Evaluating the atmospheric columns of CH$_4$ retrieved from space using vertical profiles from aircraft and stratospheric balloon campaigns

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Focus on validation of \( \text{CH}_4 \) mid-tropospheric columns retrieved from IASI.

**Retrieval procedure**: non-linear inference scheme (Crevoisier et al., 2013)

- Use of IASI channels around 7.7 \( \mu \text{m} \).
- Based on the 4A RT code and the latest edition of the GEISA database.
- Radiative biases are computed using the ARSA database.
- Version V8.3: global, day/night, vertical sensitivity provided for each retrieval.

| Tropics: max at 12 km. Mid-lat: max at 8 km. |

**IASI CH\(_4\) average – 24 March to 8 April 2016**

**Vertical sensitivity of IASI CH\(_4\) retrieval**
Comparisons with measurements from surface networks

- **Tropics (N&S):**
  - Seasonality and amplitude OK.
- **Southern hemisphere:**
  - 2-month shift, very few stations
- **Northern hemisphere:**
  - Strong differences!!
  - Large bias and shift in seasonality.
Comparisons with measurements from surface networks

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Not appropriate due to vertical sensitivity of IASI and large variation of CH$_4$ along the vertical.
Validation with aircraft measurements

• Use of HIPPO flights.
• 5 campaigns (H1...H5).
• Along each flight: profile measurement of several trace gases including CH$_4$.

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Validation with HIPPO aircraft measurements

Averaged CH₄ profiles in 4 latitudinal bands

60S:30S

30S:Equator

Equator:30N

30N:60N

Quite constant in the tropics

Quite constant in the tropics

Strong decrease above the tropopause (~8km)

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Averaged CH$_4$ profiles in 4 latitudinal bands

- **60S:30S**
  - CH$_4$ profiles with altitude and CH$_4$ concentration.
  - Weighting function indicated.

- **30S:Equator**
  - CH$_4$ profiles with altitude and CH$_4$ concentration.

- **Equator:30N**
  - CH$_4$ profiles with altitude and CH$_4$ concentration.

- **30N:60N**
  - CH$_4$ profiles with altitude and CH$_4$ concentration.

8 km = max of vertical sensitivity

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Validation with HIPPO aircraft measurements

Overall (229 situations): $7.7 \pm 17.0$ ppbv (R = 0.76).
Tropics (180 situations): $5.8 \pm 14.9$ ppbv (R = 0.76).
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Small bias and std for straight profiles.

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Using a proper characterization of stratospheric CH₄ is mandatory to fully validate the retrievals.

Sources: models or balloons.
What's an AirCore?

AirCore = an **atmospheric sampling system** that allows **greenhouse gas measurements**

**AirCore in 3 key points:**
- Stems from an original Idea from P.Tans at NOAA
- **Long stainless steel tube**: treated with Suflinert® coating to avoid interaction with water vapor
- Magnesium Perchlorate dryer at inlet

**Required flight parameters:**
- Pressure probe(s) (Ambient P)
- Temperature probe(s) (Ambient T, Coil Temperature)
- GPS data...
- Relative humidity...

NOAA AirCore © Karion et al. 2010
**What’s an AirCore? – sampling method**

AirCore = an **atmospheric sampling system** that allows **greenhouse gas measurements**

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1. **Preparation**

   Tube is filled with calibrated standard

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**Surface**

**30km**

**Ceiling**
What’s an AirCore? – sampling method

AirCore = an atmospheric sampling system that allows greenhouse gas measurements

1. Preparation
   - Tube is filled with calibrated standard

2. Ascent
   - Tube empties

Ceiling

Surface

30km
What’s an AirCore? – sampling method

AirCore = an atmospheric sampling system that allows greenhouse gas measurements.

