

**Recent Feasibility Studies by  
NCAR/RAL of Weather  
Modification Programs:  
Emphasis on programs with  
hygroscopic seeding**

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**International Symposium on Weather Modification  
JCSEPA – Tsukuba, Japan  
31 January-1 February 2007**

# Hygroscopic Seeding Programs



**Mexico\*** – 1996-1998 (1999 – different location)

**United Arab Emirates (UAE)\*** – 2001-2004  
(current operational seeding program)

**Saudi Arabia** – 2004

(current research program in central Saudi Arabia)

**Indonesia** – 2005

**Related Studies: Flare characterization,  
Stratocumulus seeding case**

\*denotes randomized seeding experiments

# Hygroscopic Seeding with Flares



## RESULTS FROM SOUTH AFRICA

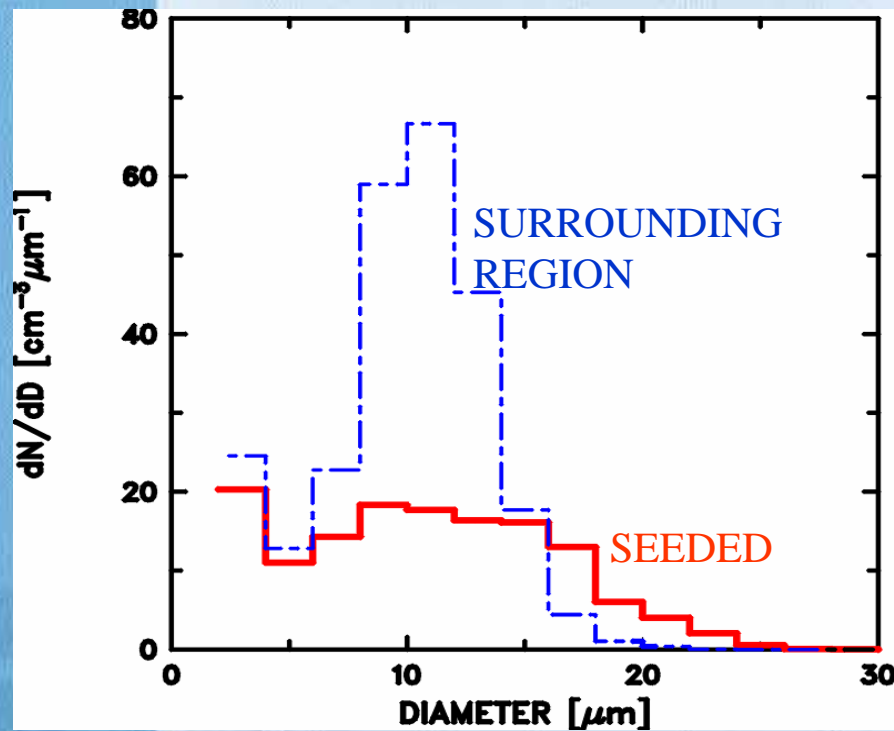
- *Recognized altered cloud properties and enhanced precipitation in storms affected by the plume of a paper mill.*
- *Developed a flare to introduce hygroscopic particles into the clouds at cloud base – similar to the paper mill plume.*
- *Devised a randomized seeding experiment to detect changes in individual storms (radar analysis using software like TITAN).*



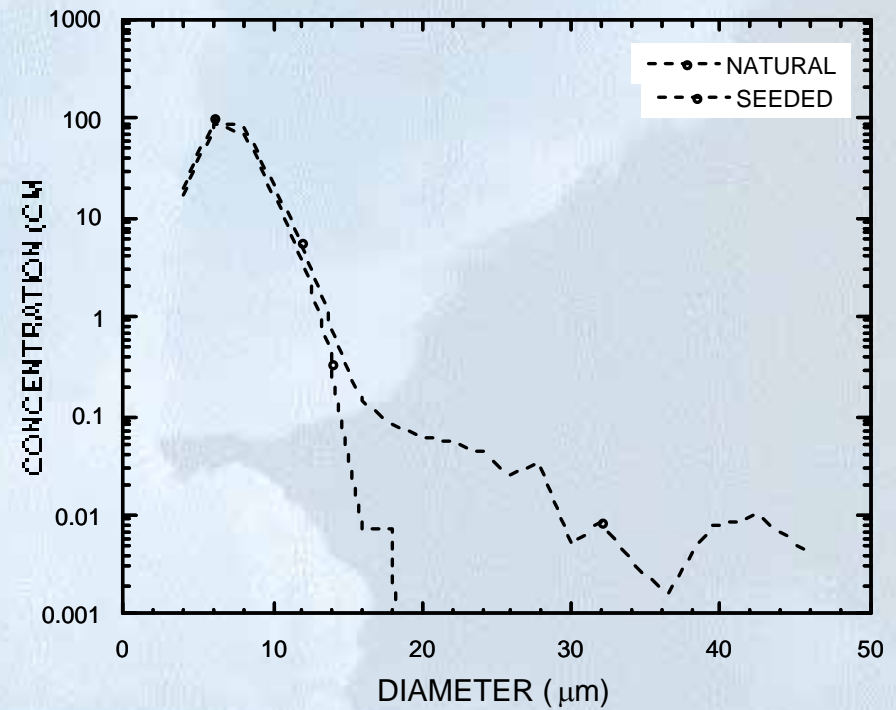
# Supporting Observations – cloud droplet distributions



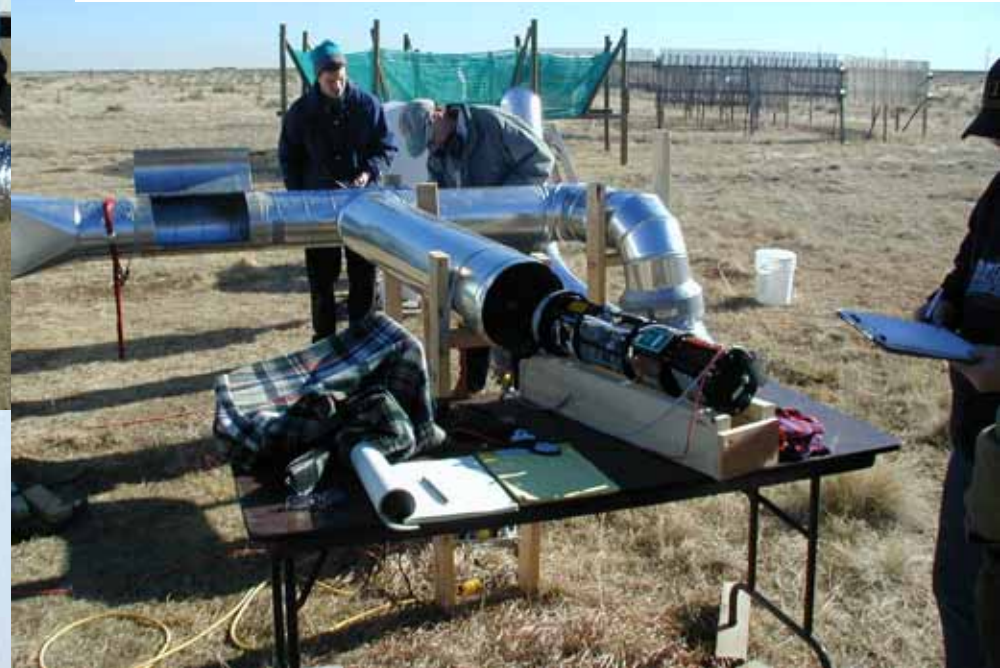
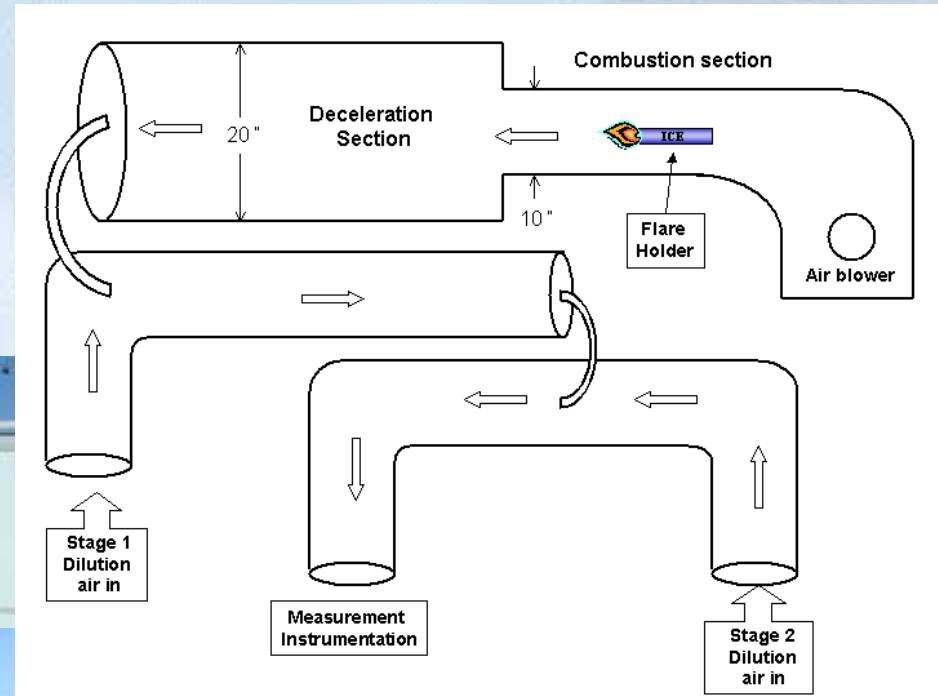
South Africa:



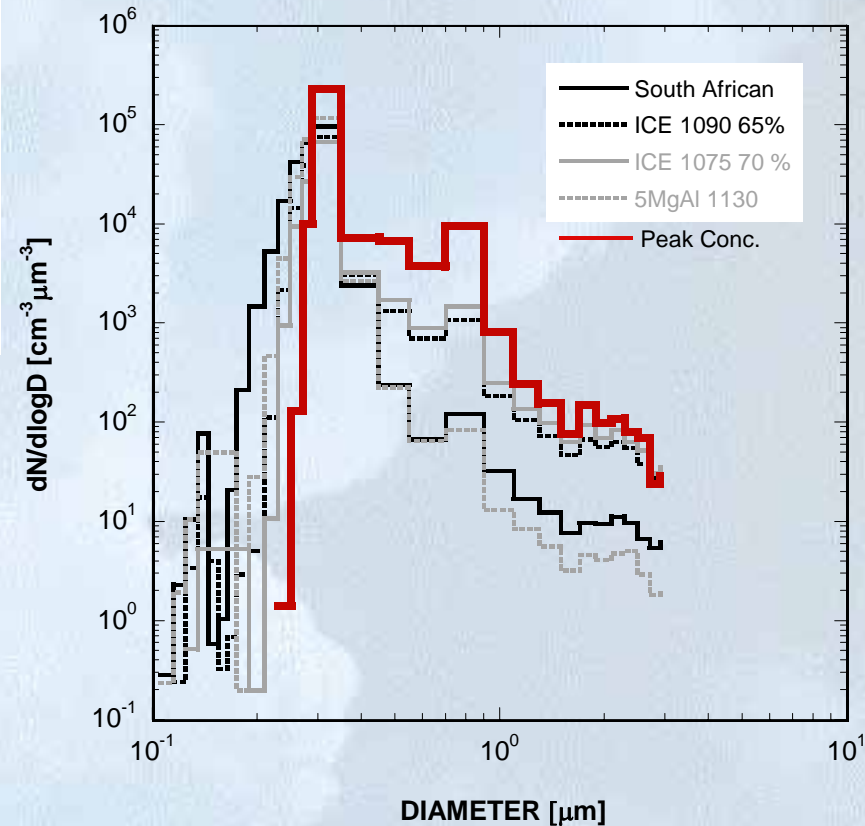
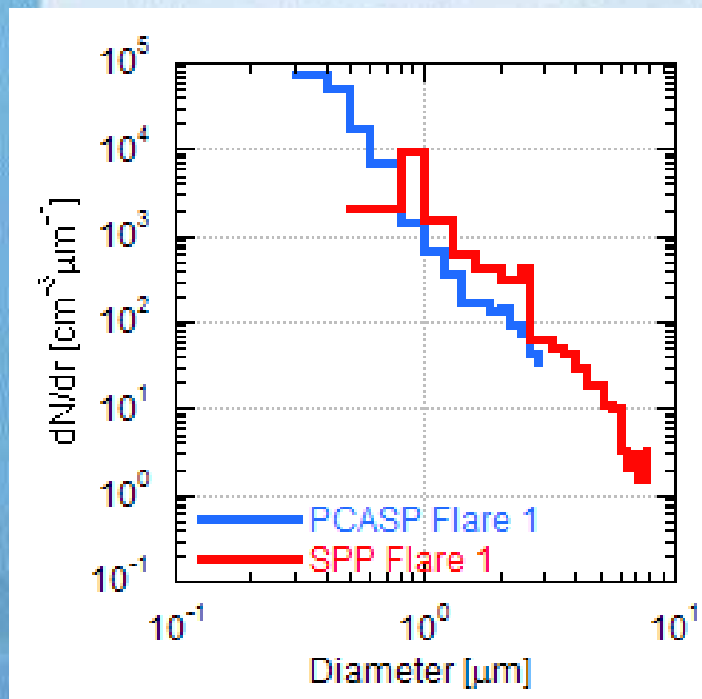
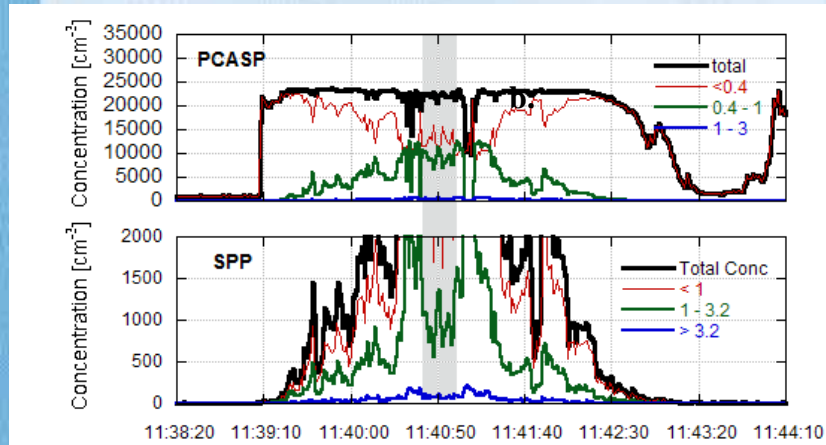
Argentina:



# Flare Test Facility



# Flare particle distributions



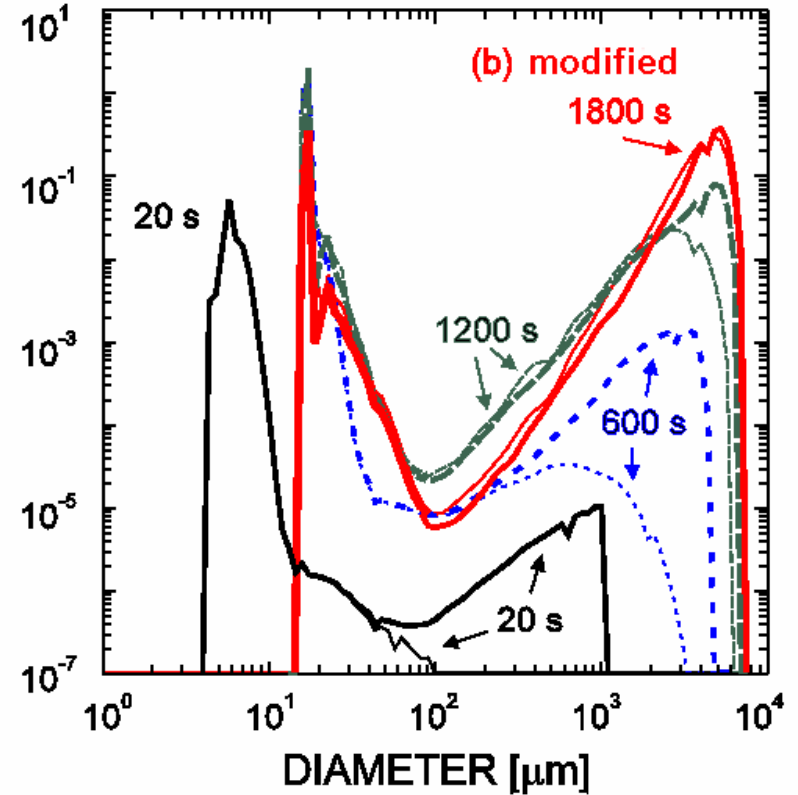
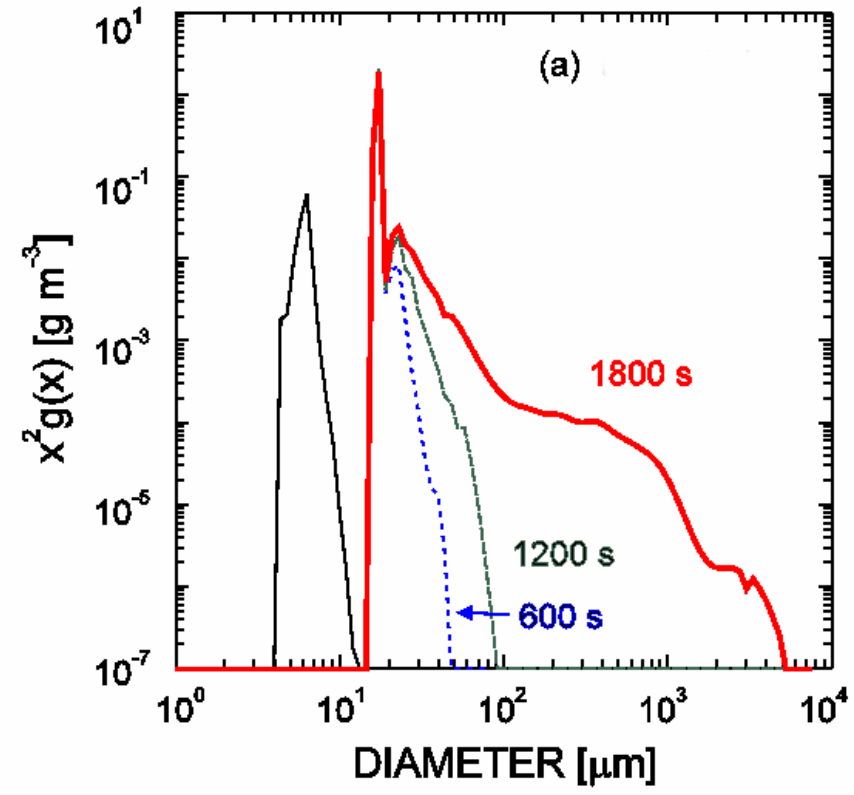
PCASP comparison of different flares



NCAR

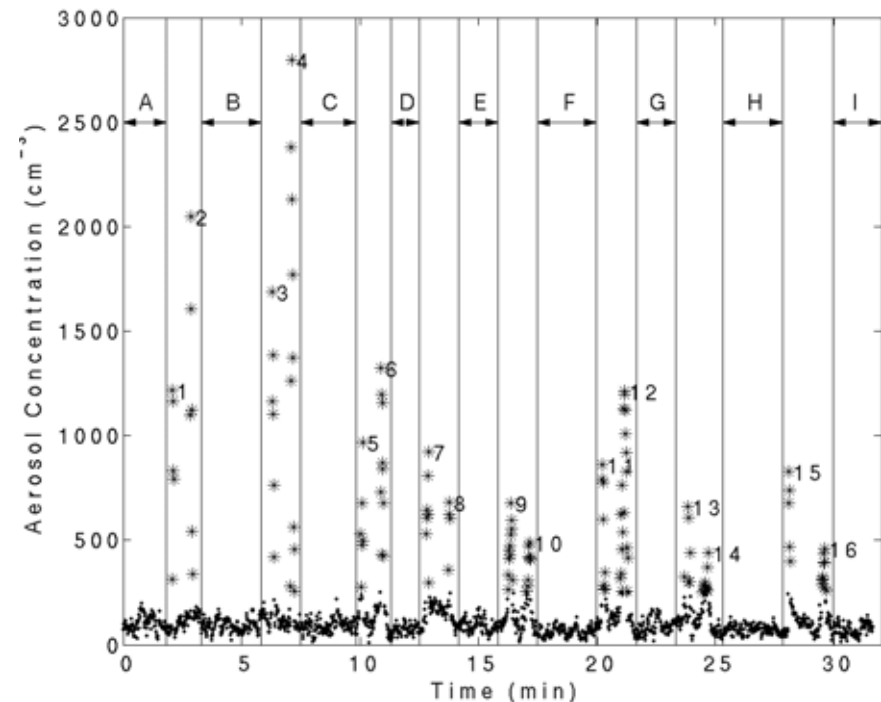
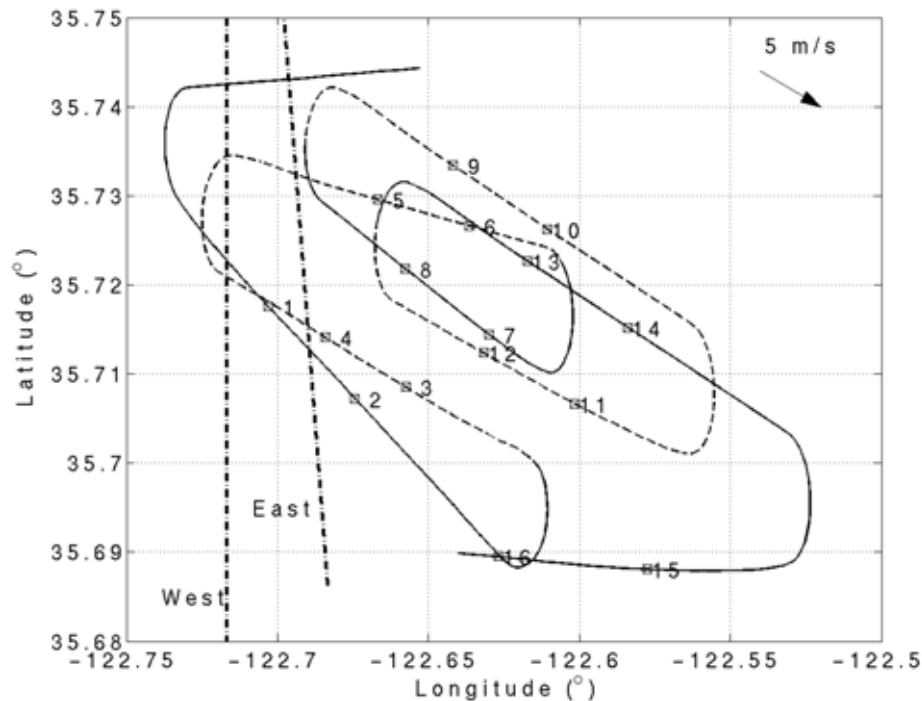
Condensate after 30 min: 0.02 % in raindrops

