# IRS contribution to atmospheric composition

*+ identify where developments are needed*

**Outline**

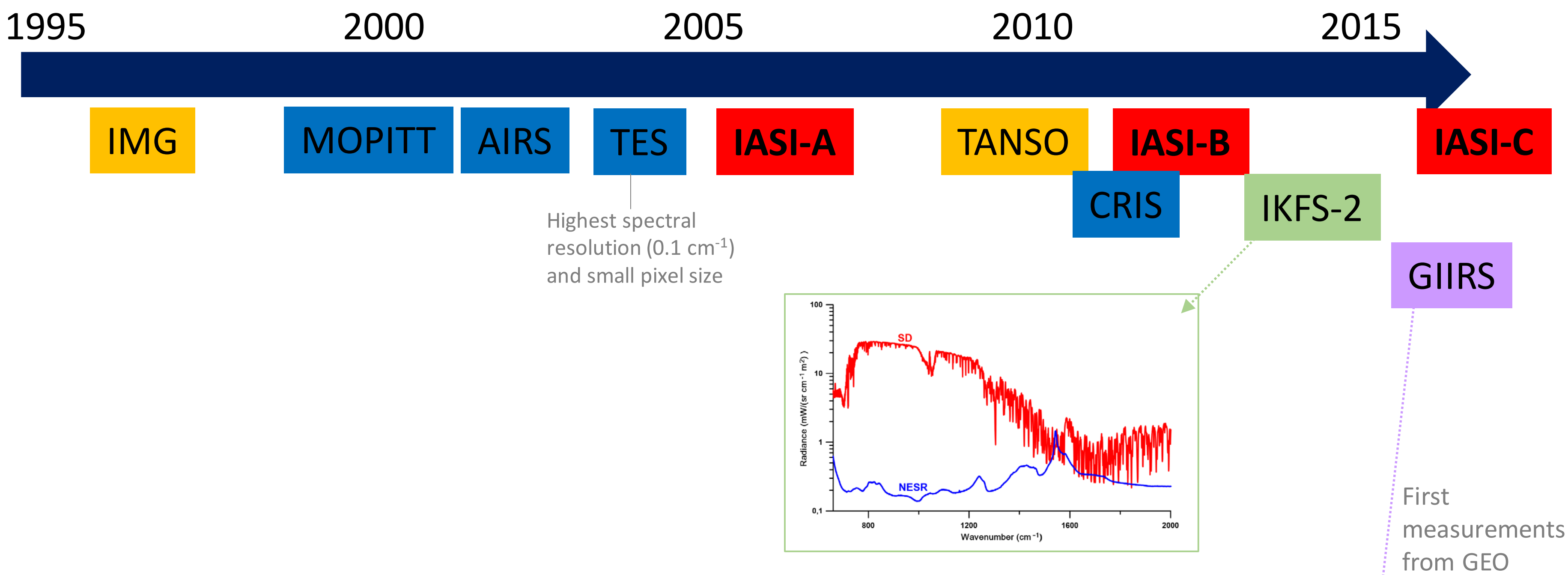
1. Heritage from hyperspectral IR sounders (IASI as “best” example)
2. Atmospheric composition applications
    - Known from IASI and other polar sounders
    - Opportunities for IRS (Where IRS would, could, would unlikely contribute)
3. Wrap-up ; questions; synergy with other missions

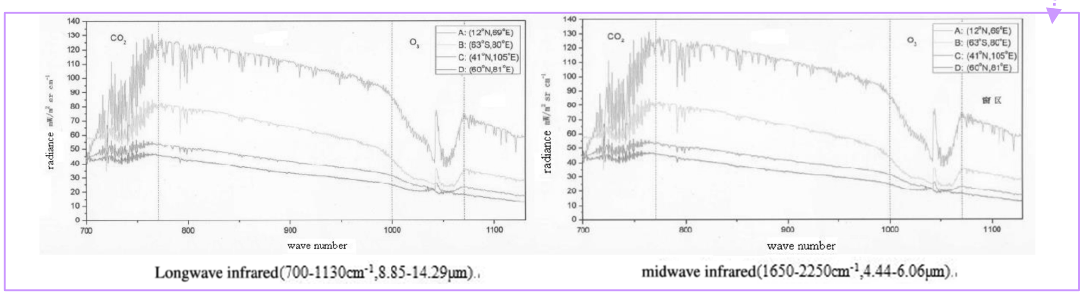
*Input from the group appreciated*

# Heritage from hyperspectral IR sounders

- JAXA
- NASA / NOAA
- EUMETSAT / ESA

## *Hyperspectral* IR nadir sounding



## IASI success

- Large continuous spectral coverage of the TIR
- Medium spectral resolution
- Low noise
- Medium spatial resolution

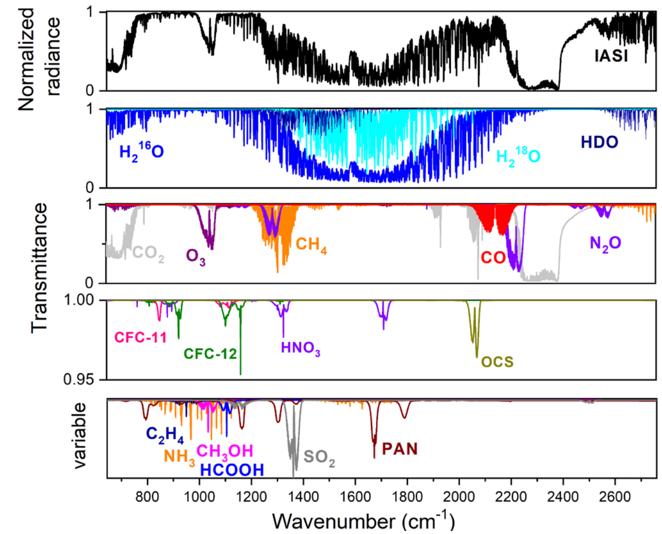
> 25 species

10 species routinely monitored; other above sources or during extreme events

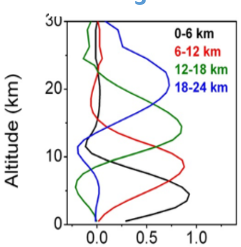
Aerosols *with type differentiation* (coarse mode)

Weakly resolved vertical profiles for $H_2O$/HDO, $O_3$, CO

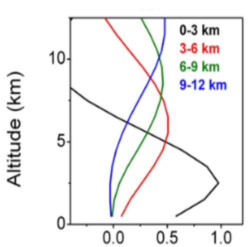
*+ altitude information on volcanic and fire plumes*



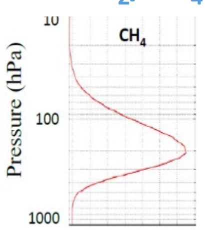

$O_3$




CO




$CO_2/CH_4$




- Near global coverage twice daily (including polar night)
- More than 15 years of global measurements

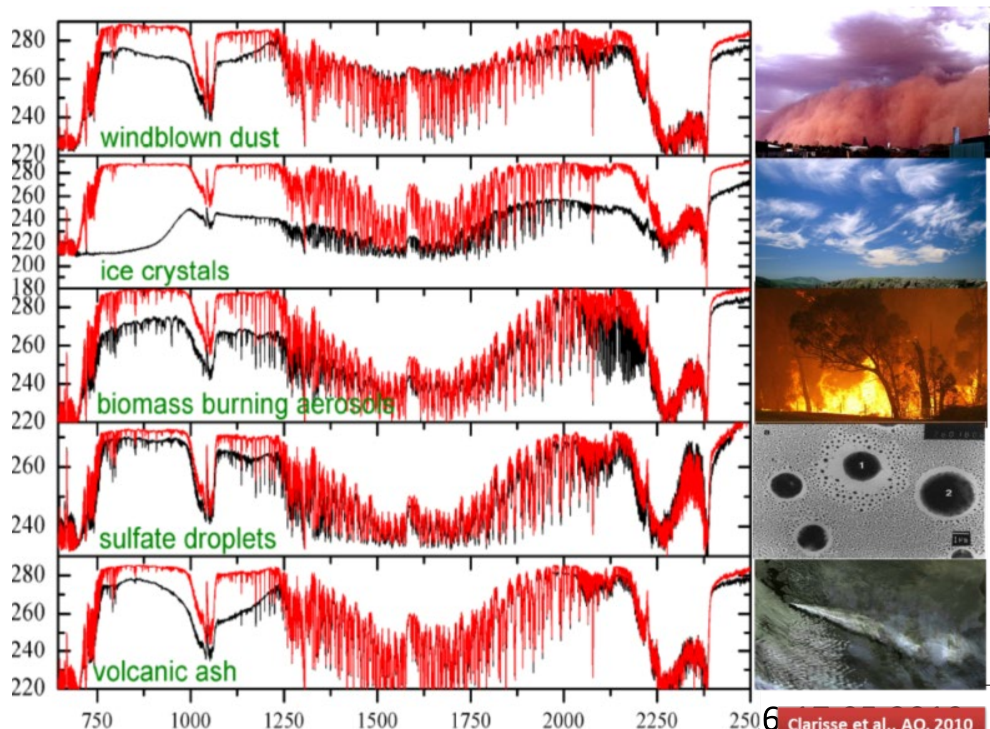
Reference L1 for IR TOA radiances and fluxes

consistent time series (L1 and L2) to support trend analysis and climate applications

## IASI success

- Large continuous spectral coverage of the TIR
- Medium spectral resolution
- Low noise
- Medium spatial resolution

> 25 species
10 species routinely monitored; other above sources or during extreme events
Aerosols ***with type differentiation*** **(coarse mode)**

