Microphysical Retrievals from Simultaneous Measurements by Airborne and Ground Radars during OLYMPEX

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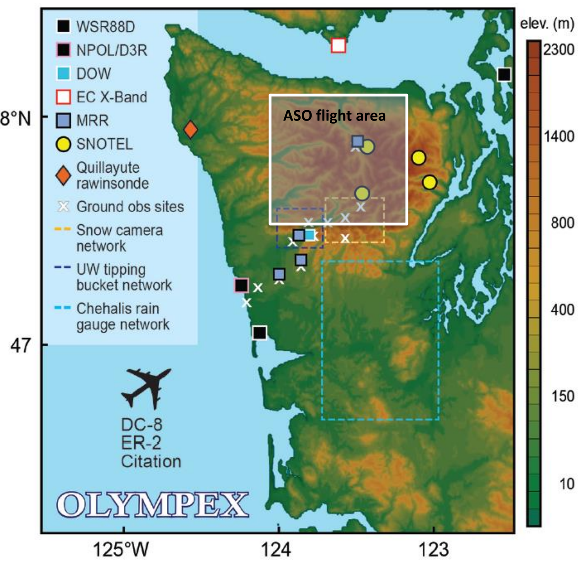
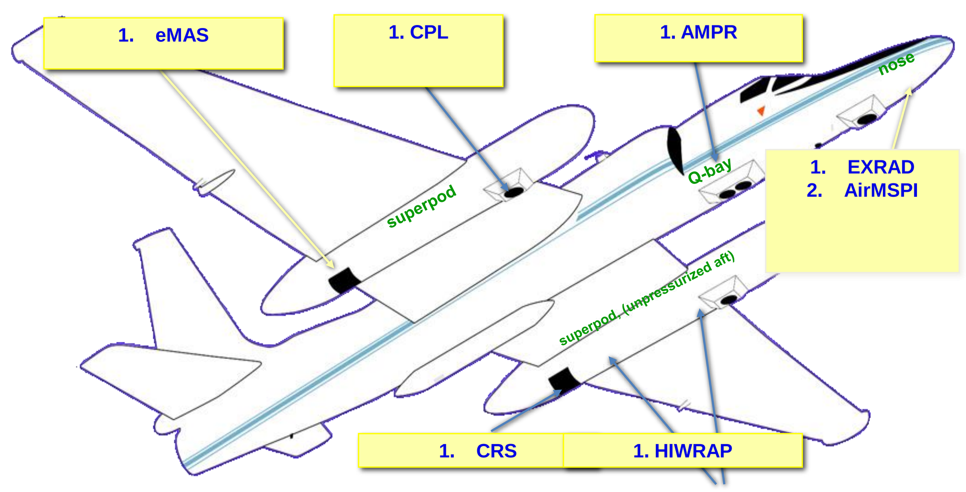
OLYMPEX Background

The Olympic Mountains Experiment (OLYMPEX) was a ground validation field campaign held in late 2015 in support of NASA's Global Precipitation Measurement Mission. The goal of the campaign was to collect detailed measurements of precipitation from systems undergoing orographic enhancement in the Olympic Peninsula of Washington.





In addition to numerous ground sites equipped with gauges and disdrometers, remote sensing assets included ground radars (S-band NPOL, C-band DOW, and Ku/Ka band D3R) augmenting the operational NEXRAD and Canadian networks. Airborne instrument suites included radar frequencies at X-, Ku-, Ka-, and W-band, along with passive microwave radiometers and in-situ probes to make detailed microphysical measurements of cloud and precipitation properties.

