Comparison of global monthly CO emission maps derived from remotely sensed burned area datasets

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Summary

- Introduction
- **Global data sets**
  - bottom up & top-down
- **Spatial & temporal distribution**
  - continental and land cover
- Conclusion
Since the late 70’s vegetation fires have been recognized as a significant anthropogenic source of greenhouse gases, CO$_2$ and CH$_4$ (Crutzen et al., 1979).

Other carbonaceous compounds are emitted from the incomplete combustion of vegetation biomass such as CO.

About 40% of the CO annual budget in the atmosphere is due to fires (IPCC 2001). CO, being a precursor of ozone and an important sink for hydroxil radical (OH), plays a key role in chemistry transport models of atmospheric pollutants (Jain, 2007).

Large uncertainty still exists in the assessment of gas and particulates emissions from vegetation fires because of their higher temporal dynamic with respect to other sources and high spatial variability (Liousse et al, 2004, Langmann et al, 2009).

Satellite observation data potentially have all the characteristics for quantifying seasonal and inter-annual information on the emissions from vegetation fires because of their global and continuous coverage.
BBSO (Burnt Biomass and Satellite Observations) workshop within the ACCENT European network and the GEIA/AIMES/IGBP international project in Toulouse, France, December 2005 (www.accent-network.org)

Intercomparison exercise was organized to analyse emission inventories (CO and particulate matter) derived from Remote Sensing global products: AF (Active Fires) and BA (Burnt Area) under the coordination of the JRC/EC

The participants agreed on
  i) a common experimental year (2003)
  ii) a common land cover map (GLC2000) and
  iii) a common set of factors to be used in a 'bottom up’ approach
Objectives

- To highlight the agreements/disagreements in terms of spatial and temporal patterns of a set of global CO inventories ('bottom-up' approach)

- To compare the results with inventories performed with different approaches (e.g. inverse modeling “top-down”)

- To investigate the role that the land cover plays in these differences

- To assess the impact of the choice of one product over another (regionally based analysis)
Datasets (July 2009)

**Bottom-up modeling approach**

**Common Static Information**

- Land cover map GLC2000
- Biomass Density \( BD_i \)
- Burning Efficiency \( BE_i \)
- Emission factors \( EF_i \)

**Specific Dynamic Information**

- Three monthly global CO emission products (0.5°x0.5°) for the year 2003:
  - L3JRC-COR inventory BA product (source: Liousse, Univ. Toulouse, France)
  - WFA-GBA2000 inventory AF product (source: Mieville, Univ. P. M. Curie, Paris)
  - MODIS inventory AF product (source: Mian Chin, NASA Greenbelt, USA)

Bartholomé E., A. Belward, I.J. Rem Sens., 26 (9) 2005.
Global CO emission products

Monthly CO emission maps over the globe for each 0.5° x 0.5° cell and land cover class.

1. **L3JRC COR (VGT)**: based on burnt areas from daily SPOT/VGT available for the period 2000 to 2007 (Tansey et al. 2008) with corrections applied to land cover classes GLC3 & GLC12: Deciduous broad-leaved tree, Deciduous shrub (Lioussse et al. 2009)

2. **WFA-GBA 2000 (AATSR)**: burnt areas derived from night time active fires derived from AATSR (ESA ENVISAT) between 1997 and 2005 (Mieville et al., 2009) with calibration derived using the GBA2000 dataset for three latitudinal bands (Tansey et al., 2004)

3. **MODIS**: burnt areas based on MODIS (TERRA & AQUA) 8-day active fire counts at 1-km resolution using a conversion factor (Giglio et al., 2006; Chin et al., 2002)

   These inventories are not exhaustive, but they share common static information
   Land cover classes are extracted from the GLC2000.
Global CO emission products

**Top-down inverse modeling approach**

Monthly CO emission maps over the globe for each 0.5° x 0.5° cell

1. **MOPITT** (TERRA): CO profiles from MOPITT (Measurements Of Pollution In The Troposphere) are used together with the chemistry and transport model MOZART (Model for Ozone and related chemical Tracers; Horowitz et al. 2003) that simulates the distribution of 63 trace gases in the lower atmosphere. For the optimization of the inversion process, a set of a priori sources of emissions (fossil fuel, biogenic fuel, vegetation fires) are used. The a priori biomass burning emissions have been derived from MODIS fire counts (Petron et al. 2004).

