An Atmospheric CO_2 Gap Analysis for CEOS

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Systems Approach to Climate

Systems taxonomy for organization

Strategy for collaboration and action

Societal Benefit and Policy Decisions

Decision Makers

Applications

Information products & services

Process and Forecasting

Science Knowledge & Models

Space Hardware

Measurements

Instruments and Missions

Requirements

What are the user requirements and corresponding measurement needs ?

Capabilities

What are current and planned assets in space and their capabilities ?

Gap Assessments

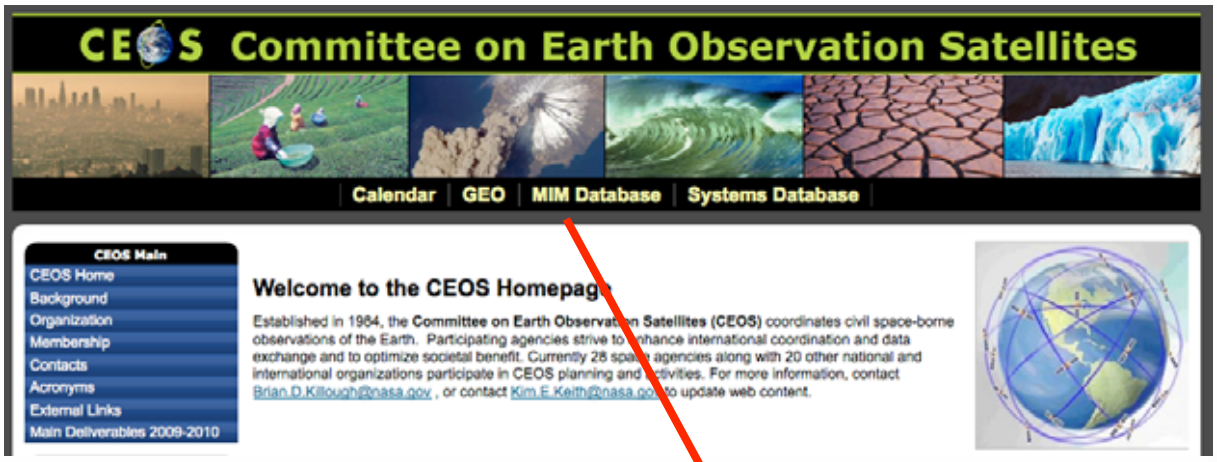
What are the measurement or user requirement gaps ?

Agency Action

How can space agencies collaborate and act to fill gaps and critical needs ?

