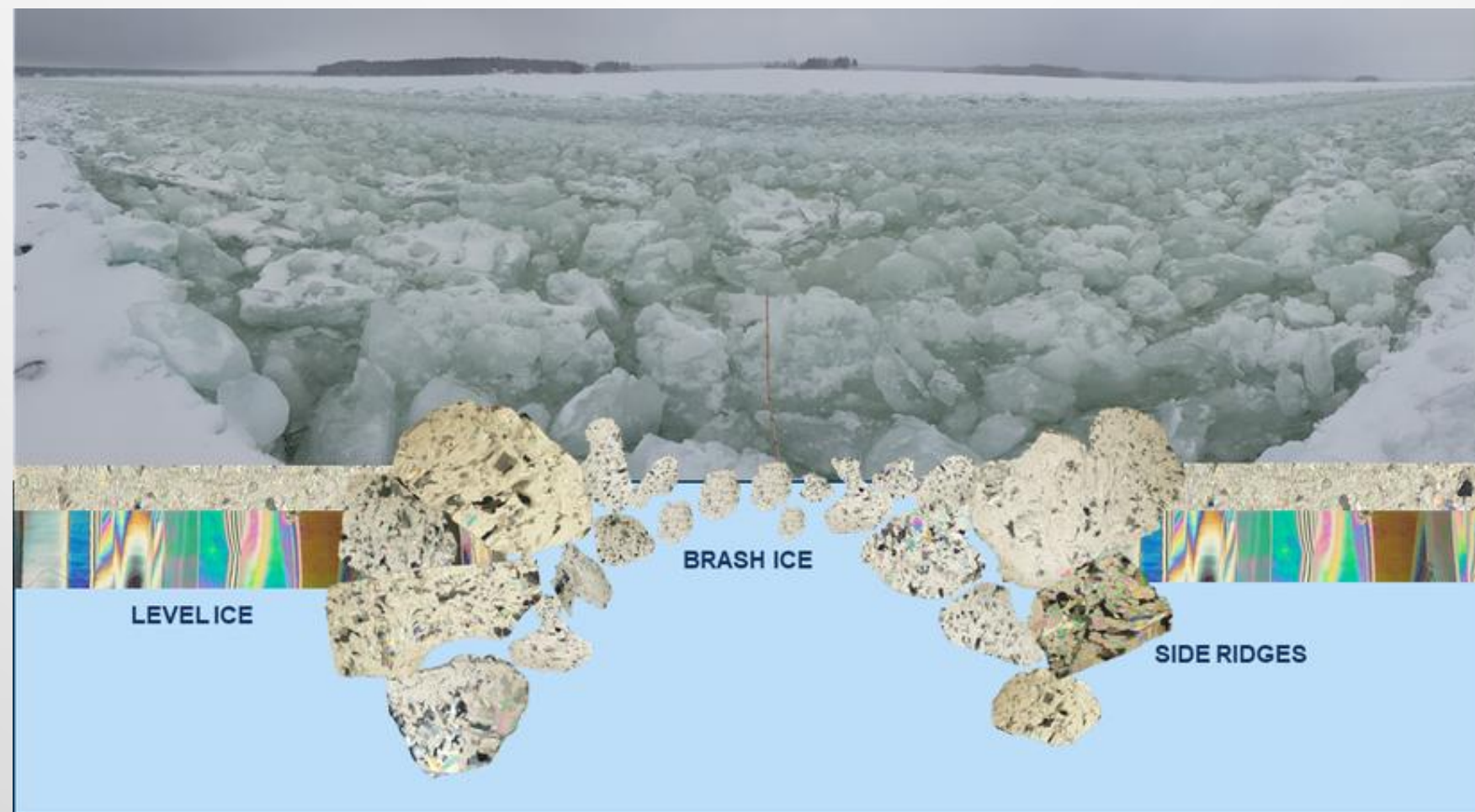


Brash Ice and Level Ice Growth, Effects of Snow

Vasiola Zhaka



C2B2 Ice conference 2026
Luleå, 2026-03-17



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Researcher
Uppsala University

PROJECT PORTFOLIO 1

- Potential Impacts of Wind Farms on Shipping in the Bay of Bothnia (**UU & CHALMERS, Lighthouse, Swedish Maritime Competence Centre, Trafikverket**) *2025*
- **AI-augmented ship traffic digital twin for optimal marine planning** and assisting winter navigation in the Northern Baltic (**CHALMERS, UU, RISE, Lighthouse, Swedish Maritime Competence Centre, Trafikverket**) *2026-27*

PROJECT PORTFOLIO 2

- Developing a system for **large-scale hydrogen refuelling** (**Lighthouse, Swedish Maritime Competence Centre, Trafikverket**) *2024-26*
- Sustainable and Resilient **Hydrogen Infrastructure: Intermediate Storage and Distribution for Maritime and Land Transport** (**Energimyndigheten**) *2026-30*
- **Compressed hydrogen in marine propulsion systems:** Temperature development and structural integrity of onboard components (**Trafikverket**) *2026-30*