vs. 82 - 85% in raindrops



Model comparison: “natural” aerosols and seeded aerosols

# Recent Results of Flare Experiment in StratoCumulus (west of Monterey, CA)

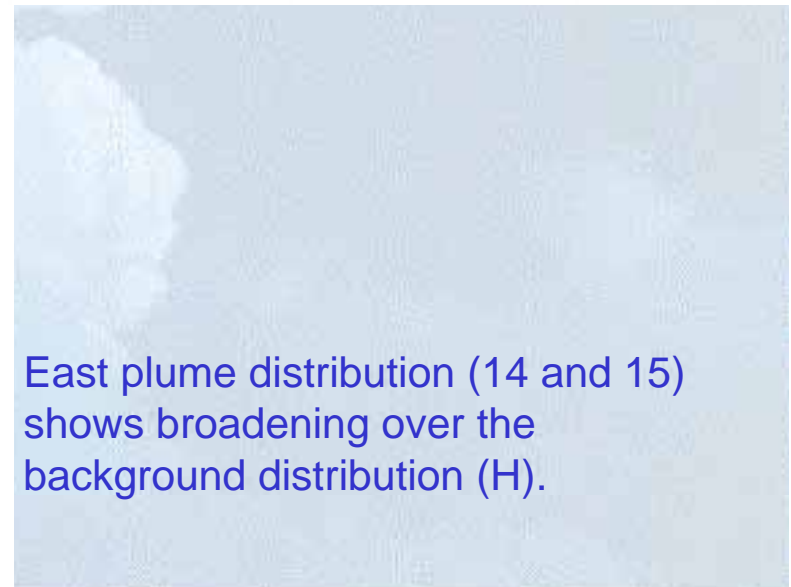
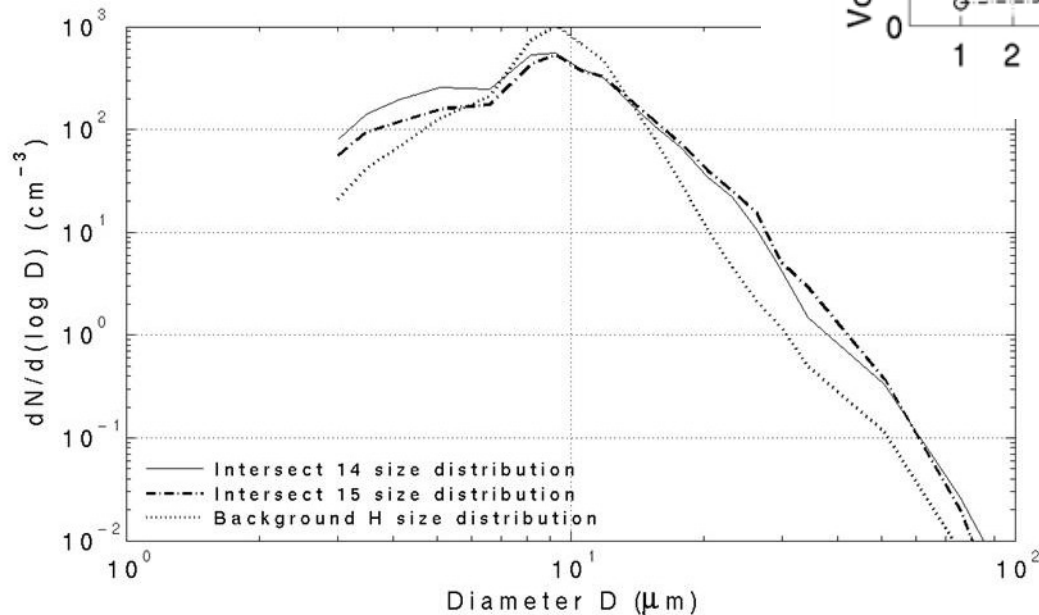
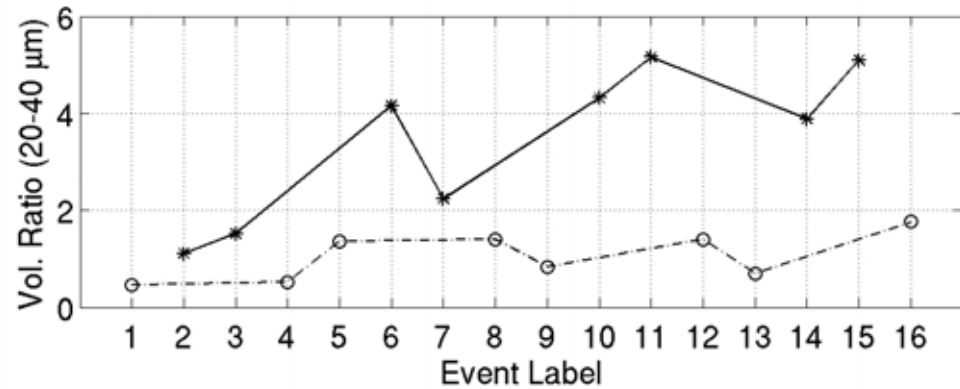
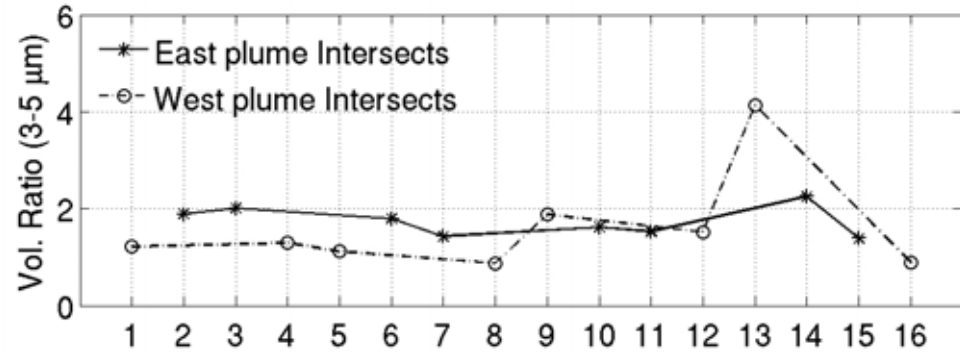


Flight track of the CIRPAS Twin Otter during the seeding experiment on June 28, 2006. The flight level was at 350 m. Numbers correspond to plume crossings. The two dashed lines indicate the initial flare burn lines conducted by the Cheyenne II aircraft.

PCASP concentrations: Numbers indicate plume crossings and vertical lines indicate the boundaries of the plumes. Background areas are designated by letters.

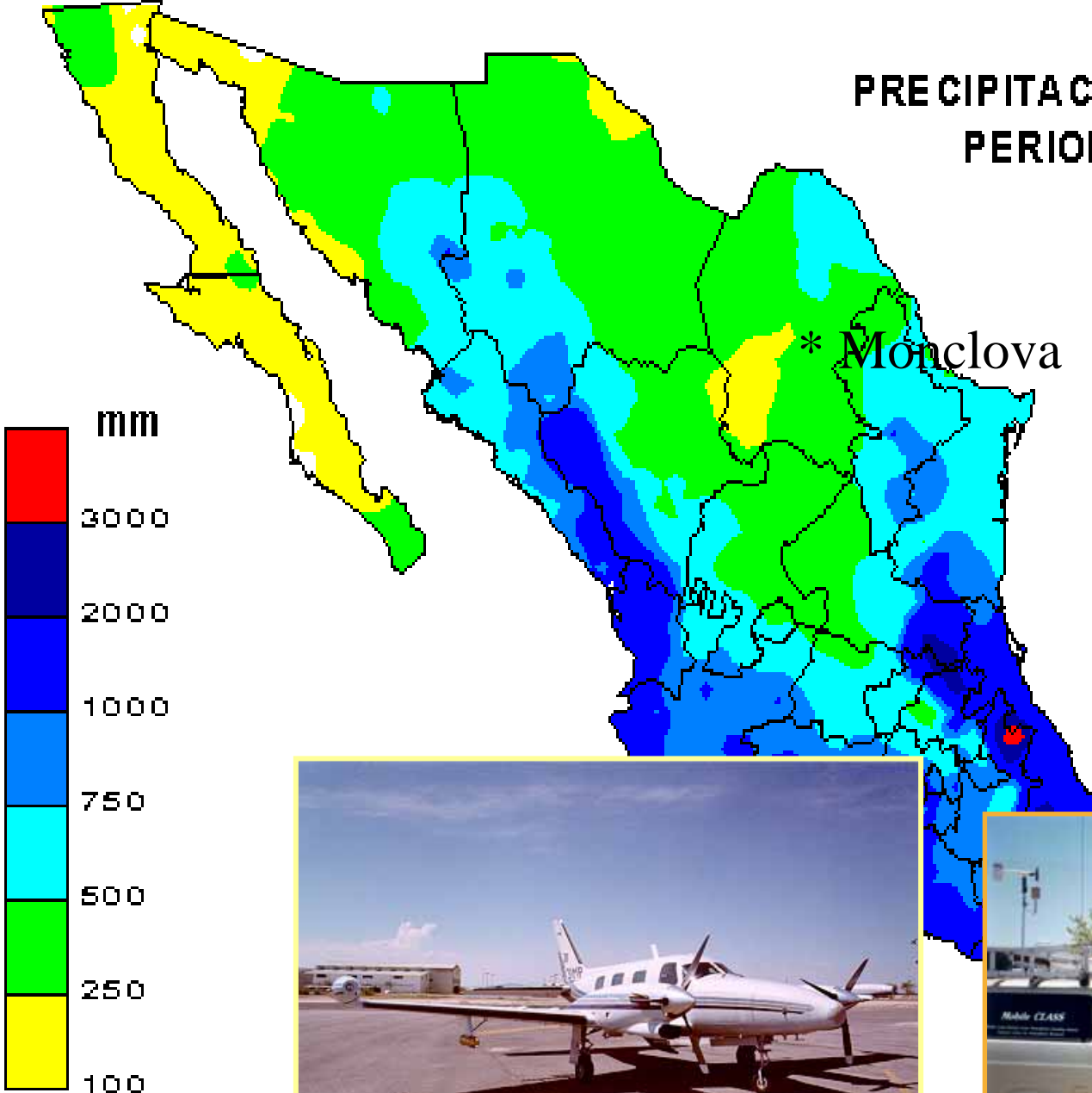
West plume shows no noticeable change.

East plume broadens consistently to 4-5 times the number of large droplet  
No drizzle forms however.



East plume distribution (14 and 15) shows broadening over the background distribution (H).

# PRECIPITACION MEDIA ANUAL PERIODO 1941-1997



# Mexico design the same as the South African experiment

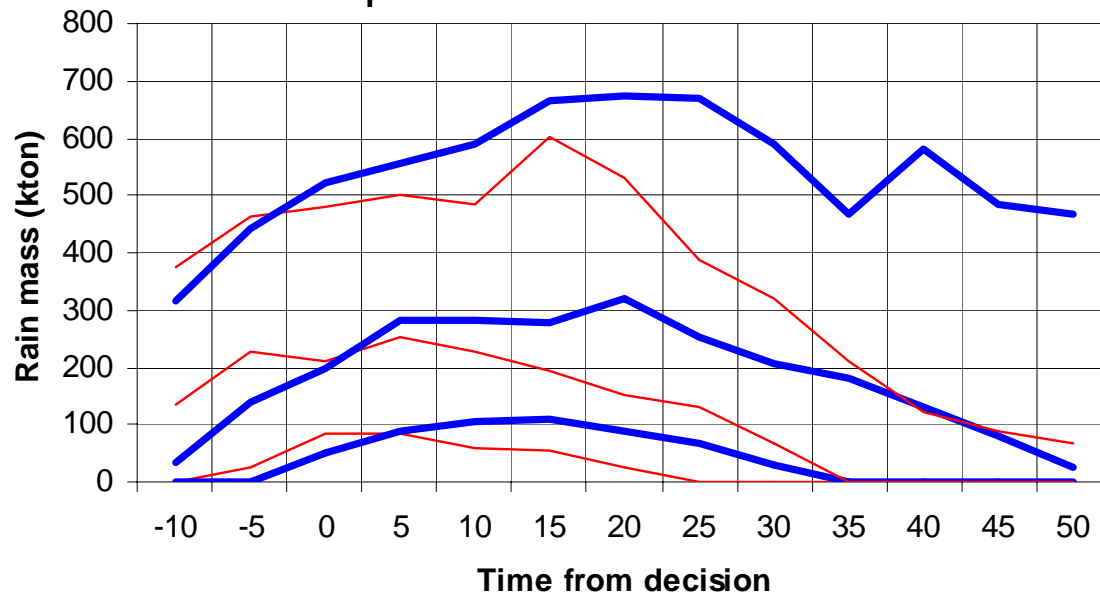


- Cloud/storm characteristics similar: cloud droplet distributions, storm evolution, size, and maximum reflectivities.
- Differences: storm lifetimes somewhat shorter in Mexico. Wind speeds and windshear less than South Africa also.
- Same case selection criteria (same pilots).
- Same seeding technique and same flares.
- Same evaluation technique (quartile analyses) using TITAN software.
- 94 cases over two seasons (43 seeded, 51 non-seeded).

