CO₂ and CH₄ in the tropics from spaceborne hyperspectral infrared observations:
2.5 years from MetOp IASI and AMSU

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Retrievals of CO$_2$ and CH$_4$ from Thermal-IR observations

A brief history of CO$_2$ retrievals from TIR...

• Study of the ability of Thermal-IR sounders to measure CO$_2$ and other GHG

• First retrievals of CO$_2$ from the 1$^{st}$ generation TOVS
  Chédin et al. 2003

• 2002: Launch of Aqua/AIRS

  Spectral resolution: 20 cm$^{-1}$ (20 channels)
  Precision of retrieval: ~3.0 ppmv
  (1 month-15°x15°)

• 2006: Launch of MetOp-A/IASI
  Crevoisier et al., ACP, 2009

  Spectral resolution: 0.5-2 cm$^{-1}$ (2378 ch.)
  Precision of retrieval: ~2.5 ppmv
  (1 month-15°x15°)

• 2012 & 2016: Launch of MetOp-B/IASI and MetOp-C/IASI

  Spectral resolution: 0.5 cm$^{-1}$ (8461 ch.)
  Precision of retrieval: ~2.0 ppmv
  (1 month-5°x5°)
Retrievals of CO$_2$ and CH$_4$ from Thermal-IR observations

A brief history…

7 years (Apr. 2003 - 2009) of monthly averaged mid-to-upper tropospheric CO$_2$ integrated content are available from AIRS (until July 2007) and then IASI.

Averaged seasonal cycle of CO$_2$ over [0-20N]

Trend: +2.1 ppmv.yr$^{-1}$

Instrumental problem

2003 - AIRS

2005 - AIRS

2007 - AIRS

2009 - IASI

Blank areas denote cloudy situations.
Retrievals of CO₂ and CH₄ from Thermal-IR observations

A brief history…

7 years (Apr. 2003 - 2009) of monthly averaged mid-to-upper tropospheric CO₂ integrated content are available from AIRS (until July 2007) and then IASI.

**Averaged seasonal cycle of CO₂ over [0-20N]**

- Instrumental problem
- Trend: +2.1 ppmv.yr⁻¹

**Averaged seasonal cycle of CH₄ over [0-20N]**

- Trend: +10 ppbv.yr⁻¹
How do we measure \( \text{CO}_2 \) and \( \text{CH}_4 \) from TIR observations?

\( \text{CO}_2 \) and \( \text{CH}_4 \) spectral impacts

Sensitivity of IASI \( T_B \) to variations of atmospheric and surface variables
(simulations with the 4A radiative transfert model)

Scott et Chédin, 1981
http://www.noveltis.fr/4AOP/

Jacquinet-Husson et al., 2008
http://ether.ipsl.jussieu.fr
How do we measure $CO_2$ and $CH_4$ from TIR observations?

$CO_2$ and $CH_4$ spectral impacts

Sensitivity of IASI $T_B$ to variations of atmospheric and surface variables (simulations with the 4A radiative transfert model)

How do we measure $CO_2$ and $CH_4$ from TIR observations?

$CO_2$ and $CH_4$ spectral impacts

Sensitivity of IASI $T_B$ to variations of atmospheric and surface variables (simulations with the 4A radiative transfert model)

$CO_2$ (1%)  $CH_4$ (20%)  $T$ (1K)  $H_2O$ (20%)  $O_3$ (10%)  $CO$ (40%)  $T_{surf}$ (1 K)

Variation of brightness temp. (K)

Wave number (cm$^{-1}$)

15 $\mu$m  7.7 $\mu$m  4.3 $\mu$m

Jacquinet-Husson et al., 2008
http://ether.ipsl.jussieu.fr

Scott et Chédin, 1981
http://www.noveltis.fr/4AOP/
How do we measure $CO_2$ and $CH_4$ from TIR observations?