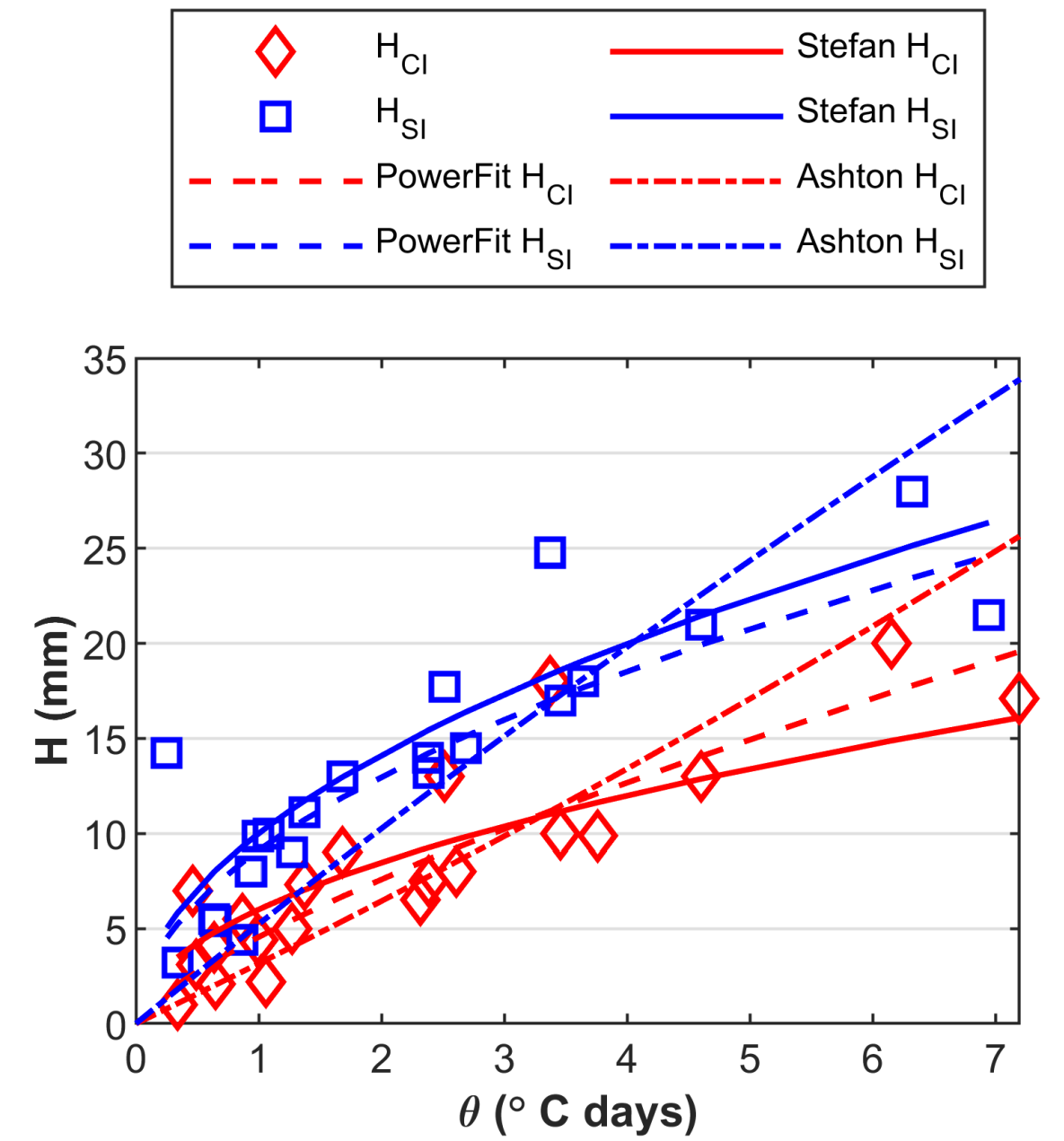
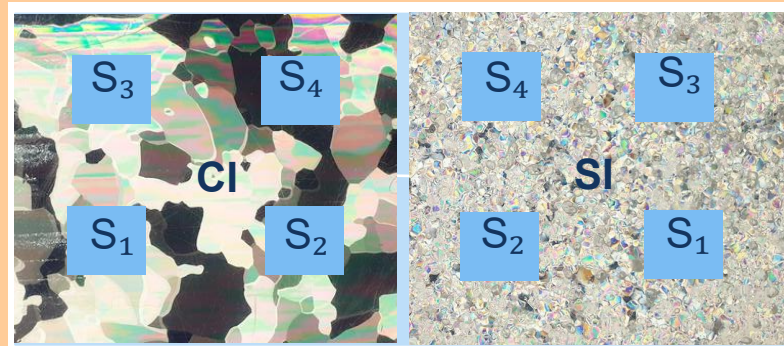
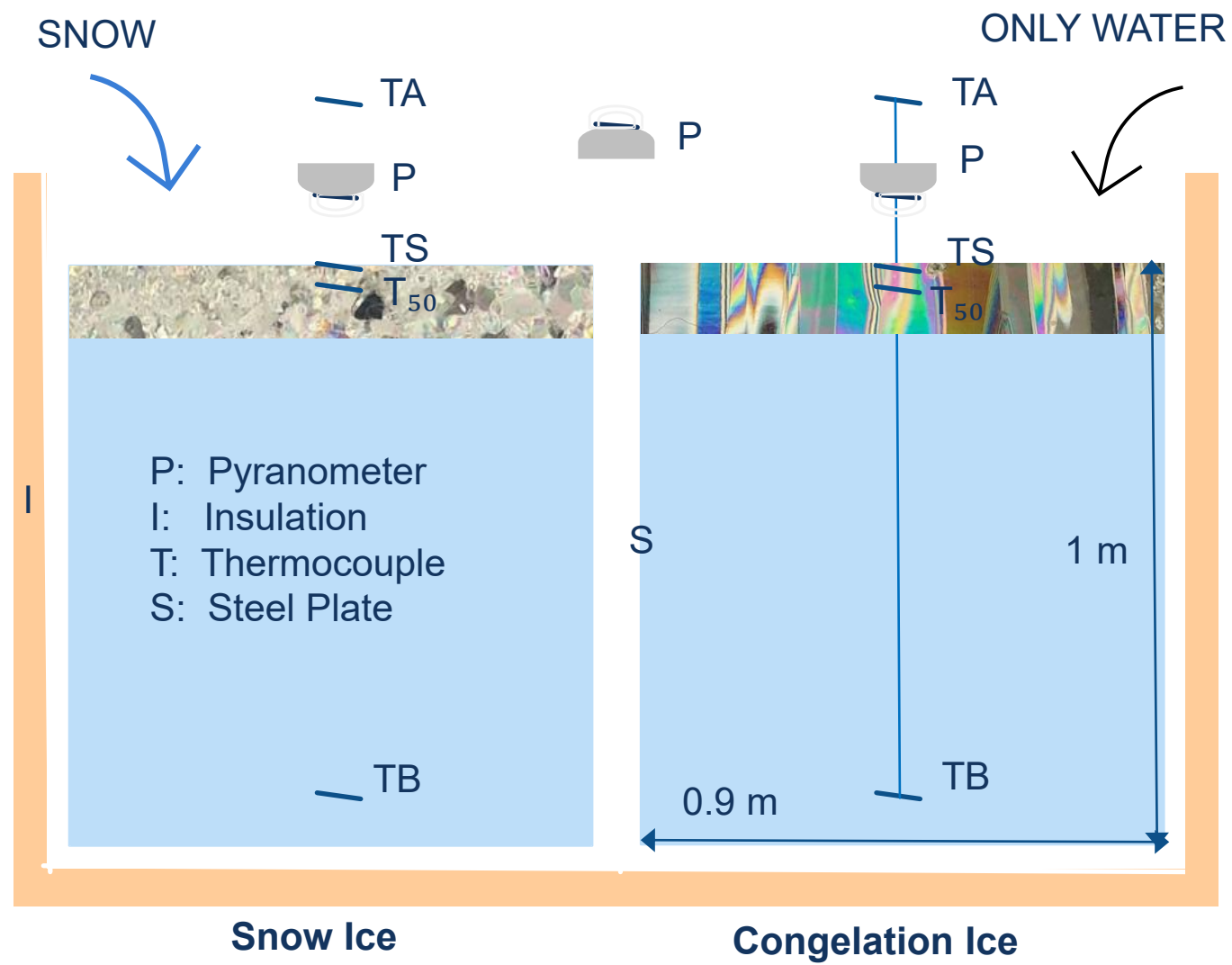


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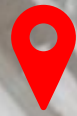
Brash Ice and Level Ice Growth, Effects of Snow

