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Optimization and application of satellite observations for AQ monitoring in Central Europe

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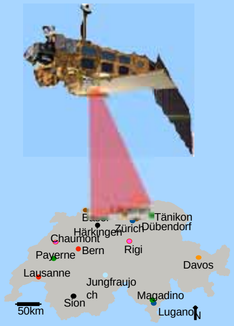


Outline

Traditional monitoring
- **goals**
- **networks**
- **applications**

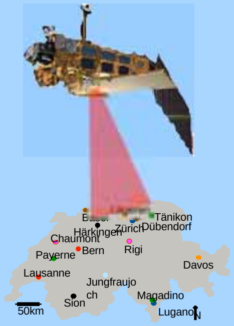
Scales of air pollution
- **wide range**
- **target range for satellites**

Imp. retrievals
- **topography**
- **albedo**
- **a priori NO2**

Conclusions & Outlook

Outline

- **Traditional AQ monitoring**
  - **Goals of AQ observations**
  - **Existing networks and applications**
- **Spatial scales of air pollution**
  - **What scales are of interest for AQ applications**
  - **What scales can be covered by satellites**
- **Improved retrievals for the regional scale**
  - **Improved topography**
  - **Improved surface reflectance data**
  - **Improved a priori NO_2 profiles**
- **Conclusions and outlook**



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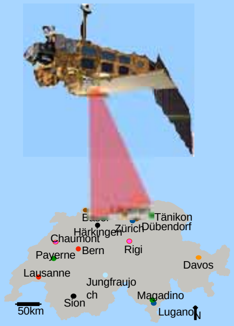
Traditional AQ monitoring

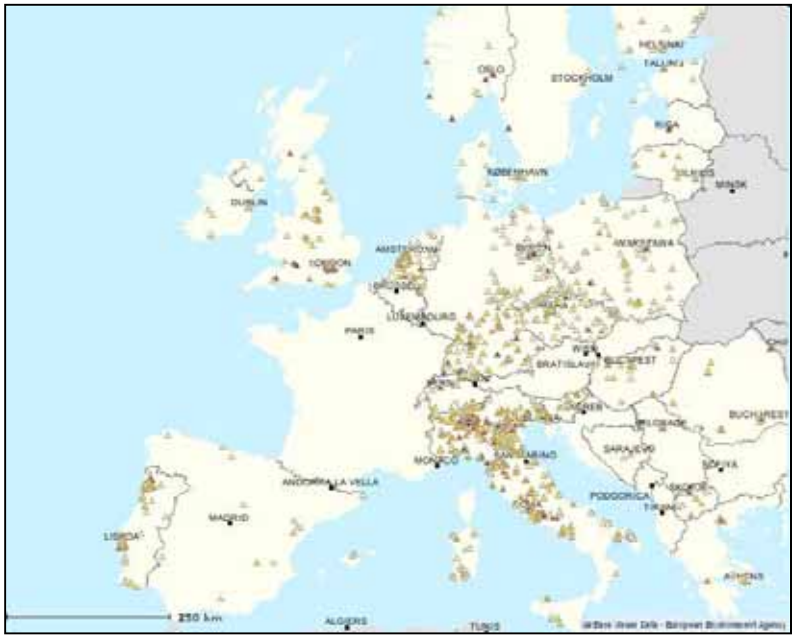
- **Purpose of a monitoring network**
  - Representative observations of major (regulated) air pollutants relevant for **human health, agriculture, ecosystems, and material degradation**
  - Monitor **current** pollution levels and **long-term** trends
  - **Support for decision makers** (warnings, control of success)

- **Monitoring networks in Europe**
  - Organized on country / sub-country level
  - Designed to cover all exposure levels and area types
  - Near-real time data availability
  - Heterogeneous network (instruments, quality, coverage) but large efforts for homogenization: EU directives, AQUILA expert group, Clean Air for Europe (CAFÉ)





Traditional AQ monitoring



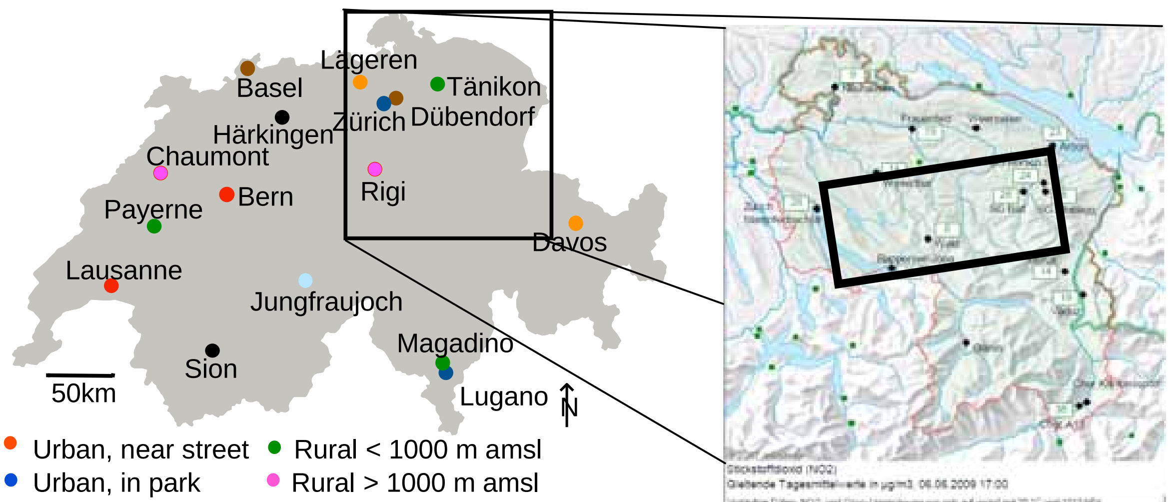
EEA - Airbase

European Environment Agency
Annual mean NO_2 2007

>1200 stations for NO_2 (including France & Austria)

Nitrogen oxides (air), annual mean, daily values, 2007
- 0 - 30 ug NO2/m3
- 30 - 60 ug NO2/m3
- 60 - 90 ug NO2/m3
- 90 - 120 ug NO2/m3
- 120 - 200 ug NO2/m3
- Country border
- EU and EEA Member and Collaborating Countries

Swiss national network NABEL



- Urban, near street
- Urban, in park
- Motorway
- Agglomeration
- Rural < 1000 m amsl
- Rural > 1000 m amsl
- Prealpine, forest
- Alpine

Additional stations of Cantons, e.g. „Ostluft“
Daily mean NO_2 on 6 June 2009

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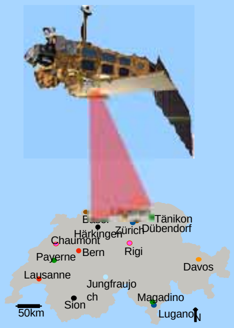
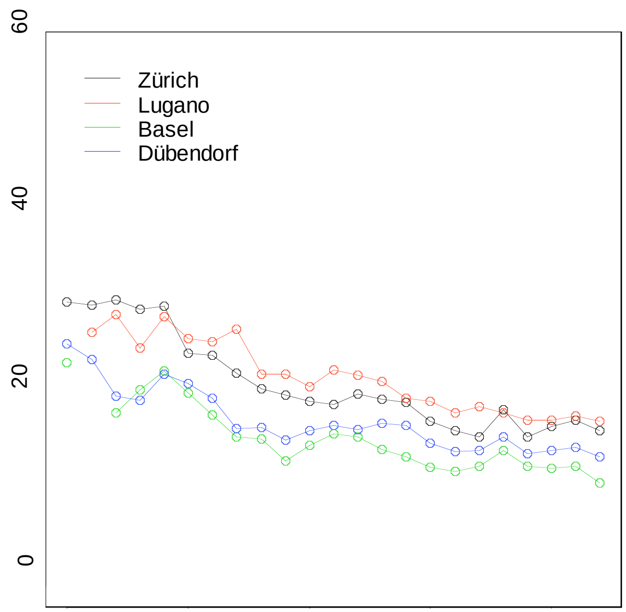


