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Monitoring bedfast ice in lakes of the Lena River Delta using TerraSAR-X backscatter and coherence time series

Introduction

25% of all lakes on Earth are found at northern high latitudes. **40%** of the land area is covered by lakes in some permafrost regions (Grosse et al., 2013). They were shown to be an important part of land-atmosphere exchange of greenhouse gases and energy fluxes (e.g. Zimov et al., 1997). Shallow lakes which freeze to their bed during the winter and deeper lakes which feature a water layer beneath the ice cover during the entire winter bear a contrasting impact on the underlying permafrost (Fig.1) and differ in terms of organic carbon and heat fluxes (Fig.2). Decrease in the fraction of bedfast ice in Barrow, Alaska was reported by Surdu et al., 2014 and was connected to the overall decrease of ice thickness due to changes in the regional climate (Fig.3).

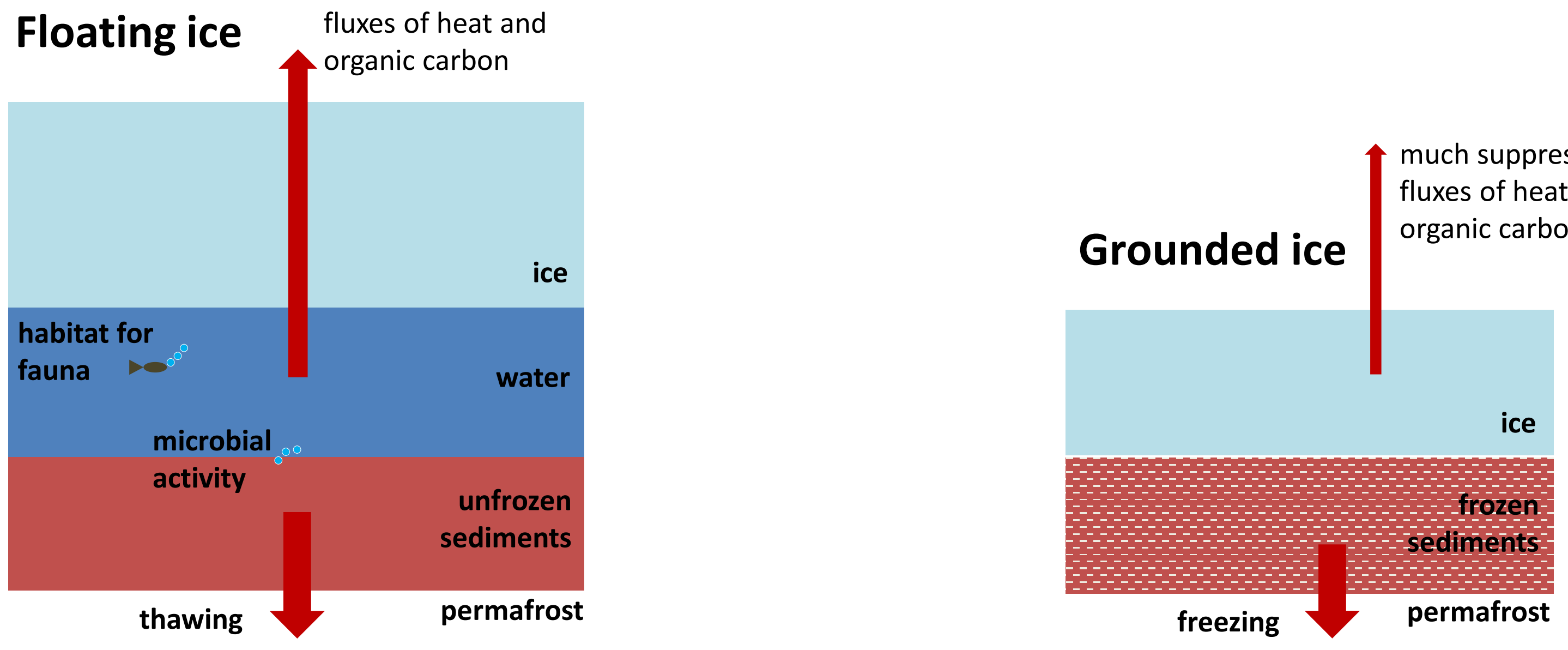

Figure 1. Principal difference in ice regimes of deep and shallow lakes

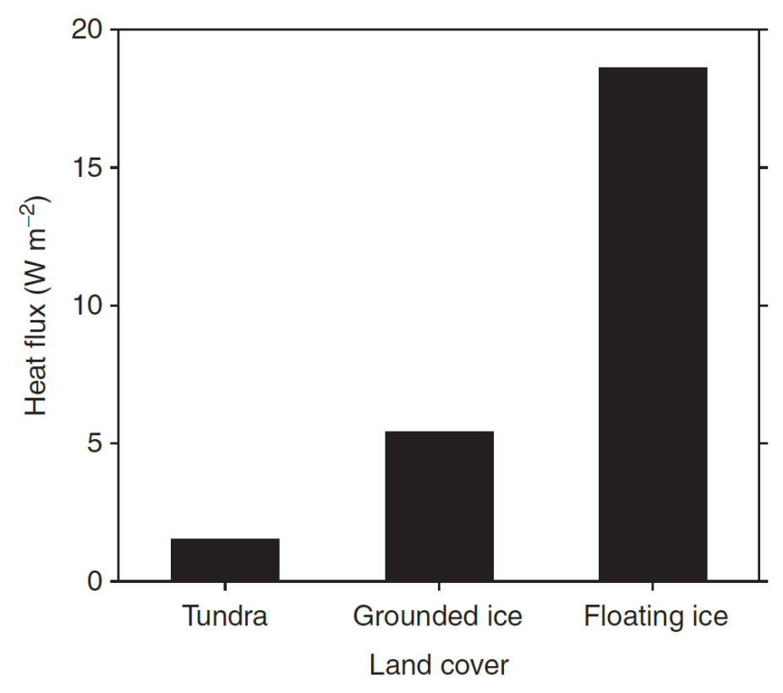

Figure 2. Difference in winter heat fluxes from lakes with grounded and floating ice (Grosse et al., 2013 based on data from Jeffries et al., 1999)

