The Abdus Salam International Centre for Theoretical Physics

2256-14

Workshop on Aerosol Impact in the Environment: from Air Pollution to Climate Change

8 - 12 August 2011

History and basics of aerosol-cloud interactions

R.T. Bruintjes

National Center for Atmospheric Research, Colorado
USA

Aerosol-cloud interactions and precipitation development

Roelof T. Bruintjes

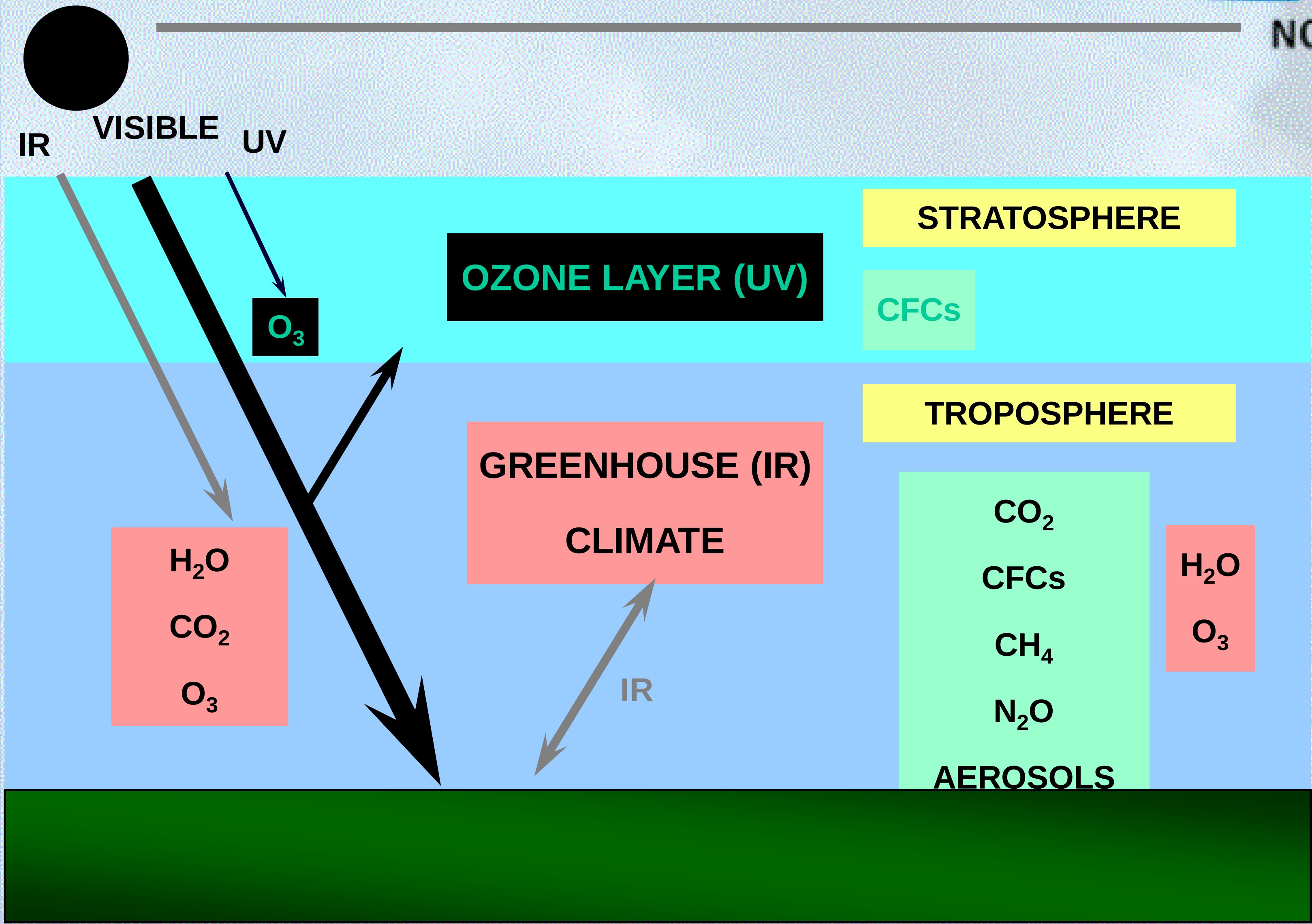
ICTP 10 August 2011

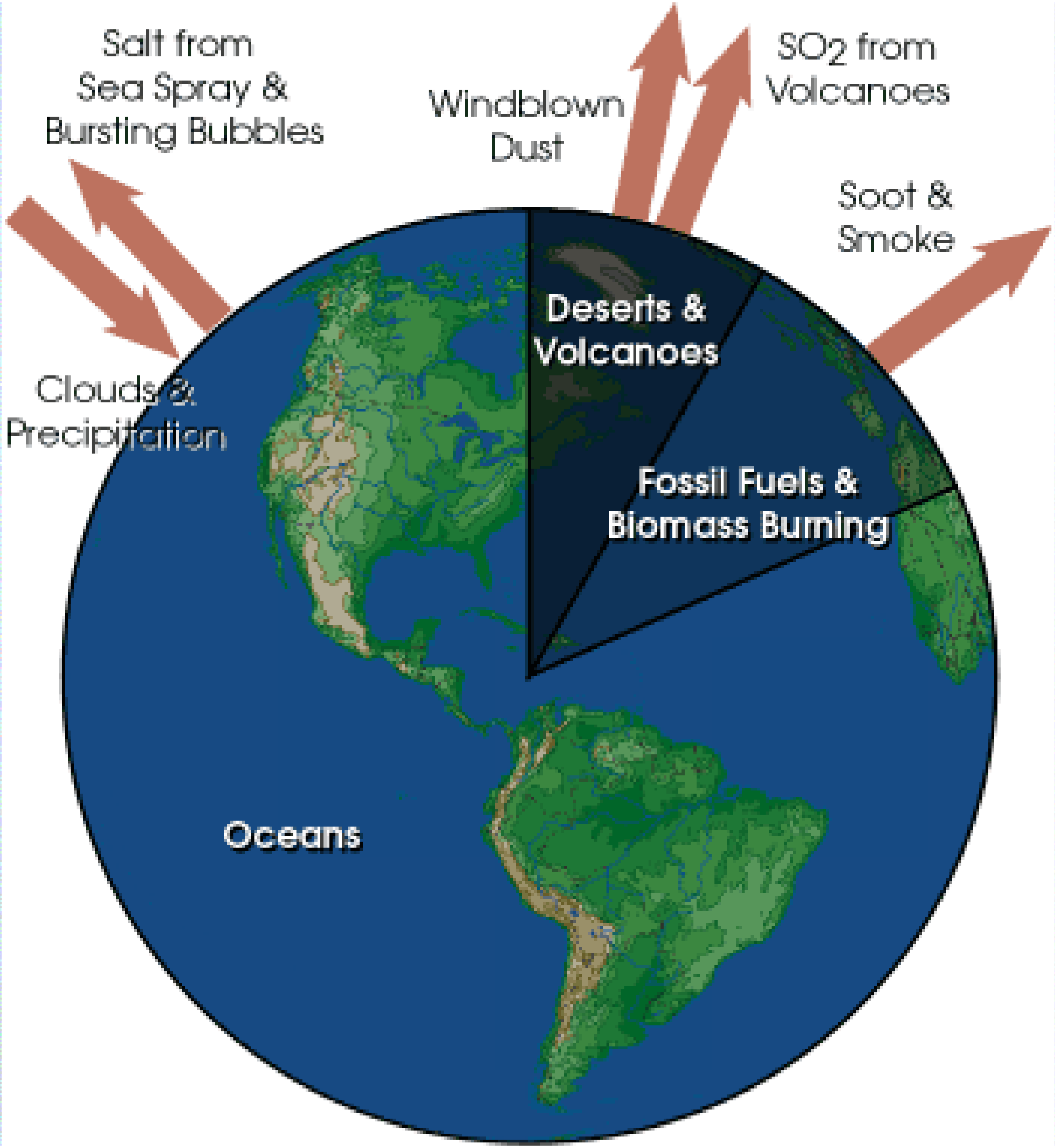
Workshop on Aerosol Impact in the Environment: From Air Pollution to Climate Change

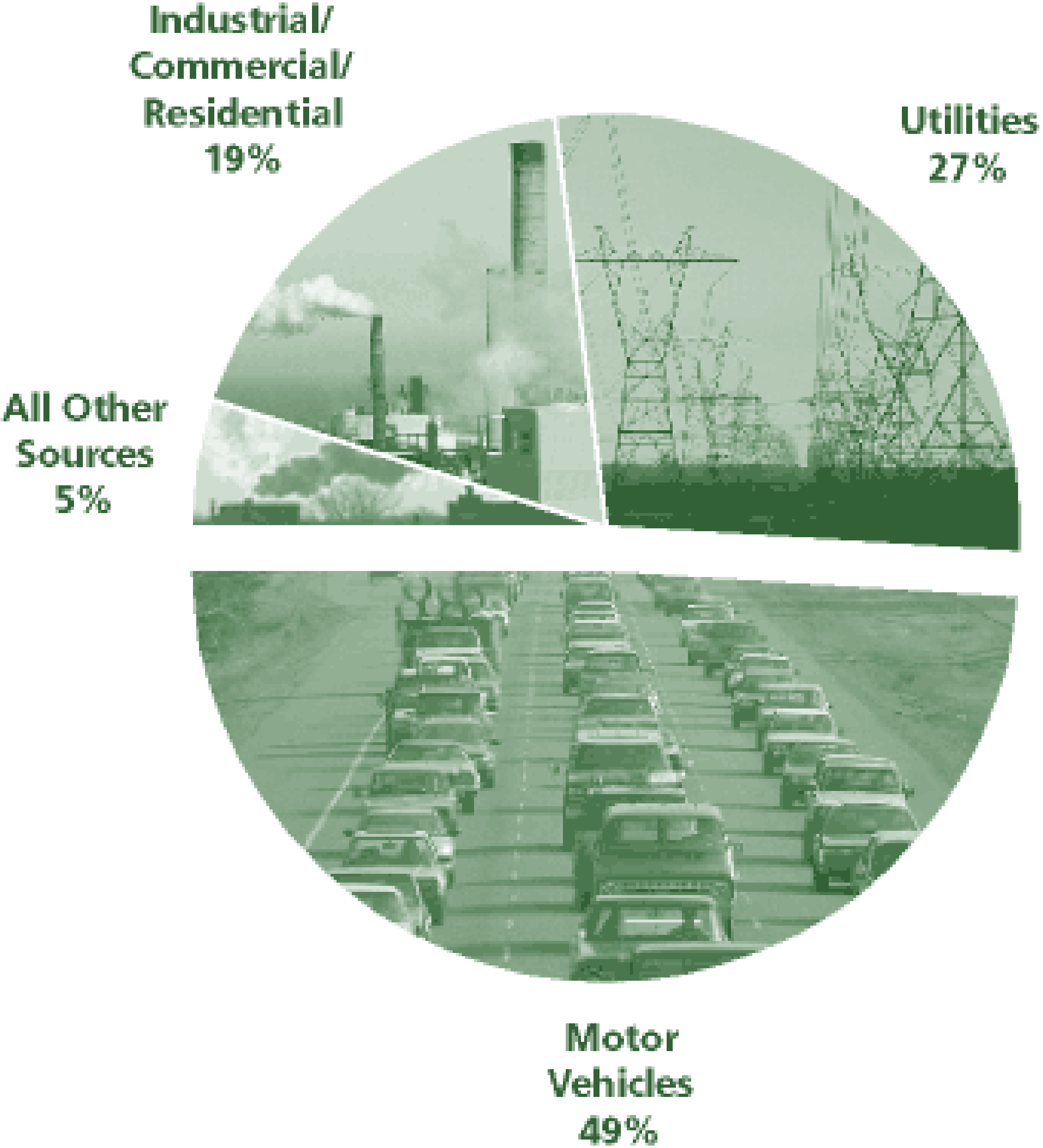
NCAR/Research Applications Laboratory

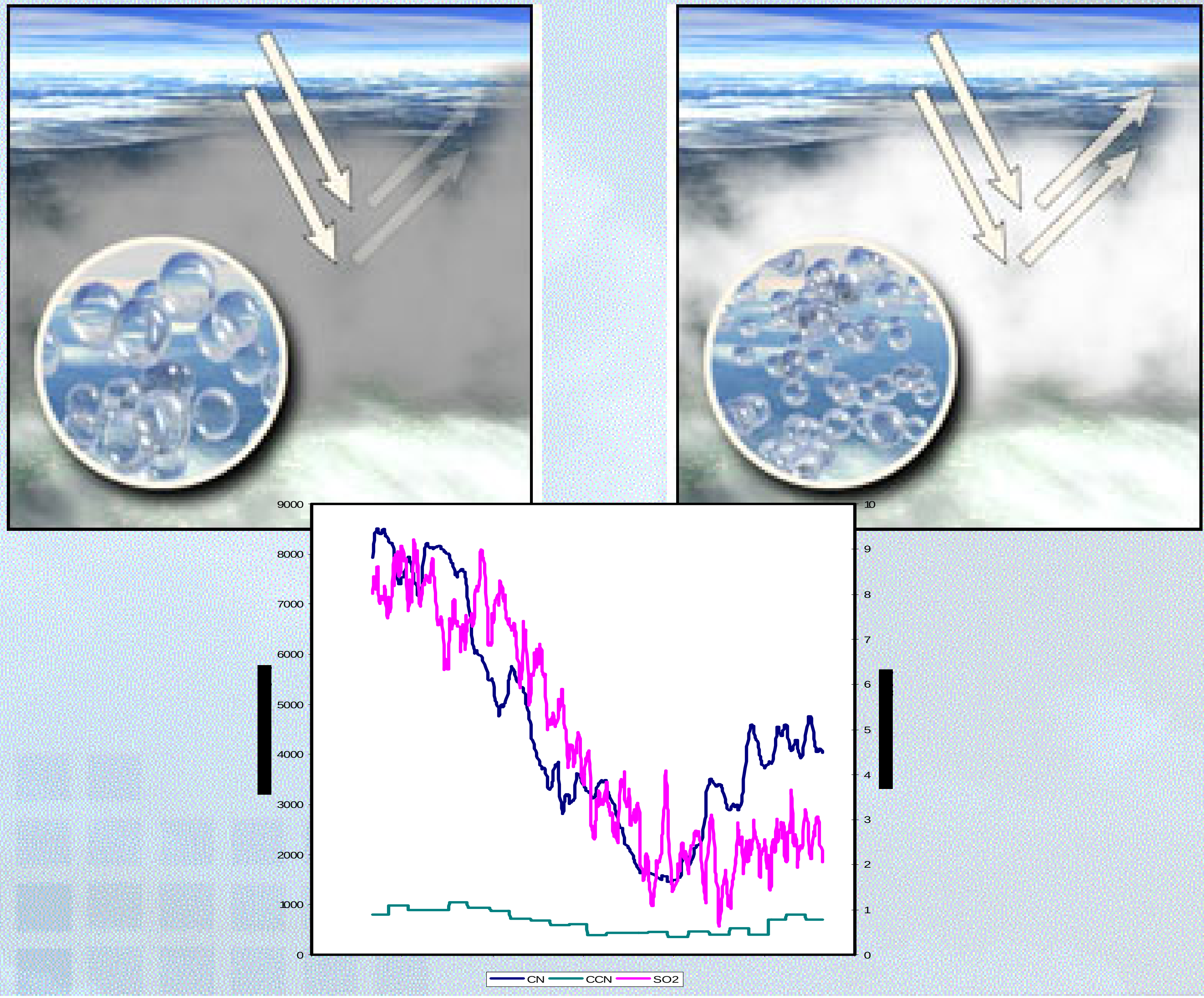
www.ral.ucar.edu

GLOBAL ATMOSPHERIC CONCERNS

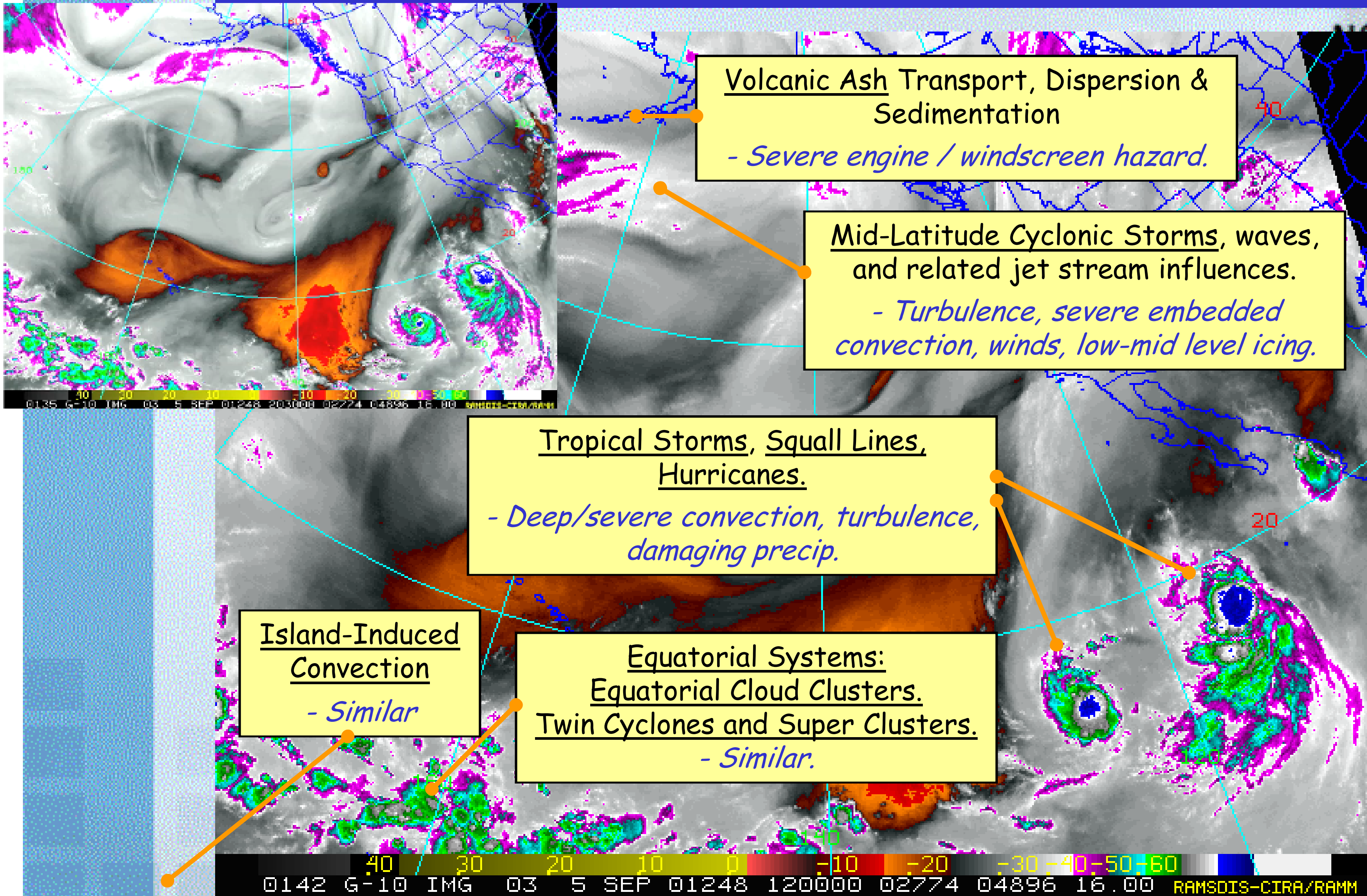



Salt from
Sea Spray &
Bursting Bubbles
Windblown
Dust
SO2 from
Volcanoes
Soot &
Smoke
Clouds &
Precipitation
Deserts &
Volcanoes
Fossil Fuels &
Biomass Burning
Oceans
NCAR


Industrial/
Commercial/
Residential
19%
Utilities
27%
All Other
Sources
5%
Motor
Vehicles
49%


9000
8000
7000
6000
5000
4000
3000
2000
1000
0
10
9
8
7
6
5
4
3
2
1
0
CN
CCN
SO2

Phenomenology – Oceanic Weather



Volcanic Ash Transport, Dispersion & Sedimentation

- Severe engine / windscreen hazard.

