# FROM SCIENCE TO OPERATIONAL SERVICE - GLOBAL GREENHOUSE GAS MONITORING WITH THE CARBONSAT CONSTELLATION

Contact Author: Robert Ernst (1)
Co-Authors: Wei Sun (1), Heinrich Bovensmann (2), Michael Buchwitz (2), J. Notholt (2), John P. Burrows (2)

(1) OHB-System AG, Universitätsallee 27-29, D-28359 Bremen, Germany
Phone: +49 421 2020 8, Fax: +49 421 2020 700, www.ohb-system.de

(2) Institut für Umweltphysik (IUP), Otto-Hahn-Allee 1, D-28359 Bremen, Germany
Phone: +49 421 218 62170, Fax: +49 421 218 4555, www.iup.uni-bremen.de

**Abstract**

The recent IPCC Assessment Report 4 pointed out clearly that Carbon dioxide, CO2, and Methane, CH4, are by far the two most significant long lived greenhouse gases (GHG), being released to the troposphere by anthropogenic activity. The increase in atmospheric loading of these radiatively active gases is the dominant process driving global climate change. The key scientific issue is now to understand the current regional consequences of global climate change and to predict accurately the future changes. This is required for policymakers in respect of mitigation, adaptation and the management of ecosystem services in a changing climate. Surprisingly and in spite of their importance, our knowledge about their variable natural sources and sinks, which are determined by the underlying biogeochemical cycles and feedbacks, is inadequate. This results in large uncertainty in our prediction of global climate change and the impact on changing ecosystem services in addition to that recognized in IPCC AR4.CO2 monitoring and trading is often based on bottom-up calculations or even estimates with no independent top down verification. Due to the lack of global measurement data the top down verification is limited. SCIAMACHY, the first CO2 and CH4 mapping Instrument on ENVISAT shows that satellites are able to add valuable missing global information. So far GHG measurement satellites need to collect data over a long period to produce global regional fluxes products. This period is currently a year or even longer. Since consequently global, timely, higher spatial resolution is required the CarbonSat constellation idea comes up. CarbonSat origins from the resolution and swath width trade off during CarbonSat mission definition studies. A constellation of five CarbonSat satellites will be able to provide global, daily CO2 and CH4 measurement with high spatial resolution of only 2 × 2 km. To enable more reliable services associated with reduced uncertainty, e.g. to 0.3 ppm CO2 per month in 1000 km² and even more timely products, the constellation will provide unique global daily measurement capability and therefore significantly increased number of cloud free measurements.

The CarbonSat Constellation is proposed to be implemented through an internationally coordinated constellation. Each participating country contributes a full system consisting of a CarbonSat satellite and a ground station, which will be able to provide data for national applications. For the constellation operation, a central coordination centre will be set up to handle data calibration and international data distribution. For each partner this approach provides independence and financial feasibility. This international forum provides worldwide transparency of CO2 and CH4 emissions which is critical in supporting Kyoto protocol and upcoming international agreement in man-made Greenhouse emission reduction. The paper will present the CarbonSat Constellation build up through a multilateral collaboration comprising satellite design and proposed products / services to verify GHG sources and sinks.

## 1. INTRODUCTION

The recent IPCC Assessment Report 4 pointed out clearly that Carbon dioxide, CO2, and Methane, CH4, are by far the two most significant long lived greenhouse gases (GHG), being released to the troposphere by anthropogenic activity. The Kyoto protocol, which was meant to handle the consequences of GHG emission on our everyday life, will be expired in 2012.

In 2009 in Copenhagen, the international board failed to reach an agreement for a post Kyoto protocol. The UNFCCC Secretary in Cancun Mexico 2010 called for more information to “guide political discussions of the need to take difficult decisions on agreement among countries” The actions are 10 years overdue to avoid reaching the tip point in 2050.

Climate Change clearly is the major problem of the 21th

Century.

The global warming is mainly driven by the Greenhouse Gases CO2 and CH4. According to Intergovernmental Panel for Climate Change (IPCC) reports, CO2 accounts for ~60% and CH4 accounts for ~20 % of the Greenhouse Effect.

In the short time of human history, compared to the history of earth, the increase of CO2 in the pre-industrial times was equal to 1ppm / 200 years. Since industrialization the earth is now faced with an increase of 1-2 ppm / 1 year. The actual effect is correlated to a global temperature increase of already +0.8K. As stated from all parties involved in the Climate protocol actions the internationally agreed limit that should not be exceeded is set to +2K. A temperature increase beyond this limit will cause global severe issues leading to increasing incidence of droughts, occurrence of weather extremes, sea level rise and other severe consequences. Therefore a good understanding of the CO2 and CH4 sources and sinks is a absolutely mandatory for reliable climate prediction to maintain a stable global environment for all humankind.

Based on the IPCC 2007 statistic shown in Figure 1, the concentration over time and the correlation with global temperature and sea level increase is shown.