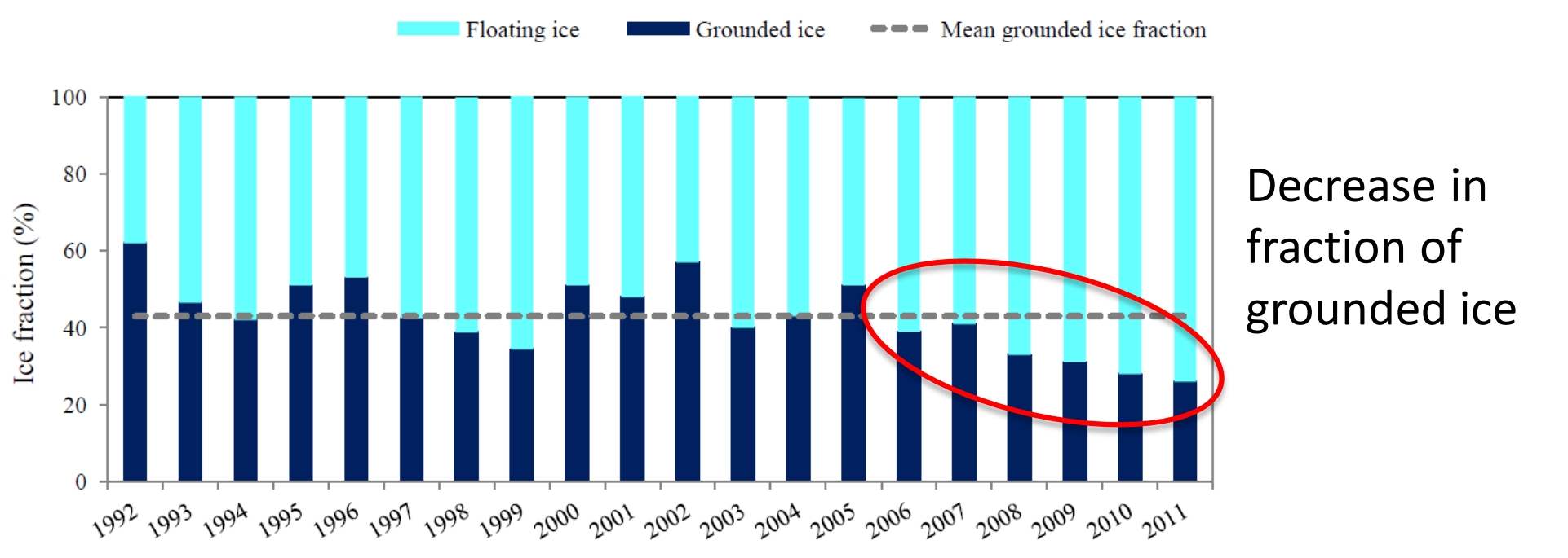

Figure 3. Decrease in fraction of grounded ice in Barrow, Alaska (Surdu et al., 2014)

Radar principles (shallow lakes)

