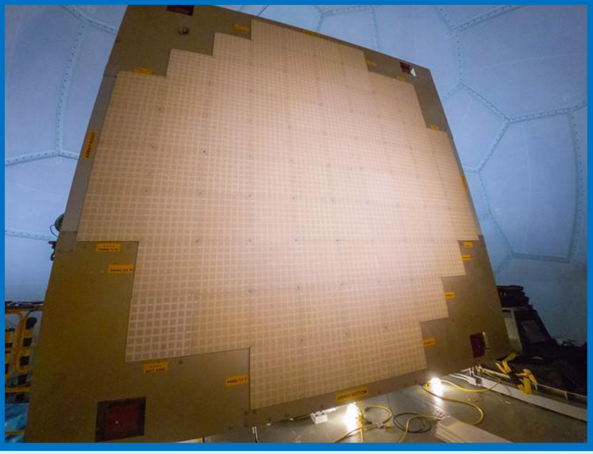
Optimized polarimetric radar relations for snow estimation

Petar Bukovčić, Alexander Ryzhkov, and Dušan Zrnić

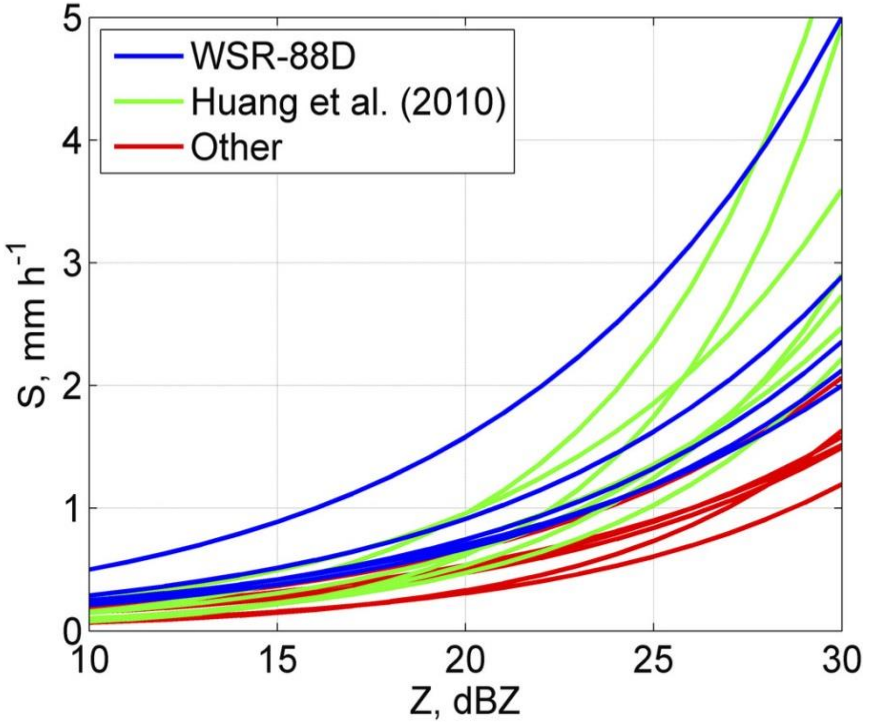





Current state of radar snow estimates

Source	$Z(S)$ relation for dry snow
Gunn and Marshall (1958)	$Z = 448S^2$
Sekhon and Srivastava (1970)	$Z = 399S^{2.21}$
Ohtake and Henmi (1970)	$Z = 739S^{1.7}$
Puhakka (1975)	$Z = 235S^2$
Koistinen et al. (2003)	$Z = 400S^2$
Huang et al. (2010)	$Z = (106\text{–}305)S^{(1.11\text{–}1.92)}$
Szyrmer and Zawadzki (2010)	$Z = 494S^{1.44}$
Wolfe and Snider (2012)	$Z = 110S^2$
WSR-88D, Northeast	$Z = 120S^2$
WSR-88D, north plains–upper Midwest	$Z = 180S^2$
WSR-88D, high plains	$Z = 130S^2$
WSR-88D, Intermountain West	$Z = 40S^2$
WSR-88D, Sierra Nevada	$Z = 222S^2$

The multiplier in the power-law relations varies by an order of magnitude, no clear path how to chose optimal S(Z)



Multitude of S(Z) relations (Bukovčić et al. 2018)

Basic formulas

Snow rate

$$S = 6\,10^{-4}\pi \int_0^{D_{\max}} \frac{\rho_{\mathrm{s}}(D)}{\rho_{\mathrm{w}}} D^3 V_{\mathrm{t}}^{(s)}(D) N(D)\,dD \sim M_{2+\gamma}$$

Radar reflectivity

$$Z = \frac{|K_{\mathrm{i}}|^2}{|K_{\mathrm{w}}|^2} \int_0^{D_{\max}} \frac{\rho_{\mathrm{s}}^2(D)}{\rho_{\mathrm{i}}^2} D^6 N(D)\,dD \sim M_4$$

$$M_n = \int D^n N(D)\,dD$$

$$S \sim f_{rim}^{0.12} N_{0s}^{0.35} Z^{0.62}$$

The multiplier in the S(Z) relation changes more than an order of magnitude because N0s varies by 4 orders of magnitude

Snow size distribution

$$N(D) = N_{0s} D^{\mu} \exp(-\Lambda_s D)$$

Snow density

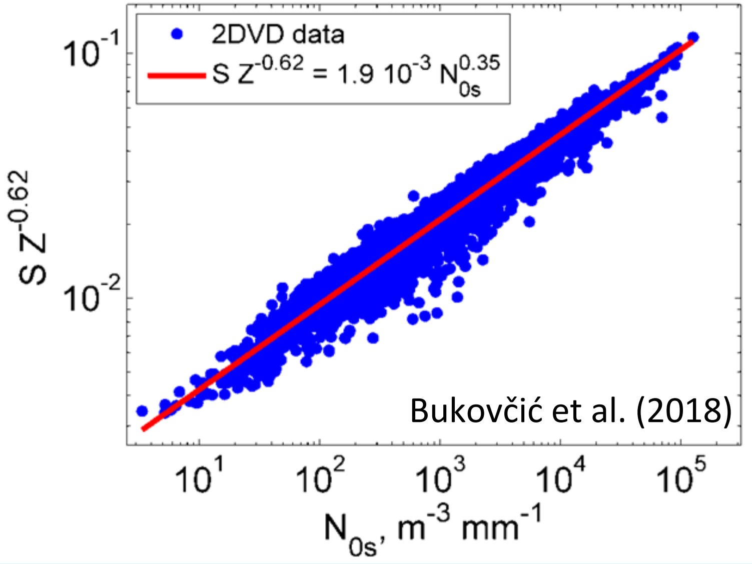
$$\rho_{\mathrm{s}}(D) = \alpha_u f_{\mathrm{rim}} D^{-1}$$

