Examining the relationships between basal channels and ice shelf structural evolution with repeat, high-resolution elevation models and altimetry

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Abstract

Ice shelves control the stability of ice sheets and regulate ice sheet contribution to sea level rise by buttressing ice ow. Most of Greenland's ice shelves have already been lost, and many ice shelves around Antarctica are thinning and retreating. Ice shelves are increasingly vulnerable to thinning and destabilization due to surface and basal melting, and these processes may be exacerbated by the presence of basal channels, which are deep grooves that entrain meltwater at the base of ice shelves. Basal channels have been observed alongside spatial and temporal changes in grounding line geometry, strain rates and stress transfer, and the incidence and advection of other surface and basal features. The relationships between these processes, and their implications for ice shelf stability, remain largely unknown due to the lack of observations of suciently high spatial and temporal resolution. Our methodology employs high temporal and spatial resolution digital elevation models (DEMs) from REMA and ArcticDEM, laser altimetry from ICESat-2, radar sounding and laser altimetry from Operation IceBridge, and velocity data derived from interferometry, enabling us to constrain the morphology and evolution of channels and other ice shelf features at the fringes of both ice sheets. We intend to investigate how the relationships between channels, grounding line processes, and rifts and crevasses impact the persistence of ice shelf area necessary to maintain a "safety band", or sucient buttressing force, against grounded ice. Where time-evolving grounding line position data are sparse, we use the DEMs to track the boundary of hydrostatic equilibrium, which we use as a proxy for changes in grounding line position in order to investigate changes in ice shelf geometry. We have completed analysis of three ice shelves and plan to observe at least twelve more in order to develop an inventory of at- risk ice shelves. Based on our preliminary results, we hypothesize that rapidly evolving basal channels are associated with high rates of change in the grounding zone. This work is integral to assessing past and future ice shelf stability, and it will help the glacier dynamics community more accurately account for small-scale ice shelf processes in computational models which predict ice sheet contribution to sea level rise.

EXAMINING THE RELATIONSHIPS BETWEEN BASAL CHANNELS AND ICE SHELF STRUCTURAL EVOLUTION WITH REPEAT, HIGH-RESOLUTION ELEVATION MODELS AND ALTIMETRY

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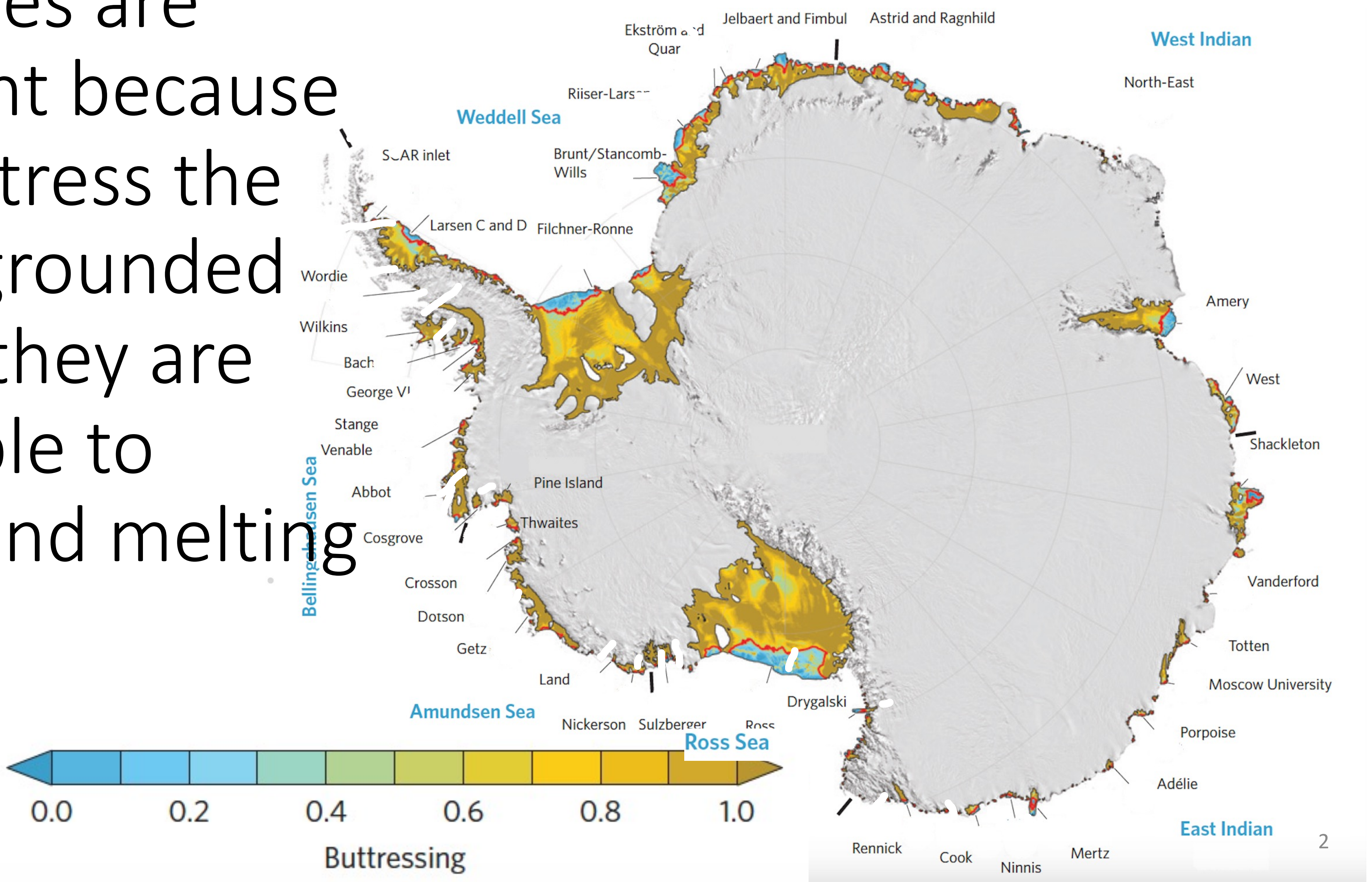
BYRD POLAR AND CLIMATE RESEARCH CENTER

NASA pgc NSF

AGU FALL MEETING

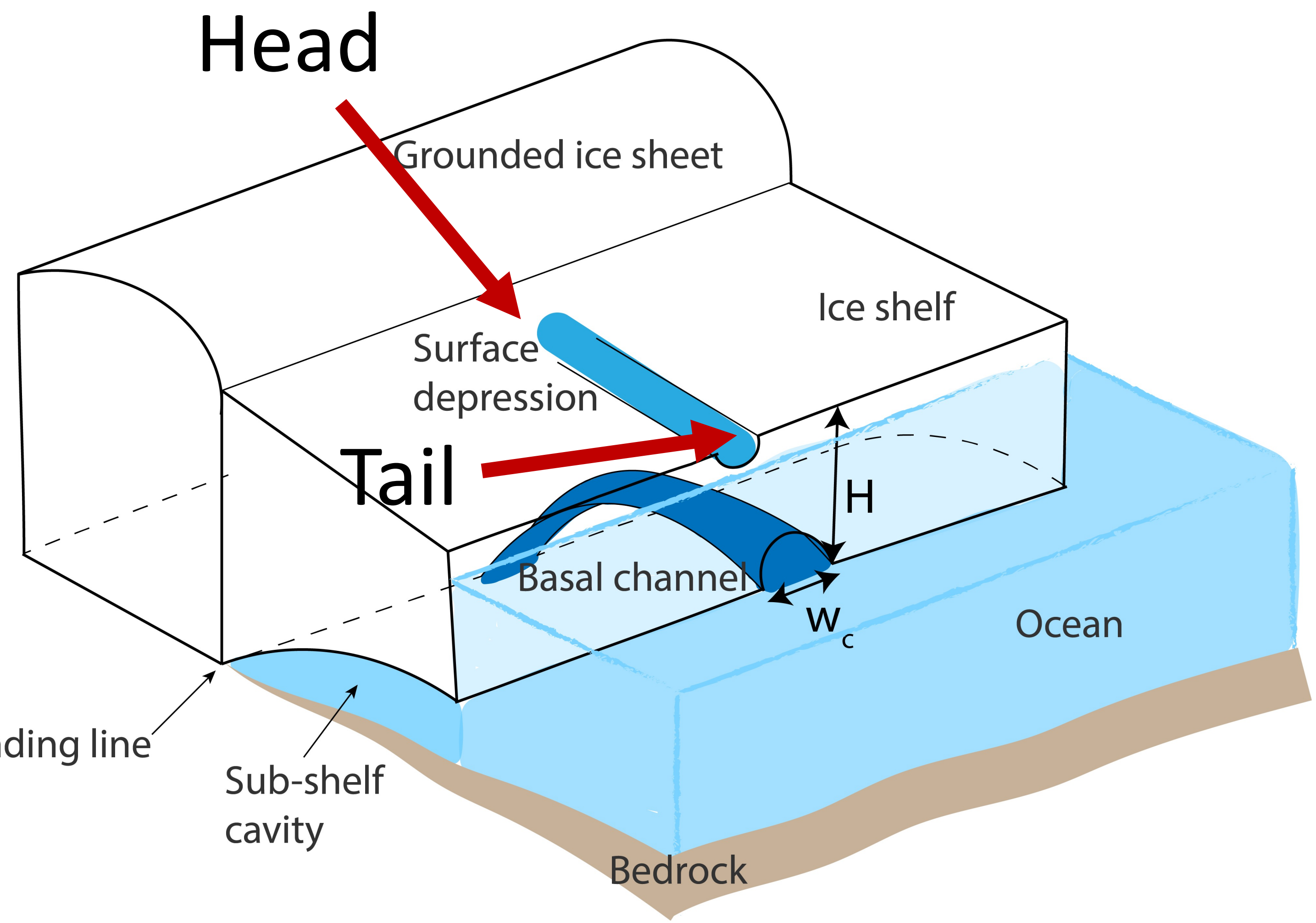
SCIENCE is SOCIETY

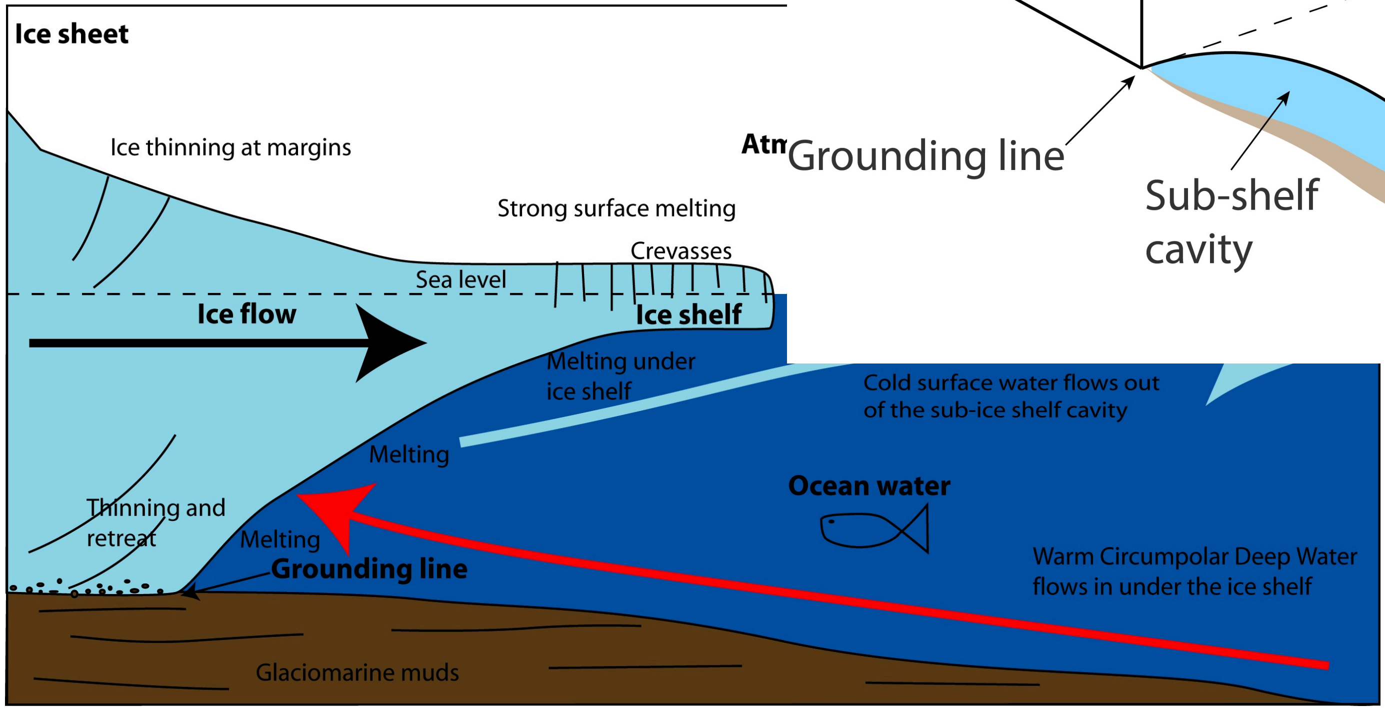
Ice shelves are important because they buttress the flow of grounded ice, but they are vulnerable to calving and melting



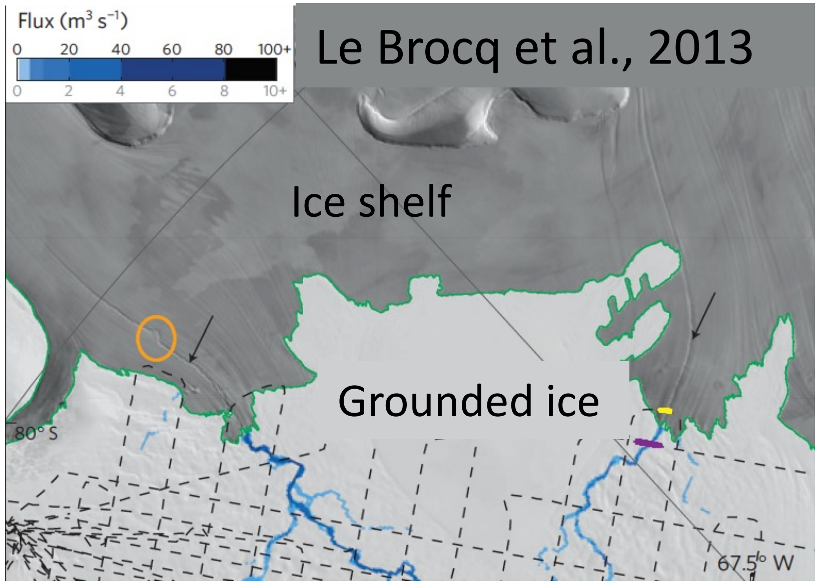
Fürst et al., 2016

Basal channels are deep grooves at the base of ice shelves through which buoyant water is entrained