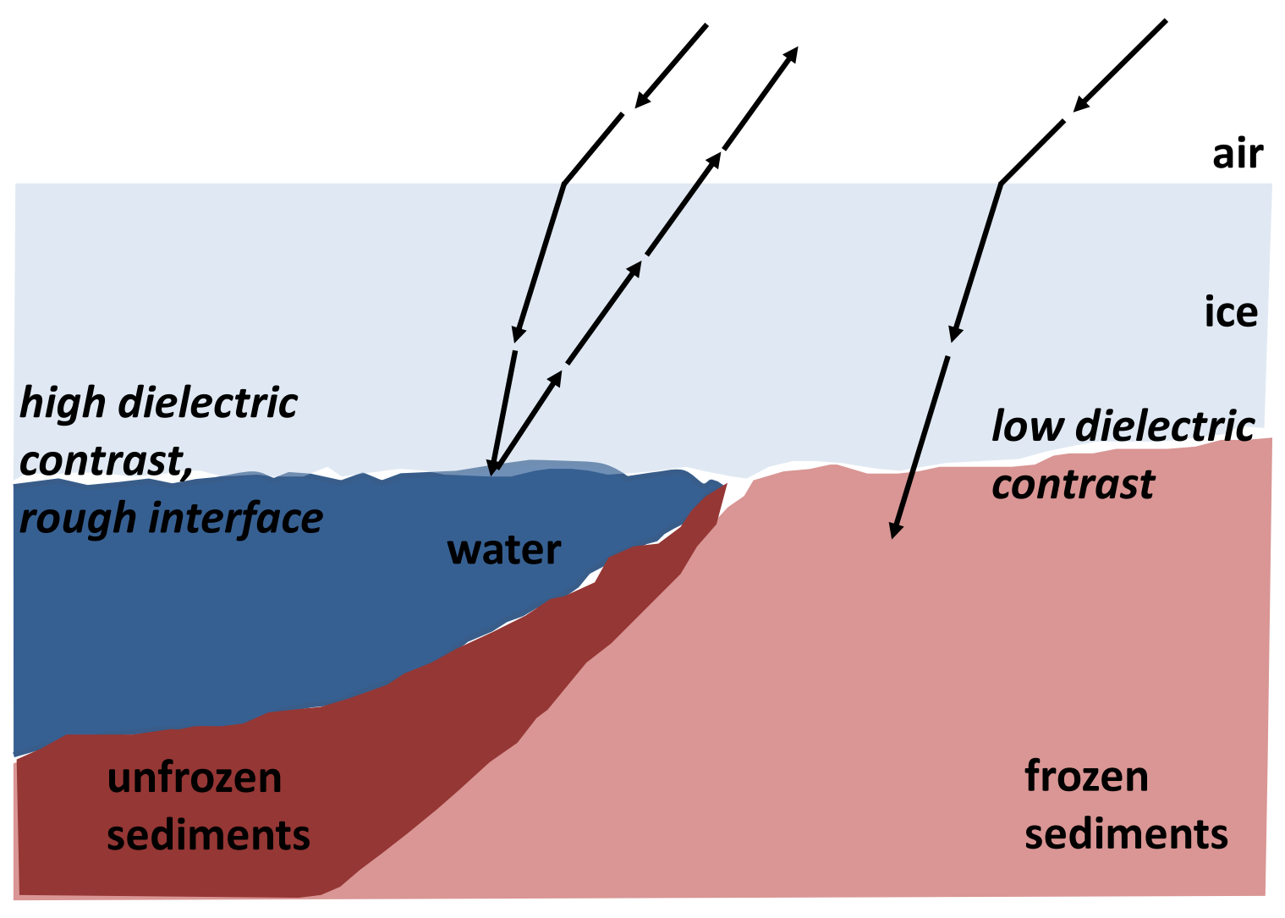

Figure 4. Principles of radar backscattering from the floating and grounded lake ice

- Radar signal penetrates through the lake ice and scatters back from the ice-water interface due to a high dielectric contrast between water and ice. Backscatter intensity is high due to rough ice-water interface. Interferometric coherence is low due to continuously evolving ice-water interface
- In case of grounded ice the dielectric properties of the ice and frozen clay sediments are similar, causing the absorption of the signal and low backscatter intensity. Coherence is high because backscattering interface does not change.

Data and Methods

TerraSAR-X data	
Wavelength	3.1 cm
Frequency	9.6 GHz
Cell size of georeferenced product	10x10 m
Revisit cycle	11 days
Incidence angle	~32°
Overpass	Descending
Polarization	HH
First acquisition	3 Aug 2012
Last acquisition	2 Oct 2015

