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Supporting Information for

Effect of snow salinity on CryoSat-2 Arctic first-year sea ice freeboard measurements

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Introduction

Figure S1 illustrates field campaign locations (red stars) on undeformed and deformed first-year sea ice (FYI) in the Canadian Arctic. Areas in green indicate monthly CryoSat-2 first-year sea ice (FYI) freeboard retrievals for March 2016, with FYI areas classified following *Hendricks et al.* [2016].

Figure S2 illustrates the mean and one standard deviation of (a) snow density (ρ_S), (b) snow temperature (T_S) and (c) snow salinity (S_S) as a function of snow thickness, for 16 cm snow covers on FYI. The snow/sea ice interface is located at 0 cm on the y-axis.

Figure S3 illustrates relative error (E_R) (%) estimates for original CS-2 FYI thickness $T_{FYI(ORIG)}$ (TFMRA50%), against $T_{FYI}(\Delta_{S(+1SE)})$ at $\Delta_{S(+1SE)}$, for CryoSat-2 derived Arctic first-year sea ice thickness for March 2016.

Flowchart F1 illustrates the workflow for parameterizing the main scattering horizon (S_H) and snow thickness correction factor (Δ_S). Table T1 represents the list of notations used in this study.

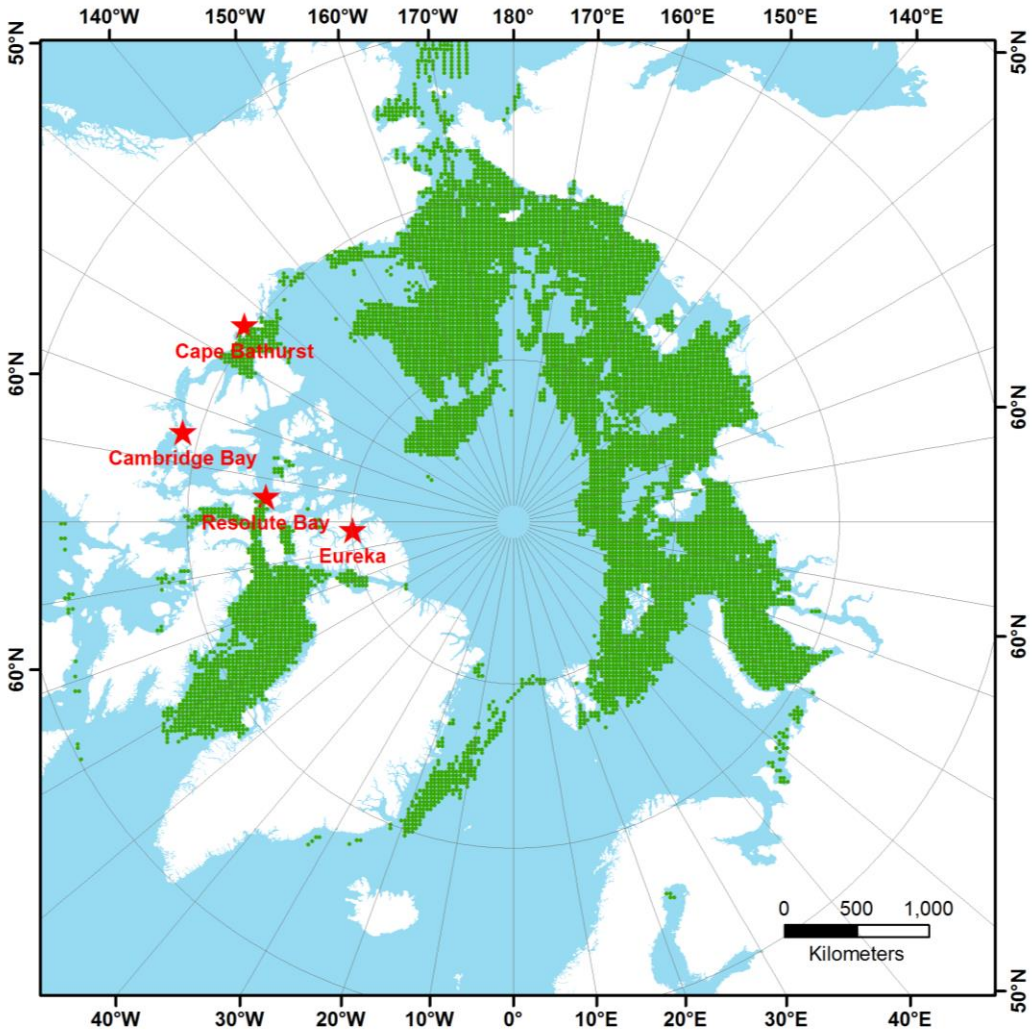


Figure S1: Field campaign locations (red stars) on undeformed and deformed first-year sea ice (FYI) in the Canadian Arctic. Areas in green indicate monthly CryoSat-2 first-year sea ice (FYI) freeboard retrievals for March 2016, with FYI areas classified following *Eastwood* [2012].

