

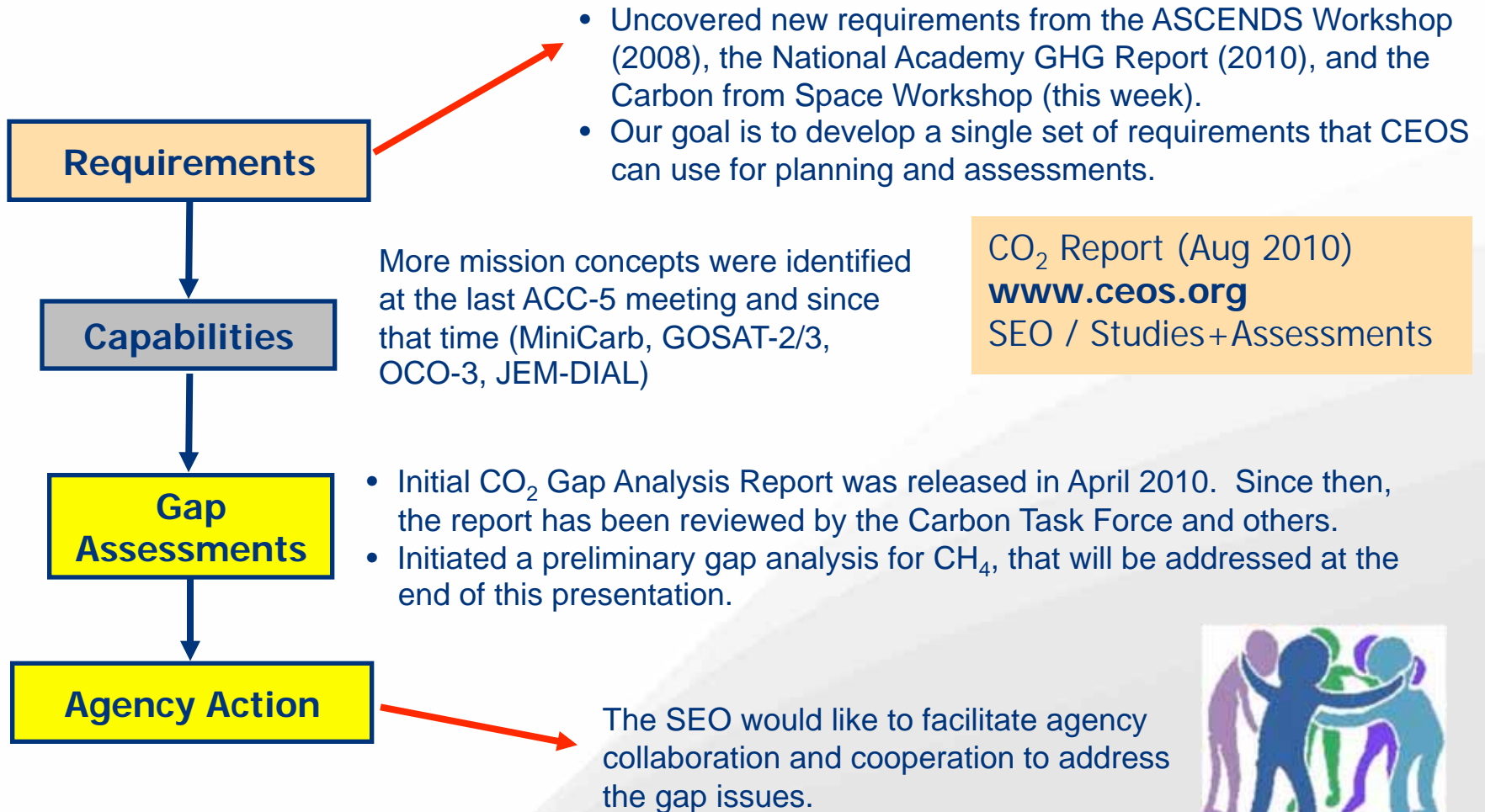
# CEOS Atmospheric CO<sub>2</sub> and CH<sub>4</sub> Gap Analysis Report

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# CO<sub>2</sub> efforts since ACC-5 (April 2010)



# Where do you find CO<sub>2</sub> Mission and Requirements data ?



[www.ceos.org](http://www.ceos.org)

