NASA Research on Nano-particle Emissions

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Nanoparticle Air Monitoring Workshop

Research TrianglePark, NC

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Why Measure Nanoparticle Emissions/Properties

Space Program

- Avoid micro-contamination of sensitive hardware
- Monitor cabin air quality
- Investigate material degradation
- Study impact of high-velocity particles on space vehicles

Atmospheric Science

- Better understand atmospheric chemical cycles and budgets (S, N, C)
- Delineate cloud-aerosol interactions/aerosol impacts on H_2O cycle
- Establish particle impacts on radiation transfer/atmospheric heat budget

Aeronautics

- Assess the impact of aviation on the environment (local, regional, and global)
- Help U.S. industry get ahead of the curve on anticipated regulatory changes

Space Program Nanoparticle Interests

Issues

- Contamination of optics/electronics during hardware assembly
- Contamination of spacecraft during upload
- Contamination of spacecraft environment by component emissions
- Degradation of vehicle components by bombardment from space particles

Response

- Extensive use of cleanrooms for fabrication and assembly
- Out-gassing and wear studies conducted on all components
- In situ collection of samples in/outside vehicles for AQ monitoring

Measurement Methods

- Clean-room particle concentrations monitored with CNCs and OPCs
- Particle collected on filters/impactor media; analyzed off line with EM and chemical techniques

Probably much more going on that I don't know about; Cannot comment on specific monitoring needs of the Space community

Atmospheric Science Nano-particle Interests

Fundamental Questions being Addressed

- What are the sources of nanoparticles to the atmosphere?
- What is their size-dependent composition and mixing state?
- How do they interact with light? With water vapor and clouds?
- How do they evolve/grow? What is their atmospheric lifetime?
- How do they influence gas-phase chemistry?

Research Venues

- Airborne field investigations (at 1 to 2-year intervals)
- Ground-based studies (University Grantees)
- Laboratory studies and simulations (University Grantees)

Measured Parameters

- Number densities and size distributions
- Optical parameters
- Mass loading, composition, mixing state, BC content, etc.

Langley DC-8 Aerosol Measurements Address Needs

Aerosol Properties

-Number Density (CN and UFCN)

-Size Distributions (SMPS, OPC)

-Volatility (hot/cold CN)

-Wavelength Dependent Scattering and Absorption (Nephelometers, Aethelometers)

-Size-Resolved CCN (SMPS+CCN)

-Elemental/Organic Carbon Mass (Filter)

Cloud Microphysical Properties

-Number Density

-Size Distributions

-Ice Particle Images

-Liquid Water Content

Other Aerosol Properties

-Size dependent comp (AMS)

-Bulk composition (Filters/offline analysis)

-Single particle soot (SP2)

Impact of Urban Emissions on Regional Air Chemistry

NASA TRACE-P Mission, Spring 2001

-Investigated impact of Asian emissions on atmospheric composition over the Pacific

-Used instrumented DC-8 and P-3B aircraft

-Flew missions from Guam, Hong Kong, Tokyo and Hawaii

-Measured full suite of aerosol and gas properties

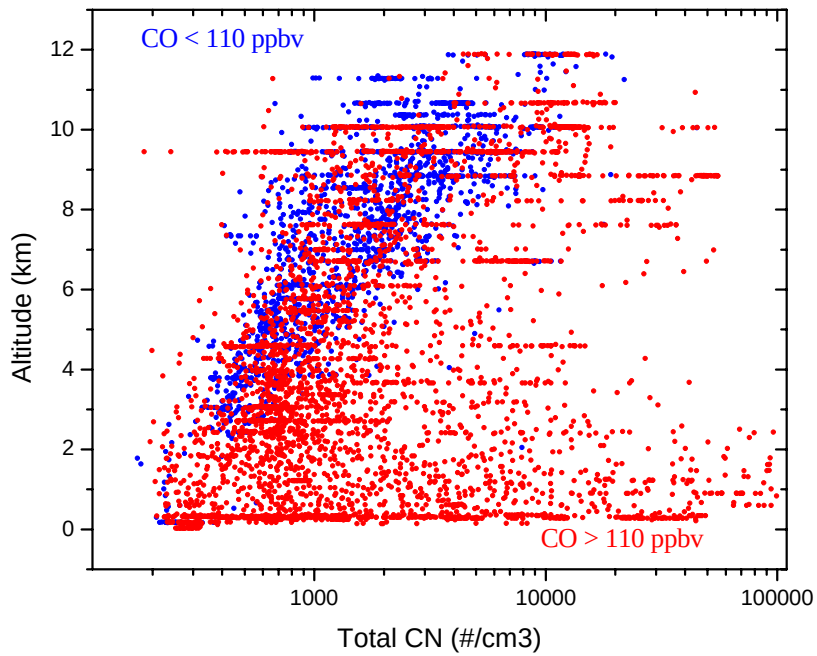
Mission Observations

-Found high concentrations of both volatile and nonvolatile nanoparticles in air masses sampled 100's of km off the Asian coast.