(frim is the degree of riming)

Snow fall velocity

$$V_t^{(s)} \sim D^{\gamma}$$

Analysis of snow disdrometer data



Polarimetric algorithms for snow estimation

Specific differential phase

$$K_{DP} = \frac{0.27\pi}{\lambda \rho_i^2}\left(\frac{\varepsilon_i - 1}{\varepsilon_i + 2}\right)^2 F_{shape} F_{orinet} \int \rho_s^2(D) D^3 N(D) dD \sim M_1$$

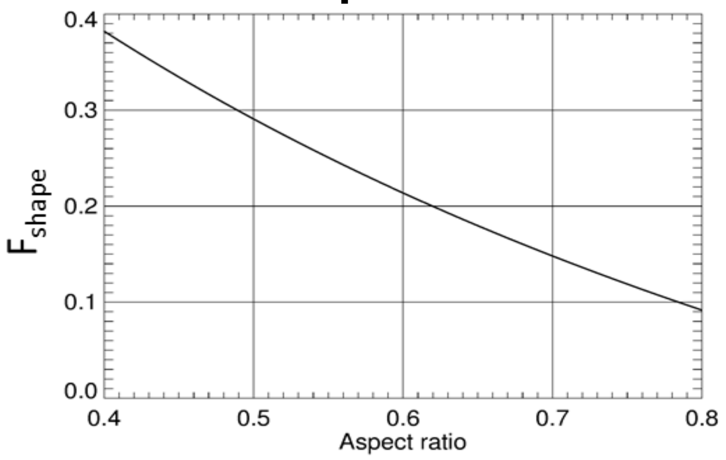
Z is proportional to the 4th moment of snow SD whereas KDP is proportional to its 1st moment

Number concentration

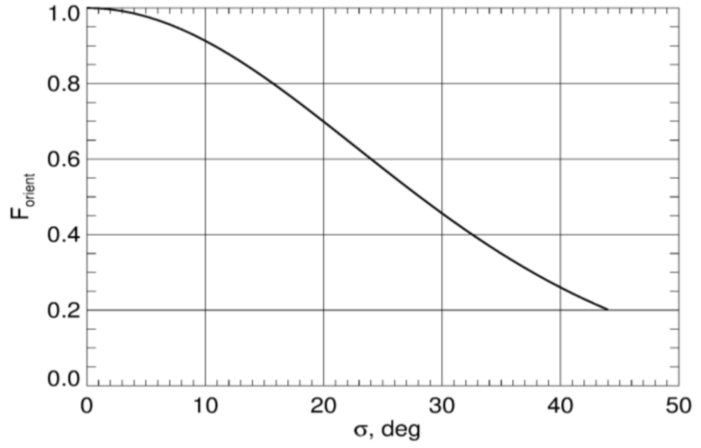
$$N_t = \int N(D) dD \sim M_0$$

Z is proportional to the 4th moment of snow SD whereas N_t is proportional to its 0th moment

Shape factor



Orientation factor



Polarimetric relations for snow estimation

S(Kdp, Z)-based

$$S(K_{\mathrm{DP}}, Z) = 1.48 K_{\mathrm{DP}}^{0.61} Z^{0.33}$$

Bukovčić et al. (2018), V1

$$S(K_{\mathrm{DP}}, Z) = \frac{27.9 \times 10^{-3}}{(F_o F_s)^{0.615}} (p_0 / p)^{0.5} (K_{\mathrm{DP}} \lambda)^{0.615} Z^{0.33}$$

Bukovčić et al. (2020), V2

$$S(K_{DP}, Z) = f(\mathrm{f}_{\mathrm{rim}}, F_o, F_s, \mu, p, \lambda, K_{DP}, Z)$$

Current + future res, V3

S(Z)-based

$$S(Z) = f(\mathrm{f}_{\mathrm{rim}}, \mu, N_t, Z)$$

Current + future research, V4

$\mathrm{f}_{\mathrm{rim}}$ – riming degree, F_o & F_s – particle orientation & shape parameters, μ – PSD shape parameter, N_t – number concentration, p – atmospheric pressure, λ – radar wavelength

Polarimetric relations for snow estimation

f_{rim}, F_oF_s, and N_t can be retrieved at ASOS stations – snowfall rate + extinction coefficient σ_e needed!

S, σ_e – ASOS

$$f_{rimA}(S_{ASOS}, \sigma_{eASOS}, Z, \mu) = const \times f_1(\mu) \frac{S_{ASOS}{}^a}{\sigma_{eASOS}{}^b Z^c}$$

Z, Kdp – radar

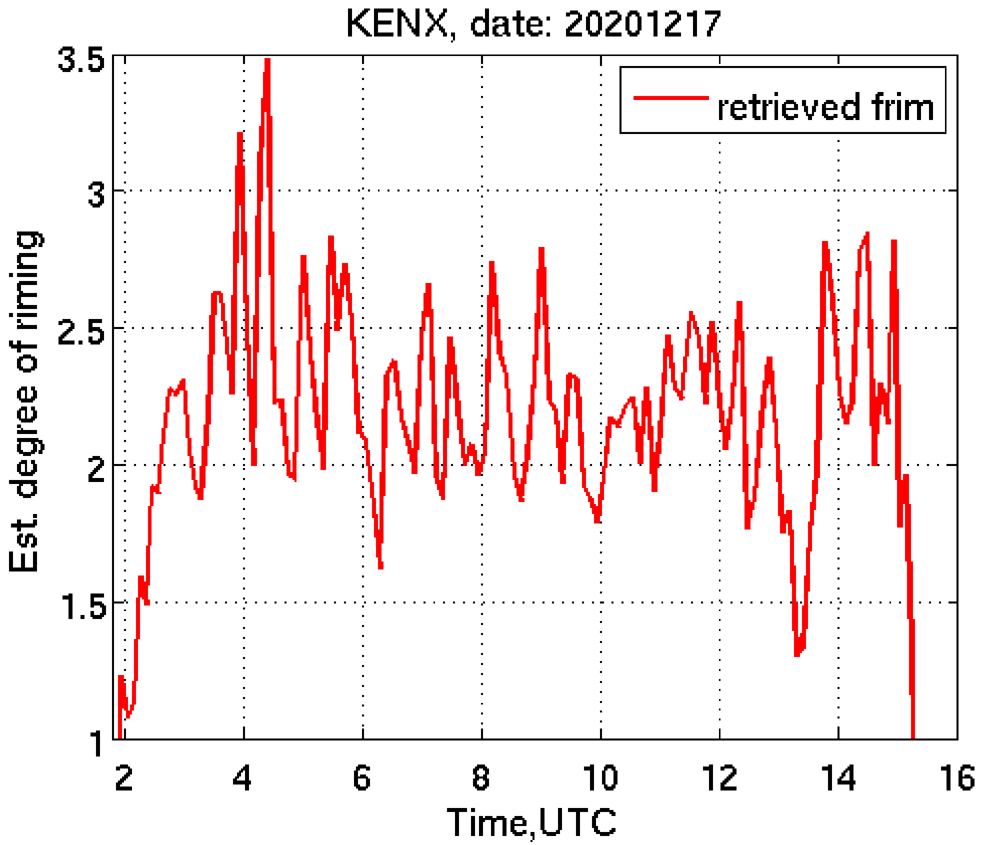
$$F_oF_s = F_{osA}(K_{DP}, Z, \sigma_{eASOS}, f_{rimA}, \mu) = const \times f_2(\mu) \frac{Z^g (K_{DP}\lambda)^h}{f_{rimA}^i \sigma_{eASOS}{}^j}$$

