Workshop on a Pilot Design for
Air Quality in Africa

Virtual Agenda

Format: *Presenters for sessions 1,2 and 3 will make 12-minute presentations followed by discussions and summary of discussion results.*

June 8-11, 2021 Daily at

9 AM – 12:30 PM** - **US Eastern daylight time
4:00 PM to 7:30 PM East African Time
2:00 PM to 5:30 PM Western Europe (England)
3:00 PM to 6:30 PM Central Europe (Stockholm, Paris, Berlin etc.)
1:00 PM to 4:30 PM West African Time (Ghana)

Day 1– June 8, 2021

9:00 am – 9:10 am – Opening remarks, setting the goals of the workshop

Solomon Bililign – North Carolina A&T State University,
Vernon Morris – Arizona State University,
Belay Demoz – University of Maryland Baltimore County

Welcome statements

9: 10 am – 9: 20 am
Everette Joseph, Director, National Center for Atmospheric Research

9: 20 am – 9: 25 am
Brandon Jones, Program Director, National Science Foundation

9:25 am – 9:30 am

Eric Roger Muth, Vice Chancellor for Research and Economic Development, NCAT 1

9:30 am – 12:30 PM

Format: *Presenters will make 12-minute presentations followed by discussions and summary of discussion results.*

Session 1– Understanding the African Megacity Atmosphere

Chairs: Francis Pope – University of Birmingham
Gizaw Mengistu –Botswana International University of Science and Technology

Session Goal: *This session seeks to understand- the unique reactive volatile organic compounds (VOCs), their sources and their influence on O_3-NOx-VOC-PM chemistry that is different from well-studied regions of the world. This includes known modeling and observation results, and identifying the gaps*

Steve Brown (NOAA–Earth System Research Laboratory)
"Ozone air quality in North America and Africa: Measurement programs in the U.S. and how they might inform observations in an African megacity"

William Brune (Penn State University)
"Linking in situ radical observations to pollution production in megacities"

Eloise Marais (University College London)
"Air Pollution Emissions in Africa"

Gizaw Mengistu Tsidu (Addis Ababa University and BIUST)
"*Modeling and observational studies of aerosols and some criterion pollutants over Africa*"

Kassahun Ture (Addis Ababa University)
"Mechanisms of Ozone Enhancement during Stratospheric Intrusion Coupled with Convection Over Upper Troposphere Equatorial Africa"

Rajesh Kumar (National Center for Atmospheric Research-ACOM)
"*First assessment of the WRF-Chem air quality simulations for Africa and insights into carbon monoxide distribution and source attribution"*

Jiayuan Wang (University of Massachusetts, Amherst, USA)
"Ambient NOx (NO and NO_2) pollution in Greater Accra Metropolitan Area, Ghana: Spatiotemporal patterns and role of meteorology"

Xiao-Mong Hu (University of Oklahoma)
Improving WRF-VPRM terrestrial respiration parameterization to reproduce nighttime CO_2 peaks and daytime CO_2 band ahead of cold fronts"

Break- 10 minutes

Discussion and Summary of discussion

- *Session chairs will lead the discussion*
- *Session chairs will develop summaries*
- *Session chairs will present summaries in Session 5*

Day 2 – June 9, 2021
9 am – 12 noon

Format: *Presenters will make 12-minute presentations followed by discussions and summary of discussion results.*

Session 2: Quantifying the Impacts of Air Quality in Africa: Health and Visibility Impacts

Chairs- Steve S. Brown – *NOAA-Earth System Research Laboratory*
Akua A. Asa-Awuku – *University of Maryland - College Park*

***Session Goal**: These discussions will explore the connections between. air quality, visibility, and health as it relates to African Megacities and their regional environment.*

Speakers
Jim Roberts (NOAA– Earth System Research Laboratory)
"Chemical Markers for Potential Health Actors in African Megacities"

Francis Pope (University of Birmingham)
"Air quality and visibility"

William Vizuete (University of North Carolina – Chapel Hill)
"In Vitro Toxicity of Complex Aerosols: What are the key drivers?

Akua A. Asa-Awuku (University of Maryland – College Park)
"*Under African Skies: Hygroscopicity and the links to visibility and Regional Haze"*

Raphael E Arku (University of Massachusetts Amherst)
"High-resolution spatiotemporal measurement of air and environmental noise pollution in sub-Saharan African cities: Pathways to Equitable Health Cities Study protocol for Accra, Ghana"

Tesfaye B. Mersha (Cincinnati Children's Hospital Medical Center and University of Cincinnati) *"Urban Air Pollution and Health Burden Experience in Sub-Saharan African Countries"*

Vernon Morris (Arizona State University)
"Airborne Mineral Dust Aerobiology and Health in North Africa"

Break 10 minutes

Discussion and Summary of discussion
- *Session chairs will lead the discussion*
- *Session chairs will develop summaries*
- *Session chairs will present summaries in Session 5*

Day 3: June 10, 2021
9:00 am – 12:00 pm

Format: *Presenters will make, 12-minute presentations followed by discussions and summary of discussion results.*

Session 3: Measurement and Modeling Techniques

Chairs: Dan Westervelt – Columbia University
Vernon Morris – Arizona State University

Session Goal: *These discussions will address the role of low-cost sensors (LCS), and methods to synthesize disparate data streams, and satellite measurements. In particular this session explores ways to integrate LCS networks, calibration and data sharing procedures. The session also discusses the gaps in measurements and identify needs for a robust air quality monitoring*

David Diner (Jet Propulsion Laboratory, California Institute of Technology)
Plans for integrating satellite aerosol data and surface measurements to map speciated PM2.5 in Africa as part of NASA's Multi-Angle Imager for Aerosols (MAIA) investigation