# Rain Mass Results

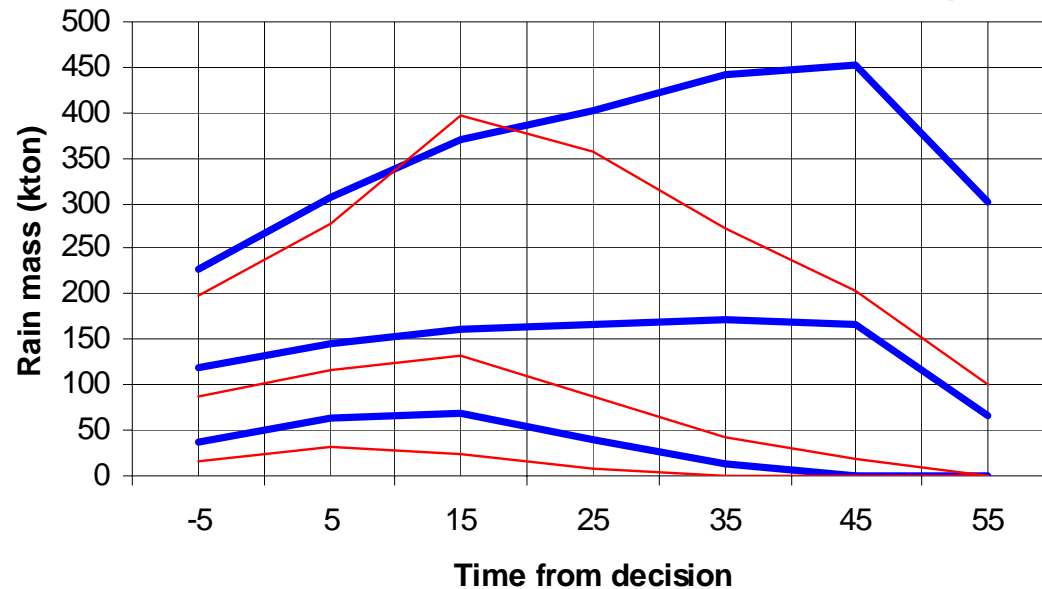


## Mexico Experiment

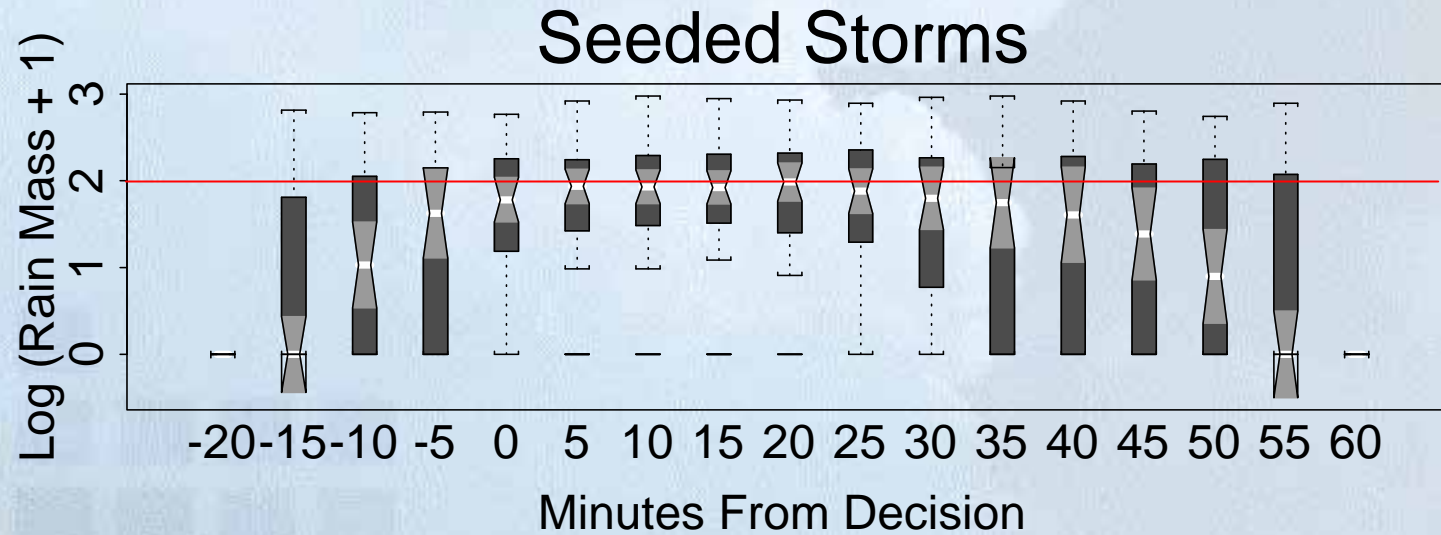
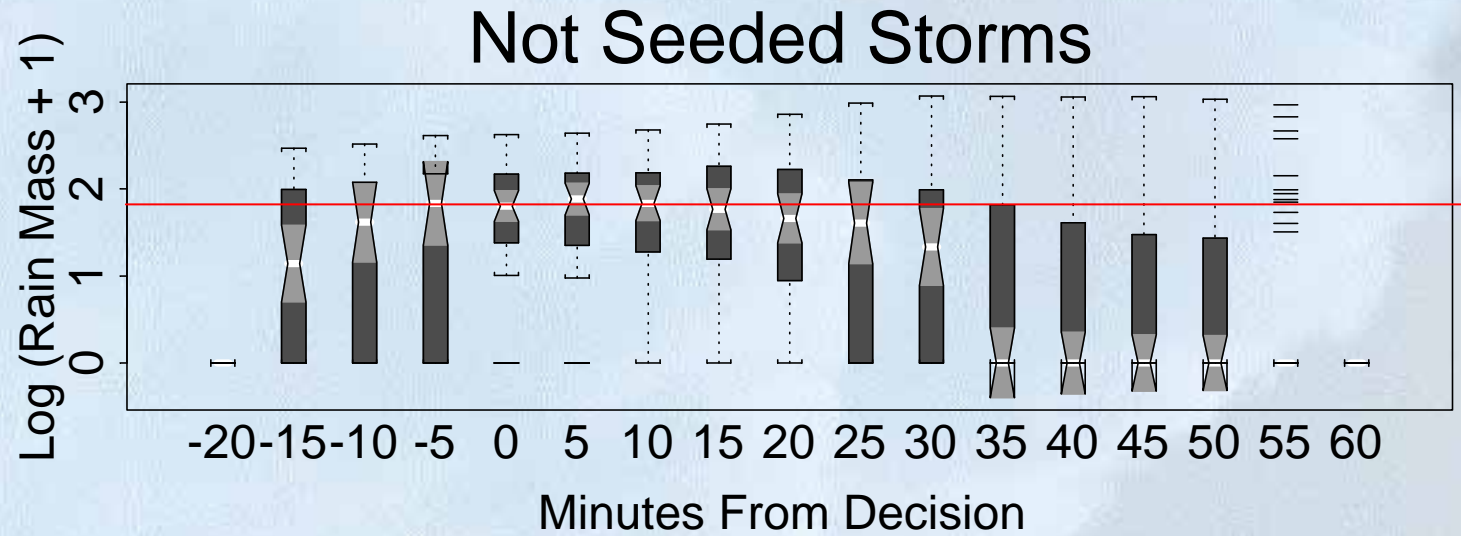


Thin red line – control (unseeded)  
Thick blue line – seeded

## South Africa Experiment



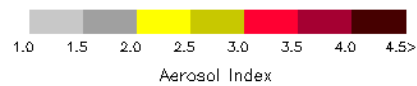
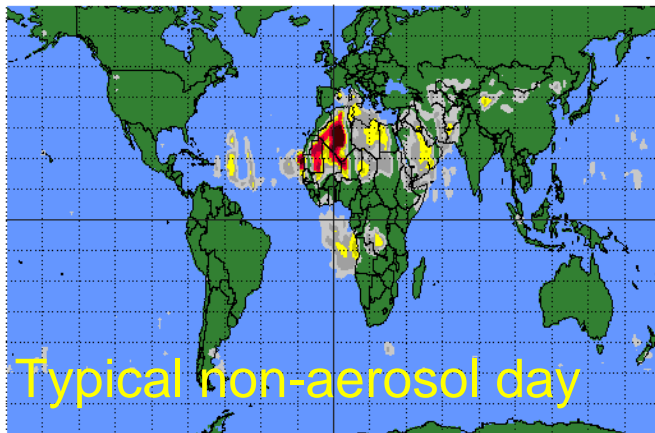
# Mexico Experiment – All Storms



# Aerosol and non-aerosol days classification

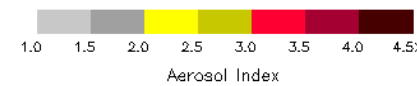
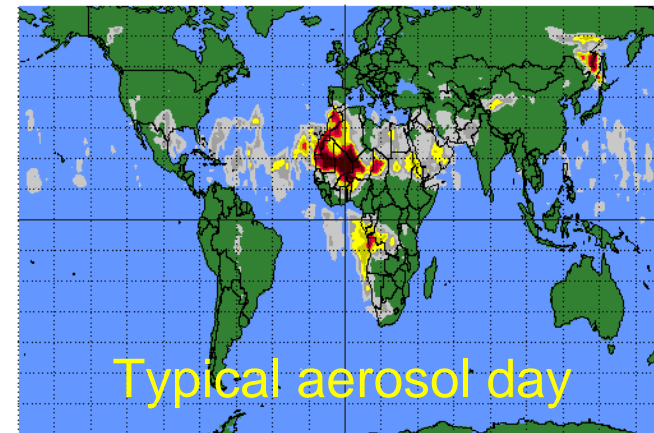


