

Measurement Needs for Examining the Feedbacks Between Regional Air Quality and Climate Change

Dr. Vernon R. Morris

Center for the Study of Terrestrial and Extraterrestrial Atmospheres, Howard University,
Presently at the NASA Laboratory for Atmospheres, Goddard Space Flight Center,
Greenbelt, MD 20771

Summary

It is generally accepted that a better understanding of the Earth environment will enable highly accurate forecasts of the physical, chemical, and biological state of the Earth on short-, intermediate-, and long-term scales. Our ability to quantify the connections between atmospheric chemistry and meteorology, i.e. the chemical forcing of global climate change, is central to obtaining better predictive capacity. Two primary linkages between atmospheric chemistry and global climate change are the impacts of greenhouse gas emissions and budgets and aerosol formation, evolution, and microphysics.

Air quality is characterized largely by EPA definitions of pollutants. The six “criteria” pollutants designated by the EPA are ozone, carbon monoxide, nitrogen dioxide, sulfur dioxide, 10- μm particulate matter (particularly those particles with lead incorporation), and 2.5- μm particulate matter. With respect to air quality and pollutant emissions, the central greenhouse gases of concern are: ozone, carbon dioxide, carbon monoxide, and methane.

Ozone produced as a secondary boundary layer pollutant will tend to have near-negligible implications to global climate change through direct forcing. This is due to the high concentrations of nitrogen oxides and hydrocarbons, which are also present in high concentrations near the Earth’s surface. The indirect effects of ozone on global climate change may be tremendous. Increased ozone can enhance secondary particle formation, decrease surface UV flux and thereby alter regional radiation balance, degrade photosynthetic behavior of plants and thereby alter carbon storage, etc. These effects are less quantified and require a better understanding of the spatial distribution of ozone than current EPA monitoring networks are able to provide. On the other hand, if this ozone is lofted into the free troposphere, its lifetime increases significantly, and the implications for direct impact on global climate also increases significantly.

Carbon dioxide, carbon monoxide, and methane have much longer lifetimes and their contributions to global climate change occur primarily through direct forcing, i.e. absorption of IR radiation. Sulfur dioxide has not been shown to contribute significantly to global warming as an IR absorber, but it is the primary precursor for sulfuric acid and sulfate aerosol in the troposphere.

Aerosols can impact global climate directly - through scattering & absorption of UV, visible, and IR radiation or indirectly - through cloud and precipitation modification,

fog prevalence, reaction catalysis (as in the case of stratospheric ozone depletion), and perturbations to photochemical cycles by redistribution of reservoir species and enhanced tropospheric production of ozone. The specific impact of the aerosol is heavily dependent on its composition – both macroscopic (internally well-mixed, sulfate-coated, etc.) and microscopic (uptake coefficients and reactivity). A key challenge is the elucidation of spatio-temporal distributions that would allow better prediction of these dependencies on regional or global scales.

We can distill the challenges we face in developing a better understanding of the impact of regional air quality on global climate into two strategic science questions:

- What are the physical and chemical properties of aerosols and how do they impact on regional climate?
- What are the spatio-temporal distributions of key tropospheric aerosol and trace gas species?

Several secondary questions associated with scientific and technological barriers also arise:

- How do we monitor aerosol physical and chemical evolution during long-range transport?
- How do we measure or map the three-dimensional global greenhouse gas distributions and their climatologies?
- Can the impacts of aerosols on meteorology be accurately quantified using measurement and modeling capabilities?

The central African basin (CAB) represents a potentially important source region for both natural and anthropogenic greenhouse gas and aerosol emissions affecting air quality, climate system change, industrialization, and rapid land cover land use change (Slide 1). The CAB is particularly interesting because of its proximity to centers of rapid urbanization (Lagos, Nairobi), huge sources of airborne mineral dust (Slide 3), an upper altitude source of global NO_x (Slide 4), and surface sources of biomass burning aerosols and greenhouse gases. The complex feedbacks (Slides 2 and Slide 5) between the chemistry, the meteorology, and the consequent climate forcing of this region provide an ideal case study for the questions articulated above.

No single type of measurement (surface, airborne, or satellite) can alone effectively provide useful constraints or inputs required to improve model predictions. This is especially true in the lower troposphere where the spatial, vertical, temporal, and chemical variability of sources and sinks largest. A concerted program of surface-based, airborne and satellite measurements be used to improve our understanding of urban emission sources, high-resolution tropospheric chemistry, and aerosol processes and feedbacks. It is also imperative that such a field campaign be integrated with both urban-scale and chemistry transport models. This is critical because it maintains a relevant context for the measurements, can allow for careful planning of closure studies, and can

provide the parameters for the desired improvements in the models. There are a few existing models of the application of this strategy that can be found in current field programs, e.g. SOS, ACE-Asia, SAFARI but high-resolution space-based measurements must also be a central part of the strategy.