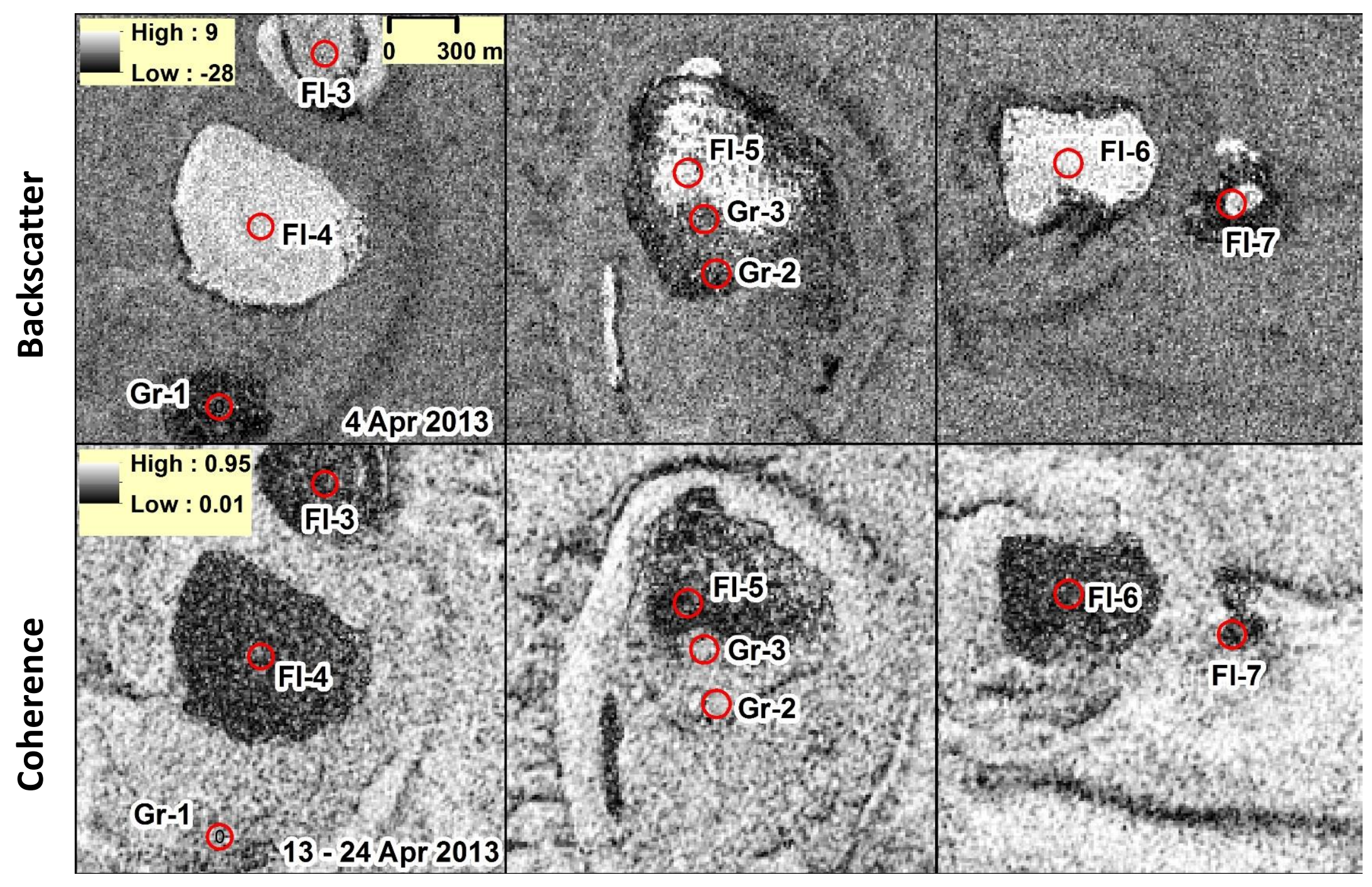

Figure 5. Differences in backscatter and coherence signatures from the floating and grounded lake ice. Red circles are regions of interest (ROIs) used for the retrieval of mean values of backscatter and coherence

