The evolution of subglacial water pathways and catchment areas derived from observed ICESat and CryoSat-2 ice surface elevation changes at the Siple Coast, Antarctica

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Introduction

The mass export of the West Antarctic Ice Sheet (WAIS) is dominated by fast flowing ice streams which transport ice from the interior of the ice sheet towards its coast lines with velocities of several hundred meters per year. Understanding their dynamics is considered as a key to estimate the contributions of the WAIS to global sea level rise.

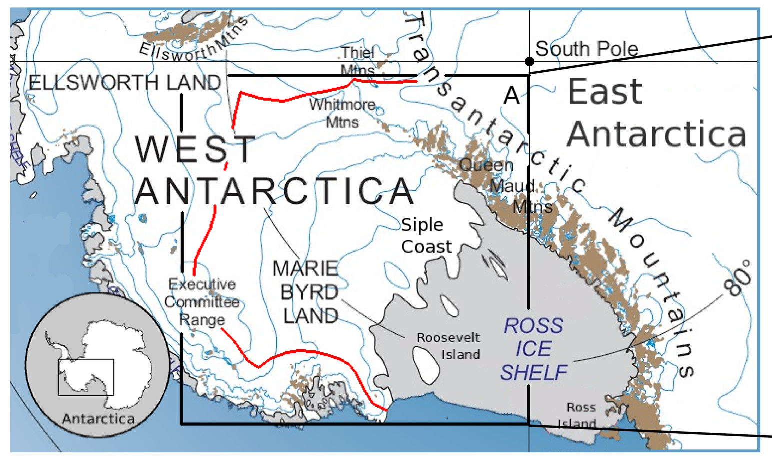

Fig. 1: West Antarctica with Marie Byrd Land, Siple Coast and Ross Ice Shelf. The study area is defined by rectangle A and relevant ice divides (AGAP) are marked in red (Fig. after BAS).

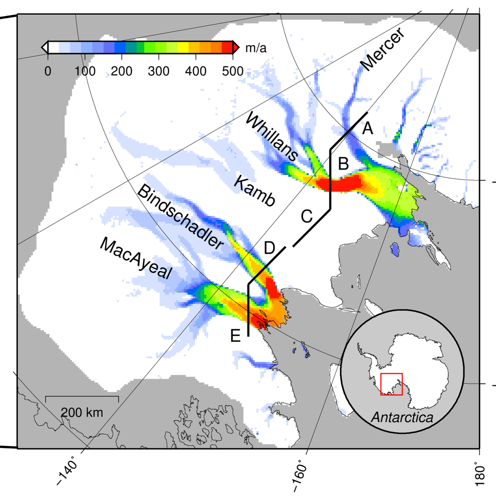

Fig. 2: Present-day ice surface velocity (Rignot, 2011) with Ross Ice Streams. Velocity color scale is truncated (max. values are 709 m/a in the WIS and 668 m/a in the BIS).

This study focuses on the Ross Ice Streams (RIS) at the Siple Coast (Fig. 1,2) where observations reveal a high variability of ice stream pathways and velocities in the past. A meters thick basal layer of unconsolidated sediments beneath the ice sheet creates the precondition for high basal sliding rates by sediment deformation. However, the exact locations of the RIS are determined by the pathways of basal melt water flow. Flow within a till layer at low effective pressure (ice minus water pressure) belongs to the distributed flow regimes, which are known to enhance the basal sliding of ice.

Questions

Can simulated drainage patterns explain the current configuration of the Ross Ice Streams?

Which potential impact have satellite-observed surface changes on the evolution of drainage pathways and what might be the implications for future ice stream dynamics?

Method

The hydraulic potential P at the base of the ice sheet (Shreve, 1972; Alley et al., 1996) is calculated with

$$P = B + H \rho_{ice} / \rho_{water},$$

where B is the bedrock elevation and H the ice thickness. Under the assumption that the basal water flow follows the gradient of the potential P the water flow is computed with the balance flux approach (Budd and Warner, 1996)

$$M = \mathrm{div}(\Phi).$$

The application of a constant basal melting rate M allows to express the local scalar water flux Φ as percentage of the total catchment area. Additionally, cross sections of about 140 km length (Fig. 2) are defined at the main trunks of the RIS. Thus, the size of the catchment area draining underneath each particular ice stream can be determined

Satellite observations

For the present-day simulations the ice sheet geometry is given by the Bedmap2 data set (Fretwell et al., 2013).

For the prognostic simulations satellite-observed ice sheet surface elevation change rates from the ICESat (Fig. 3) and CryoSat-2 (Fig. 4) campaign are applied to the current ice sheet geometry (Fretwell et al., 2013).

