MONITORING AIR POLLUTION AT GLOBAL SCALE USING IASI THERMAL INFRARED INSTRUMENT

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Introduction

Monitoring air quality using TIR observations

**Difficulty:** Sensitivity limited by the thermal contrast

\[ TC = T_{skin} - T_{air} \]

Typical vertical sensitivity function for a TIR nadir sounder (Averaging kernels AK)

- Maximum sensitivity of TIR sounders in the mid troposphere
Introduction

Monitoring air quality using TIR observations

How deep can we see?

Three general cases:

1. $T_{\text{skin}}^{\text{eff}} = T_1 \rightarrow$ we’re blind
2. $T_{\text{skin}}^{\text{eff}} > T_1 \rightarrow$ absorption from the first layer (usual case during day time)
3. $T_{\text{skin}}^{\text{eff}} < T_1 \rightarrow$ emission from the first layer (temperature inversion)
Introduction

Monitoring air quality using TIR observations

How deep can we see?

\[ L^\uparrow = \left[ B_\nu \left(1, T_{\text{skin}}^{\text{eff}}\right) - B_\nu \left(T_{\text{air}}\right) \right] t + B_\nu \left(T_{\text{air}}\right) \]

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The larger the thermal contrast, the better the sensitivity of TIR sounders to ABL
Recent studies have demonstrated the capabilities of TIR sounders to monitor near-surface pollution from local to global scales in favorable conditions.
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Use of IASI observations

- **NH₃**  
- **SO₂**  
- **CO**  

- Spectral range: 645-2760 cm⁻¹
- Spectral resolution after apodization: 0.5 cm⁻¹
- Radiometric noise: ~0.1K – 0.2K

- Conversion of radiance indexes into columns using LUT
- NRT OE using LUT for spectroscopy (FORLI)

- 12 km pixel x 4 @ nadir
- 120 spectra along the swath (±48.3° Scan → 2400 km), each 50 km along the trace
- Small ground pixel size

Global coverage twice daily (morning and evening orbits)
**NH₃ global product**

Developed at the ULB by M. Van Damme¹

- **Method** based on Walker et al. (2011, AMT)
- **Idea**: computation of radiance indexes (HRI), which represent the strength of NH₃ spectral signal, and conversion into NH₃ total column using LUT
- **Results**: 7 years of NH₃ measurements, global distributions, temporal evolution in the NH and SH, validation², comparison with models³,…

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¹Van Damme et al. (2014, ACP)
²Van Damme et al. (2015, AMT)
³Van Damme et al. (2014, JGR)
1. In Norilsk\(^1\)

- Retrieval of very low altitude SO\(_2\) plumes
- High sensitivity in winter (high negative TC, low H\(_2\)O)

\(^1\)Bauduin et al. (JGR, 2014)
SO$_2$ near-surface local studies

1. In Norilsk$^1$
   - Retrieval of very low altitude SO$_2$ plumes
   - High sensitivity in winter (high negative TC, low H$_2$O)

2. In the North China Plain$^2$
   - Simultaneous retrievals of 4 different pollutants (CO, SO$_2$, NH$_3$, (NH$_4$)$_2$SO$_4$)
   - Buildup of pollutants + large temperature inversions

$^1$Bauduin et al. (JGR, 2014)  
$^2$Boynard et al. (GRL, 2014)
**SO$_2$ near-surface local studies**

**BUT**
- Two studies limited to local sources
- Limited to negative thermal contrast

→ Positive thermal contrast can also be exploited

→ Development of global product allowing the retrieval of near-surface SO$_2$ columns from IASI observations
SO$_2$ near-surface global product

- Method based on the one developed by Walker et al. (AMT, 2011)
- **Idea**: calculation of a radiance index (HRI), which represents the strength of the SO$_2$ signal in IASI measurements, and conversion of this index into SO$_2$ concentrations
- **Problem**: one index per spectrum $\rightarrow$ integrated over the whole atmosphere $\rightarrow$ no vertical information!
- **Solution**: determination of the altitude of the plume
SO$_2$ near-surface global product

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**Procedure in 2 steps:**

1. Determination of the altitude of the plumes
   - Method developed by Clarisse et al. (2014, ACP) for the eruption of Nabro
   - Based on the computation of radiance indexes

$\rightarrow$ Selection of plumes below 4 km of height
SO\textsubscript{2} near-surface global product

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**Procedure in 2 steps:**

1) Determination of the altitude of the plumes
   - Method developed by Clarisse et al. (2014, ACP) for the eruption of Nabro
   - Based on the computation of radiance indexes
   - Selection of plumes below 4 km of height

