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

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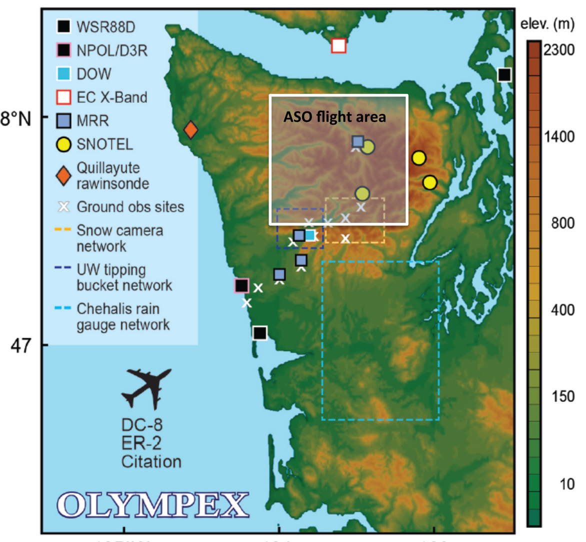
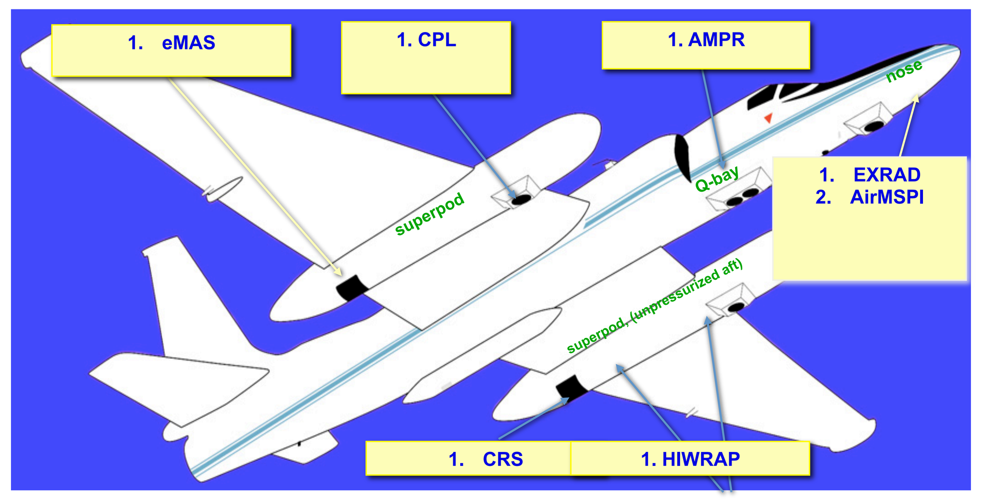
OLYMPEX Background

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.





- NASA DC-8:
- ~80 flight hours

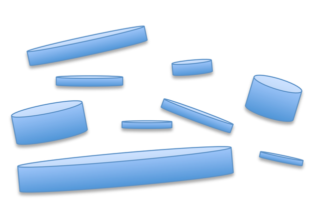
- UND Citation
- Microphysics
- 60 flight hours

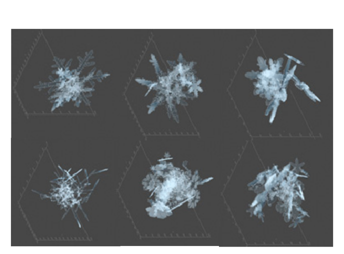
Instrument	Measurement
CoSMIR H+V (Radiometer)	50, 89, 165.5, 183.3+/-1, 183.3+/-3, 183.3+/-8 GHz Cross track/conical scan
Footprint (@10 km	0.7 km
APR3 (Radar)	13.4 GHz,35.6 GHz, 95 GHz w/ dual-polarization
Transmit Peak Power	200 W (Ku), 1000 W (Ka)
3dB Beamwidth	3.8º (Ku), 4.8º (Ka)
Footprint (@10 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