Dan Westervelt (Columbia University)
In-field calibration of low-cost sensors in East and West Africa and application to data-sparse African megacities

Paul Kucera (University Corporation for Atmospheric Research)
Development of a Low-Cost Air Quality Monitoring System

Kathryn McKain (NOAA – Earth Systems Research Laboratory)
A New Aircraft Measurement Program for CO_2, CH_4, and CO in Uganda

Ana Prados (University of Maryland Baltimore County)
Building Capacity to use Satellite Data for Air Quality Monitoring in Africa

William Vizuete (University of North Carolina – Chapel Hill)
Aerosol Phase State: Implementation in Air Quality Models and Implications on Aerosol Formation

Frank Flocke (National Center for Atmospheric Research – ACOM)
Options, scientific and logistical considerations for a field project in Africa

Break -10 Minutes

Discussion and Summary of discussion
- *Session chairs will lead the discussion*
- *Session chairs will develop summaries*
- *Session chairs will present summaries in Session 5*

Day 4: June 11, 2021
9:00 am – 12:30 pm

Format: *Presenters will make, 5-minute presentations followed by discussions and summary of discussion results.*

Session 4: Funding Agency Session

Chairs: Solomon Bililign – North Carolina A&T State University
Vernon Morris – Arizona State University

Session Goal: *Session focuses on possible funding opportunities and explore interests on the subject by various funding agencies and possible coordination of funding for a comprehensive air quality study in Addis Ababa. Speakers will be program officers of funding agencies*

Speakers/attendees

Brandon Jones – National Science Foundation

Makoto Suwa –World Bank

Wassila Thiaw – NOAA NCEP
Needs and requirements for forecasting African atmospheric dust

Jack Kaye – NASA
Integrated airborne/surface/satellite/modeling field campaigns at NASA

Dave Apurva – Department of State
Air Quality Foreign Assistance Programming at the U.S. State Department - Building Capacity for AQ Monitoring and Management

Sara Terry – Environmental Protection Agency
Air Quality Management Planning in Addis Ababa

Monica Kopacz – NOAA Climate Program Office

Iyad Kheirbek– C40 Cities
C40 Cities projects in air quality management and climate action planning in Addis Ababa.

Matt Whitney – Clean Air Fund
Improving air quality with data: perspectives from philanthropy

Katherine Swanson and Pete Epanchin – USAID
An overview of USAID air quality programs and goals in the sector.

Pallavi Pant – Health Effects Institute
State of Air in Africa: Recent Trends in Air Quality and Health Impacts

Break 10 minutes

Session 5: Discussion: Next Steps

Chairs: Belay Demoz – *University of Maryland Baltimore County*
Vernon Morris – *Arizona State University*

Session Goal*: This session synthesizes the main ideas of all the sessions and charts the next steps for a comprehensive air quality pilot study in Addis Ababa Ethiopia to be replicated in other African Mega cities.*

Meeting led by organizing committee members and session chairs.

- *Summaries will be presented by session chairs.*
- *The meeting will designate a team to explore funding opportunities and work on a proposal for a comprehensive air quality study.*
- *Arrange a follow up meeting if needed*
- *The team will plan a follow up meeting in Addis Ababa, Ethiopia with local stakeholders towards the end of 2021 to get local input and gauge local investment.*

Ozone air quality in North America and Africa: Measurement programs in the U.S. and how they might inform observations in an African megacity

Steven S. Brown
NOAA Chemical Sciences Laboratory, Boulder, CO USA

Photochemically produced urban ozone is a primary air quality concern throughout the major economies of the U.S., Europe and China. In the U.S. for example, ozone is responsible for a smaller share of excess mortality attributed to air pollution than particulate matter, but ozone exceeds national air quality standards over a wider geographic region and affects a larger fraction of the population. While the trend in ozone has been decreasing for approximately two decades in the U.S. and Europe, it has been increasing in recent years in China, where monitoring networks and control strategies have been implemented more recently. The severity of ozone pollution in major urban areas in Africa is far less clear, due largely to the absence of data for ozone and its major precursors, VOCs and NOx. Despite rapid recent growth in African megacities, there remain only a few tens of air quality monitors across the entire African continent compared to several thousand each in regions with well supported national monitoring programs. Field intensives with the chemical detail necessary to assess ozone photochemistry are also limited, although there are recent examples. This presentation will provide an overview of measurement strategies to understand and assess ozone air quality in the U.S. together with an assessment of what is currently known about this issue in selected regions of Africa

Linking in situ radical observations to pollution production in megacities

William H Brune
Pennsylvania State University

Megacities concentrate the ingredients necessary to initiate air pollution – nitrogen oxides and volatile organic compounds – and, because megacity populations are so large, many people are exposed to health risks. The production of the pollutants ozone and small particles is driven primarily by the hydroxyl radical (OH) and peroxyl radicals, hydroperoxyl (HO_2) and organic peroxyl (RO_2). Thus, understanding and being able to predict ozone and small particle pollution amounts requires an understanding of these radicals and their chemistry. Many studies show that the pollution-producing chemistry is pretty well understood, but there are discrepancies that have important implications for mitigation strategies that deserve a closer look, especially for megacities with few or no enforced air pollution control measures. Here we focus on using in situ radical measurements to examine ozone pollution production in Seoul, South Korea, where both $PM_{2.5}$ and ozone pollution can be high. As has been seen in other megacities, models can correctly calculate OH amounts, but they under-calculate HO_2 amounts during morning rush hour when nitrogen oxide levels are high. This underprediction has implications for ozone production and ozone control strategies