- MOPITT inventory  CO profile product (source: G. Petron-NOAA and J.Gille/D. Edwards, NCAR, USA)
Bottom-up approach

\[ E_i(X) = BA_i \times BD_i \times BE_i \times EF_i(X) \]

Model by Seiler and Crutzen, 1980

- **E**: emissions of the compound \(X\) for the land cover \(i\) [Kg]
- **BA**: burnt area in the land cover \(i\) [m²]
- **BD**: biomass density of the land cover \(i\) [kg m⁻²]
- **BE**: burning efficiency in the land cover \(i\) [kg kg⁻¹]
- **EF**: emission factor for the compound \(X\) in the land cover \(i\) [g kg⁻¹]
- **i**: land cover class
- **X**: chemical compound
## Land cover classes and factors

<table>
<thead>
<tr>
<th>GLC2000 (14 out of 21 global classes)</th>
<th>BD kg/m²</th>
<th>BE</th>
<th>EF gCO/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>GLC01: Tree Cover, broadleaved, evergreen</td>
<td>23.35</td>
<td>0.25</td>
<td>104</td>
</tr>
<tr>
<td>GLC02: Tree Cover, broadleaved, deciduous, closed</td>
<td>20</td>
<td>0.25</td>
<td>107</td>
</tr>
<tr>
<td>GLC03: Tree Cover, broadleaved, deciduous, open</td>
<td>36.70</td>
<td>0.25</td>
<td>107</td>
</tr>
<tr>
<td>GLC04: Tree Cover, needle-leaved, evergreen</td>
<td>18.90</td>
<td>0.25</td>
<td>107</td>
</tr>
<tr>
<td>GLC05: Tree Cover, needle-leaved, deciduous</td>
<td>14.00</td>
<td>0.25</td>
<td>107</td>
</tr>
<tr>
<td>GLC06: Tree Cover, mixed leaf type</td>
<td>10.00</td>
<td>0.35</td>
<td>86</td>
</tr>
<tr>
<td>GLC09: Mosaic: Tree Cover/Other natural vegetation</td>
<td>1.25</td>
<td>0.90</td>
<td>65</td>
</tr>
<tr>
<td>GLC11: Shrub Cover, closed-open, evergreen</td>
<td>3.30</td>
<td>0.40</td>
<td>65</td>
</tr>
<tr>
<td>GLC12: Shrub Cover, closed-open, deciduous</td>
<td>1.43</td>
<td>0.90</td>
<td>65</td>
</tr>
<tr>
<td>GLC13: Herbaceous Cover, closed-open</td>
<td>0.90</td>
<td>0.60</td>
<td>77.7</td>
</tr>
<tr>
<td>GLC14: Sparse herbaceous or sparse shrub cover</td>
<td>0.44</td>
<td>0.60</td>
<td>92</td>
</tr>
<tr>
<td>GLC16: Cultivated and managed areas</td>
<td>1.10</td>
<td>0.80</td>
<td>70</td>
</tr>
<tr>
<td>GLC17: Mosaic: Cropland/Tree Cover/Other natural</td>
<td>1.00</td>
<td>0.75</td>
<td>73.8</td>
</tr>
<tr>
<td>GLC18: Mosaic: Cropland / Shrub and/or grass cover</td>
<td>1.25</td>
<td>0.90</td>
<td>65</td>
</tr>
</tbody>
</table>

(Liousse et al., 2009; Michel et al., 2005)

**BD range:** 1 – 36  
**BE range:** 0.25 -0.9  
**EF range:** 65 - 107
Year 2003: total CO emissions

Spatial distribution of CO emission [Tg] estimates for 0.5 x 0.5 degree cells over the globe

- VGT: 1422 Tg
- ATSR: 547 Tg
- MODIS: 769 Tg
- MOPITT: 594 Tg
Temporal dynamics of the emissions