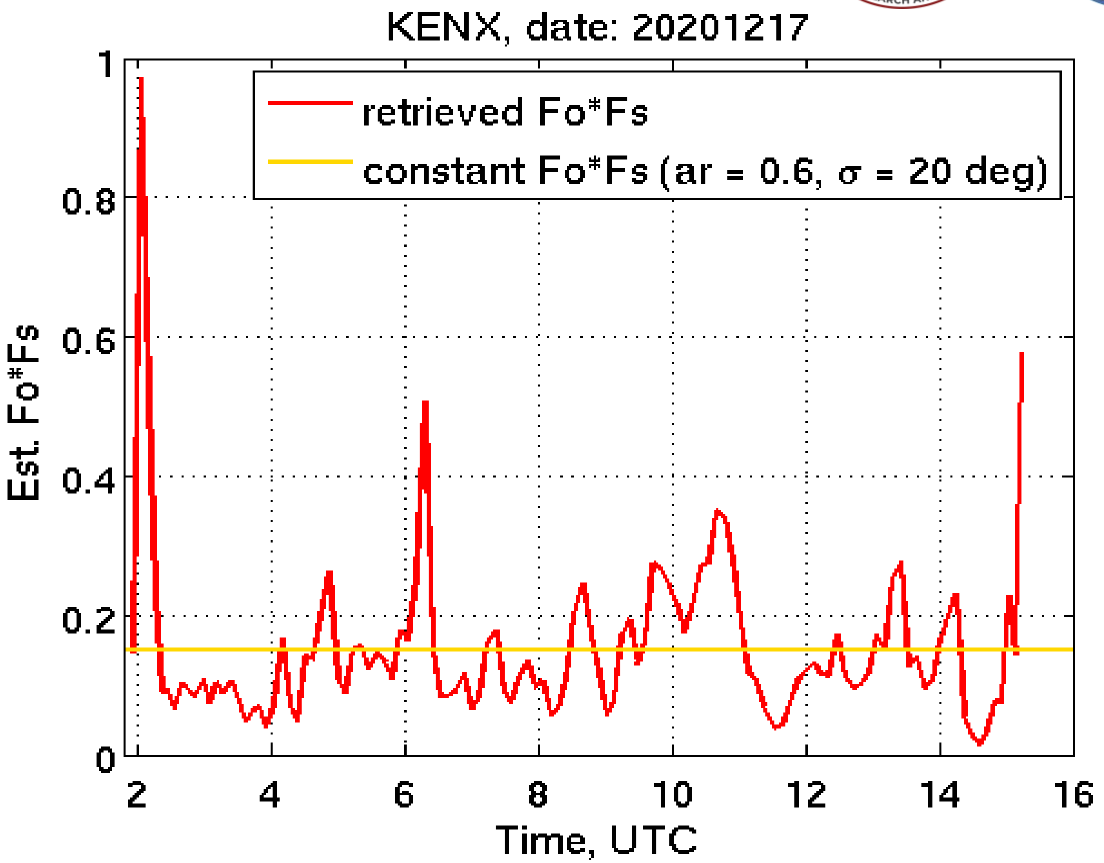
D_m = f(f_{rim}, μ, σ_e, Z) – mean volume diameter

$N_t = 2f_3(\mu)\sigma_e/(\pi D_m^2)$

We can use ASOS measurements to directly evaluate "goodness" of our relations – how much the best possible radar estimate deviates from the ASOS measurements of S

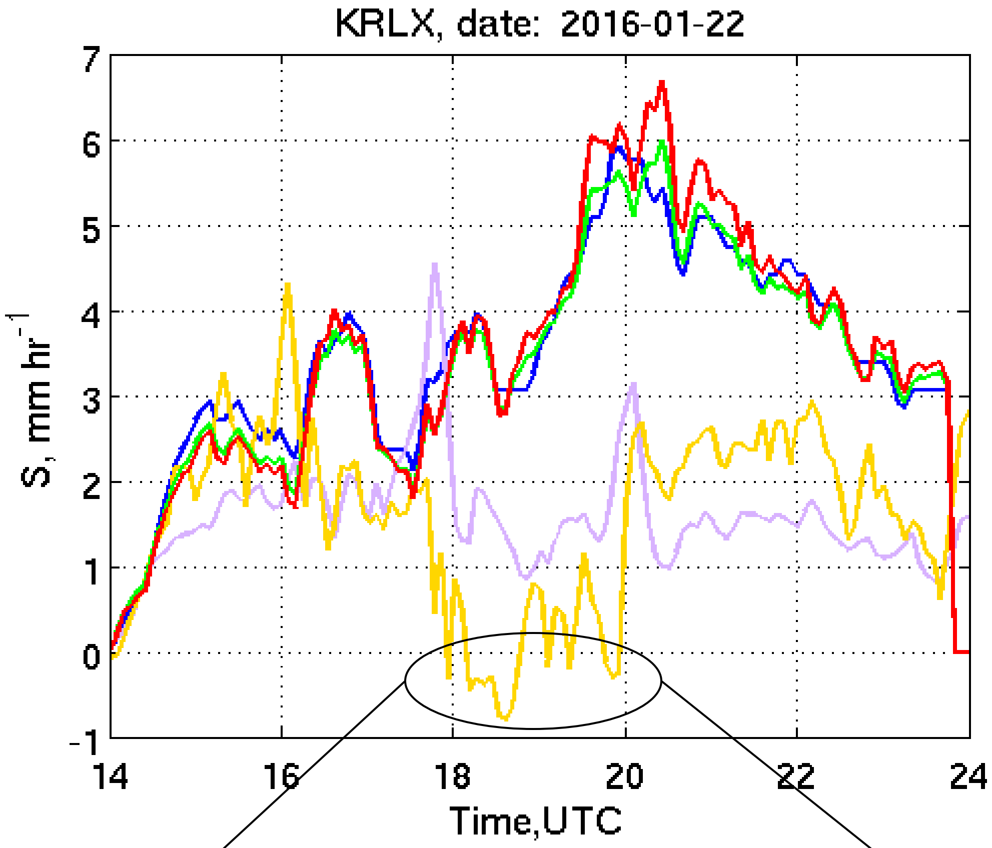
Example of f_{rim} and F_o*F_s retrieval