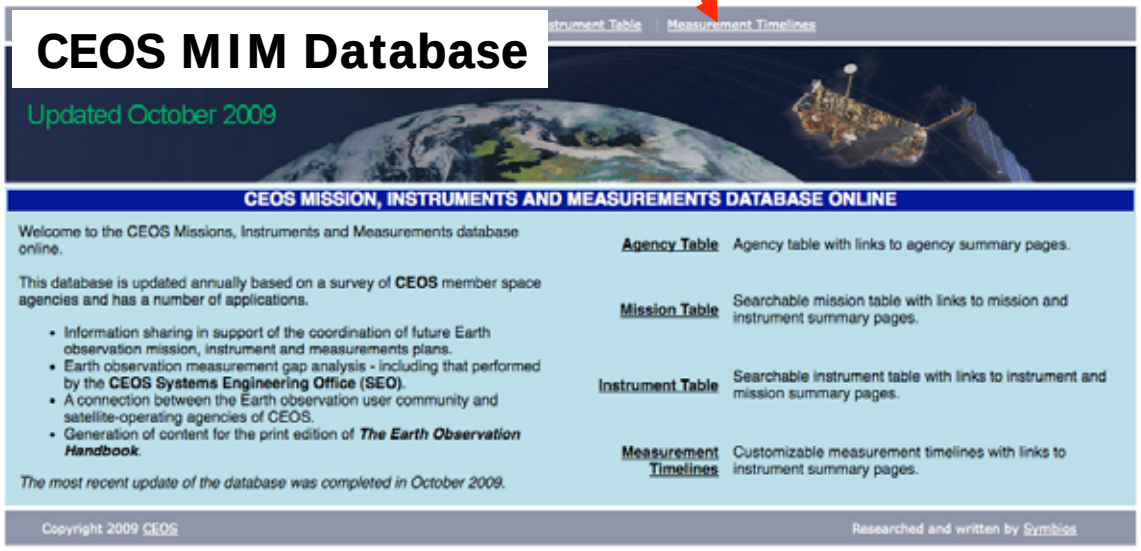
Starting Point… the CEOS Databases

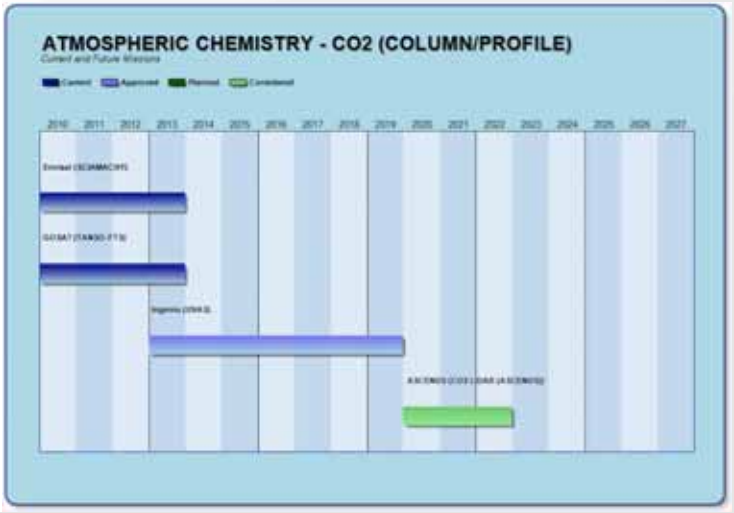
www.ceos.org



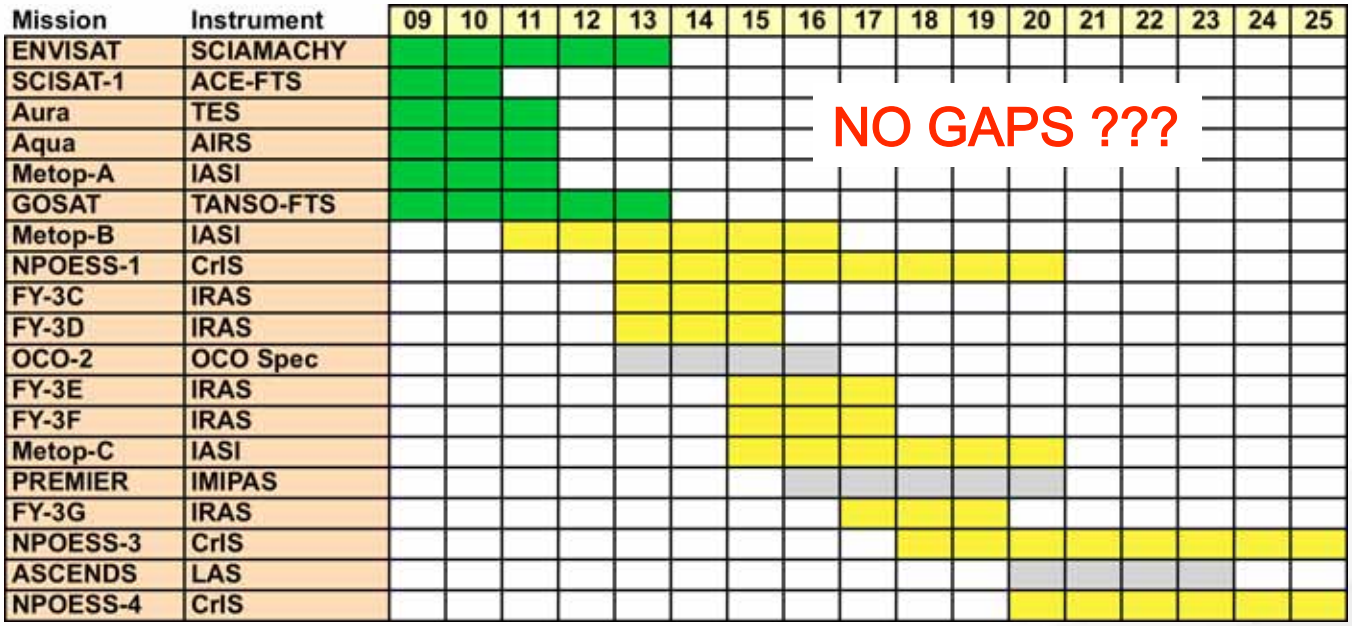
Search for CEOS missions that measure CO_2 … you will find only 4 on the "official" agency MIM list. We know there are many more …

Further web searches found valid CO_2 data products produced by 19 CEOS missions.