Mid-Latitude Cyclonic Storms, waves, and related jet stream influences.

- Turbulence, severe embedded convection, winds, low-mid level icing.

Tropical Storms, Squall Lines, Hurricanes.

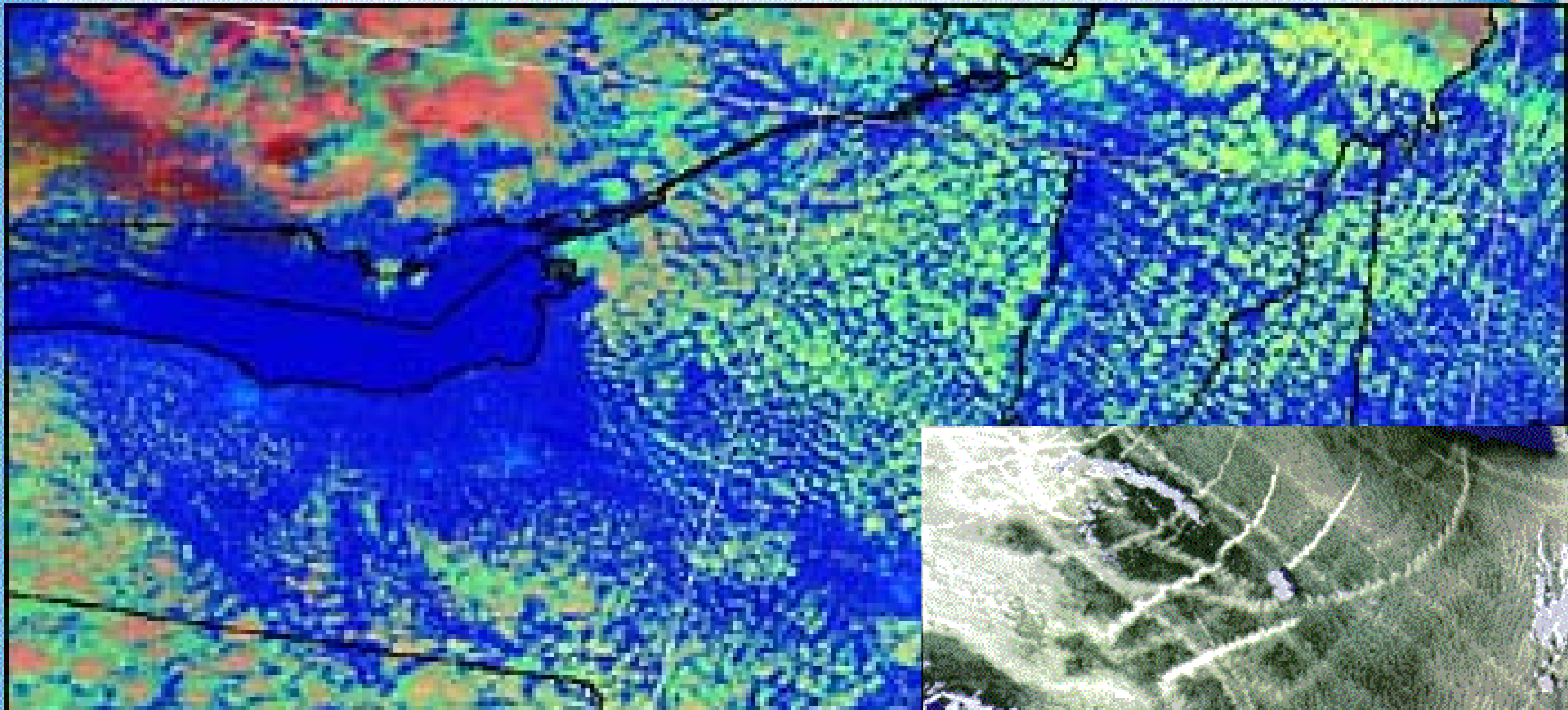
- Deep/severe convection, turbulence, damaging precip.

Island-Induced Convection

- Similar

Equatorial Systems: Equatorial Cloud Clusters. Twin Cyclones and Super Clusters.

- Similar.



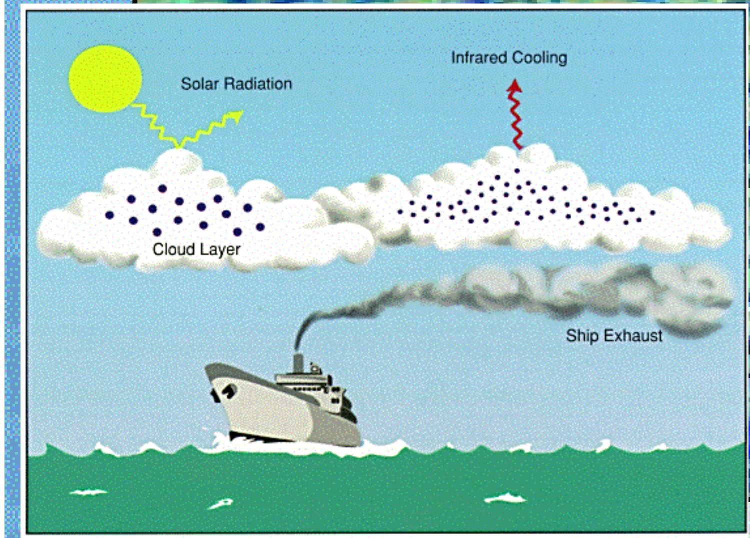


Figure 2: Illustration depicting the effects of aerosols from ship exhaust on cloud reflectivity

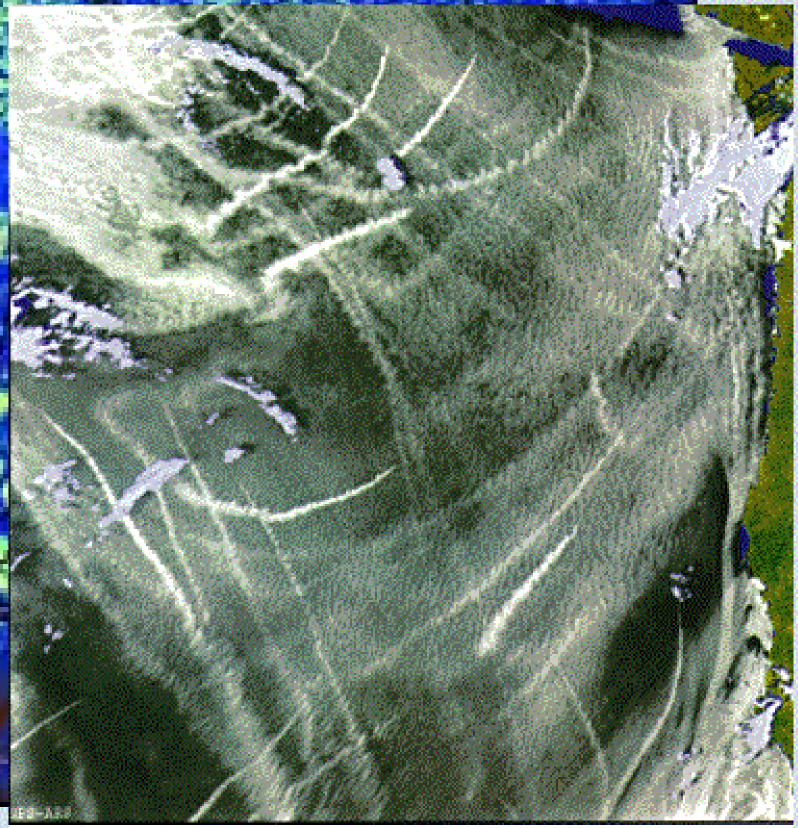
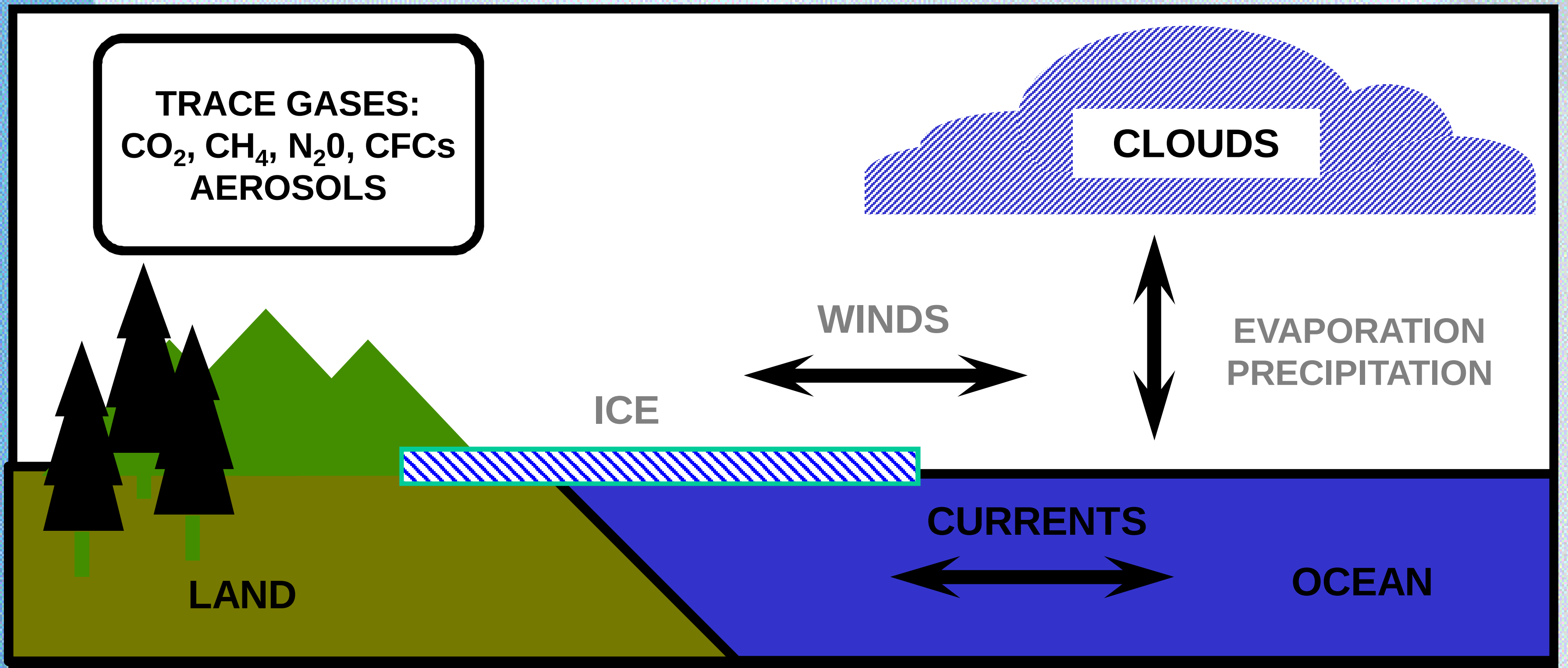


Figure 1: Ship tracks off the coast of Washington

NATURAL SCIENCE: ELEMENTS OF CLIMATE & FEEDBACKS IN MODEL PROJECTIONS

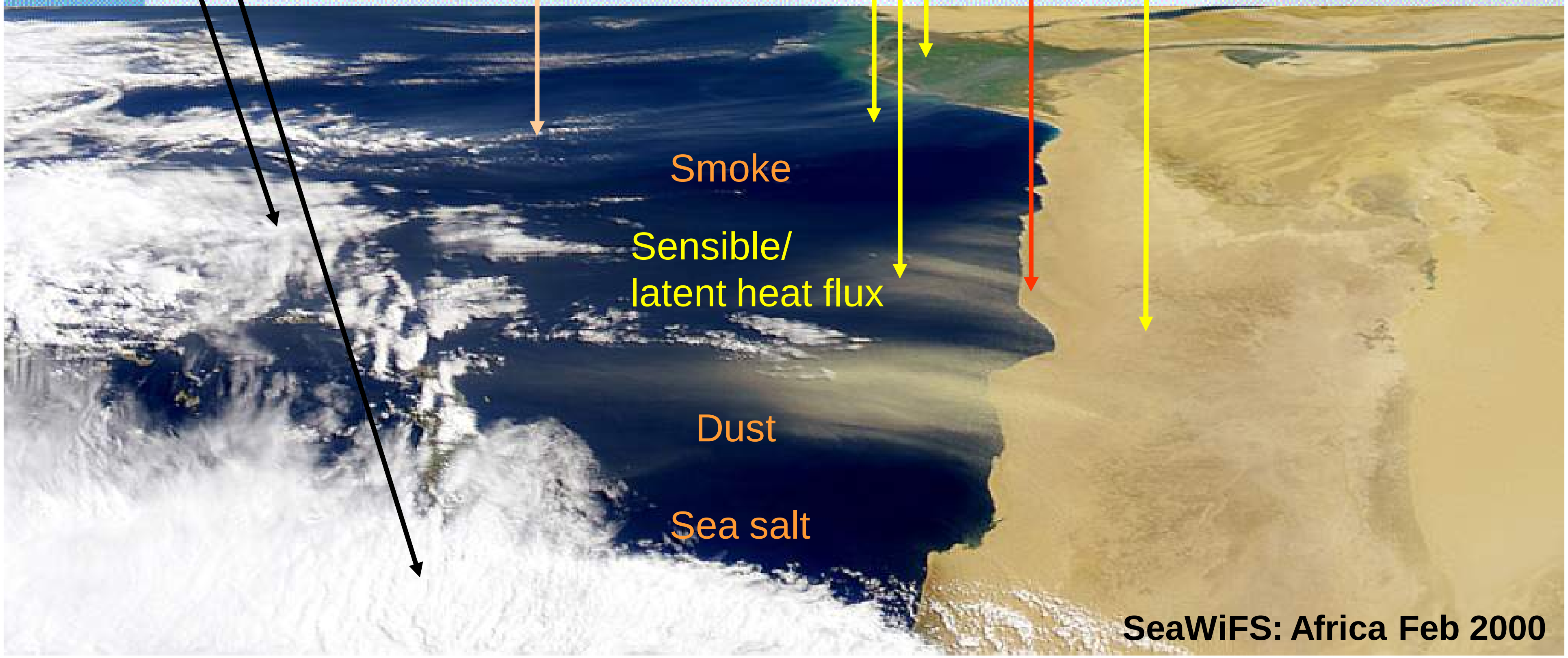


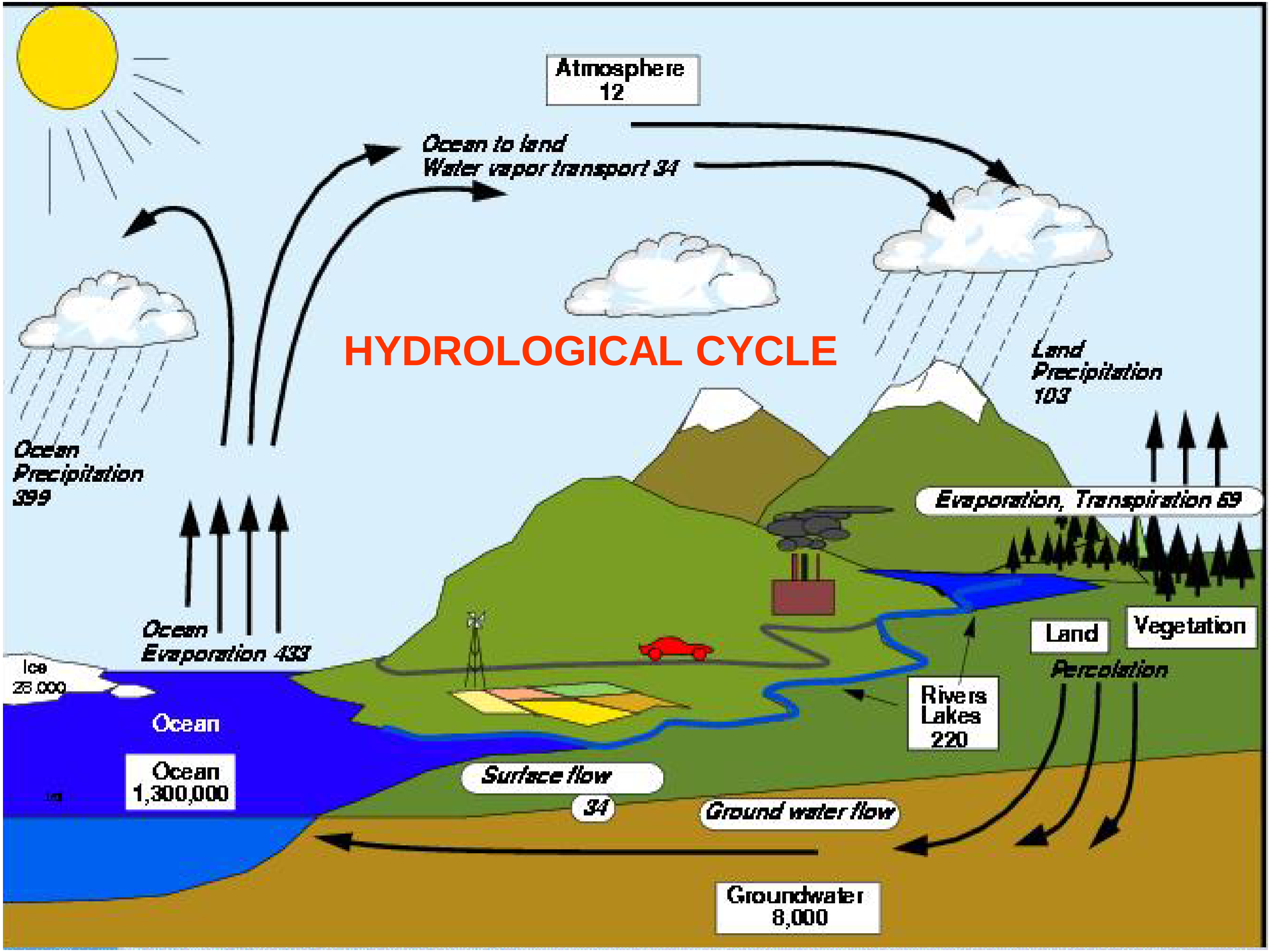
- MODEL LIMITS
  - COARSE RESOLUTION
  - MISSING SCIENCE
  - INCOMPLETE DATA

→

- **UNCERTAIN PREDICTIONS**
  - **MAGNITUDE**
  - **TIMING**
  - **REGIONAL DISTRIBUTION**

Putting pieces together: to add context and understanding to the aerosol-physical meteorology system




