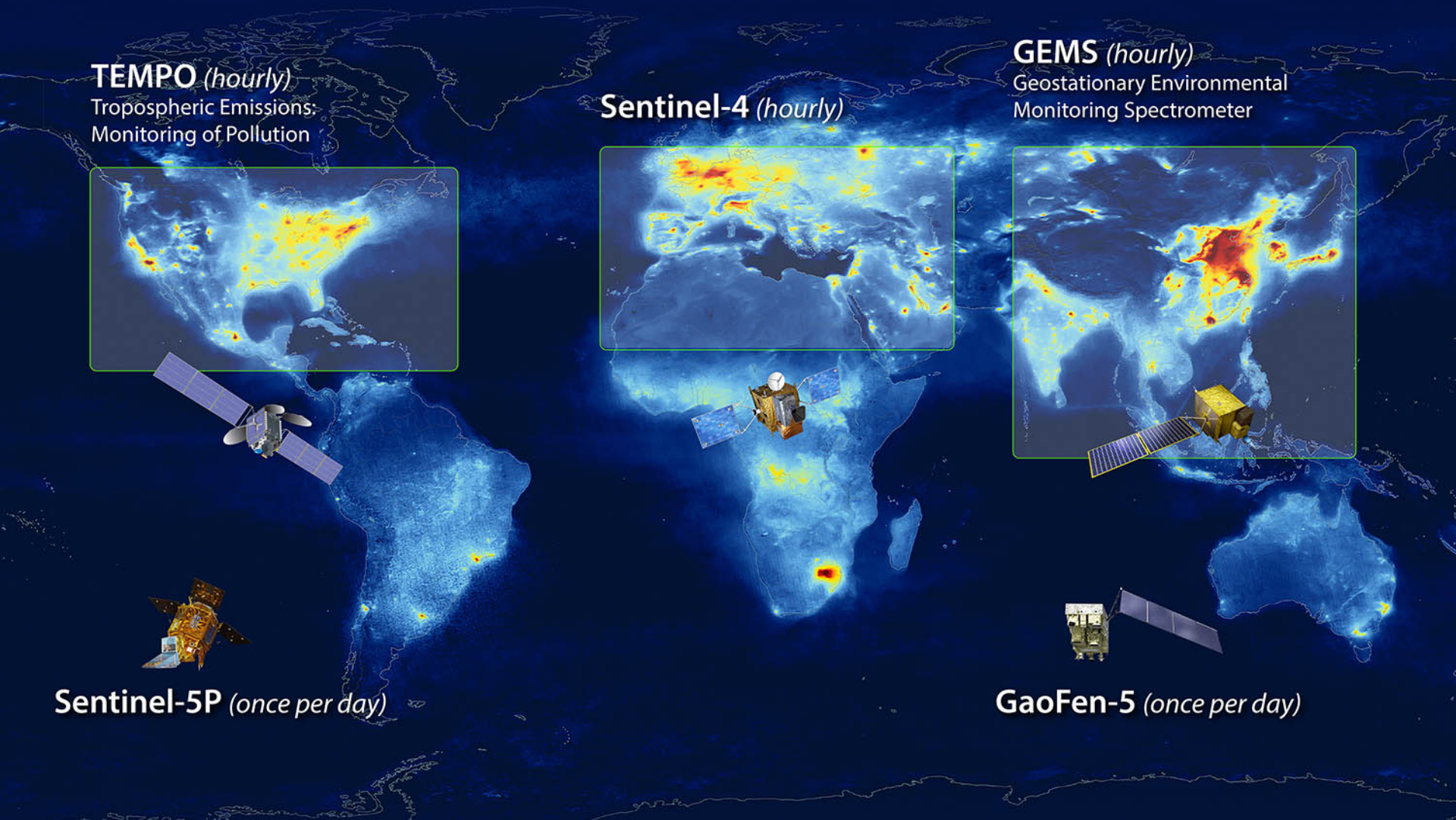
Status of CEOS Air Quality Virtual Constellation and TEMPO

