Satellite remote sensing of trace gases - Nadir sounding geometry

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Sounding the bottom of the atmosphere...
Atmospheric composition

$\text{N}_2 + \text{O}_2 + \text{Ar} + \text{H}_2\text{O} + \text{CO}_2 + \text{trace gases}$

$> 99.9 \%$

$< 0.10 \%$

$1 \text{ ppm} = 1 \times 10^{-6}$

$1 \text{ ppb} = 1 \times 10^{-9}$

$1 \text{ ppt} = 1 \times 10^{-12}$
EPS contributes to the Global Operational Satellite Observation System.

Satellites mentioned include:
- FY-1/3 (China)
- GOES (USA) 75W
- GOES (USA) 135W
- METEOR 3M (Russian Federation)
- Aqua QuickScat TRMM
- ALOS
- ENVISAT/ERS-2
- METEOR 3M N1
- SPOT-5
- MSG (EUMETSAT) 0 Longitude
- Meteosat (EUMETSAT) 63E
- Meteosat (EUMETSAT) 83E
- FY-2/4 (China) 105E
- INSATs (India) 83E
- COMS-1 (Rep. of Korea) 120E
- GOMS / Electro N2 (Russian Federation) 76E
- Terra NPP Jason-1/2 Okean series
- MTSAT-1R/2 (Japan) 140E

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Satellite atmospheric sounding

Geostationnary orbit, 32 000 km

Polar orbit, around 700-800 km
Current nadir-looking satellite-borne missions

US/EOS
-
Terra 1999
Mopitt

EU/EPS
-
Metop-A 2006
MetOp-B 2012
Metop-C 2018

US/NPP Suomi
-
CrIS
OMPS

OCO-2

GOSAT
+
Calipso on the A-train

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Atmospheric sounding

What we see...

What a nadir-looking thermal infrared instrument sees...

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How radiation and molecules interact
Jean Poitou, « Composition atmosphérique et bilan radiatif », Reflets de la Physique, n°33, 2013
What can be seen by GOME-2?

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What can be seen by IASI?

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Cuesta et al., ACP 2013
Pollution

Short live trace gases (a few seconds to a few weeks)

Climat

Long live gases (a few months to hundreds of years)

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Atmospheric lifetime

**Climate gases**
- H\textsubscript{2}O
- CO\textsubscript{2}, NO\textsubscript{2} [100 yr]
- CH\textsubscript{4} [10 yr]
- (O\textsubscript{3})

**Pollutants**
- CO [4-8 weeks]
- O\textsubscript{3} [weeks]
- NO\textsubscript{2} [days]
- Formaldehyde, methanol, formic acid [days]
- NH\textsubscript{3} [hours - days]
Whose map is it (retrieved from TIR IASI)?

Tropo $O_3$, $C_2H_2$, column CO column, ammonia column?
Ash-volcano, dust (sand)?
Whose map is it?

- CO
- O$_3$
- NH$_3$
- C$_2$H$_2$
- Dust
- SO$_2$

Gases and particles behave differently depending on their lifetime

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Pollution from space

4 examples

1/ NO₂
2/ CO
3/ Tropo O₃
4/ coarse PM
5/ NH₃

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OMI/AURA

$\text{NO}_2$

Credit NASA
$\text{NO}_2$

Figure 2: Tropospheric vertical columns of NO$_2$ retrieved from measurements of the GOME, SCIAMACHY, GOME2 A, GOME2 B and CMI instruments over East Central China (30°N - 40°N, 110°E - 123°E). All data are IUP retrievals using the same AMF and reference sector stratospheric correction and a cloud screening of 0.2.

Richter et al., Nature, 2005
Pollution in rest days - NO₂

Fig. 1. Six years mean (1996–2001) of global tropospheric NO₂ Vertical Column Density in $10^{15}$ molecules/cm$^2$. The weekly cycle of the framed areas 1. US East Coast, 2. Europe, 3. East Asia and 4. Middle East, as well as 5. the marked individual Metropolises are considered in detail in this study.

