The Atmospheric Science Program: Aerosol Radiative Forcing for Fun & Profit!

Jeff Gaffney and Nancy Marley
Argonne National Laboratory
AEROSOLS - URBAN

PM-10 - <10 micrometer
PM-2.5  <2.5 micrometer

Primary –
Wind-blown dusts – Pollen, Spores, etc.
Carbonaceous soot – elemental or black C

Secondary -
Sulfate– Sulfuric Acid, Ammonium sulfate
Nitrate – Ammonium Nitrate
Organic Carbon – PAH, Oils, etc.

Mexico City
ATMOSPHERIC CHEMISTRY PROGRAM
ENVIRONMENTAL METEROLOGY PROGRAM
JUNE 3, 2003

REFOCUS YOUR EFFORTS TOWARDS AEROSOL RADIATIVE EFFECTS

NOVEMBER 2003

BERAC SUBCOMMITTEE MEETING TO DEFINE THE FOCUS OF THE PROGRAM
DOE Program Officers
   Mr. Peter Lunn
   Mr. Rick Petty
Chief Scientist Named - March 1, 2004 – ASP
   Steve Schwartz – Brookhaven National Laboratory
Leadership Team Named – March 4, 2004
   Peter Daum – Brookhaven National Laboratory
   Jeff Gaffney – Argonne National Laboratory
   Steven Ghan – Pacific Northwest National Laboratory

CALL FOR PROPOSALS – JUNE 21, 2003 DUE DATE
Science Steering Committee to come from Science Team
Program Goals

The Atmospheric Science Program (ASP) has both a long-term goal, and a specific science focus that changes from time to time according to national and DOE needs. The long-term goal is to develop a comprehensive understanding of the atmospheric processes that control the transport, transformation, and fate of energy related chemicals and particulate matter, especially in the context of climate change.

Beginning in FY 2005 the specific science focus will be aerosol radiative forcing of climate. Associated with this focus is the objective of enhancing the scientific knowledge needed to simulate and predict radiative forcing and other climatic effects of aerosols.
Photochemical Smog Formation
CLIMATE EFFECTS OF FINE AEROSOLS

Light Scattering – Cooling (short wave)

Light Absorption – Heating (long wave - all aerosols!)

*Carbonaceous Soot* – short and long wave

Indirect – Cloud Condensation Nuclei – Increased Clouds to HAZY SKIES – Depending upon Concentration and Composition.

IMPACT DEPENDS ON POSITION IN THE ATMOSPHERE AND THEIR LIFETIMES
FIGURE 12.9. Schematic of an atmospheric aerosol size distribution showing the three modes, the main source of mass for each mode, and the principal processes involved in inserting mass into and removing mass from each mode (from Whitby and Sverdrup, 1980).
0.1 Micron to 1 Micron Stability to Removal!
Atmospheric Science Program:

DOE Research Aircraft Facility
Gulfstream 159 Aircraft for Airborne Atmospheric Research
DOE Research Aircraft Facility

Grumman Gulfstream G-159 (G-1) twin turboprop aircraft
DOE Research Aircraft Facility
Attributes of the G-1 Aircraft

• Dimensions: Length 20 m, Wingspan 24 m, Height 21 m, Weight 16,330 kg max
• Nominal operation: Altitude 0.5-7.5 km, Speed 80-150 m/s, Sampling speed 100 m/s, Climb 160-330 m/min
• Endurance with maximum fuel: 6 hr
• Electrical Power: 4,000 VA @ 110&220 VAC, 28 VDC
• Crew: 2 pilots, 1-4 scientists
• Cabin payload: 1,300 kg
Research Electrical Power
Instrumentation on G-1

- PNNL and collaborative
  - ANL, BNL, Battelle Columbus
  - Other research organizations

- Meteorological sensors
  - Temperature, pressure, dew point temperature
  - Gust probe vector winds

- Chemical sensors
  - Real-time: O3, CO, SO2, NO/NO2/NOy, H2O, H2O2; VOCs via PTR-MS; H2SO4, HNO3, HONO via API-MS
  - Integrating: NO2, PAN, HCHO, VOC

