Studies of cloud structure and microphysics with ground-based multi-sensor measurements

OUTLINE

1. Inferring cloud phase and estimation of cloud microphysical parameters from cloud radars and combined radar–radiometer-lidar systems

2. Polarimetric radar studies of clouds and weakly precipitating cloud systems [ice crystal habit recognition, monitoring crystal habit change and liquid to ice conversion, super-cooled liquid detection]

3. Polarimetric scanning radar tracking of cloud seeding material

Studies of non-precipitating clouds with ground-based mm-wavelength radars (typically K_a-band or W-band) and combined radar–radiometer-lidar systems

Objective: to derive layer averaged and vertically resolved quantitative information on cloud microphysical and optical properties such as ice water content (IWC), [or liquid water content – LWC], characteristic cloud particle size (e.g., median size, D_m, or mean size, D_{mean} , effective radius R_e), cloud optical thickness, τ, (optical extinction coefficient, α)

Approach: time-series measurements from vertically pointing instruments are used for retrievals of cloud information on a long term basis from permanent (semi-permanent) “cloud observatories”, and shorter instrument deployments are used to collect information for different field experiments

Instruments for ground-based remote sensing of clouds

Ka-band (8.66 mm) Doppler radar

IR Spectral Radiometer (10-12 μm)

Lidar (different wavelengths)

Microwave radiometer (23.8 & 31.4 GHz)

Multi-sensor cloud retrieval methods

Liquid water clouds:

combination of radar reflectivity profiles and integrated liquid water path (LWP) estimates from microwave radiometer data are used to derive profiles of cloud microphysics: R_e, LWC, conc

Ice clouds:

(a) radar – radiometer method

combination of the infrared spectral radiometer measurements and radar reflectivity profiles are used for retrievals of ice clouds that are unobstructed by lower level liquid clouds; → IWC, D_m, α

(b) Doppler radar method

Doppler moment measurements are used for retrievals of ice clouds which are a part of multi-layer cloud systems → IWC, D_m, α

(c) radar – lidar method

combination of radar and lidar measurements can be used for thin ice clouds → IWC, D_m, α

Mixed-phase clouds:

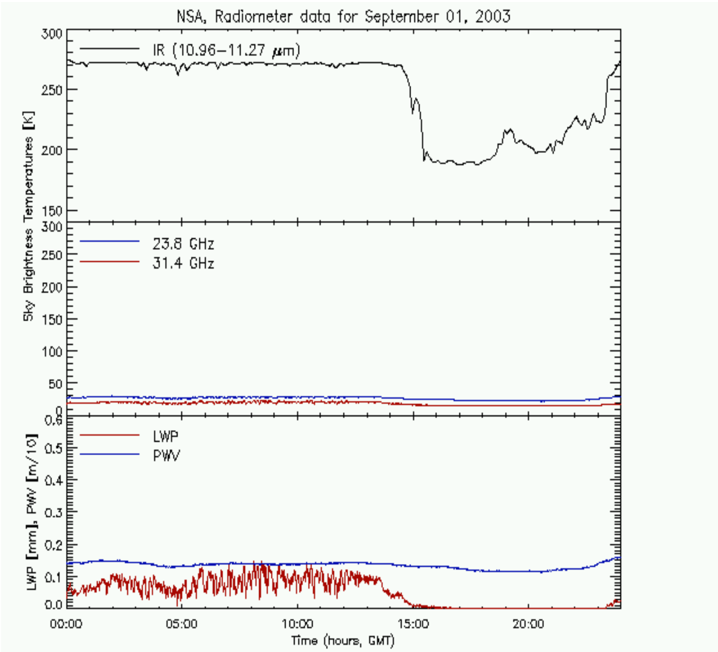
spectral Doppler measurements are used for retrievals

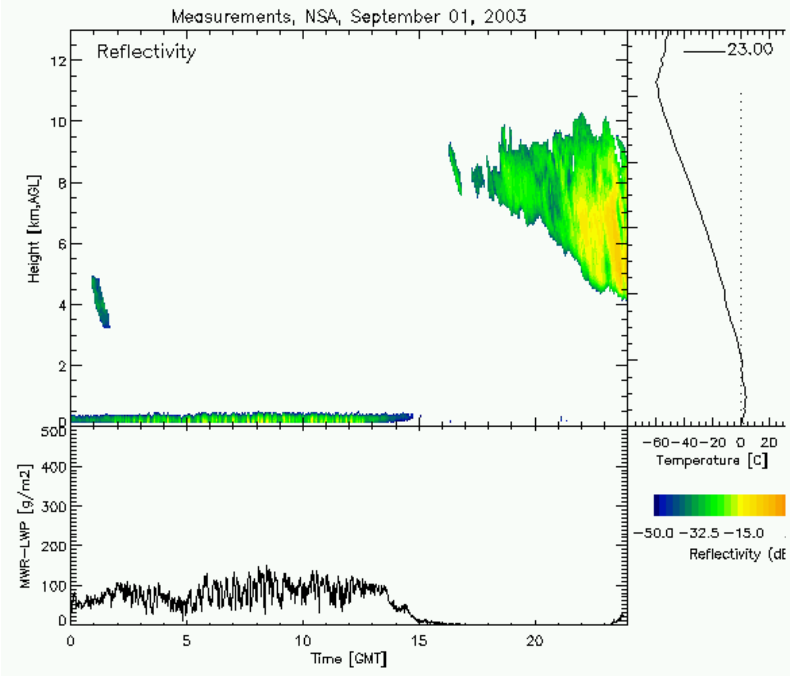
Radar-only cloud retrieval methods

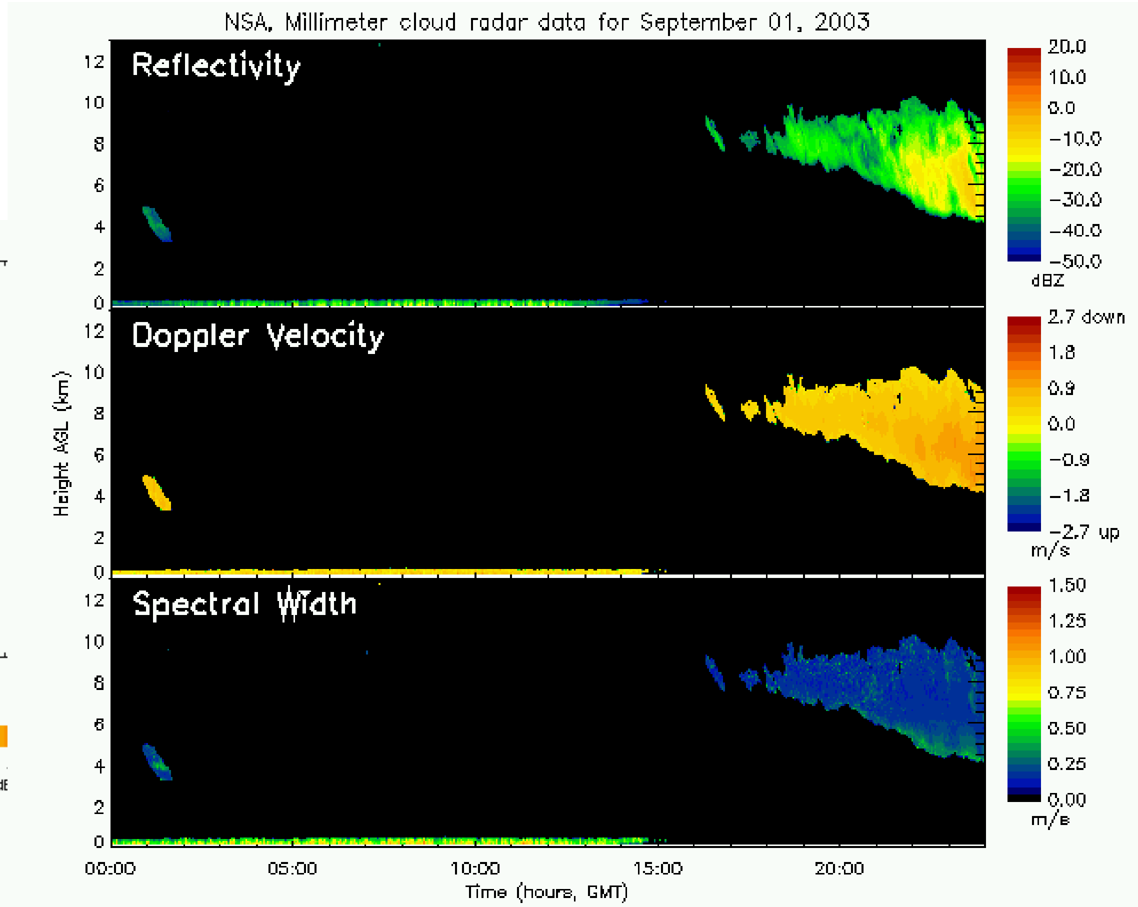
Regressions between different cloud parameters and radar measurables (e.g., Z_e)