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

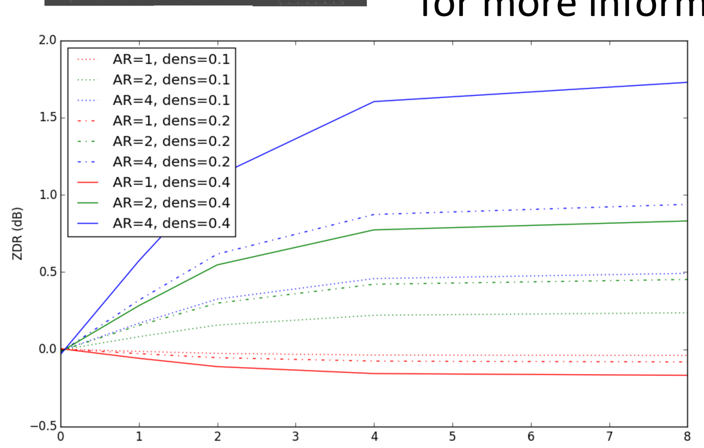
In addition to numerous ground sites equipped with gauges and disdrometers, remote sensing assets included ground radars (S-band NPOL, C-band DOW, and Ku/Ka band D3R) augmenting the operational NEXRAD and Canadian networks. Airborne instrument suites included radar frequencies at X-, Ku-, Ka-, and W-band,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

Scattering Models

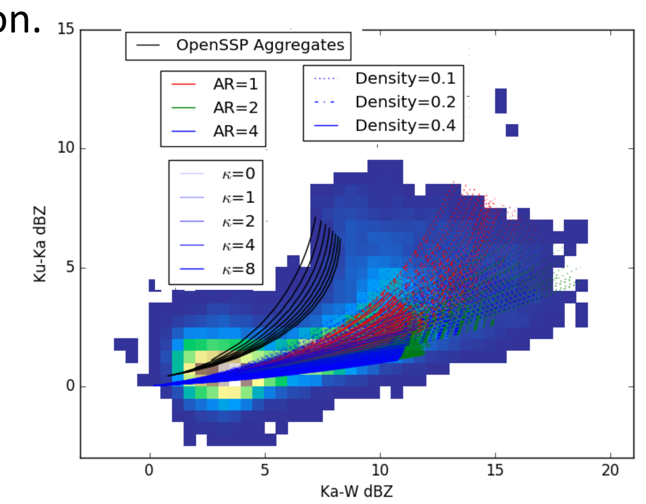




In order to retrieve properties of the ice particle size distribution (PSD), we employ two models for scattering by pristine and aggregate crystals. Pristine crystals are approximated by thin cylinders, with scattering properties obtained by the T-Matrix method. Scattering properties of aggregates were obtained from the OpenSSP database (Kuo et al., 2016, *JAMC*). See oral presentation by Ian Adams (18B.2; 9:15am Wednesday) for more information.