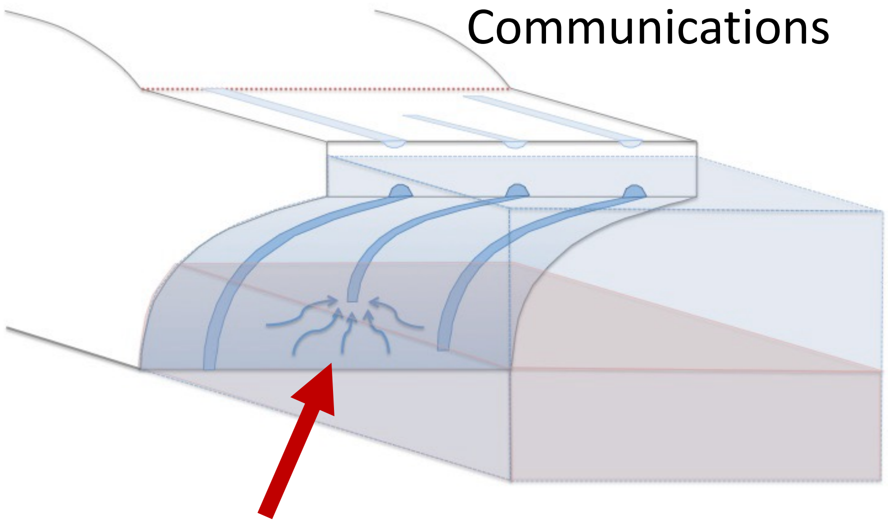




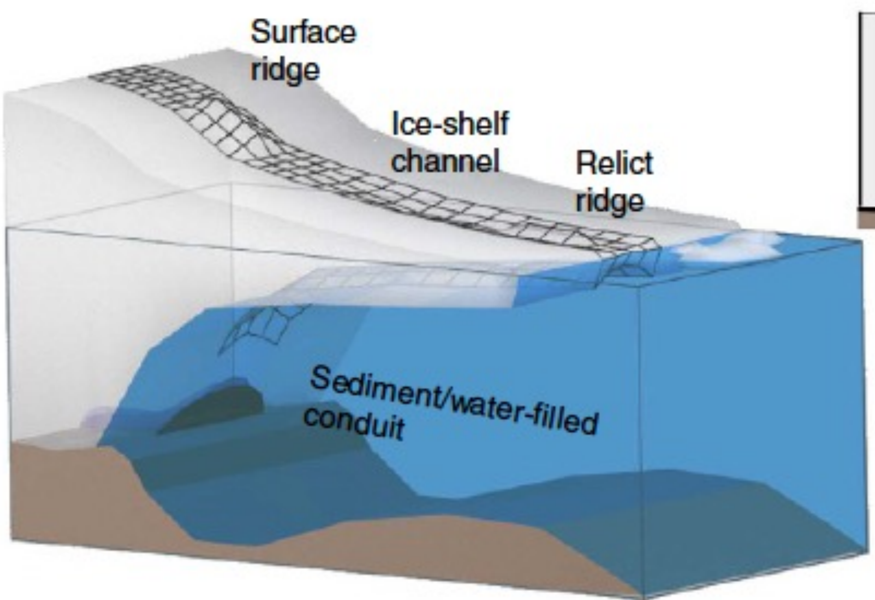
Basal channel formation

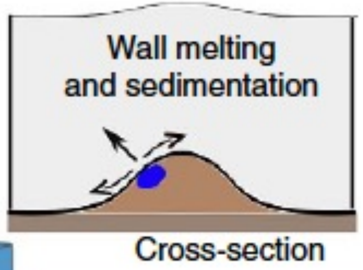


Le Brocq et al., 2013

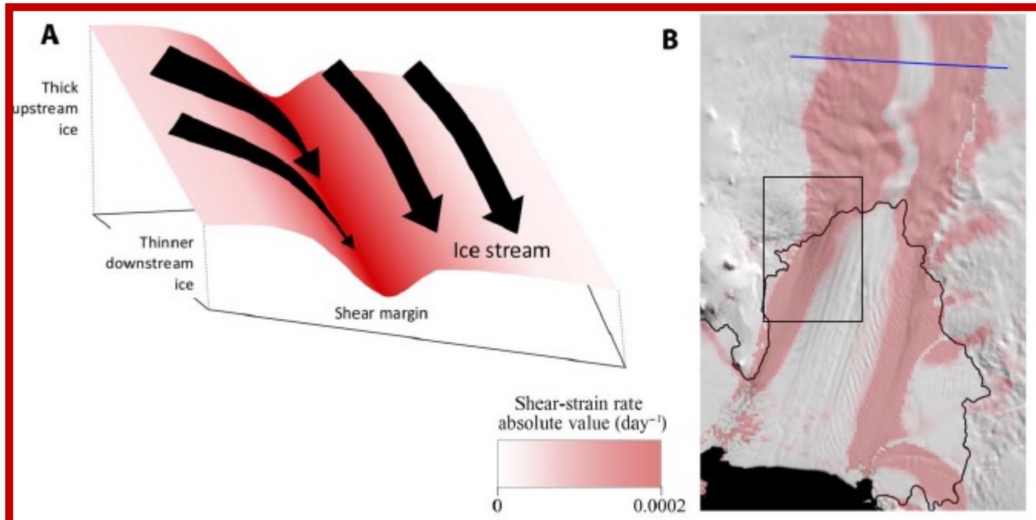


Alley et al., 2016;
Nature Communications





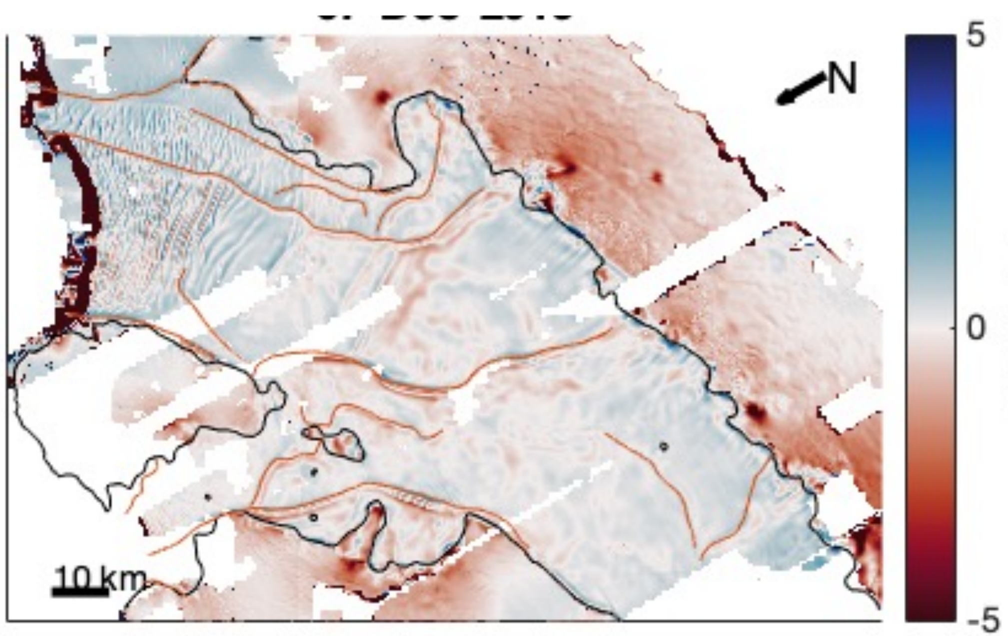
Drews et al., 2017;
Nature Communications

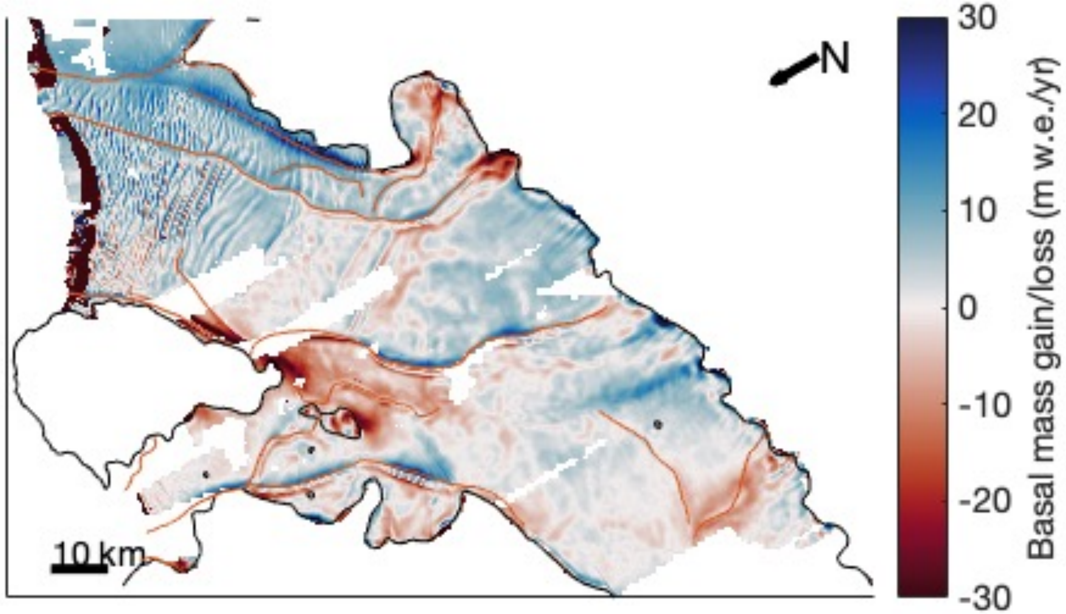


Alley et al., 2019;
Science Advances

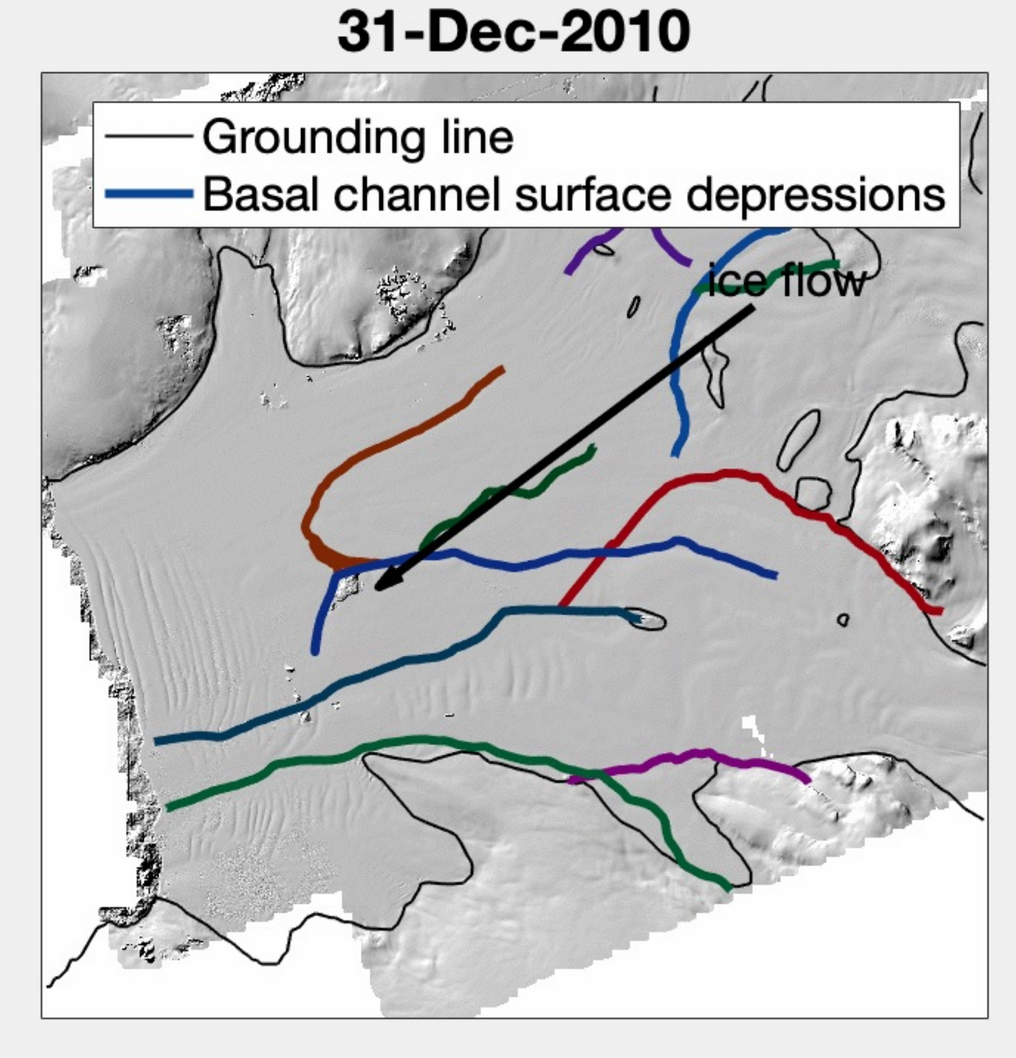
How is basal channel evolution related to changes at or upstream of the grounding line?

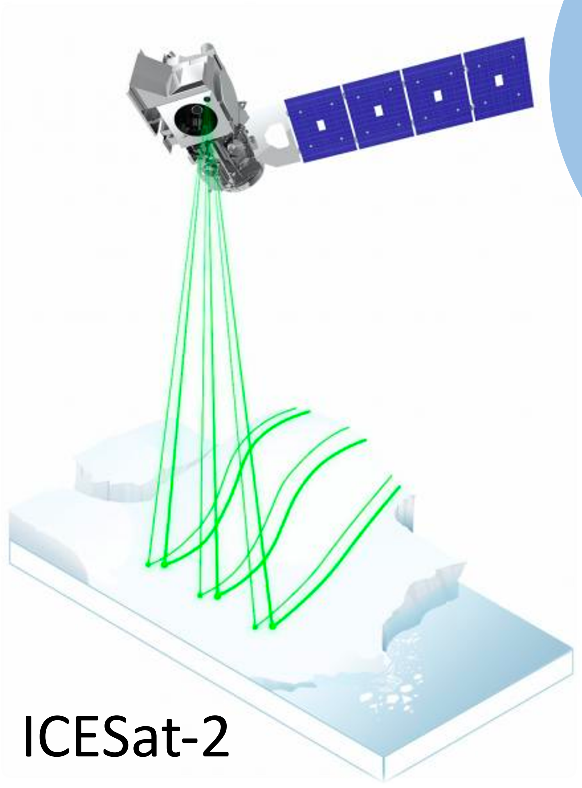
Rates of change between 2015 - 2019



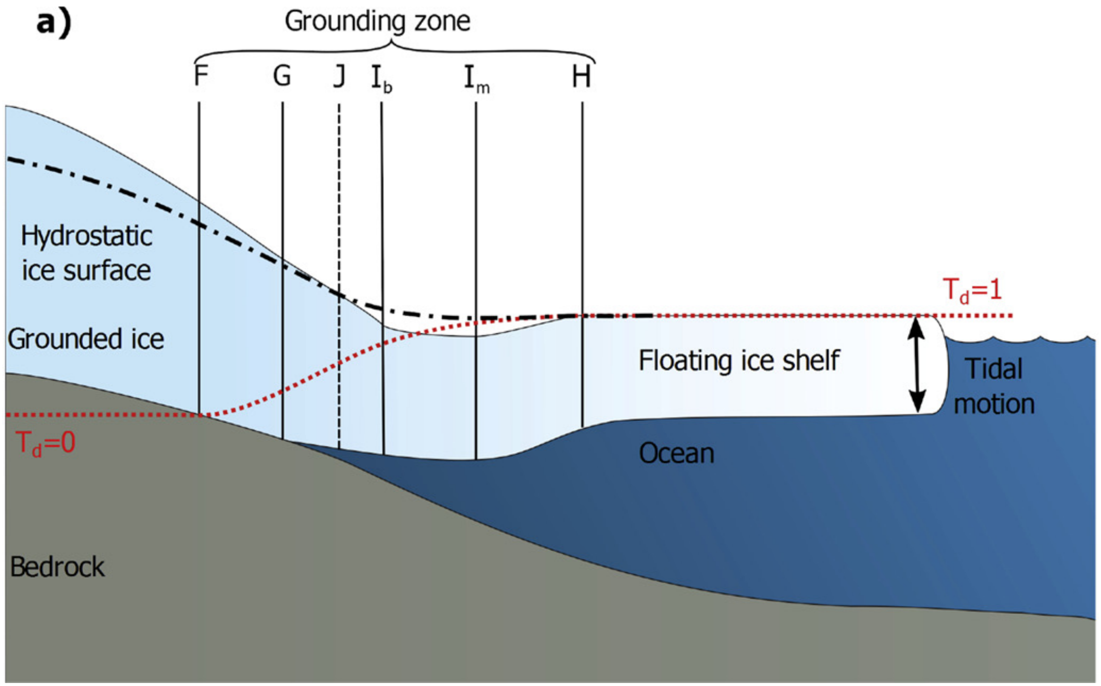


Surface elevation data are used to track surface depressions.