Earth Probe TOMS Version 8 Aerosol Index  
on July 23, 1997



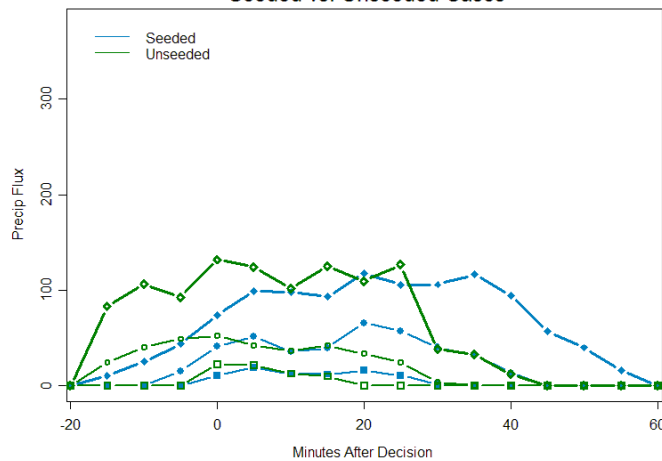
Goddard Space Flight Center

Earth Probe TOMS Version 8 Aerosol Index  
on July 30, 1998

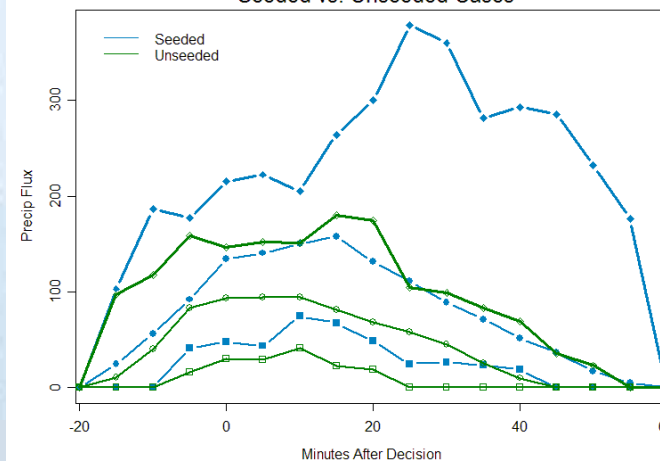


Goddard Space Flight Center

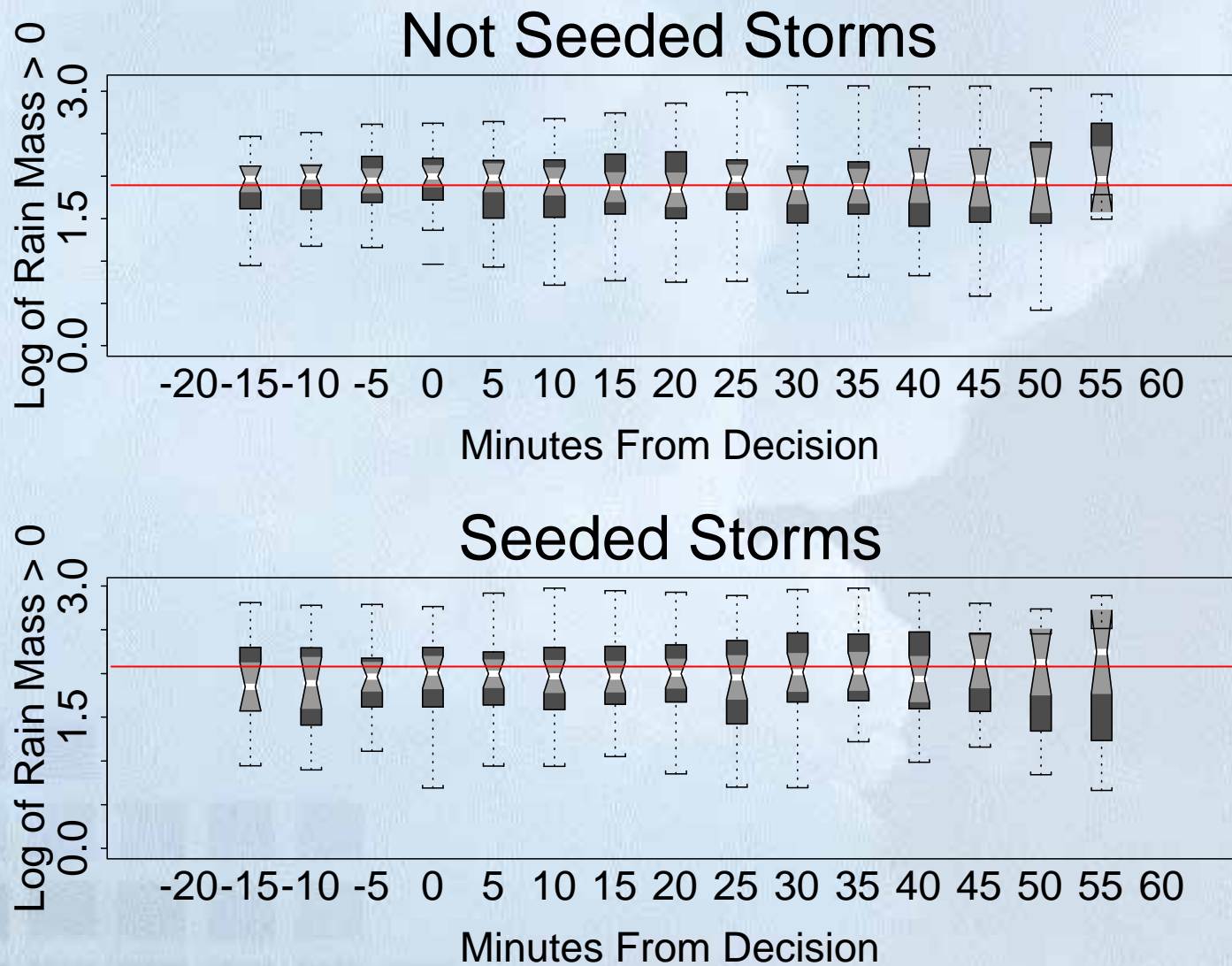
Non-Aerosol Days  
Seeded vs. Unseeded Cases



Aerosol Days  
Seeded vs. Unseeded Cases



# MEXICO RANDOMIZED EXPERIMENT ONLY STORMS WITH REFLECTIVITY



# Feasibility Study for Rainfall Enhancement in the United Arab Emirates: Phase I (2001 and 2002)



**Phase I consisted of studies to address two fundamental questions for the UAE:**

- 1. Is the frequency of cloud occurrence sufficient for investing in a cloud seeding program?***
- 2. Are the clouds that do occur amenable to hygroscopic seeding?***

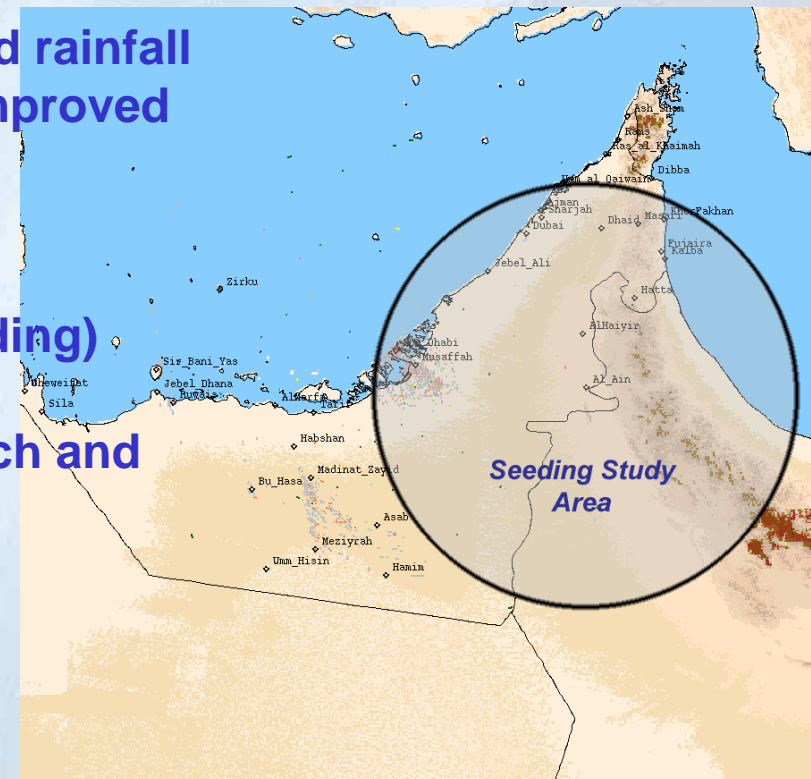
- Storm climatologies/statistics using radar data – summer and winter
- Aerosols and trace gases
- Cloud microphysics



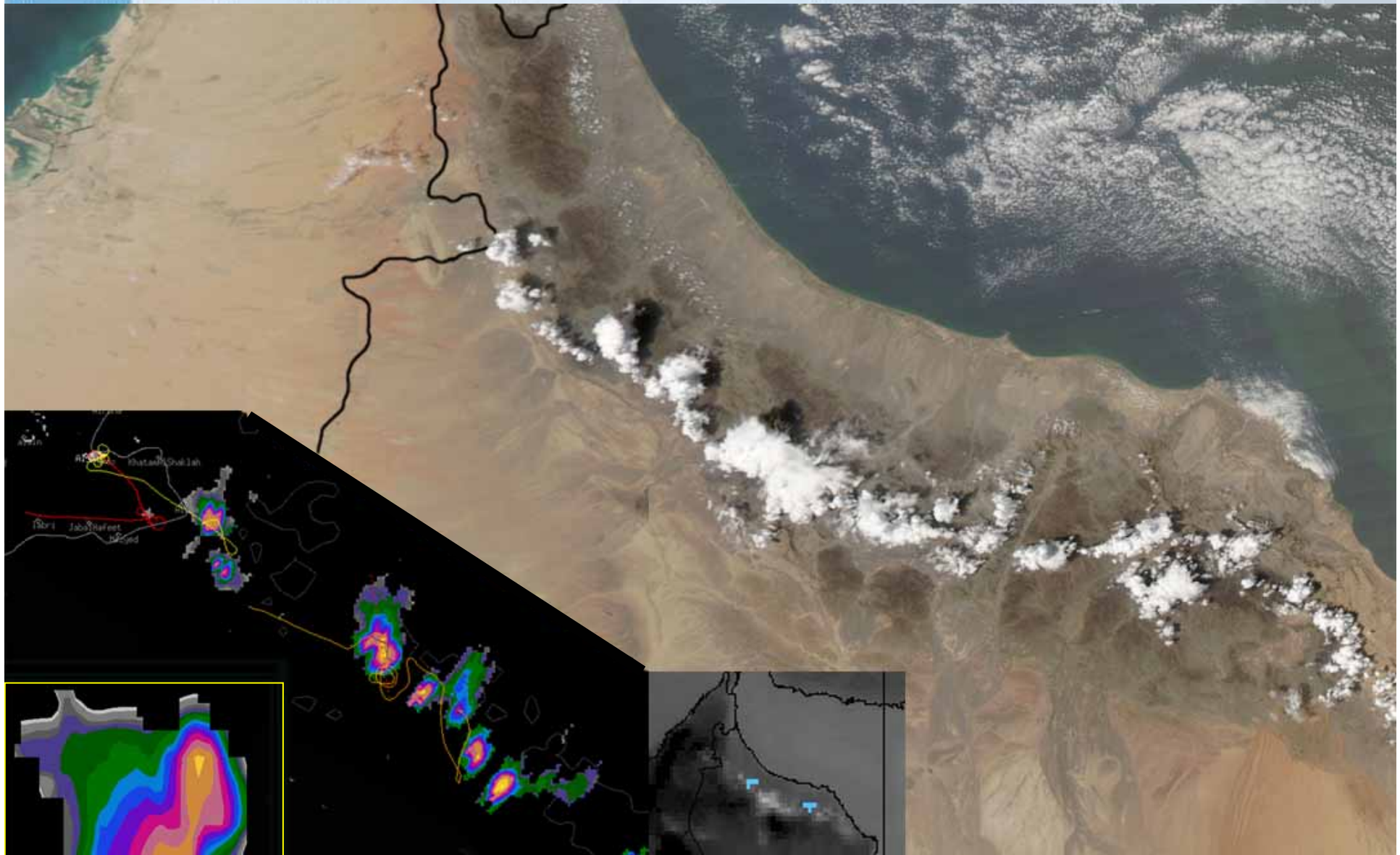
# The results from 2001-2002 supported proceeding with a Phase II



- Randomized hygroscopic seeding experiment
- Target the Hajar (Oman) mountains during the summer convective season
- Evaluate storms using radar-derived rainfall from the Al Ain weather radar with improved signal and data processing.
- Utilize two aircraft: Research 1 (seeding/research); Research 2 (seeding)
- Develop training program in research and seeding operations.



