GEO "Global Monitoring of Greenhosue Gases from Space" Task
CEOS High Profile Publication

The concentration of the greenhouse gases are increasing every year and the atmospheric temperature rises from year to year. To monitor the greenhouse gases, the in situ monitoring stations such as the ground stations, observation ships, airplanes and satellites have been used. As of this moment, Satellites are only means to obtain global coverage. And the ground segments are not able to provide global data but their data are useful as the reference data for the validation. Global Monitoring of Greenhouse Gases from Space (GMGGS) aims to build the global monitoring system of greenhouse gases and CEOS assumes the space segments and coordinate the requirement for the greenhouse gases observation from space.

1. Increase of the Greenhouse Gases and Global Warming

The concentrations of CO_2 and CH_4 in the atmosphere are higher now than at any time in the past 20 million years. Current levels of CO_2 have increased nearly 40% from pre-industrial levels of about 280 ppm to more than 386 ppm today, and they continue to rise at about 2 ppm per year.

Current levels of CH_4 of over 1800 ppb are two-and-a-half times the preindustrial value of 700 ppb. After a decade of stability, CH_4 has recently begun rising again.

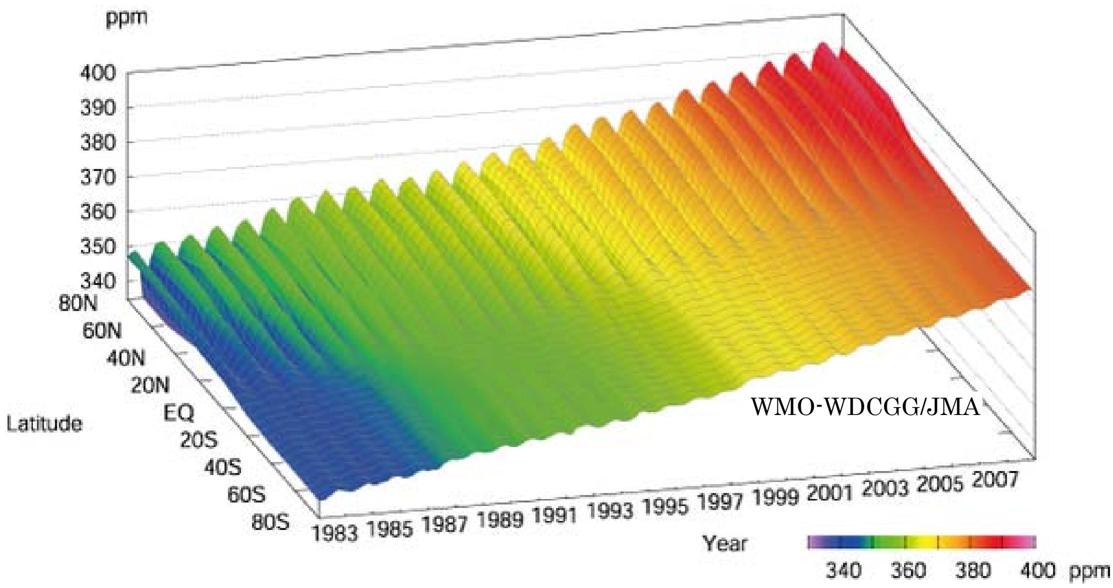


Figure 1. *Variation of zonally averaged monthly mean CO_2 mole fractions calculated for each 20 degree zone (Image credit:WMO WDCGG/JMA)*

The main causes of the observed increase in CO_2 are fossil fuel combustion and modifications of global vegetation through deforestation, and changes in land use and agricultural management. The amount of CO_2 released each year through fossil fuel burning alone, continues to increase exponentially. In 2008, 8.7 Pg C were emitted. An estimated 0.5-2.5 Pg C per year were also emitted from deforestation and land-use change during that year. Emissions rose sharply between 2000 and 2008 reflecting increasing per capita emissions, with emerging economies contributing the largest share of the increase; coal burning was the dominant source of the increased emission.

Almost half of the total anthropogenic CO_2 emission accumulates in the atmosphere; the rest is absorbed by sinks in the ocean and terrestrial ecosystems. These natural sinks thus provide a discount of around 50% on the potential greenhouse effect caused by increasing CO_2 emission. The ocean takes up some 2.2 Pg C per year and soils and vegetation 2.7 Pg. The global magnitude of these sinks is uncertain,ven more so their patterns in time and space.

Natural CO_2 sink strengths vary with weather and climate. The large global climate perturbations driven by events such as El Niño or volcanic eruptions exert a strong influence on the exchange of CO_2. Regional climate anomalies such as the 2005 drought in Amazonia, or the 2002 and 2003 droughts in North America and Western Europe can cause the land biosphere to switch from being a sink of carbon to being a temporary source.

After being stable for the past decade, CH_4 concentration started to increase again early in 2007. The CH_4 emissions include man-made sources reflecting the use of fossil fuel, waste decomposition in landfills, livestock production and rice cultivation, as well as natural sources such as wetlands, termites and wildfire. These sources are sensitive to both socioeconomic drivers and climate variations. The spatial distribution of CH_4 fluxes is highly uncertain. The atmospheric chemistry cycle of CH_4 is quite unlike that of CO_2. Hydroxyl radicals (OH) remove CH_4 from the atmosphere on a time scale of eight years, a process that is also sensitive to climate change, through chemical reactions in the atmosphere. Therefore, a small change in CH_4 sources or in the chemical sink can tip the CH_4 budget out of balance.