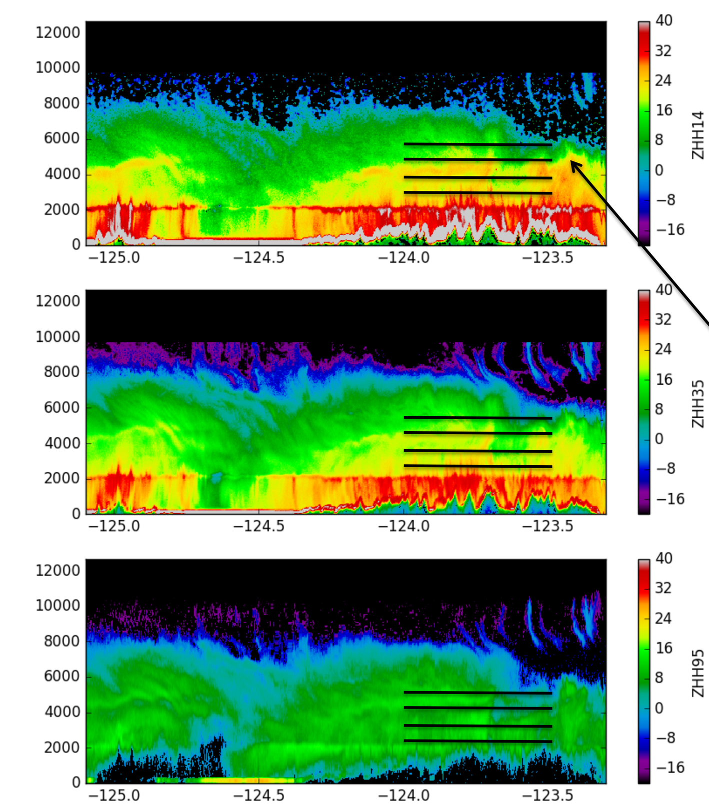


S-band ZDR as a function of aspect ratio, density, and orientation distribution.

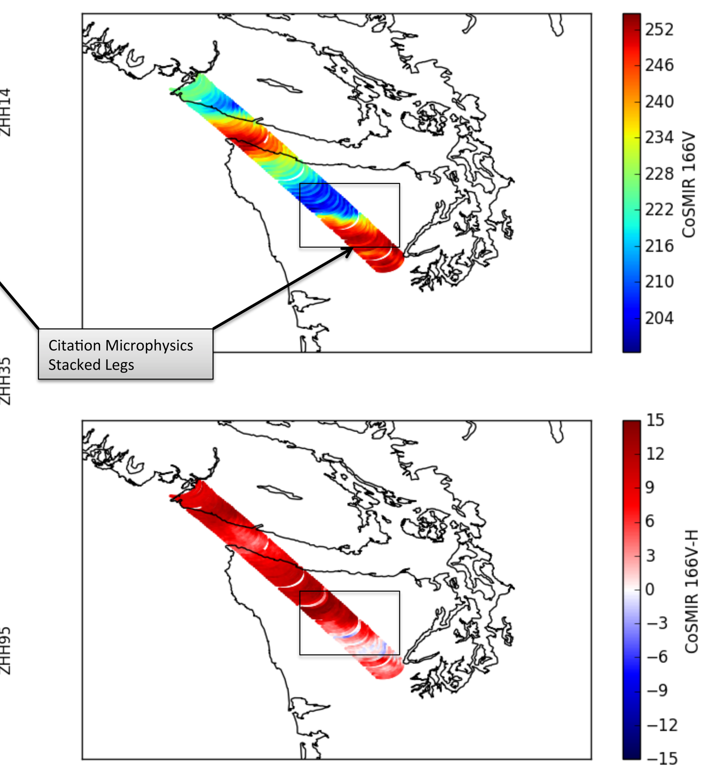


Ku-Ka vs. Ka-W DFR for aggregate and pristine PSDs (Dm increases to the upper right), superimposed on the observed DFR histogram from APR3.