Air Pollutant Emissions in Africa

Eloise Marais,
Department of Geography, University College London
Christine Wiedinmyer,
CIRES, University of Colorado Boulder
David Pfotenhauer,
Department of Mechanical Engineering, University of Colorado Boulder
Evan Coffey,
Department of Mechanical Engineering, University of Colorado Boulder
Michael Hannigan,
Department of Mechanical Engineering, University of Colorado Boulder

Air pollutant emissions across the continent of Africa are significant and rapidly changing, particularly in urbanized areas. There have been several efforts to constrain our understanding of the emissions of key air pollutants from important sources across the continent. This presentation will highlight recent results of emissions measurements from various sources including open waste burning, traffic, and cooking in Ghana and elsewhere. Source apportionment has also been used to identify the sources of measured ambient pollution, helping further constrain the impact of sources on air pollutant concentrations. An overview of current emissions inventories used for chemical modeling applications will be presented and used to identify gaps in current understanding.

Modeling and observational studies of aerosols and some criterion pollutants over Africa

G. Mengistu Tsidu,
Botswana International University of Science and Technology

Atmospheric aerosols are important components of Earth's climate system which play crucial roles in the global energy budget and the hydrological cycle. They also act as pollutants along with gaseous pollutants in ambient air and could be detrimental to human health in large concentration. Africa is one of the world's largest sources of aerosol due to both its large deserts and prolific biomass burning (BB) during the dry seasons. In these regions, naturally induced desert particles constitute the main form of mineral dust aerosols. For instance, the Makgadikgadi (in the northern Botswana) and Etosha (in the eastern Namibia) Pans as well as the Kalahari (large areas of Botswana and eastern Namibia), the Namib (across coastal areas of Namibia) desert areas and Saharan dust over west Africa are found to be the main source of desert dust particles in Africa. On the other hand, BB is one of the most poorly understood aerosol sources, but one of the most prevalent in tropical regions resulting from natural and anthropogenic fires. In particular, open BB activities, such as deforestation and crop residue burnings are major sources of carbonaceous aerosols and pollutants such as NO_2 and CO. The coal-fired electricity generating plants and residential combustion for energy sources are other sources of criterion gas and particulate pollutants. The continent is developing rapidly, with both population and anthropogenic emissions being predicted to increase substantially in coming years. For example, previous studies have indicated that BB from southern Africa contributes approximately 21% of the global active fire counts. Therefore, the radiative perturbations induced by mineral dust and

BB aerosols as well as their semi-direct effects are quite important for the Southern Africa region. In particular, the feedbacks of the thermal, hydrological and dynamical fields of the climate (viz-a-viz changes in temperature, surface heat and moisture fluxes, cloud cover, precipitation and atmospheric dynamics) to these aerosols have profound impact on the human and the biophysical environment. In addition, a number of studies have shown that dust aerosol has a significant impact on West Africa Monsoon (WAM) system through its shortwave (SW) radiative forcing at the top of the atmosphere (TOA) and longwave (LW) radiative forcing. In this talk, we present gaseous pollutants and aerosol distributions from in-situ and satellite observations over Africa as well as aerosol direct and semi-direct effects over Southern Africa based on regional climate model simulations. We will also present retrieval of aerosol microphysical properties from measured AOD based on Mie theory over Equatorial Africa. The performance of reanalysis model (e.g., MERRA-2) in simulating AOD (e.g., at 550 nm) in comparison to satellite and a few ground-based observations in the region is assessed. Recent efforts to compliment and improve satellite retrievals with observations from cheap ground-based sensors over data sparse areas in the region such as Ethiopia and Botswana through NSF funded IRES project will also be highlighted.

Mechanisms of Ozone Enhancement during Stratospheric Intrusion Coupled with Convection Over Upper Troposphere Equatorial Africa

Kassahun Ture,
Center for Environmental Science, Addis Ababa University, Addis Ababa Ethiopia
Gizaw Mengistu,
Dept. of Earth and Environmental Sciences, Botswana International University of Science and Technology (BIUST), Palapye, Botswana

The possible cause and sources of enhanced ozone at upper tropospheric equatorial Africa, observed by cruise Measurements of Ozone by Airbus In Service Aircraft (MOZAIC) during the Northern Hemisphere winter in 1996 and 1997 on flight routes from Johannesburg to Vienna, are investigated. Two enhanced ozone events over upper tropospheric equatorial Africa are identified from MOZAIC observations on April 6, 1996 and March 27, 1997. High resolution ECMWF reanalysis GOME ozone has exhibited enhancement as well during these periods suggesting that the two events are not isolated small-scale events but part of a larger scale process. As a result, the source and mechanisms of ozone increase over the region are further analyzed using reanalysis data from ECMWF, outgoing long wave radiation (OLR) from NOAA and Meteosat images from NASA, International Satellite Cloud Climatology Project. Equivalent latitude computed from potential vorticity has shown that massive mid- and high- latitude stratospheric ozone rich airmass is funneled into lower latitude troposphere through troughs extending from large amplitude planetary waves towards equator. The Space-time Fourier decomposition of meridionally averaged zonal wind has revealed that these planetary wave activities are linked to waves with zonal wavenumber 1-2, which prevail during Northern Hemisphere winter. Additional analysis to understand the mechanisms of ozone enhancement was made using Multitaper- Method Singular Value Decomposition (MTM-SVD) spectral approach. The analysis confirms that ozone enhancement over the region is dependent on the relative position of positive PV and direction of wind anomalies. The high relative humidity measured simultaneously with ozone onboard MOZAIC, Meteosat imageries and circulation during the events have shown presence of deep convection. The coherent variation of OLR and ozone found over 8-day temporal cycle determined from MTM-SVD has indicated existence of OLR negative forcing in the upper troposphere and positive forcing in the lower stratosphere. These results show coupling of PV intrusion and deep convection over continental equatorial Africa in the same manner as the climatologically preferred intrusion over mid-ocean in eastern

pacific. Moreover, the results enrich previous understanding with purely observational high resolution MOZAIC and ERA-Interim datasets, and statistical method.

