The IPWG-11 training course program
Active Microwave Algorithm
Shinta Seto (Nagasaki University)

The Precipitation Rate Retrieval Algorithms for the GPM Dual-frequency Precipitation Radar

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Contents of Seto et al. (2021)

1. Introduction
2. Framework
3. Scattering table
   3.1 Liquid-phase precipitation
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4. R-Dm relation
5. Non-uniform beam filling
6. Single-frequency algorithms
   6.1 Range bin classification (rain possible/no-rain)
   6.3 DSD database
7. Dual-frequency algorithm
8. Performance

Included in today's talk

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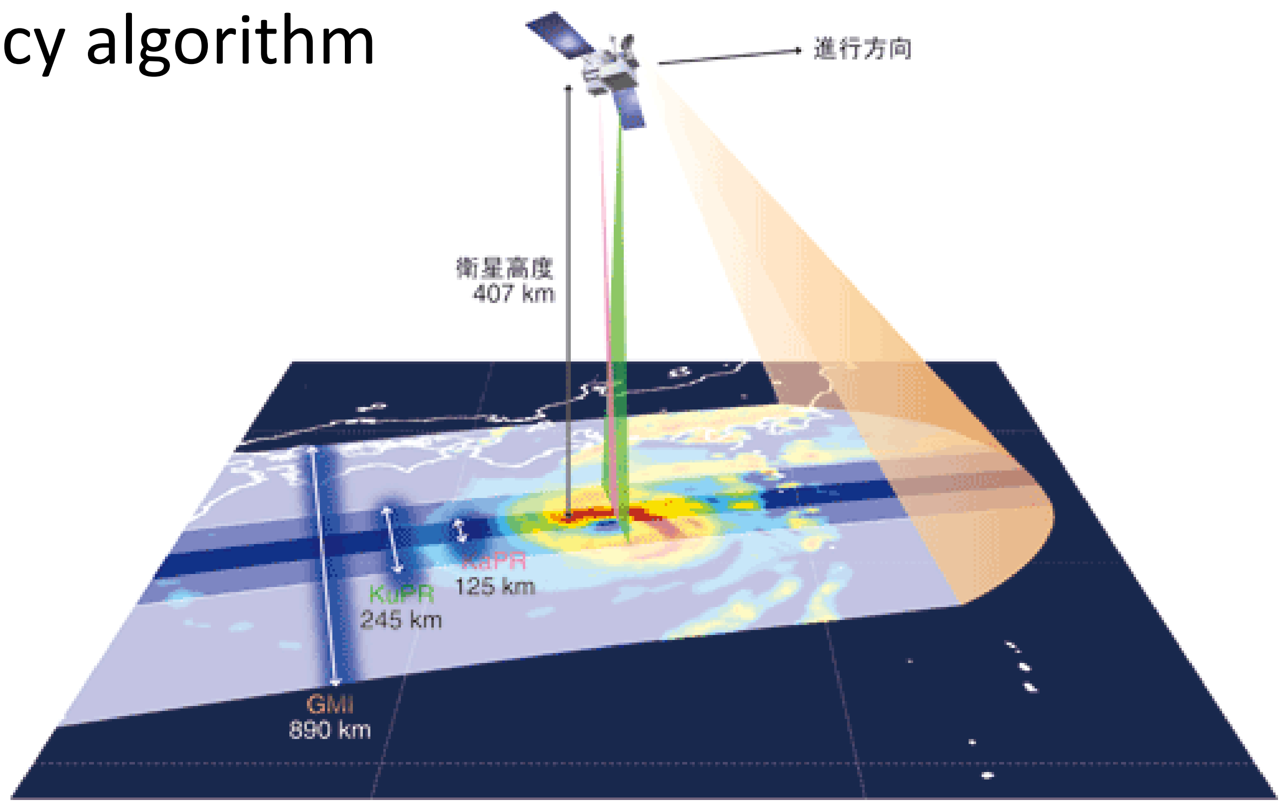
Please read the paper later