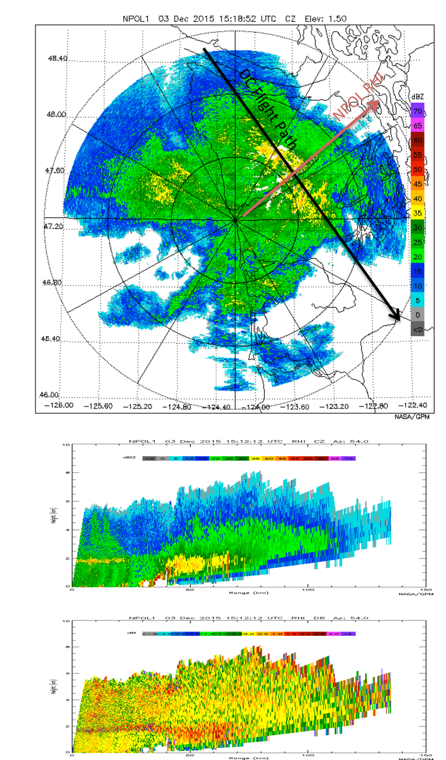
Case study: 3 December 2015



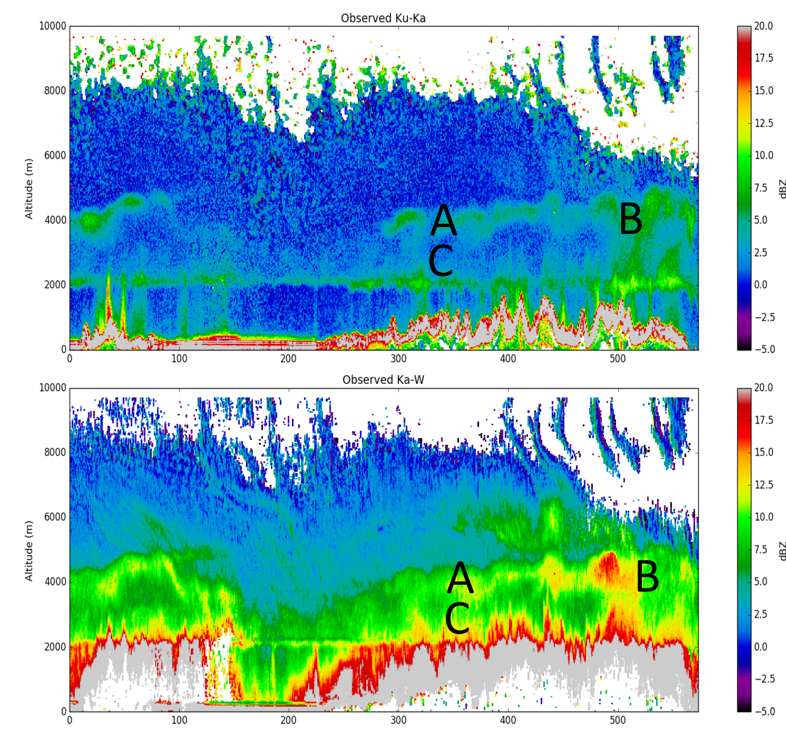
A large area of orographically-enhanced pre-frontal precipitation associated with an approaching baroclinic shortwave was sampled by all 3 aircraft and GPM at 1500 UTC on 3 December. The APR3 revealed some complex structure with a band of enhanced reflectivity at 4km (-12C), reduction in echo over the Strait of Juan de Fuca, and reduction in echo top south of the Olympic Mountains.



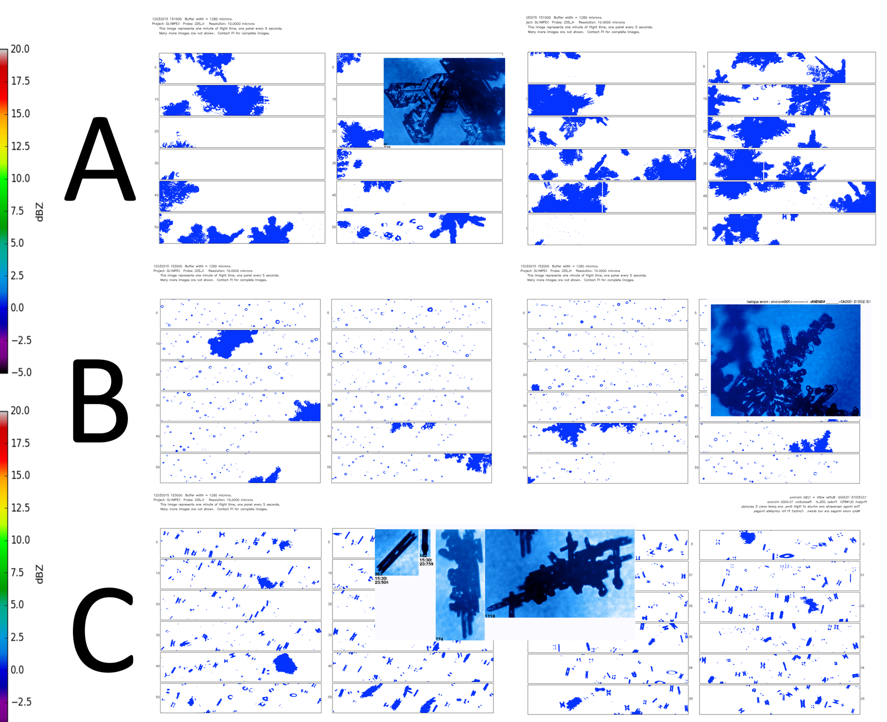
CosMIR is a passive microwave radiometer measuring in cross-track and conical scan configuration at several frequencies between 50 and 183 GHz. Shown are brightness temperatures at 166 GHz in conical scan mode at vertical polarization (top) and the vertical-horizontal polarization difference (bottom). Colder Tbs and stronger polarizations are associated with deeper and stronger echoes in ice-phase precipitation.



