Challenges in Weather modification status in different countries

Thara Prabhakaran

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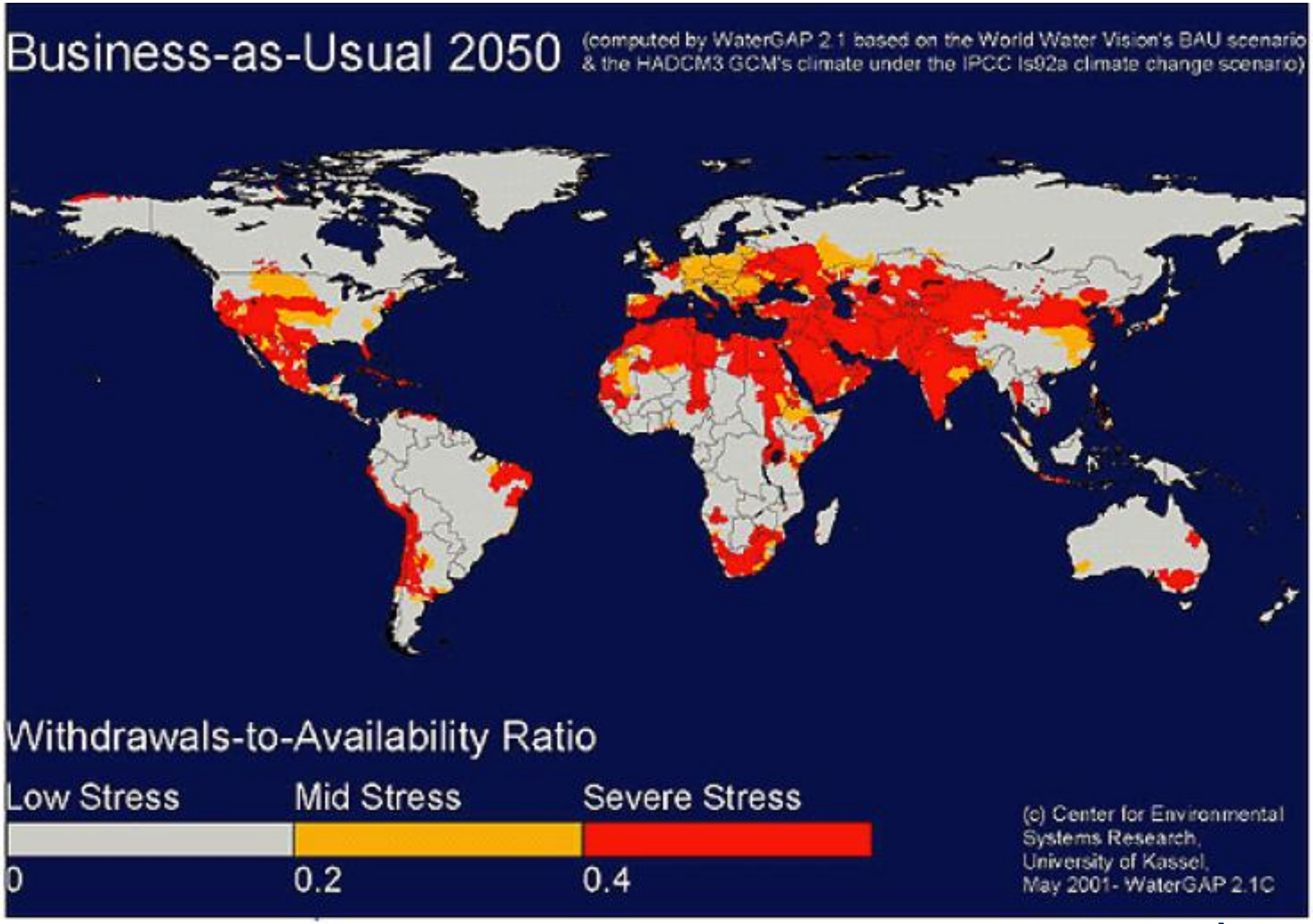
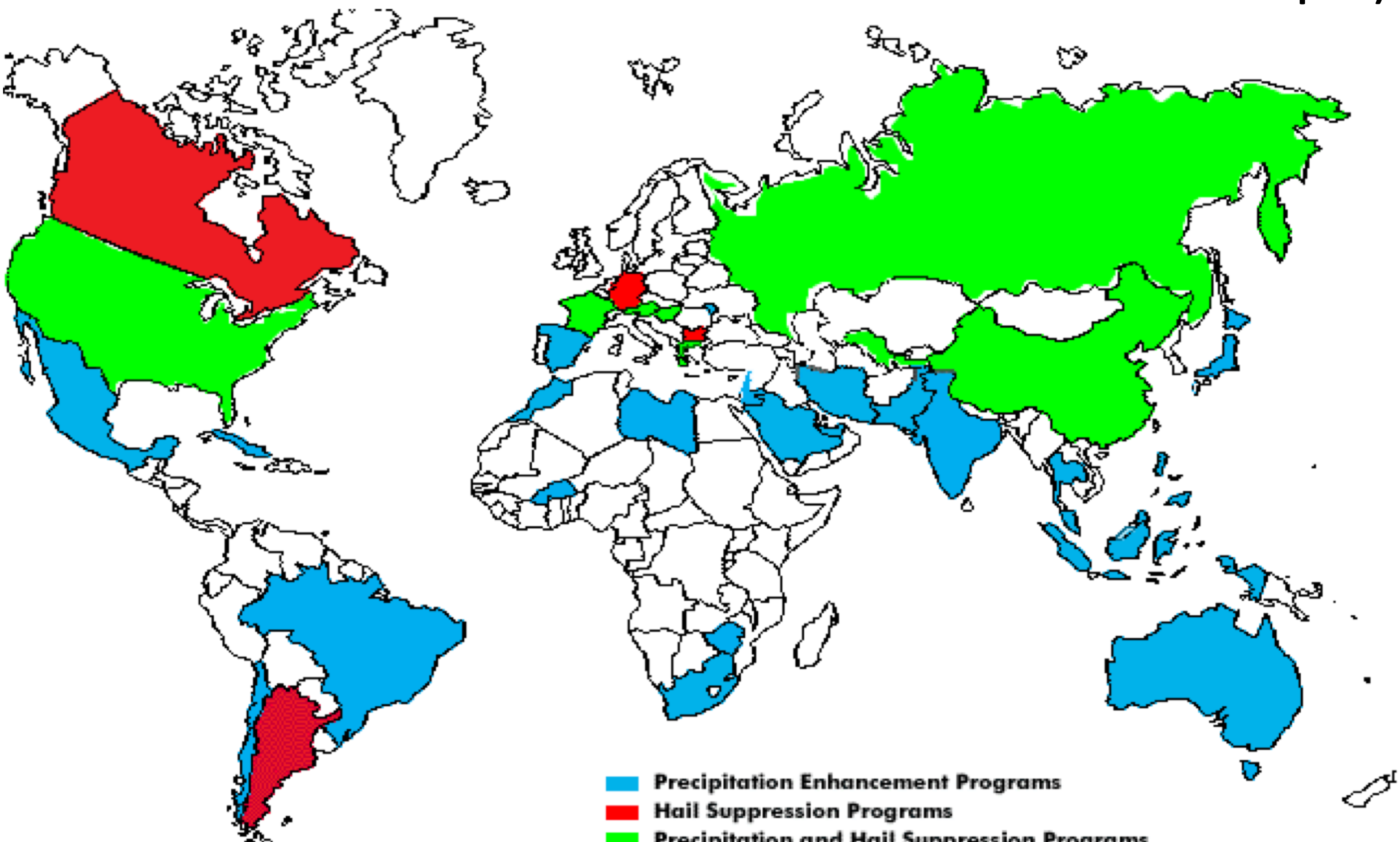

Business-as-Usual 2050
(computed by WaterGAP 2.1 based on the World Water Vision's BAU scenario & the HADCM3 GCM's climate under the IPCC Is92a climate change scenario)
Withdrawals-to-Availability Ratio
Low Stress
Mid Stress
Severe Stress
0
0.2
0.4
(c) Center for Environmental Systems Research, University of Kassel, May 2001- WaterGAP 2.1C

Quote: ‘it never rains but it pours!’

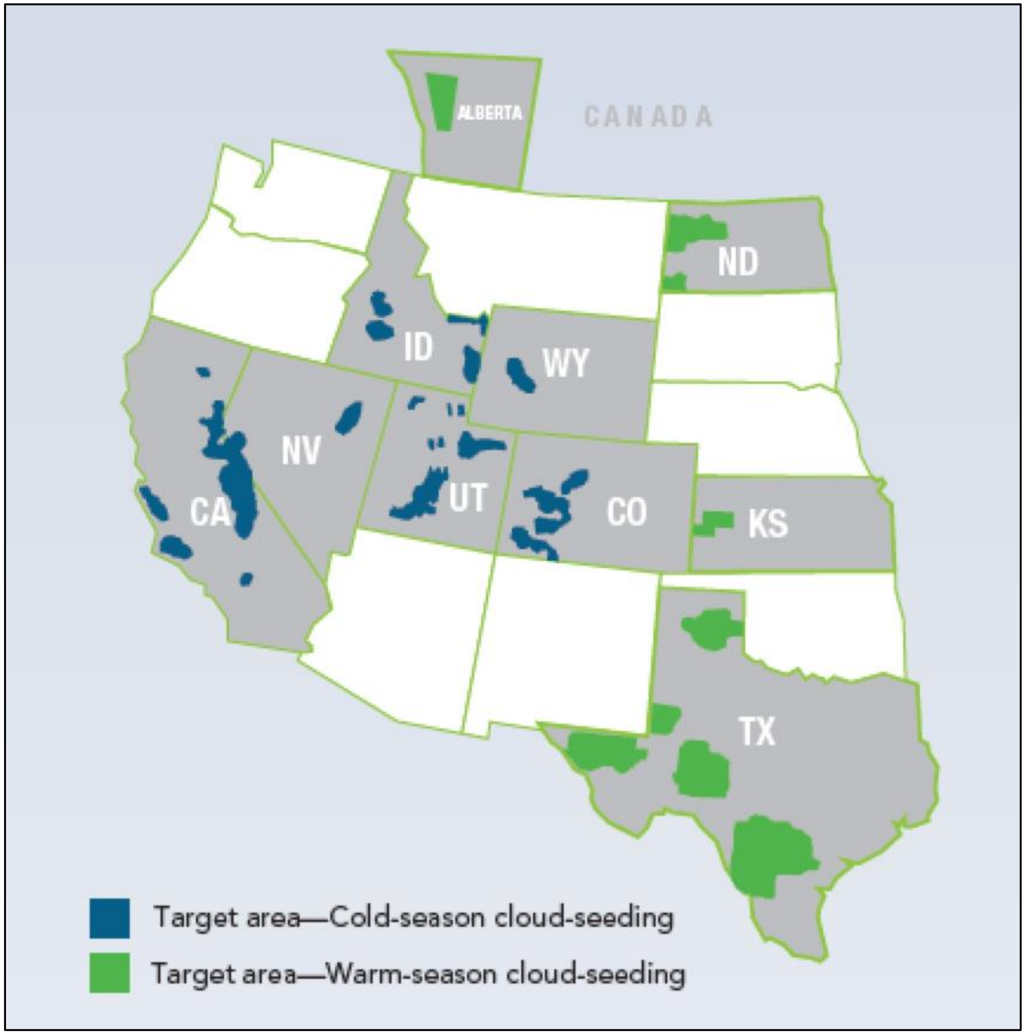
“There is a direct influence of global warming on precipitation. Increased heating leads to greater evaporation and thus surface drying, thereby increasing the intensity and duration of drought. However, the water holding capacity of air increases by about 7% per 1°C warming, which leads to increased water vapor in the atmosphere. Hence, storms, whether individual thunderstorms, extratropical rain or snow storms, or tropical cyclones, supplied with increased moisture, produce more intense precipitation events. Such events are observed to be widely occurring, even where total precipitation is decreasing.”

Trenberth, 2011

56 countries with active cloud seeding programs (Figure not updated after National academies report)

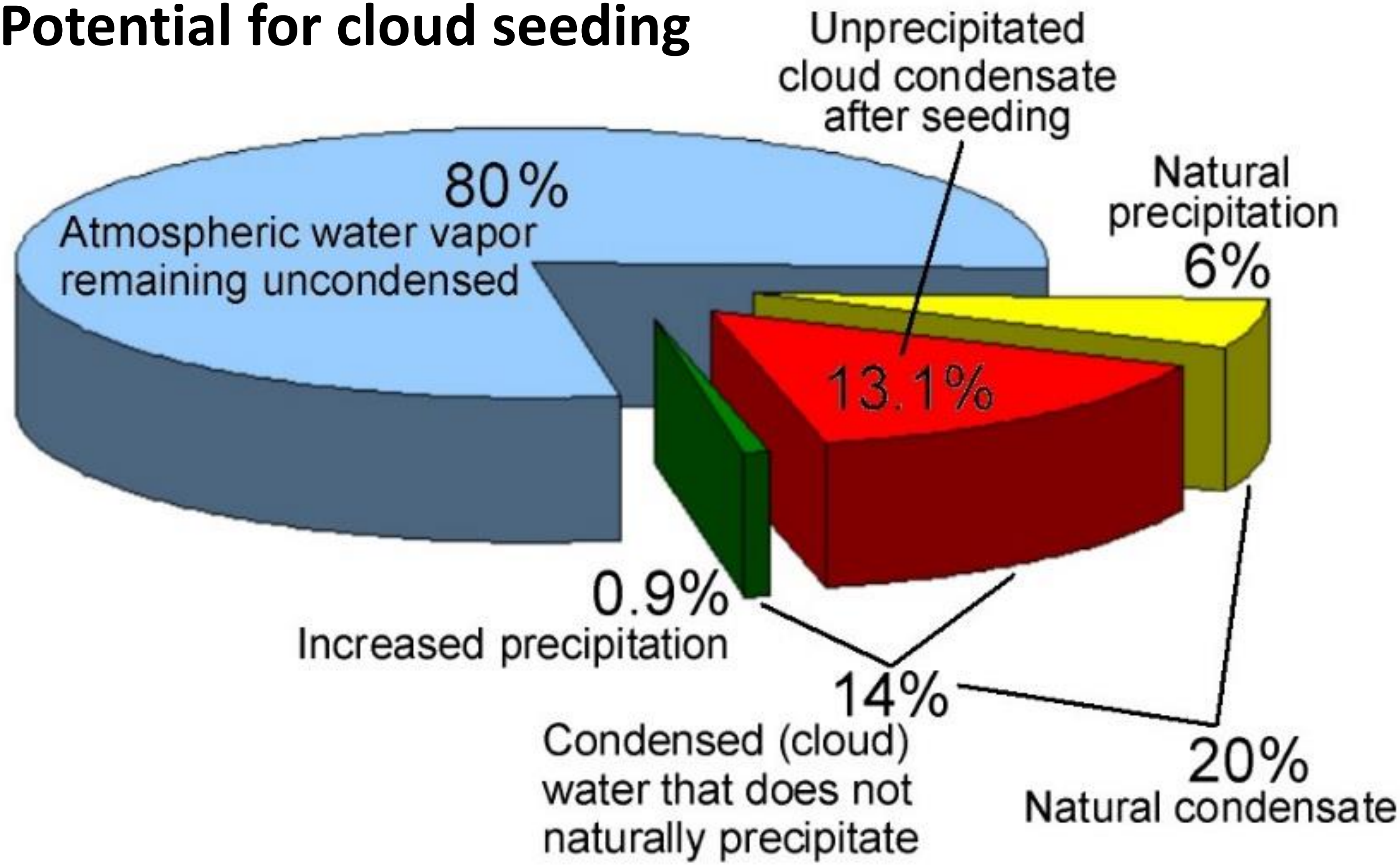


Weather modification in the USA



- 36 active weather modification programs in the USA.
- About half of the projects operate in summer and the other half in winter.
- Projects are funded by state government, local government, private sector and insurance companies.
- Some projects incorporate a research component.

Potential for cloud seeding



Ref: (Braham 1952; Gao and Li 2008; Trenberth et al. 2007; Li et al. 2011).

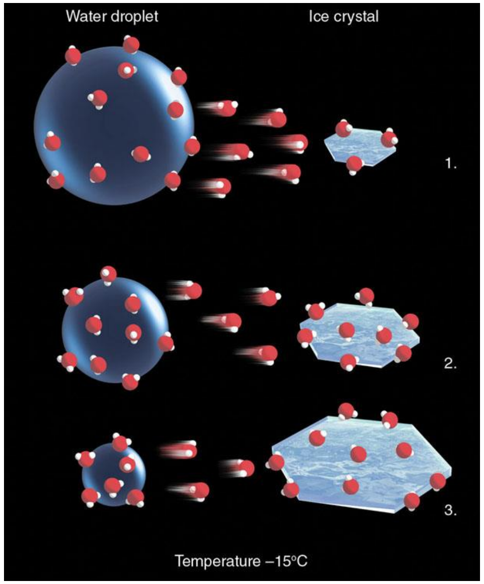
Challenges in Weather modification (cloud seeding)

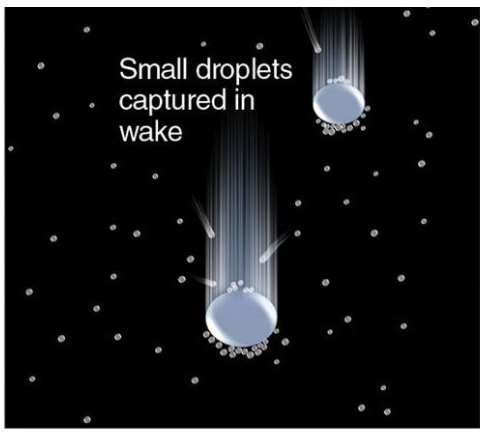
- Cloud seeding is a form of (**advertent**) weather modification.
- Weather modification technologies may be effectively applied to facilitate the water and energy cycles
- Need science and technology that improve the appropriate systems used to monitor and manage atmospheric water
- Bottle neck: Limited advances have been made in the development of present-day cloud seeding technologies and the ability to recognize treatable clouds.

