*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?*

A key challenge in global human health is the degradation of air quality in the major population centers of developing countries. The NASA GSFC group listed above presented this topic to the NASA workshop on Outstanding Questions in Atmospheric Composition, Chemistry, Dynamics and Radiation for the Coming Decade that was conducted at NASA Ames Research Center in May 2014. This topic was voted as the top priority for atmospheric composition by the attendees of the workshop, demonstrating broad community support for future research on this issue.

Global population is expected to increase from ~7 billion to 9.6 billion by 2050 with most of the increase occurring in the developing world, including over half in Africa. Today, many of the world’s megacities (>10 million population) exist in the developing world and their global number is expected to increase from 22 currently to 36 by 2050. Air pollution, particularly in the developing world, is already the single largest environmental health risk, claiming 7 million lives annually (<http://www.who.int/mediacentre/news/releases/2014/air-pollution/en/>). Extreme pollution events in China and India are often reported by the media, but they also occur frequently in large cities of the Middle East, Africa, South America, and other Asian countries (Zhu et al., 2012). Major sources of air pollution in the developing world include motor vehicles, burning of household waste, domestic fuel (charcoal, wood, agricultural waste, dung), electricity generation, industry, and unpaved roads. Naturally occurring aerosols (e.g., dust) are another regionally important contributor to air quality issues. In addition, urban populations can be strongly affected by large-scale biomass burning on a seasonal basis. Megacities have large energy consumption and are concentrated sources of both pollution and greenhouse gas emissions. The air pollution created from these activities causes detrimental health effects, such as respiratory and cardiovascular diseases. Many of the tropical and subtropical megacities exceed the WHO annual mean guidelines for PM2.5 and NO2 concentrations and exceed national and WHO standards for ozone.

Observations are needed to answer the following questions:

- What is the current (i.e., baseline) impact of anthropogenic activities and natural emissions on urban air quality, tropospheric composition, and climate?

- How will emissions of trace gases, greenhouse gases, and aerosols change over the coming decades from urbanization, economic development, and policy decisions?

- To what extent does biomass burning pollution affect megacity air quality and how will these emissions change in response to population growth in the developing world?

- What will be the effects of population growth and spatial distribution on weather and climate (aerosol radiative forcing, temperature and water vapor changes, etc.)?

*Why are these challenges/questions timely to address now especially with respect to readiness?*

Most of the population growth in the coming decades will be in urban areas of developing countries, thereby deteriorating air quality. For example, Liousse et al. (2014) estimate that ~50% of global organic carbon emissions of particulate matter could be from Africa by 2030. Air quality will be monitored hourly by satellite over much of the heavily populated regions of the Northern Hemisphere by the geostationary constellation of TEMPO, Sentinel 4 and GEMS by ~2019. However, this constellation will not cover Central and South America, much of Africa, and parts of the Middle East and South Asia -- regions with expected explosive population growth and air quality degradation. Therefore without additional space-borne instruments, fine-resolution diurnal measurements of air quality in the tropics and subtropics will not be possible.

The ability to monitor air quality and changing emission patterns from space has been proven from low-earth orbiting (LEO) satellites such as Aura, Aqua, Terra, ENVISAT, and METOP. UV-Vis and IR instruments on these platforms have demonstrated ability to monitor NO2, HCHO, SO2, CO, (CHO)2, and aerosols. However, near-surface ozone monitoring will require simultaneous UV/Vis/TIR observations on new platforms. To understand contributions of various emission sources will require finer spatial and temporal resolution than is provided by the current LEO instruments. The LEO Sentinel 5P TROPOMI instrument due to be launched in 2016 will provide 7-km horizontal resolution, but will still only provide one observation per day. Such data will be insufficient to better understand the chemical processing that occurs in the diurnal evolution of ozone and in the buildup of aerosol loading. To ensure that major urban areas are sufficiently sampled every day, geostationary observations are required. The necessary instrument technology exists to perform these observations.