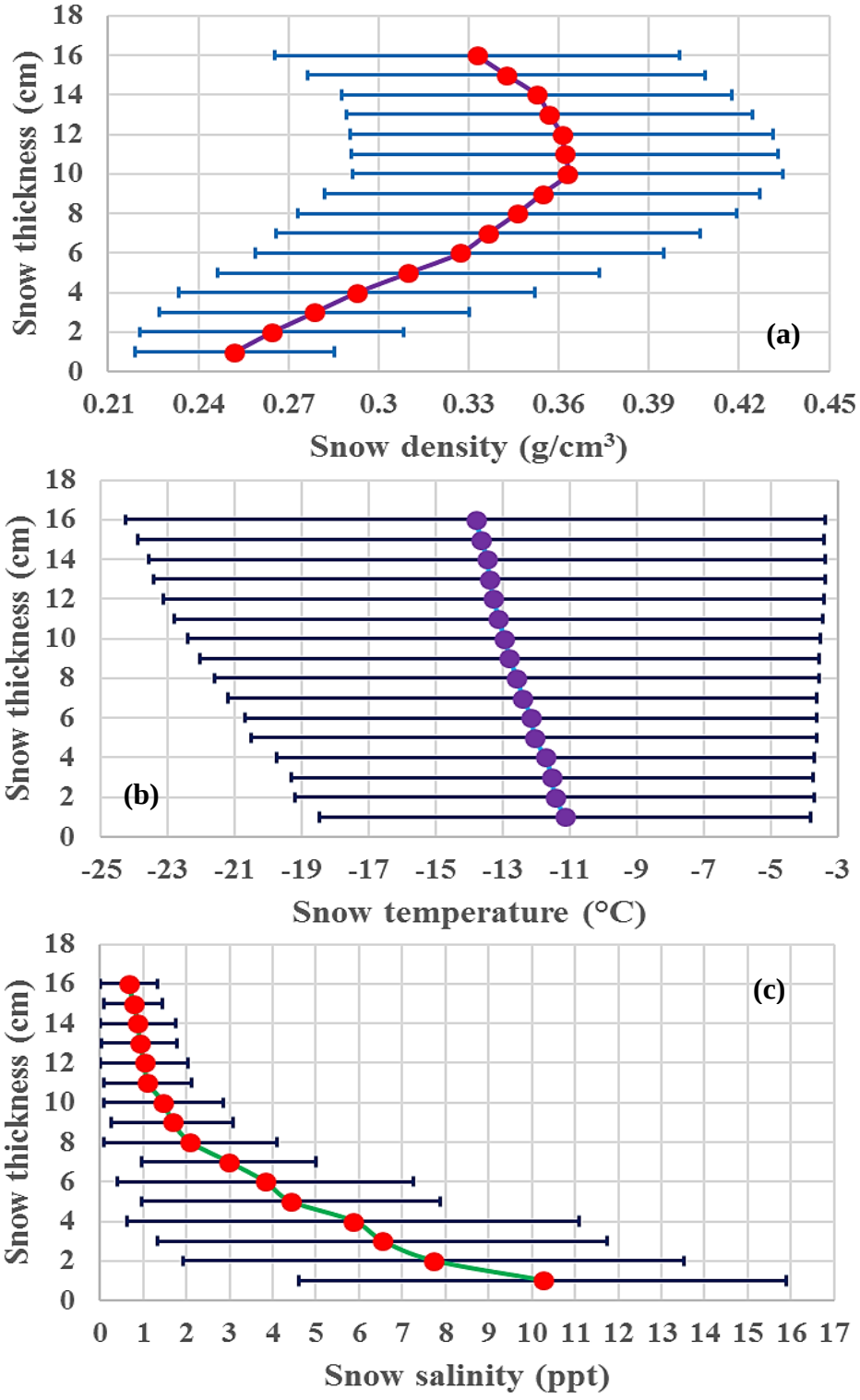