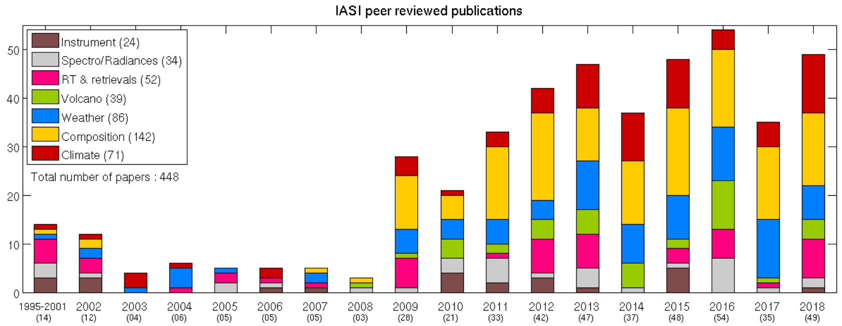



Clarisse et al., AO, 2010

# Heritage from hyperspectral IR sounders

## 7 (?) Application areas based on atmospheric composition monitoring

**IASI**



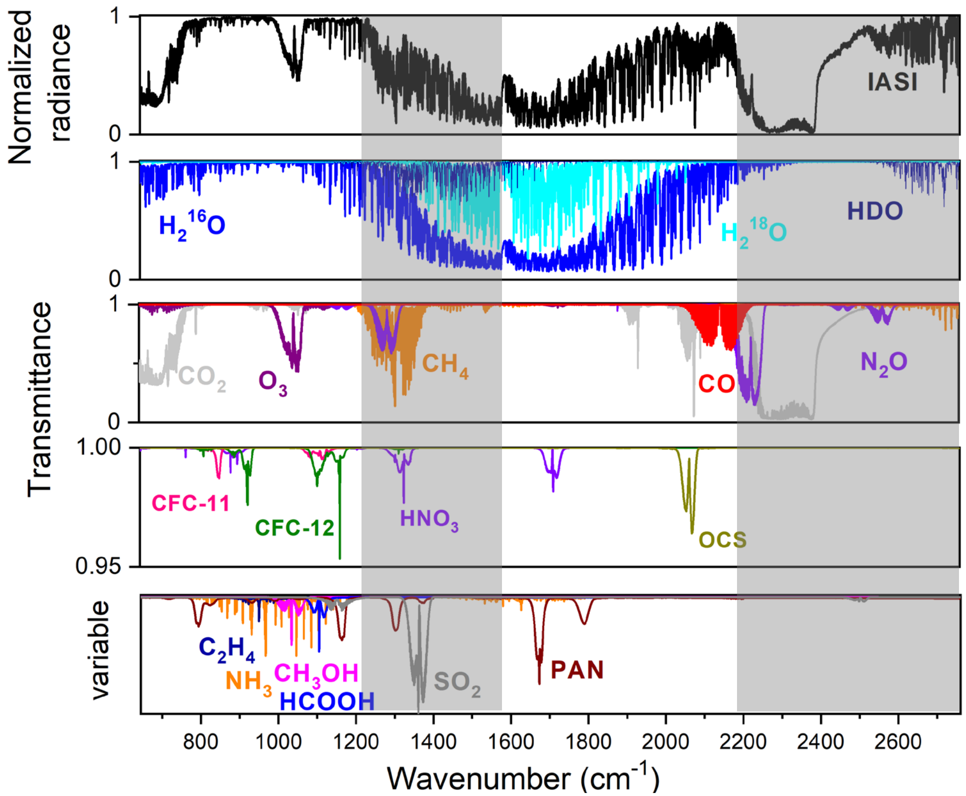

The amount of IASI publications per year is obtained by counting all rank-A published papers (impact factor > 1) where the word "IASI" appears either in the title, and/or in the abstract.

# IRS vs. IASI and IASI-NG

**IASI-NG = IASI with twice better spectral resolution and noise**
**Similar sampling**

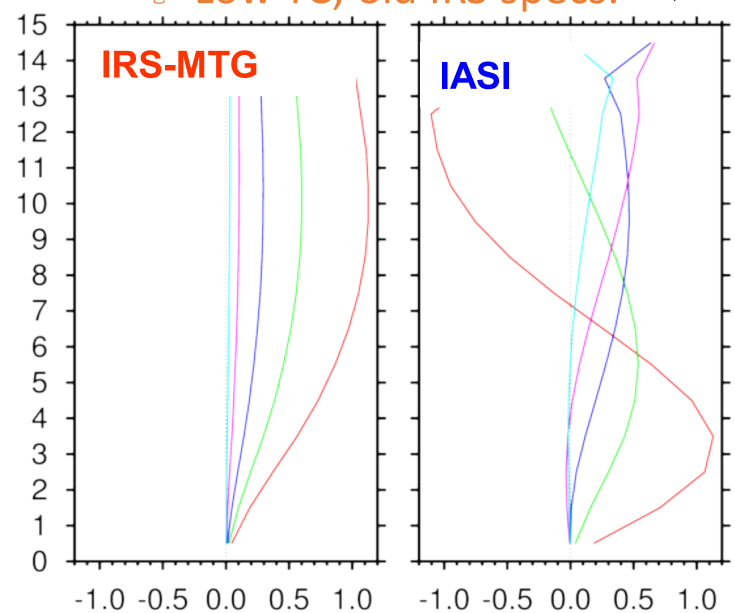
## Instrument - Key points

- narrower spectral range ⇨ will miss $CH_4$, $N_2O$, $SO_2$ $\nu_3$, HDO
- Coarser spectral resolution and larger noise (especially in MW channels)
  ⇨ reduced vertical sensitivity + surface sensitivity




CO averaging kernels

Low TC; old IRS specs.



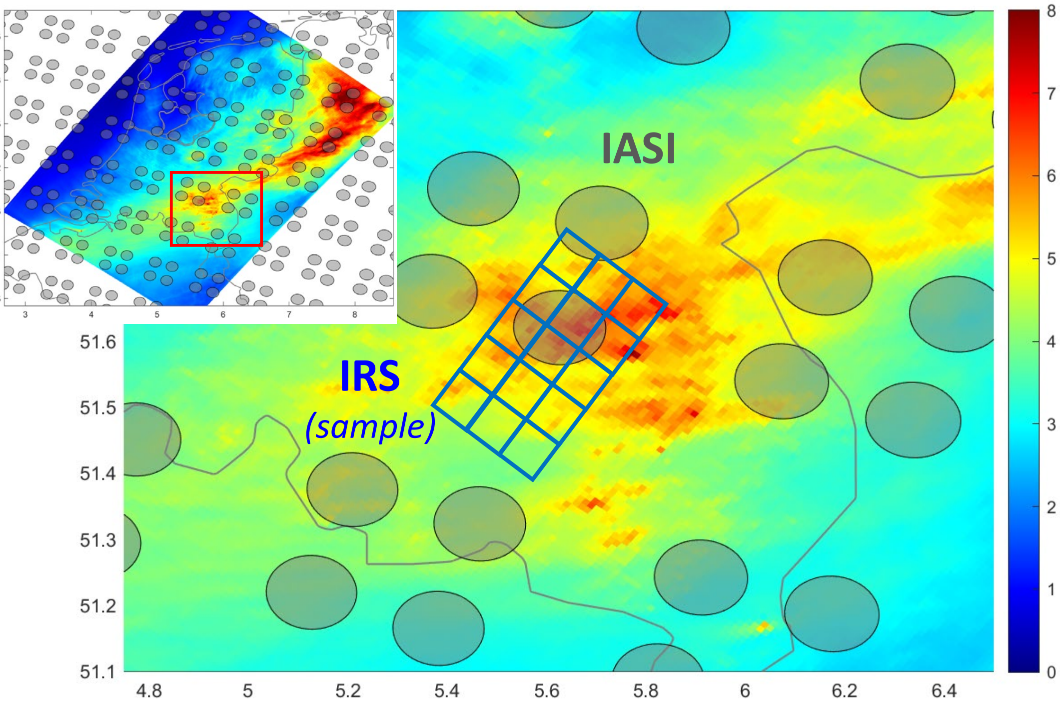
# IRS vs. IASI and IASI-NG

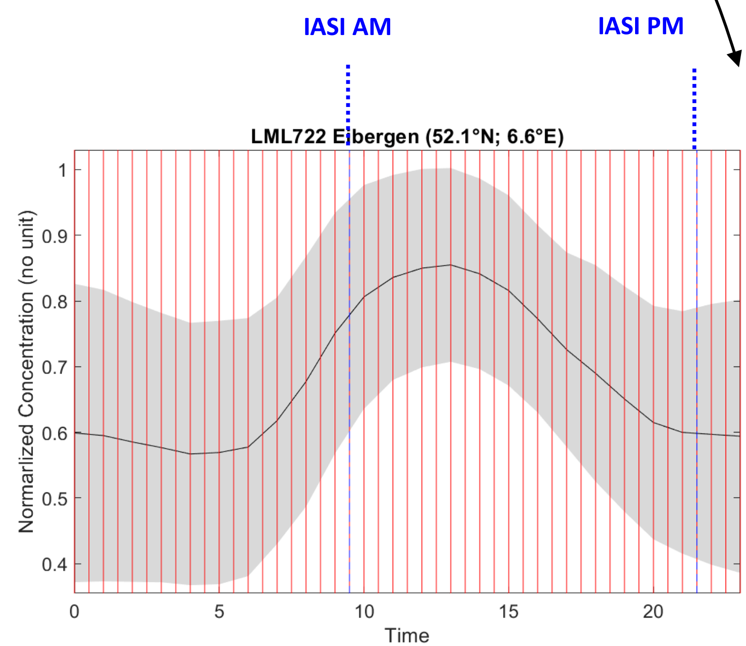
**IASI-NG = IASI with twice better spectral resolution and noise**
**Similar sampling**

