Chemical and Microbial Transport and Evolution by Mineral Dust Particulate and Implications to Health and Food Security

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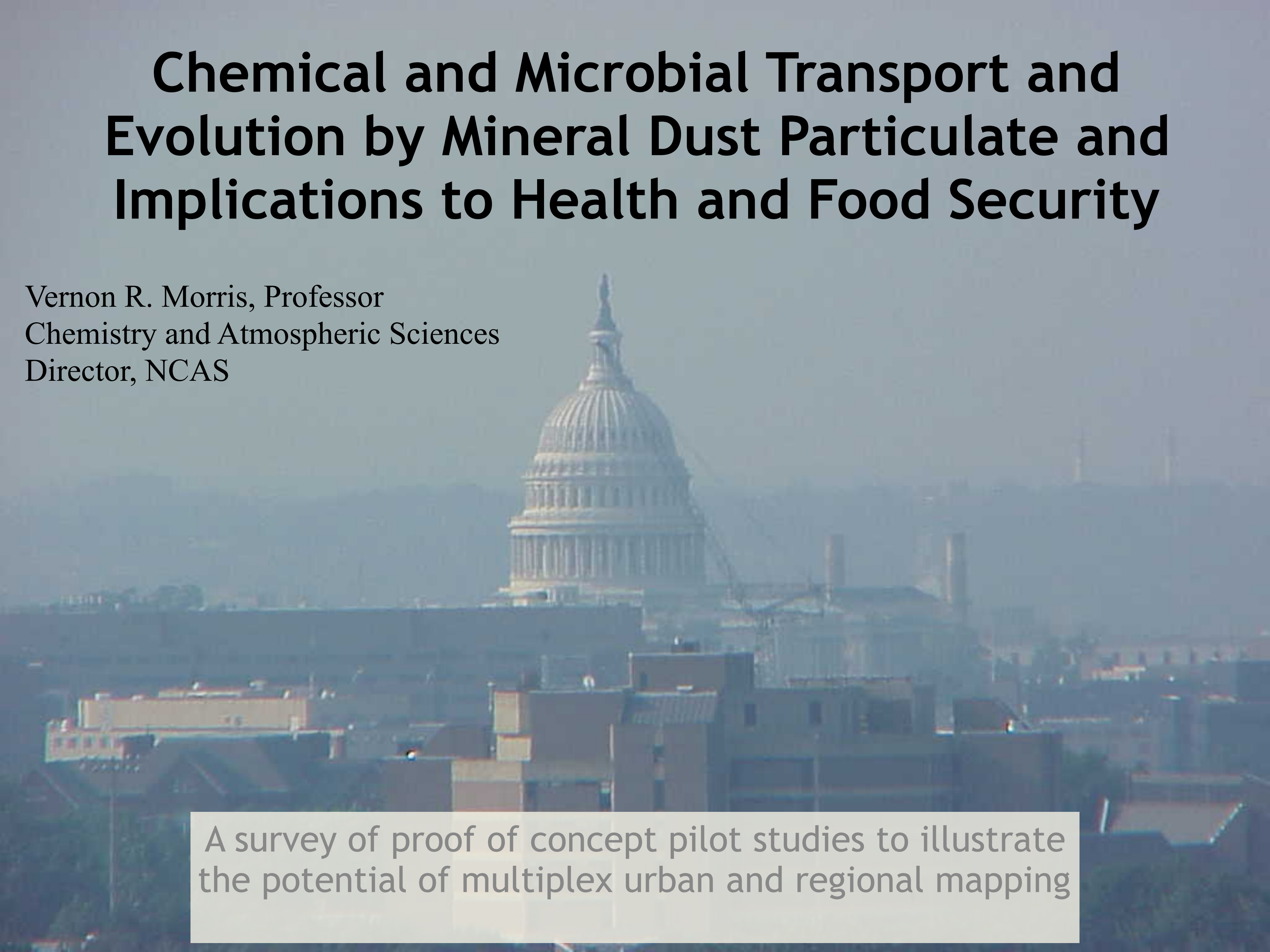


A survey of proof of concept pilot studies to illustrate the potential of multiplex urban and regional mapping

White House Initiative on Data and Innovation at the Climate-Health Nexus

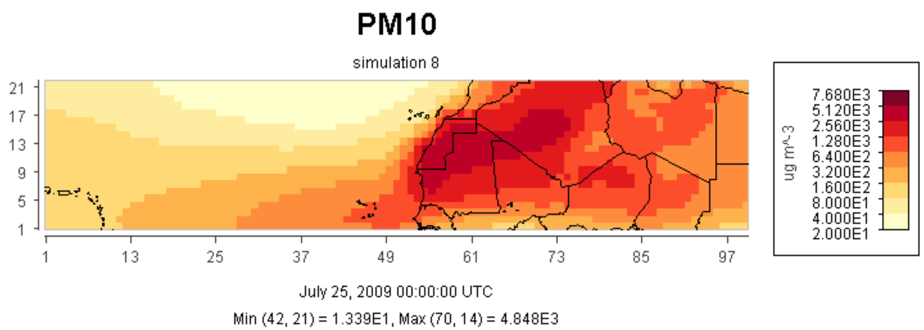
- President Obama has articulated renewed commitment to combating the health impacts of climate change and protecting the health of future generations.

- Climate change is not is not a distant threat and it affects numerous communities across the country with disproportionate an differential impact

- Increases in emerging pathogens, increased asthma and respiratory ailments(Americans with asthma has more than doubled in the past three decades)

- Rising temperatures can lead to more smog, longer allergy seasons, and an increased incidence of extreme-weather-related injuries.

A Variety of Infectious Bacteria Easily Spread Through the Air.



- *Mycetoma*
- *Bordetella pertussis*
- *Clostridium diphtheriae*
- *Mycobacterium tuberculosis*
- *Neisseria meningitis*
- *Staphylococcus aureus*
- *Yersinia pestis*
- *Haemophilus infuenzae*
- Skin pathogens from the *Staphylococcus* and *Streptococcus* species.

Research Overview

Impact Areas

- Environmental microbiology
- Aerobiology
- Global Health Disparities
- Environmental health
- Regional and global food security

Science Questions

- What type of bacteria are generally present in the air and what are their associations with aerosol distributions in each site of interest?
- How does air mass origin and aging (aerosol life cycle) affect endpoint microbial distributions?
- What are the observed transport and deposition patterns of the various microbial species?
- How do airborne microbial communities contribute to public and environmental health?
- What is the diurnal and seasonal variability inherent in the types of bacteria during the observation periods?

This research builds upon work performed over the past several years

- AEROSE (2004 – present)
  - Physico-chemical evolution of aerosols during long range transport across the tropical Atlantic Ocean (2004 – present)
  - Evaluation of microbial communities in trans-Atlantic Dust storms (2006 – present)
  - Fungal diversity associated with trans-Atlantic Saharan dust storms (2004 – present)
  - Fungal diversity and food security implications of trans-Atlantic Saharan dust storms (2011 – present)
- Evaluation of Culture-based methods to investigate microbial diversity in urban aerosols in Washington, DC (2006 – present)
- Comparison of culture-based and genomic methods for analysis of microbial communities in Bamako, Mali (2006 – 2007)
- Bio-aerosol characterization in SE Asian megacities (2010 – present)
- Particulate matter, aerobiology, and health in Northern Ethiopia (2015 – present)

International Locations for Climate-Environment -Health Activities

Ongoing collaborations and MOU for Climate-Air Quality and Health Studies - Philippines (Manila)

Collaborations and MOU developed for Climate-Health Studies - MALI (Bamako, Missira, Mopti)

Ongoing collaborations and MOU for Climate-Air Quality and Health Studies - SENEGAL (Dakar)

MOUs estabilished for Climate-Air Quality and Health Studies - SUDAN (Khartoum, Dongola)

Ongoing collaborations and MOU for Climate-Air Quality and Health Studies – HoAREC (Kenya, Djibouti, Eritrea, Somalia, Sudan, Ethiopia)

Ongoing field research and collaborations for Climate-Health Studies - ETHIOPIA (AAU, Gondar)

Ongoing Aerobiological work in Washington, DC, El Paso, TX. Plans for La Parguera, PR

Approach

Instrumentation

- ✓ Sampling Methods (Quartz fiber filters or Quartz crystals)
- ✓ Microbiological Methods (Standard molecular techniques)
- ✓ Mapping and Modeling Methods (PCA, ANOVA, ArcGIS)
- ✓ In-situ aerosol mass densities were measured using a quartz-crystal microbalance cascade impactor (California Measurements and derived from TSI Dust Track measurements)
- ✓ In-situ aerosol number densities were measured using laser particle counters (Climet, TSI Dust Track)
- ✓ Microbial Samples were collected using a Staplex microbial sampler

Publications

- V. Morris, V. A. Keene, B. Eribo, K. Molla Aerobiological Dynamics During the Monsoon Transition in Northen Ethiopia in an Open-Air Hospital (Manuscript in Preparation)
- M.A. Fayissa, V. Morris, S. Abegaz, N. Greene Variations in Ambient Aerosol Size Distributions, Deposition Fluxes, and Risk in Washington DC (Manuscript in Preparation)
- A. D. Allen, B. Eribo, M. A. Velez-Quinones, V. R. Morris MALDI-TOF MA and 16SrRNA as Tools of the Evaluation of Bacterial Diversity in Soils from Sub-Saharan Africa and the Americas Aerobiologia 31:111-126, 2015
- S. Abegaz, N. Greene, V. Morris Spatio-Temporal Distributions of Particulate Matter Exposures in Washington, D.C. Journal of Natural and Environmental Sciences 2(1) 1 2011
- S. Abegaz, D. Raghavan, C. Hosten, V. R. Morris Evaluation of Heavy Metal Variability in Ambient Air in Washington, D.C. Environmental Pollution 155 (1) 88-98 2008.

Microbiological Methods

Phenotypic Characterization

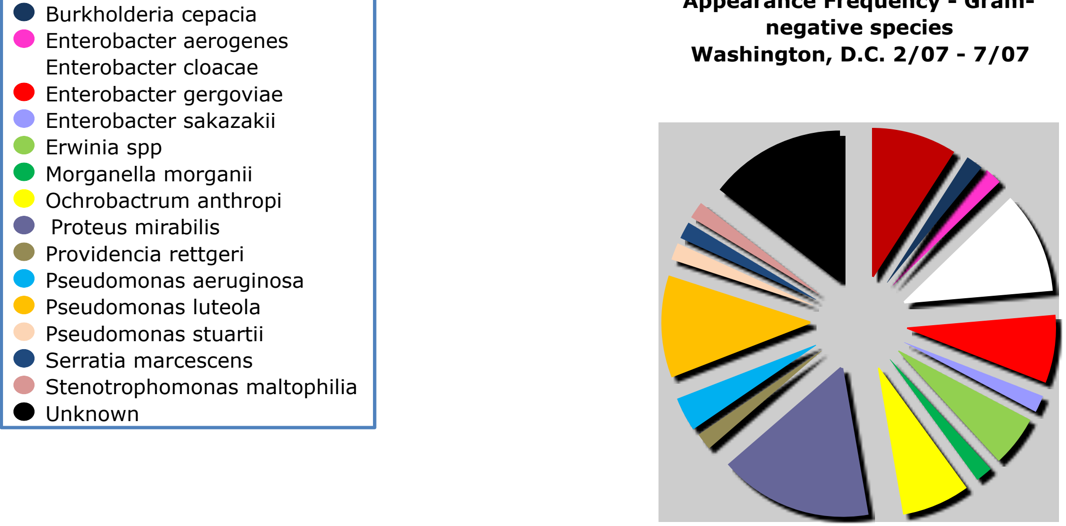
- Physiological and biochemical characterization of bacterial isolates
- Identifying nutritional requirements and optimal conditions required for growth. Primarily for viable culturable isolates