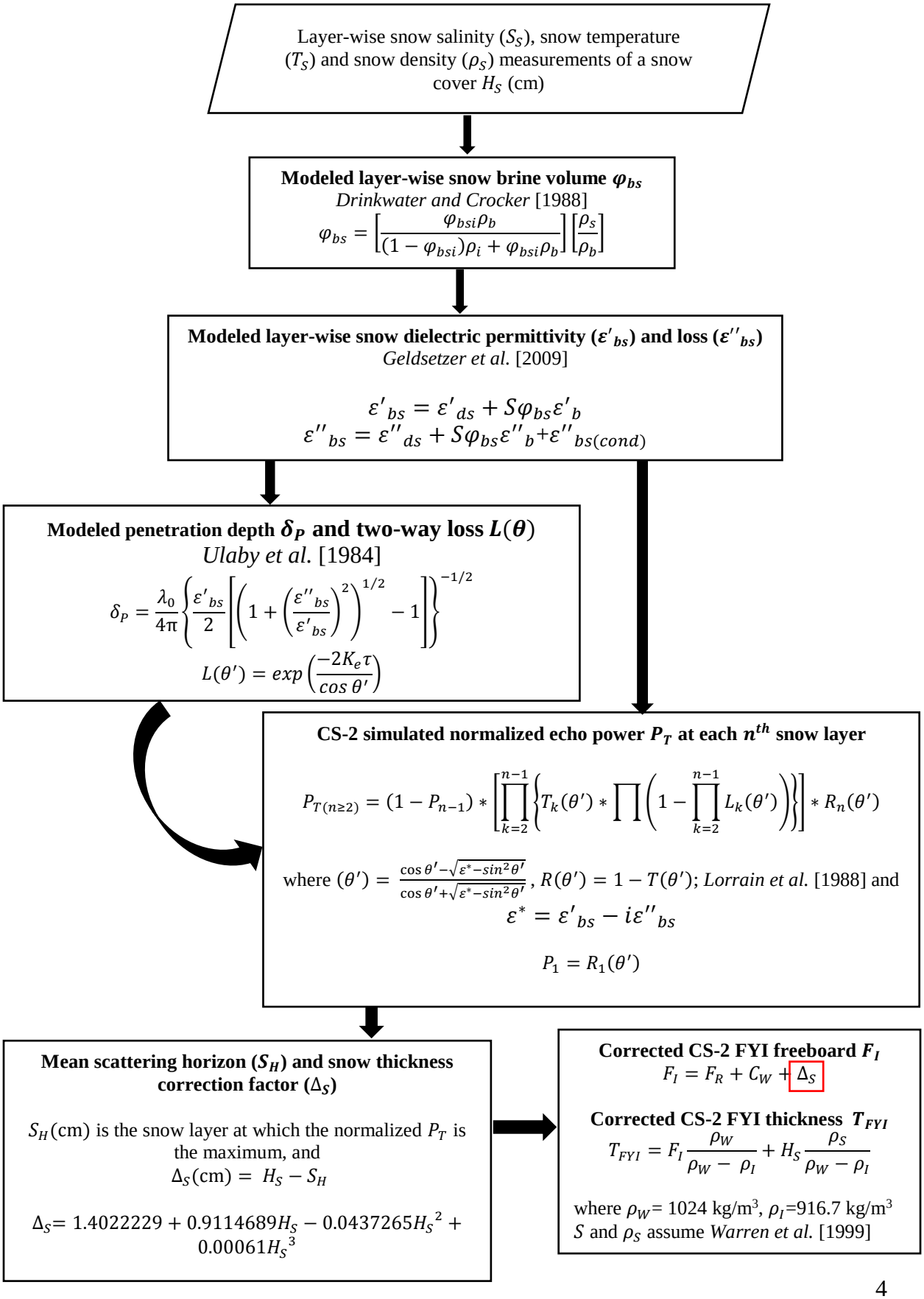