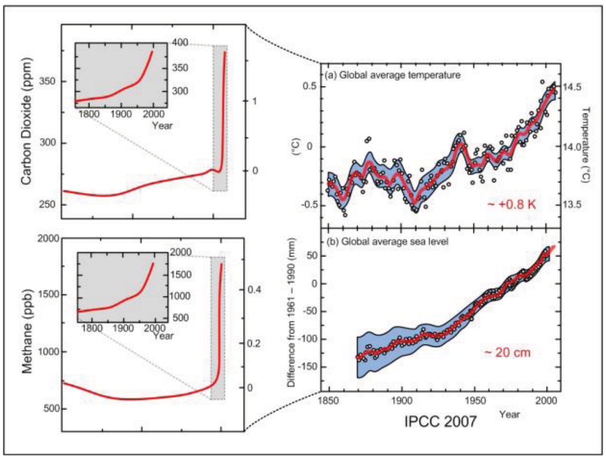


Figure 1. Intergovernmental Panel on Climate Change (IPCC) statistic (http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf)

Apart from the evident issue most of our knowledge about CO2 and CH4 sources and sinks on the global scale is derived from a globally sparse network of highly accurate and precise in-situ surface observations (e.g., NOAA ESRL). About 100 stations exist, with poor coverage in many important and interesting regions. These stations are only able to provide information on the CO2 or CH4 concentration in a very large regional scale such as continents and ocean basins. Recently the ground network has been expanded using spectrometers which measure the concentrations of gases in the air column above the sites. This network, Total Carbon Column Observing Network (TCCON), has been set up, e.g., to validate satellite column observations. Figure 2 shows the current location of the TCCON sites.

As a consequence our knowledge of the actual concentration possesses significant gaps for CO2 and CH4 sources and sinks.

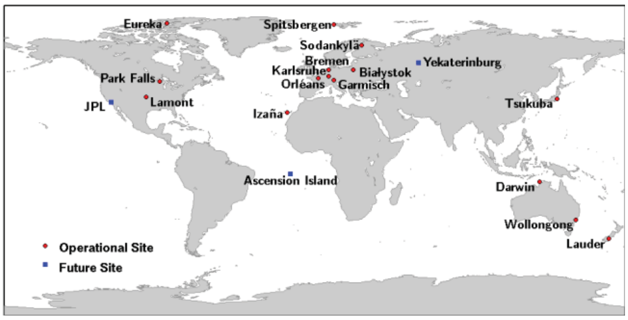


Figure 2. Total Carbon Column Observing Network (TCCON) 201 (http://www.tccon.caltech.edu/ )

As a consequence of the Kyoto protocol, some countries, especially European, implemented the Emission Trading System (ETS) to get hold of the increasing emission of CO2. It is a bottom up approach in which facilities above a certain level of emission have to report the CO2 amount produced within a year. These values of CO2 are used to divide the overall emission reduction goal (nationally) to all relevant emitting companies. The calculation of emission of each company is based on pre-set calculation rules. Still, this method neither covers the overall system behaviour nor the source and sink correlation. Most important, these rules are established nationally, which implies, that a global, transparent and agreed view on the emission is not existing.

Figure 3 shows the European 2007 CO2 emission report in the implementation of the Kyoto protocol.

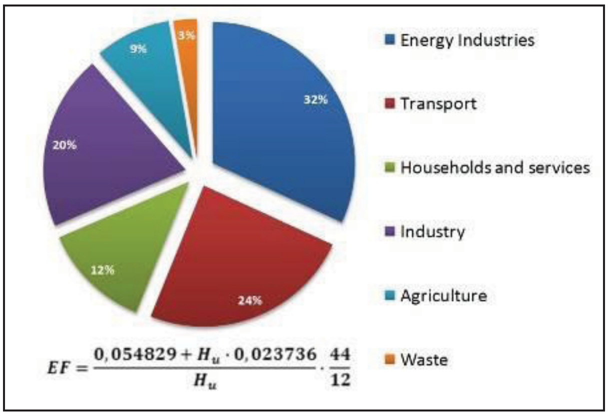


Figure 3. Reported 2007 CO2 Emission based on calculation (Source: European Environment Agency, based on provisional 2007 data)

Clearly, Kyoto protocol and upcoming international agreements also stimulate the need for global, independent, and transparent verification of sources and sinks, as the agreement on verified global emission data is the most crucial issue to prevent the global collapse.

## 2. GREENHOUSE GAS OBSERVATION MISSION MATURITY

Space systems can provide this global, no-intrusive, independent, transparent and operational monitoring of man-made and natural CO2 and CH4 emissions as well as CO2 sinks. They are able to allow the scientists and authorities to answer to the impacts of GHG emission on the Climate Change, can provide reliable emission status reports, in particularly strong local sources.

Space system are able to support treaty negotiation, verifying treaty obligation, certifying tradable permits, offsetting GHG emissions and providing more accurate inventories of emissions and offsets. The global information of space systems can be provided due to their global coverage.

First global measurements of CO2 and Methane are already obtained by the "Scanning Imaging Absorption Spectrometer for Atmospheric ChartographY" (SCIAMACHY) on ENVISAT satellite. SCIAMACHY which provided the first greenhouse gas measurements from space covers the relevant absorption bands of CO2, CH4, and O2, in the NIR/SWIR spectral regions; albeit at quite low spectral and spatial resolution. The number of cloud free observations is relatively small due to coarse spectral resolution.