- LAB-SCALE
- FULL-SCALE

LAB-SCALE STUDY



FULL-SCALE STUDY

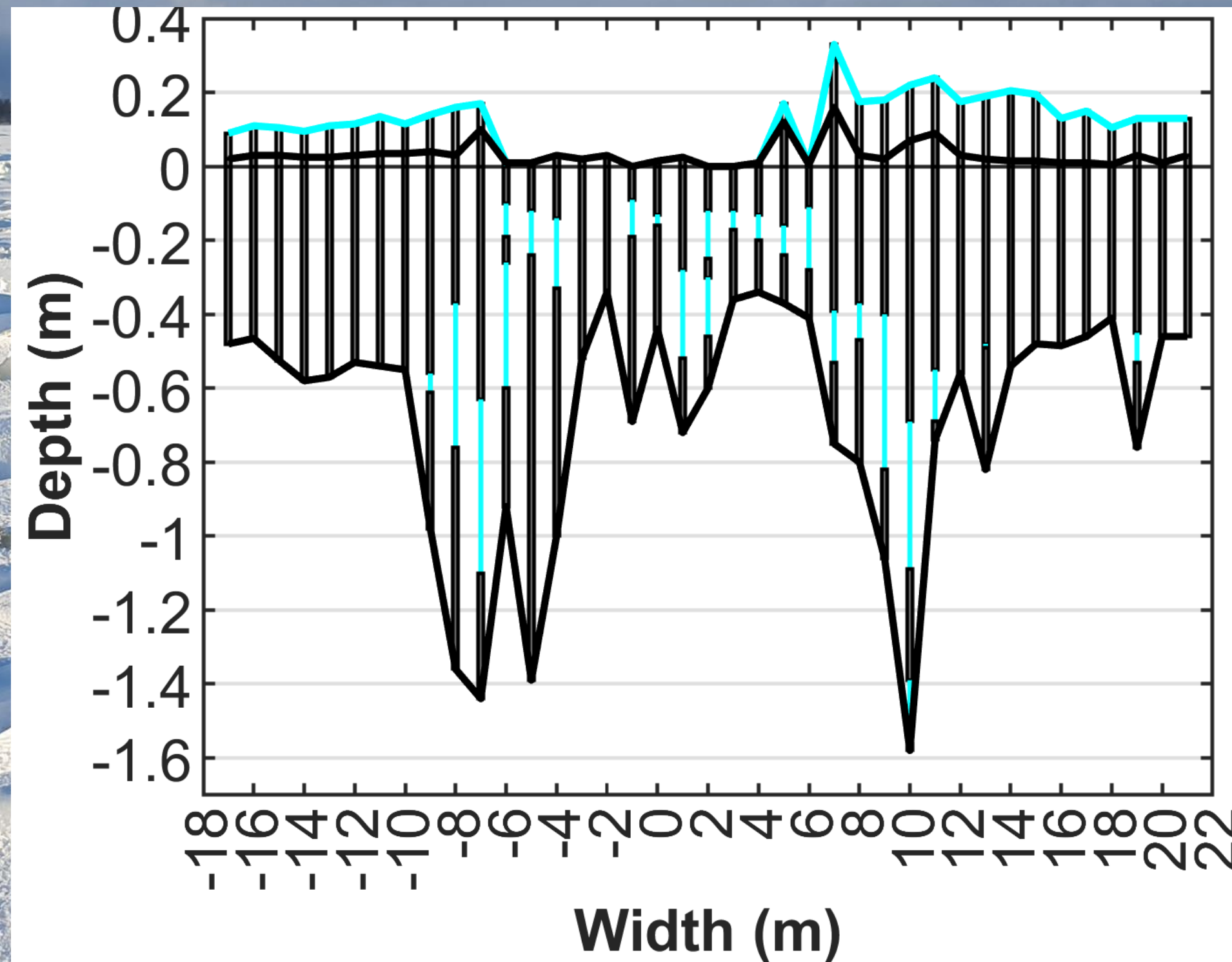


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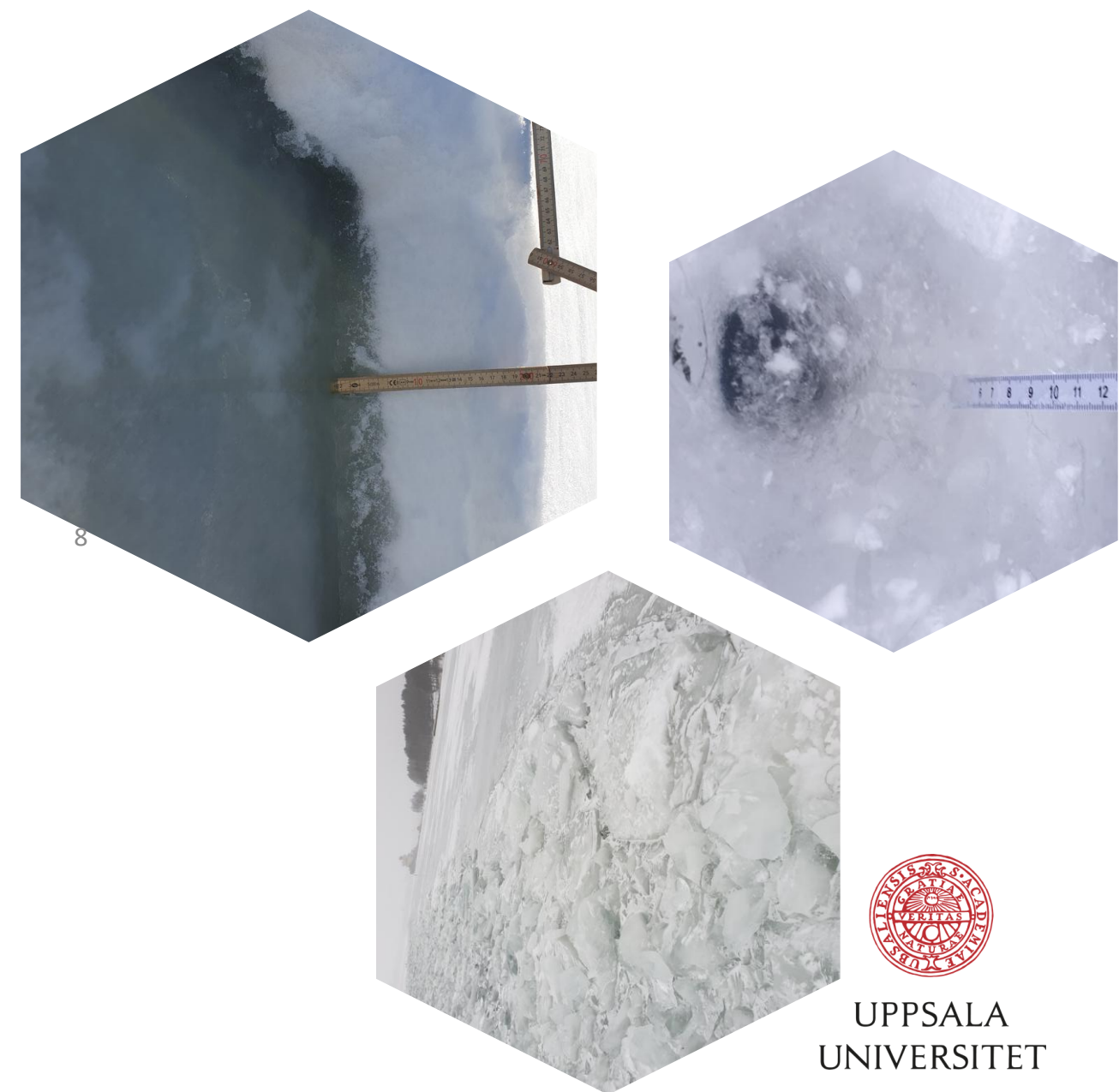
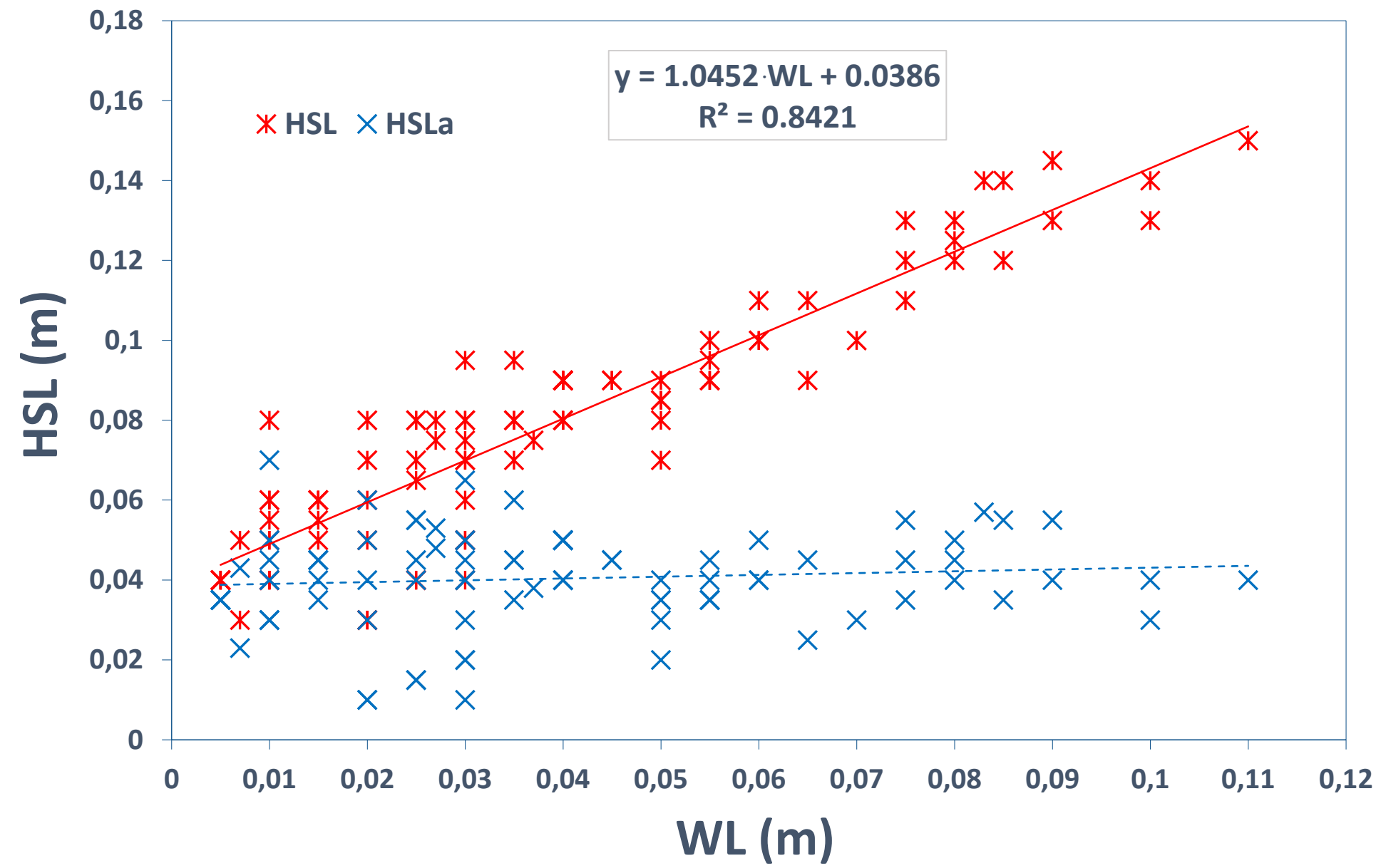
TEST AND MAIN CHANNELS



