

### Step 1: ML training on PICASSO dataset

PICASSO in-situ PSDs + Nevzorov IWC

→ compute  $M_2, M_3, M_4, M_6$

→ define  $D_{\text{mmw}} = M_3/M_2$

Train ML ensemble:

$[T_c, p, \text{IWC}_{\text{Nevzorov}}, D_{\text{mmw}}] \rightarrow [M_2, M_3, M_4, M_6]$

ML mapping

### Step 2: ML first guess for CCREST-M

Inputs (profiles):

$T_c(z), p(z)$  (dropsondes)

$\text{IWC}_{3\text{GHz}}(z)$  from 3 GHz retrieval

$D_{\text{mmw}}(z)$  from PICASSO  $D_{\text{mmw}}(T_c)$  fit

ML ensemble  $\rightarrow \widehat{M}_2, \widehat{M}_3, \widehat{M}_4, \widehat{M}_6$

Convert to first-guess Gamma PSD:

$\mu(z) = \mu_{\text{first-guess}}(z)$ , obtain  $\lambda^{(0)}(z), N_o^{(0)}(z)$

first-guess PSD

### Step 3: Physics-based multi-frequency radar retrieval

Inputs:

$N_o^{(0)}(z), \lambda^{(0)}(z), \mu(z)$  (first guess)

$Z_{35}(z), Z_{94}(z)$

$T_c(z), p(z)$

Use same  $m(D)$  and scattering model.

Adjust  $N_o(z), \lambda(z)$  to match observed  $Z(z)$ .

Outputs:

$N_o(z), \lambda(z)$ , (retrieved),  $\mu(z)$

Retrieved PSDs  $\rightarrow$  IWCs (use same  $m(D)$ )

Forward-modelled  $Z_{35}(z), Z_{94}(z)$  (+ $Z_{200}(z)$  for GRaCE in C374)