A simple case example 1-SEP-03, NSA

Input information

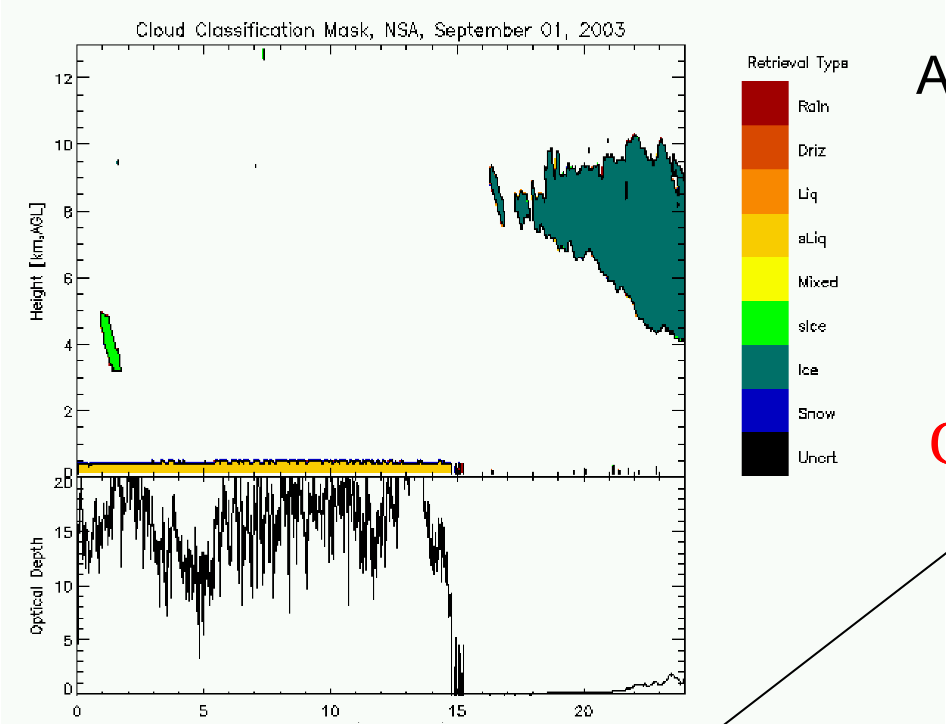






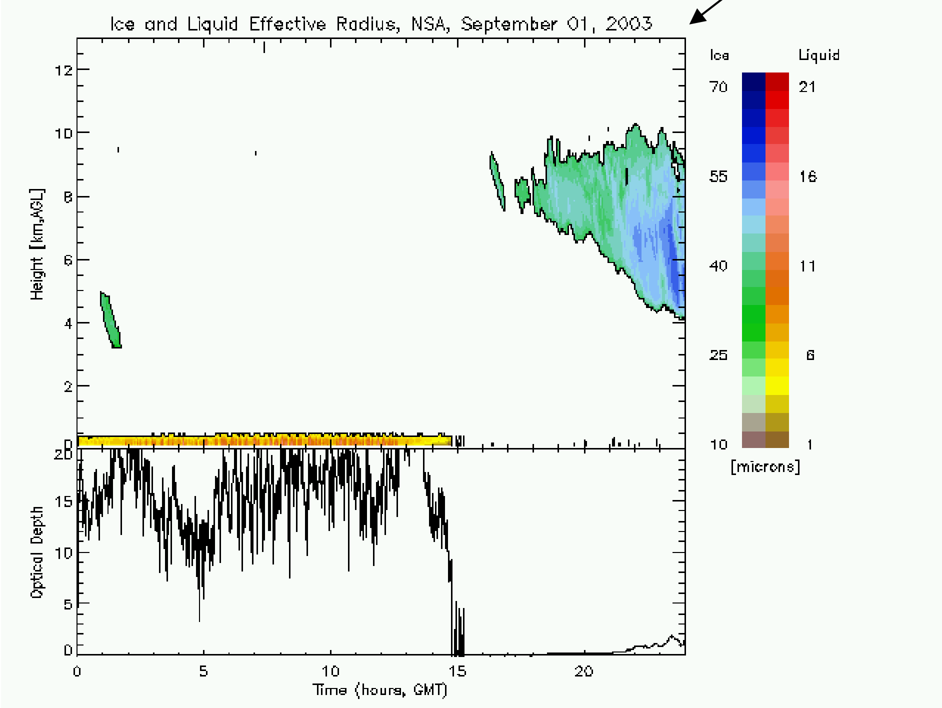
A simple case example 1-SEP-03, NSA

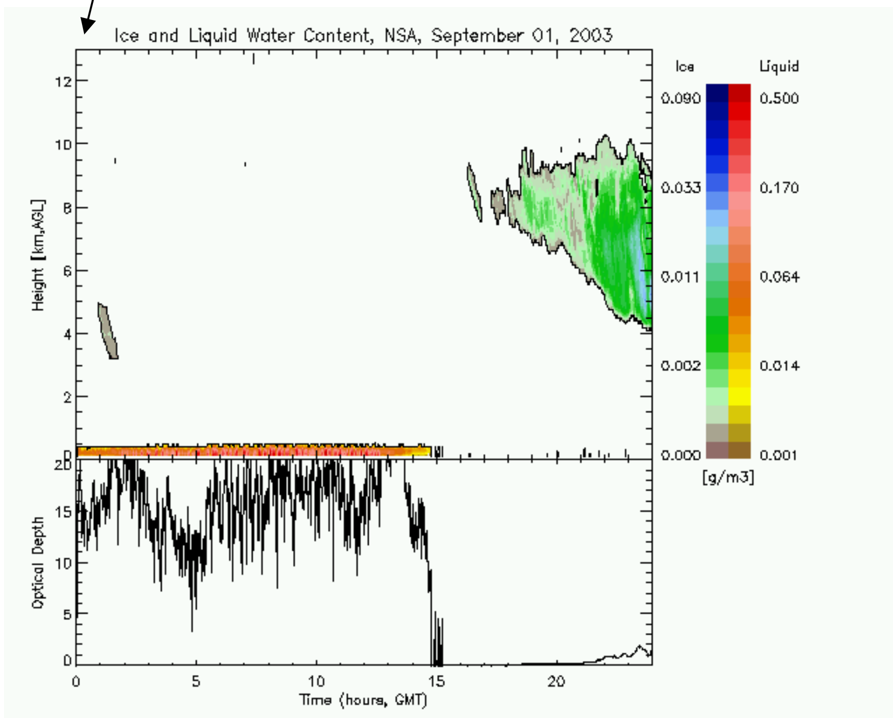
Retrieved information



Cloud particle R_e

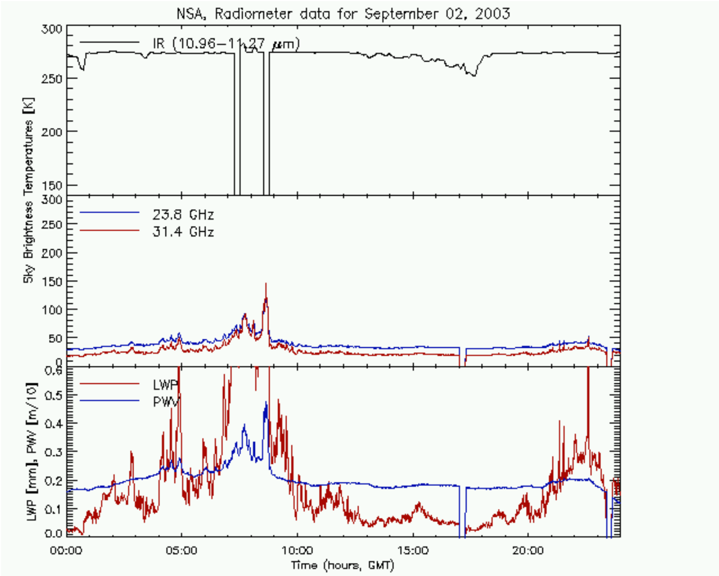
Cloud content (IWC and LWC)