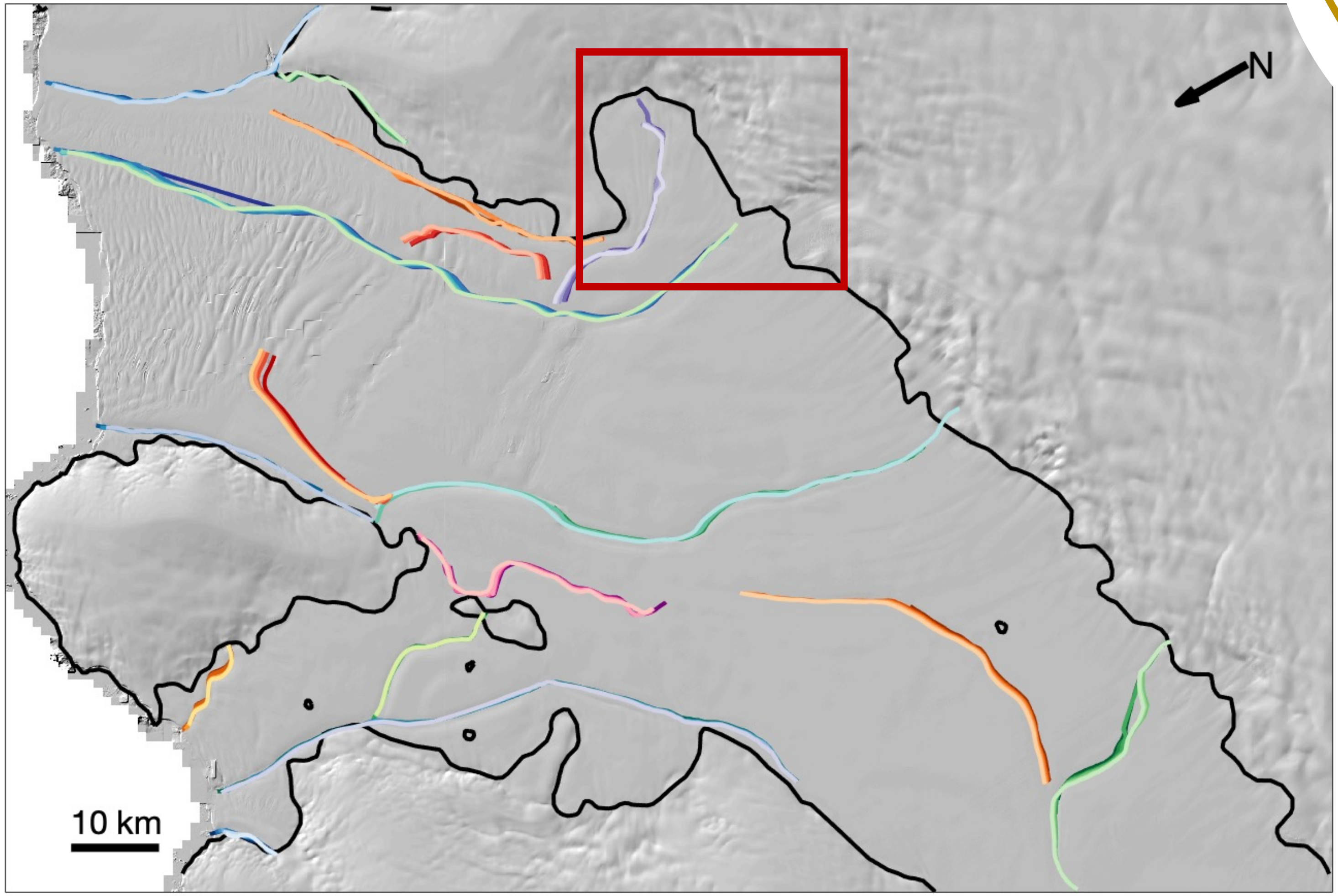

ICESat-2

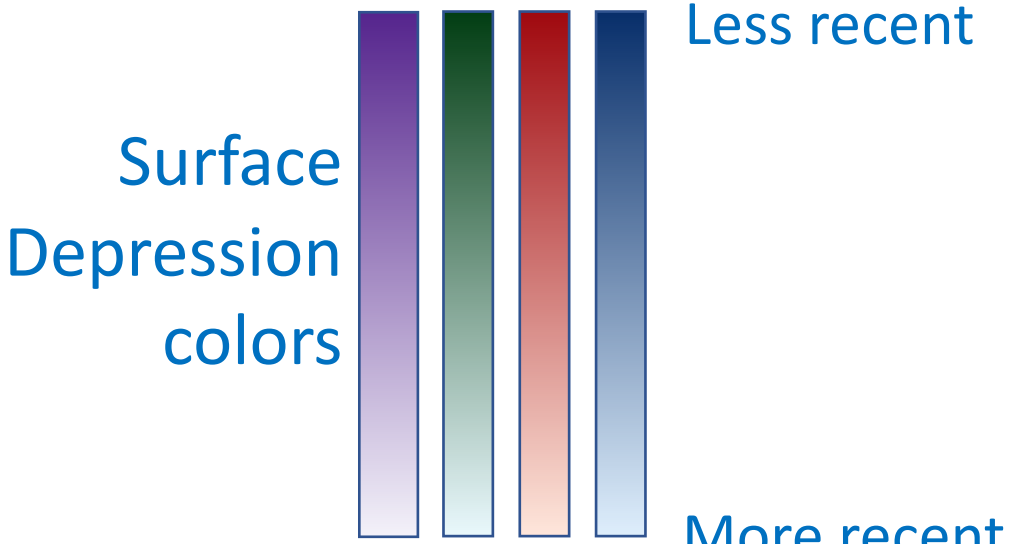
Ice-penetrating radar data are used to validate surface inferences.

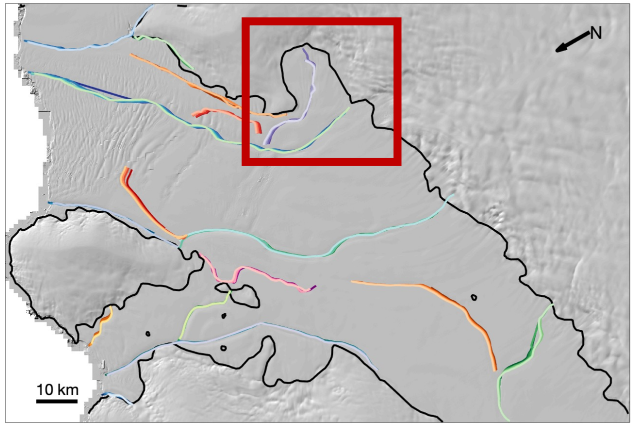


Friedl et al., 2020, Earth-Science Reviews

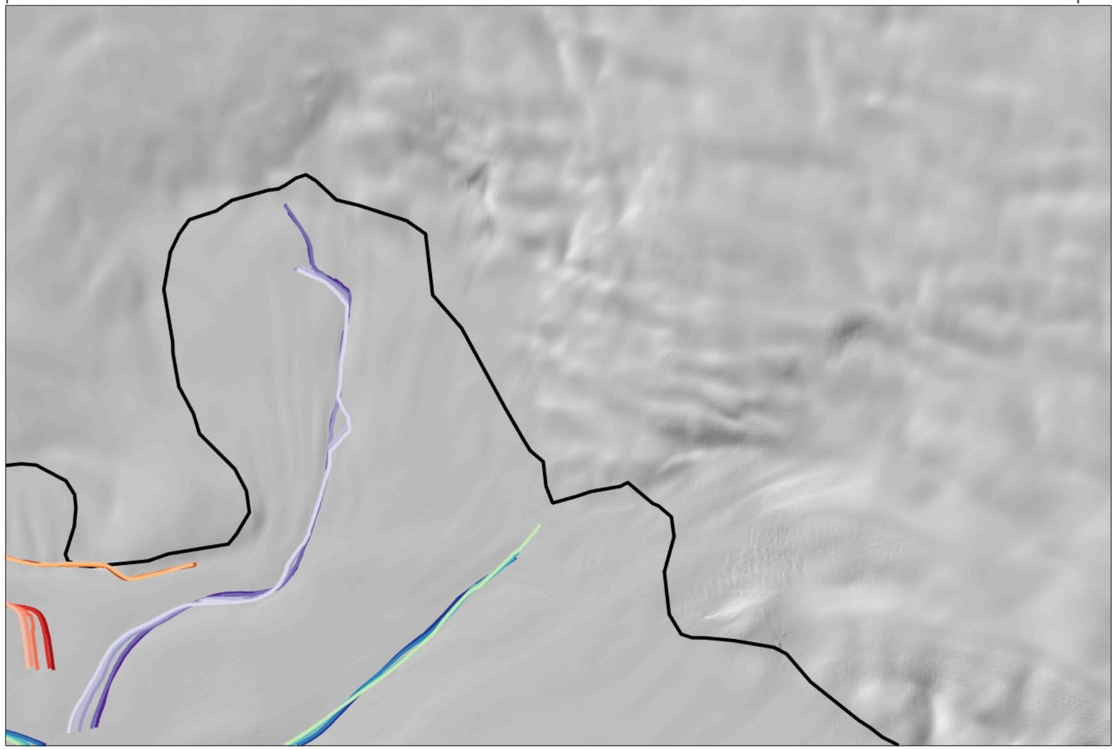
Getz Ice Shelf

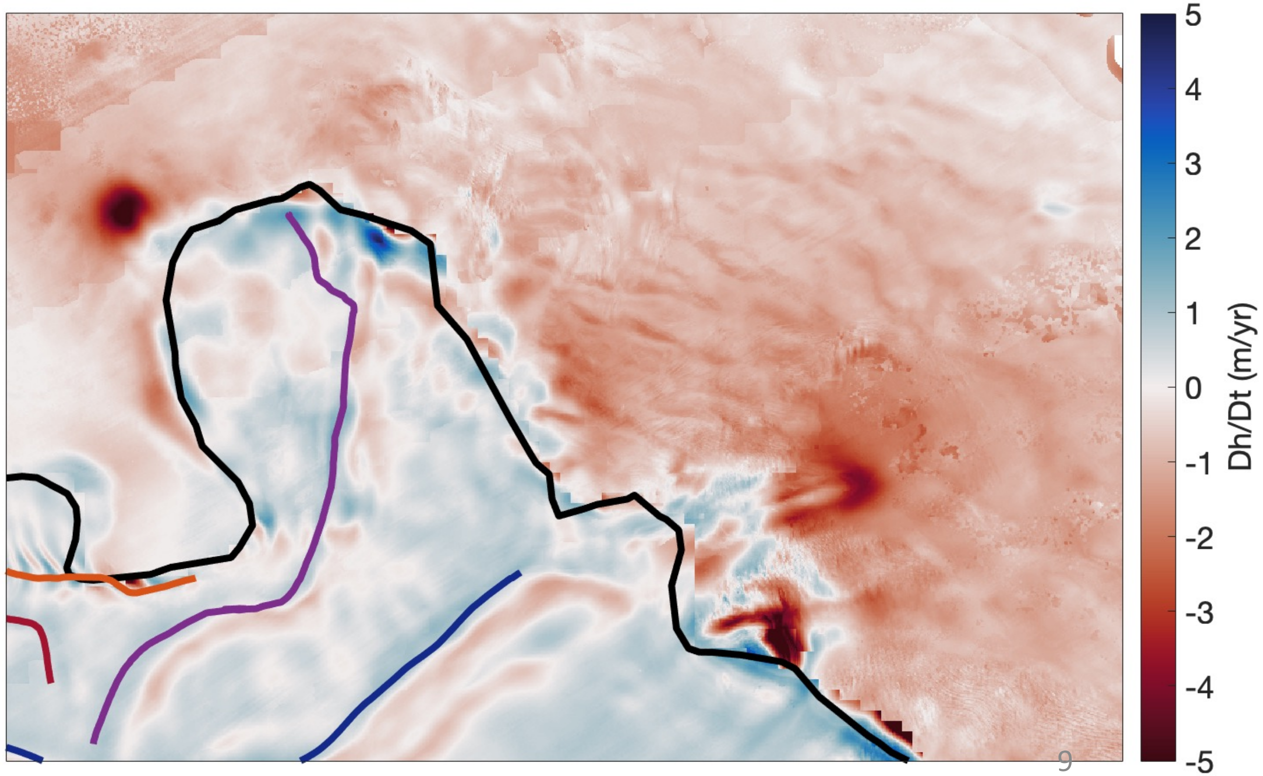


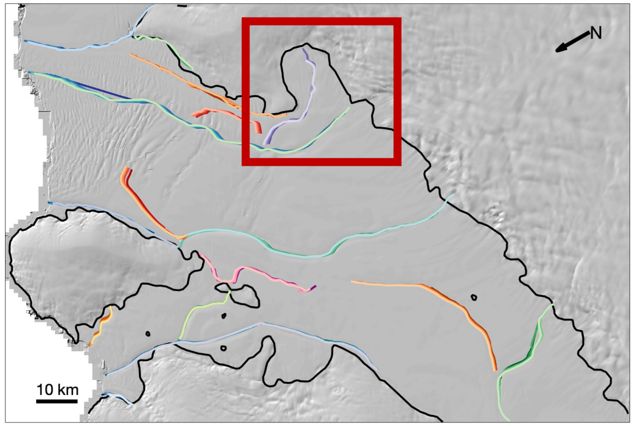


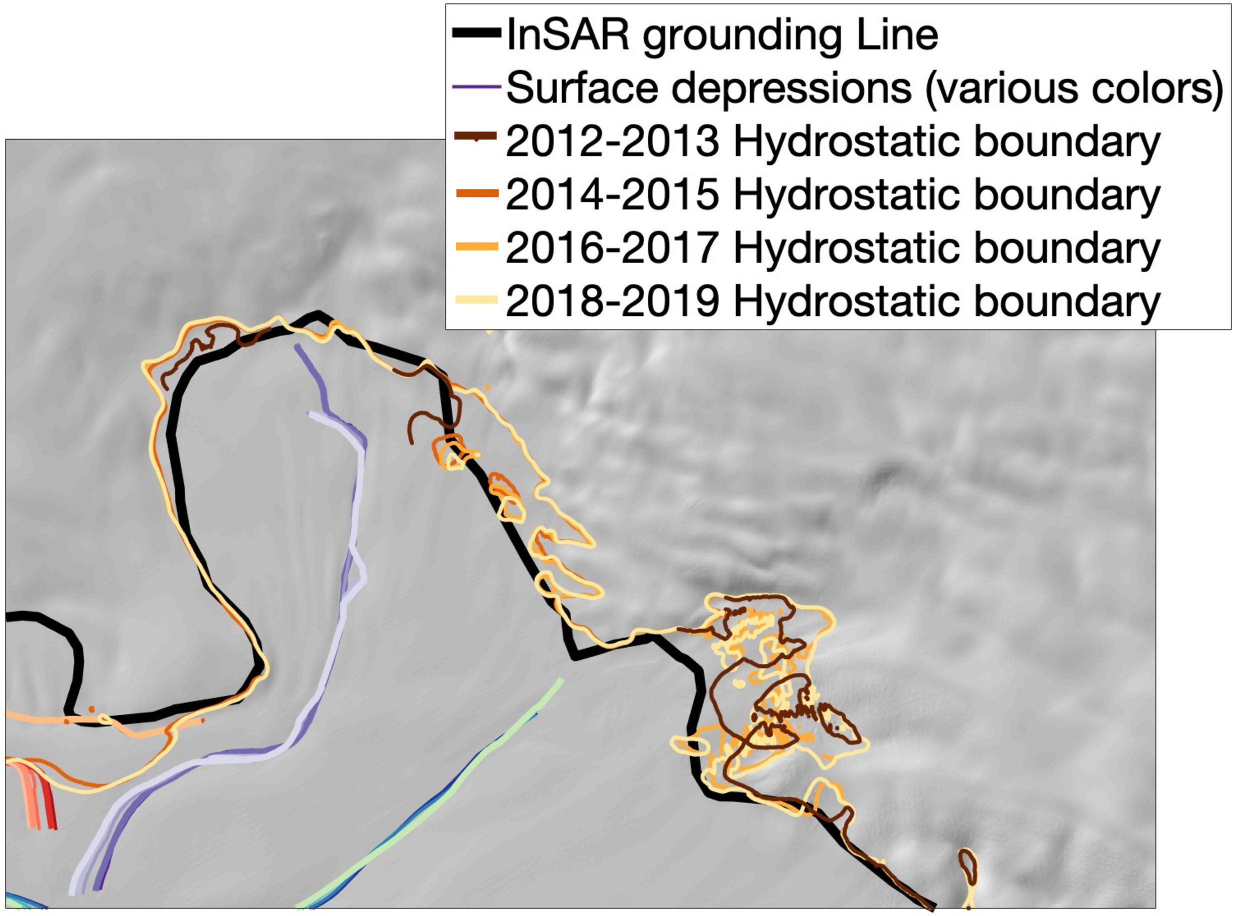

N
10 km

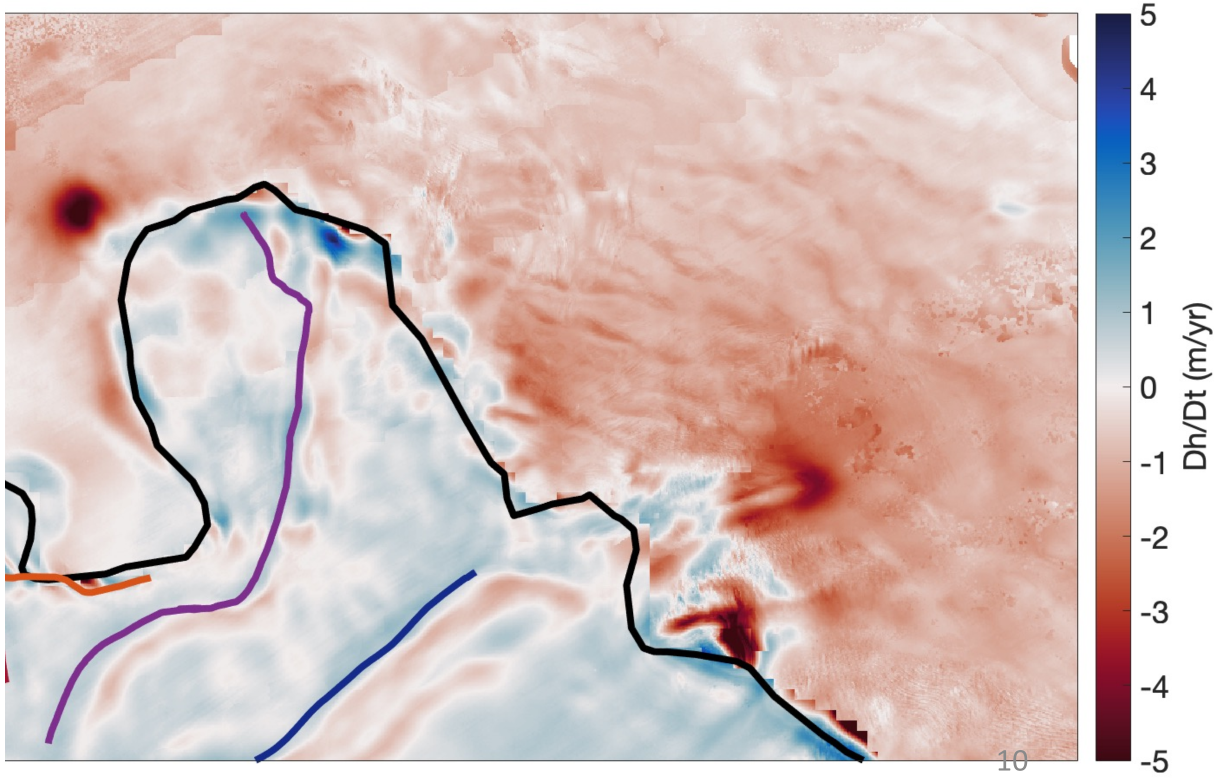

InSAR grounding line
Surface depression location (various colors)