TEST AND MAIN CHANNELS



SNOW CAPILLARITY



FULL-SCALE STUDY LEVEL ICE GROWTH

APPROACH 1

$$\rho_s H_S - \rho_s H_{SL} = (\rho_w - \rho_i) H_I + (\rho_w - \rho_{sl}) H_{SL}$$

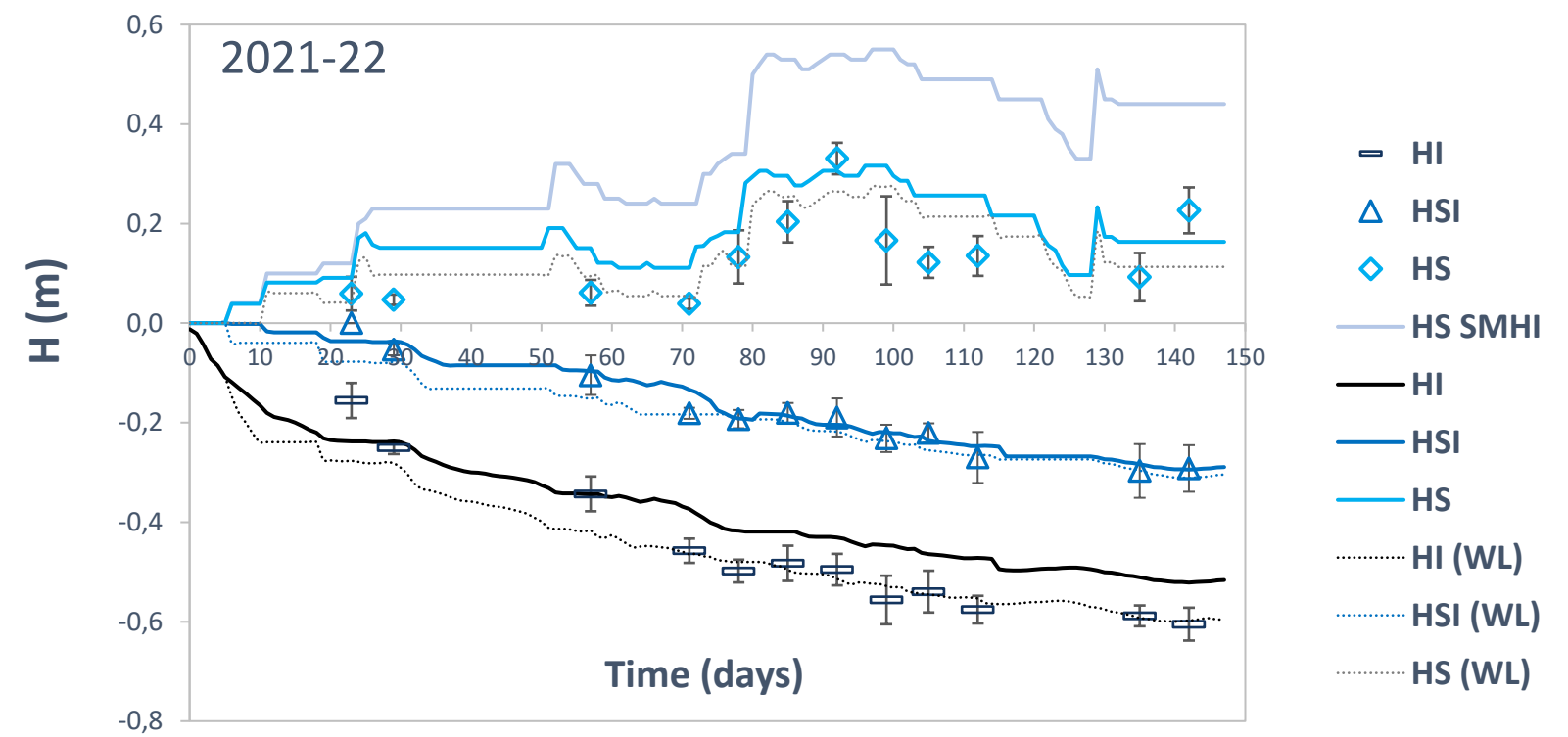
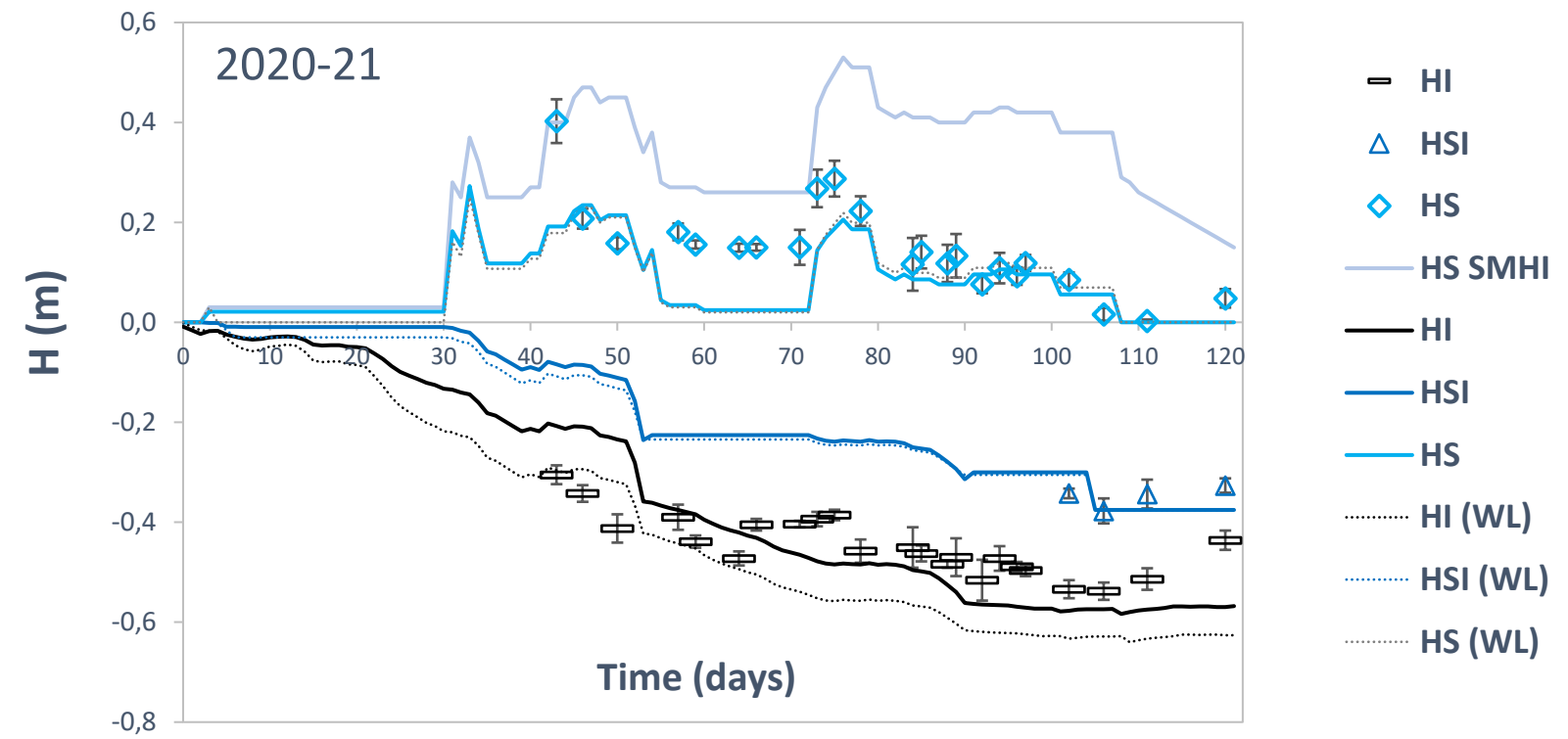
$$H_{SL} = \frac{H_S \rho_s - H_I (\rho_w - \rho_i)}{\rho_s + \rho_w - \rho_{sl}}$$