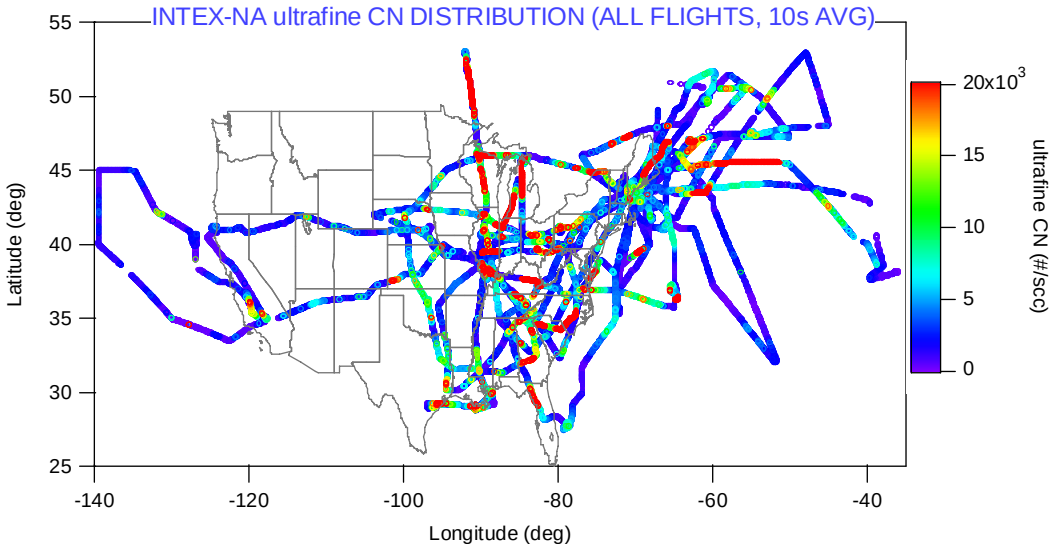
-Particles influenced cloud properties and hydrological cycles

-Asian particle and gas pollution seen in NA at times

-Emissions can be transported to arctic; influence snow albedo and atmospheric radiation budget



Nanoparticles over North America: Summer 2004



NASA INTEX-NA Mission

-Investigated import/export of pollution to/from North America

-Used instrumented DC-8

-Flew missions LA, St. Louis, and Portsmouth, NH

-Measured full suite of aerosol and gas properties

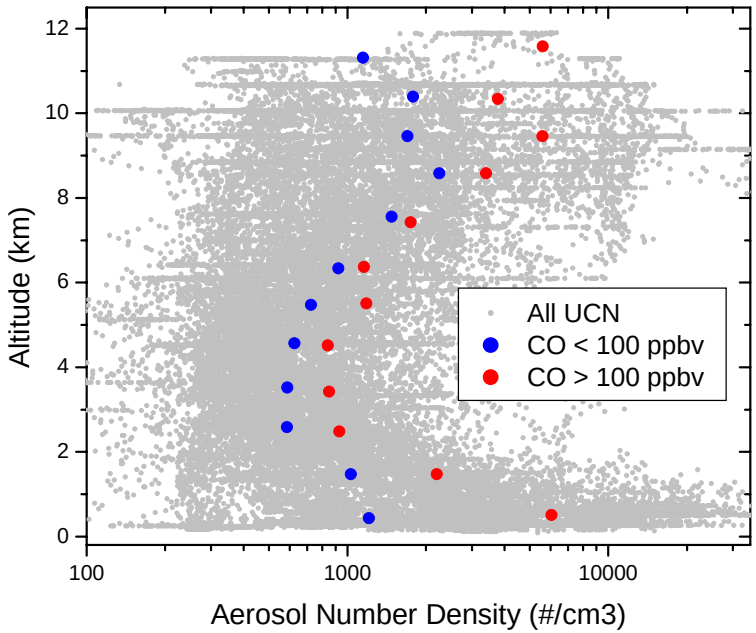
Mission Observations

-Typically clean comes into U.S. from Pacific/particle-laden air exits over the Atlantic

-High particle concentrations found in urban, biomass burning, and power-plant plumes

-Observed volatile nano-particles produced from SO_2 and organic gas oxidation

-Nano-particle number densities sometimes anti-correlate with PM2.5



Atmospheric (Airborne) Science Needs

Nano-particle Instruments

- Improvements in CPC and SMPS performance at reduced or varying pressures
- Fast-response (1 Hz), sensitive (100/cm3) nanoparticle sizing instruments
- On-line instruments for single and bulk nano-particle chemical composition
- Highly sensitive (ng/m3), black carbon mass sensor
- Reliable, wide-temperature range Ice Nuclei Spectrometer
- More modularized instrument software to allow collecting data from several instruments with a single computer (labview modules?)