Jay Al-Saadi, NASA Langley Research Center
Kelly Chance, Smithsonian Astrophysical Observatory



CEOS Atmospheric Composition Virtual Constellation (AC-VC):

Air Quality highlights from AC-VC-13 meeting, 28-30 June 2018

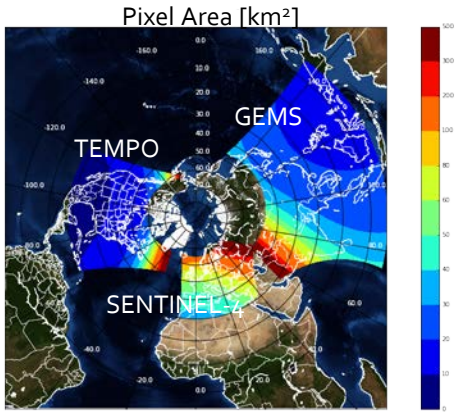
- **AC-VC currently includes 3 activities: Air Quality, O_3 Trends, GHG**
- **Air quality trace gas (Ozone, NO_2, HCHO, SO_2) session**
  - **White paper on Geophysical Validation Needs for the AQ Constellation is proceeding on schedule for a complete draft in Q3 2017**
  - **Coordination of validation activities remains our most important objective as S5P is launched this year and the geostationary missions approach launch**
  - **Given that NASA and the EU now have open data policies, including Level-1b and Level-2, enabling constellation objectives for open data exchange now relies on data access policies for the Asian missions to be established**
- **Air quality aerosol session**
  - **A session was held to explore a potential AC-VC coordination activity for aerosol observations from space with application to air quality**
  - **Participants expressed the need for developing a new constellation activity on air quality associated with aerosol, planned to be further explored in next AC-VC meeting**
  - **Particular consideration will be given to possible leveraging of the next-generation operational GEO imagers (e.g., AMI on GK-2, ABI on GOES-16)**

Talks and executive summary are available:

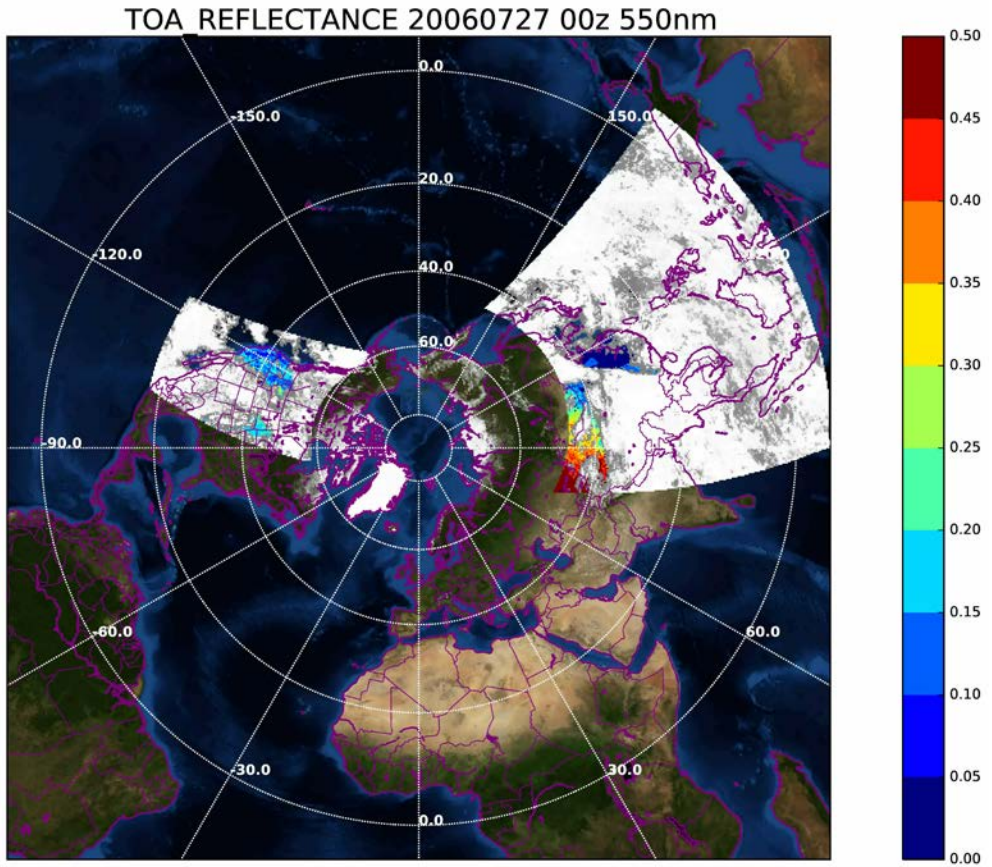
http://ceos.org/meetings/ac-vc-13/

Geostationary Constellation: TEMPO+GOES-R, GEMS and SENTINEL-4

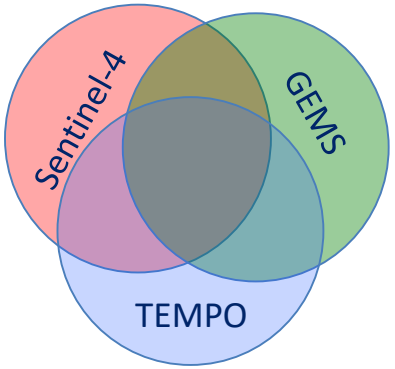
- TOA Reflectance for 6 aerosol relevant channels
- 354, 388, 412, 470, 550, and 670 nm
- Radiative Transfer Model: VLIDORT
- Surface
- MAIAC BRDF Kernels
- Atmosphere
  - GEOS-5 Nature Run with GOCART aerosols



Download TEMPO, GEMS, SENTINEL-4, and GOES-R synthetic data from http://g5nr.nccs.nasa.gov/data/OBS



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		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			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}		$1\text{-}2\times10^{15}$ (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