DPR algorithms

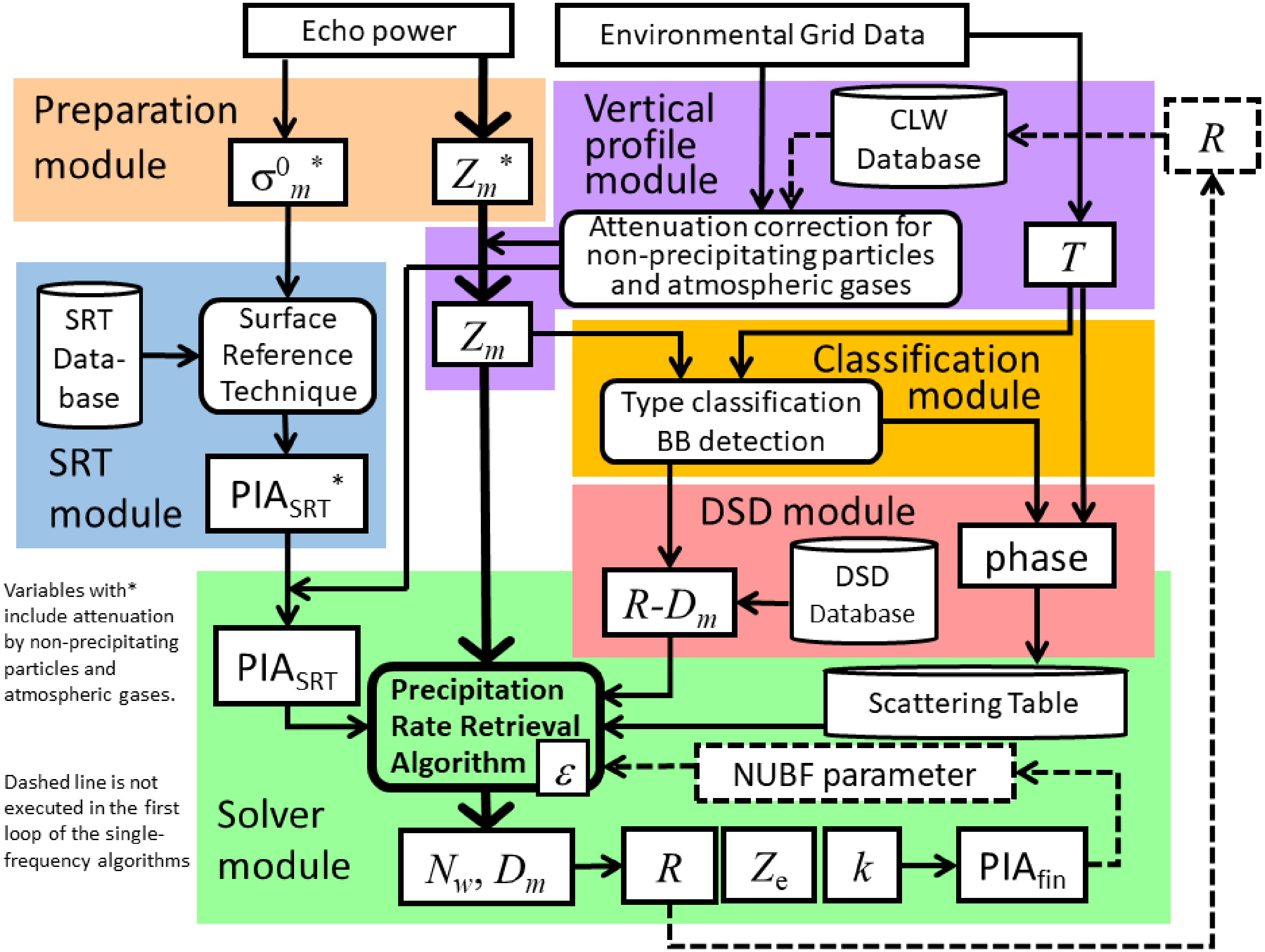
- KuPR algorithm
- KaPR algorithm

Single-frequency algorithms

- Dual-frequency algorithm



Modules of the DPR algorithms



Masaki et al. (2020)
IEEE Trans. Geosci. Rem. Sen.
10.1109/TGRS.2020.3039978

Kubota et al. (2020)
J. Atmos. Ocean. Technol.
10.1175/JTECH-D-20.0041.1

Awaka et al. (2021)
J. Meteorol. Soc. Japan
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Meneghini et al. (2021)
J. Meteorol. Soc. Japan