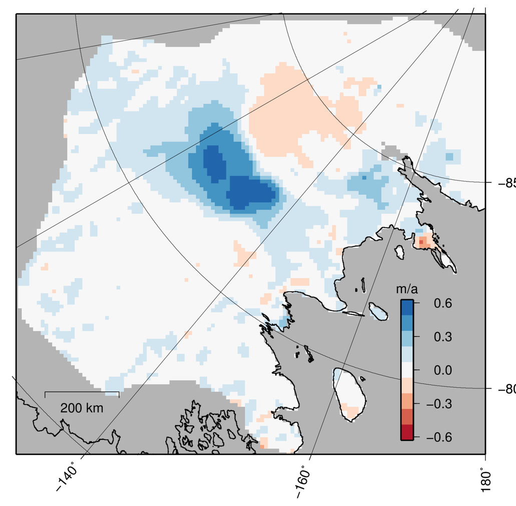

Fig. 3: Ice surface elevation change rates (dS/dt) derived from ICESat (Pritchard, 2012).

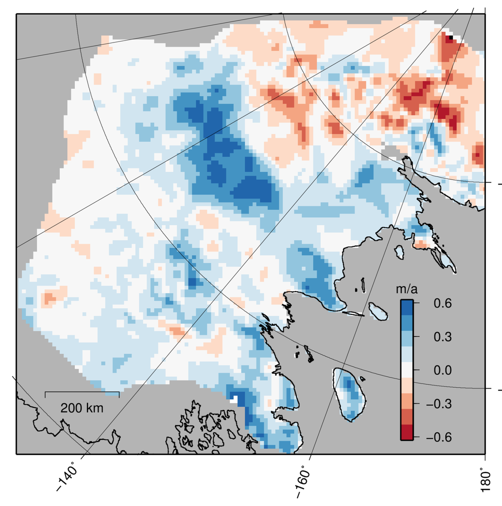

Fig. 4: Ice surface elevation change rates (dS/dt) derived from CryoSat-2 (Helm et al., 2014).

Results: Present day simulation

Subglacial water pathways today

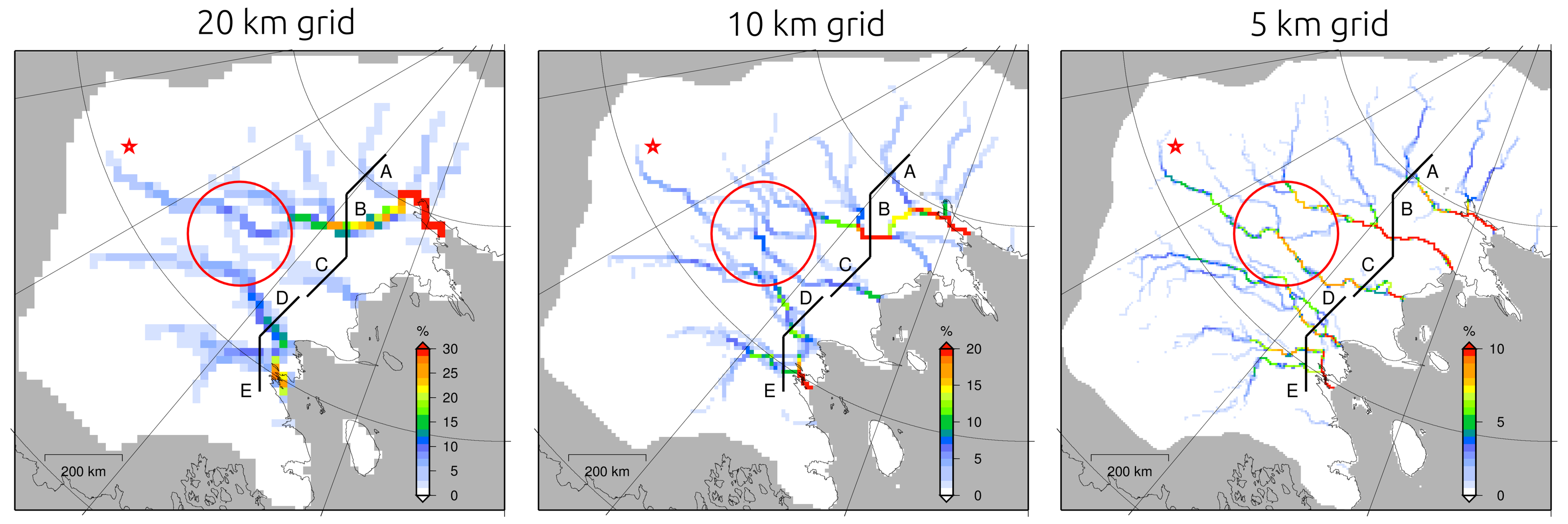

Fig. 5: Simulated basal water pathways at the Siple Coast for present-day bedrock elevation and ice thickness. The color scale shows the drainage in percent of the total catchment area and is truncated for a better visibility of the pathways, maximum values at the grounding line are 20 % (5 km), 31 % (10 km) and 42 % (20 km).