➔ As of AC-VC-13 29 June 2017

* in molec/cm^2 unless specified otherwise

Committee on Earth Observation Satellites

Issues and potential resolutions that may require SIT Chair support: AC-VC

Atmospheric Composition Virtual Constellation

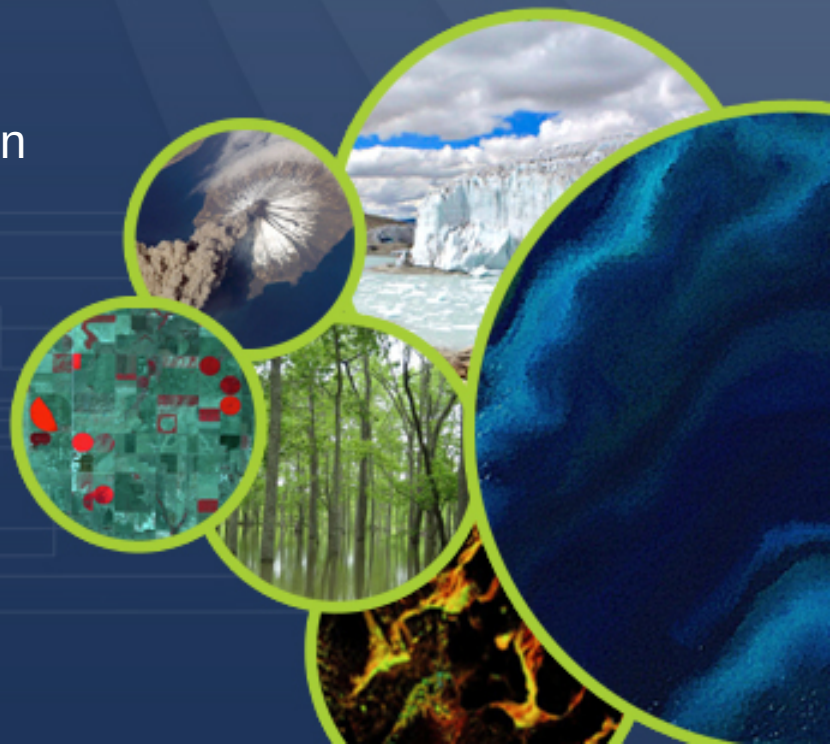
SIT Tech Workshop 2017 Agenda Item #21

CEOS WP Section 3.8, VC-2, VC-3

CEOS Strategic Implementation Team Tech Workshop

ESA/ESRIN, Frascati, Italy

13th-14th September 2017

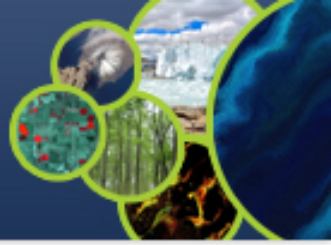


AC-VC Issue: Data Access Policies

- Enabling the Air Quality (AQ) Constellation objectives for open data exchange now relies on **data access policies for the Asian missions** to be established by their organizations
  - CEOS-endorsed AQ constellation position paper (2011) recommended “establishing protocols for mutual open and timely data distribution” to collaboratively enhance the quality of data products from all missions, thereby extending a global focus to the observations
  - Initial missions include Europe’s S4 and S5P, USA’s TEMPO, Korea’s GEMS, and potentially China’s Gaofen-5
  - NASA and the EU now have open data policies including L-1b and L-2

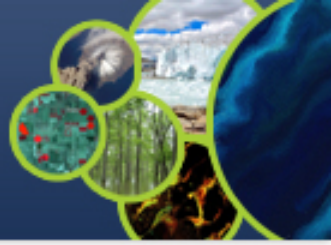
- Request CEOS actively engage (or continue) conversations with appropriate agencies in Republic of Korea and China to facilitate open sharing of satellite data between all partner space agencies