NPOL conducted routine PPI and RHI sector scans during OLYMPEX. The elevated area of enhanced reflectivity is less obvious than in the APR3 data, and doesn't appear to be associated with enhanced ZDR values.



Dual-frequency ratio (DFR) from APR3 can be used to indicated particle size, type, and attenuation (from cloud liquid as well as hydrometeors). The band of enhanced reflectivity also shows up as enhanced DFR at 4km, with secondary maximum in Ka-W DFR at 5.5km towards the end of the flight leg. The DFR also increases in and below the melting layer.



To further examine the causes of the observed reflectivity structure and to validate retrievals, images from the 2DS and CPI (inset) probes mounted in orthogonal directions on the Citation are shown above. Region A, positioned in the layer of enhanced reflectivity and DFR at 4km, contains predominately large aggregates. Region B, at the same altitude but further south (where lower echo tops and warmer Tbs were observed), contains cloud water and rimed aggregates. Region C, below region A, contains mostly smaller plate and capped column crystals.

Retrieval Output

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

$$J(X) = \left[(\mathbf{X}-\mathbf{X}_a)^T \times \mathbf{S}_a^{-1} \times (\mathbf{X}-\mathbf{X}_a)\right] + \left[(\mathbf{Y}-f(\mathbf{X}))^T \times \mathbf{S}_y^{-1} \times (\mathbf{Y}-f(\mathbf{X}))\right]$$