Methods

- An aircraft inlet that will allow sampling aerosols within clouds
- More standarized techniques for determining aerosol mixing state, volatility and hygroscopic properties
- CALIBRATION STANDARDS FOR PARTICLE NUMBER AND MASS!!

Aeronautics Nanoparticle Interests

Obama 2009 Budget Directive:

AERONAUTIC RESEARCH

Renews NASA's commitment to aeronautics research. NASA will renew its commitment to cutting-edge, fundamental research in traditional and emerging disciplines to help transform the nation's air transportation system and to support future aircraft. NASA research will increase airspace capacity and mobility, enhance aviation safety, and **improve aircraft performance while reducing noise, emissions, and fuel consumption**

Aircraft Particle Emission Situation

- Aircraft generate large numbers of black carbon particles and precursors which form secondary organic and sulfate aerosols; emissions cannot be controlled through catalytic converters, etc.
- Airline traffic is increasing and will probably double in next 20 years
- Airports located in EPA non-attainment areas must assess environmental impacts before expanding
- Europeans are pushing for greater regulation of particle emissions from the transportation sectors; are considering number-based standards
- Smoke Number data inadequate for assessing air quality or

Detailed measurements of aircraft particle emissions/characteristics are needed to support assessments, development of standards, validate fundamental combustion and chemical models, and guide technology development.

Aeronautics Nano-particle Research

Fundamental Questions being Addressed

- What exactly comes out of the tailpipe of gas-turbine powered aircraft?
- What are the best and most reliable techniques for measuring these emissions?
- How do particle concentrations/characteristics evolve in time?
- How do fuel composition and ambient conditions influence particle emissions?
- How do combustor/injector design and operating conditions effect BC emissions?
- How do particle emissions from the existing fleet impact LAQ and climate?

NASA Research Venues

- Laboratory studies (flame tubes, combustor rigs)
- Ground-based studies (EXCAVATE, APEX, PW308, AAFEX)

Note: CARB, DOD, EPA, FAA, and SERDP are also conducting/sponsoring tests

On-Wing Tests Establish Emission Profiles

EXCAVATE, 2002

Fuels: 810, 1050, 1820 ppmS
Inlets: 1, 10, 25, 35 m
Powers: 6,23,45,60,75%
NASA, Aerodyne, Air Force

APEX-1, 2004

Fuels: 383, 530, 1595 ppmS
Inlets: 1, 10, 30 m
Powers: 4,7,30,45,65,85,100%
NASA, FAA, Aerodyne, EPA, Air Force, UMR

Additional On-Wing Tests Conducted During APEX-2/3 and AAFEX

Nanoparticle Measurement Approaches

Number and Size

- CNCs (TSI-3022, -3025, -3775, -3776)
- N-SMPS and L-SMPS (TSI, Grimm, and custom)
- Electrical Exhaust Particle Sizer (EEPS, TSI)
- Differential Mobility Spectrometer (DMS-500, Cambustion)
- Electrical Low-Pressure Impactor (ELPI, Dekati)
- Electrical Aerosol Detector (EAD, TSI)