## Sampling

- Continuous coverage of the Earth surface ⇨ Better mapping opportunities
- Higher spatial resolution ⇨ improved resolution of sources
- High temporal sampling ⇨ Diurnal sampling; rapidly changing chemistry

NH3 distribution –The Netherlands -1km$^2$

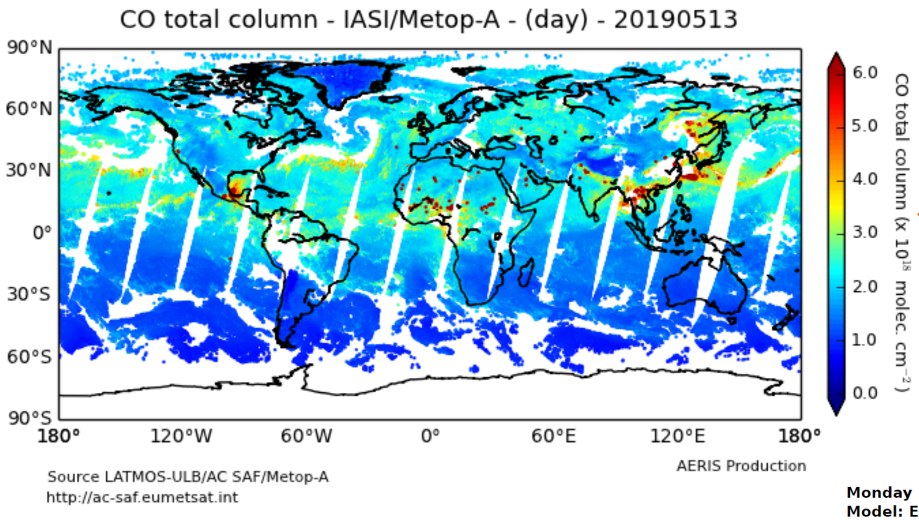


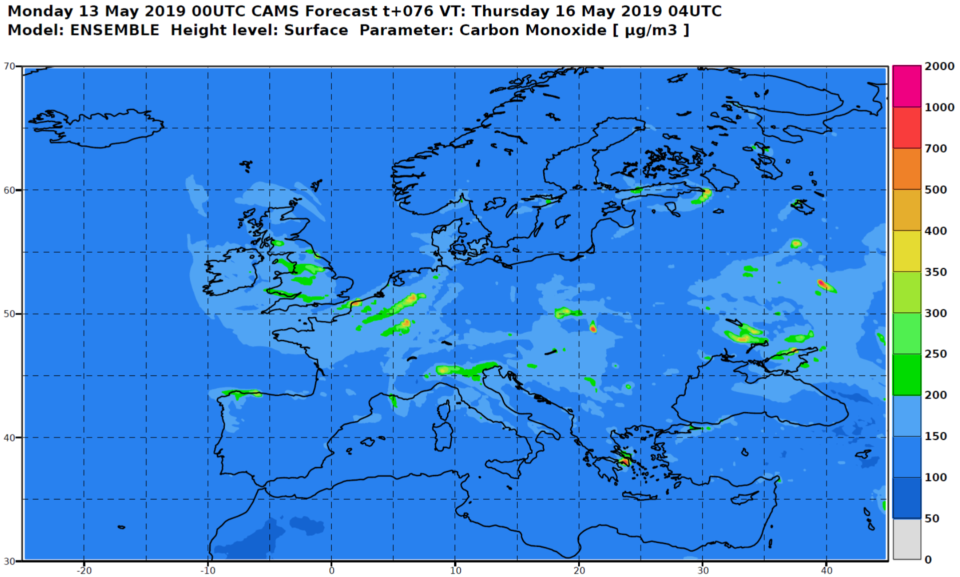
Air Quality

# **Demonstrated applications** with polar sounders (IASI)

## CO assimilation in CAMS and Air Quality forecast




**Contribution to CAMS assimilation system and AQ forecast**




**Evaluation of the MACC operational forecast system – potential and challenges of global near-real-time modelling with respect to reactive gases in the troposphere**

A. Wagner[1], A.-M. Blechschmidt[2], I. Bouarar[3,a], E.-G. Brunke[4], C. Clerbaux[3], M. Cupeiro[5], P. Cristofanelli[6], H. Eskes[7], J. Flemming[8], H. Flentje[1], M. George[3], S. Gilge[1], A. Hilboll[2], A. Inness[8], J. Kapsomenakis[9], A. Richter[2], L. Ries[10], W. Spangl[11], O. Stein[12], R. Weller[13], and C. Zerefos[9]

Air Quality

**Demonstrated applications** with polar sounders (IASI)

Improving the modelisation of spring haze episodes using $NH_3$ daily concentrations/emissions

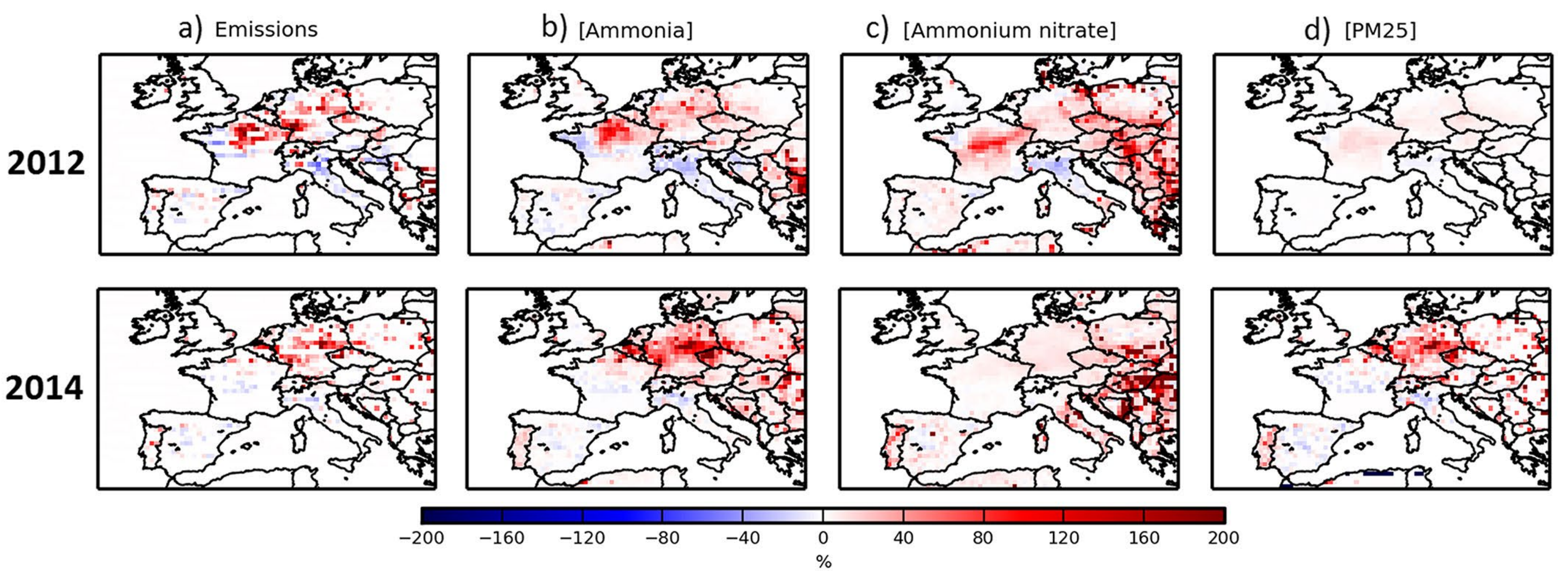
Geophysical Research Letters

Research Letter | Free Access

## Unaccounted variability in $NH_3$ agricultural sources detected by IASI contributing to European spring haze episode

A. Fortems-Cheiney, G. Dufour, L. Hamaoui-Laguel, G. Foret, G. Siour, M. Van Damme, F. Meleux, P.-F. Coheur, C. Clerbaux, L. Clarisse, O. Favez, M. Wallasch, M. Beekmann

First published: 11 May 2016 | https://doi.org/10.1002/2016GL069361 | Cited by: 5




*Differences between optimized emissions (with IASI) and EMEP, with resulting changes PM*

Air Quality

## **Demonstrated applications** with polar sounders (IASI)

### Monitoring of tropospheric, lower tropospheric ozone

Ozone pollution: What can we see from space? A case study
G. Foret, M. Eremenko, J. Cuesta, P. Sellitto, J. Barré, B. Gaubert, A. Coman, G. Dufour, X. Liu, M. Joly, C. Doche, and M. Beekmann
J. Geophys. Res., 119, 8476-8499, doi:10.1002/2013JD021340, 2014.