AC-VC Recommendation: Unmet Air Quality Measurement Goals

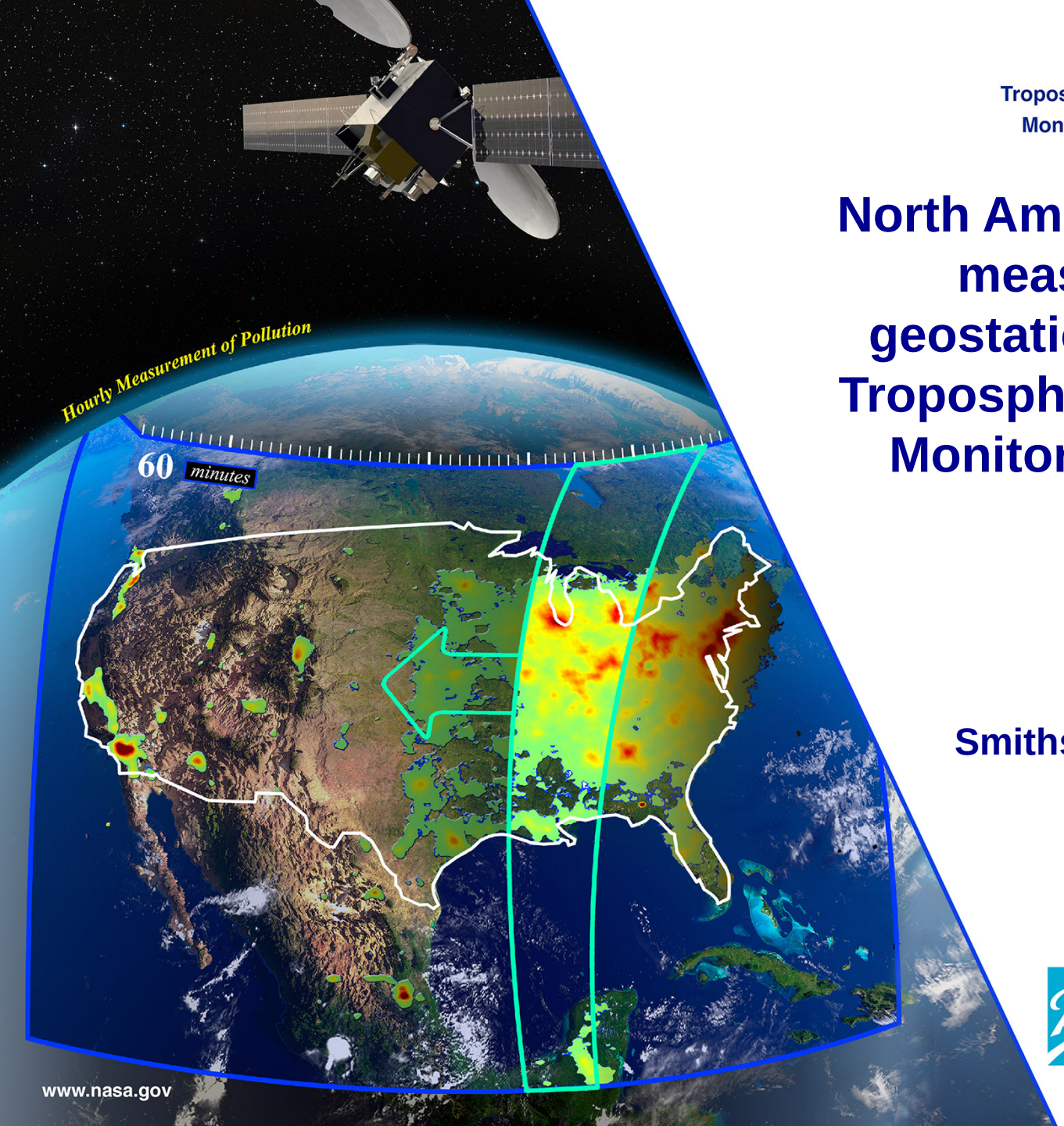


- Though the emergent AQ constellation is a success story, **two measurement goals remain unmet**: extending hourly AQ observations to the rest of the world and providing hourly CO vertical profile measurements with near-surface sensitivity
  - The emergent AQ constellation includes hourly geostationary (GEO) observations over Europe, East Asia, and North America
  - **Requisite CO measurements are not currently planned anywhere**; MTG IRS (Europe) and GeoCARB (US) will provide limited capability
  - **Air quality in the developing world** is a growing societal challenge (increasing industrialization and population) with global impact
  - Extending GEO observational capability to the southern hemisphere and tropics will leverage experience and capabilities from the emergent missions to be an **effective capacity-building** activity
- Encourage agencies to identify strategies to meet remaining AQ measurement goals, possibly including innovative funding and partnership approaches to build capacity in the developing world

AC-VC Recommendation: Enable Joint AQ/GHG Constellations



- Constellations for observing air quality (AQ) and greenhouse gases (GHG) have developed separately but **are highly interdependent**
  - Similar emission sources (i.e., combustion) control AQ and GHG
  - AQ affects natural carbon cycles, modulating net GHG abundances
  - Simultaneous AQ and GHG observations provide **better constraints on emission fluxes and transformation**, critical for policy strategies
- Atmospheric composition Observing System Simulation Experiment (OSSE) capability has matured rapidly
  - AC-VC is fostering AQ and GHG OSSE development with involvement of ECMWF, ESA, Copernicus, NASA, JAXA, NIER, and others
  - International objectives for both AQ and GHG observations could be achieved more effectively through coordinated planning
- Agencies should be encouraged to **coordinate existing AQ and GHG OSSE capabilities** to efficiently enable joint AQ/GHG satellite constellation studies