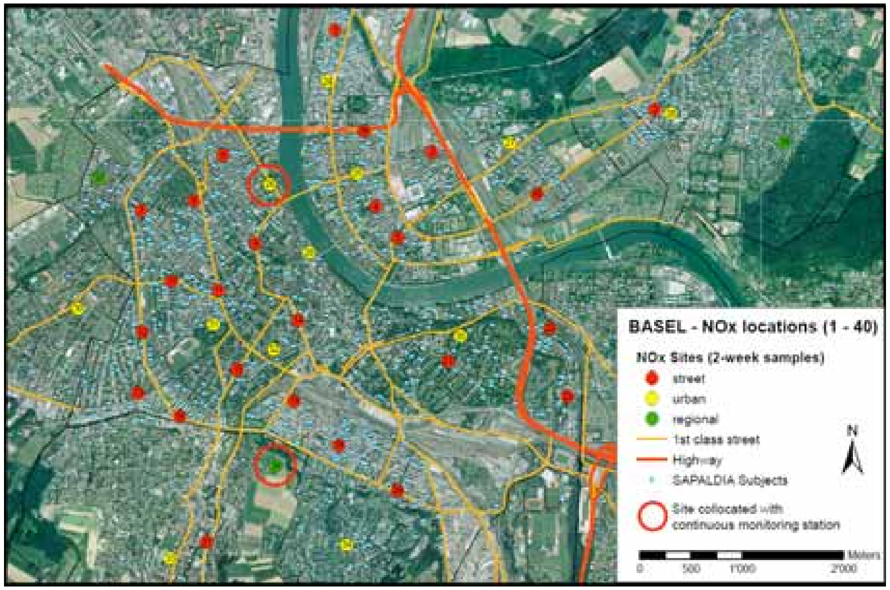
Applications of AQ monitoring networks

Analysis of long-term trends



Reliable long-term trends important for policy makers to control success of emission reduction measures

Assessment of human exposure



SAPALDIA long-term study on respiratory and cardiovascular health effects (9500 subjects, started in 1991), supported by high-resolution immission measurements

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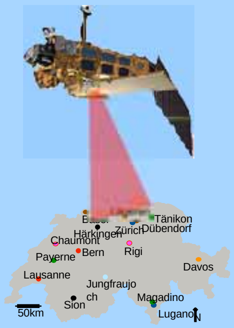

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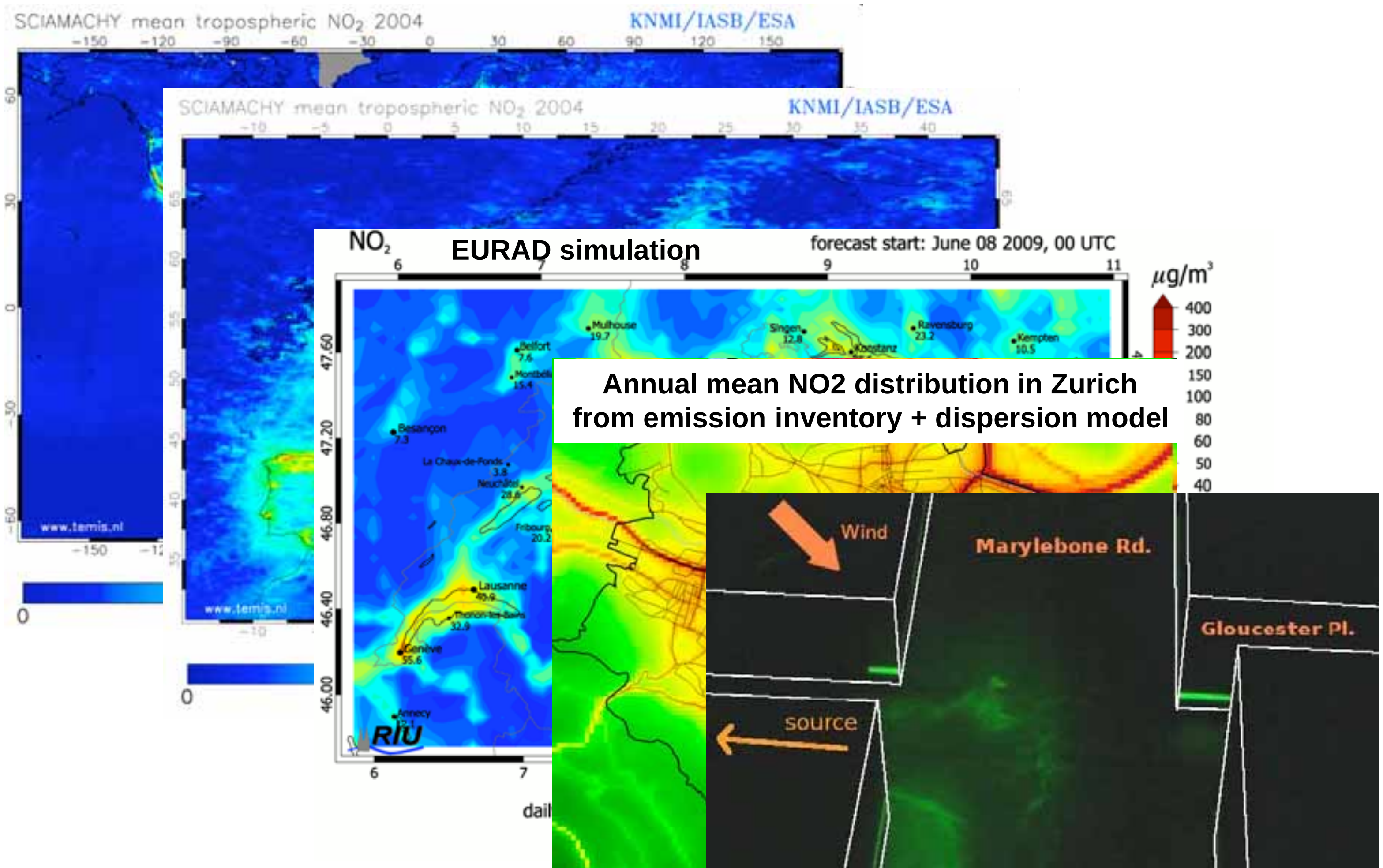
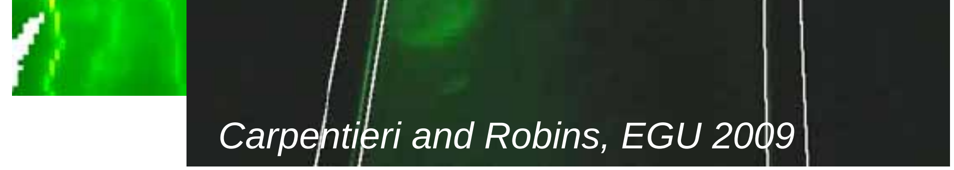
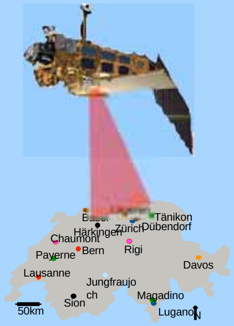
Spatial scales of air pollution





There is no way we can observe all scales from satellites. What should we focus on?