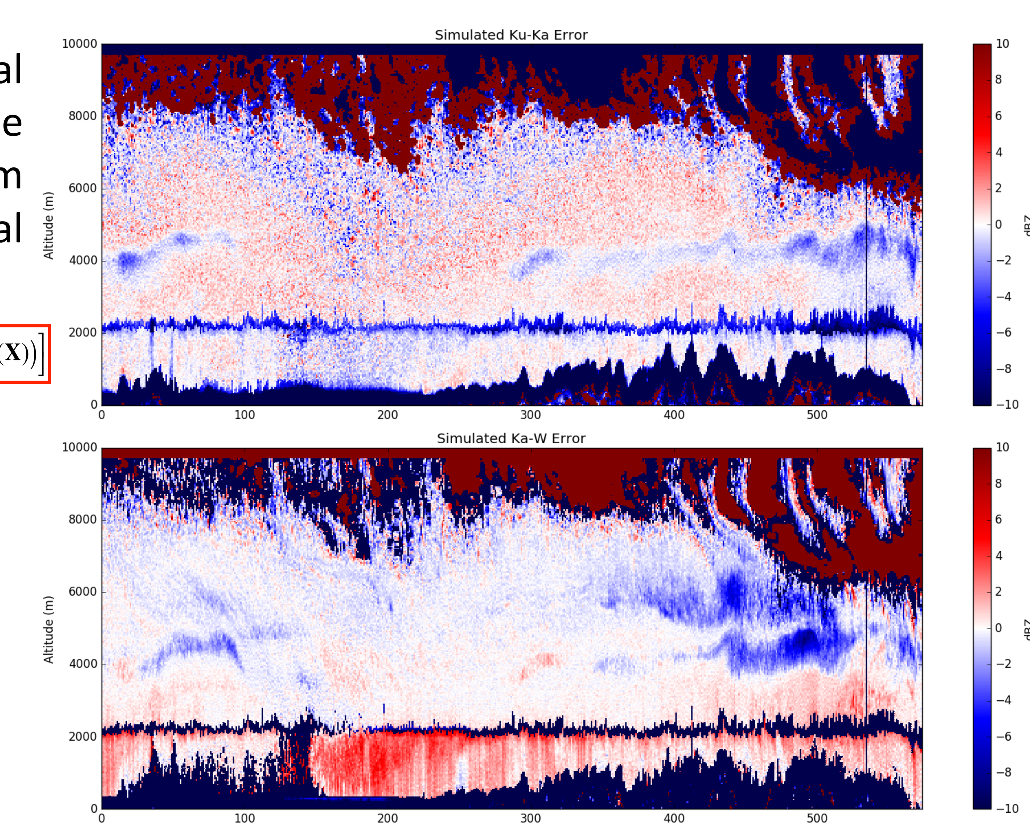
where

X = [N_w, μ, aggregate fraction, cloud liquid]

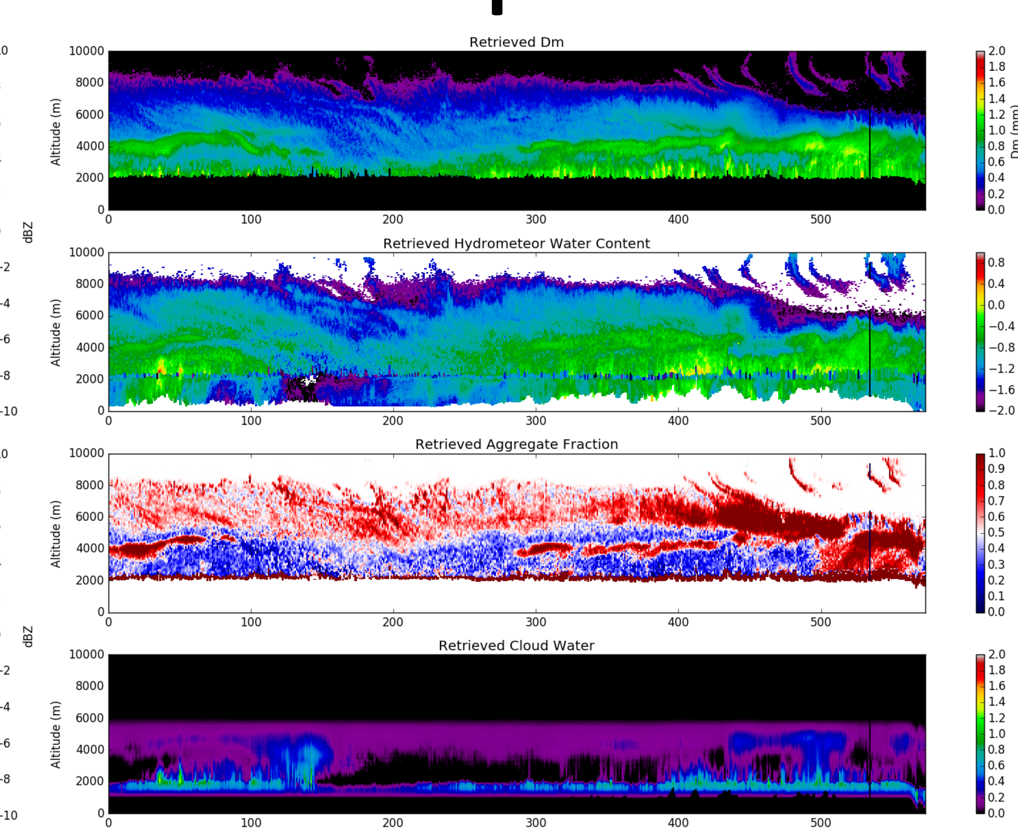
and

Y = [Ku-Ka DFR, Ka-W DFR, PIA]