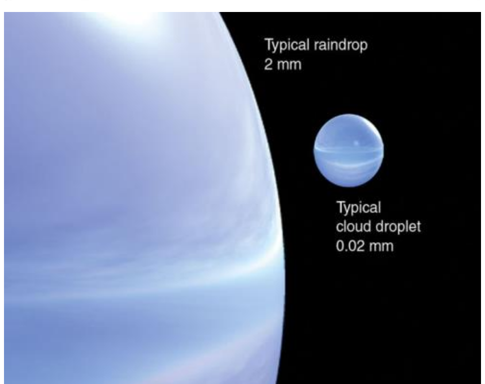
Checklist before a seeding program

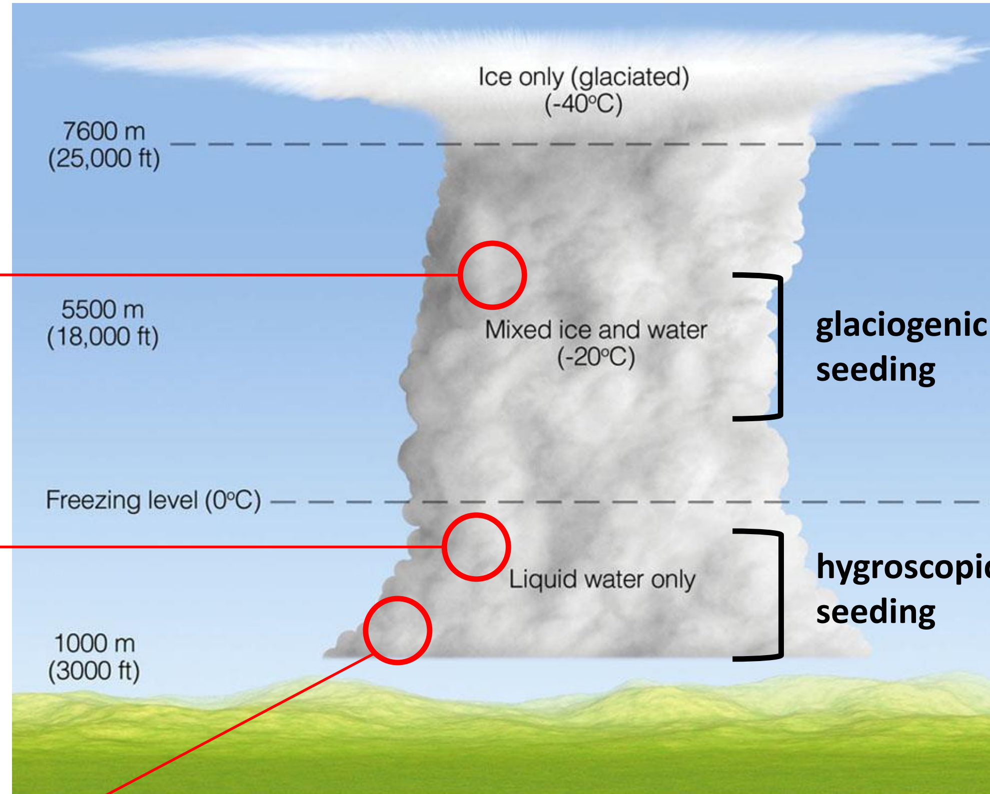
- Climatology
- Type of cloud
- Environmental conditions
- Type of seeding
- Type of seed material
- Method of dispensing the seed material
- Evaluation strategy (randomization and physical)
- Selection of instruments and parameters
- Use of numerical models
- Environmental and extra area effect
- Social aspects

Cloud seeding success is about identifying the window of opportunity









- Cloud droplets must grow in volume by a factor of a million before they become raindrops.
- Collision-coalescence requires a few large drops to be active.
- Cloud water remains supercooled up to temperatures of -37 °C

Images from http://www.atmos.washington.edu/~hakim/101/snowflakes/

REVIEW OF ADVANCES IN PRECIPITATION ENHANCEMENT RESEARCH

Andrea I. Flossmann, Michael Manton, Ali Abshaev, Roelof Bruintjes, Masataka Murakami, Thara Prabhakaran, and Zhanyu Yao

The World Meteorological Organization Expert Team on Weather Modification has assessed recent progress on precipitation enhancement research.

Weather modification methods (Flossman et al., 2019, BAMS)

Seeding agent	Hypothesized functioning and delivery method	Some method details and comments	Some recent references
AgI, $AgIO_3$	Glaciogenic seeding via aircraft, ground burner, rocket, cannon; pyrotechnic flares with 10 to 100 g of seeding agent per minute	Mean size of 0.1 μm; can also act as CCN in liquid clouds	Abshaev et al. (2006); Dessens et al. (2016)
Liquid CO_2	Glaciogenic seeding via aircraft	Cools down to −80°C and triggers homogeneous nucleation	Seto et al. (2011)
Dry ice (solid CO_2)	Glaciogenic seeding via aircraft	Pelletized (diameters of 0.6–1 cm and 0.6–2.5 cm) or small particles	Seto et al. (2011)
Hygroscopic flares	Hygroscopic seeding via aircraft	Sodium chloride (NaCl), potassium chloride, or calcium chloride particles; size range of 0.1–10-μm diameter	Bruintjes et al. (2012)
Micropowders	Hygroscopic seeding via aircraft	Optimum suggested size of NaCl crystals is 7.5–10 μm	Drofa et al. (2013)
Core/shell NaCl/TiO_2 (CSNT) particle	Hygroscopic seeding	Adsorbs ~295 times more water vapor at 20% RH than NaCl	Tai et al. (2017)
Ionization of aerosols and clouds	Negative ions are generated from a corona discharge wire array; the ions then become attached to particles in the atmosphere, which later act as CCN	No scientific basis that this could increase precipitation	Tan et al. (2016)
Electrification of clouds	Electric discharges under certain conditions can lead to temperature increase of drop freezing	No studies have addressed quantitatively how this would impact precipitation at the surface	Adzhiev and Kalov (2015)
Laser-induced condensation	Triggering condensation in subsaturated conditions	Condensation has been shown to occur on very local scales; problem of converting droplets into precipitation in a dry atmosphere remains unaddressed	Leisner et al. (2013)
Hail or acoustic cannon	Shock wave generator using a mixture of acetylene and oxygen to increase collision–coalescence growth of water droplets	No scientific basis	Wieringa and Holleman (2006)

Hygroscopic seeding

- Applicable in clouds with tops below freezing level; warm clouds containing water droplets
- Hygroscopic material is dispersed into the updraft region at cloud base
- Particles are larger and more hygroscopic than the natural particles
- The cloud droplets nucleate preferentially on the seeding particles
- This inhibits smaller natural cloud condensation nuclei from becoming activated
- The result is a broader-than-natural droplet spectrum near cloud base
- Increases potential for precipitation to develop earlier and more efficiently in the lifetime of the cloud.
- Despite the wide use of hygroscopic seeding, the results have been inconclusive due to a lack of physical understanding and inconclusive statistical evaluations.

Hygroscopic Seeding

(Applied to cumulus congestus/cumulonimbus with hygroscopic nuclei)

Static seeding hypothesis:

- Cloud base below the melting level
- Large soluble nuclei are used
- To trigger the collision–coalescence early
- Rapid growth of raindrops and fallout quickly

Very few physical observations were taken as part of the randomized experiments. Exception is Queensland, Australia, 2009, indicated variability in physical processes and in the seeded and unseeded clouds

Dynamic seeding hypothesis:

- Initiates rainfall through the collision–coalescence process
- Rain develops
- Evaporation below cloud base triggers the formation of cold pool
- There is cold air outflows, which propagate away
- New convective cells for at the boundaries of outflow where there is lifting
- Increase areal coverage of convection
- Expect more rain from the convective complex

Optimistic view of the potential of hygroscopic seeding
Silverman (2003)

A dynamic effect was suspected as “downdrafts creating long lived clouds along their peripheries”

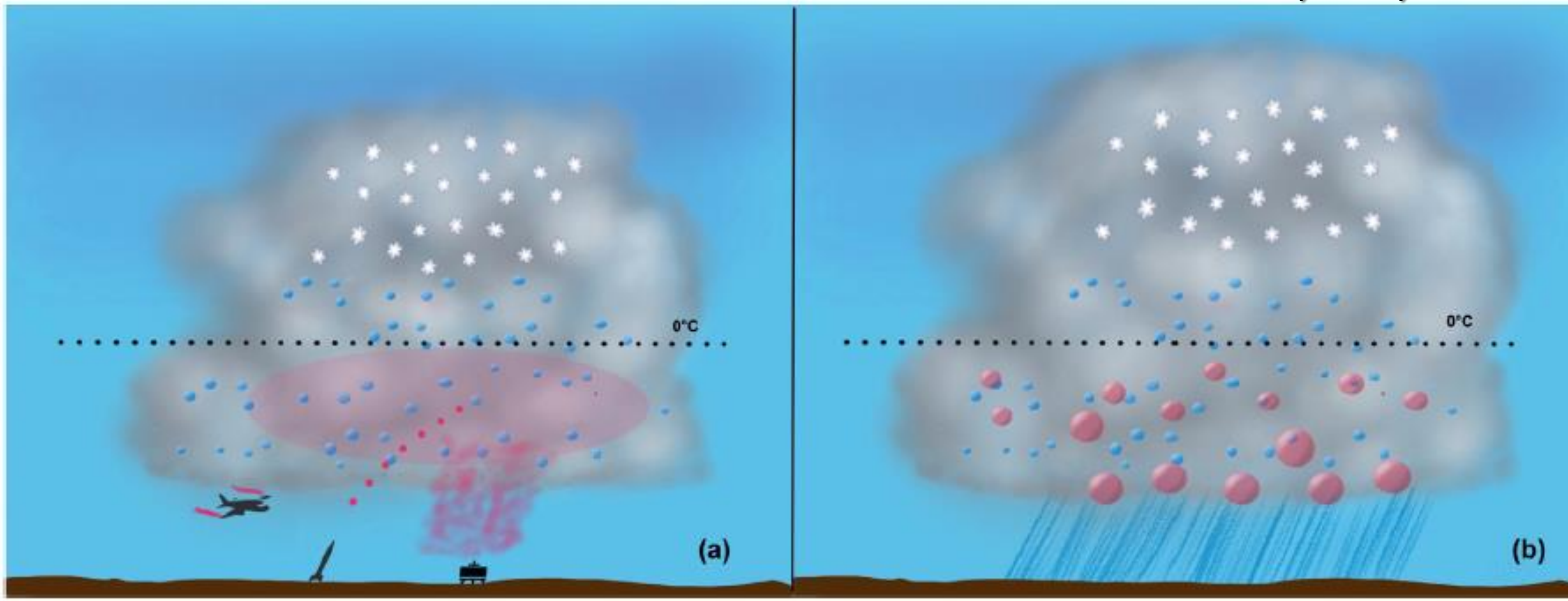
Historical Hygroscopic seeding experiments

- South African experiments (Mather et al., 1997)
- Mexico experiments (WMO, 2000)
- Indian experiments (Murty et al., 2000)
- Thailand experiments (Silverman and Sukarnjanasat, 2000)
- Static-mode seeding concept: Seeding for microphysical effects
  - ❑Competition effect: Introducing cloud condensation nuclei to affect the condensation process by broadening the initial cloud drop size spectrum
  - ❑Tail effect: Introducing ultra-giant condensation nuclei to jump start the collision–coalescence process

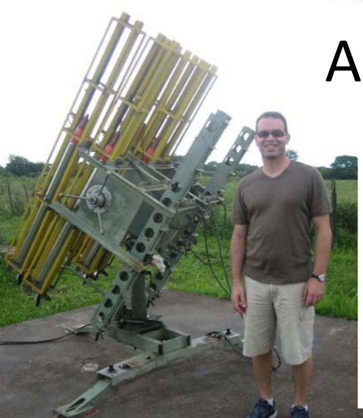
More detailed list is given in WMO Peer Review report (2018)

Hygroscopic seeding in convective cloud

Flossman et al., 2019, BAMS



Artillery



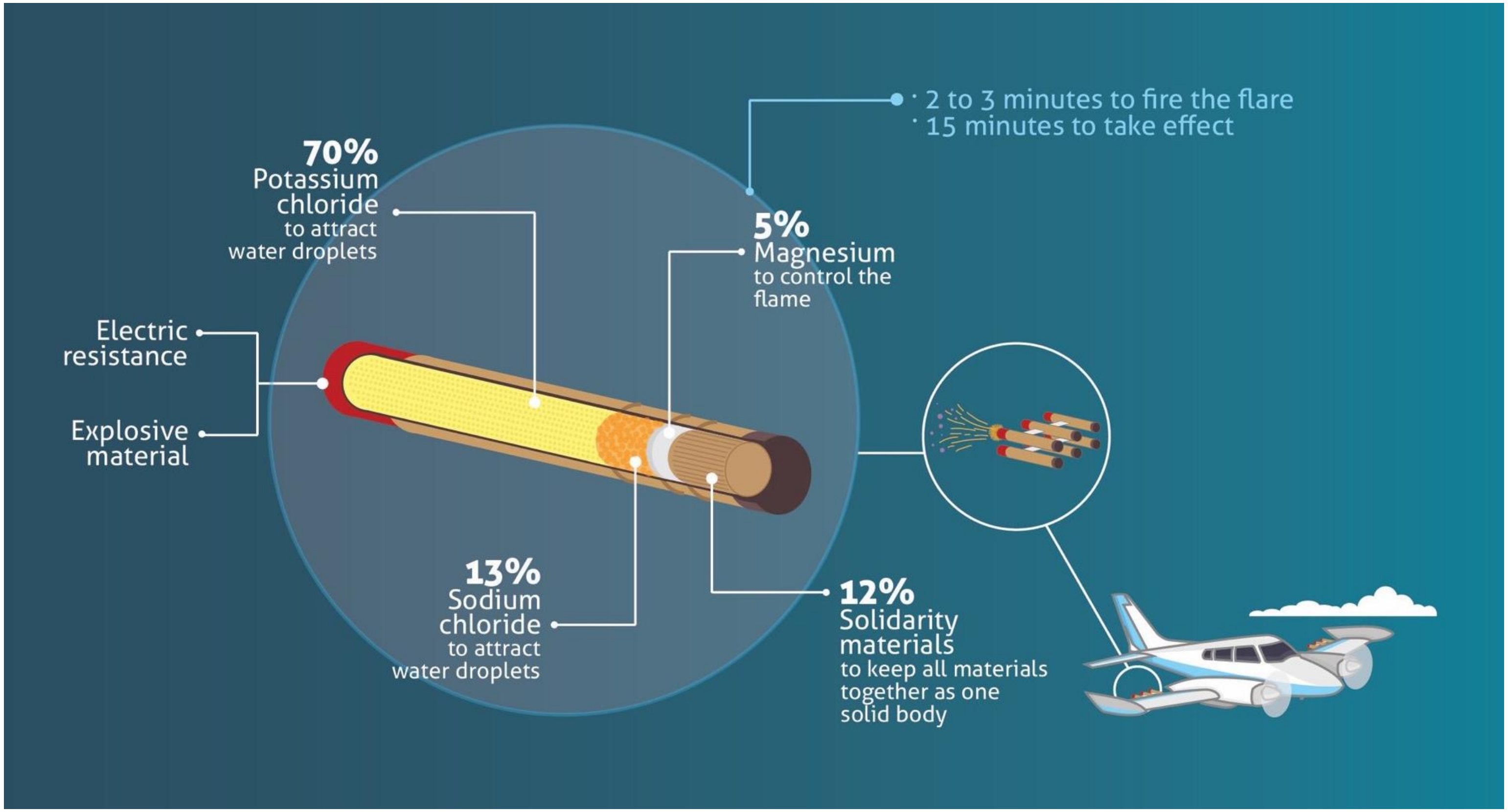
Airborne

Ground based burners

Hygroscopic flares

- Provide larger CCN than naturally occurs which activate at lower supersaturations
- Condense water more readily and tend to limit the total number of droplets activated
- Droplets grow to larger(than normal)sizes through condensation
- Droplets grow further through collision with other droplets within 15-min, initiate the rain process within the convective cell.

Flares used on aircraft wings



- The flares are fitted in the racks attached to the wings of the aircraft.
- Hygroscopic flare contains sodium chloride or calcium chloride, produce small salt particles in the size range 0.1 - 1 micrometer diameter.
- The flares are in cardboard container (12 cm long 7 cm diameter)
- The linear burning rate of the flare is ~ 0.66 mm per second.

Hygroscopic Burn-in-Place (HBIPs) flares

- To enhance collision-coalescence processes through development of large cloud droplets. A flare comprised of KCl (Potassium Chloride) and NaCl (Sodium Chloride)
- burn time of approximately 4 minutes.
- Pairs of flairs are burned and a total of 8 flares (4 burns x 2 per burn, on each wing) per event is burned which takes 16 minutes.
- Up to 3 seeding events are carried out per flight

- During hygroscopic seeding the aircraft flies near cloud base and burns flares attached to the wings

Glaciogenic seeding in orographic cloud

Flossman et al., 2019, BAMS

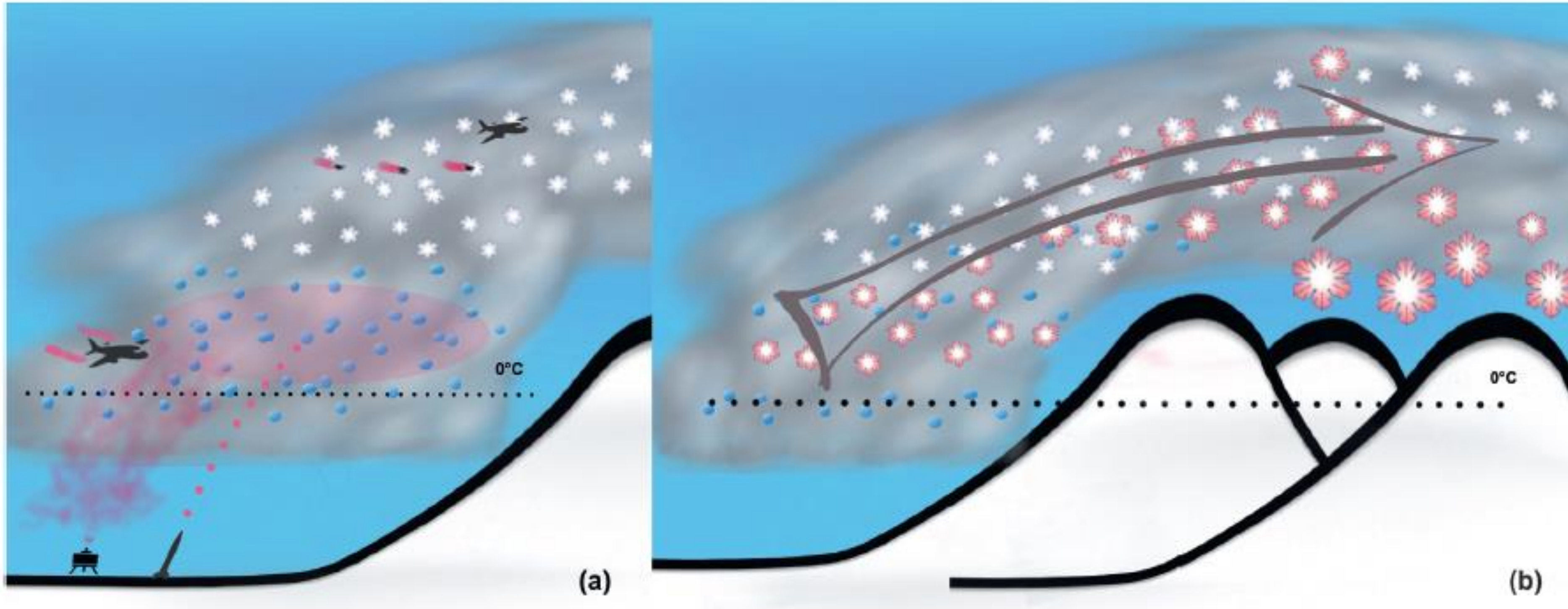
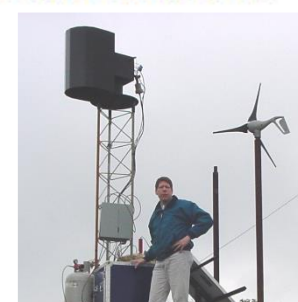


FIG. 1. (a) Glaciogenic seeding of an orographic wintertime cloud. Red indicates the supercooled seeded area and the seeding material to be added by plane, burner, or rocket. (b) The intended outcome of the seeding (red), when the added INP form crystals that grow via the WBF effect and riming to form snow. The additional release of latent heat may invigorate the cloud. The arrow indicates the sense of the space and time evolution.