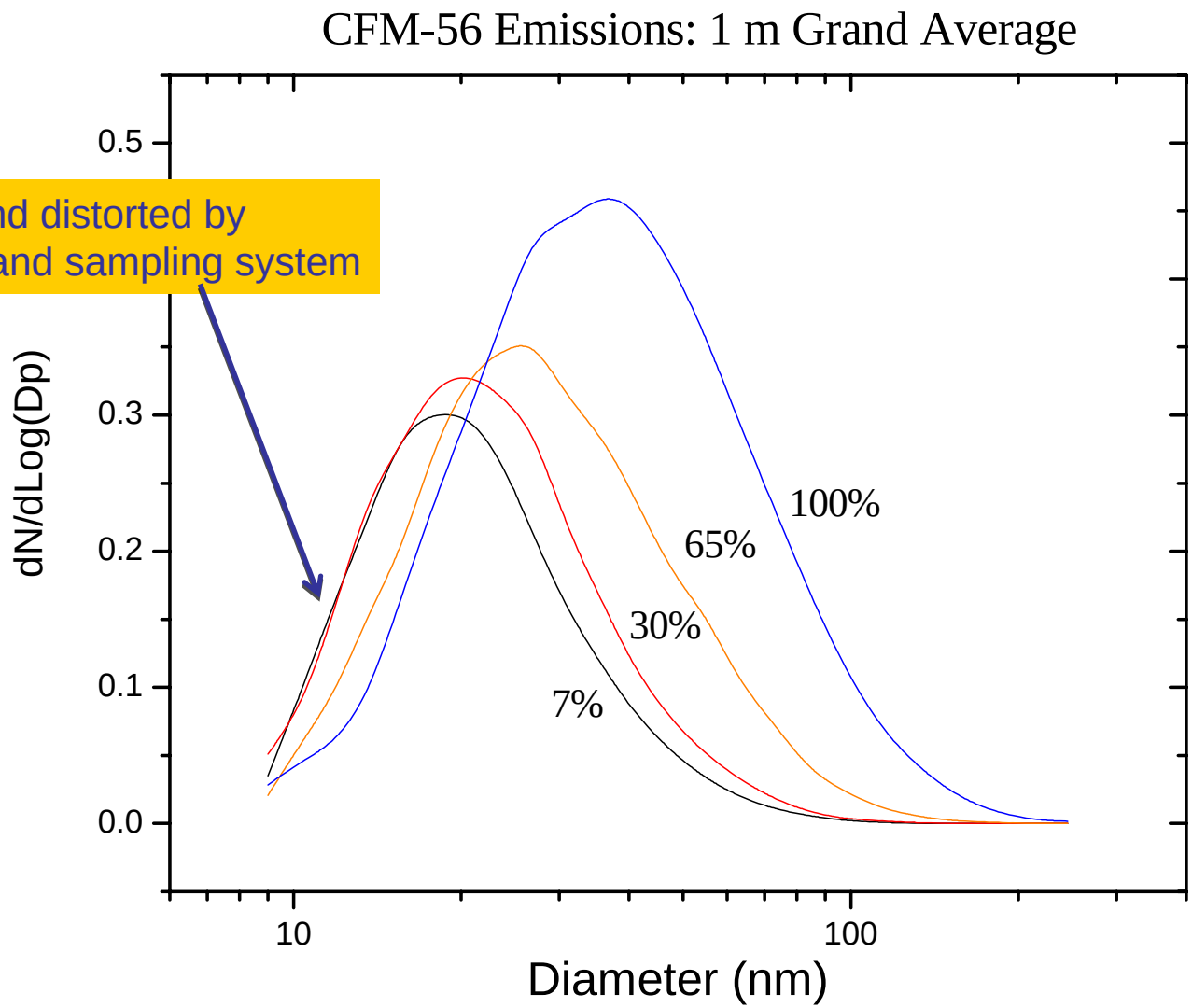
BC and Total Mass

- Aethelometers (Magee Scientific, MAAP and PSAP)
- Laser Induced Incandescence (Artium, DMT)
- Tapered Element Oscillating Microbalance (TEOM, R&P)
- Differential Mass Monitor (DMM, Dekati)
- EC/OC filters (Sunset, others)
- Teflon filters/gravimetric analysis
- Quartz Crystal Microbalance (QCM)