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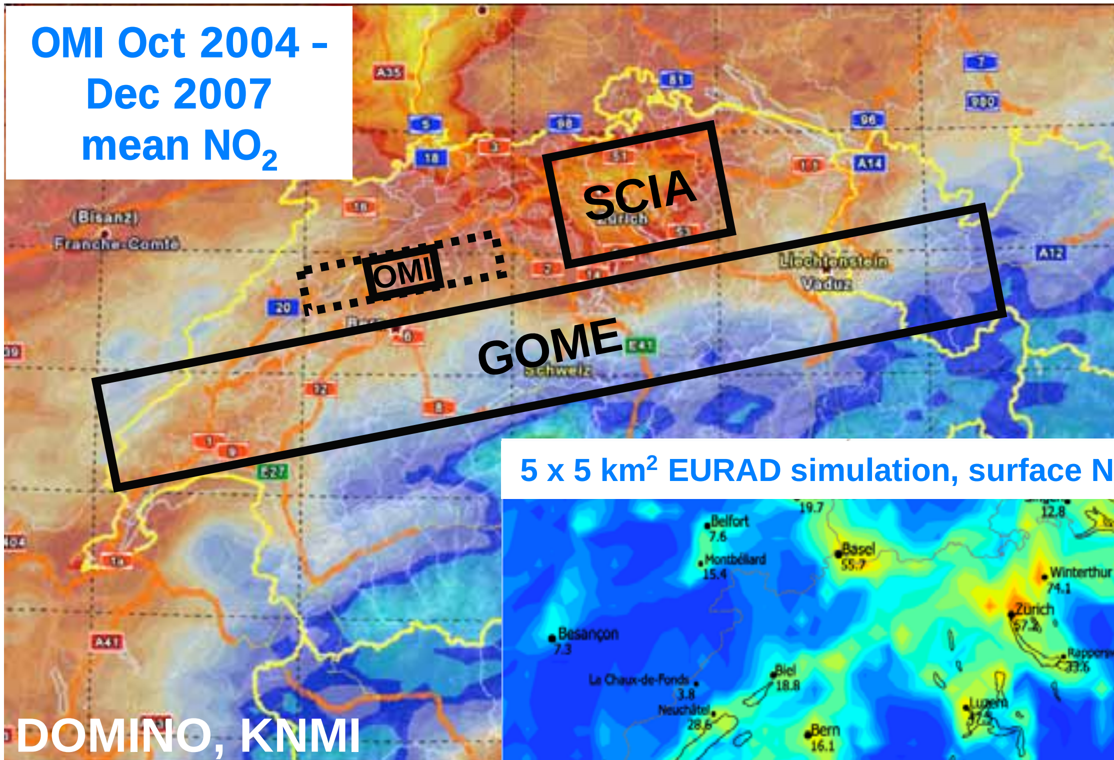
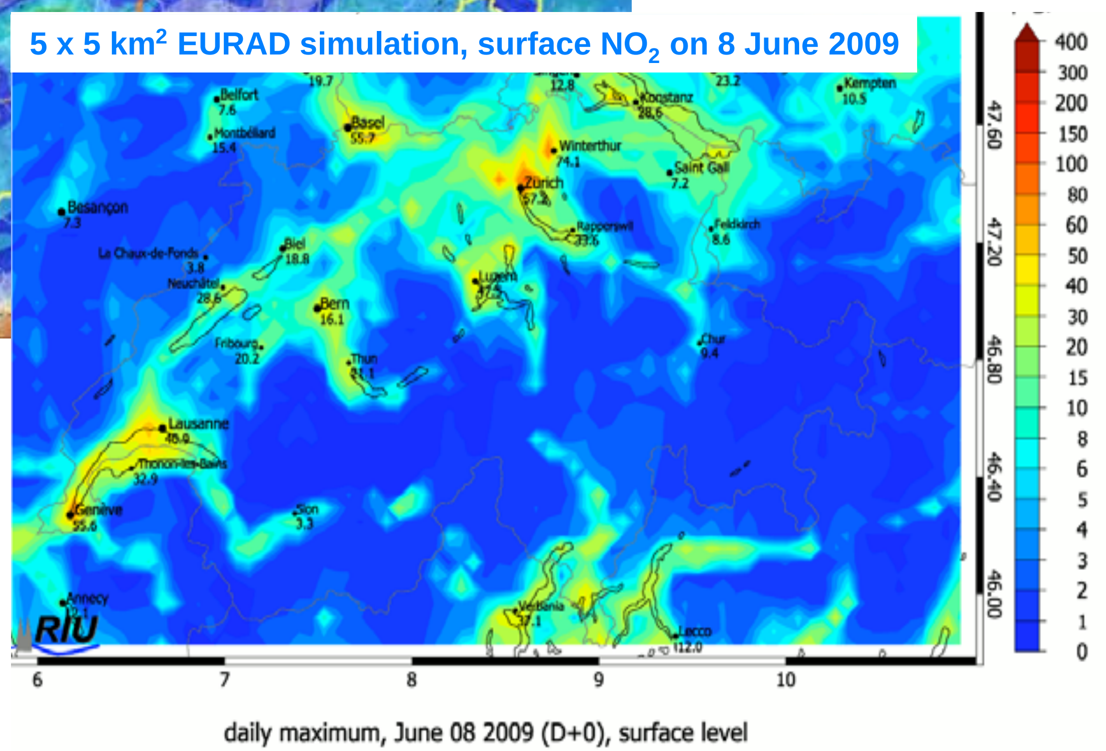
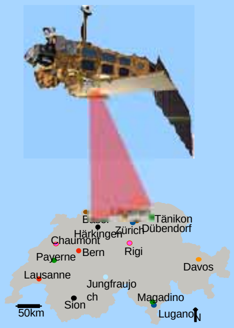
Spatial scales of air pollution

A realistic goal: Monitoring air pollution at regional scale





Measuring features with dimensions of a few km is realistic. Allows distinguishing e.g. urban from rural environments



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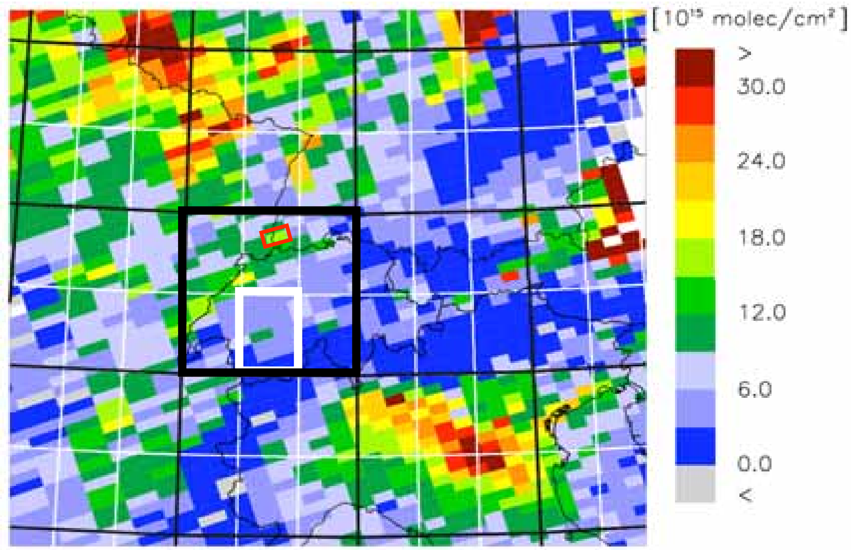
Improved retrievals for the regional scale

Main problem: Poor resolution of retrieval input data

NO_2 over central Europe from single OMI overpass on January 3rd 2006

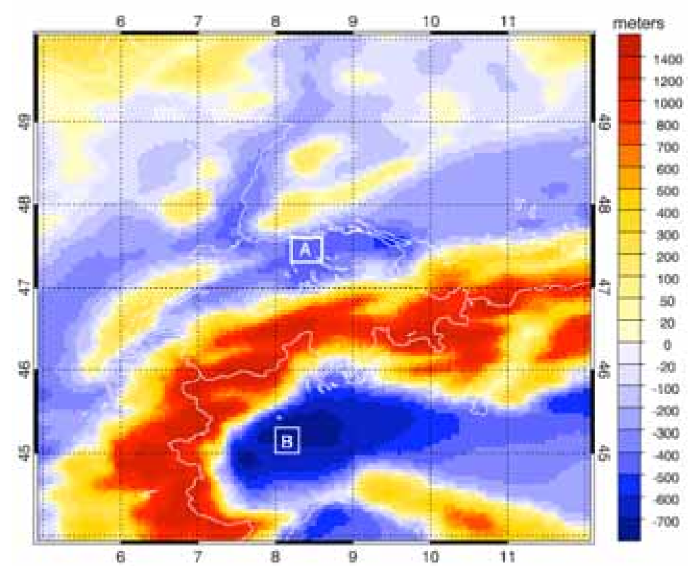


Resolution of input data used in Dutch OMI NO_2 product (DOMINO):

OMI:	~0.15°x0.25°
Albedo:	1°x1°
Surface pressure:	3°x2° (TM4 model)
A-priori NO_2 profile:	3°x2° (TM4 model)

Example: terrain height

Difference between effective pixel-averaged and TM4 model terrain height (meters)



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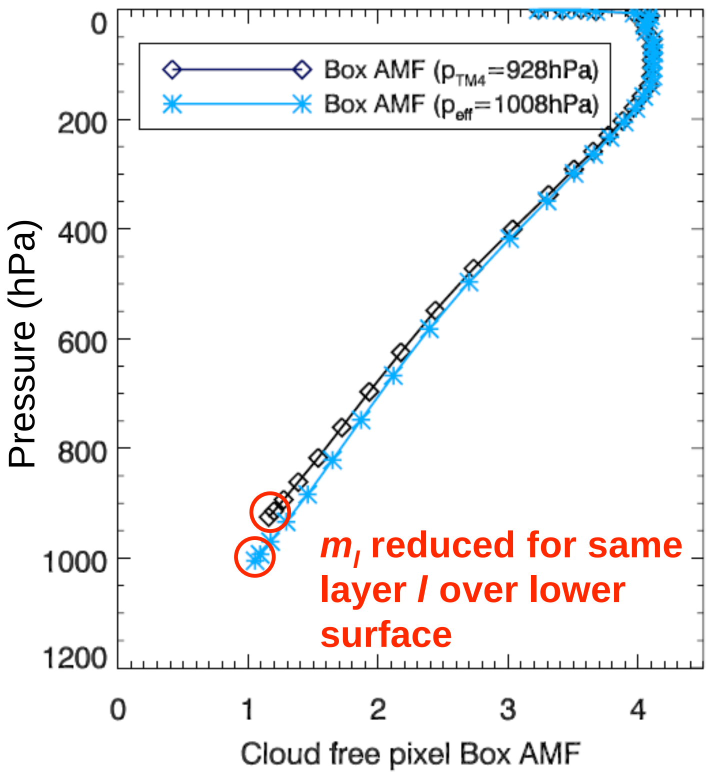
Improved retrievals: Surface pressure

