

Tidal Modulations of Antarctic Ice Shelf Melting

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Publication status

- First round: Major revisions, mostly questioning model evaluation and our approach to entangle tidal melt mechanisms

Review status: this preprint is currently under review for the journal TC.

Tidal Modulation of Antarctic Ice Shelf Melting

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Abstract. Tides influence basal melting of individual Antarctic ice shelves, but their net impact on Antarctic-wide ice-ocean interaction has yet to be constrained. Here we quantify the impact of tides on ice shelf melting and the continental shelf seas by means of a 4 km resolution circum-Antarctic ocean model. Activating tides in the model increases the total basal mass loss by 57 Gt/yr (4 %) while decreasing continental shelf temperatures by 0.04 °C, indicating a slightly more efficient conversion of ocean heat

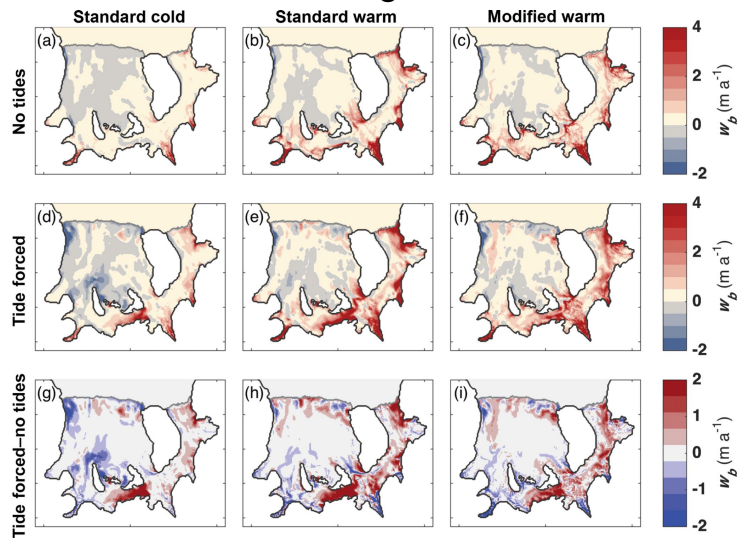
Importance

- Tides around Antarctica can be large (up to 3.5 m range)
- Regional ocean models show that they modulate ice shelf basal melting
- Potentially large consequences for ice sheet discharge and climate

Movie of tides around Antarctica

<https://www.esr.org/research/polar-tide-models/movies/>

Modelled tidal melting under Filchner-Ronne Ice Shelf



Mueller et al. (2018)

Gap

- The impact of tides on ice shelf basal melting has not been quantified in a pan-Antarctic context.
- Little is known about the underlying tidal melt mechanisms (tide ice shelf interactions) and their relative importance.

Aims

- Quantification of Antarctic ice shelf melting driven by tides.
- Exploration of the relative importance of the underlying mechanisms.

Method

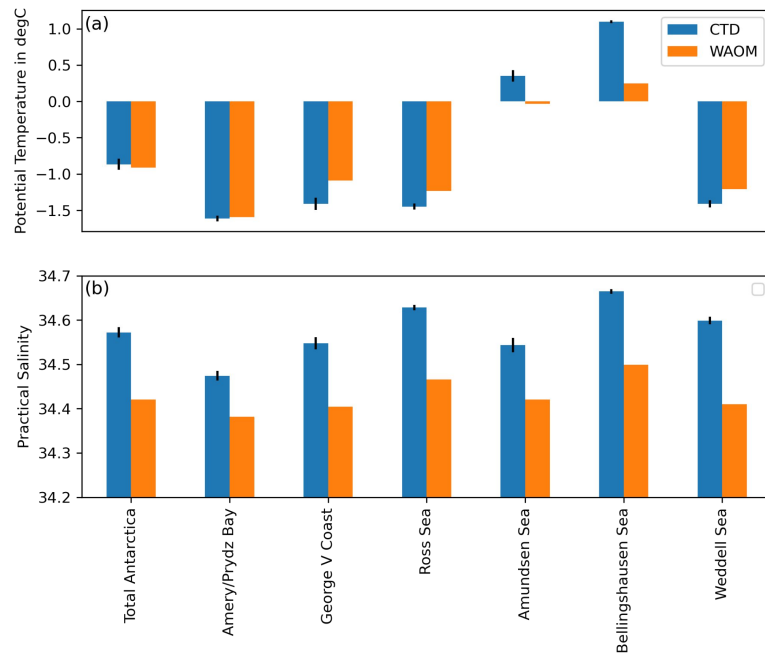
- pan-Antarctic ocean-ice shelf model with tides: The Whole Antarctic Ocean Model (WAOM v1.0; [GMDD preprint](#); major revisions)
- 4 km resolution; based on ROMS; repeated single year forcing (tides, surface fluxes)
- Tidal accuracy is comparable with widely used barotropic tide models
- Reasonable agreement with CTD observations on the shelf and satellite derived ice shelf average mass loss (evaluation in GMDD preprint)