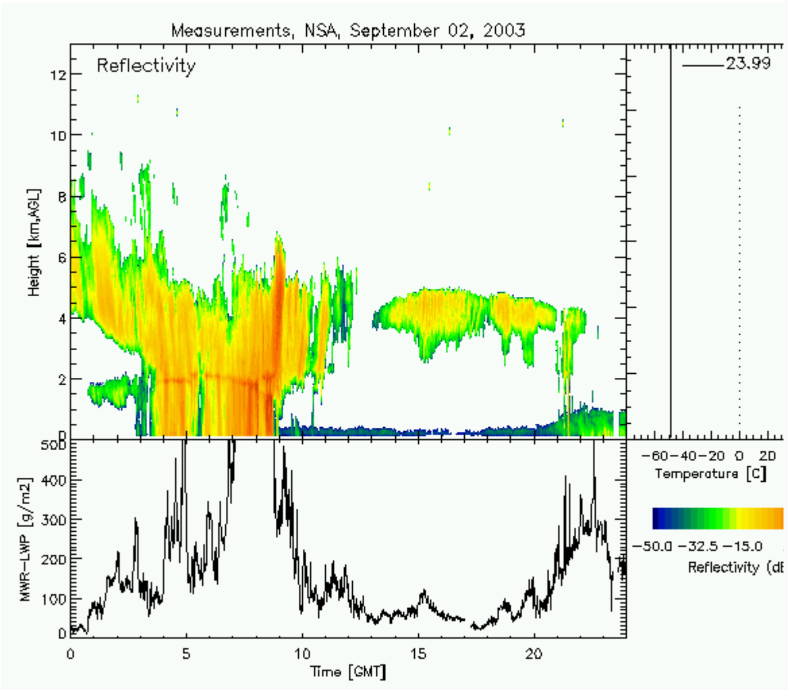


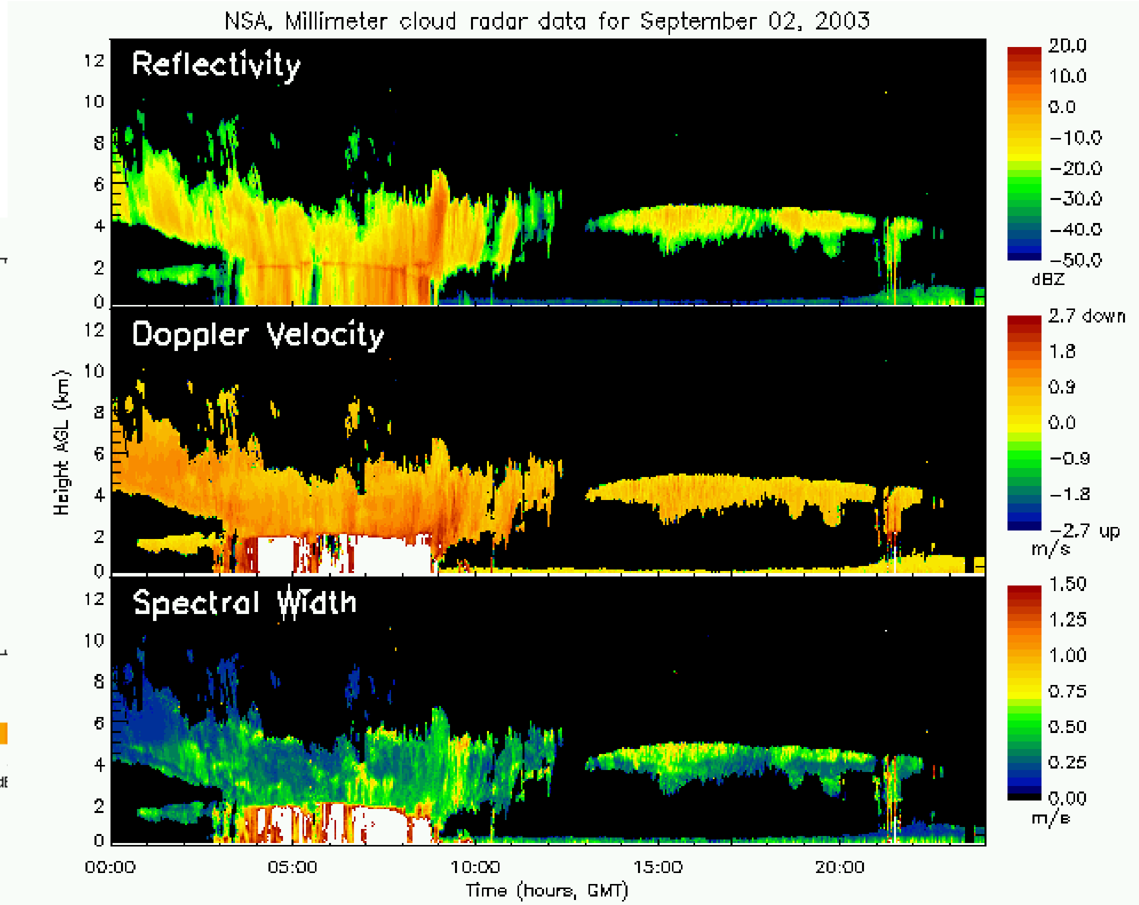


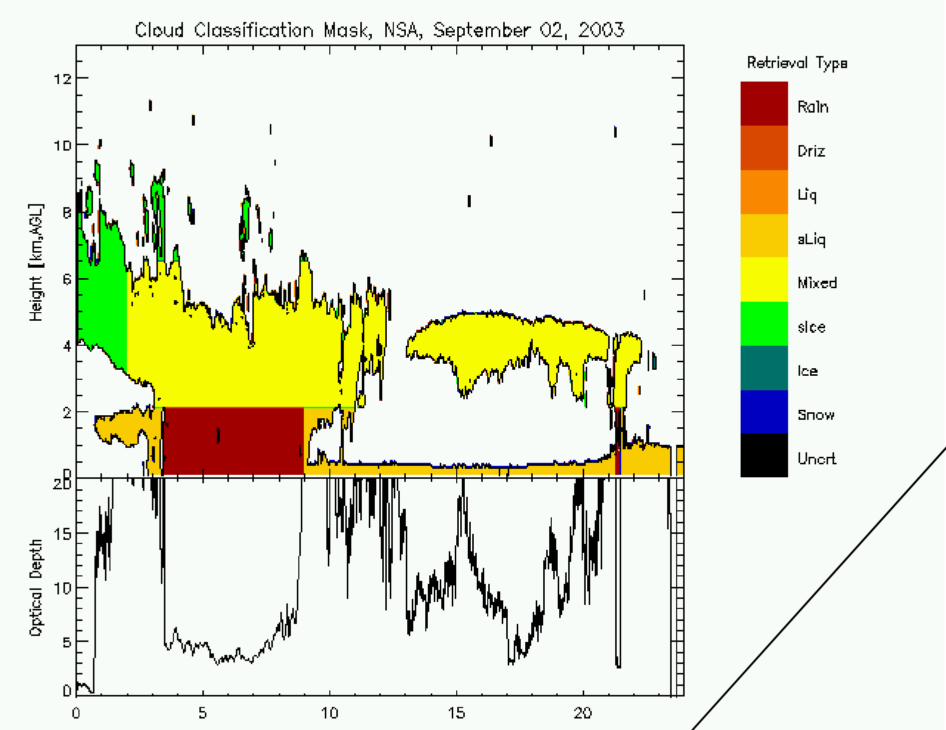
A complex case example 2-SEP-03, NSA

Input information







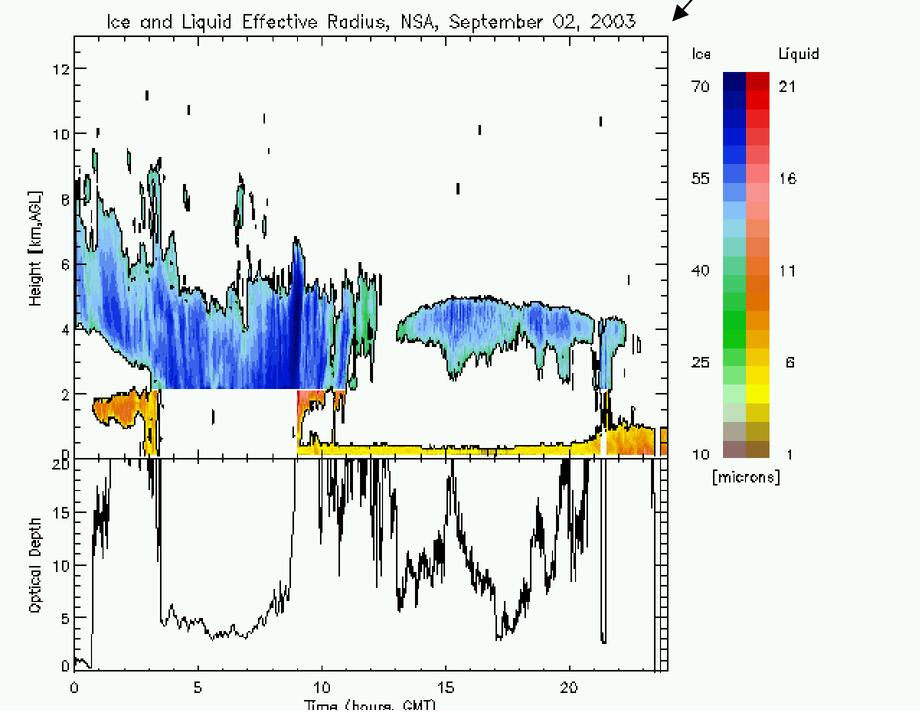


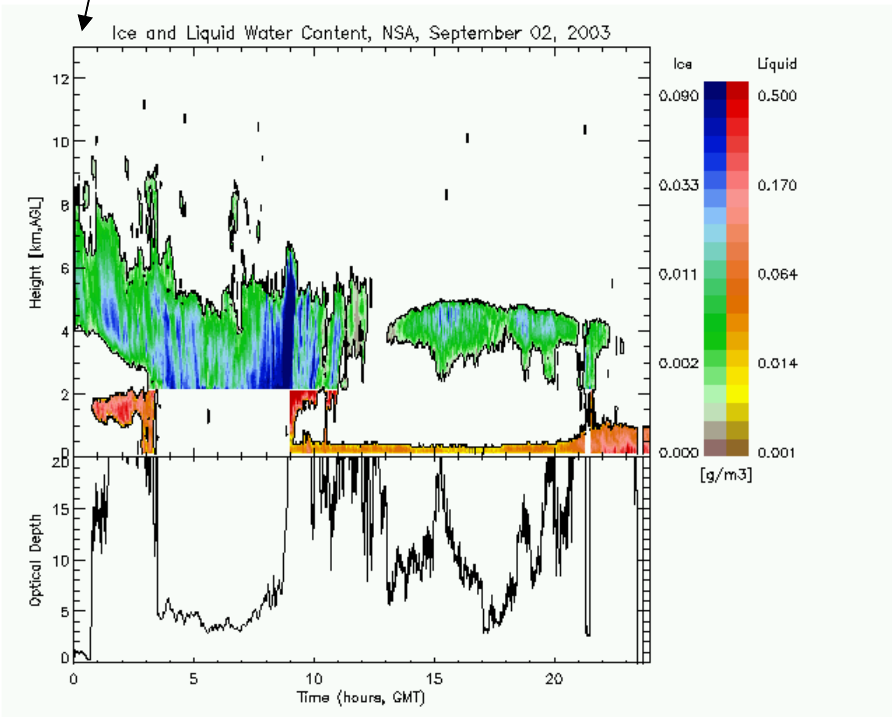
A complex case example 2-SEP-03, NSA

Retrieved information

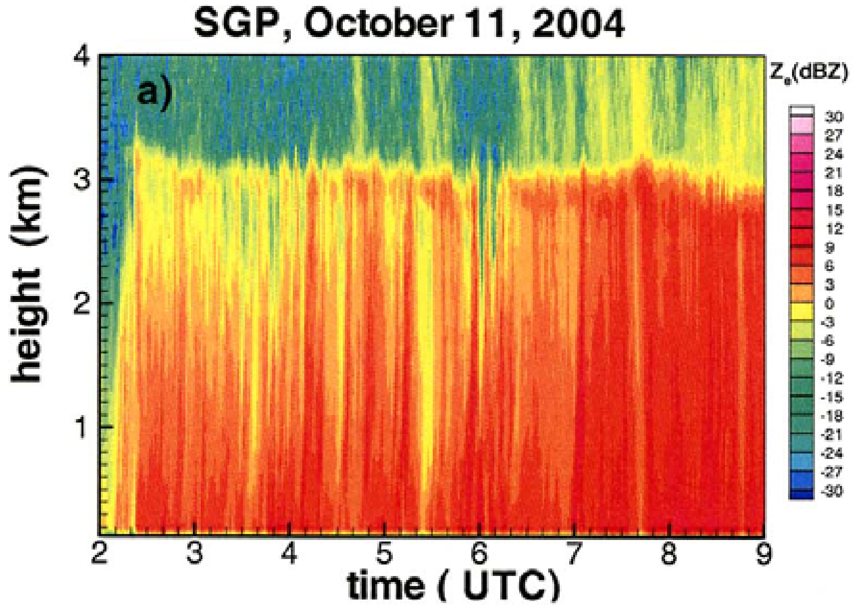
Cloud particle R_e

Cloud content (IWC and LWC)