1. Preparation
   - Tube is filled with calibrated standard

2. Ascent
   - Tube samples ambient air

3. Descent
   - Tube empties

Surface

30km Ceiling

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What’s an AirCore? – sampling method

AirCore = an atmospheric sampling system that allows greenhouse gas measurements

1. Preparation
   Tube is filled with calibrated standard

2. Ascent
   Tube empties

3. Descent
   Tube samples ambient air

4. Closed
   Surface

Ceiling

30km

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1. **Preparation**
   - Tube is filled with calibrated standard

2. **Ascent**
   - Tube empties

3. **Descent**
   - Tube samples ambient air

4. **Closed**

5. **Analysis**
   - Calibrated Gas Standard ≠ Fill Gas
   - Continuous Gas Analyzer

**Mixing ratios of gases**

- CO$_2$,
- CH$_4$,
- CO...
  depending on the analyzer

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Vertical resolution can be estimated thanks to:

- Molecular Diffusion
- Taylor Dispersion

and is directly affected by \textbf{(Length, diameter)}

Expected \textit{vertical resolution} for air sampled at different altitudes
(for 3h waiting time before analysis)

\begin{figure}
\centering
\includegraphics[width=\textwidth]{chart.png}
\caption{Expected vertical resolution for CO\textsubscript{2}/CH\textsubscript{4} profiles (m)}
\end{figure}
Overview of AirCore Data

LMD AirCores flown during the annual Stratoscience campaigns from CNES (in partnership with CSA)

Regular flight from Sodankyla
University of Groningen / Finnish Meteorological Institute

15 independent flights from Summer 2013 to 2015

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The AirCore Profiles

15 AirCore CH₄ profiles from Sodankyla (Finland) and Timmins (Canada)

- Troposphere is quite stable (with respect to seasonal and regional variation)
- Strong decrease in the stratosphere (on average 800 ppb gradient between 120 hPa and 30 hPa)

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Completing HIPPO profiles with Stratospheric Information from AirCores

HIPPO profiles in the North Mid-Lat

Comparison of IASI mid-tropospheric $\text{CH}_4$ with HIPPO $\text{CH}_4$

North Mid-Lat (33 situations): 18.8 ppb
Bias between HIPPO and IASI is corrected when taking into account realistic stratospheric behavior.

Large dispersion due to unappropriate stratospheric correction.

Need for collocated in-situ measurements.

North Mid-Lat (33 situations): 18.8 ppb → 6.1 ppb
Comparison of AirCore profiles with models

CH₄ Profiles from AirCore-HR and forecast from ECWMF

Legend

- CH₄ IFS/MACC (137 levels) (29/08/2014 12UTC)
- CH₄ AirCore-HR (29/08/2014)

- Excellent agreement in the troposphere (signatures)
- Not satisfactory above the tropopause

Impact on integrated columns when comparing to integrated CH₄:

IFS CH₄ = + 13 ppb

IFS Data: Courtesy of S. Massart & A. Augusti-Panareda

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Validation of IASI CH₄ Data with AirCores

15 AirCore Profiles

IASI CH₄ Weighting Function

*qAirCore CH₄*

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Validation of IASI CH$_4$ Data with AirCores

15 AirCore Profiles

IASI CH$_4$
Weighting Function

$\ast$

qAirCore CH$_4$

Collocation with LMD AirCore-HR
Timmins, Canada (29 August 2014)

➢ To get enough statistics averaging is done over a 10°x10° box on 1 day.
Validation of IASI CH$_4$ Data with AirCores

Comparison of IASI mid-tropospheric CH$_4$ with AirCore CH$_4$

Overall (10 cases) : 2.56 ± 15.08 ppb (R = 0.88).

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Conclusion & Future Validation Strategies

Use of AirCore Balloon Data

- CH₄ validation in the Northern Hemisphere
- Possibility to extend this study to CO₂ and CO
- Other gases could be studied with AirCores

Future Campaigns

Aire-sur-Adour, France (2016),
- AirCore-light (Wheater Balloon), regular flights, starting from June

Trainou (Orléans), France (2016),
- multi-instrument campaign: on ICOS/TCCON site, AMULSE laser diode spectrometers, Lidar, AirCraft campaign, AirCore-light (Wheater Balloon)

Validation plans for IASI-NG, Merlin CH₄ and MicroCarb CO₂

- opportunities for intensive balloon campaigns together with aircraft flights

Remaining Questions

- What vertical resolution is needed?
- Assessment of temporal and spatial variability of the profiles