Tropospheric Emissions:
Monitoring of Pollution

TEMPO

North American pollution measurements from geostationary orbit with Tropospheric Emissions: Monitoring of Pollution (TEMPO)

tempo.si.edu

Kelly Chance
Smithsonian Astrophysical Observatory

GEMS Science Team
September 25, 2017

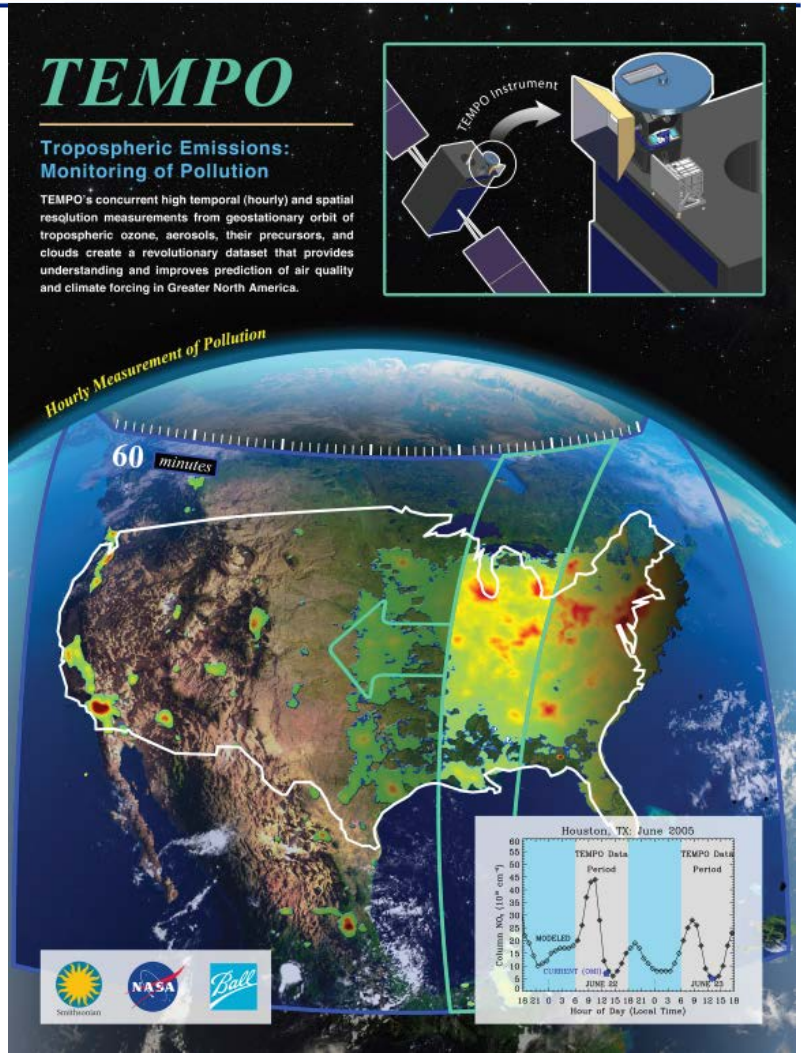
Ball

Smithsonian

NASA

Hourly atmospheric pollution from geostationary Earth orbit

PI: Kelly Chance, Smithsonian Astrophysical Observatory
Instrument Development: Ball Aerospace
Project Management: NASA LaRC
Other Institutions: NASA GSFC, NOAA, EPA, NCAR, Harvard, UC Berkeley, St. Louis U, U Alabama Huntsville, U Nebraska, RT Solutions, Carr Astronautics
International collaboration: Mexico, Canada, Cuba, Korea, U.K., ESA, Spain



Selected Nov. 2012 as NASA's first Earth Venture Instrument

- Instrument delivery March 2018
- NASA will arrange hosting on commercial geostationary communications satellite with launch expected 2019 or later

