GHG-CCI satellite XCO$_2$: comparisons with global models

Will Hewson $^1$
Hartmut Bösch $^1$, Rob Parker $^1$
Michael Buchwitz and the GHG-CCI team

$^1$Earth Observation Science, Dept. Physics and Astronomy, University of Leicester, U.K.

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GHG-CCI partners
CO₂ and CH₄ – two most important anthropogenic GHGs. Reliable climate prediction requires good understanding of natural and anthropogenic (surface) CO₂ and CH₄ sources and sinks:

▶ Distribution?
▶ Magnitude?
▶ Climate change response?

Better understanding requires appropriate global observations and (inverse) modelling.
CO₂ and CH₄ – two most important anthropogenic GHGs.

Reliable climate prediction requires good understanding of natural and anthropogenic (surface) CO₂ and CH₄ sources and sinks:

- Distribution?
- Magnitude?
- Climate change response?

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Global distribution of atmospheric GHGs CO₂ and CH₄, of sufficient quality to estimate regional sources and sinks.
Retrieval procedure

Global satellite observations → Calibration (L0–L1) → Calibrated radiances → Retrieval (L1–L2) → Reference observations → Validation → Atmospheric GHG distributions → Improved information on GHG sources and sinks → Inverse modelling (L2–L4)

Small XCO₂ column gradients (column averaged CO₂ dry air mole fraction)):
- High precision to resolve small CO₂ source / sink (0.2–0.3%) variations.
- High accuracy essential to avoid regional-scale biases (<0.15%).
**GHG-CCI ECV products**

<table>
<thead>
<tr>
<th>Algorithm ID</th>
<th>Type</th>
<th>Data product</th>
<th>Institution / algorithm</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2_SCI_BESD</td>
<td>ECA</td>
<td>XCO₂ from SCIAMACHY</td>
<td>IUP, Univ. Bremen, FP algorithm BESD</td>
</tr>
<tr>
<td>CO2_SCI_WFMD</td>
<td>ECA</td>
<td>XCO₂ from SCIAMACHY</td>
<td>IUP, Univ. Bremen, PR algorithm WFM-DOAS</td>
</tr>
<tr>
<td>CO2_GOS_OCFP</td>
<td>ECA</td>
<td>XCO₂ from GOSAT</td>
<td>Univ.Leicester (ULE), FP algorithm (OCO algo.)</td>
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<tr>
<td>CO2_GOS_SRFP</td>
<td>ECA</td>
<td>XCO₂ from GOSAT</td>
<td>SRON, FP algorithm of SRON</td>
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<tr>
<td>CH4_SCI_WFMD</td>
<td>ECA</td>
<td>XCH₄ from SCIAMACHY</td>
<td>IUP, Univ. Bremen, PR algorithm WFM-DOAS</td>
</tr>
<tr>
<td>CH4_SCI_IMAP</td>
<td>ECA</td>
<td>XCH₄ from SCIAMACHY</td>
<td>SRON, PR algorithm IMAP</td>
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<tr>
<td>CH4_GOS_OCFP</td>
<td>ECA</td>
<td>XCH₄ from GOSAT</td>
<td>Univ.Leicester (ULE), FP algorithm (adjusted OCO algo.)</td>
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<tr>
<td>CH4_GOS_SRPR</td>
<td>ECA</td>
<td>XCH₄ from GOSAT</td>
<td>SRON, PR algorithm for GOSAT XCH₄</td>
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<tr>
<td>CH4_GOS_SRFP</td>
<td>ECA</td>
<td>XCH₄ from GOSAT</td>
<td>SRON, FP algorithm for GOSAT XCH₄</td>
</tr>
</tbody>
</table>

*Table S-1:* Overview GHG-CCI ECV Core Algorithms (ECAs).
The achieved accuracy and precision of the various (ECA) data products has to be compared with the user requirements for XCO$_2$ and XCH$_4$, which are formulated in the GHG-CCI User Requirements Document (URD GHG-CCI v1), available from the GHG-CCI website.

The performance in terms of accuracy and precision has been estimated using various approaches including analysis of simulations, comparison with ground-based observations as performed by the GHG-CCI retrieval team (note that an independent validation is being performed in parallel by the independent validation team), comparisons with models, and inter-comparisons of the data products generated with the different GHG-CCI algorithms and algorithms developed elsewhere, most notably with the official GOSAT data products generated by NIES, Japan, and with the NASA ACOS-team XCO$_2$ data product.

Based on the analysis performed, which is described in this document, the achieved accuracy and precision of the various data products are listed in Table S-3 for XCO$_2$ and Table S-4 for XCH$_4$. The following abbreviations have been used: NA = Not Assessed, DP = Data Provider comparison/assessment method, EMMA = Assessment method used in the context of the evaluation of the EMMA ensemble product (as described in Section 12). As can be seen, not all requirements have been met yet.

