The greenhouse gas project of ESA’s Climate Change Initiative (GHG-CCI): Phase 2 achievements & future plans

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C. Zehner, ESA/ESRIN, Frascati, Italy, ESA technical officer
Outline

• **Overview** ESA Climate Change Initiative (CCI) & GHG-CCI project

• **Selected results from SCIAMACHY and GOSAT:**
  - **Terrestrial vegetation CO$_2$ sink:**
    - European terrestrial carbon sink from SCIAMACHY and GOSAT (Reuter et al., ACP, 2014)
  - **Anthropogenic CO$_2$ emissions from SCIAMACHY:**
    - Schneising et al., ACP, 2013
    - Reuter et al., Nature Geoscience, 2014
  - **Anthropogenic CH$_4$ emissions from SCIAMACHY:**
    - First results from major US „fracking“ areas (Schneising et al., Earth‘s Future, 2014)

• **Future aspects**
ESA Climate Change Initiative (CCI)
to generate Essential Climate Variables (ECVs)

www.esa-ghg-cci.org/

ESA programme
led by Mark Doherty, ESA/ESRIN

ECV projects:
• Aerosol-CCI
• Cloud-CCI
• Fire-CCI
• GHG-CCI - CO₂ & CH₄
• Glaciers-CCI
• LandCover-CCI
• OceanColour-CCI
• Ozone-CCI
• SeaLevel-CCI
• SST-CCI
• SoilMoisture-CCI
• Sealce-CCI
• IceSheets-CCI (Greenland, Antarctica)

+ CMUG (Climate Modelling User Group)
• Lead: Roger Saunders (Met Office Hadley Centre)
• Met Office Hadley Centre, ECMWF, MPI-Meteorology, Météo France, IPSL, SMHI, DLR
ECV Greenhouse Gases

CO₂ and CH₄ are the two most important anthropogenic greenhouse gases and increasing concentrations result in global warming.

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

Important questions are, for example:

- Where are they?
- How strong are they?
- How do they respond to a changing climate?

A better understanding requires appropriate global observations and (inverse) modelling.

ECV GHG / Product A.8.1 (GCOS-154*): “Retrievals of greenhouse gases, such as CO₂ and CH₄, of sufficient quality to estimate regional sources and sinks.”

*) „SYSTEMATIC OBSERVATION REQUIREMENTS FOR SATELLITE-BASED DATA PRODUCTS FOR CLIMATE“
Global satellite observations

Global information on near-surface CO$_2$ & CH$_4$

Upper layer CO$_2$ & CH$_4$

SCIAMACHY/ENVISAT

TANSO/GOSAT

Comparisons etc.: OCO-2

Calibrated radiances

Calibration (L 0-1)

Retrieval

(L 1-2)

Atmospheric GHG distributions

Reference observations

Validation

Improved information on GHG sources & sinks

Inverse modelling (L 2-4)
## GHG-CCI: Data sets

<table>
<thead>
<tr>
<th>Product ID</th>
<th>Product (Level 2, mole fractions)</th>
<th>Years processed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2002 03 04 05 06 07 08 09 10 11 12 13 14 15</td>
</tr>
<tr>
<td>XCO2_SCIA</td>
<td>XCO₂</td>
<td></td>
</tr>
<tr>
<td>XCH4_SCIA</td>
<td>XCH₄</td>
<td></td>
</tr>
<tr>
<td>XCO2_GOSAT</td>
<td>XCO₂</td>
<td></td>
</tr>
<tr>
<td>XCH4_GOSAT</td>
<td>XCH₄</td>
<td></td>
</tr>
<tr>
<td>XCO2_EMMA</td>
<td>XCO₂</td>
<td></td>
</tr>
</tbody>
</table>

### GHG-CCI Core Products: ECV Core Algorithm (ECA) Products

- XCO2_SCIA: BESD, WFMD
- XCH4_SCIA: WFMD, IMAP
- XCO2_GOSAT: SRFP (RemoTeC), OCFP (UoL-FP)
- XCH4_GOSAT: SRFP & SRPR (RemoTeC), OCFP (UoL-PR)
- XCO2_EMMA: Various (SCIA & GOSAT merged)