Composition

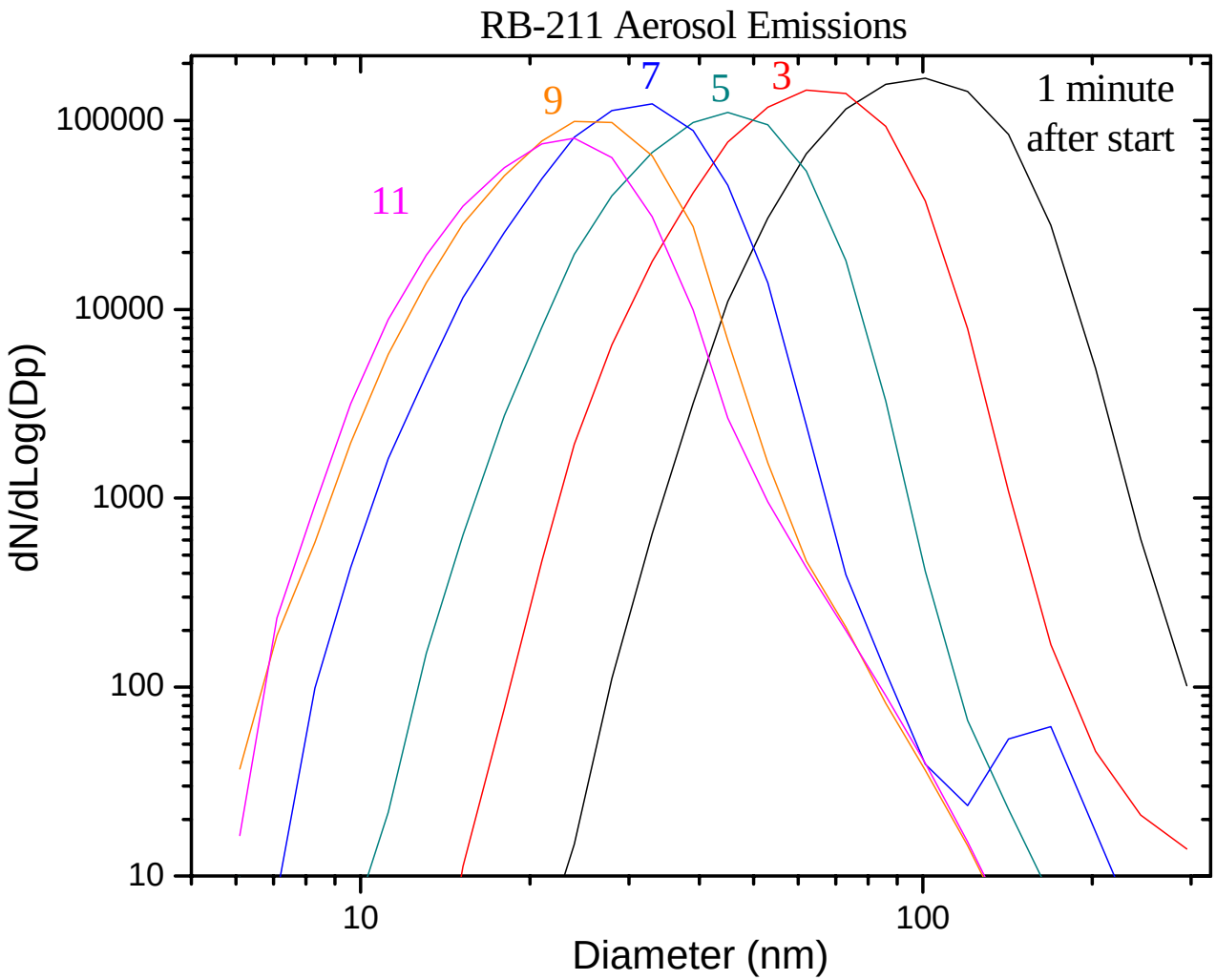
- Aerosol Mass Spectrometer (Aerodyne)
- Filters + offline chemical analysis
- Particle-into-Liquid-Sampler + offline analysis
- PAH sensor (Ecochem)
- SO4 analyzer (Thermo)

Characteristics of Aircraft Emissions



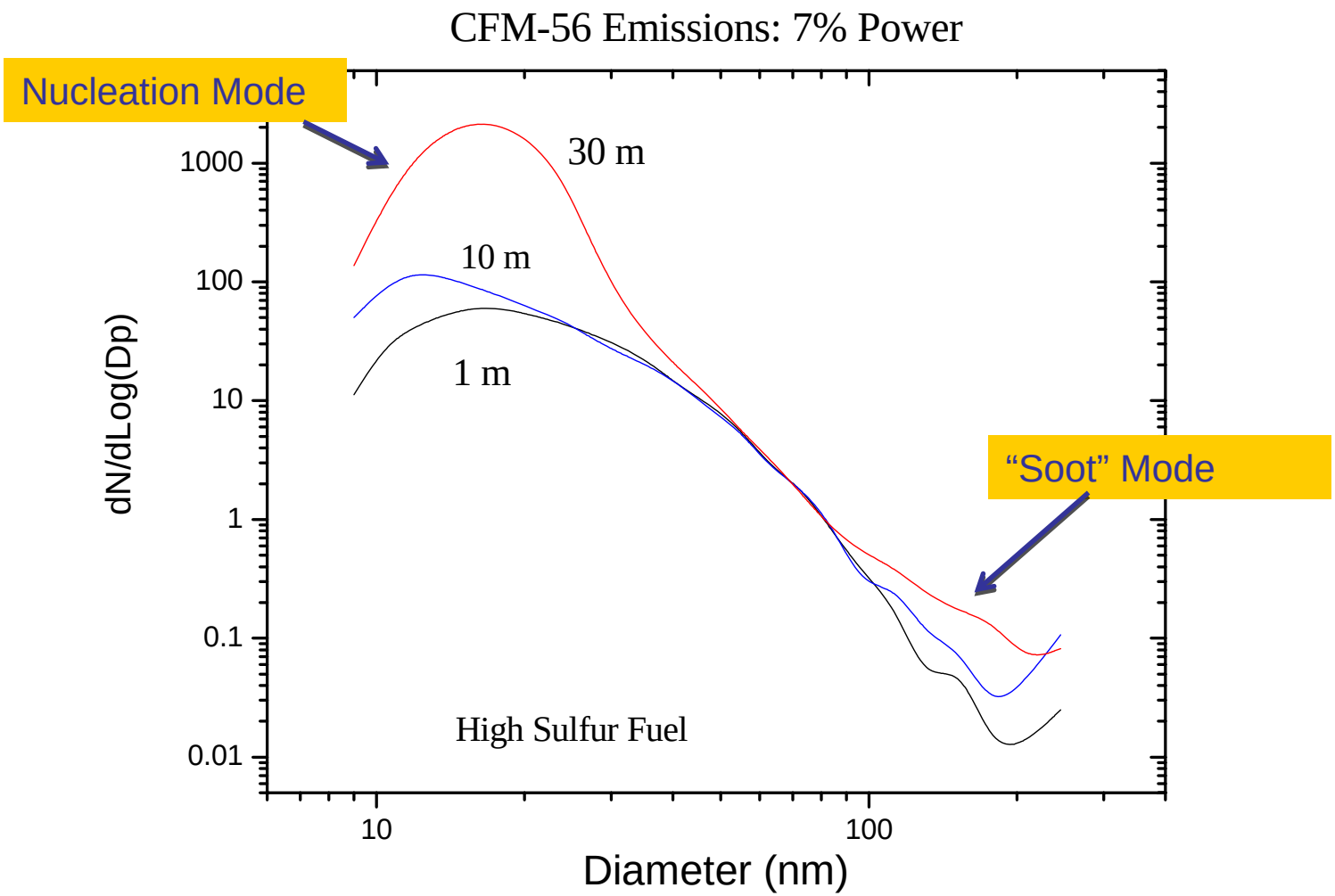
Mean Dp < 100 nm, but varies with power and engine type; Range of interest from 3 to 300 nm for engine emissions