- Seeding material must be successfully and reliably produced.
- Seeding material must be transported into a region of cloud that has SLW.
- Seeding material must be dispersed sufficiently in the SLW cloud, so that a significant volume is affected by the desired concentration of INP and a significant number of ice crystals (IC) are formed.
- The temperature must be low enough, for substantial IC formation.
- ICs formed by seeding must remain in an environment suitable for growth long enough to enable them to fall into the target area.

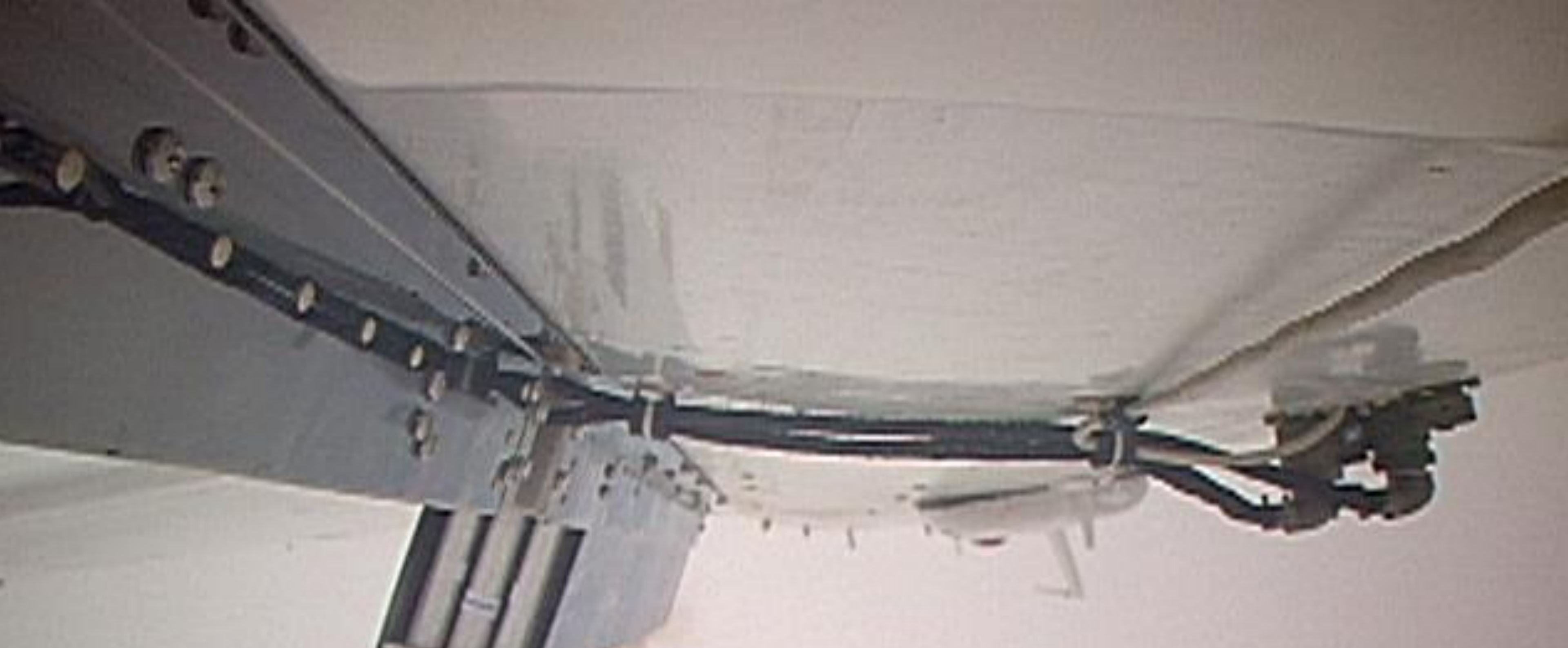
Key components physical evaluation of orographic glaciogenic seeding

1) Identifying suitable clouds for AgI application
2) Natural precipitation processes
3) Presence of supercooled liquid water (location and time)
4) Conditions favouring the transport of ground-released AgI to the cloud base
5) Documenting the micro-physical chain of events after seeding
6) Checking hypothesis
7) Identify impacts on the water supply
8) Assess any environmental impact
9) Assess extra area effect

Where Ground based glaciogenic seeding have been successful?

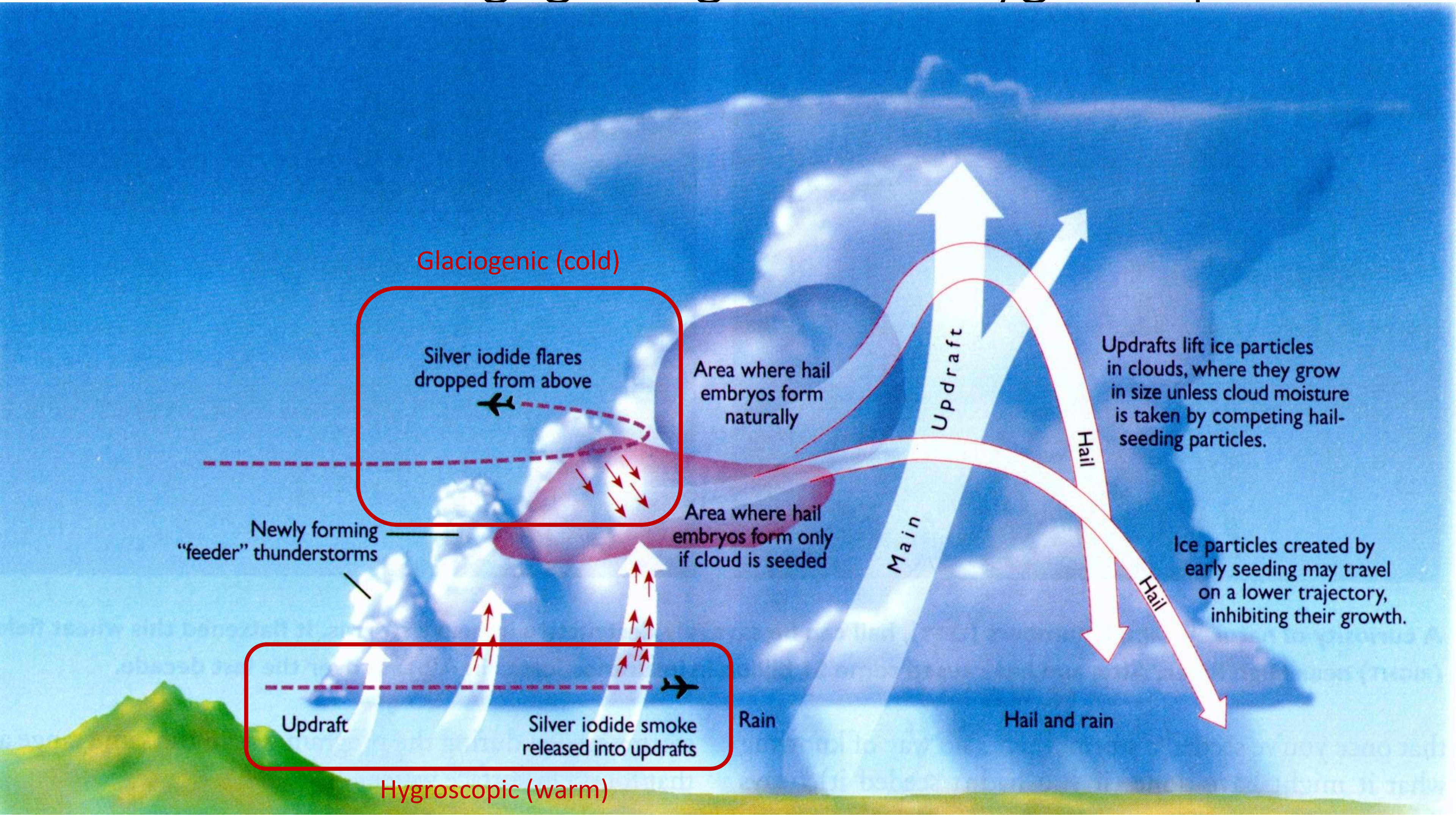
1) Over steep mountain slopes
2) Embedded convection
3) Orographic clouds where cloud-top temperatures are warmer than -15oC
4) In turbulent eddies induced by local mountainous terrain;
5) in updrafts associated with mountain-induced gravity waves
6) Cloud base below melting level
7) Terrain-forced ascent of cloud water through the melting level

Result: Winter orographic cloud seeding can result in increases in precipitation from seedable storms in the range of 5%–15%. Only one third of the storms are seedable from the ground to be effective.



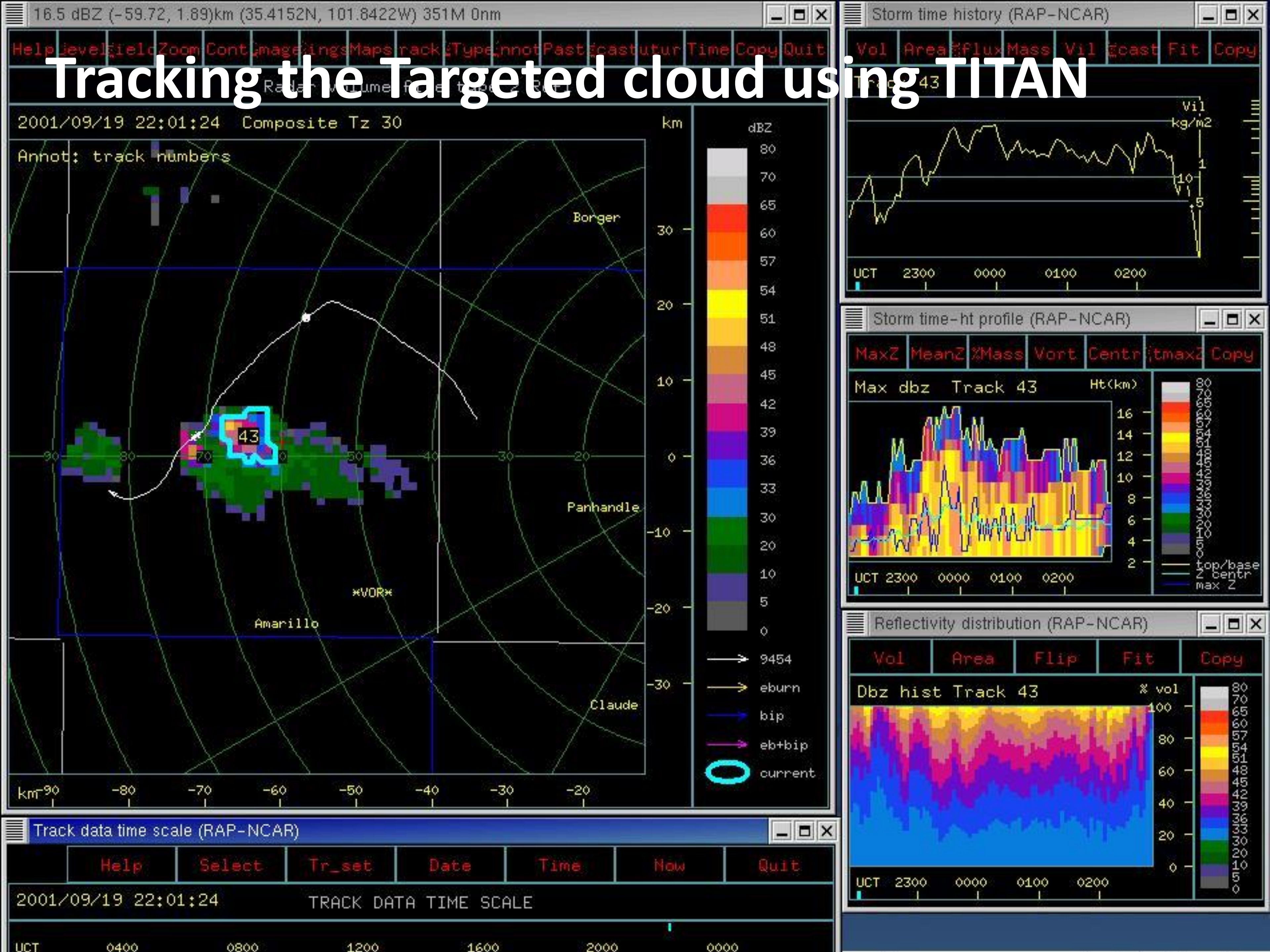
During glaciogenic seeding the aircraft flies near cloud top and ejects the flare, which drops inside cloud and burns .