Review status: a revised version of this preprint is currently under review for the journal GMD.

The Whole Antarctic Ocean Model (WAOM v1.0): Development and Evaluation

Ole Richter^{1,2}, David E. Gwyther¹, Benjamin K. Galton-Fenzi³, and Kaitlin A. Naughten⁴

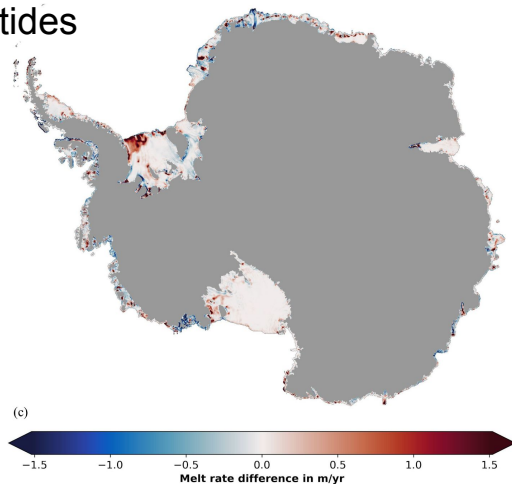
Bottom layer potential temperature compared against observations from Schmidt et al. 2014 (sector averages)



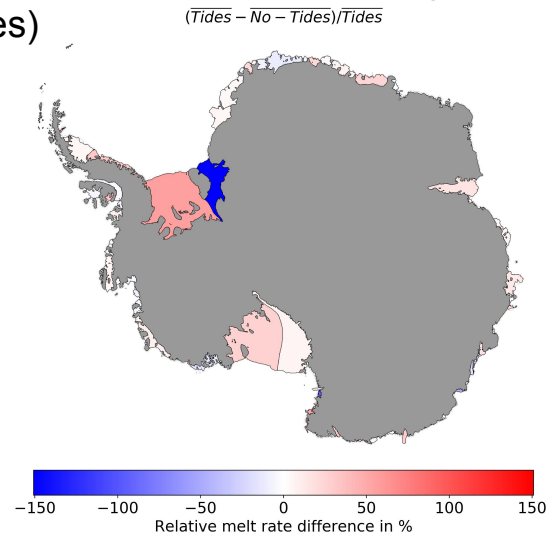
Results: Tidal melting

- Antarctic-wide impact small (~4% increase in mean melt rate when activating tides)
- Ice shelf average impact for Filchner and Ronne is about ~150% with opposing sign (Ronne increase with tides, Filchner decrease)
- Melting at high resolution can change by more than 400 % (often balanced within nearby regions)

Melt rate difference when activating tides



Relative melt rate difference when activating tides
(ice shelf averages)