Results: Prognostic simulation

Subglacial water pathways after 200 years

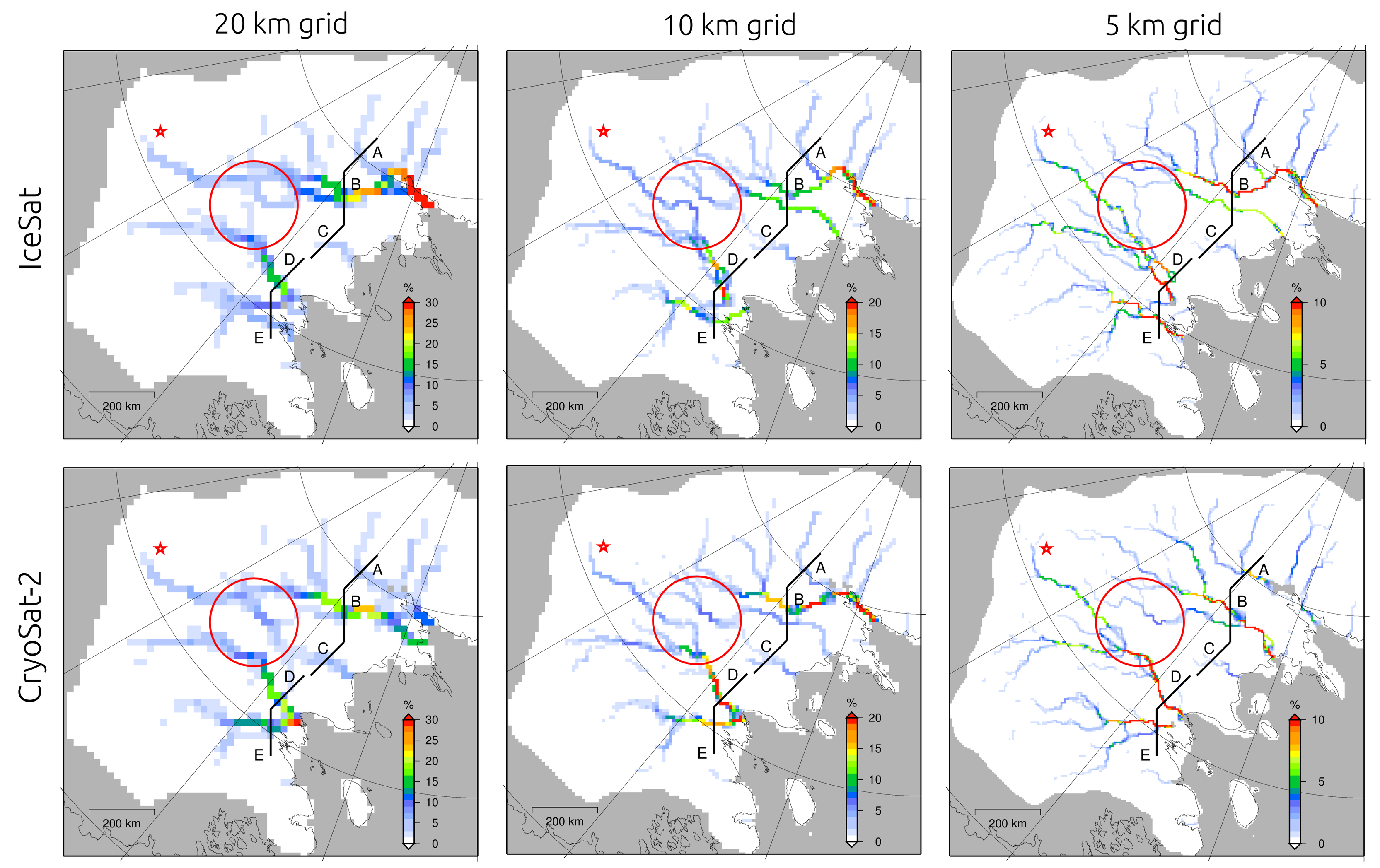

Fig. 6: Simulated present-day basal water pathways beneath the Ross Ice Streams (A-E) and their simulated positions after 200 years using ICESat (Fig. 3) and CryoSat-2 (Fig. 4) surface elevation change rates at three different model resolutions. The color scale shows the drainage in percent of the total catchment area. The red circle marks the area where a redirection of a major hydraulic tributary (marked with a red star) of the Kamb (C) and Whillans Ice Stream (B) to the Bindschadler Ice Stream (D) takes place at the higher model resolutions.