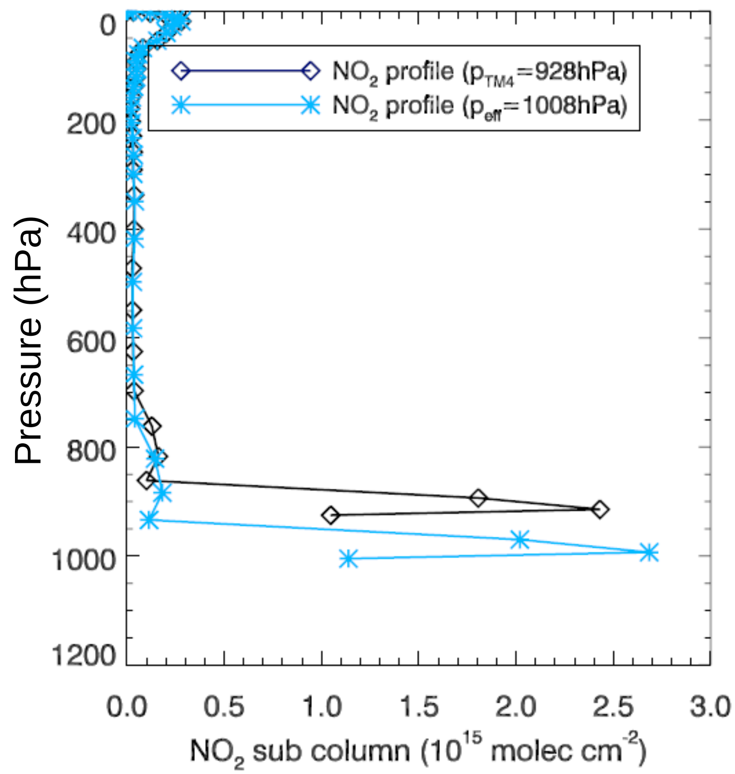
Effect of surface shift on NO_2 retrieval

Tropospheric air mass factor: $$AMF_{trop} = \frac{\sum_l m_l(\hat{b}) x_{a,l}}{\sum_l x_{a,l}}$$

Profile of box AMF m_l from DAK radiative transfer code



A priori NO_2 profile $x_{a,l}$ from TM4 model (winter)



Zhou et al., Atmos. Meas. Technol. Discuss., 2009

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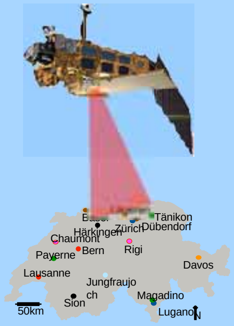
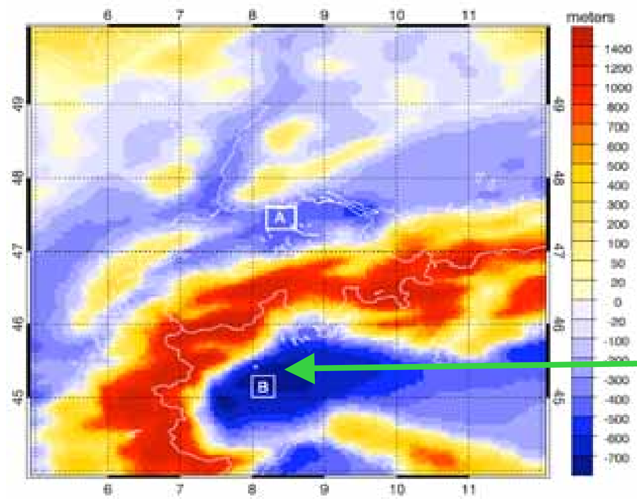


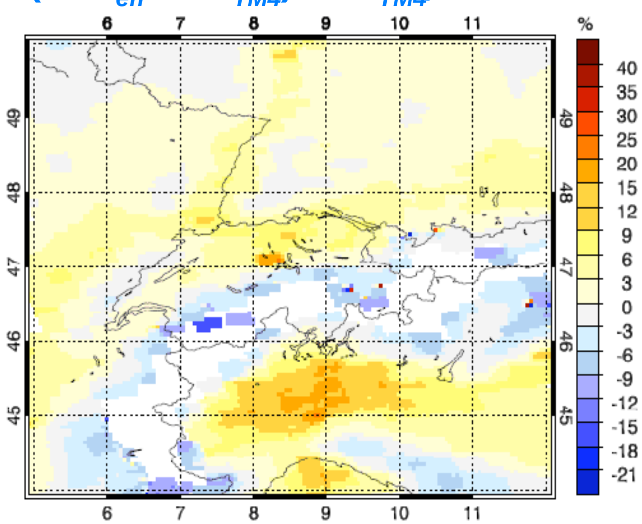
Improved retrievals: Surface pressure

Relative difference in NO_2 VTC retrieved with p_{eff} and p_{TM4}

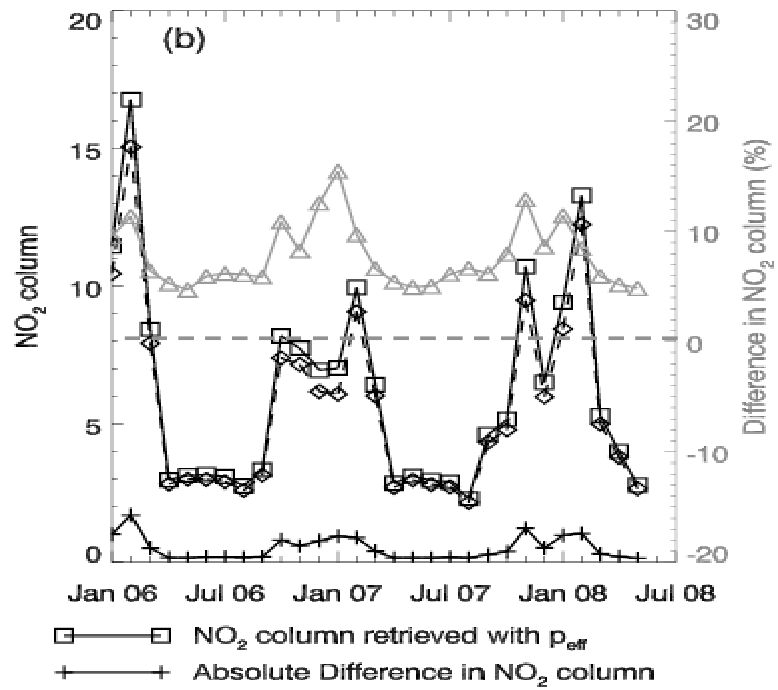
Terrain height difference h_{eff}-h_{TM4}