Atmos. Chem. Phys., 10, 3787–3801, 2010
www.atmos-chem-phys.net/10/3787/2010/

Atmospheric Chemistry and Physics

**IASI observations of seasonal and day-to-day variations of tropospheric ozone over three highly populated areas of China: Beijing, Shanghai, and Hong Kong**

G. Dufour[1], M. Eremenko[1], J. Orphal[1,2], and J.-M. Flaud[1]

Atmos. Chem. Phys., 18, 16439–16459, 2018
https://doi.org/10.5194/acp-18-16439-2018

Atmospheric Chemistry and Physics — Open Access — EGU

**Lower tropospheric ozone over the North China Plain: variability and trends revealed by IASI satellite observations for 2008–2016**

Gaëlle Dufour[1], Maxim Eremenko[1], Matthias Beekmann[1], Juan Cuesta[1], Gilles Foret[1], Audrey Fortems-Cheiney[1], Mathieu Lachâtre[1], Weili Lin[2], Yi Liu[3], Xiaobin Xu[4], and Yuli Zhang[3]

Atmos. Chem. Phys., 14, 10119–10131, 2014
www.atmos-chem-phys.net/14/10119/2014/
doi:10.5194/acp-14-10119-2014

Atmospheric Chemistry and Physics — Open Access

**Summertime tropospheric ozone assessment over the Mediterranean region using the thermal infrared IASI/MetOp sounder and the WRF-Chem model**

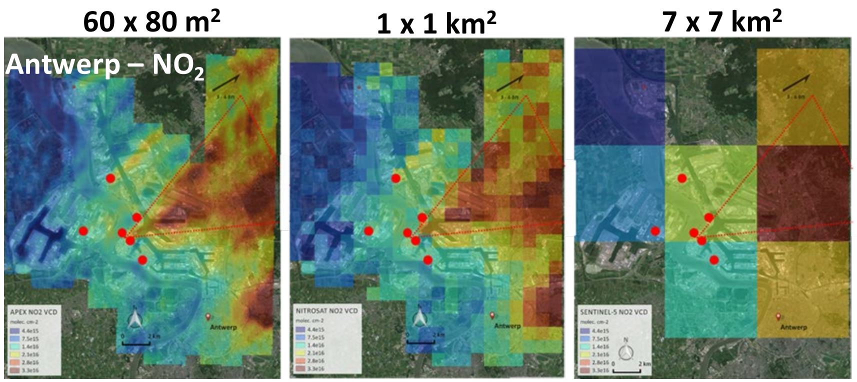
S. Safieddine[1], A. Boynard[1], P.-F. Coheur[2], D. Hurtmans[2], G. Pfister[3], B. Quennehen[1], J. L. Thomas[1], J.-C. Raut[1], K. S. Law[1], Z. Klimont[4], J. Hadji-Lazaro[1], M. George[1], and C. Clerbaux[1,2]

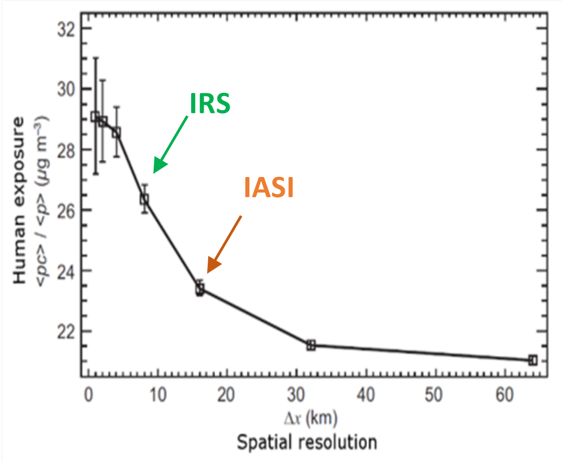
……

Air Quality

# Limitations with polar sounders (IASI)

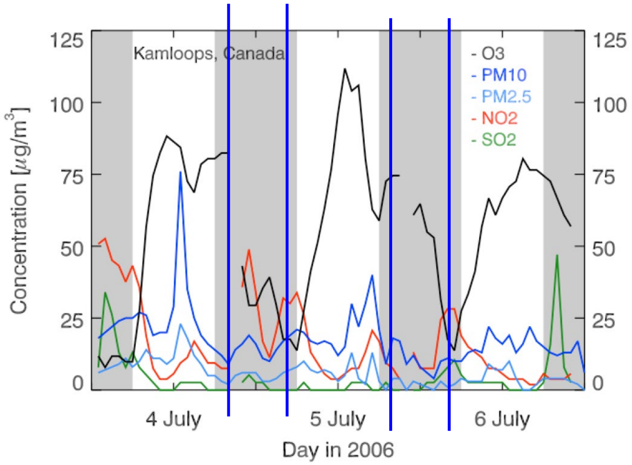
**Spatial resolution**: separating sources at city scale and improve exposure assessment



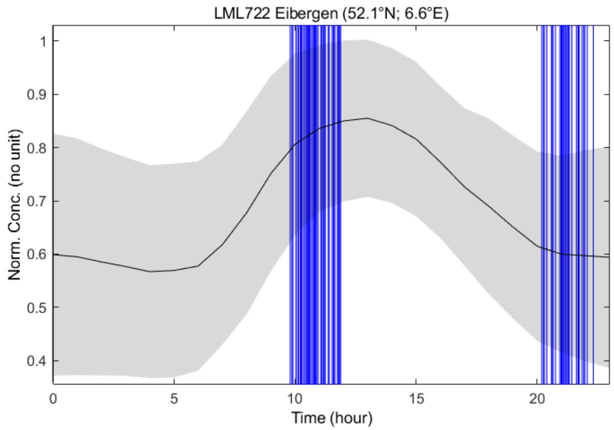




**Diurnal sampling**

Urban pollution




Agricultural pollution



Air Quality

## Opportunities for IRS-MTG

Time resolved measurements of **CO**, **$O_3$**, tropospheric/total columns, **$NH_3$** columns at better spatial resolution over the Europe-Africa disc

*but:*

- Over polar sounders IRS will have reduced vertical sensitivity in the troposphere for $O_3$ and CO
- Varying sensitivity to boundary layer as function of thermal contrast
- Anthropogenic $SO_2$ is unlikely to be measured (no coverage of $\nu_3$ band) spectral range

**Questions**

- Will IRS allow resolving the diurnal cycle of pollution / emission?
- Is the reduced vertical sensitivity compromising AQ applications?
- Will operational assimilation system benefit from the diurnal measurements

**Likely answer**

⇨ Major benefit for $NH_3$ and aerosols (probably short lived VOCs)

⇨ Added value for CO and $O_3$ ?

*To be confirmed by new studies?*

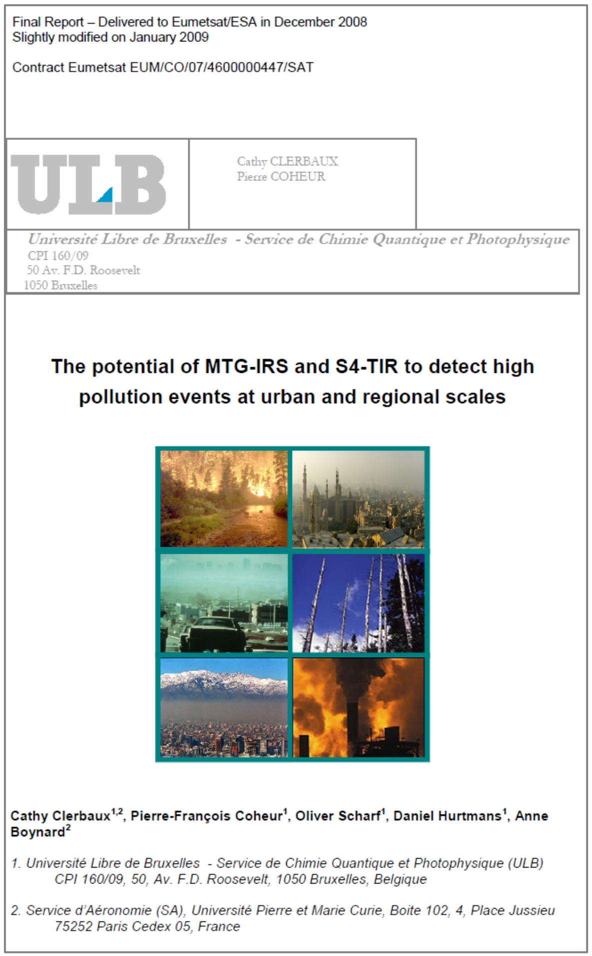
Air Quality

# Opportunities for IRS-MTG

⇨ Small added value for $O_3$?

See previous studies conducted for MTG **(but old instrument specs; $NH_3$ not tested)**

**Need for new assesment?**


Final Report – Delivered to Eumetsat/ESA in December 2008
Slightly modified on January 2009

Contract Eumetsat EUM/CO/07/4600000447/SAT

ULB

Cathy CLERBAUX
Pierre COHEUR

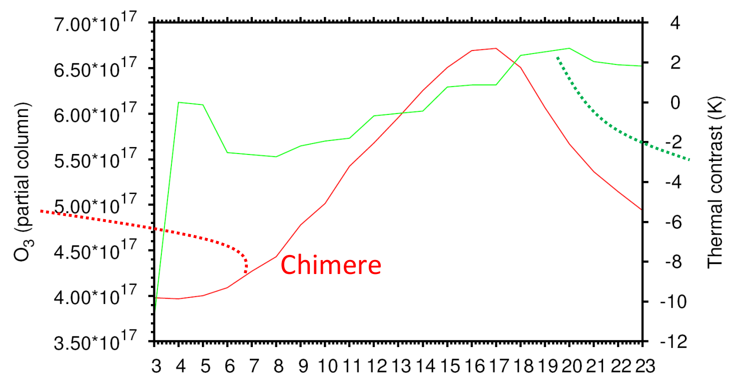
*Université Libre de Bruxelles - Service de Chimie Quantique et Photophysique*
CPI 160/09
50 Av. F.D. Roosevelt
1050 Bruxelles

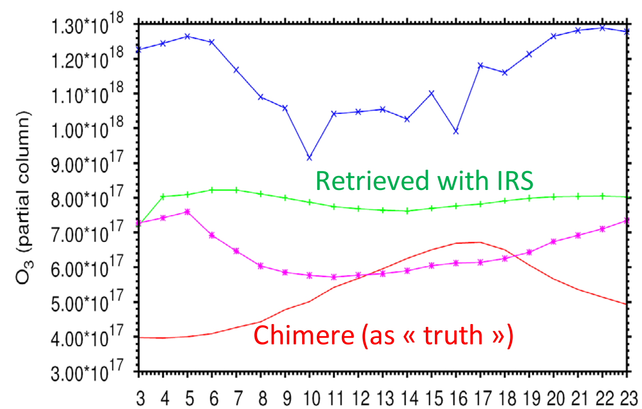
**The potential of MTG-IRS and S4-TIR to detect high pollution events at urban and regional scales**

