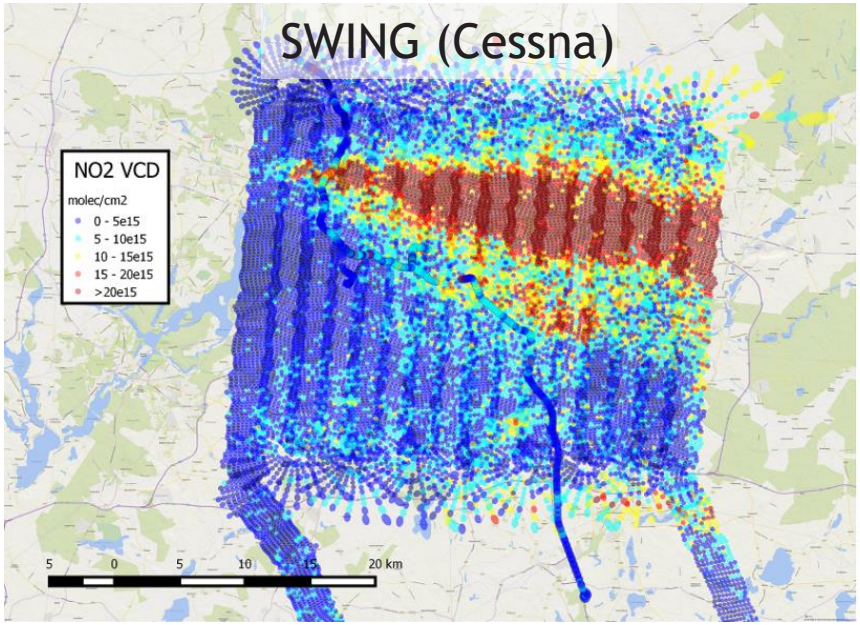


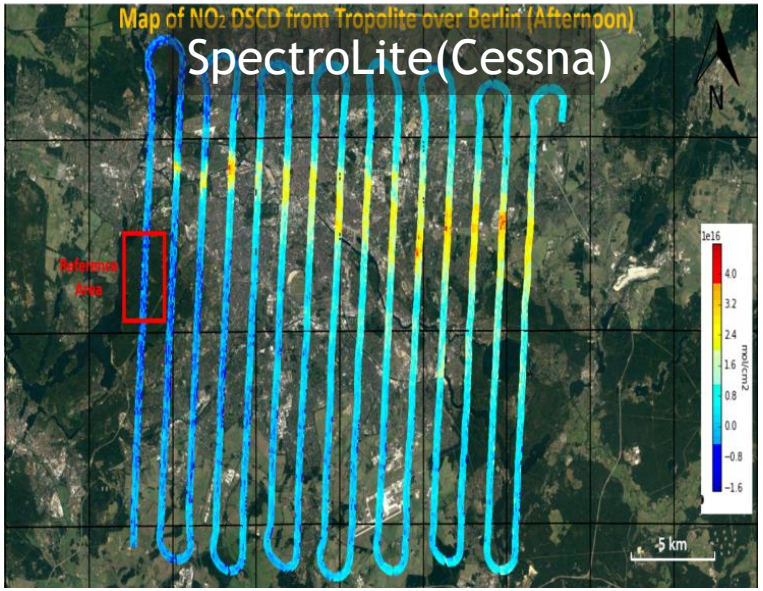



13 kts
Reuter West CHP
Berlin
APEX NO2 VCD (AM)
molec. cm-2
1.0e15
2.2e15
5.5e15
8.8e15
1.2e16
1.8e16
N
0
1.5 km

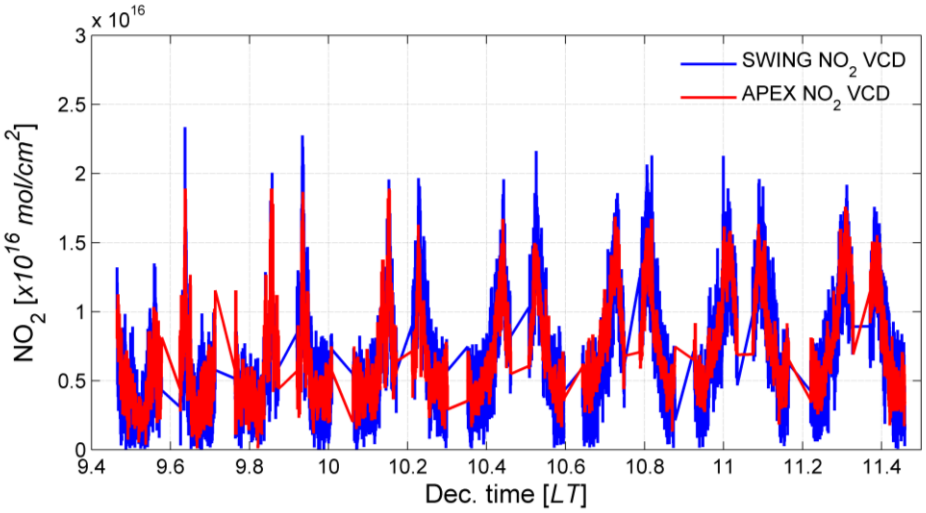

8 kts
Reuter West CHP
Berlin
APEX NO2 VCD (PM)
molec. cm-2
1.0e15
2.2e15
5.5e15
8.8e15
1.2e16
1.8e16
N
0
1.5 km
APEX (Dornier)