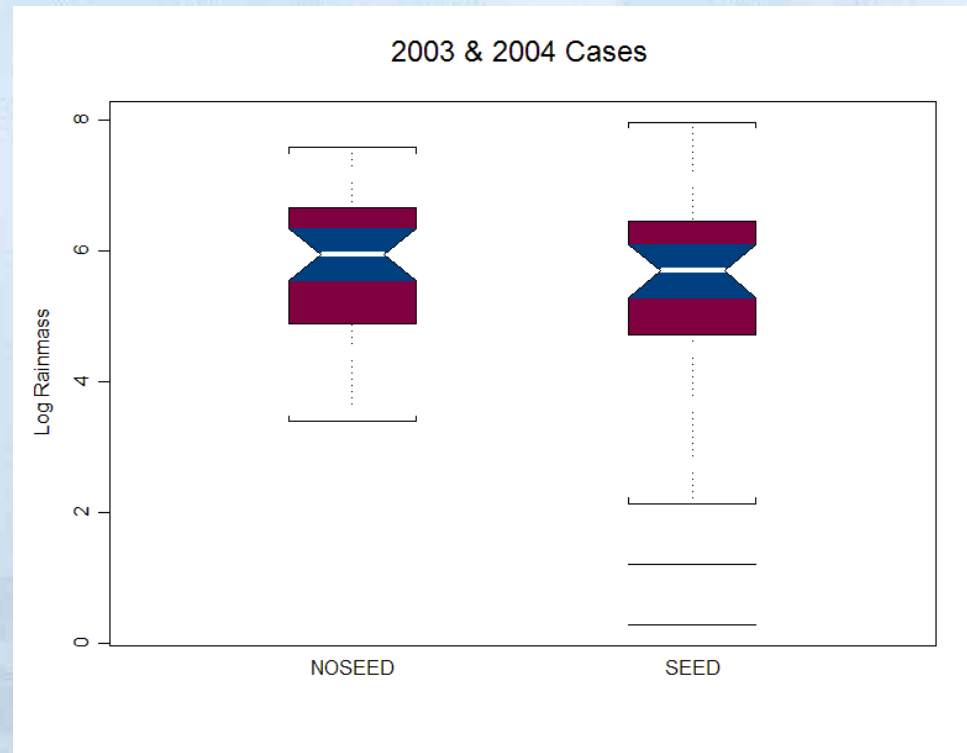
# COMBINED SATELLITE AND RADAR (UAE randomized seeding experiment)



# Results



- Estimated that ~250 cases needed to show 25% increase (per TITAN track)
- 134 “treated” cases – but only 96 met criteria for acceptance
- 45 seeded, 51 not seeded

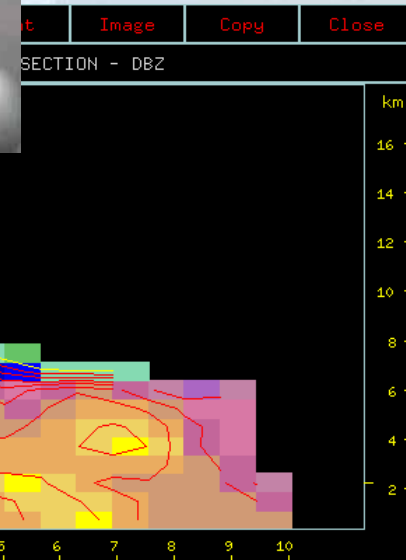
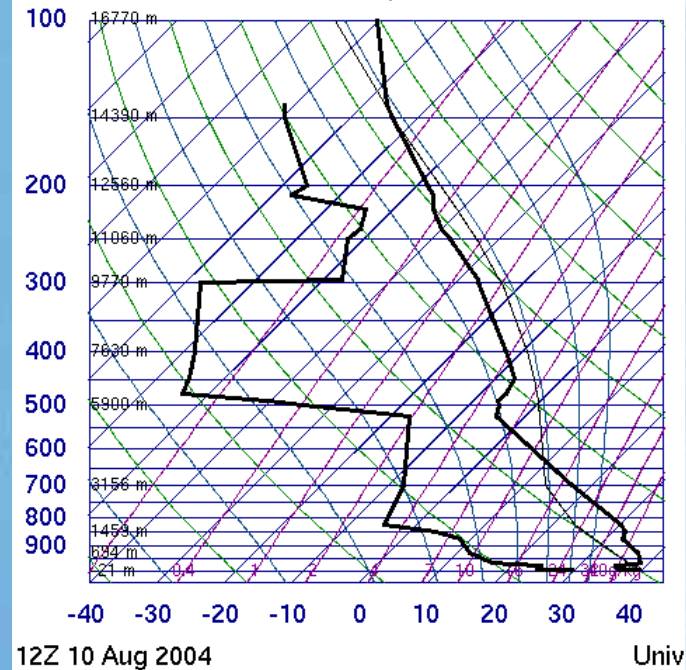




# Reasons: Stability and cloud development

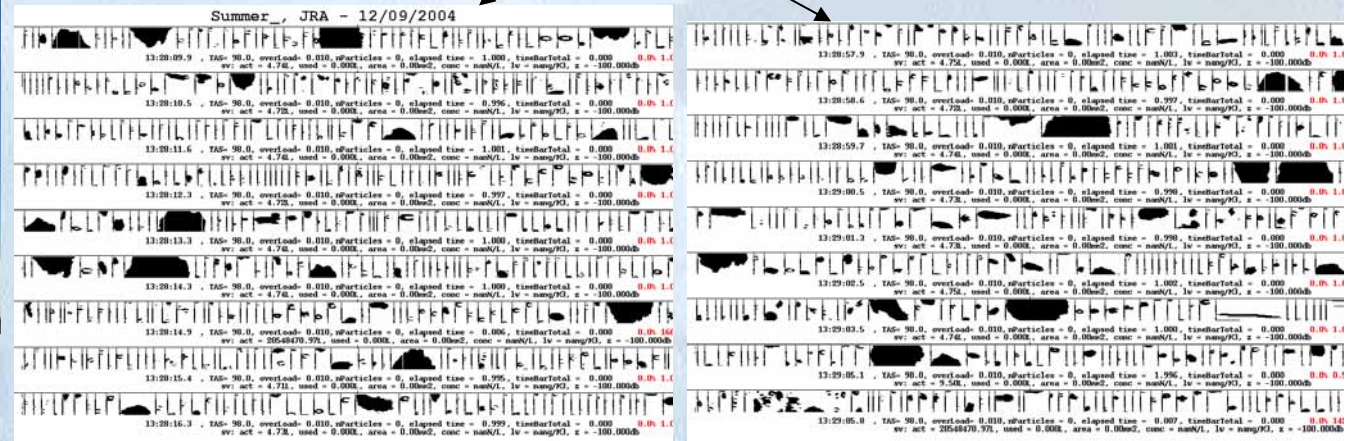
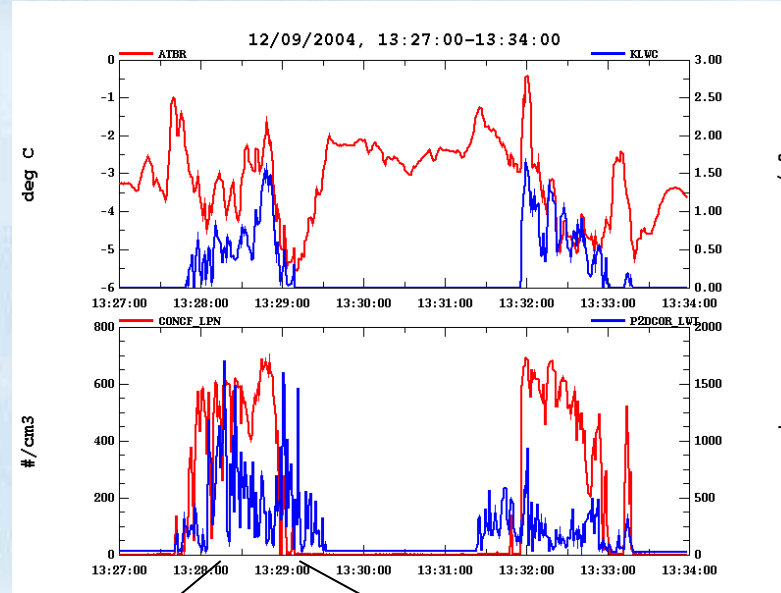
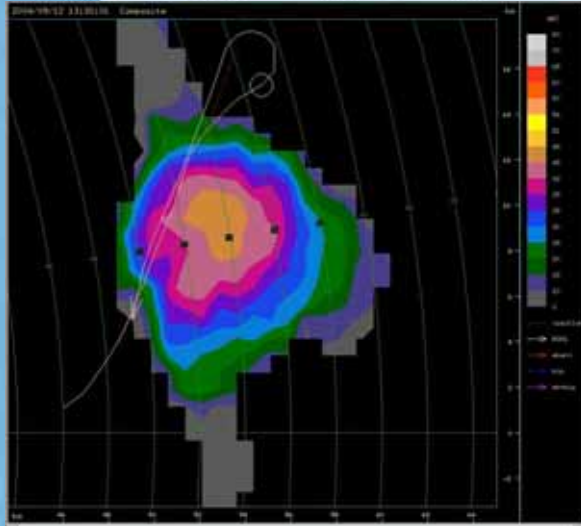


41217 OMAA Abu Dhabi Inter Arpt



- Capped clouds
- Weak or sporadic updrafts
- Cycling of cells – possibly pumping particles aloft
- Recycling particles into subsequent cells.