Airborne seeding: glaciogenic and hygroscopic

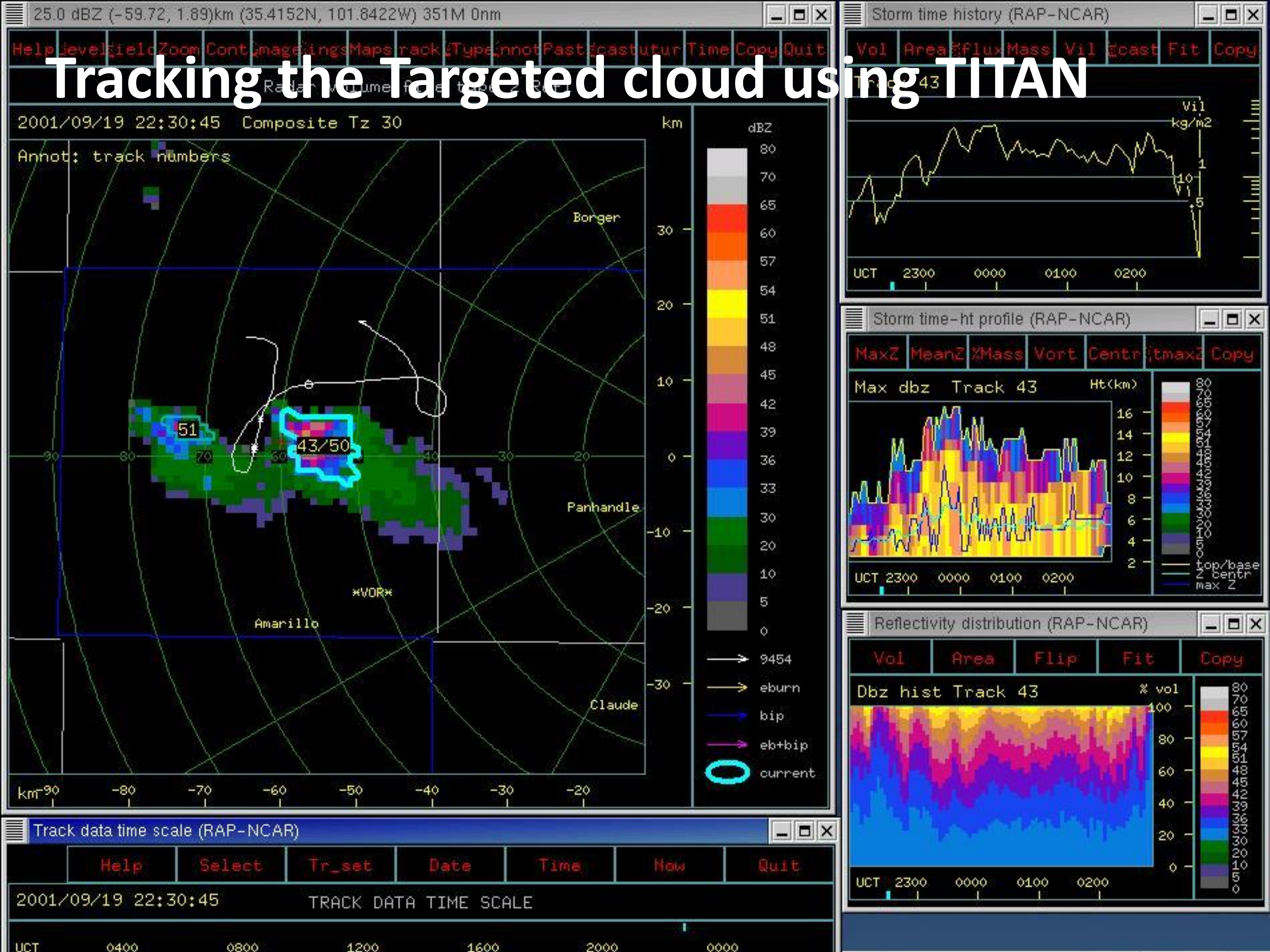


Targeting video in fast forward speed

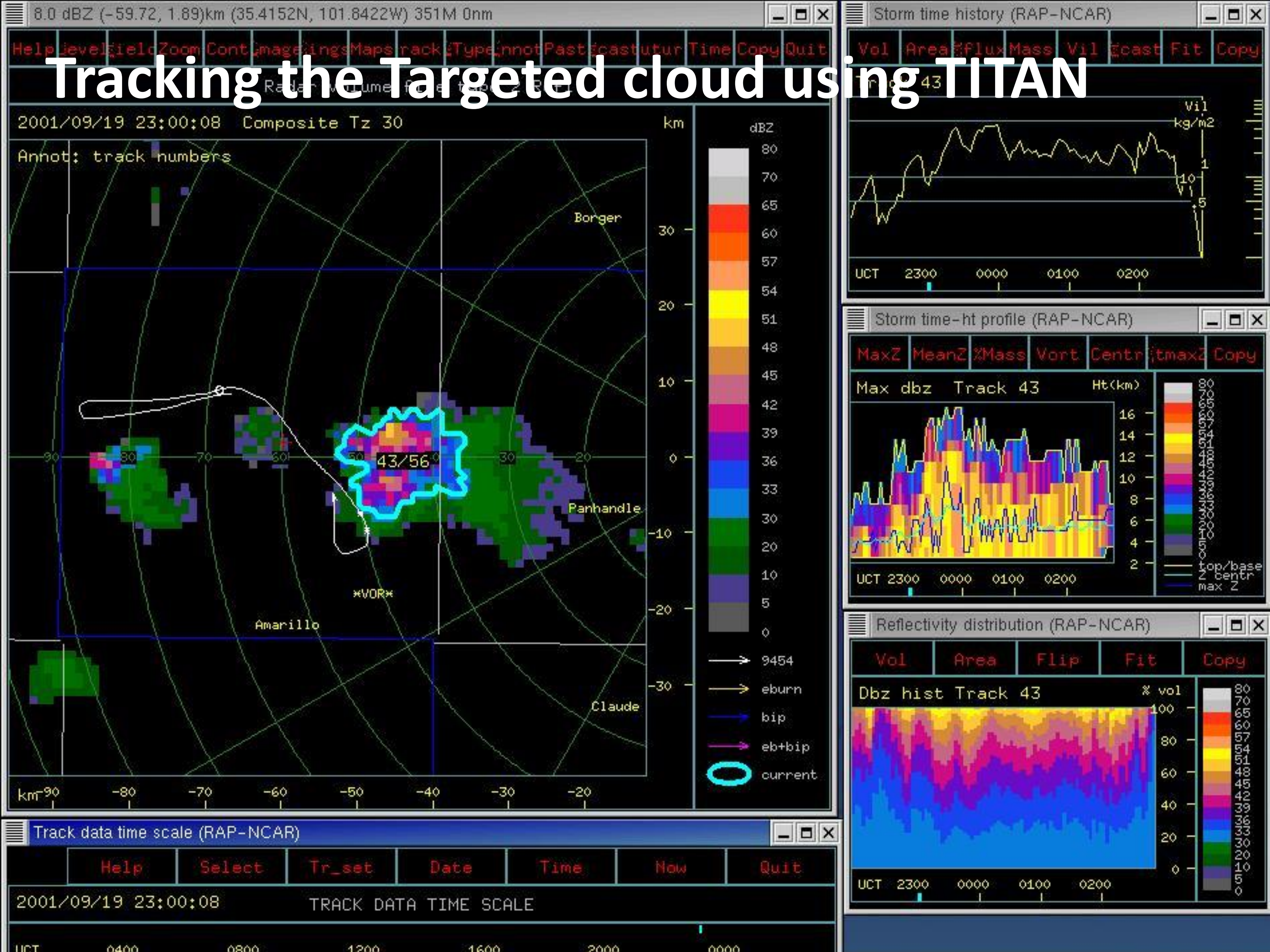
Tracking the Targeted cloud using TITAN

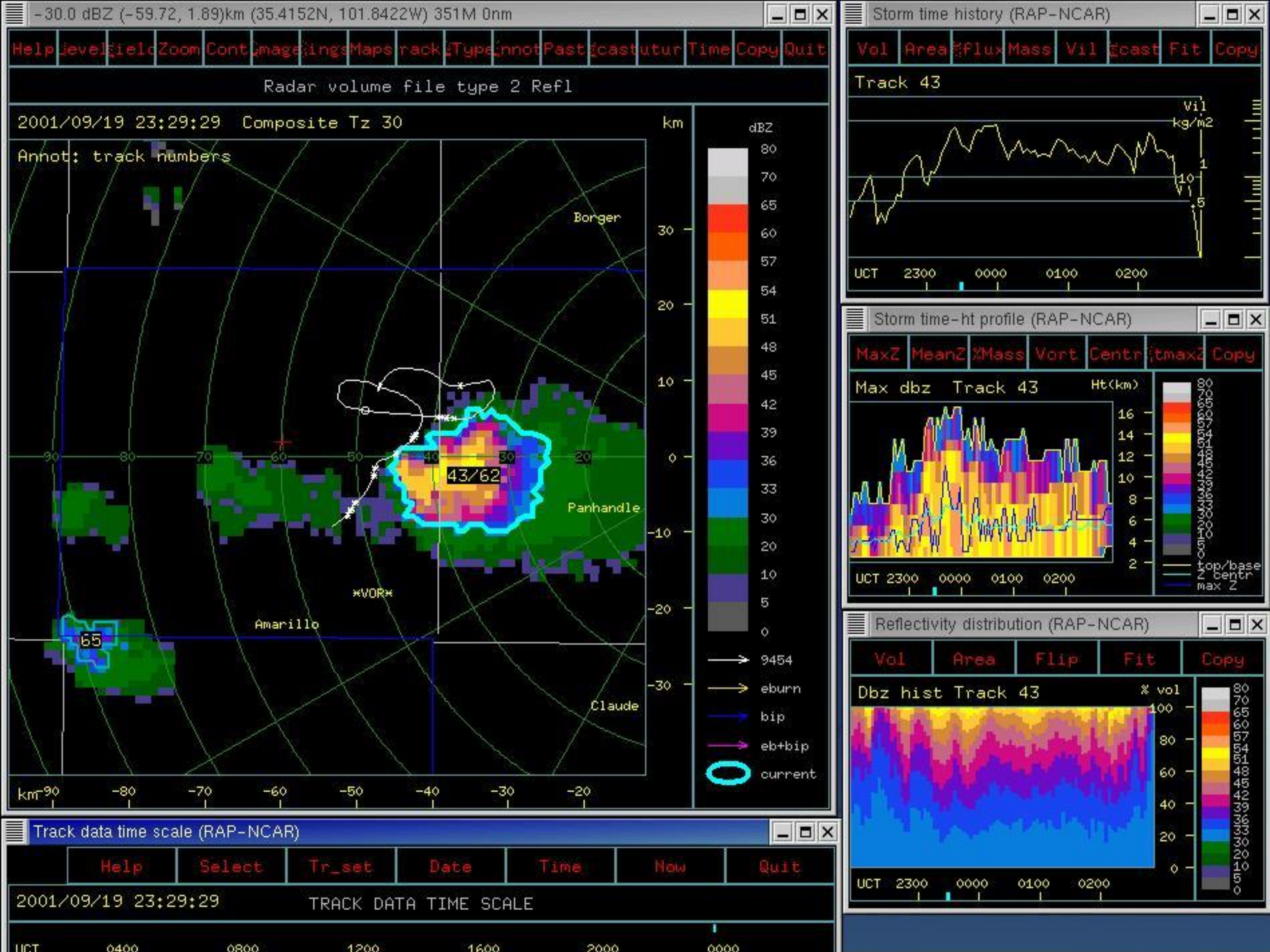


Tracking the Targeted cloud using TITAN



Tracking the Targeted cloud using TITAN




-30.0 dBZ (-59.72, 1.89)km (35.4152N, 101.8422W) 351M 0nm
Radar volume file type 2 Refl
2001/09/19 23:29:29 Composite Tz 30
Annot: track numbers
Borger
Panhandle
Amarillo
VOR
Claude
43/62
65
dBZ
9454
eburn
bip
eb+bip
current
Storm time history (RAP-NCAR)
Vol Area Mass Vil Fit Copy
Track 43
Vil kg/m2
UCT 2300 0000 0100 0200
Storm time-ht profile (RAP-NCAR)
MaxZ MeanZ %Mass Vort Centr Copy
Max dbz Track 43
Ht(km)
top/base
Z centr
max Z
Reflectivity distribution (RAP-NCAR)
Vol Area Flip Fit Copy
Dbz hist Track 43
% vol
Track data time scale (RAP-NCAR)
Help Select Tr_set Date Time Now Quit
2001/09/19 23:29:29
TRACK DATA TIME SCALE
UCT 0400 0800 1200 1600 2000 0000

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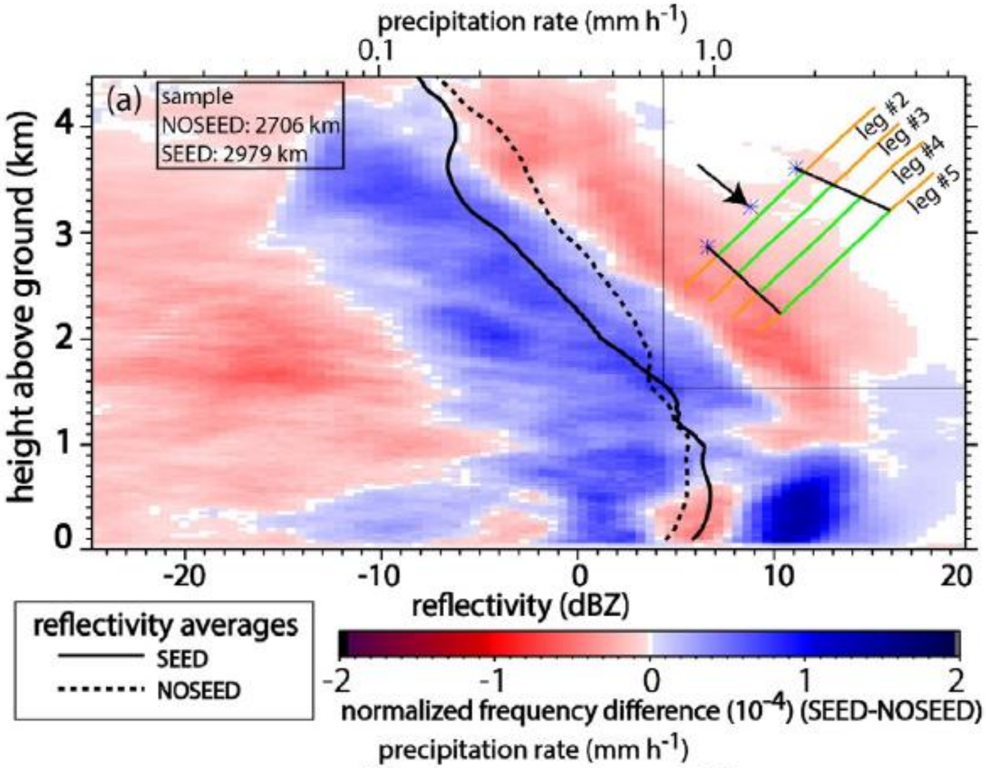
Ground based Glaciogenic seeding and snow growth in two mountains in Wyoming, USA

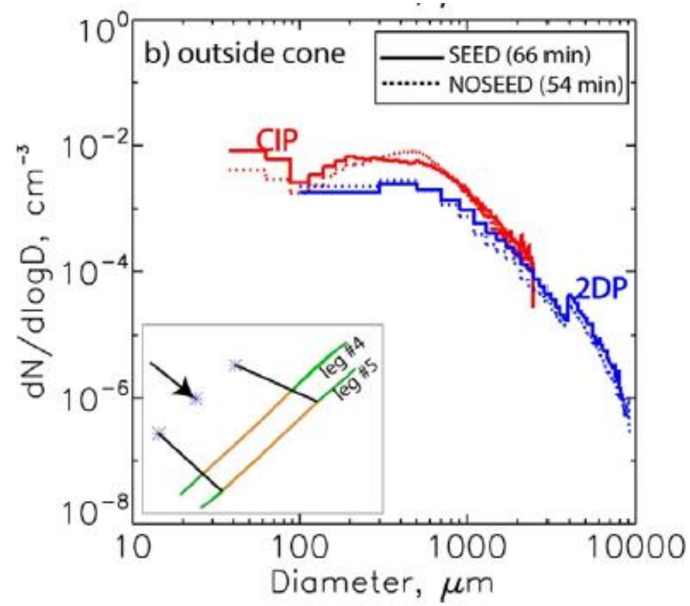
A multi-sensor study of the impact of ground-based glaciogenic seeding on clouds and precipitation over mountains in Wyoming. Part II: Seeding impact analysis

Binod Pokharel [a,*], Bart Geerts [a], Xiaoqin Jing [a], Katja Friedrich [b], Kyoko Ikeda [c], Roy Rasmussen [c]

Used airborne cloud radar and cloud physics instruments

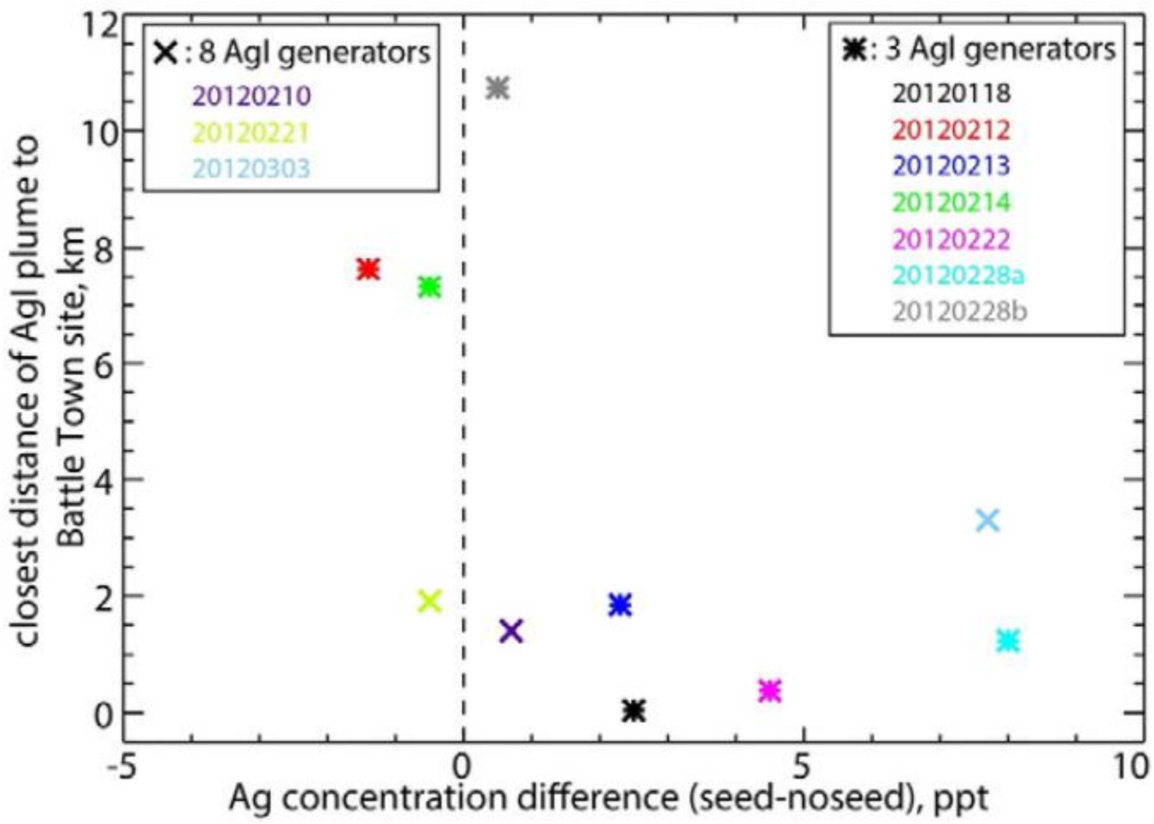


Ice particle size distributions show more small snow



Conclusion: A large sample is needed for ”clear observational evidence regarding the seeding efficacy to atmospheric and cloud conditions”

Environmental effects: Investigating Ag in the precipitation



THE QUEENSLAND CLOUD SEEDING RESEARCH PROGRAM

BY SARAH A. TESSENDORF, ROELOF T. BRUINTJES, COURTNEY WEEKS, JAMES W. WILSON, CHARLES A. KNIGHT, RITA D. ROBERTS, JUSTIN R. PETER, SCOTT COLLIS, PETER R. BUSECK, EVELYN FRENEY, MICHAEL DIXON, MATTHEW POCERNICH, KYOKO IKEDA, DUNCAN AXISA, ERIC NELSON, PETER T. MAY, HARALD RICHTER, STUART PIKETH, ROELOF P. BURGER, LOUISE WILSON, STEVEN T. SIEMS, MICHAEL MANTON, ROGER C. STONE, ACACIA PEPLER, DON R. COLLINS, V. N. BRINGI, M. THURAI, LYNNE TURNER, AND DAVID MCRAE

An innovative approach to studying the effects of cloud seeding on precipitation is to focus on understanding the natural variability of precipitation and the microphysical responses to aerosol.

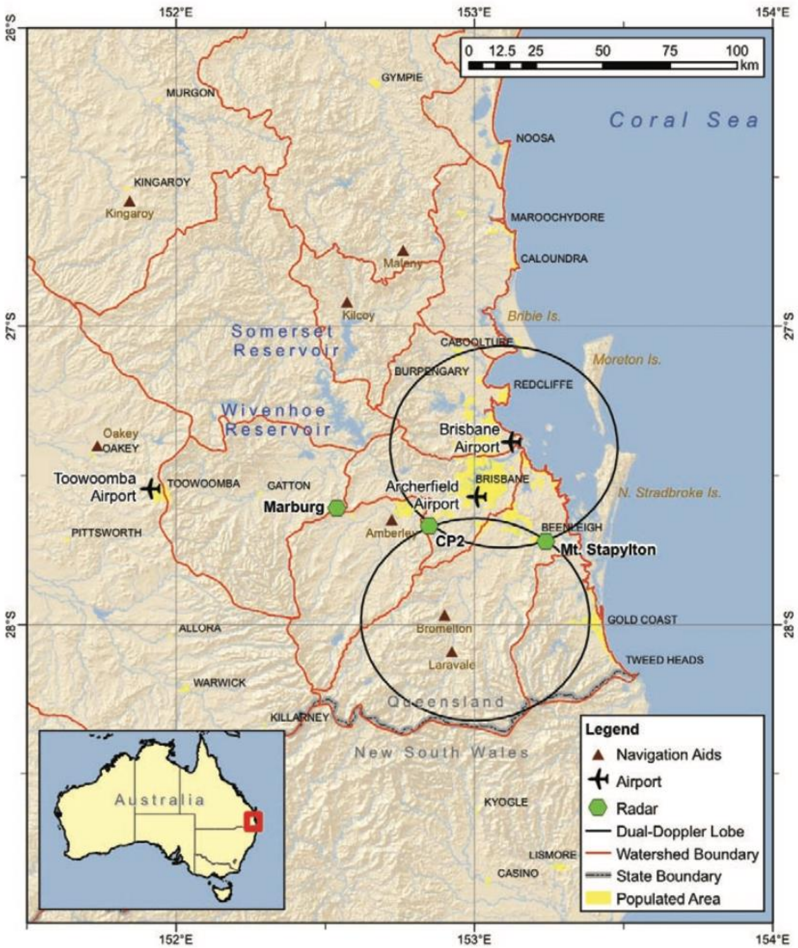


Fig. 1. Map of southeast Queensland region targeted for the QCSRP field effort and associated facilities and landmarks. The 30° beam crossing angle dual-Doppler lobes are overlaid in black. [Courtesy of Kevin Sampson, NCAR.]