2. The purpose of GMGGS Task

With the advent of the technical means to provide new monitoring and measurement of GHGs from space in 2009, CEOS has identified the coordination of these measurements and their application as a top priority for the coming years. NASA, NOAA, ESA and JAXA have agreed to work to establish the necessary international framework to facilitate this coordination, aimed at access to the data, its application, and security of future supply.

In 2009 GEO established the Global Monitoring of Greenhouse Gases from Space

(GMGGS) Task to foster the use of space-based greenhouse gas (GHG) observations and consolidate data requirements for the next-generation GHG monitoring missions, to establish an international group in close cooperation with the CEOS Atmospheric Composition constellation and the Carbon Cycle Community of Practice, to initially generate and implement plans for the end-to-end utilization of space-based GHG data and to coordinate these efforts with ground-based systems for validation and build upon, as appropriate, existing observations and products to date – from satellites (e.g. GOSAT, SCIAMACHY and AIRS), aircrafts, and surface-based instruments (in-situ and total column).

The task will create a synergistic strategy for easy access to GHG satellite observations, and to harmonise the next generation of GHG satellite observations. The task will pursue the technical and organisational progress required for the application and integration of results with those of the other GEO Carbon CL-09-03 tasks, to which it is closely linked CL-09-03a (Integrated Global Carbon Observations (IGCO)) and CL-09-03b (Forest Carbon Tracking). To ensure the necessary coordination and integration of outcomes of these tasks, the task will also serve as a vehicle for the purposes of coordinated reporting to CEOS and GEO. To facilitate this function, and to raise the profile and priority of all 3 Carbon tasks within GEO, the task will establish an international coordination Task Force within the CEOS structure (and reporting to SIT with the other GEO tasks which CEOS leads). This Task Force will work with, and seek to ensure maximum synergies from, the various initiatives within CEOS contributing to the GEO Carbon tasks – including within the CEOS Virtual Constellations and Working Groups.

3. Current Status of the Greenhouse gases observation

The stationary measurements of the atmospheric greenhouse gases are in execution by the Global Atmosphere Watch(GAW) programme of WMO and so on, and the GAW data are gathered and preserved by the World Data Center for Greenhouse Gases (WDCGG) operated by Japan Meteorological Agency (JMA). The data also include the one which are acquired by ocean station vessels and Buoys, airplanes of JAL. The stationary measurements points are over 300. But These measurement points are unevenly distributed and there are a lot of data gaps.

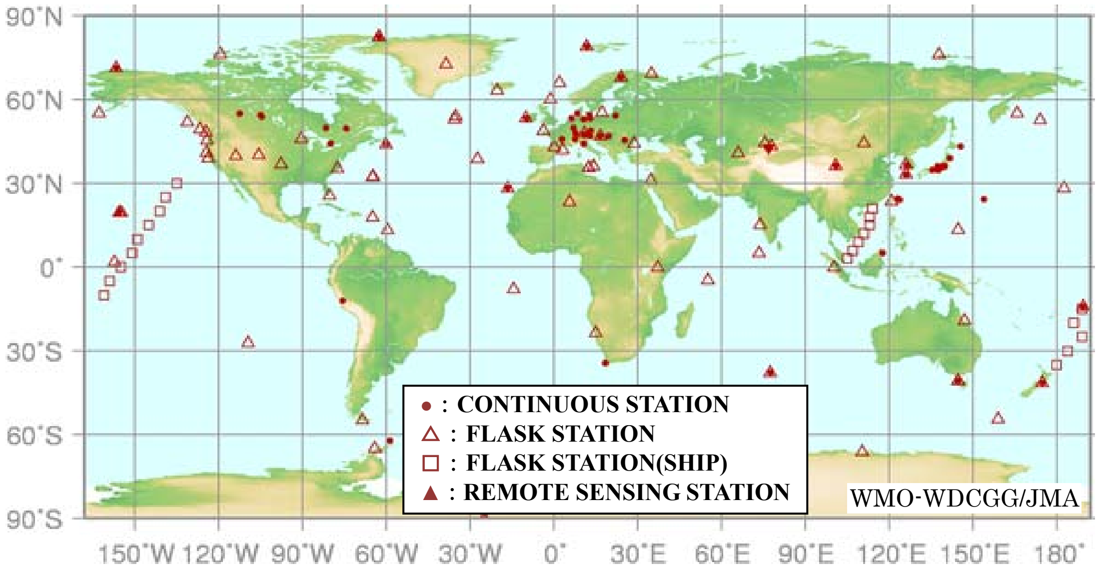


Figure 2. Location map of the sites from which the monthly mean CO_2 mole fractions are submitted

(Image credit:WMO WDCGG/JMA)

To take hold on the increase and decrease of the atmospheric greenhouse gas concentraion and to bring out the anthropogenic greenhouse gas budget, it is necessary to collect a lot of data on the global distribution of the greenhouse gases as well as to improve the accuracy of a variety of models.

Especially it is necessary to distinguish natural flux to take hold on the anthropogenic greenhouse gas flux. The stationary measurement points are unevenly distributed, especially there are very few measurement points on the ocean.