# Reasons: Microphysical – recycling

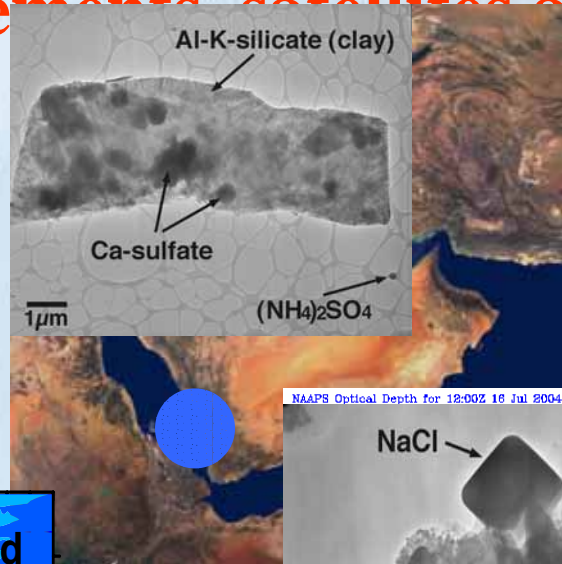


# Saudi Arabia (ASIF Region)

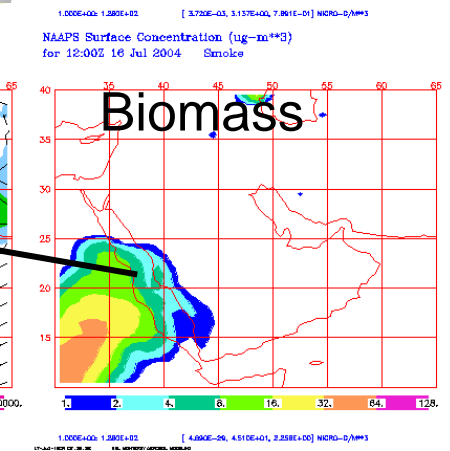
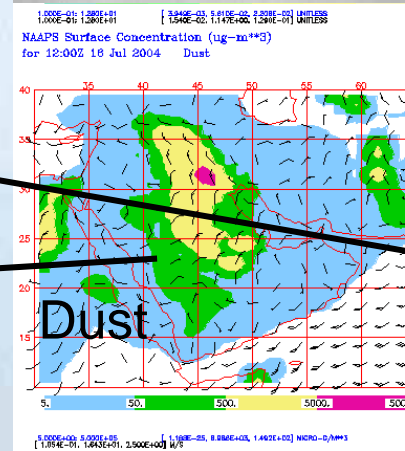
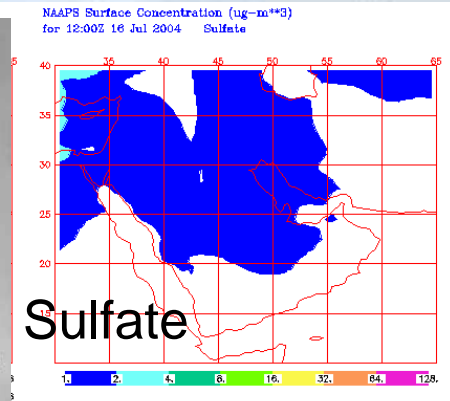
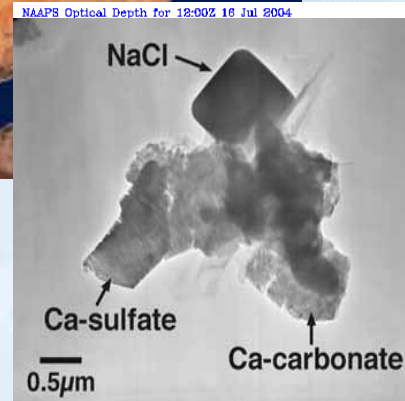
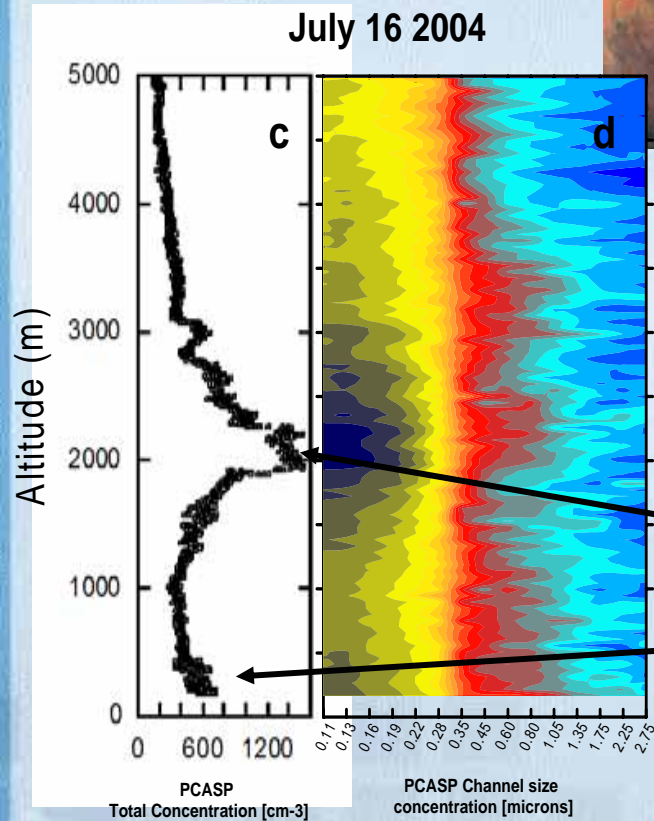
## Aerosols and Composition (Saudi Arabia): In-situ measurements, satellites and models



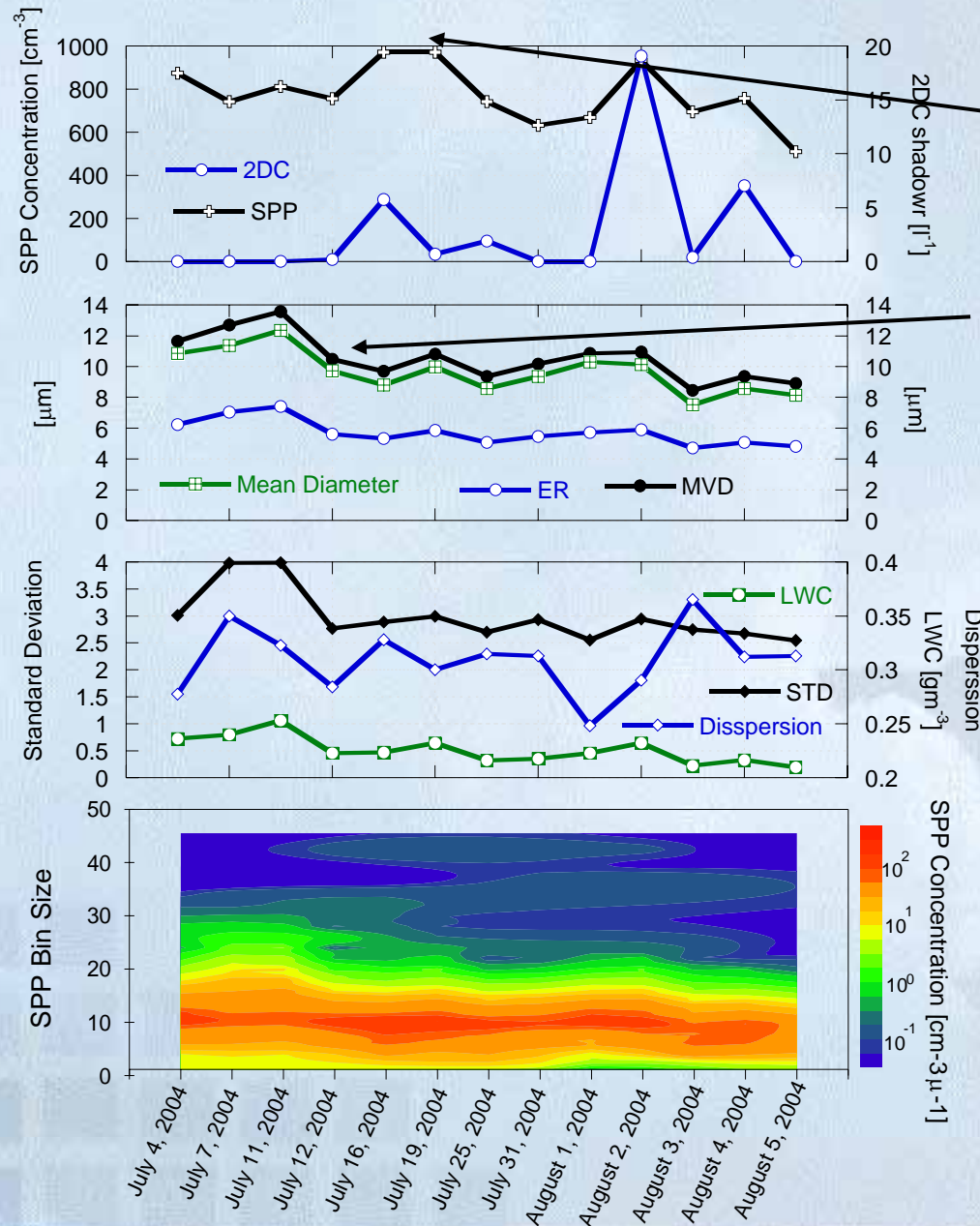
Vertical measured size distribution of aerosols between 0.1 and 3  $\mu\text{m}$  diameter