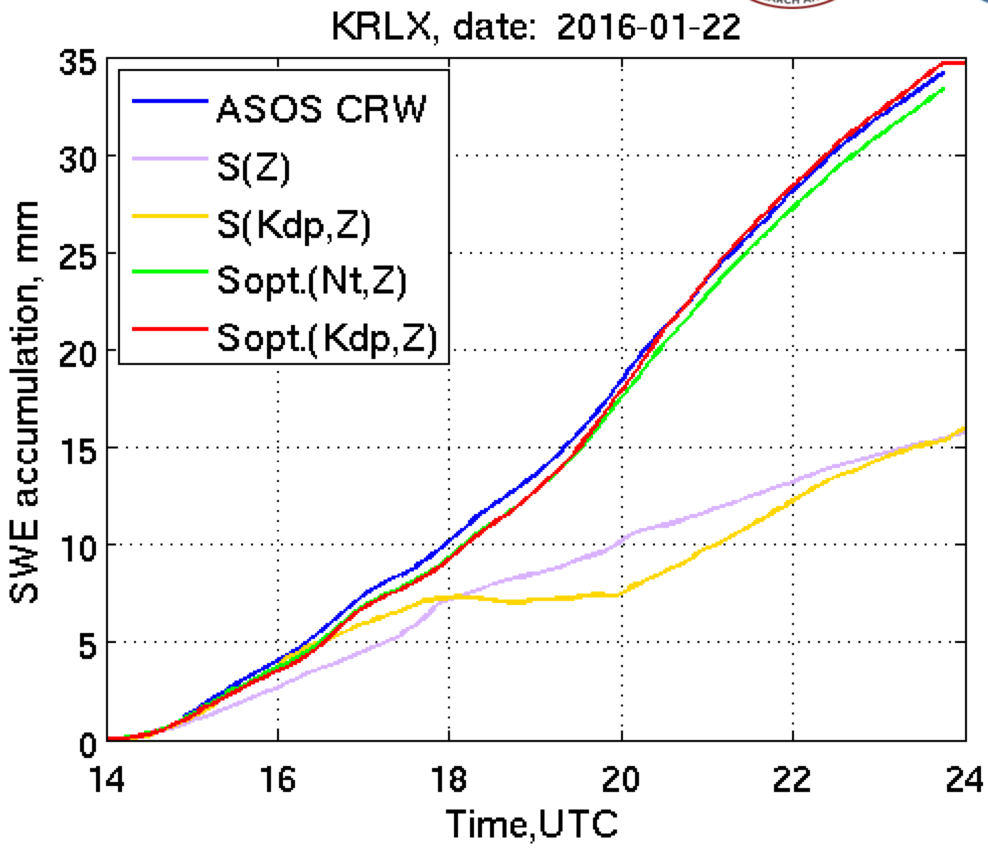




Constant F_o*F_s factor deviates significantly from the retrieved F_o*F_s, potentially introducing large biases.

Evaluation of frim, Fo Fs, μ, and Nt effects on radar polarimetric snow rate (S, mm hr^{-1}) relations