HYDROLOGICAL CYCLE
Atmosphere
12
Ocean to land
Water vapor transport 34
Land
Precipitation
103
Ocean
Precipitation
399
Evaporation, Transpiration 69
Ocean
Evaporation 433
Land
Vegetation
Percolation
Ice
26,000
Ocean
Ocean
1,300,000
Rivers
Lakes
220
Surface flow
34
Ground water flow
Groundwater
8,000

NCAR

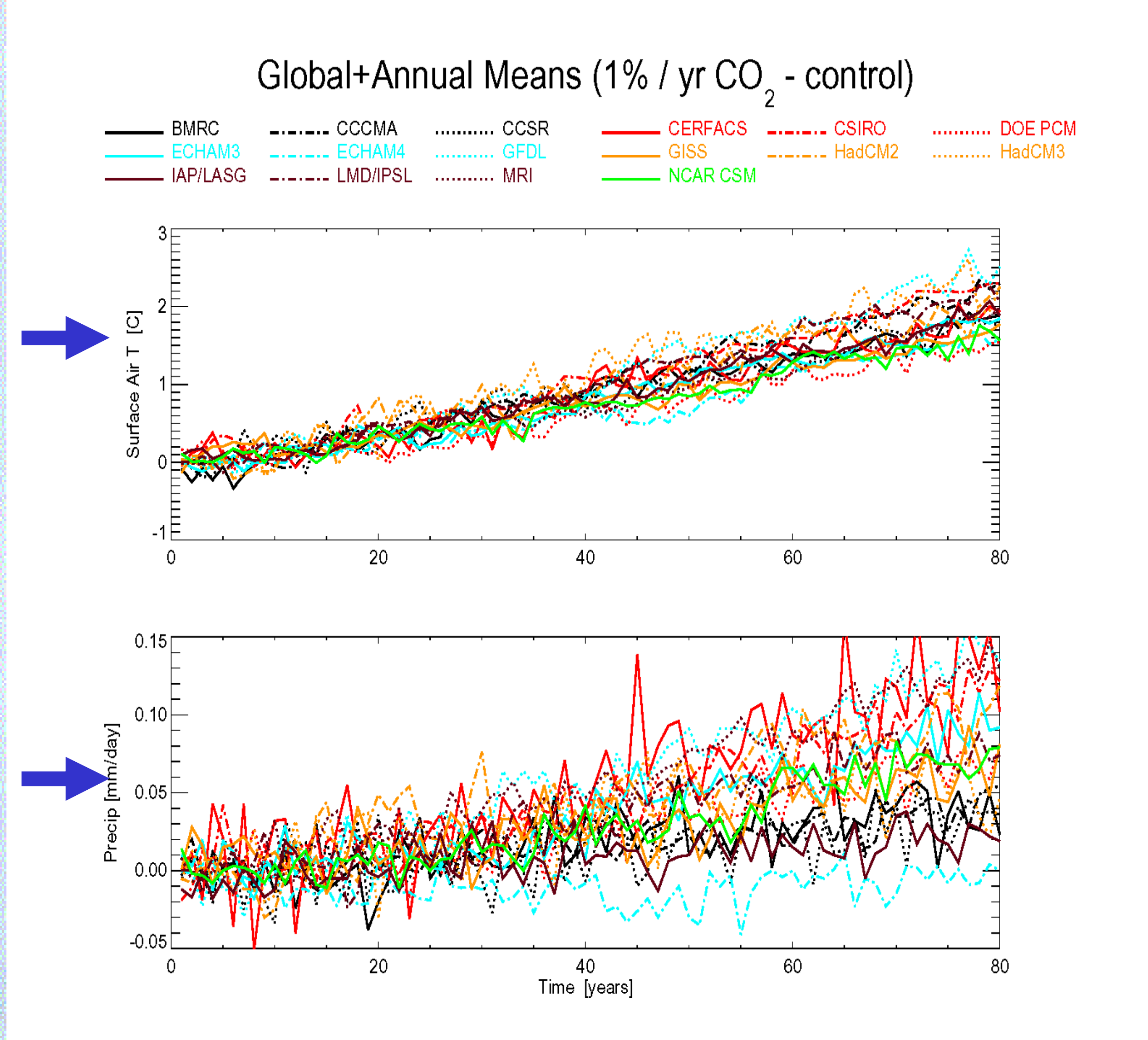
How does rainfall change as climate changes?

The Climate Problem

80 yr. Temp. Rise

CMIP

80 yr. Precipitation Trend ?

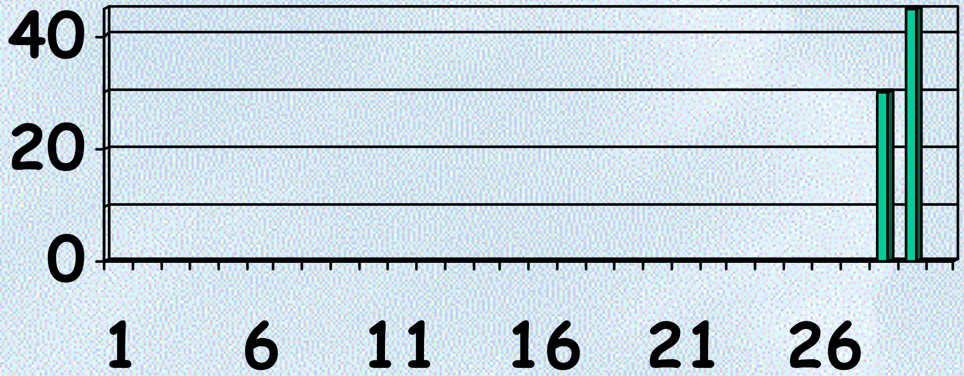


Covey et al. 2003

Daily Precipitation at 2 stations

NCAR

A



drought
wilting plants

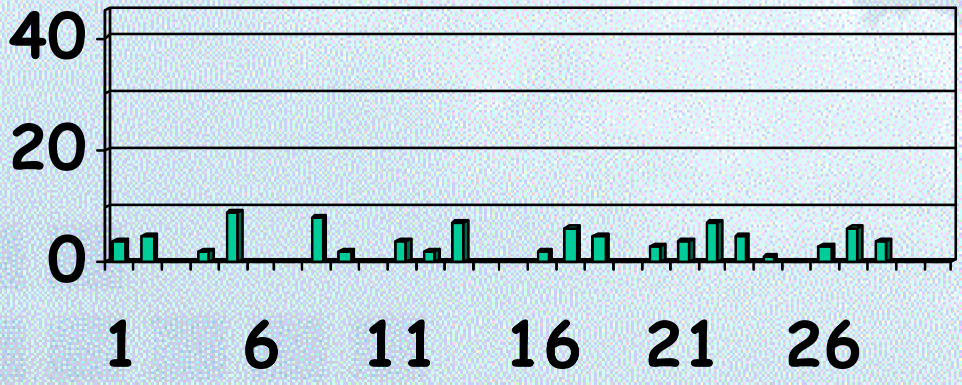
wild fires

local
floods

Monthly
Amount 75 mm

Frequency 6.7%
Intensity 37.5 mm

B



soil moisture replenished
virtually no runoff

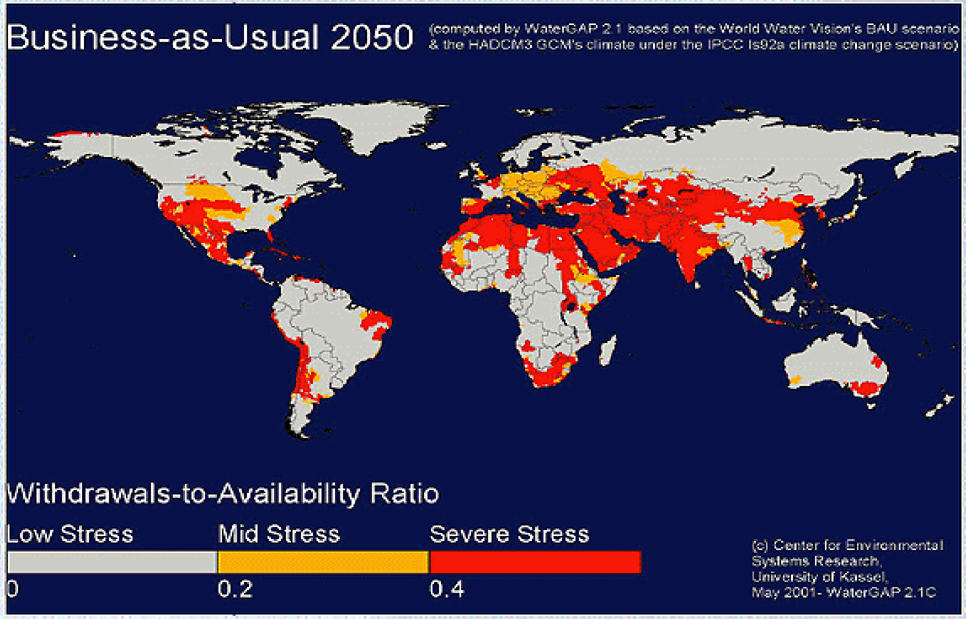
Amount 75 mm

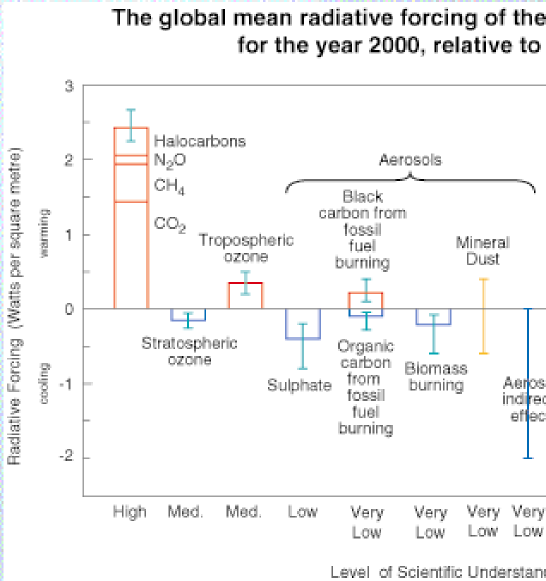
Frequency 67%
Intensity 3.75 mm

Motivation

- Worldwide water resource stresses
- Severe weather hazards
- New observational, computational, statistical technologies
- Increasing environmental and air quality processes
- Population and demographic changes
- Inadvertent weather modification

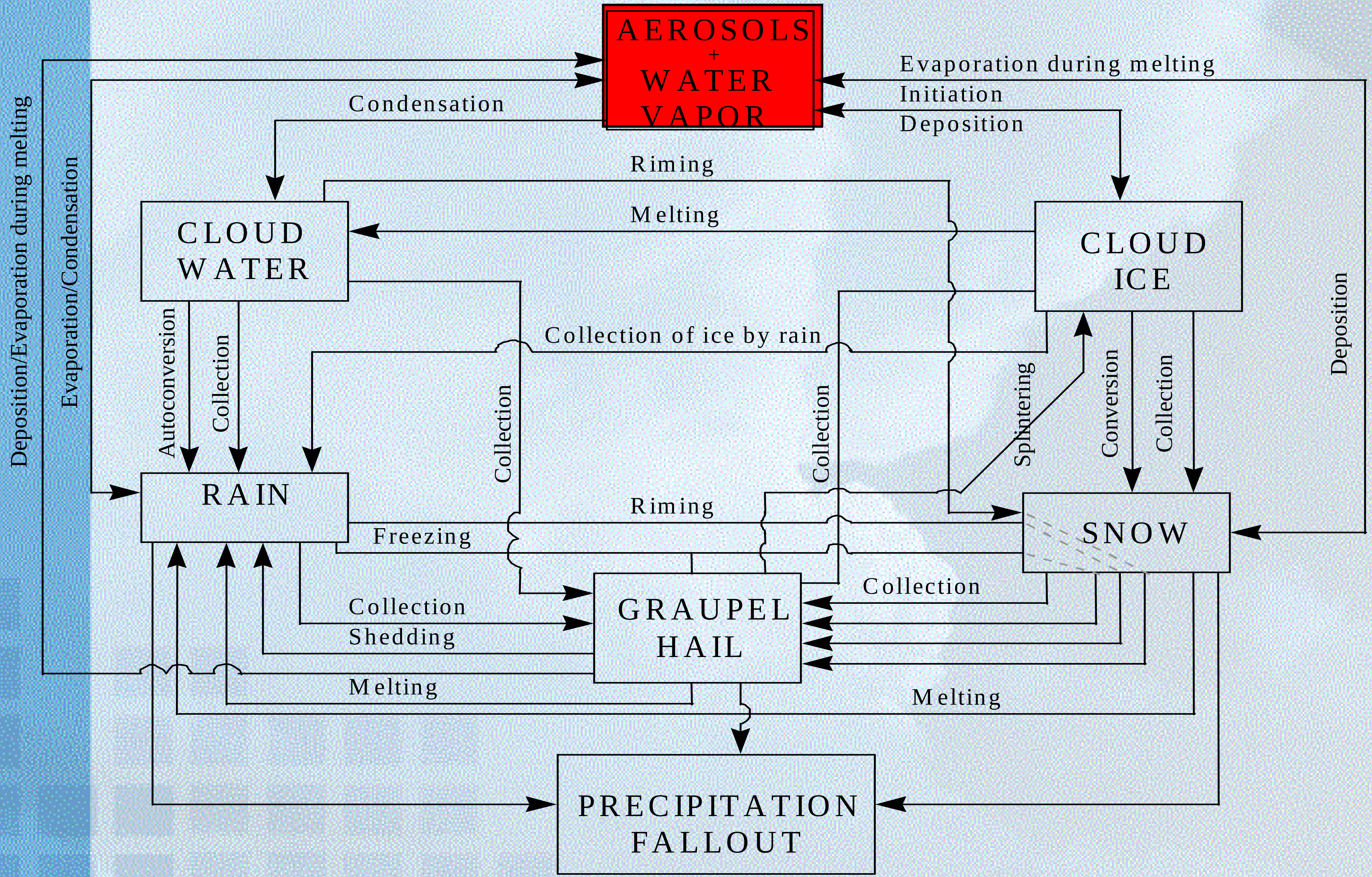
  → similar physical processes as active weather modification



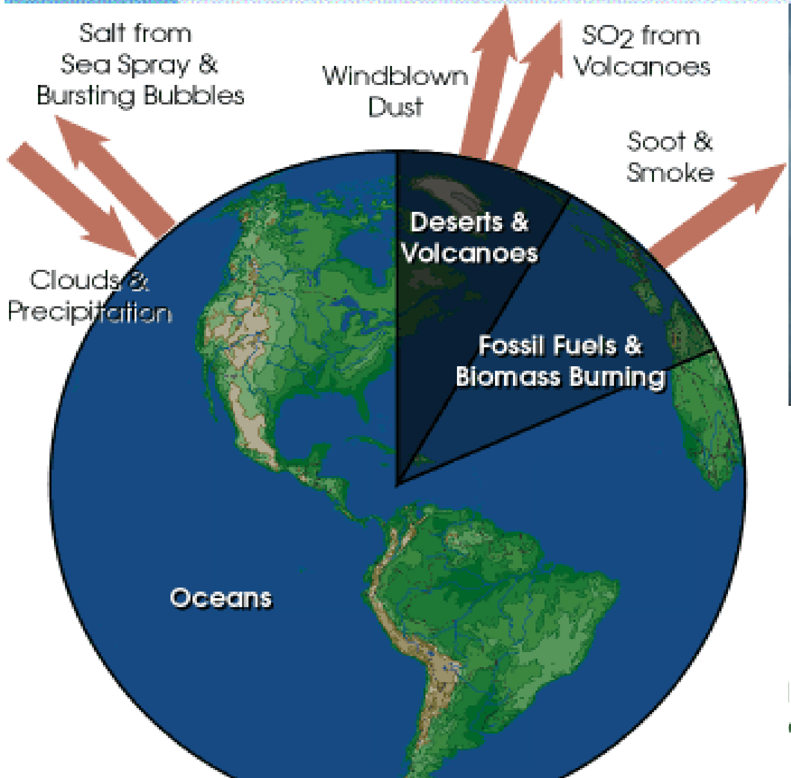


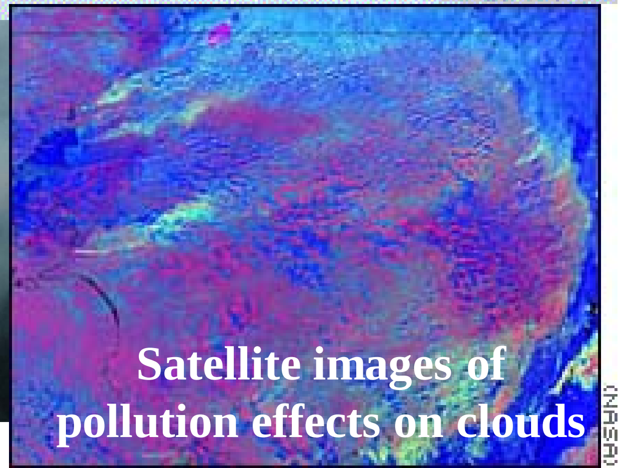
"estimates of indirect forcing that include feedback to the liquid-water path and cloud amount from changes in cloud microphysics and precipitation efficiency range from $-1.1 Wm^{-2}$ to $-4.8 Wm^{-2}$"

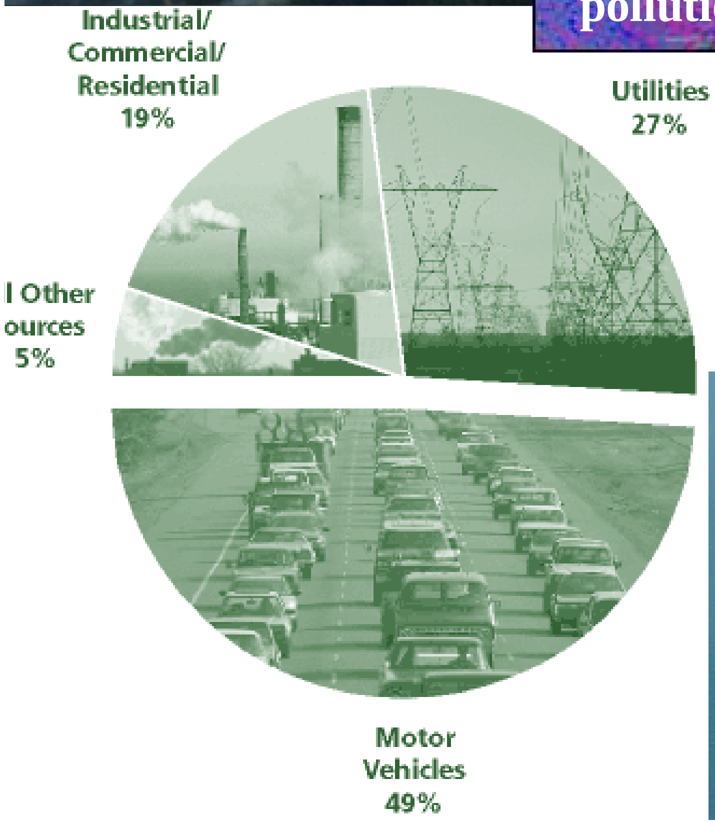
Microphysical processes in precipitation development



Inadvertent weather modification



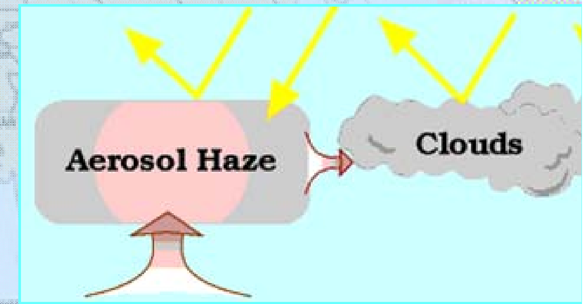




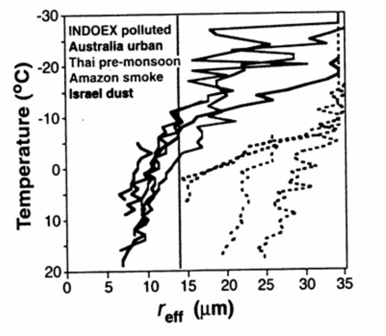
The aerosol/precip connection

NCAR

- Aerosol environment has changed
  - CCN/sulfates are about 70% anthropogenic with strong variation in emissions geographically
  - Desert dust concentrations vary widely; appear to be important IN
- Clear anthropogenic effects **(e.g., satellite evidence)**
- Well known climate connections
  - Direct (reflect incoming solar radiation back to space)
  - Indirect (modify properties and lifetime of clouds)
- Linkage to precip understood in principle, but hard evidence is scanty and scattered; we lack quantitative/predictive skill



Rosenfeld et al., 2000



Key Uncertainties (Possible solutions)

NCAR

Cloud and precipitation microphysics issues

- Background concentration, sizes, and chemical composition of aerosols participating in cloud processes (in-situ and satellite measurements, models)

Cloud dynamics issues

- Cloud-to-cloud and mesoscale interactions relating to updraft and downdraft structures and cloud evolution and lifetimes (Multi-parameter radar, models)

Cloud modeling issues

- Combination of best cloud models with advanced observing systems in carefully designed field tests and experiments (data assimilation, development of two-way interactive aerosol and microphysical parameterizations, land-surface interactions, upgraded and new parameterizations)

Main Point:

NCAR

Aerosols Have Changed:

- CCN: sulfate is about 70% anthropogenic, with emissions that have varied with location (e.g., peaking for the US about 1970 but increasing concentrations in some other parts of the world)
- Desert dust concentrations fluctuate over a wide range and possibly show increases. These have good ice nucleating ability, and are likely candidates for the ice nuclei that are of importance to precipitation formation.