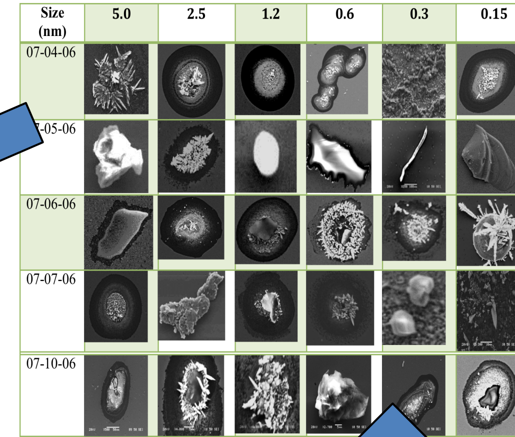
Molecular Characterization

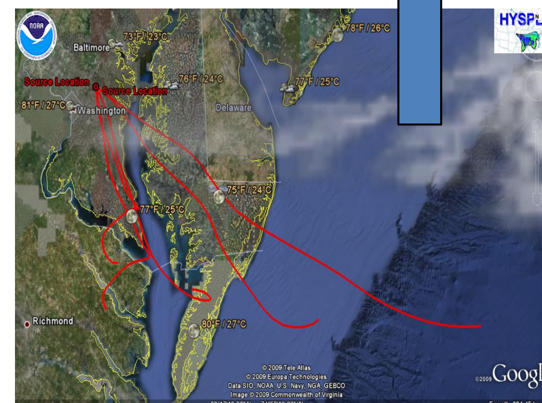
- 16S rRNA Sequencing; pyrosequencing etc.
- Complete bacterial diversity identification directly from the environment (no requirement for cultivation).
- Rapid and useful technique for detecting incidences of biological warfare.
- Does not differentiate viable from nonviable isolates

Evaluation of Virulence

- More comprehensive suite of isolates
- Peptide mass fingerprinting (PMF) + Phospholipid fatty acids (PLFA), Fatty acid methyl esters (FAME)
- Specific virulence factors + PCR and sequencing
- Chromogenic isolates
- the mechanism of action underlying various pigments/secondary metabolites in the survival/susceptibility of bacterivorous protozoa







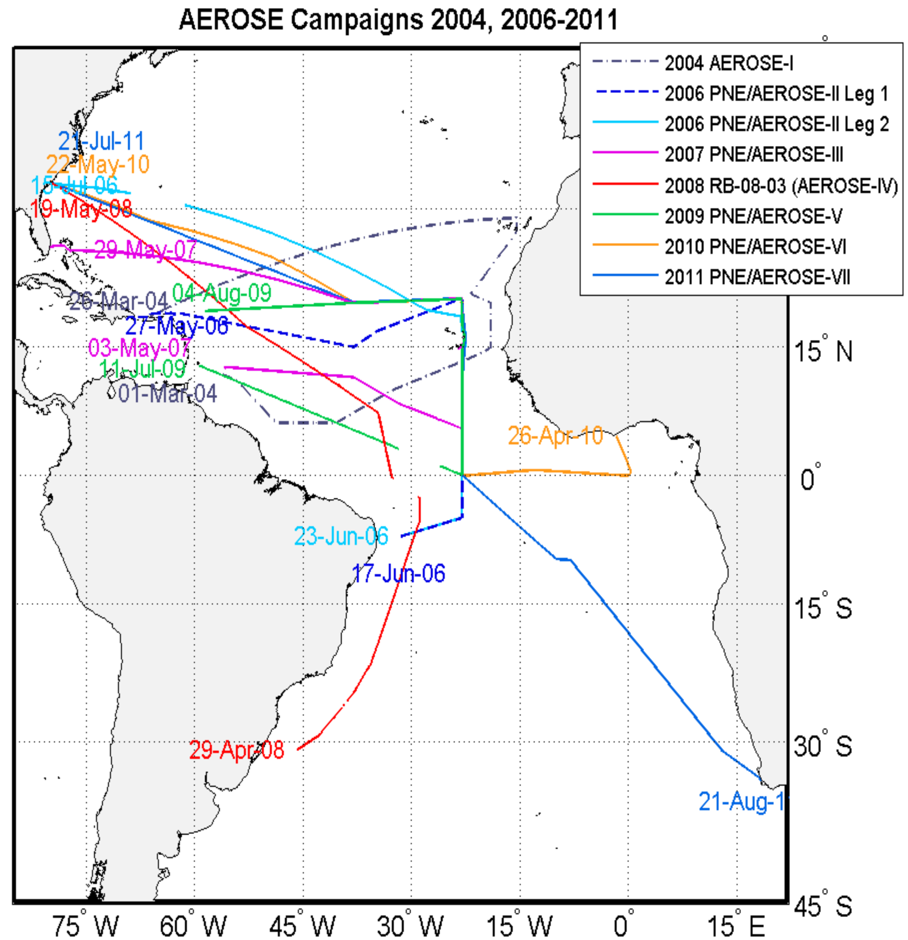
Screening Techniques for Virulence

How does the atmospheric biome evolve in a changing climate system and what are the health implications?

- Atmospheric Scientists
- Chemists
- Engineers
- Pharmacists
- Microbiologists
- Epidemiologists

AEROSE Overview

- The NOAA **Aerosols and Ocean Science Expeditions (AEROSE)** are a series of trans-Atlantic intensive atmospheric field campaigns conducted onboard the NOAA Ship *Ronald H. Brown (RHB)*
  - AEROSE-I (March 2004; 4 weeks)
  - PNE*/AMMA*/AEROSE-II (Jun-Jul 06)
    - Leg 1 (4 weeks)
    - Leg 2 (4 weeks)
  - PNE/AEROSE-III (May 07; 4 weeks)
  - AEROSE-IV transit (Apr-May 08; 3 weeks)
  - PNE/AEROSE-V (July-Aug 09; 4 wks)
  - PNE/AEROSE-VI (Apr-May 10; 4 wks)
  - PNE/AEROSE-VII (Jul-Aug 11; 5 wks)
  - PNE/AEROSE-VIII (Jan-Feb 13; 5 wks)
  - PNE/AEROSE-IX (Nov-Dec 13; 4 wks)
  - PNE/AEROSE-X (Nov-Dec 15; 5 wks)**



*AMMA – African Monsoon Multidisciplinary Analysis
**Anticipated

*PNE – PIRATA Northeast Extension

EOS

EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

VOLUME 87 NUMBER 50

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PAGES 565–580

Measuring Trans-Atlantic Aerosol Transport From Africa

PAGES 565,571

An estimated three billion metric tons of mineral aerosols are injected into the troposphere annually from the Saharan desert [*Prospero et al.*, 1996]. Additionally, smoke from biomass burning sites in the savanna grasslands in sub-Saharan Africa contribute significant quantities of smaller-sized aerosols [e.g., *Hobbs*, 2000]. These windswept aerosols from the African continent are responsible for a variety of climate, health, and environmental impacts on both global and regional scales that span the Western Hemisphere. Unfortunately, in situ measurements of aerosol evolution and transport across the Atlantic are difficult to obtain, and satellite remote sensing of aerosols can be challenging.

The trans-Atlantic Aerosol and Ocean Science Expeditions (AEROSE) are a series of intensive field experiments conducted aboard the U.S. National Oceanic and Atmospheric Administration (NOAA) ship *Ronald H. Brown* during the Northern Hemisphere spring (March 2006) and summer (June-July 2007) and proposed follow-on cruises in alternating seasons through 2010. The ongoing AEROSE mission focuses on providing a set of critical measurements that characterize the impacts and microphysical evolution of aerosols from the African continent as they transit the Atlantic Ocean.

The three central scientific questions addressed by AEROSE are as follows: (1) What is the extent of physical and chemical evolution in the mineral dust and smoke aerosol during trans-Atlantic transport? (2) How do Saharan and sub-Saharan aerosols affect the regional atmosphere and ocean during trans-Atlantic transport? (3) How can these unique aerosol measurements be used to resolve or improve remote sensing algorithms and models of the above processes?

While there have been a variety of aerosol campaigns that have encountered mineral dust or smoke, few have focused on Saharan dust as well as sub-Saharan smoke, and none has sought to characterize the evolution of these aerosols during long-range transport as a function of season. Thus, a comprehensive suite of aerosol measurements and size-segregated sampling were performed during each AEROSE cruise to characterize the evolution of the mineral dust mass distribution with respect to number density and chemical composition.

Project Overview

AEROSE-I was a 27-day cruise conducted during March 2004. A combination of climatological and near-real-time satellite observations, along with meteorological forecasts, helped steer the vessel into one of the largest (with respect to spatial extent) dust storms ever observed during that time of the year (Figure 1a). The AEROSE science team

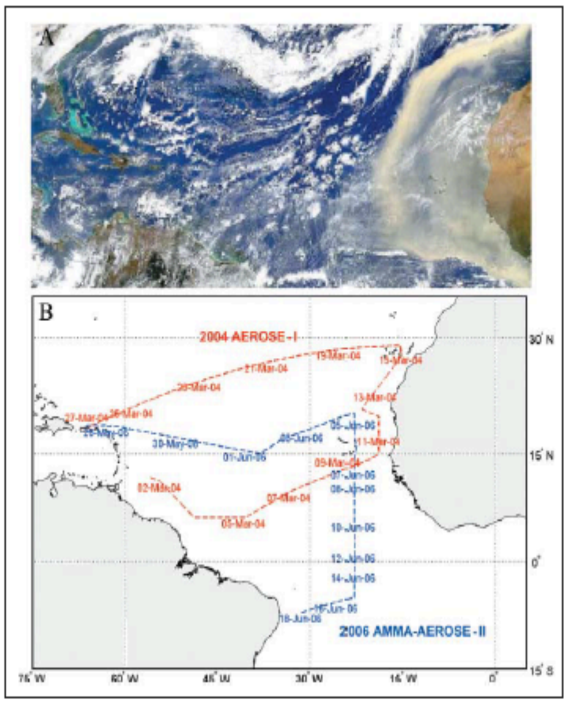


Fig. 1. (a) Moderate Resolution Imaging Spectrometer (MODIS) true color average image (5–6 March 2004) of the Saharan dust plume crossing the North Atlantic Ocean during AEROSE. (b) Cruise tracks of the Ronald H. Brown *for the 2004 AEROSE-I and Leg 1 of the 2006 AMMA-AEROSE-II.*

V. Morris, P. Clemente-Colón, N. R. Nalli, E. Joseph, R. A. Armstrong, Y. Detrés, M. D. Goldberg, P. J. Minnett, and R. Lumpkin

NOAA Relevance

- *HU obtains and provides key observational data sets for aerosols, ozone, and water vapor used by NCEP for model validation and by NESDIS for improvement of satellite retrievals*
- *HU scientists developed and led a series of research expeditions that have produced one of the most extensive collections of in situ measurements of the Saharan air layer (SAL) and associated African dust and smoke outflows over the tropical Atlantic Ocean, including vertical profiling of atmospheric water vapor, ozone, and aerosols.*
- *Investigation of the microphysical and chemical evolution of aerosols originating from West Africa during their trans-Atlantic transport, their interactions with clouds, and their microbial diversity*

Science Synergism

– **NESDIS/STAR Cal/Val** work benefits from collaboration with HU/NCAS intensive campaigns-of-opportunity. These provide correlative data in dynamic regions of interest to the sounder missions.