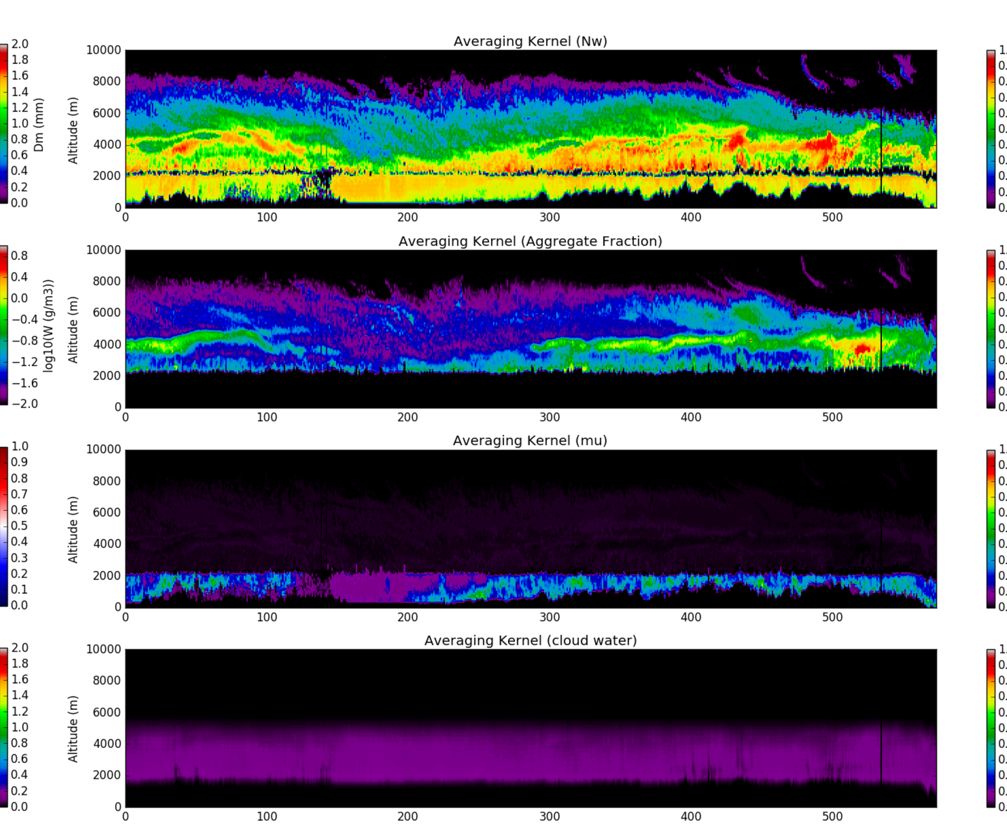
This method is similar to the one developed by Grecu et al. (2011; *JAMC*) and extended to include a third frequency, multiple ice species, and cloud liquid water.



It is important to examine the simulated reflectivity profiles to find discrepancies between the simulation and observations. Such discrepancies may indicate a deficiency in the forward model or retrieval parameter set. There is an obvious failure to simulate bright band reflectivities due to lack of realistic melting particle scattering models. Aside from this, there seems to be an inability for the scattering models to replicate the highest observed Ku-Ka DFRs at 4km and some Ka-W DFRs at higher altitudes near scan #500. Meanwhile, there is a positive bias in the Ka-W DFR in the rain layer near scan #200.



The retrieved parameter set generally agrees qualitatively with the Citation observations. The layer of enhanced reflectivity at 4km is associated with large aggregates; below and above, pristine particles dominate. Pockets of enhanced cloud water are retrieved in regions of heavier orographic enhancement over Vancouver Island (scans 0-150) and the Olympic Mountains (scans 400-500), some of which reach to higher altitudes.



Optimal estimation provides the averaging kernel which can be thought of as a weight of observations vs. prior knowledge. Values near 1 provide stronger confidence that there is information content in the observations regarding a given parameter. For the 3-frequency radar retrieval, there is substantial information regarding N_w (which is directly related to D_m at a given reflectivity), and some information regarding the relative concentration of pristine particles and aggregates, especially if the DFR is large. There is almost no information on the PSD shape (mu) outside of the rain layer, and relatively little information about the cloud water profile.