Preliminary indications are that this could have changed precipitation processes in significant ways depending on the background pollution and aerosols in a specific region. These results apply both to inadvertent and advertent weather modification.

Important Point:

NCAR

Conditions may have changed in significant ways during the last century. Climate change especially through the aerosol component could have changed the feedback mechanism of clouds and climate

There is a need for development of reliable benchmark studies in cloud and precipitation processes that rely upon physical studies.

Potential differences between start and end of the rainy season because of washout of aerosols by rain providing for cleaner conditions towards the end

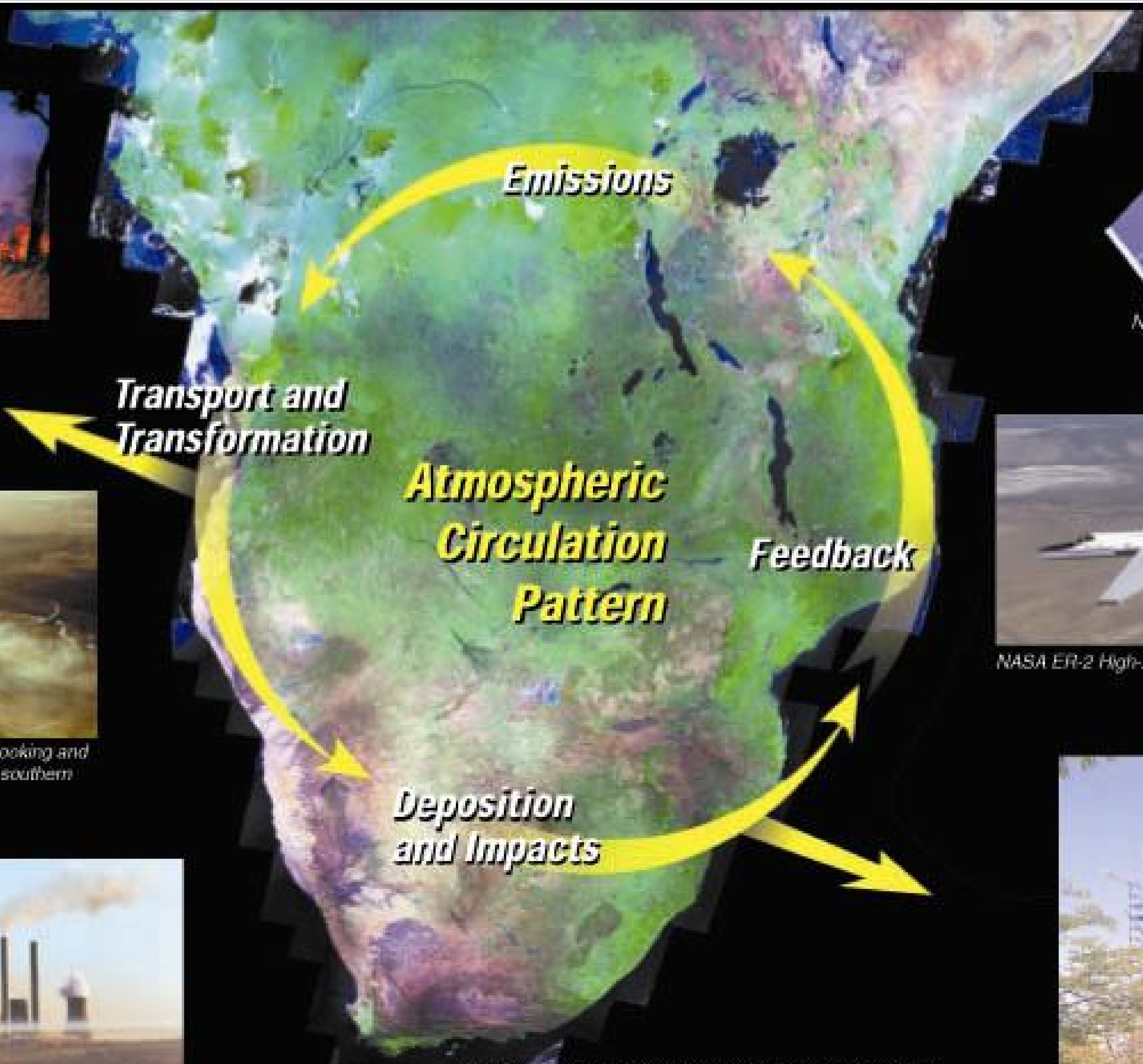
During dry periods aerosol concentrations may increase and decrease effectiveness of natural clouds to produce precipitation.

Southern African Regional Science Initiative—SAFARI 2000

Brush fire in miombo woodlands.

Smoke from coal fires for domestic cooking and heating blankets a small township in southern Africa.

Industrial emissions from a power plant in South Africa.



Landsat-5 Thematic Mapper composite image of southern Africa. Vegetation appears in green, bare soil is reddish-purple, and urban features are purple and white. Water bodies (shown in black) contrast sharply with the colorful land features. (Image courtesy of the Earth Satellite Corporation, Rockville, MD, www.earthsat.com)

NASA EOS Terra Satellite.

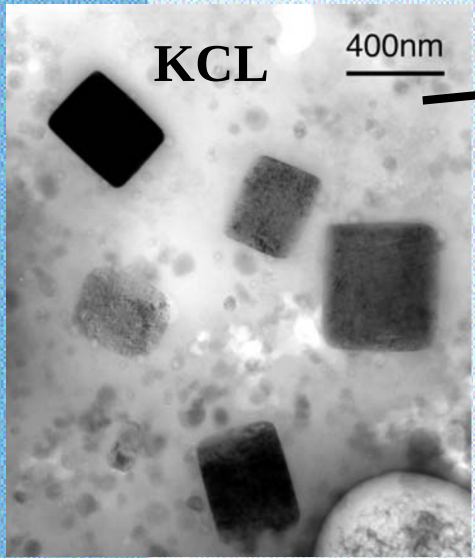
NASA ER-2 High-Altitude Research Aircraft.

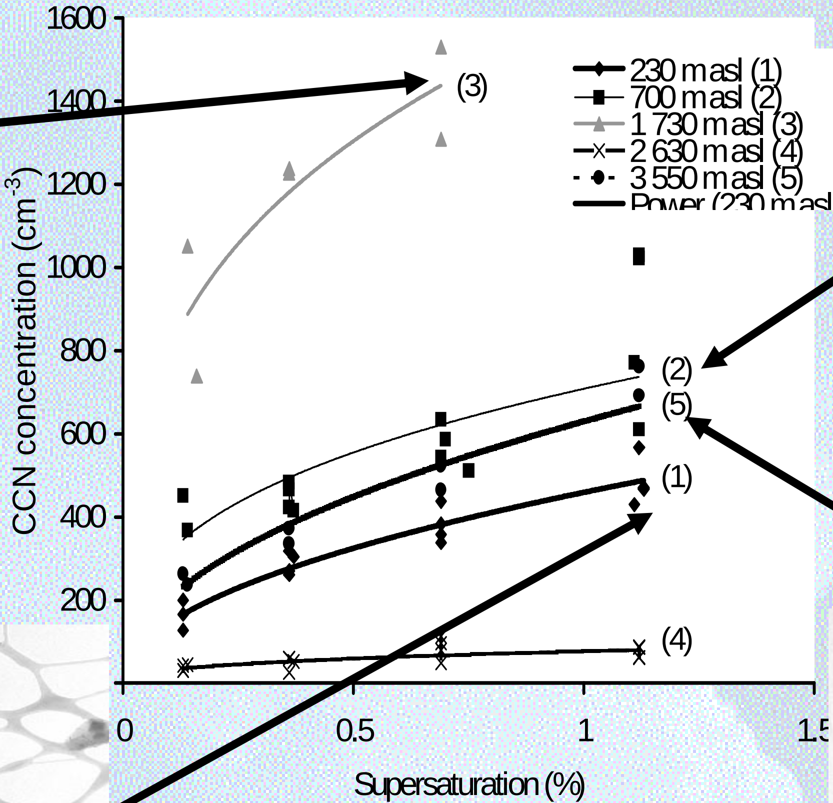
Typical instrument tower used for data collection.

CCN SUPERSATURATION SPECTRA AND ASSOCIATED PARTICLE TYPES FROM TEM/SEM IMAGES FROM BIOMASS SMOKE IN SOUTHERN AFRICA

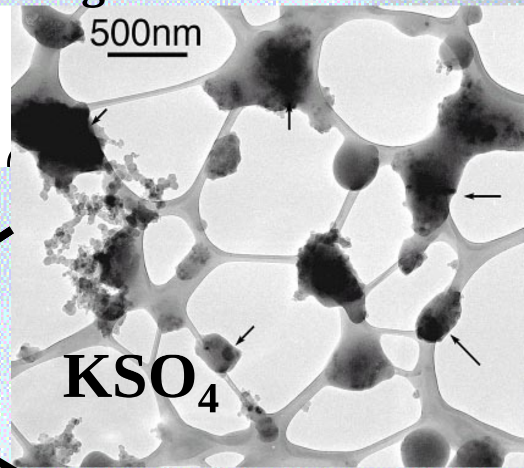
NCAR

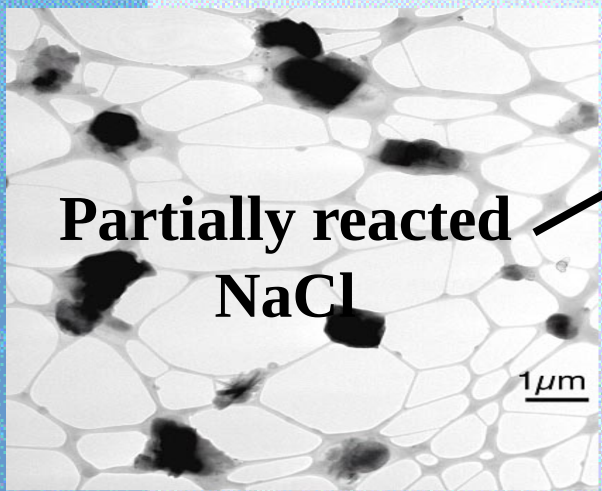
Fresh smoke





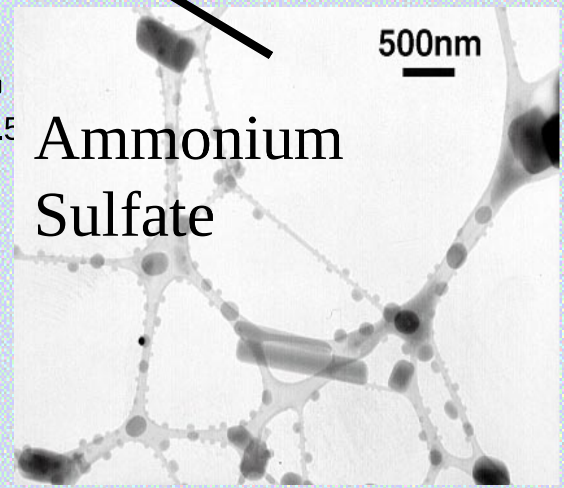
Aged Biomass smoke





Marine/Haze

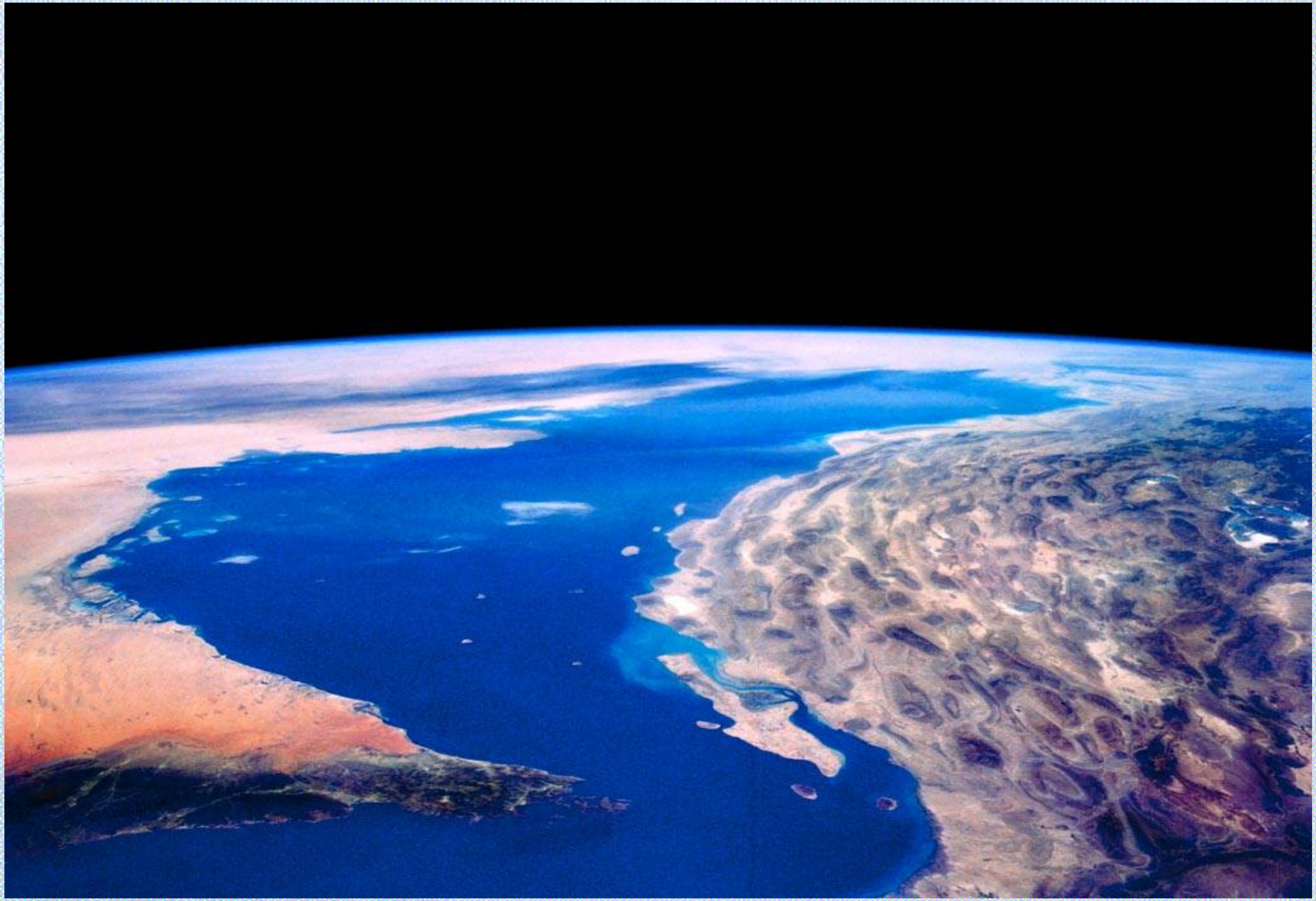
CCN spectra at different altitudes in different layers of aerosols continuously changing composition, concentration, and size at the same location and time