10.2151/jmsj.2021-010

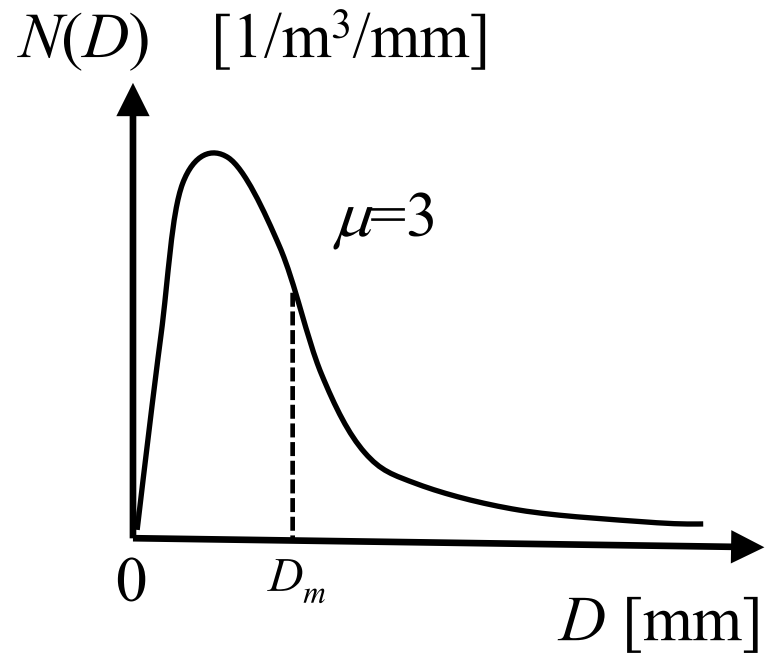
Seto et al. (2021)
J. Meteorol. Soc. Japan
10.2151/jmsj.2021-011

Seto (2024) New!
Advances in Weather Radar Volume 1, pp153-187.

Section 2.1

DSD model

$$N(D) = N_w f(D; D_m)$$



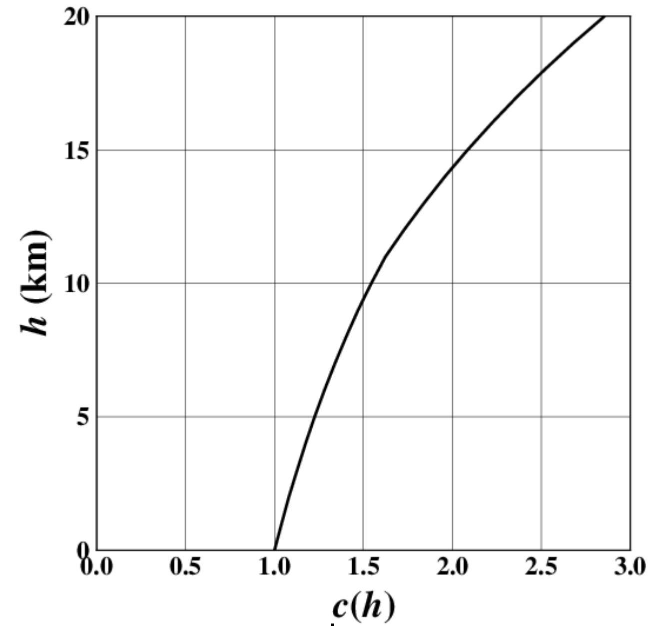
$$f(D; D_m) = \frac{6(\mu+4)^{\mu+4}}{4^4 \Gamma(\mu+4)} \left(\frac{D}{D_m}\right)^{\mu} \exp\left[\frac{-(\mu+4)D}{D_m}\right]$$

$$D_m = \frac{\int_{D=0}^{\infty} D^4 N(D) dD}{\int_{D=0}^{\infty} D^3 N(D) dD}$$