$(VTC_{eff}-VTC_{TM4})/VTC_{TM4}$, Dec 2006



Annual cycle of NO_2 difference for selected area in Po Valley



2006-2007,cloud radiance fraction <10%

Largest retrieval error (up to 20%) in winter

Zhou et al., Atmos. Meas. Technol. Discuss., 2009

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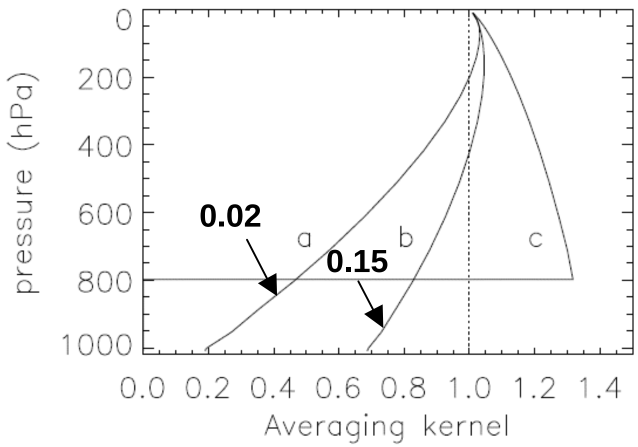
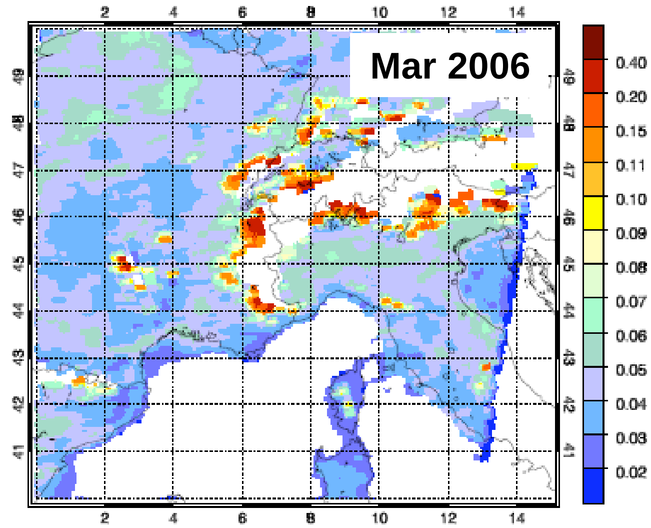
Improved retrievals: Surface reflectance

Comparison of different surface albedo data sets

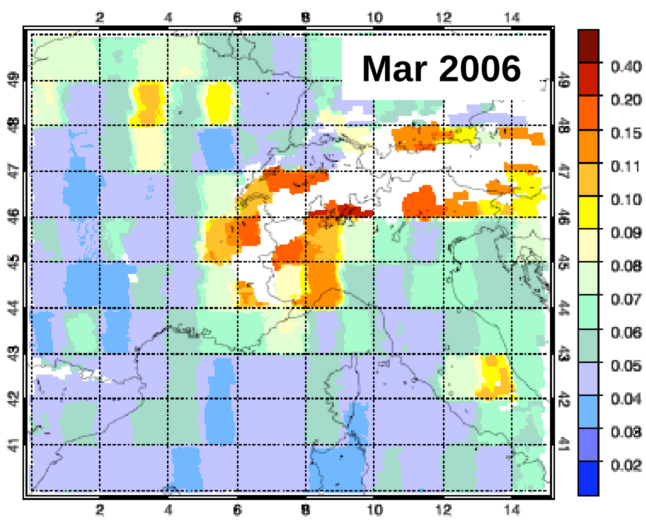
Averaging kernels for different surface albedo (Eskes & Boersma, 2003)



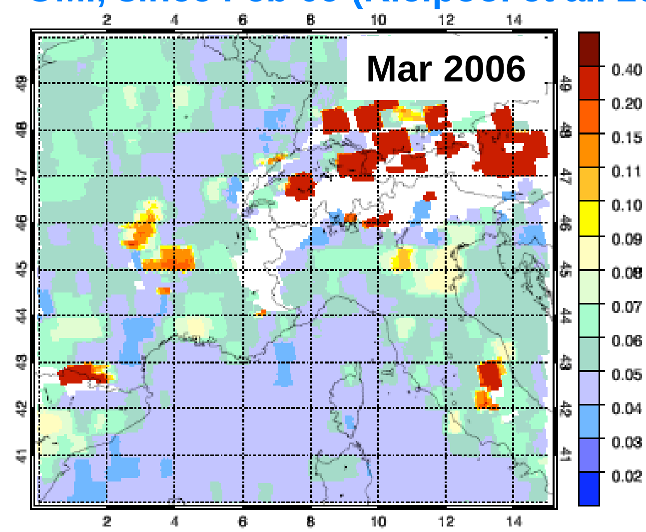
MODIS black albedo at 470 nm

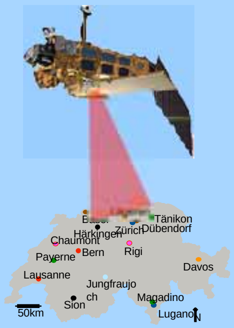


GOME/TOMS (Koelemeijer et al. 2003)



OMI, since Feb 09 (Kleipool et al. 2008)





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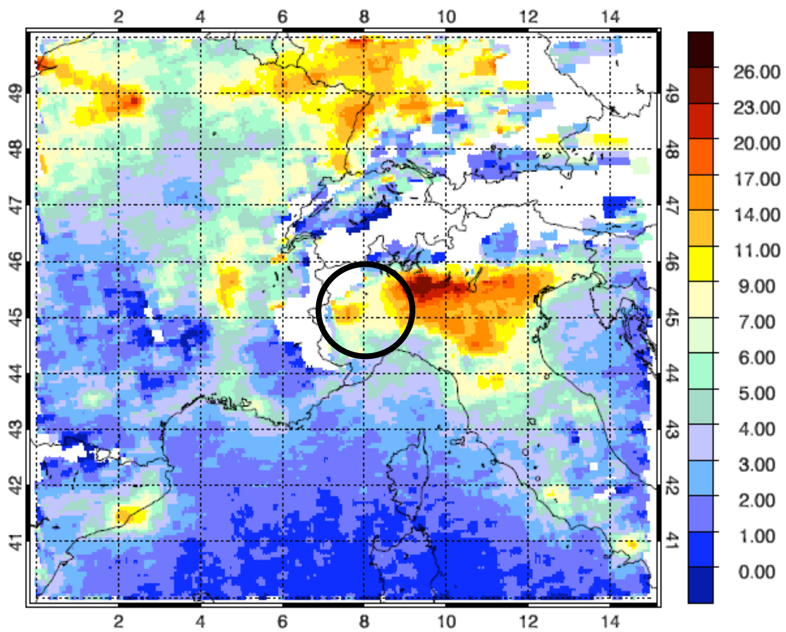
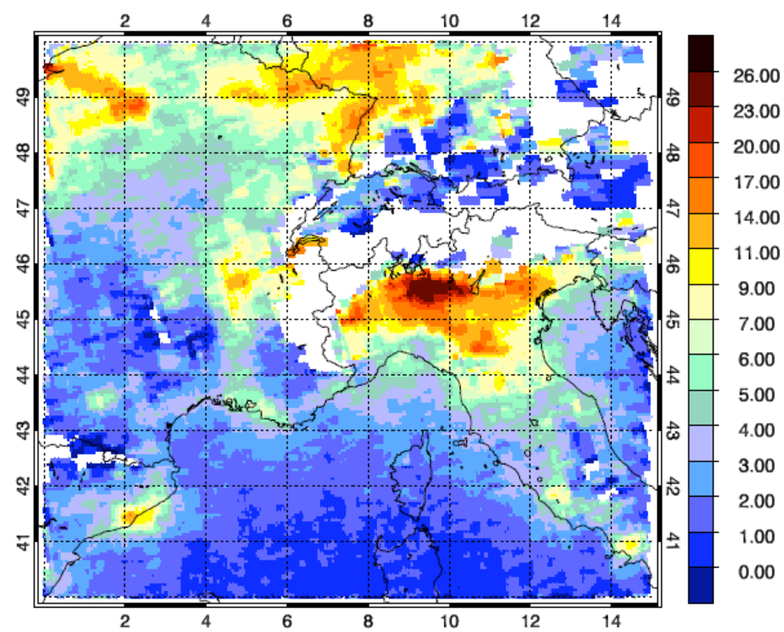
NO_2 VTC (GOME/TOMS LER)



NO_2 VTC (OMI LER)



Monthly mean map March 2006
(albedo < 0.4, cloud radicance fraction < 50%)

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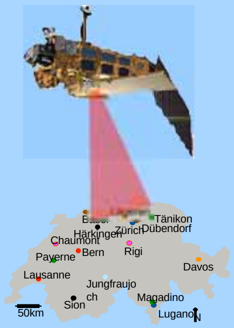

