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Ocean dynamics on Enceladus

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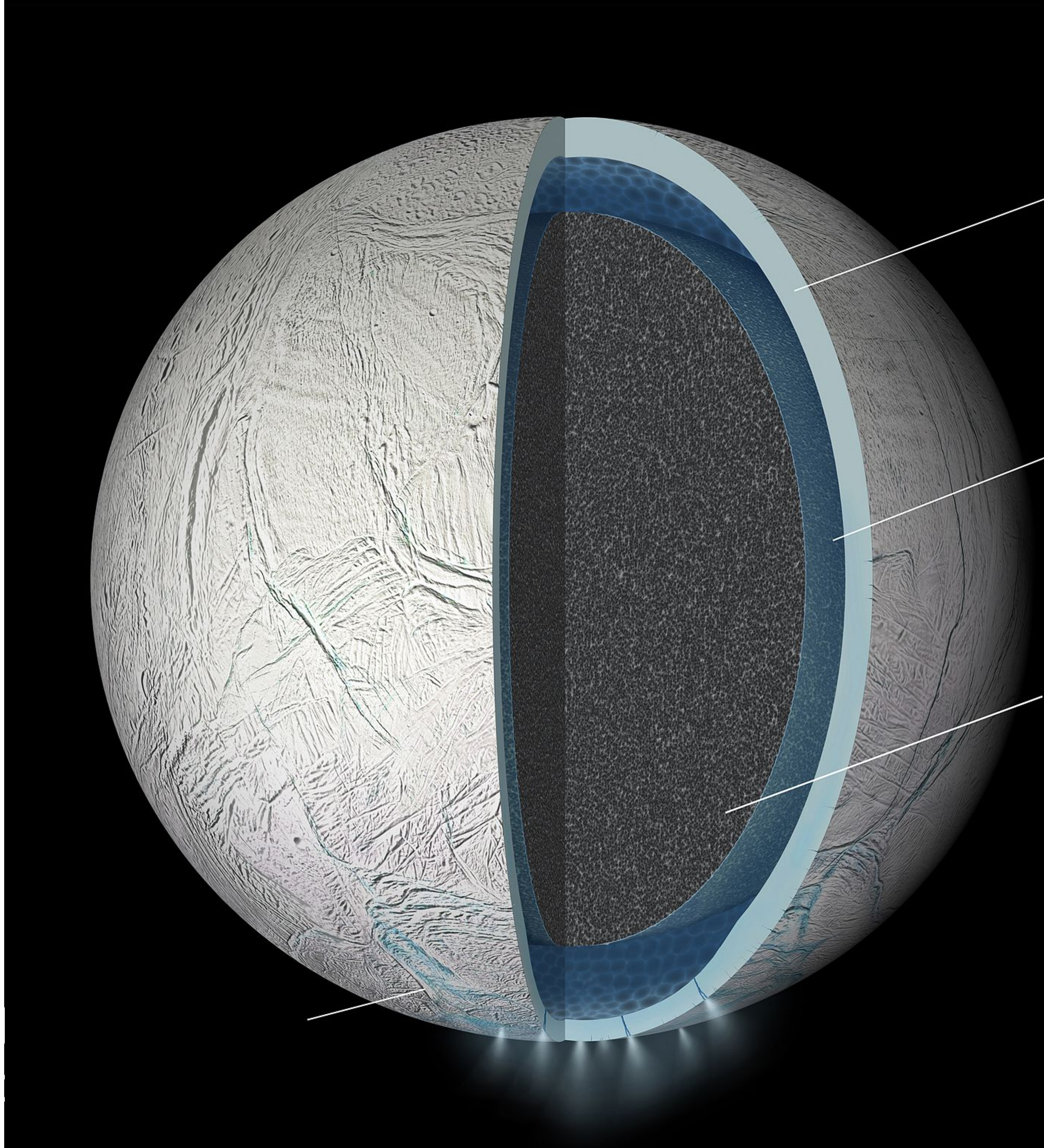
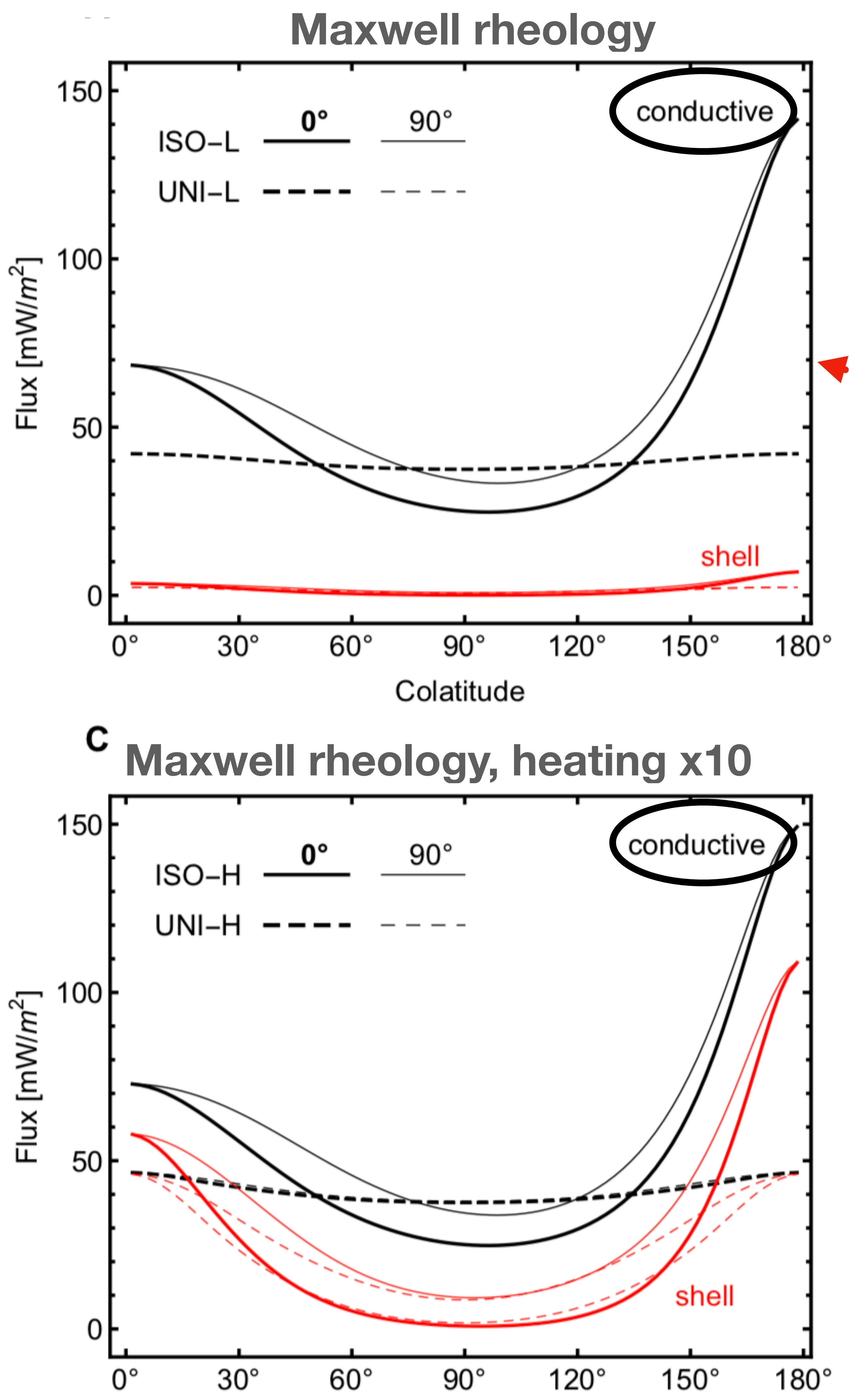
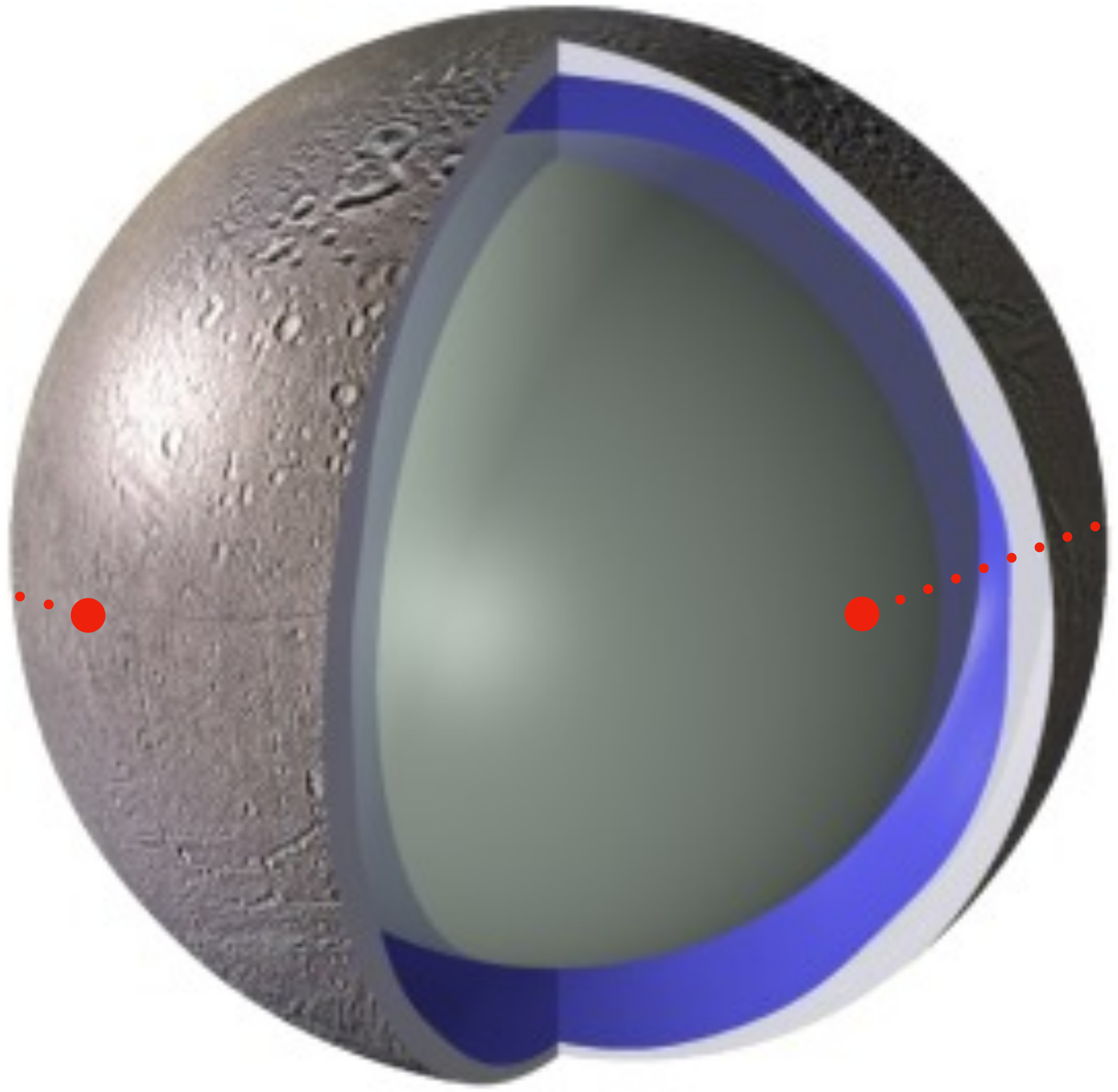