Results

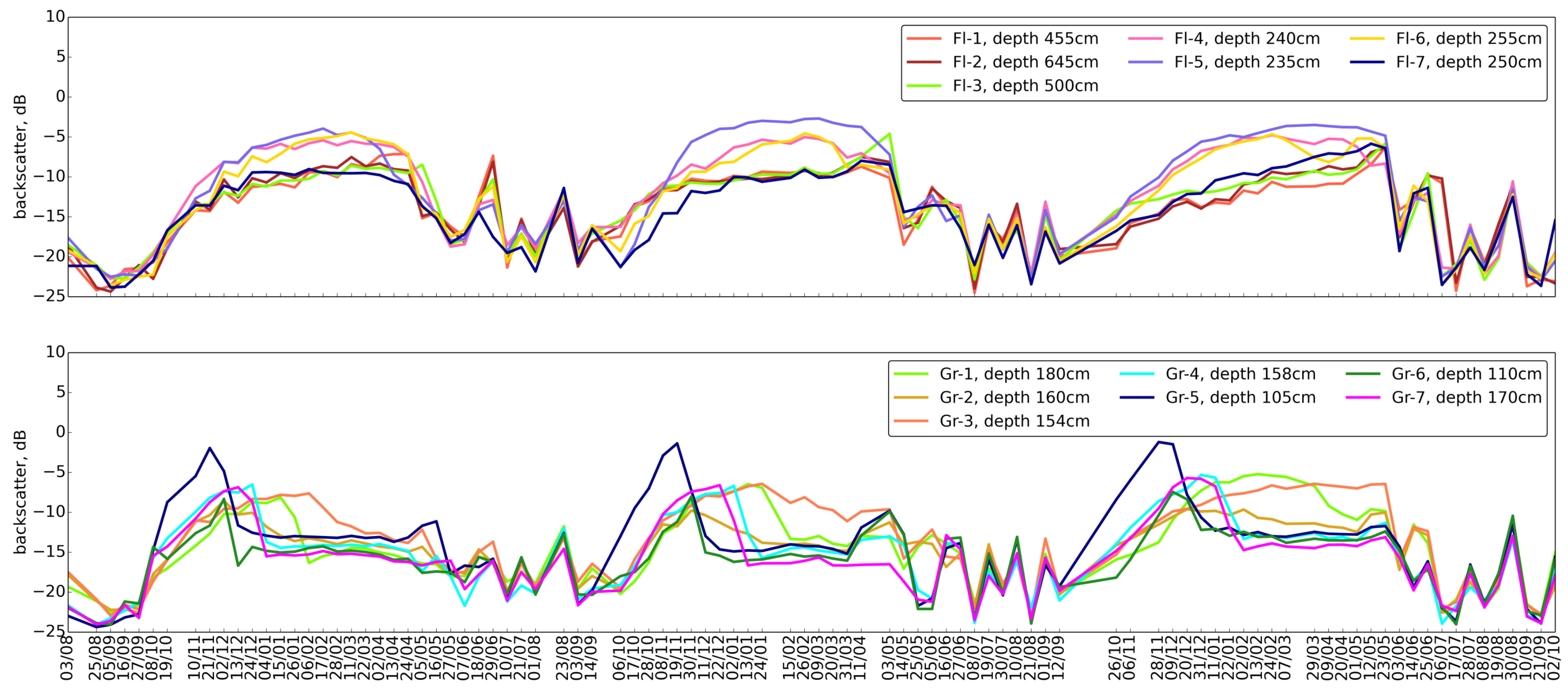

Figure 6. Time series of mean TSX backscatter for each ROI. ROIs are divided into two groups based on April 2015 field observations. TSX signatures generally confirm ice regime observed in the field. Grounded ice locations are characterized by an abrupt decrease in backscatter during the winter period.

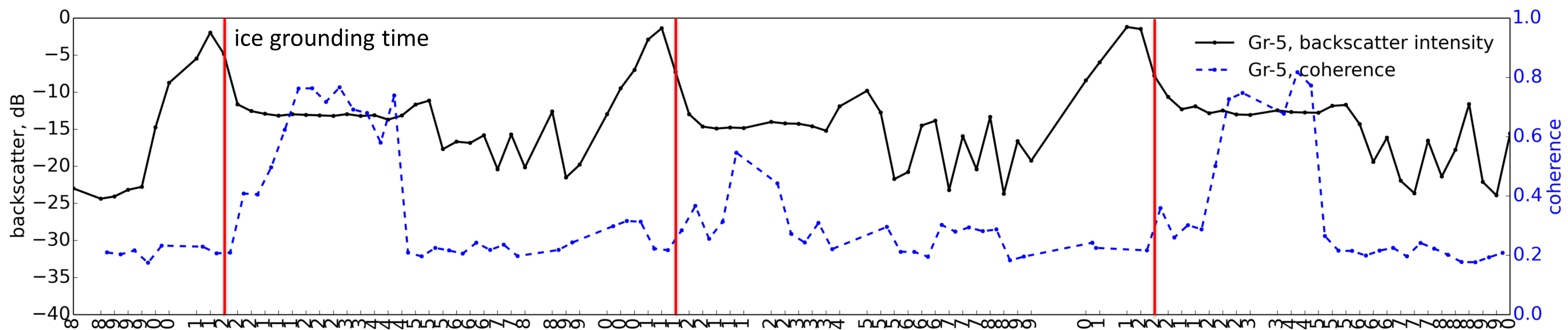

Figure 7. Time series of mean TSX backscatter and 11-day coherence for one selected ROI. Coherence can be affected by evolving snow cover properties. Increase of coherence indicates grounded ice conditions. Delayed increase of coherence (compared to the backscatter drop) may be explained by the sensitivity of coherence to the progression of freezing in sediments.