At the same time, the satellite can measure the greenhouse gases concentration globally and evenly.

And this data acquired by the satellite are useful for the improvement in the variety of models which are needed to calculate the carbon flux.

4. GEO Carbon Task and CEOS Carbon Task Force

GEO Carbon Task goal is to implement a global carbon observation and analysis system addressing the three components of the carbon system, that is, atmosphere, land and ocean.

GEO Carbon Task consists of the following three sub-tasks.

-Integrated Global Carbon Observation (IGCO) (CL-09-03 a)

-Forest Carbon Tracking (FCT) (CL-09-03 b)

-Greenhouse Gas Monitoring from Space (GGMS) (CL-09-03 c)

The Greenhouse Gas Monitoring from Space has the following five scopes.

- to foster the use of space-based greenhouse gases (GHG) observations ans consolidate data requirements for the next-generation GHG monitoring missions from space.

  The GEO Carbon CoP was re-started to create the GEO Carbon Strategy.

- to create a synergistic strategy for easy access to GHG satellite observations, including GOSAT and current observations, and to harmonise the next generation of GHG satellites observations.

  Now the Carbon from space web portal in now available.

- Includes comparison and potential integration of GOSAT GHG products with mid-tropospheric AIRS and IASI GHG products.

  This activities are underway by NOAA.

- to pursue the technical and organisational progress required for the application and integration of results with those of the other GEO Carbon CL-09-03 task, to which it is closely linked CL-09-03a (IGCO) and CL-09-03b (FCT).

- to ensure the necessary coordination and integration of outcomes of these tasks, the task (CL-09-03 c) will also serve as a vehicle for the purposes of coordinated reporting to CEOS and GEO.

  For this scope the CEOS Carbon Task Force was established as a vehivle of all CL-09-03 tasks at the CEOS-SIT23 held on 3rd to 5th March 2009 in Florida.

5. Current Greenhouse Gases Monitoring from Space

Satellite data are key to improving the spatial coverage of the sparse in situ observations, particularly where there are large gaps in coverage. To monitor the minor constituent in the atmophere such as greenhouse gases, an sensor which is able to observe with very high spectral resolution is needed.

(1)Data obtained by Aqua/AIRS

A thermal infrared bands from the AIRS aboard on Aqua has produced estimates of midtroposphere column integral CO2. But as these observations are weighted to the upper troposphere they cannot be used to constrain surface fluxes.

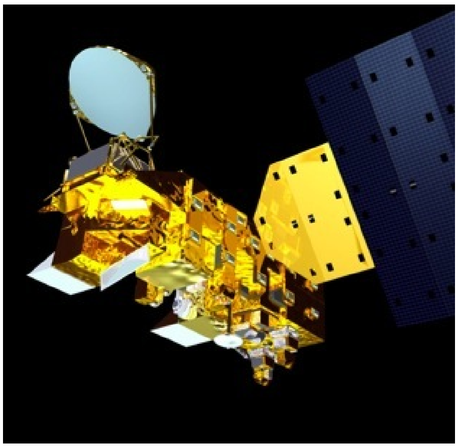
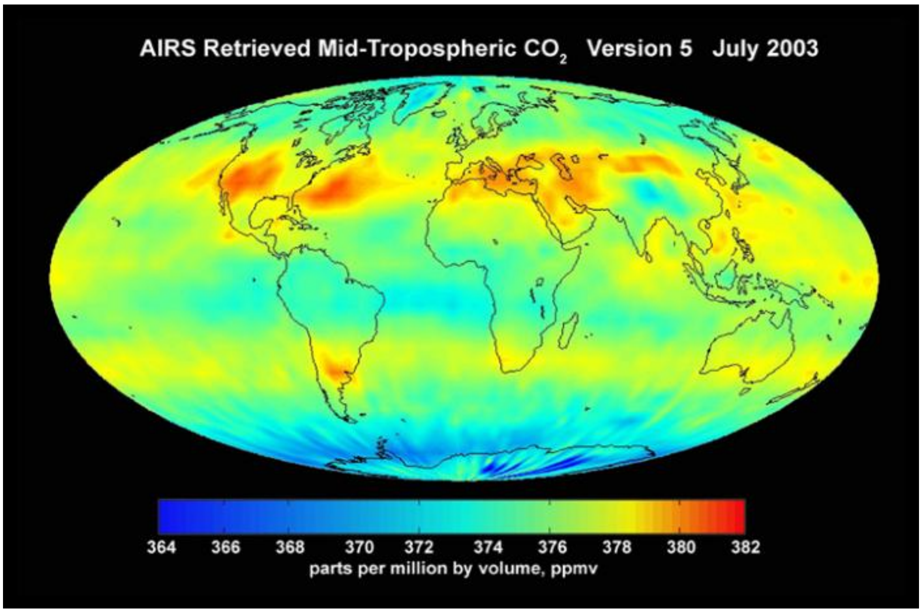


Figure 3. *Artist's illustration of Aqua*
(Image credit:NASA/JPL)



