Case study of the 9 April 2009 'brown' cloud: Observations and modeling of convective clouds in Saudi Arabia,

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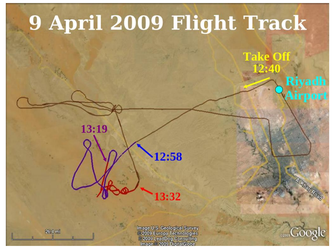
Introduction

Photographs of ice accumulation on the unprotected leading edge of the aircraft's wing during a 9 April 2009 research flight in central Saudi Arabia indicated a color change in the accumulated ice. Specifically, the ice color changed from white, during periods where low droplet number concentrations were encountered , to brown, during periods where high droplet number concentrations were encountered. Through a combination of aircraft observations, radar scans and in-progress modeling studies, we are examining the hypothesis that the high droplet number concentrations observed (as well as other changes in the convective cloud properties that were documented) are associated with the ingestion of a large condensation of aerosols into the convective cloud .

Aircraft Sampling Methodology

The King Air 200 aircraft used for airborne measurements had an Aircraft-Integrated Meteorological Measurement System (AIMMS), 2DC, PCASP, FSSP, Cloud Condensation Nuclei Counter (CCNC), Liquid Water Content (LWC) probe, and a Temperature (Temp) probe.



Flight tracks for research flights conducted near Riyadh, Saudi Arabia during the spring 2009 field project.

Visual Observations

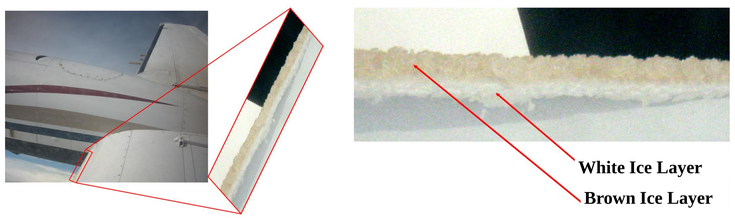
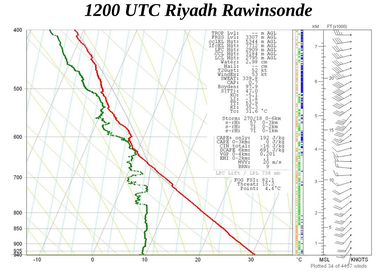


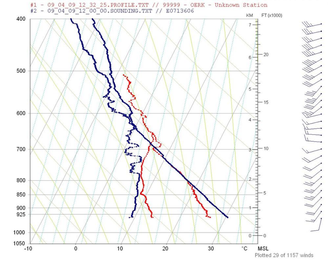
Image taken at 13:32 UTC 9 April 2009 showing accumulation of different colors of ice on the unheated leading edge of the wing on the King Air 200 research aircraft.

Soundings

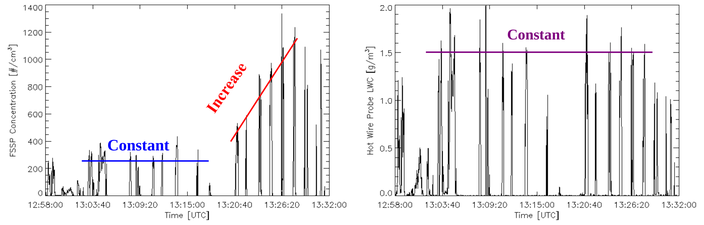
1200 UTC Riyadh Rawinsonde

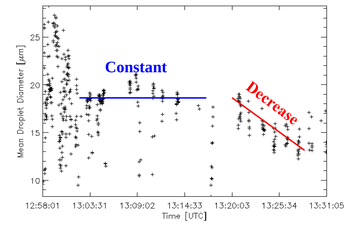


1240 UTC Aircraft Ascent to Southwest

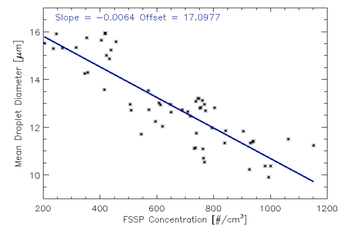


Cloud Properties

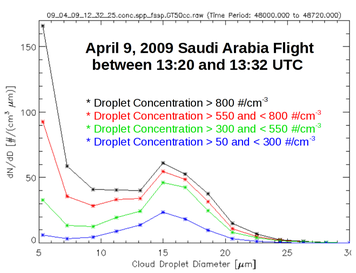




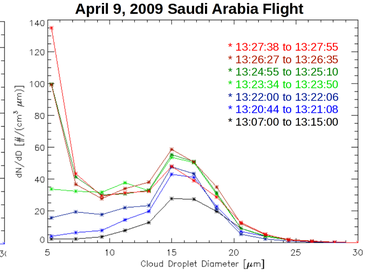
Time series (1 Hz) of cloud properties at 18,000 ft on the 9 April 2009 flight in Saudi Arabia. Droplet concentration and mean diameter are measured with an FSSP, while liquid water content (LWC) is measured with a DMT hot wire probe. The blue and red lines correspond to sampling different cloud cells.