Beirle et al., ACP 2003
Pollution & Economic crise - NO$_2$

30-40% decrease since 2008

Pollution in Boats - NO₂

Indian Ocean: Boats travelling from Sri Lanka to Singapour, Singapour to China; Red Sea, Mediterranean area
Pollution in Boats - NO$_2$

Période 2007-2009

GOME2 - Credit J. Burrows/A. Richter
Carbon monoxide (CO) : seasonal distribution

Clerbaux et al., ACP 2009
Large fires: Moscou August 2010
Large fires: Moscou August 2010

IASI CO data
July 22 → Aug. 22

LATOMS-IPSL / ULB

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I. Ozone: seasonal variability over cities

Seasonal Cycling of Ozone in Urban Regions

- Stratospheric intrusions
- High photochemical production in summer
- Drop due to monsoon

Safieddine et al., JGR 2013
Ozone: seasonal variability over Mediterranean area

Safieddine et al., ACP, 2014
High and alerting tropospheric O$_3$ values are recorded in summer, especially to the east of the basin because of:

Safieddine et al., ACP, 2014
Coarse PM: eg dust, ash, ...
Sand storm

23 septembre over Sydney...
5 millions of tons/600 km
Volcanic eruptions

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Volcanic eruptions

Eyjafjallajökull eruption - IASI Ash radiance index - 14.04.2010 ~22h UTC

Credit L.Clarisse, ULB
Volcanic eruptions

Eyjafjallajökull eruption - IASI Ash radiance index

Credit L.Clarisse, ULB
Volcanic eruptions

- **Grimsvotn**: > 0.5 Tg
- **Nabro**: > 1.5 Tg
- **Puyehue**: > 0.3 Tg

**Volcanic ash types**:
- Basalt ash
- Rhyolitic ash
- Ice particles

Credit L.Clarisse, ULB
Ammonia
Ammonia

... dealing with a signal hardly detectable ...

Clarisse et al., Nature Geo 2009

Ammonia 2008 average – IASI data
Ammonia

Mapping from local to global scale
→ 28 emission hotspots identified

Clarisse et al., Nature Geo 2009

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Ammonia (NH₃)

Corporate
Martin Van Damme (ULB)

Land use systems of the world

4 years mean 2008→2011
What can we see from space?

Sand over Sydney  
Fires in Moscow  
Ozone at the Pole  
Eyjafjöll Volcano

Ozone peaks  
Economic crisis  
Silk Road  
Strong pollution

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What can we see from space?

- Sand over Sydney
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What can we see from space?

**Radioactivity** (e.g., Fukushima) because detectors don’t see gamma rays and atmosphere is not transparent to gamma-rays.

**Short scale phenomena** because of the pixel size (horizontal) and/or sensitivity.

**Short live species** because concentration are too low.

Highly resolved **vertical information**

**Emission flux**

>> we need **ground-based** and **aircraft measurements**

>> we need **atmospheric models** to integrate the data (data assimilation, inversion sources)
Future nadir-looking satellite-borne missions

**US/EOS**
- Terra 1999 Mopitt
- Aqua 2002 AIRS
- Aura 2004 TES/OMI

**EU/EPS**
- Metop-A 2006
- MetOp-B 2012
- Metop-C 2018

**US/NPP Suomi**
- CrIS
- OMPS

**EU/Sentinel 4 precursor TROPOMI**
- Merlin, Earthcare

**EU/EPS-SG-sentinel 5**
- Metop-SG-A1
- Metop-SG-A2
- Metop-SG-A

**IASI-NG**
- UVS
- 3MI

**OCO-2**

**GOSAT**

**Future nadir-looking satellite-borne missions**

**+ Geo orbit :**
- **US TEMPO**
- **EU/MTG-sentinel 4 : IRS, UVN**
- **Asia: GEMS**

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Data availability and download:

**Total O₃, NO₂, formaldehyde**
http://o3msaf.fmi.fi/ GOME2
http://www.temis.nl GOME2, OMI

**CO**
https://eosweb.larc.nasa.gov/project/mopitt/mopitt_table MOPITT
http://www.pole-ether.fr/ IASI

**NH₃** upon request to me

Interesting websites to look at:

**SO₂ volcano alerts for aviation:** http://sacs.aeronomie.be/
**MACC forecasts:** https://www.gmes-atmosphere.eu/services/raq/raq_nrt/

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