Cloud Aerosol Interaction and Precipitation Enhancement Experiment

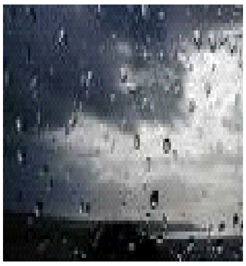
IMPLEMENTATION PLAN

Phase II: 25 August - 24 October 2010







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CAIPEEX PHASE II IMPLEMENTATION PLAN

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CAIPEEX PHASE-II IMPLEMENTATION PLAN

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1) Introduction

Phase-I of the CAIPEEX has been completed successfully during the period May-September 2009, wherein aircraft observations of aerosols and cloud microphysical parameters have been carried out over different parts of the country. The preliminary results of the CAIPEEX Phase-I brought out new findings. Based on the scientific conclusions obtained during the Phase-I, Phase-II of the CAIPEEX is planned to be conducted over rain shadow regions of the peninsular India. The first part of Phase II will be conducted during the period August-October 2010. It was scheduled to be conducted during July-August 2010, however due to court matters; it had to be postponed by two months period.

Objectives of Phase-II are:

(1) Conduct the randomized seeding experiments
(2) Aerosol and Cloud microphysical Observations over selected parts of India and seas.

The seeding will be carried out using pyrotechnique flares and salt powder. The flares consist of hygroscopic material (NaCl) for base seeding and glaciogenic material (AgI) for top seeding in the mixed phase clouds. Two aircrafts will be used: (1) cloud microphysical, aerosol observations and (2) seeding. C-band Doppler radar will be utilized for tracking the clouds. The data for trace gases and radiation will be collected. The upper air sounding will be conducted at the time of aircraft flights. At the base, Disdrometer, Microrain radar and Microtops will be set up.

Details of aircraft are given in Appendix 1, Radar in 2, Instruments in 3.

2) Experimental design for seeding

The proposed approach for the seeding is based on the South African experiment design. The success of the South African experiment during 1995-1997 triggered such experiments over different parts of the world. Some of the prominent experiments conducted or in the process are in the countries: Mexico, Australia, Indonesia, Saudi Arabia etc. The randomized procedures are also the same as used in the South African experiment. The experiment unit is defined as the storm measured by the radar and tracked by TITAN using a 30-dBZ threshold for a time period 20 minutes prior to the decision time. Decision time is defined as the time when the pilot first selects a sample cloud. The TITAN tracking and analysis is fully automated to avoid the possibility of bias based on the knowledge of the seed/no-seed decision. TITAN produces time series of storm properties for use in the analysis. The following response variables are chosen for the analysis.

2.1 Response variables

Radar estimated precipitation flux
Total storm mass
Storm mass above 6 km asl
Storm area
Height of maximum reflectivity
In addition, following cumulative quantities will be considered.
Total case precipitation from decision time until 60 minutes after decision time.

Area-Time-Integral from decision time until 60 minutes after decision time

2.2 Statistical Hypothesis

The hypothesis to be tested for each time series of response variable is that the value of the variable is higher for the seeded cases than for non-seeded cases during the time period 10-60 minutes after decision time. The null hypothesis is: No difference in response variable for the seeded and non-seeded cases. The time response variables will be tested using first three quartiles of the distribution of the values for seeded and non-seeded cases.

The Wilcoxon-Mann-Whiteney (WMW) statistic will be used to test the hypothesis. The test compares the sums of the ranks from two samples to detect the differences in location (i.e. mean or median). The WMW test is non-parametric i.e. it does not require that the samples come from a specified distribution. The WMW test is chosen over the student t-test because cloud seeding measurements tend not to be normally distributed. One of the estimates of the sample size is: for 5% error and 80% power to detect a 25% increase in rain mass due to seeding is 266 cases evenly distributed between the seeded and non seeded cases.

We hope to achieve this in flying 40 days with 4 cases per flight. It has been planned to use 80 hours of each aircraft (total 160 hours) for the seeding purpose.