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

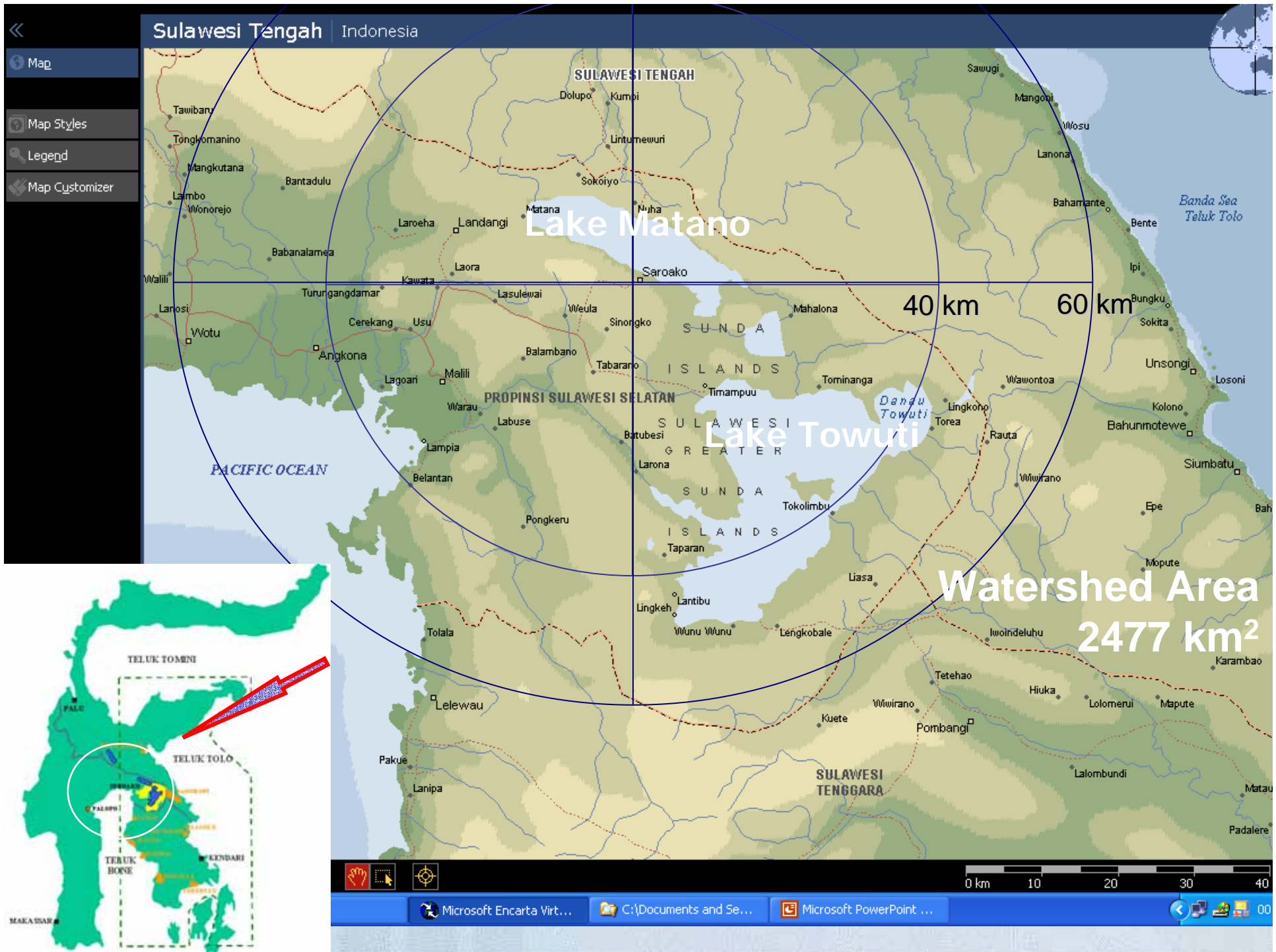


# Near cloud base measurements



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

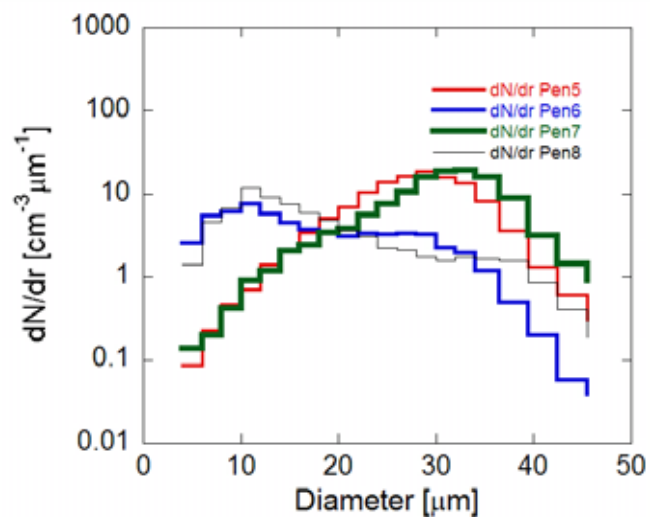
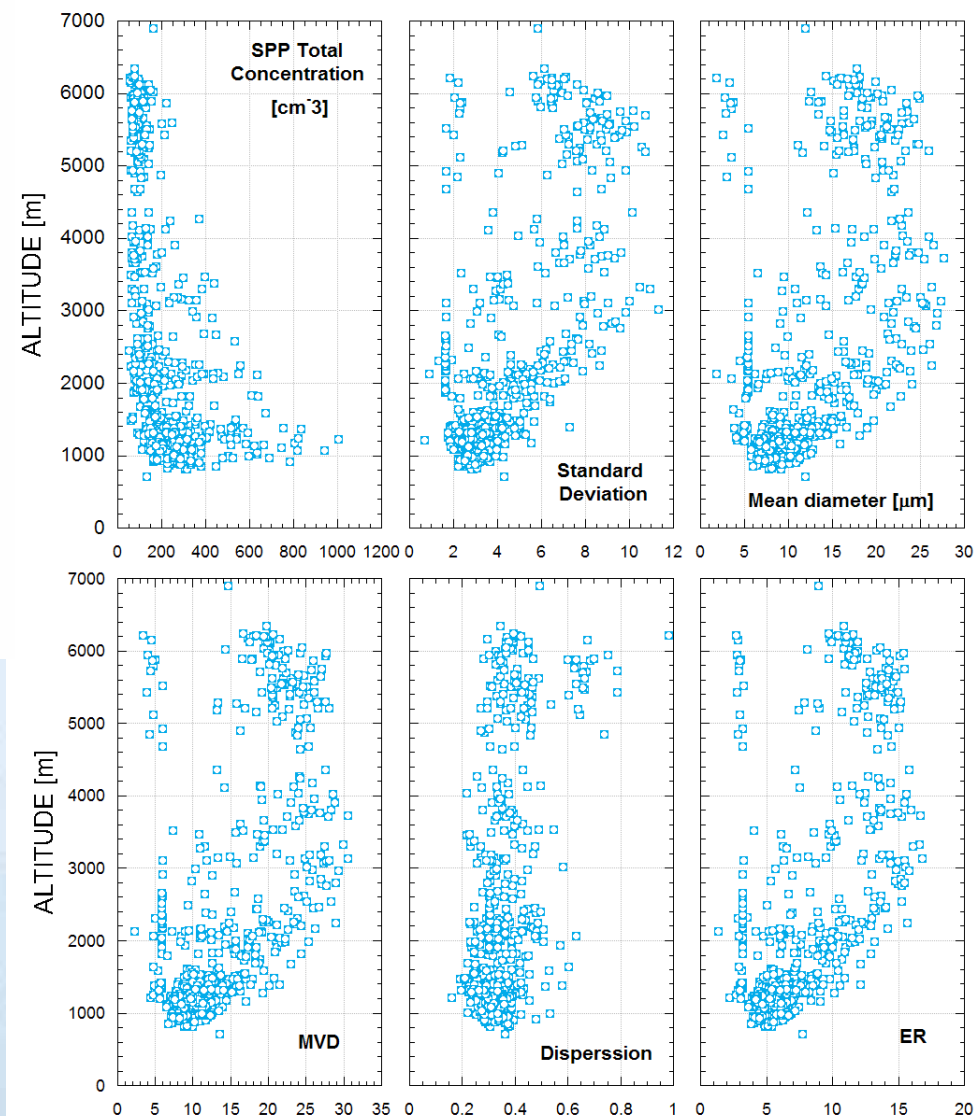
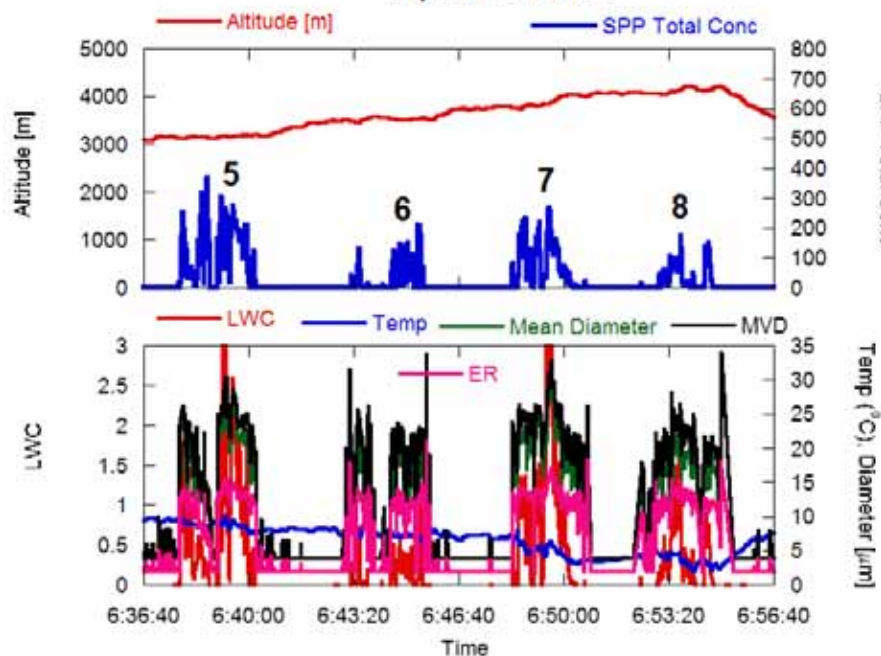
Microphysical measurements in clouds in Saudi Arabia during July and August 2004



# Sulawesi microphysical measurements



April 24 2005

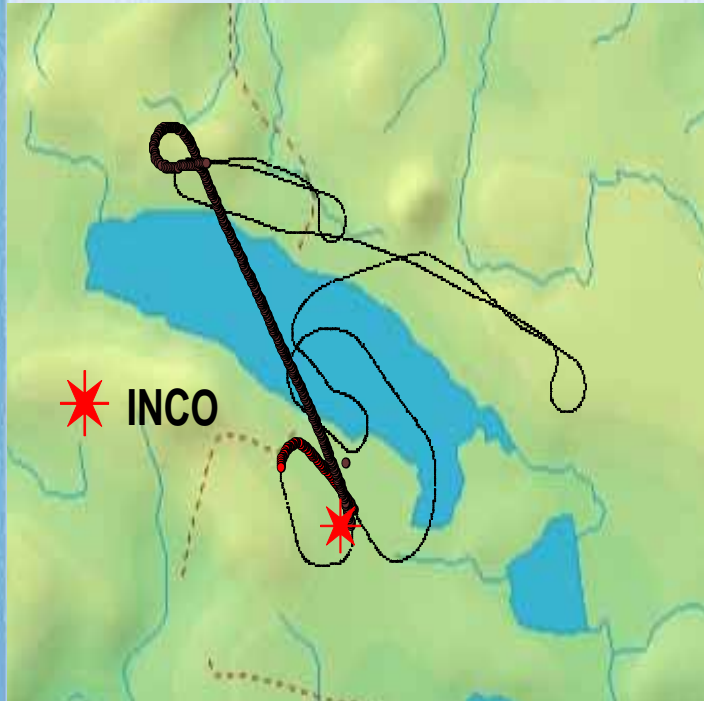




# Smelter plume

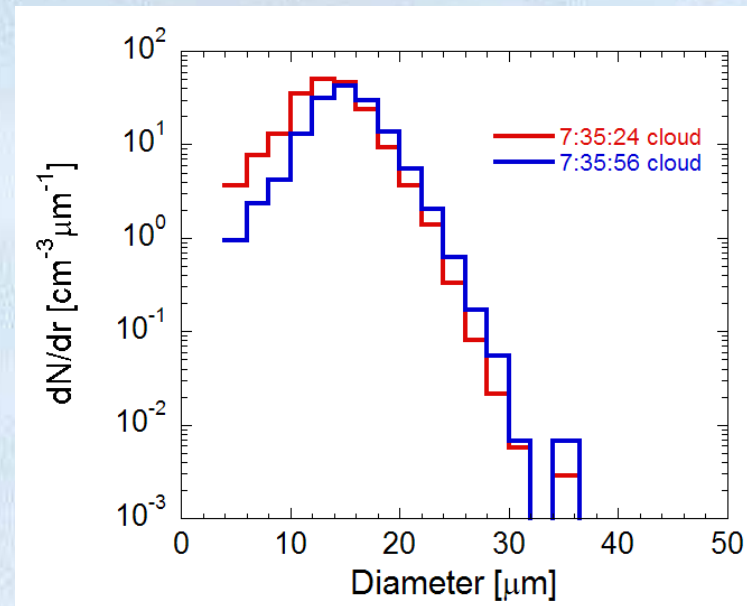
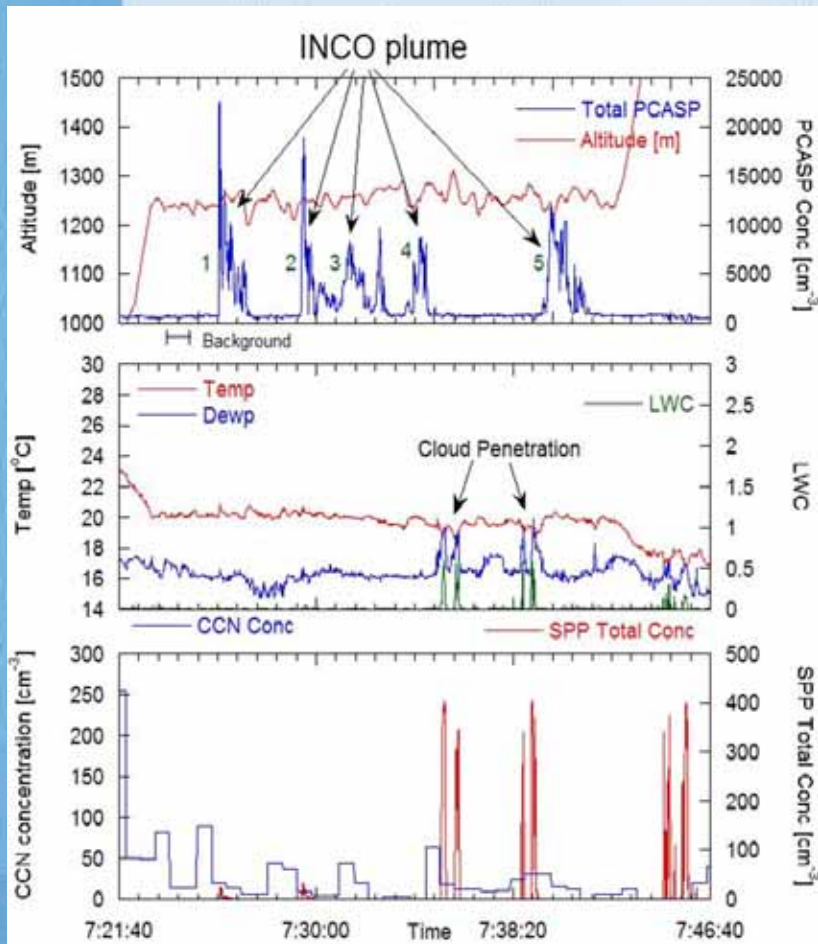


NCAR



- Five plume intercepts
- Near cloud base penetrations in clouds close to the plume

# Smelter plume



Cloud penetrations partially influenced by smelter plume

- Extremely high aerosol concentrations in plume
- Nonetheless, nearby cloud droplet distribution is still somewhat broad (also evident in other examples)

# Summary



- **Mexico – replicated South African results**
  - Why do storms last longer?
  - If drizzle drops are the result of seeding, how does that make ice processes more efficient?
- **UAE – no clear effects from hygroscopic seeding; importance of cloud thermodynamics/dynamics and background aerosols**
  - Are these the real or only reasons?
- **Saudi Arabia – variability in aerosol background; narrow droplet spectra and deep convective clouds (ice processes)**
  - Is knowing the aerosol characteristics and typical droplet spectra adequate to justify hygroscopic seeding?
- **Indonesia – efficient warm rain process; even polluted clouds show a warm rain process**
  - How would plume-affected clouds respond to seeding (hygroscopic or glaciogenic)?