D_m: mass-weighted mean diameter

Sections 2.2 and 3.1

Rain rate



$$R = 0.6\pi \times 10^{-3} \int_{D=0}^{\infty} V(D)c(h)D^3 N(D)dD$$

$$= N_w \times 0.6\pi \times 10^{-3} \int_{D=0}^{\infty} V(D)c(h)D^3 f(D;D_m)dD$$

$$R = N_w f_R(D_m)c(h)$$

$$f_R(D_m) = 0.6\pi \times 10^{-3} \int_{D=0}^{\infty} V(D)D^3 f(D;D_m)dD$$

$$V(D) = 3.78D^{0.67}$$

$$f_R(D_m) = 0.6\pi \times 10^{-3} \times 3.78 \times \frac{6\Gamma(\mu+4.67)}{4^4(\mu+4)^{0.67}\Gamma(\mu+4)} D_m^{4.67}$$

$$= 0.1644 \times 10^{-3} \times D_m^{4.67}$$

Sections 2.2 and 3.1

Radar Reflectivity Factor

$$Z_e = \frac{\lambda^4}{\pi^5 \left|K_w(\lambda)\right|^2} \int_{D=0}^{\infty} \sigma_b(D;\lambda,T) N(D) dD$$

$$= N_w \frac{\lambda^4}{\pi^5 \left|K_w(\lambda)\right|^2} \int_{D=0}^{\infty} \sigma_b(D;\lambda,T) f(D;D_m) dD$$

σ_b: backscattering cross section

$$K_w(\lambda) \equiv \frac{n_{w0}(\lambda)^2 - 1}{n_{w0}(\lambda)^2 + 2}$$

$$Z_e = N_w f_z(D_m)$$

$$f_Z(D_m) = \frac{\lambda^4}{\pi^5 \left|K_w(\lambda)\right|^2} \int_{D=0}^{\infty} \sigma_b(D;\lambda,T) f(D;D_m) dD$$

Radar Reflectivity Factor

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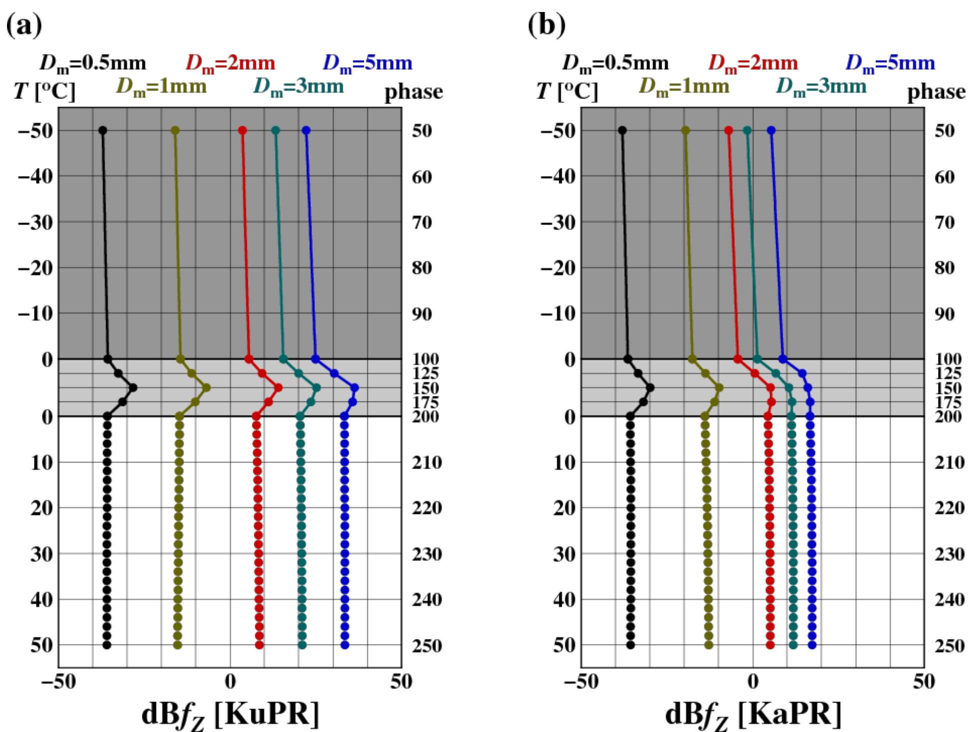


