Geophysical Validation Needs of the Geostationary Air Quality (GeoAQ) Constellation GEMS + Sentinel-4 + TEMPO

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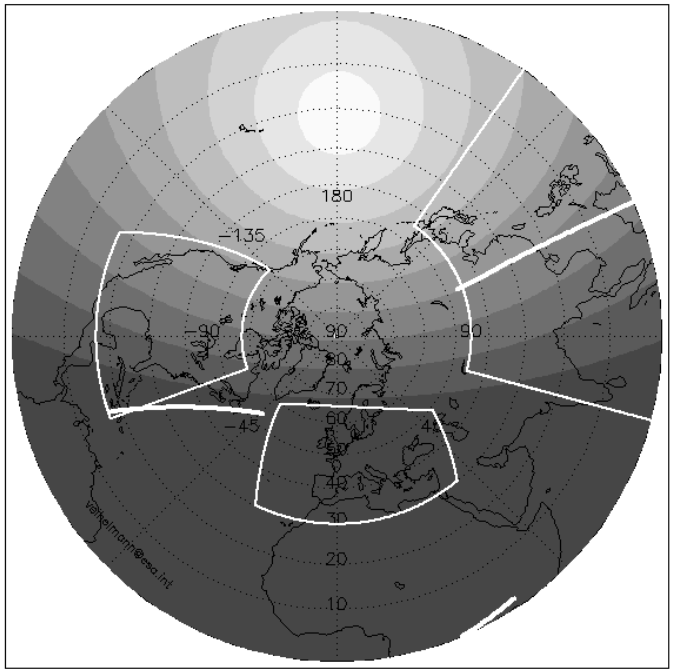
GeoAQ = GEMS + Sentinel-4 + TEMPO + LEO



Position paper
"A Geostationary Satellite Constellation for Observing Global Air Quality"
www.ceos.org

	USA TEMPO	Europe Sentinel-4	Korea GEMS	LEO (eg Sentinel-5P)
Orbit	Geostationary	Geostationary	Geostationary	LEO
Domain	North America	Europe and surrounding	Asia-Pacific	Global
Revisit [h]	1 hour	1 hour	1 hour	Daily, more @ higher lat
Spectral ranges	UV-Vis	UV-Vis-NIR	UV-Vis	UV-Vis-NIR-SWIR
Key products	O_3, NO_2, SO_2, HCHO, CHOCHO, aerosol	O_3, NO_2, SO_2, HCHO, CHOCHO, aerosol	O_3, NO_2, SO_2, HCHO, CHOCHO, aerosol	O_3, NO_2, SO_2, HCHO, CHOCHO, aerosol, CH_4, CO, …
Spatial resolution [km²]	9 x 5 at 35°N	8 x 8 at 40°N	8 x 7 (gas), 8 x 3.5 (aerosol) at 38°N	7 x 7 at nadir

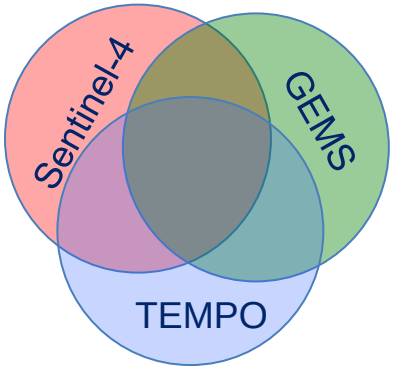
GeoAQ Geophysical Validation Needs Document

- **New Validation Challenges**
- **Constellation Products**
- **Inter-mission Bias Targets**
- **Specific Validation Needs**

New Challenges

- **Temporal sampling of diurnal cycle**
- **Horizontal resolution (S5P forerunner)**
- **Inter-mission consistency without geographic overlap**
- **Slant viewing and illumination angles**
- **Directionality of surface and atmosphere**
- **Geo-location knowledge**
- **Vertical distribution of constituents**
- **Near surface ozone (TEMPO)**
- **Stratospheric NO_2 correction (S4 lack of clean sector)**
- **High expectations wrt data quality and availability (➔ FRM, QA4EO)**

