Case study of the 9 April 2009 ‘brown’ cloud: Observations of Unusually High Cloud Droplet Concentrations in Saudi Arabia

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Research Motivation for Weather Modification

- Water Resource Stresses
- Severe Weather Hazards
- Inadvertent Weather Modification
- New Observational, Computational, Statistical Technologies
- Operational Programs with Little Scientific Basis
Scope of Operational Programs

- Operational programs in more than 37 countries worldwide
Objective

• Determine if cloud seeding in Saudi Arabia could be beneficial.
• Characterize the aerosol and cloud micro-physics in Saudi Arabia to determine optimal seeding method for enhancing precipitation in the region.
King Air 200
Saudi Arabia
Spring 2009

CCNC
Temp
LWC

2DC
AIMMS
PCASP
FSSP
Saudi Arabia Dust

Sun Low in the Sky
Riyadh, Saudi Arabia

MODIS Image 11 March 2009

Al Faisaliyah Center
Airborne Data Set

Quality Control - The process of conducting tests to check that measurements are being made correctly and accurately.

Quality Assurance - The process of reviewing a data set to eliminate (replace with missing value codes) measurements that are invalid due to known problems.
Observation: Ice accumulation on the unprotected leading edge of the aircraft’s wing show a color change from white to brown.

Objective: Test the hypothesis that the observation of brown ice build up on the aircraft wings were the result of the ingestion of a large concentration of aerosols by the cloud and document the differences in cloud properties between the brown ice cloud and a typical cloud.
9 April 2009 Flight Track

Take Off 12:40

Riyadh Airport

13:32

13:19

12:58

13:32
9 April 2009 Riyadh Sounding

TROZ Lvl: 3697 m AGL
FZG Lvl: 3307 m AGL
ccEL Hgt: 5434 m AGL
LFC Hgt: 7712 m AGL
LPC Hgt: 2909 m AGL
CCL Hgt: 3184 m AGL
LCL Hgt: 2795 m AGL
Water: 2.58 cm
Hail: 0 cm
T2Gust: 52 kt
WindEx: 53 kt
SWBAT: 339.8
CAP: 0.7
Boyd: 97.9
S(TT): 47.0
KO: -5.1
Li: -1.8
TT: 55.9
K1: 38.3
Tc: 31.6 °C

Storm: 270/18 0-6km
s-rH: 57 0-3km
s-rH: 71 0-2km
s-rH: 71 0-1km

CAPE+ only: 192 J/kg
CAPE 0-3km: 0 J/kg
CIN total: -16 J/kg
DCAPE 6km: 691 J/kg
VGP 0-4km: 0.201
EHI 0-2km: 0.1
MV: 20 m/s
BRN: 9

LFC Lift / LPL 738 mb

FOG FSI: 82.1
Threat: 15.2
Point: 4.4 °C

Plotted 34 of 557 winds
Riyadh Sounding Comparisons
TITAN Radar Display

Riyadh Saudi Arabia

9 April 2009 13:19:40

Aircraft Track
Liquid water content at 1 Hz measured by a DMT Hot Wire Probe on the 9 April 2009 research flight in Saudi Arabia.
Time serial of cloud droplet concentration (1 Hz average) at 18,000 ft measured by an FSSP on the 9 April 2009 Saudi Arabia flight.
Time series of mean droplet diameter (1 Hz data) at 18,000 ft measured by an FSSP on the 9 April 2009 Saudi Arabia flight.
Radar Reflectivity Composite
9 April 2009

13:14:17

13:26:42

Aircraft Track
Only 1 Hz measurements with DMT Hot Wire liquid water content above 1.0 g/m³ are included.
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Descent Profile 9 April 2009

Dust (1-3 um)  Optical Aerosols (0.1-3 um)
Cloud Condensation Nuclei (0.6 %)  Condensation Particle

Pressure Altitude [m]

Aerosol Concentration [#/cm³]
Conclusions

- The 'brown' ice cloud cell had very high droplet concentrations (up to 1200#/cm$^3$) and reduced average mean droplet diameters compared to a normal cell.

- Cloud base CCN measurements in Saudi Arabia are variable with some very high concentrations.

- The increases in droplet concentration was probably the result of increases in cloud base CCN concentration which may have resulted in the cell's death.
Acknowledgments

The participation of the University of North Dakota in the spring 2009 Saudi Arabia field project was funded by the Kingdom of Saudi Arabia through a contract with Weather Modification Inc (WMI).

Thanks to Terry Krauss, Jeff Tilley, Gökhan Sever and Robert Mitchell for support during the Spring 2009 Saudi Arabia project field project.
Thanks for Listening

Any Questions
Liquid water content equivalent (1 Hz data) at 18,000 ft measured by 2-DC probe on a research flight in Saudi Arabia.
9 April 2009 Flight

Images from the 2-DC between 13:00:26.45 and 13:00:28.19 (less than 2 seconds total) which correspond to the maximum liquid water content equivalent (1 Hz data) measured by 2-DC probe between on 9 April 2009 research flight in Saudi Arabia.
Images from the 2-DC between 13:24:52.46 and 13:24.59 (9 seconds total) which correspond to the low liquid water content equivalent (1 Hz data) measured by 2-DC probe on 9 April 2009 research flight in Saudi Arabia.