Alpert et al. (2012) have examined trends in AOD over the world’s largest cities using data from MODIS (Terra and Aqua) and MISR over the period 2002 – 2010. AOD in large cities in West Africa show upward trends from all three sensors. In some major cities of South America there is disagreement between the sensors in terms of the direction of the trend, leaving considerable uncertainty concerning air quality trends for aerosols. Duncan et al. (2015) computed the trends in NO2 over 2005 to 2014 for a number of cities worldwide as measured by OMI on the Aura satellite. Figure 1 shows the percentage change in tropospheric NO2 column amounts over this period for three African cities (Cairo, Nairobi, and Luanda). Strong positive trends are detected in each of these metropolitan areas, demonstrating the effects of explosive population growth and economic development in these regions. These trends urgently call for more comprehensive monitoring of air quality in the developing world in the near future.

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

Most tropical and subtropical cities lack continuous, sustained air quality monitoring at surface sites, and while there are more measurements available from South American cities, the reliability and accessibility of the data are less than desired. Therefore, geostationary satellite observations are required to estimate air quality levels throughout the day such that pollution warnings can be issued. Suborbital observations would clearly aid in establishing baseline data. One or two prototype urban areas should be selected for intensive sampling. Perhaps an international consensus concerning needed suborbital and surface field programs would be required before such experiments could be conducted. International partners would also likely



 

Figure 1. OMI tropospheric column NO2 trends over 2005 to 2014 for Cairo (upper left), Nairobi (upper right), and Luanda (lower left). Gray values indicate no significant trend.

be desirable in conducting such measurements. Suborbital research should also contain components that examine impacts of biomass fires on air quality and on GHG emissions, in addition to urban impacts.

The existing and planned LEO instruments provide at best one or two observations per day. This limited temporal coverage limits characterization of pollution sources on diurnal scales and limits the determination of pollutant transport and spatial variability. Clouds are a hindrance to polar orbiting observations during the wet season. Hourly observations from a geostationary platform increase the probability of obtaining cloud-free scenes. Many of the existing instruments are approaching the ends of their lifetimes. Therefore:

* Geostationary UV/VIS/NIR/TIR observations are needed over the tropics and subtropics to measure hourly O3, NO2, SO2, HCHO, CO, CH4, (CHO)2, NH3, and AOD with sufficient sensitivity to the lowest 2 km of the atmosphere for air quality application.
* To cover the major population centers of the tropics and subtropics that will not be observed by the currently planned constellation, observations are needed over the latitude range of 15°N to 35°S and longitude range of 80°W to 75°E. This is a region of dimensions 50° of latitude by 155° of longitude, requiring two geostationary platforms and international collaboration.
* NASA and USAID collaborate on making satellite products available in developing countries under the SERVIR program. SERVIR should be expanded to include air quality applications.

*Summary*

The population explosion over the next few decades will primarily impact the tropics and subtropics. The planned geostationary view of major gaseous pollutants misses many of the tropical and subtropical megacities and near megacities (particularly in South America and Africa). Emissions and relative source contributions of pollutants affecting air quality in these cities are very poorly known. Therefore, geostationary instruments focused on the tropics and subtropics are needed. In addition, there is a need for surface and aircraft measurements to derive today’s baseline emissions and air quality in the fast-growing population centers of the tropical and subtropical developing world. The impacts of biomass burning and dust on urban air quality, the interactions of pollution with the aerosol-cloud-radiation environment, and long-range transport must be quantified. Air quality in these regions is closely linked with land-use changes and the hydrological cycle. Therefore, atmospheric composition measurements in this region should be accomplished in conjunction with studies of land-use change, cloud-aerosol interaction, and greenhouse gas emissions.

In the near-term there is a need for suborbital observations to **establish baseline tropical megacity atmospheric composition, sources, and regional impacts**in conjunction with ground stations and modeling. In the longer-term, **geostationary satellite observations of atmospheric composition over the tropics and subtropics** are needed for reactive gases, aerosols, and longer-lived species such as CO and methane as an aid in predicting severe air quality events, as well as for gaining insight on the diurnal emission patterns and chemical processing occurring in each megacity.

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