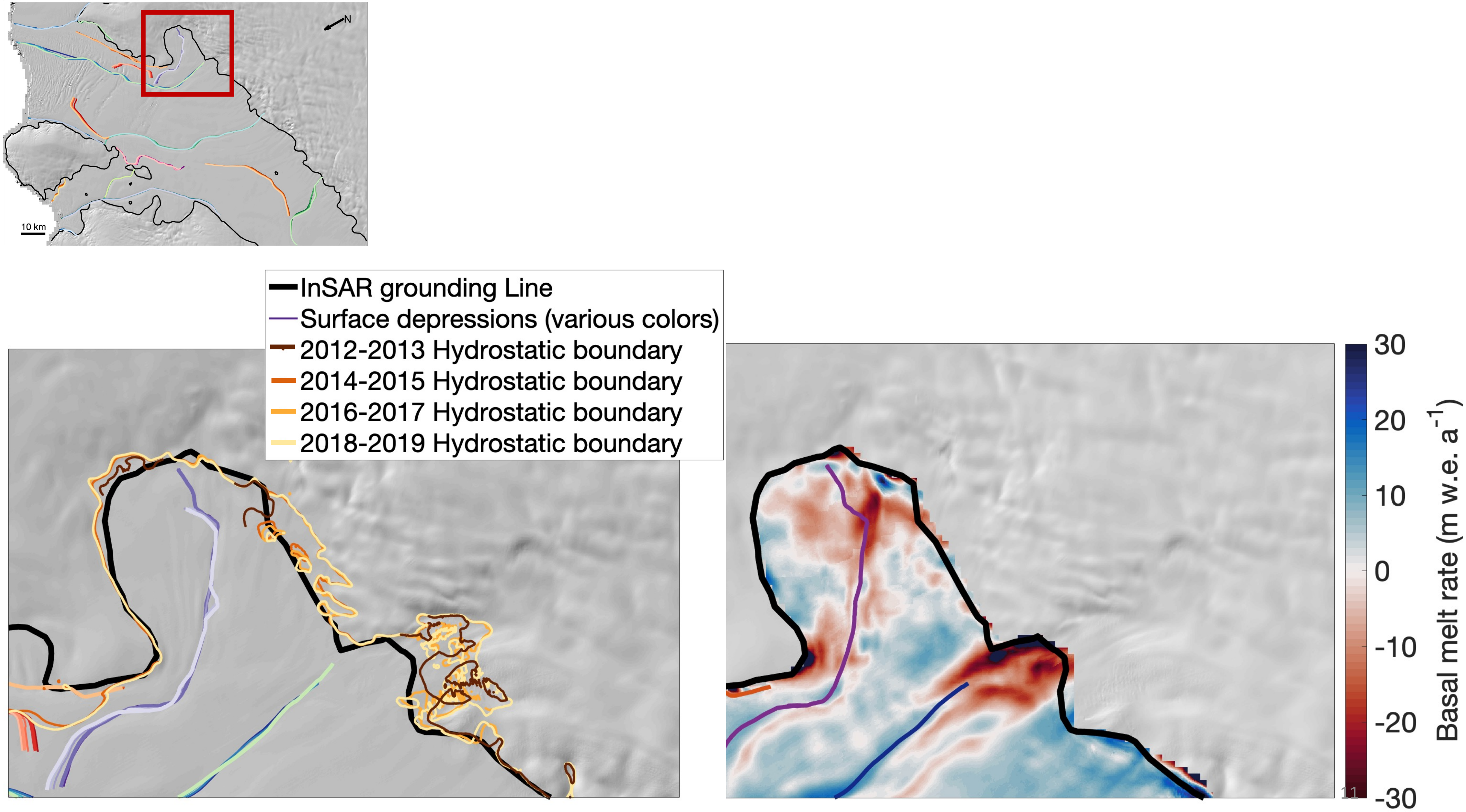



5
4
3
2
1
0
-1
-2
-3
-4
-5
Dh/Dt (m/yr)

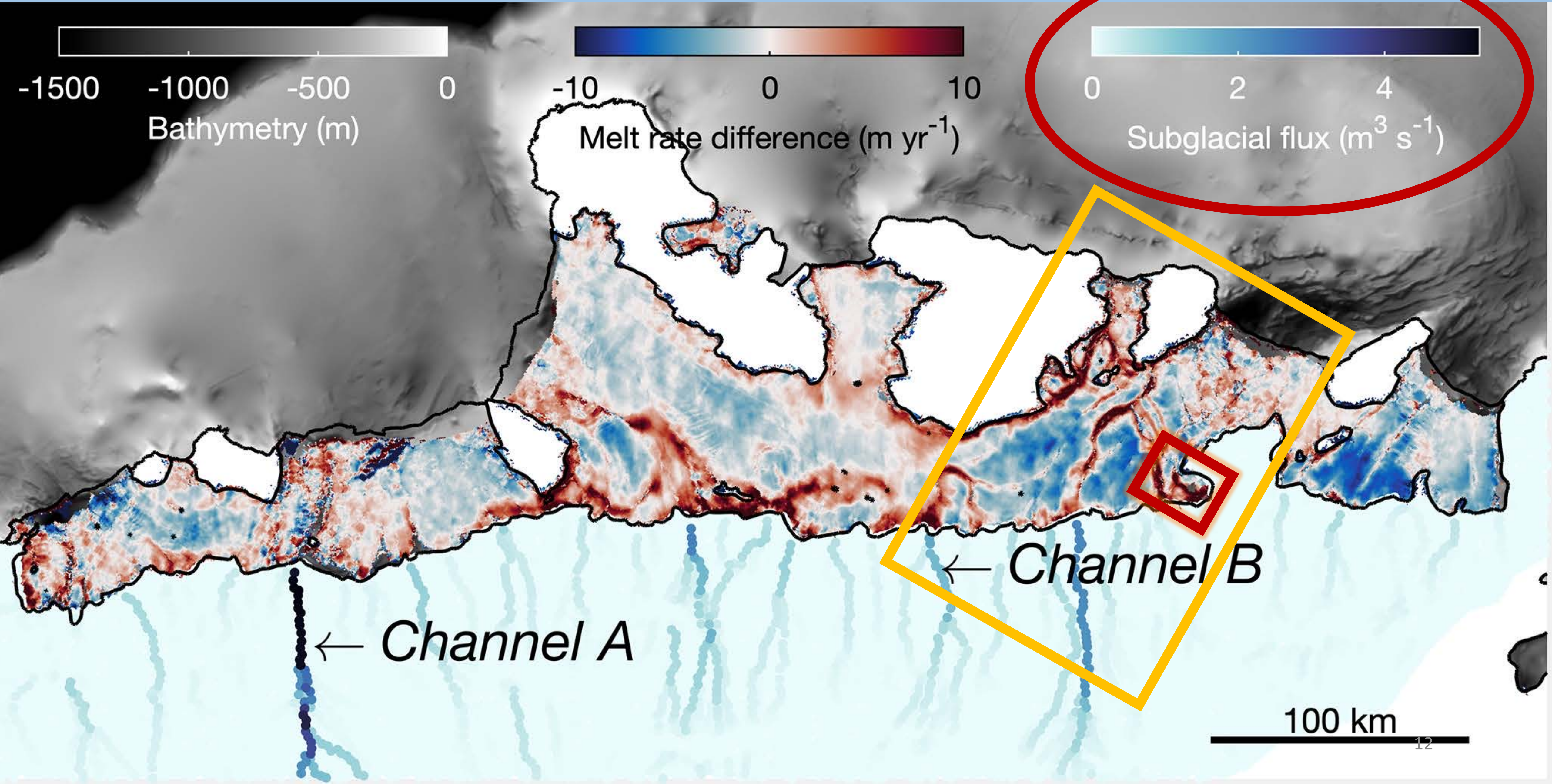

N
10 km

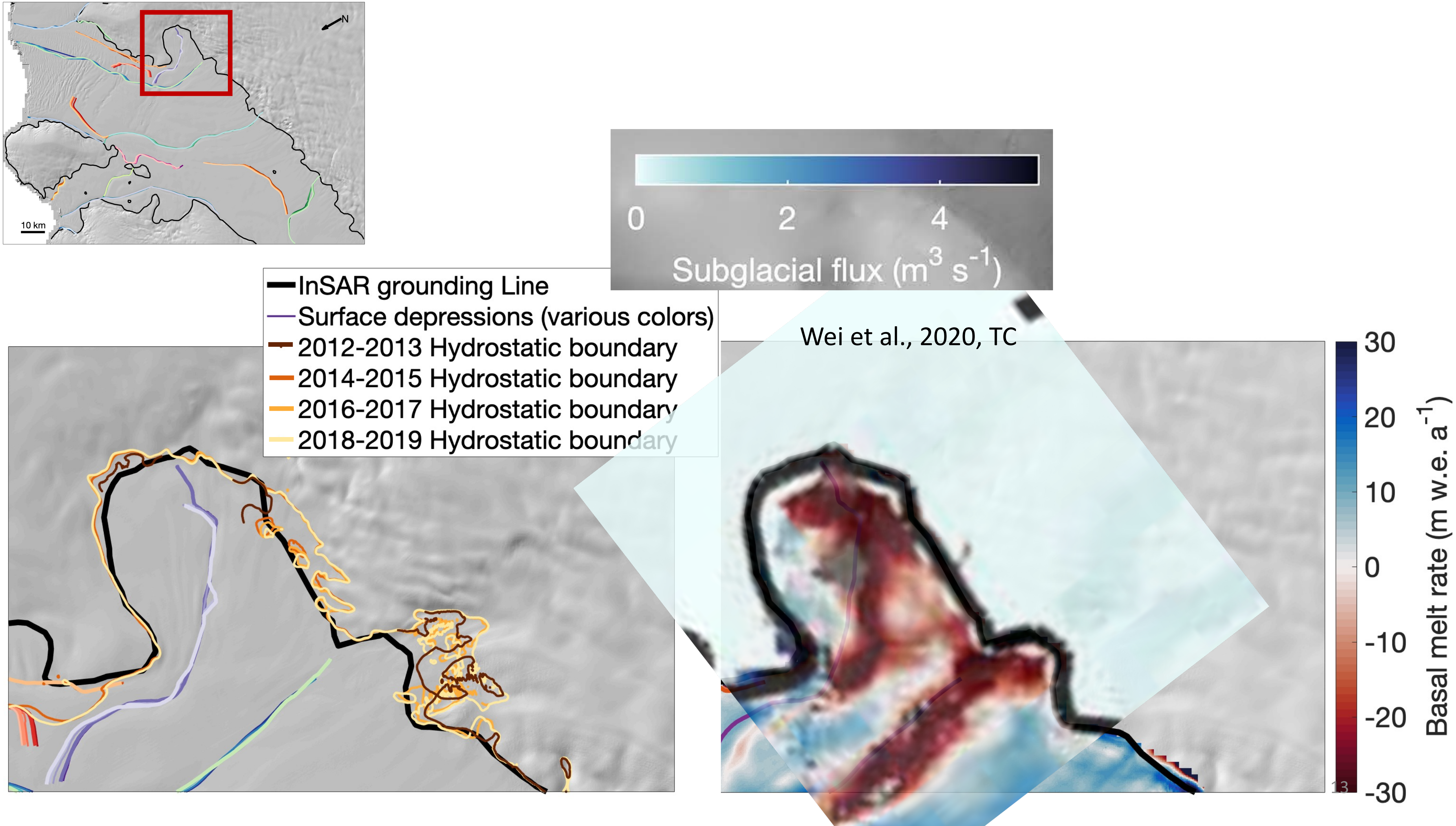

InSAR grounding Line
Surface depressions (various colors)
2012-2013 Hydrostatic boundary
2014-2015 Hydrostatic boundary
2016-2017 Hydrostatic boundary
2018-2019 Hydrostatic boundary


5
4
3
2
1
0
-1
-2
-3
-4
-5
Dh/Dt (m/yr)


N
10 km
InSAR grounding Line
Surface depressions (various colors)
2012-2013 Hydrostatic boundary
2014-2015 Hydrostatic boundary
2016-2017 Hydrostatic boundary
2018-2019 Hydrostatic boundary
30
20
10
0
-10
-20
-30
Basal melt rate (m w.e. a^{-1})

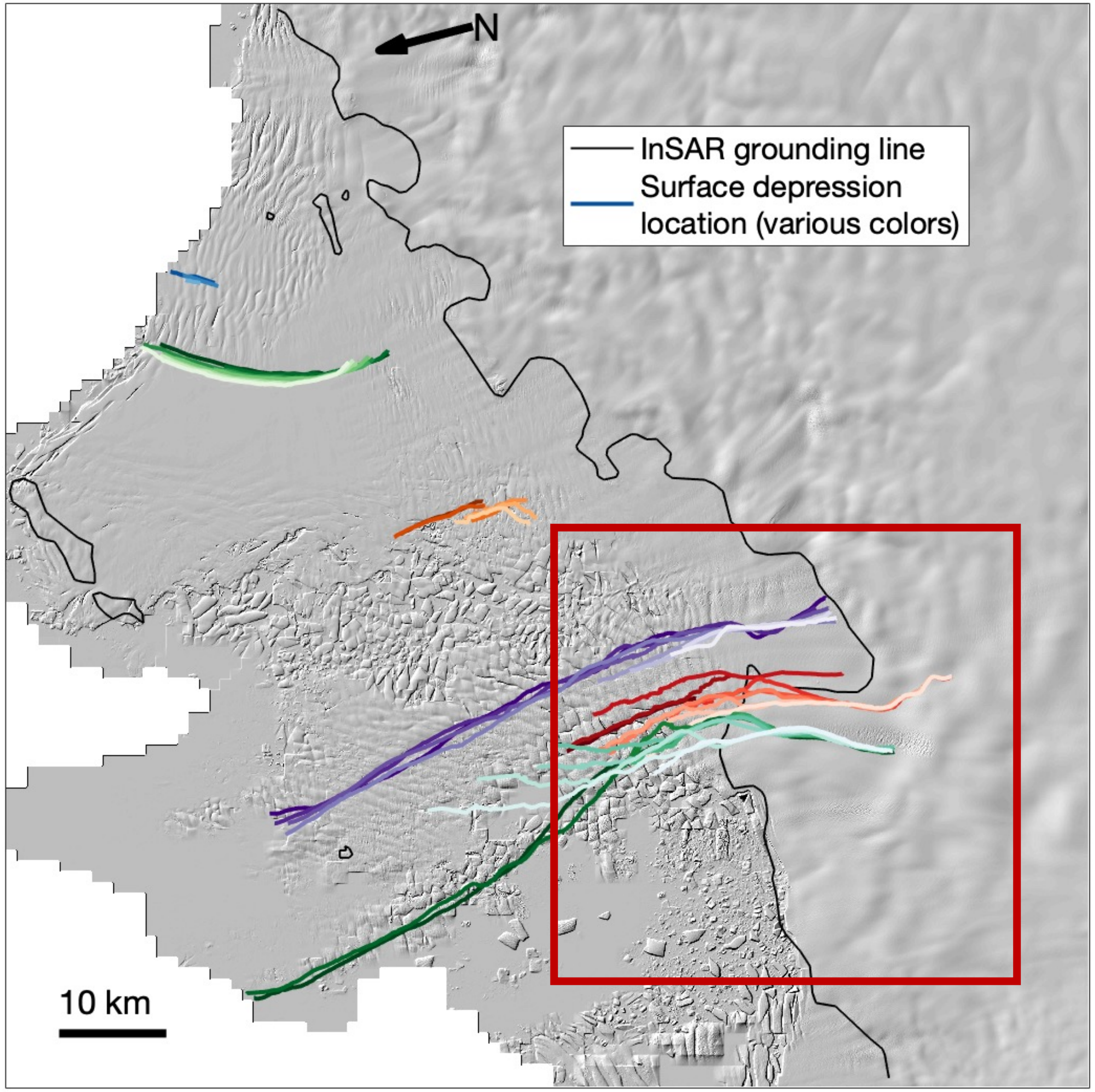
Modeled subglacial discharge - Wei et al., 2020, TC