2.3 Physical Hypothesis

It is generally accepted that scientific understanding of the physical processes affected by seeding is needed to reinforce the statistical results before such results are full accepted. As we have two aircraft one with instrumented to conduct the cloud microphysical measurements, it provides unique opportunity to validate following physical hypothesis.

We will use giant nuclei (GM. 3 µm diameter) for the seeding purpose. The seeding will generate following processes in the cloud.

Broadens the cloud droplet spectra near base
Enhance the production of drizzle.
Drizzle enters in to high LWC regions of the same turret and spread to other turrets.
Above 0C the drizzle drops will freeze and will become primary graupel embryos.
Broader cloud droplet spectra below 0 C would result in higher riming rates.
Combination of large drop freezing and broader cloud droplet spectra result in secondary ice generation.
These provide embryos for formation of new drops.

Seeded storms will differ from unseeded storms
Broader droplet spectra near cloud base.
Enhanced drizzle concentration near the tops of turrets.
Enhanced drizzle in the downdraft regions
Enhanced large drop graupel embryos above 0C
Enhance secondary ice generation below 0C.

2.4 Randomization procedure

The randomization procedure will be the same as that was used in South African and Mexican experiments.

The assignments of clouds to seeded (target) and non-seeded (control) groups will be done using randomization technique. There will be two sets of envelops with the radar meteorologists and with pilots. The envelop at radar meteorologist contains options Seed or No-seed and that of pilot contains Yes or NO. After seeing the cloud pictures on the radar screen, the decision of the seeding will be taken. The pilot will take off and will be directed towards the area of seeding. The pilot and the radar meteorologist will talk each other about the clouds in the area of the seeding. If pilot sees good number of clouds, then he will take decision and will declare the case. Both the radar meteorologist and pilot will select the envelop randomly and open it. The radar meteorologist will communicate the result to the pilot who then will determine whether to seed nor not based upon following decision table.

Radar	Aircraft	Action
Seed	No	No-seed
Seed	Yes	Seed
No-seed	Yes	No-seed
No-seed	No	Seed

The pilot will not tell the radar meteorologist whether the decision is seed or not and pilot and radar meteorologist will not communicate on issues related to the effects of seeding.

The seeder aircraft will release SF6 as the tracer for seeding. The instrumented aircraft has SF6 detector installed in it. Using SF6 detector, instrumented aircraft will identify the seeded cloud for the cloud microphysical observations.

3. Aerosol and microphysical observations over different parts of India.

It is planned to continue the observations of the aerosols, cloud microphysics, trace gas and radiation over selected regions of India. 40 flying hours of the instrumented aircraft will be utilized for it. The missions and objectives are as follows.

3.1 Arabian Sea

Number of studies has reported that the deep convection develops 100-150 km upwind of the western Ghats. NCAR Electra was flown on 24 June 1979 (0800-1030 Z) over Arabian sea in the MONEX experiment to collect the wind data. It was shown that the downwind convergence generates the deep convection away from the coast. It has been planned to further investigate the dynamics of the deep convection taking flights over the Arabian Sea. Existence of deep convection, associated rainfall imply source of latent heat for the monsoon circulation which remained unrecognized so far. The flight data may reveal the dynamic structure of the deep convection. The flight is planned from Panjim / Pune base in the first week of September.

3.2 Bay of Bengal

Monsoon starts withdrawing from the northernmost part from 15 September. Over the peninsular India and adjoining Bay of Bengal, the trough is found during the month of October. Occasionally, the cyclonic storms also are formed during the same period. In order to study the convection over the Bay of Bengal, the flights are planned in the month of October from Vishakhapattanam/ Vijayawada base.

3.3 Bareilly

In CAIPEEX Phase I aircraft flights were conducted from Bareilly base to collect the data over CTCZ area. It has been planned to continue these observations in this phase also. This has been planned in the month of September.

3.4Udaipur

The missions have been planned from Udaipur base to collect the aerosol and other data over the desert regions. Ground observations of trace gases, meteorological parameters will be taken by scientist from the Udaipur University.