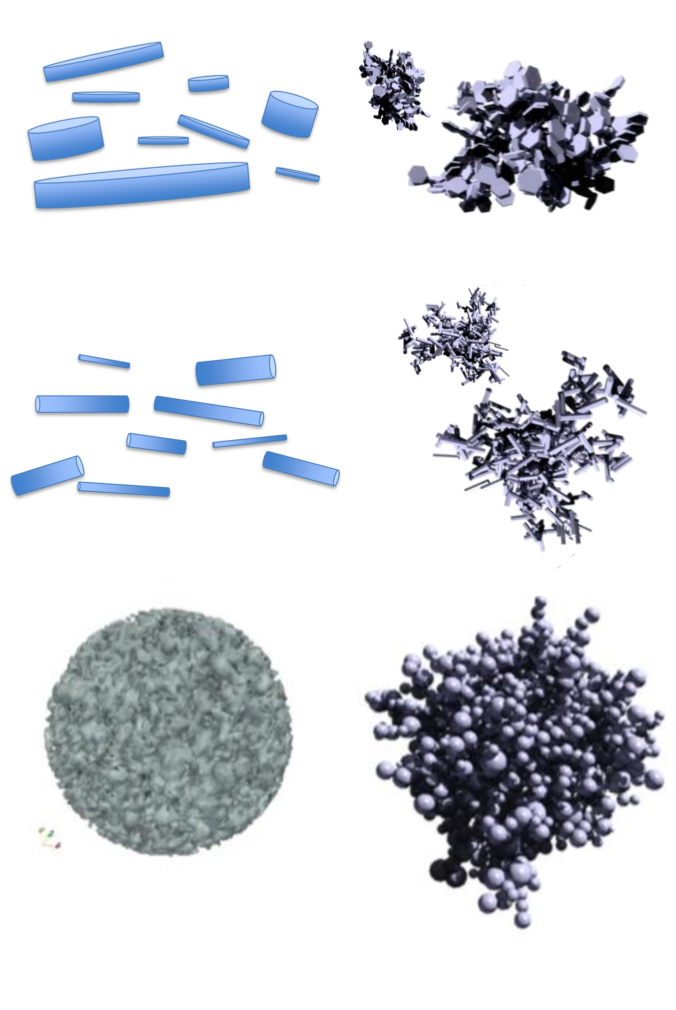
- NASA DC-8:
- ~80 flight hours

Instrument	Measurement
CoSMIR H+V (Radiometer)	50, 89, 165.5, 183.3+/-1, 183.3+/-3, 183.3+/-8 GHz Cross track/conical scan
Footprint (@10 km	0.7 km
APR3 (Radar)	13.4 GHz,35.6 GHz, 95 GHz w/ dual-polarization
Transmit Peak Power	200 W (Ku), 1000 W (Ka)
3dB Beamwidth	3.8º (Ku), 4.8º (Ka)
Footprint (@10 km)	0.7 km (Ku), 0.8 km (Ka)
Range Gate spacing	30 m
Swath Width	+/- 25º (+ zenith Ka option)
Sensitivity (@ 10 km)	0 dBZ (Ku), -17 dBZ (Ka)
Doppler prec.	0.4 m/s
MASC (Radiometer)	118 GHz, 183 GHz, cross-track scan
AVAPS Dropsondes	Upstream P,T,RH,Wind

- UND Citation
- Microphysics
- 60 flight hours

Instrument	Measurement
King	Cloud liquid water
2D-C / 2D-S	Cloud and precipitation size spectra
HVPS-3 (2; one H one V mounted)	Precipitation size spectra
CPI	Cloud particle images
CSI	Total cloud water content
CDP	Cloud droplet size spectra
Nevzorov	Total water content
Rosemount icing probe	Supercooled water

Scattering Models



In order to obtain scattering properties across a range of ice crystal geometries for and radar frequencies/polarizations, we used two sources of scattering information:

1. IITM (Invariant Imbedded T-Matrix) calculations for axial symmetric geometries (approximating plates and columns with variable axis ratios)
2. ARTS (Atmospheric Radiative Transfer Simulator) Single Scattering Database for aggregates of plates and columns, as well as rimed particles.