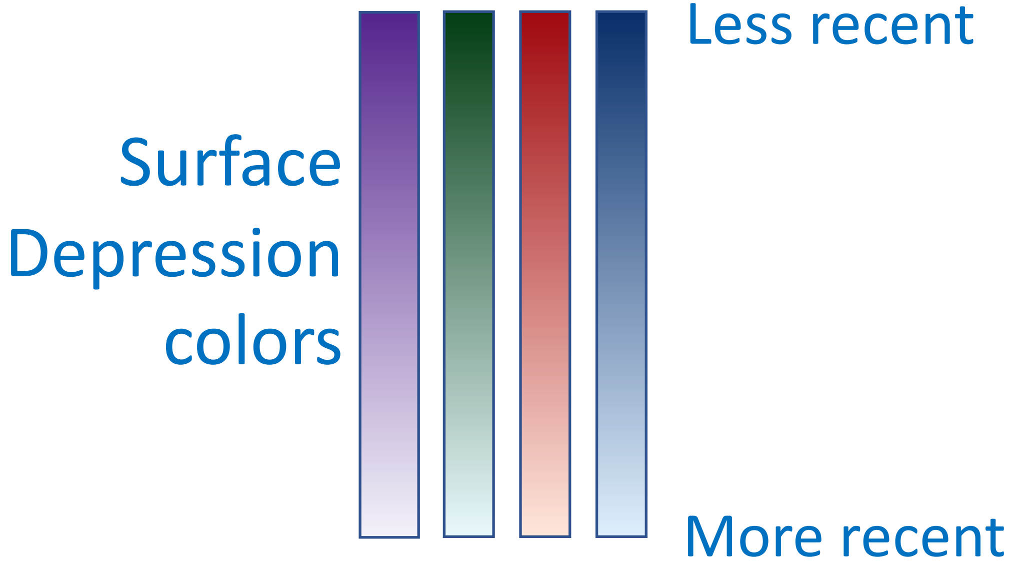


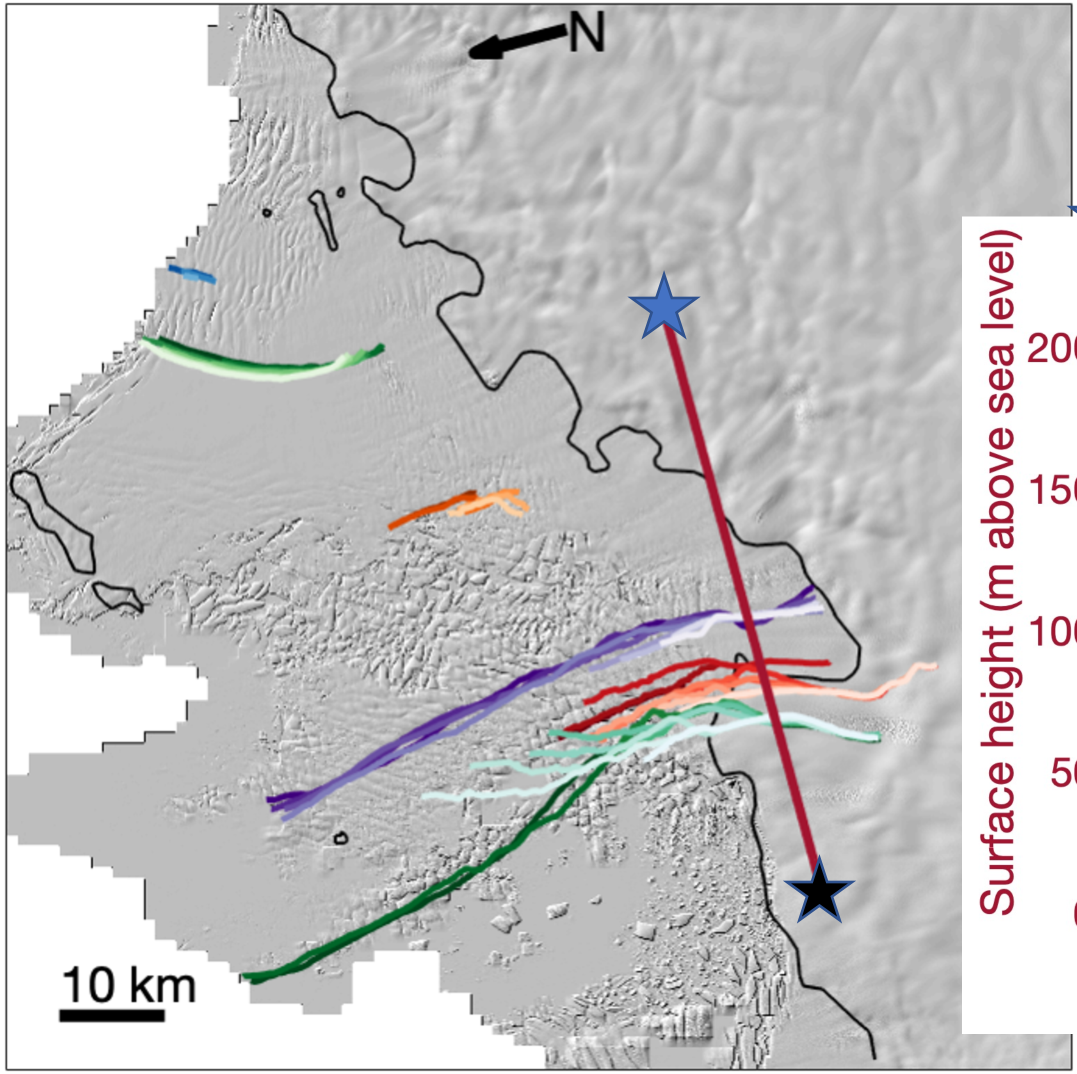


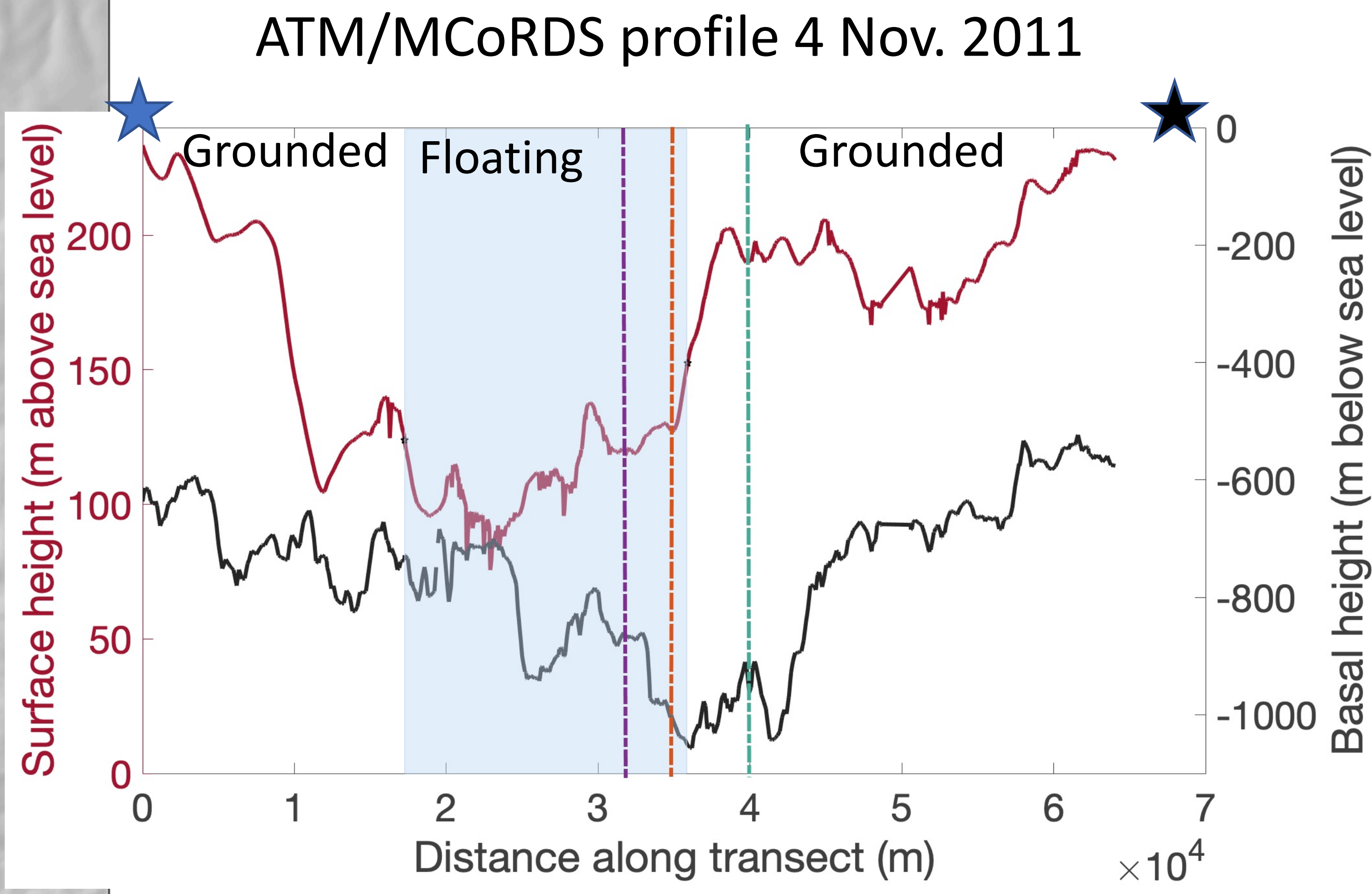
N
10 km
InSAR grounding Line
Surface depressions (various colors)
2012-2013 Hydrostatic boundary
2014-2015 Hydrostatic boundary
2016-2017 Hydrostatic boundary
2018-2019 Hydrostatic boundary
0
2
4
Subglacial flux (m^3 s^{-1})
Wei et al., 2020, TC
30
20
10
0
-10
-20
-30
Basal melt rate (m w.e. a^{-1})