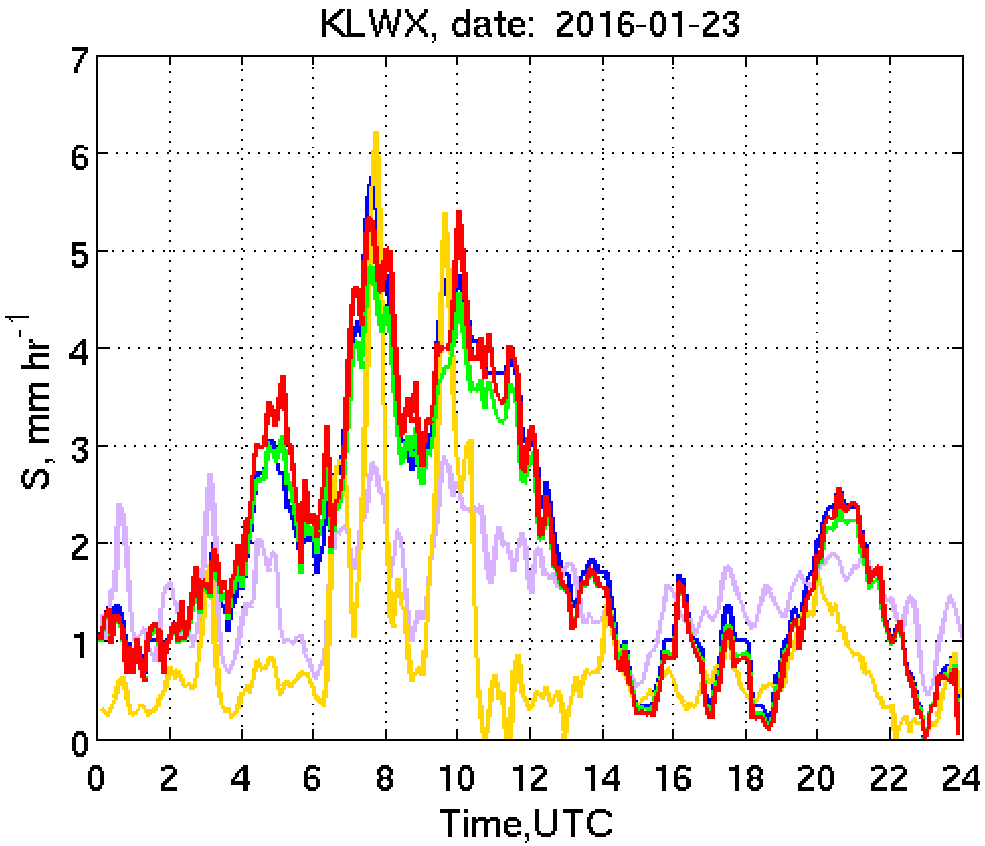


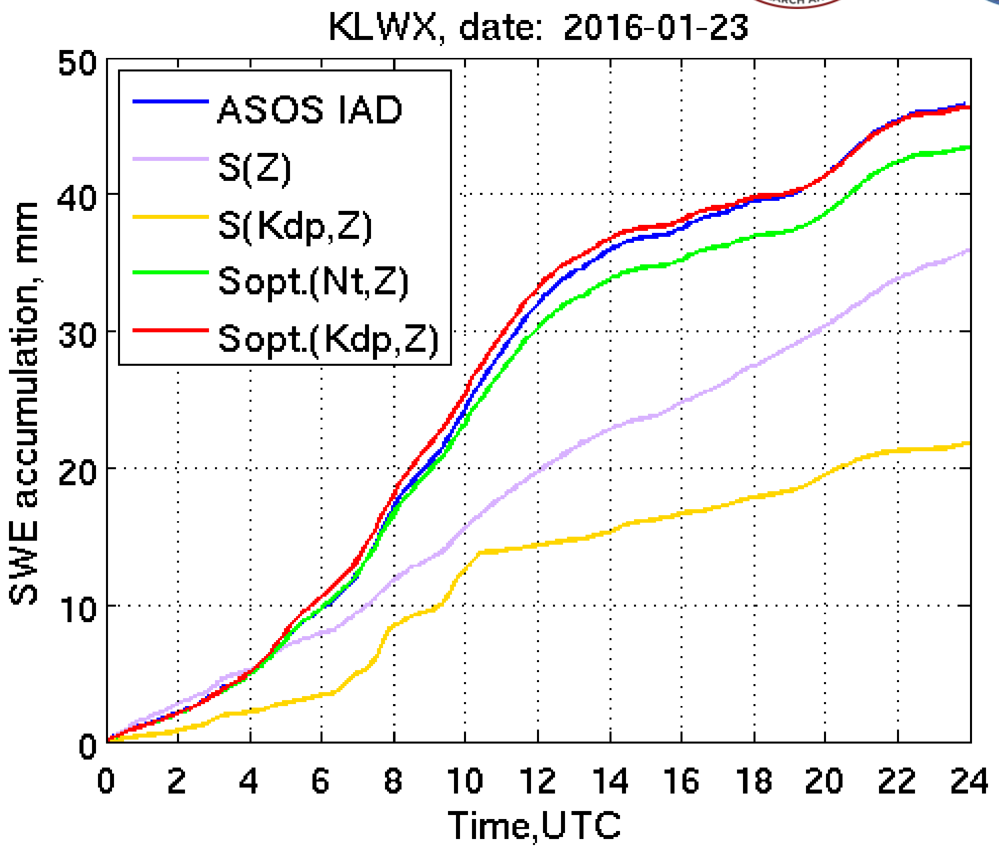


Underestimation due to low and erratic Kdp in aggregated snow

Addition of dynamically estimated N_t, f_{rim}, F_o, and F_s introduces large improvement

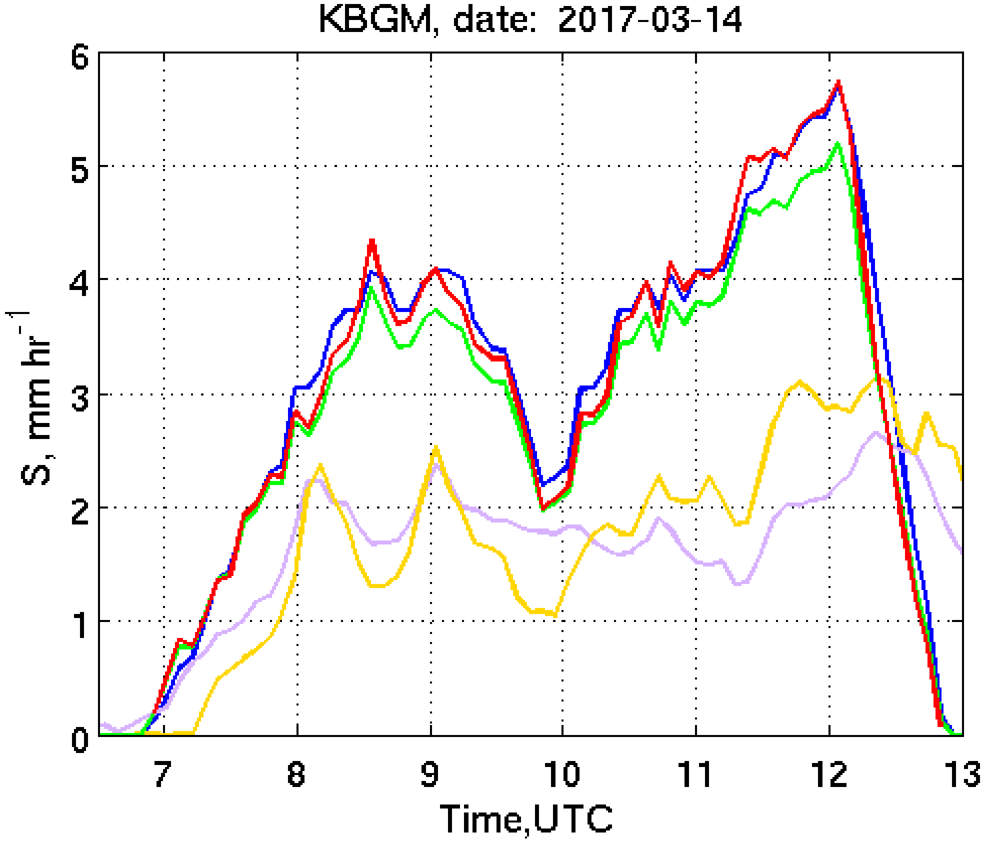
Evaluation of frim, FoFs, μ, and Nt effects on radar polarimetric snow rate (S, mm hr^{-1}) relations