GeoAQ Constellation Products



Product / Parameter	Common to the 3 GEOs	Comment
Solar irradiance	305 to 490 nm	
Earth radiance		
Reflectance		
Ozone profile	stratosphere, troposphere, free troposphere, possibly 0-6 km	Differences in averaging kernels
Ozone total column	Slant and vertical columns	Consider applying same algorithm to all missions
NO_2 total column		
SO_2 total column		
HCHO total column		
CHOCHO		
NO_2 tropospheric col.	tropospheric sub-column	Differences in separation of troposphere/stratosphere
Aerosol	AOD, UV absorbing index	S4 joint retrieval with surface

Inter-mission Bias Targets

- **Product performance**
- **Accuracy of verification method**
- **Consistency of heritage data sets**
- **Proposed bias targets**

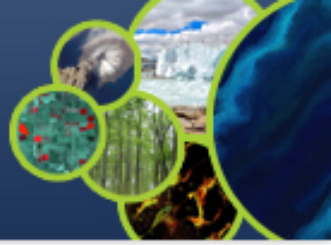
➔ **Your feedback**

Inter-mission Bias Targets

Product		Uncertainty*			Accuracy* of method	Consistency* heritage data	Proposed bias target*
		GEMS	S4	Tempo			
Solar irrad			2-3%		2-4% consistency of ref spectra, direct comparison	2-5%	2%
Earth rad			2-3%		2% acc GSICS inter-cal factors	2-5%	3%
Reflect.			2-3%		2%	2-5%	3%
O_3	total	3%	3%	3%	1-3%	<1% monthly zonal mean	1%
	strat	5%	-	5%			5%
	trop	20%	25%	10 ppbv	➔ Your feedback		20%
	0-2km	-	-	10 ppbv			
NO_2	total	$1x10^{15}$	-	1×10^{15}			1×10^{15}
	trop	-	30%, 1.5×10^{15}	1×10^{15}		1-2×10^{15} (OMI-SCIA), bias in strat 0.5×10^{15}	1×10^{15}
SO_2		$1x10^{16}$	60%, 3×10^{16}	1×10^{16}			1×10^{16}
HCHO		$1x10^{16}$	50%, 1.5×10^{16}	1×10^{16}			1×10^{16}
CHOCHO			50%, 7×10^{14}	4×10^{14}			4×10^{14}
AOD		20%, 0.1	-	0.05			0.05

*) in molec/cm^2 unless specified otherwise

Validation Goals in Phases E1/E2



	Commissioning Phase (E1)	Exploitation Phase (E2)
Level-1b	• In-flight Cal Key Data • System verification and acceptance • Establish data quality	• Maintain data quality • Degradation monitoring • Anomaly detection • Inter-mission consistency
Level-2	• Processor verification and acceptance • First check data quality	• Establish data quality • Maintain data quality • Degradation monitoring • Anomaly detection • Inter-mission consistency

Validation Needs

- **NO_2 selected as an example**
  - **Establish and maintain Data Quality**
  - **Validate Diurnal Cycle Observation Capability**
  - **Validate Stratospheric Correction**
  - **Validate Source Estimation**
  - **Verify Inter-Mission Consistency**

- **Document should**
  - **Identify type of correlative data**
  - **Identify activities and approaches**

  ➔ Your feedback

Validation Needs for NO_2

Establish and maintain data quality

Systematic validation by operational data quality center

- **Domain**
  - **All conditions, full geographic coverage area, all seasons**
- **Fiducial Reference Measurements**
  - **Co-located NO_2 measurements**
    - **total column (ground based, inter-calibrated network)**
    - **profile in lower troposphere (ground based, inter-calibrated instrumentation)**
  - **Cloud fraction, optical depth, height (ground based and met imagers)**
  - **Aerosol optical depth, type (ground based, inter-calibrated network)**
- **Other data**
  - **Surface albedo (climatology, near-real time satellite product)**
  - **CTM data (NO_2 field)**
  - **Stratospheric NO_2! From model, OMPS limb, ..?**

Validation Needs for NO_2

Validate Diurnal Cycle Observation Capability

Campaign capturing the relevant variations

- **Domain**
  - **Polluted area including sources, limited transport into domain**
  - **Diurnal evolution of NO2 (sources, processes, transport, sinks)**
- **Correlative measurements**
  - **NO_2 with hourly sampling or better**
    - **total column: high spatial resolution (~1km), various viewing geometries**
    - **total column: at selected locations**
    - **profile: lower troposphere, also stratosphere, at selected locations**
  - **Cloud fraction, optical depth, height**
  - **Aerosol optical depth, type**
  - **Surface reflectance directionality (BRF)**
- **Auxiliary data**
  - **CTM data (NO_2 sources, sinks, profiles, related species, …)**
  - **Emission strength (NO/NO_2) diurnal variation**