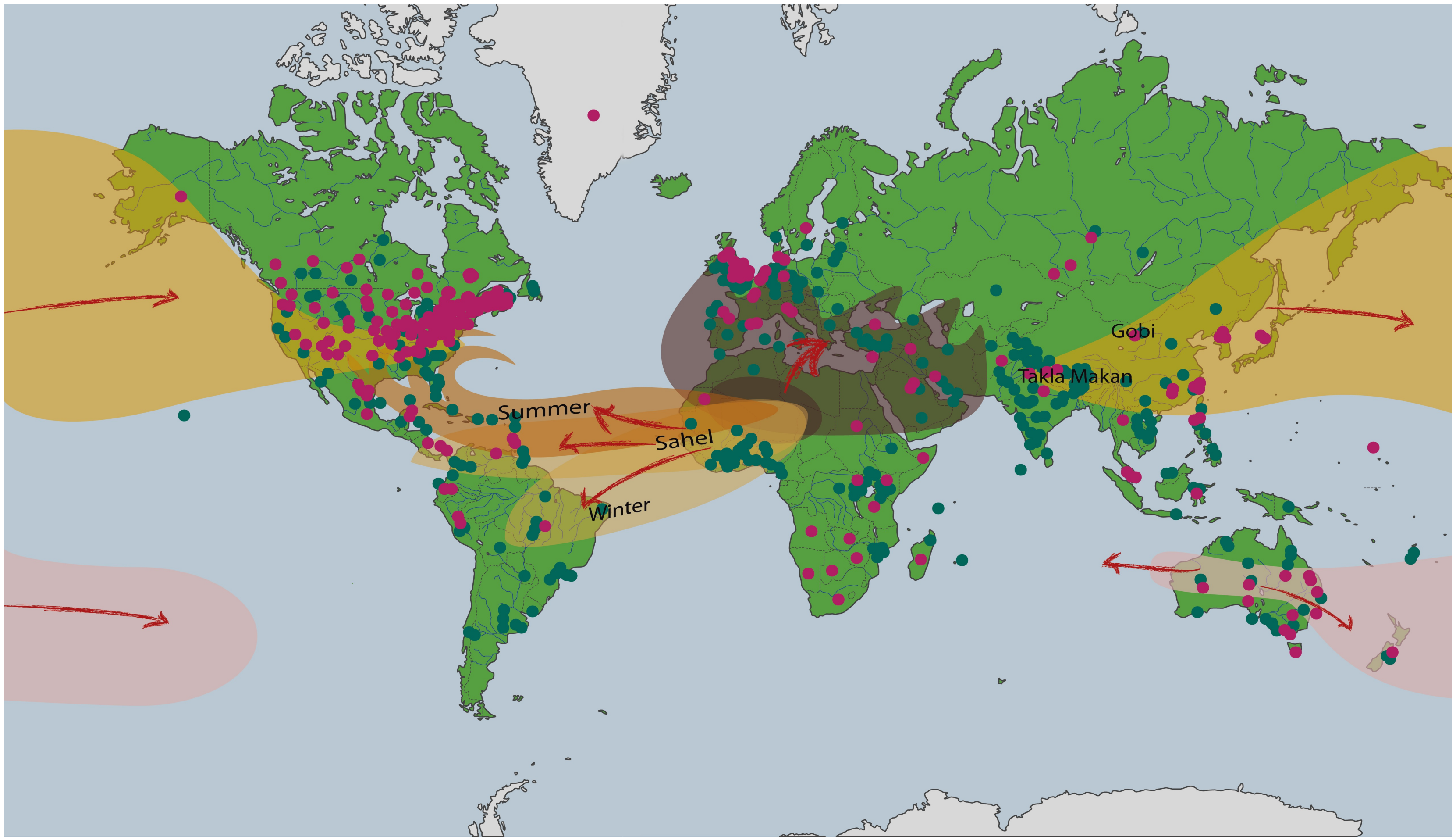
– The science community (NCAS) learns about, and gains access to, STAR satellite data products, which provide multi-scale datasets that support the science objectives of the campaigns

– **PNE/AEROSE** intensive campaigns continue to compile a multiyear set of ship-based, marine *in situ* **cross-sectional correlative measurements** over the **tropical Atlantic Ocean.**

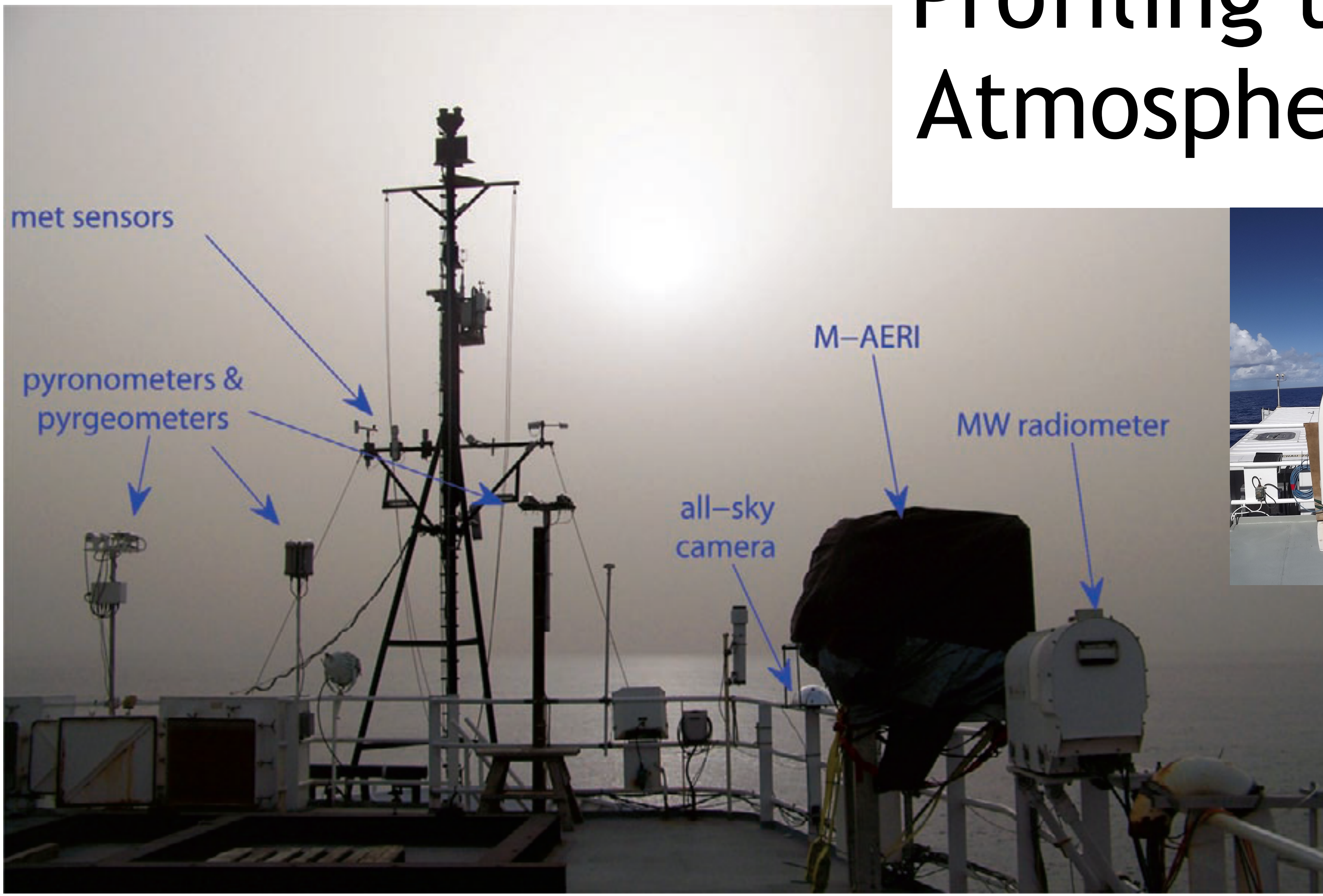
– The cruise domains span **a region of meteorological interest** in terms of the SAL, tropical storm formation, and tropospheric ozone/carbon/aerosol chemistry and transport.
  - There are numerous interdisciplinary applications of these data.
  - This presentation only broached the surface of these - more research is necessary and available (e.g., student research…).

– The PNE/AEROSE cruises provide **students** with **unique field campaign experience** as well as **data for research.** Students, in turn, are essential for the execution and near-real time analysis/QA of data.

Dust Storm Trajectory & Pathogen Emergence of Past 15 yrs

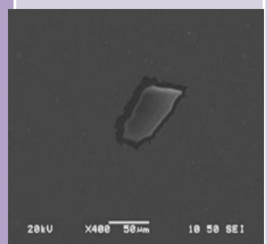
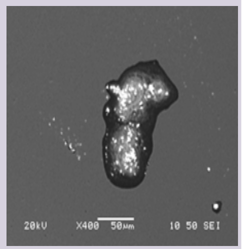
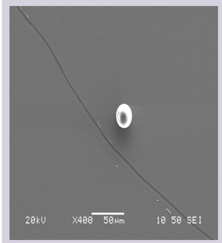
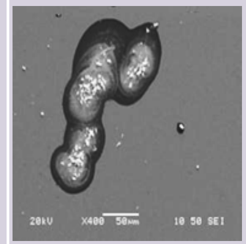
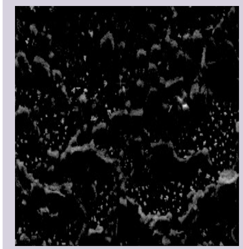
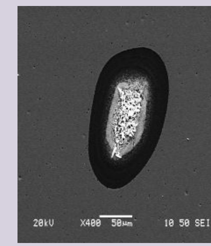
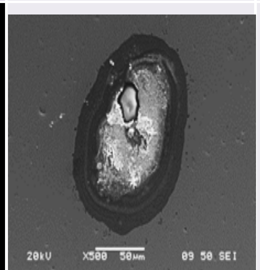
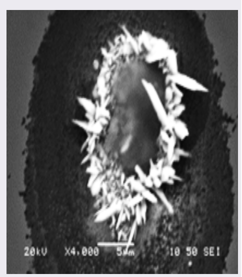
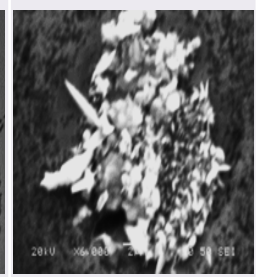
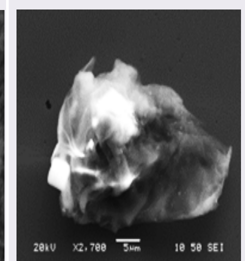
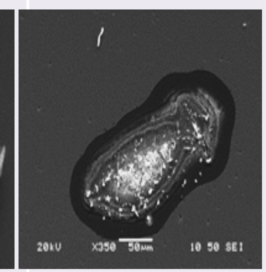
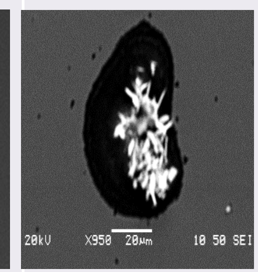


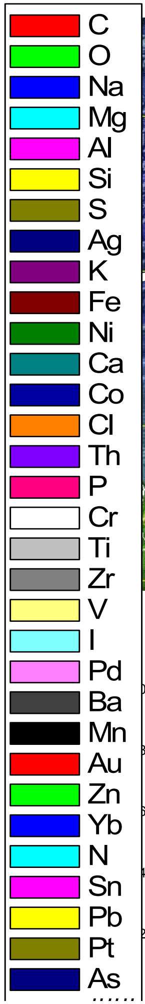
Profiling the Atmosphere

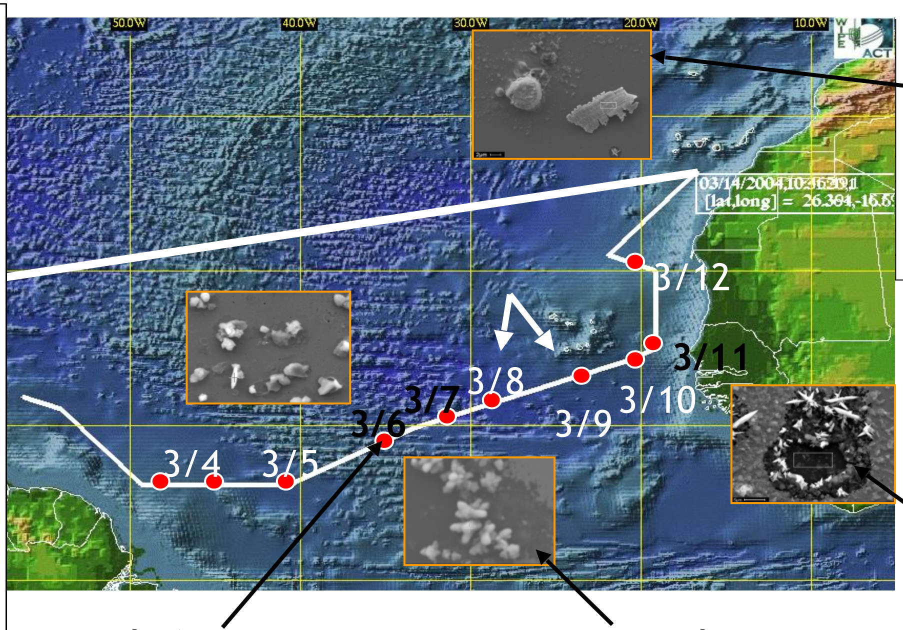


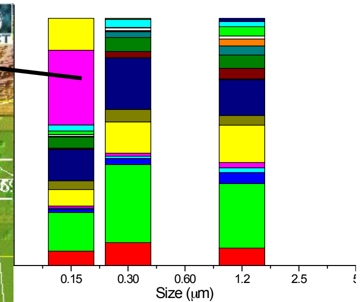
Unenhanced digital color photograph of the forward 02 level of the *Ronald H. Brown* during the major Saharan dust outflow 13 May 2007 (Nalli et al. 2011)