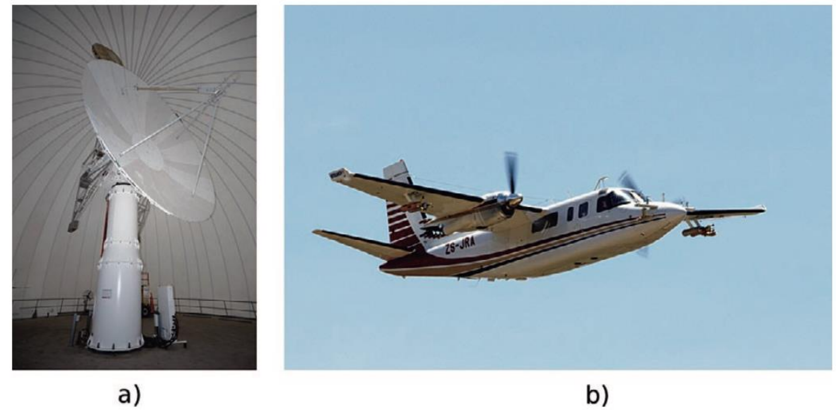
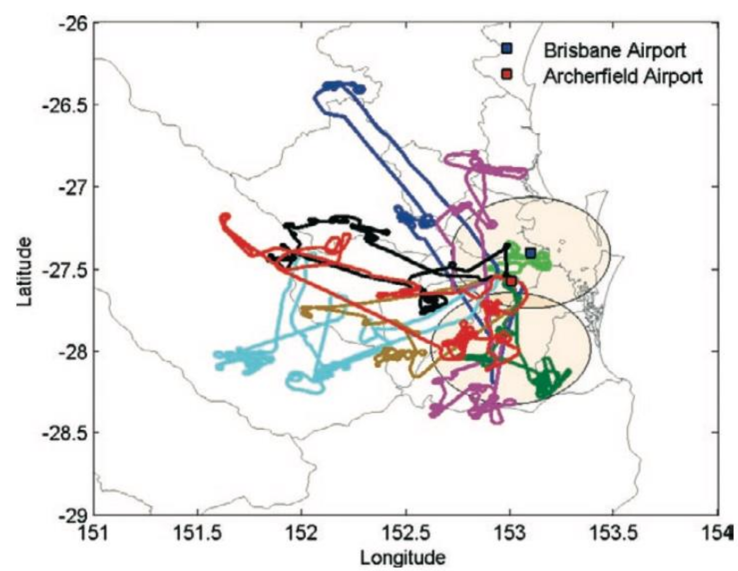
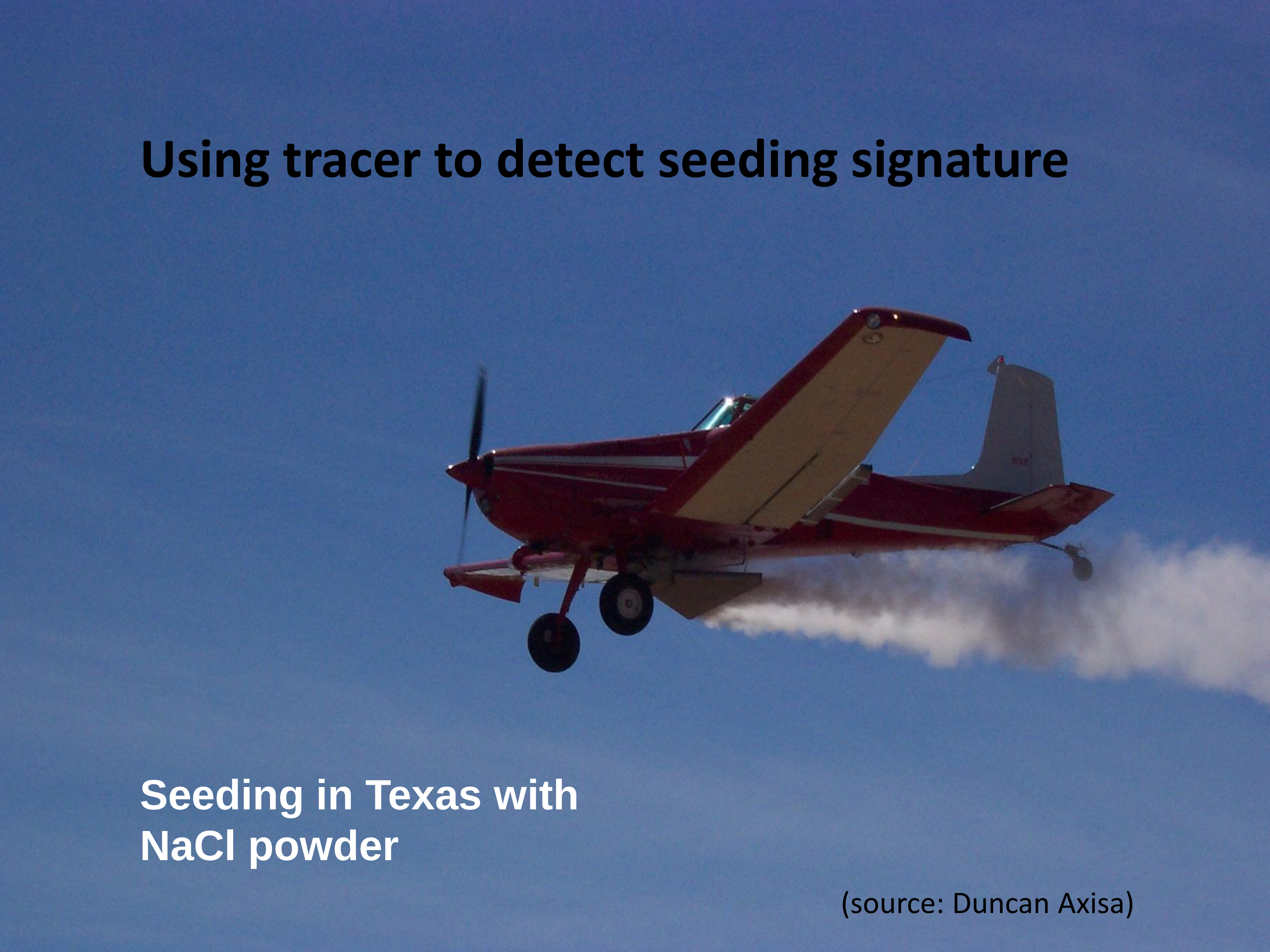


Fig. 2. Facilities operated during the QCSRP included (a) the CP2 radar (photo depicts the S-band and X-band antennae), and (b) the SAWS Aero Commander research/seeding aircraft depicted in flight on a research mission. [Photos courtesy Scott Collis, CAWCR.]



Using tracer to detect seeding signature



Seeding in Texas with NaCl powder

(source: Duncan Axisa)

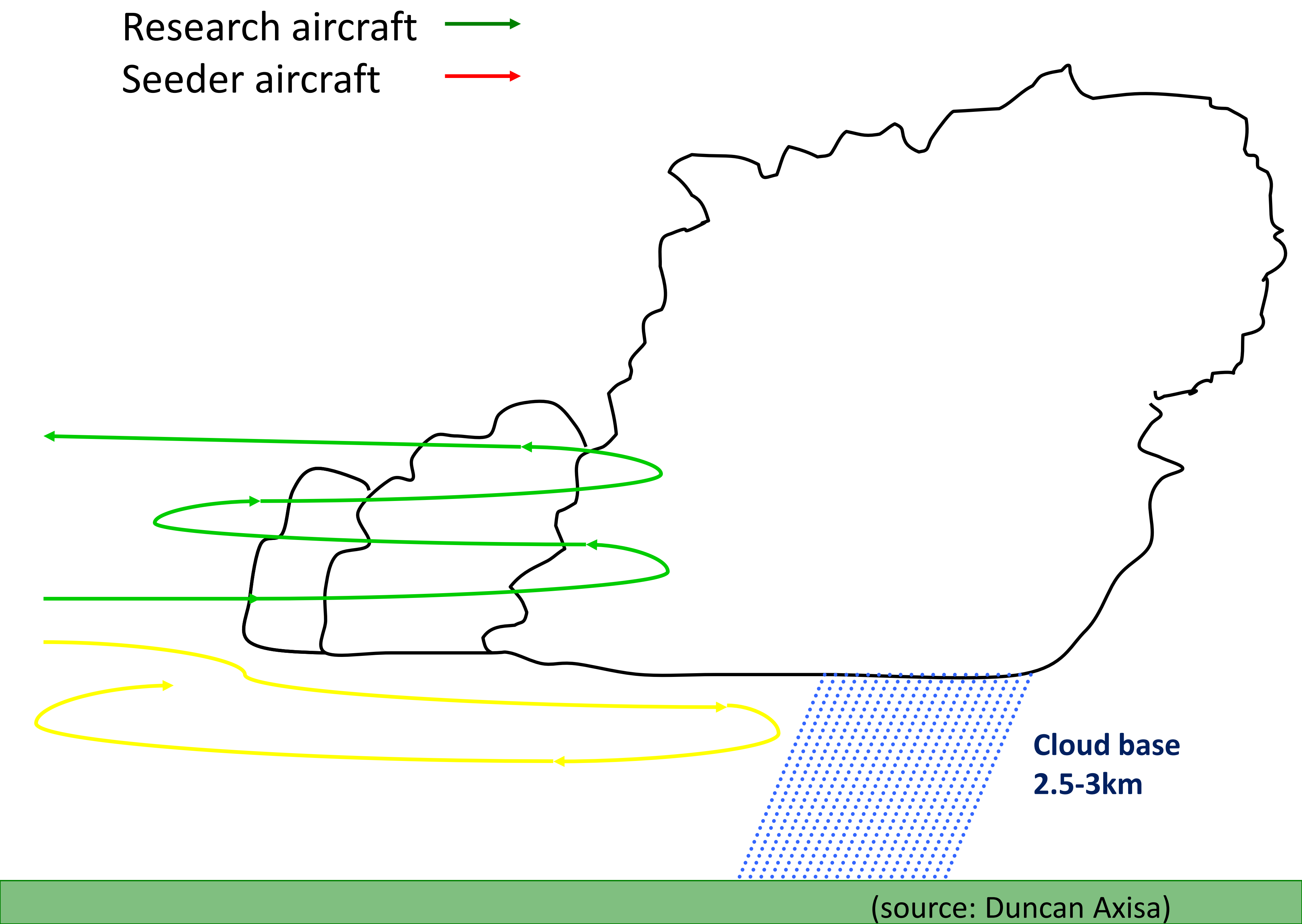
OPERATIONAL OVERVIEW

35 Potential days of experimentation in May and early June 2005
7 of 35 days were suitable for experimentation
SF6 tracer gas was detected in 4 of 7 cases
3 of the 4 cases were suitable for analysis

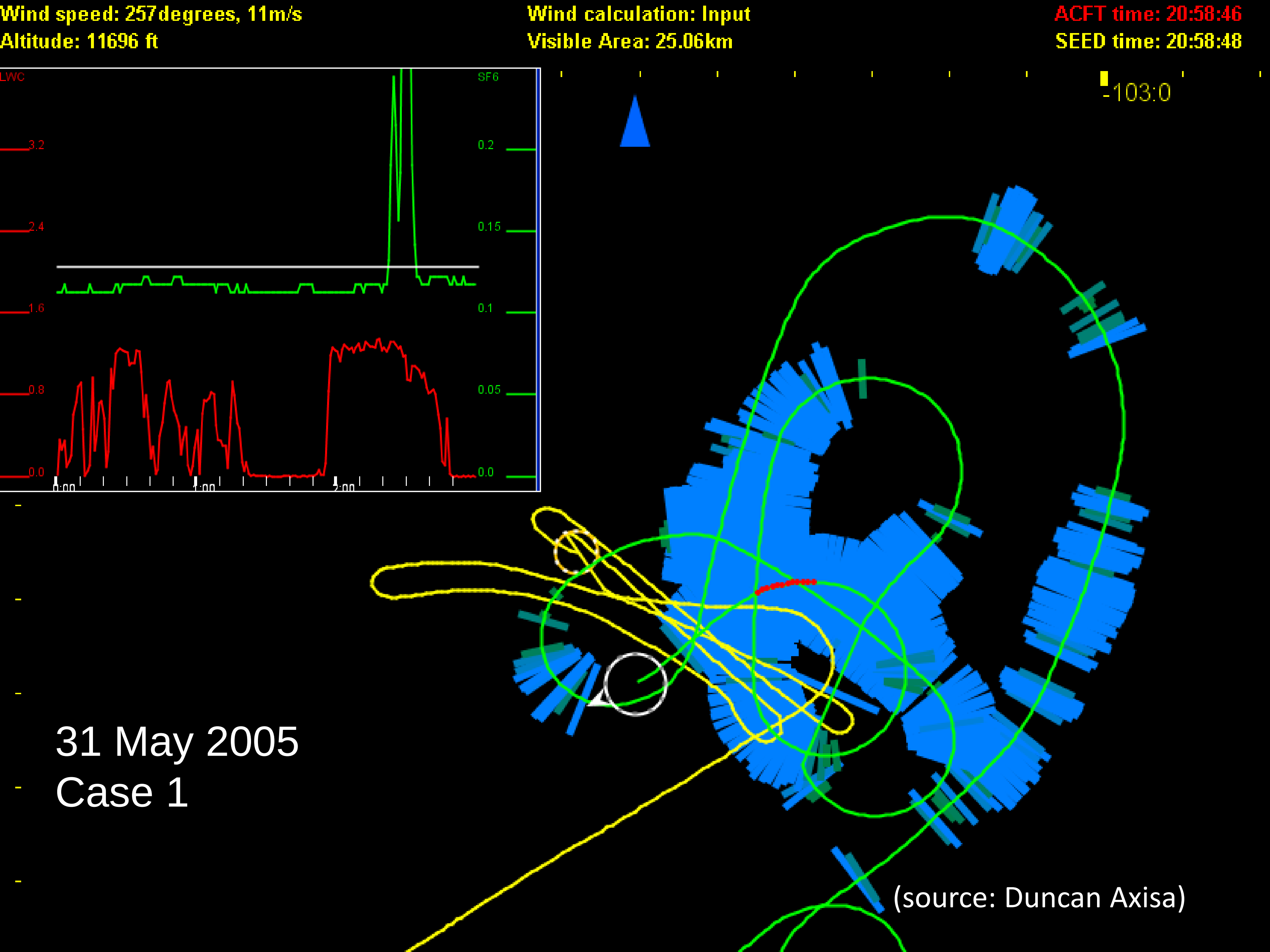
CASE SEEDING DOCUMENTATION

Date	Case #	Salt Rate (kg/min)	Total Salt (kg)	Gas Rate (kg/min)	Total Gas (kg)
25 May 05	1	8.2	49.4	2	11.8
31 May 05	1	10.2	80.3	1	7.5
31 May 05	2	10.2	47.1	1	4.4

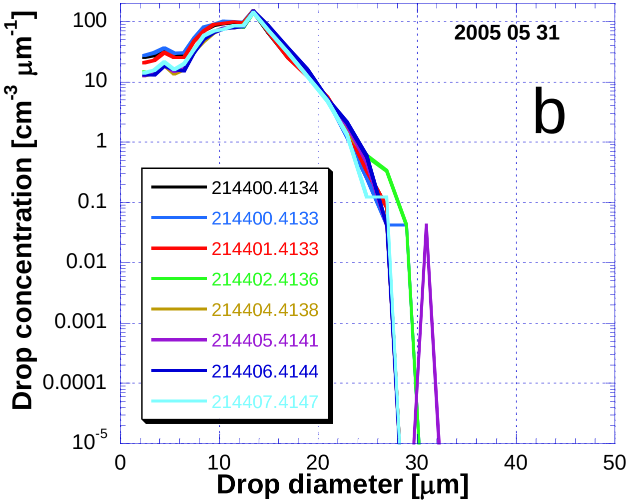
(source: Duncan Axisa)

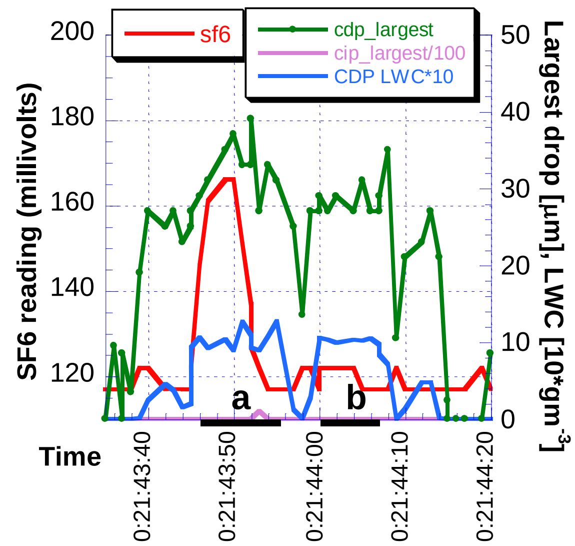


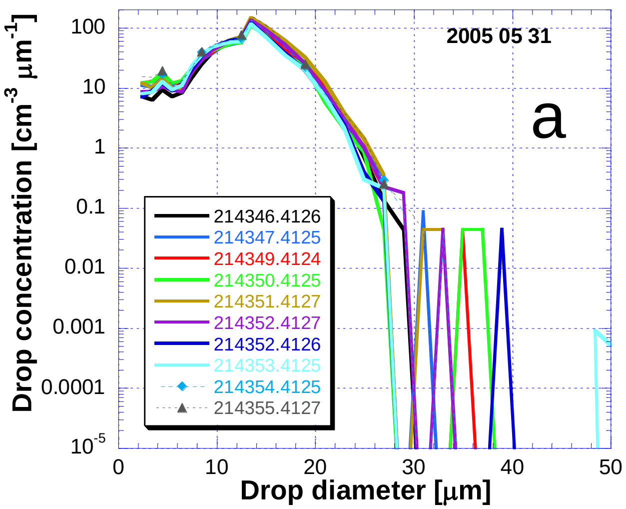
Research aircraft
Seeder aircraft
Cloud base
2.5-3km
(source: Duncan Axisa)


Wind speed: 257degrees, 11m/s
Altitude: 11696 ft
Wind calculation: Input
Visible Area: 25.06km
ACFT time: 20:58:46
SEED time: 20:58:48
LWC
SF6
3.2
2.4
1.6
0.8
0.0
0.2
0.15
0.1
0.05
0.0
-103:0
31 May 2005
Case 1
(source: Duncan Axisa)

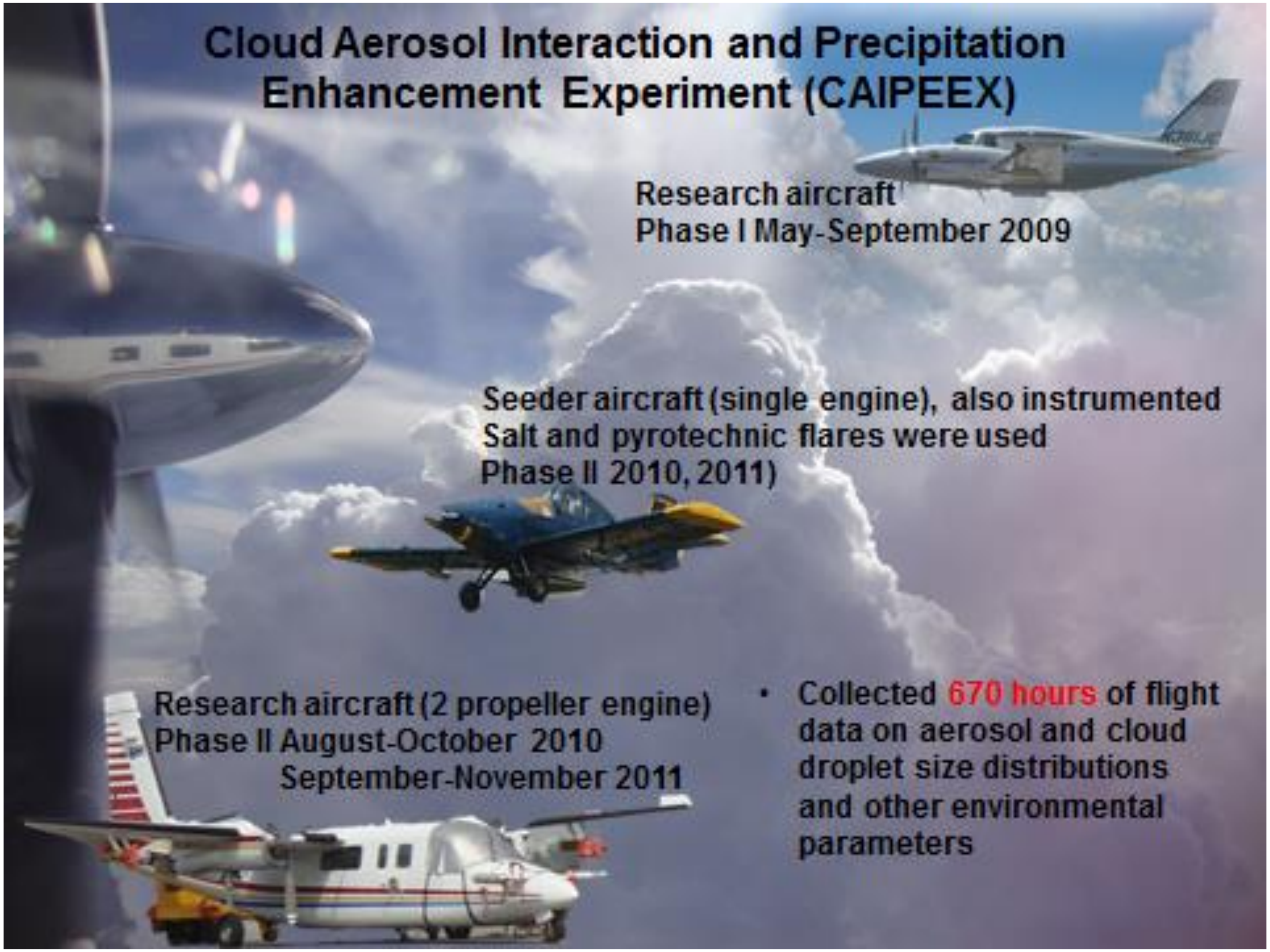
Seeded vs non-seeded volumes 31 May 2005 (Case 2)