As it is the first instrument of its kind, methodologies where developed in the years after launch in order to produce highly accurate CH4 and CO2 data products [Schneising et al. 2011). Apart from the initial issues with its high tech instrument, it has been demonstrated that the SCIAMACHY measurements, using inverse modelling, provide strong constraints on regional methane fluxes – information which cannot be obtained from the sparse ground based or aircraft observations.

SCIAMACHY covers a broad range of applications (stratospheric ozone chemistry, tropospheric air quality, etc.) and is not a dedicated GHG mission such as GOSAT and OCO-2, Very useful data products have been generated. Figure 4 shows an example of SCIAMACHY CO2 retrievals. This map bases on three years data collection by SCIAMACHY on ENVISAT.

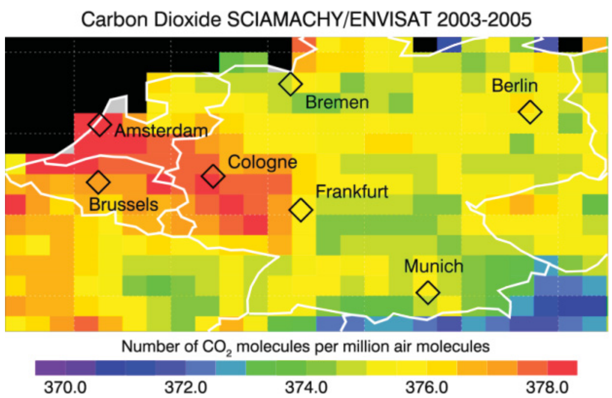


Figure 4. Regional CO2 map

## 2.1. CarbonSat

CarbonSat (Bovensmann et al. 2010) is proposed to be the follow on mission of SCIAMACHY. It is a dedicated mission to observe the amounts and distribution of CO2 and CH4, during a key period in the evolution of the Anthropocene. The instrument design will be based on the heritage of SCIAMACHY, GOSAT and OCO, exceeding the performance capabilities by far. Where SCIAMACHY provided a 30 x 60 km resolution, CarbonSat will be able to measure CO2 and CH4 with a dramatically increased ground resolution of 2x2 kilometres.

The CarbonSat instrument will follow the typology of the SCIAMACHY instrument. A spectrometer measures the reflected light energy in the selected spectral bands which are sensitive to CO2 and CH4. The concentration of CO2 and CH4 in the air column along the light path can then be derived from the measurements via absorption spectroscopy. The imaging spectrometers core sensors will image in NIR/SWIR wavelength. Spectral absorptions of CO2 (~1.6 µm and ~2 µm), O2 (~760 nm) and CH4 (~1.65 µm) are measured with high spectral resolution (~0.04-0.3 nm) and high signal-to-noise ratio (SNR).

The CarbonSat spectral bands are shown in Figure 5. The relative transparent band SWIR-1 delivers information on the columns concentrations of CO2 and CH4 with high near-surface sensitivity. Bands NIR and SWIR-2 contain strong absorption bands of O2 and CO2, respectively, and provide essential information on atmospheric scattering to correct for and additional information on aerosols and clouds as a by-product. They are needed for the conversion of the vertical columns into column-averaged mixing ratios (via O2) and to reduce scattering related errors caused by aerosols and clouds.

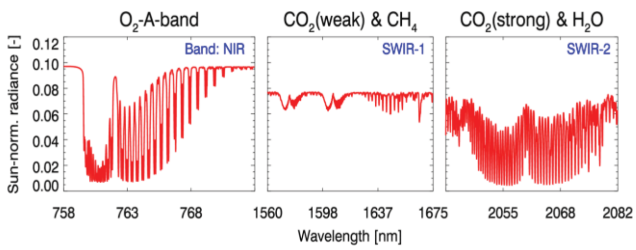


Figure 5. CarbonSat spectral bands

In addition, after the CO2 and or CH4 observing missions SCIAMACHY (2002-2013), GOSAT and OCO2 (2009-2014/15) there is high risk for an observational gap in the 2016-2020 time period, especially for CO2 but also for CH4. This is illustrated in Figure 6. CarbonSat can close this gap.

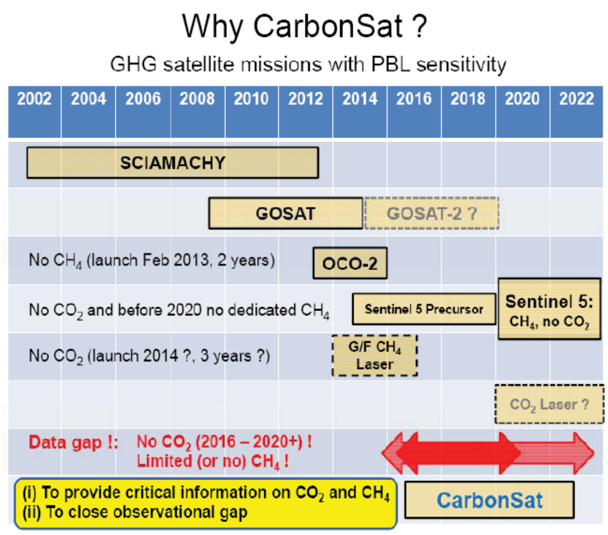


Figure 6. GHG satellite missions with PBL sensitivity

A comparison of missions with similar scientific objectives in Figure 7 shows, that none of the current or planned future missions can achieve two important and essential goals simultaneously (either high resolution or large swath width). CarbonSat achieves these goals with its high spatial resolution (2 x 2 km2) and good coverage (500km), which best meets the demand of a single satellite mission.