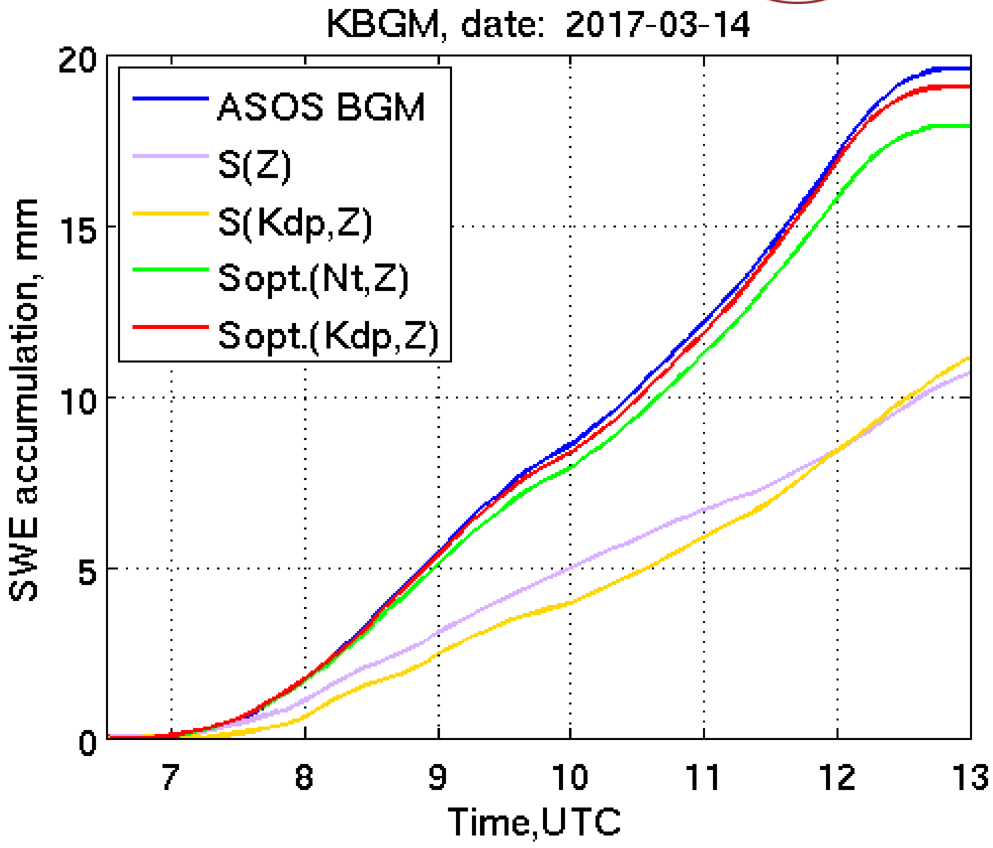




Addition of dynamically estimated N_t, f_{rim}, F_o, and F_s introduces large improvement. Adjusting μ from 0 to -0.6 in Sopt.(Kdp, Z) provides even better results for this event.

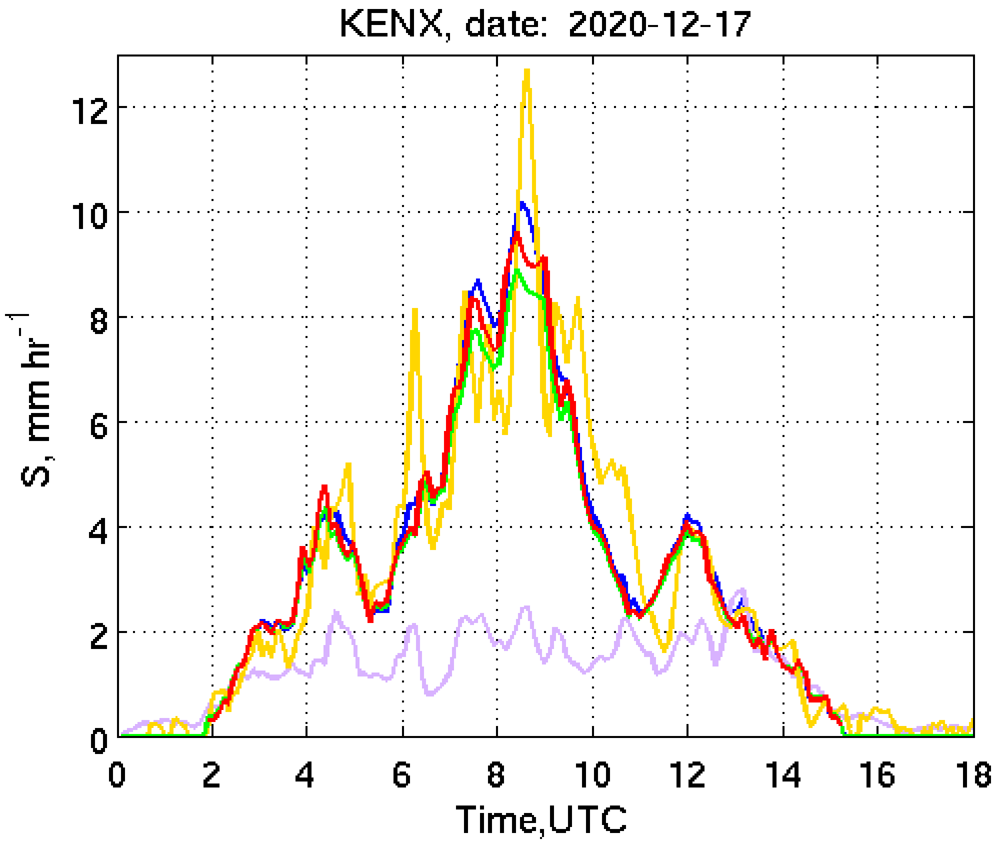
Evaluation of frim, FoFs, μ, and Nt effects on radar polarimetric snow rate (S, mm hr^{-1}) relations

