**Air quality and climate forcing over North America in the next decade**

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Air quality management challenges in the US are evolving rapidly and increasingly convolved with concerns over biogeochemical cycles and climate change. The Air Quality Applied Sciences Team (AQAST) supported by the NASA Applied Sciences Program (ASP) has been working with US air quality managers since 2011 to maximize the utility of satellite data for air quality applications. Over this time we have built deep relationships with air quality agencies at national, state, and local levels. Many of these agencies are now extensively using satellite data for a variety of applications including improved emission estimates for state implementation plans (SIPs), mapping of particulate matter (PM) and hazardous air pollutants (HAPs), interstate and international transport, exceptional events, and long-term trends.

Air quality management needs in the US are evolving rapidly, in a direction that increases the importance of satellites for providing a comprehensive, sustained, large-scale perspective. For example, the recent tightening of the ozone national ambient air quality standard (NAAQS) to 70 ppb raises the imperative to better quantify the ozone background and understand its origins. Emerging pressure to meet climate change mitigation targets is pushing air quality managers to include greenhouse gases in their regulatory process, and to look to satellite observations for understanding emissions. Fires and dust are an increasing air quality issue and satellites provide a unique viewing perspective. Growing interest in secondary standards to protect vegetation can be informed by an integrated view of atmospheric composition and ecosystem function from space. Anthropogenic emissions in the US are changing rapidly, and air quality managers are increasingly looking to satellites to quantify these changes as well as foreign emissions and transboundary transport. Climate and land-use changes are altering the physical atmosphere which then impacts emissions, boundary layer dilution, and other aspects of air quality.

All satellite observations of atmospheric composition so far have been from low Earth orbit (LEO). They have shown significant value for constraining anthropogenic emissions, evaluating models, tracking fire and dust plumes, and documenting high-ozone episodes of background origin. TROPOMI to be launched in mid-2016 will have 7x7 km2 nadir pixel resolution and daily revisit time. This is still short of a continuous view and (because of noise) will have limited value on a sub-monthly time scale. The TEMPO geostationary satellite mission for North America, selected in 2012 by the Earth Venture program and expected to launch in the 2018-2020 time frame, will revolutionize our ability to observe air quality from space. Its UV/Vis solar backscatter channels will provide hourly data at 2.5 x5 km2 resolution for aerosol optical depth (AOD), NO2, formaldehyde, SO­2, and ozone. This will provide powerful new constraints to map emissions of ozone and PM precursors. Concurrent geostationary UV/Vis sensors will observe Europe and East Asia (the geostationary “constellation”). But TEMPO has no IR channels and so will not be able to observe methane, CO, CO2, ammonia, or upper tropospheric ozone. It also has a design lifetime of just two years, which makes it more a demonstration than a program to support air quality management needs.

We make the case here that a UV/Vis/SWIR/TIR geostationary satellite mission for North America over the next decade is critical for addressing national air quality and climate management needs in a turbulent policy period where these needs are evolving rapidly. This satellite mission will provide a unique resource for the US and its neighbors (Canada and Mexico) to quantify emissions of pollutants and greenhouse gases, to understand the contribution of pollution transported into and out of the North American domain, to measure regional radiative forcing, and to map surface concentrations of ozone and PM. Together with LEO observations to provide a global perspective, and with geostationary observations monitoring air quality and climate forcing in other parts of the world, it will contribute to a powerful space-based system for observing atmospheric composition and has been endorsed by the Atmospheric Science Working Group of the GEO-CAPE satellite mission.

*1.What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?*

Managing air quality and climate change together will be a critical national challenge for the US over the coming decade. A suite of new air quality issues is emerging including background ozone, wildfires, dust storms, nitrogen deposition, transboundary pollution transport, and emissions from oil/gas production. The current air quality observing system is not adapted to these issues. Satellite observations can play a critical role. Climate change mitigation will also become an important component of air quality management over the next decade, requiring accurate emission inventories for greenhouse gases (including biospheric uptake for CO2) and quantification of regional radiative forcing from aerosols and ozone. Satellite observations will be key for evaluating the inventories and for enabling radiative forcing estimates.

TEMPO will provide a first demonstration of geostationary observations of air quality for gases, and an expansion of geostationary observations for PM beyond GOES and GOES-R. It will provide unprecedented capability to map NOx and VOC emissions and to observe the distribution of ozone. But the short duration of TEMPO and the lack of IR channels is a serious limitation. There is a critical need for investment into a longer-term program of geostationary observations of air quality, including the capability to constrain national budgets of greenhouse gases (CO2, methane) and regional radiative forcing (aerosols, tropospheric ozone). The capability for doing all these measurements from LEO has been previously demonstrated. Doing them from geostationary orbit presents minor additional technical challenge but considerable additional reward.

Geostationary observation of air quality and climate forcing over North America will need to be integrated into a broader observing system including LEO observations and suborbital platforms.The DISCOVER-AQ campaign has played an important role in developing a better understanding of how satellite observations can be effectively complemented by observations from aircraft, ground sites, and sondes. Ground-based lidars should also play an important role.

A geostationary mission for air quality and climate forcing over North America will have major scientific benefits, for example through improved understanding of the carbon budget and its coupling with the nitrogen cycle. It will enable detailed constraints on the methane budget by source type and allow detection of methane emission hotspots (the “superemitters”). The societal benefits will be considerable. The mission will provide the US and its neighbors with (1) an observing system to constrain national inventories of greenhouse gases, including short-term variability; (2) the capability to respond to mandates on mitigation of emissions causing climate forcing; (3) a tool for addressing changing demands of air quality management, (4) an improved initialization of air quality forecasts. Multispectral geostationary observation of North America will engage not only atmospheric chemists and air quality managers but also climate scientists, policy analysts, terrestrial ecologists, and land-use managers.

*2. Why are these challenge/questions timely to address now especially with respect to readiness?*

Air quality and climate forcing will be pressing national issues over the next decade. Quantifying emissions of greenhouse gases and the contributions from different sources will be a challenge of considerable importance for climate policy, as reflected by the Carbon Monitoring System (CMS) program presently led by NASA. Observations from geostationary orbit will provide unprecedented capability for addressing these issues. A long-term geostationary mission covering the UV/Vis/SWIR/TIR multispectral range is required for targeting air quality and climate forcing objectives in a synergistic manner. Such measurements could be obtained from a new mission covering this full multispectral range or perhaps by extending the TEMPO mission and complementing it with the required SWIR/TIR measurements.

1. *Why are space-based observations fundamental to addressing these challenges/questions?*

Geostationary space-based observations provide a continuous fine-grained mapping of atmospheric concentrations that is fundamental for addressing air quality and climate forcing issues. The value of satellite observations of atmospheric composition to constrain emissions through inverse modeling has been amply demonstrated over the past decade. Geostationary observations will revolutionize our ability to constrain emissions from space including daily variability on km scales. This will provide an essential complement to bottom-up inventories and allow continual testing of these inventories in terms of changing emissions and the contributions from different source types.

Space-based observations from geostationary orbit will support the enforcement of air quality standards and the conduct of epidemiological studies for air quality. For example, the Intermountain West will likely fail to meet the new ozone NAAQS because of elevated background ozone, new emissions from oil/gas production, and increasing frequency of wildfires. Surface monitors in that region are sparse. Geostationary observations will provide complete coverage including the information on contributions from the ozone background and local emissions. Epidemiological studies of the health effects of PM have been limited by the poor geographical coverage of PM surface observations. Geostationary observations will provide the fine spatial granularity needed for these studies.