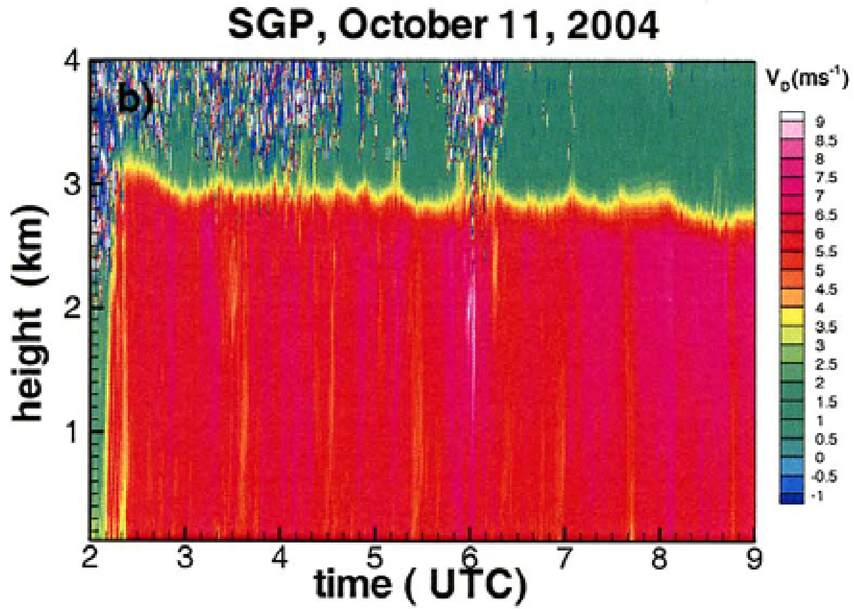


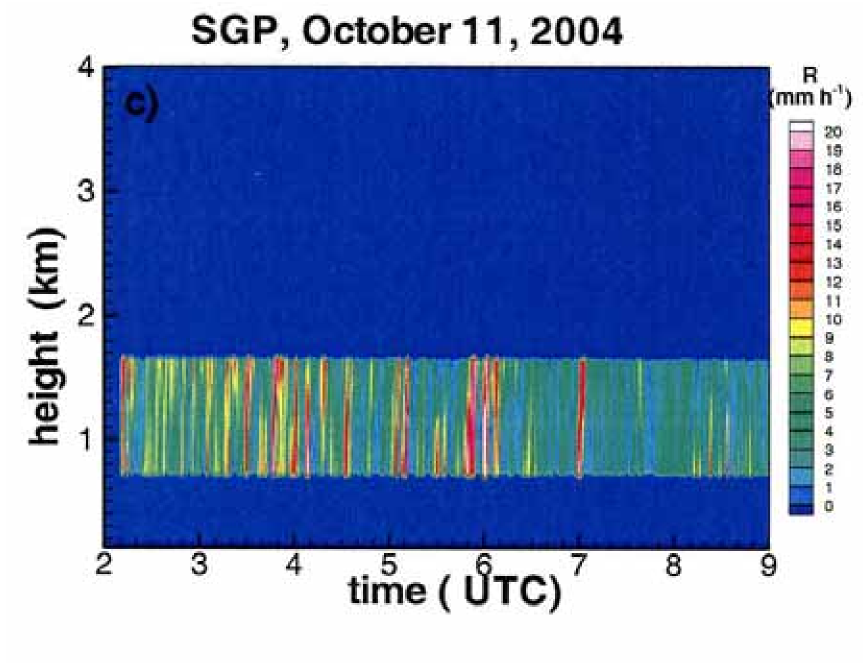


Rainfall can also be retrieved using vertically pointing cloud radar



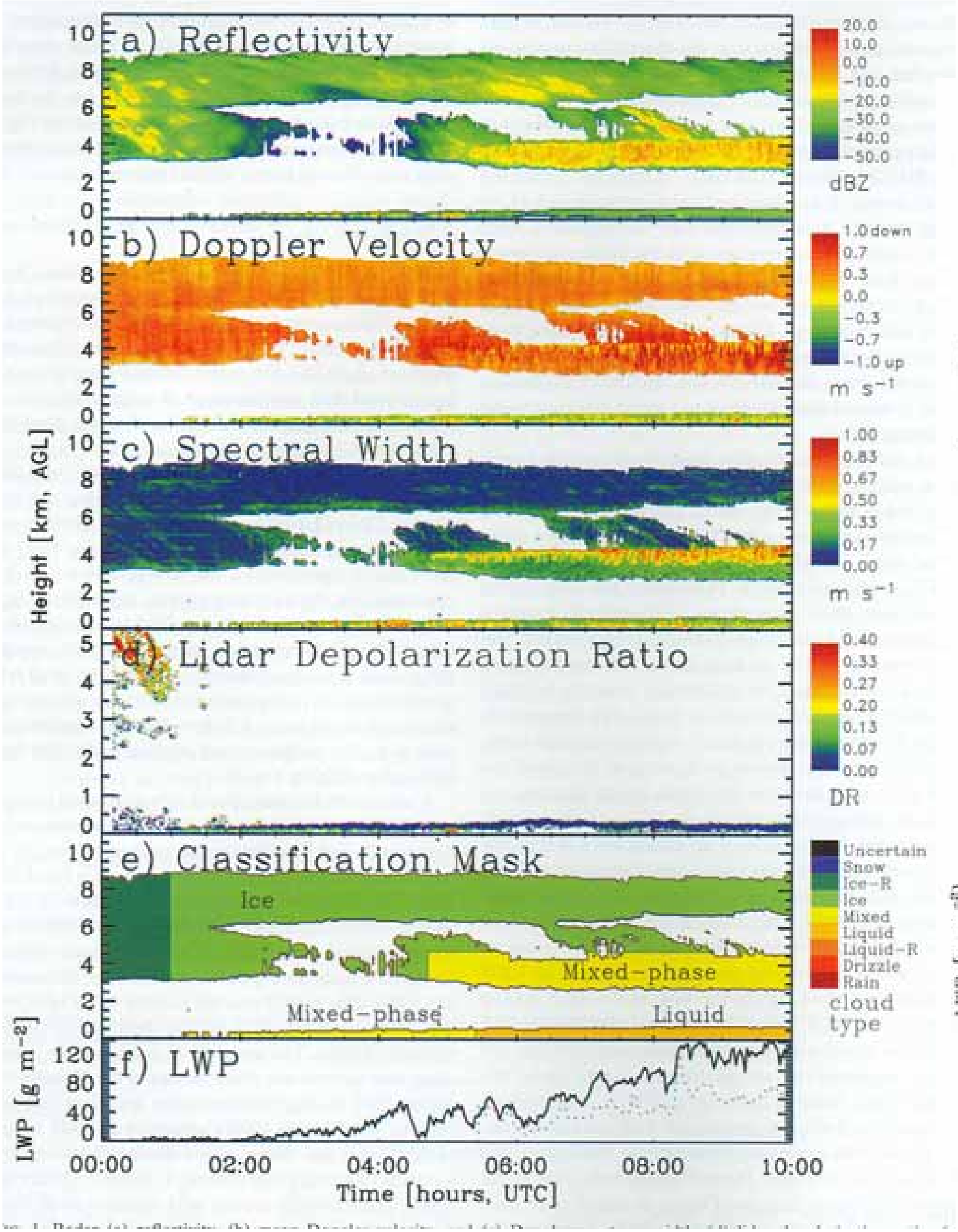
An example of attenuation-based retrievals of vertical profiles of rainfall rates for a stratiform rain observed at SGP





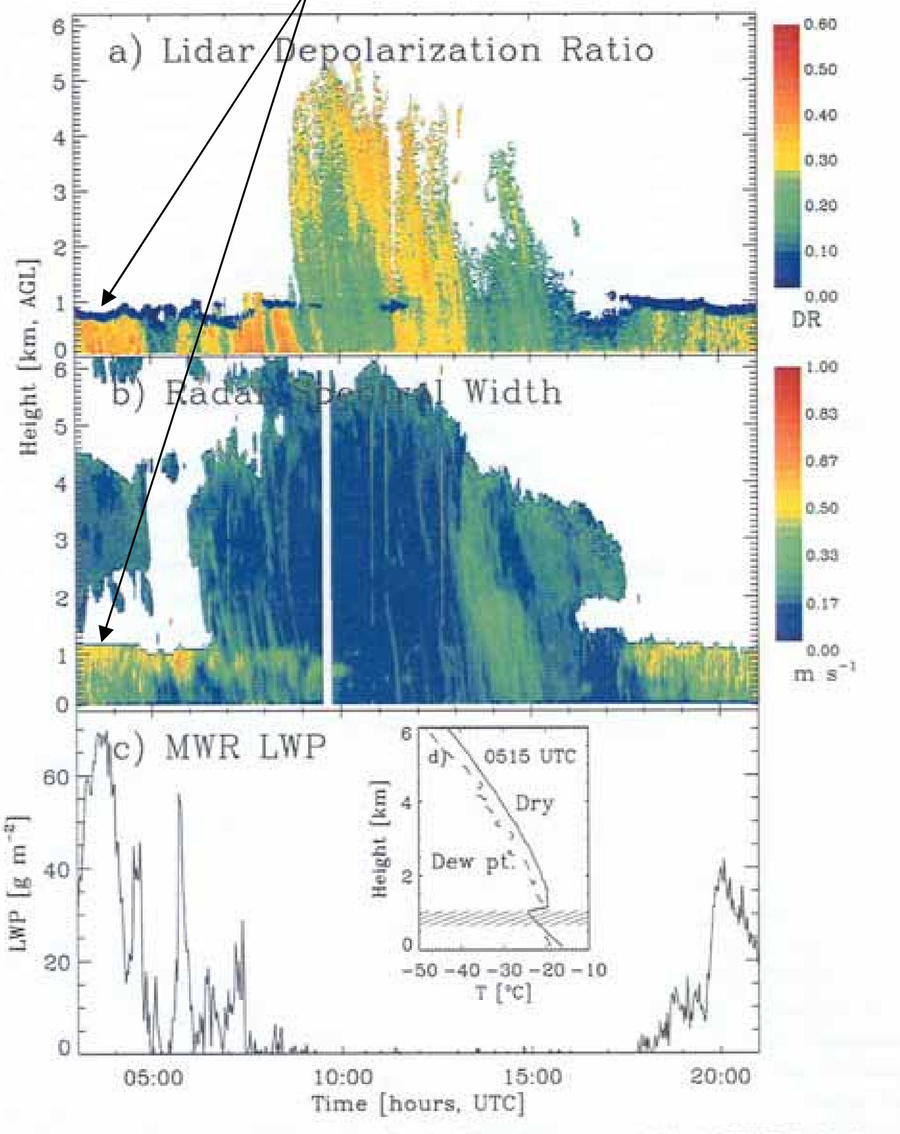
Depolarization lidar is a useful tool for identifying cloud phase

May 18, 1998



May 6, 1998

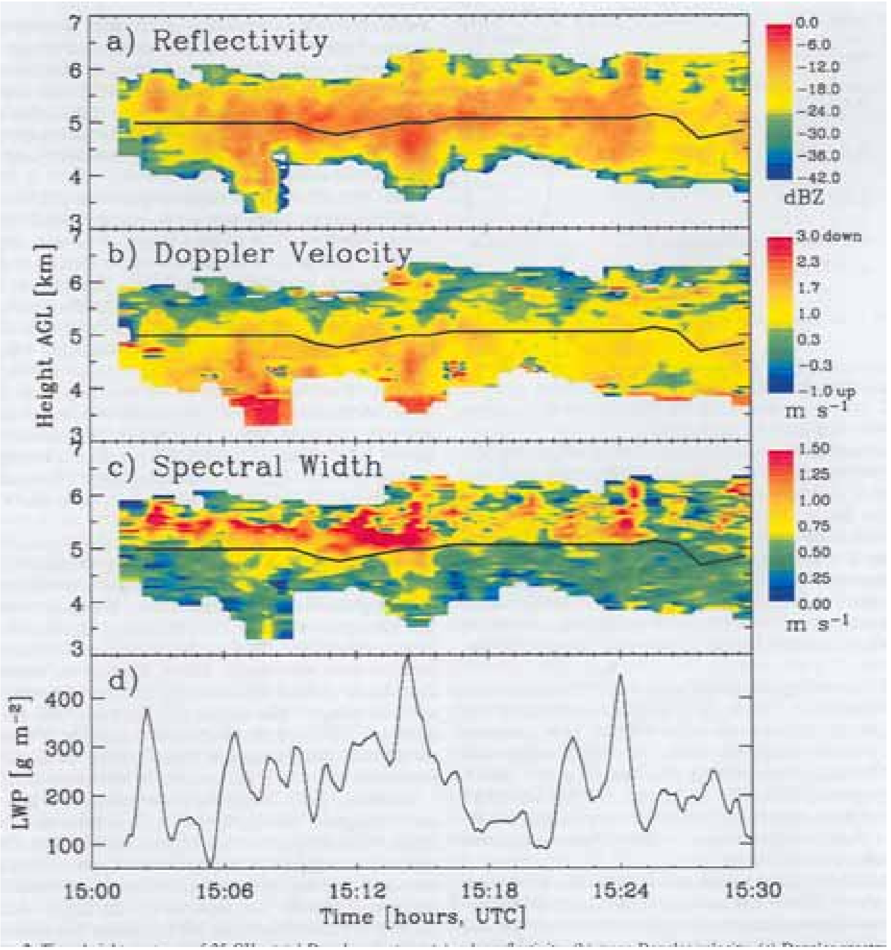
thin layer of liquid water identified by low lidar depolarization and high radar Doppler spectral width



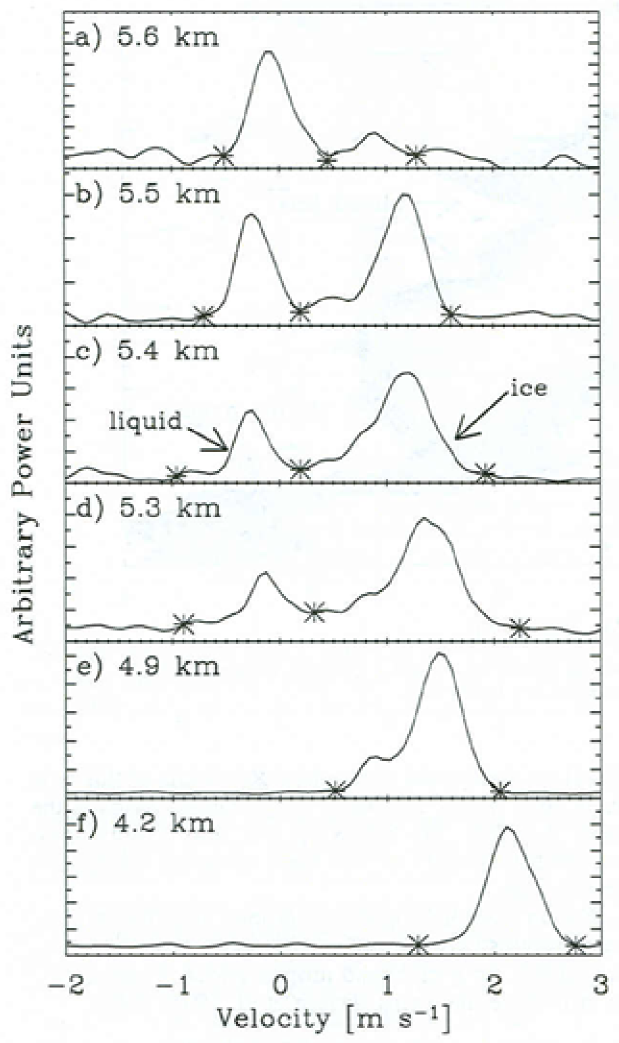
Full Doppler spectra measurements help to get estimates of both ice and liquid components in mixed-phase cloud