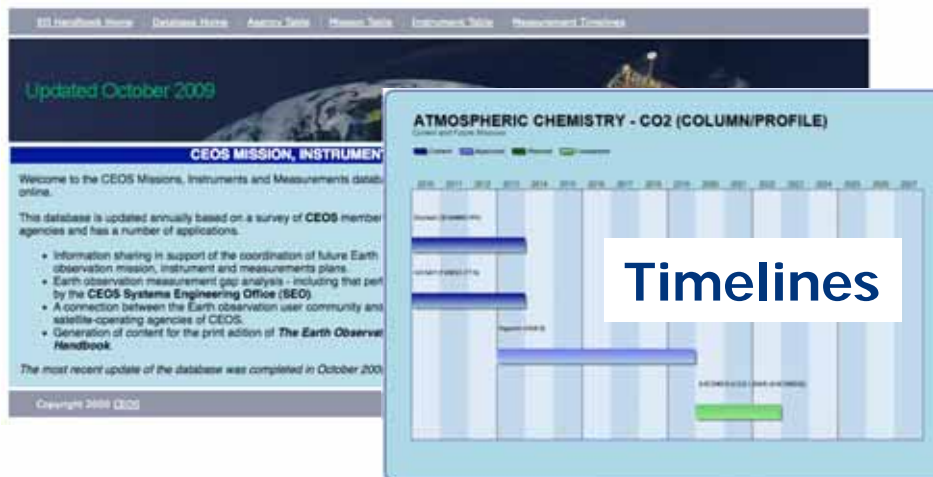


The CEOS resources are a good start ... but most of the data is found through Google searches and meeting reports.

The MIM shows only 4-CO<sub>2</sub> and 13-CH<sub>4</sub> missions. We found many more missions and concepts.

The Systems Database captures requirements from WMO, GCOS, EUMETSAT, but there are many more sources.

## CEOS MIM Database



## CEOS Systems Database

[www.ceos-sysdb.org](http://www.ceos-sysdb.org)

**CEOS Systems Database**

Table showing mission requirements (Param Type, Application, Source, Mission, etc.).

# What are the CO<sub>2</sub> Requirements ?



Profile or Column Atmosphere Layer	Application	Source	Accuracy (ppmv)			$\Delta x$ (km)			$\Delta z$ (km)			Repeat Cycle (h)		
			thresh	break	obj	thresh	break	obj	thresh	break	obj	thresh	break	obj
CO <sub>2</sub> Profile Lower Troposphere Weighted Columns	Chemistry	WMO	19	12	8	500	150	50	4	2	1	24	12	6
	Climate	GCOS	8	5	4	500	70	10	2	1	0.5	12	6	3
	Composition & Climate	EUMETSAT	19	12	8	250	50	10	5	2	0.5	24	12	6
CO <sub>2</sub> Profile Higher Troposphere Weighted Columns	Climate	GCOS	8	5	4	250	100	50	2	1.5	1	6	4	3
	Composition & Climate	EUMETSAT	19	12	8	250	50	10	5	2	0.5	24	12	6
CO <sub>2</sub> Column Total Atmosphere	Climate	GCOS	8	5	4	500	100	50	-	-	-	6	4	3
	Composition & Climate	EUMETSAT	4	3	2	50	25	5	-	-	-	12	6	3

- The starting point is the set of requirements above, which are compiled in the WMO GOS-Dossier (2009).
- Stratosphere requirements are not shown in this presentation due to their limited use for CO<sub>2</sub> transport or flux studies.
- Requirements from the ASCENDS Workshop (Aug 2008), the National Academy of Science GHG Report (April 2010), and then Carbon from Space Workshop (September 2010) have now been added.