Characteristics of Aircraft Emissions



Emissions vary rapidly in time with changes in engine temperature and thrust; 1 Hz response sizing would be a plus

Characteristics of Aircraft Emissions



Volatile material condenses very quickly in plume to form new particles and coat soot—processes depend on ambient conditions; mixing state data needed to elucidate plume chemistry/validate models

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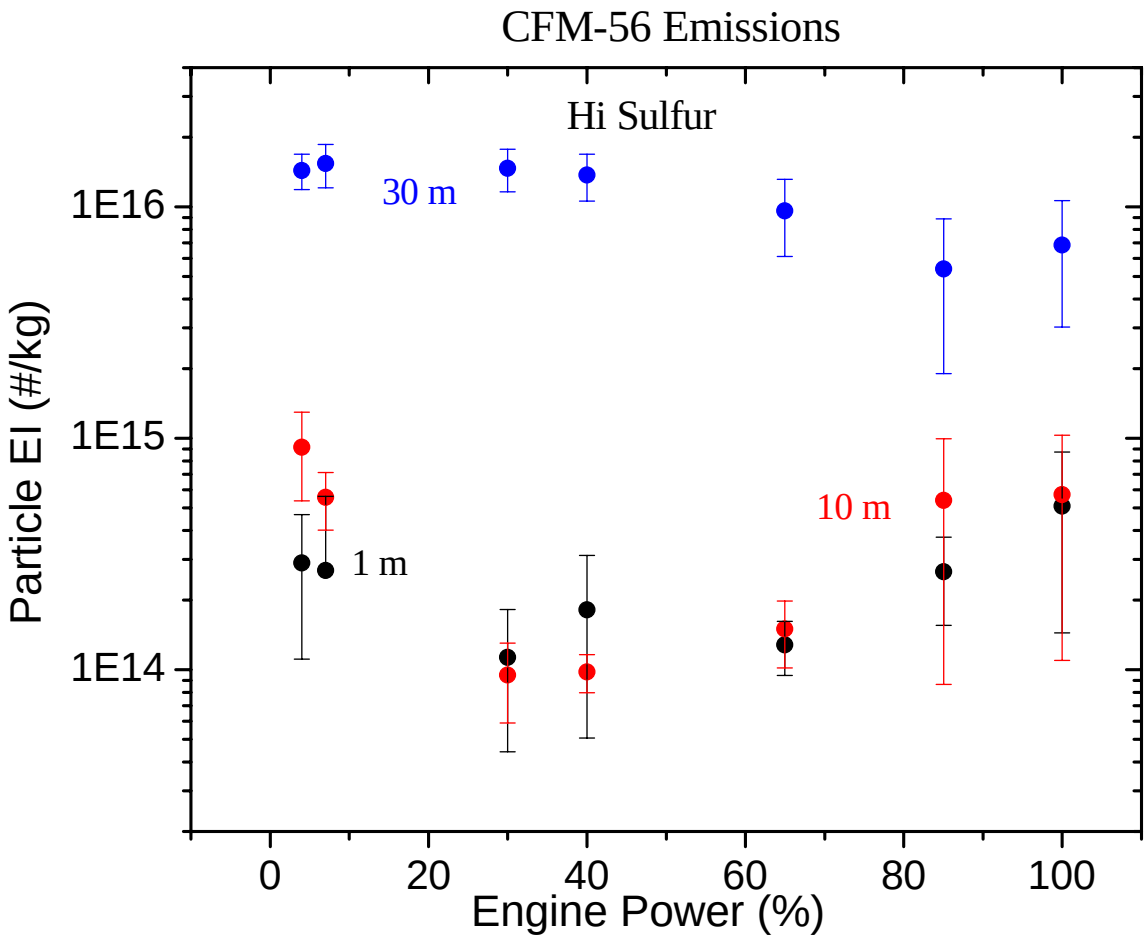