**Cathy Clerbaux[1,2], Pierre-François Coheur[1], Oliver Scharf[1], Daniel Hurtmans[1], Anne Boynard[2]**

*1. Université Libre de Bruxelles - Service de Chimie Quantique et Photophysique (ULB) CPI 160/09, 50, Av. F.D. Roosevelt, 1050 Bruxelles, Belgique*

*2. Service d'Aéronomie (SA), Université Pierre et Marie Curie, Boite 102, 4, Place Jussieu 75252 Paris Cedex 05, France*



**Point Sources**

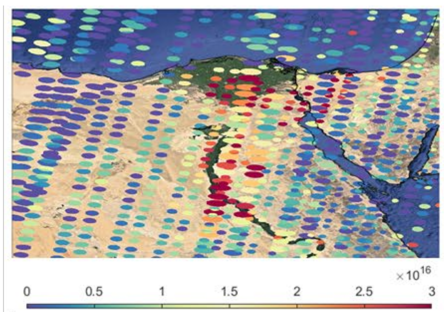
## **Demonstrated applications** with polar sounders (IASI)

- **Achieved only for reactive species** (showing considerable concentration gradients)
- **After exploiting large** (at least yearly) **datasets**

The example of $NH_3$

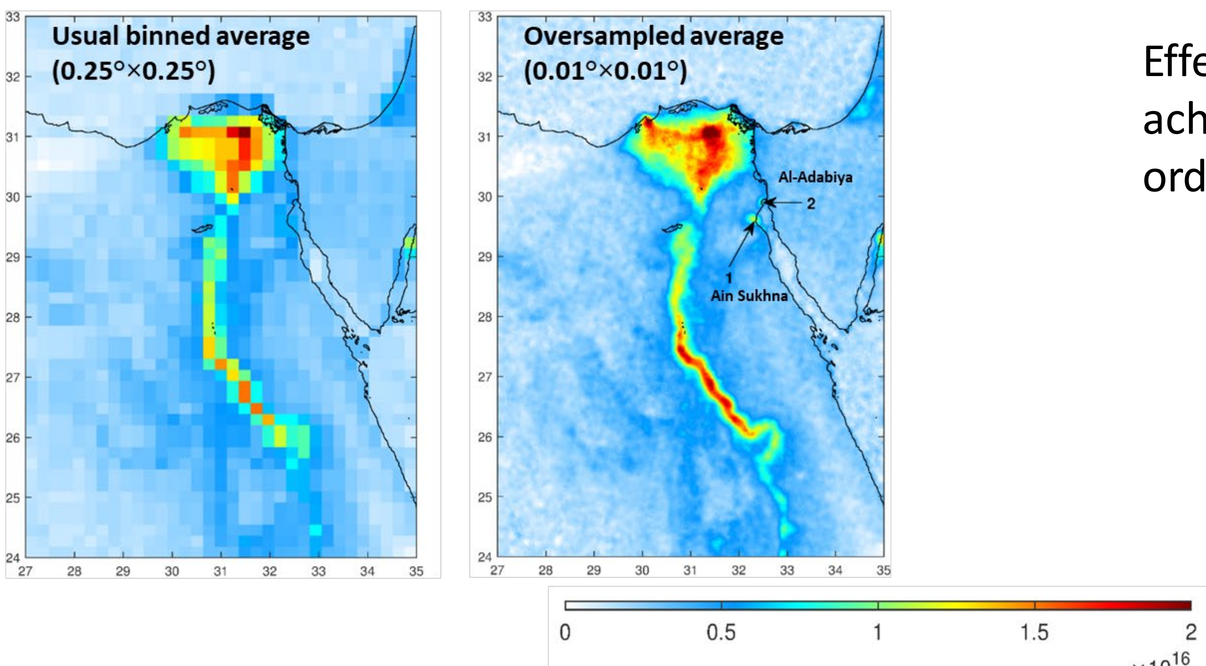
*oversampling (supersampling) on 10 years of IASI data*

**2 days**




The elliptical footprints of IASI are averaged on a **0.01°x0.01°** high-resolution grid and weighted by the inverse of their footprint area

**10 years**




Effective resolution achieved is of the order of 1 km

**Point Sources**

**Demonstrated applications** with polar sounders (IASI)

- **Achieved only for reactive species** (showing considerable concentration gradients)
- **After exploiting large** (at least yearly) **datasets**

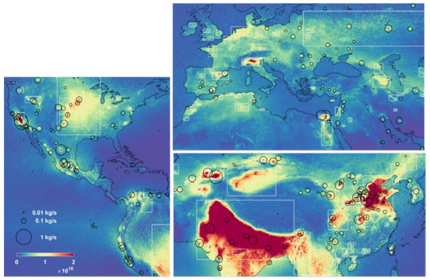
The example of $NH_3$


LETTER

https://doi.org/10.1038/s41586-018-0747-1

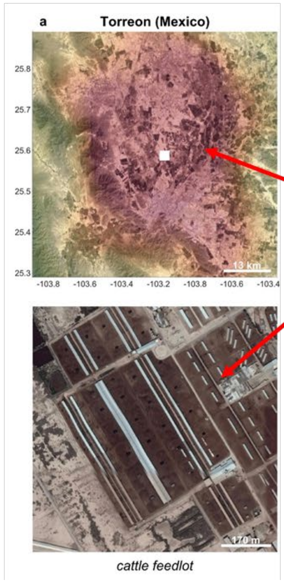
Industrial and agricultural ammonia point sources exposed

Martin Van Damme[1,3*], Lieven Clarisse[1,3*], Simon Whitburn[1], Juliette Hadji-Lazaro[2], Daniel Hurtmans[1], Cathy Clerbaux[1,2] & Pierre-François Coheur[1]

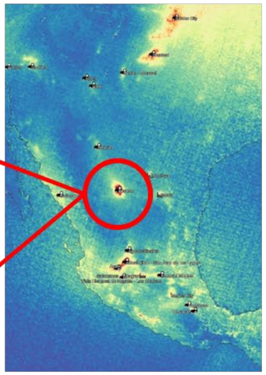


⇨ **Agricultural** point sources

⇨ *CAFOs*



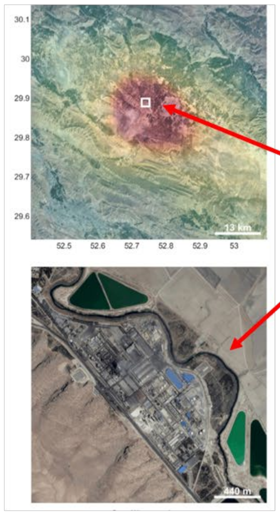
cattle feedlot

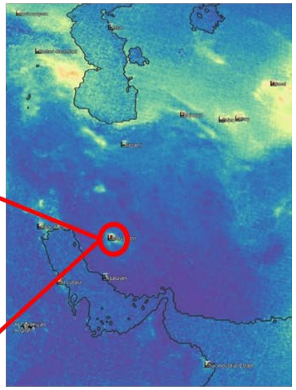


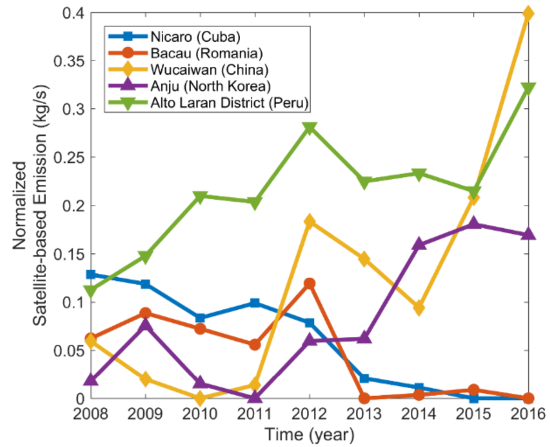
⇨ **Industrial** point sources

⇨ *Fertilizer plants*

**Marvdasht –Iran–**



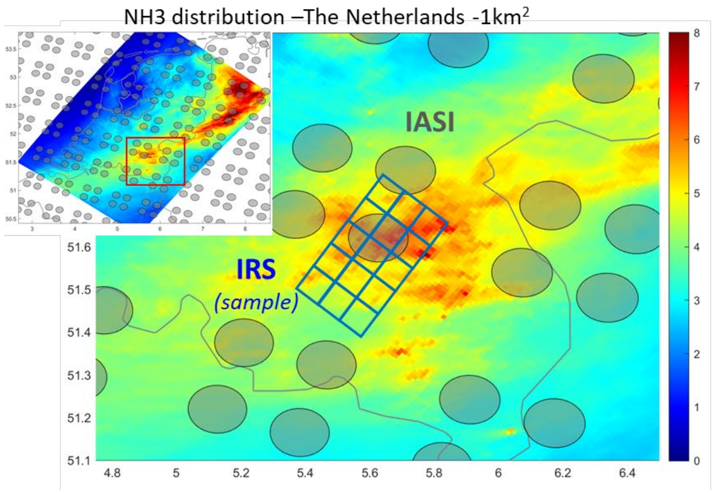


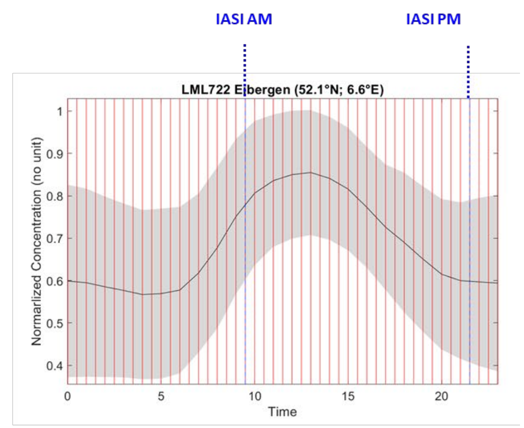


Point Sources

# Opportunities for IRS-MTG

## Mapping at higher spatial resolution and high sampling




**Questions**

- Will the spatial resolution be sufficient to resolve large point sources?
- Will oversampling/supersampling approaches be possible?
- **Will it be possible to monitor point sources for longer-lived species ($CO_2$? Others?)**

⇨ ??????