(source: Duncan Axisa)



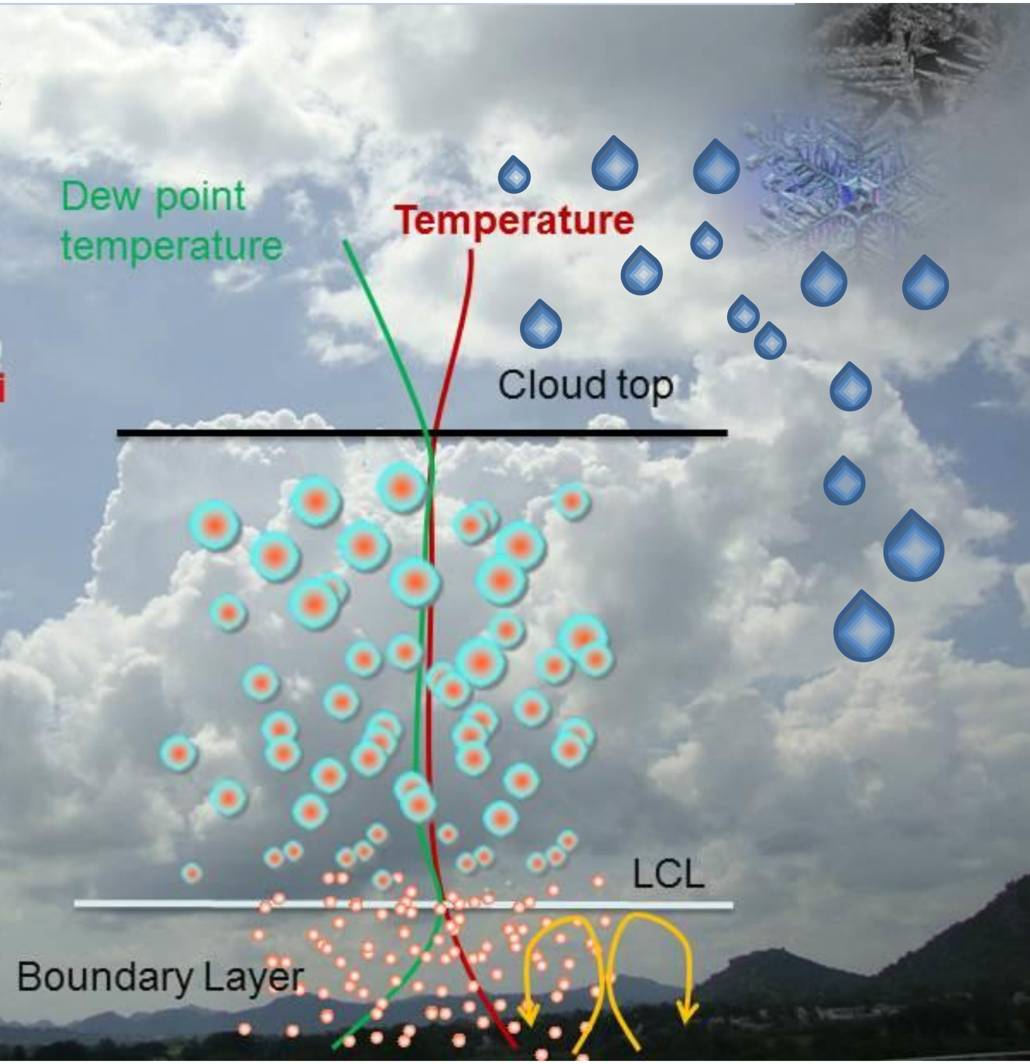
Major achievement:

CAIPEEX has finished 820 hours of research flights and two integrated ground campaigns (2009-2015)

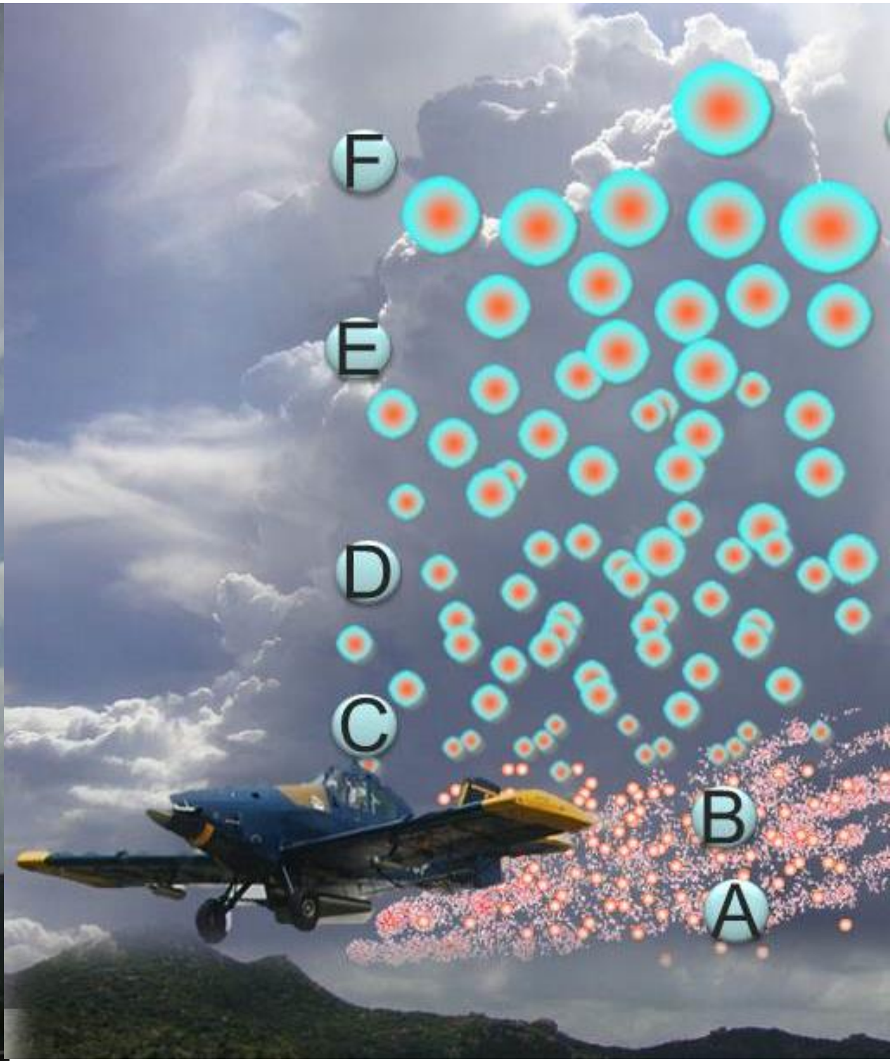
Phase III (2014-15)
150 hours of research flights
Varanasi, Mahabaleswar, Arabian Sea, Kohlapur, Solapur

objectives

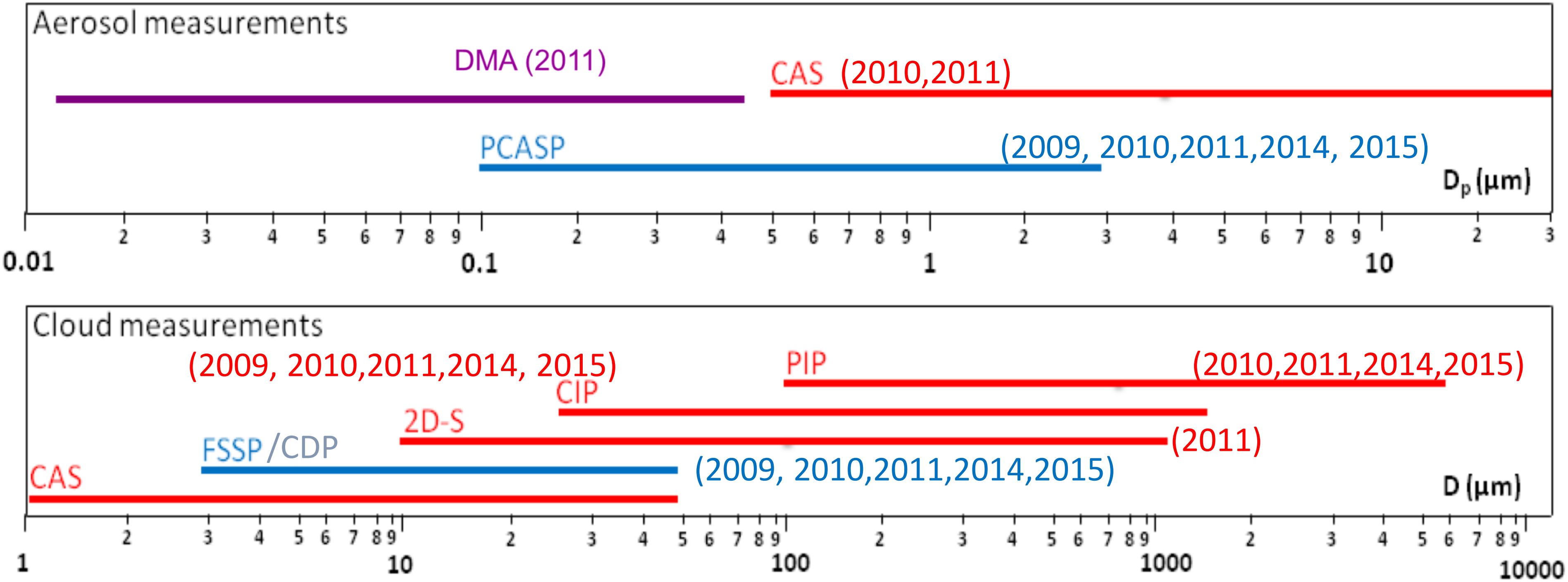
Aerosol-Cloud-Precipitation interaction

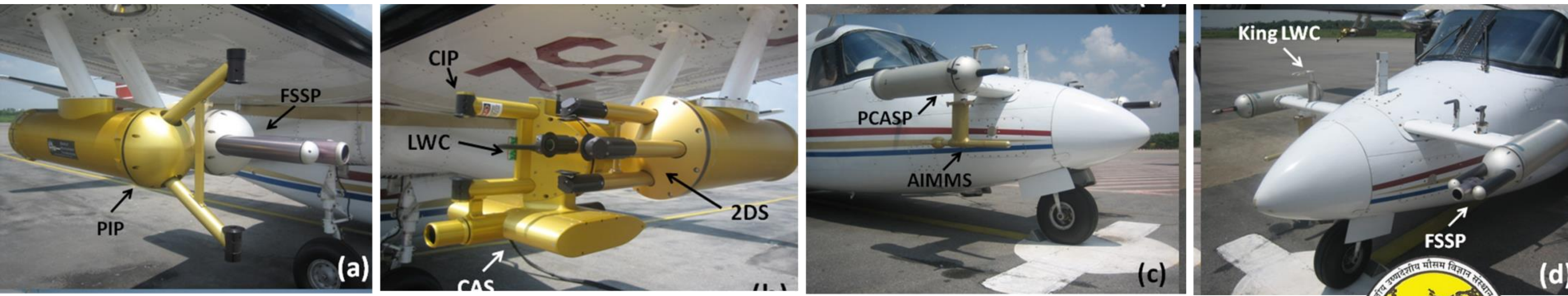


Hygroscopic cloud seeding



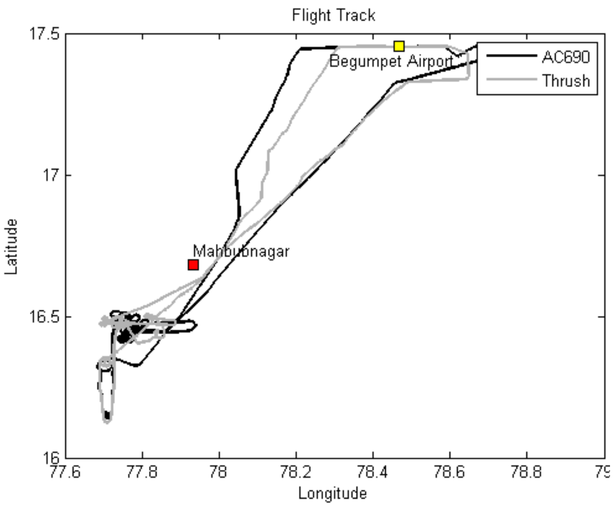
Aircraft instruments for aerosol and cloud microphysics

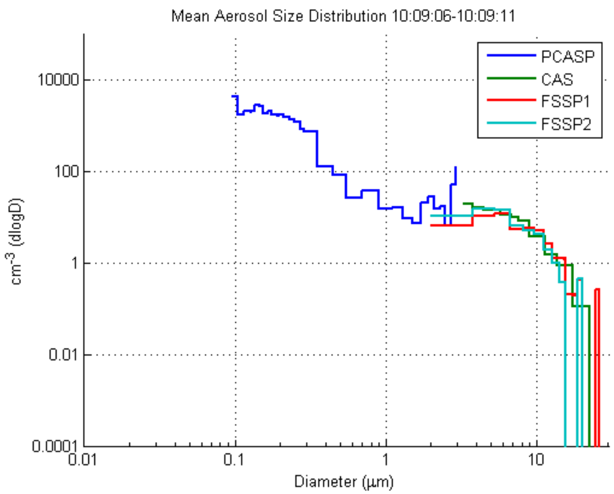




website: http://www.tropmet.res.in/~caipeex/

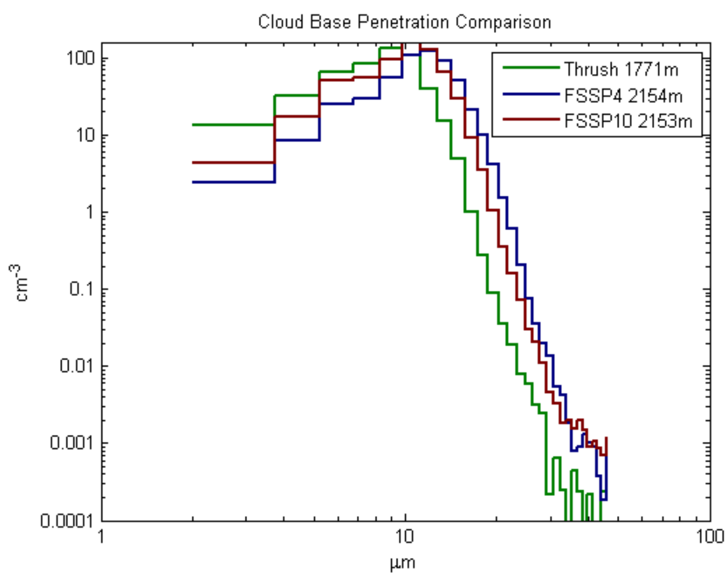
Salt seeding example from CAIPEEX

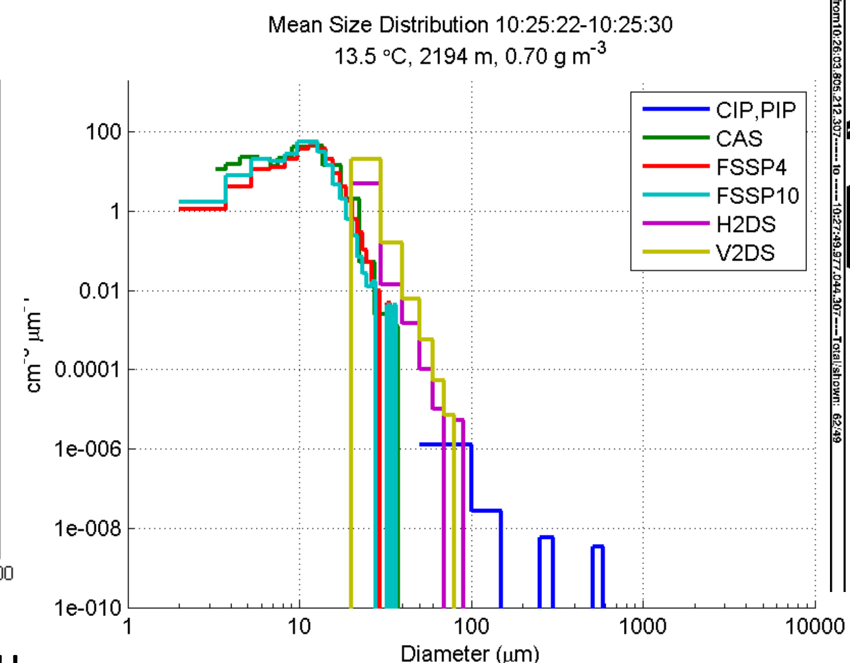


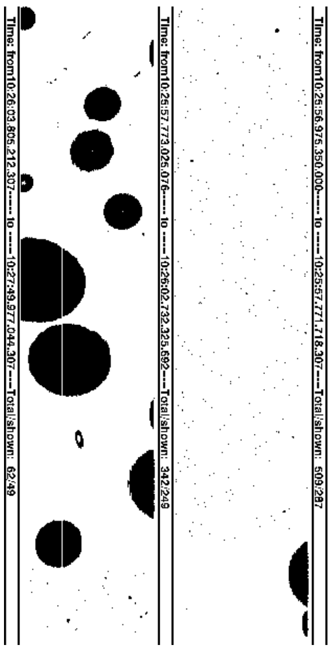


Cloud base ~4800 ft

Dissipating base of seeded target (10:47)