July 29, 2000 CRYSTAL-FACE mixed-phase cloud case

Doppler moments



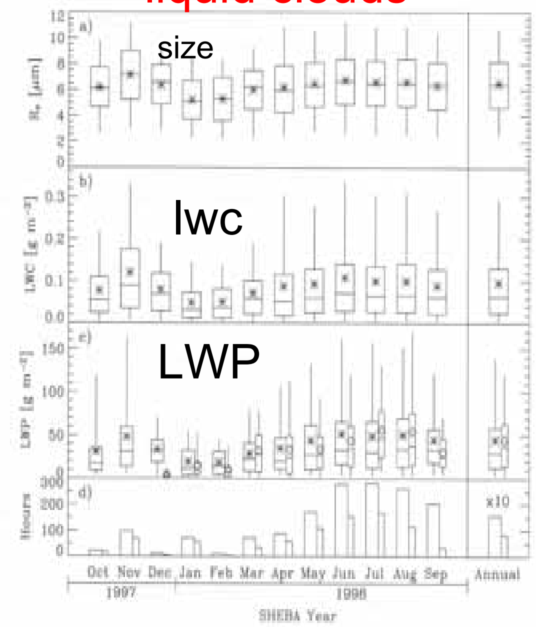
Doppler spectra at 15:08 UTC



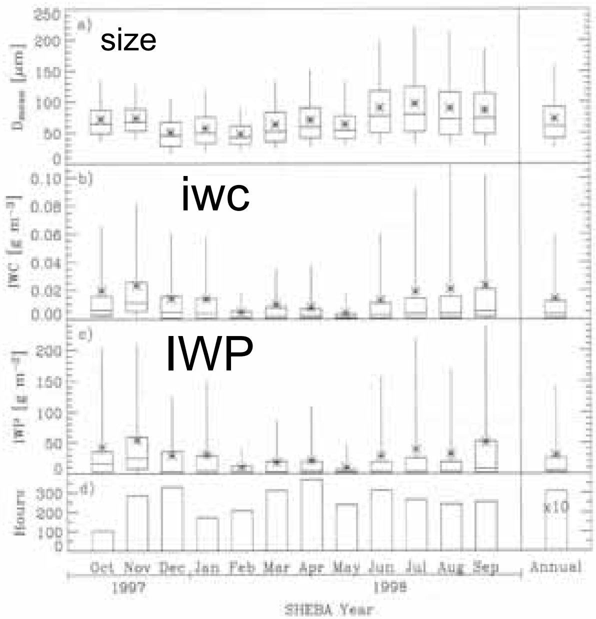
Deriving long term statistics of retrieved cloud microphysical parameters in Arctic

annual cycle (based on SHEBA)

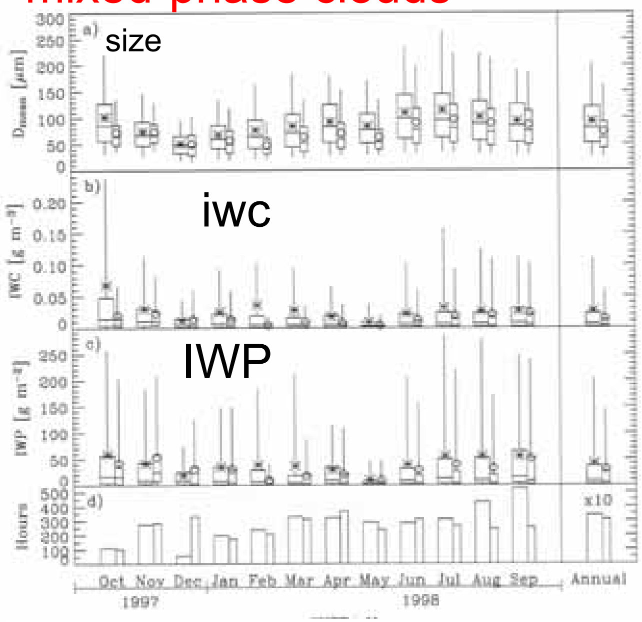
liquid clouds



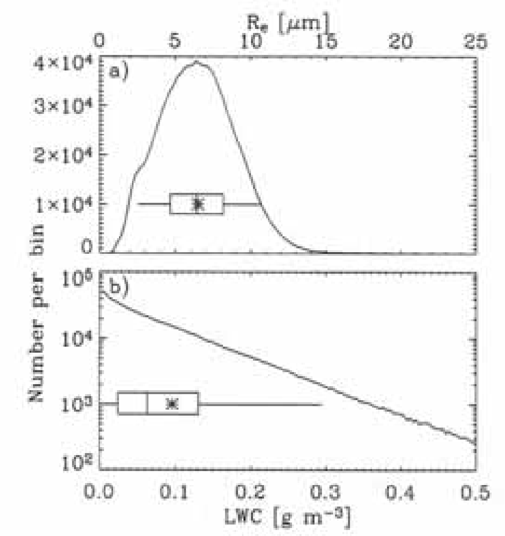
ice clouds

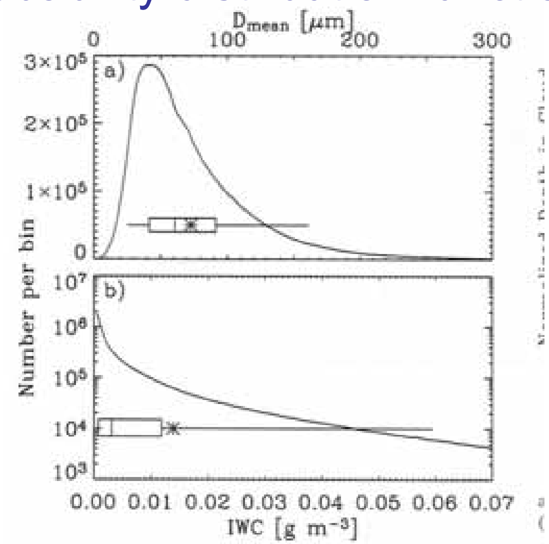


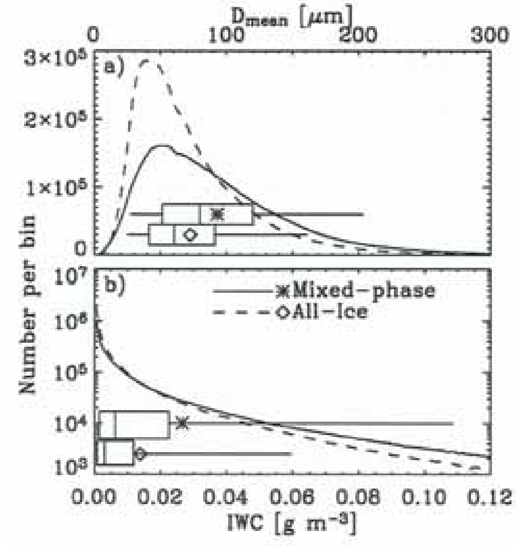
mixed-phase clouds



probability distribution functions



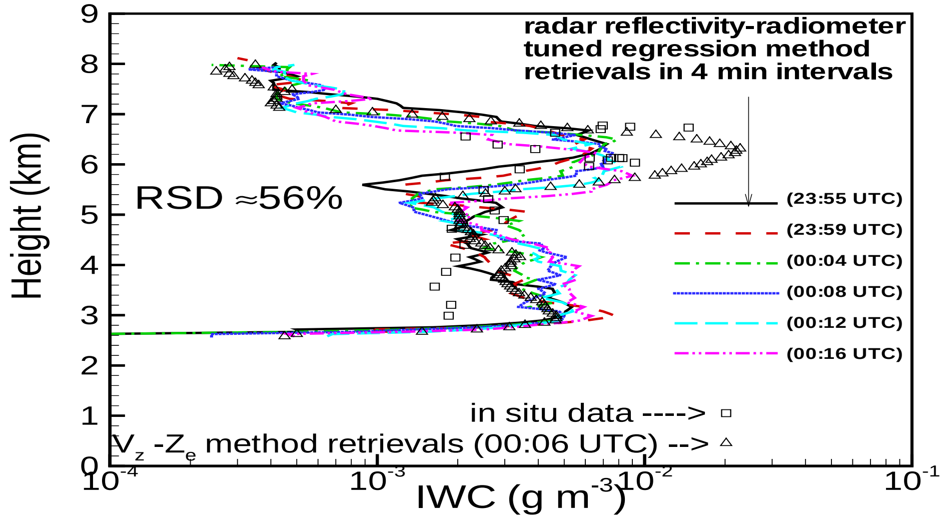




Typical uncertainties of cloud microphysical retrievals are about 30-60%

Comparisons of in situ and remote measurements 28-29.04.98

Comparisons of remote (tuned regressions and Doppler radar methods) and in situ data (Canadian CV-580 spiral descent above the SHEBA site: 23:58-00:15)