Specific Attenuation

$$k = \frac{0.01}{\ln 10} \int_{D=0}^{\infty} \sigma_e(D;\lambda,T) N(D) dD$$

$$= N_w \frac{0.01}{\ln 10} \int_{D=0}^{\infty} \sigma_e(D;\lambda,T) f(D;D_m) dD$$

σ_b: extinction cross section

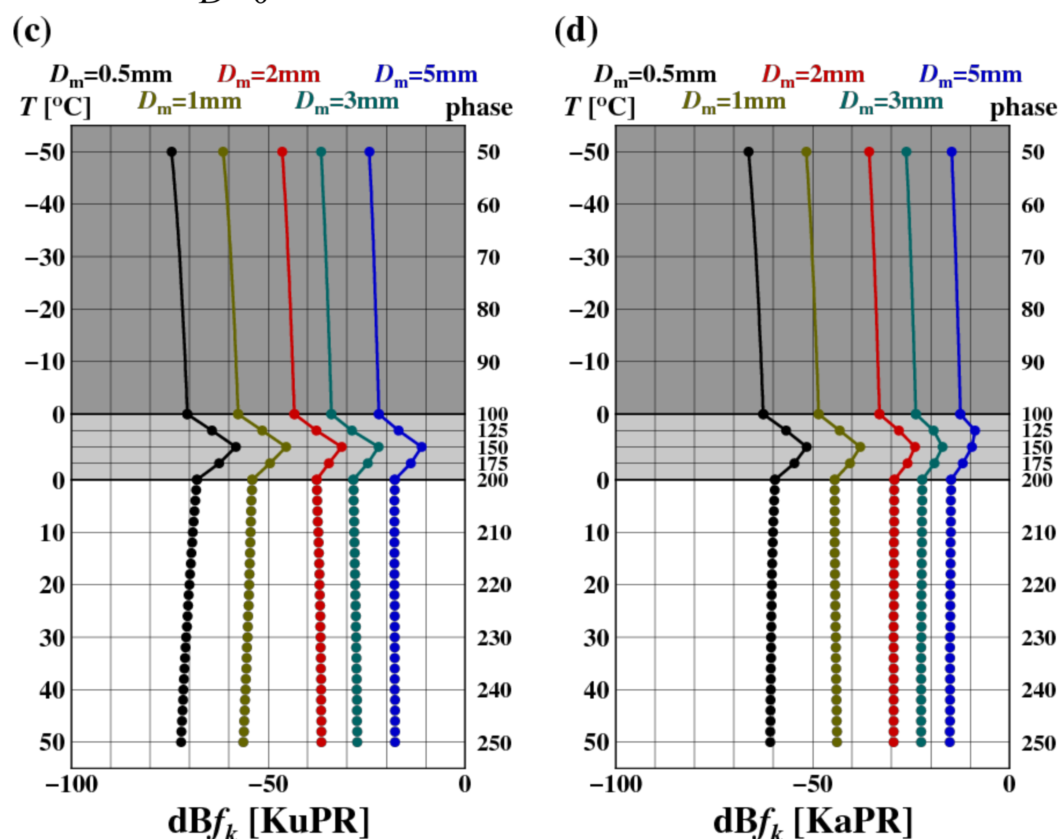
$$k = N_w f_k(D_m)$$

$$f_k(D_m) = \frac{0.01}{\ln 10} \int_{D=0}^{\infty} \sigma_e(D;\lambda,T) f(D;D_m) dD$$