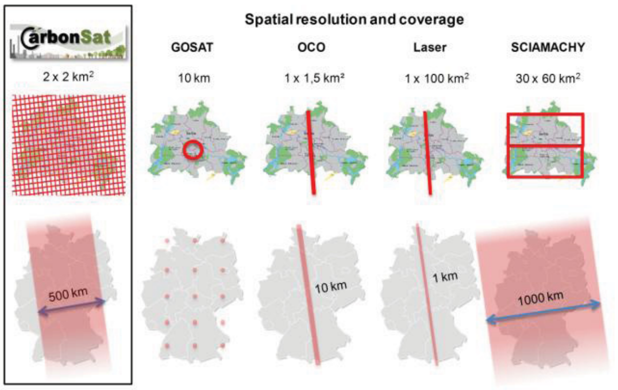


Figure 7. Comparison of missions with similar scientific objectives as CarbonSat

To provide more reliable and timely operational services the CarbonSat concept includes the extension to a multi satellite mission.

Within initial feasibility and sensitivity studies, it could be demonstrated that the CarbonSat concept is feasible to fulfil key mission requirements (Bovensmann et al. 2011).

In parallel to that, airborne instrument development of MAMAP (Gerilowski et al 2011) and the application of the airborne instrument to test power plant emission monitoring with real data (Krings et al. 2011) demonstrates the maturity of the chosen approach.

## 2.2. CarbonSat Constellation

The baseline space segment consists of 5 CarbonSat Conventional Satellites, which were identified and analysed in previous studies. Within these studies the basis for a constellation design was laid.

The target of the constellation design is to provide daily global CO2 and Methane measurements everywhere on Earth. A constellation of 5 CarbonSat (with ~500km swath width instruments) satellites is required to meet this design target. With 5 satellites, the constellation will be able to measure any point on the Earth once per day with some gaps in the equator but more frequent measurements on higher latitudes. The combined ground coverage of the constellation is equal to 2500 km on ground, obtained in a single orbit phase, leading to a 98% global coverage per day. This is sufficient to provide global, more frequent, high resolution and accuracy improved measurements.

The CarbonSat constellation will orbit in an altitude of ~800 km on a single orbital plane with an LTAN 13:30.

Using these parameters, CarbonSat constellation will be able to significantly reduce the CO2 measurement uncertainty. The system design will allow to achieve less than 1ppm accuracy on the CO2 pinpoint measurement which is the requirement defined by IPCC for the first time. Subject to the cloud and wind statics, the constellation is able to deliver much more timely data:

- For CH4, the constellation will be able to deliver global updates at accuracy 7kt/y once per month to once per half year, in average, once per three months.
- For CO2, the constellation will be able to deliver global updates at accuracy 1Mt/y once per month to once per half year, in average, once per three months

It is expected that many new applications could be made available by the CarbonSat Constellation data which have to be further evaluated.

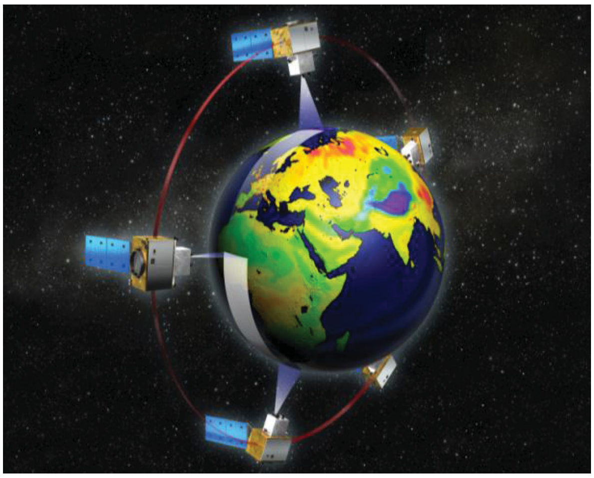

Figure 8. Satellite constellation observing the earth

The ideal deployment of the constellation will be to launch all satellites equally spaced in the same orbit using one dedicated launcher. It is easy to manage with funding for all five satellites come from the same source; however, an internationally coordinated constellation has its attractions. The organisation itself is naturally “global and independent”. Therefore, a deployment of the satellites with one launch manifest per satellite is by far more realistic. The low mass range of CarbonSat will allow to use several small launcher concepts.

With members from both developed and developing countries, it will be possible to encourage knowledge and technology transfer and help to establish common understandings of the climate change. The member of the CarbonSat Constellation Consortium will be able to access the entire constellation and its operational services through the investment on only one satellite, which is financially more feasible for most of nations.