4. Large Scale Heat and Moisture budgets

Estimates of the heat and moisture budgets ate key factors in validation of the cumulus parameterization schemes in the numerical models. The estimates from model produced data are biased towards the convection scheme used in the model. There are large variations in the estimates derived from different schemes. Most of schemes are developed using the Marshall Island data during the period 15 April to 22 July 1956 in which four upper air soundings were conducted during the day.

It is planned to estimate the Heat and moisture profiles over the closed domain shown in figure 4 (Appendix 4). The outer domain represents the Synoptic scale and inner domain represents the Meso scale. IMD is requested to take two additional RS/RW flights during IOP period of 2 days in the month of September.

Appendix 1

1) **Instrumented Aircraft**

Aero Commander 690 A is equipped with 2 twin prop engines, and a pressurized cabin. The aircraft has been used in weather modification experiments and also atmospheric chemistry studies. The design of the Aero Commanders lends to use in harsh environments, like severe icing and turbulence, warm temperatures, high altitudes and long endurance. This makes them ideal for use in atmospheric research.

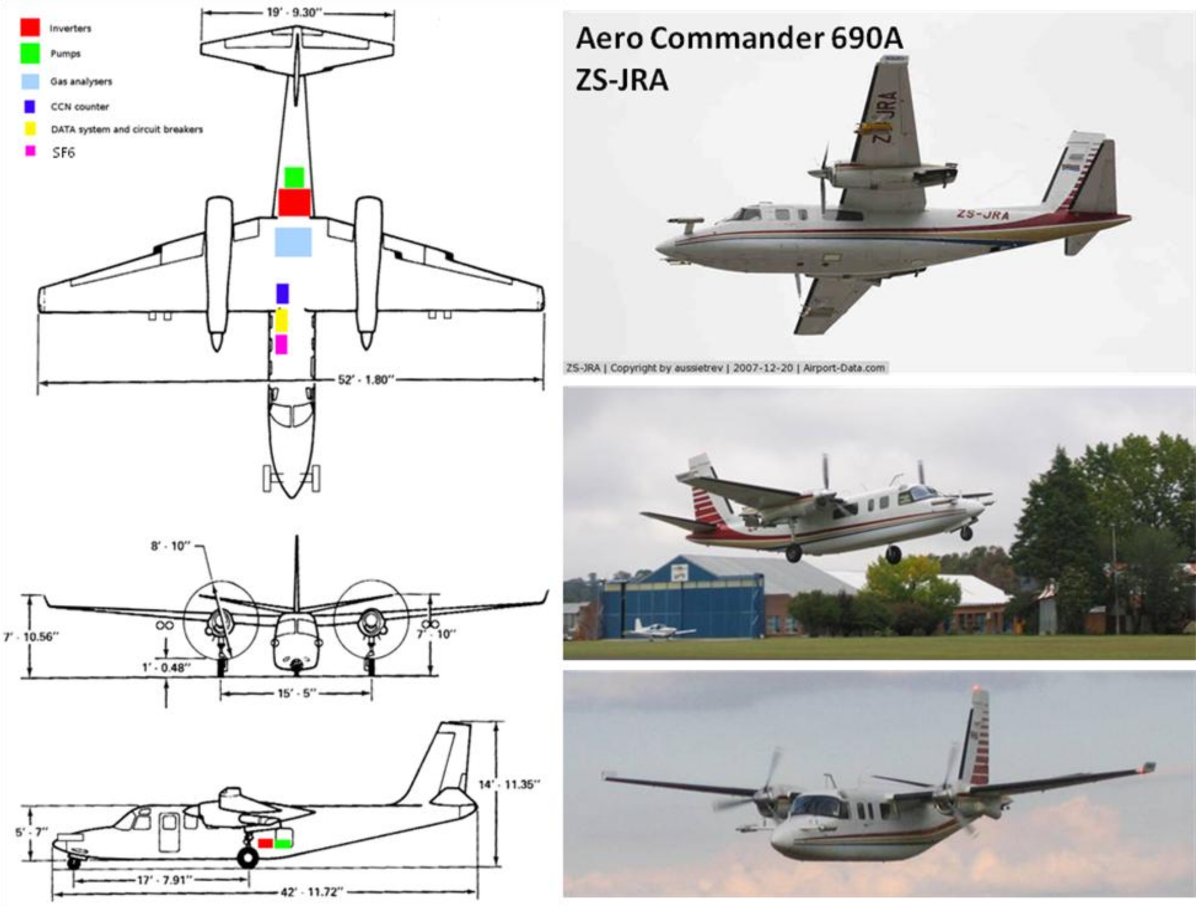

Figure : 1 **Picture of Aerocommander (ZS-JRA)**

Technical Specifications :