picture credit: NASA

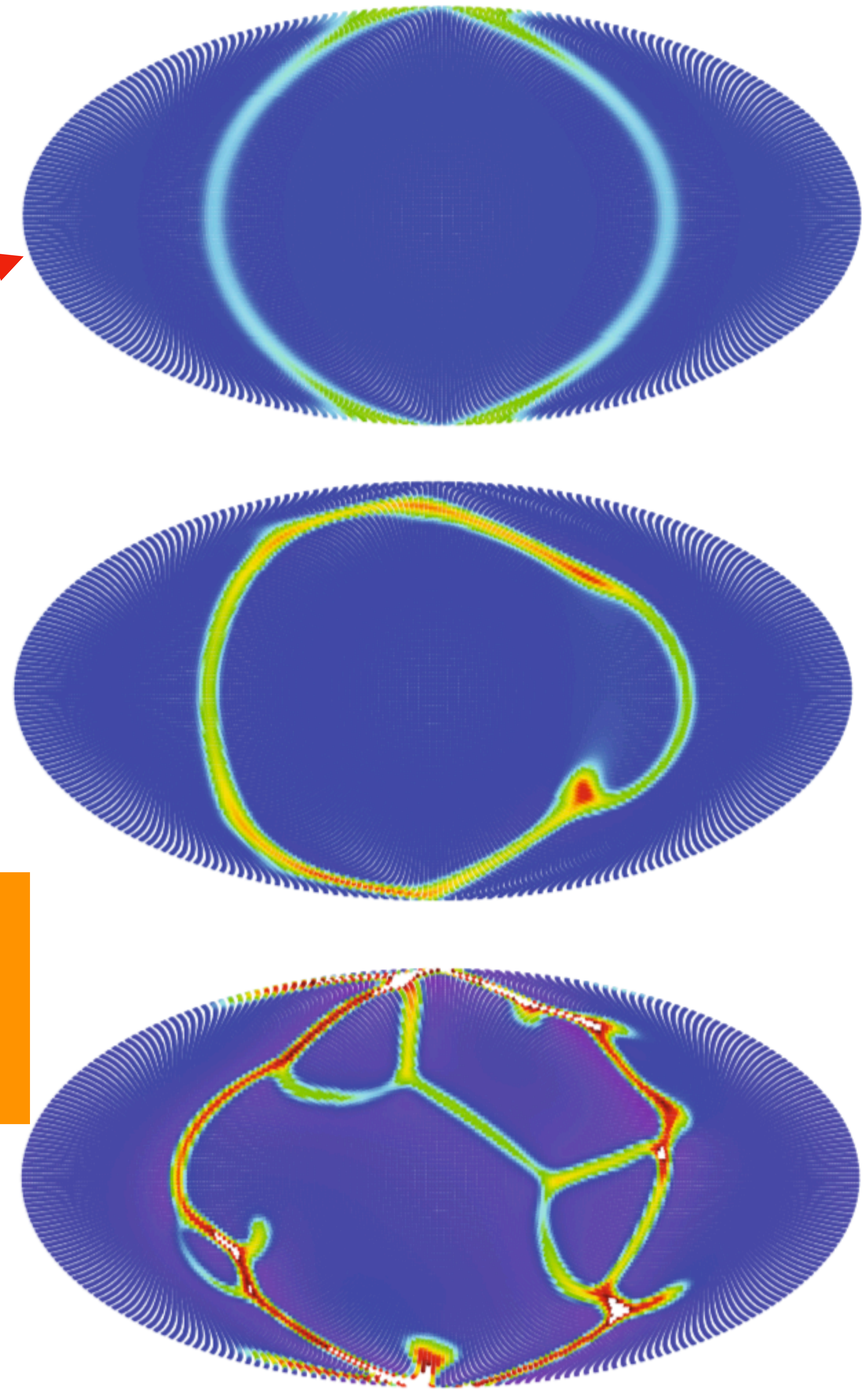
The main heat sources to maintain the thin ice shell of Enceladus

Meridional heat profile *(Beuthe 2019)*





Heat genration in the porous silicate core
(Choblet et al. 2017)

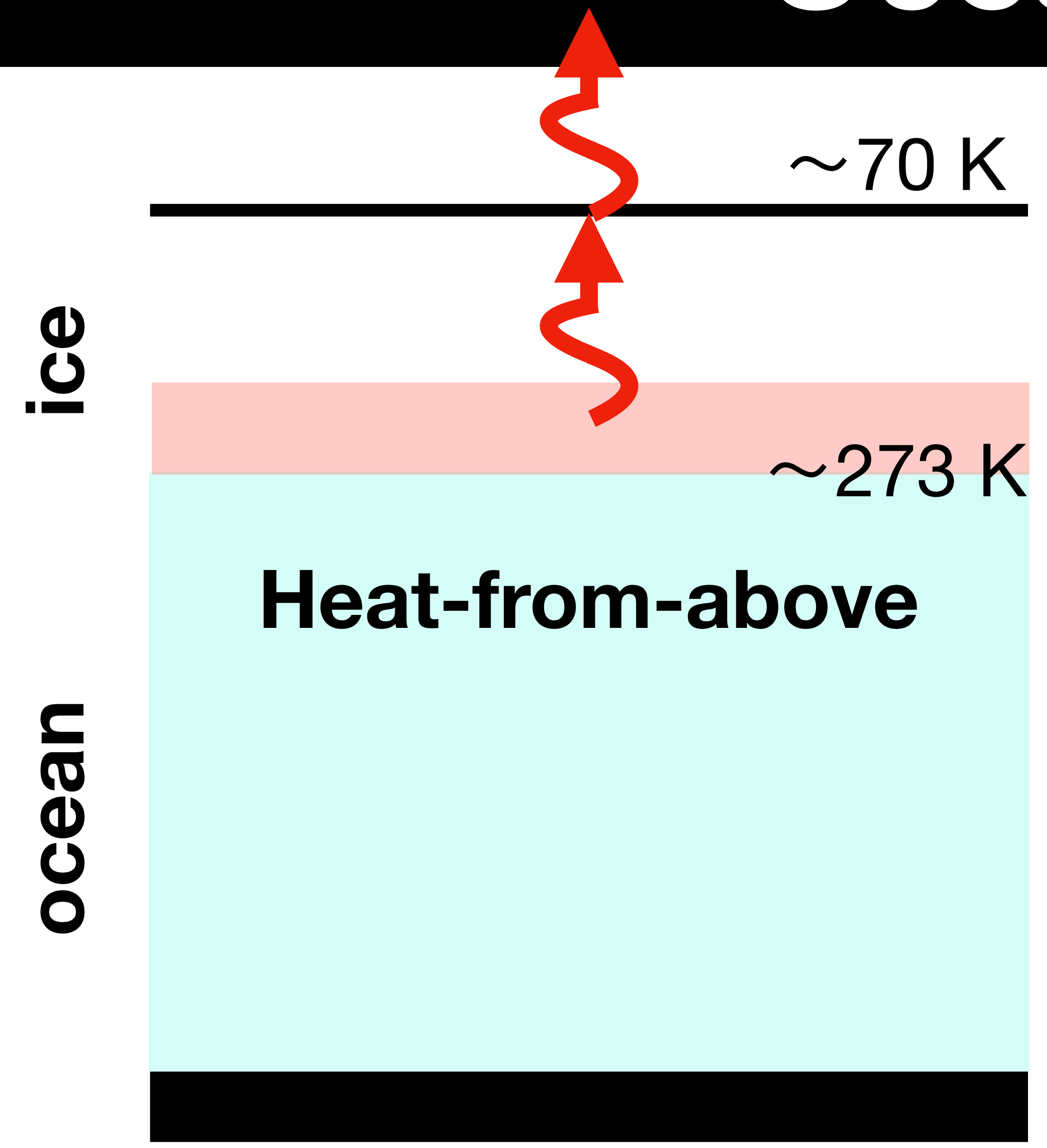


Is heat most generated in the ice shell or in the core?