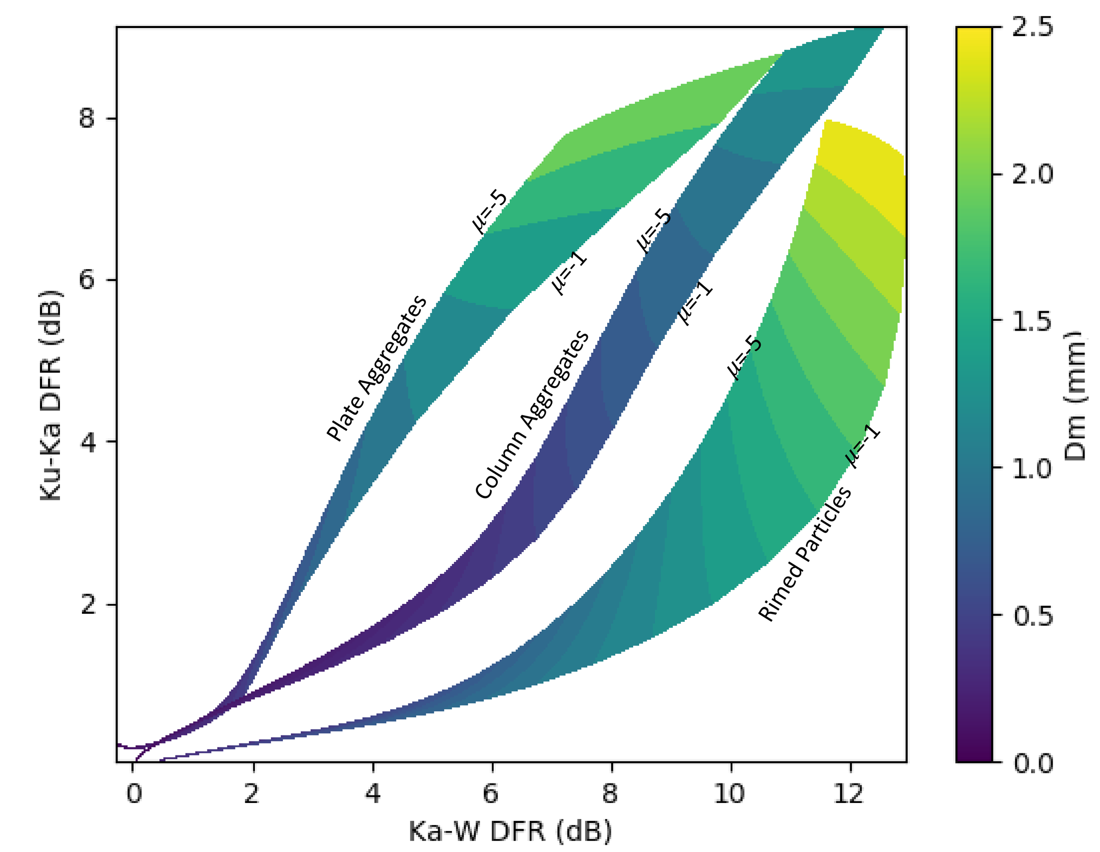
The pristine (IITM) particles are assumed to be horizontally aligned and thus produce positive Z_{DR} and K_{DP} when viewed from a ground radar. Aggregates and rimed particles are assumed to be randomly oriented.

Information Content of Combined Multi-Frequency Airborne + Ground Polarimetric Radar Measurements