- Aircraft length: 44'4.25"
- Aircraft wingspan: 46'6.64"
- Aircraft height: 14'11.35"
- Maximum gross weight: 10 250 lbs
- Nominal operating altitude: 25 000' to 28 000' AMSL
- Maximum operating altitude: 31 000' AMSL
- Minimum speed: 82 KTS Nominal cruise speed: 245 KTS
- Maximum speed: 260 KTS @ 25000' (as equipped)
- Nominal sampling speed: 100 to 180 KTS
- Nominal rate of climb: 1200'/min@ 18000' & 120KTS & 10000lbs
- Maximum rate of climb: 3400'/min@ 2000'MSL & 140KTS & 9000lbs
- Endurance with maximum fuel: 5.5 HRS @ 5000'MSL & 150KTS (no reserve)
- Crew Capacity: 1 to 4 (with instrument racks)

2) **Seeder Aircraft**

A Two-seater, single engine Ayres Turbo-Thrush aircraft equipped with salt seeding capability with SF_6 dispenser, along with wing-mounted hygroscopic flares for warm cloud seeding.

Figure 2 : Pictures of the seeder aircraft with wing mounted hygroscopic flares

Turbo Thrush Technical Information

Total Length :	32.808 ft	10.000 m
Greatest height :	9.186 ft	2.800 m
Wingspan :	44.291 ft	13.500 m
Wing area :	326.149 sqft	30.300 qm
Max. speed :	138 kts	256 km/h
Cruising speed :	130 kts	241 km/h
Initial climb rate :	1732.28 ft/min	8.80 m/s
Wing load :	18.45 lbs/ft2	90.00 kg/qm
Range :	664 nm	1230 km
Maximum Weight carried	2399.0 lbs	1088.0 Kg

Appendix 2
C- Band Doppler Radar Specifications

Properties	C Band Doppler Radar
Frequency Range	5400 – 5700 MHz Doppler Radar
Transmitter Type	Magnetron
Maximum measuring range	200 Km
Beam width	0.95 deg
Pulse repetition frequency	786/1180 PPS
Peak Power	250 kW
Pulse Width	0.8 or 2.0 microsec
Receiver Type	Parabolic Antenna
IF Frequency	60 MHz
Digital Receiver	Yes
Minimum Detectable Signal	-113 dBm
Radar Constant	
Reflector Type	Parabolic Dish
Reflector size	8 ft
Polarization	Single
Antenna Gain	38 dB
Beam Width	1.65, 0.95 deg
Precipitation	Yes
Intensity	Yes
Turbulence	Yes
Velocity	Yes

The systems including the relevant software will be utilized for cloud seeding and tracking of the seeding aircraft. The systems shall be capable of transmitting data in a known standard format at specified intervals to a remote processing center by using an efficient way of data compression. This processing center shall be able to process, display, archive and distribute the radar data to a number of remote users.