No tidal model can generate the amount of heat required in ice shell alone

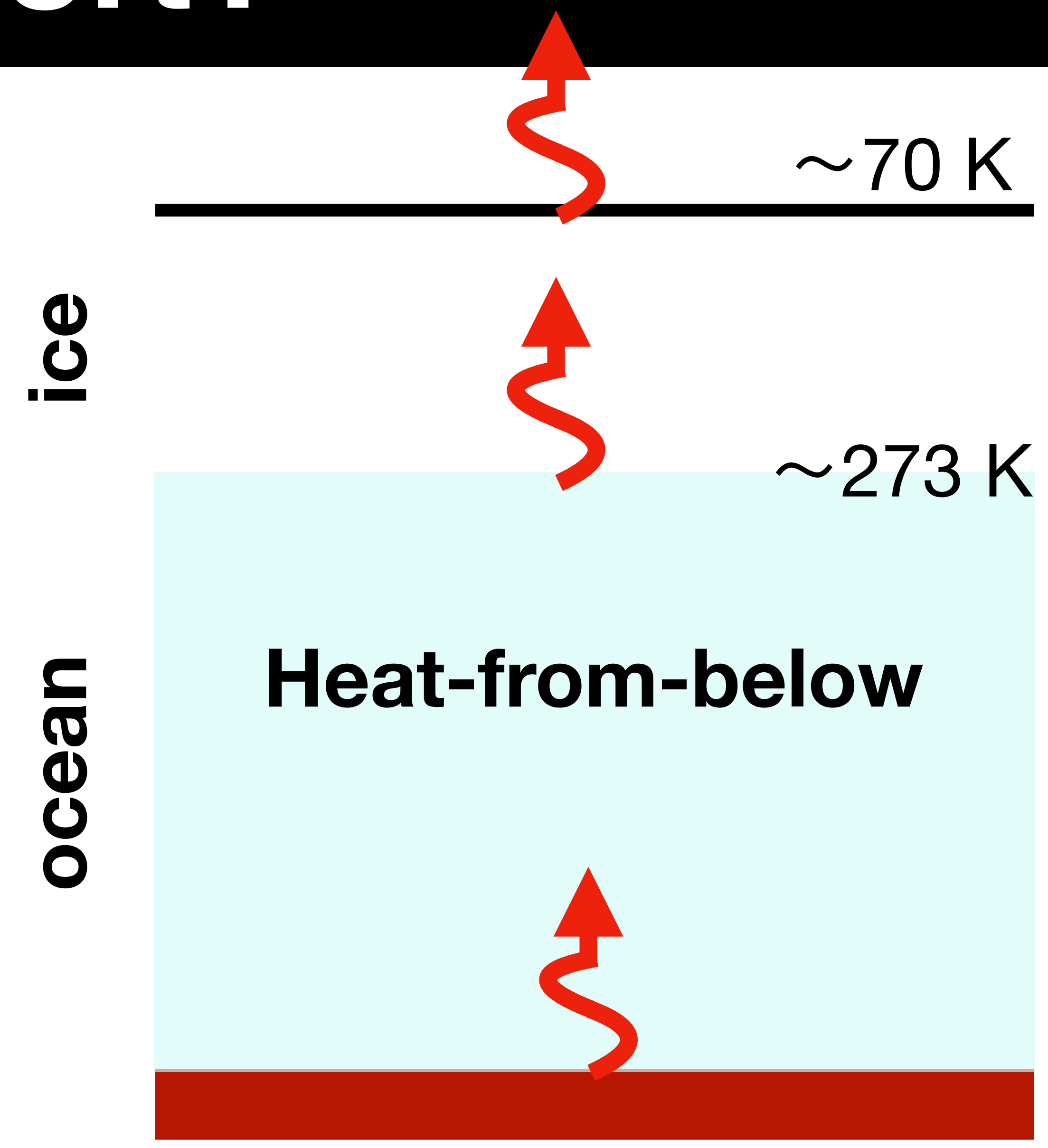
High uncertainties about the heating magnitude and distribution

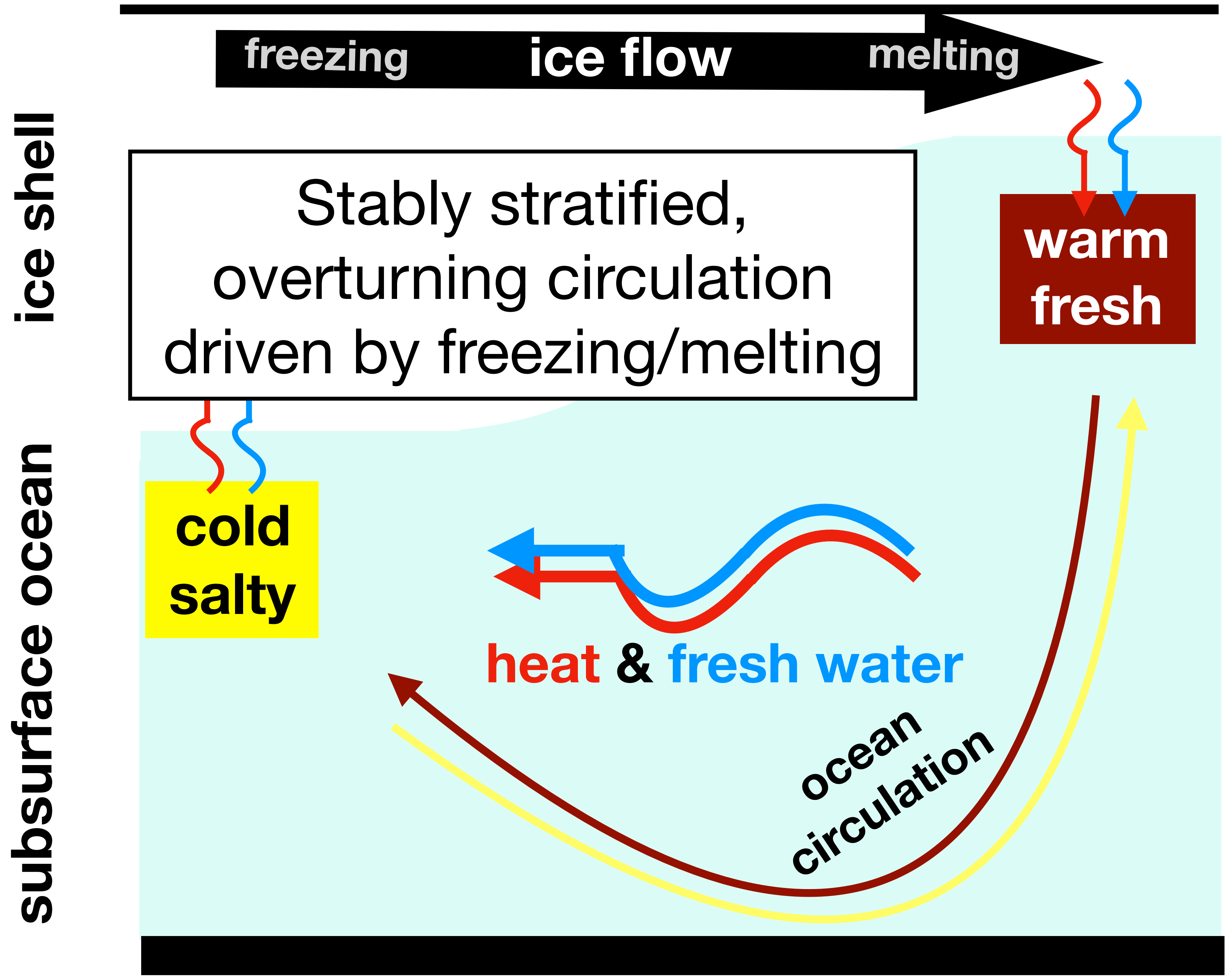
Ocean dynamics, heat & tracer transport?