$CO_2$ and $CH_4$ spectral impacts

For IASI: use of the 15 μm band only, even if channels at 4.3 μm peak lower.
How do we measure $CO_2$ and $CH_4$ from TIR observations?

$CO_2$ and $CH_4$ spectral impacts

- AIRS
  - 15 $\mu$m

- IASI
  - 4 $\mu$m

$CO_2$ (3%) $H_2O$ (20%) $O_3$ (10%) $T_{surf}$ (1 K)

- TIR observations
  - Satellite data
  - Surface temperature

- $T_B$ pert, $T_B$ ref (K)
  - Water vapor
  - Methane
  - Noise

Wavenumber (cm$^{-1}$): 650 - 750 for AIRS, 2220 - 2380 for IASI

Surface T

$T_B$:
- $CO_2$
- $H_2O$
- $CH_4$
- Noise
How do we measure $\text{CO}_2$ and $\text{CH}_4$ from TIR observations?

**CO$_2$ and CH$_4$ spectral impacts**

\[
\begin{align*}
\text{AIRS} & & \text{15} \ \mu\text{m} \\
\text{CO}_2 (3\%) & \quad \text{H}_2\text{O} (20\%) & \quad \text{O}_3 (10\%) & \quad \text{Tsurf} (1 \text{ K}) \\
\text{IASI} & & \text{CO}_2 \quad \text{O}_3 & \quad \text{H}_2\text{O} & \quad \text{surface } T
\end{align*}
\]

\[
\begin{align*}
\text{CO}_2 & : 1\% \rightarrow 0.1 \text{ K} \\
T & : 1 \text{ K} \rightarrow 1 \text{ K} \\
\text{Radiometric noise} & \sim 0.2 \text{ K}
\end{align*}
\]

$\Rightarrow$ Very low signal/noise ratio!
Retrievals of $CO_2$ and $CH_4$ from Thermal-IR observations

What can be retrieved from TIR observations from space?

• Need to decorrelate $T/CO_2$ (or $T/CH_4$)

$\implies$ Use of independent info on $T$: we use simultaneous microwave observations from AMSU flying onboard both Aqua and MetOp-A.

$\sim$ The quality of the retrieval is linked to the quality of both IASI and AMSU.

$\sim$ The coincidence IASI/AMSU is a strong (and even crucial) asset of MetOp!

• We use a non-linear inference scheme based on neural networks.

• The decorrelation between $T/GHG$ is easier to do in the tropics.
  $\implies$ a better precision is expected there.

• Need to average the retrievals: here, 1 month, $5^\circ$x$5^\circ$.

• Retrievals in clear sky only (no clouds, no aerosols).
  $\implies$ design of specific IASI threshold tests to detect clouds and aerosols.
Retrievals of CO$_2$ and CH$_4$ from Thermal-IR observations

What can be retrieved from TIR observations from space?

• We retrieve a mid-to-upper tropospheric content:
  ~“one degree of freedom”.
  ~boundary layer not measured.

• NB: the weighting function points higher for IASI than for AIRS because of the choice of channels, and because of the use of 4.3 μm AIRS channels.

• **Application**: 30 months of IASI/AMSU data

• IASI data are routinely archived at LMD via the Ether Centre for Atmospheric Chemistry Products and Services (http://ether.ipsl.jussieu.fr/), through EUMETCast, the Broadcast System for Environmental Data of EUMETSAT.
Retrievals of CO$_2$ and CH$_4$ from Thermal-IR observations

Results (1) - Seasonal cycle of CO$_2$

Detrended CO$_2$ seasonal cycle in the northern tropics

MLO 4 km

[GLOBALVIEW-2008]
Retrievals of CO$_2$ and CH$_4$ from Thermal-IR observations

Results (1) - Seasonal cycle of CO$_2$

- Decrease in amplitude with altitude
- Surf. ↔ 1 month ↔ mid-tropo
• Decrease in amplitude with altitude