*Need for studies?*

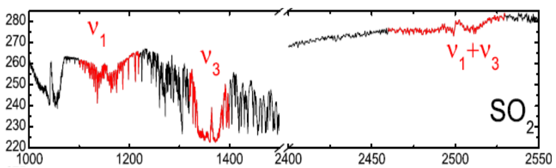
# Atmospheric composition – Applications / Opportunities for IRS

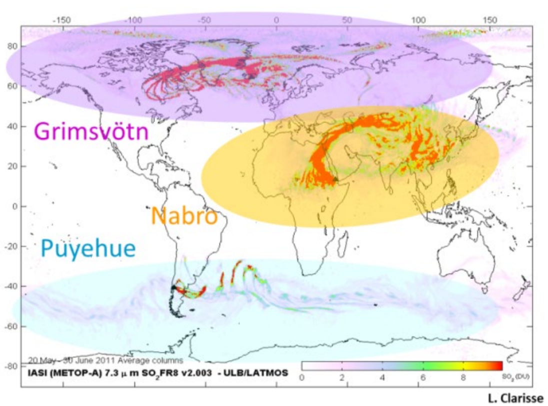
Events

**Demonstrated applications** with polar sounders (IASI)

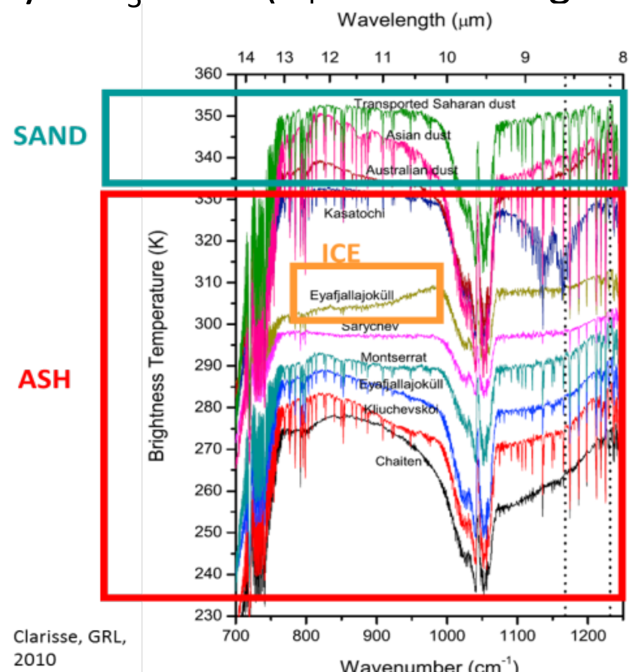
## Volcanoes

Uses signature from $\mathbf{SO_2}$, mainly in $\nu_3$ band ($\nu_1$ seen for large eruptions)or volcanic **ash**

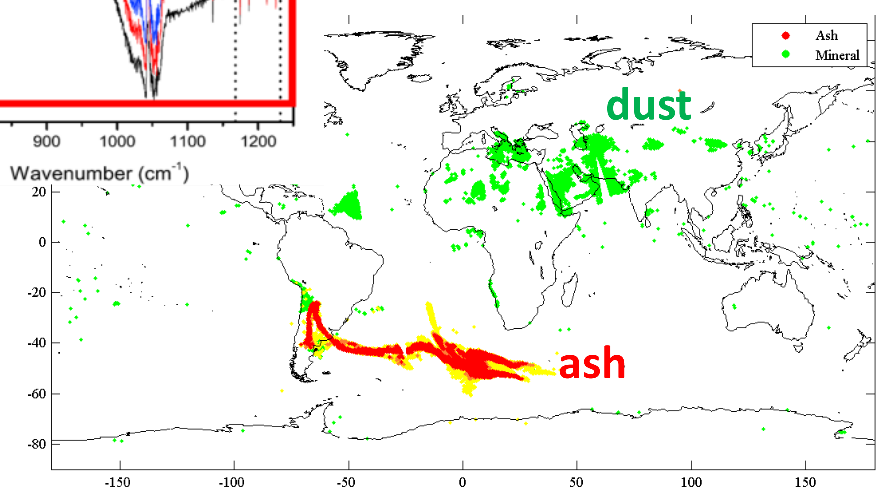



+ plume altitude at ~ vertical 1 km resolution




Clarisse, GRL, 2010



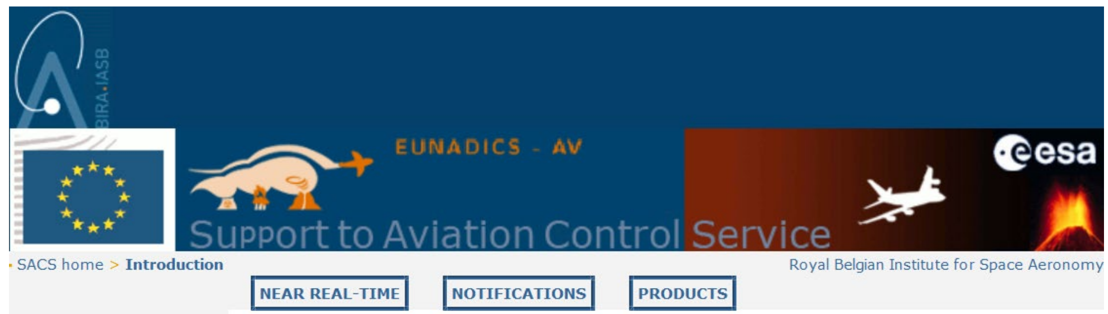
Events

**Demonstrated applications** with polar sounders (IASI)

## Volcanoes

Uses signature from **$SO_2$**, mainly in $\nu_3$ band ($\nu_1$ seen for large eruptions) or volcanic **ash**

**« Operational » in the SACS alert system** (SACS= Support to Aviation Control Services)




http://cpm-ws4.ulb.ac.be/Alerts/

http://sacs.aeronomie.be/

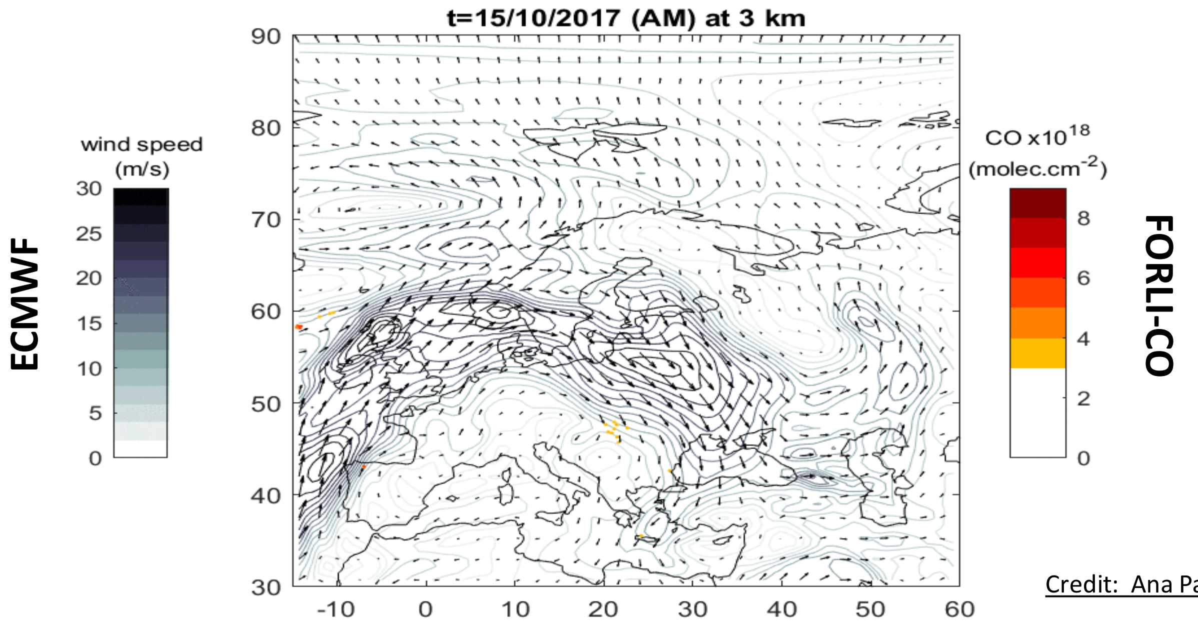
Large user base; main users being the VAACs (Volcanic Ash Advisory Centers)

Events

**Demonstrated applications** with polar sounders (IASI)

## Fires

Mainly from the monitoring of **CO, $NH_3$**, $C_2H_4$....