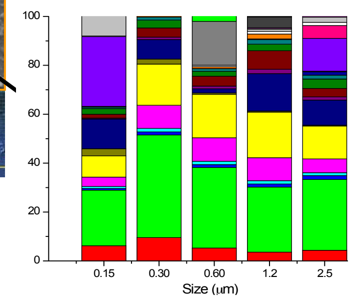
Atmospheric Particulate Serve as Efficient Vehicles for Pathogen Transport

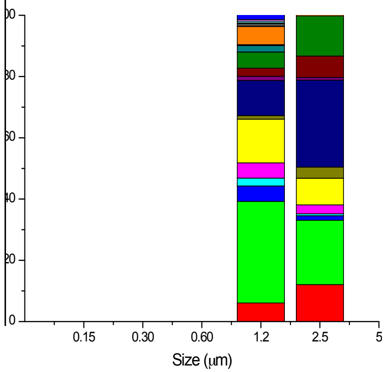
Size, µm / Date	5.0	2.5	1.2	0.6	0.3	0.15
07/04/06						
07/10/06						

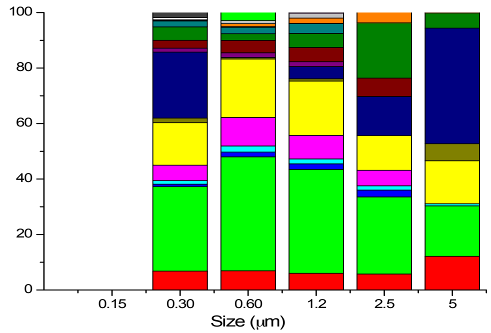


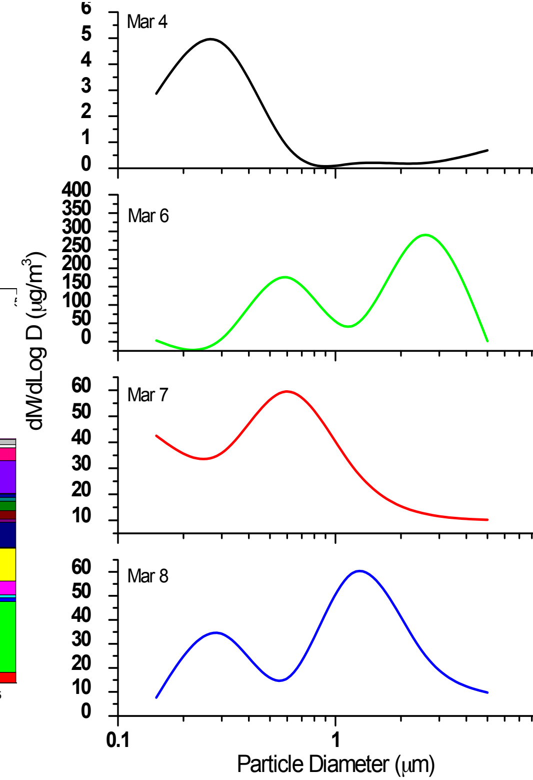


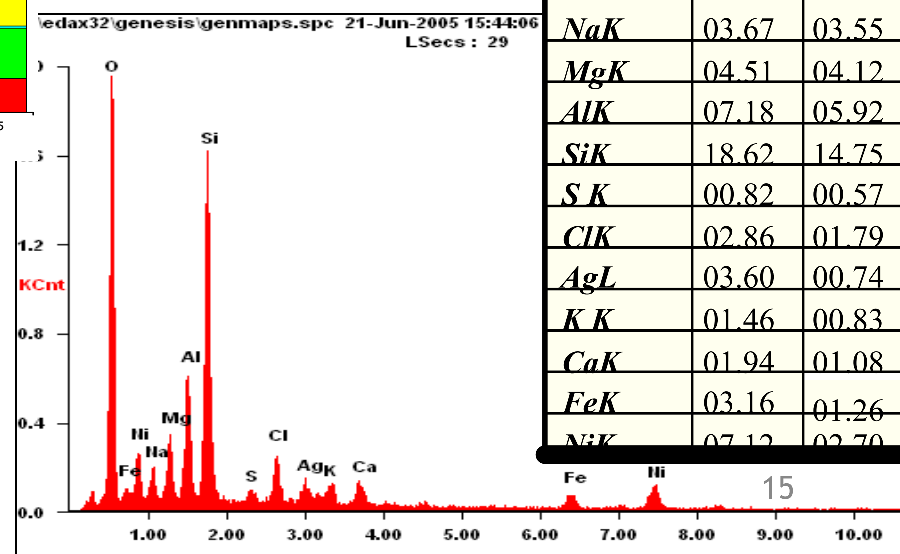








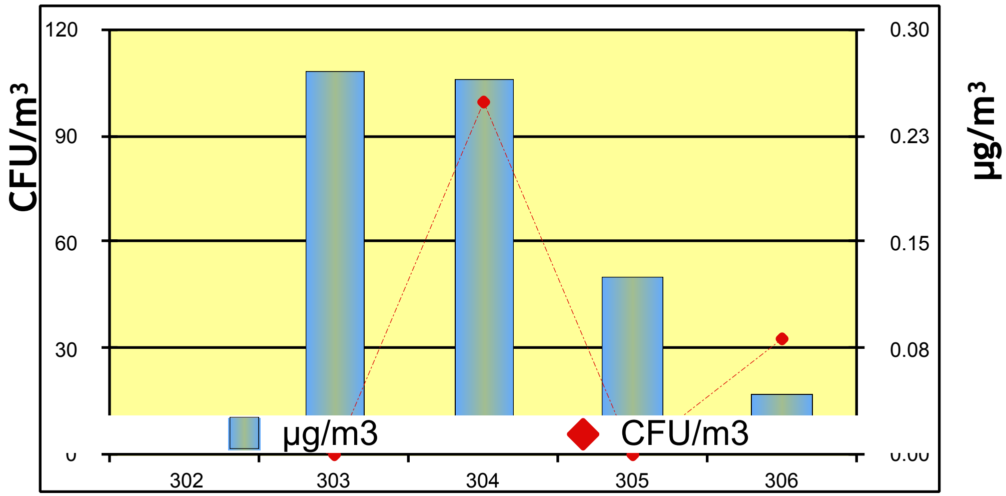


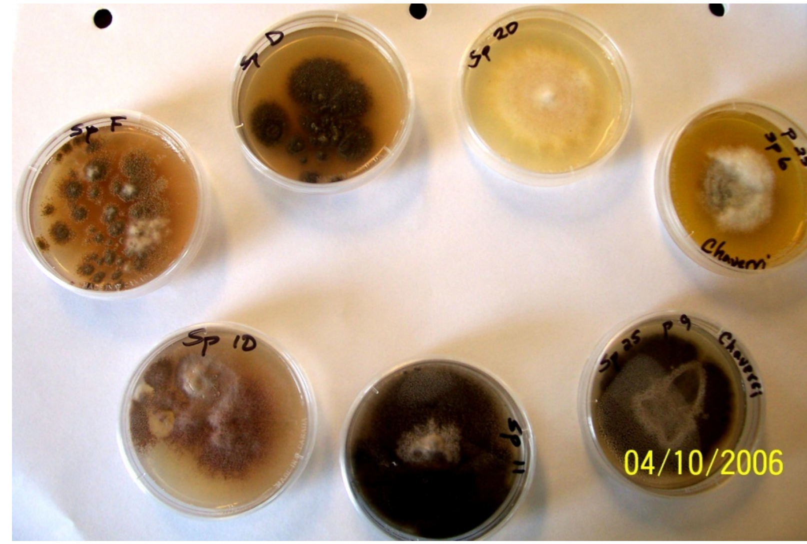


Element	Wt%	At%
O K	45.06	62.68
NaK	03.67	03.55
MgK	04.51	04.12
AlK	07.18	05.92
SiK	18.62	14.75
S K	00.82	00.57
ClK	02.86	01.79
AgL	03.60	00.74
K K	01.46	00.83
CaK	01.94	01.08
FeK	03.16	01.26
NiK	[illegible]	[illegible]

Evolution of Aerosol Surface Elemental Composition

Identification of Fungi in Saharan Dust





302: 3/3 -3/5
303: 3/5 – 3/7
304: 3/7- 3/9
305: 3/9 – 3/11
306: 3/11 – 3/13

Salal Root
Associated Fungi

Aspergillus fumigatus
Penicillium chrysogenum
Thielavia fragilis

Thielavia subthermophila

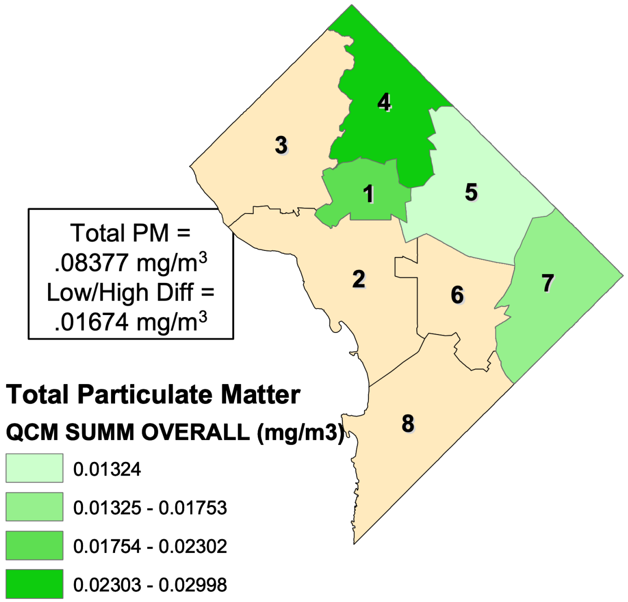
Results From Intercontinental Transport of Fungi – AEROSE Environmental Samples (454 Pyrosequencing)

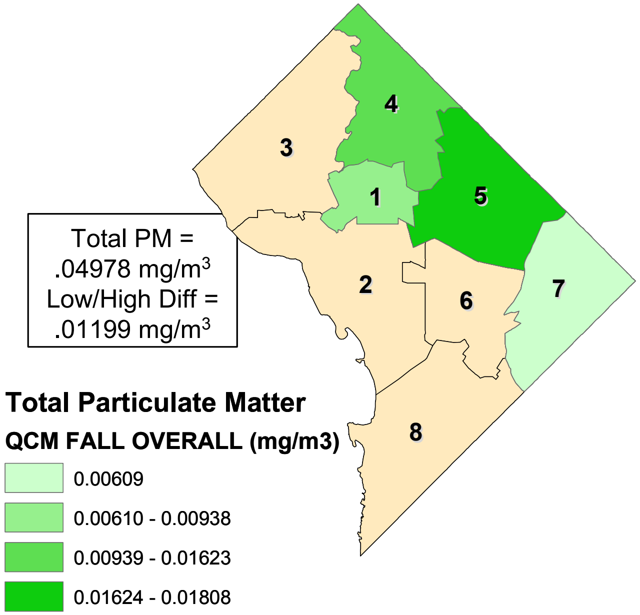
Most abundant species, 2009

Trichoderma cf. harzianum	**19751**	**Mycoparasite**	
Trichoderma reesei	**11807**	**Saprophyte / rarely human pathogen**	**Wide range**
Humicola fuscoatra var. fuscoatra	**2836**	**Pathogen - Roots**	**Tomato plants**
Bionectria ochroleuca	**1612**	**Mycoparasite**	**fungi/insects**
Botryosphaeria viticola	**1236**	**Pathogen**	**Vitis vinifera**
Monochaetia sp. 162	**444**	**Pathogen/canker**	**Apples (if *M. mali*)**
Madurella mycetomatis	**410**	**Pathogen/mycetoma**	**Humans**
Endothia sp. IFB-E023	**348**	**Pathogen/dieback**	**wood**
Fusarium sp. BI	**179**	**Pathogen**	**Wide range**
Discostroma botan	**140**	**Pathogen/stem lessions**	**Paeonia suffruticosa**