or

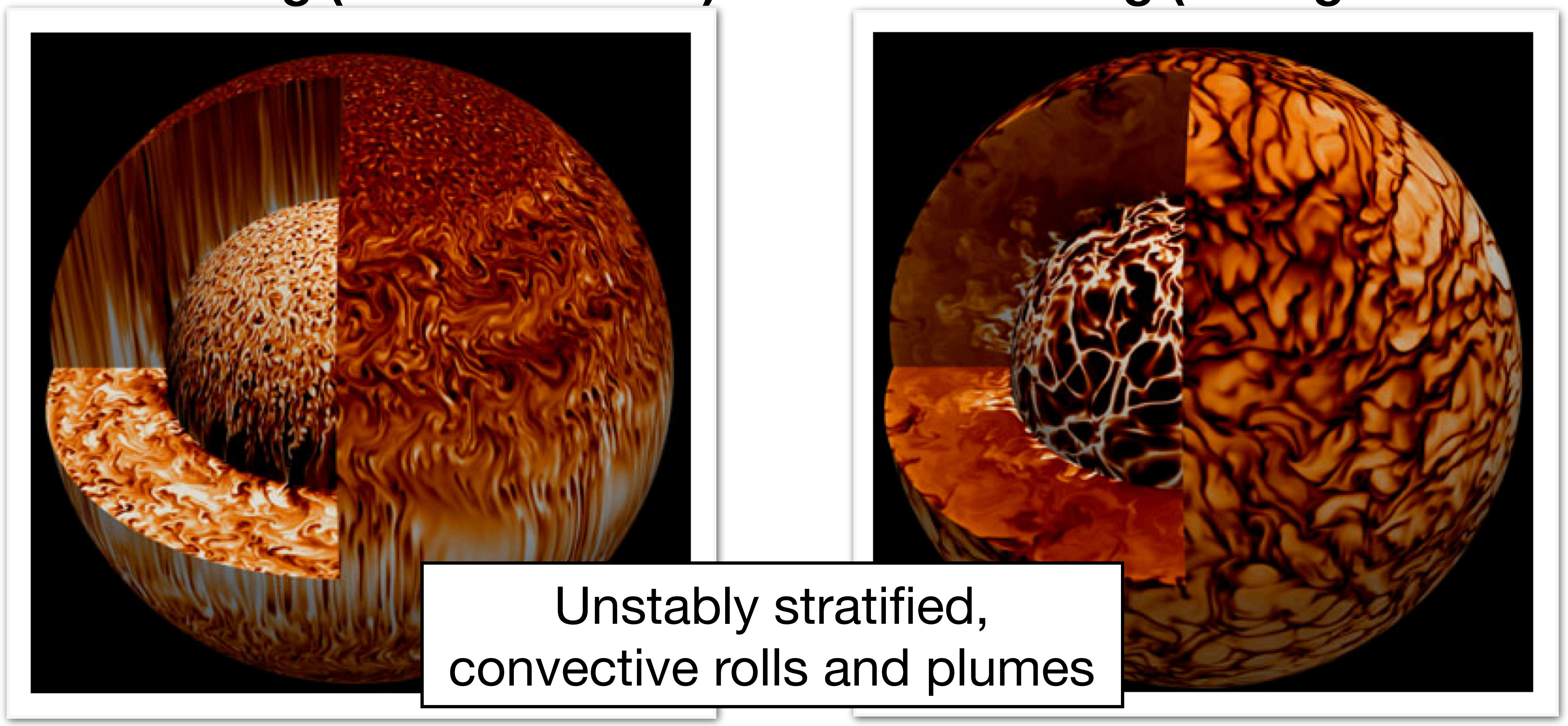
What is the ocean circulation on Enceladus?
How tracers are transported?





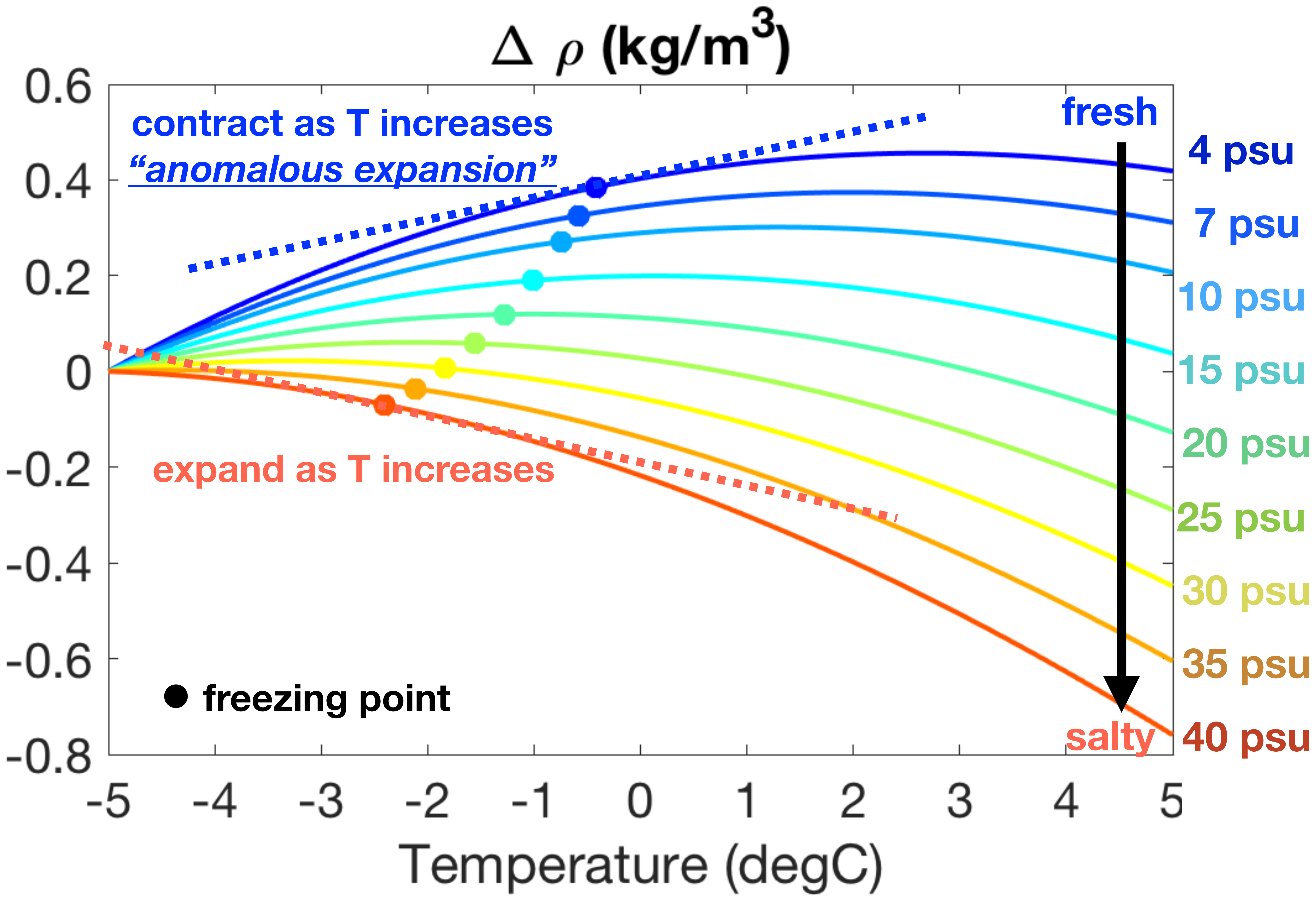
Kang et al. 2021 (submitted)

fast-rotating (weak heat flux) **slow-rotating (strong heat flux)**



Dormy (2004), Gastine et al. (2016), Amit et al. (2020), Soderlund et al. (2014), Soderlund (2019), Aurnou et al. (2007,2020),

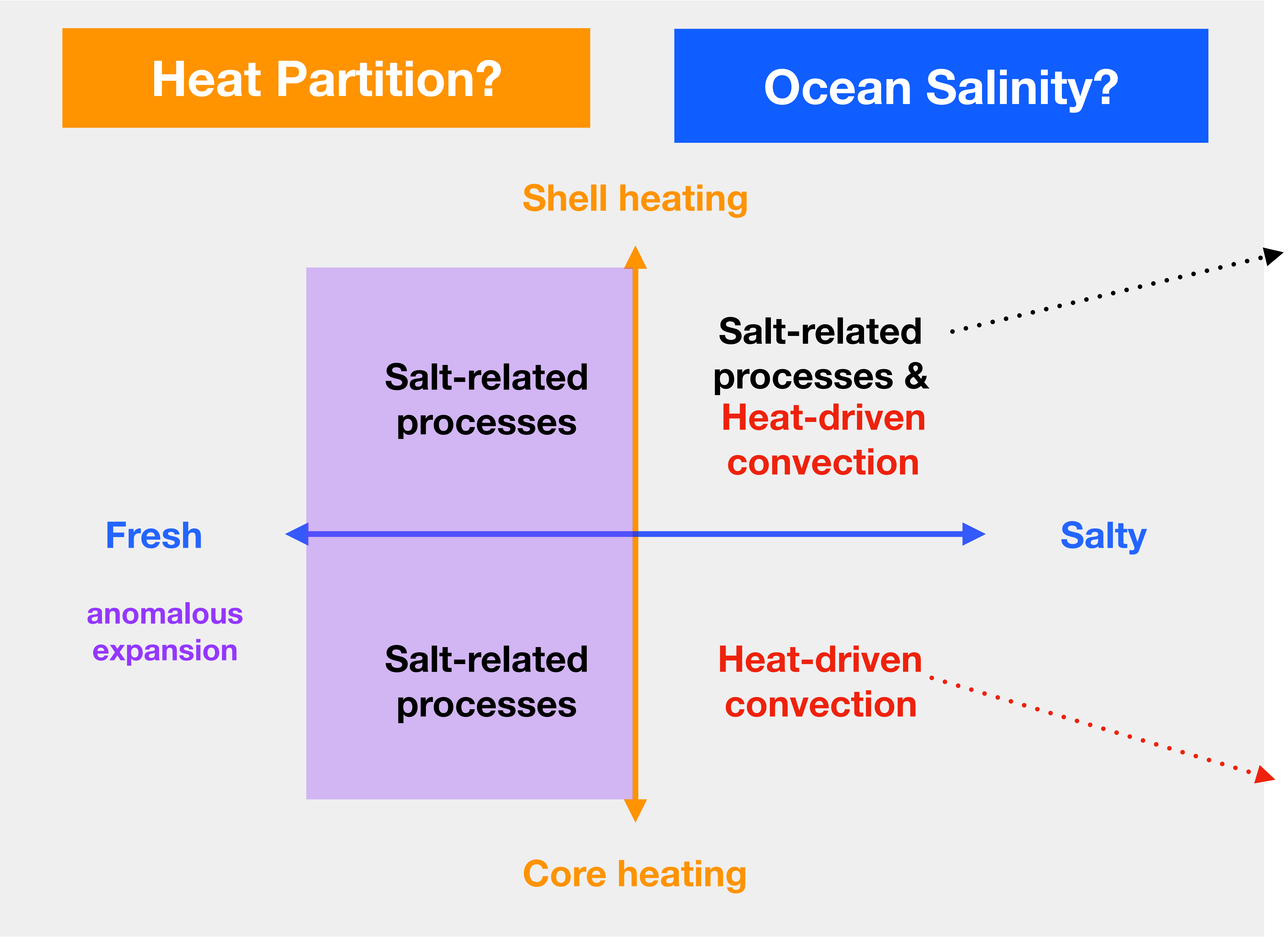
Salinity?