Specific Attenuation

$$k = N_w f_k(D_m)$$

$$f_k(D_m) = \frac{0.01}{\ln 10} \int_{D=0}^{\infty} \sigma_e(D;\lambda,T) f(D;D_m) dD$$



Measured radar reflectivity factor

$$\mathrm{dBZ}_m(l) = \mathrm{dBZ}_{e,i} - 2K_iL - 2k_il$$

$$Z_m(l) = Z_{e,i}10^{-0.2K_iL-0.2k_il}$$

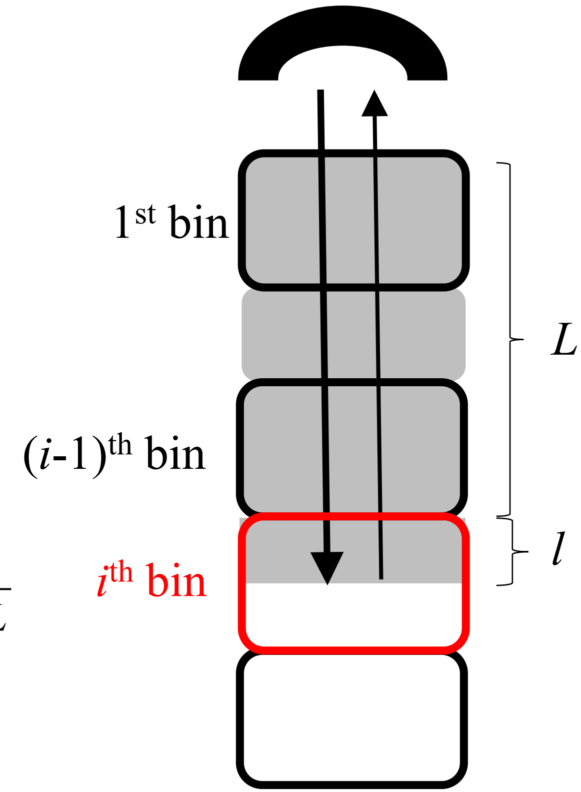
$$K_i \equiv \sum_{j=1}^{i-1} k_j$$

$$Z_{m,i} \equiv \frac{1}{L}\int_{l=0}^{L} Z_m(l)dl = \frac{1}{L}Z_{e,i}10^{-0.2K_iL}\int_{l=0}^{L}10^{-0.2k_il}dr = Z_{e,i}10^{-0.2K_iL}\frac{1-10^{-0.2k_iL}}{0.2(\ln 10)k_iL}$$

$$\mathrm{dBZ}_{m,i} = \mathrm{dBZ}_{e,i} - 2K_iL - \gamma k_iL$$

γ satisfies the following eqn. and $0 < \gamma < 1$.