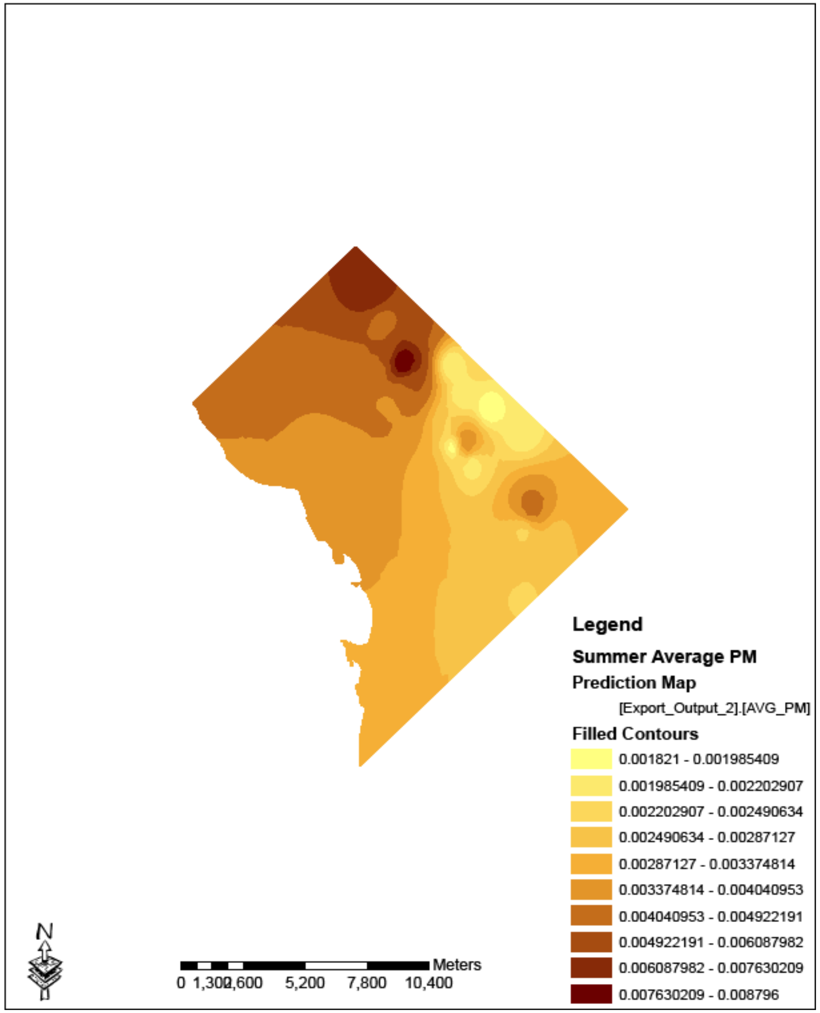
Seasonal Mass Density Distributions and Fluxes

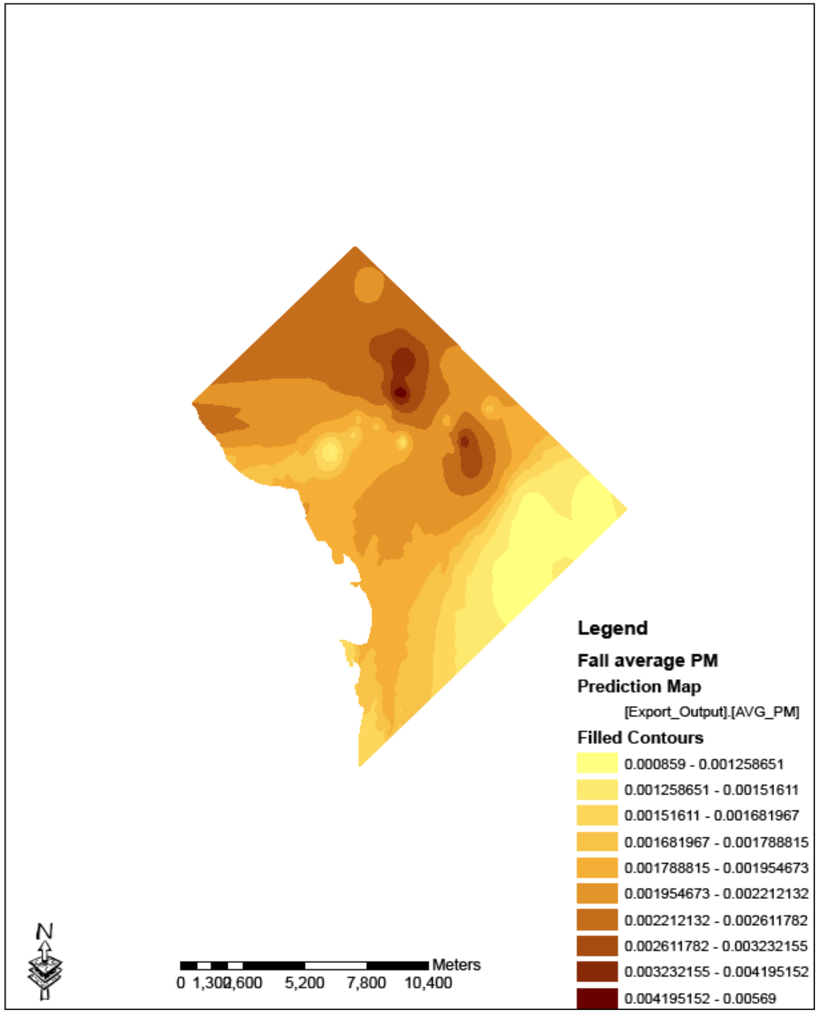
Ward	Fall (LPC)	Fall (QCM)	Winter (LPC)	Fall/ Winter (LPC)
1	19	58	49	.39
4	23	58	37	.61
5	28	23	41	.69
7	11	32	13	.84



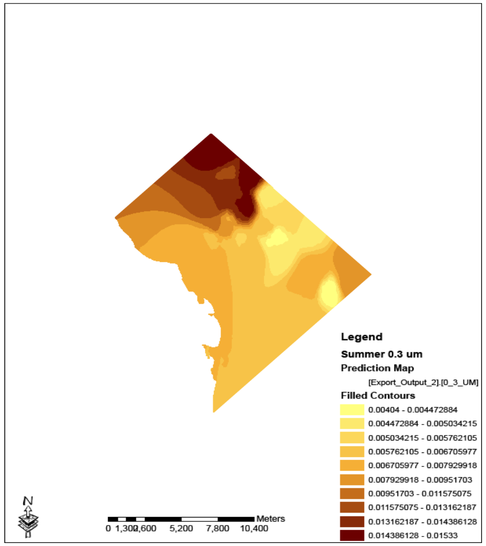


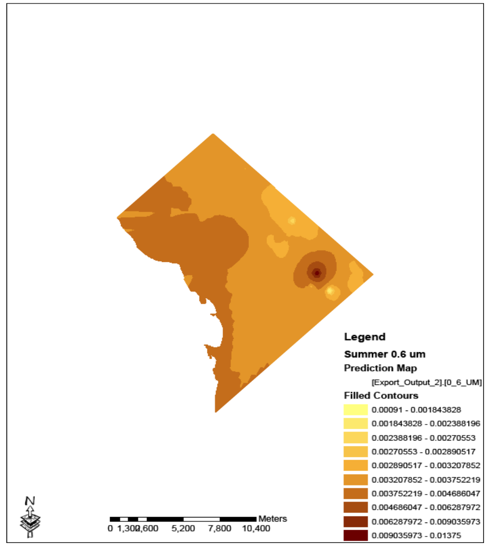
Seasonally-Averaged Urban Aerosol Mapping

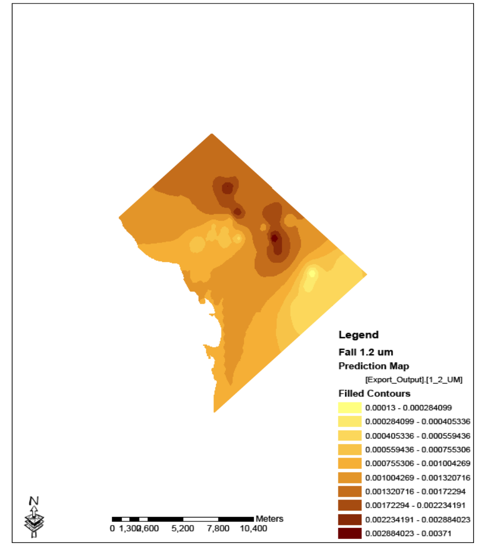


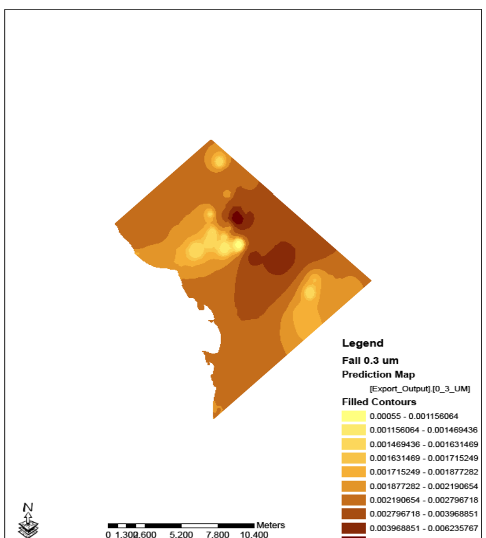


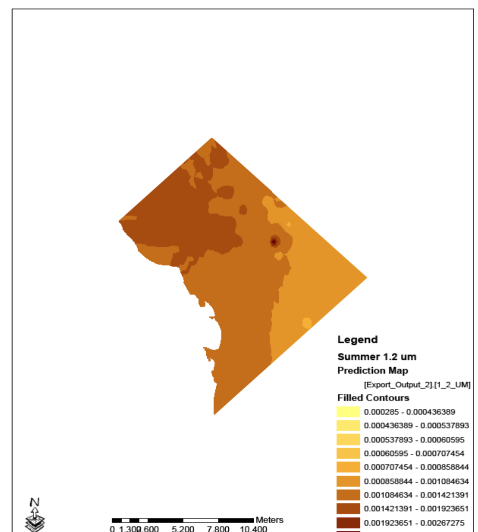
Seasonal Mapping and Comparison of Inhalation-Level Sub-Micron Aerosol