Looking at the monthly CO emissions

VGT

MODIS

ASTR

VGT 2003 01

MODIS 2003 01

ATSR 2003 01
Looking at the monthly CO emissions

<table>
<thead>
<tr>
<th></th>
<th>VGT</th>
<th>MODIS</th>
<th>ATSR</th>
<th>MOPITT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly max</td>
<td>258</td>
<td>152</td>
<td>90</td>
<td>87</td>
</tr>
<tr>
<td>Year total</td>
<td>1422</td>
<td>769</td>
<td>547</td>
<td>594</td>
</tr>
</tbody>
</table>
Geographical distribution of emissions

Six continental windows used for the analysis (Boschetti et al., 2004)

<table>
<thead>
<tr>
<th>Region</th>
<th>VGT</th>
<th>ATSR</th>
<th>MODIS</th>
<th>MOPITT</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. America</td>
<td>276.60</td>
<td>48.07</td>
<td>19.20</td>
<td>25.48</td>
</tr>
<tr>
<td>Europe</td>
<td>87.85</td>
<td>7.33</td>
<td>13.16</td>
<td>9.33</td>
</tr>
<tr>
<td>N. Asia</td>
<td>559.15</td>
<td>139.49</td>
<td>241.64</td>
<td>101.96</td>
</tr>
<tr>
<td>S. America</td>
<td>121.74</td>
<td>93.08</td>
<td>35.59</td>
<td>121.89</td>
</tr>
<tr>
<td>Africa</td>
<td>302.69</td>
<td>201.63</td>
<td>367.38</td>
<td>274.83</td>
</tr>
<tr>
<td>Oceania</td>
<td>73.96</td>
<td>57.90</td>
<td>92.60</td>
<td>60.51</td>
</tr>
<tr>
<td><strong>GLOBAL</strong></td>
<td><strong>1422.0</strong></td>
<td><strong>547.50</strong></td>
<td><strong>769.56</strong></td>
<td><strong>594.00</strong></td>
</tr>
</tbody>
</table>

Co emissions

Percentage Co emissions
Seasonality of Northern Regions

**N. America**
- VGT: N. America
- ATSR: N. America
- MODIS: N. America
- MOPITT: N. America

**Europe**
- VGT: Europe
- ATSR: Europe
- MODIS: Europe
- MOPITT: Europe

**N. Asia**
- VGT: N. Asia
- ATSR: N. Asia
- MODIS: N. Asia
- MOPITT: N. Asia
Seasonality of Southern Regions
Seasonality agreement

- **Cell by cell** seasonal correlation of CO emissions

<table>
<thead>
<tr>
<th></th>
<th>ATSR</th>
<th>MODIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO (Tg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td>Feb</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Mar</td>
<td>0.003</td>
<td>0.004</td>
</tr>
<tr>
<td>Apr</td>
<td>0.005</td>
<td>0.006</td>
</tr>
<tr>
<td>May</td>
<td>0.007</td>
<td>0.008</td>
</tr>
<tr>
<td>Jun</td>
<td>0.009</td>
<td>0.010</td>
</tr>
<tr>
<td>Jul</td>
<td>0.011</td>
<td>0.012</td>
</tr>
<tr>
<td>Aug</td>
<td>0.013</td>
<td>0.014</td>
</tr>
<tr>
<td>Sep</td>
<td>0.015</td>
<td>0.016</td>
</tr>
<tr>
<td>Oct</td>
<td>0.017</td>
<td>0.018</td>
</tr>
<tr>
<td>Nov</td>
<td>0.019</td>
<td>0.020</td>
</tr>
<tr>
<td>Dec</td>
<td>0.021</td>
<td>0.022</td>
</tr>
</tbody>
</table>

\[ r = +0.95 \]

\[ r = +0.19 \]

\[ r = -0.34 \]
Forest and tree (GLC 1 to 9) land cover classes are major responsible as percentage

<table>
<thead>
<tr>
<th>Broad LC class</th>
<th>GLC codes</th>
<th>VGT</th>
<th>ATSR</th>
<th>MODIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadleaved forest</td>
<td>1, 2</td>
<td>359</td>
<td>163</td>
<td>278</td>
</tr>
<tr>
<td>Needleleaved forest</td>
<td>4, 5, 6</td>
<td>636</td>
<td>153</td>
<td>223</td>
</tr>
<tr>
<td>Mixed tree cover</td>
<td>3, 9</td>
<td>181</td>
<td>104</td>
<td>132.2</td>
</tr>
<tr>
<td>Savanna &amp; grassland</td>
<td>11, 12, 13, 14</td>
<td>203</td>
<td>104</td>
<td>104</td>
</tr>
<tr>
<td>Agriculture</td>
<td>16, 17, 18</td>
<td>43</td>
<td>22</td>
<td>32</td>
</tr>
</tbody>
</table>
Land cover and CO emissions