Remote sensing measurements from space are essential because they can provide the required global perspective, continuous coverage, and the ability to track long-range transport. The current capabilities measurement of global air quality are summarized in Table 1. There are still several critical technological barriers to improving our understanding of the air quality – global climate connection. Among them:

- Our measurement capabilities are hampered by sparse ground detection networks, which also tend to be both labor and resource limited.
- Distinguishing between aerosol types (soot vs. organic aerosols) from space is extremely difficult, relies on assumptions, that are often invalid for the region(s) of interest, and thus, requires a much greater understanding of the optical properties of different types of aerosols as a function of relative humidity.
- There are innate difficulties in deriving aerosol size distributions and single scattering albedo from space-based instruments. The ability of space-based sensors to “see” lower troposphere and boundary layer constituents with vertical resolution is non-existent at this point

In order to overcome these barriers, careful inter-comparison of space-based, airborne, and surface measurements must be used to:

- Provide a critical set of validation data to ensure that the satellite data retrievals are accurate and quantitative representations of the tropospheric quantities,
- Perform long-range tracking of pollutant plumes (dust, fires, volcanic, and anthropogenic particulate)
- Permit monitoring of cloud albedo properties, droplet size distributions, and temperatures,
- Characterize long-term monitoring of regional scale air quality, and
- Quantify in-situ production and impacts of atmospheric phenomena (i.e. lightning-produced NO_x)

The ability of satellite measurements to ever contribute meaningfully to our understanding of chemistry on an urban scale is arguable. Certainly, the capacity does not exist at present. However, in the next few years satellite measurements from new sensors will be able to provide reasonably high resolution mapping of the tropospheric (and EPA criteria) pollutants (down to 1 km x 1 km horizontal and as good as 2 km x 2 km vertical). Satellite measurements are also critical for examining regional air quality and regional to long-range transport – especially of aerosols. Satellite sensors such as OMI, GOME, TES, MODIS, MISR, and POLDER will soon provide unprecedented profiling of the lower atmosphere, and in particular aerosols. These instruments employ

various combinations of multi-channel and multi-angle radiometry to distinguish between aerosol types and locations at high resolution.

A new proposal for a comprehensive strategy for unraveling the feedbacks between regional air quality and global climate is the **High Resolution Aerosols and Sulfur dioxide Experiment (HASE)**. The HASE Mission is designed to provide critical data for the investigation of regional and urban scale air quality by measuring tropospheric aerosol and trace gases- SO₂, NO₂, and O₃. Two space-based hyperspectral digital cameras will combine stereoscopic dual-viewing and high-resolution imaging in the near-UV through visible spectral regions (310-530 nm). The combination of dual viewing and the multispectral push broom technique will enable the distinction between different aerosol types (soot, sulfate, mineral dust, organic aerosol) and for limited vertical profiling of dense aerosol plumes. The spatial resolution will be as high as 0.7 km x 0.7 km for aerosols over continental regions. The HASE data products will be combined with comprehensive robust ground and aircraft based field measurements of aerosol microphysics and chemistry to provide a well-balanced approach to the study of global air quality.

A final note is that laboratory-scale measurements of aerosol microphysics and chemistry must be made in support of field measurements. These will provide the mechanistic inputs to models for accurate descriptions of the aerosol chemistry and NMOC oxidation, which are particularly lacking in quantitative understanding at present. Laboratory measurements of aerosol optical properties such as single scattering albedo, absorption cross sections, and refractive indices (as a function of relative humidity, phase/temperature, and compositions) must be used to guide and improve satellite retrievals of aerosol properties.

<i>Climate or Environment Effects</i>	<i>Aerosol Properties</i>	<i>Chemical Information</i>	<i>Physical Measurement</i>	<i>Satellite Platform</i>	<i>Fundamental Knowledge/ Lab Measurement</i>	<i>Species</i>
Smog	Mass as a function of relative humidity (RH) Liquid water content as a function of RH Surface area distribution	Precursor emissions Ambient oxidant levels	Size distribution Number distribution	TES HASE OMI MOPITT	Nucleation Gas-to-particle form. Scattering properties Gas kinetics	O ₃ , NO _x , NO _y , H ₂ CO, OH, CO, H ₂ O
Visibility Direct forcing Haze/fogs	Morphology Refractive index Mass as function of radius LWC as a function of RH	Mixing state Total amounts & distribution of organics, carbon, inorganics, Molecular forms	Size distribution Number distribution Aerodynamic size RH in situ Light absorption and scattering	POLDER MODIS GLI MISR	Optical properties as a function of mixing state Secondary particle formation	VOC, O ₃ , H ₂ O
Indirect climate forcing	Size distribution Soluble mass Thermodynamics (Van't Hoff factor Surface tension, etc) morphology	Mixing state Molecular distribution as a function of size	Size & spatial distribution Solubility & phase	POLDER MODIS	Refractive indices of aerosol mixtures	GHGs
Effects on rain, Lightning, Cloud formation	Solution pH Conductivity Solubility see smog & fog Van's Hoff factor Electrical properties	Molecular forms of solutes Presence of metallic Soluble fraction NO _x production Organic content Nature of CN	Total solute mass Size distribution (CN, drops) Number distribution Flash rates Field strength	MODIS LIS other TRMM sensors	Nucleation props Charge formation LNO _x production efficiency, Rain water chemistry Electrical props of aerosols	NO _x , NO _y , organic acids, O ₃
Biogeochemical Cycling	Size distribution (affects removal) Gas-particle partitioning Reactivity, Aerosol age, Transport, Solubility	Molecular forms Mixing state Organic/inorganic fraction	Size distribution Cloud processing Aerosol aging Source strengths Global distribution	HASE MODIS TOMS POLDER MISR MOPITT	Gas-to-particle Heterogeneous chemistry	acetone, nitrates, oxidants, H ₂ O, CH ₄ , sulfates aerosols