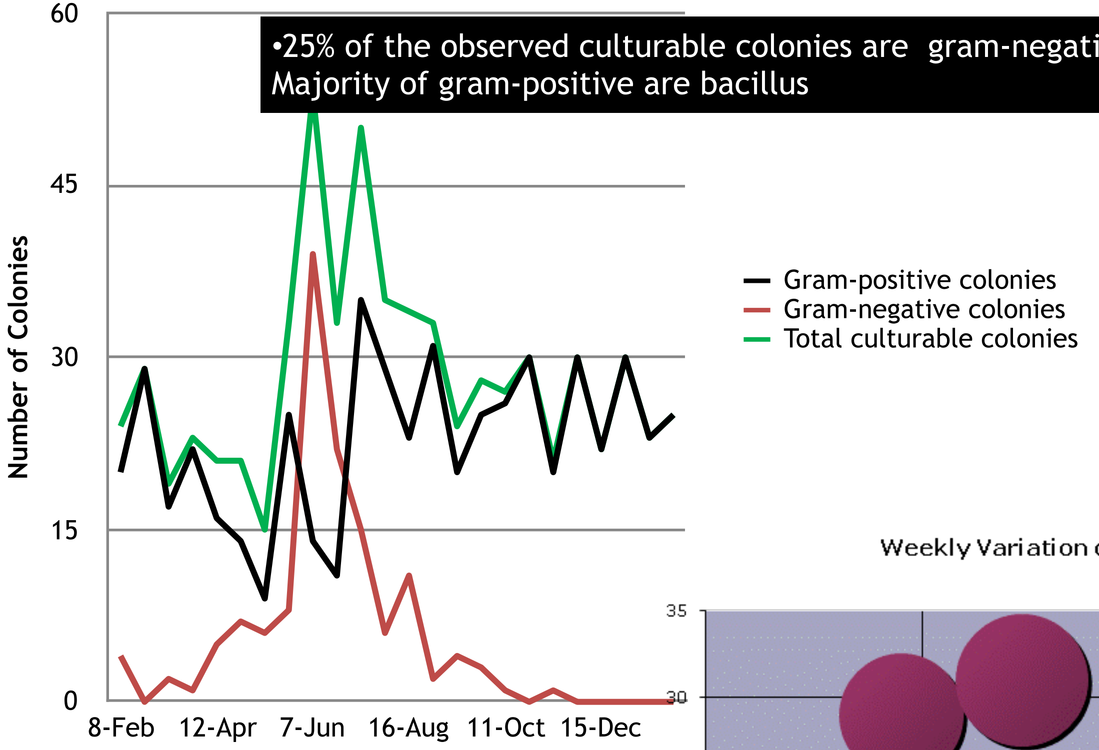


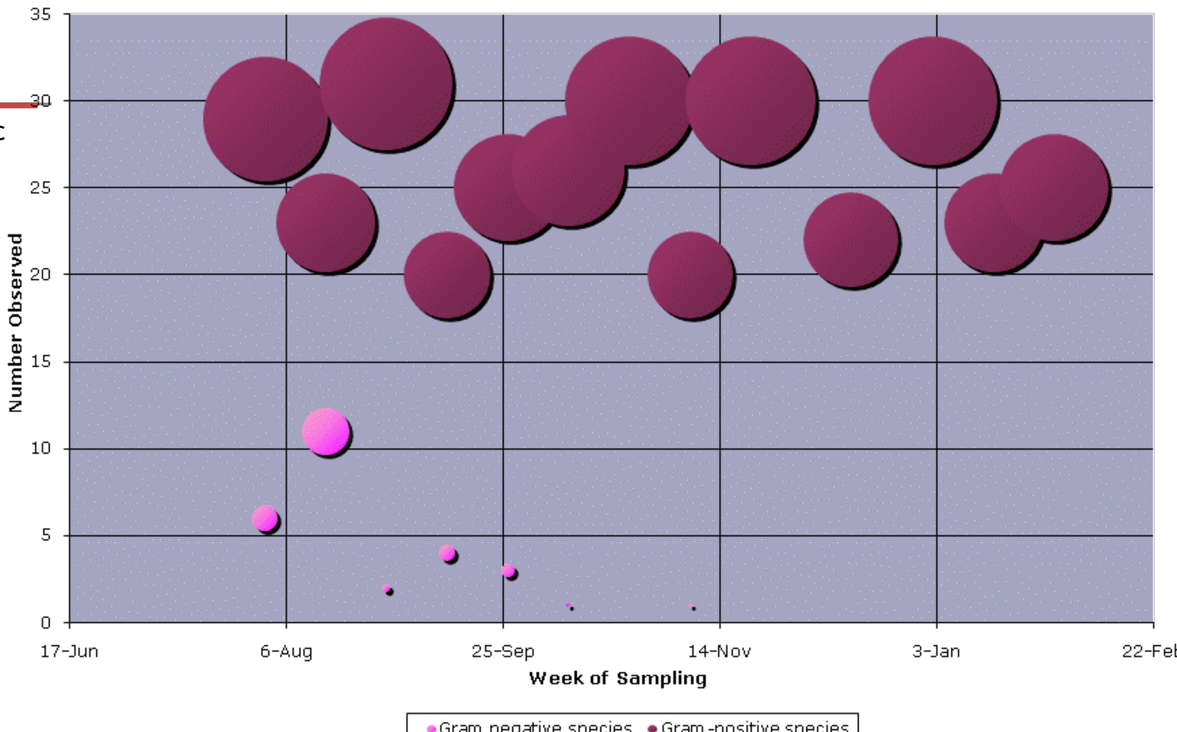


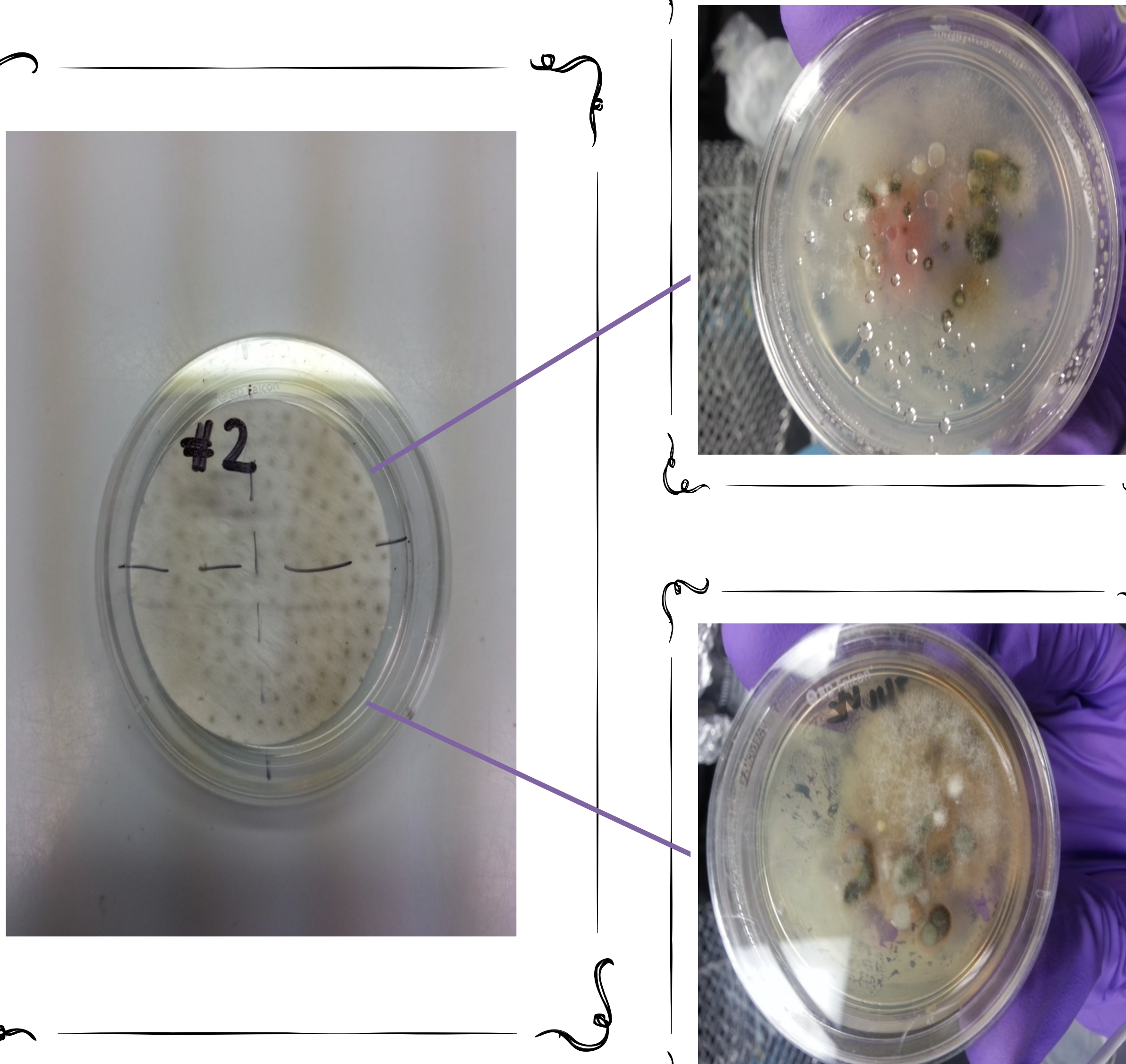


Airborne Bacteria - Washington, DC

•25% of the observed culturable colonies are gram-negative
Majority of gram-positive are bacillus

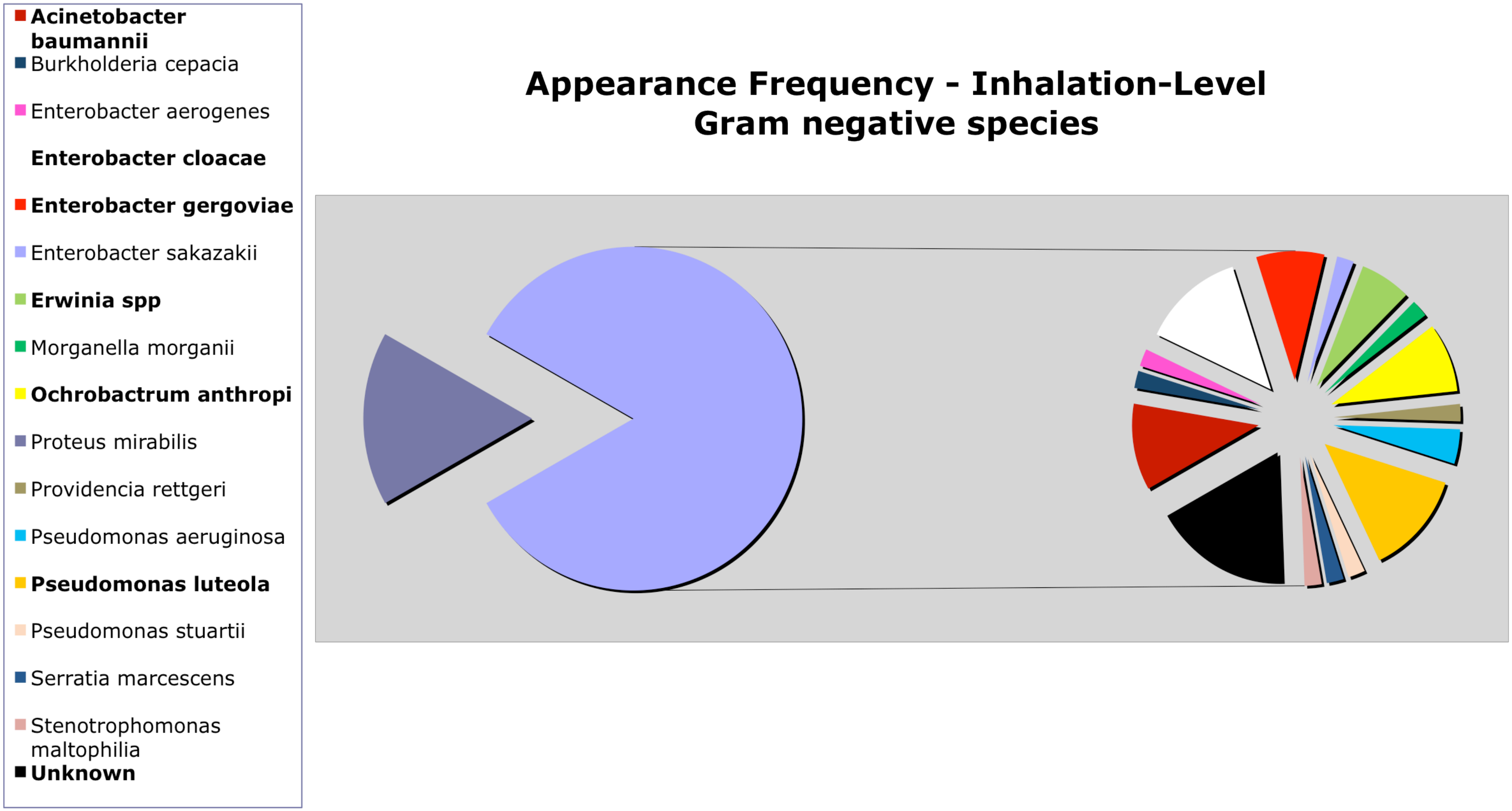






Representative images of cultured bacteria for the 0.65 – 1.1μm size fraction For each collection a quarter of the filter was used to culture bacteria at 30ºC for 24 h.