First assessment of the WRF-Chem air quality simulations for Africa and insights into carbon monoxide distribution and source attribution

Rajesh Kumar[1], Cenlin He[1], Forrest Lacey[1] and Guy P Brasseur[1,2]
[1]National Center for Atmospheric Research, Boulder, CO, USA
[2]Max Planck Institute for Meteorology, Hamburg, Germany

The African continent is home to more than a billion people with ~38% of the population living in fast growing megacities. The rapid economic growth of sub-Saharan Africa has also led to an increase in air pollution with satellite-based tropospheric column nitrogen oxide showing an increase of up to 75% in some of the African cities. While our understanding of air quality problems in Africa is severely limited by the lack of comprehensive in situ air pollution monitoring, the integration of space-borne observations with atmospheric composition models can shed light on Africa air quality issues. In this perspective, we have performed one year of air quality simulations over the entire African continent at 20 km x 20 km grid spacing using the Weather Research and Forecasting model coupled with Chemistry (WRF-Chem) for the year 2017. The model simulations have been evaluated against a variety of in situ and space-borne observations. The model captures the spatial and temporal variations in 2 m temperature very well including the seasonal cycles in both hemispheres of Africa. The model also captures the Measurement of Pollution in the Troposphere (MOPITT) retrieved elevated total column CO in equatorial Africa during northern hemispheric winter but the maxima seems to be shifted somewhat east in the model. The model also underestimates the MOPITT total column CO in the southern hemisphere of Africa during August-October. To understand the reasons behind the discrepancy between the model and observations, and relative importance of various CO sources, as well as to highlight the importance of regional transport in distributing CO across Africa, we have also included 16 CO tracers in the model to track CO emitted from anthropogenic and biomass burning emissions in different parts of Africa and also to understand the long-range transport of CO from other global areas (i.e., outside Africa). A source attribution analysis of CO using these tracers is under progress and will be presented during the presentation.

Ambient NOx (NO and NO_2) pollution in Greater Accra Metropolitan Area, Ghana: Spatiotemporal patterns and role of meteorology

*Jiayuan Wang[1], Abosede Sarah Alli[1], Sierra Clark[2], Michael Brauer[5], Andrew Beddows[10], Majid Ezzati[2,4], Jill Baumgartner[6,7], Jose Vallarino[8], James Nimo[3], Josephine Bedford-Moses[3], Solomon Terkpertey[3], Allison Hughes[3], Samuel Agyei-Mensah[9], Ernest Agyemang[9], Frank Kelly[4,10], Benjamin Barratt[4,10], Sean Beevers[4], George Owusu[11], Raphael E Arku1**
[1]Department of Environmental Health Sciences, School of Public Health and Health Sciences, University of Massachusetts, Amherst, USA

[2]Department of Epidemiology and Biostatistics, School of Public Health, Imperial College, London, UK [3]Department of Physics, University of Ghana, Legon, Ghana
[4]MRC Centre for Environment and Health, Imperial College London, London, UK
[5]School of Population and Public Health, The University of British Columbia, Vancouver, Canada [6]Institute for Health and Social Policy, McGill University, Montreal, Canada
[7]Department of Epidemiology, Biostatistics, and Occupational Health, McGill University, Montreal, Canada [8]Harvard T.H. Chan School of Public Health, Boston, MA, USA
[9]Department of Geography and Resource Development, University of Ghana, Legon, Ghana [10]NIHR HPRU in Environmental Exposures and Health, Imperial College London, UK [11]Institute of Statistical, Social and Economic Research, University of Ghana, Legon, Ghana

With the rapid economic growth and urbanization going, air pollution has become huge public health problems in sub-Saharan Africa (SSA) cities, with diverse and complex local and regional sources. As the economies of SSA countries transform from low- to middle-income status, the dominant emission sources of air pollution may be also shifting from biomass to road traffic. While measurements are emerging from SSA on particulate matters, there is very limited data on major combustion gaseous pollutants like nitrogen oxides (NOx, NO and NO_2). We collected weekly NO_2 and NOx samples using OGAWA passive samplers at 134 sites in the Greater Accra Metropolitan Area (GAMA), 10 fixed (yearlong) and 124 rotating (week-long), which covered a range of land-uses and emission sources (traffic and biomass burning), from April 2019 to June 2020. The average NO and NO_2 concentrations from the rotating sites were 38 and 48 μg/m^3, with ~60% of the sites exceeded World Health Organization (WHO)'s annual guideline for NO_2 (40 μg/m^3). Commercial/business/industrial areas had the highest NO and NO_2 concentrations (66 and 76 μg/m^3), followed by medium/high-density residential areas (47 and 59 μg/m^3), and low-density residential (28 and 78 μg/m^3) and peri-urban areas (23 and 24 μg/m^3) were significantly lower. Traffic was the most important source of NO_2 and NOx, especially within 250 m from major roads. Across the year-long sites, we observed clear seasonal changes – NO_2 concentrations increased by 25-56% across all site types during the dusty Harmattan period (November to March), which is probably mainly attributed to meteorological changes. Discussion: Ambient NOx concentrations in the GAMA are significantly higher than most of the regions in the world, and the local pollution level gets enhanced during the Harmattan period largely due to meteorology changes. Therefore, besides stronger enforcement of current polices all year around, stringent emission polices should be implemented during the dust outbreaks.