Figure S2 illustrates the mean and one standard deviation of (a) snow density (ρ_S), (b) snow temperature (T_S) and (c) snow salinity (S_S) as a function of snow thickness for 16 cm snow covers on FYI. The snow/sea ice interface is located at 0 cm on the y-axis.


Layer-wise snow salinity (S_S), snow temperature (T_S) and snow density (ρ_S) measurements of a snow cover H_S (cm)
Modeled layer-wise snow brine volume φ_{bs}
Drinkwater and Crocker [1988]
$\varphi_{bs} = \left[\frac{\varphi_{bsi}\rho_b}{(1-\varphi_{bsi})\rho_i + \varphi_{bsi}\rho_b}\right]\left[\frac{\rho_s}{\rho_b}\right]$
Modeled layer-wise snow dielectric permittivity (ε'_{bs}) and loss (ε''_{bs})
Geldsetzer et al. [2009]
$\varepsilon'_{bs} = \varepsilon'_{ds} + S\varphi_{bs}\varepsilon'_b$
$\varepsilon''_{bs} = \varepsilon''_{ds} + S\varphi_{bs}\varepsilon''_b + \varepsilon''_{bs(cond)}$
Modeled penetration depth δ_P and two-way loss $L(\theta)$
Ulaby et al. [1984]
$\delta_P = \frac{\lambda_0}{4\pi}\left\{\frac{\varepsilon'_{bs}}{2}\left[\left(1+\left(\frac{\varepsilon''_{bs}}{\varepsilon'_{bs}}\right)^2\right)^{1/2} - 1\right]\right\}^{-1/2}$
$L(\theta') = exp\left(\frac{-2K_e\tau}{cos\,\theta'}\right)$
CS-2 simulated normalized echo power P_T at each n^{th} snow layer
$P_{T(n\geq 2)} = (1 - P_{n-1}) * \left[\prod_{k=2}^{n-1}\left\{T_k(\theta') * \prod\left(1 - \prod_{k=2}^{n-1} L_k(\theta')\right)\right\}\right] * R_n(\theta')$
where $(\theta') = \frac{\cos\theta' - \sqrt{\varepsilon^* - sin^2\theta'}}{\cos\theta' + \sqrt{\varepsilon^* - sin^2\theta'}}$, $R(\theta') = 1 - T(\theta')$; Lorrain et al. [1988] and
$\varepsilon^* = \varepsilon'_{bs} - i\varepsilon''_{bs}$
$P_1 = R_1(\theta')$
Mean scattering horizon (S_H) and snow thickness correction factor (Δ_S)
S_H(cm) is the snow layer at which the normalized P_T is the maximum, and
Δ_S(cm) = $H_S - S_H$
$\Delta_S = 1.4022229 + 0.9114689H_S - 0.0437265H_S^2 + 0.00061H_S^3$
Corrected CS-2 FYI freeboard F_I
$F_I = F_R + C_W + \Delta_S$
Corrected CS-2 FYI thickness T_{FYI}
$T_{FYI} = F_I\frac{\rho_W}{\rho_W - \rho_I} + H_S\frac{\rho_S}{\rho_W - \rho_I}$
where ρ_W= 1024 kg/m^3, ρ_I=916.7 kg/m^3
S and ρ_S assume Warren et al. [1999]

Flowchart F1 illustrates the workflow for parameterizing the main scattering horizon (S_H) and snow thickness correction factor (Δ_S). Table T1 represents the list of symbols used in this study.

Table T1: List of symbols used in this study

Symbol (Unit)	**Meaning (Assumed value, Reference)**
T_{FYI} (m)	First-year sea ice thickness
F_I (m) F_R (m)	CryoSat-2 estimated First-year sea ice freeboard Radar freeboard (Range measurement from CryoSat-2)
ρ_W (kg/m^3) ρ_I (kg/m^3) ρ_S (kg/m^3)	Sea water density (1024 kg/m^3) First-year sea ice density (916.7 kg/m^3) Snow density (following *Warren et al.* [1999])
S_S (ppt) T_S (°C)	Snow Salinity Snow temperature
H_S (cm)	Statistically representative *in-situ* measured snow thickness
φ_{bs} $\varphi_{bs(+1\sigma)}$ $\varphi_{bs(-1\sigma)}$	Snow brine volume fraction (Mean) (*Drinkwater and Crocker* [1988]) Snow brine volume fraction (+1 standard deviation) Snow brine volume fraction (-1 standard deviation)
S_H (cm) $S_{H(+1\sigma)}$ (cm) $S_{H(-1\sigma)}$ (cm)	Main scattering horizon (Mean) Main scattering horizon (+1 standard deviation) Main scattering horizon (-1 standard deviation)
Δ_S (cm) $\Delta_{S(+1SE)}$ (cm) $\Delta_{S(-1SE)}$ (cm)	Snow thickness correction factor (Mean) Snow thickness correction factor (+1 standard error) Snow thickness correction factor (-1 standard error)
δ_P (cm)	Maximum penetration depth
ε'_{bs} ε''_{bs}	Brine-wetted snow dielectric permittivity (*Geldsetzer et al.* [2009]) Brine-wetted snow dielectric loss (*Geldsetzer et al.* [2009])
$L(\theta')$	Two-way loss factor (*Ulaby et al.* [1984])
P_T	CryoSat-2 simulated normalized echo power
$T(\theta')$ $R(\theta')$	Power transmission coefficient (*Lorrain et al.* [1988]) Power reflection coefficient (*Lorrain et al.* [1988])
C_P C_R C_W α	Penetration depth correction Bias due to roughness effects Correction for lower propagation speed through snow layers Correction due to choice of TFMRA retracker threshold
$T_{FYI(ORIG)}$ $T_{FYI}(\Delta_S)$ $T_{FYI}(\Delta_{S(-1SE)})$ $T_{FYI}(\Delta_{S(+1SE)})$	Original uncorrected first-year ice thickness (following *Ricker et al.* [2017]) Corrected first-year ice thickness at Δ_S Corrected first-year ice thickness at $\Delta_{S(-1SE)}$ Corrected first-year ice thickness at $\Delta_{S(+1SE)}$
E_R (%)	Relative error (Statistical uncertainty) (following *Ricker et al.* [2017])