Gust Probe Ports
Instrumentation on G-1
(continued)

- Cloud & Aerosol Microphysics
  - PCASP, FSSP, 2D aerosol/cloud size spectra
  - Total scatter/back scatter nephelometers
  - Condensation particle counters
  - Ultrafine particle counter
  - Liquid water content probe

- Radiation
  - UV/solar/IR radiometers
  - Up/down-looking IR thermometers
Instrumentation on G-1
(continued)
Instrumentation on G-1
(continued)
Inlets and Exhausts for Research Instruments

• Inlets need to be
  – chemically inert (Teflon, SS)
  – insensitive to angle of attack
  – isokinetic for particles

• Exhausts are needed to
  – remove excess heat
  – vent sensor trace gases

• Venturis needed to draw sample air through some instruments

NO/NO₂/NO₃, O₃, CO, SO₂

Venturi
Scoop
Scoop
Instrumentation Racks

- Racks fastened to floor tracks
  - Two on left
  - Three on right
- Racks come in different sizes
  - Single-wide: 22"Wx19"Dx42"H
  - Double-wide: 42"Wx24"Dx42"H
- Racks protect
  - Instruments from mechanical shock & accidental jolts
  - Flight crew from injury
- Racks withstand high g-forces
  - Turbulence
  - Landings
Data Acquisition System

- Science & Engineering Associates M200
  - 64 channels of analog (±5 VDC) input
    - space available for another 32 channels
  - Special interface cards for
    - FSSP, PCASP aerosol probes
    - TANS/Vector attitude GPS
  - Output to 8 mm tape or save on hard disk
  - Flat panel display for real-time monitoring
    - Aircraft position superimposed on map
    - Strip-chart trace of selected parameters
    - Parameter versus Altitude for profiles
Cabin Configuration for FY02 Field Studies

- 2700 lb equipment
- 5000 VA @ 110 VAC
- 4 scientific crew
- 2900 VA @ 220 VAC
Locations of ACP Projects Using the DOE RAF-G-1

- PNNL
- NARE 92+93
- SOS 95+99
- NARSTO-NE 95+96
- NEOPS 99
- AMS/NEAQS/NAOPEX 02
- KUWAIT 91
- TX2000
- SOS 95+99
- NGS 91
- ARM IOPs 97+98
- SALT RIVER
- CCOS 00
- PHOENIX 98+01
- ITEX 98
- PNW 2001
Figure 5
The interrelationship between different parameters used to describe the size distribution of airborne particulate matter. (Adapted from Wilson and Suh, 1997.)
BASIC PHYSICS OF AN IMPACTOR

Sizing Dependent on Flow Velocity and Geometry

Air and Particles

Air

Teflon Filter
STAGE 5
50% CUTOFF 0.5 μm

STAGE 4
50% CUTOFF 1.0 μm

1 cm = 25 μm
STAGE 3
50% CUTOFF 2.0 μm

STAGE 2
50% CUTOFF 4.0 μm

1 cm = 25 μm
Aerosol Samples - Argonne, IL

Size Fraction 5; 0.5 um.
FIGURE 1.9 Global average mean radiation and energy balance per unit of earth's surface [adapted with permission from IPCC (1996) with numbers from Kiehl and Trenberth (1997)].
UV, NO2 Usery Pass, Mesa AZ 1998

The graph shows the UV and NO2 levels from Julian Date 135 to 163. The y-axis represents UV intensity in uW/cm² with values ranging from 0 to 30, and NO2 in ppb with values ranging from 0 to 60. The x-axis represents Julian Dates from 135 to 163. The data points indicate fluctuations in both UV and NO2 levels throughout the period.
Ozone Comparison Usery Pass Mesa AZ 1998

Ozone ppb vs. Julian Date

- Ozone ppb
- ADEQ Ozone
Fig. 2.1. (a) Curves of black-body energy \( B_\lambda \) at wavelength \( \lambda \) for 5750 K (approximating to the sun’s temperature) and 245 K (approximating to the atmosphere’s mean temperature). The curves have been drawn of equal areas since integrated over the earth’s surface and all angles the solar and terrestrial fluxes are equal.