Improving WRF-VPRM terrestrial respiration parameterization to reproduce nighttime CO_2 peaks and daytime CO_2 band ahead of cold fronts

Xiao-Ming Hu[1,2], Sharon M. Gourdji[3], Sean Crowell[2], and Ken Davis[4]
[1]Center for Analysis and Prediction of Storms and [2]School of Meteorology, University of Oklahoma, Norman, Oklahoma, 73072, USA
[3]Greenhouse Gas Measurement Program, National Institute of Standards and Technology
[4]Department of Meteorology and Atmospheric Science, The Pennsylvania State University, University Park, PA 16802, USA

An enhanced CO_2 concentration band was often observed immediately ahead of cold fronts during the Atmospheric Carbon and Transport (ACT)-America mission. Three such CO_2 bands (particularly the one on Aug 4, 2016) are investigated using WRF-VPRM, a weather-

biosphere-online-coupled model, in which the biogenic fluxes are handled by an improved Vegetation Photosynthesis and Respiration Model (VPRM). While VPRM satisfactorily parameterizes Gross Ecosystem Exchange, its parameterization for terrestrial respiration, which simply depends on temperature, was inadequate to simulate contribution from vegetation that highly depends on biomass. Recently an improved terrestrial respiration parameterization has been developed by incorporating Enhanced Vegetation Index (EVI), water stress scaler (Wscale), and quadratic temperature (Gourdji et al., 2020). Nested-domain WRF-VPRM simulations with this improved respiration parameterization are conducted with the first domain covering the contiguous United States at a 12 km grid spacing and the second domain covering the Northern Great Plains at a 4 km grid spacing. Spectral nudging is applied on the first domain to maintain large scale forcing. WRF-VPRM is shown to be able to capture characteristics of the CO_2 bands, albeit with certain biases in magnitudes and/or locations. Terrestrial respiration leads to accumulation of CO_2in the shallow stable boundary layer through the night. As the cold fronts with low-CO_2 air mass penetrate southeastward, together with strong photosynthesis further to the southeast of fronts, enhanced CO_2 concentration bands develop immediately ahead of the fronts.

Chemical Markers for Potential Health Actors in African Megacities

James M. Roberts,
NOAA Chemical Sciences Laboratory, Boulder, Colorado

The connection between air pollution and human health effects is undeniable, yet almost all of these relationships have only been established through indirect means, i.e. statistical correlations between measured species, and broad health measures (e.g. hospitalizations for asthma). Knowledge of specific health actors and their physiological mechanisms has progressed to the point that we as a community could hope to partner with the biomedical community to directly examine air pollution health effects. This would help solidify our understanding and that could lead to better regulations and could help the health community to develop improved therapeutic and preventative measures. Defining and measuring the markers for the major sources of air pollution in African Megacities can help in this process. Sources such as biomass burning, trash burning, motor vehicles, and dust and other fugitive particles, both in direct emissions and after photochemical processing could be good candidates for this kind of analysis. This talk will present some ideas about how this kind of research could fit within an African Megacities project.

Air quality and visibility

Francis Pope
Chair of Atmospheric Science
School of Geography, Earth and Environmental Sciences
University of Birmingham

Many urban areas in Africa do not have sufficient monitoring programs to understand their air quality. This study uses visibility as a proxy for PM pollution to provide insight into PM air pollution in three East African cities: Addis Ababa, Nairobi and Kampala, from 1974 to 2018. Overall, a significant loss in East African visibility was observed since the 1970s, where Nairobi shows the greatest loss (60%), as compared to Kampala (56%) and Addis Ababa (34%). These changes are likely due to increased anthropogenic PM emissions. This talk will discuss the advantages and disadvantages of using visibility as a proxy for PM. It will highlight what information can be extracted from these long term and underused data sets.

In Vitro Toxicity of Complex Aerosols: What are the key drivers?

William Vizuete
University of North Carolina – Chapel Hill
Department of Environmental Sciences & Engineering

Airborne particulate matter (PM) is responsible for up to 4.8 million premature deaths worldwide and 92% of those deaths occur in low- and middle-income countries (LMICs). Emissions from combustion sources consist of PM, various volatile organic compounds, and other gases that are harmful to human health. Epidemiological and toxicological studies, however, have focused separately on the adverse health effects of exposures either to gas-phase pollutants or PM. Much less is known about the combined effects of PM and gases and their interaction with other pollutants. In addition, most studies use freshly generated particles that have not been photochemically aged. Because the components of PM constantly change due to photochemically-mediated transformations, the overall toxicity of the mixture is also likely to change. Due to the difficulty in producing these types of mixtures, the toxicity of dynamic and complex gas/PM exposures is currently understudied. We hypothesize that fresh and photochemically aged emissions have different biological impacts. Through this work we have generated and chemically characterized fresh and photochemically aged emissions from a hardwood source in an indoor smog chamber and generated real time in vitro exposures of lung epithelial cells to emitted gas/PM mixtures at an air-liquid interface (ALI). This was accomplished using the CelTox Sampler; a novel instrument providing a more sensitive and realistic ALI in vitro exposure that enables studying biological and chemical impacts without the artifacts associated with conventional resuspension methods. The exposed cells were then analyzed for gene expression changes and cytotoxicity levels in an effort to correlate biological data with chemical characterization data. These analyses will provide new insights on the scientific drivers of the health impacts of aerosol exposure. This is especially relevant in megacities where the novel mix of VOCs make it a challenge to measure or predict all species and thus a prioritization is needed of the most relevant to public health. These results will thus inform future field studies, interventions, and policy by determining the key drivers of aerosol exposure. Questions Addressed: 1.a. To what extent do natural emissions contribute to atmospheric composition, and how does the natural background interact with the unique anthropogenic source from Addis Ababa. 1.b. What are the unique VOCs and atmospheric chemical processes in the multi-pollutant and multiphase urban environment of Addis Ababa that control the abundance and production mechanisms of O_3 $PM_{2.5}$ brown carbon and secondary organic aerosols?

