Feasibility Study for Rainfall Augmentation in the Kingdom of Saudi Arabia

Sampling Strategy for the Research Aircraft

The following document details flight profiles that are recommended to be flown in Saudi Arabia based on the flight scientists' experience from the 2006-2007 campaign. These profiles are guidelines for the pilots and instrumentation PIs and will be followed at the discretion of the Pilot-In-Command (PIC).

The numerical order of the flight plans is indicative of the measurement priorities.

Flight plan 1 – Hygroscopic seeding process study

The objective is to characterize the microphysical changes that occur following hygroscopic seeding at cloud base.

CCN table 1: 0.2 (4min), 0.5 (3min), 0.8 (3min)

Task A: Seeding process study with the research aircraft

i. Penetrate the cloud base at 1000ft above the cloud formation level starting in the updraft area and continuing in a direction upshear to downshear. Stay away from the precipitating core.
ii. Descend to cloud base at a fast rate of descent (2000 ft/min) and start seeding the updraft. Seeding rate should be at least 2 HBIP every 3.5 minutes.
iii. Immediately after seeding, ascend through the cloud base at 500 ft/min up to 2000 ft above the cloud formation level and circle in the updraft drifting downshear but staying away from precipitating cloud

Task B: Simultaneous aircraft measurements

i. Coordinate with the seeder aircraft and penetrate the cloud base 1000-2000ft above the seeder, first perpendicular to the upshear vector then turning out of cloud to penetrate along the upshear vector (upshear to downshear). Stay away from the precipitation core.
ii. Penetrate the cloud along the same vector multiple times until seeding stops.

Flight plan 2 – Glaciogenic seeding process study

The objective is to characterize the microphysical changes that occur following glaciogenic seeding at cloud top.

CCN table 1: 0.2 (4min), 0.5 (3min), 0.8 (3min)

i. Penetrate cloud tops between -5ºC and -10ºC 200 to 500ft below the tops of high SLWC areas that contain updraft. Pick young visibly growing towers.
ii. Continue cloud top penetrations at -5ºC to -10ºC 200 to 500ft below the tops following seeding with ejectable flares. Continue for 10 minutes after the last seeding event. Repeat the penetrations as quickly as possible.

Flight plan 3 – Aerosol/cloud interactions and cloud microphysical properties

The objective is to characterize the aerosol size distribution and the CCN activity (out of cloud) and aerosol-cloud interactions at the precipitating cloud base level (cloud layering may be present below the precipitating cloud base).

CCN table 1: 0.2 (4min), 0.5 (3min), 0.8 (3min)

Task A: Characterize the sub-cloud aerosol layer (remain out of cloud and out of rain)

i. Climb at 500ft/min as soon as possible after takeoff and throughout the aerosol profile. Maintain around 80m/s (~155kts).
ii. Observe any aerosol layering or stratification. Pick 2 intermediate altitudes from the surface to the cloud base.
iii. Fly for at least 10 minutes in straight and level flight (or standard rate turns) at each of the intermediate altitudes (one CCN SS cycle).
iv. If a dusty layer is located below cloud base, the aircraft should fly for 15 minutes at constant altitude flight while orbiting in a standard rate turn and maintaining 80m/s (filters).
v. A clean slot may be present immediately below the precipitating cloud base. This is usually a very shallow layer (100 to 200ft thick). If possible to sample this shallow layer while staying out of the cloud base, this should be done for 10 minutes (one CCN SS cycle).
vi. Avoid areas where precipitation may fall on the aircraft as much as possible

Task B: Characterize the cloud droplet spectra at about 500-1000ft above the base

i. Note the cloud base altitude
ii. Pick an altitude (500ft above the cloud formation level) where the ground is not visible in the cloud throughout the cloud base penetration
iii. Penetrate the cloud perpendicular to the upshear vector to avoid any cloudy areas where precipitation may be falling from above (often clouds are moving from west to east, so the penetrations should be oriented north to south or south to north)

Task C: Characterize cloud droplet growth and the evolution of cloud hydrometeors

i. Penetrate the cloud perpendicular to the upshear vector at 500-1000ft intervals (depending on cloud depth) from cloud base to cloud top. Avoid cloudy regions where precipitation may fall from above. If precipitation falling from above is observed during the penetration, repeat the penetration.
ii. Note the cloud top altitude

In addition, flight scientists may focus on the following specific objectives:

Objective: Characterize the vertical structure of the different cloud layers

- Climb through the layered cloud at 500 ft/min

Objective: Characterize the cloud microphysics with radar first echo

- Find altitude of cloud with radar echo from ground radar
- Penetrate the cloud at 500-1000ft intervals (depending on cloud depth) starting from the altitude

of the first radar echo

Objective: Characterize cloud turrets that pushes into dry air (bubble pushing above the layered cloud deck)

- Penetrate the cloud top at 200 to 500ft below the top
- Repeat several times until cloud top collapses (Updraft velocity, typical lifetime, evolution of cloud particles, surrounding humidity profile)

Flight plan 4 – Aerosol profile (no cloud present or forecast)

The objective is to characterize the aerosol size distribution and the CCN activity through the aerosol boundary layer. The departure of the aircraft should be timed with the release of the Riyadh sounding (11:00Z) when possible. The descending profile (part iii) should be as close as possible to the Solar Village which is located about 50 km northwest of Riyadh at an altitude of 650m (Latitude 24 54' 36" N. Longitude 46 24' 36" E).