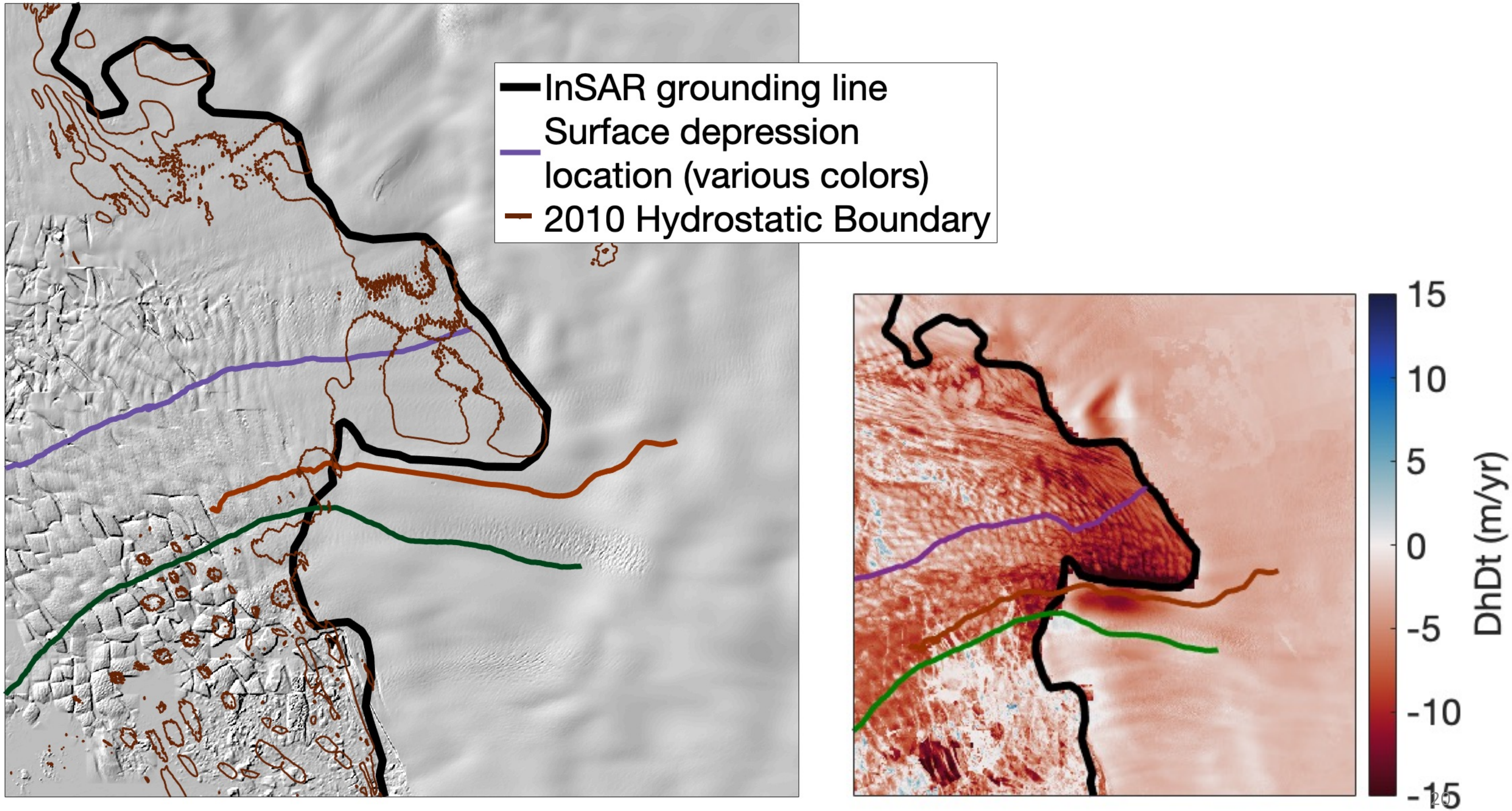
Thwaites Ice Shelf

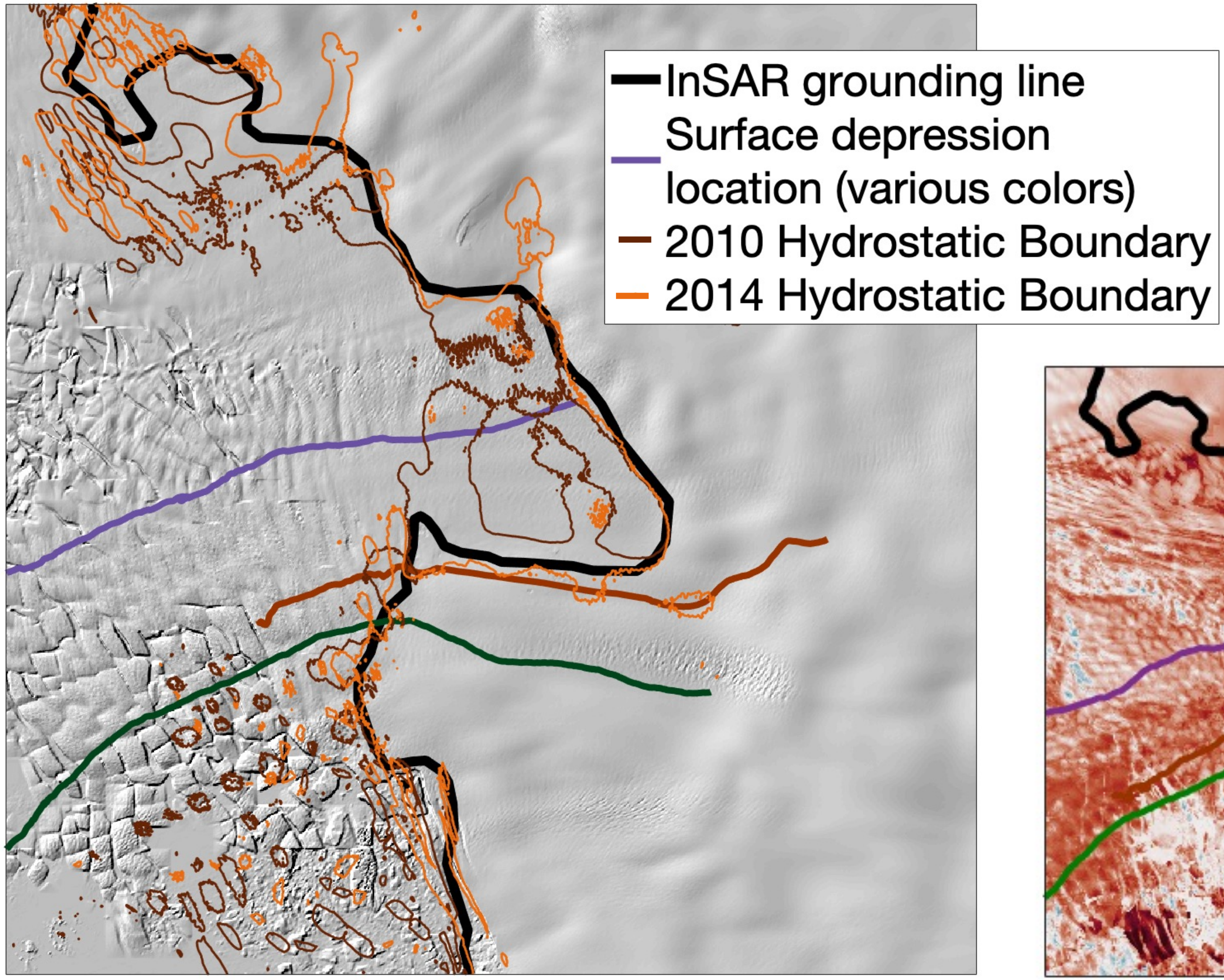


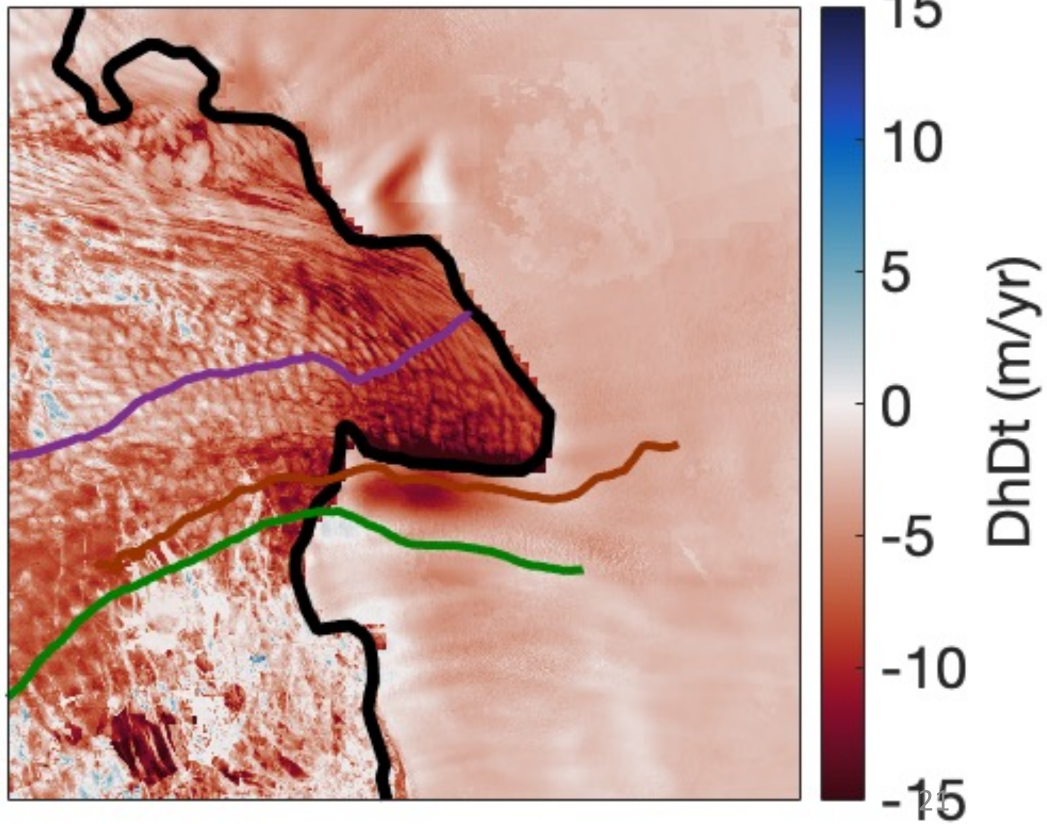


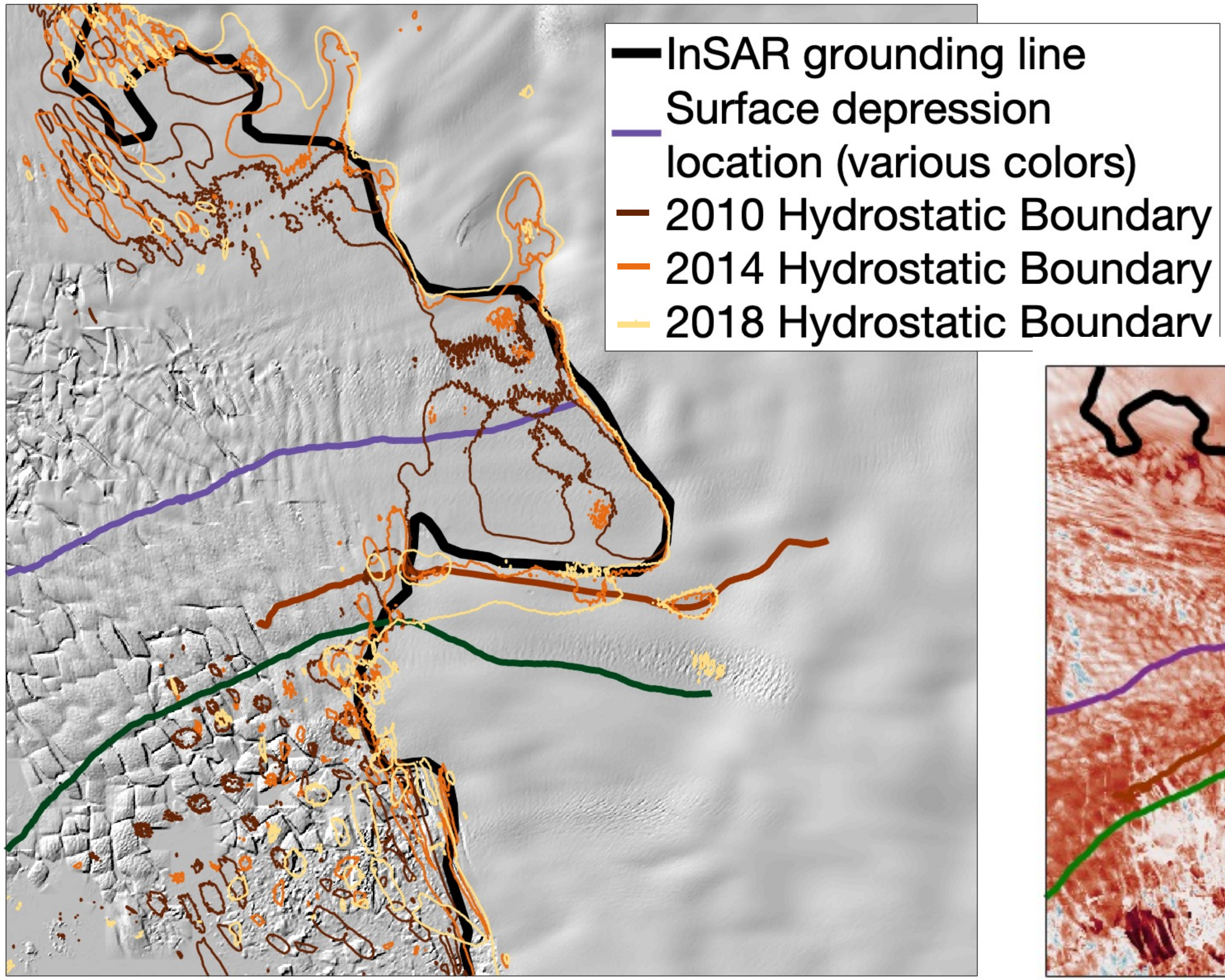

N
10 km

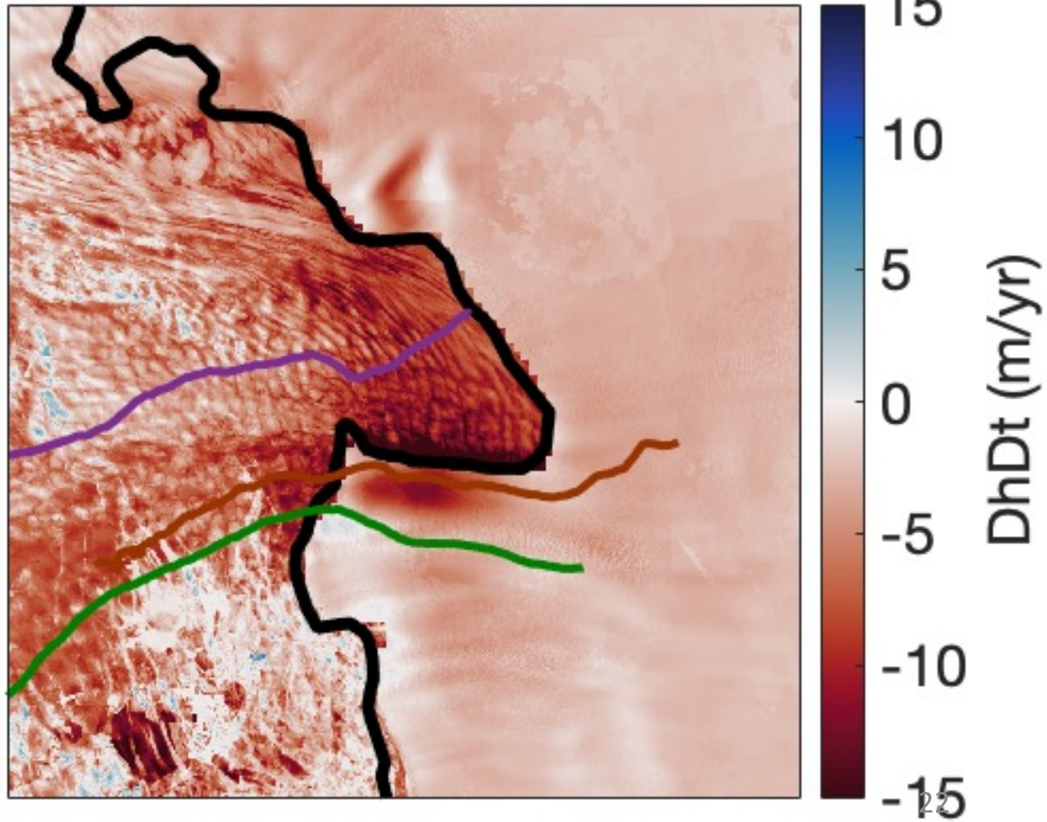

ATM/MCoRDS profile 4 Nov. 2011
Grounded
Floating
Grounded
Surface height (m above sea level)
Basal height (m below sea level)
Distance along transect (m)
$\times 10^4$

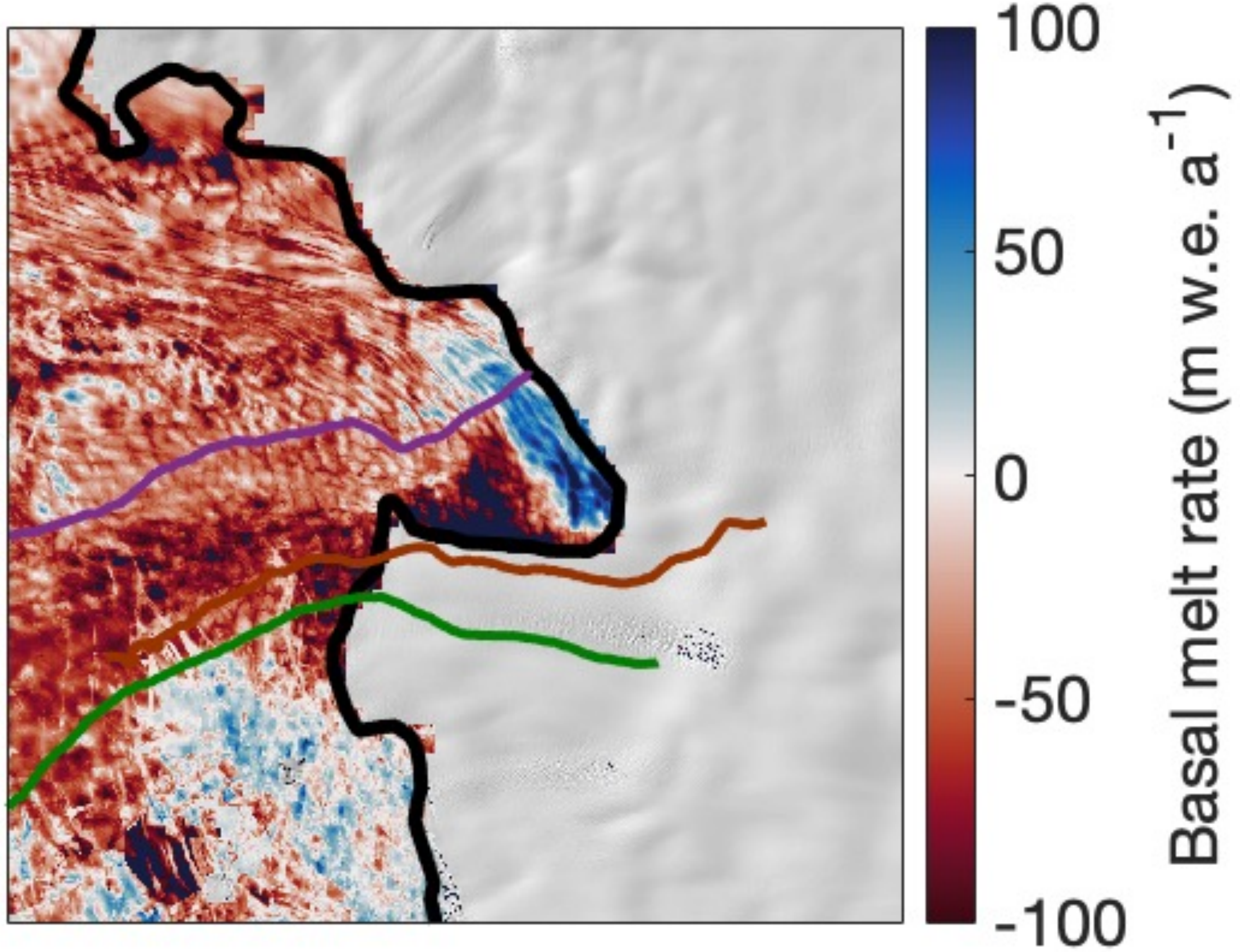

InSAR grounding line
Surface depression location (various colors)
2010 Hydrostatic Boundary
15
10
5
0
-5
-10
-15
DhDt (m/yr)