The constellation deployment will be coordinated by the CarbonSat Constellation Consortium. Each participating satellite will be controlled by its own ground station for national applications. To provide global daily coverage the Constellation Coordination Centre (CCC) coordinates the constellation operation (incl. calibration) and international data distribution. The constellation coordination is to assure permanently an optimal coverage of earth even in case one satellite is not available (e.g. due to maintenance) and to keep all satellites on track for best constellation data output.

The payload on the satellite is able to monitor in two modes. Primary mode is the Nadir mode, which accounts for all landmasses. The secondary mode is the Sun-Glint mode, in which the instrument is pointing to the reflective point of the sun light over ocean area. Pointing on the Sun-Glint allows having a better reflection signal over ocean and will give reasonable information about the CO2 and CH4 fluxes impacting the oceanic environment. The mission planning unit is encapsulated in the processing chain of the ground segment to allow exclusive access to the space segment for the scientists who are working on the data output of CarbonSat. The collected data is downloaded during every orbit within every ground station overpass. As CarbonSat is proposed to use steerable X-Band antennas, data download can be performed independently from payload activities.

## 3. GROUND SEGMENT

The collected raw data from the satellites will be processed and automatically stored within the Payload data ground segment. The data of a single CarbonSat can then be used to process certain products. I direct stream of the raw level0 data of all satellites will be send to the international “Carbon Centre” (CC). The CC will then be able to process the gathered raw data to produce the high level CO2 and CH4 Emission global flux maps and hot spot results, with advanced precession and high time resolution. Making use of the data of all satellites in the constellation, the resulting data packages will have outstanding quality.

The CC will as well make use of external sources of data, like for example GOSAT, OCO, SCIAMACHY, Airborne and in Situ measurements, to even extent the information content. To identify possible scenarios for the setup of the ground segment architecture the overall system is split into functional units. The single elements can be seen in the Figure 9.

The overall Ground Segment is divided into three main fields; first, the field that covers the data acquisition domain where all satellite related functionalities are included, second, the payload data processing functionalities and third, the information services. This allows for a separation of the functions that are directly space related from the data processing and geo-information domain.

The possible scenarios for the realization of the final architecture are built from the single elements in different combinations.

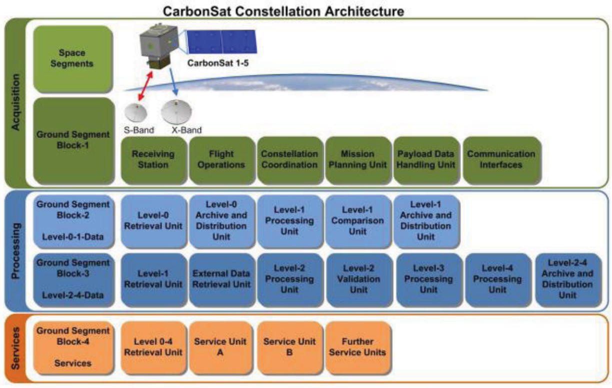


Figure 9. CarbonSat Constellation Architecture

It is important to notice that the Block 1 shown in the Figure 9 above has been decided to introduce a strict border between those elements that have some kind of direct access or impact to the space segment. No element below Block 1 directly “communicates” with the space segment, although some units of Block 2 and 3 of course provide information for the planning and mission control units.

The units presented are functional units. It is possible that units are combined to allow for synergies. For example the archive units could be included into one system that provides the functions of all single units.

## 4. EXAMPLE PRODUCTS

### 4.1. Data Level Definition

Level 0: Raw data

Level 0 data are basically the original raw data as send from the satellite. This includes the detector readouts in binary units (counts) and auxiliary data such as time information, orbit information, and information from various sensors such as temperature sensors. Reconstructed unprocessed instrument/payload data at full resolution; any and all communications artefacts (e.g., synchronization frames, communications headers) removed.

Level 1: Calibrated and geo-located radiances

Level 0 data are processed on ground to Level 1. Two Level 1 data products will be available: Level 1b and Level 1c. The Level 1b data product (one file per consolidated orbit) contains the un-calibrated but geo-located spectra and calibration parameters needed to calibrate the spectra. The calibration parameters are however not yet applied. Level 1c is the calibrated data product.

Level 2: Geophysical data product for individual readouts ("swath data")

Derived geophysical variables at the same spatial resolution and location as the Level 1 source data. The Level 1c data are converted to Level 2 using retrieval algorithms. This data product provides the information on the atmospheric trace gas total columns at ground pixel resolution.

Level 3: Geophysical data product after spatio-temporal averaging ("maps")

Variables mapped on uniform space-time grid scales (“maps”), usually with some completeness and consistency.

Level 4: Surface fluxes

Model output or results from analyses of lower level data (i.e., variables derived from multiple measurements).

## 4.2. PRODUCTS

Level 1:

The Level 1b data will be delivered to users together with tools that allow conversion of Level 1b data to calibrated and geo-located spectra, i.e., the Level 1c data product.

The conversion depends on various flags for the different calibration options which have to be chosen by the user. Examples are options to use radiometric calibration or wavelength calibration. This makes sense only for educated users.