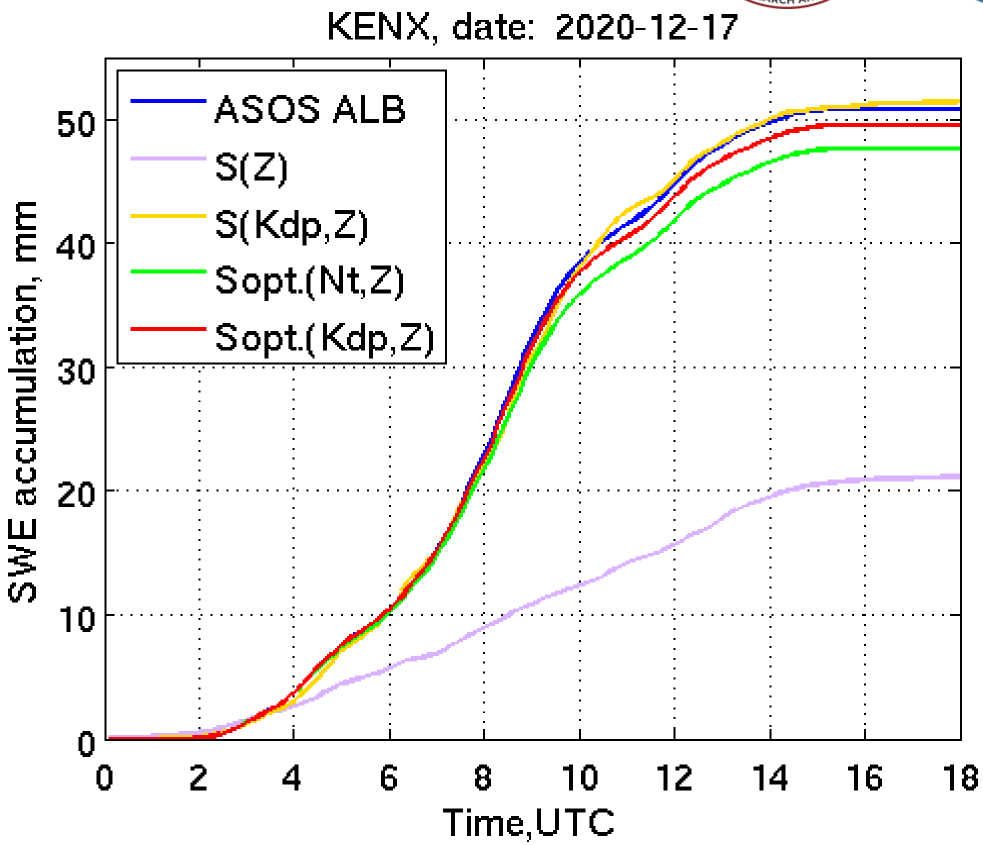




Addition of dynamically estimated N_t, f_{rim}, F_o, and F_s introduces large improvement. Adjusting μ from 0 to -0.4 in Sopt.(Kdp, Z) provides even better results for this event.

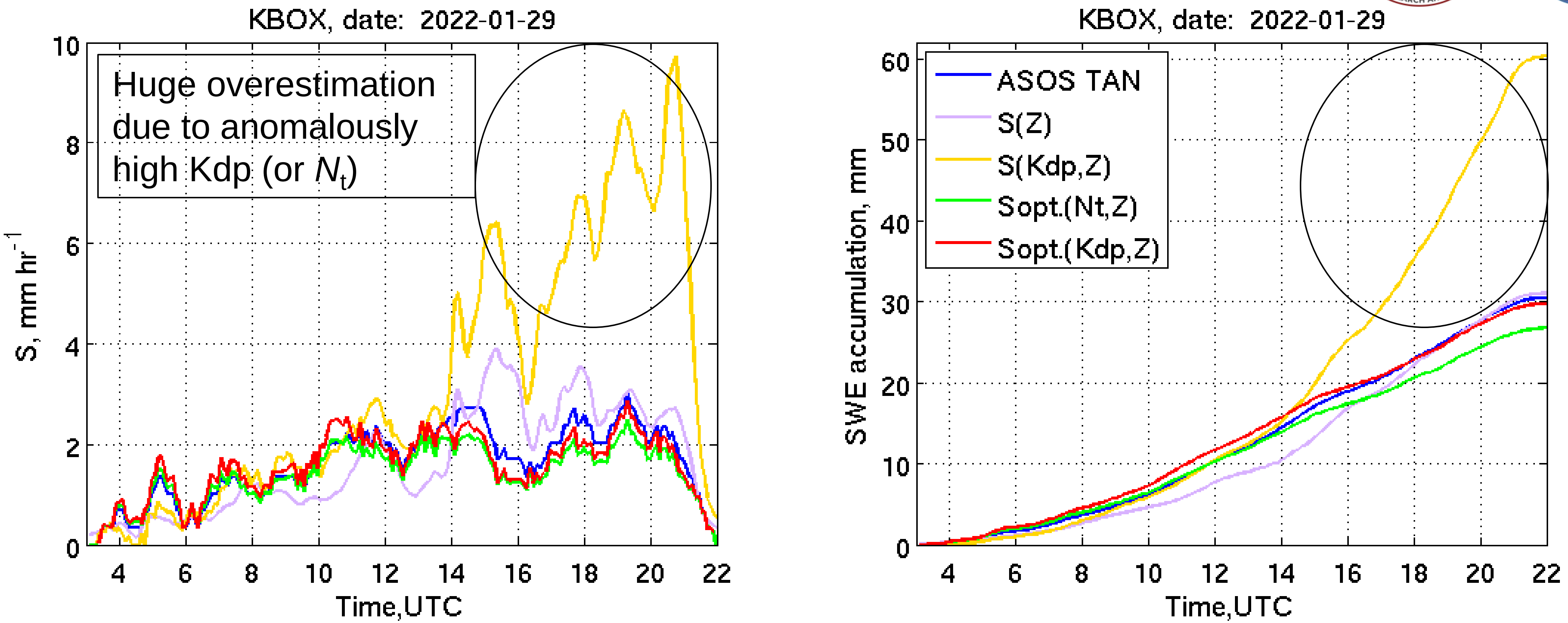
Evaluation of frim, FoFs, μ, and Nt effects on radar polarimetric snow rate (S, mm hr^{-1}) relations