### Comments:

- ACA products:
  1. Mid / upper tropospheric column
  2. Upper tropospheric / stratospheric profile
- CRDP#2
- Also available

Details please see: [www.esa-ghg-cci.org](http://www.esa-ghg-cci.org) -> CRDP (Data)
GHG-CCI: XCO$_2$ time series

Carbon Dioxide (CO$_2$) - NH (0°-60°N)

<table>
<thead>
<tr>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>XCO$_2$ [ppm]</td>
<td>370</td>
<td>380</td>
<td>385</td>
<td>390</td>
<td>395</td>
<td>400</td>
<td>405</td>
</tr>
</tbody>
</table>

SCIAMACHY/ENVISAT: WFMD(WFM-DOAS) BESD
TANSO/GOSAT: SRFP(ReMoTeC) OCFP(UoL-FP)
Ensemble: Key to success

- Multiple satellite algorithms / products
- Multiple models / inverse models

http://www.northpacificmusic.com/ensemble.east.west.jpg
Terrestrial carbon sink
Regional carbon budgets

**Land**

- **a) N.Amer**
  
  \(-0.72\pm0.45\) PgC yr\(^{-1}\); \(-31.20\) gC m\(^{-2}\) yr\(^{-1}\)

- **b) Europe**
  
  \(-0.44\pm0.45\) PgC yr\(^{-1}\); \(-40.42\) gC m\(^{-2}\) yr\(^{-1}\)

- **c) N.Asia**
  
  \(-1.05\pm0.43\) PgC yr\(^{-1}\); \(-26.11\) gC m\(^{-2}\) yr\(^{-1}\)

**Oceans**

- **d) N. Atlantic**
  
  \(-0.63\pm0.10\) PgC yr\(^{-1}\); \(-15.82\) gC m\(^{-2}\) yr\(^{-1}\)

- **e) N. Pacific**
  
  \(-0.55\pm0.14\) PgC yr\(^{-1}\); \(-9.82\) gC m\(^{-2}\) yr\(^{-1}\)

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSCEa</td>
<td>Piao et al. (2009)</td>
</tr>
<tr>
<td>MACC-II</td>
<td>Chevallier et al. (2010)</td>
</tr>
<tr>
<td>CCAM</td>
<td>Rayner et al. (2008)</td>
</tr>
<tr>
<td>MATCH</td>
<td>Rayner et al. (2008)</td>
</tr>
<tr>
<td>CT2011_oi</td>
<td>Peters et al. (2007)</td>
</tr>
<tr>
<td>CTE2013</td>
<td>Peters et al. (2010)</td>
</tr>
<tr>
<td>JENA</td>
<td>Rödenbeck (2005)</td>
</tr>
<tr>
<td>(s96, v3.5)</td>
<td>Patra et al. (2005a)</td>
</tr>
<tr>
<td>RIGC</td>
<td>Maki et al. (2010)</td>
</tr>
<tr>
<td>(TDI-64)</td>
<td>Gurney et al. (2008)</td>
</tr>
<tr>
<td>JMA</td>
<td>Niwa et al. (2012)</td>
</tr>
</tbody>
</table>

No satellite XCO\(_2\) data used

Peylin et al., 2013
European terrestrial carbon fluxes from SCIAMACHY and GOSAT

„Continental Europe only“ inversion using STILT-based short range (days) particle dispersion modelling using an ensemble of satellite XCO₂ retrievals:

- 2 satellites
- 5 retrieval algorithms / products
- New flux inversion method insensitive to observations outside Europe, large-range transport & other errors
- Various sensitivity studies

Satellite data suggest a continental (TransCom) European C sink of 1.02 +/- 0.3 GtC/yr (for 2010)

Reuter et al., ACP, 2014
European terrestrial carbon fluxes from SCIAMACHY and GOSAT

Summary for continental (TransCom) Europe:

European carbon uptake
in gigatons of carbon in 2010

Reuter et al. (ACP, 2014) with satellite CO₂
1.0±0.3

Previous estimate without satellite CO₂
0.4±0.4

Related ESA webstory: Is Europe an underestimated sink for carbon dioxide?
http://www.esa.int/Our_Activities/Observing_the_Earth/Is_Europe_an_underestimated_sink_for_carbon_dioxide
Elevated uptake of CO₂ over Europe inferred from GOSAT X_CO₂ retrievals:

An inter-comparison of inverse models for estimating sources and sinks of CO₂ using GOSAT measurements

L. Feng¹, I. Morino⁷

Anthropogenic emissions
Anthropogenic CO$_2$

Bottom-up estimate
Currently not possible to verify this using satellite data !?
-> We hope for CarbonSat !
SCIAMACHY CO$_2$ over anthropogenic source regions

**SCIAMACHY XCO$_2$**

**EDGAR CO$_2$ emissions**

**Schneising et al., ACP, 2013**

**Regional enhancement = Source - Background**

**SCIAMACHY EDGAR**

**Trend [%CO$_2$/yr]**

**EDGAR emissions consistent with SCIAMACHY**
Anthropogenic emissions: Good and bad news

Reuter et al., Nature Geoscience, 2014
„Decreasing NO\textsubscript{x} relative to CO\textsubscript{2} emissions in East Asia inferred from satellite observations“

Satellite derived trends of anthropogenic NO\textsubscript{x} and CO\textsubscript{2} emissions

- North America & Europe: 34+/-15% less CO\textsubscript{2} emitted during weekends

- North America & Europe: Decreasing emissions (but uncertain for CO\textsubscript{2})

- East Asia: Increasing emissions but less NO\textsubscript{x} per CO\textsubscript{2}: Trend towards cleaner technology in East Asia
SCIAMACHY methane:

Remote sensing of fugitive methane emissions from oil and gas production in North American tight geologic formations

Oliver Schneising¹, John P. Burrows¹,²,³, Russell R. Dickerson², Michael Buchwitz¹, Maximilian Reuter¹, and Heinrich Bovensmann¹

Schneising et al., Earth’s Future, 2014

Estimated emission increase 2009-2011 relative to 2006-2008:
- Bakken: 990±650 ktCH₄/yr
- Eagle Ford: 530±330 ktCH₄/yr

Emission estimates correspond to leakages of
- Bakken: 10.1±7.3% and
- Eagle Ford: 9.1±6.2%

in terms of energy content.

Exceeds 3.2% “climate benefit” threshold (Alvarez et al., 2012) for switching from coal to natural gas

Likely underestimated in inventories.
Anthropogenic CO$_2$ and CH$_4$ emissions from space

Today: SCIAMACHY, GOSAT, OCO-2

Future?: CarbonSat
We aim at „More & better“ via

- Extension of existing „Carbon from Space“ time series (updates are planned once per year)
- Quality improvements (algorithms, error characterization, documentation, …)
- Enhanced data exploitation: Extracting as much information on CO$_2$ and CH$_4$ sources & sinks as possible (inverse modelling, CCDAS, other)

Achieving our long-term climate-relevant goals requires

- Continuity e.g. in terms of funding (e.g., „CCI+“) not only for „operations“ but also for the mandatory „research“ (to push the state-of-the-art & to make sure that products are state-of-the-art)
- New sensors (e.g., CarbonSat, …)
Thank you very much for your attention!

The GHG-CCI team
GHG-CCI: Documents

- **User Requirements**
  - URDv2

- **Processing system**
  - DARD SSD SVR

- **Algorithm descriptions**
  - ATBDs

- **Quality assessments**
  - CECRs

- **Product Specification and User Guides**
  - PSD PUGs

- **Other**

... and many more ...