Relationship between cloud droplet concentration and mean droplet diameter between 13:20 -13:28 9 April 2009. Only measurements with 1 Hz hot wire probe liquid water measurements above 1 g/m³ are included in the analysis.

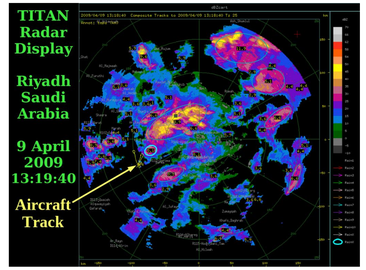


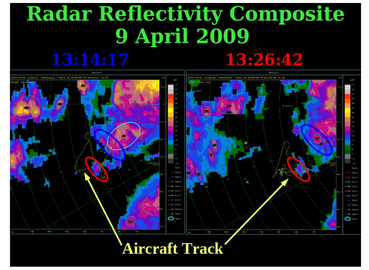
Family of curves showing relationships between cloud droplet diameter (μm), droplet concentration (#/cm³) and dN/dD (#/cm³μm).
Note that as droplet concentration increases, the prominence of a droplet mode with diameters < 7 μm also increases. Such a mode is consistent with droplets formed with dust particles (typical size 1-3 μm) acting as CCN.



Family of curves showing relationships between cloud droplet diameter (μm), and dN/dD (#/cm³μm) over time.
The black curve represents the time of accumulation of the 'White Ice' layer on the wing, while the other curves represent the transition to and accumulation period of the 'Brown Ice' layer on the wing, which also corresponds to the period of increasing droplet concentrations shown at left.

Radar Observations

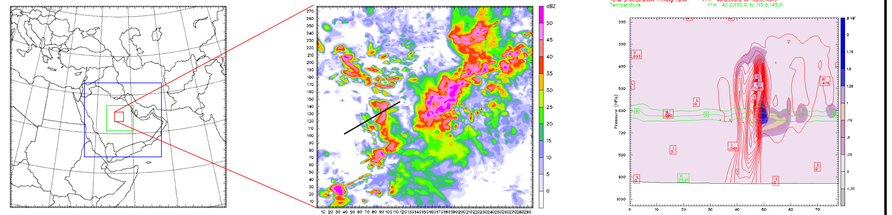




Blue ellipse denotes cell sampled from 13:03-13:19, while red ellipse denotes cell sampled from 13:20 - 13:28.

Preliminary WRF Modeling

We plan to utilize the Weather Research and Forecasting Model system to examine in detail the processes of this storm relative to our hypothesis. The preliminary runs (a free forecast and nudging data assimilation) are establishing the ability of the WRF system to reproduce the convection in this case with sufficient fidelity to warrant detailed experiments incorporating realistic Arabian dust aerosol/CCN interactions with WRF-Chem.



WRF –ARW Configuration
2-way interactive nested grids
24/8/2.67 /0.89 km, 60 levels
Initialized 00 UTC 4 April 2009
Lin et al. 6-class microphysics
RRTM/Dudhia radiative transfer
PBL: YSU/Monin-Obukhov
Noah LSM
Kain-Fritsch cumulus (24 km grid)

Above: *Max. reflectivity on 0.89 km domain at 14 UTC 4/4/09. Black line indicates x-section.*
Right: *Vertical x-sections at 13 UTC and 14 UTC 4/4/09. Fields shown: Temperature (C; bright green) Cloud ice+liquid water (g/kg; bright red) Cloud snow+graupel+hail (g/kg: shaded)*
Note decrease in extent and magnitude of hydrometeor mixing ratio fields during the hour interval.

Conclusions

- **The 'brown' cloud cell had very high droplet concentrations (up to 1200 /cm3) and reduced average mean droplet diameters compared to a normal cell. These high droplet concentrations do not appear to be associated with a narrower spectrum at a smaller mean diameter but instead suggest an additional mode of droplets superposed on the previously encountered distribution.**
- **Early WRF modeling results are encouraging though more work is needed before the fidelity of the simulations is sufficient for detailed aerosol-dust ingestion studies.**
- **The increases in droplet condensation was probably the result of increases in cloud base CCN concentration which possibly resulted in the cell's death.**

Acknowledgments

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