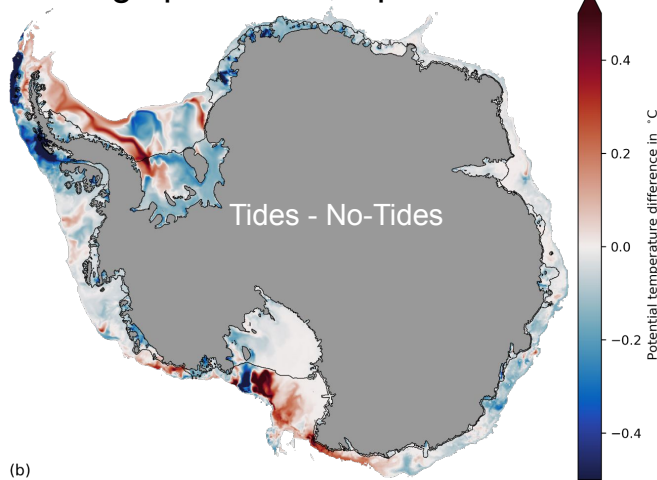
Results: Impact on ice sheet flow

- Melting at high resolution is sensitive to tides -> does it matter for ice sheet flow?
- Melt rate change due to tides + buttressing flux response numbers (Reese et al., 2018) = instantaneous grounding line flux response when activating tides
- Ice shelf average grounding line flux response is small compared to discharge rates (ice shelf averages are below 0.015%)
- However, longer term response and feedbacks might matter (tides are highly sensitive to water column thickness; see Mueller et al. 2018; Griffiths and Peltier, 2009; Rosier et al., 2014; Wilmes and Green, 2014)
- We need: Coupled ocean - ice shelf - ice sheet model **with tides**

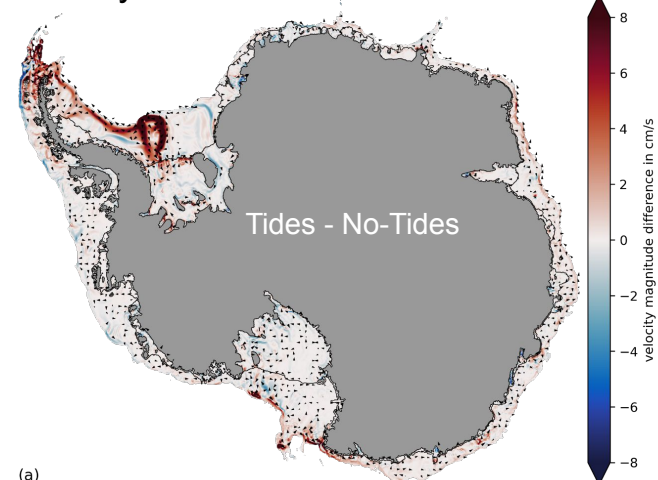
Results: Ocean

- Total impact on continental shelf temperature is small (-0.04 degC when activating tides)
- Regional changes in depth average temperature can be higher than 0.5 degC
- Tidal melting of Ronne ice shelf coincides with tide induced Gyre on the western Weddell Sea continental shelf

Tide induced change in mean depth average potential temperature



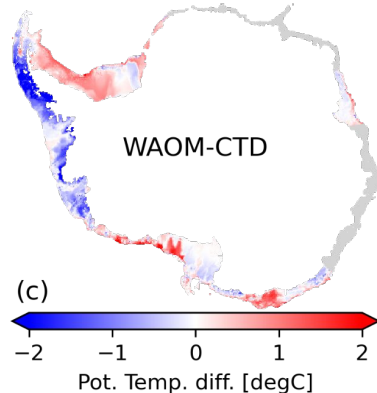
Tide induced change in mean barotropic velocity



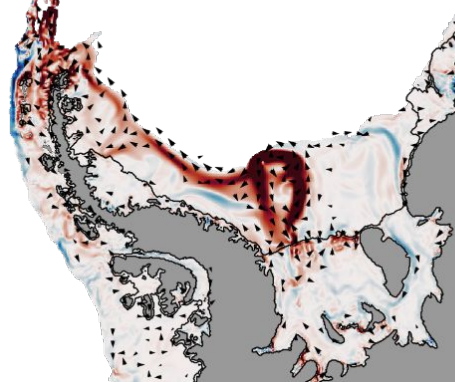
Results: Tidal modulations in the Weddell Sea

- Regional study by Makinson & Nicholls (1999) also get tide induced Gyre in Weddell Sea (barotropic model without ice shelf melting)
- The gyre is (at least in part) forced by tide-topography interaction
- WAOM might overestimate its impact on melting, due to a warm bias on the continental shelf
- Regional ocean-ice shelf study by Mueller et al. 2018 doesn't show the gyre
- -> further studies needed

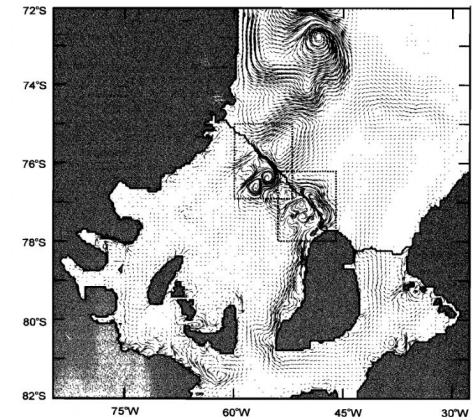
Bottom layer temperature comparison against observations



Tide induced change in mean barotropic velocity (WAOM v1.0)



Residual tidal currents from a barotropic model without ice shelf melting (Makinson & Nicholls, 1999)



Tidal melt mechanisms: towards the Why.

