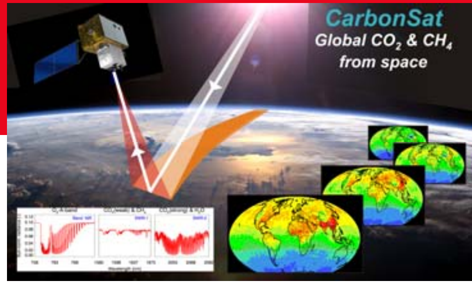
CarbonSat: Error analysis for XCO_2, XCH_4 and Vegetation Chlorophyll Fluorescence



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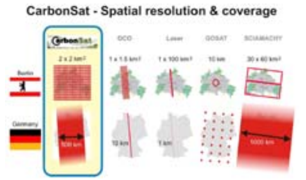
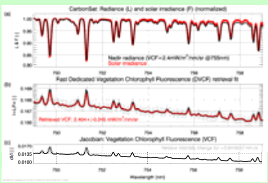
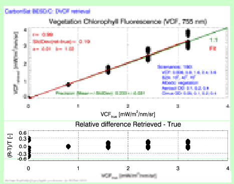


Abstract

Carbon Monitoring Satellite (CarbonSat) is one of two candidate missions for **ESA's Earth Explorer 8** (EE8) satellite - the selected one to be launched around the end of this decade. The objective of the CarbonSat mission is to improve our understanding of natural and anthropogenic sources and sinks of the two most important anthropogenic greenhouse gases (GHG) carbon dioxide (CO_2) and methane (CH_4). The unique feature of CarbonSat is its "**GHG imaging capability**"', which is achieved via a combination of **high spatial resolution (2 km x 2 km) and good spatial coverage** (wide swath and gap-free across- and along-track ground sampling). This capability enables global imaging of localized strong emission source such as cities, power plants, methane seeps, landfills and volcanos and better disentangling of natural and anthropogenic GHG sources and sinks. Source/sink information can be derived from the retrieved atmospheric column-averaged mole fractions of CO_2 and CH_4, i.e., XCO_2 and XCH_4, via inverse modeling. Using the most recent instrument and mission specification, an error analysis has been performed using the BESD/C retrieval algorithm. We focus on systematic errors due to aerosols and thin cirrus clouds, as this is the dominating error source especially with respect to XCO_2 systematic errors. To compute the errors for each single CarbonSat observation in a **one year time period**, we have developed an **error parameterization scheme** based on six relevant input parameters: We consider solar zenith angle, surface albedo in two bands, aerosol and cirrus optical depth, and cirrus altitude variations but neglect, for example, aerosol type variations. Using this method we have generated and analyzed one year of simulated CarbonSat observations. **Using this data set we estimate that scattering related systematic errors are mostly (approx. 85%) below 0.3 ppm for XCO_2 (< 0.5 ppm: 99.5%) and below 2 ppb for XCH_4 (< 4 ppb: 99.3%). We also show that the single measurement precision is typically around 1.2 ppm for XCO_2 and 7 ppb for XCH_4 (1-sigma). The number of quality filtered observations over cloud and ice free land surfaces is in the range 33-47 million per month depending on month.** Recently it has been shown that terrestrial Vegetation Chlorophyll Fluorescence (VCF) emission needs to be considered for accurate XCO_2 retrieval. We therefore retrieve VCF from clear Fraunhofer lines located at 755 nm and show that CarbonSat will provide valuable information on VCF. **The VCF single measurement precision is approximately 0.3 $mW/m^2/nm/sr$ (1-sigma).** As a first application of the one year data set we assess the capability of CarbonSat to quantify the CO_2 emissions of large cities using Berlin, the capital of Germany, as an example. **We show that the precision of the inferred Berlin CO_2 emissions as obtained from single CarbonSat overpasses is in the range 5-10 $MtCO_2/yr$ (10-20%).** We found that systematic errors could be on the same order depending on which assumptions are used with respect to observational and biogenic XCO_2 modeling errors.

Vegetation Fluorescence





Selected references

[1] Bovensmann, H. Buchwitz, M., Burrows, J. P., Reuter, M., et al., A remote sensing technique for global monitoring of power plant CO_2 emissions and related applications, Atmos. Meas. Tech., 3, 781-811, 2010.