Number densities vary greatly with thrust, sample dilution, ambient temperature and fuel composition; Range from $<10^3$ to $>10^7 cm^{-3}$

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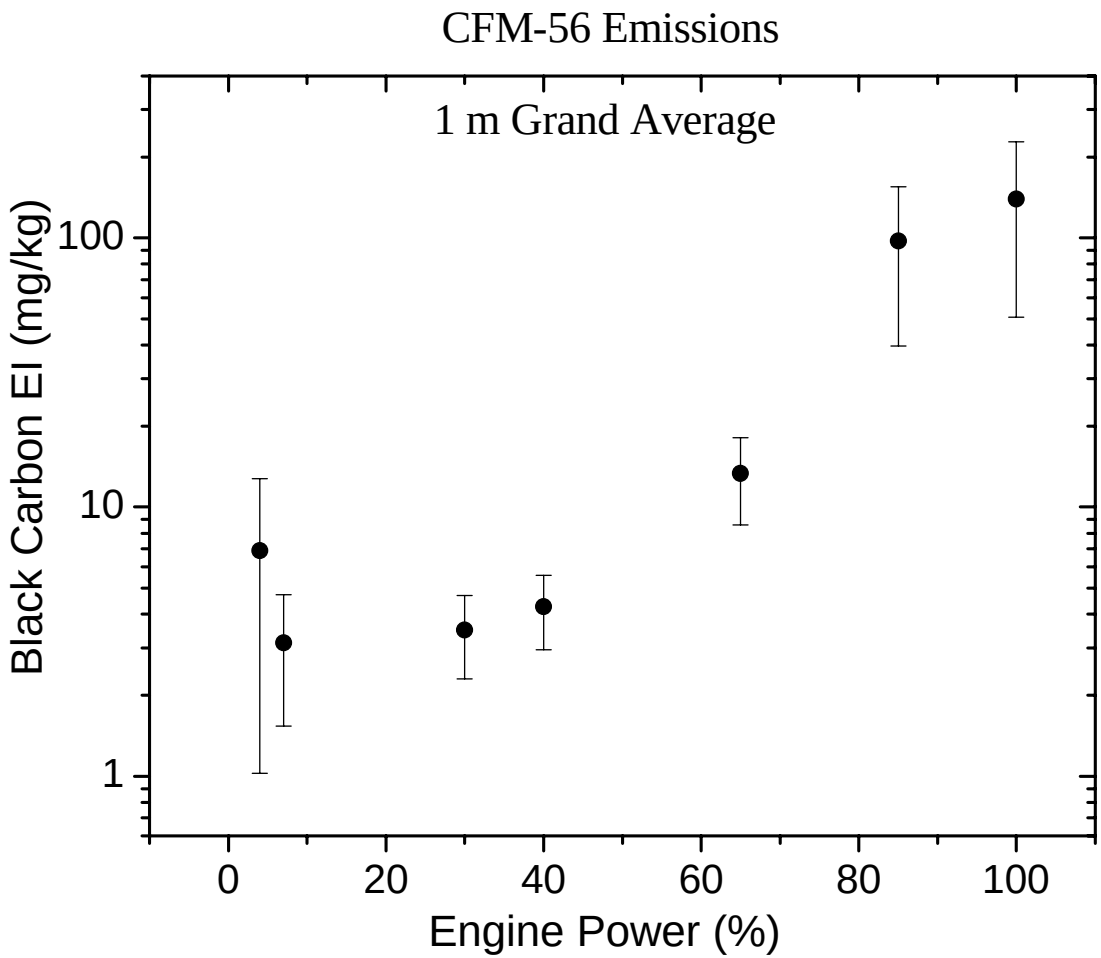
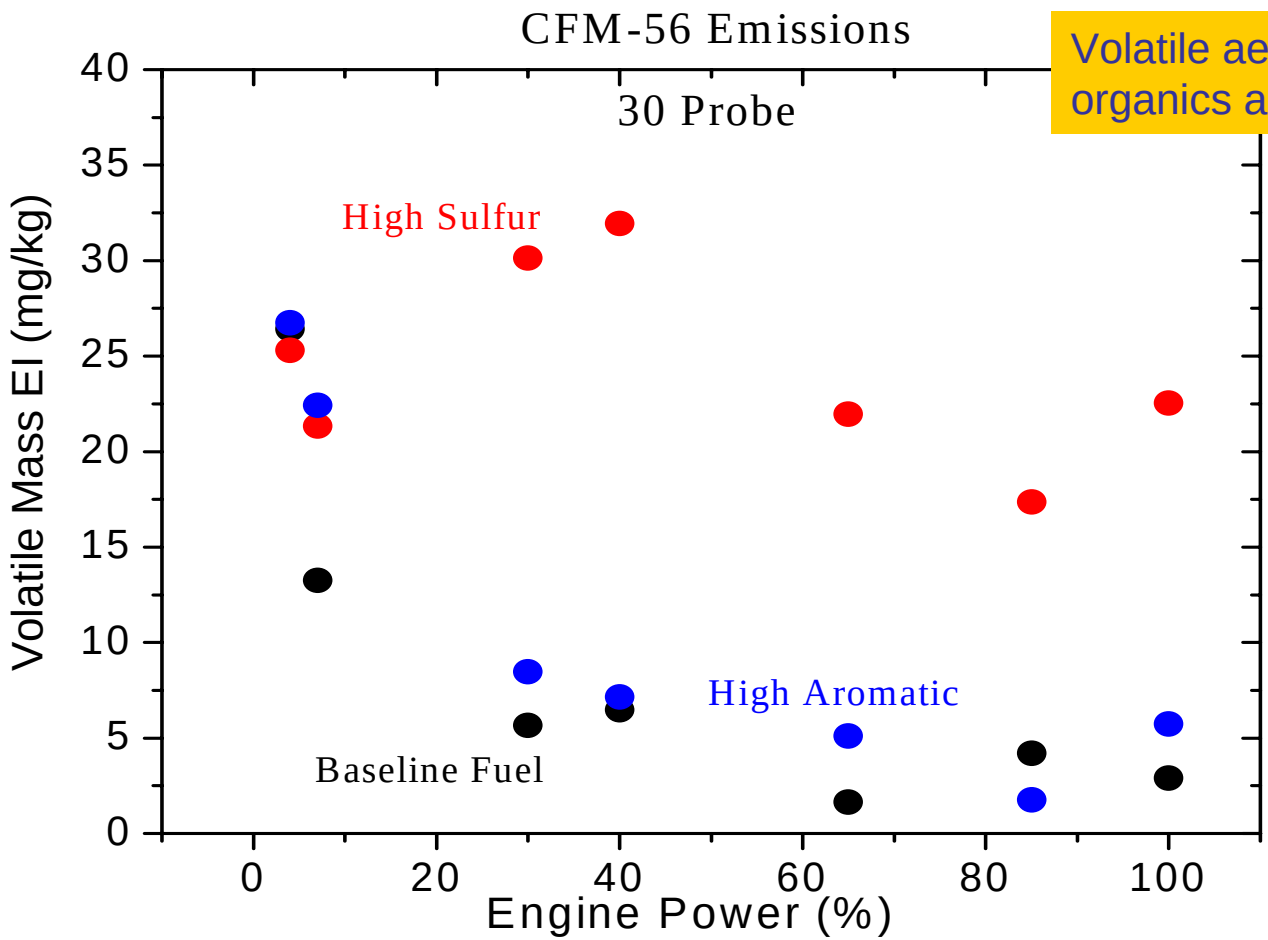