- Resolving tides is expensive.
- Understand the relative importance of the mechanisms behind tidal melting, we might get away with parameterising these effect (if we decide that we need them).
- Approaches to modify the friction velocity have been developed (Jenkins et al. 2010) and tested for some regions (e.g. Amundsen-Bellingshausen Seas, Jourdain et al. 2019)
- However, Tide-Topography interaction and the Weddell sea gyre would not be captured by these approaches.

Tidal melt mechanisms: far field vs. nearby

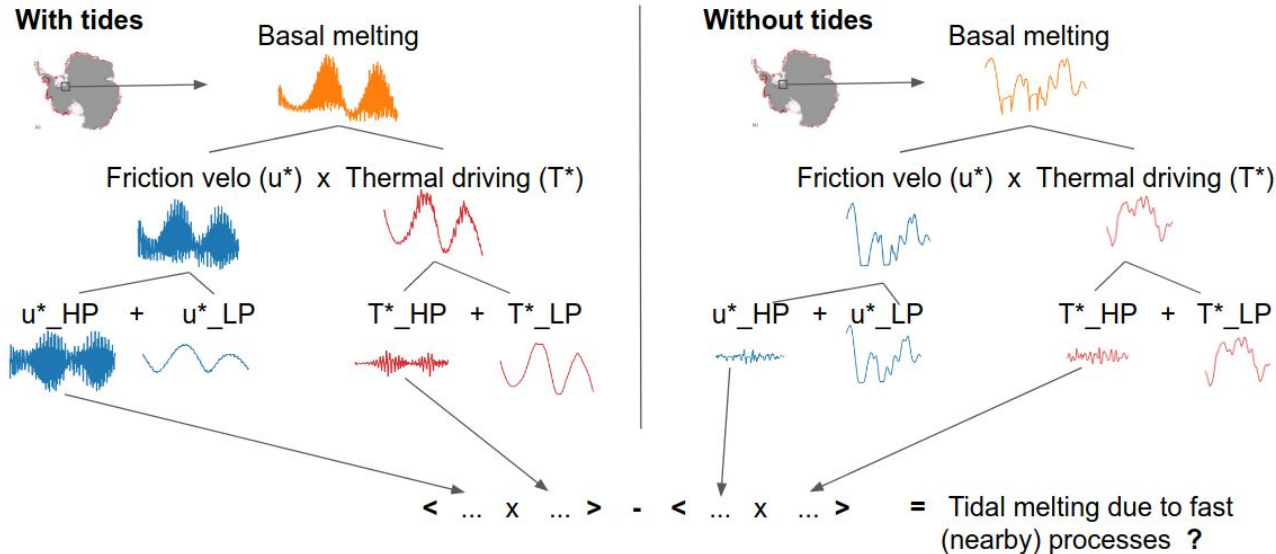
- Main characteristics of modelled melt rate variations can be approximated as the product of friction velocity (u^*) and thermal driving (T^*).
- Temporal filtering can be used to separate tidal current interaction from residual effects (less expensive than harmonic analysis, see, e.g. Stewart et al. 2018)
- Tidal residual effects can arise from interactions between, e.g.:
 - Tide-Topography
 - Tide-Ocean Stratification
 - Tide-Ice shelf melting (buoyant plumes)
- High frequency tidal effects (oscillatory) can arise from, e.g.:
 - Tidal currents (shear, mixing)
 - Tidal current amplification (buoyant meltwater plumes)
 - ...?

Tidal melt mechanisms: far field vs. nearby

- Only ideas so far. Feedback would be great.
- Questions:
 1. Can we separate nearby (far field) effects by only considering the time mean covariance of high pass (low pass) filtered u^* and T^* ?
 2. Can we estimate the relative importance of including tidal effects in u^* vs T^* by neglecting individual frequency bands in u^* or T^* ?