CCN table 1: 0.2 (4min), 0.5 (3min), 0.8 (3min)
Swap to 2DP with second FSSP (aerosol range)

i. Climb at 500ft/min as soon as possible after takeoff and maintain 500ft/min throughout the aerosol profile. Maintain around 80m/s (~155kts). Continue the climb to 2000ft above the top of the aerosol boundary layer. Fly for 10 minutes above the aerosol boundary layer while maintaining standard rate turns. Aerosol PI should check CCN supersaturation (SS) cycle to make sure that a full SS cycle is flown at a constant altitude.
ii. Observe any aerosol layering or stratification. Pick 2 intermediate altitudes from the surface to the top of the aerosol boundary layer.
iii. Descend at 500 ft/min maintaining a standard rate turn to the lowest possible altitude.
iv. Fly for at least 10 minutes in straight and level flight (or standard rate turns) at each of the intermediate altitudes (one CCN SS cycle)
v. If a dusty layer is located, the aircraft should fly for 15 minutes at constant altitude flight while orbiting in a standard rate turn and maintaining 80m/s (filters).
vi. RTB at the lowest possible altitude.

Flight plan 5 - Pollution plume survey flight (no cloud present or forecast)

CCN table 2: 0.5 (continuously)
Swap to 2DP with second FSSP (aerosol range)

i. Plan 2 or 3 (40nm) flight legs oriented perpendicular to the wind direction and <30nm from the city center.
ii. Climb at 500ft/min as soon as possible after takeoff and maintain 500ft/min and 80m/s (155kts). Continue the climb to 500 to 2000ft AGL. Intercept one end point of your planned flight track. If possible do not change the altitude for the duration of the track.
iii. Repeat the track for the second time at an altitude 1000ft above the first track.
iv. If a dusty layer is located, the aircraft should fly for 15 minutes at constant altitude flight while orbiting in a standard rate turn and maintaining 80m/s (filters).
v. RTB at the lowest possible altitude.

Flight plan 6 - Satellite overpass (cloud)

CCN table 1: 0.2 (4min), 0.5 (3min), 0.8 (3min)

i. Climb at 500ft/min immediately after takeoff. Maintain 80 to 100 m/s (155kts to 195kts).
ii. Intercept the satellite track. Continue the climb at 500 -1000 ft/min to the satellite overpass point. Plan to be in cloud top at the satellite overpass point at the satellite overpass heading and at the satellite overpass time (layered cloud). If the cloud is convective, penetrate the tops of feeder towers that are not shielded by any other higher level cloud. Continue cloud penetrations up to the cloud top as close to the overpass time as possible (convective time scales are much shorter).
iii. Resume navigation and RTB while maintaining a descent rate <1000ft/min.
iv. If a dusty layer is located en-route, the aircraft should fly for 15 minutes at constant altitude flight while orbiting in a standard rate turn and maintaining 80m/s (filters).

Flight plan 7 - Satellite overpass (aerosol, no cloud present or forecast)

CCN table 1: 0.2 (4min), 0.5 (3min), 0.8 (3min)
Swap to 2DP with second FSSP (aerosol range)

i. Climb at 500ft/min immediately after takeoff and throughout the aerosol profile. Maintain 80m/s (155kts).
ii. Intercept the satellite track. Continue the climb to the middle of the aerosol boundary layer. Fly for 10 minutes at this altitude.
iii. Resume aircraft climb at 500ft/min and plan to be at the satellite overpass point 2000ft above the aerosol boundary layer. Fly for 10 minutes at this altitude in standard rate turns around the satellite overpass point. Aerosol PI should check CCN supersaturation (SS) cycle to make sure that a full SS cycle is flown at a constant altitude.
iv. Descend at 500 ft/min maintaining a standard rate turn around the satellite overpass point down to the lowest possible altitude. Plan to be at an altitude in the middle of the aerosol layer at the satellite overpass time.
v. Once the profile is complete, RTB at the lowest possible altitude.
vi. If a dusty layer is located en-route, the aircraft should fly for 15 minutes at constant altitude flight while orbiting in a standard rate turn and maintaining 80m/s (filters).

Flight plan 8 - Sounding comparison flight

i. Climb at 500ft/min immediately after takeoff and throughout the profile. Maintain 80m/s (155kts).
ii. Once reaching the point of ascent, climb at 500ft/min up to 20000ft in standard rate turns.
iii. Resume navigation and RTB while maintaining a descent rate <1000ft/min.
vi. If a dusty layer is located, the aircraft should fly for 15 minutes at constant altitude flight while orbiting in a standard rate turn and maintaining 80m/s (filters).