Catchment area evolution

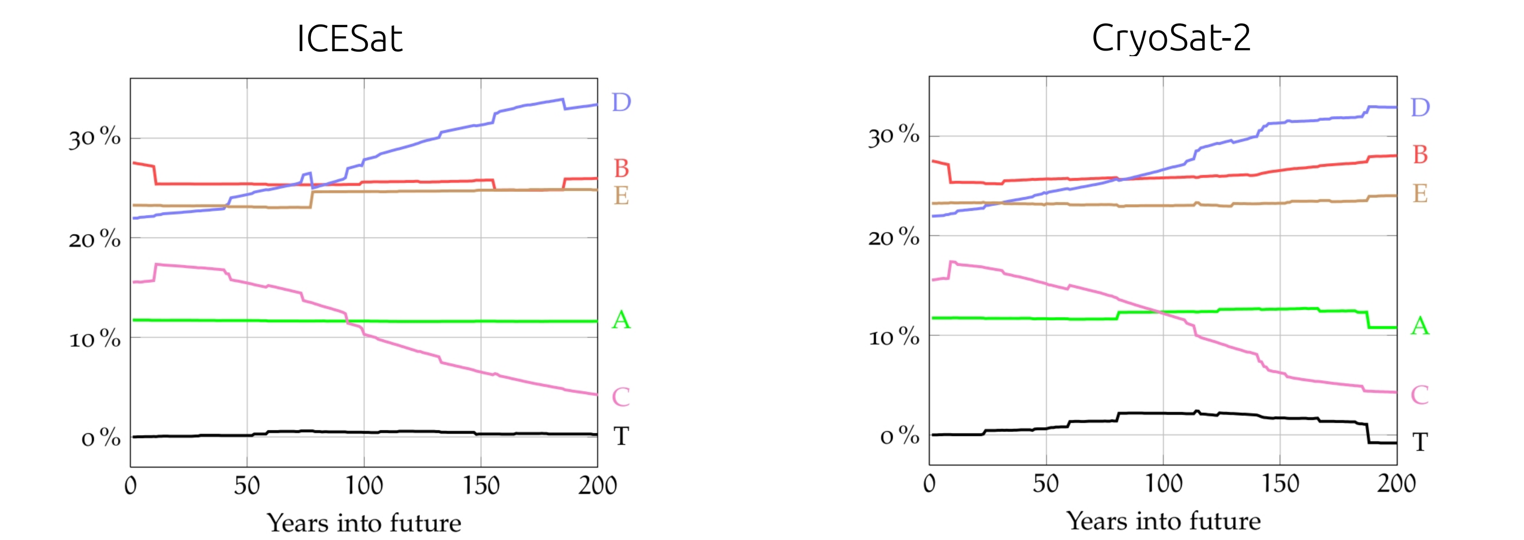

Fig. 7: The temporal evolution of the water catchment areas upstream of the defined cross sections for all Ross Ice Streams (A–F, Fig. 2) under the impact of the observed surface elevation changes from ICESat (Fig. 3) and CryoSat-2 (Fig. 4) for the next 200 years. T shows the variation of the total upstream catchment area. Model resolution is 5 km.

Conclusion

All current ice stream outlines are found to be clearly associated with areas of enhanced water flow (Fig. 2 and 5). Furthermore, the ice velocities of the particular Ross Ice Streams are found to be related to the water catchment area sizes draining underneath (Fig. 2 and 7).

According to the applied satellite-observed ice surface change rates one major hydraulic tributary of the Kamb (C) and Whillans Ice Stream (B) (marked with a star in Fig. 6) is redirected underneath the Bindschadler Ice Stream (D) within the next 200 years. As a consequence, the water catchment area feeding underneath the Bindschadler Ice Stream is estimated to grow by about 50 percent while the lower part of the stagnated Kamb Ice Stream becomes increasingly separated from the upper hydraulic tributaries of the Siple Coast (Fig. 6 and 7). This might be a continuation of the subglacial hydraulic processes which caused the past stagnation of the Kamb Ice Stream. Furthermore, this might also lead to a future increase of the ice velocity within the Bindschadler Ice Stream and an increased ice drainage of the corresponding hinterland.

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