Provides hourly daylight observations to capture rapidly varying emissions & chemistry important for air quality

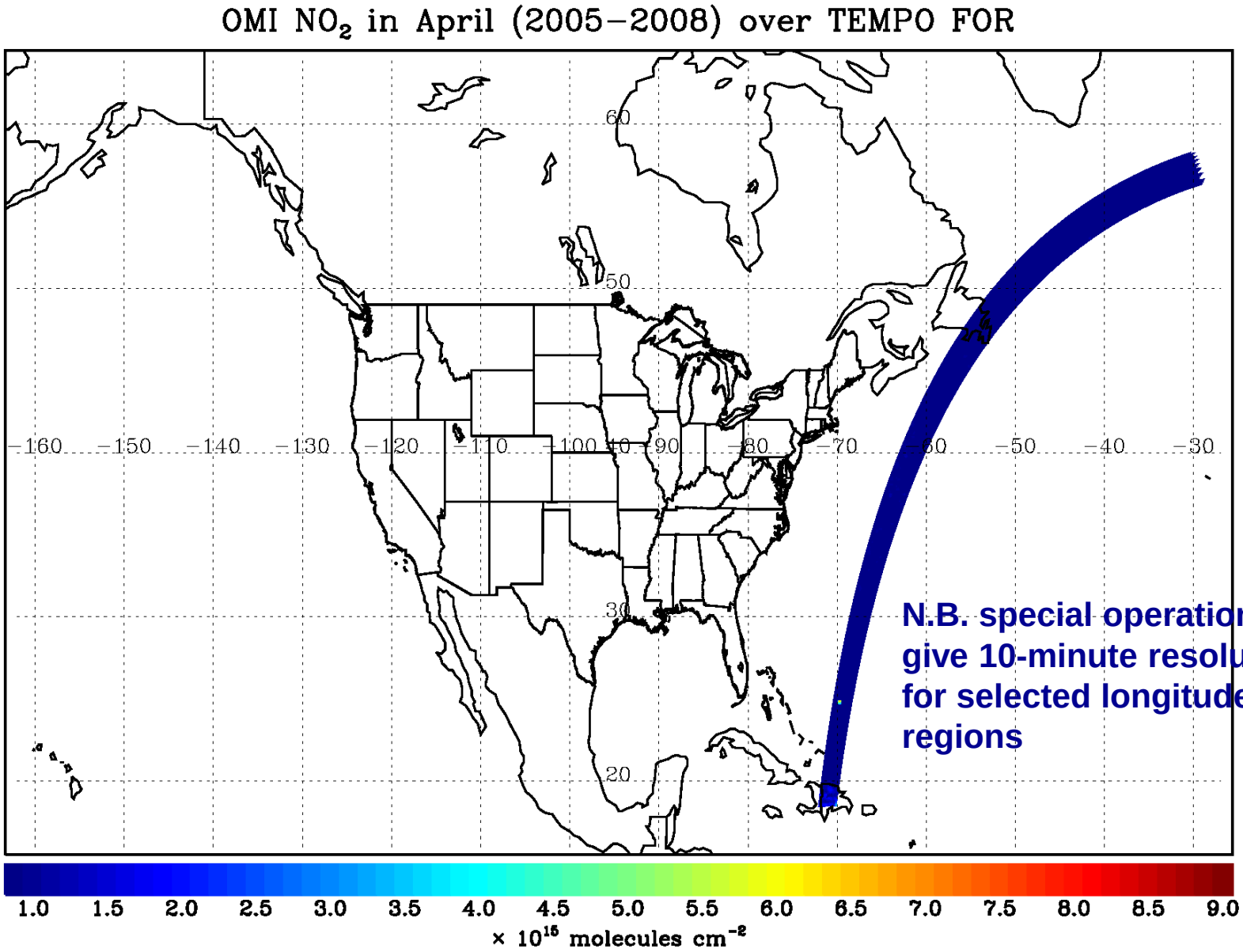
- UV/visible grating spectrometer to measure key elements in tropospheric ozone and aerosol pollution
- Distinguishes boundary layer from free tropospheric & stratospheric ozone