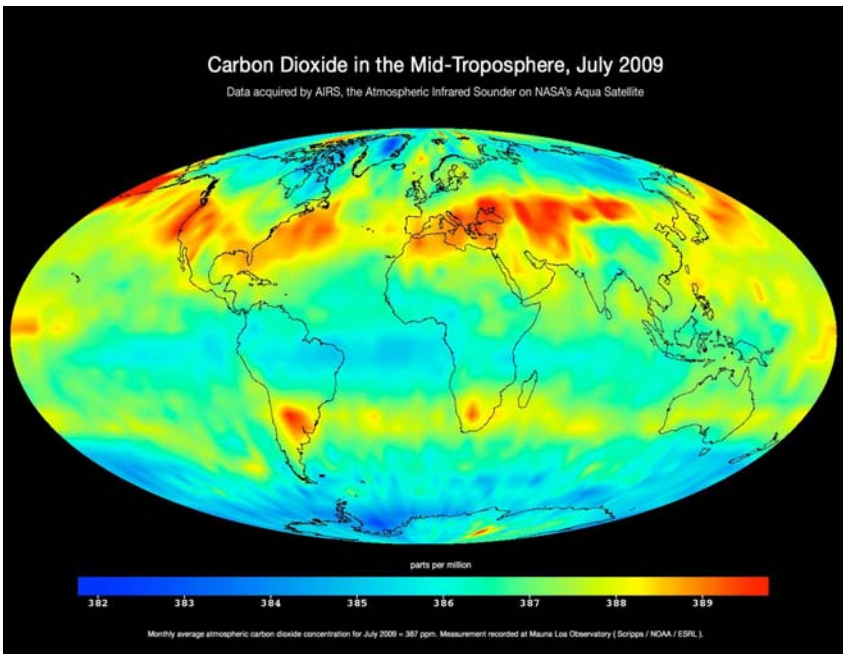


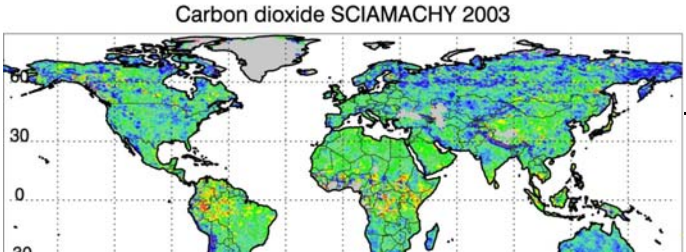
Figure 4.

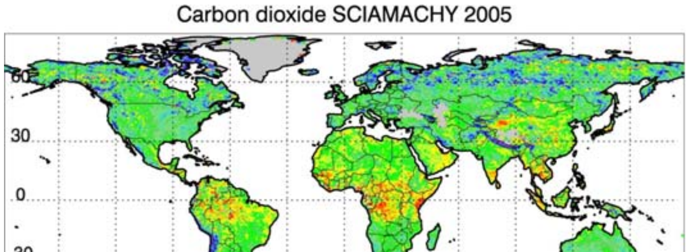
AIRS Global Distribution of Carbon Dioxide in the Mid-Troposphere at 8-13 km Altitudes during July 2003 and 2009. (Image credit:NASA/JPL)

(2)Data obtained by ENVISAT/SCIAMACHY

The SCIAMACHY instrument on the European environmental satellite ENVISAT (launched in 2002) is the first whose CO2 and CH4 measurements are sensitive to all altitude levels, including the atmospheric boundary layer and the first CO2 column integrated retrievals over land. This capability comes from its nadir observations in the near-infrared/shortwave-infrared spectral range of the electromagnetic spectrum. The accuracy for CO2 is several parts per million with around 1% relative accuracy for CH4. This accuracy is sufficient to improve quantification of regional-scale methane surface fluxes. The observed CO2 horizontal gradients agree well with those derived from assimilation modeling based on in situ station data. SCIAMACHY data are already being used for initial inverse modeling of CH4 fluxes.