Appendix 3

Aircraft Instrumentation:

VARIABLE	INSTRUMENT	RANGE	ACCURACY	RESO.	FRE.
Air temperature	Rosemount 102DB1CB	-50°C to +50°C	0.1°C	0.01°C	1 Hz
Air temperature (reverse flow)	0.038" DIA. Bead Thermistor	-30°C to +50°C	0.05°C/0.3°C incl DHC	0.01°C	< 1 s TC
Relative humidity (reverse flow)	Thermoset Polymer RH Sensor	0 to 100% RH	2% RH	0.1% RH	5 s TC @ 20°C
Barometric pressure	MEMS Pressure Sensor	0 to 110000 Pa	100 Pa	10 Pa	20 Hz
u wind component	Extended Kalman Filter (EKF)		0.50 m/s @ 75 m/s TAS	0.01 m/s	5 Hz
v wind component	Extended Kalman Filter (EKF)		0.50 m/s @ 75 m/s TAS	0.01 m/s	5 Hz
w wind component	Extended Kalman Filter (EKF)		0.50 m/s @ 75 m/s TAS	0.01 m/s	5 Hz
Position (Lat/Long)	WAAS DGPS		2 m (2 □)	< 1 m	5 Hz
Altitude	WAAS DGPS	-300 to 18000 m	5 m (2 □)	< 1 m	5 Hz
Geometric Altitude	King KRA 405 Radar Altimeter	0 to 2000 ft	3% < 500 ft 5% > 500 ft	0.48 ft (0.15 m)	
Roll Attitude (^{o})	MEMS IMU/GPS/EKF	-60 to +60°	0.1°	0.01°	5 Hz
Pitch Attitude (^{o})	MEMS IMU/GPS/EKF	-60 to +60°	0.2°	0.01°	5 Hz
Yaw Attitude (^{o})/	MEMS	0 to 360°	0.1°	0.01°	5 Hz

Heading	IMU/GPS/EKF				
Angle of attack (°)	MEMS Pressure Sensor	-15 to +15°	0.03° @ 150 m/s	0.001° @ 150 m/s	20 Hz
Side-slip (°)	MEMS Pressure Sensor or equivalent	-15 to +15°	0.03° @ 150 m/s	0.001° @ 150 m/s	20 Hz
True Air Speed	MEMS Pressure Sensor	0 to 150 m/s	0.1 m/s	0.01 m/s	20 Hz
Logging, telemetry & event markers	ESD DTS (GPS)				1 Hz
Cloud droplet spectra	DMT CDP	2 to 50 µm		1 to 2 µm, 30 bins	1 Hz
Cloud particle spectra	DMT CIP	25 to 1550 µm		25 µm, 62 bins	1 Hz
Cloud particle image	DMT CIP	25 to 1550 µm		25 µm	
Precipitation imaging and spectra	DMT PIP	100 to 6000 µm			
Liquid water content	DMT LWC-100	0 to 3 g/m^3	0.05 g/m^3	0.01 g/m^3	1 Hz
Liquid water content	CDP calculated	> 3 g/m^3			1 Hz
Isokinetic aerosol inlet	Brechtel double diffuser inlet	28 lpm			100 m/s
Aerosol spectrometer	PMS PCASP SPP-200	0.1 to 3 µm		0.02 µm, 30 bins	1 Hz
CCN	DMT CCN counter	0.5 to 10 µm 0.1 to 1.2 % SS	See text	0.5 µm, 20 bins	1 Hz
Gadget for cloud water collection					

Trace Gases and Radiation Instruments

		Instruments
Trace Gases	• O_3 • SO_2 • Oxides of Carbon and Oxides of Nitrogen	Horiba Model APOA 370 Horiba Model APSA 370 Thermo Model 48i Thermo Model 41C Thermo Model 42i Additional Gas calibration system – Thermo 146C These measurements will be integrated with the main data and will be displayed online.
Radiation Equipments	• All downwelling and upwelling SW and LW radiations	KIPP & Zonnen Model CMP-22 (for SW) KIPP & Zonnen Model CGR-4 (for LW)

Apart from the above, Aircraft will be equipped with Continuous Tracer (SF6) Analyzer for real-time, in-situ measurement of SF_6 with sensitivity better than 5 ppt in spray of .7 liters/sec.