Tidal melt mechanisms: far field vs. nearby

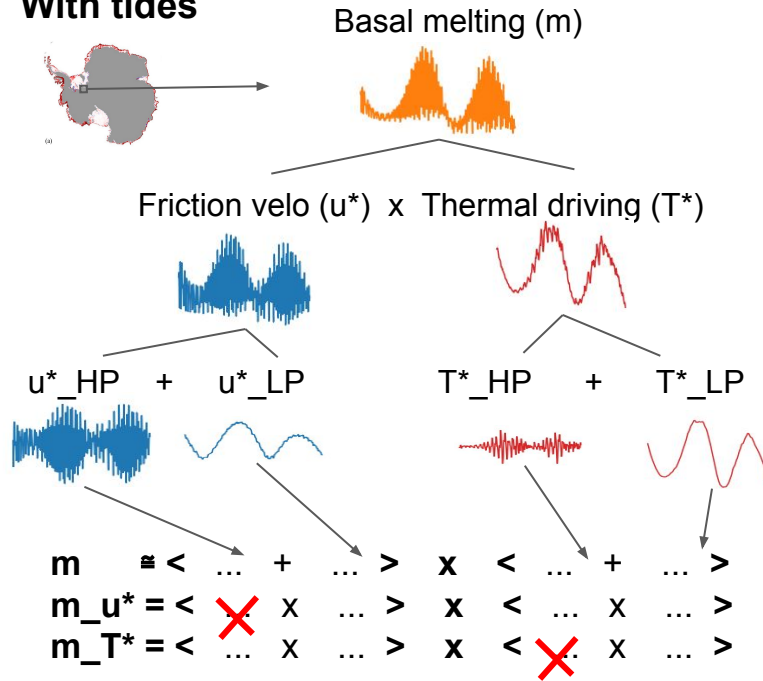
- Question 1: Can we separate nearby (far field) effects by only considering the time mean covariance of high pass (low pass) filtered u^* and T^* ?



Tidal melt mechanisms: importance of u^* vs T^*

- Question 2: Can we estimate the relative importance of including tidal effects in u^* vs T^* by neglecting individual frequency bands in u^* or T^* ?

With tides



$m_{u^*} - m$ = sensitivity of melting due to the direct impact of tidal currents on u^* (the importance of high frequency u^*)

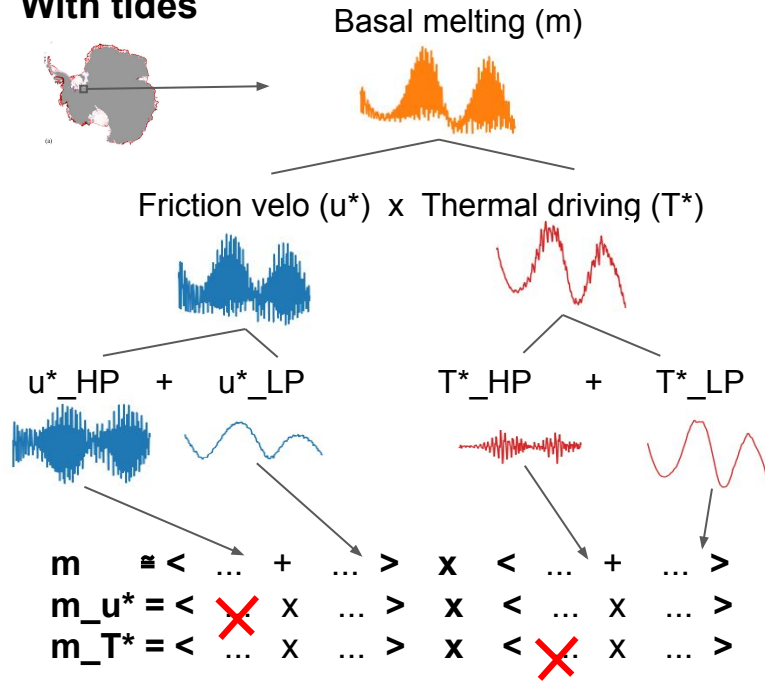
$m_{T^*} - m$ = sensitivity of melting due to the direct impact of tidal currents on T^* (the importance of high frequency T^*)

$(m_{u^*} - m) / (m_{T^*} - m)$ = measure of the direct impact of tidal currents on melting via u^* compared to via T^*

Tidal melt mechanisms: importance of u^* vs T^*

- Question 2: Can we estimate the relative importance of including tidal effects in u^* vs T^* by neglecting individual frequency bands in u^* or T^* ?