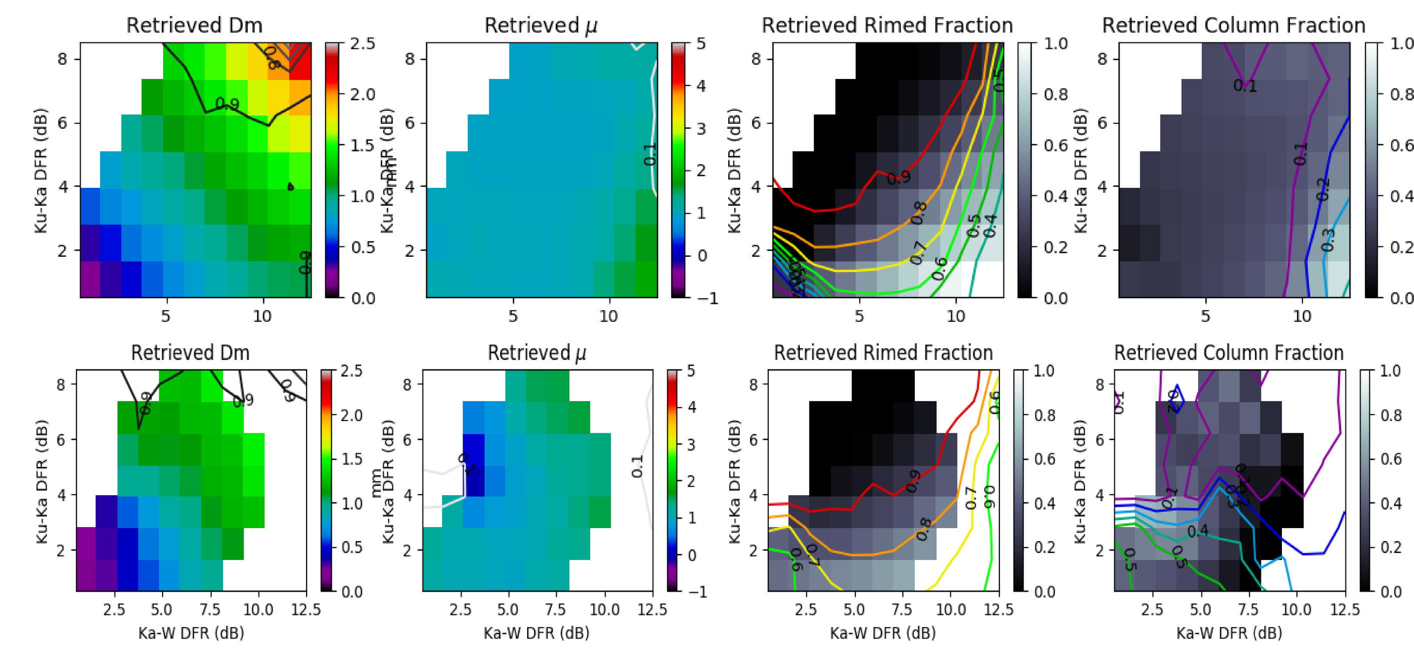
During OLYMPEX, both of the radar-equipped "satellite simulator" aircraft (the DC-8 and ER-2) flew flight lines along radials from the ground radars (NPOL, DOW, and D3R). These provide an opportunity to perform retrievals using information from nadir-looking multi-frequency radars and the ground radar. Both systems offer complementary information to each other:

- Airborne radars have superior vertical resolution, providing an ability to resolve the melting layer and other structures above it such as aggregation zones;
- The dual-frequency ratio(s) from airborne radars provide information about particle shape and density;
- Polarimetric variables from ground radars provide information about particle shape and orientation;
- Lower-frequency (S-band) ground radars provide a reference for range-resolved attenuation corrections.

To take advantage of this complementary information, measurements must be combined in a retrieval framework with internally consistent forward models.



Lookup tables of radar reflectivity (Z_{HH}), differential reflectivity (Z_{DR}), specific differential phase (KDP), and attenuation (k_{ext}) were constructed for each of the three particle families considered. These were integrated over gamma size distributions with a range of mean mass-weighted diameter (D_m) and shape parameter (μ) shown above.



The information content (averaging kernel; contours, where 0 is low information and 1 indicates high information) of **nadir-looking Ku+Ka+W band measurements only (top)** can be compared to that when **ground-based Z_{DR} measurements are included (bottom)**. Small improvements in D_m information (which is already quite high with the 3-frequency measurements) and rimed fraction information are noted. Little improvement in estimation of μ, which is poorly contrained, and modest improvements in the ability to distinguish plates from columns is noted when Z_{DR} measurements are included in the retrieval.

Case Study: 3 December 2015

An optimal estimation retrieval was developed to estimate profiles of PSD properties from the APR3 data. This retrieval minimizes the cost function

$$J(X) = \left[(X - X_a)^T \times S_a^{-1} \times (X - X_a)\right] + \left[(Y - f(X))^T \times S_\varepsilon^{-1} \times (Y - f(X))\right]$$