Under African Skies: Hygroscopicity and the links to visibility and Regional Haze

Akua Asa-Awuku
University of Maryland, College Park
Department of Chemical and Biomolecular Engineering

Atmospheric visibility is reduced by regional haze events and has steadily declined in African metropolitan cities over the last 50 years. The formation of haze is directly related to the particulate matter concentrations and the ability of particles to uptake-water and form droplets. In this talk we will discuss the relationship between hygroscopicity and particle physical and chemical composition. Furthermore, we will discuss the potential of unexplored sources that may contribute to regional haze on the continent.

High-resolution spatiotemporal measurement of air and environmental noise pollution in sub-Saharan African cities: Pathways to Equitable Health Cities Study protocol for Accra, Ghana

Raphael E Arku
University of Massachusetts Amherst

Introduction: Air and noise pollution are emerging environmental health hazards in sub-Saharan African (SSA) cities, with potentially complex spatial and temporal patterns. Limited local data is a barrier to the formulation and evaluation of policies to reduce air and noise pollution in the region. Methods: We designed a year-long measurement campaign to characterize air and noise pollution and their sources at high-resolution within Accra, Ghana. Our design utilized a combination of fixed (year-long, n = 10) and rotating (week-long, n = ~140) sites, selected to represent a range of land uses and source influences (e.g. background, road-traffic, commercial, industrial, and residential areas, and various neighborhood socioeconomic classes). We collected data on fine particulate matter ($PM_{2.5}$), nitrogen oxides (NOx/NO_2), weather variables, sound (noise level and audio) along with street-level time-lapse images. We deployed low-cost, low-power, lightweight monitoring devices that were robust, socially unobtrusive, and able to function in the SSA climate. We are using state-of-the-art methods, including spatial statistics, deep/machine learning, and processed-based emissions modelling, to capture highly resolved temporal and spatial variations in pollution levels across Accra and to identify their potential sources. Results: In preliminary results, $PM_{2.5}$ and oxides of nitrogen vary by between 10 to 20-fold, by land uses factors, source variables, season, and time of day. Sound levels follow similar spatial and temporal patterns, but for season as daily and weekly levels appear representative of yearly trends. Audio captured varied sound types specific to site-types and neighborhood SES. Features extracted from imagery seemed predictive of variation in pollution levels. Conclusion: Outdoor fine PM, NOx, and sound levels in Accra are high and dominated by major sources. Levels generally exceeded guidelines. Community air and noise pollution should be prioritized as key urban environmental health risk factors in Accra.

Urban Air Pollution and Health Burden Experience in Sub-Saharan African Countries

Tesfaye B Mersha, Ph.D.
Division of Asthma Research, Cincinnati Children's Hospital Medical Center, Department of Pediatrics, University of Cincinnati, 3333 Burnet Ave., Cincinnati, OH 45229

Endalkachew Sahle-Demessie, Ph.D.
US Environmental Protection Agency, Office of Research and Development Center for Environmental Solutions and Emergency Response, 26 W. Martin Luther King Dr,Cincinnati, OH 45268

The urban population in Sub-Saharan Africa (SSA) countries are increasingly experiencing a double burden of infectious and chronic non-communicable and communicable diseases. The health burden stems from informal living conditions in urban slums, poor environmental conditions, and the lack of access to health services. Urban dwellers are exposed to increasing levels of both outdoor and indoor air pollution. About 90 percent of the world's urban population lives in cities where air quality does not meet World Health Organization (WHO) standards. Air pollution contributes to the global burden of diseases (Disability Adjusted Life Years and Mortality) from lung, cardiovascular disease, and diabetes, coronavirus and maybe a contributor to cognitive decline. Epidemiologic studies have demonstrated that urbanization and high levels of vehicle emissions are correlated with an increased frequency of respiratory allergy. These numbers are likely underestimated in SSA because of the lack of data on air pollution and related health impacts. In the most severely polluted countries, 25 percent of premature deaths could be attributed to pollution, especially in the air. This presentation discusses the rapid population growth in the urban centers of SSA counties, the growing urban and industrial pollution issues impacting people's health, particularly vulnerable populations such as children and the economically disadvantaged that is causing an increase in the Disability Adjusted Life Years. In this context, we also discuss opportunities and challenges introduced by economic growth, industrialization and dynamic economic activities that puts pressure on the environment inevitably due to an increasing population and socio-environmental exposure risk factors.

Airborne Mineral Dust Aerobiology and Health in North Africa

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The Harmattan and other dry, dust-bearing systems in North and West Africa drive significant amounts of fugitive dust throughout the regional atmosphere. This particulate mixes with biomass burning aerosols, urban aerosol, and natural aerosols in. largely unexplored ways. These desert winds may originate in the Sahara but may also have source regions in the Arabian Peninsula and middle east (e.g. Iraq) depending on the time of year. Mineral dust particles present in these dust episodes are known to be carriers of significant concentrations of active microbes. The atmospheric dispersion of bacteria and pathogens over continental-scale distances thus represents an important but largely unknown facet of microbial ecology. Certain groups of dispersed bacteria can adapt to their new location and affect established ecosystems. These species can trigger disease outbreaks and may pose significant risk to co-infected individuals in

this region. I will discuss aerobiological studies in Bamako, Mali and Gondar, Ethiopia and the potential implications to health care provision.