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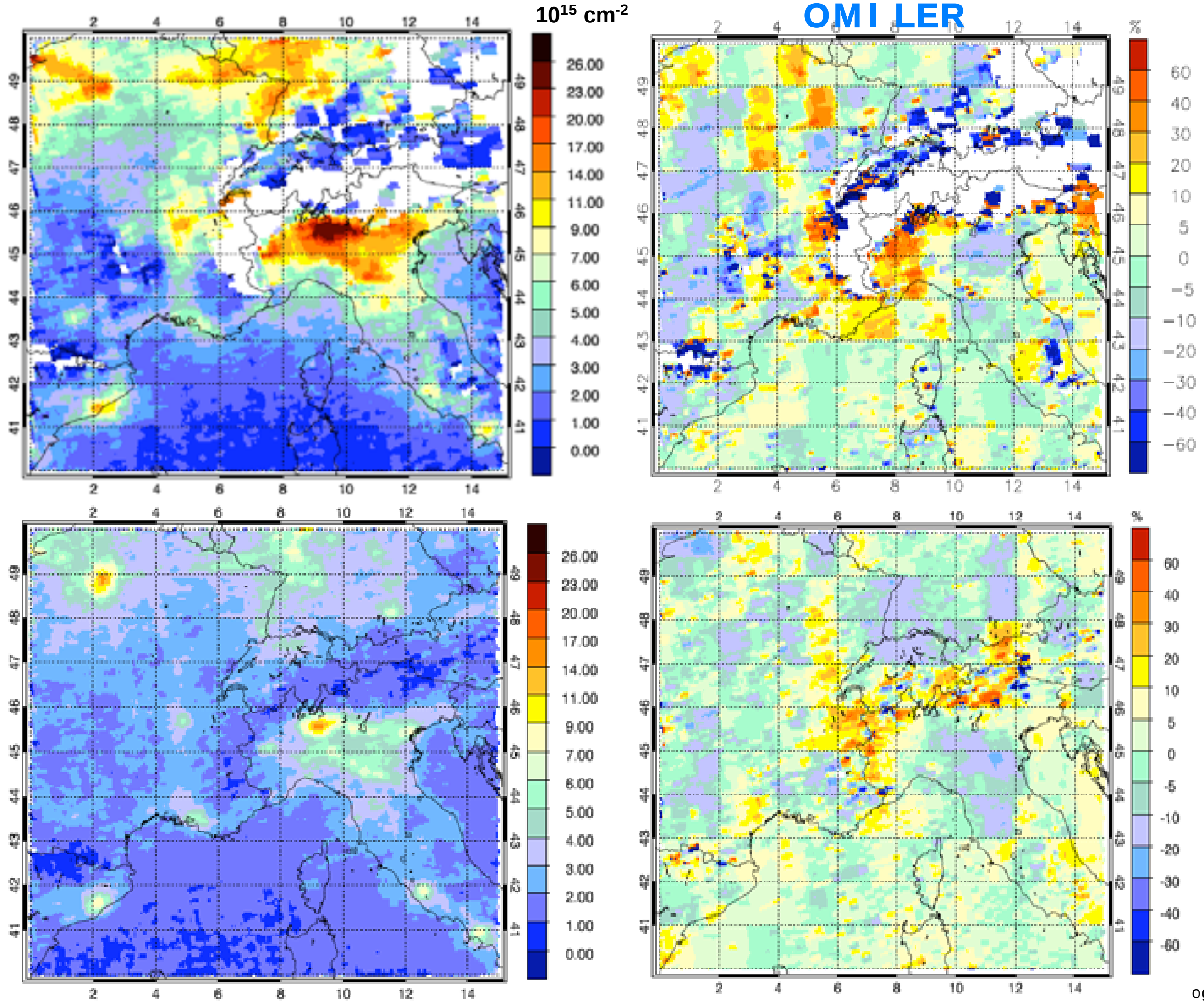
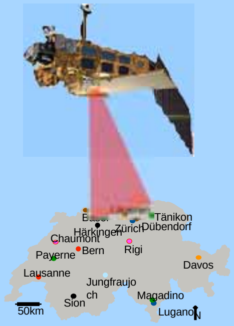
NO_2 VTC with OMI LER

relative difference (OMI – GOME / TOMS LER) / OMI LER

March 2006

July 2006





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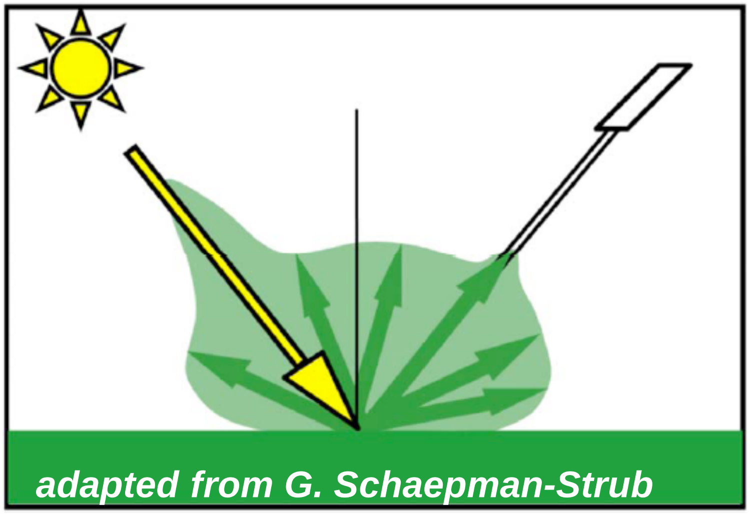
Improved retrievals: Surface reflectance

Next step: Use of MODIS bi-directional reflectance (BRDF)