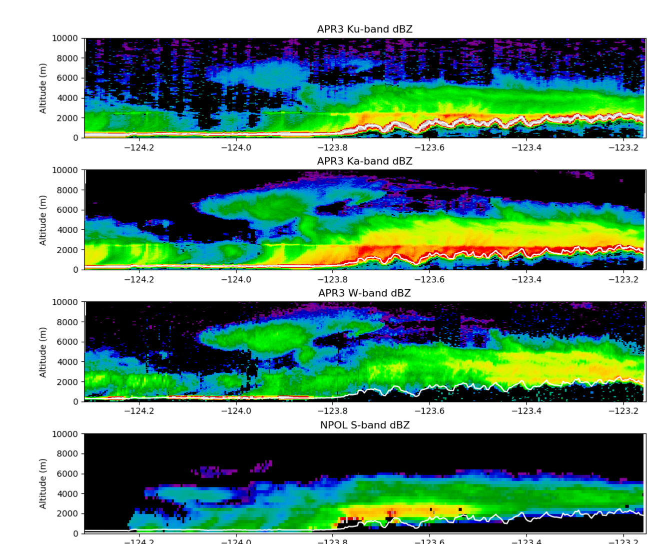
where

X = [N_w, μ, Rimed fraction, Column/Plate fraction, cloud liquid]

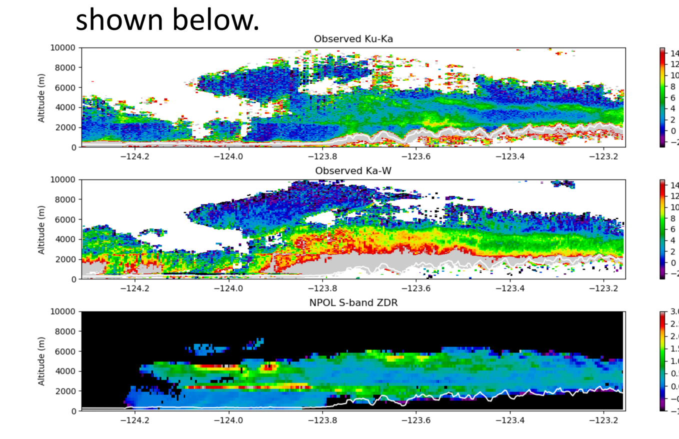
and

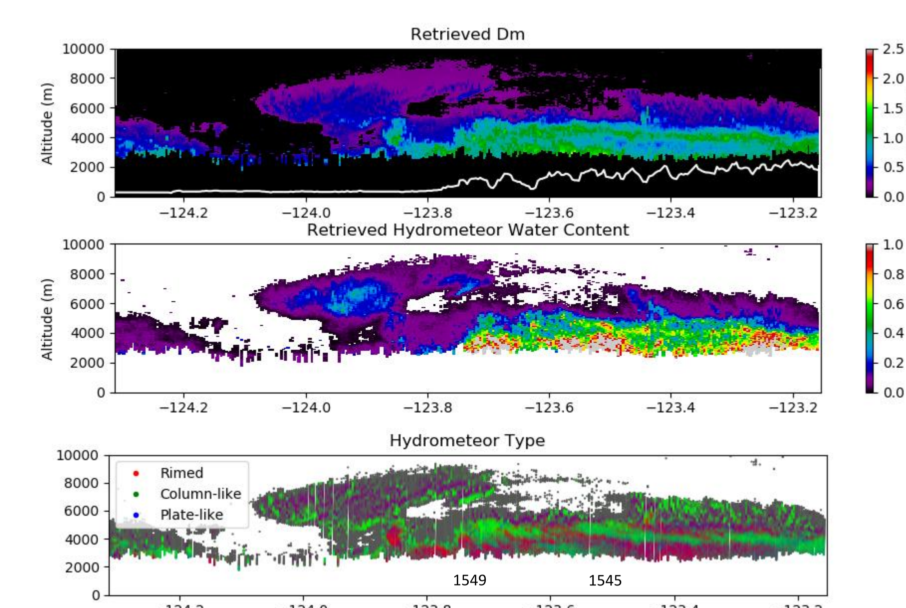
Y = [Ku-Ka DFR, Ka-W DFR, S-band ZDR, PIA]

This method is similar to the one developed by Grecu et al. (2011; *JAMC*) and extended to include a third frequency, multiple ice species, and cloud liquid water.