APPROACH 2

$$H_{FB} = H_I - \left[\frac{H_S \rho_s}{\rho_w} + \frac{H_I \rho_i}{\rho_w} \right]$$

$$WL = |H_{FB}|$$

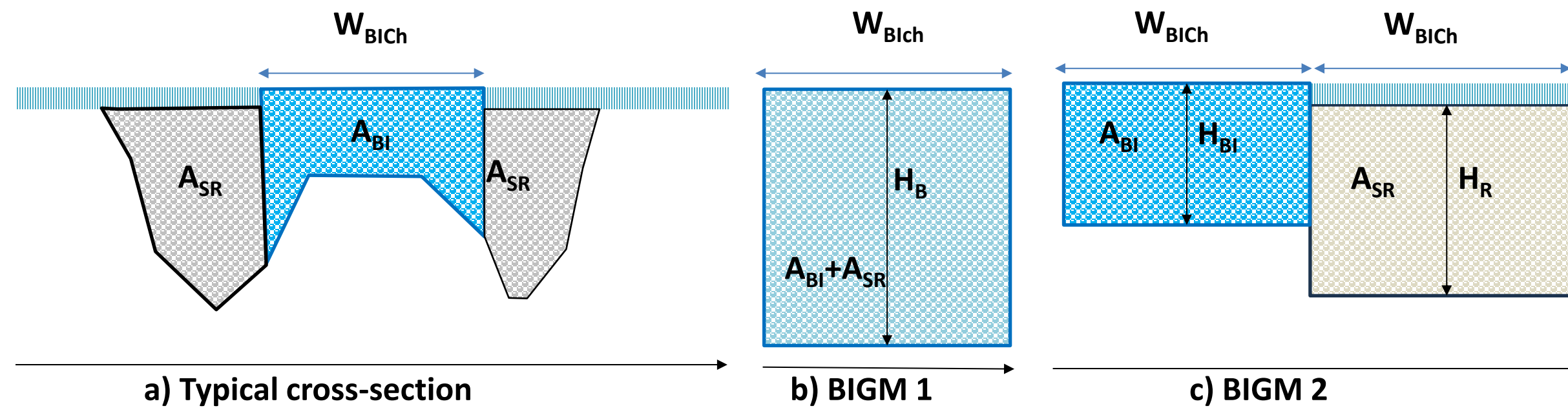
$$H_{SL} = 1.0452 WL + 0.0386 \text{ (m)}$$



BRASH ICE GROWTH MODEL



BRASH ICE GROWTH MODELS



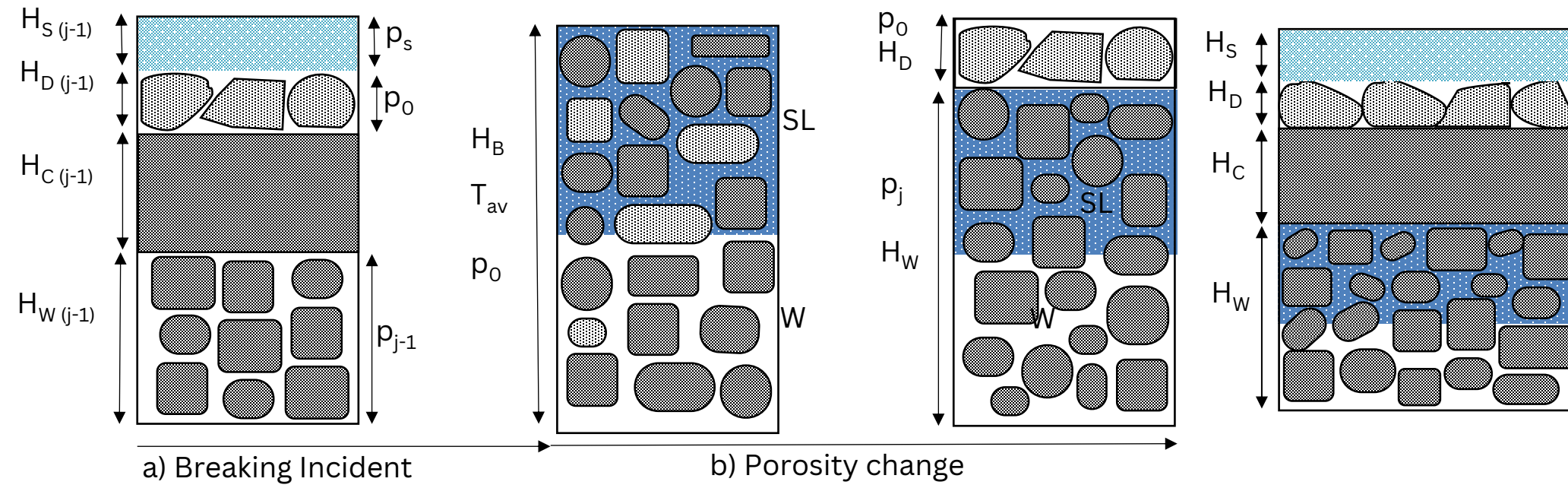
$$H_B = \frac{A_{SR} + A_{BI}}{W_{BICh}}$$

$$H_R = \frac{A_{SR}}{W_{BICh}}$$

$$H_{BI} = \frac{A_{BI}}{W_{BICh}}$$

$$\chi_c = \frac{H_R}{H_B}$$

BRASH ICE GROWTH MODELS



1. $h_{sa}(T_{SA} - T_A) = k_s \frac{(T_{DS} - T_{SA})}{H_S}$
2. $k_s \frac{(T_{DS} - T_{SA})}{H_S} = k_d \frac{(T_{SI} - T_{DS})}{H_D}$
3. $k_d \frac{(T_{SI} - T_{DS})}{H_D} = k_{bi} \frac{(T_F - T_{SI})}{H_C}$
4. $k_{bi} \frac{(T_F - T_{SI})}{H_C} = \rho_{bi} p_j v_w L_i \frac{dH_C}{dt}$

$$H_C = \sqrt{k_{bi}^2 h_e^2 - \frac{2k_i}{\rho_{bi} p_j v_w L_i} \theta - k_{bi} h_e}$$