With tides



$m_{u^*} - m$ = sensitivity of melting due to the direct impact of tidal currents on u^* (the importance of high frequency u^*)

$m_{T^*} - m$ = sensitivity of melting due to the direct impact of tidal currents on T^* (the importance of high frequency T^*)

$(m_{u^*} - m) / (m_{T^*} - m)$ = measure of the direct impact of tidal currents on melting via u^* compared to via T^*

Limitations:

- T^*_HP will still be impacted by u^*_HP (and vice versa) via melting (we could only measure the sensitivity to the **direct** impact of u^*_HP and T^*_HP).
- Do we even need to know this (meaning)?

Summary

- We have a pan-Antarctic ocean-ice shelf model with tides (based on ROMS)
- Total impact of activating tides on melt rate and continental shelf temp is small.
- Modulations at high resolution can be large ($> 400\%$),
- but with little consequences for instantaneous ice sheet discharge rates.
- Impact on longer timescales is unknown.
- In the model, tides induce $\sim 150\%$ melt increase under Ronne ice shelf, coinciding with a tide induced gyre on the adjacent continental shelf (likely from tide-topography interaction).
- We have ideas to start entangling tidal melt mechanisms.

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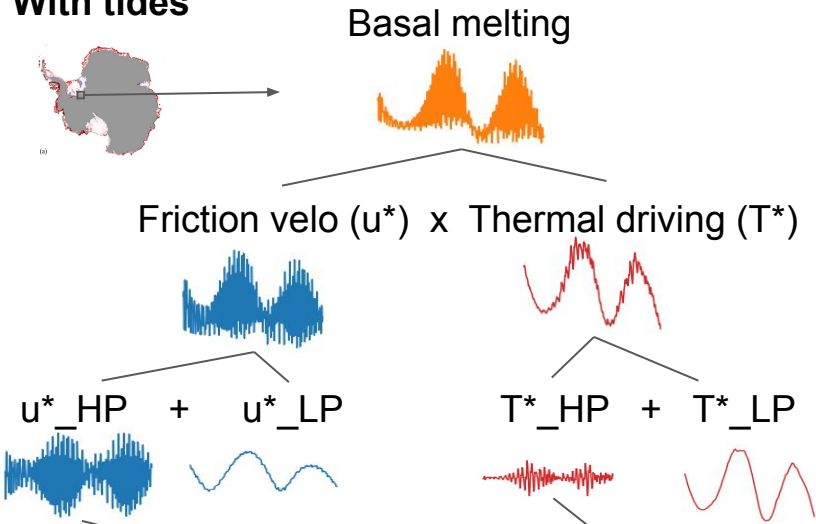
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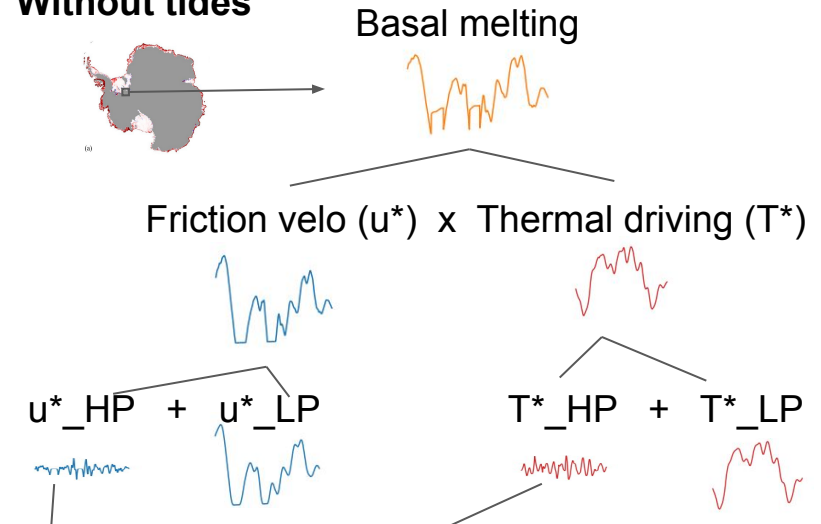
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The effects of tides on ice shelf basal melting: Towards separating far-field and nearby effects

With tides



Without tides



$$\langle \dots \times \dots \rangle - \langle \dots \times \dots \rangle = \text{Tidal melting due to fast (nearby) processes ?}$$