Reflectance is anisotropic

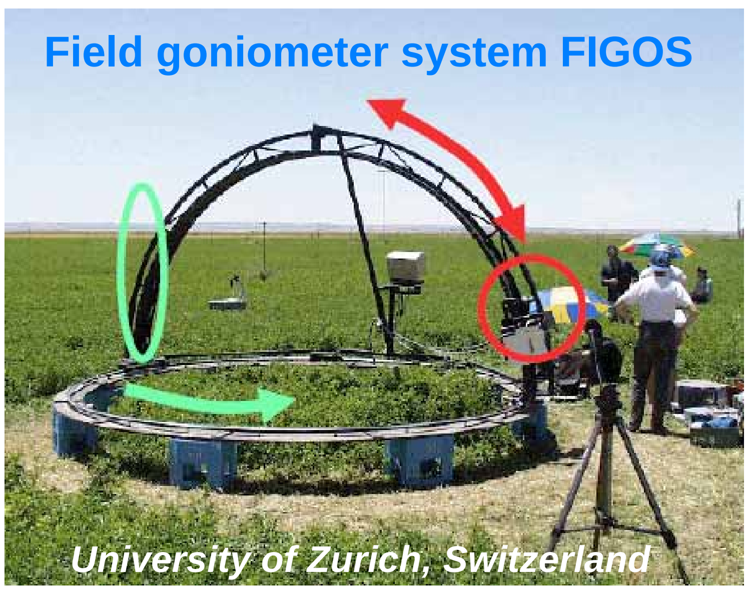


adapted from G. Schaepman-Strub

Example: forest

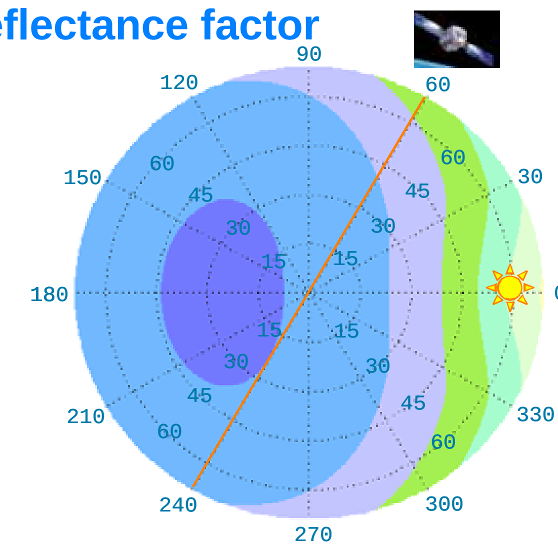
from MODIS website: BRDF explained

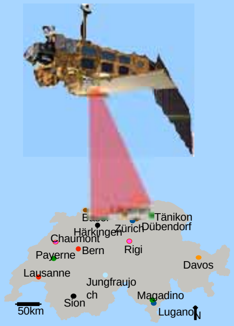
Field goniometer system FIGOS



University of Zurich, Switzerland

Polar plot of bidirectional reflectance factor





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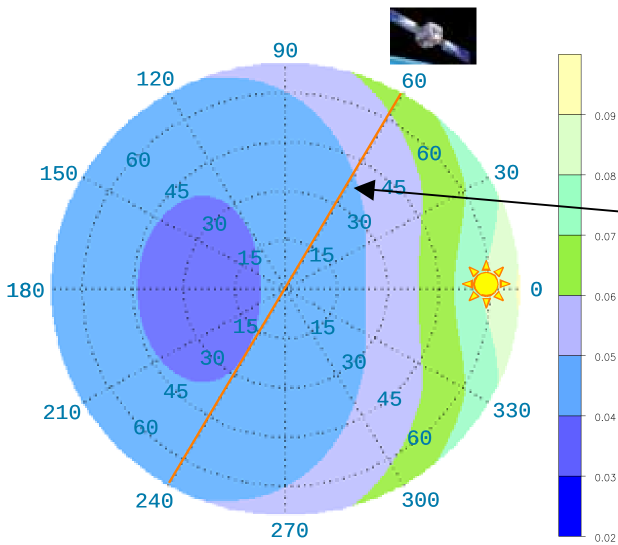
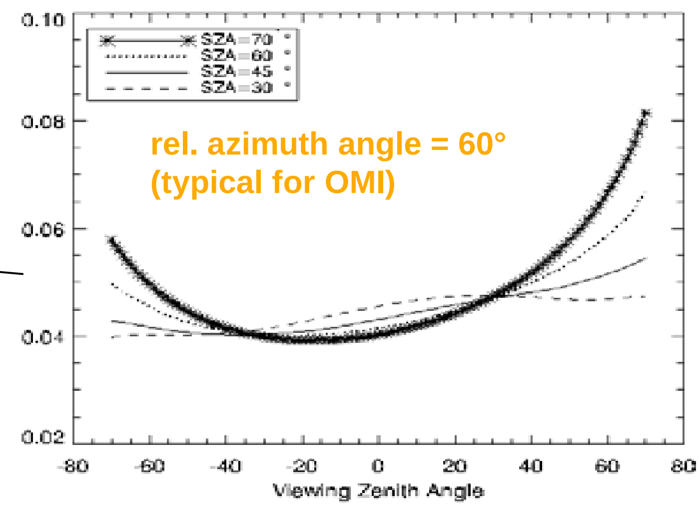
MODIS RossThick-LiSparse bidirectional reflectance model
(Schaaf et al., 2002)

$$BRF(\theta,\upsilon,\phi,\lambda) = \boxed{f_{iso}(\lambda)} + \boxed{f_{vol}(\lambda)K_{vol}(\theta,\upsilon,\phi)} + \boxed{f_{geo}(\lambda)K_{geo}(\theta,\upsilon,\phi)}$$

Isotropic (lambertian) — volume scattering — surface scattering & geometric shadowing

Example BRF, SZA = 60°





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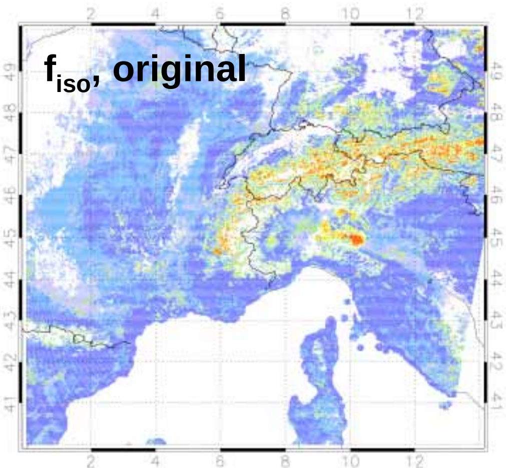
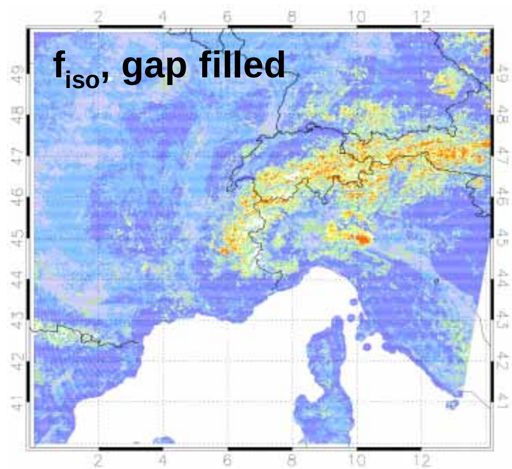
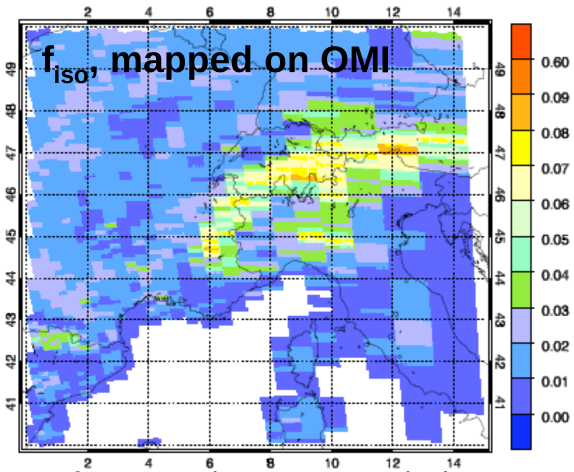


Original MODIS MCD43B1 product (One map every 8 days for each of f_{iso}, f_{vol} and f_{geo})



After recovering missing pixels by temporal and spatial interpolation and smoothing.

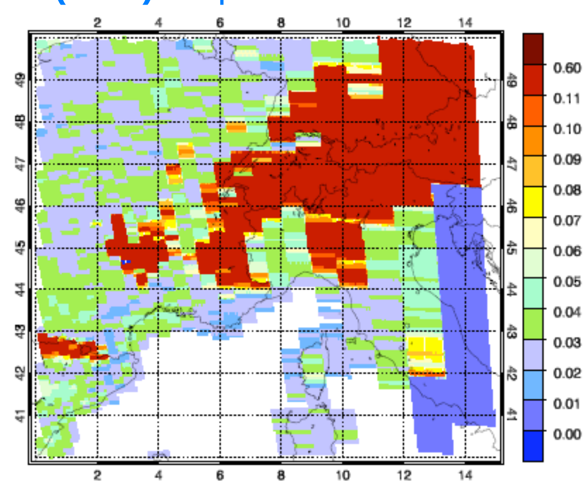


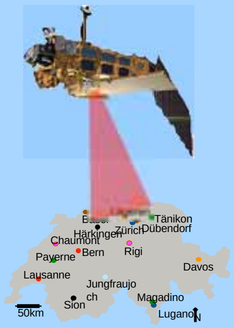
After averaging over OMI pixels (One map for each orbit)