### Current estimates of achieved data quality: XCO$_2$ (in ppm)

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Algorithm</th>
<th>Precision Single observation</th>
<th>Precision Regional / monthly</th>
<th>Relative accuracy</th>
<th>Method / comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCIAMACHY</td>
<td>BESD v01.00.01</td>
<td>2.5</td>
<td>NA</td>
<td>0.8</td>
<td>DP (IUP, Section 7.1)</td>
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<tr>
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<td></td>
<td>2.3</td>
<td>1.5</td>
<td></td>
<td>EMMA (Section 12.5)</td>
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<tr>
<td>SCIAMACHY</td>
<td>WFMD v2.2</td>
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<td>1.6</td>
<td>0.8</td>
<td>DP (IUP, Section 7.2)</td>
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<td></td>
<td>4.4</td>
<td>2.0</td>
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<td>EMMA (Section 12.5)</td>
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<tr>
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<td>0.2</td>
<td>0.8</td>
<td>DP (ULE, Section 7.3)</td>
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<td></td>
<td></td>
<td>2.3</td>
<td>1.6</td>
<td></td>
<td>EMMA (Section 12.5)</td>
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<tr>
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<td>SRFP v1.1</td>
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<td>NA</td>
<td>1.0</td>
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<td></td>
<td>2.5</td>
<td>1.0</td>
<td></td>
<td>EMMA (Section 12.5)</td>
</tr>
<tr>
<td>SCIAMACHY and GOSAT</td>
<td>EMMA v1.3a</td>
<td>3.1</td>
<td>0.8</td>
<td>0.8</td>
<td>EMMA (Section 12.5)</td>
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<tr>
<td>Required:</td>
<td>&lt; 8.0</td>
<td>&lt; 1.3</td>
<td>&lt; 0.5</td>
<td></td>
<td>/URD GHG-CCI v1/</td>
</tr>
</tbody>
</table>
GHG-CCI ECV products

GHG-CCI

Carbon Dioxide SCIAMACHY/WFMD

2012 04

XCO₂ [ppm]

380 387 394 401 408

Mean Uncertainty [ppm]

0.0 1.2 2.4 3.6 4.8

StdDev [ppm]

0.0 1.2 2.4 3.6 4.8

Nobs

CRDP#1 WFMD_v3.3  MB/2013/07/08 Nobs:min= 9 grid: 10x10
Considerations for direct comparison of satellite and model data:

- Vertical sensitivity of satellite observations, and retrieval dependence on a-priori.
- Apply averaging kernel $A$ to model output ($x_{model}$) to simulate instrument sensitivity to atmosphere $x_{a}$:
  \[ x = x_{a} + A(x_{model} - x_{a}) \]  
- Spatio-temporal interpolation between grids.
- Vertical interpolation especially careful, model and retrieval on different grids:
  - Interpolation of VMR will not maintain total column.
  - Layer vs level.
Considerations for direct comparison of satellite and model data: Vertical sensitivity of satellite observations, and retrieval dependence on a-priori.

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Considerations for direct comparison of satellite and model data: Vertical sensitivity of satellite observations, and retrieval dependence on a-priori. Apply averaging kernel $A$ to model output ($x_{model}$) to simulate instrument sensitivity to atmosphere $x_a$:

$$X = X_a + A(x_{model} - x_a)$$

Spatio-temporal interpolation between grids. Vertical interpolation especially careful, model and retrieval on different grids:

- Interpolation of VMR will not maintain total column.
- Layer vs level.
Satellite assessment

UoL GOSAT FP (obs.) vs. Edinburgh GEOS-Chem (model)

Max. model–data $\Delta$ in regions where both models and satellite data are uncertain (no validation; high cirrus + aerosols loads).
Sampled for satellite location, AKs applied.

Note large spread between models.
Model assessment – satellite

UoL GOSAT FP vs. model ensemble mean

GOSAT – model mean $\Delta$ comparable to $\Delta$ between individual models and model mean
Model assessment – satellite

UoL GOSAT FP and IUP Bremen SCIAMACHY FP vs. model ensemble mean

S. Asia: Stronger annual cycle or bias in Satellite data?  Australia: Influence of Indonesian fires?

Satellite datasets agree on locations and time of uncertainty… capturing events missed by models?
Ensemble median algorithm (EMMA) combines individual soundings of 7 ECAs into one new data set.

Takes advantage of ECAs’ independent developments, less influenced by regional and temporal biases of individual algorithms.

Reuter et al., ACP 13-4, 2013:
http://dx.doi.org/10.5194/acp-13-1771-2013
EMMA – retrieval ensemble
EMMA – retrieval ensemble

Regional bias - ensemble spreads (std. dev. of algorithms) < 1 ppm, rising to 2 ppm in Tropics and East Asia.

EMMA tends to better agree with validation data (TCCON).
Many geographical regions where models are poorly constrained by surface measurements:

- Models might not well reproduce regional carbon cycle and year-to-year variations, or miss specific events.

Satellite XCO₂ data should help to assess and improve models if they have sufficient accuracy and can be properly validated for these regions.

CO₂ models show good consistency (with notable regional differences). Model data represents a reasonable dataset for testing satellite column data.