# What are the CO<sub>2</sub> Mission Capabilities ?



		Resolutions			Accuracy
Mission	Instrument	Spatial Sample $\Delta x$ (km)	Spatial Swath (km)	Temporal Repeat Cycle $\Delta t$ (hrs/days)	Total Troposphere Column
Nadir Absorption, Total Troposphere Columns weighted to the Lower Troposphere					
ENVISAT	SCIAMACHY	30 x 60	960	72 (3 days)	2% (8 ppm)
GOSAT	TANSO-FTS	10.5	790*	72 (3 days)	1% (4 ppm)
OCO-2	OCO Spectrometer	1.3 x 2.25	10	384 (16 days)	0.25% (1 ppm)
Minicarb	FTS	8 x 16	TBD	TBD	0.25% (1 ppm)
GOSAT-2	FTS	10.5	790 (1)	72 (3 days)	1% (4 ppm)
CarbonSat	Spectrometer	2.0 x 2.0	500	144 (6 days)	0.5% (2 ppm)
ASCENDS	Laser Spectrometer	0 (2)	0 (2)	384 (16 days)	0.25% (1 ppm)
GOSAT-3	Laser Spectrometer	0**	0**	TBD	TBD
Nadir Emission, Total Troposphere Columns weighted to the Mid-Troposphere and Upper-Troposphere					
EOS-AQUA	AIRS / AMSU	13	1620	12 hours	0.4% (1.5 ppm)
EOS-AURA	TES	0.5 x 5.0	50	384 (16 days)	0.3% (1.3 ppm)
METOP and NOAA	HIRS	10	2240	12 hours	1% (4 ppm)
Metop (A,B,C)	IASI	12	2052	12 hours	0.5% (2 ppm)
FY-3 (C,D,E,F,G)	IRAS	17	952	12 hours	0.5% (2 ppm)
NPOESS (1,3,4)	CrIS	14	2200	12 hours	0.5% (2 ppm)

**Note:** OCO-3 is not shown, but should be considered as a possible "Mission of Opportunity" beyond 2015. This is an exact copy of the OCO-2 instrument.

- Repeat cycle requirements are **not met** for all lower troposphere missions and most mid-troposphere missions. GCOS threshold requirements are 12 hours (lower trop) and 6 hours (middle trop), which requires multiple coordinated LEO satellites with wide swath capabilities.
- Accuracy requirements are met for all middle-troposphere instruments and most lower-troposphere instruments (exception is SCIAMACHY). Most future instruments target ~1-ppm accuracy.

# Is one set of CO<sub>2</sub> requirements possible ?



## Requirements

### Stratosphere

Spatial: 50-500-km  
Temporal: 3-hr to 7-days  
Accuracy: 4-8-ppm

### Middle to Upper Troposphere

Spatial: 10-500-km (transport, climate)  
Temporal: 3-24-hr (multiple daily, diurnal)  
Accuracy: <4-ppm (1%)

### Lower Troposphere

Spatial: 10-500-km (flux studies)  
Temporal: 3-24-hr (multiple daily, diurnal)  
Accuracy: <4-ppm (1%)

### Surface

Spatial: 1-10-km (sources and sinks)  
Temporal: 3-24-hr (intraday variation)  
Accuracy: 1-4-ppm (0.25% to 1%)

## Capabilities

### Limb Sounders

ACE, SCIAMACHY, MIPAS

### LW Thermal Emission

AIRS, IASI, TES, HIRS,  
CriS, IRAS

### SW Passive Absorption

SCIAMACHY, TANSO-FTS,  
OCO Spec, MiniCarb-FTS,  
CarbonSat-FTS

### Laser Absorption

ASCENDS, GOSAT-3,  
JEM-DIAL, A-SCOPE

Stratosphere  
12 to 50 km

Middle to Upper  
Troposphere  
3 to 12 km

Lower Troposphere  
< 3km

Sources and Sinks



\* Assume global coverage for all cases.

# CO<sub>2</sub> Mission Timelines



Mission	Instrument	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Nadir Absorption, weighted to the Lower Troposphere																		
ENVISAT	SCIAMACHY																	
GOSAT	TANSO-FTS																	
OCO-2	OCO Spectrometer																	
Minicarb	FTS																	
GOSAT-2	FTS																	
CarbonSat	Spectrometer																	
ASCENDS	Laser Spectrometer																	
GOSAT-3	Laser Spectrometer																	
Nadir Emission, weighted to the Mid-Troposphere and Upper-Troposphere																		
EOS-AQUA	AIRS / AMSU																	
EOS-AURA	TES																	
METOP and NOAA	HIRS	5	5	5	5	4	4	3	3	2								
Metop (A,B,C)	IASI																	
FY-3 (C,D,E,F,G)	IRAS						2	2	3	2	3	2	3	2	2			
NPOESS (1,3,4)	CrIS										2	2	3	2	2	2	2	2