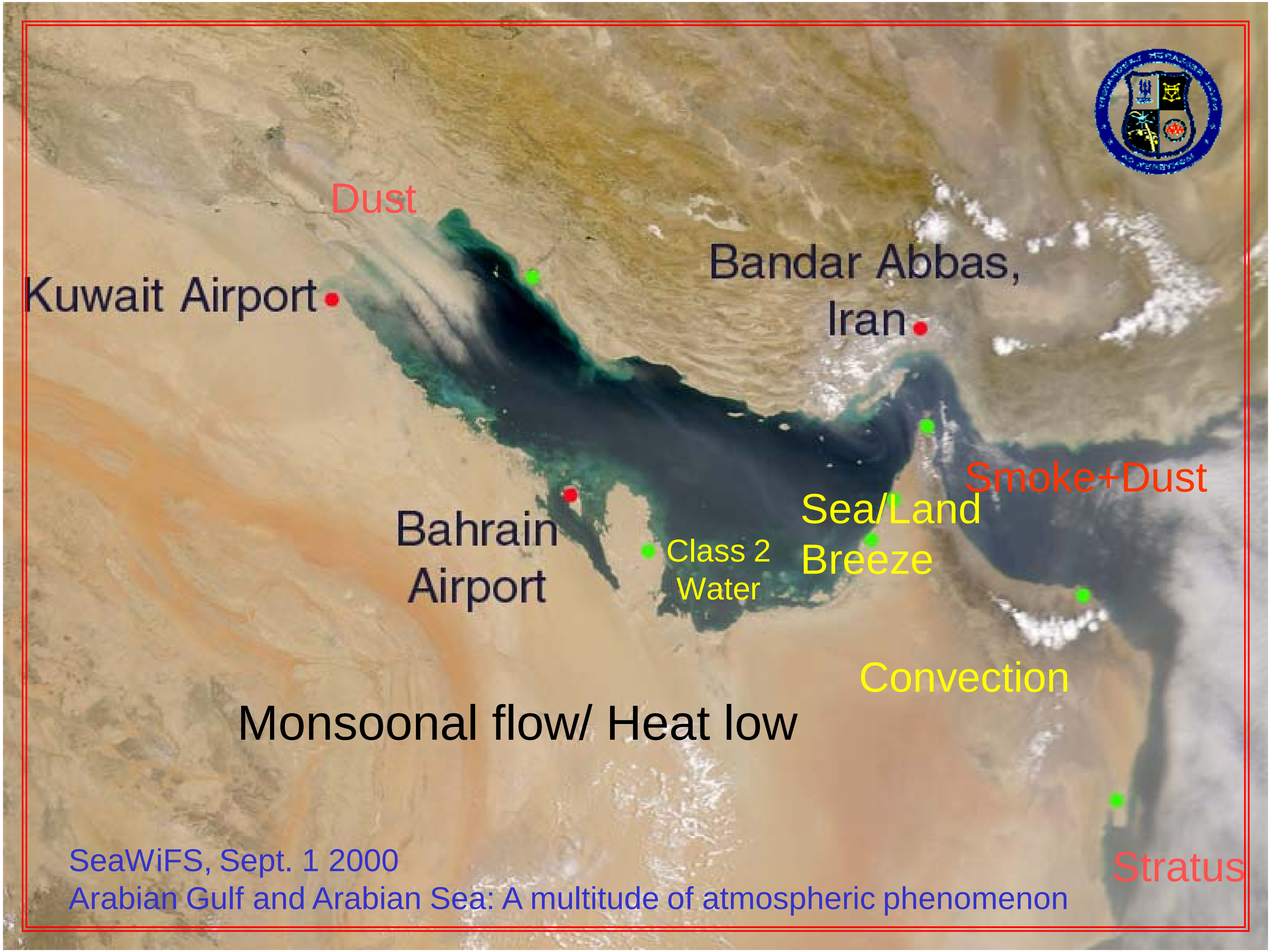


Regional Haze

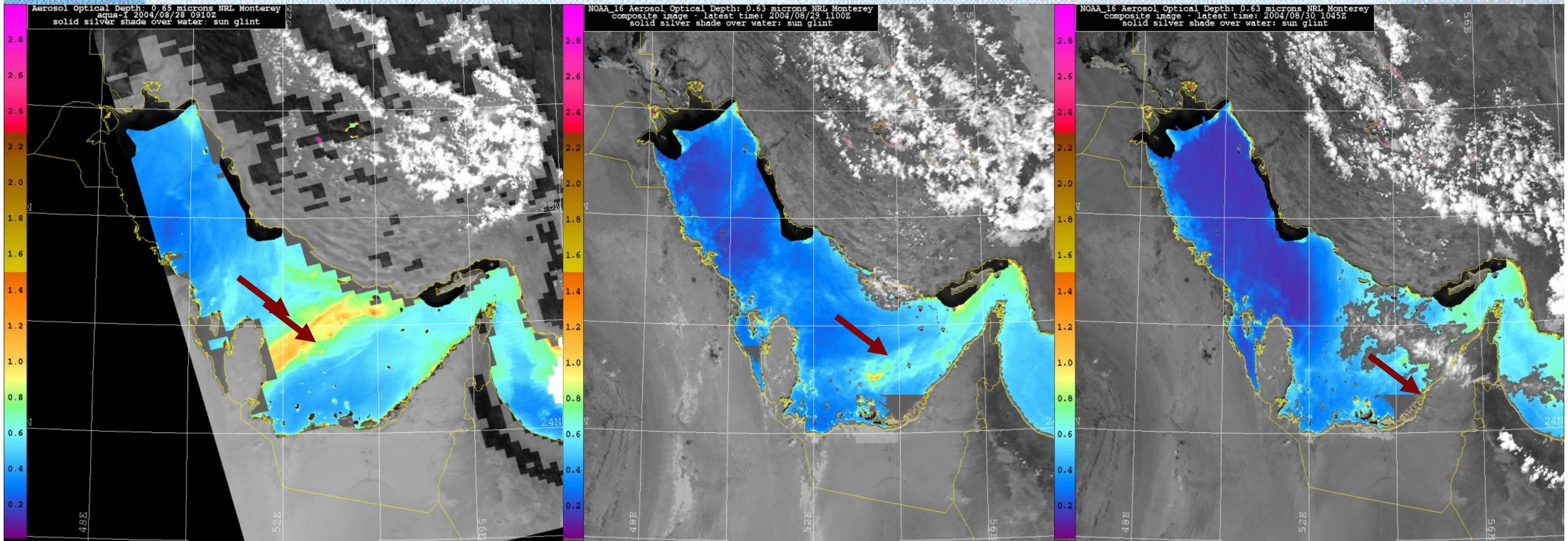
The Unified Aerosol Experiment-United Arab Emirates:UAE^2

A Study of Arabian Gulf Aerosol Microphysics, Radiation, and Transport Phenomenology




Dust
Kuwait Airport
Bandar Abbas,
Iran
Smoke+Dust
Sea/Land
Breeze
Bahrain
Airport
Class 2
Water
Convection
Monsoonal flow/ Heat low
Stratus
SeaWiFS, Sept. 1 2000
Arabian Gulf and Arabian Sea: A multitude of atmospheric phenomenon

Satellite tracking of dust and pollution: Aug 30th Dust and Pollution from Saudi Arabia and Iran

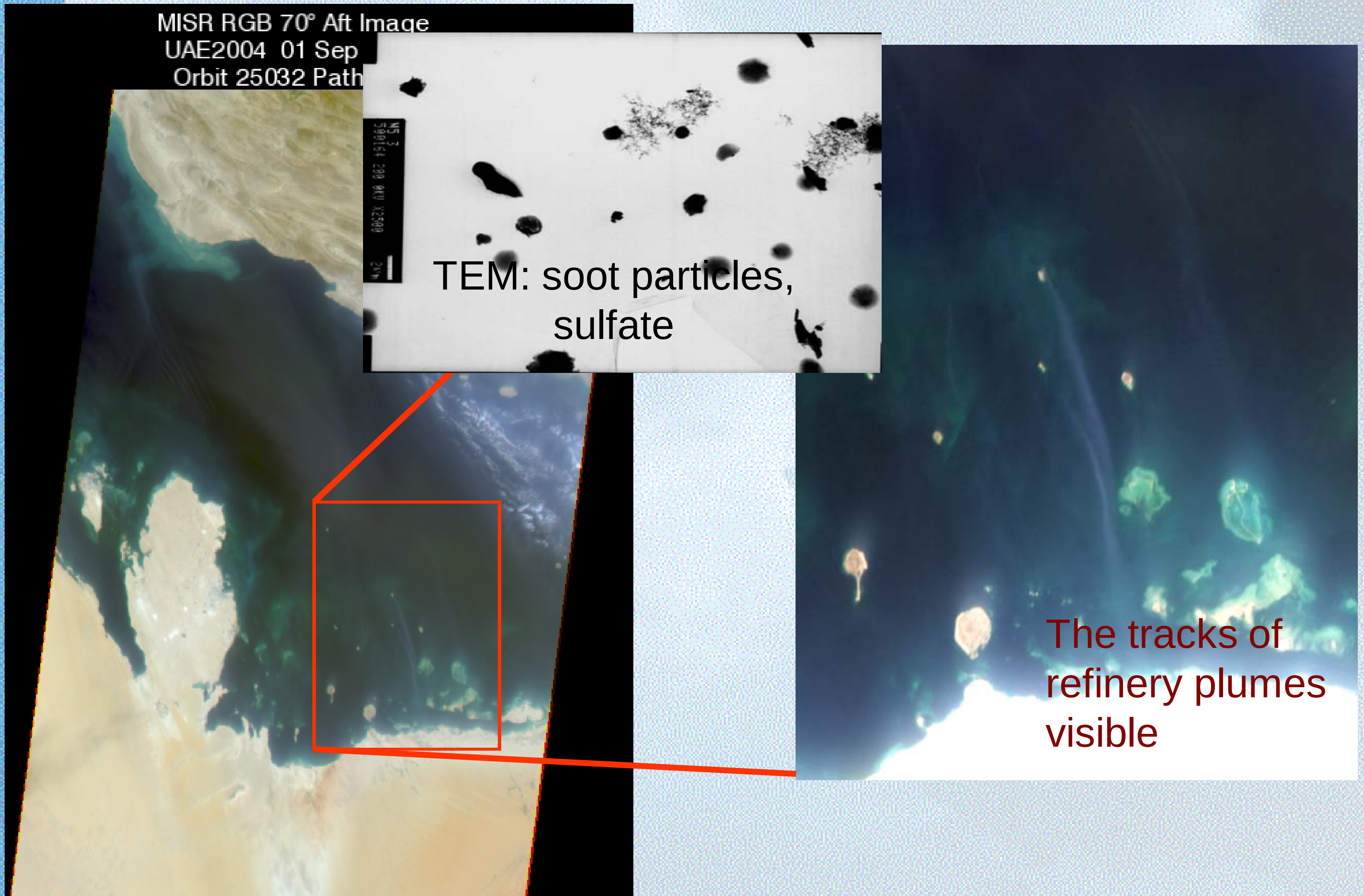


Aug. 28: Stagnant air in the central Gulf builds up pollution levels

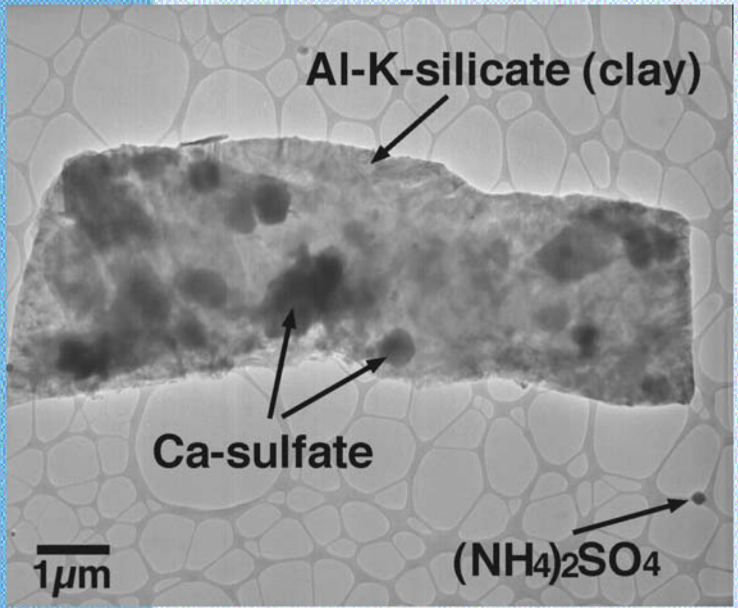
Aug. 29: Air moves south towards UAE

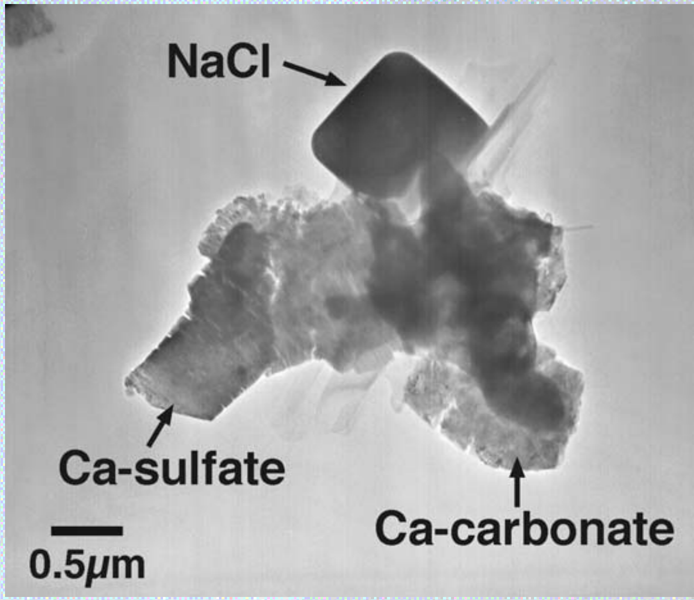
Aug. 30: Humid air mass creates severe air quality episode in UAE

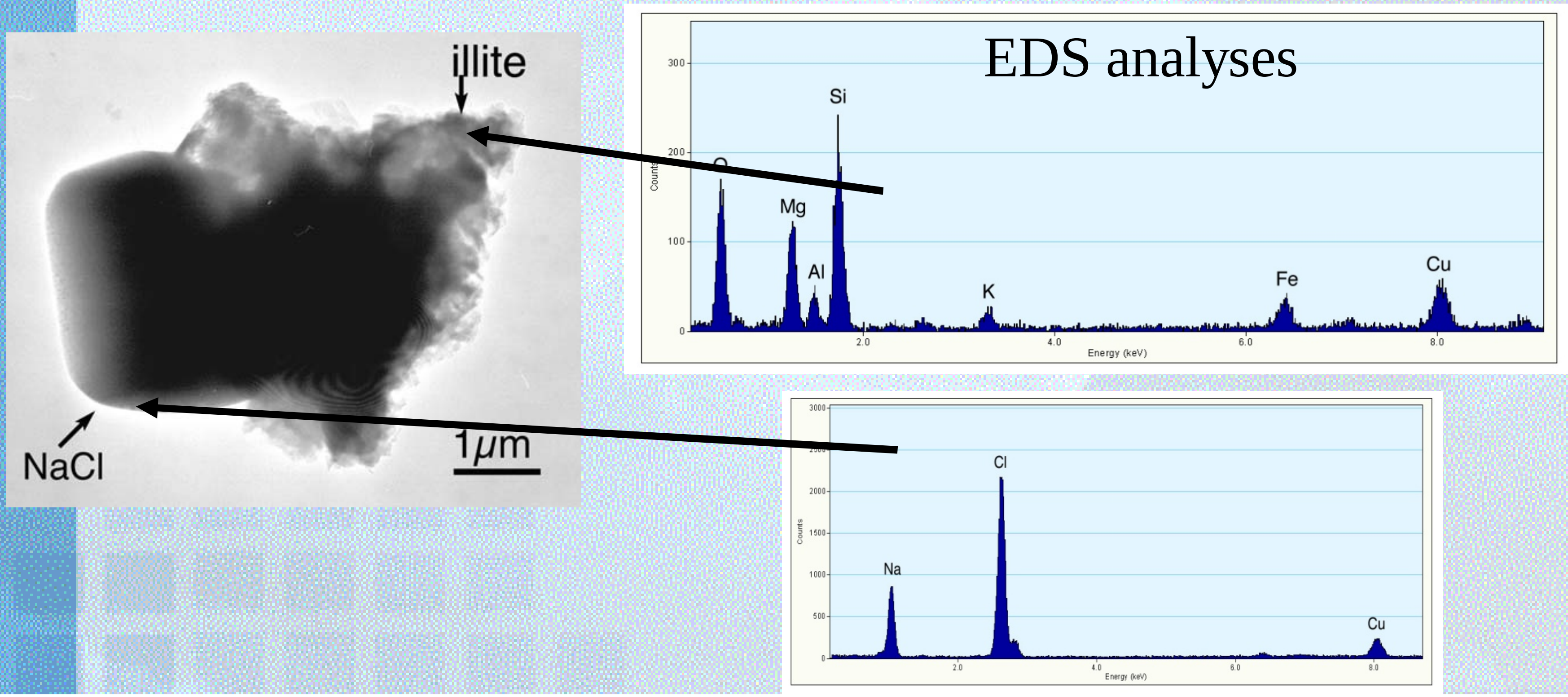
MISR/MODIS Plume Research
Implications for Winds/Trajectory Modeling



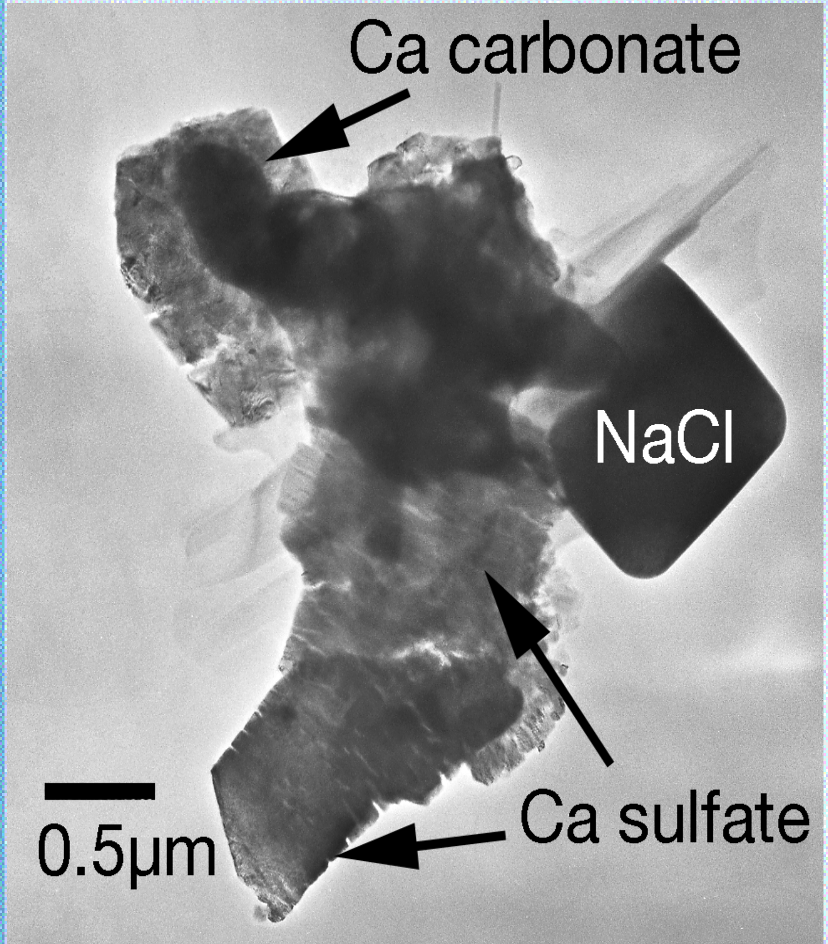
TEM Aerosol Images from UAE



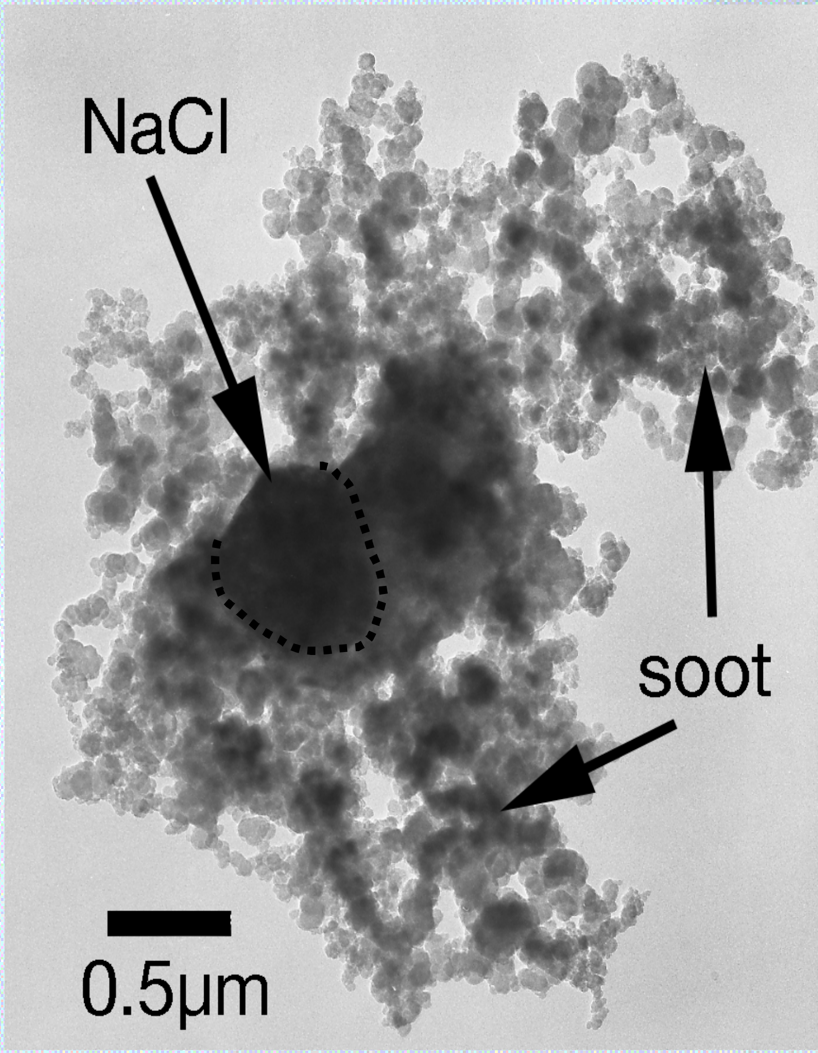




Aggregation of NaCl particles
UAE



Habshan: 150m alt.