Validation Needs for NO_2

Validate Stratospheric Correction

Dedicated analysis

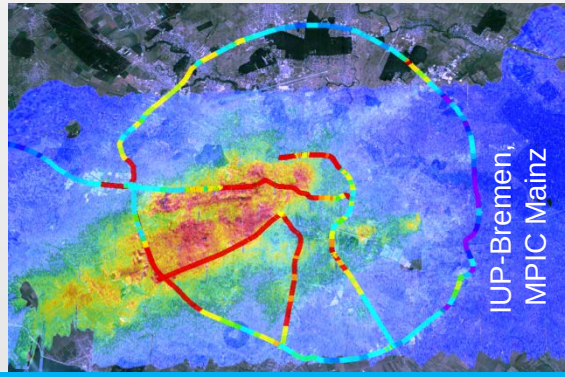
- **Approaches**
  - **use of model forecast**
  - **spatial filtering & interpolation**
  - **clean sector (not available for S4)**
- **Domain**
  - **latitude bands covered by the mission**
  - **various local times**
- **Correlative data**
  - **Stratospheric NO_2! From model, OMPS limb, ..?**
  - **NO_2 total column**

Validation Needs for NO_2

Validate Source Estimation

Campaign dedicated to higher level product

- **Domain**
  - **Similar as for diurnal cycle**
  - **Polluted area including sources, clean surrounding**
- **Correlative Measurements**
  - **NO_2 column and profile reference measurements in domain**
  - **Near-simultaneous NO_2 profile on domain boundary**
  - **Cloud fraction, optical depth, height**
  - **Aerosol optical depth, type**
- **Compare**
  - **Inverse modelling of satellite NO_2 data**
  - **Inverse modelling of correlative NO_2 data**
  - **Simplistic estimate using divergence theorem**
  - **Emission estimates**



$$\int Source\, dA = \oint \overrightarrow{Flux} \cdot \vec{n}\, ds$$

Validation Needs for NO_2

Verify Inter-Mission Consistency

Various approaches

- **LEO missions used as travelling standard**
  - **Systematic assessment as part of operational QA**
  - **Dedicated assessment of sub-sets (e.g. best understood, polluted/background, …)**
- **Stationary inter-calibrated instrumentation**
  - **Systematic assessment as part of long-term QA**
  - **Dedicated assessments, e.g. best understood sub-set**
- **Travelling ground-based and airborne instrumentation**
  - **Link campaigns**
  - **Inter-compare instrumentation and algorithms**
- **Direct comparison of similar targets?**
- **Comparisons with CTM**

Thank you

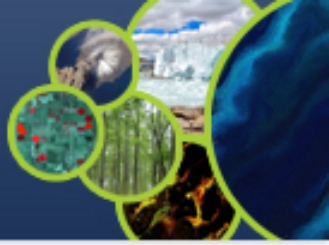
Validation Needs for Irradiance

Establish and maintain Data Quality

Systematic validation by operational data quality center

- **Comparisons**
  - **measured reference spectra (ground-based, atmosph. corrected)**
  - **simulated reference spectra (line lists, models)**
  - **measured spectra from LEO mission**
  - **measured spectra from GeoAQ missions**
- **Monitoring of trends and dependencies**
- **Global Space-Based Inter-Calibration System (GSICS): verify inter-mission consistency, determine inter-calibration factors**

Validation Needs for Radiance and Reflectance



Establish and maintain Data Quality

Systematic validation by operational data quality center

- **Comparison with expected signal for known targets**
  - **bright clouds, dark ocean**
  - **vicarious calibration targets**
  - **dark space, moon (S4)**
- **Monitoring of trends and dependencies**
- **Inter-comparisons with LEOs used as travelling standard**
  - **geometry matching**
  - **bridge goniometry by modelling**
- **Global Space-Based Inter-Calibration System (GSICS): verify inter-mission consistency, determine inter-calibration factors**