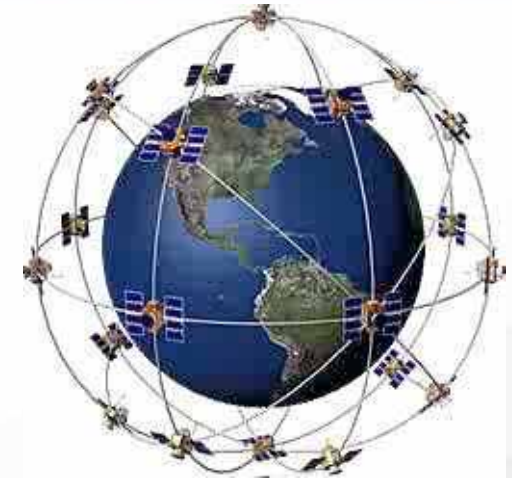
GAP ???

- Lower Troposphere missions beyond OCO-2 (2016) are uncertain. All of the missions are in concept development and may not be flown, as shown. **A timeline gap may exist.**
- It is unlikely that ENVISAT and GOSAT will last beyond 2015 due to mission fuel constraints. OCO-2 has fuel for 8-years (till 2020).
- OCO-2 could be the only CO<sub>2</sub> mission measuring the lower troposphere beyond 2015 with limited repeat cycle (16 days) and spatial coverage (swath width 10-km). **More wide-swath CO<sub>2</sub> missions are needed.**

# CO<sub>2</sub> Constellation Solutions



- A constellation of CEOS satellites dedicated to CO<sub>2</sub> and/or CH<sub>4</sub>, requires careful consideration of requirements and must be coordinated with in-situ and ground resources.
- Constellation design must balance atmospheric sampling (layers), revisit cycle (swath and orbit), spatial sampling, and accuracy (ppm), and most importantly ... funding.
- Significant challenges exist with data assimilation, calibration, and agency priorities.



## Other Ideas:

- Extended operations
- Orbit Optimization
- GEO concepts
- Advanced technologies

## **SW Absorption (near surface, lower troposphere)**

3 satellites, >500-km swath, 2-km spatial sampling  
<1-day combined revisit, <4-ppm (1%) accuracy

## **Laser Absorption (vertical profiling, day+night)**

>1 satellite, <10-km spatial sampling, <1-ppm (0.25%) accuracy

## **LW Emission (middle to upper troposphere)**

>2 satellites, >2000-km wide swath, 10-km spatial sampling  
<6 hours combined revisit, <4-ppm (1%) accuracy



# CH<sub>4</sub> Preliminary Assessment



## Requirements

- 10 to 500 km spatial resolution
- 3 to 24-hour temporal sampling
- 2 to 10% accuracy

A first draft of the CH<sub>4</sub> Gap Analysis Report will be completed by late 2010.

		Resolutions			Accuracy																				
Mission	Instrument	Spatial Sample $\Delta x$ (km)	Spatial Swath (km)	Temporal Repeat Cycle $\Delta t$ (hrs/days)	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	30 x 60	960	72 (3 days)	1.5 - 2%																				
GOSAT	TANSO-FTS	10.5	790*	72 (3 days)	0.5 - 1.8%																				
Sentinel-5 Precursor	UVNS	15	2400	24 hours	TBD																				
Germany/France Climate Mission	DIAL Laser	TBD	TBD	TBD	TBD																				
Sentinel-5 Post-EPS	UVNS	15	2400	24 hours	TBD																				
GEO-CAPE (GEO orbit)	IR Correlation Radiometer	4	TBD	12 hours	1%																				
Nadir Emission, Total Troposphere Columns weighted to the Mid-Troposphere and Upper-Troposphere																									
EOS-AQUA	AIRS / AMSU	13	1620	12 hours	1.2 - 1.5 %																				
EOS-AURA	TES	0.5 x 5.0	50	384 (16 days)	0.70%																				
Metop (A,B,C)	IASI	12	2052	12 hours	1%	5	5	5	5	4	4	3	3	2											
METEOR-M N2	IKFS-2	35	2000	12 hours	TBD																				