$$\frac{1-10^{-0.2k_iL}}{0.2(\ln 10)k_iL} = 10^{-0.1\gamma k_iL}$$



Retrieval

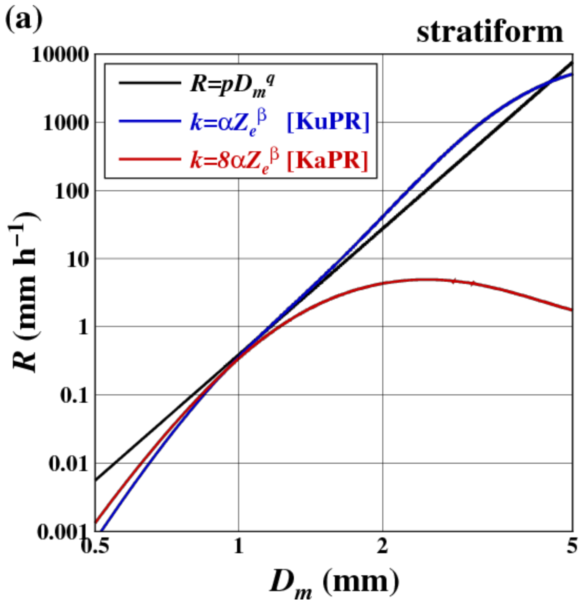
$$\mathrm{dBZ}_m = \mathrm{dBZ}_e - 2KL - \gamma kL$$

$$R = N_w f_R(D_m)c(h)$$

$$R = g(D_m)$$

$$Z_e = N_w f_z(D_m)$$

$$k = N_w f_k(D_m)$$



R-Dm relation

$$Z \equiv \int_{D=0}^{\infty} D^6 N(D) dD$$

$$N(D) = N_w f(D; D_m)$$

$$Z = N_w \int_{D=0}^{\infty} D^6 f(D; D_m) dD$$

$$f(D; D_m) = \frac{6(\mu+4)^{\mu+4}}{4^4 \Gamma(\mu+4)} \left(\frac{D}{D_m}\right)^{\mu} \exp\left[\frac{-(\mu+4)D}{D_m}\right]$$

$$\mu = 3$$

$$Z = 0.034439 \times N_w D_m^{\ 7}$$

$$R = N_w f_R(D_m) c(h)$$

$$V(D) = 3.78 D^{0.67}$$

$$R = 0.1644 \times 10^{-3} \times N_w D_m^{\ 4.67}$$

$$Z = aR^b$$

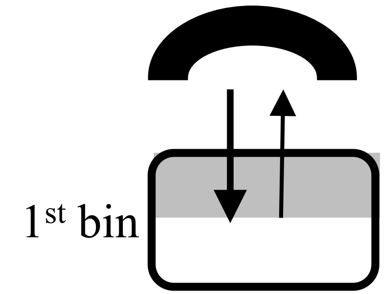
$a = 298.84$ and $b = 1.38$ (Kozu et al. 2009)

$$R = p D_m^{\ q}$$

$$p = \left(\frac{0.034439}{a \times 0.1644 \times 10^{-3}}\right)^{\frac{1}{b-1}} \qquad q = \frac{2.33}{b-1}$$

Retrieval (i=1)

At i=1, K=0.



$$\mathrm{dBZ}_m = \mathrm{dBZ}_e - \gamma k L$$

$$R = N_w f_R(D_m) c(h)$$

$$R = g(D_m)$$

$$Z_e = N_w f_z(D_m)$$

$$N_w = \frac{g(D_m)}{f_R(D_m) c(h)}$$

$$k = N_w f_k(D_m)$$

$$\mathrm{dBZ}_m = 10 \log_{10}\left[\frac{g(D_m) f_z(D_m)}{f_R(D_m) c(h)}\right] - \gamma(D_m)\frac{g(D_m) f_k(D_m)}{f_R(D_m) c(h)} L$$

Retrieval (i>1)