Figure 5. *Artist's illustration of ENVISAT (Image credit:NASA/JPL)*





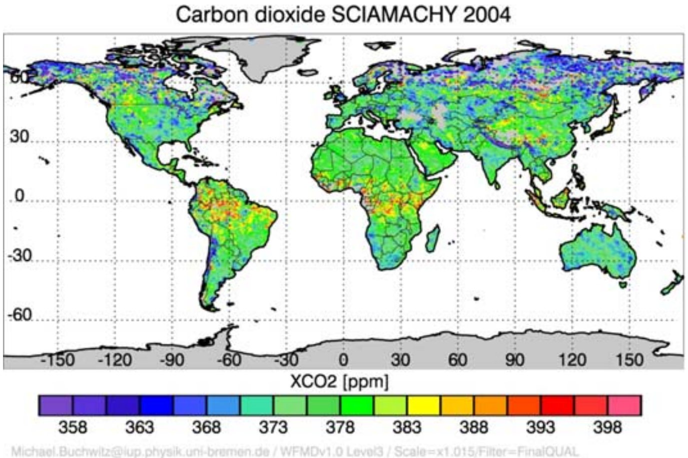
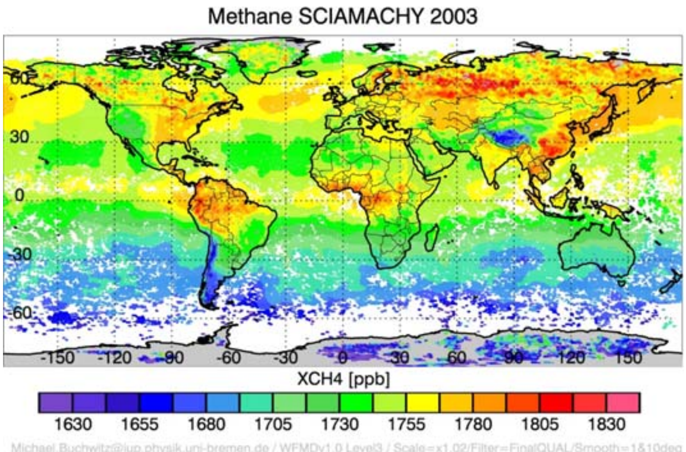
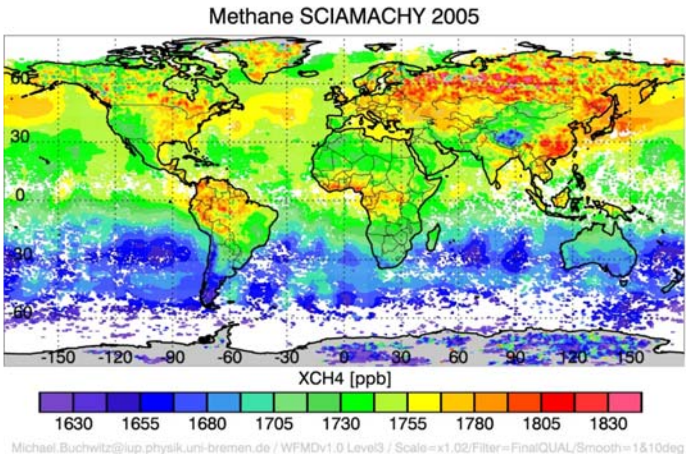


Figure 6. *SCIAMACHY annual Global Distribution of Carbon Dioxide Column Averaged mixing ratio from 2003 to 2005*.

(Image credit:University of Bremen/IUP)





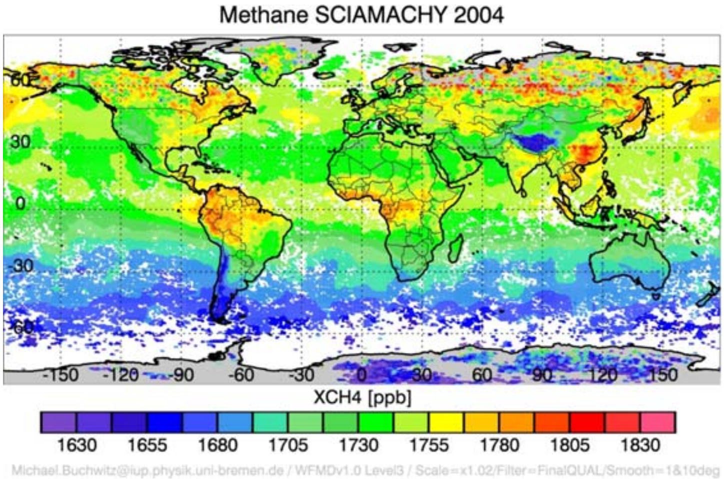


Figure 7. *SCIAMACHY annual Global Distribution of Methane Column Averaged mixing ratio from 2003 to 2005*.
(Image credit: University of Bremen/IUP)

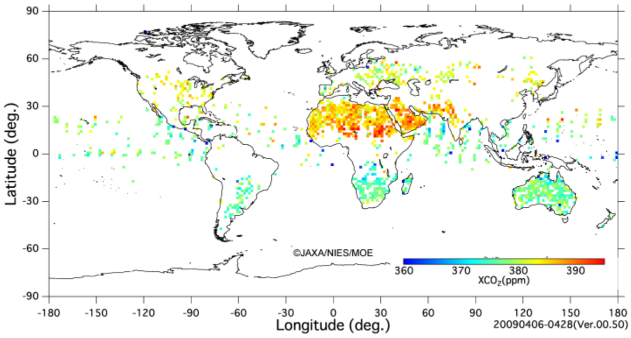
(3)Data obtained by GOSAT/TANSO-FTS

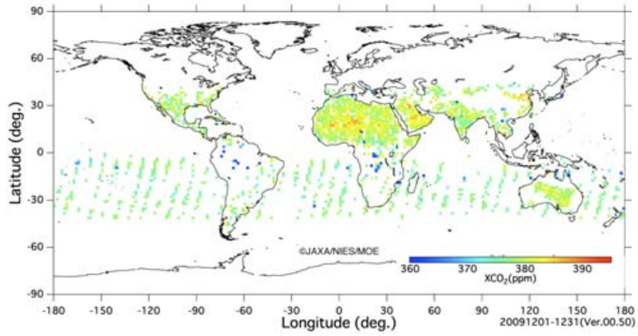
The Greenhouse Gases Observing Satellite (GOSAT) was launched in Janary 2009 as the world's first purpose built satellite to observe the concentration of CO2 and CH4, from space. The mission goals of the GOSAT is to produce more accurate estimates of the flux of greenhouse gases on a subcontinental basis (several 100 km resolution) by measuring CO2 and CH4 column integrals at better than 1% accuracy. This accuracy would be sufficient to improve the surface flux estimates compared with that obtained from using the surface in situ network alone.