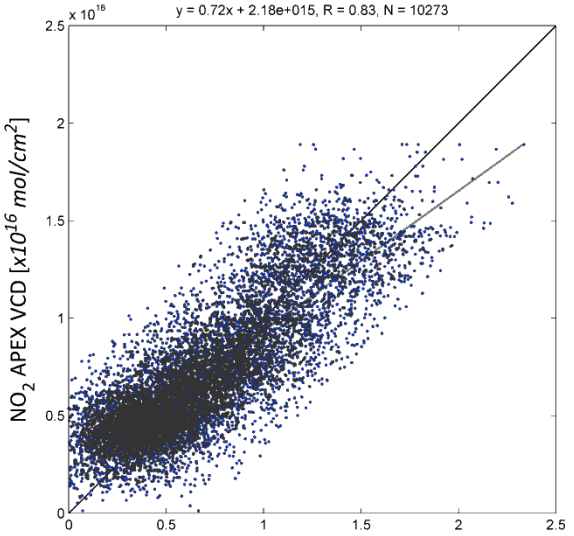

x 10^16
3.25
3
2.75
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
VCD NO2 [molec cm-2]
Berlin
AirMap (Cessna)

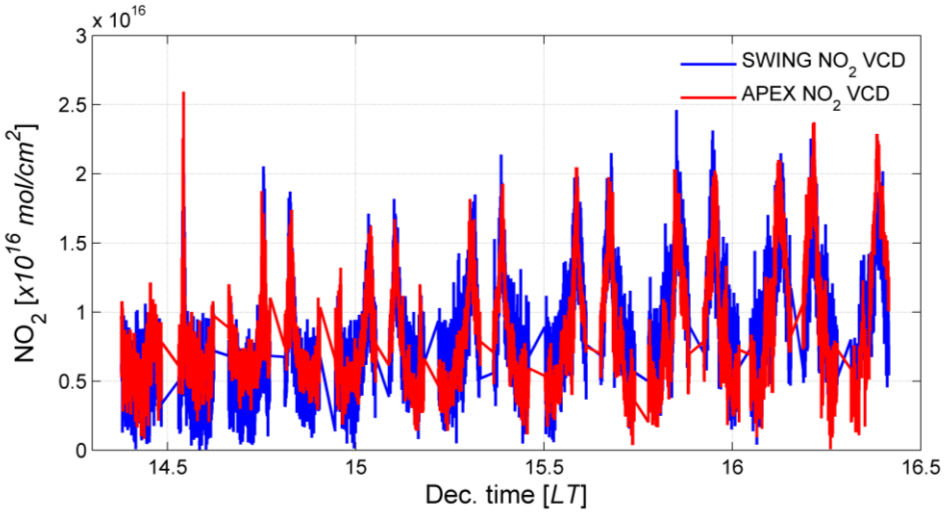

SWING (Cessna)
NO2 VCD
molec/cm2
0 - 5e15
5 - 10e15
10 - 15e15
15 - 20e15
>20e15
5
0
5
10
15
20 km

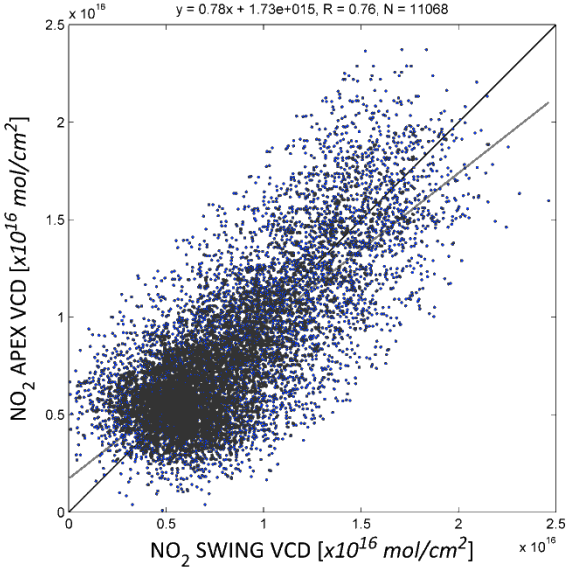

Map of NO2 DSCD from Tropolite over Berlin (Afternoon)
SpectroLite(Cessna)
N
Reference Area
1e16
4.0
3.2
2.4
1.6
0.8
0.0
-0.8
-1.6
molec/cm2
5 km

APEX-SWING NO_2 VCD COMPARISON









CONCLUSION & PERSPECTIVES

- Demonstrated that a clear NO_2 signal and NO_2 spatial patterns can be retrieved over cities based on APEX data
  - High spatial resolution (60 x 80 m^2)
  - High spatial coverage (350 km^2 within 90 minutes)
  - NO_2 VCD accuracy of 20%
  - **BUT** unstable spectral performance

- High potential for **validation of satellite measurements, and 3-dimensional AQ models in urban areas + support to satellite mission design**

- **Perspectives**
  - BUMBA: column to surface concentrations and RIO-IFDM model validation (**ongoing…**)
  - AROMAPEX: quantitative comparison of NO_2 VCD distribution maps (**ongoing…**)
  - APEX successor
  - ~~BUMBA paper submitted to AMTD soon~~

vito

http://www.bumbair.be
http://uv-vis.aeronomie.be/airborne/bumba.php