- Salinity of samples collected from the south polar geyser (> 5-20 psu, *Postberg et al. 2009*)
- The geyser's liq-gas interface needs to remain convective unstable to prevent freezing (> 20 psu, *Ingersoll et al. 2016*)
- The size of silica particles collected from the south polar geyser is small, indicating a slow growth rate and thus low salinity (< 15-40 psu, *Hsu et al. 2015*)
- The chemical equilibrium salinity given the rock-water ratio in Enceladus (2-20 psu, *Zolotov 2007*)

How salinity affects ocean dynamics?
Can ocean dynamics provide a constraint to the salinity?

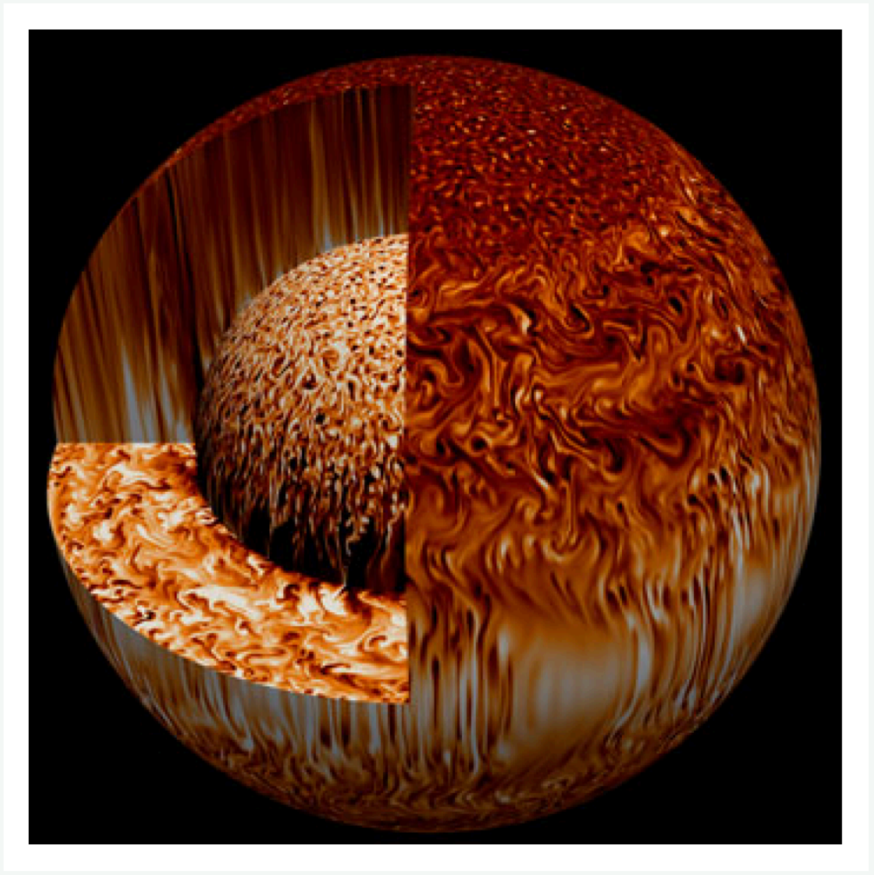
Where is Enceladus in the parameter space?



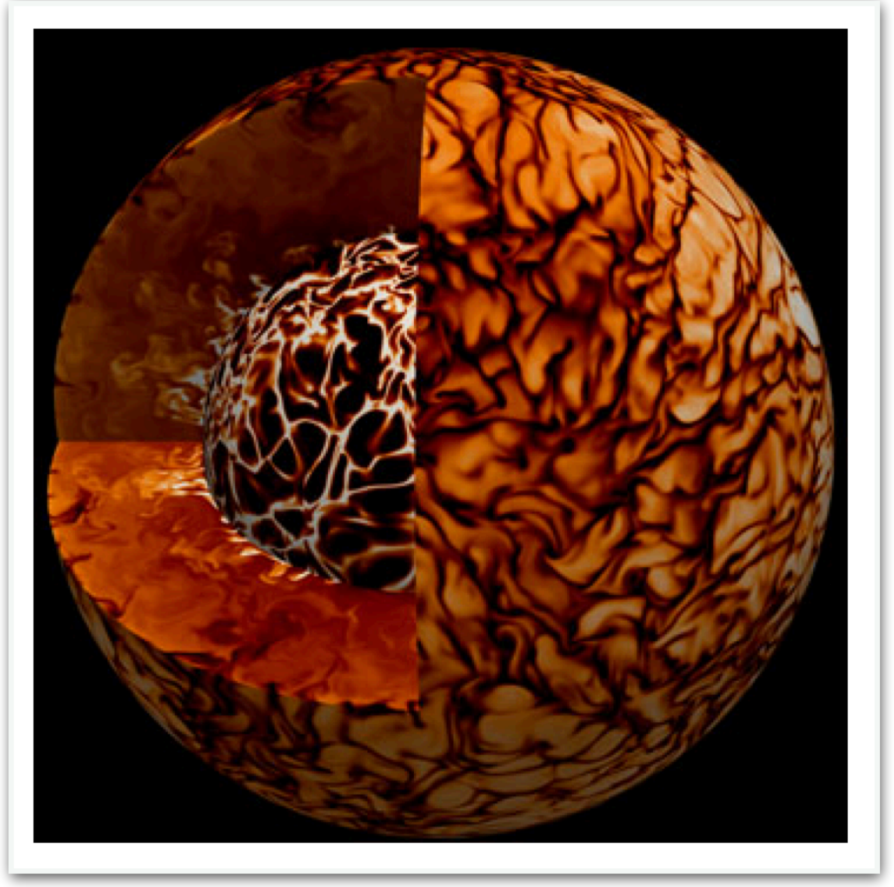
Salt-related processes:

1. convection driven by freezing
2. overturning circulation driven by salinity gradient

fast-rotating (weak heat flux)



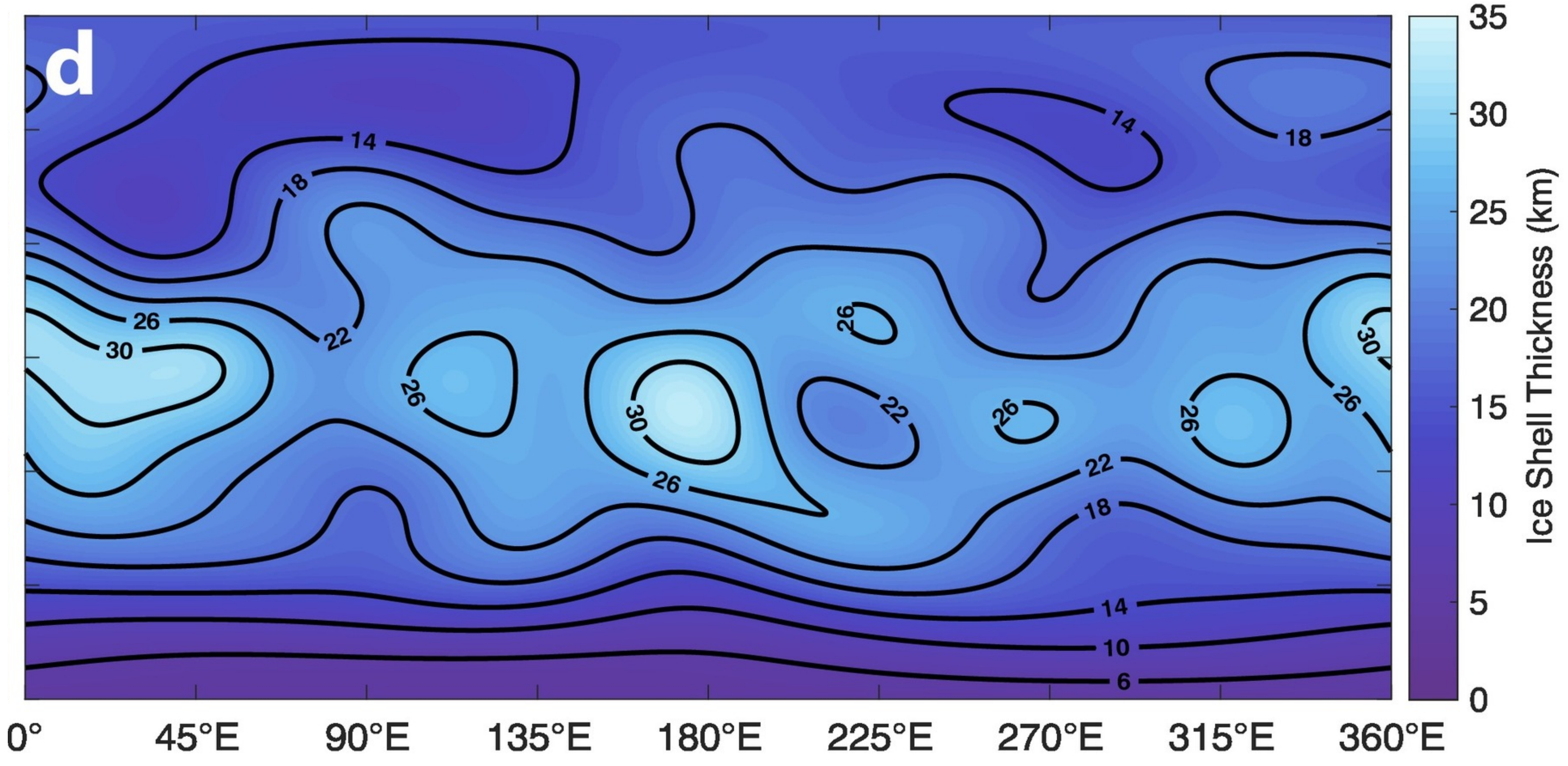
slow-rotating (strong heat flux)