Acknowledgements

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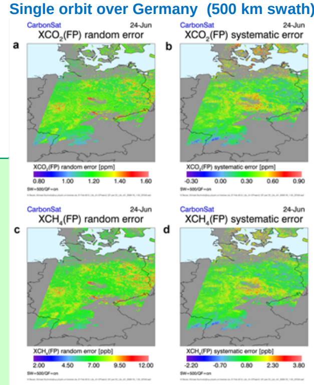
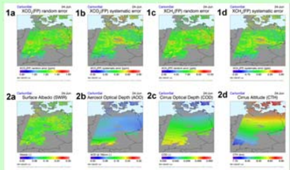
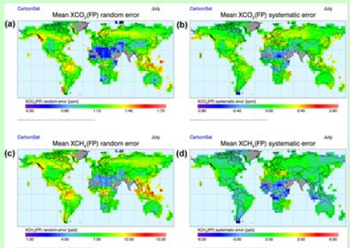
GHG results

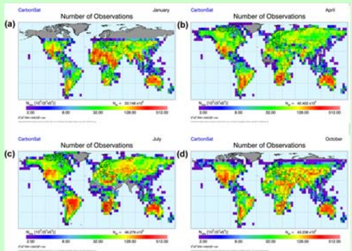
Single orbit over Germany (500 km swath)

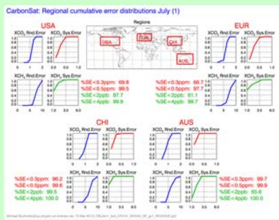




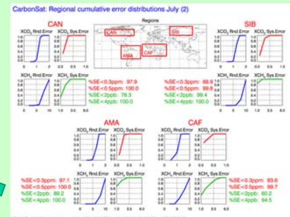
Monthly 5°x5° averages (240 km swath, snow & ice free land only)







Regional error distributions



Regional cumulative error distribution results							
Region ID	Region Name	Latitude [deg]	Longitude [deg]	Percentage of XCO_2 retrievals with systematic error		Percentage of XCH_4 retrievals with systematic error	
				< 0.3 ppm	< 0.5 ppm	< 2 ppb	< 4 ppb
USA	USA	+20 - +49	-130 - -70	69.8	99.5	87.7	99.9
EUR	Europe	+35 - +60	-15 - +30	66.7	97.7	81.1	99.7
CHI	China	+20 - +50	+80 - +125	96.2	99.6	99.5	100.0
AUS	Australia	-45 - -10	+110 - +160	99.7	99.9	65.6	100.0
CAN	Canada	+49 - +70	-140 - -50	97.9	100.0	78.3	100.0
SIB	Siberia	+50 - +80	+60 - +130	88.9	99.8	99.4	100.0
AMA	Amazonia	-30 - +15	-90 - -30	97.1	100.0	89.2	100.0
CAF	Central Africa	-20 - +20	-25 - +50	83.6	99.7	60.2	94.5
		Mean:		87.5	99.5	82.6	99.3
		Standard deviation:		11.5	0.7	12.7	1.7

Table 1: Regional cumulative error distribution results summarizing the percentages of errors less than a given value.

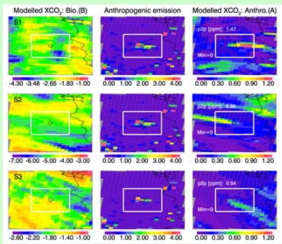
Berlin CO_2 emissions

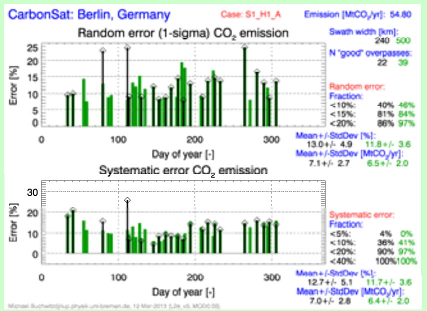
Berlin Scenarios			
Scenario	Berlin CO_2 emission [$MtCO_2$/yr]	Anthropogenic XCO_2 peak enhancement [ppm]	Comments
S1	[illegible]	1.47	Workday, wind speed [illegible] m/s
S2	[illegible]	[illegible]	Workday, wind speed [illegible] m/s
S3	[illegible]	[illegible]	Sunday, wind speed [illegible] m/s

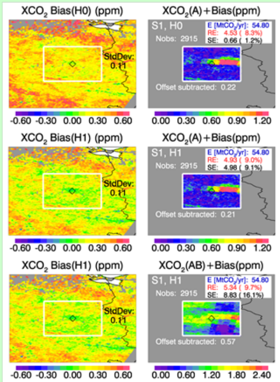
Table 2: Description of the three scenarios S1, S2, S3 as used for the Berlin emission inversion study. For each scenario the used anthropogenic (fossil fuel) CO_2 emission of Berlin is listed and the resulting XCO_2 enhancement above the XCO_2 background value. The last column reports the near-surface wind speed and if the scenario corresponds to a workday or not.