$$p_j = p_0 - \frac{c_i \Delta T}{L_i} (1 - p_0)$$

$$p_j = v_w p_0 - \frac{c_i \Delta T}{L_i} (1 - p_0)$$

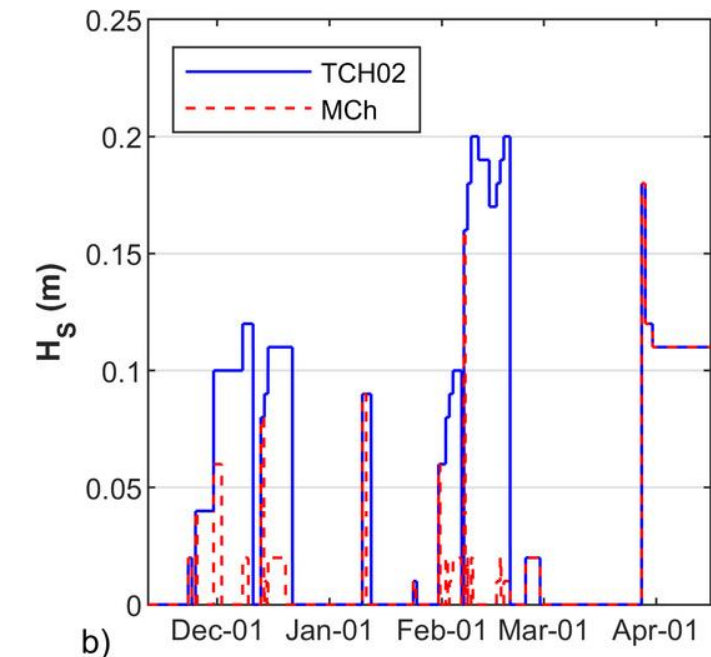
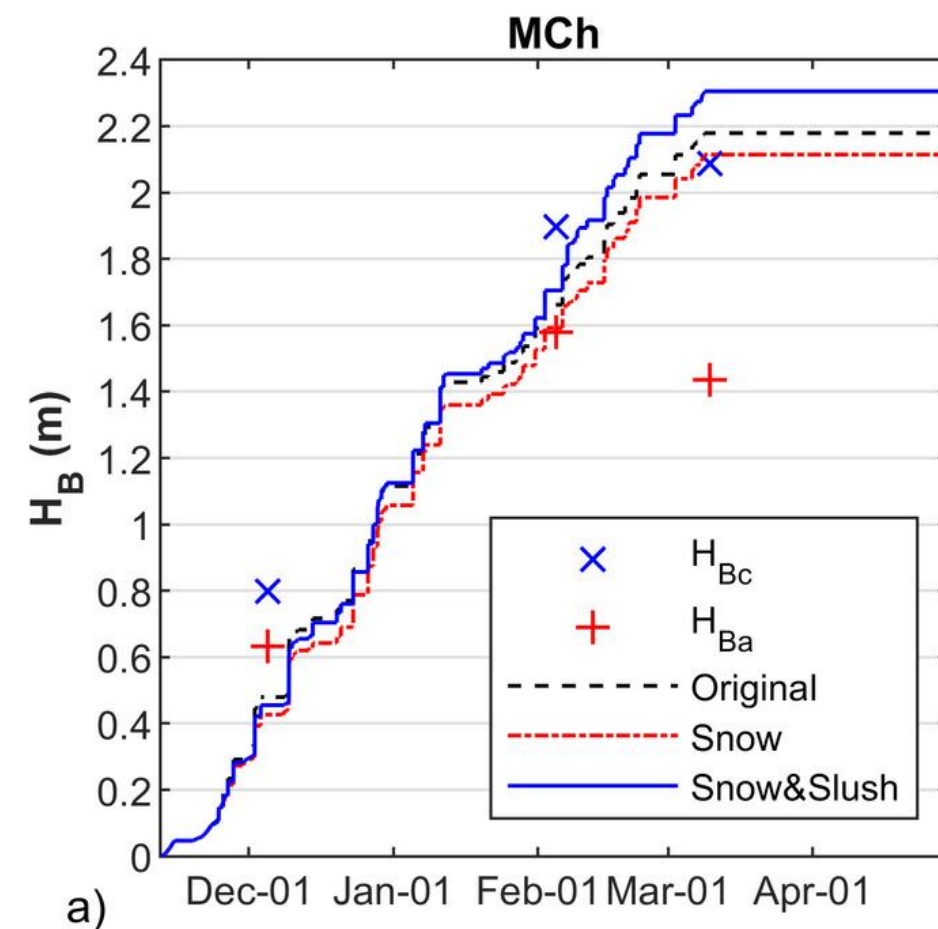
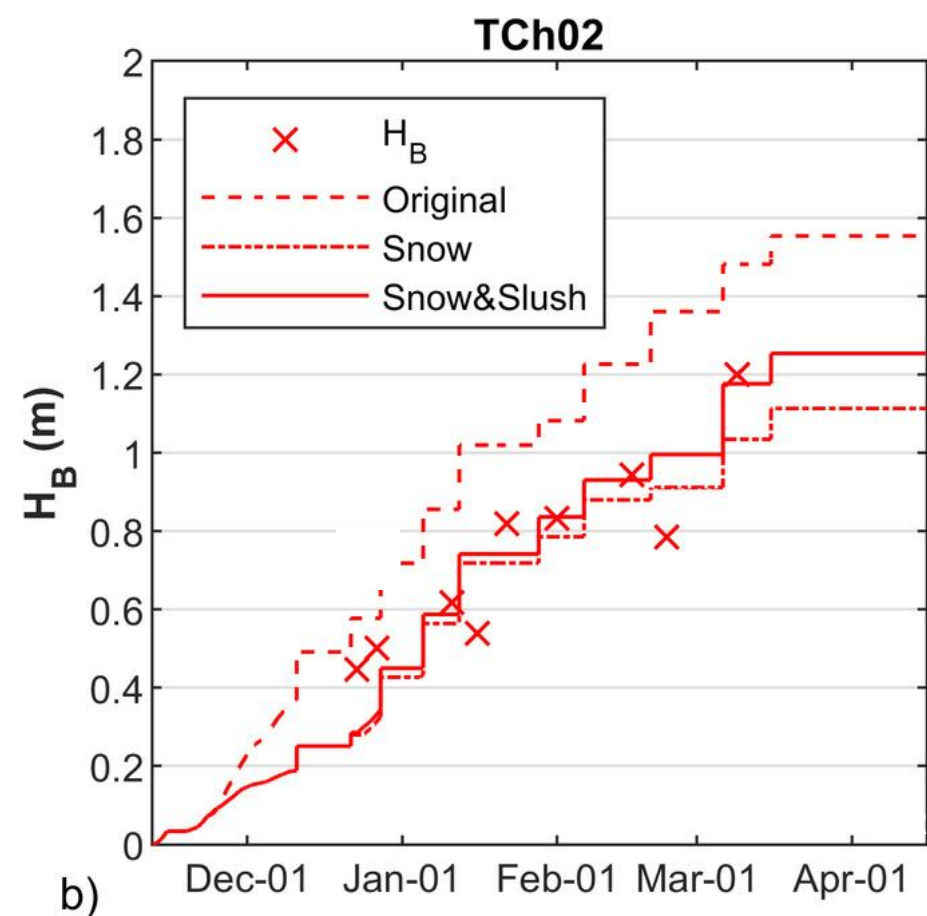
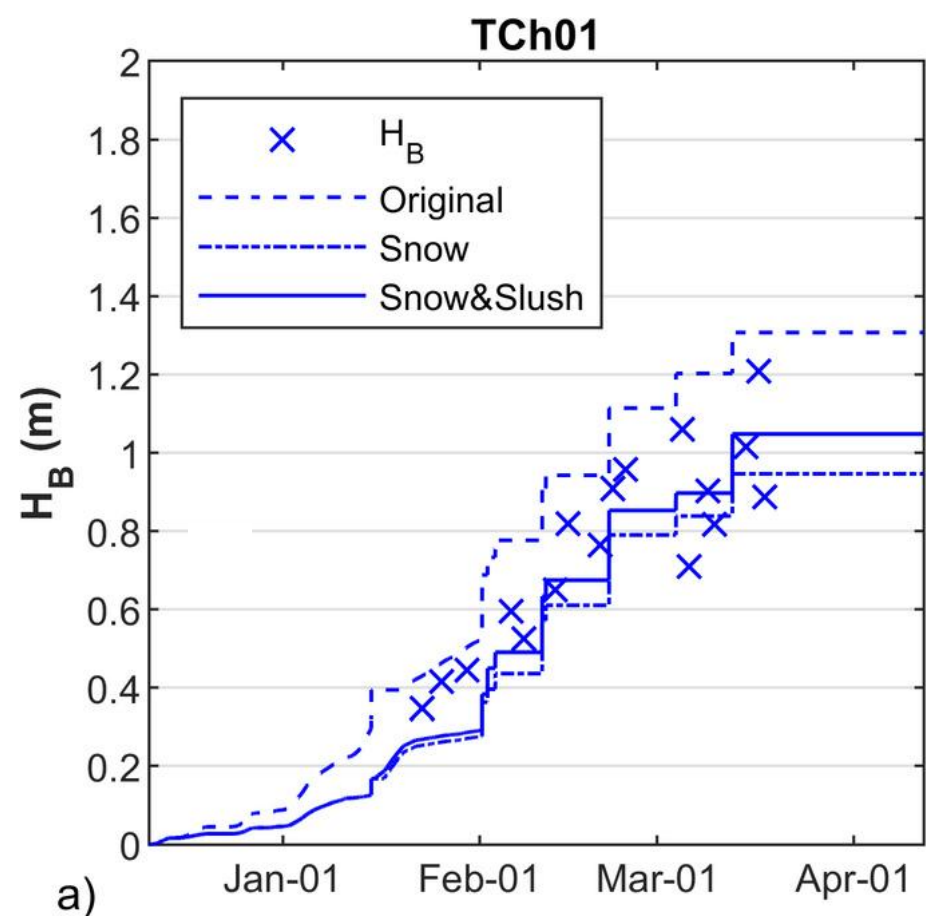
$$p_j = \frac{H_S(v_w - 1) + H_W(p_0 - \frac{c_i \Delta T(1 - p_0)}{L_i})}{H_W}$$

$$H_{Bj} = H_{D(j-1)} + \frac{H_{C(j-1)}}{(1 - p_0)} + H_{W(j-1)} \frac{(1 - p_{j-1})}{(1 - p_0)}$$