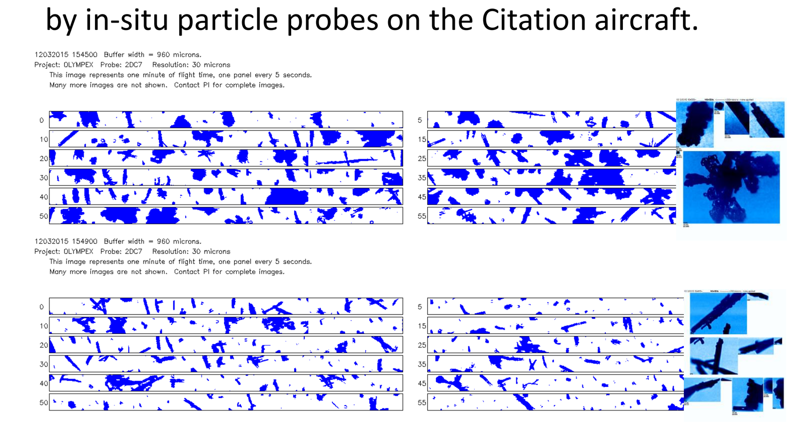


During the passage of an upper-level shortwave with strong orographic enhancement of precipitation, the DC-8 flew along an NPOL radial at 1553 UTC. APR3 and NPOL reflectivity profiles are shown above, and the corresponding DFR from APR3 and ZDR from NPOL are shown below.



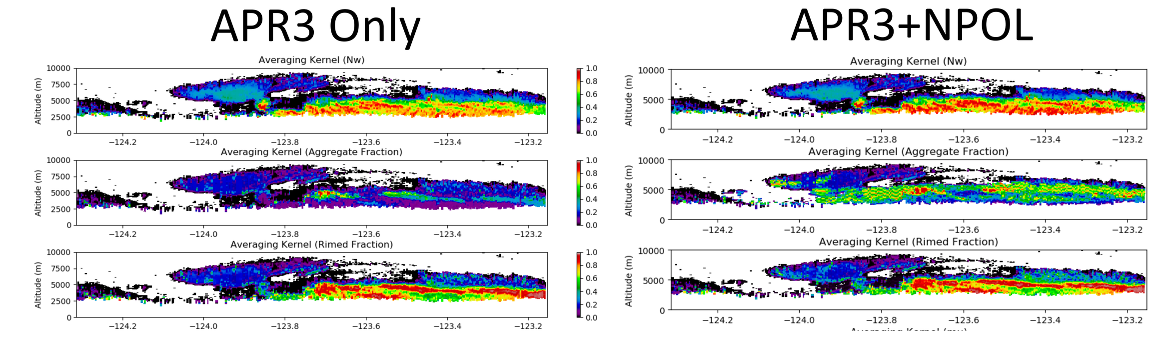


The multi-frequency, dual polarization information is used to retrieved parameters related to the particle size distribution (N_w, from which D_m and water content can be inferred for an given observed Ku dBZ), as well as the partitioning of ice hydrometeors into plates and plate aggregates, columns and column aggregates, and rimed particles, confirmed by in-situ particle probes on the Citation aircraft.



APR3 Only

APR3+NPOL



The additional information provided by NPOL can be quantified using the Averaging Kernel output of from the optimal estimation algorithm. In essence, the Averaging Kernel is a measure of the sensitivity of observations to a physical parameter relative to the prior uncertainty in that parameter. Values close to one indicate an estimate that is primarily informed by observations, whereas values close to zero indicate that the observation did not improve upon the prior knowledge of the state. Above, the Averaging Kernel is shown for N_w, the composition of particles (plate-like or column-like), and riming fraction. When only the APR3 observations are used, there is relatively high information content regarding the N_w, especially at levels where the DFR becomes significantly different than zero. There is also some information about the riming fraction where all 3 frequencies are present due to the separation of rimed and unrimed aggregates in triple frequency space.

The addition of ground-based polarimetric variables (in this case, S-band Z_{DR} from NPOL, although in principle others could be added) improves the N_w and rimed fraction information content marginally, but the most significant improvements come from the distinction of plate- or column-like particles from the Z_{DR} data. In this case, columns and their aggregates dominate although there are pockets of plate- or dendritic-shaped particles as well as rimed particles, all of which were observed by instruments on board the Citation aircraft during this case.

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