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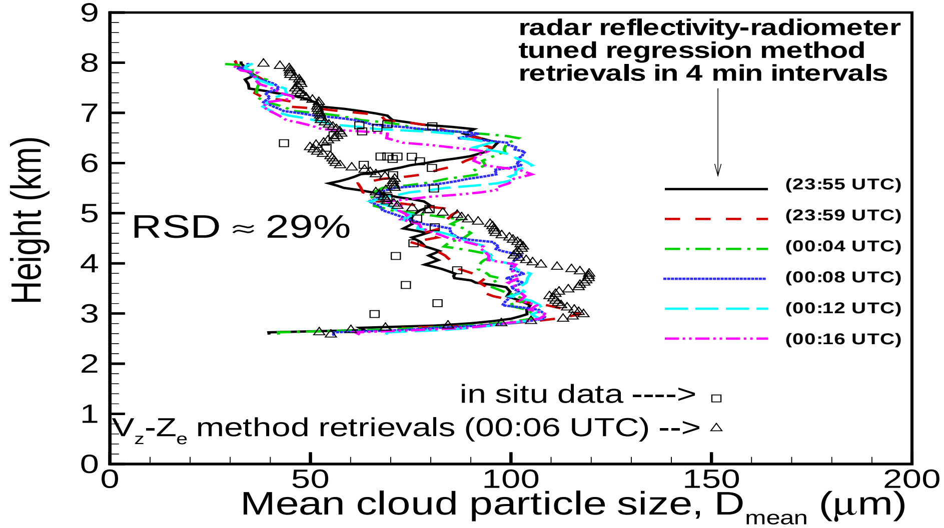
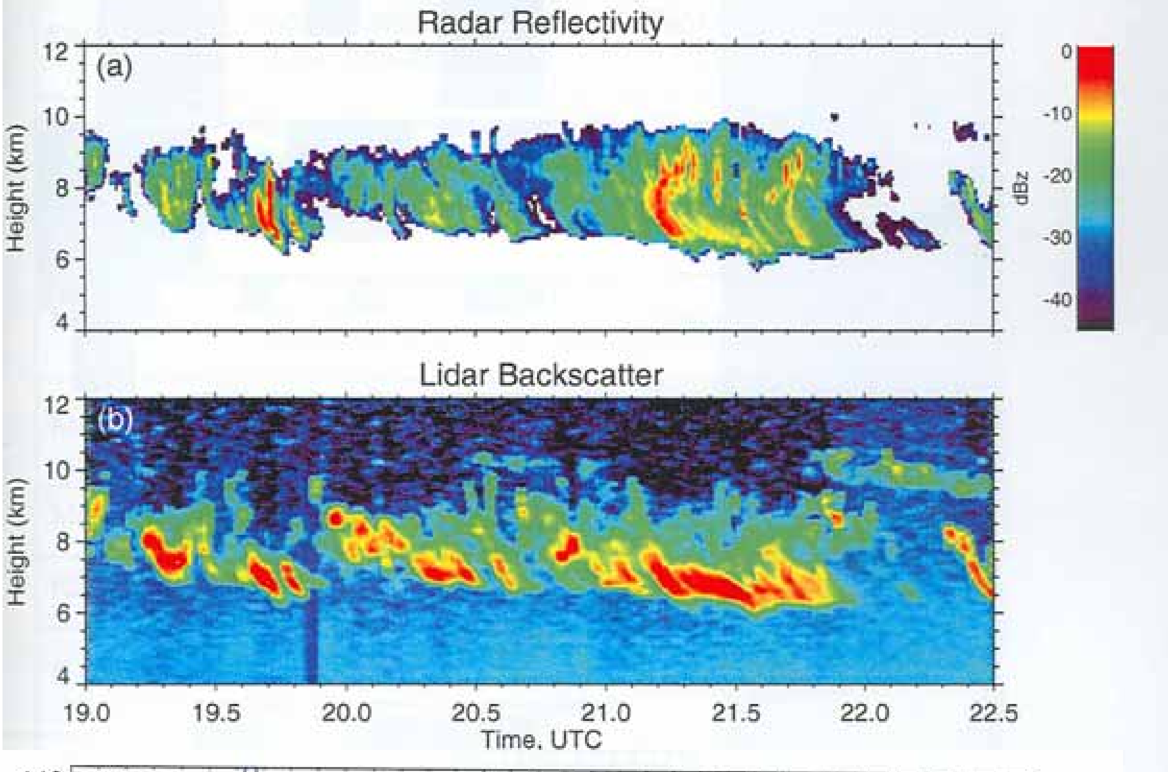
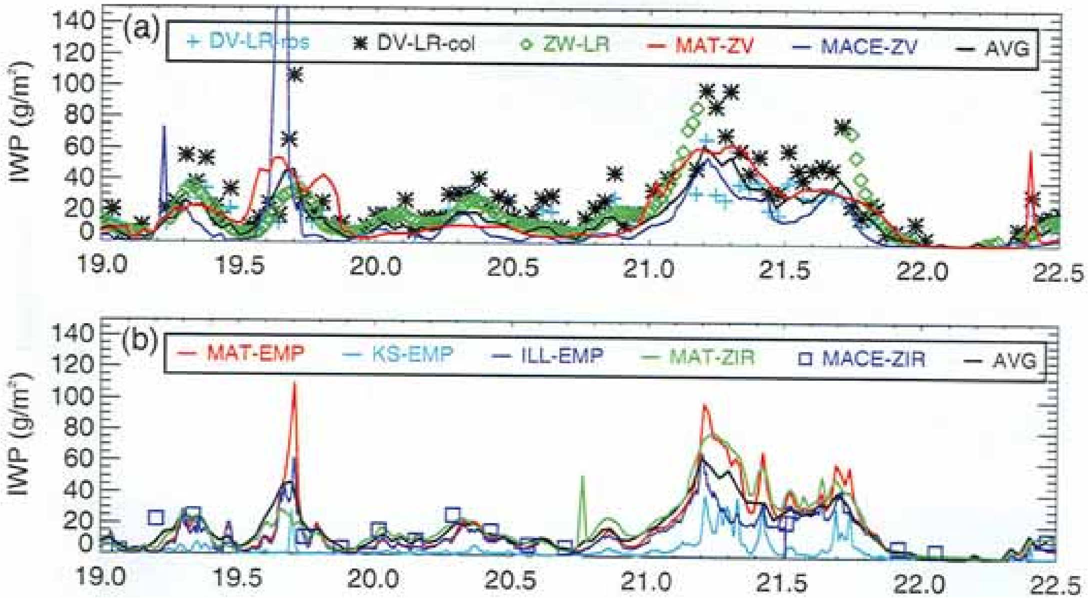


Inter-comparisons of different methods for the ARM March 9, 2000 case





Ice crystal type identification and shape estimation with polarimetric radars

NOAA-K scanning polarimetric Doppler radar (λ=8.6 mm).

quasi-optical technology for changes of polarimetric basis (linear, circular, elliptical)

simultaneous receiving of co- and cross-polarized components of radar echoes

Depolarization ratio: $DR=10\log_{10}(P_1/P_2)$

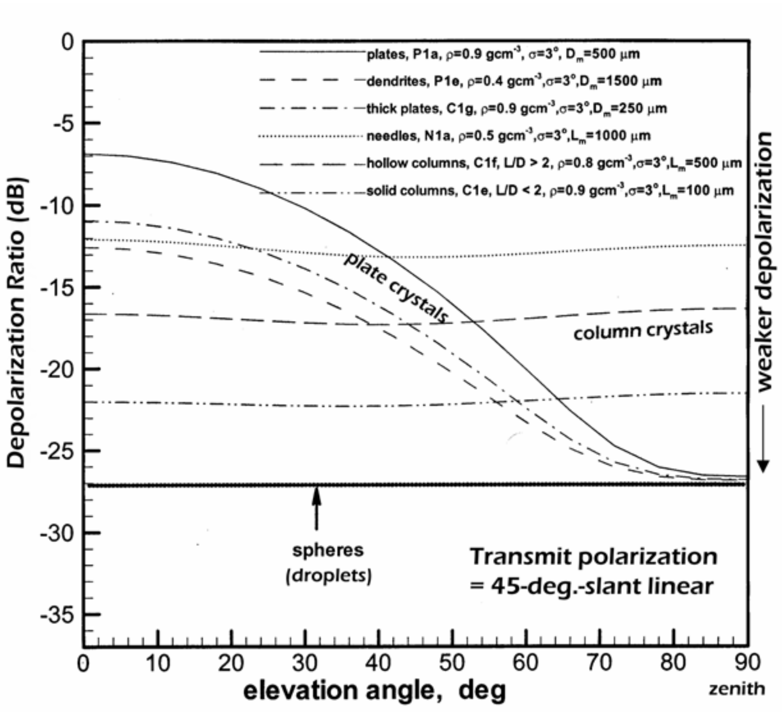
Choice of the polarization basis:
circular depolarization ratio (CDR) or
slant-45 linear depolarization ratio (SLDR)
versus linear depolarization ratio (LDR) :

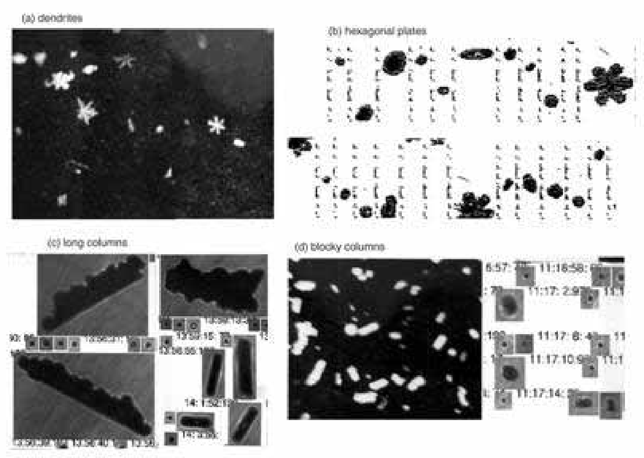
CDR depends on the particle aspect ratio in the polarization plane and particle density

LDR depends on the particle aspect ratio in the polarization plane, particle density, and orientation

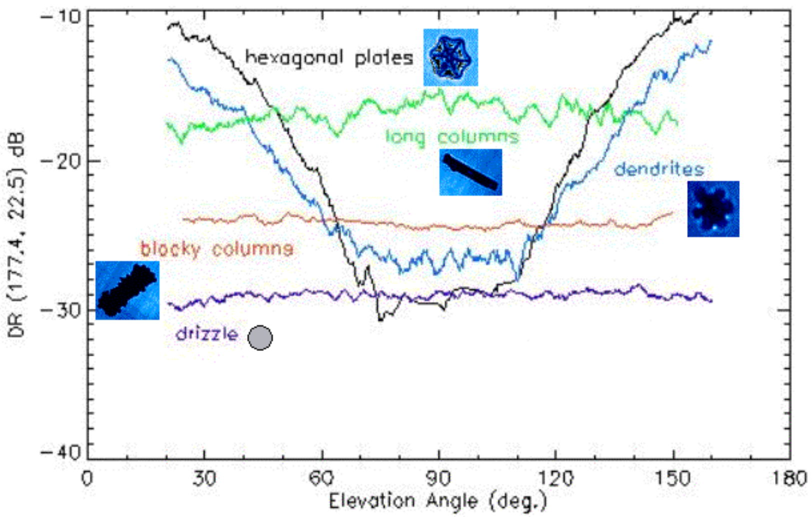
CDR (and SLDR) are more useful than LDR for the purpose of ice particle identification and aspect ratio estimation crystal type (planar vs columnar) is identified using the elevation angle dependences of depolarization ratios

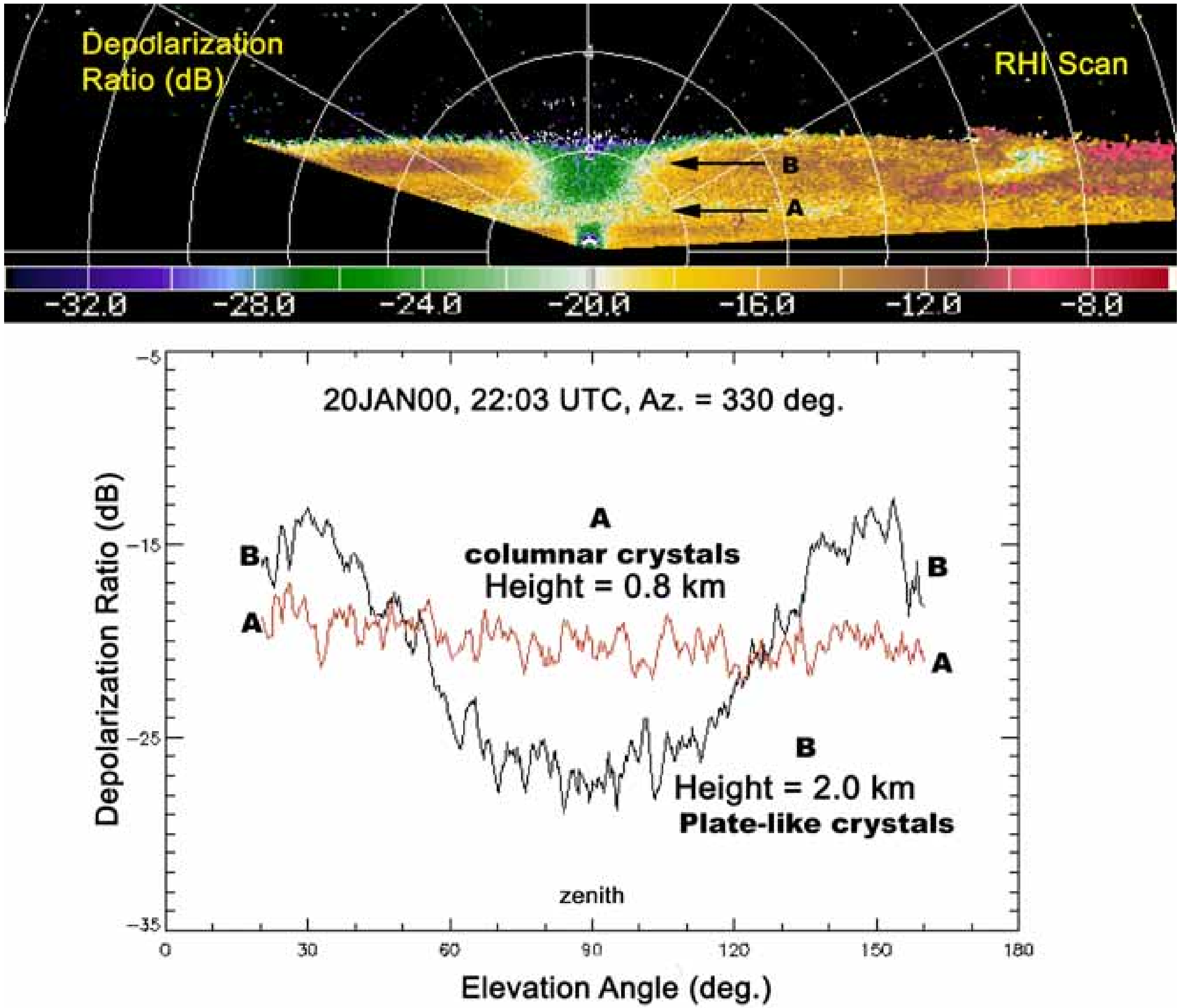
crystal aspect ratio is estimated from depolarization ratios at 45 deg elevation