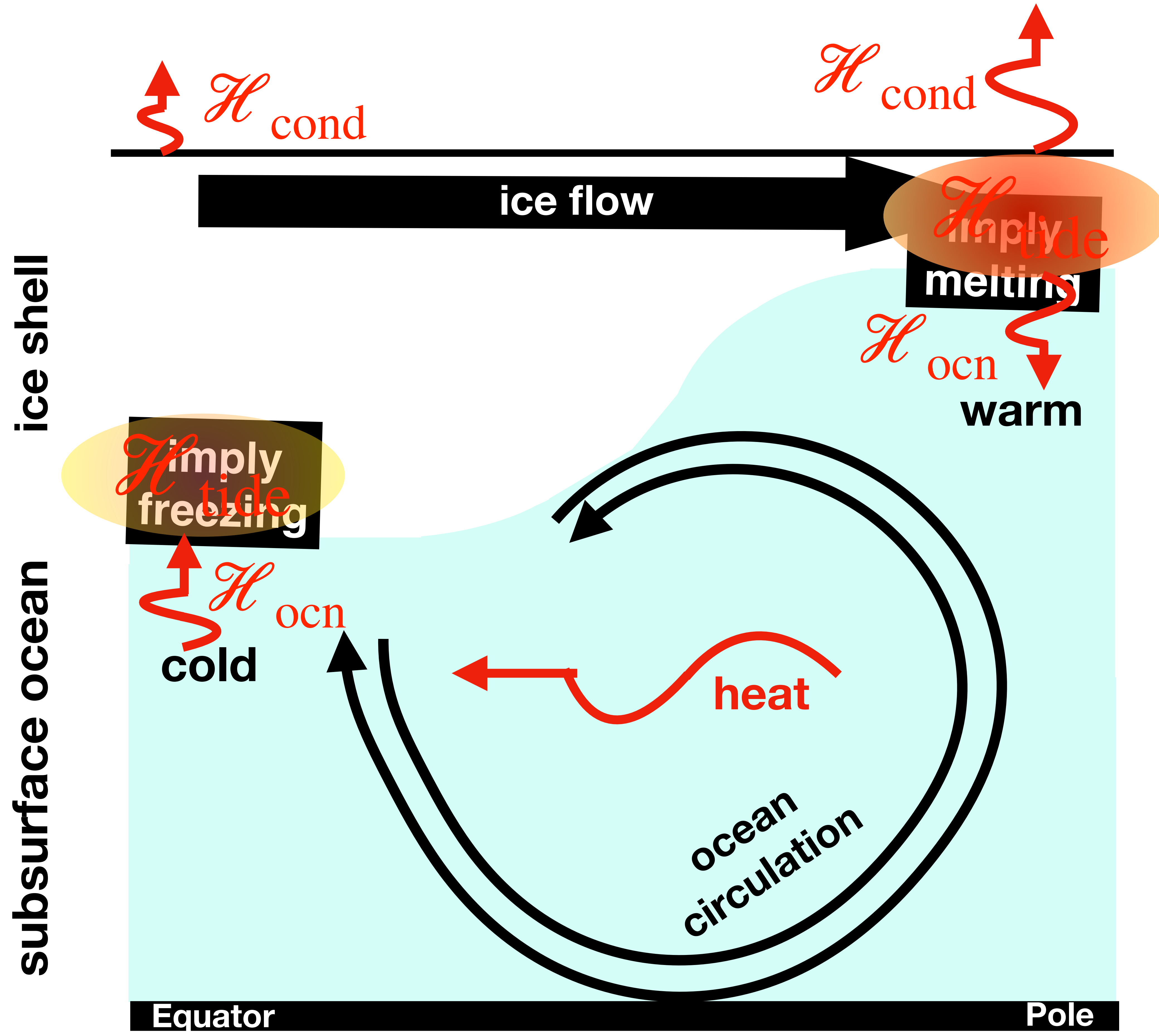
Dormy (2004), Gastine et al. (2016), Amit et al. (2020), Soderlund et al. (2014), Soderlund (2019), Aurnou et al. (2007,2020)

Constraints provided by Enceladus' ice shell geometry

Ice shell thickness



Hemingway and Mittal 2019
(see also less et al. 2014, Beuthe et al. 2016, Tajeddine et al. 2017, Cadek et al. 2019)



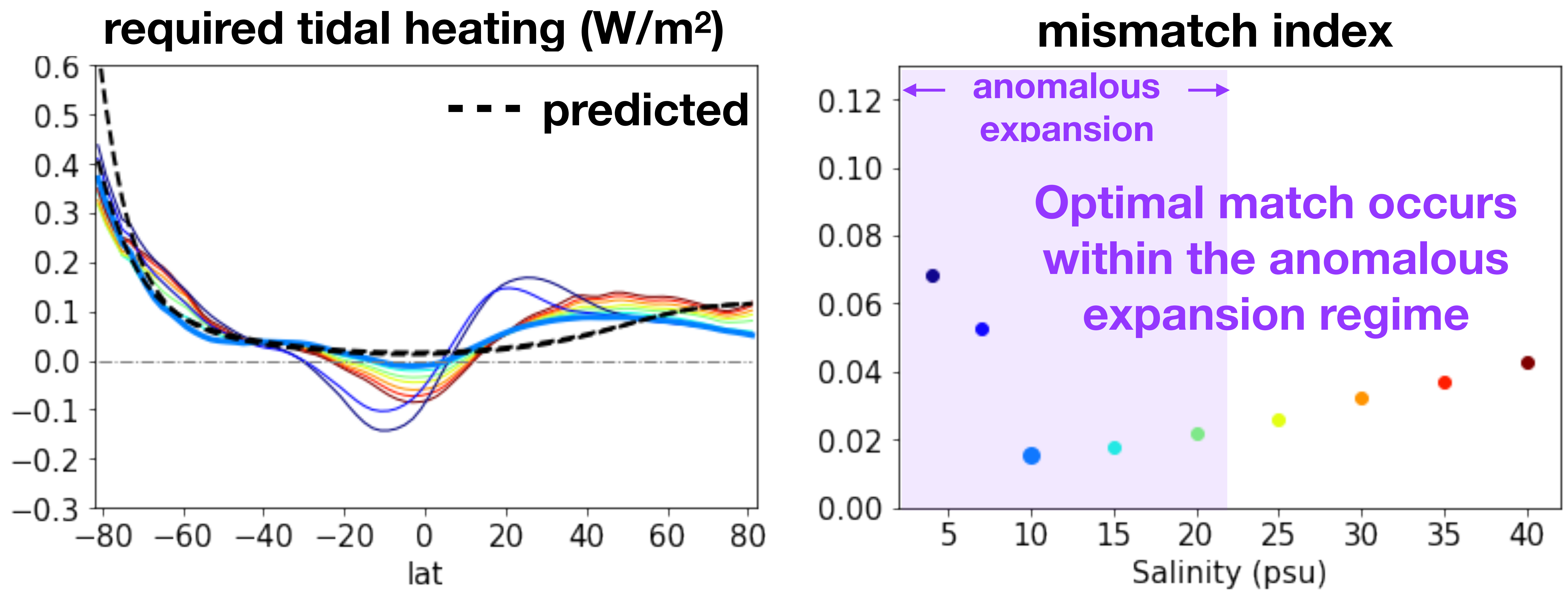
South Pole: ~6km
North Pole: ~15km
Equator: ~28km
(based on mean density, momentum of inertia, liberation amplitude, surface topography, gravity anomalies)