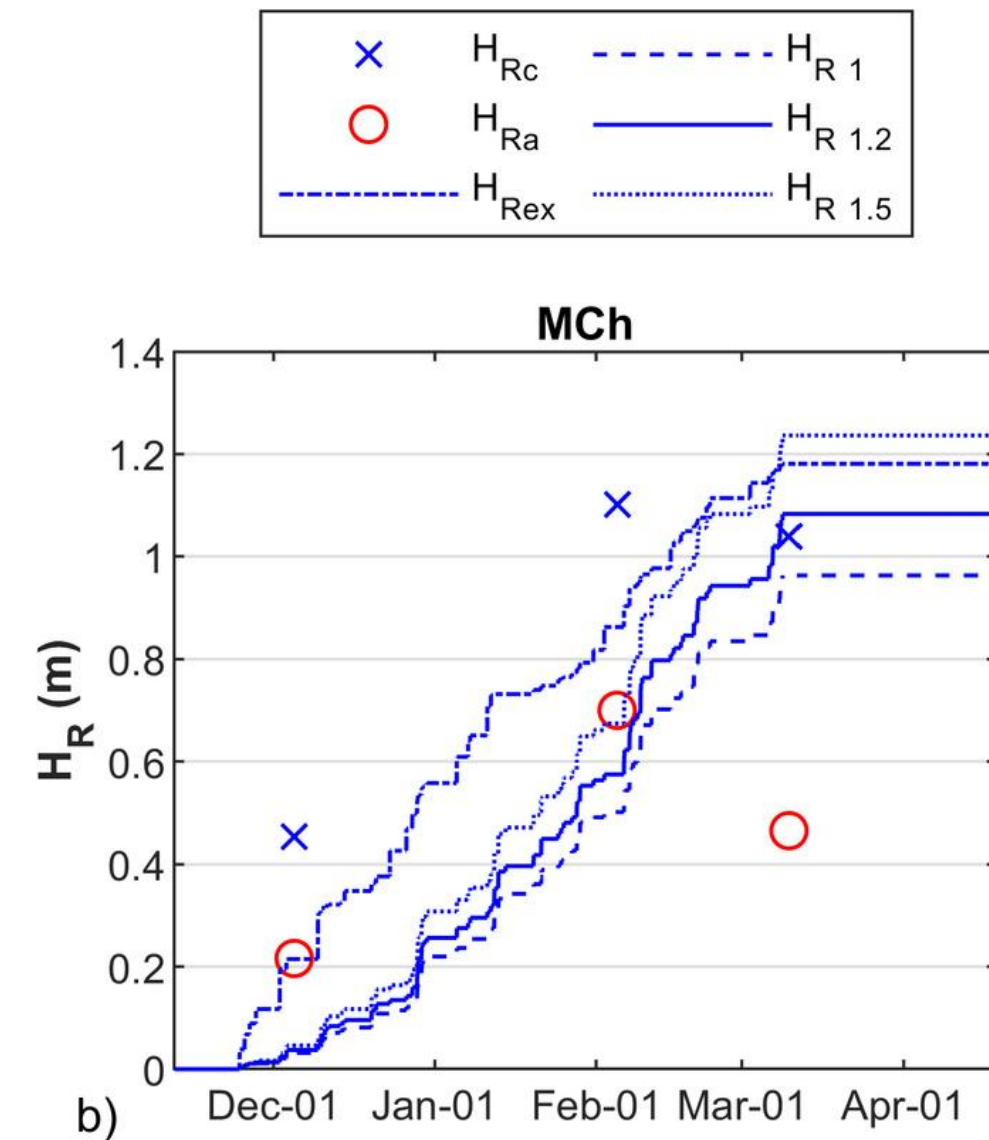
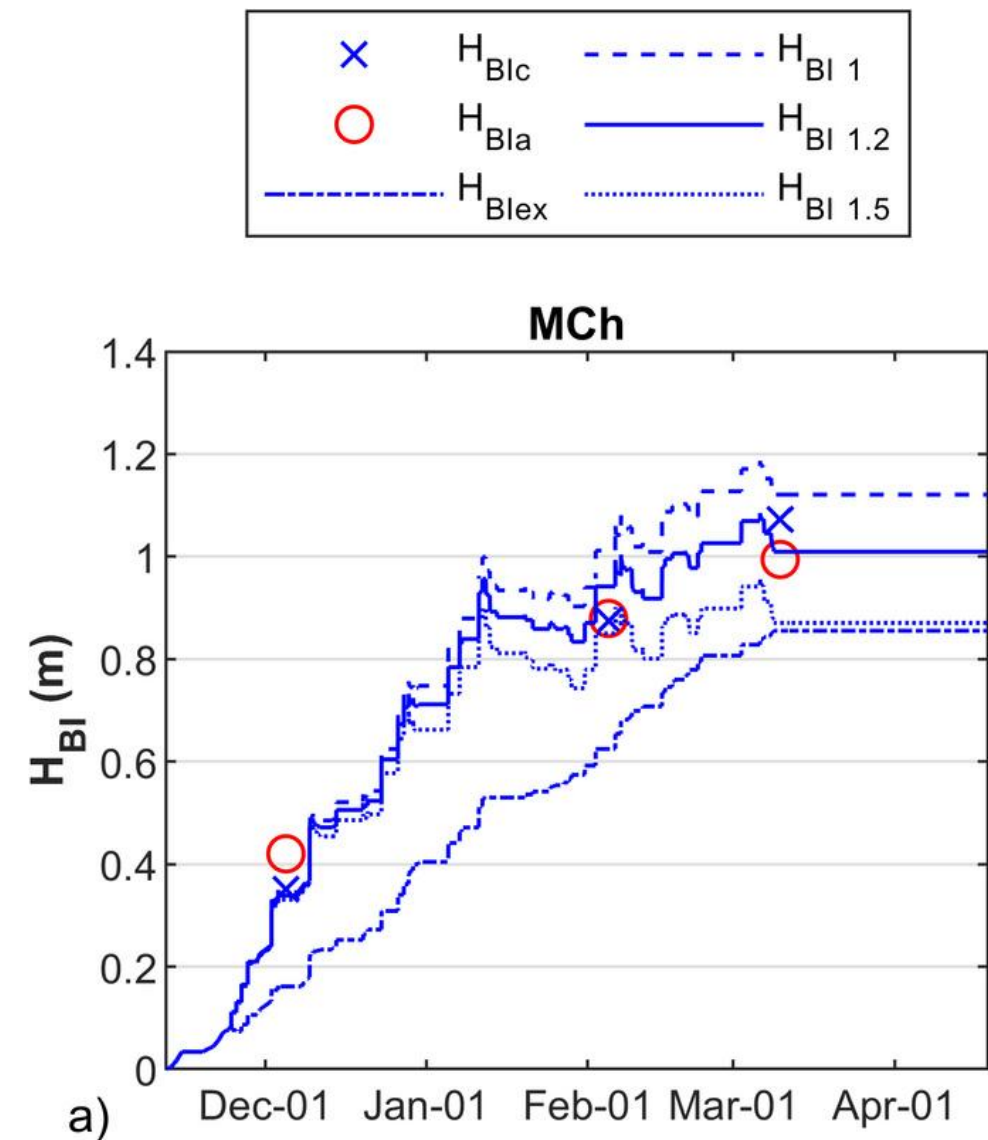
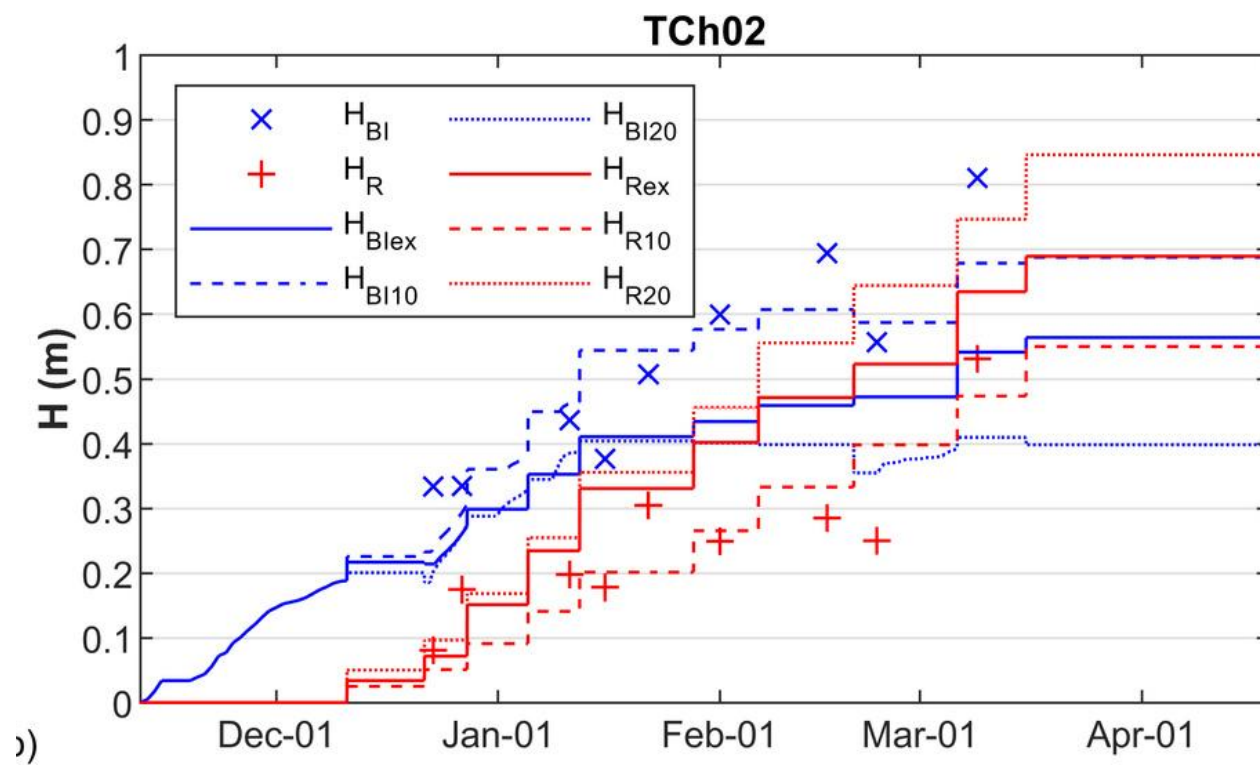
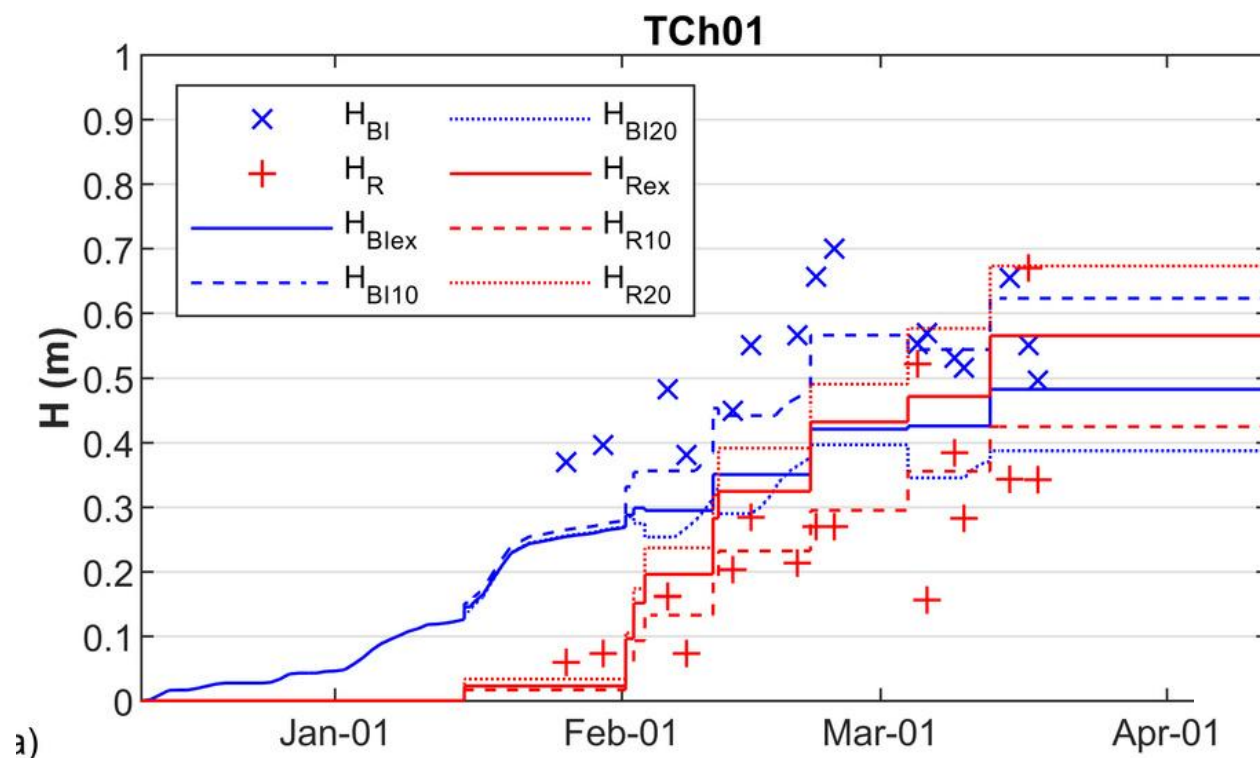
$$T_{av} = \frac{\left(\frac{T_{SA} + T_{DS}}{2}\right) (1 - p_s) H_{S(j-1)} + \left(\frac{T_{SI} + T_{DS}}{2}\right) (1 - p_0) H_{D(j-1)} + \left(\frac{T_F + T_{SI}}{2}\right) H_{C(j-1)} + T_F (1 - p_{j-1}) H_{W(j-1)}}{(1 - p_0) H_{D(j-1)} + H_{C(j-1)} + (1 - p_{j-1}) H_{W(j-1)}}$$