Berlin Anthropogenic CO_2 Emission Results					
				CO_2 emission error	
Case	Scenario	Systematic XCO_2 error	Biogenic XCO_2 Modeling error	Random (precision) [$MtCO_2$/yr]	Systematic (bias) [$MtCO_2$/yr]
S1_H0_A	S1	default (H0)	no (A)	4.53 (8.3%)	0.66 (1.2%)
S1_H1_A	S1	additional aerosol (H1)	no (A)	4.83 (9.0%)	4.98 (9.1%)
S1_H1_AB	S1	additional aerosol (H1)	yes (AB)	5.34 (9.7%)	8.83 (16.1%)
S2_H0_A	S2	default (H0)	no (A)	6.70 (12.4%)	-2.18 (-4.0%)
S2_H1_A	S2	additional aerosol (H1)	no (A)	7.24 (13.4%)	2.03 (3.8%)
S2_H1_AB	S2	additional aerosol (H1)	yes (AB)	9.45 (17.5%)	14.16 (26.3%)
S3_H0_A	S3	default (H0)	no (A)	5.87 (18.7%)	3.61 (11.5%)
S3_H1_A	S3	additional aerosol (H1)	no (A)	6.45 (20.6%)	6.10 (19.5%)
S3_H1_AB	S3	additional aerosol (H1)	yes (AB)	4.18 (13.3%)	-7.75 (-24.7%)

Table 3: Results of the Berlin emission study. The first column lists the "case" defined by the scenario (S1, S2 or S3; see **Table 2**), the assumed systematic error of the CarbonSat XCO_2 retrievals (H0 or H1; see below) and the assumed modeling error (A or AB; see below). The second column lists the used scenario. The third column reports which method has been used to compute the systematic XCO_2 error: The "default" error ("H0") is the error computed via an error parameterization method using the input parameters (cirrus, AOD, etc.). As the AOD input parameters are only available at quite low resolution, error "H1" contains an additional aerosol related error which correlates perfectly with the Berlin anthropogenic CO_2 emission plume (worst case scenario; see also Figure 15). This additional aerosol related error has been computed assuming ΔAOD(550 nm) = 0.2 per 1% (4 ppm) ΔXCO_2 enhancement, where ΔXCO_2 is the XCO_2 enhancement relative to the background due to anthropogenic CO_2 emissions. The fourth column lists which assumption has to been used with respect to biogenic XCO2 modeling errors: (A) means that it is assumed that the spatial pattern (not however the amplitude) of the anthropogenic CO_2 emission plume of Berlin can be accurately modeled in addition to accurate modeling of the spatial XCO_2 pattern due to biogenic emissions; (B) assumes the other extreme: here it is assumed that the biogenic pattern cannot be modeled at all resulting in a significant systematic error of the modeling of the spatial XCO_2 pattern. The last two rows list the random and systematic errors of inferred Berlin anthropogenic CO_2 emission derived from a single overpass of CarbonSat over Berlin.







Berlin Anthropogenic CO_2 Emissions: Time series analysis results					
		CO_2 emission error (Mean +/- Standard Deviation)			
Case	Number of "good" overpasses	Random error (precision)		Systematic error (bias)	
		[%]	[$MtCO_2$/yr]	[%]	[$MtCO_2$/yr]
S1_H0_A	22	11.8 +/- 4.4	6.5 +/- 2.4	3.6 +/- 4.4	2.0 +/- 2.4
S1_H1_A	22	13.0 +/- 4.9	7.1 +/- 2.7	12.7 +/- 5.1	7.0 +/- 2.8
S1_H1_AB	18	12.0 +/- 3.6	6.6 +/- 2.0	16.0 +/- 11.7	8.7 +/- 6.4
S2_H0_A	19	15.0 +/- 3.9	8.1 +/- 2.1	0.3 +/- 5.6	0.2 +/- 3.0
S2_H1_A	17	15.3 +/- 2.7	8.3 +/- 1.5	9.1 +/- 7.0	4.9 +/- 3.8
S2_H1_AB	13	18.2 +/- 3.5	9.8 +/- 1.9	25.1 +/- 8.6	13.5 +/- 4.6
S3_H0_A	10	19.4 +/- 2.7	6.1 +/- 0.9	7.1 +/- 8.2	2.2 +/- 2.6
S3_H1_A	9	21.2 +/- 2.6	6.6 +/- 0.8	17.1 +/- 9.5	5.4 +/- 3.0
S3_H1_AB	21	17.0 +/- 4.0	5.3 +/- 1.2	-30.6 +/- 16.4	-9.6 +/- 5.1

Table 4: Results of the time series analysis with respect random and systematic errors of the Berlin CO_2 emissions for all 9 cases obtained from analyzing the one year data set of CarbonSat XCO_2 error simulations (details for S1_H1_A see figure).

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