Tidal dissipation required to close heat budget

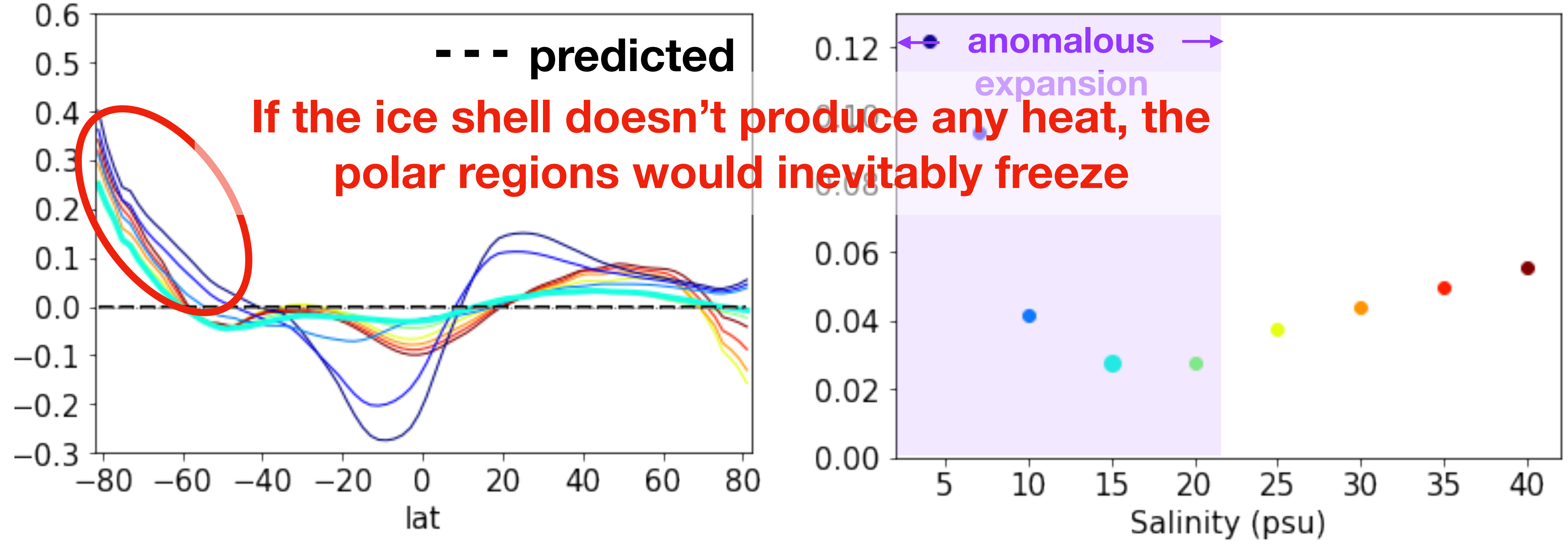
$$\mathscr{H}_{\text{tide}} = \mathscr{H}_{\text{cond}} - (\mathscr{H}_{\text{ocn}} + \rho_i L_f q)$$

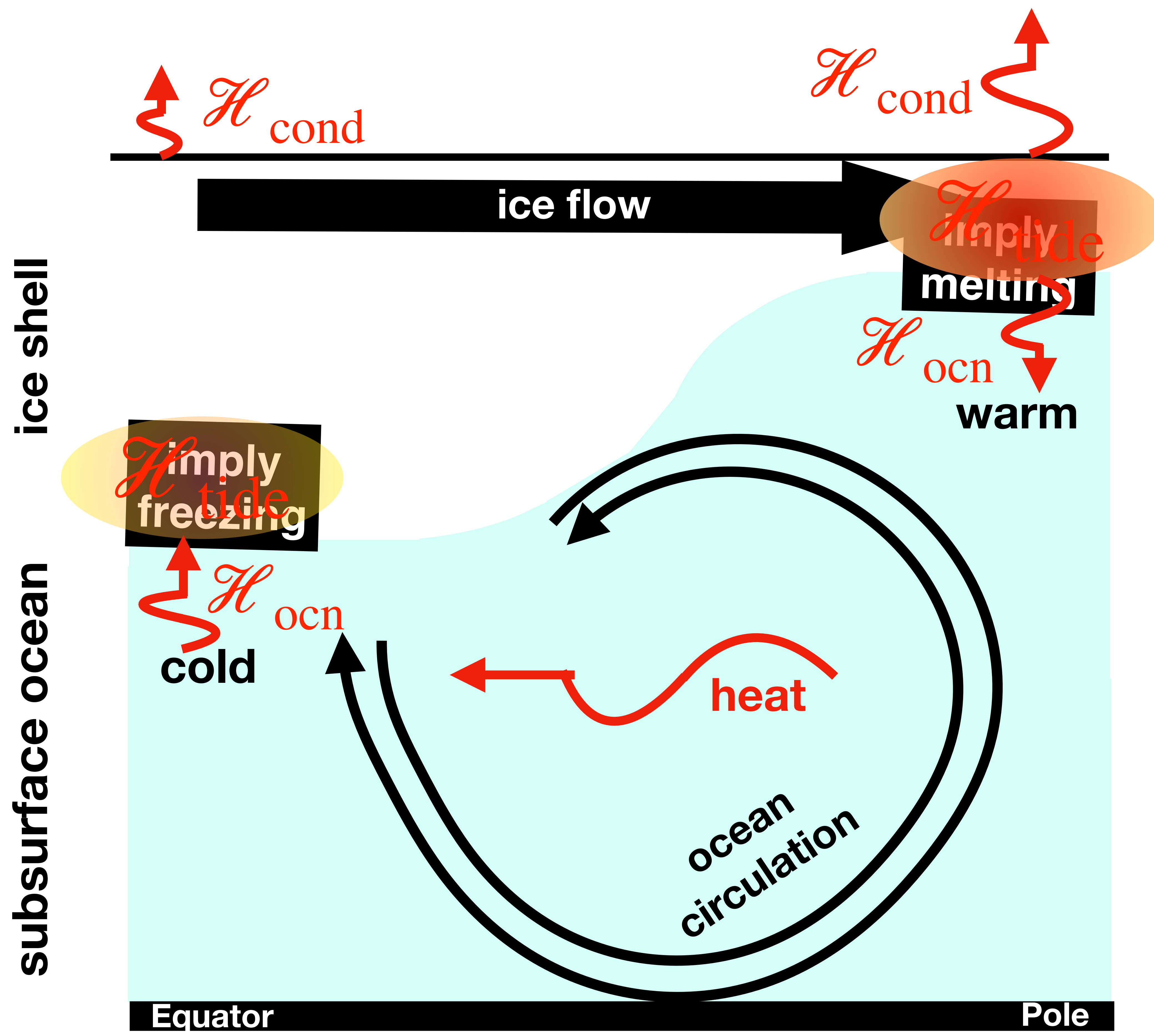
Constraints provided by Enceladus' ice shell geometry

Heat in shell



Heat in core





Tidal dissipation required to close heat budget

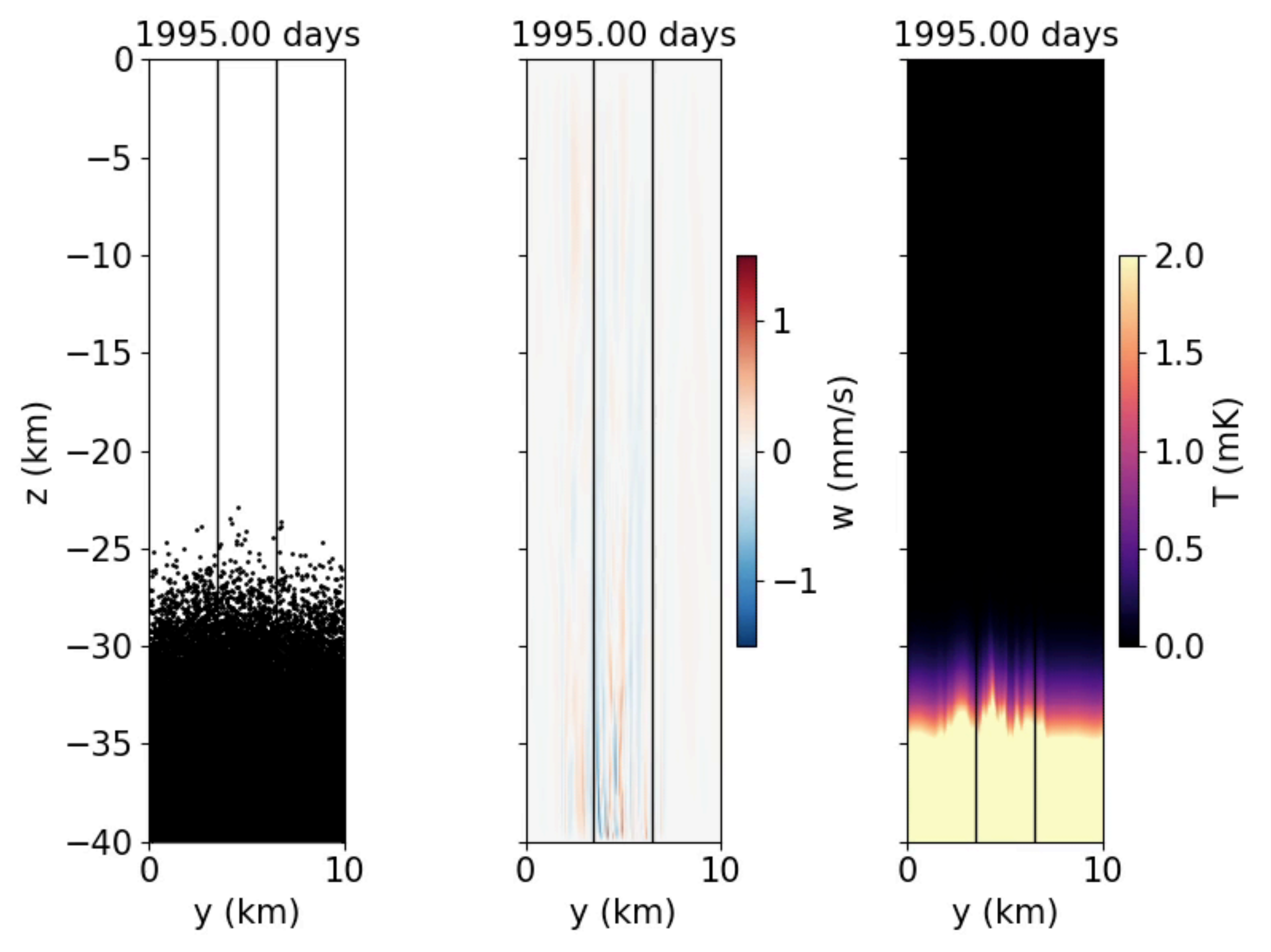
$$\mathscr{H}_{\text{tide}} = \mathscr{H}_{\text{cond}} - (\mathscr{H}_{\text{ocn}} + \rho_i L_f q)$$

Kang et al. 2021, *How does salinity shape ocean circulation and ice geometry on Enceladus and other icy satellites?,* ***Nature Astronomy (under review)***

What does a relatively fresh ocean suggest?