Zirku island: 120m alt.

- Also common: NaCl + $(NH_4)_2SO_4$

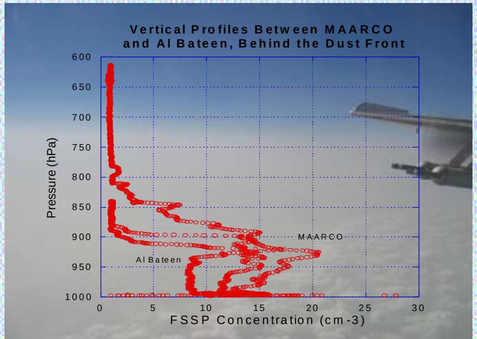
Real time Aerosol and Environmental Monitoring in the United Arab Emirates

Joint Dept of Water Resource Studies, NCAR, NASA, and NRL Development

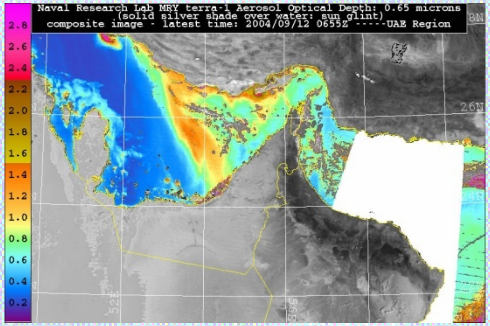
NCAR

An Example: September 12th, 2004

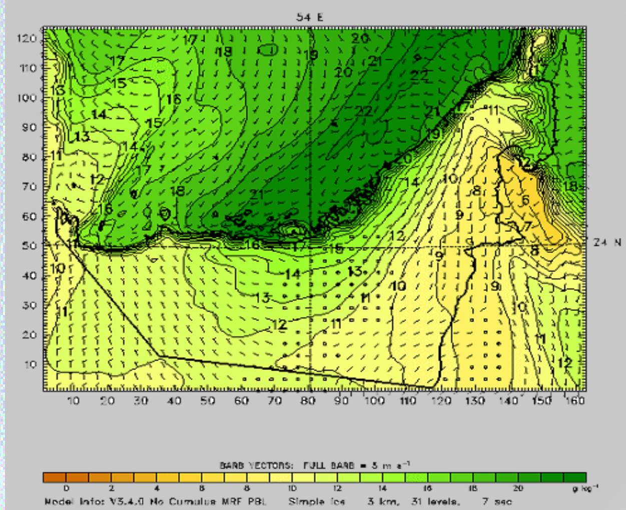
Sept. 12, 2004, had one of the best organized dust storms of 2004. This coincided with the UAE2 campaign



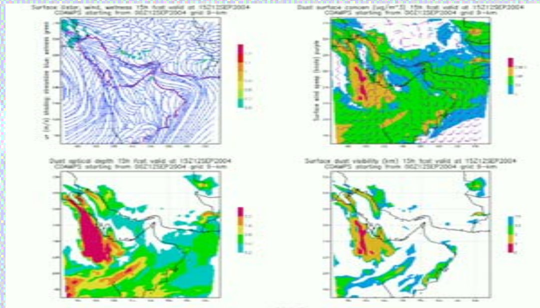
Dust Concentration ($\mu g\ m^{-3}$)



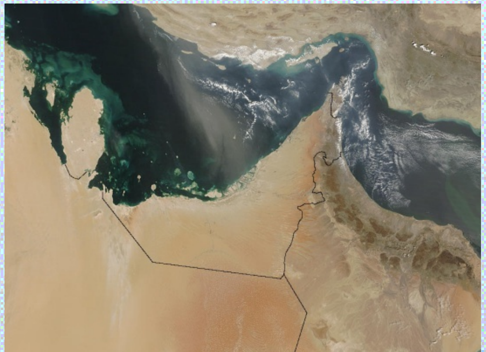
Step 2. From the 52 MODIS channels, atmospheric properties can be determined (e.g. aerosols/dust in air).



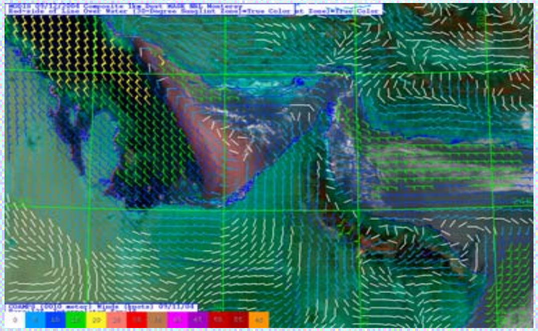
Step 4. Based on monitoring such events, improved weather models are developed and improved.



Step 1. MODIS images are taken twice a day over the world.



Step 3. Derived information from satellites are then fused with weather models

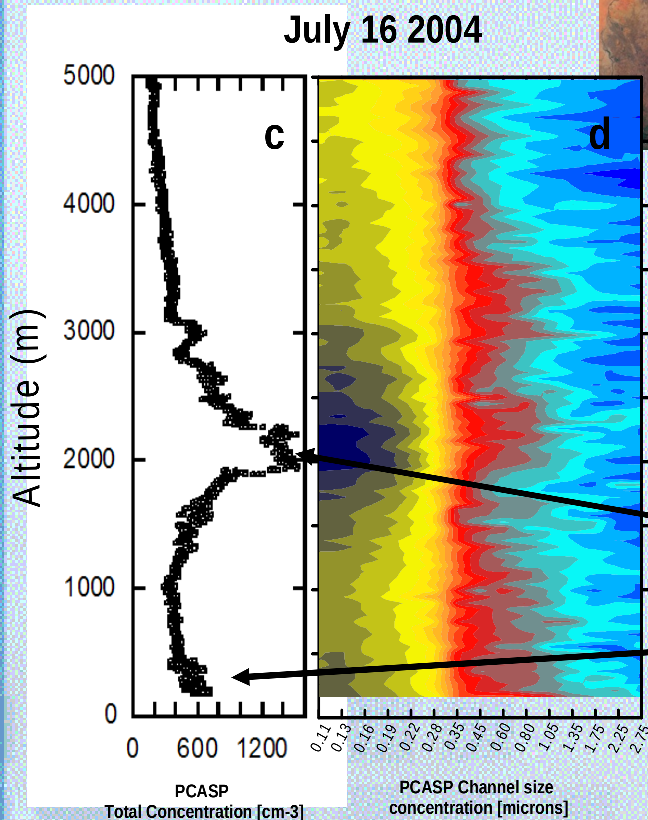


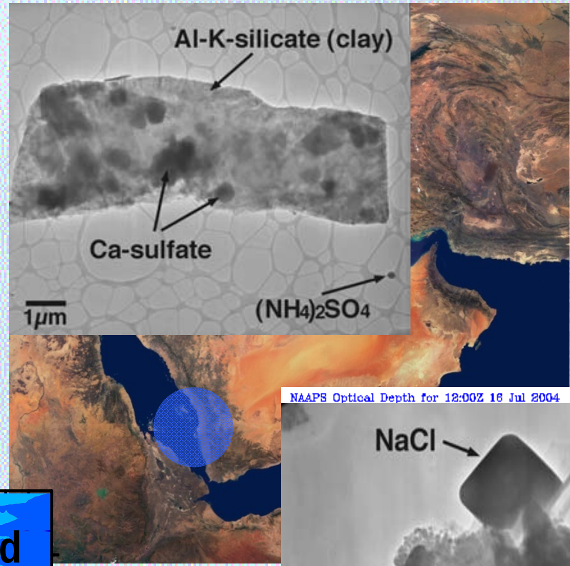
Eventually, satellite data and observations will be assimilated directly into the models to provide an up to the minute assessment of aerosol and environmental conditions

Aerosols and Composition (Saudi Arabia): In-situ measurements, satellites and models

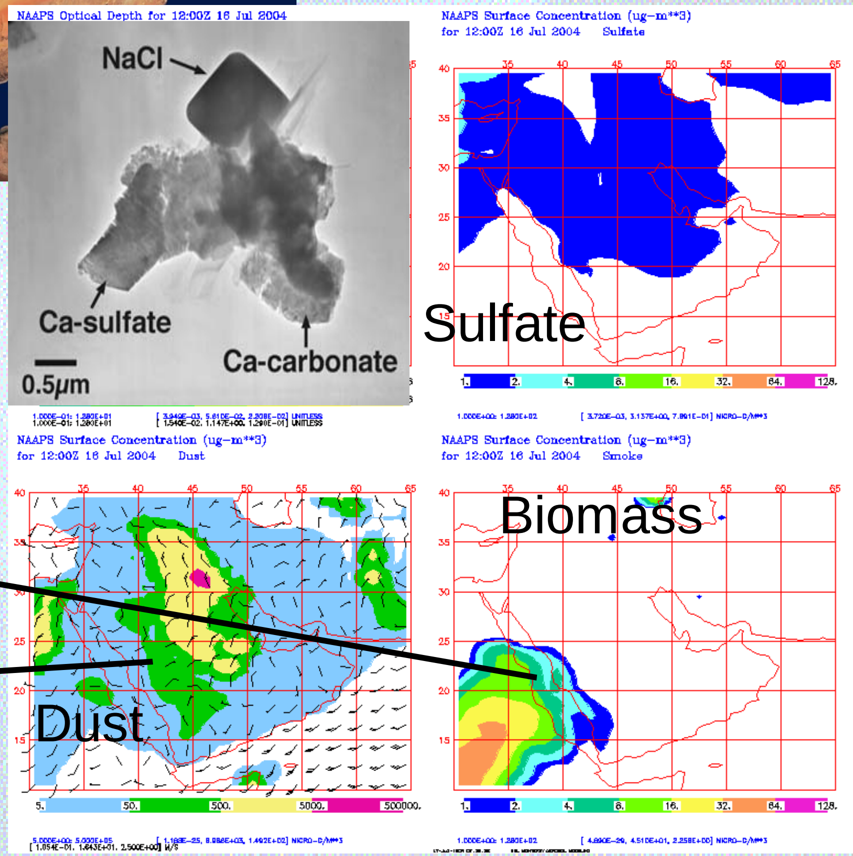
NCAR

Vertical measured size distribution of aerosols between .1 and 3 μm diameter

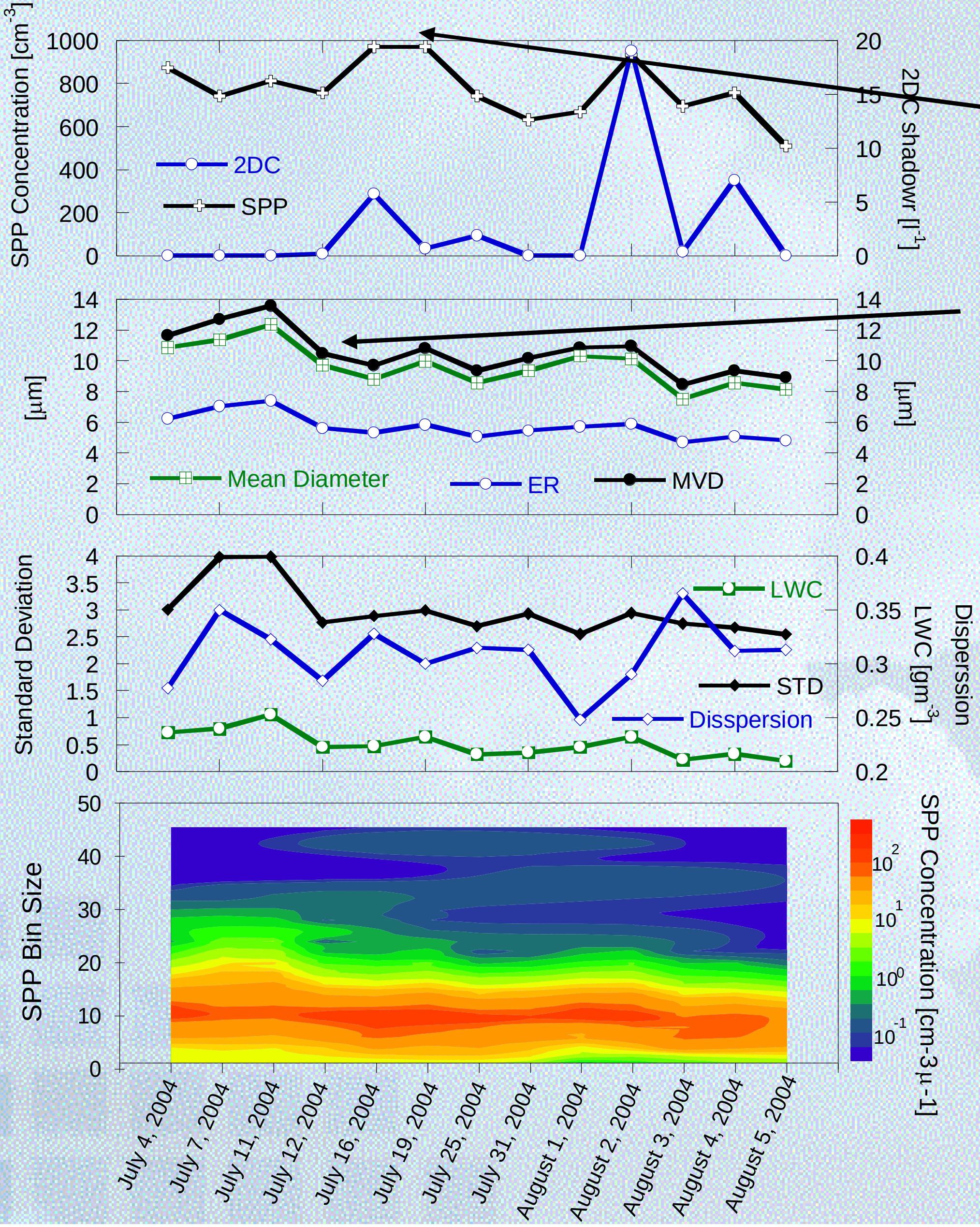




NAAPS (model and satellite) optical depth Sulfate, dust and biomass aerosols



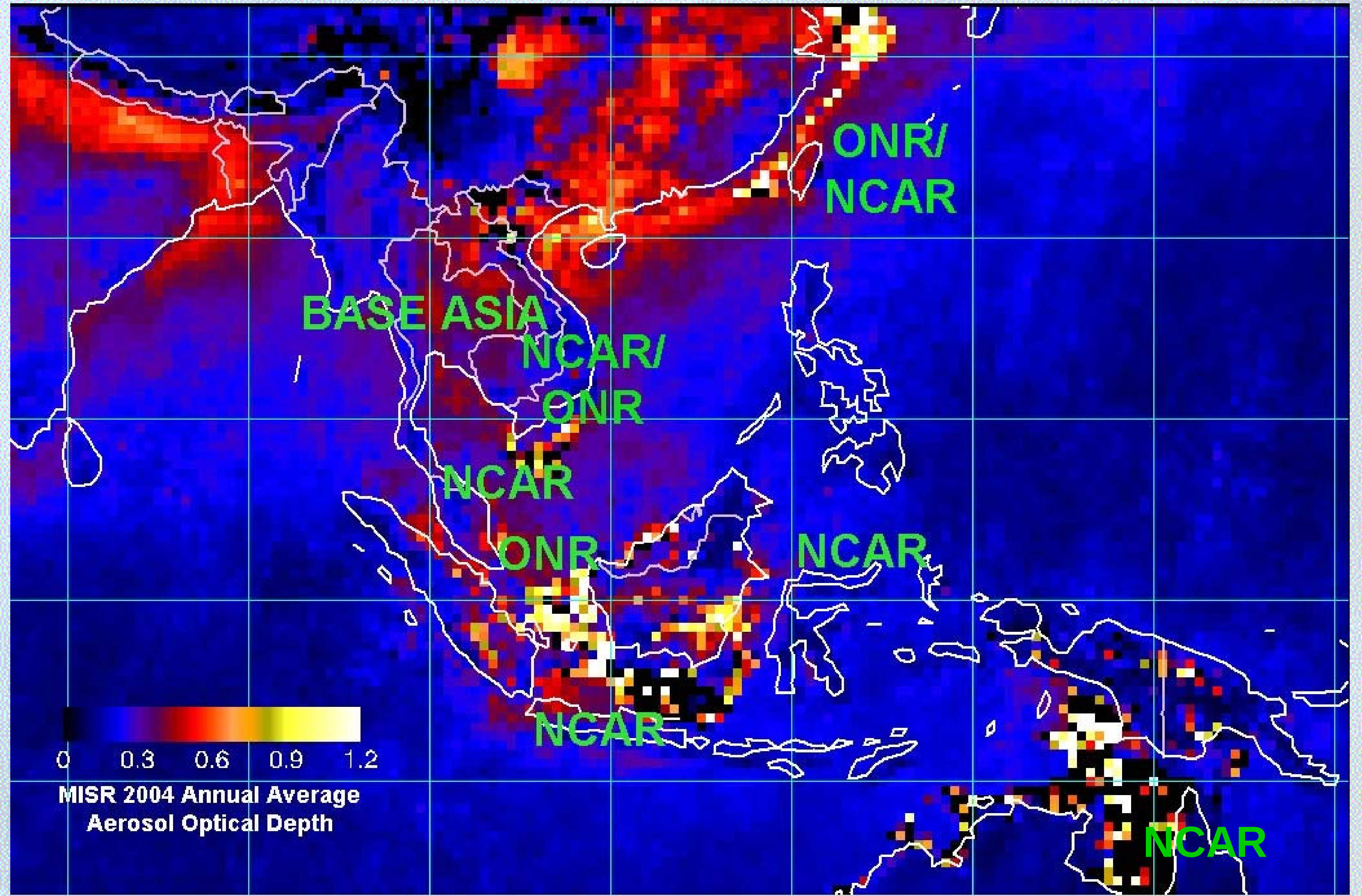
Aerosols and Clouds



Extremely high droplet concentrations during incursion of biomass smoke from Africa associated with drop in mean sizes of droplets