At $i>1$, $\mathrm{dBZ}_f \equiv \mathrm{dBZ}_m + 2KL$

$$\mathrm{dBZ}_f = \mathrm{dBZ}_e - \gamma k L$$

$$R = N_w f_R(D_m) c(h)$$

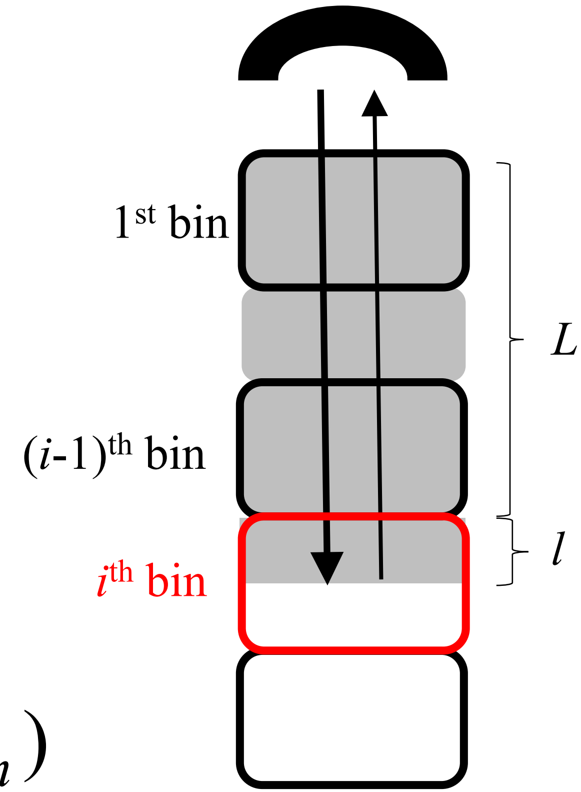
$$R = g(D_m)$$

$$Z_e = N_w f_z(D_m)$$

$$N_w = \frac{g(D_m)}{f_R(D_m) c(h)}$$

$$k = N_w f_k(D_m)$$

$$\mathrm{dBZ}_f = 10\log_{10}\left[\frac{g(D_m) f_z(D_m)}{f_R(D_m) c(h)}\right] - \gamma(D_m)\frac{g(D_m) f_k(D_m)}{f_R(D_m) c(h)} L$$



PIA (Path Integrated Attenuation)

$$\mathrm{dBZ}_m = \mathrm{dBZ}_e - 2KL - \gamma kL$$

$$R = N_w f_R(D_m) c(h)$$

$$R = g(D_m)$$

$$Z_e = N_w f_z(D_m)$$

$$k = N_w f_k(D_m)$$

SRT module

$$\mathrm{PIA}_g \equiv \sum_{i=1}^{n} 2k_i L \leftrightarrow \mathrm{PIA}_{\mathrm{SRT}} \equiv \mathrm{dB}\sigma^0{}_e - \mathrm{dB}\sigma^0{}_m$$

Modification of R-Dm relation

$$R = N_w f_R(D_m)c(h)$$

$$k = \varepsilon \alpha Z_e{}^{\beta}$$

$$Z_e = N_w f_z(D_m)$$

$$R = \left\{ \frac{\varepsilon \alpha \left[f_z(D_m) \right]^{\beta}}{f_k(D_m)} \right\}^{\frac{1}{1-\beta}} f_R(D_m)c(h)$$

$$k = N_w f_k(D_m)$$

$$R = g(D_m) = \varepsilon^r p D_m{}^q$$

$$r = \frac{1}{1-\beta}$$

Maximum Likelihood method

ε

$$R = g(D_m)$$

SRT module

$$\mathrm{PIA}_g \equiv \sum_{i=1}^{n} 2k_i L \quad \longleftrightarrow \quad \mathrm{PIA}_{\mathrm{SRT}} \equiv \mathrm{dB}{\sigma^0}_e - \mathrm{dB}{\sigma^0}_m$$

$$p_1(x) = \frac{1}{\sqrt{2\pi}\sigma_x} \exp\left[-\frac{(x-\mu_x)^2}{2{\sigma_x}^2} \right]$$

$$x = \log_{10}\varepsilon$$

$$p_2(\mathrm{PIA}_{\mathrm{SRT}} \,|\, \mathrm{PIA}_g) = \frac{1}{\sqrt{2\pi}\sigma_{\mathrm{SRT}}} \exp\left[-\frac{(\mathrm{PIA}_{\mathrm{SRT}} - \mathrm{PIA}_g)^2}{2{\sigma_{\mathrm{SRT}}}^2} \right]$$

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