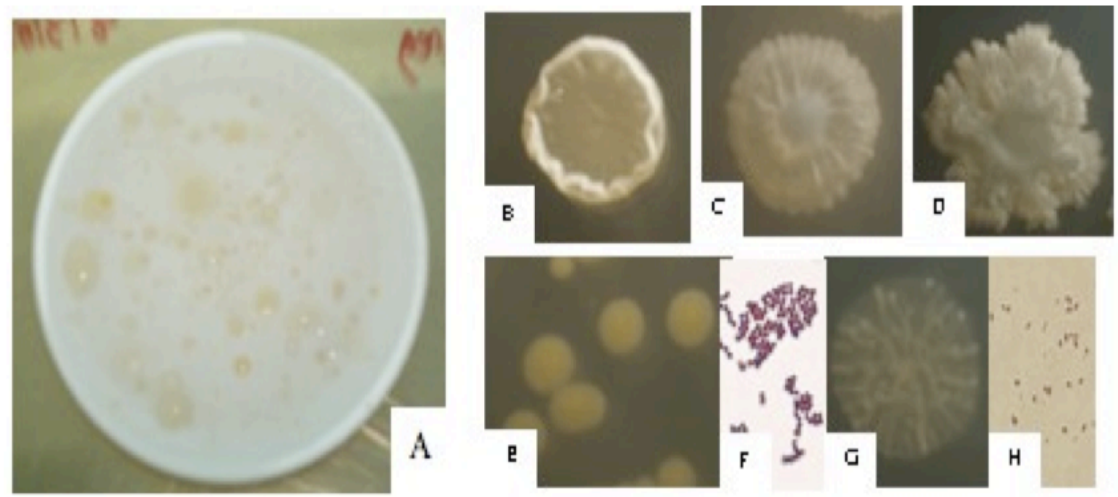
Appearance Frequency - Inhalation-Level Gram negative species



Aerobiology in Mali

Phenotypic Characterization

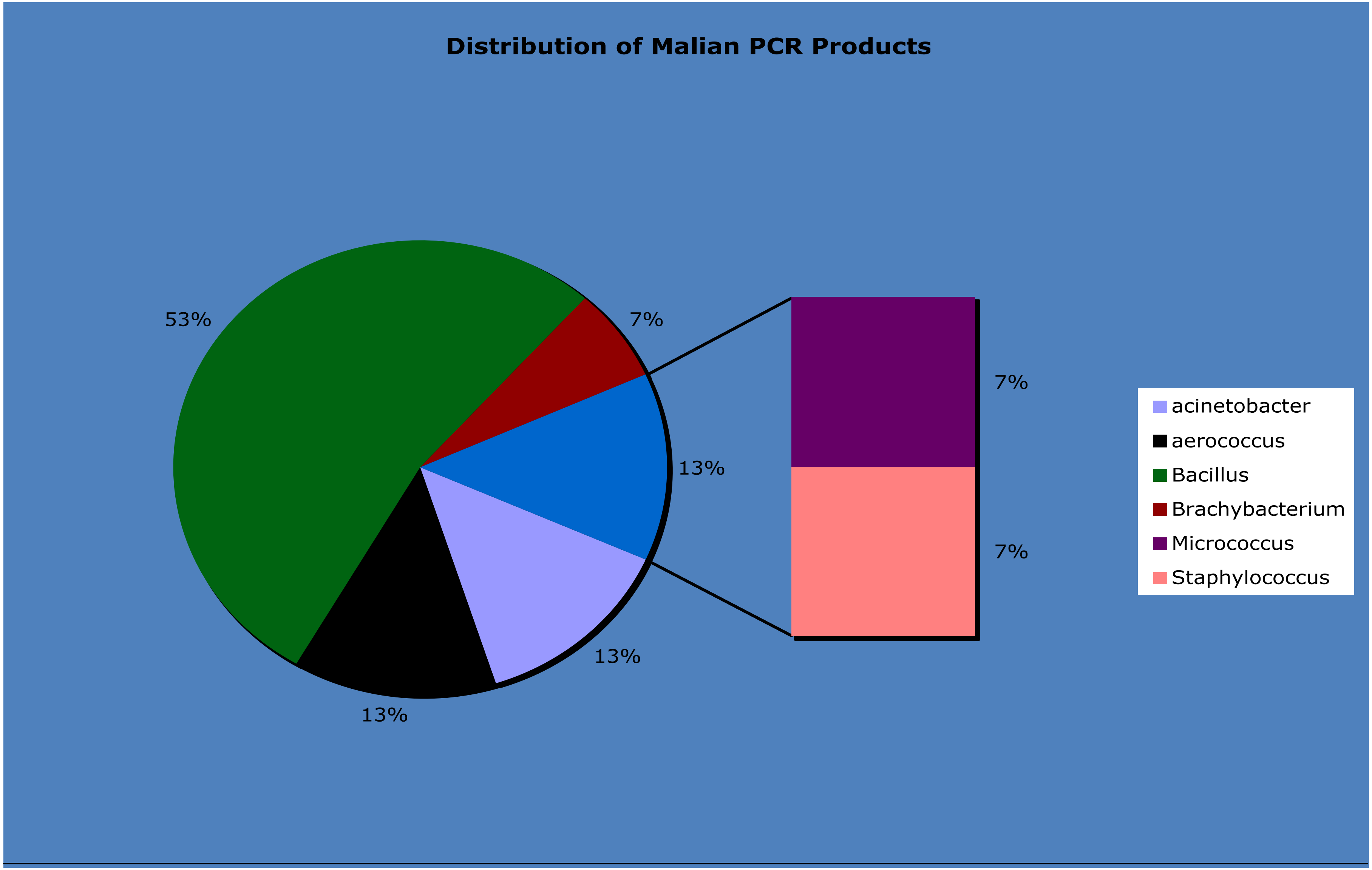
- Mali (July-Aug '07)
  - 46-195 CFUs
  - Total of 115 bacterial isolates
    - 83% Gram positive, 70% spore-formers
- Mali (Oct '07)
  - 71-185 CFUs
  - Total of 107
    - 82% Gram positive



Cultured filter sample, isolated colonies and microscopic characteristics

(A): Microbial growth after 24hr incubation in BHI agar. (B, C, D, E and G): Microbial colonies visualized by stereometer. Microscopic photographs of gram stained (F) cocci tetrads and (H) Rods

For comparison …



Sample Results Diversity Index

June 28th-July 3rd

Diversity Index(H')		
PM size	R2A (A)	TSBA (B)
1.1-0.65μm	6.26	8.50
2.1-1.1μm	6.34	7.49
3.3-2.1μm	3.79	3.79

July 5th-July 11th

Diversity Index(H'')		
PM size	R2A (A)	TSBA (B)
≤0.65μm	3.30	2.00
1.1-0.65μm	2.00	3.79
2.1-1.1μm	1.44	2.00
3.3-2.1μm	1.44	0.37

Sample Results: Evenness

June 28th-July 3rd

Evenness (H'/Ln S)		
PM size	R2A (A)	TSBA (B)
1.1-0.65μm	0.554	0.82
2.1-1.1μm	1.08	0.969
3.3-2.1μm	1.45	1.45

July 5th-July 11th

Evenness (H'/Ln S)		
PM size	R2A (A)	TSBA (B)
≤0.65μm	1.09	--
1.1-0.65μm	--	1.45
2.1-1.1μm	0.903	--
3.3-2.1μm	0.290	0.903