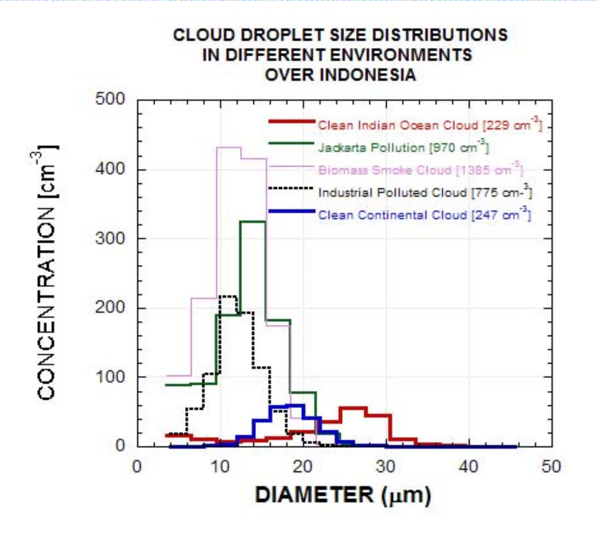
Daily microphysical measurements in clouds in Saudi Arabia during July and August 2004

Southeast Asian Programs



Contrasts in Indonesia 1997-1998 and 2005 Studies

NCAR

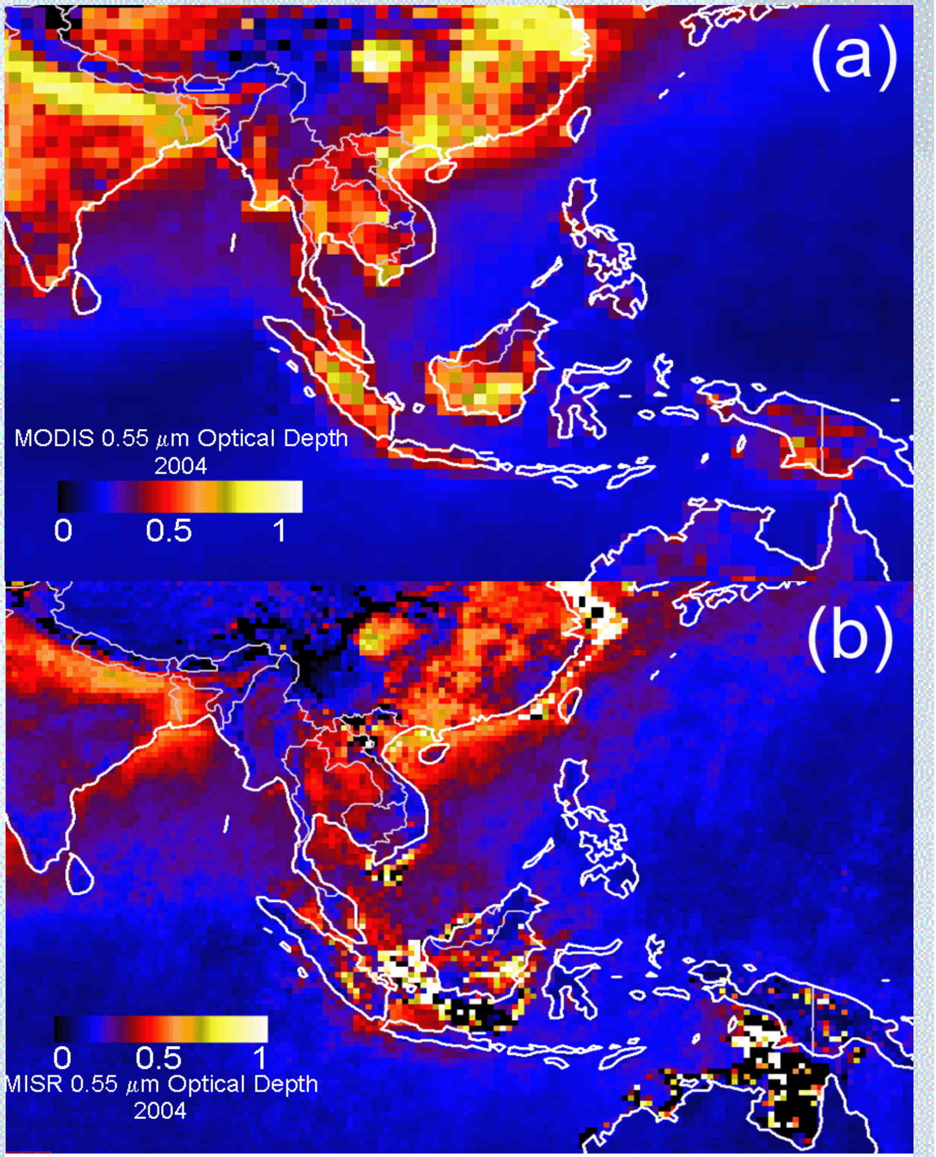


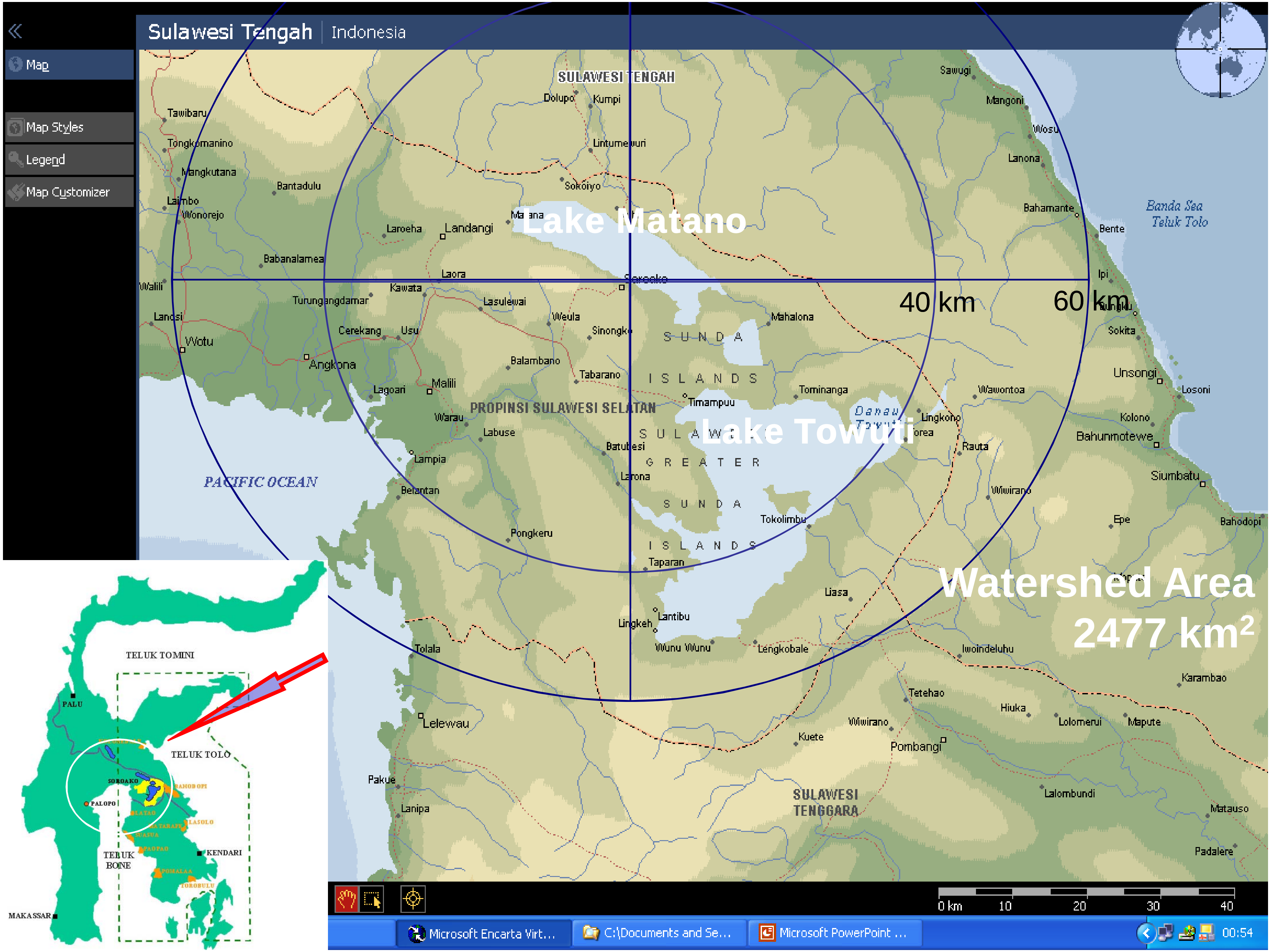
Measured cloud base cloud droplet size distributions in different environments over Indonesia.

Biomass smoke at an airport in Sumatra during the peak of the forest fires in Southeast Asia during the 1997/98 biomass smoke event.

Phase 3: Coordinated campaigns

- •Develop Indonesian in house ability to study the atmosphere
- •Utilize NRL aircraft instrumentation
- •NCAR will also coordinate radar sites
- •Deploy AERONET mesonet of sun photometers.
- •Fully integrate local

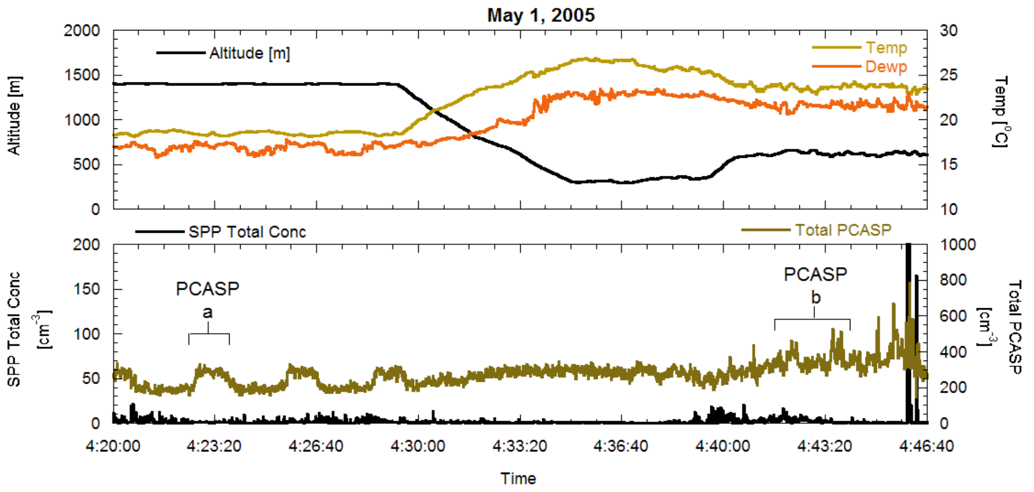


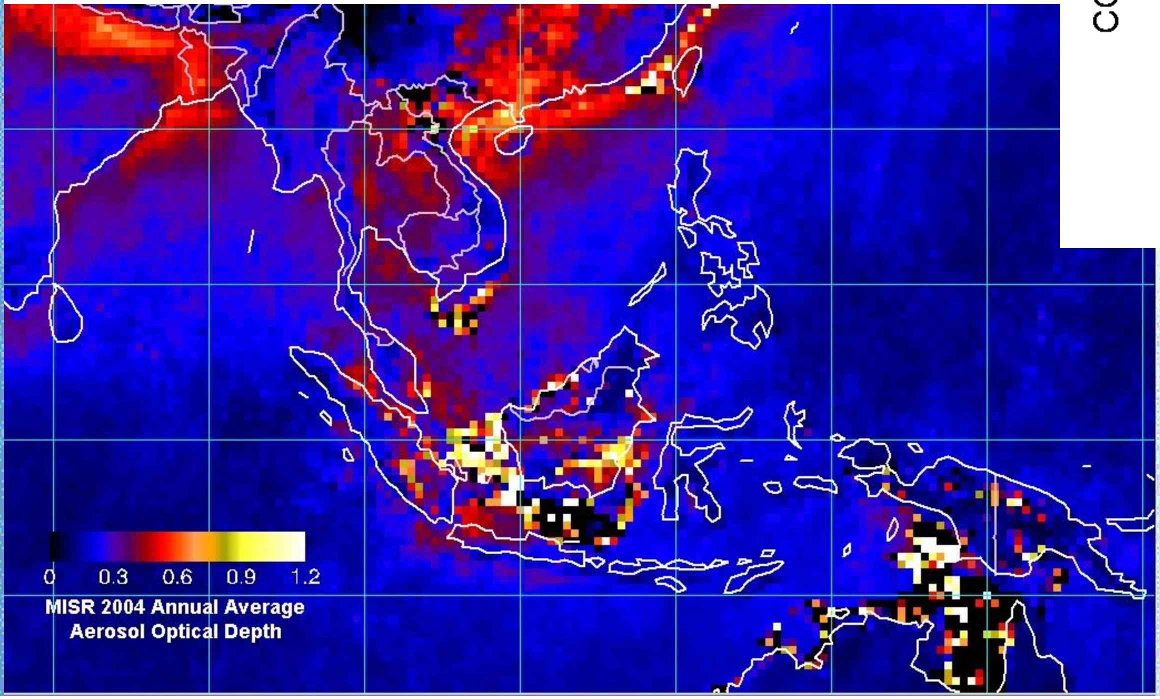


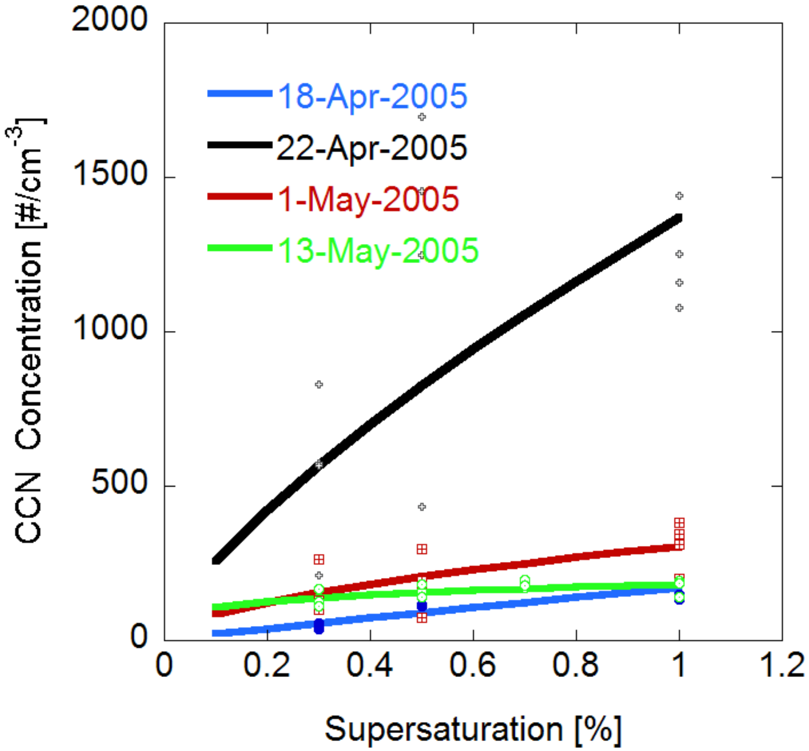
Sulawesi Tengah | Indonesia
Map
Map Styles
Legend
Map Customizer
Lake Matano
Lake Towuti
40 km
60 km
Watershed Area
2477 km²
SULAWESI TENGAH
PROPINSI SULAWESI SELATAN
SULAWESI TENGGARA
GREATER SUNDA ISLANDS
PACIFIC OCEAN
Banda Sea
Teluk Tolo
Danau Towuti
Sorowako
Malili
Wotu
Angkona
Lampia
Dolupo
Kumpi
Lintumewuri
Sokoiyo
Tawibaru
Tongkomanino
Mangkutana
Bantadulu
Laimbo
Wonorejo
Laroeha
Landangi
Babanalamea
Laora
Kawata
Lasulewai
Turungangdamar
Cerekang
Usu
Weula
Sinongko
Mahalona
Balambano
Tabarano
Timampuu
Tominanga
Lagoari
Warau
Labuse
Batubesi
Larona
Belantan
Pongkeru
Tokolimbu
Taparan
Liasa
Lantibu
Lingkeh
Wunu Wunu
Lengkobale
Tolala
Lelewau
Pakue
Lanipa
Sawugi
Mangoni
Wosu
Lanona
Bahamante
Bente
Ipi
Sokita
Unsongi
Losoni
Wawontoa
Lingkono
Rauta
Kolono
Bahunmotewe
Siumbatu
Wiwirano
Epe
Bahodopi
Iwoindeluhu
Karambao
Tetehao
Hiuka
Lolomerui
Mapute
Wiwirano
Kuete
Pombangi
Lalombundi
Matauso
Padalere
Walili
Landsi
0 km 10 20 30 40
Microsoft Encarta Virt...
C:\Documents and Se...
Microsoft PowerPoint ...
00:54
TELUK TOMINI
PALU
TELUK TOLO
SOROAKO
BAHODOPI
PALOPO
TELUK BONE
KENDARI
MAKASSAR