For the operational stream consistent Level 1c data for the whole constellation is the overall goal.

Level 2:

- Dry-air column-averaged mixing ratio of CO2, denoted XCO2, in part per million (ppm) plus error estimate and averaging kernel information
- Dry-air column-averaged mixing ratio of CH4, denoted XCH4, in part per billion (ppb) plus error estimate and averaging kernel information
- Total column of CO2 in molecules/cm2 plus error estimate
- Total column of CH4 in molecules/cm2 plus error estimate
- Auxiliary information such as: measurement time, ground pixel centre and corner coordinates, solar zenith angles (zenith and azimuth), scan angles (zenith and azimuth), nadir / sun-glint observation flag, and a-priori vertical profiles, cloud information, quality flags etc.

Level 3:

- Gridded maps (e.g., 0.5 deg x 0.5 deg and/or 0.1 deg x 0.1 deg) of daily, weekly and/or monthly data
- XCO2, XCH4, error estimates, standard deviation, and number of data points averaged, etc.

Level4:

- Regional scale CO2 flux maps at different resolutions (e.g. 8 deg x 10 deg weekly and/or 4 deg x 5 deg monthly)
- Regional scale CH4 flux maps at different resolutions (e.g. 8 deg x 10 deg weekly and/or 4 deg x 5 deg monthly)
- CO2 hot spot emission data product for various localized emission sources including power plants
- CH4 hot spot emission data product for various localized emission sources including pipeline compressor stations, vented CH4 from coal mining activi-ties, large waste disposal sites, geological sources (e.g. seeps, mud volca-noes) etc.

The data products described above will be the basis of the CarbonSat services. Envisaged services can be subdivided in data delivery services and information services.

For example, Velazco et al (2011) demonstrated using synthetic CarbonSat data, that annual coal-fired power plant emissions of the US could be idependently verified with random errors smaller then 6% for power plants > 5 MtCO2/yr. In addition, as shown in figure XX below, even single emitters can be detected and the year-to-year variability in emissions can be monitored and verified with good precision (Velazco et al. 2011).

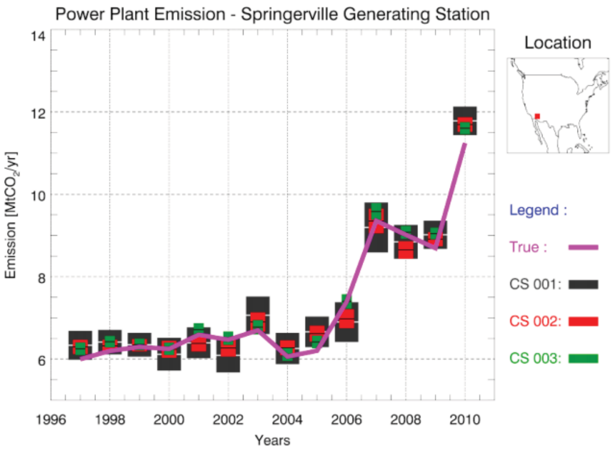


Figure 10. Annual emissions from the Springerville generating station in Arizona, USA (1997–2010). The yearly (true) emissions are denoted by the magenta line. The simulated measurements from three different CarbonSat constellation configurations are represented by the bars (color coded) CS 001: single CarbonSat, C2 002: 5 CarbonSat’s at different local time overpasses, CS003: 5 CarbonSat’s, all 13:30, daily global coverage at the equator. The heights of the bars represent the random errors for the annual emission estimate (details see Velazco et al. 2011).

Data delivery services will comprise:

- Delivery of Level 1 data products
  - Calibrated spectra and errors stored per orbit
  - Can be tailored in geolocation and temporal coverage to user needs
- Delivery of Level 2 data products
  - Retrieved data e.g. XCO2 and errors stored per orbit
  - Can be tailored to user needs by adapting geolocation and times, e.g. all data over Bremen within 50 km radius as function of time.
- Delivery of Level 3 data products
  - Global or regional maps of greenhouse gas concentration for different gridding resolution on different time scales (weekly, monthly or annual means)
  - To be tailored to in space and time to user needs
- Delivery of Level 4 data products
  - Flux maps [gC/m²/year] at different resolution
  - Emission trends [GtC/year] for regions or point sources.

- To be tailored to in space and time to user needs

Information services will comprise:

- Development of special data products for dedicated users
- Support in using and interpreting the data products
- Training to use CSC data products
- Dedicated information services for the public and industrial sector
  - Monitoring trends in fluxes for regions, cities, industrial areas and facilities,
  - reporting about newly identified emission hot spots,
  - independent verification of emission reduction measures,
  - monitor how fluxes change in a changing climate
  - support treaty verification etc.

Products and Services of the CarbonSat Constellation are for example high resolution CO2 Concentration maps and Hot Spot monitoring of emissions as shown in Figure 11. These products include the Hot Spot observation of for example Power plants, Steelworks, Cities and Volcanoes.

Figure 11. Example of high resolution CO2 map (Oda and Maksyutov, 2009)

Figure 12 shows a CH4 observation example of CarbonSat Constellation, providing high resolution Methane maps as well as Hot Spot measurements of for example pipelines, compressor stations, landfills, seeps, oil & gas Fields, and mud volcanoes.