Plans for integrating satellite aerosol data and surface measurements to map speciated PM2.5 in Africa as part of NASA's Multi-Angle Imager for Aerosols (MAIA) investigation

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While many epidemiological studies have focused on the adverse health effects of exposure to $PM_{2.5}$ mass concentration, the relative toxicity of different compositional mixtures is less well understood, in part due to the sparseness of surface monitors that measure chemical speciation. NASA's Multi-Angle Imager for Aerosols (MAIA) investigation aims to address this issue. Aerosol concentrations and particle properties retrieved from satellite imagery acquired by a pointable spectropolarimetric camera will be integrated with surface monitor measurements and outputs from the WRF-Chem chemical transport model to generate maps of total PM_{10}, $PM_{2.5}$, and speciated $PM_{2.5}$in a globally distributed set of target areas.

Launch of the MAIA instrument into Earth orbit is currently planned for mid- to late-2022. A dozen Primary Target Areas (PTAs) in North America, Europe, Africa, Middle East, and Asia are the main focus of the investigation. PTAs are 352 km x 420 km regions where the MAIA team will deploy speciated PM surface monitors (if not already available) and conduct epidemiological studies. With support from the US Agency for International Development, two PTAs are situated in Africa: one in Ethiopia including Addis Ababa and Adama, and one in South Africa including Johannesburg and Pretoria.

Generation of daily PM maps, including sulfate, nitrate, organic carbon, elemental carbon, and dust concentrations at 1 km spatial resolution will employ geostatistical regression models (GRMs) constrained by data from the MAIA instrument, geospatial parameters such as roadway and population density, and meteorology and PM chemistry data from the WRF-Chem model. The surface monitor measurements will be used to "calibrate" the GRMs. PM estimates from WRF-Chem, corrected for biases using surface monitor data, will be merged with the satellite results for spatial and temporal gap-filling.

MAIA satellite observations are also planned for a set of Secondary Target Areas (STAs) in Africa, including Dakar, Accra, Lagos, Cape Town, Nairobi, and Harar. While generation of imagery and aerosol products is planned for these areas, generation of PM products will depend on the availability and accessibility of surface monitor data.

MAIA data products will be publicly available, free of charge, from NASA's Atmospheric Science Data Center. Workshops in Africa geared toward training users how to use these products are planned prior to and following launch.

In-field calibration of low-cost sensors in East and West Africa and application to data-sparse African megacities

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Air pollution causes millions of premature deaths and a host of illnesses in the world's cities each year. This is especially true in sub-Saharan Africa, where sparse air pollution monitoring imparts high uncertainty to estimates of exposure and impact. In Africa, air pollution causes an estimated 780,000 premature deaths annually, and a significant number of diseases (comorbidities) that are known to be worsened by chronic exposure to air pollution, like asthma, lung cancer, and chronic obstructive pulmonary disease (COPD). More than 40,000 premature deaths per year in Ethiopia are attributable to air pollution alone. Five hundred million African children live in areas with no reliable air quality monitoring, making actual impacts uncertain. In many nations, regulatory networks serve as the foundation for air quality management with precise, local, real-time information that is readily communicated to the public. A few reference monitors have been recently placed in several African cities. Reference air quality monitors can serve as an important basis for correction and calibration of low-cost sensors (LCS) for air quality. LCS for measuring air pollution and identifying sources offer a possible path forward to remedy the lack of data, though significant knowledge gaps and caveats remain regarding the accurate application and interpretation of such devices. We present two of the first ever in-field calibrations of LCS against reference monitors (such as MetOne BAM-1020) in two cities in East and West Africa: Kampala, Uganda and Accra, Ghana. Two PurpleAir $PM_{2.5}$ monitors were collocated next to the US Embassy reference BAM-1020, starting in August 2019 in Kampala and February 2020 in Accra. In Kampala, raw PurpleAir $PM_{2.5}$ is strongly correlated with BAM $PM_{2.5}$ (r = 0.94), but the mean absolute error is 12 μg m^{-3}. We show that two simple calibration models, a multiple linear regression and random forest machine learning approach, each can improve both correlation (r = 0.96) and mean absolute error (<0.01 μg m^{-3}) using the collocated data. We then apply our local, in-field correction factor to additional sensor networks within East and West Africa, resulting in a high-quality, FEM-like dense network dataset. We apply the corrections to two other cities: Kinshasa, DRC, where data collection has been ongoing since March 2018, and Lomé, Togo, where data collection began in October 2019. A similar methodology can be applied to Addis Ababa, where several reference $PM_{2.5}$ monitors exist.

Development of a Low-Cost Air Quality Monitoring System

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UCAR has developed a low-cost automatic weather station that includes measurements of temperature, pressure, humidity, wind speed and direction, light, and precipitation. The low-cost instrumentation has been designed using innovative new technologies such as 3D printers, Raspberry Pi computing systems, and wireless communications. Recently, the project has expanded the automatic weather station (3D-PAWS) capabilities to include instrumentation for air quality monitoring. The air quality system that is being developed includes sensors for monitoring common gaseous pollutants including ozone (O_3), nitrous oxides (NO_X), sulfur oxides (SO_X), and volatile organic compounds (VOCs). The prototype system also includes a particulate matter ($PM_{2.5}$; PM_{10}) sensor. The system is an open-source design that can be fabricated locally. The presentation will provide an overview of the sensor development and a discussion the applications for air quality monitoring in Africa.