Aligned with Earth Science Decadal Survey recommendations

- Makes many of the GEO-CAPE atmosphere measurements
- Responds to the phased implementation recommendation of GEO-CAPE mission design team

North American component of an international constellation for air quality observations

TEMPO hourly NO_2 sweep



TEMPO instrument concept

- **Measurement technique**
  - Imaging grating spectrometer measuring solar backscattered Earth radiance
  - Spectral band & resolution: 290-490 + 540-740 nm @ 0.6 nm FWHM, 0.2 nm sampling
  - 2 2-D, 2k×1k, detectors image the full spectral range for each geospatial scene
- **Field of Regard (FOR) and duty cycle**
  - Mexico City/Yucatan, Cuba to the Canadian oil sands, Atlantic to Pacific
  - Instrument slit aligned N/S and swept across the FOR in the E/W direction, producing a radiance map of Greater North America in one hour
- **Spatial resolution**
  - 2.1 km N/S × 4.7 km E/W native pixel resolution (9.8 km^2)
  - Co-add/cloud clear as needed for specific data products
- **Standard data products and sampling rates**
  - Most sampled hourly, including eXceL O_3 (troposphere, PBL)
  - NO_2, H_2CO, $C_2H_2O_2$, SO_2 sampled hourly (average results for ≥ 3/day if needed)
  - Nominal spatial resolution 8.4 km N/S × 4.7 km E/W at center of domain (can often measure 2.1 km N/S × 4.7 km E/W)
  - Measurement requirements met up to 50^o for SO_2, 70^o SZA for other products

Baseline and threshold data products

Species/Products	Required Precision	Temporal Revisit
0-2 km O_3 (Selected Scenes) Baseline only	10 ppbv	2 hour
Tropospheric O_3	10 ppbv	1 hour
Total O_3	3%	1 hour
Tropospheric NO_2	1.0×10^{15} molecules cm^{-2}	1 hour
Tropospheric H_2CO	1.0×10^{16} molecules cm^{-2}	3 hour
Tropospheric SO_2	1.0×10^{16} molecules cm^{-2}	3 hour
Tropospheric $C_2H_2O_2$	4.0×10^{14} molecules cm^{-2}	3 hour
Aerosol Optical Depth	0.10	1 hour

- Minimal set of products sufficient for constraining air quality
- Across Greater North America: 18°N to 58°N near 100°W, 67°W to 125°W near 42°N
- Data products at urban-regional spatial scales
  - Baseline ≤ 60 km^2 at center of Field Of Regard (FOR)
  - Threshold ≤ 300 km^2 at center of FOR
- Temporal scales to resolve diurnal changes in pollutant distributions
- Collected in cloud-free scenes
- Geolocation uncertainty of less than 4 km
- Mission duration, subject to instrument availability
  - Baseline 20 months
  - Threshold 12 months

TEMPO status

- **Currently on-budget and close to on-schedule**
  - **System Requirements Review and Mission Definition Review in November 2013**
  - **PDR on July 31, 2014**
  - **Now in Phase C (implementation): KDP-C April 10, 2015**
  - **Instrument CDR June 2015**
  - **Ground Systems CDR May 2016**
  - **Test Readiness Review August 2016**
  - **Currently undergoing assembly, integration, and test**
- **Select commercial geostationary satellite host 2018**
  - **TEMPO operating longitude and launch date are not known until after host selection**
- **Instrument delivery 3/2018 for launch 2019 or later, most likely in 2020 or 2021**

Backup

New Challenges

- **Temporal sampling of diurnal cycle**
- **Horizontal resolution (Sentinel-5P is a 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)**