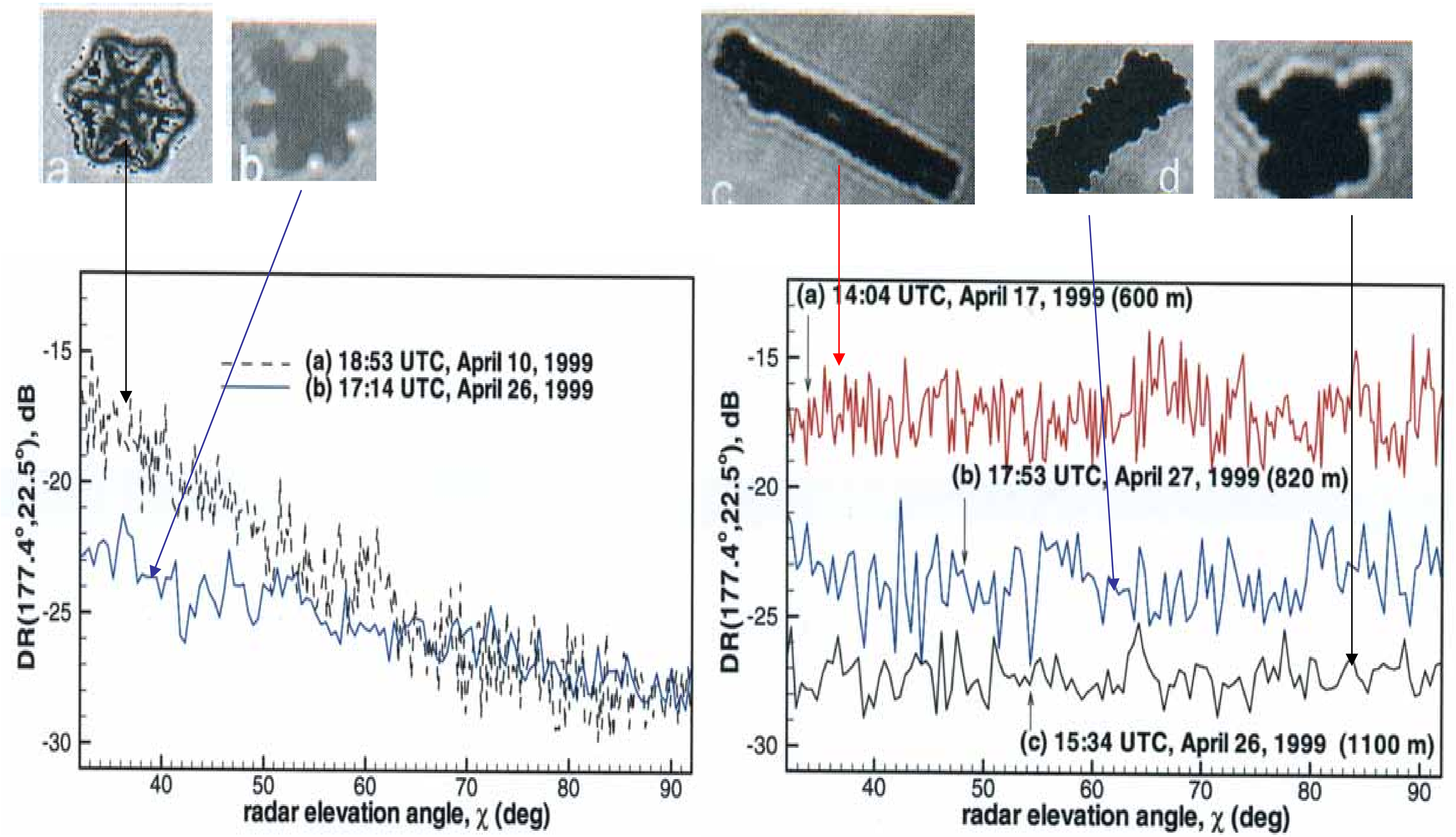
45 degree slant quasi-linear polarization



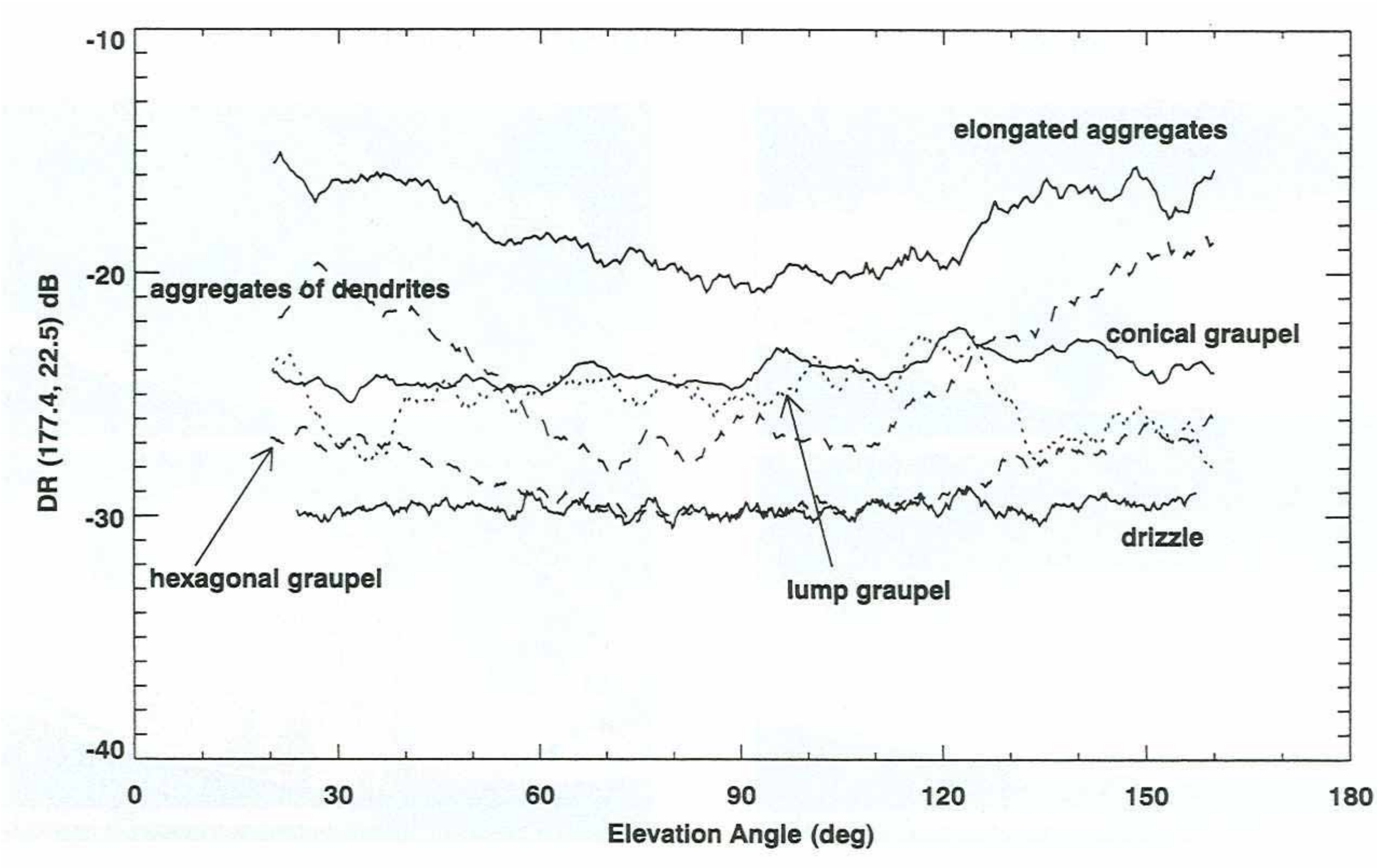


HAWC Project

SLDR measurements during MWISP



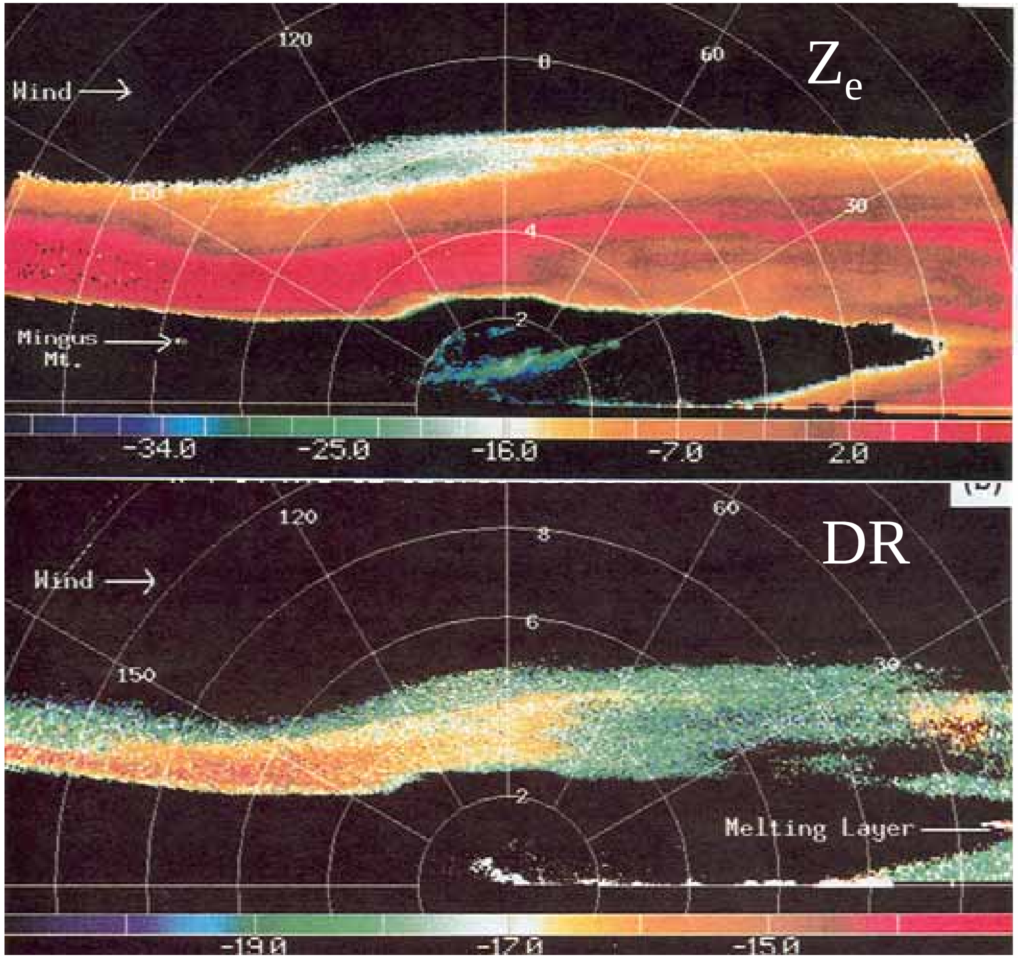
Discrimination of graupel and aggregate snow crystals from freezing drizzle