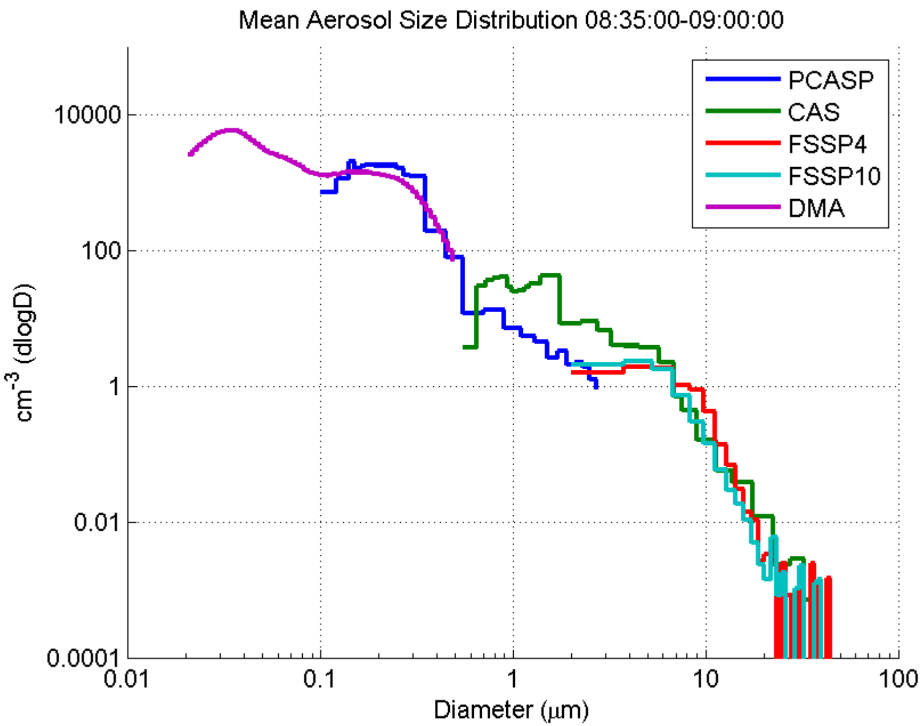


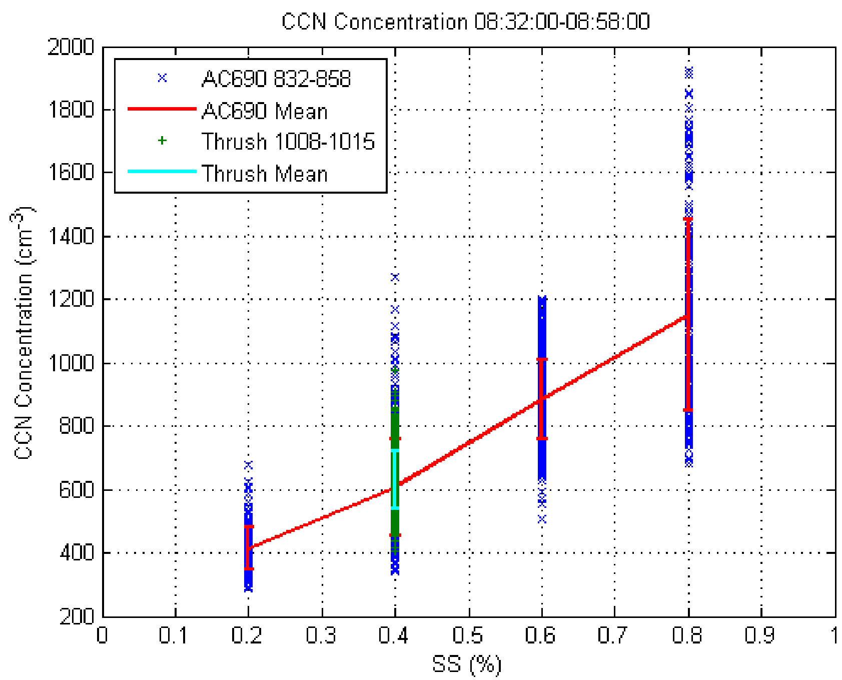




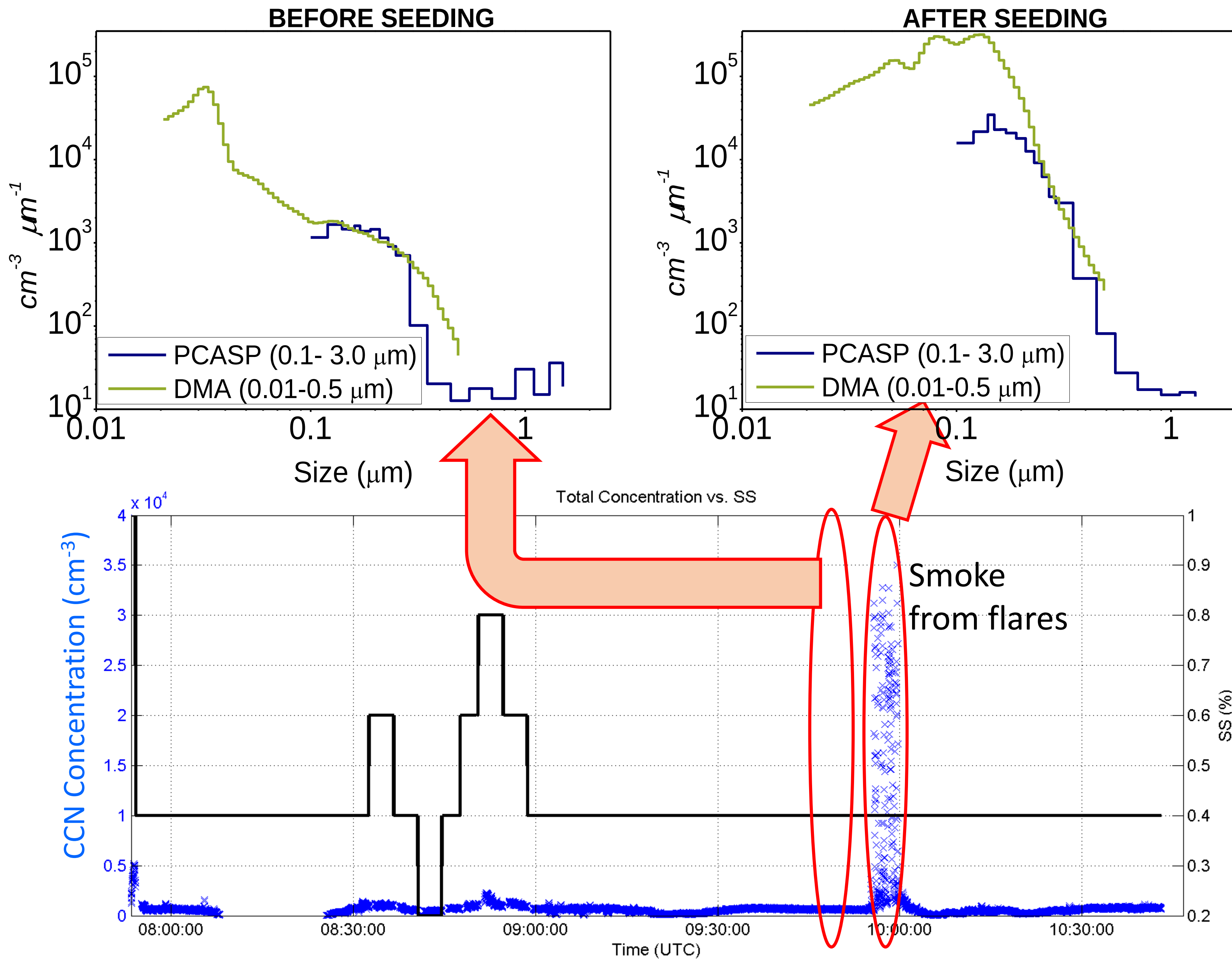
Salt seeding at base was ineffective !!

Background Aerosol PSD and CCN spectra during seeding material (flare) characterization

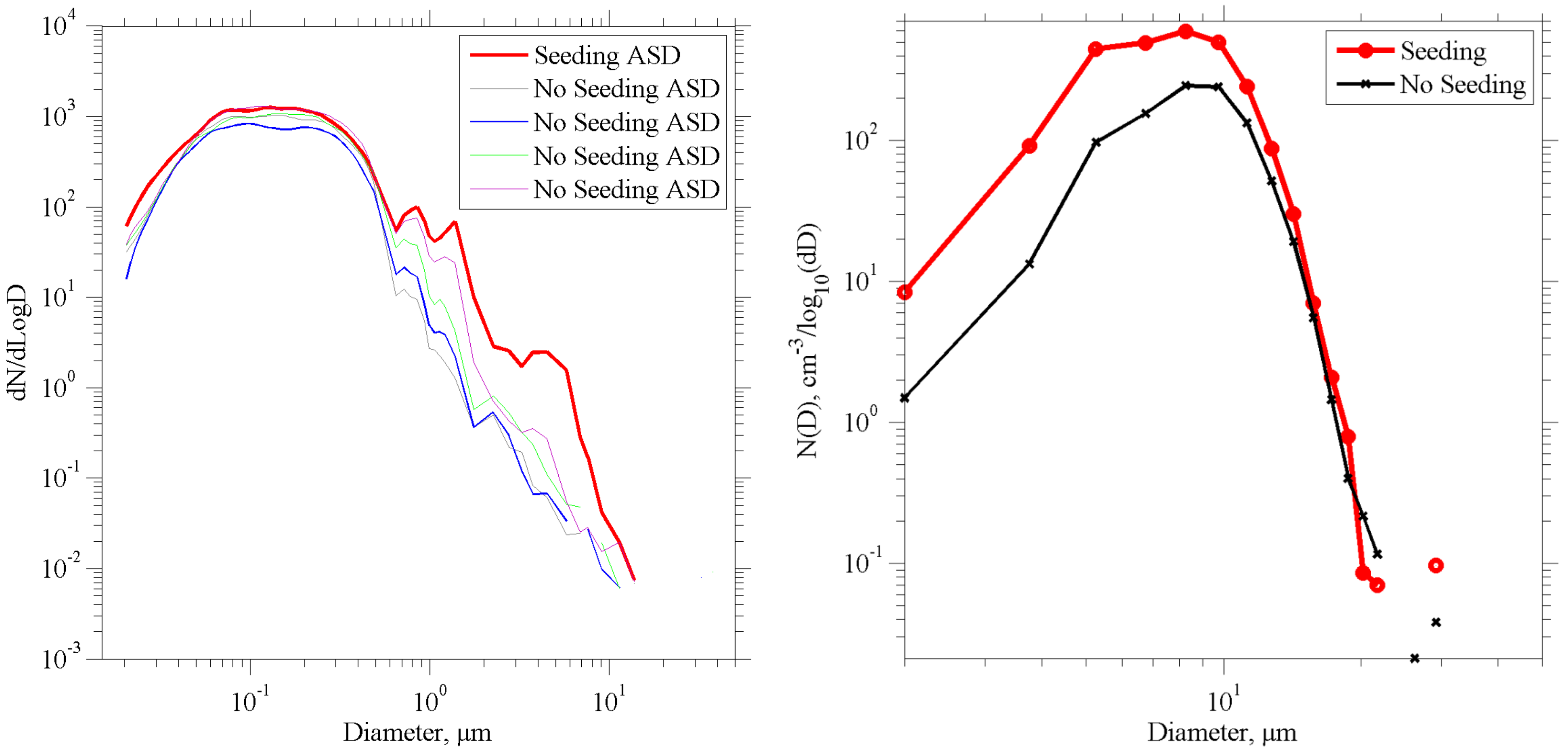




Seeding material characterization



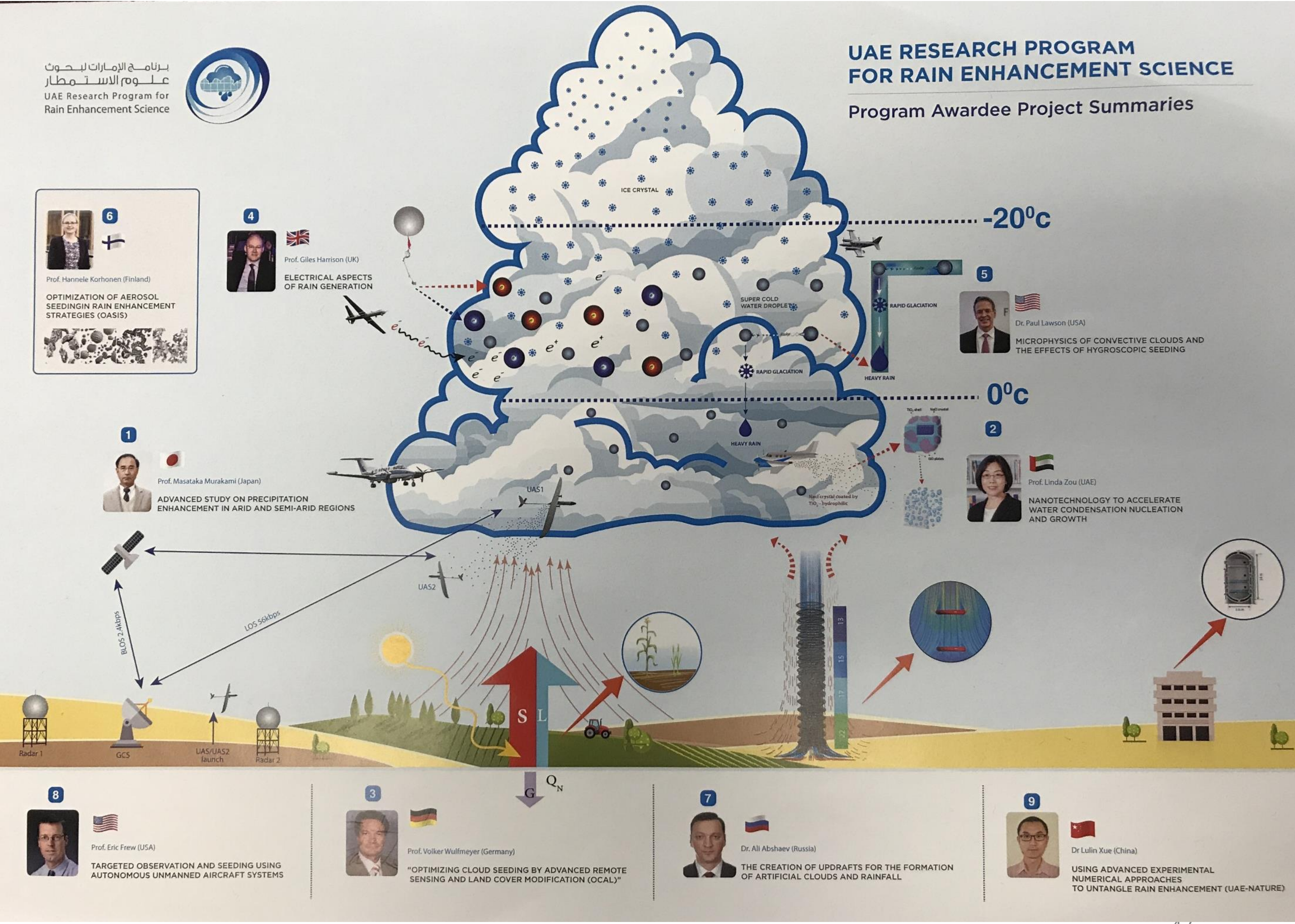
Joint PSD with DMA and PCASP seeding and no-seeding times and associated cloud droplet spectra from FSSP



Cloud seeding science Experiment 2018-19

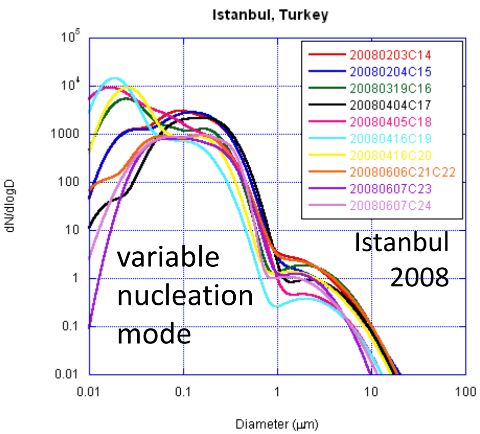
CAIPEEX Phase IV

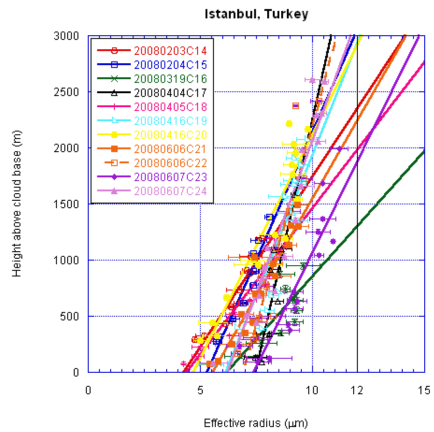
C-band polarimeteric radar, Raingauge network
Ground station with radiaometer, wind profiler, MRR, disdrometer
SMPS, CCNC, Aerosol and gas Chemistry, Aethalometer,



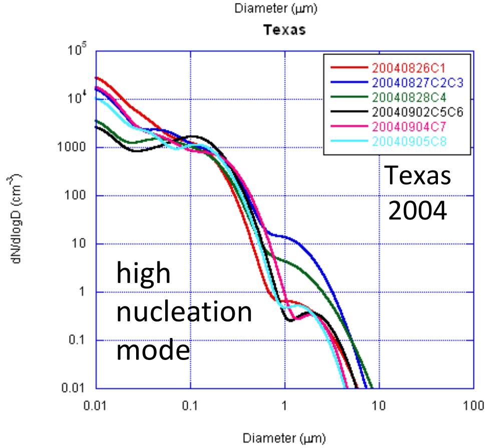
برنامـج الإمارات لبحـوث علـوم الاستمطار
UAE Research Program for Rain Enhancement Science
UAE RESEARCH PROGRAM FOR RAIN ENHANCEMENT SCIENCE
Program Awardee Project Summaries
6
Prof. Hannele Korhonen (Finland)
OPTIMIZATION OF AEROSOL SEEDINGIN RAIN ENHANCEMENT STRATEGIES (OASIS)
4
Prof. Giles Harrison (UK)
ELECTRICAL ASPECTS OF RAIN GENERATION
ICE CRYSTAL
-20⁰c
SUPER COLD WATER DROPLETS
RAPID GLACIATION
HEAVY RAIN
0⁰c
5
Dr. Paul Lawson (USA)
MICROPHYSICS OF CONVECTIVE CLOUDS AND THE EFFECTS OF HYGROSCOPIC SEEDING
2
Prof. Linda Zou (UAE)
NANOTECHNOLOGY TO ACCELERATE WATER CONDENSATION NUCLEATION AND GROWTH
1
Prof. Masataka Murakami (Japan)
ADVANCED STUDY ON PRECIPITATION ENHANCEMENT IN ARID AND SEMI-ARID REGIONS
UAS1
UAS2
BLOS 2.4kbps
LOS 56kbps
Radar 1
GCS
UAS/UAS2 launch
Radar 2
S
L
G
Q_N
8
Prof. Eric Frew (USA)
TARGETED OBSERVATION AND SEEDING USING AUTONOMOUS UNMANNED AIRCRAFT SYSTEMS
3
Prof. Volker Wulfmeyer (Germany)
"OPTIMIZING CLOUD SEEDING BY ADVANCED REMOTE SENSING AND LAND COVER MODIFICATION (OCAL)"
7
Dr. Ali Abshaev (Russia)
THE CREATION OF UPDRAFTS FOR THE FORMATION OF ARTIFICIAL CLOUDS AND RAINFALL
9
Dr Lulin Xue (China)
USING ADVANCED EXPERIMENTAL NUMERICAL APPROACHES TO UNTANGLE RAIN ENHANCEMENT (UAE-NATURE)

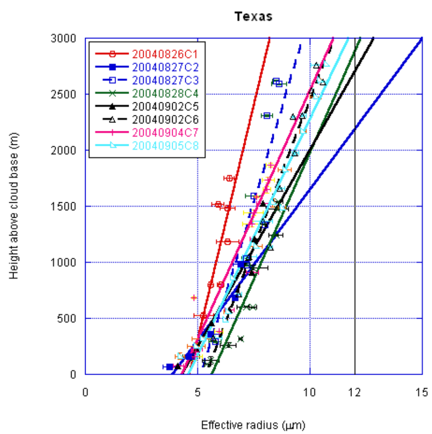
Effect of aerosol on cloud drop size – from wx mod programs



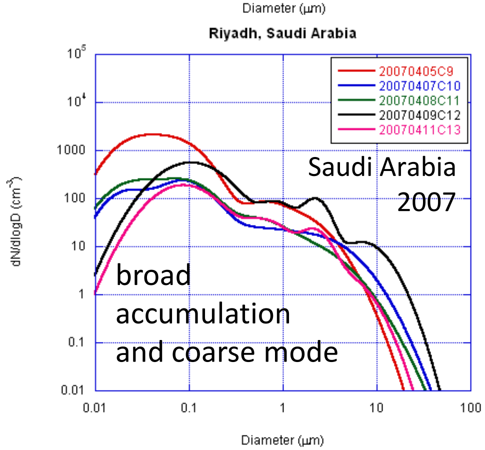


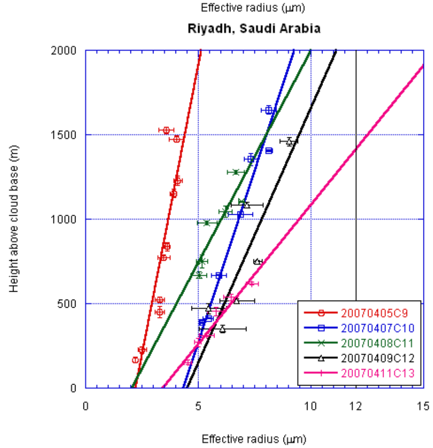
Large variability in cloud microphysical properties.