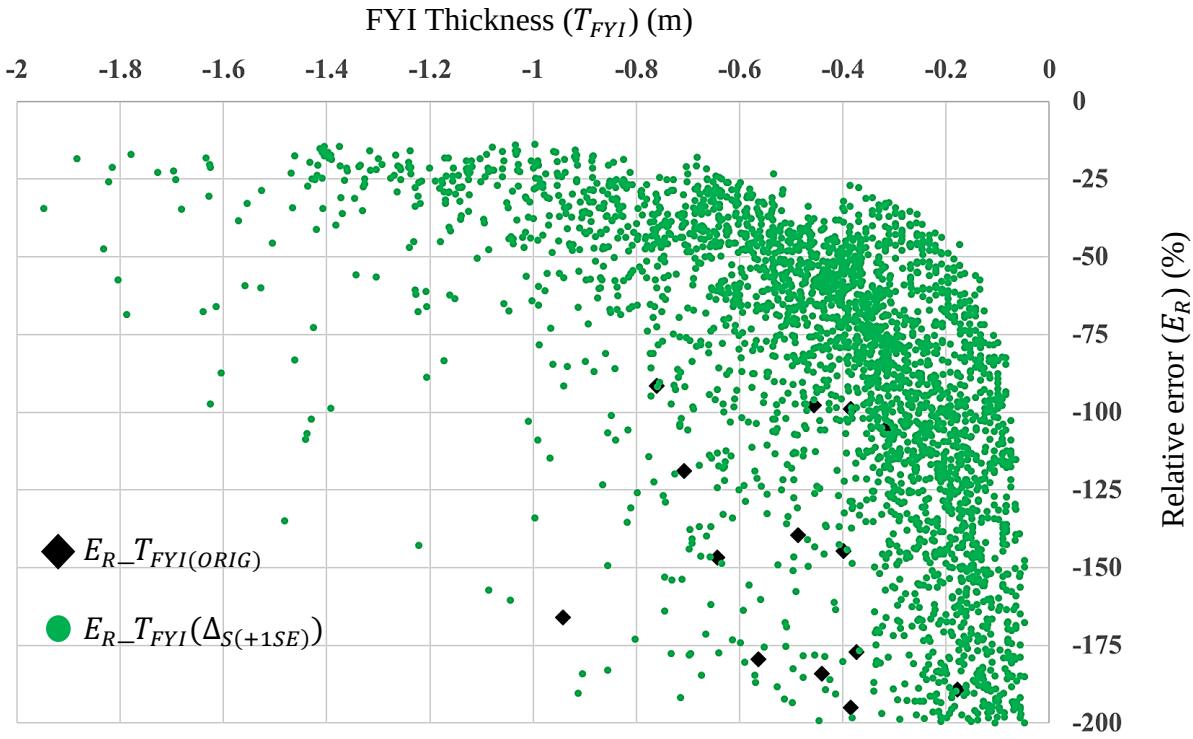


Figure S3: Relative error (E_R) (%) estimates for original CS-2 FYI thickness $T_{FYI(ORIG)}$ (TFMRA50%), against $T_{FYI}(\Delta_{S(+1SE)})$, for CryoSat-2 derived Arctic first-year sea ice thickness for March 2016.