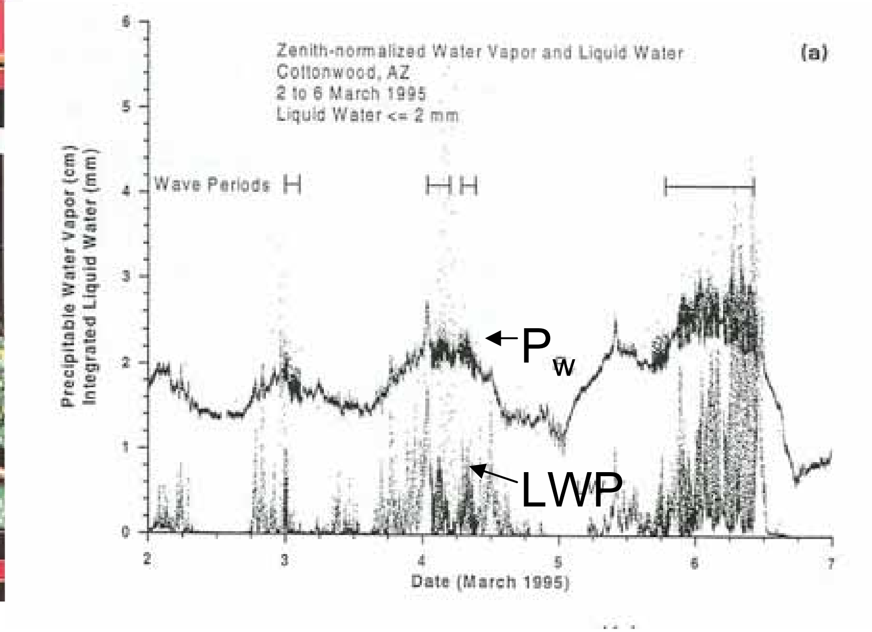
seeder (wave cloud) – feeder (orographic cloud) couplets increase the conversion of water condensed in orographic clouds to precipitation

NOAA ETL scanning K_a-band radar studies

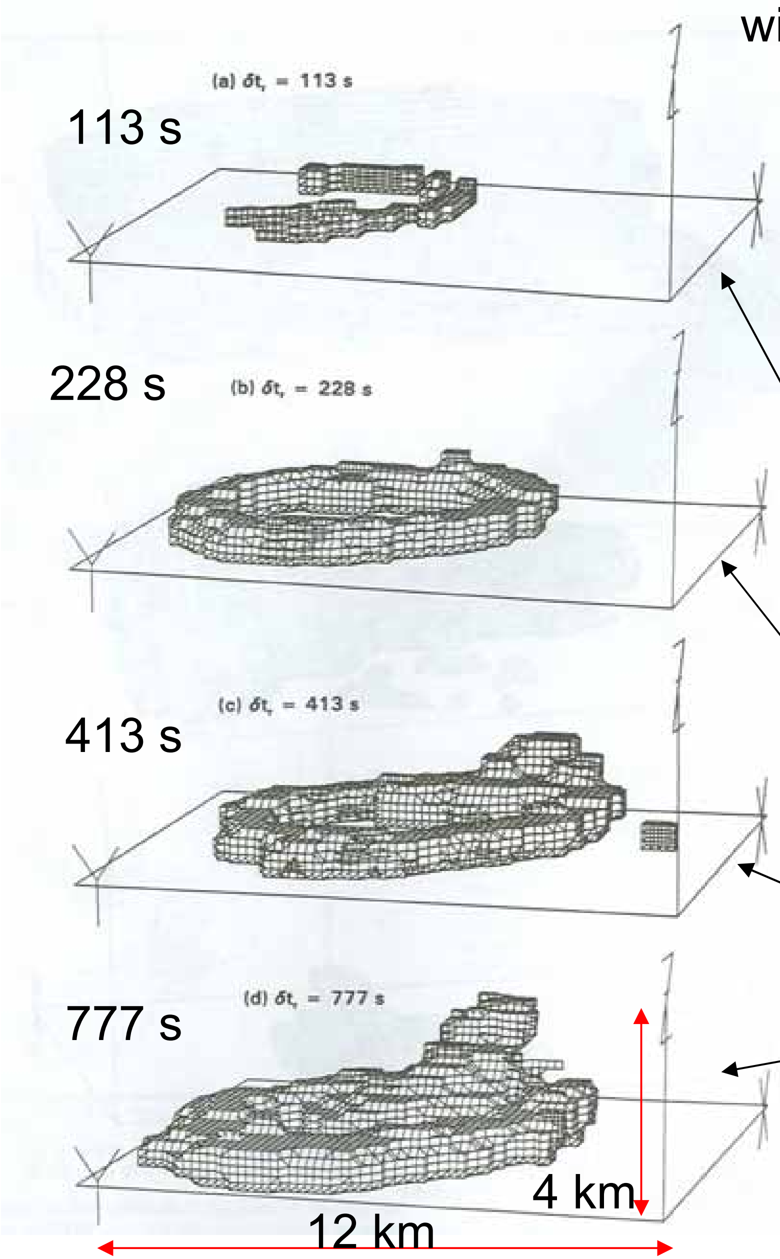
4-MAR-95 4:30 UTC, 0^o degree isoterm at ~ 2 km



Precipitable water vapor and LWP from MWR



Use of chaff to track dispersion of seeding material with the NOAA ETL polarimetric scanning radar



Chaff fibers are aluminum-coated 25 μm glass filaments with λ/2 length

At circular polarization for chaff:
$P_{main} \approx P_{cross}$ (CDR is very high ~0 dB)

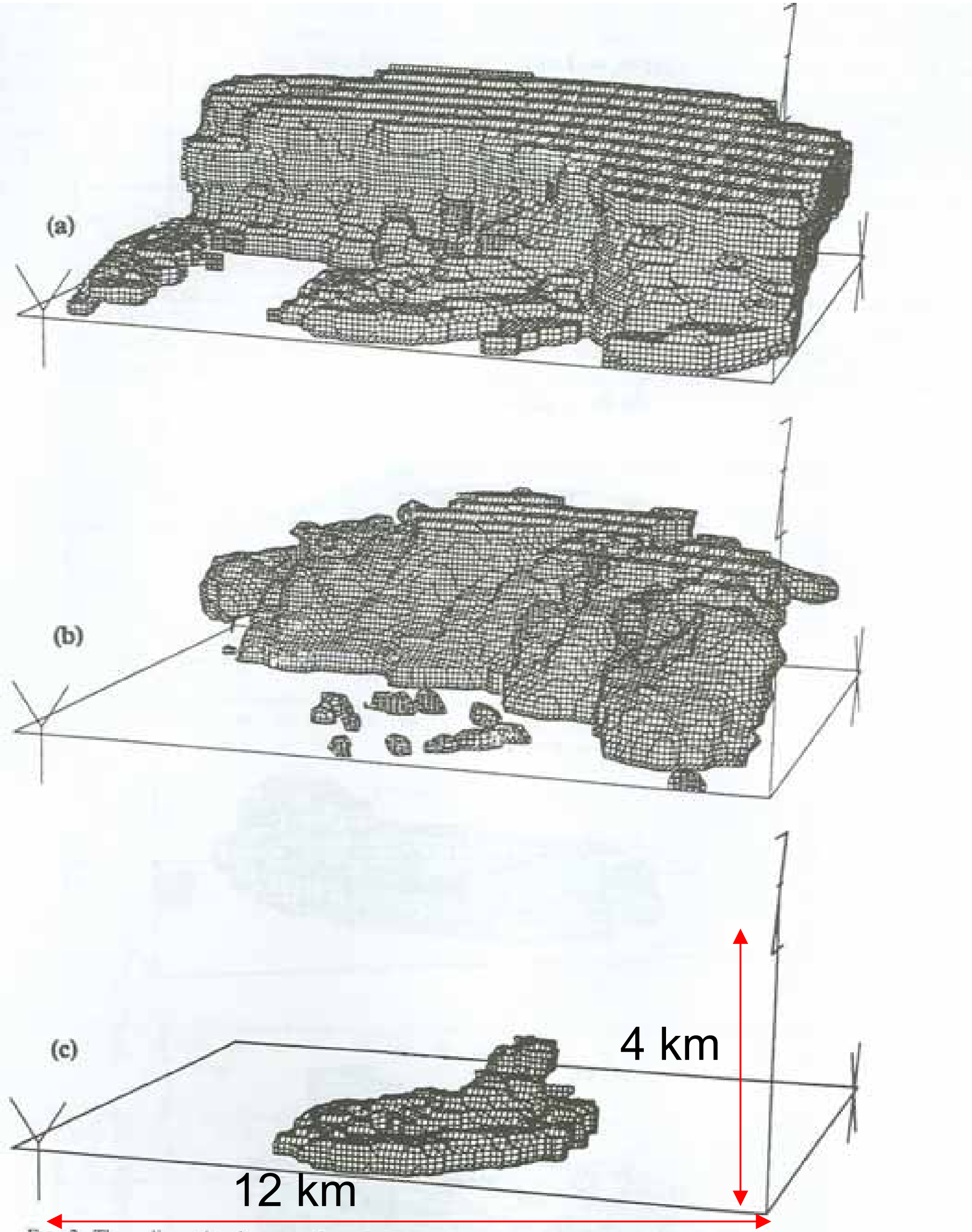
For hydrometeors:
$P_{main} << P_{cross}$ (CDR < -10 dB)

After releasing chaff (and seeding material), P_{main} /CDR is used to track chaff entrainment in cloud

Chaff fibers were released at the cloud base and then were risen in a convective plume

Reinking et al 1996

777 seconds after chaff release / seeding



Convective cloud with Z_e > -10 dBZ

Convective cloud with Z_e > 20 dBZ

Chaff signature (CDR > -10 dB)

Implication for weather modification studies

Use of multi-sensor cloud microphysical retrievals to compare cloud properties before and after seeding with an emphasis, for example, by analyzing:

- trends in different cloud properties (LWC, IWC, characteristic particle size);
- changes on PDFs of different cloud parameters;
- changes in cloud geometrical structure, morphology and phase.

Use of scanning polarimetric radars:

- to monitor ice crystal habit change in space and time (in natural developments and/or as a result of seeding);
- to monitor development of precipitation, seeder-feeder processes;
- to monitor the transport of seeding material alongside with chaff