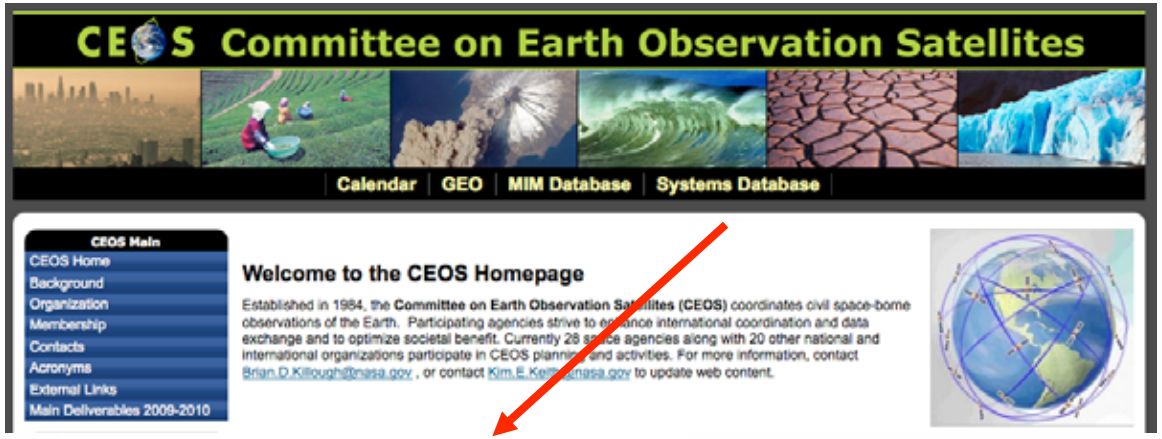
General Mission Timeline Results



- Timelines from the expanded mission list (above) **DO NOT** accurately reflect gaps.
- Gap analyses must consider **instrument types** (measurement approach), **atmospheric layers**, and **detailed requirements** (accuracy, spatial resolution, temporal resolution).
- Automation of the detailed gap analysis process using existing CEOS databases is not currently possible … maybe in the future.

Next… Search the Systems Database for Requirements

www.ceos.org



CEOS Systems Database

www.ceos-sysdb.org

Search for CO_2 measurement requirements from GCOS, EUMETSAT, and WMO.

Requirements

Param Type	Application	Source	Accuracy (RMS)		Δx (km)		Δz (km)		Δt (h)		δ (h)	
			thresh	break	thresh	break	thresh	break	thresh	break	thresh	break
Lower Troposphere	Climate	GCOS	2.00000	1.50000	500.00000	70.00000	2.00000	1.00000	12.00000	6.00000	1440.00000	480.00000
Lower Troposphere	Composition and climate	EUM	5.00000	3.00000	250.00000	50.00000	5.00000	2.00000	24.00000	12.00000	6.00000	0.50000
Lower Troposphere	Atmospheric chemistry	WMO	5.00000	3.00000	500.00000	150.00000	4.00000	2.00000	24.00000	12.00000	168.00000	96.00000
Higher Troposphere	Climate	GCOS	2.00000	1.50000	250.00000	100.00000	2.00000	1.50000	6.00000	4.00000	1440.00000	480.00000
Higher Troposphere	Composition and climate	EI									6.00000	0.50000
Lower Stratosphere	Climate	GC									4380.00000	1680.00000
Lower Stratosphere	Composition and climate	EUM	5.00000	3.00000	250.00000	100.00000	3.00000	2.00000	168.00000	24.00000	6.00000	0.50000
Upper Stratosphere & Mesosphere	Climate	GCOS	2.00000	1.50000	500.00000	350.00000	4.00000	3.00000	6.00000	4.00000	4380.00000	1680.00000
Upper Stratosphere & Mesosphere	Composition and climate	EUM	10.00000	7.00000	500.00000	200.00000	5.00000	2.00000	168.00000	24.00000	6.00000	0.50000
At Cloud Top	Climate	GCOS	2.00000	1.50000	500.00000	100.00000	N/A	N/A	6.00000	4.00000	4380.00000	1680.00000
At Cloud Top	Composition and climate	EUM	1.00000	0.70000	50.00000	25.00000	N/A	N/A	12.00000	6.00000	6.00000	0.50000

What are the Detailed Requirements ?

Profile or Column Atmosphere Layer	Application	Source	Accuracy (ppmv)			Δx (km)			Δz (km)			Δt (h)		
			thresh	break	obj	thresh	break	obj	thresh	break	obj	thresh	break	obj
CO_2 Profile	Chemistry	WMO	19	12	8	500	150	50	4	2	1	24	12	6
Lower Troposphere Weighted Columns	Climate	GCOS	8	6	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_2 Profile	Climate	GCOS	8	6	4	250	100	50	2	1.5	1	6	4	3
Higher Troposphere Weighted Columns	Composition & Climate	EUMETSAT	19	12	8	250	50	10	5	2	0.5	24	12	6
CO_2 Profile	Climate	GCOS	8	6	4	500	350	25	4	2	1	6	4	3
Lower Stratosphere	Composition & Climate	EUMETSAT	19	12	8	250	100	50	3	2	1	168	24	12

- **GCOS Climate requirements are the most restrictive. For example, objectives of 4-ppm accuracy, 10-km spatial resolution and 3-hour sampling are required in the lower troposphere.**

Source: WMO GOS Dossier Volume-5 compiled for WMO by B. Bizzarri.