BRASH ICE GROWTH MODEL 1, VALIDATION



BRASH ICE GROWTH MODEL 2, VALIDATION



RESULTS

RQ1. How does the snow-slush-snow ice transformation from snow submerging in freshwater differ from the other mechanism resulting from flooded snow?

- *Only 30% of the initial slush thickness transformed into snow ice, while the remaining 70% melted or compressed. In the full-scale level ice study, 70% of the flooded snow transformed into snow ice and 30% melted or compressed.* In the tank tests, the melting of slush resulted from direct contact with the relatively warmer water. When slush formed due to flooding, it was insulated from direct contact with water from the ice layer.



RESULTS

RQ6. How does snow capillarity influence the snow-ice and level ice predictions?

Incorporating an empirical linear regression function that correlated the water level with the corresponding slush thickness in an analytical level ice growth model led to slightly higher ice thicknesses (1st year). Both methods, however, showed good agreement with the observed snow-ice thickness.



RESULTS

RQ7. How do the snow and the lateral expulsion influence the brash ice growth and accumulation in ship channels?

•In the TChs (9 &10 BE), the snow insulation effect was found to be more significant than the growth acceleration caused by the snow-slush-snow ice transformation. In the main channel (116 BE), the growth acceleration due to the snow-slush-snow ice transformation was more prominent than the snow insulation. In the test channels, Snow remained on the test channel for a longer period, while in the main channel remained briefly and mostly transformed into slush and then snow ice.

•The brash ice thickness remaining in the test channels was better predicted considering a loss coefficient of 10%, while for the main channel, this value was much lower, around 1.2%. This difference was primarily due to the width of the channel and the total number of ship passages.



THANK YOU!



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