Credit: Ana Parracho (LATMOS)

interests:

- **Emissions (and emission factors from various regions)**
- **Transport**
- **Interannual variabiltiy and the relation to climate (El Nino…)**
- **Plume Chemistry**
- **….**

Events

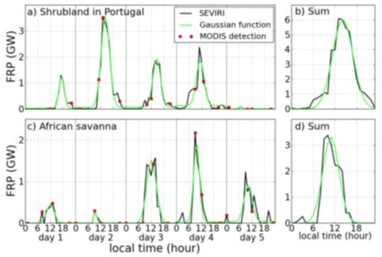
# Opportunities for IRS-MTG

## Volcanoes

- $SO_2$ $\nu_3$ band will not be accessible; alerts based on $SO_2$ will be possible using signal in $\nu_1$, likely only for large eruptions
- Ash alerts will be possible and benefit from the improved spatial/temporal sampling

## Fires

- CO, $NH_3$ and VOCs at higher resolution with diurnal sampling




### Questions

- Will IRS contribute to identifying/monitoring extreme events?
- Are there new operational applications to develop?
- Technical: Will these applications not be impacted by the use of PCAs

⇨ important contribution expected, (*despite for volcanoes the main $SO_2$ band will not be accessible*).

⇨ development of a fire alert/monitoring system could/should be foreseen

⇨ Other « alert » applications likely

Global tropos.

**Demonstrated applications** with polar sounders (IASI)

Mainly using averaged (monthly seasonally, yearly) global distributions of chemistry species (**CO**, **$O_3$**, several **VOCs**) and the combination with chemistry-transport models

⇨ Control on tropospheric budgets and their related processes (emissions, deposition, chemistry; LRTAP)

⇨ Inter-annual variability and trends

Example with IASI

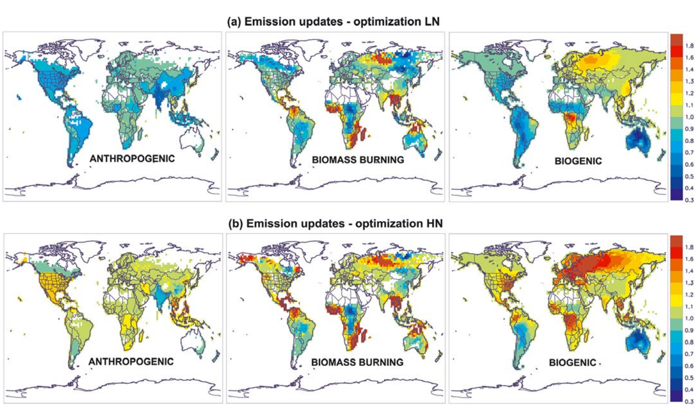
**CO**

Geophysical Research Letters

Research Letter | Open Access

Top-Down CO Emissions Based On IASI Observations and Hemispheric Constraints on OH Levels

J.-F. Müller, T. Stavrakou, M. Bauwens, M. George, D. Hurtmans, P.-F. Coheur, C. Clerbaux, C. Sweeney




**O3**

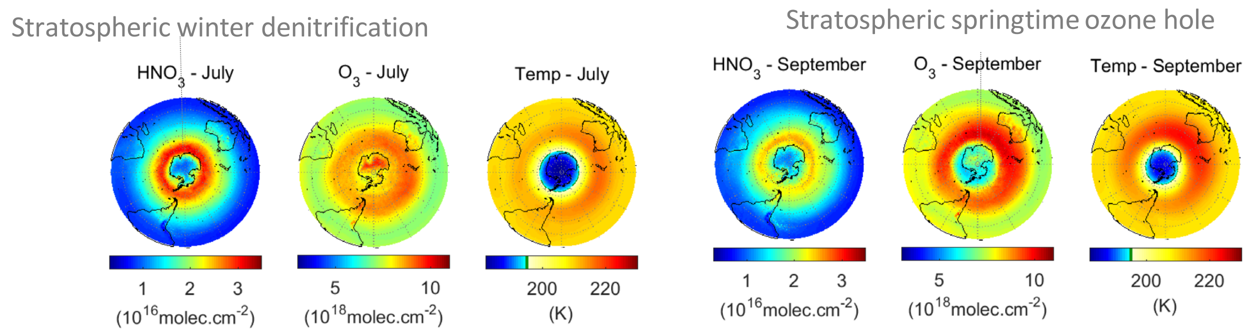
TOAR
tropospheric ozone assessment report

**Global stratos.**

## **Demonstrated applications** with polar sounders (IASI)

supported with global measurements of stratospheric or total columns of **$O_3$** and **$HNO_3$** during day and night, including at high polar latitudes.

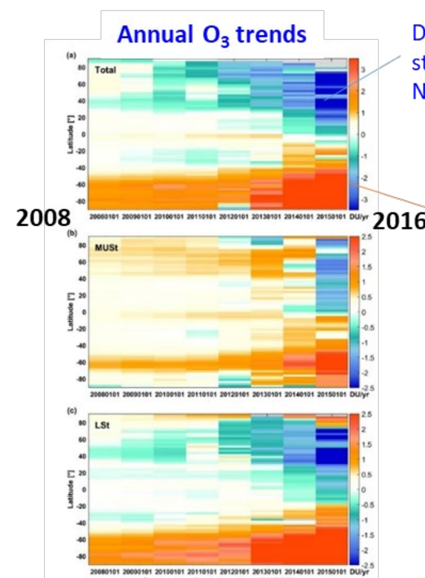
⇨ *Control on stratospheric processes*




- Time evolution over several years contributes to the determination of trends

  ⇨ *control of the Montreal protocol*

Significant speeding up in stratospheric $O_3$ recovery in the S.H. *vs* an accelerated decline in the N.H.
*Catherine Wespes, submitted*




Decreasing stratospheric O3 in NH –speeding up-

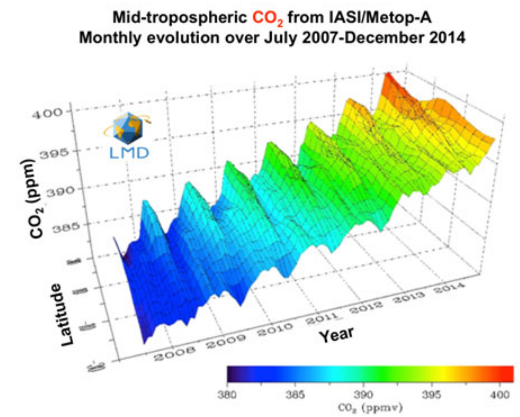
Increasing stratospheric $O_3$ in SH –speeding up-

**Climate**

**Demonstrated applications** with polar sounders (IASI)

As far as atmospheric composition is concerned climate applications relate to the distributions and time evolutions (monthly, yearly)

- of long-lived greenhouse gases **$CO_2$, $CH_4$, $N_2O$** in the form of a column or column-averaged mixing ratio
- Of shorter-lived direct climate forcers **$O_3$, aerosols**
- Of indirect climate forcers, **CO, $NH_3$**




**Contribution to ESA CCI and EU C3S**

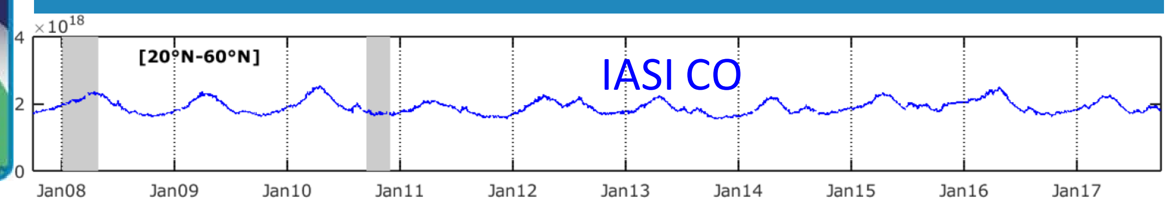
aerosol cci

ozone cci

ghg cci

QA4ECV

Quality Assurance for Essential Climate Variables



## Opportunities for IRS-MTG

**Global stratos.**

**Global tropos.**

The relevant species (**$O_3$, CO, $HNO_3$, VOCs**) for monitoring the global troposphere and stratosphere will be accessible with IRS. However,

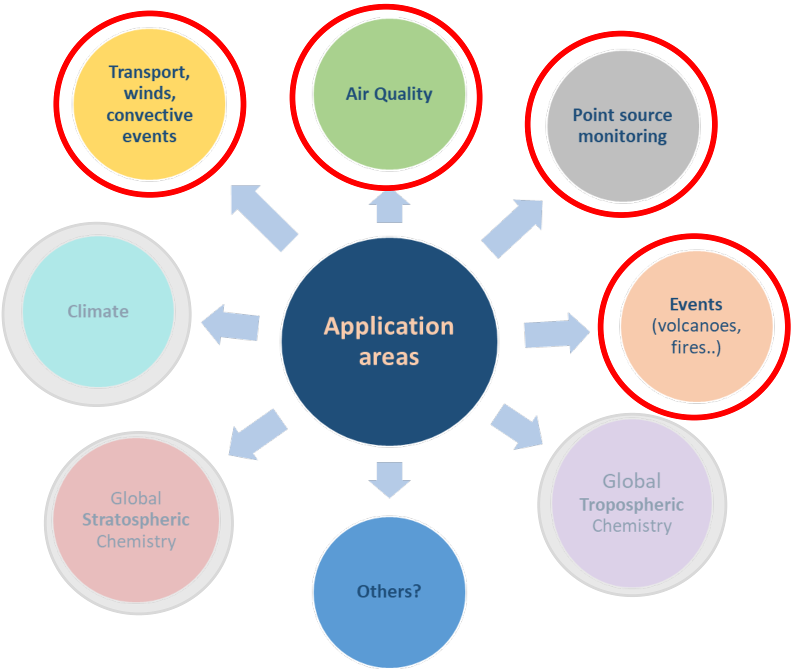
- With less vertical sensitivity
- On temporal/spatial scales that are smaller than the processes currently looked at (most applications use averages, in time and space)

**Climate**

Among the main long-lived greenhouse gases, only $CO_2$ will be measurable (not $CH_4$ and $N_2O$). Several short-lived or indirect climate forcers will be accessible but –as above- with less vertical sensitivity and accuracy.