What are the Detailed Mission Capabilities ?

Detailed mission capability information is not currently available in the MIM or Systems Databases so this step requires extensive web searches. Hopefully, in the future this level of detail will exist in the databases so this process can be automated.

		Resolutions				Accuracy
Mission	Instrument	Spectral res (cm-1)	Spatial Δx (km)	Vertical Δz (km)	Temporal Δt (hrs/days)	Total Troposphere Column
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-Tropospher						
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)
FY-3 (C,D,E,F,G)	IRAS	0.066	17		12	0.5% (2 ppm)
NPOESS (1,3,4)	CrIS	0.625	14		12	0.5% (2 ppm)
Limb Viewing, Stratosphere Profiles						
SCISAT-1	ACE-FTS	0.02	500	3	annual	2.5% (10 ppm)
ENVISAT	SCIAMACHY	0.5 - 1.5	960	3	840 (35 days)	1% (4 ppm)
SCISAT-2	ACE-FTS	0.02	500	3	annual	2.5% (10 ppm)
ENVISAT	MIPAS	0.035	300	3	840 (35 days)	0.7% (3 ppm)
PREMIER	IMIPAS	0.025	300	3	840 (35 days)	0.7% (3 ppm)

Which Missions Meet the Requirements ?

		Requirements Summary			
Mission	Instruments	Accuracy	Spatial	Temporal	Vertical
Lower Troposphere					
ENVISAT	SCIAMACHY				
GOSAT	TANSO-FTS				
OCO-2	OCO Spectrometer				
ASCENDS	LAS				
Mid-Troposphere and Upper-Troposphere					
EOS-AQUA	AIRS / AMSU				
EOS-AURA	TES				
Metop (A,B,C)	IASI				
METOP and NOAA	HIRS				
FY-3 (C,D,E,F,G)	IRAS				
NPOESS (1,3,4)	CrIS				
Stratosphere					
SCISAT-1	ACE-FTS				
ENVISAT	SCIAMACHY				
SCISAT-2	ACE-FTS				
ENVISAT	MIPAS				
PREMIER	IMIPAS				

Meets Some or All Objectives (maximum)

Meets Some or All Threshold Requirements (minimum)

DOES NOT MEET REQUIREMENTS

Largest issue is temporal sampling near the surface …

Limited LEO missions do not allow adequate sampling to achieve desired threshold requirement of 24-hr (one-day) repeat cycle. GOSAT is best at 3-days due to its wide (+/- 35-deg) crosstrack scanning capability.

Detailed Timeline Analysis

Mission	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Lower Troposphere																	
ENVISAT																	
GOSAT																	
OCO-2									GAP								
ASCENDS																	
Mid-Troposphere and Upper-Troposphere																	
EOS-AQUA																	
EOS-AURA																	
Metop (A,B,C)																	
METOP and NOAA	5	5	5	5	4	4	3	3	2								
FY-3 (C,D,E,F,G)						2	2	3	2	3	2	3	2	2			
NPOESS (1,3,4)										2	2	3	2	2	2	2	2
Stratosphere																	
SCISAT-1																	
ENVISAT																	
SCISAT-2																	
PREMIER																	

Detailed timeline analysis takes into consideration the instrument type and atmospheric layer.

Largest issue is the potential time gap beyond OCO-2.

It is unlikely that ENVISAT and GOSAT will last beyond 2015. In addition, ASCENDS is uncertain for a 2020 launch.

OCO-2 may be the only near-surface CO_2 mission in 2015 with limited repeat cycle(16 days) and spatial coverage (swath width 10-km).

Conclusions

Conclusions

- Atmospheric CO_2 measurements in the lower troposphere (near surface), critical for measuring sources and sinks, have a critical time gap beyond 2016. – see **TIMELINE ANALYSIS**
- Temporal sampling requirements are not met for most missions. Threshold requirements are 6 hours for GCOS climate needs, which requires multiple coordinated LEO satellites with wide swath width capabilities like GOSAT. – see **REQUIREMENTS ANALYSIS**

Lessons Learned

- Future gap analyses efforts will require detailed assessments of **timelines and requirements** to reach valid conclusions.
- Online automation of the gap analysis process is not yet possible.

Future Work

- Plan to mature agency inventories of missions, instruments and measurements in SEO and MIM Databases.
- Plan to add more space-based measurement requirements for key parameters such as climate ECVs and include a broader list of sources.

The full CO_2 Gap Analysis report is available on the CEOS website.