Percentage of spatial occupation by the GLC2000 land cover classes

- GLC 1 to 9: 40%
- GLC 11 to 14: 40%
- GLC 16 to 18: 20%

Percentage of CO emissions by the broad land cover classes

- VGT: GLC 1 to 9: 83%, GLC 11 to 14: 14%, GLC 16 to 18: 3%
- ASTR: GLC 1 to 9: 77%, GLC 11 to 14: 19%, GLC 16 to 18: 4%
- MODIS: GLC 1 to 9: 82%, GLC 11 to 14: 13%, GLC 16 to 18: 4%
Forest & tree land cover seasonality

Broadleaved forest (GLC 1, 2)

Needleleaved forest (GLC 4, 5, 6)

Mixed tree cover (GLC 3, 9)

Broad classes GLC2000 spatial distribution
Regional land cover

- Exceptionally high emissions by VGT in forest classes GLC02, GLC04 and GLC05
- Among the non forest classes, deciduous shrubs (GLC12) strongly contribute
- Contribution of forest classes at the northernmost latitudes
- Africa: good agreement in forest and non forest; source of emissions from deciduous shrubs
Specific land cover: forest

GLC-01 evergreen broadleaved forest

VGT 59
ATSR 45
MODIS 128

GLC-05 deciduous needleleaved forest

VGT 259
ATSR 54
MODIS 113
Specific land cover: savanna

GLC-12 closed / open deciduous shrubs

- VGT: 135
- ATSR: 63
- MODIS: 75

GLC-13 closed / open herbaceous cover

- VGT: 43
- ATSR: 37
- MODIS: 22
Conclusions

- At global level: 2003 CO emissions as estimated with VGT are 1.8 times higher than MODIS and 2.5 times higher than ATSR and MOPITT estimates.
- Emission peak for VGT and MODIS occurs in May, while for ATSR and MOPITT is between July and August.
- At regional level: large discrepancies in northern regions (Asia and America) compared with the southern ones.
- In South America for VGT and MOPITT CO emissions coincide (121 Tg).
- Good agreement also for Africa (VGT: 302, ATSR: 202, MODIS: 367 and MOPITT: 275 Tg).
- The best seasonal agreement is in Africa between ATSR and MODIS and MOPITT.
- At the Land cover level: Forest classes (GLC01 to GLC05) require particular attention due to the high biomass involved in burning.
Conclusions

- High VGT emissions (in disagreement with ATSR and MODIS) are observed in the deciduous needle-leaf forest (GLC05) in September/October 2003.
- The choice of one inventory over the other appears particularly critical in the northern regions.
- The intercomparison exercise should include emissions based on Fire Radiative Power (FRP/FRE) and other top-down approaches.

BBSO-2 Burnt Biomass and Satellite Observations workshop is planned for 18-19 November 2009 in Toulouse (France) bringing together specialists of fire products and atmospheric chemistry to understand how to correctly reproduce the global distribution of biomass burning and related emissions.

Should the future emission inventories be based on the integration (at regional or land cover level) of multiple BA / AF / FRE biomass burnt products?
Similarities and discrepancies …

Monthly Global CO emissions maps 2003

VGT

- \text{face/width} = \text{jan}
- \text{earlevel} = \text{feb}
- \text{hatface/height} = \text{mar}
- \text{upface/occ/centricty} = \text{apr}
- \text{lotface/occ} = \text{may}
- \text{neck/length} = \text{jun}
- \text{mouth/cent} = \text{jul}
- \text{mouth/curv} = \text{aug}
- \text{mouth/l = sep}
- \text{eyes/h = oct}
- \text{eyes/sep = nov}
- \text{eyes/slitant = dec}

ATS

MODIS

Thank you for your attention!

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