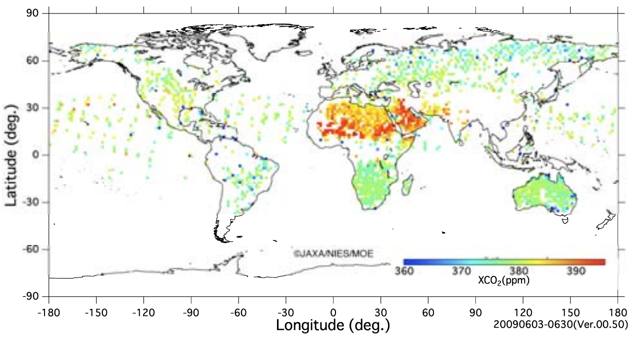
Data and retrieval algorithms from GOSAT are currently being tested and early retrievals look promising (Figure 6). Improvements to the treatment of the aerosol and/or cloud disturbances are in progress, including the retrieval of surface pressure from an O2 absorption band. Further data integration activities are required to take full advantage of this new data product, i.e. validation with surface based total column observations from the TCCON network and comparison with data measured from aircraft.

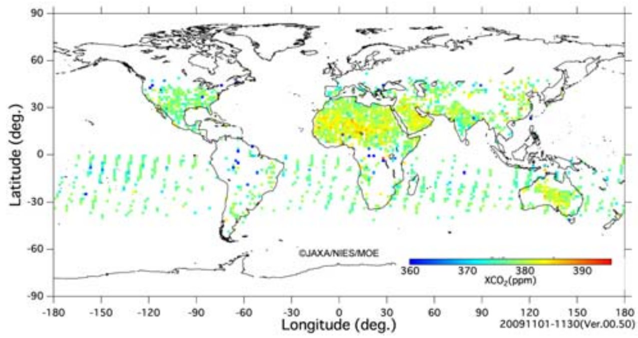
Figure 8. *Artist's illustration of GOSAT*

(Image credit:JAXA)









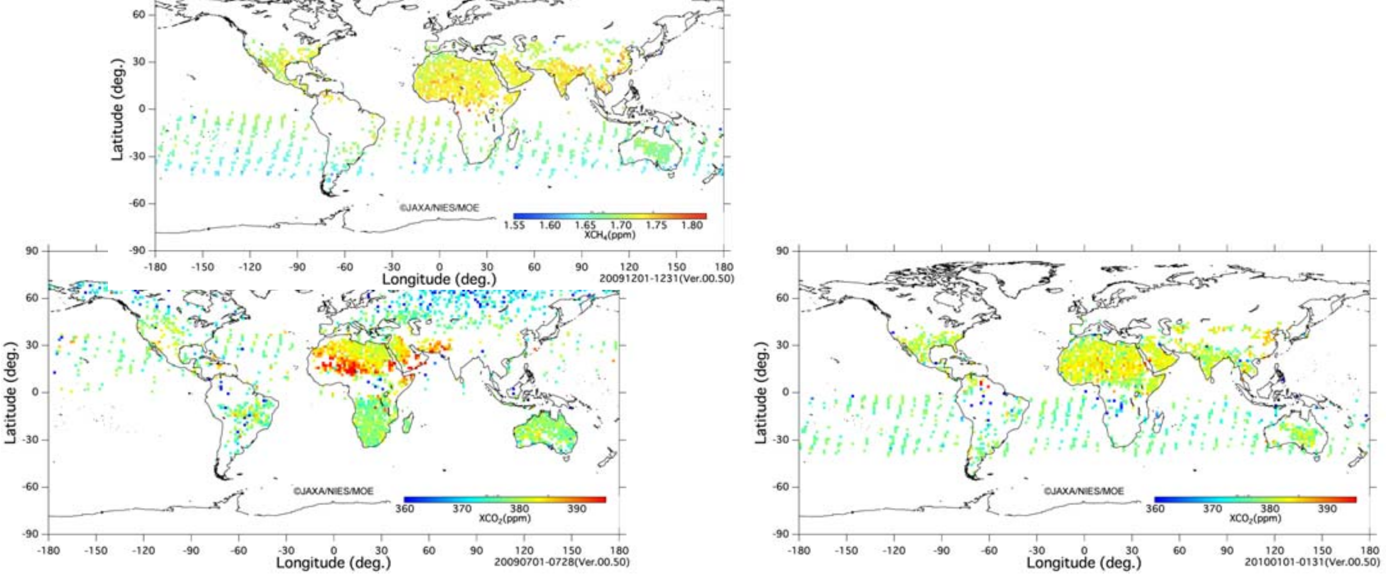


Figure 9. *GOSAT monthly Global Map of the Carbon Dioxide Column Averaged Volume mixing ratio in 1.5 deg by 1.5 deg mesh*

(Image credit: JAXA/NIES/MOE)