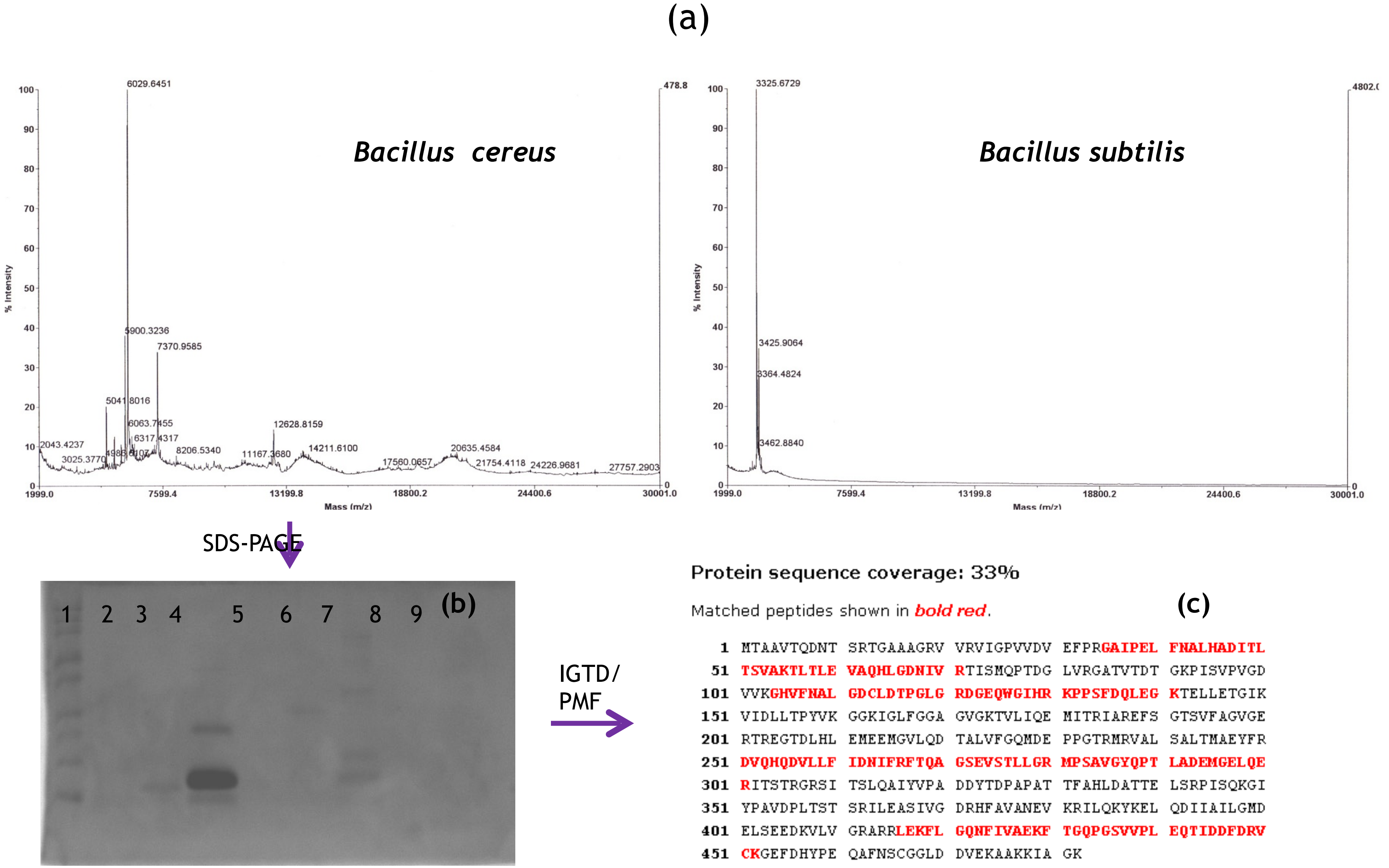
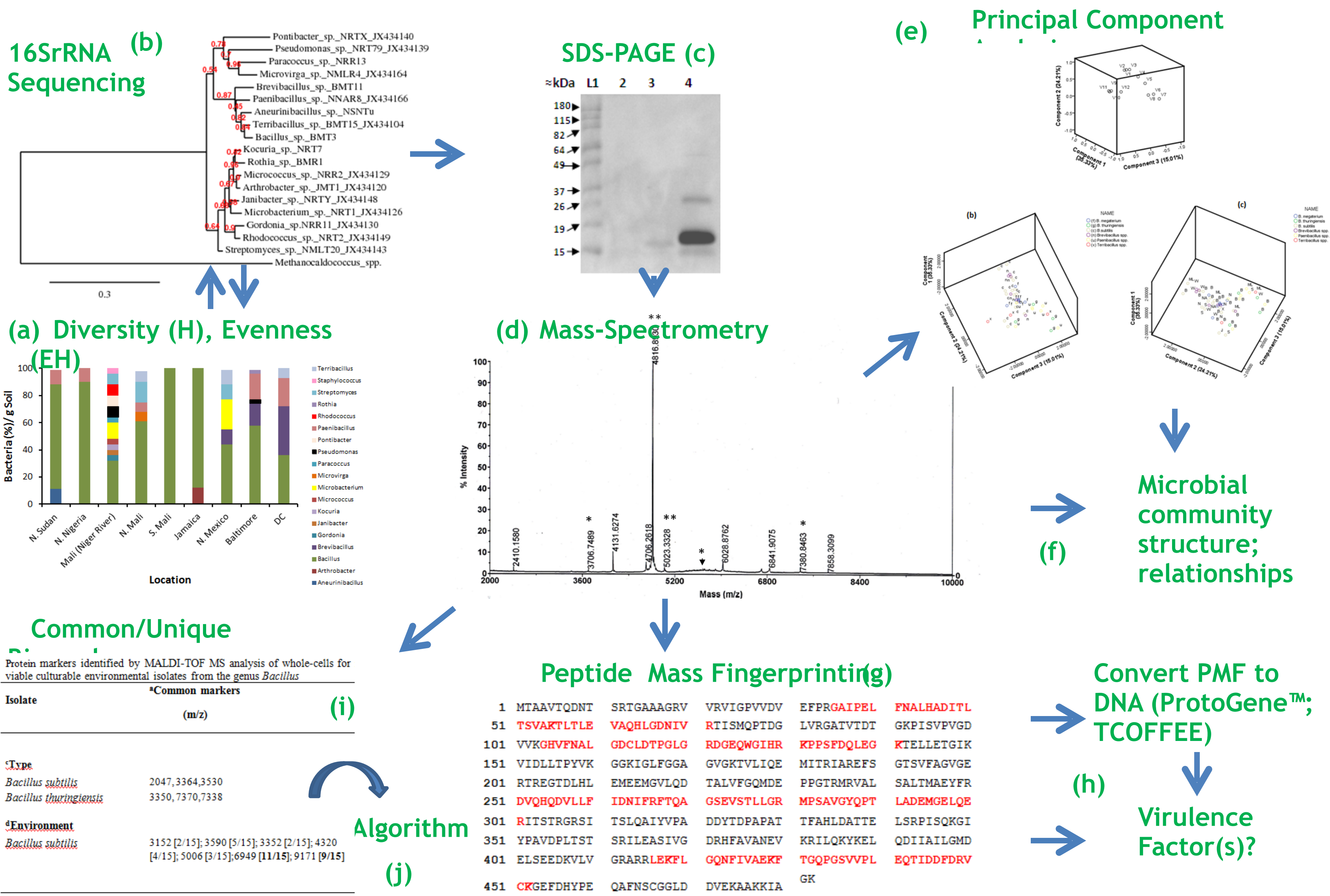
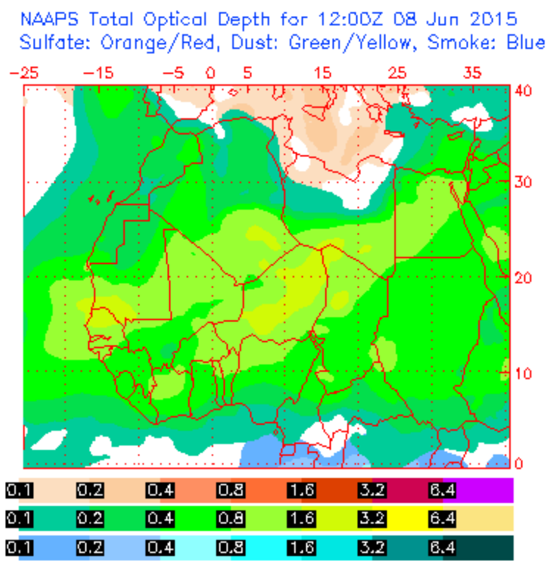


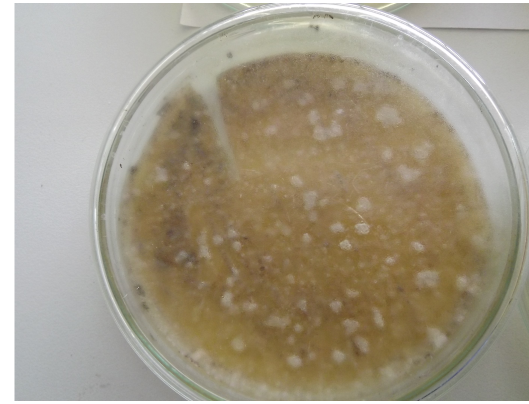
Figure 1. (a) MALDI-TOF mass spectra showing distinctive protein profiles for type cultures *Bacillus cereus* and *Bacillus subtilis*. Data was acquired in reflector mode at 20 kV with 150 transients, sinapinic acid was used as the matrix. (b) SDS-PAGE of bacteria surface proteins separated on a SDS-12% polyacrylamide gel stained with Comassie Brilliant Blue R-250 (Lane 1 , molecular weight marker; lanes 2-9 proteins from Saharan soil bacteria); (c) Peptide map of IGTD (in-gel-tryptic-digest) identified using Expasy/SwissProt protein database. Red color letters indicate peptides matched (33%) from in database.

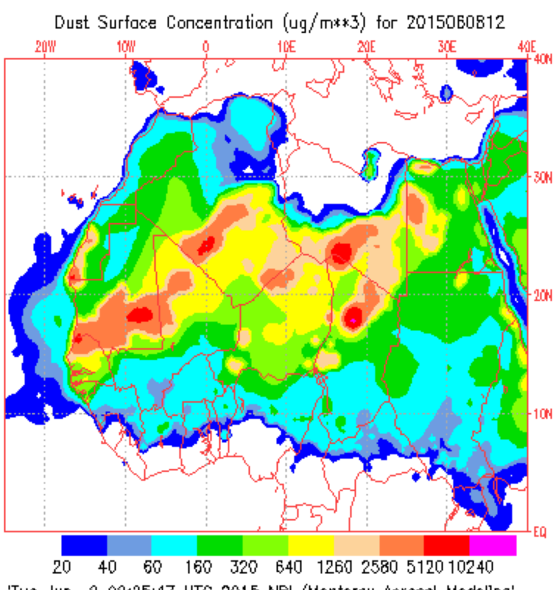
MALDI-TOF MS and 16SrRNA as Tools for the Evaluation of Bacterial Diversity in Soils from Sub-Saharan Africa and the Americas



Gondar – June 2015







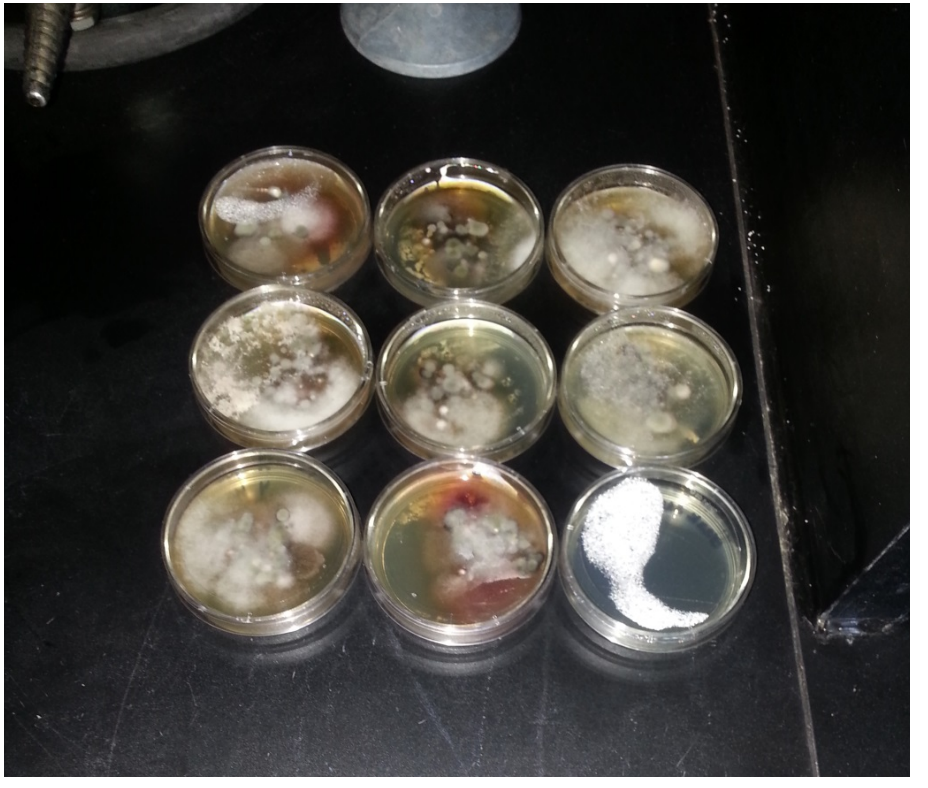
Summary of Results

- Appearance frequencies of species appears to be a complex function of wind direction, time of year, and human activity
- More human pathogens detected from the molecular techniques during the late summer than any other period
- Strong evidence of trans-Atlantic transport of crop pathogens
- Ongoing and future studies will seek to:
  - identify the “unknown” fraction of the gram negative population
  - Exploit high-throughput genomic methods for more expansive characterization
  - Characterize virulence of observed microbes
  - Develop a systematic seasonal metric for PM exposure and microbial load using historical data

Aerobiology in Washington, DC

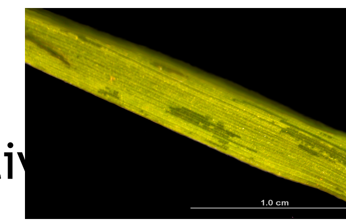
Phenotypic Characterization

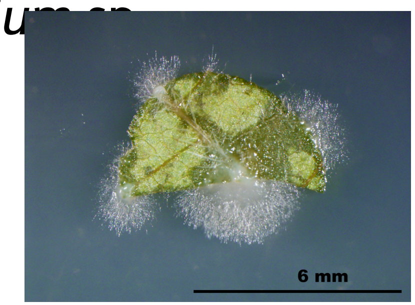
- Feb – June 2007
  - A total of 228 isolates were identified,
  - 111 Gram negative organisms, and 117 Gram positive organisms.
  - The entire collection of 228 were PCR, and 64 were applied the API 20 test for identification process. There were 16 non-duplicate isolates
- Summer 2013
  - 15 weekly samples between June and September
  - Size segregated sampling and size-specific characterization of microbial communities
  - Analysis of the relationship between air mass characteristics, synoptic conditions, and microbial populations
- Summer 2014
  - Planned repeat of 2013 campaign for comparative analysis and baseline studies



Summary Results: Food Security

- ~80% percent of the sample is dominated by pathogens or mycoparasites (species with biocontrol potential
  - 5-6 fold increase in species diversity with the dominant species represent about 10% of the total species diversity)
  - Observed an as yet undiscovered inter-annual dynamic diversity of species.
- Wheat and Soy are the most susceptible cash crops
- Bacterial pathogens species: gram positive and gram negati *Xanthomonas*
- Fungal pathogens identified:*Sclerotinia* sp., *Fusariu*





Ambient Aerosol Chemistry and Environmental Microbiology (AACEM)

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Questions??

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