Building Capacity to use Satellite Data for Air Quality Monitoring in Africa

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Joint Center for Earth Systems Technology (JCET)
University of Maryland Baltimore County

Online and classroom training is an effective means to build the capacity of researchers, decision-makers, and citizens to utilize satellite data for air quality monitoring. We will present best practices for building the skills to access and analyze satellite data and images of nitrogen dioxide, sulfur dioxide, and particulate matter. Best practices include the blending of e-learning and classroom instruction, targeted science communication, approaches to multi-language instruction, and the development of geographically relevant case studies for each region or country. We also discuss how stakeholders can collaborate in conceptualizing and delivering these educational activities.

Aerosol Phase State: Implementation in Air Quality Models and Implications on Aerosol Formation

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A major assumption in air quality models (AQMs) are that the organic and inorganic constituents found in aerosols are homogenously mixed. In recent years studies have shown that these aerosols can in fact form organic coatings with an inorganic core. This core-shell morphology has implications on human health, cloud condensation nuclei, and the formation of secondary organic aerosols. Atmospherically relevant aerosols contain water, a small number of inorganic salts and hundreds of organic compounds that can undergo a range of aerosol phase state transitions. When an aerosol undergoes phase separation it can create an organic shell with a wide range of viscosities that surrounds an inorganic core. This shell can potentially alter the partitioning of semi-volatile species, and the extent of acid-catalyzed heterogeneous reactions, leading to bias in model predictions. The composition of organics in the aerosol is a key parameter in determining the aerosol phase state and other impacts on formation chemistry. This is an especially important point given that megacities found in developing countries include a diverse source of VOCs, many of which are not found in European and North American cities. The magnitude and variety of organics can have implications on how fine particulate matter is formed. Current AQMs, however, lack aerosol phase separation thus introducing uncertainty in PM predictions and hampering our understanding of how the natural background and unique anthropogenic sources in Addis Ababa influence aerosol formation. This work describes a recent implementation in the Community Multi-Scale Air Quality Model (CMAQ), version 5.2, that uses glass transition temperature (Tg), composition of the bulk aerosol, and relative humidity to determine the phase state and organic-inorganic separation of the aerosol. When conditions were favorable for phase separation, the Tg of the bulk aerosol was used to predict the viscosity and thus the diffusivity of the organic shell. This work will show results of phase state determinations and Tg equations into the latest iteration of CMAQ, version 5.3. Furthermore, a renaissance of laboratory-based studies on organic aerosol Tg have developed new equations based on oxygen to carbon ratios, saturation concentrations, and elemental composition. Taking advantage of these new implementations, and new ALW estimates in CMAQ 5.3, this study evaluated various Tg parameterizations effect on phase state and multi-phase chemistry reactions of IEPOX-derived SOA. This research aims

to support the development of a CMAQ model that can inform SOA production in the unique megacity environment. Questions Addressed: 1.a. To what extent do natural emissions contribute to atmospheric composition, and how does the natural background interact with the unique anthropogenic source from Addis Ababa. 1.b. What are the unique VOCs and atmospheric chemical processes in the multi-pollutant and multiphase urban environment of Addis Ababa that control the abundance and production mechanisms of O_3 $PM_{2.5}$ brown carbon and secondary organic aerosols? 1.c. What are the roles of VOCs and inorganics such as NH_3, sulfate and nitrate in the formation mechanisms of regional haze and reduction in visibility?

Options, Scientific and Logistical Considerations for a Field Project in Africa

Frank Flocke
National Center for Atmospheric Research
Atmospheric Chemistry Observation and Modeling

I will discuss options and considerations for conducting a field project to investigate atmospheric chemical processes and the emissions contributing to these processes in and around an African megacity. Both scientific and logistical requirements will be dependent on the scope of an initial pilot campaign and possible follow-up studies involving a larger number of measurement resources. Together with the other presentations in this section we expect to be able to define a roadmap to which in-situ observations are recommended to complement possible existing infrastructure and remote sensing data available for a target region, and how to implement the deployment of these resources.

A New Aircraft Measurement Program for CO_2, CH_4, and CO in Uganda

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NOAA Global Monitoring Laboratory, Boulder, Colorado, USA

We have recently established a new program to collect vertical profile measurements of CO_2, CH_4, and CO from an aircraft based out of Kampala, Uganda. The primary purpose of this program is to investigate a large CO_2 signal from tropical Africa seen from OCO-2 and GOSAT satellites that is not predicted by existing models of anthropogenic emissions or biogenic fluxes, and for which no insitu data exist for evaluation. This program has been implemented entirely remotely during the global pandemic by designing a measurement system that is robust and easy-to-operate and working closely with a local aircraft charter company. Flights will be conducted every ~20 days for one year or more (depending on funding) and will include transects in the boundary layer spanning 0-4°N latitude and vertical profiles from near the surface up to 5-8 km altitude. Initial data provide evidence of strong and varied emission sources from the urban Kampala region and rural areas upwind of the flight track. The magnitude of observed enhancements will provide strong constraints on total emissions and tracer-tracer correlations will be used to characterize source types throughout Uganda.

Improving air quality with data: perspectives from philanthropy

Matt Whitney
Clean Air Fund

Air quality data underpins action on air pollution, but worsening air quality in many cities around the world shows that the current access and availability of data is not sufficient. Technological advances promise to address these barriers, but adoption needs to accelerate, and innovation fostered further. The Clean Air Fund is a global philanthropic initiative that is working with partners around the world to address these challenges. This talk will provide an insight to the role philanthropy can play in overcoming these challenges and its relevance to improving air quality in African megacities.