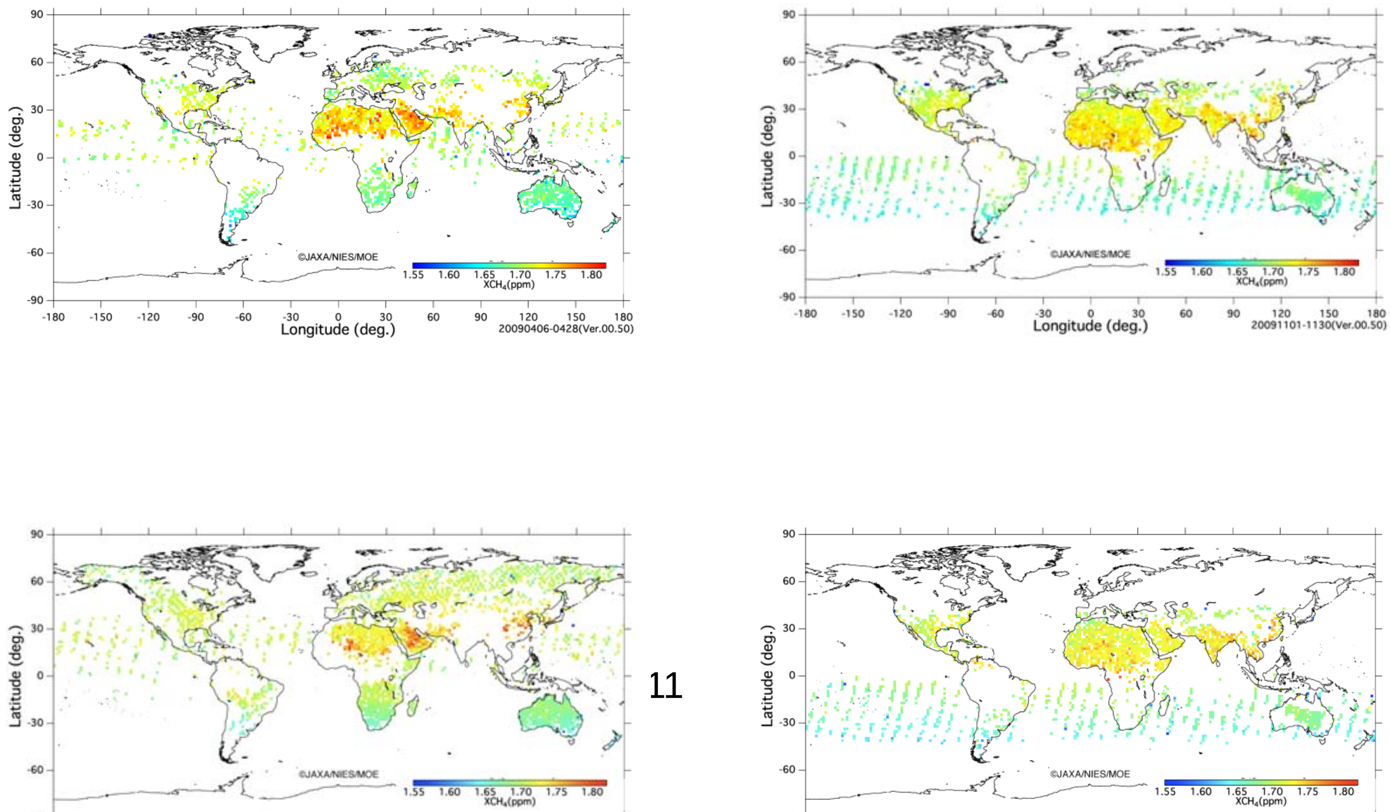


Figure 10. *GOSAT monthly Global Map of theMethane Column Averaged Volume mixing ratio in 1.5 deg by 1.5 deg mesh*

(Image credit: JAXA/NIES/MOE)

6. Towards a building of the Global Monitoring System of Greenhouse gases from Space and CEOS coordination

It is necessary to monitor the global distribution of the concentration and whose fluctuation of the greenhouse gases over a long duration and on a regular basis to gain an understanding of the actual situation in the global warming.

To attain this purpose, the Satellite and other remote sensing observations will be needed to create an effective greenhouse gases observing system.

And the satellites, though whose data needs to be improved, are currently our only means to obtain global coverage.

And that, Space-based high-precision (1 ppm or so) measurements of the column-integrated CO2 molecular density with frequent global coverage are of extraordinary and unique value in determining terrestrial and oceanic CO2 fluxes provided they are linked to a reference scale. By linking the spatial distributions of CO2 with atmospheric flux inversions, data assimilation techniques, and coupled atmospheric, terrestrial and ocean carbon modeling, the scientific community will be able to determine sources and sinks of CO2 at unprecedented space and time resolution. In addition, this measurement stream will have value in its independence from in-situ measurements or “bottom-up” model-derived estimates of CO2 flux. The atmospheric inversion approach exploits the atmospheric gradients in CO2, which are strongest in the lower part of the atmosphere. The flux retrieval accuracy is a function of the precision and sample density of measured total column CO2. The measurements of the total column integrated CO2 molecular density down to the Earth’s surface need to be at 0.3% (1 ppm) precision or better for significant improvements in our knowledge of sources and sinks. They have high spectral resolution, which allows isolation of a large set of specifically sensitive CO2-channels from the interfering water vapor and temperature signals from the free troposphere and above, but exclude the lower troposphere. A precision of about 0.5% at a space-time scale of 100 km/weekly is achieved for the middle-tropospheric CO2 column abundances.

To fulfill the GCOS requirements on the GHG ECV’s CO2 and CH4 the next generation of GHG satellite measurements needs to provide high accuracy measurements with high spatial resolution (1-2 km) and good global coverage (global coverage at the Equator with 1-3 day repeat-frequency to get good monthly mean GHG fields), the latter to effectively monitor emissions from strong local source areas for example industrialized urban areas or power plants.