| Questions | Likely answer |
| --- | --- |
| - Is there an added value of IRS for these applications, which imply processes on larger scales? | ⇨ ? |

## Summary

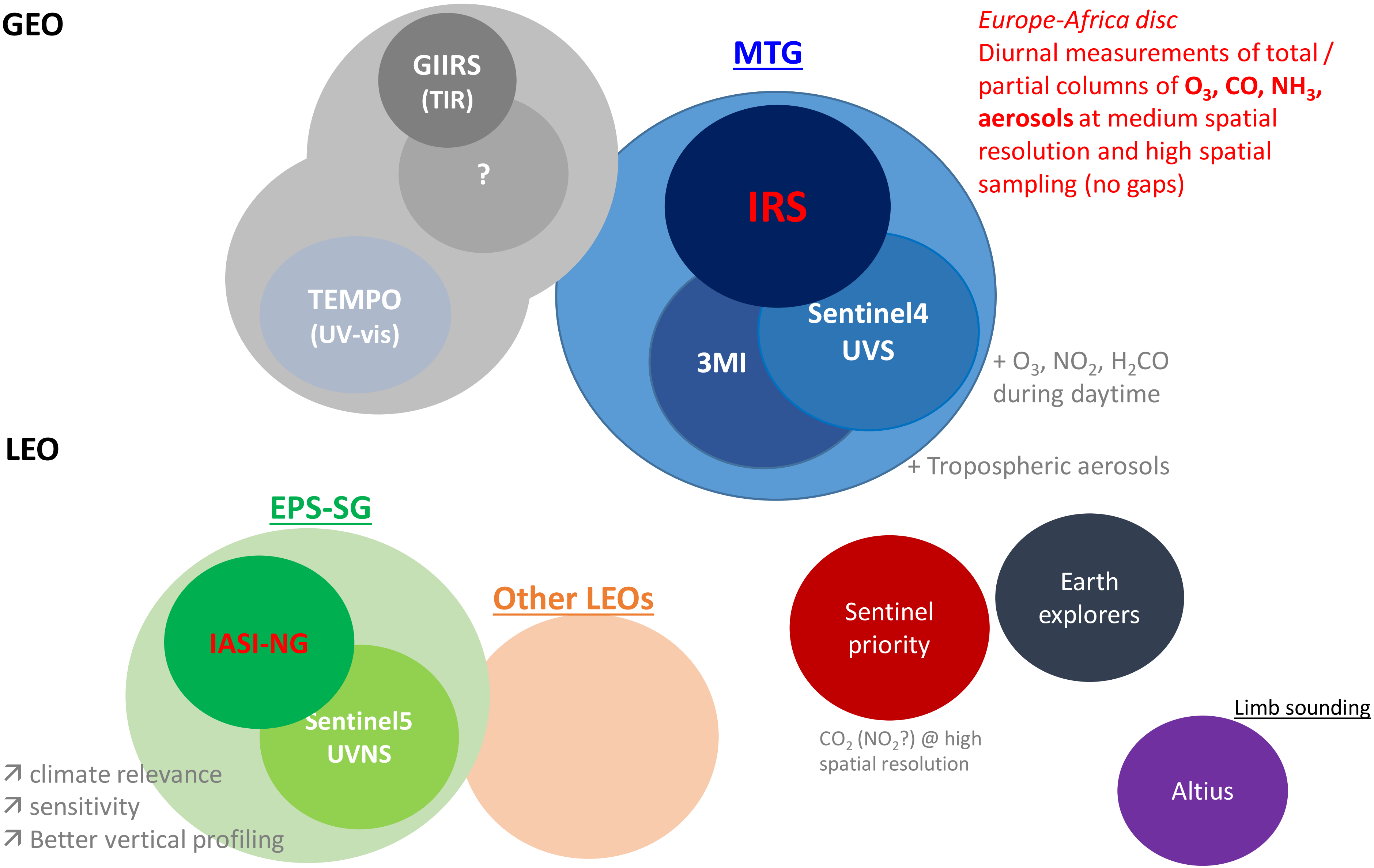



- Very substantial contribution expected from IRS to the applications implying processes that vary rapidly in time /space (benefiting from the IRS resolution and sampling)
  - **Air quality**
  - **Event monitoring**
  - **Point sources**
  - **Transport**
- Added value probably less for global tropospheric and stratospheric chemistry and for climate (because slow varying processes and reduced measurement performances from IRS) but to be explored

## Issues deserving attention and/or detailed studies

- Possibility with IRS to infer the diurnal cycle of pollution for $O_3$, CO, $NH_3$, dust (need to revise / extend the conclusions from the earlier IRS studies?)?
- Capability of IRS to detect point sources, for short-lived maybe also for long-lived species ($CO_2$? Others?). Will oversampling approaches be possible?
- Added value of IRS for large scale processes (global tropospheric, stratospheric chemistry, climate)
- Possibility to develop new alert/monitoring systems for large events (fires, dust, volcanoes…)
- Benefit for synergies (IR/UV; LEO/GEO IASI-NG and IRS; Nadir/limb)
- Can existing algorithms be used without substantial changes (off-angles; PCs)
- What is the impact of PCAs on applications; especially event monitoring

# Opportunities for synergies



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Point Sources

**Demonstrated applications** with polar sounders (IASI)

- **Achieved only for reactive species** (showing considerable concentration gradients)
- **After exploiting large** (at least yearly) **datasets**

The example of $NH_3$

*oversampling (supersampling) on 10 years of IASI data*

⇨ **Agricultural** point sources

# Priorities for product development

## In discussion for AC SAF CDOP4

Algorithm development for priority AC products

Priority products for IRS-MTG ?

would be in terms of:

- Support to environmental surveillance at local/regional scale
- Complementarity with IASI-NG

**IASI and IASI-NG**
**AC-SAF product portfolio**

- $O_3$ profiles
- CO profiles
- $HNO_3$ profiles
- $SO_2$ columns
- $SO_2$ plume altitude
- $NH_3$ total columns
- Dust Optical depth
- Ash Optical depth

Main $SO_2$ band is not in IRS range. A $SO_2$ flag in case of large eruption would be useful

## priorities for IRS?

- Large spatial and temporal variability
- Importance for AQ and event monitoring (volcanoes, dust events, fires…)

**Large positive impact expected from IRS**

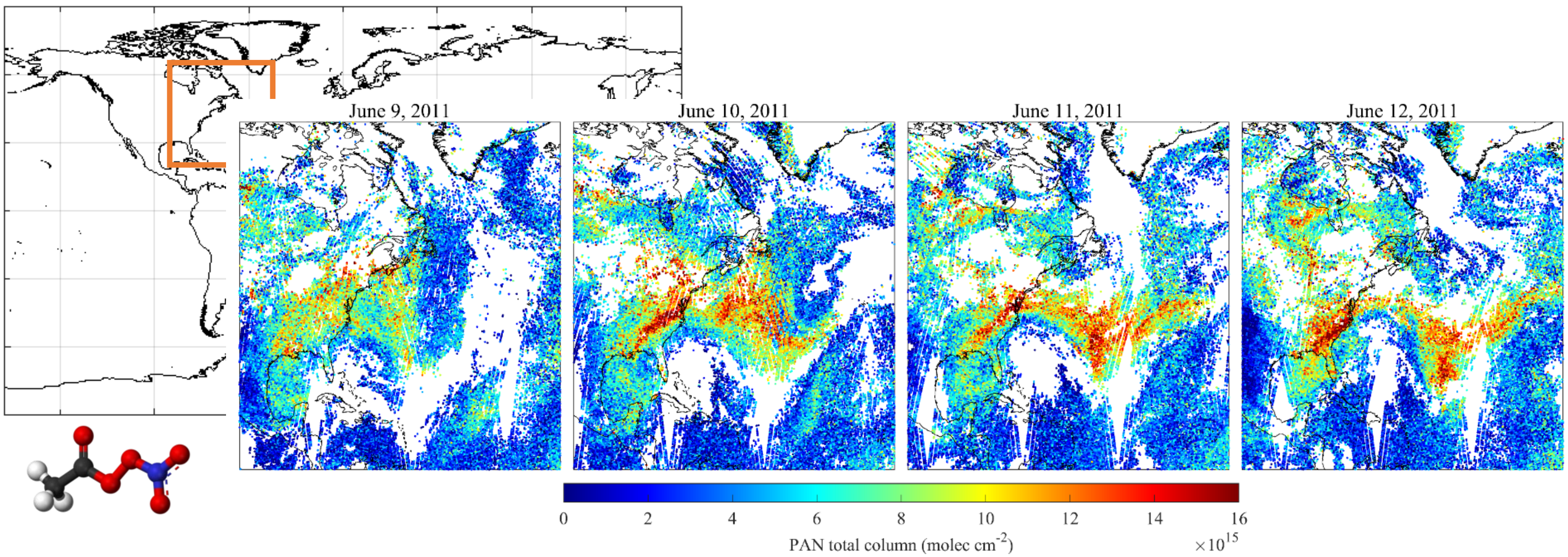
LRTAP
Winds..

**Demonstrated applications** with polar sounders (IASI)

Pollution outflow and long-range transport of pollution can be monitored using *daily* distributions of species with lifetime of several days/weeks; typically **CO, $O_3$, $C_2H_2$, PAN**.

**Examples with IASI**

daily distributions of PAN ($CH_3COONO_2$)




**Transboundary ozone pollution across East Asia: daily evolution and photochemical production analysed by IASI + GOME2 multispectral satellite observations and models**

Juan Cuesta[1], Yugo Kanaya[2], Masayuki Takigawa[2], Gaëlle Dufour[1], Maxim Eremenko[1], Gilles Foret[1], Kazuyuki Miyazaki[2], and Matthias Beekmann[1]