Data Acquisition

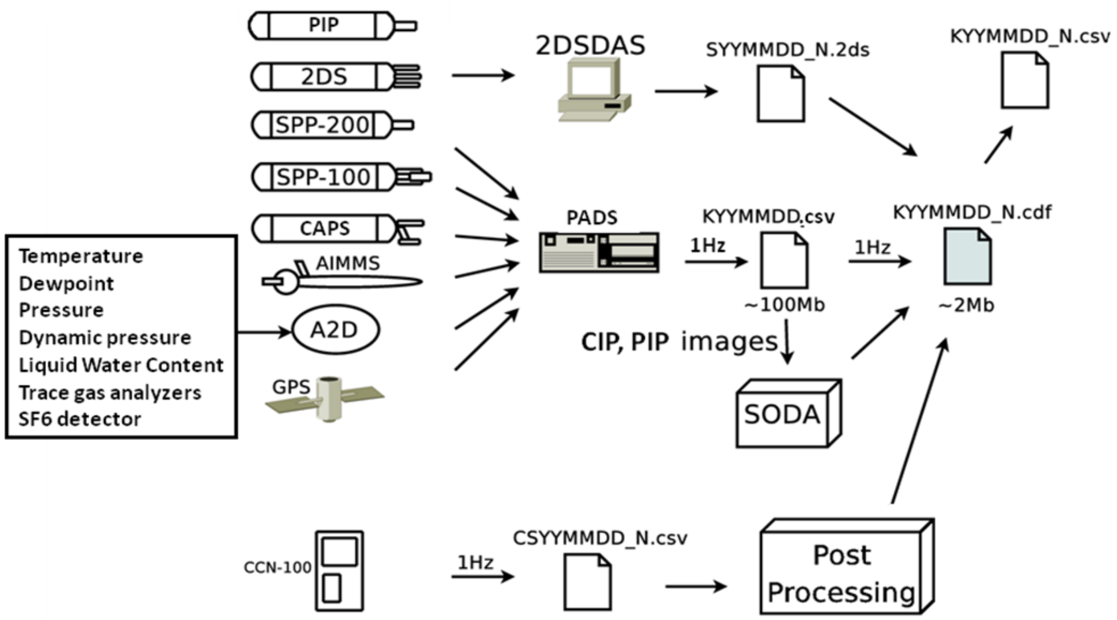

Figure 3 : **Data flow and processing schematic for the research aircraft**

Appendix 4

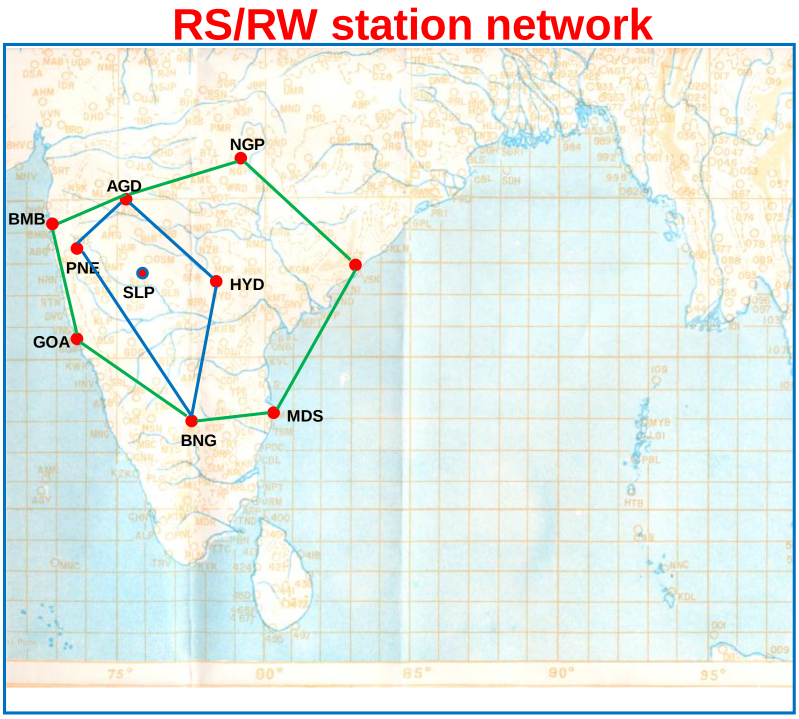

Fig. 4 RS/RW Station network for the budget studies.