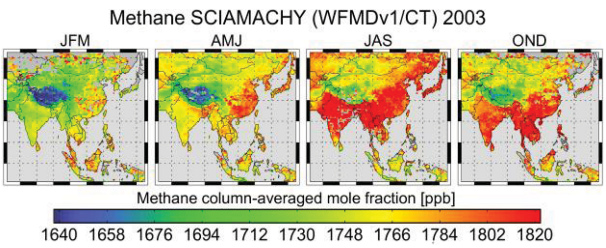


Figure 12. Example of high resolution Methane maps (SCIAMACHY / IUP)

## 5. CARBONSAT DESIGN

For the CarbonSat mission, a mission highly dependent on finding a cost-effective solution but still providing high class measurement data, OHB-System proposes to make use of its EnMAP platform. The platform is already today in an advanced development status, thus enabling lower development time and cost for CarbonSat.

EnMAP results as the best heritage baseline, providing precise pointing, orbit propulsion, flexible payload resources for power, mass and volume. Also the CarbonSat schedule constraints for launch in 2014 lead to the selected platform concept, since the EnMAP project is already in its realization in Phase C/D and currently performing the CDR . The EnMAP satellite will be operational in 2013 with mission duration of 5 + 2 years. The satellite will operate in an SSO orbit of 643 km and have a mass of about 850 kg. EnMAP's satellite platform is based on the space proven SAR-Lupe platform having five satellites in orbit with a cumulative in-orbit life time of >13 years. With this platform OHB-System is able to offer a very suitable and cost effective satellite platform for accurate, high resolution Earth observation purposes.

High spectral resolution requirements and necessity to detect CH4 and CO2 gasses with high accuracy lead to the design with three spectrometer units, which is a baseline for the conventional payload. The spectrometer units, named NIR, SWIR-1 and SWIR-2, are designed for spectral regions around 760nm, 1600nm and 2060nm accordingly.

The presence of clouds and aerosols in the atmosphere can degrade accuracy of gas measurements and therefore has to be accounted for. The Cloud and Aerosol Imager (CAI) detects affected areas by observing in several spectral bands the same swath as the CarbonSat spectrometers. Spectral bands are chosen to provide the best sensing of different types of clouds.

CAI comprises a telescope similar to the telescope of the spectrometer payload and detector with a number of filters in front of it. Such design has relatively small dimensions and allows combining the CAI instrument with any other payloads.

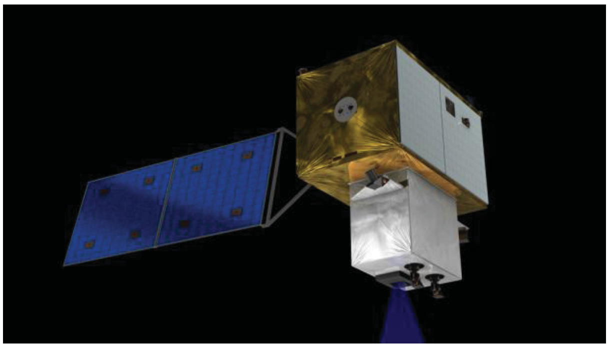

Figure 13. Example of CarbonSat Layout

The preliminary S/A baseline design for the CarbonSat mission will use sun pointing solar panels driven by a SADM. It is hence concluded that a Nadir side mounting is the best choice for the CarbonSat mission, being based upon the EnMAP P/F capabilities.

Sun-glint imaging does not occur too often and is not a standard operation mode, like the Nadir pointing mode (Nominal), and has to be treated as a deviation from the nominal pointing. Hence, the S/C will nominally keep a Nadir profile, due to the fact that it is there where most of the observations are performed.

Once the Sun-glint point no longer fulfils all restrictions, the FOV needs to return to its nominal Nadir pointing profile.

With spacecraft pointing, CarbonSat no longer maintains a Nadir pointing profile at all times, but rather slews itself so that the FOV points towards the Sun-glint. As a result, no pointing mirror is required and the instrument becomes less complex and the total system cost goes down.

Figure 14 shows the major/main constituents of the satellite in an exploded view. The P/L and the optical bench, together with a surrounding envelope, are illustrated. Two star trackers are also mounted on the optical bench which in turn is attached to the P/F.

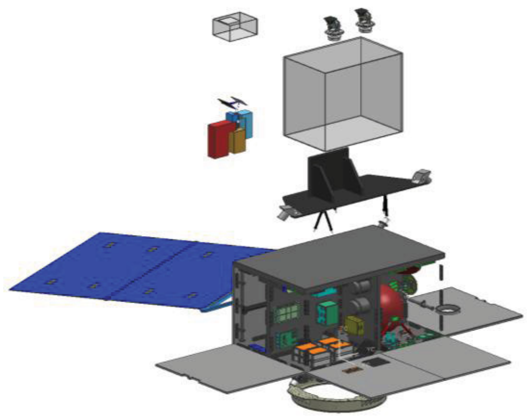

Figure 14. Exploded view of the CarbonSat S/C

Figure 15 depicts a close-up view of a first estimate of the P/L compartment configuration. It shows the 3 detectors (NIR, SWIR-1 & SWIR-2) and Cloud Imager (CAI) mounted vertically. On top, there is the instrument slit assembly that focuses the incoming light (coloured in blue) into the different units. The green marked units are Beam Splitters. Surrounding the entire set-up is a protective envelope. This envelope is not attached to the Optical Bench (although the detectors and Pointing Mirror are); rather it is mounted directly on the P/F. On top of the envelope there is mounted 2 Antenna Pointing Mechanisms. The envelope has been made transparent for better understanding; it is to be, just like the P/F, covered with Multi Layered Insulation (MLI).