BC mass varies with engine, power setting, sample dilution, and fuel composition; concentrations range from 0.1 to 1000 μg m^{-3}

Characteristics of Aircraft Emissions



Volatile aerosols are mostly organics and sulfate

Volatile mass varies with engine, power setting, oil leaks, sample dilution, plume age, fuel composition, and ambient temperature; concentrations range from 0.1 to 200 μg m^{-3}

Characteristics of Aircraft Emissions

Sampling methods are complex and non-standardized; Restricts measurement opportunities and introduces relative uncertainties between data sets

Aircraft Nano-particle Measurement Needs

Nano-particle Instruments

- Fast-response (1 Hz), sensitive (<1000/cm3), accurate sizing instruments
- Sensitive (100 ng/m3) on-line instruments for bulk chemical composition (organics/sulfates)
- Highly sensitive (100 ng/m3), fast-response (1 Hz), black-carbon mass sensor
- An integrated instrument for mixing-state determination (T-DMA)
- More modularized instrument software to allow collecting data from several instruments with a single computer (labview modules?)

Methods

- Standards for exhaust sampling inlets (downstream or tip-dilution?), sampling locations, transport lines, sampling conditions, measurement corrections, etc.
- A simple, easily-deployed sampling rake

- **CALIBRATION STANDARDS FOR PARTICLE NUMBER AND MASS!!**

Questions?