• Surf. ⇔ 1 month ⇔ mid-tropo
Retrievals of CO₂ and CH₄ from Thermal-IR observations

Results (1) - Seasonal cycle of CO₂

- Decrease in amplitude with altitude
- Surf. ↔ 1 month ↔ mid-tropo ↔ 1 month ↔ upper tropo

[IASI] 9-15 km (max at 13 km)
[JAL/CONTRAIL] aircraft ~10 km [Matsueda et al. 2008; Machida et al. 2008]
[AIRS] 5-15 km (max at 10 km)
[MLO] 4 km [GLOBALVIEW-2008]
Retrievals of CO$_2$ and CH$_4$ from Thermal-IR observations

Results (1) - Seasonal cycle of CO$_2$

- Decrease in amplitude with altitude

- Surf. $\Leftrightarrow$ 1 month $\Leftrightarrow$ mid-tropo $\Leftrightarrow$ 1 month $\Leftrightarrow$ upper tropo $\Leftrightarrow$ 1 month $\Leftrightarrow$ UTLS

$\Rightarrow$ time-lag of CO$_2$ while transported from the surface to the upper troposphere

**16 km** entering point of stratospheric air
[adapted from Strahan et al. 1998]

**IASI** 9-15 km (max at **13 km**)

**JAL/CONTRAIL** aircraft $\sim$10 km
[Matsueda et al. 2008; Machida et al. 2008]

**AIRS** 5-15 km (max at **10 km**)

**MLO** 4 km
[GLOBALVIEW-2008]
Retrievals of CO$_2$ and CH$_4$ from Thermal-IR observations

Results (2) - CH$_4$ retrievals vs. models

Monthly average of mid-to-upper tropo. CH$_4$ in the tropics

- **IASI**: precision ~16 ppbv for 1 month, 5°x5°
- **TM5**: with surface sources constrained by NOAA surface stations (4Dvar), sampled at the spatio-temporal resolution of IASI with CO$_2$ weighting function applied.

20N-20S gradient
Retrievals of CO$_2$ and CH$_4$ from Thermal-IR observations

Results (3) - Correlations between IASI CO$_2$ and IASI CH$_4$

The simultaneous retrieval of CO$_2$ and CH$_4$ from IASI gives us the opportunity to study the correlation between both gases.

\[
\begin{align*}
\text{JFM 2008} & \quad +7 \text{ ppbv/ppmv} \\
\text{AMJ 2008} & \\
\text{JAS 2008} & \quad -2.8 \text{ ppbv/ppmv} \\
\text{OND 2008} &
\end{align*}
\]
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Results (3) - Correlations between IASI CO$_2$ and IASI CH$_4$

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**JFM 2008**

+7 ppbv/ppmv

**JAS 2008**

-2.8 ppbv/ppmv

CH$_4$ vs. CO$_2$ measured at 11 km during two CARIBIC flights [Schuck et al., 2009]

August 2007
February 2008

open symbols: obs in the FT
Retrievals of CO₂ and CH₄ from Thermal-IR observations

Conclusions

• **Retrieval characteristics:**
  ~Mid-to-upper tropospheric integrated content
  ~Clear-sky only
  ~Best precision in the tropics
  ~Based on IASI/AMSU coincident observation.

• **Information on:**
  ~Atmospheric transport
  ~Strong emissions uplifted to the upper troposphere
    e.g. CO₂ emitted by fires (analysis of GHG diurnal cycle following Chédin et al. [2003, 2008] → thesis of Thibaud Thonat)

• **Perspectives: A multi-instrument (multi-species) approach**
  ~Coupling to observations in the near-IR (e.g. by Tanso/GoSat)
  ~Coupling to observations in the Thermal-IR with limb sounding techniques (e.g. ACE-FTS) which give access to profiles of CO₂ from 7 to 20 km (Foucher et al. 2009).

• **We need data to validate and analyze results** (regular measurements of CO₂/CH₄ in the mid- and upper-troposphere)