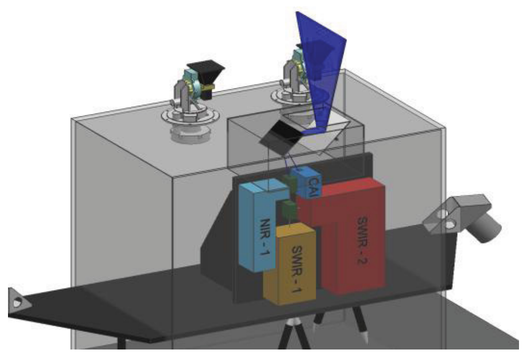


Figure 15. Close-up view of the P/L compartment (preliminary estimate)

| Budgets including margin | |
|---|---|
| Mass [kg] | 704 + 62 propellant |
| Peak Power [W] | 503 |
| Standby Power [W] | 406 |
| Volume Spacecraft [m] | 1.8 x 1.96 x 1.17 |
| Size of Solar Panel [m²] | 4.68 |
| Data per Orbit [Gbit] | 175 uncompressed |
| X-Band Downlink [Mbit/s] | 320 |

Table 1. Budgets of conventional design

## 6. CONCLUSION

CarbonSat is first, leads the CO2 and Methane monitoring from demonstration to operational service. It is, based on experience from SCIAMACHY, optimized for CO2 and Methane monitoring with significant increased spatial resolution, enabling Hot Spot measurements of for example power plants, steelworks, cities and volcanoes. It achieves a high spatial resolution (2 x 2 km2) and good coverage (500km) simultaneously, which best meets the demand of a single satellite mission.

With the extension to a constellation of five CarbonSat satellites, the combined ground coverage of the constellation leads to daily global coverage. CarbonSat constellation will significantly reduce the CO2 and CH4 measurement uncertainty and be the first to achieve less than 1ppm accuracy on the CO2 pinpoint measurement which is the requirement defined by IPCC.

With respect to the urgent need of a global greenhouse gas observation system, it is the best solution to provide reliable, transparent, global and fast information of the two most important greenhouse gases.

It enables a better understanding of regional and local sources and sinks of CO2 and Methane to contribute to a more reliable climate change predictions and in addition to support the Kyoto protocols and upcoming international agreements. It will be able to provide independent and non-intrusive CO2 and Methane emissions verification with transparency and therefore helps on reaching.

References:

Bovensmann, H., Buchwitz, M., Burrows, J. P., Reuter, M., Krings, T., Gerilowski, K., Schneising, O., Heymann, J., Tretner, A., and Erzinger, J.: A remote sensing technique for global monitoring of power plant $CO_2$ emissions from space and related applications, Atmos. Meas. Tech., 3, 781-811, doi:10.5194/amt-3-781-2010 , 2010.

Gerilowski, K., Tretner, A., Krings, T., Buchwitz, M., Bertagnolio, P. P., Belemezov, F., Erzinger, J., Burrows, J. P., and Bovensmann, H.: MAMAP – a new spectrometer system for column-averaged methane and carbon dioxide observations from aircraft: instrument description and performance analysis, Atmos. Meas. Tech., 4, 215-243, doi:10.5194/amt-4-215-2011 , 2011.

Krings, T., Gerilowski, K., Buchwitz, M., Reuter, M., Tretner, A., Erzinger, J., Heinze, D., Burrows, J. P., and Bovensmann, H.: MAMAP – a new spectrometer system for column-averaged methane and carbon dioxide observations from aircraft: retrieval algorithm and first inversions for point source emission rates, Atmos. Meas. Tech. Discuss., 4, 2207-2271, doi:10.5194/amtd-4-2207-2011 , 2011.

Schneising, O., Buchwitz, M., Reuter, M., Heymann, J., Bovensmann, H., Burrows, J. P., Long-term analysis of carbon dioxide and methane column-averaged mole fractions retrieved from SCIAMACHY, Atmos. Chem. Phys., 11, 2881-2892, 2011.

Velazco, V. A., Buchwitz, M., Bovensmann, H., Reuter, M., Schneising, O., Heymann, J., Krings, T., Gerilowski, K., and Burrows, J. P.: Towards space based verification of $CO_2$ emissions from strong localized sources: fossil fuel power plant emissions as seen by a CarbonSat constellation, Atmos. Meas. Tech. Discuss., 4, 5147-5182, doi:10.5194/amtd-4-5147-2011 , 2011.