In the long term this could be achieved by an international GHG-satellite constellation equipped with both passive sensors (for GHG imaging and monitoring the natural and anthropogenic hot spots) and active sensors (to deliver very precise but spatially sparse GHG data).

Now a few observation instruments such as the passive and the active sensor are in the planning phase.

The passive-sensor mission needs to be developed as soon as possible to continue the SCIAMACHY and GOSAT GHG time series on CO2 and CH4.

And now,the re-launch of OCO 2 came to a decision and in addition EUMETSAT and ESA are planning to include solar absorption channels for the detection of CH4 and potentially CO2 in the Sentinel 5 UVNS sensor that will be flown on the European post-METOP system from 2020 onwards.

A GOSAT follow-on mission study is now underway, and it is essential that this should take into consideration the needs of the GEO Carbon tasks.

The active sensor mission could be accomplished using the measurement technique based upon Laser Absorption Spectroscopy (LAS) and have been proposed as the next generation GHG instruments. ASCENDS, A-SCOPE, and other LIDAR instruments have been studied by ESA, NASA, JAXA and several other agencies.

But there is currently a high risk that after around 2014/15 there will be no space-based GHG sensor with sensitivity down to the surface in place.

Thus, the highest short term priority for the international community is to continue the time series of space-based planetary boundary-layer CO2 and CH4 measurements which was started with SCIAMACHY on ENVISAT (launched in 2002, expected mission end 2013) and is continued by GOSAT (launched in 2009, expected mission end 2014). These measurements should be continued over the next decades with incrementally improved passive sensors, ideally in a GHG-satellite constellation within the international system of operational meteorological satellites.

Within this overall priority, over the next 5 years, the first priority is the continuation of SCIAMACHY and GOSAT, and the development of improved passive GHG observation capabilities from space.

With the advent of the technical means to provide new monitoring and measurement of greenhouse gases (GHG) from space, CEOS has identified the coordination and application of these measurements as a top priority for the coming years. To foster the use of space–based CO_2 and CH_4 observations and consolidate data requirements for the next–generation GHG monitoring missions from space, a strategy for easy access to GHG satellite observations should be developed. A coordinated planning effort towards the next generation of a constellation of GHG satellite observations is also required.

It aims to create a global monitoring system of the greenhosue gases which consolidates a variety of the observation systems such as the satellite, ground system and plane.

It is efficient that these data are gathered in the unified data center and provided to the users and it is necessary to asimilate these data into the atmospheric transport model to create the global map.

Additionally, it is important to contribute these data to the global environmental monitoring and the scientifical assessment through the international frameworks such as Global Earth Observation system of systems (GEOSS) and United Nations Framework Convention on Climate Change (UNFCCC).

The ultimate goal of the global greenhouse gases monitoring system is to make clear country-by-country amount of emission of greenhouse gases.

Mission	Instrument	Resolutions: Spectral res (cm-1)	Resolutions: Spatial Δx (km)	Resolutions: Vertical Δz (km)	Resolutions: Temporal Δt (hrs/days)	Accuracy (%, ppm): Total Troposphere Column	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Nadir Absorption, Total Troposphere Columns weighted to the Lower Troposphere																							
ENVISAT	SCIAMACHY	0.5 - 1.5	30 X 60		840 (35 days)	3.6% (14 ppm)																	
GOSAT	TANSO-FTS	0.2	10.5		72 (3 days)	1% (4 ppm)																	
OCO	OCO Spectrometer	2.0	1.3 x 2.25		384 (16 days)	0.25% (1 ppm)																	
ASCENDS	LAS	n/a	TBD		384 (16 days)	0.25% (1 ppm)																	
Nadir Emission, Total Troposphere Columns weighted to the Mid-Troposphere and Upper-Troposphere																							
EOS-AQUA	AIRS / AMSU	0.5 - 2.0	15		384 (16 days)	0.4% (1.5 ppm)																	
EOS-AURA	TES	0.025 - 0.10	0.53 x 5.3		384 (16 days)	0.3% (1.3 ppm)																	
Metop (A,B,C)	IASI	0.25	12		12	0.5% (2 ppm)																	
METOP and NOAA	HIRS	1.8	10		12	1% (4 ppm)	5	5	5	5	4	4	3	3	2								
FY-3 (C,D,E,F,G)	IRAS	0.066	17		12	0.5% (2 ppm)						2	2	3	2	3	2	3	2	2			
NPOESS (1,3,4)	CrIS	0.625	14		12	0.5% (2 ppm)										2	2	3	2	2	2	2	2
Limb Viewing, Stratosphere Profiles																							
SCISAT-1	ACE-FTS	0.02	500	3	annual																		
ENVISAT	SCIAMACHY	0.5 - 1.5	960	3	840 (35 days)																		
SCISAT-2	ACE-FTS	0.02	500	3	annual																		
ENVISAT	MIPAS	0.035	300	3	840 (35 days)																		
PREMIER	IMIPAS	0.025	300	3	840 (35 days)																		

Figure 11. *Greenhouse Gases Monitoring Mission Timeline and Gap*

(Image credit: CEOS)