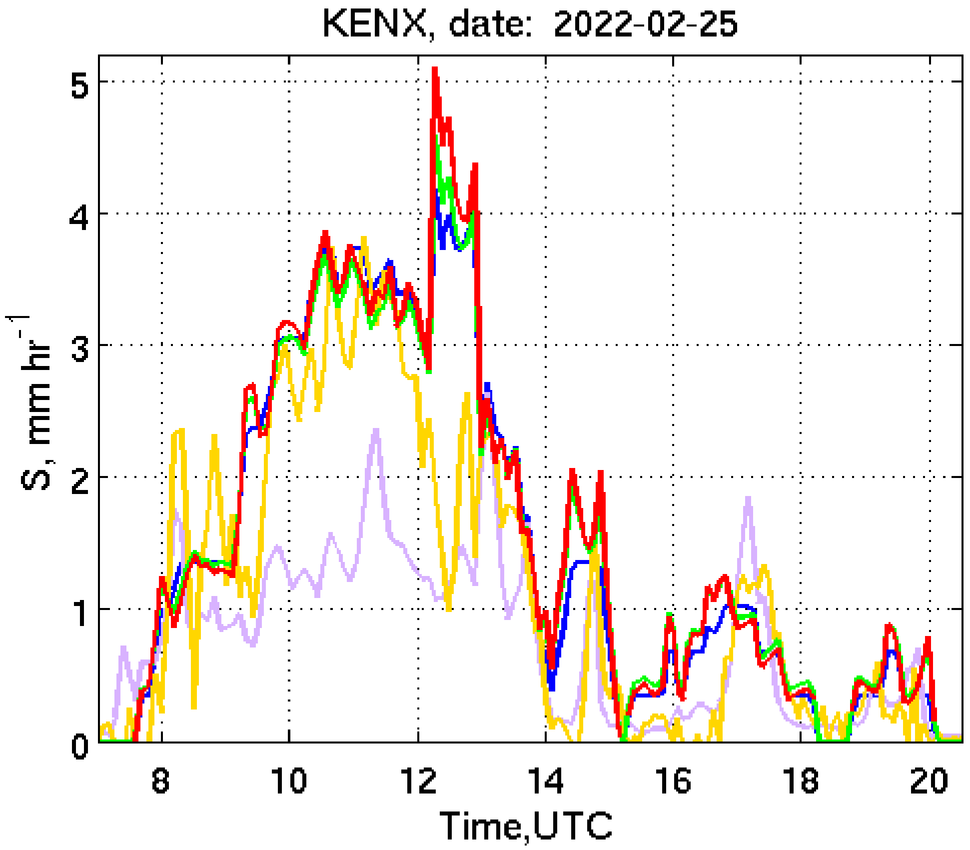
Addition of dynamically estimated N_t, f_{rim}, F_o, and F_s introduces large improvement.

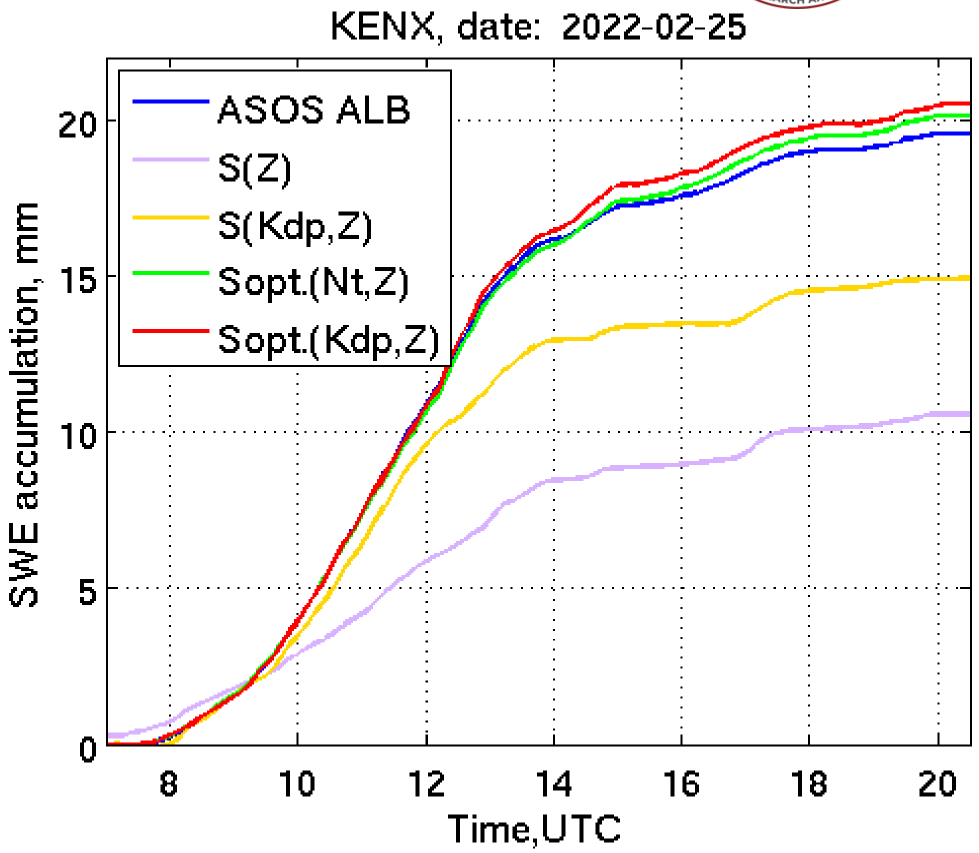
Evaluation of frim, FoFs, μ, and Nt effects on radar polarimetric snow rate (S, mm hr^{-1}) relations



Addition of dynamically estimated N_t, f_{rim}, F_o, and F_s introduces large improvement. Adjusting μ from 0 to -1 in Sopt.(Kdp, Z) provides even better results for this event.

Evaluation of frim, FoFs, μ, and Nt effects on radar polarimetric snow rate (S, mm hr^{-1}) relations





Addition of dynamically estimated N_t, f_{rim}, F_o, and F_s introduces large improvement.

Moving forward

3 paths

- Projection of polarimetric S estimates from DGL (-20ºC to -10ºC), where we have more reliable radar measurements of Kdp and estimates of N_t to the ground, using particle trajectories
- Using ASOS estimates of f_{rim}, F_oF_s, and N_t from S and extinction to learn how to optimally adjust the multipliers of proposed relations, and expand information spatially
- To use optimal S(Z) relation according to polarimetric classification (physically-based) instead of current regional dependence

References

Bukovčić, P., A. Ryzhkov, D. Zrnić, and G. Zhang, 2018: Polarimetric Radar Relations for Quantification of Snow Based on Disdrometer Data. *J. Appl. Meteor. Climatol*., **57**, 103–120, https://doi.org/10.1175/JAMC-D-17-0090.1

Bukovčić, P., A. Ryzhkov, and D. Zrnić, 2020: Polarimetric relations for snow estimation – radar verification. *J. Appl. Meteor. Climatol*., **59**, 991–1009, https://doi.org/10.1175/JAMC-D-19-0140.1