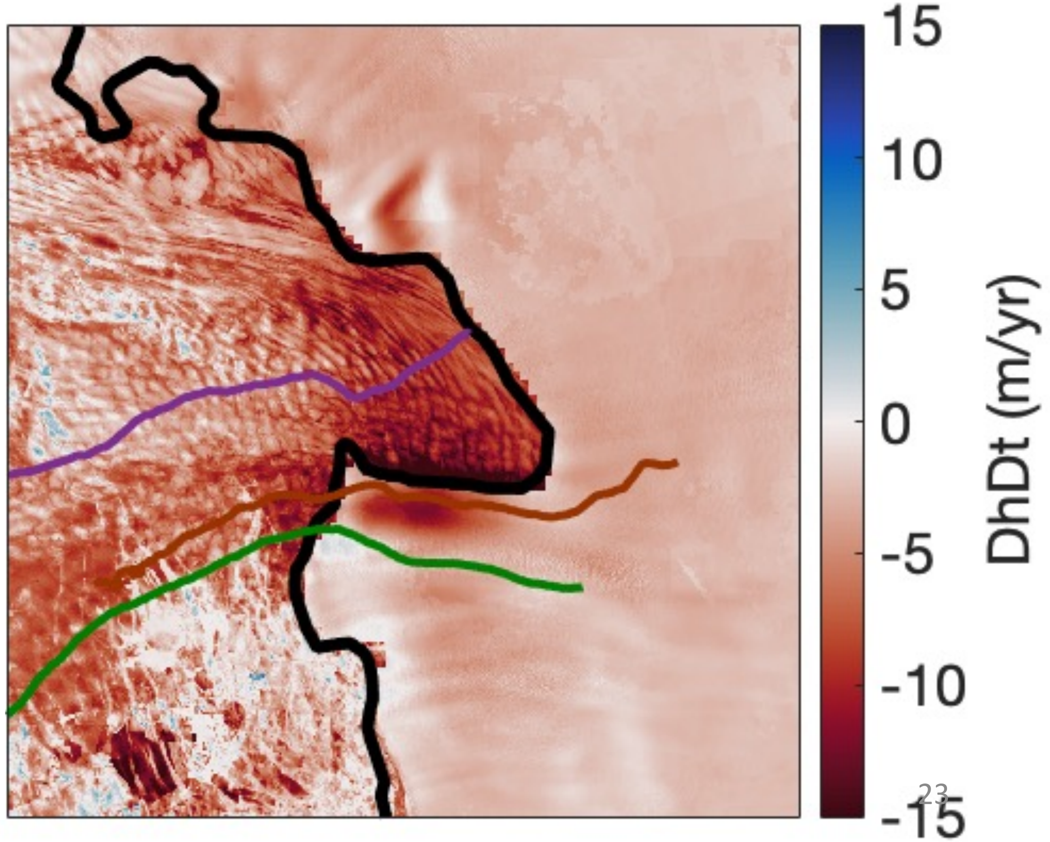

InSAR grounding line
Surface depression location (various colors)
2010 Hydrostatic Boundary
2014 Hydrostatic Boundary

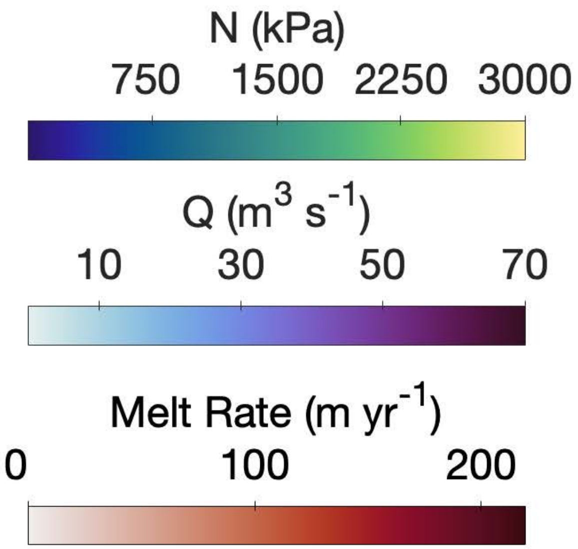

15
10
5
0
-5
-10
-15
DhDt (m/yr)

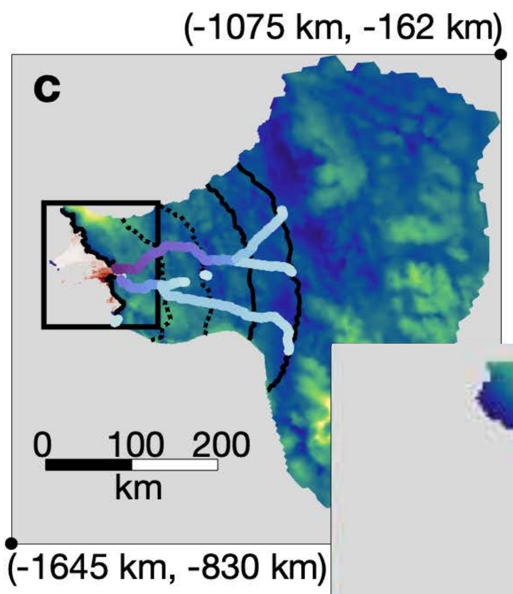

InSAR grounding line
Surface depression location (various colors)
2010 Hydrostatic Boundary
2014 Hydrostatic Boundary
2018 Hydrostatic Boundary


15
10
5
0
-5
-10
-15
DhDt (m/yr)

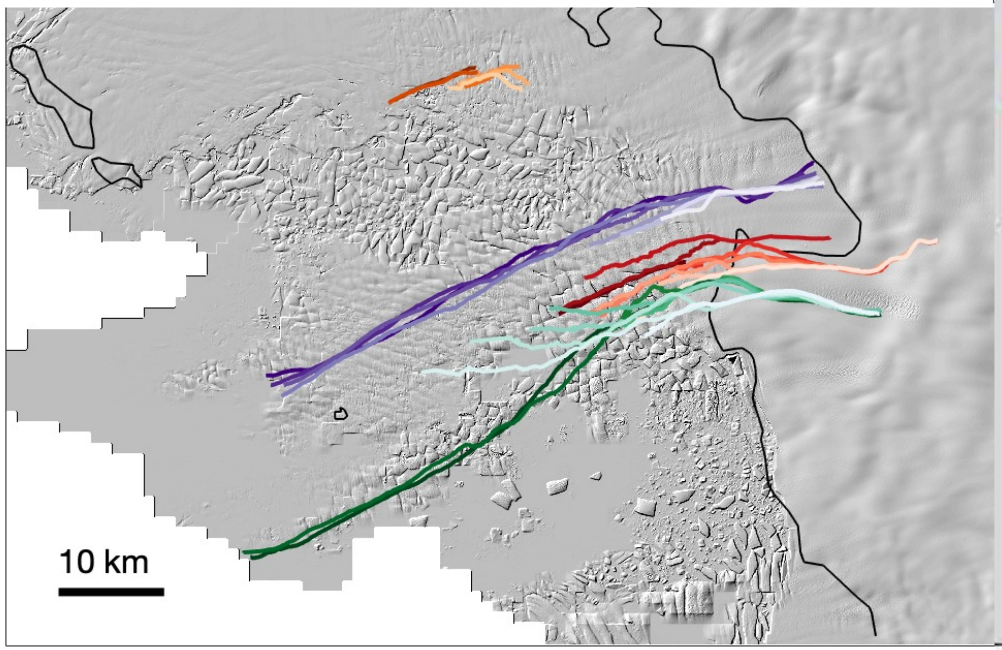

100
50
0
-50
-100
Basal melt rate (m w.e. a^{-1})

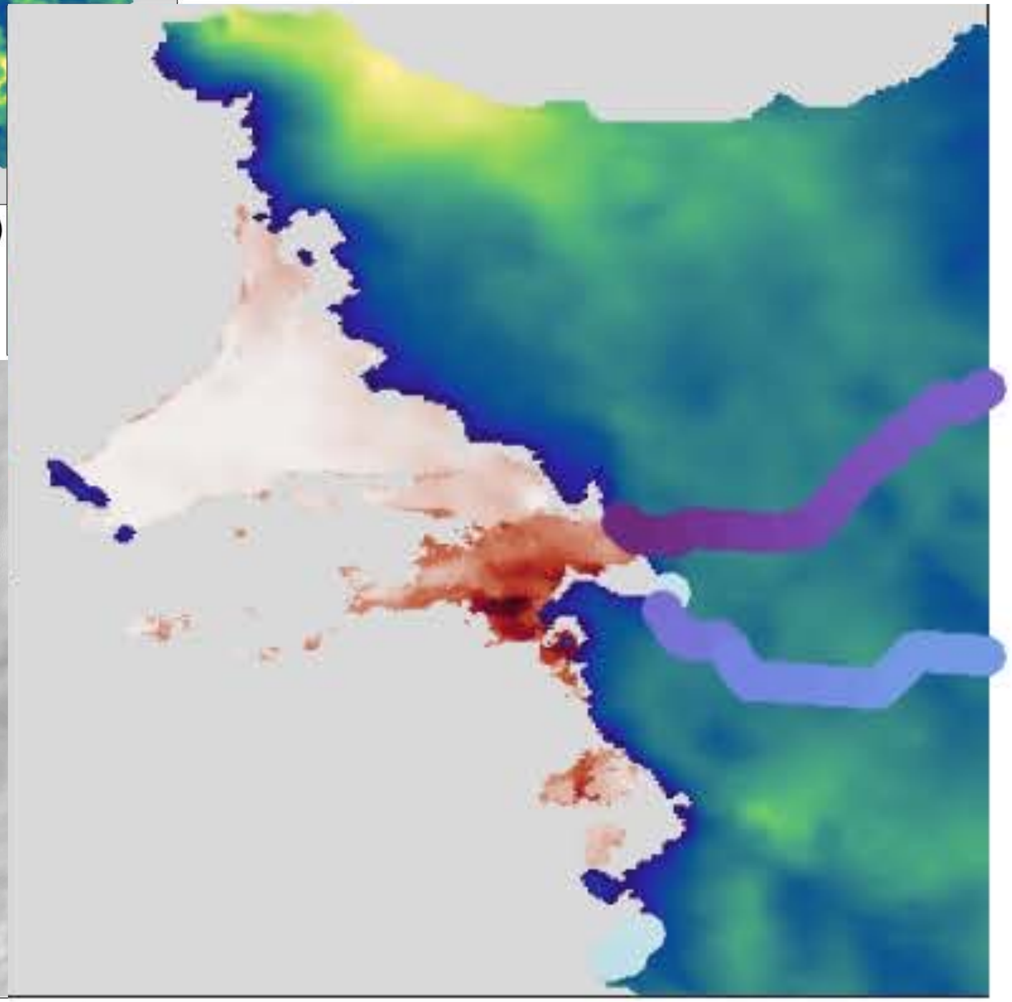

15
10
5
0
-5
-10
-15
DhDt (m/yr)