(b) Absorption by atmospheric gases for a clear vertical column of atmosphere. The positions of the absorption bands of the main constituents are marked.
SPECTRAL LOCATIONS OF THE MAJOR INFRARED ABSORPTION BANDS FOR THE GREENHOUSE GASES

- H$_2$O vapor
- CO$_2$
- O$_3$
- N$_2$O
- CH$_4$
- SO$_2$
- NO$_2$
- NH$_3$
- HNO$_3$
- OCS
- H$_2$O$_2$
- HCN
- CCl$_4$
- CHCl$_3$
- PAN
- F 11
- F 12
- F 13

Wavenumber (cm$^{-1}$) vs. Wavelength (micron)
THERMAL EMISSION FROM EARTH
Emitted vertically upwards over the Sahara.

from: "The Physics of Atmospheres"
J.T. Houghton
SOME ISSUES

ATMOSPHERIC LIFETIMES
  Course Aerosol - Hours
  Fine Aerosols - Days, Months?
LOCAL SOURCE EMISSION CONTROLS?
REGIONAL EMISSION CONTROLS?

COMBUSTION SOURCES - CARBONACEOUS AEROSOL
  Diesel Engines
  Jet Engines
  Incineration of Wastes

PM-2.5 & AIR TOXICS
  Toxic Metals
  PAH, PCBs, etc.
Radioactive Decay of Natural Atmospheric Tracers

Produced in the upper troposphere and lower stratosphere by cosmic rays

\[ ^{7}\text{Be} \rightarrow ^{7}\text{Li} \quad 53.28 \text{ day} \]

\[ \text{Rn} \rightarrow \text{Po} \quad 3.8 \text{ day} \]

\[ ^{218}\text{Po} \rightarrow ^{214}\text{Pb} \quad 3 \text{ min} \]

\[ ^{214}\text{Pb} \rightarrow ^{214}\text{Bi} \quad 26.8 \text{ min} \]

Soil and Rock outgassing lower troposphere

\[ ^{210}\text{Bi} \rightarrow ^{210}\text{Pb} \quad 22.3 \text{ yr} \]

\[ ^{210}\text{Pb} \rightarrow ^{210}\text{Po} \quad 164 \text{ usec} \]

\[ ^{210}\text{Po} \rightarrow ^{206}\text{Pb} \quad 5 \text{ day} \]

\[ ^{210}\text{Bi} \rightarrow ^{214}\text{Pb} \quad 138 \text{ day} \]
Residence Times Calculated from $^{210}\text{Po}/^{210}\text{Pb}$ Activity Ratios

![Graph showing residence time versus aerodynamic diameter with data points for ANL, MC, PHX, and NM.]
OK SO WHAT IS CAUSING THIS?

BLACK CARBON?

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<th>SIZE(µm)</th>
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Aethalometry
Chicago, IL (2001)
Daytime Attack!

$\text{O}_3 \ \text{OH} \ \text{NO} \ \text{NO}_2 \ \text{hv}$

Nighttime Attack! - $\text{NO}_3$

~C-C-C=C-C-C-C-C-C-C-C-C-C-C-C=C-C-C-C-C-C-C-C-C=C~

OILY CARBONACEOUS SOOT SURFACE
After Reaction – STILL PRETTY HYDROPHOBIC!

\[
\begin{align*}
\text{HHHHH} & \quad \text{HO} \quad \text{HHHHHH} \quad \text{HHHHHH} \quad \text{HO} \quad \text{HH} \\
\sim\text{C-C-C} &= \text{O} \quad \text{O=CC-C-C-C-C-C-C-C-C-C-C}=\text{O} \quad \text{O=CC-C-C}=\text{C} \\
\text{HH} & \quad \text{HHHHHHH} \quad \text{H} \quad \text{HH}
\end{align*}
\]

OILY CARBONACEOUS SOOT SURFACE
AEROSOL INDIRECT EFFECTS
CLOUD FORMATION PARTICLES IN CLOUDS?