f_{iso},f_{vol},f_{geo} → **BRDF model** → BRF map

K_{vol}, K_{geo} (with OMI $\boldsymbol{\theta, u, \phi}$) → **BRDF model**

Bidirectional reflectance factor (BRF) map for one OMI orbit

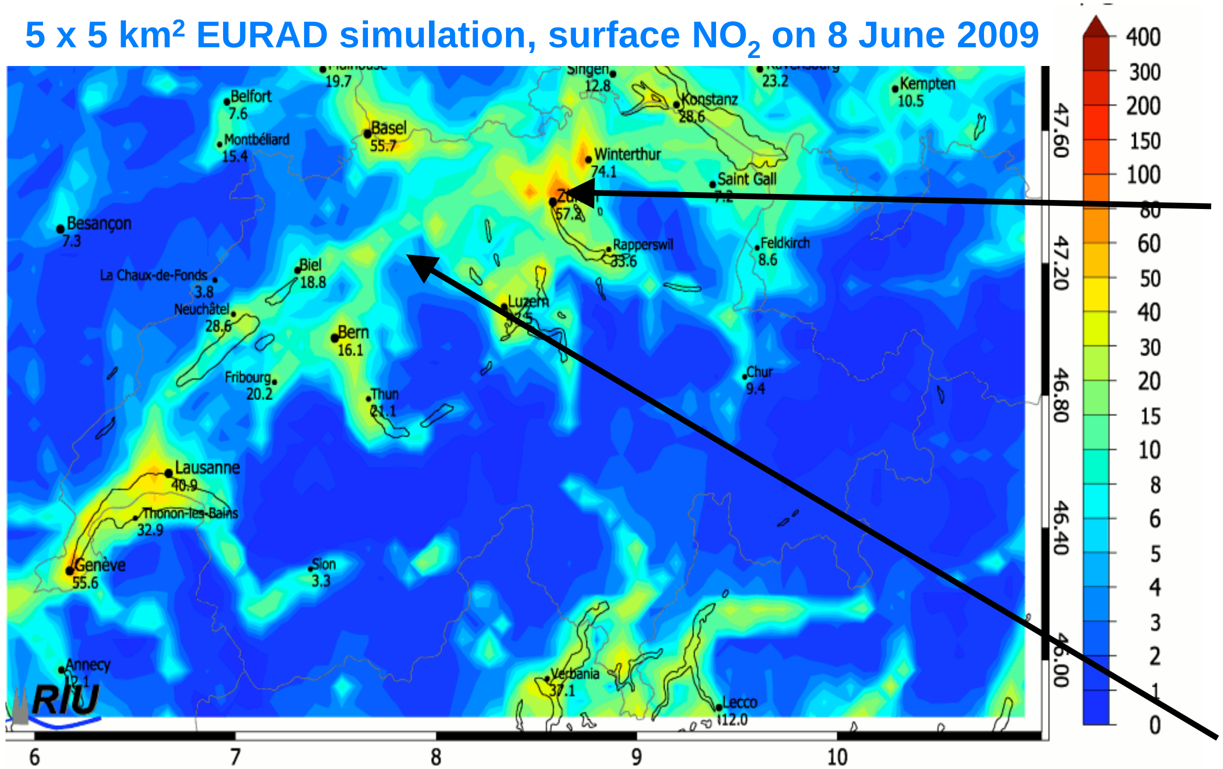




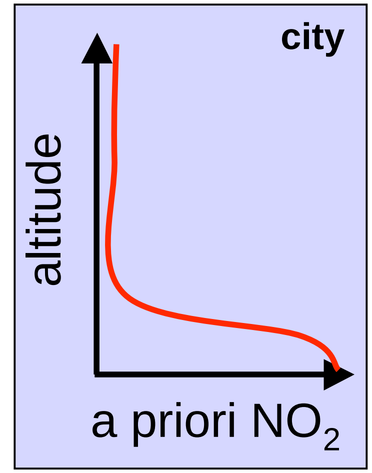
Improved retrievals: A priori NO_2 profiles

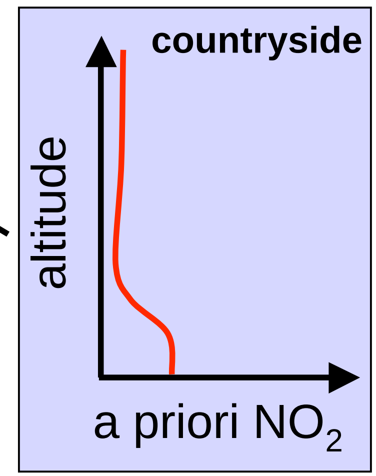
Last step: Use of a mesoscale model for a priori NO_2

5 x 5 km² EURAD simulation, surface NO_2 on 8 June 2009



daily maximum, June 08 2009 (D+0), surface level





A high resolution chemistry-transport-model will allow us to describe the spatial variability of a priority NO_2 profiles at the scale of a (OMI) satellite pixel realistically

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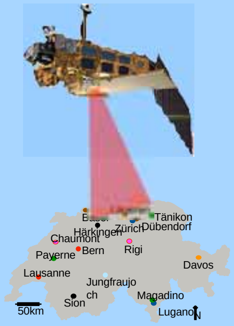

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- Traditional monitoring still backbone of AQ system
- Satellites will complement not replace in near future

- Satellites can not cover all scales, regional scale of great interest for AQ applications (trends over different areas, regional emission sources, assimilation into regional scale AQ models)
- Downscaling necessary for exposure assessments

- Operational retrievals tailored to global scale/coverage can be significantly improved for regional scale
- Potential areas of improvement: Topography, surface reflectance (incl. BRDF, snow cover), a priori profiles, aerosols, clouds

- Create more accurate NO2 data set after reprocessing OMI data with improved retrieval input data sets
- **Will be useful for trend assessment, model assimilation, emission estimation**

- Outlook: Bridging scale-gap with airborne spectral imager APEX

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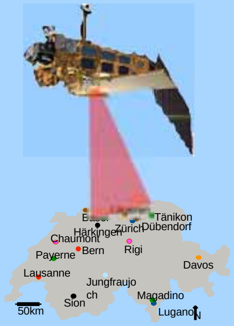


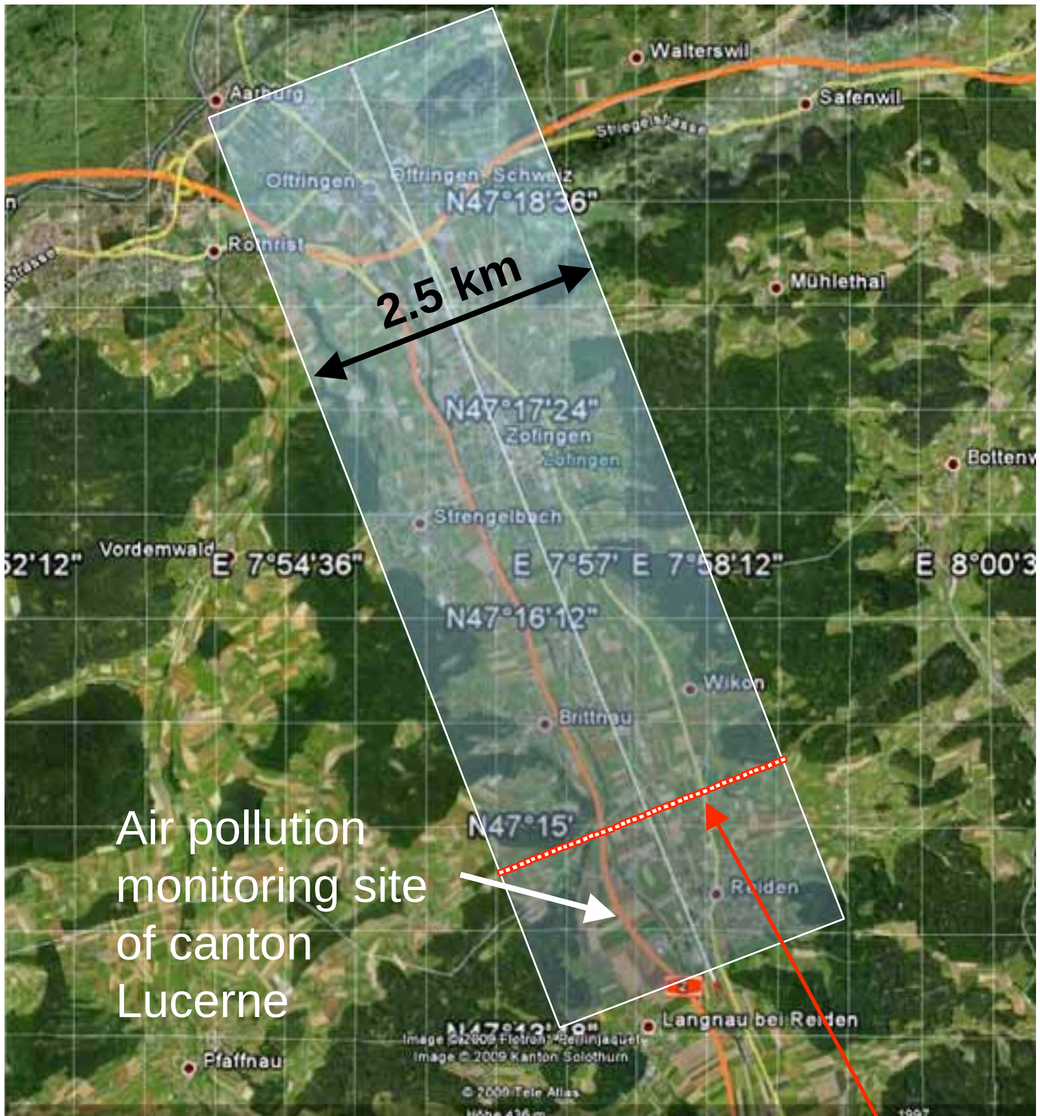
The hyperspectral future

The Airborne Prism EXperiment APEX, a joint Swiss/Belgian ESA PRODEX project

High resolution imaging spectrometer covering the UV to near IR (380-2500 nm)

Snapshot from first APEX imaging flight

First APEX flight took on Wed 17 June!



50 x 50 m² superpixels

Goals

Measure NO_2 distribution

- along motorways
- over villages and cities
- individual point sources
- over clean areas for reference

Details

Aircraft: DLR Do 228

Flight altitude: 5 km

Ground pixel: ~2 x 2.5 m²

Spec. resol.: 0.6-6.3 nm

Range: 380 – 970 nm

VNIR bands: up to 334

SNR single pixel: ~300

Expected size of „superpixel“ for NO_2 retrieval: 50 x 50 m²

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