All publicly available on [www.esa-ghg-cci.org](http://www.esa-ghg-cci.org) -> Documents and / or [www.esa-ghg-cci.org](http://www.esa-ghg-cci.org) -> CRDP (Data)
<table>
<thead>
<tr>
<th>Variable(*)</th>
<th>Resolution</th>
<th>Accuracy</th>
<th>Stability (§§)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>XCO₂</strong></td>
<td>Temporal:</td>
<td>GCOS: &lt; 1 ppm</td>
<td>GCOS: &lt; 0.2 ppm/yr</td>
</tr>
<tr>
<td></td>
<td>GCOS: 4 hours</td>
<td>URD(#): &lt; 0.5 ppm</td>
<td>URD: &lt; 0.5 ppm/yr</td>
</tr>
<tr>
<td></td>
<td>Achieved: Days</td>
<td>Achieved(#): 0.4-0.9 ppm(?)</td>
<td>Achieved: &lt;&lt; 0.5 ppm/yr(+)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(?) Depending on sensor, time period and assessment method</td>
<td>(+) Derived trends not significant</td>
</tr>
<tr>
<td></td>
<td>Spatial:</td>
<td>GCOS: &lt; 10 ppb</td>
<td>GCOS: &lt; 2 ppb/yr</td>
</tr>
<tr>
<td></td>
<td>GCOS: 5-10 km</td>
<td>URD(#): &lt; 10 ppb</td>
<td>URD: &lt; 10 ppb/yr</td>
</tr>
<tr>
<td></td>
<td>Achieved($): 10 km</td>
<td>Achieved(#): 3-8 ppb($)</td>
<td>Achieved: &lt; 4 ppb/yr(!) (§§)</td>
</tr>
<tr>
<td></td>
<td>($) for GOSAT. SCIAMACHY: 30x60 km².</td>
<td>($) for GOSAT; for SCIAMACHY 8-15 ppb depending on time period (degradation after Oct. 2005)</td>
<td>(!) Derived trends mostly not significant but note (§§)</td>
</tr>
<tr>
<td></td>
<td>URD: SCIAMACHY and GOSAT are useful to generate the ECV GHG.</td>
<td>Note: GCOS requirements are target (maximum) requirements but URD requirements listed here are threshold (minimum) requirements.</td>
<td>(#) Relative accuracy (i.e., excluding a possible constant global offset)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(§§) Stability as used here quantifies only long-term drift and therefore does not capture certain “jumps” due to detector issues as observed when analyzing the global SCIAMACHY XCH₄ (e.g., IMAP product mid 2010)</td>
<td>Estimated by comparison with TCCON ground-based observations; TCCON accuracy (1-sigma): 0.4 ppm for XCO₂ and 3.5 ppb for XCH₄</td>
</tr>
</tbody>
</table>

(*) Requirements for column-averaged mole fractions (= air column normalized vertical GHG columns) as required by URD; it is assumed here that this corresponds to GCOS variables „Tropospheric CO₂ column“ and „Tropospheric CH₄ column“

References: Requirements for ECV Greenhouse Gases (GHG):
- **GCOS-154**: “SYSTEMATIC OBSERVATION REQUIREMENTS FOR SATELLITE-BASED DATA PRODUCTS FOR CLIMATE“
- **URD**: “GHG-CCI User Requirements Document“, v2.0

Definition: ECV GHG (GCOS-154):
- Product A.8.1: Retrievals of CO₂ and CH₄ of sufficient quality to estimate regional sources and sinks
Details please see: www.esa-ghg-cci.org -> Publications
New capabilities:
Cities, power plants, oil & gas fields, geological "point" sources, …
CO2 emissions and carbon sinks

Martin Heimann @ Climate Symposium 2014

"Strong carbon sink in northern extra-tropics."

Watch video @ http://www.theclimatesymposium2014.com
Session: Monday 13th 14:00-15:30 - Setting the scene: Science perspective
Goal: Get information on European terrestrial carbon fluxes using satellite data and a method which is not or much less sensitive to potential error sources as discussed in the literature such as:

- Potential adverse impact of satellite XCO₂ biases outside of target region (e.g., XCO₂ biases over Africa due to desert dust storm aerosols)
- Potential problems related to long-range transport modelling
- Potential problems related to the used satellite

Approach:
„Europe only“ inversion using STILT-based short range (days) particle dispersion modelling using an ensemble of satellite XCO₂ retrievals

Reuter et al., ACP, 2014

- The satellite minus model (CT2011_oi) difference ΔXCO₂ shows a negative correlation with the integrated European surface influence.
- Interpretation: CarbonTracker’s European carbon sink is too weak.
- Quantitative analysis using the optimal estimation framework (1D-Var) to get optimized European surface fluxes considering satellite XCO₂ retrievals.