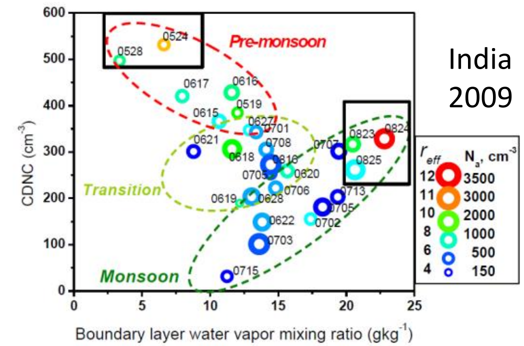


Slow droplet growth. Warm rain is absent.

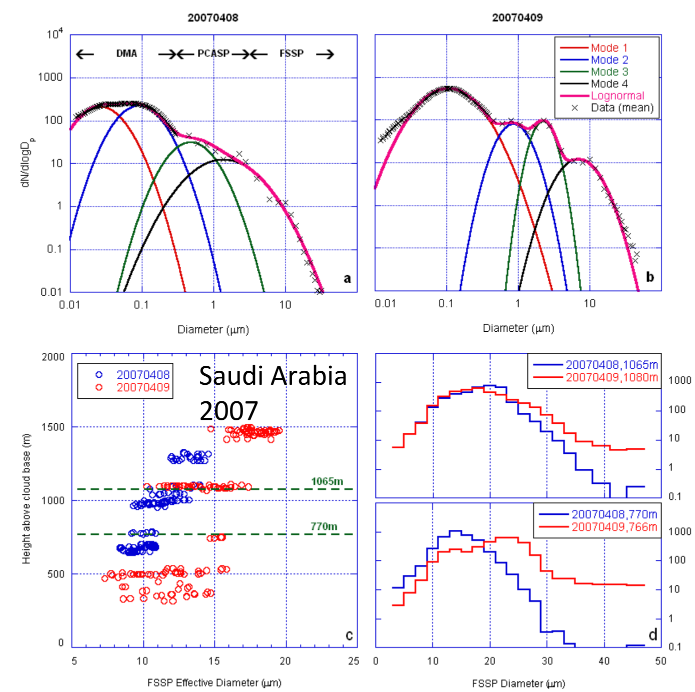




Warm rain is active when pollution aerosol concentrations are low.



Prabha, T. V., S. Patade, G. Pandithurai, A. Khain, **D. Axisa**, P. Pradeep-Kumar, R. S. Maheshkumar, J. R. Kulkarni and B. N. Goswami, 2012: Spectral width of premonsoon and monsoon clouds over Indo-Gangetic valley, J. Geophys. Res., 117, D20205, doi:10.1029/2011JD016837.



Posfai M., **D. Axisa**, E. Tompa, E. Freney, R. Bruintjes and P. Buseck, 2013: Interactions of mineral dust with pollution and clouds: An individual-particle TEM study of atmospheric aerosol from Saudi Arabia, Atmos. Res. 122, 347-361.

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2013JD021165

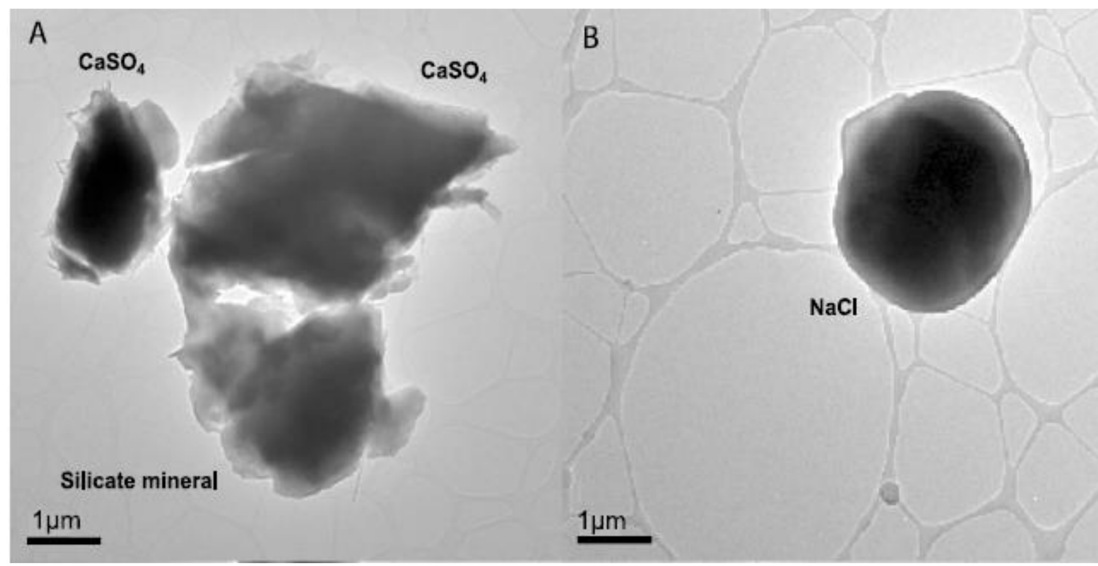
Key Points:
- Internally mixed particles enhance CCN formation on desert dust in updrafts
- Independent deliquescence of coarse- and fine-mode particles occurs in updrafts
- Industrially derived salts within aerosols leads to the formation of giant CCN

Individual aerosol particles in ambient and updraft conditions below convective cloud bases in the Oman mountain region

T. A. Semeniuk[1], R. T. Bruintjes[2], V. Salazar[2], D. W. Breed[2], T. L. Jensen[2], and P. R. Buseck[1]

[1]Department of Chemistry and Biochemistry, and School of Earth and Space Exploration, Arizona State University, Tempe, Arizona, USA, [2]National Center for Atmospheric Research, Boulder, Colorado, USA

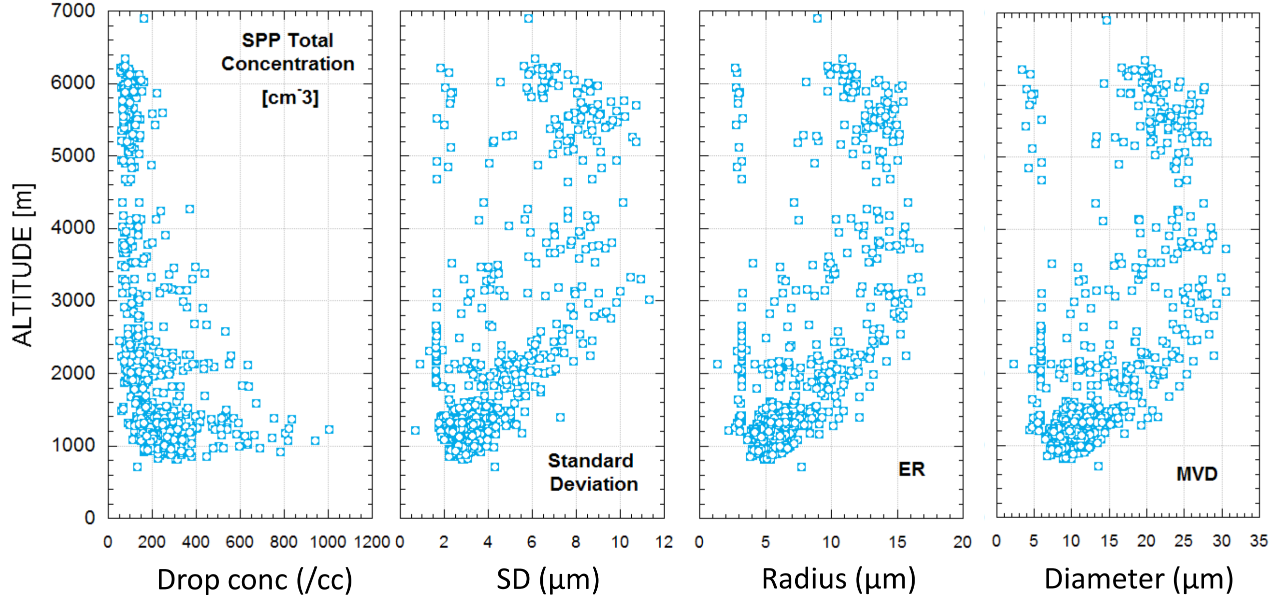
- NaCl containing with aggregates (>0.3 microns)
- Associated with high CCN and droplets
- Large droplet sizes in updrafts
- Soluble salts from local pollution and natural sources affect aerosol-cloud interaction
- Seeding with hygroscopic flares were ineffective



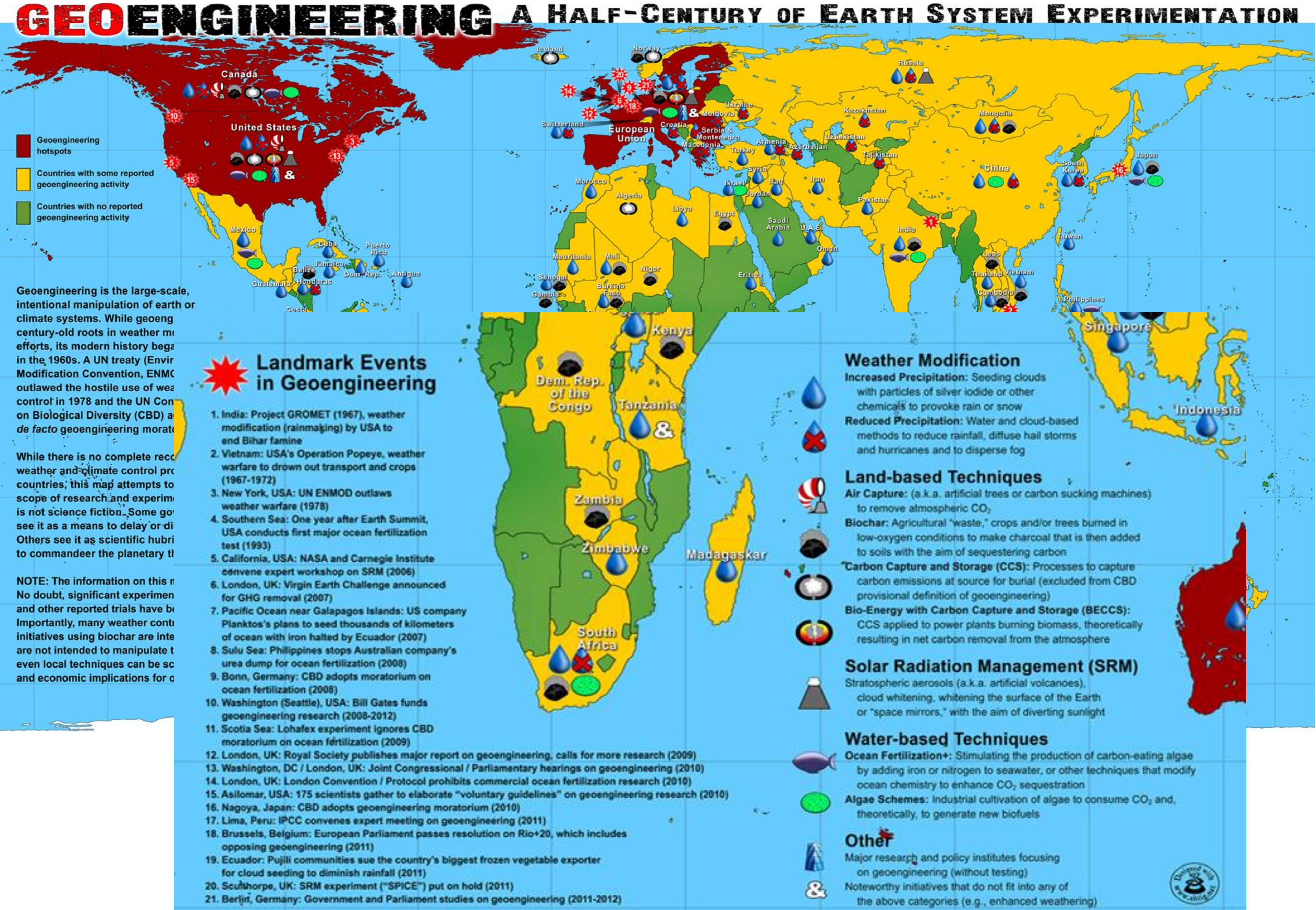
Concluding thoughts

- clouds can have a considerable effect on the Earth’s climate : the most uncertain aspects in their formation, persistence, and ultimate dissipation is the role played by aerosols.
- Certain interactions between aerosols and clouds are relatively well studied and understood. For example, it is known that an increase in the aerosol concentration will increase the number of droplets in warm clouds and decrease their average size. There is uncertainty on aerosol impacts on rate of precipitation and lifetime.
- Other effects are not as well known. For example, the interplay of dynamics versus effects purely attributed to aerosols remains highly uncertain.
- Measurement uncertainty is associated with the effect of black carbon and organics, dust, aerosol types of anthropogenic interest and bioaerosols, on droplet and ice formation.
- Research programs like SNOWIE, CAIPEEX , etc represents a leap forward in reducing the uncertainty associated with the interaction of aerosols and clouds.

Measurements in Sulawesi Indonesia (NCAR: 2005)



- Cloud droplet sizes increase rapidly with height and coalescence becomes active within 1 km of cloud base.
- Drizzle and raindrops are present at the 0° to -5°C level, freeze and activate a natural ice seeding process or ice multiplication.
- Operational cloud seeding techniques need to be adapted for this region and conventional methods may not be effective.
- Need for more field studies.



GEOENGINEERING A HALF-CENTURY OF EARTH SYSTEM EXPERIMENTATION
Geoengineering hotspots
Countries with some reported geoengineering activity
Countries with no reported geoengineering activity
Canada
United States
Mexico
Cuba
Puerto Rico
Jamaica
Dom. Rep.
Antigua
Belize
Honduras
Guatemala
Iceland
Norway
Russia
Switzerland
European Union
Croatia
Serbia & Montenegro
Macedonia
Moldovia
Ukraine
Kazakhstan
Uzbekistan
Tajikistan
Mongolia
Turkey
Armenia
Azerbaijan
Syria
Iraq
Iran
Israel
Jordan
Morocco
Algeria
Libya
Egypt
Saudi Arabia
U.A.E.
Oman
Pakistan
India
China
South Korea
Japan
Taiwan
Laos
Thailand
Vietnam
Cambodia
Philippines
Mauritania
Mali
Niger
Senegal
Gambia
Burkina Faso
Eritrea
Kenya
Dem. Rep. of the Congo
Tanzania
Zambia
Zimbabwe
Madagaskar
South Africa
Singapore
Indonesia
Geoengineering is the large-scale, intentional manipulation of earth or climate systems. While geoeng century-old roots in weather m efforts, its modern history bega in the 1960s. A UN treaty (Envir Modification Convention, ENMC outlawed the hostile use of wea control in 1978 and the UN Con on Biological Diversity (CBD) a de facto geoengineering morat
While there is no complete rec weather and climate control pr countries, this map attempts to scope of research and experim is not science fiction. Some go see it as a means to delay or d Others see it as scientific hubri to commandeer the planetary t
NOTE: The information on this n No doubt, significant experimen and other reported trials have b Importantly, many weather cont initiatives using biochar are inte are not intended to manipulate t even local techniques can be sc and economic implications for c
Landmark Events in Geoengineering
1. India: Project GROMET (1967), weather modification (rainmaking) by USA to end Bihar famine
2. Vietnam: USA's Operation Popeye, weather warfare to drown out transport and crops (1967-1972)
3. New York, USA: UN ENMOD outlaws weather warfare (1978)
4. Southern Sea: One year after Earth Summit, USA conducts first major ocean fertilization test (1993)
5. California, USA: NASA and Carnegie Institute convene expert workshop on SRM (2006)
6. London, UK: Virgin Earth Challenge announced for GHG removal (2007)
7. Pacific Ocean near Galapagos Islands: US company Planktos's plans to seed thousands of kilometers of ocean with iron halted by Ecuador (2007)
8. Sulu Sea: Philippines stops Australian company's urea dump for ocean fertilization (2008)
9. Bonn, Germany: CBD adopts moratorium on ocean fertilization (2008)
10. Washington (Seattle), USA: Bill Gates funds geoengineering research (2008-2012)
11. Scotia Sea: Lohafex experiment ignores CBD moratorium on ocean fertilization (2009)
12. London, UK: Royal Society publishes major report on geoengineering, calls for more research (2009)
13. Washington, DC / London, UK: Joint Congressional / Parliamentary hearings on geoengineering (2010)
14. London, UK: London Convention / Protocol prohibits commercial ocean fertilization research (2010)
15. Asilomar, USA: 175 scientists gather to elaborate "voluntary guidelines" on geoengineering research (2010)
16. Nagoya, Japan: CBD adopts geoengineering moratorium (2010)
17. Lima, Peru: IPCC convenes expert meeting on geoengineering (2011)
18. Brussels, Belgium: European Parliament passes resolution on Rio+20, which includes opposing geoengineering (2011)
19. Ecuador: Pujili communities sue the country's biggest frozen vegetable exporter for cloud seeding to diminish rainfall (2011)
20. Scunthorpe, UK: SRM experiment ("SPICE") put on hold (2011)
21. Berlin, Germany: Government and Parliament studies on geoengineering (2011-2012)
Weather Modification
Increased Precipitation: Seeding clouds with particles of silver iodide or other chemicals to provoke rain or snow
Reduced Precipitation: Water and cloud-based methods to reduce rainfall, diffuse hail storms and hurricanes and to disperse fog
Land-based Techniques
Air Capture: (a.k.a. artificial trees or carbon sucking machines) to remove atmospheric CO_2
Biochar: Agricultural "waste," crops and/or trees burned in low-oxygen conditions to make charcoal that is then added to soils with the aim of sequestering carbon
Carbon Capture and Storage (CCS): Processes to capture carbon emissions at source for burial (excluded from CBD provisional definition of geoengineering)
Bio-Energy with Carbon Capture and Storage (BECCS): CCS applied to power plants burning biomass, theoretically resulting in net carbon removal from the atmosphere
Solar Radiation Management (SRM)
Stratospheric aerosols (a.k.a. artificial volcanoes), cloud whitening, whitening the surface of the Earth or "space mirrors," with the aim of diverting sunlight
Water-based Techniques
Ocean Fertilization+: Stimulating the production of carbon-eating algae by adding iron or nitrogen to seawater, or other techniques that modify ocean chemistry to enhance CO_2 sequestration
Algae Schemes: Industrial cultivation of algae to consume CO_2 and, theoretically, to generate new biofuels
Other
Major research and policy institutes focusing on geoengineering (without testing)
Noteworthy initiatives that do not fit into any of the above categories (e.g., enhanced weathering)