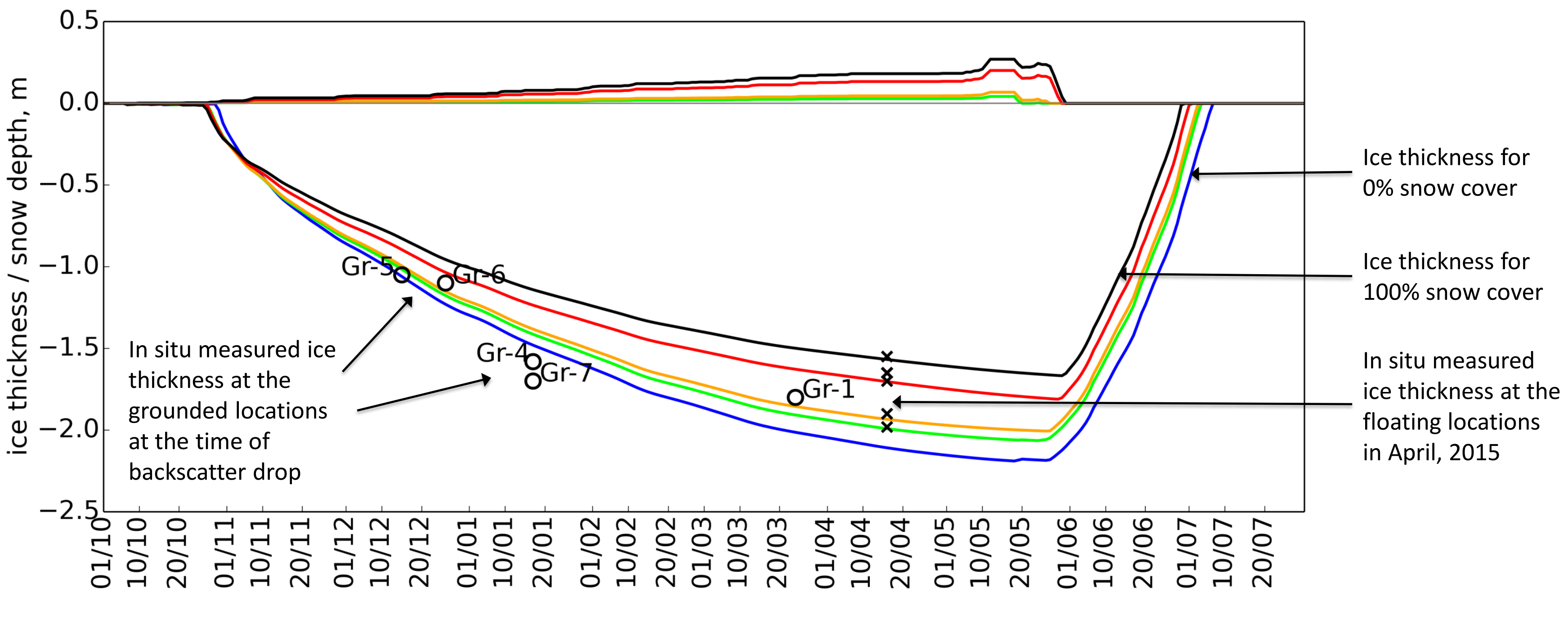

Figure 8. Canadian Lake Ice Model (CLIMo) ice thickness simulations for different snow cover scenarios (0-100%) for the winter of 2014-2015

Conclusions

- TSX backscatter is very suitable for distinguishing between floating and grounded lake ice
- TSX allows for detection of the timing of ice grounding at a higher temporal resolution (11 days) then in previous studies
- Interferometric coherence with a minimal time span provides complementary information to backscatter intensity
- SAR data used in combination with lake ice models, such as CLIMo, can be used for the retrieval of ice thickness and, consequently, bathymetry of shallow lakes

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