2) Retrieval of near-surface SO\textsubscript{2} column
   - Calculation of HRI and conversion into SO\textsubscript{2} columns using LUT
   - Thermal contrast, H\textsubscript{2}O total column and the zenithal angle are taken into account
   - One LUT per bin of 5° of zenithal angle
SO$_2$ near-surface global product

Example of LUT for the bin 0-5° of zenithal angle, total column of H$_2$O=$2 \times 10^{20}$ molec/cm$^2$. 
SO$_2$ near-surface global product

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SO$_2$ near-surface global product

Example of LUT for the bin 0-5° of zenithal angle, total column of H$_2$O=$2 \times 10^{20}$ molec/cm$^2$
SO₂ near-surface global product

Example of LUT for the bin 0-5° of zenithal angle, total column of H₂O = 2 × 10²⁰ molec/cm²

- If $SO₂ = f(TC, H₂O, HRI)$, the associated error is estimated using:

$$
\sigma_{SO₂} = \sqrt{\sigma_{TC}^2 \left( \frac{\partial f}{\partial TC} \right)^2 + \sigma_{H₂O}^2 \left( \frac{\partial f}{\partial H₂O} \right)^2 + \sigma_{HRI}^2 \left( \frac{\partial f}{\partial HRI} \right)^2}
$$

Avec $\sigma_{TC} = \sqrt{2} \times 1K$, $\sigma_{H₂O} = 10\%Col_{H₂O}$, $\sigma_{HRI} = 1$
**SO$_2$ near-surface global product**

1) Global distributions (2008-2014)

- **2009**
- **2010**
- **2011**
- **2012**
- **2013**
- **2014**
1) Global distributions
2008-2014 AM

Plumes below 4km of height

SO$_2$ near-surface global product
SO$_2$ near-surface global product

1) Global distributions

2008-2014 AM

Plumes below 4km of height

Volcanoes
SO$_2$ near-surface global product

1) Global distributions

2008-2014 AM

Plumes below 4km of height
SO$_2$ near-surface global product

- 7-year time series (Beijing, Sar Cheshmeh) $\rightarrow$ temporal evolution of IASI sensitivity as function of TC and H$_2$O total column

- Comparison with measurements made in Bauduin et al. (2014) above Norilsk $\rightarrow$ the agreement is excellent

- Comparison with OMI observations (use of data from DOAS algorithm developed by N. Theys at BIRA) $\rightarrow$ good agreement given the biases of the instruments and the difference in the overpass times

$\rightarrow$ Retrieval of near-surface sulfur dioxide (SO$_2$) concentrations at a global scale using IASI satellite observations in preparation
Near-surface CO (still on-going)

- This work has begun with the SIROCCO (Synergetic SWIR and IR retrievals of near-surface concentrations of CH$_4$ and CO for Earth and Planetary atmospheres) Project (ESA)*
  → See poster 75

*This work was funded by the SIROCCO Project under ESA contract number 4000107088. The project was conceived and supervised by A.G. Straume-Lindner and O. Witasse
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- **Our contribution on Earth:** investigating the sensitivity of IASI to near-surface CH\textsubscript{4} and CO
  1) Theoretical approach (theoretical characterization using OE diagnostic)
  2) Retrievals of test cases and comparison with in-situ measurements

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- Demonstration of the capability of IASI to measure near-surface CO in case of sufficiently large thermal contrasts
  → theoretically and with real retrievals
- E.g.: retrievals above Windhoek airport and comparison with MOZAIC aircraft measurements
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Correlation between seasonal cycle of CO and seasonal cycle of thermal contrasts:
- High CO vmrs from late summer to November when TC are large (≥10K)

During these episodes, IASI is sensitive to the surface and high CO concentrations are caught in the PBL (also found for MOZAIC)
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Same results for Hyderabad.

In Frankfurt, the agreement between the seasonality observed with MOZAIC and FORLI is worse → thermal contrast!
Conclusions and perspectives

- Demonstration of the capability of IASI to measure near-surface pollutants in case of high thermal contrast
  \[ \rightarrow \text{NH}_3, \text{SO}_2 \text{ and CO (still on-going)} \]

- Two products for the retrieval of near-surface concentrations at global scale:
  1) \( \text{NH}_3 \) Calculation of radiance indexes and conversion into columns using LUT
  2) \( \text{SO}_2 \)

- Validation of \( \text{SO}_2 \) retrieval scheme should be done

- Theoretical studies and local retrievals performed for CO in the frame of the SIROCCO project
  \[ \rightarrow \text{extension to the globe and generalization using the FORLI algorithm, which allows retrieving CO profiles for the globe in NRT} \]
Thank you!