CCN and aerosol measurements

East coast measurements







$N_{CCN}=182\ S^{0.23}$

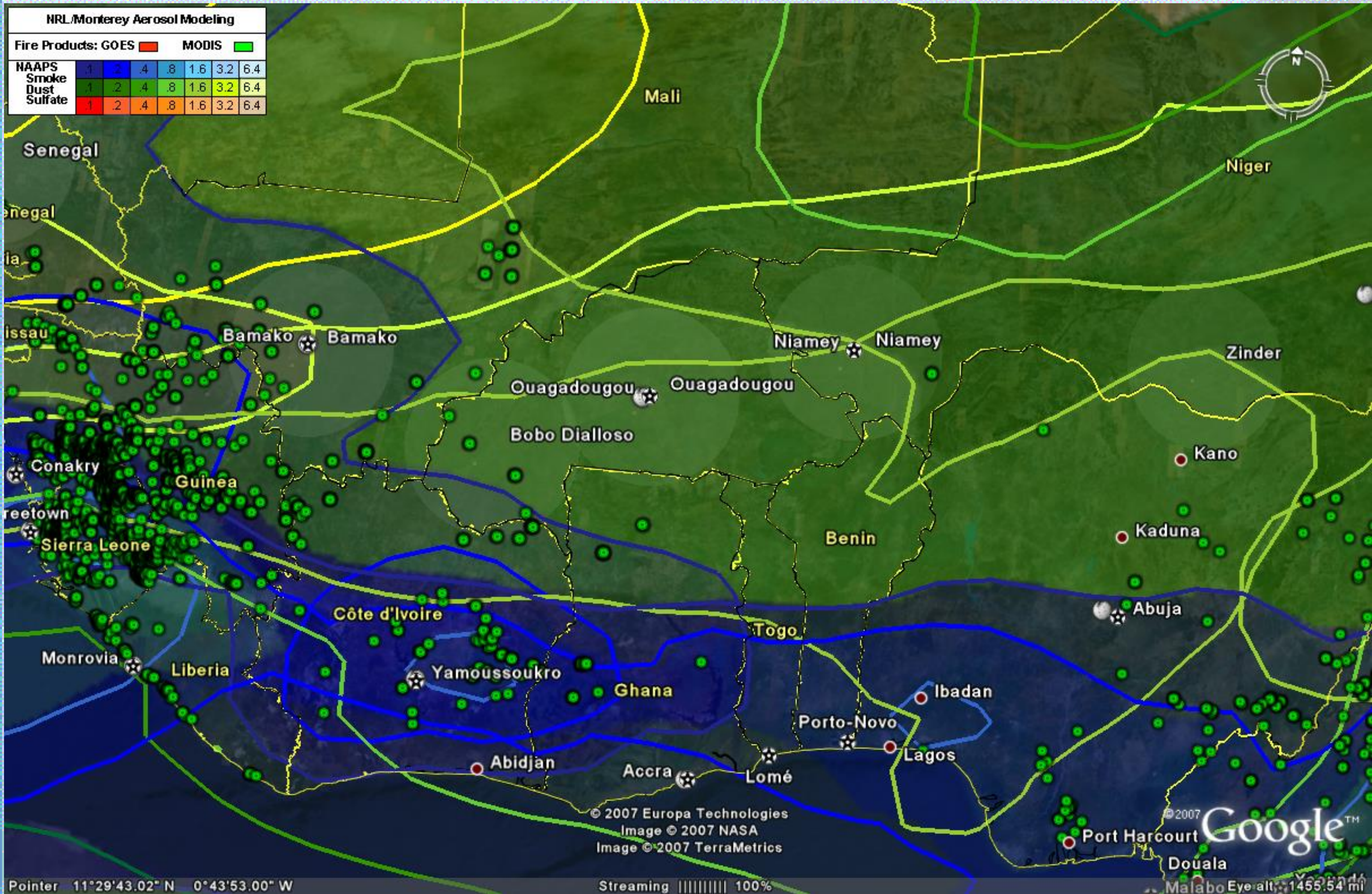
$N_{CCN}=305\ S^{0.56}$

$N_{CCN}=1369\ S^{0.73}$

$N_{CCN}=170\ S^{0.93}$

NCAR

West Africa Aerosols

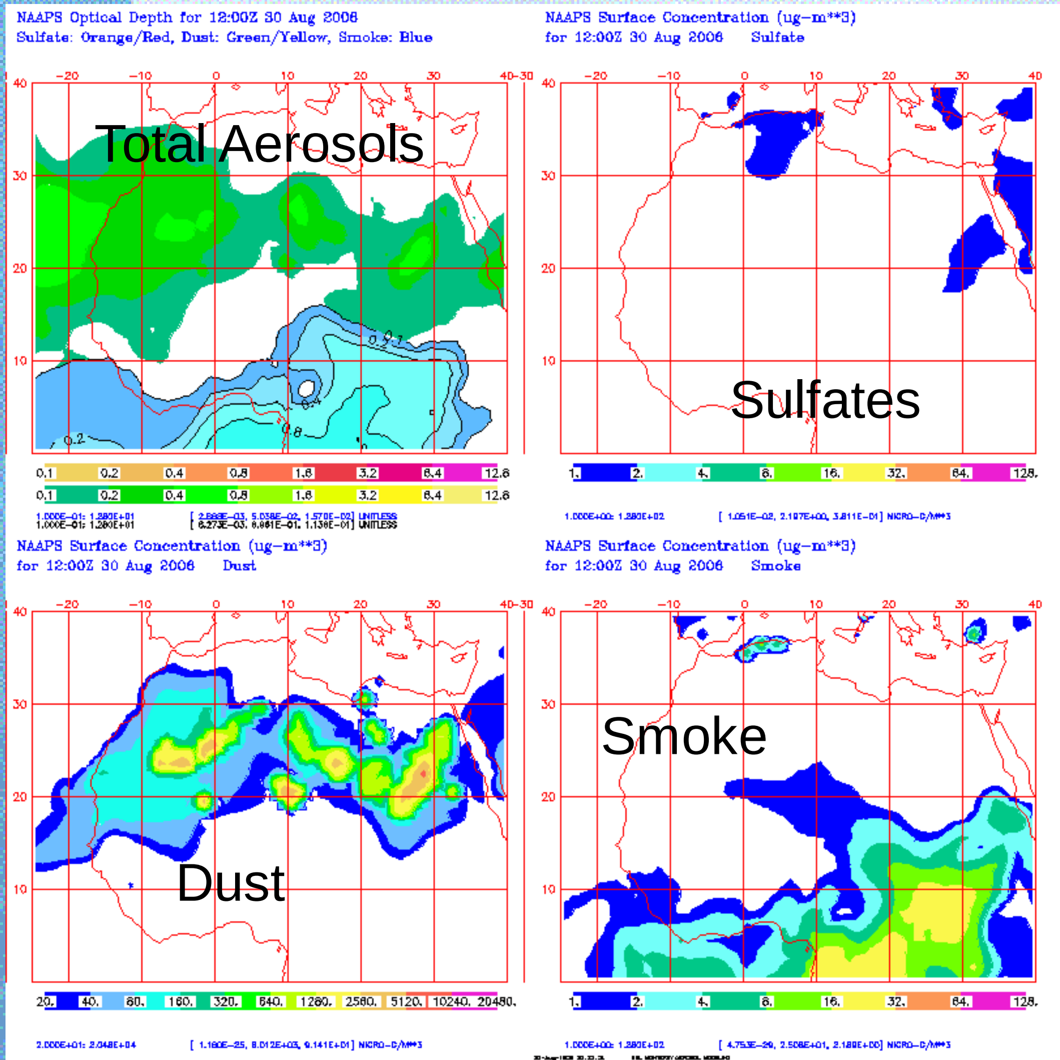


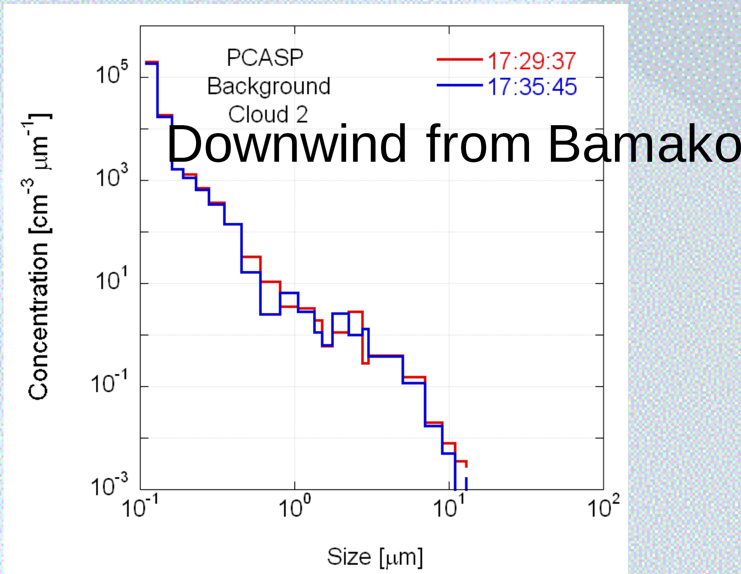
27 March 2007

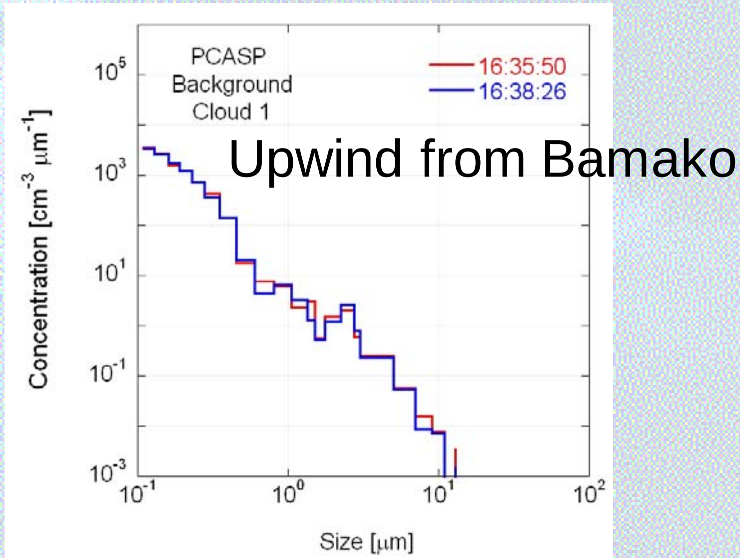
Mali Aerosols Observations

NCAR

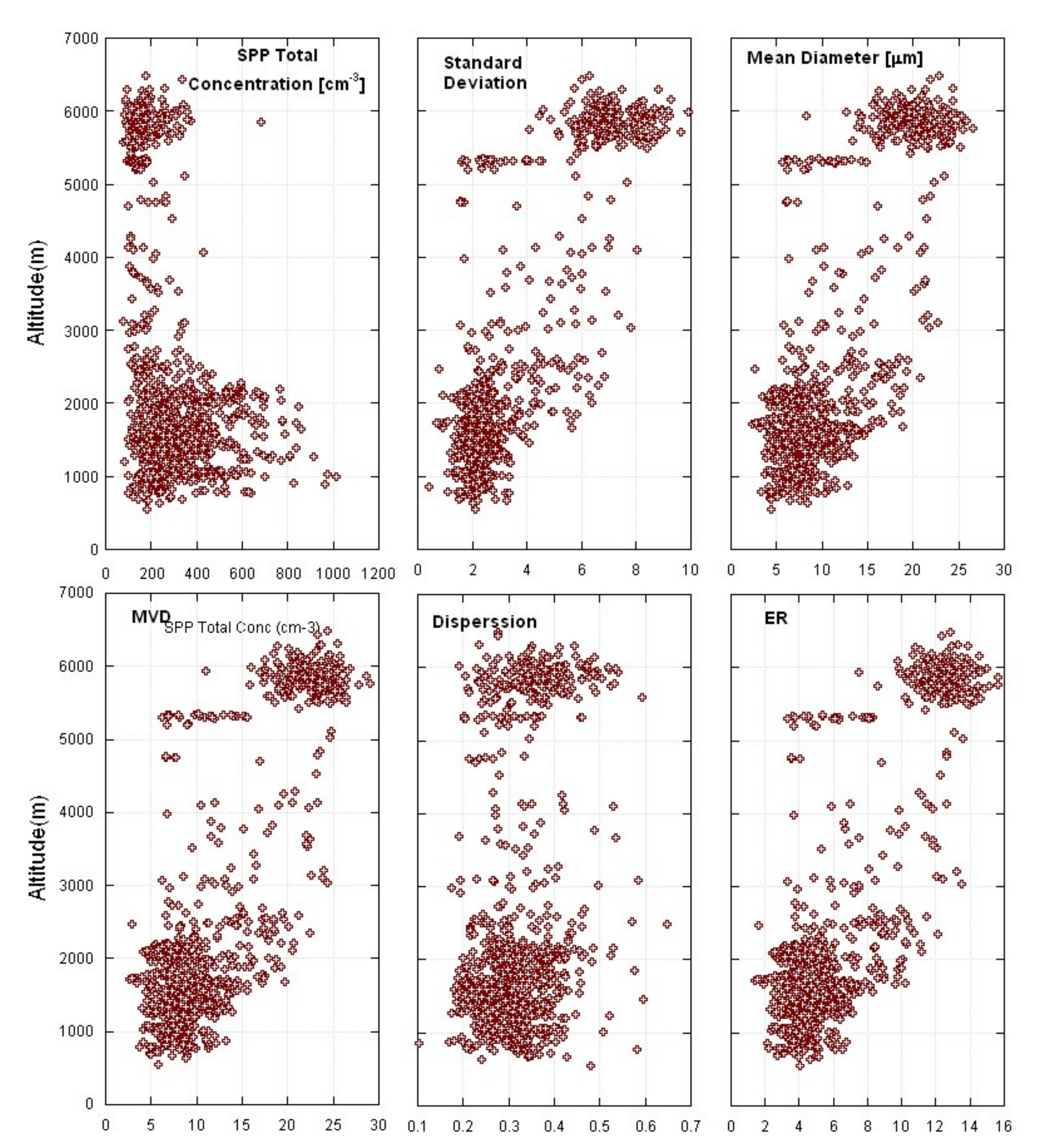
30 August 2006





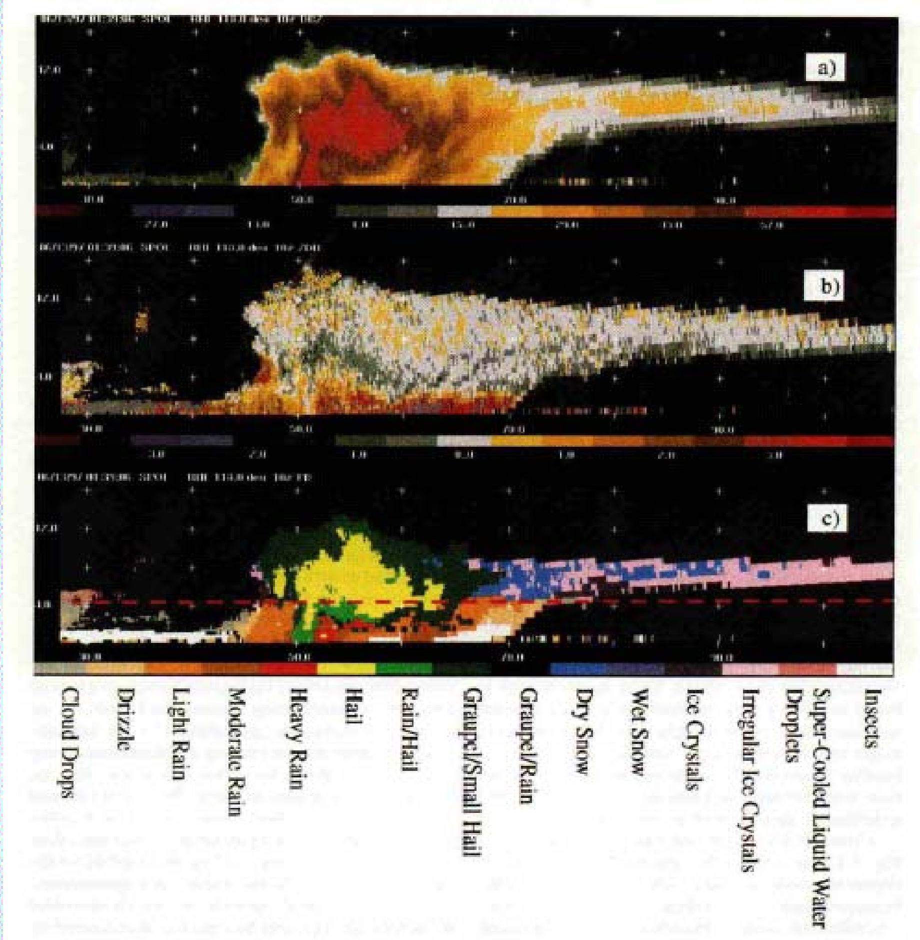


Cloud parameters



New Tools

1) New remote and in situ **observational tools**
   - **e.g., Doppler lidar and airborne radars, MW radiometer, CPI, cell-tracking software**
2) Cloud and precipitation physics **modeling**
   - **e.g., focus on** CCN, **ice nucleation processes**



INSTRUMENTED RESEARCH AIRCRAFT

Trace gases: SO_2, O_3, $NO_{x/y}$

Aerosols: CN, CCN, PCASP, filter pack sampler

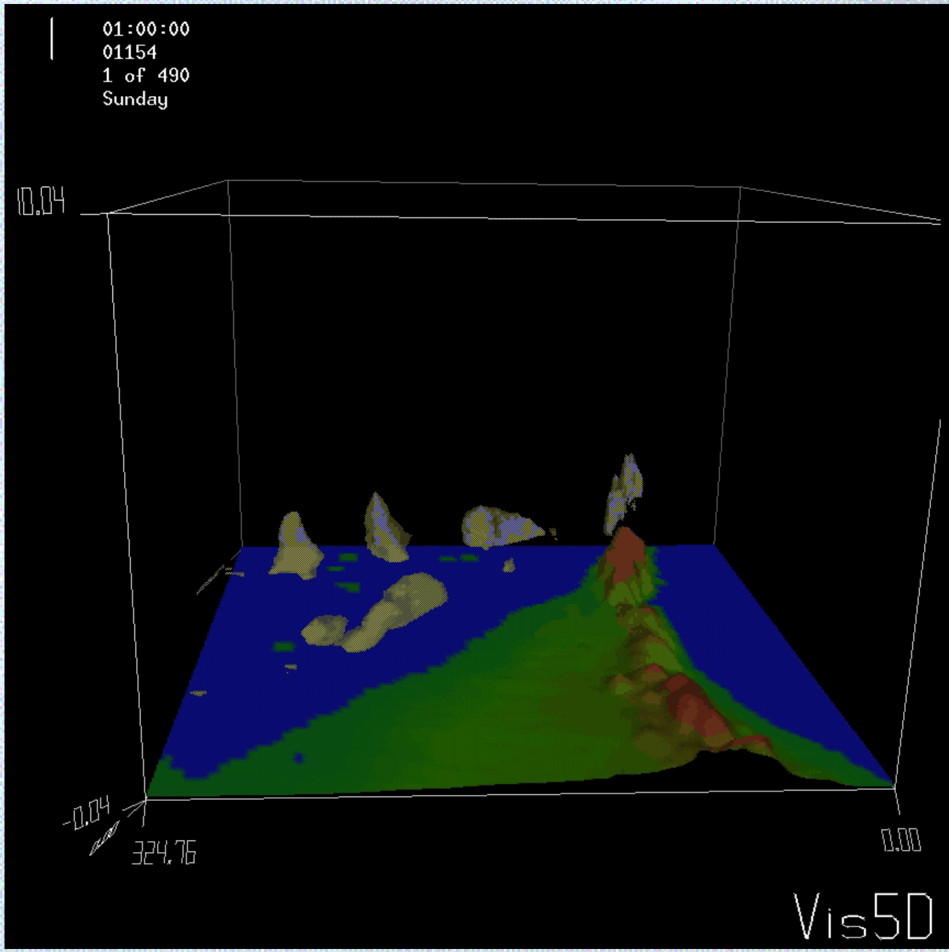
Cloud physics: FSSP, 2D-C, 2D-P, (HVPS), LWC

Missions: chemistry and aerosol mapping, cloud penetrations, seeding trials

State parameters: T, T_d, p, TAS, Hdg, GPS position, derived winds

New Tools

3) Computation and **data assimilation** capabilities
   - rapid data processing
   - simulation of cloud and precipitation processes
4) Existing **field facilities** and new **partnerships** among research and operational groups



Summary

- Spatial and temporal changes in natural concentration, sizes, and chemical composition of aerosols change microphysical and precipitation processes
- Affects of efficiency of precipitation development may widely differ from one situation to the other.
- New tools available to stratify these results

Summary

NCAR

Important Problems

- Climate and Water Resources
- Environmental and air quality
- Inadvertent weather modification effects

Opportunities

- New observing technologies
- Better models and computing
- Recent interesting research

Establish programs with major emphasis on quantification of the effects of both advertent and inadvertent weather modification