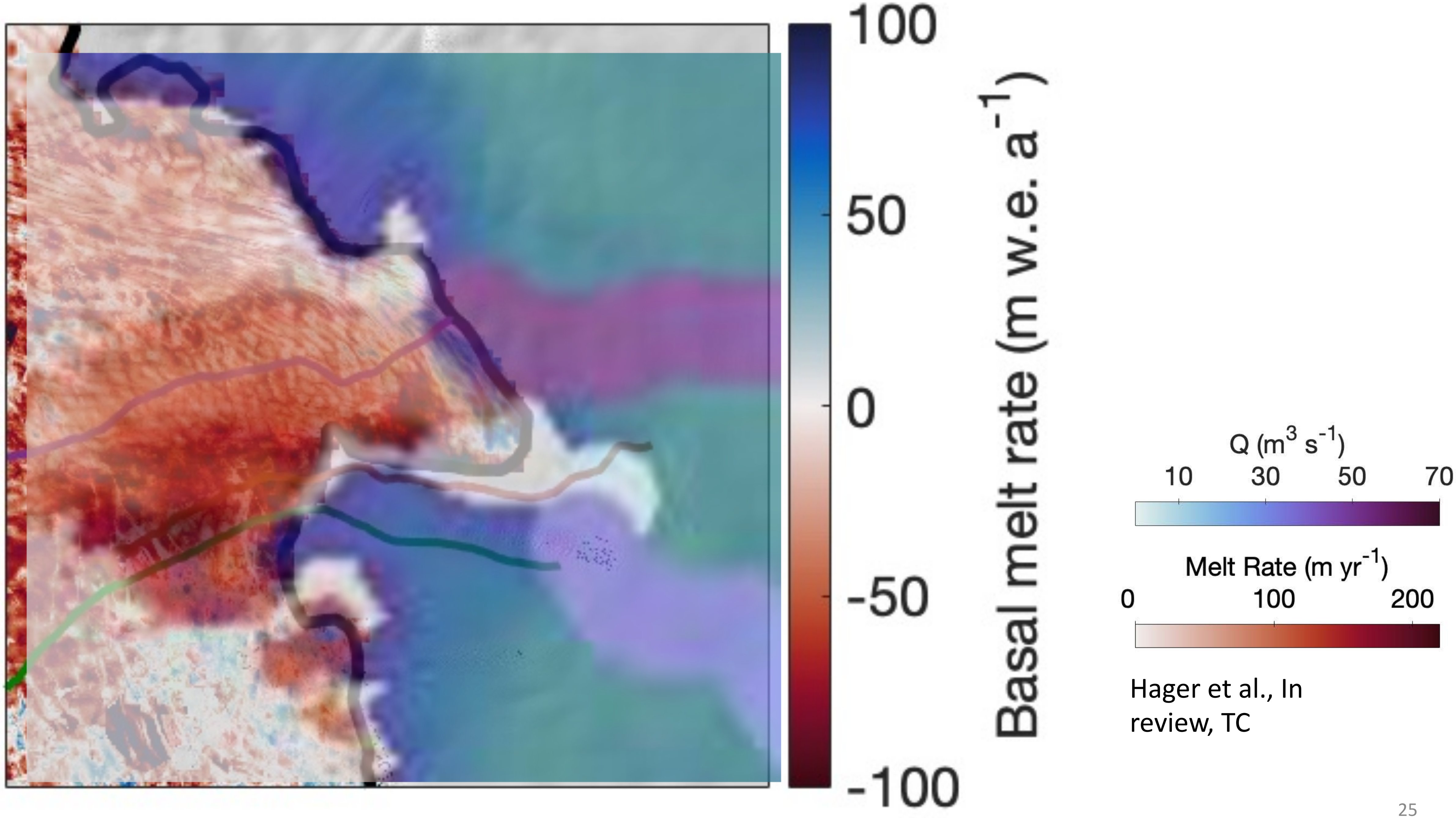




Hager et al., In review, TC

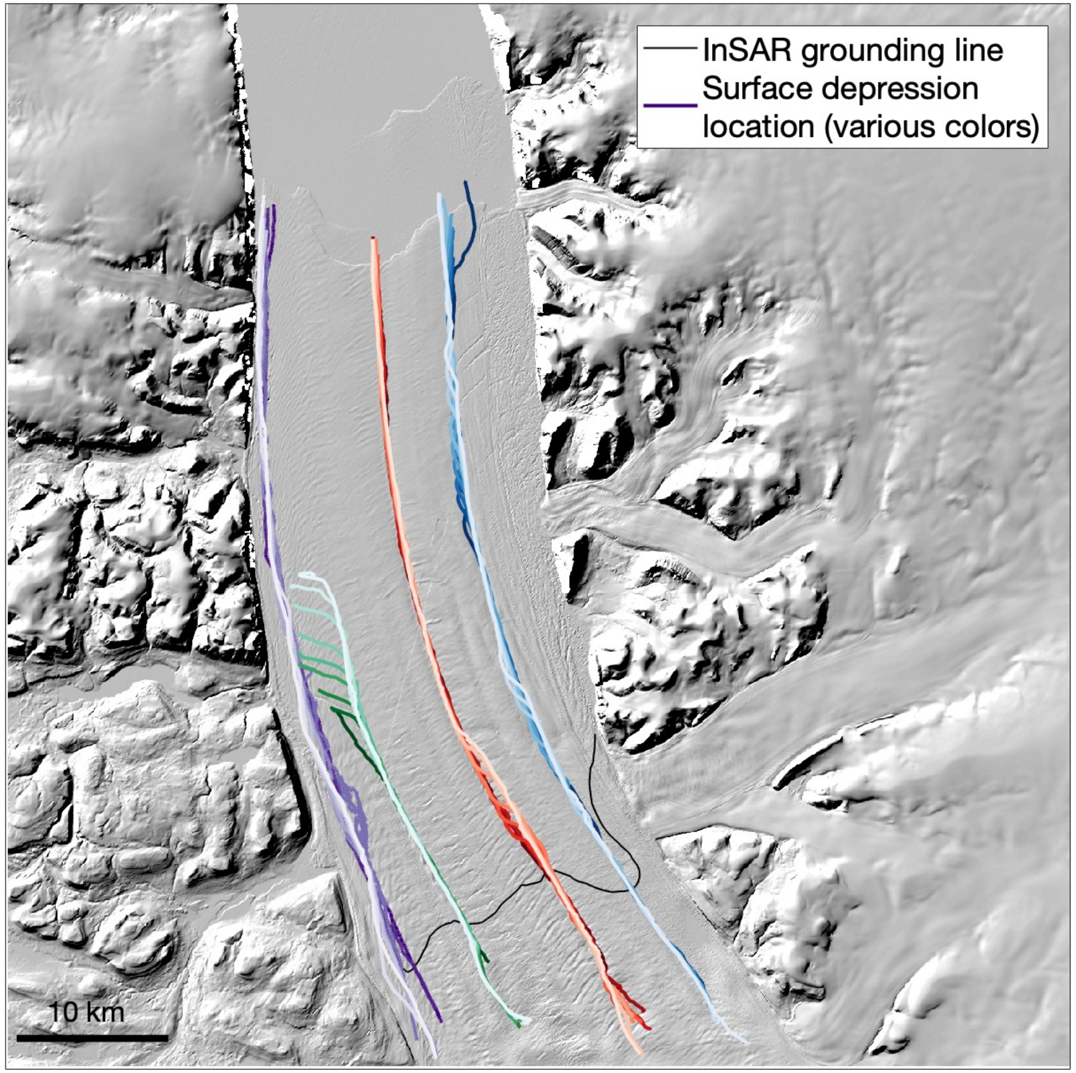


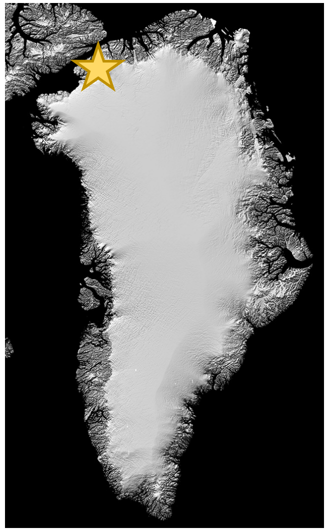


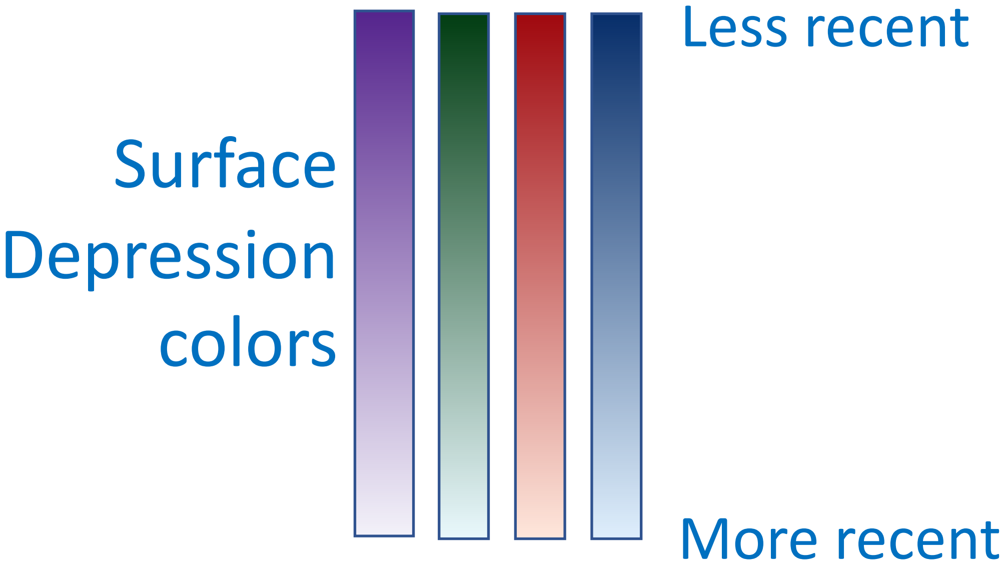


Hager et al., In review, TC

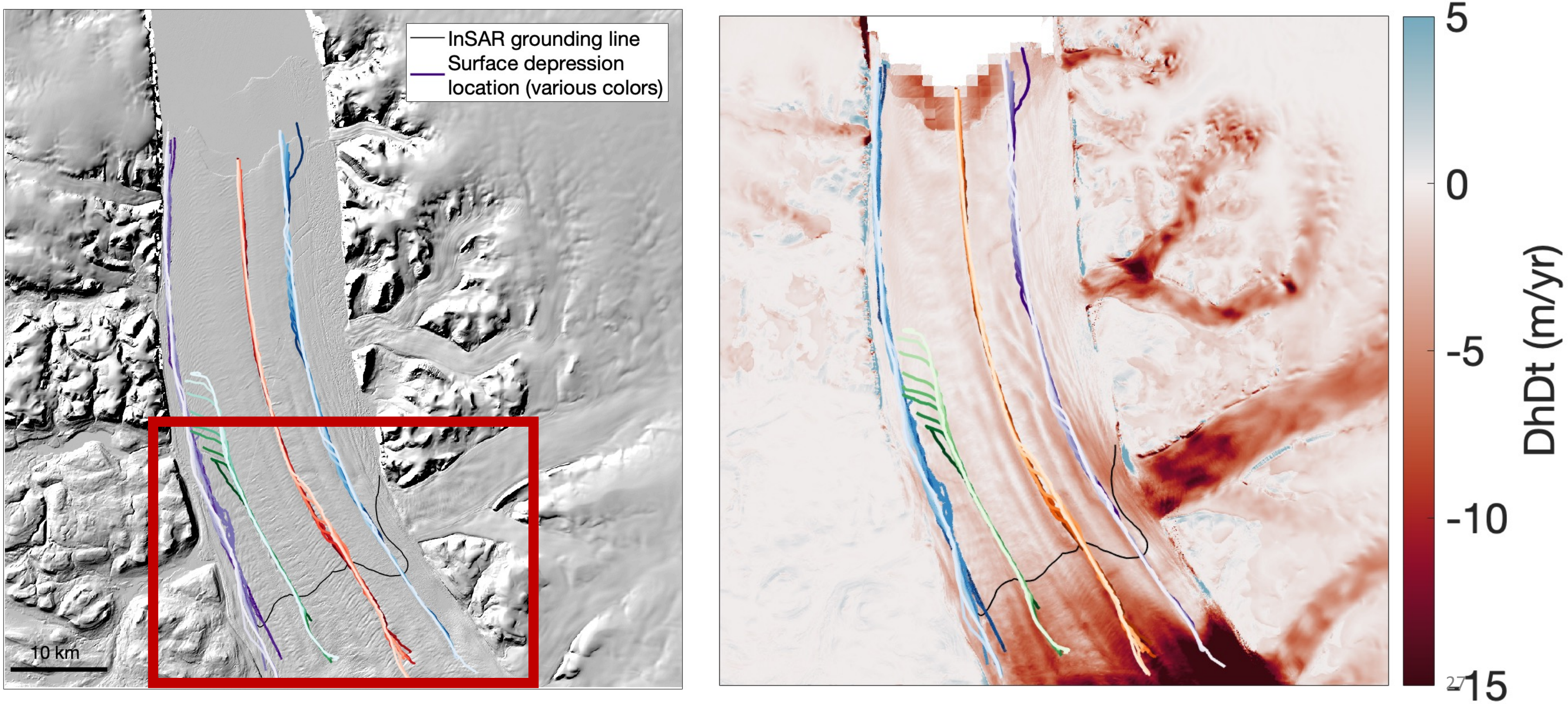
Petermann Ice Shelf

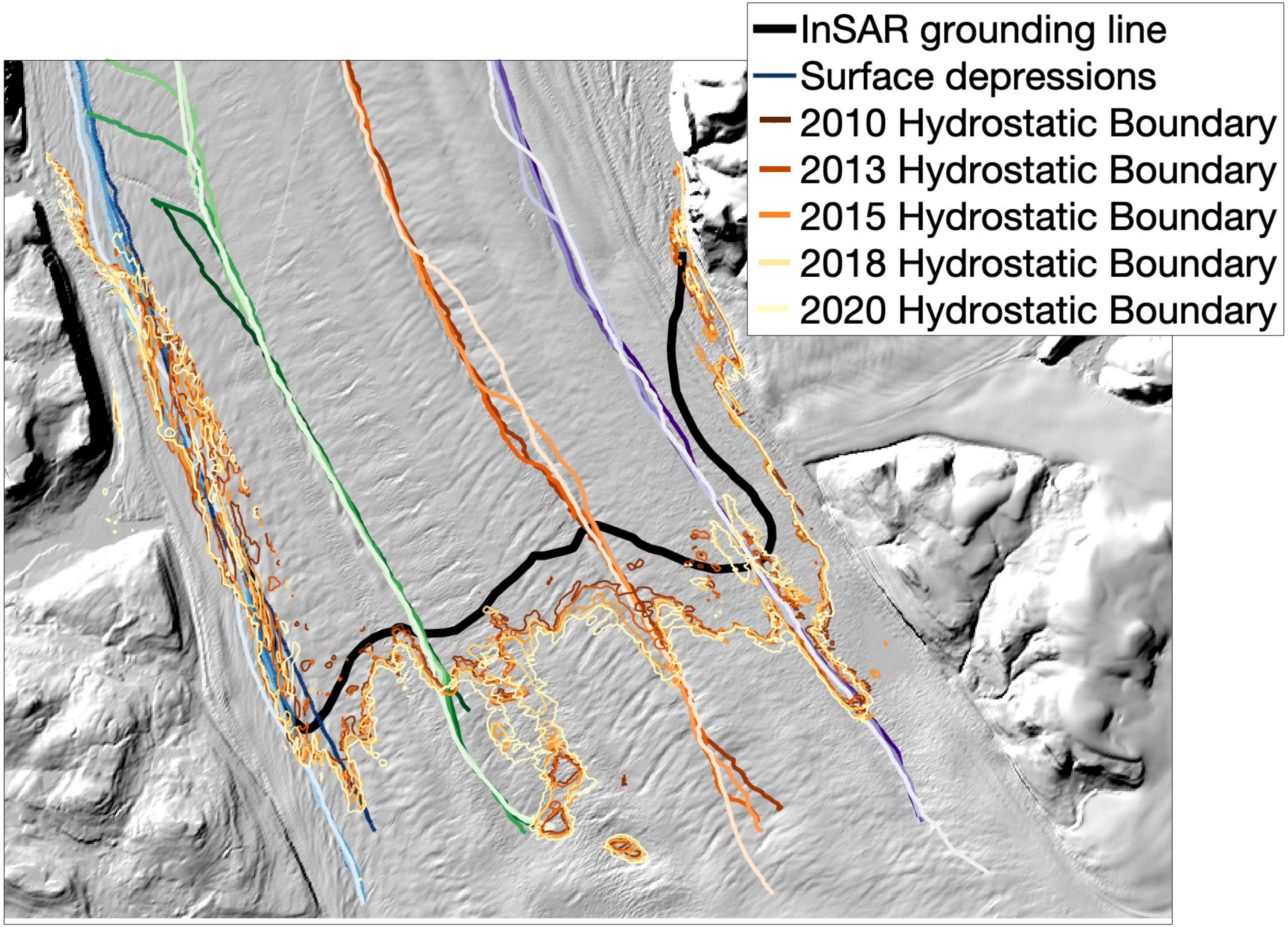


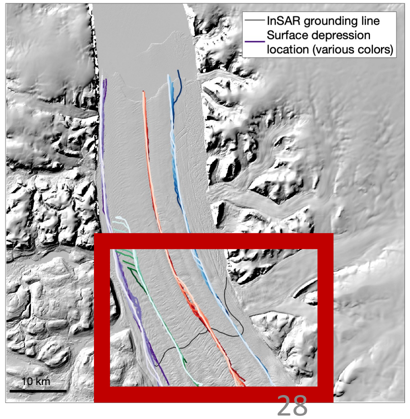


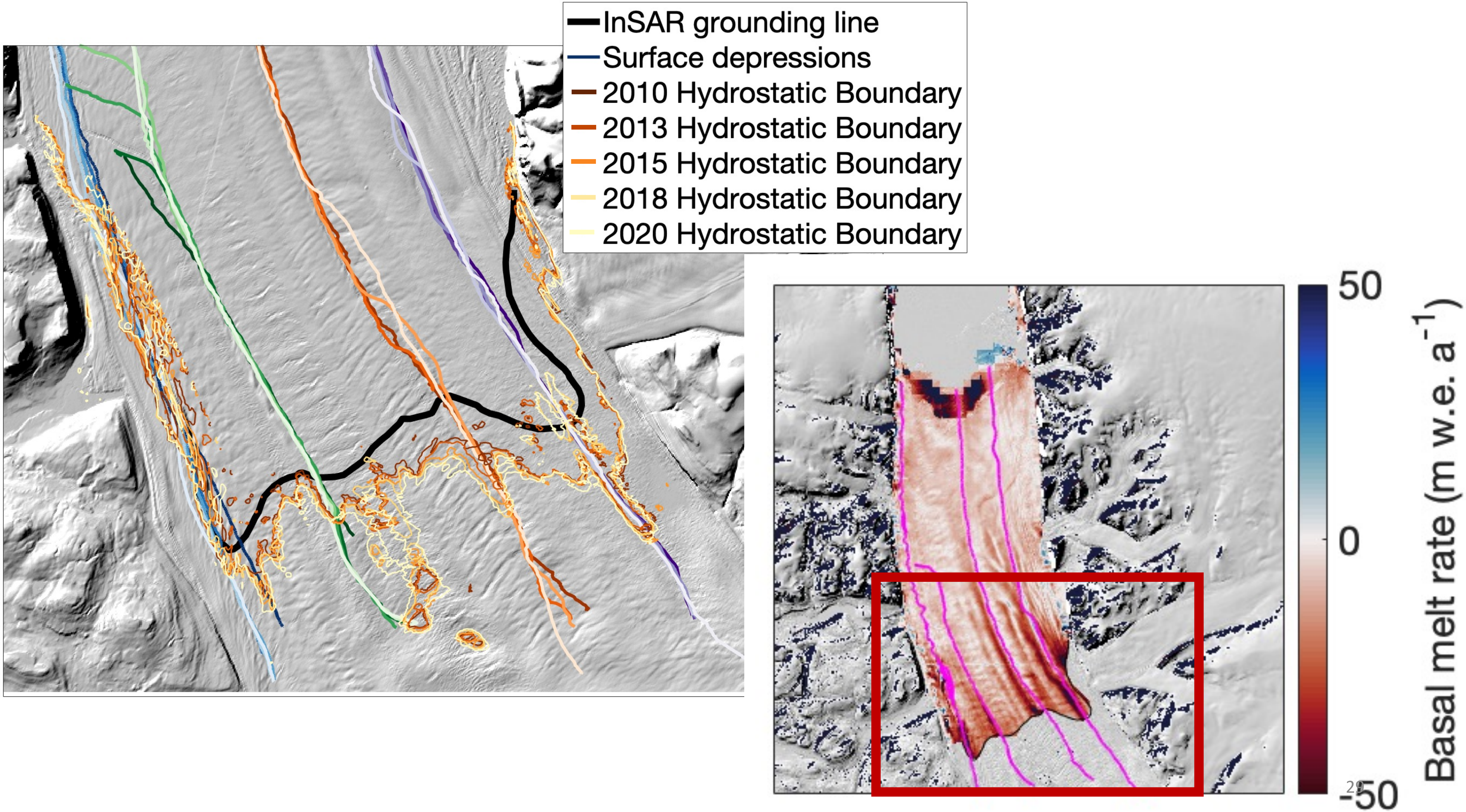


Petermann Ice Shelf




InSAR grounding line
Surface depressions
2010 Hydrostatic Boundary
2013 Hydrostatic Boundary
2015 Hydrostatic Boundary
2018 Hydrostatic Boundary
2020 Hydrostatic Boundary


InSAR grounding line
Surface depression
location (various colors)
10 km



InSAR grounding line
Surface depressions
2010 Hydrostatic Boundary
2013 Hydrostatic Boundary
2015 Hydrostatic Boundary
2018 Hydrostatic Boundary
2020 Hydrostatic Boundary
50
0
-50
Basal melt rate (m w.e. a^{-1})

Takeaways

- Several channels observed to be lengthening landward are associated with high basal melt rates, rapid thinning of grounded ice, and retreat of the hydrostatic boundary
    - What do these changes in ice shelf structure mean for ice shelf stability?

- Several channels previously thought to be ocean-sourced line up with modeled channelized subglacial discharge