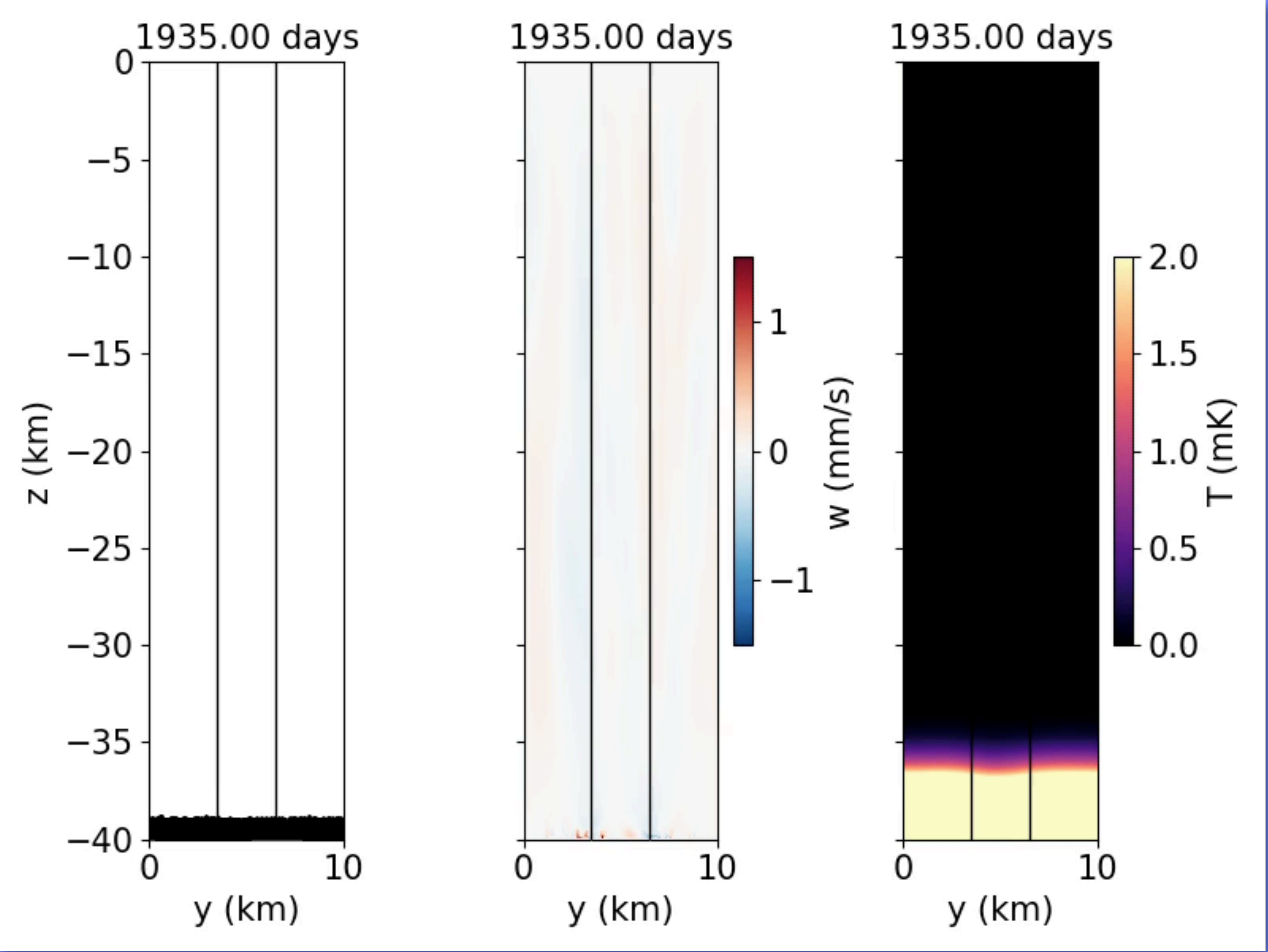
Salty

3km x 3km 10W/m² plume at the center



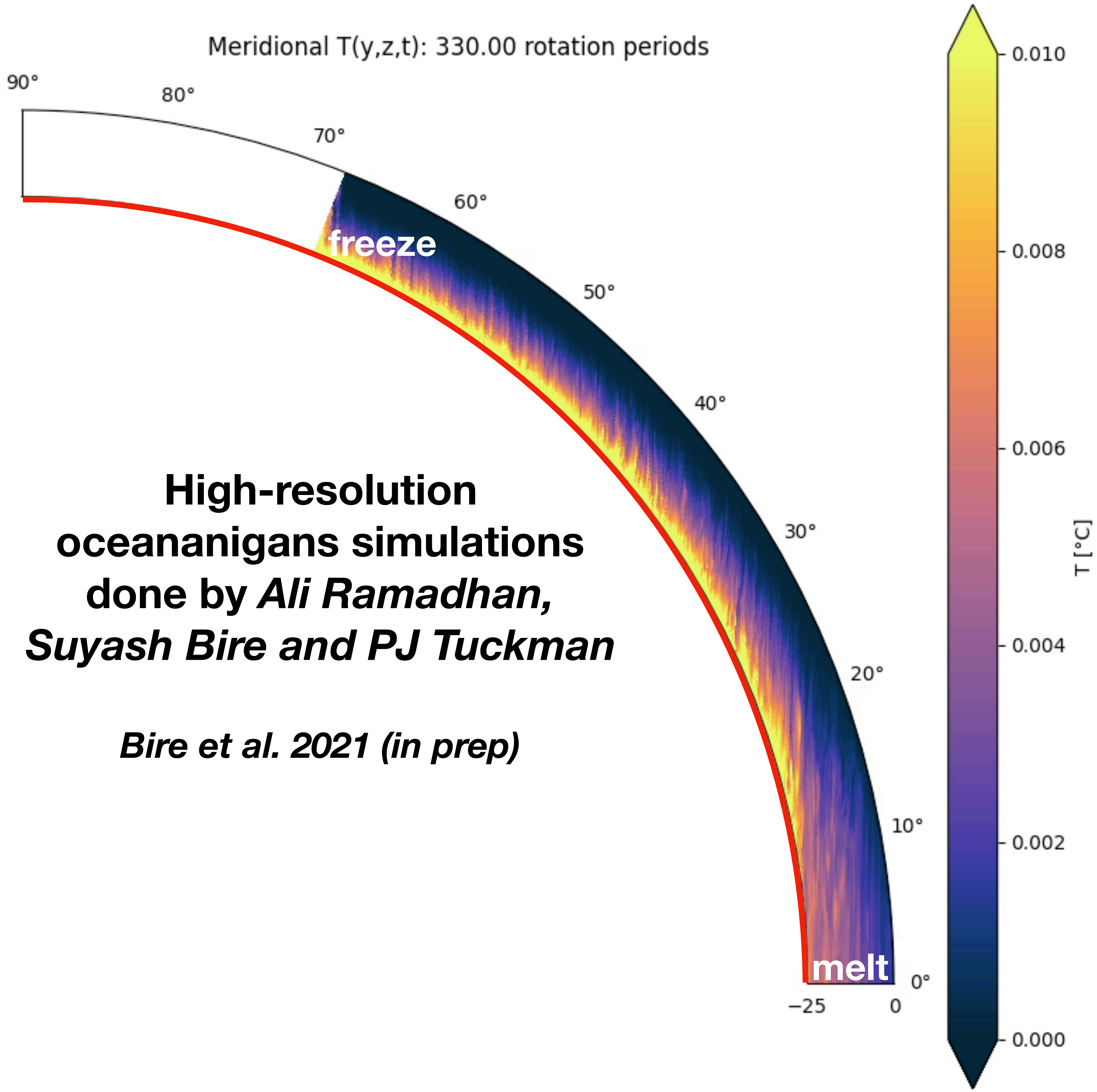
Fresh

3km x 3km 10W/m² plume at the center



High-resolution oceananigans simulations by *Suyash Bire and Ali Ramadhan (Tushar Mittal, Wanying Kang, John Marshall)*

Possible dynamics if ocean is salty on Enceladus



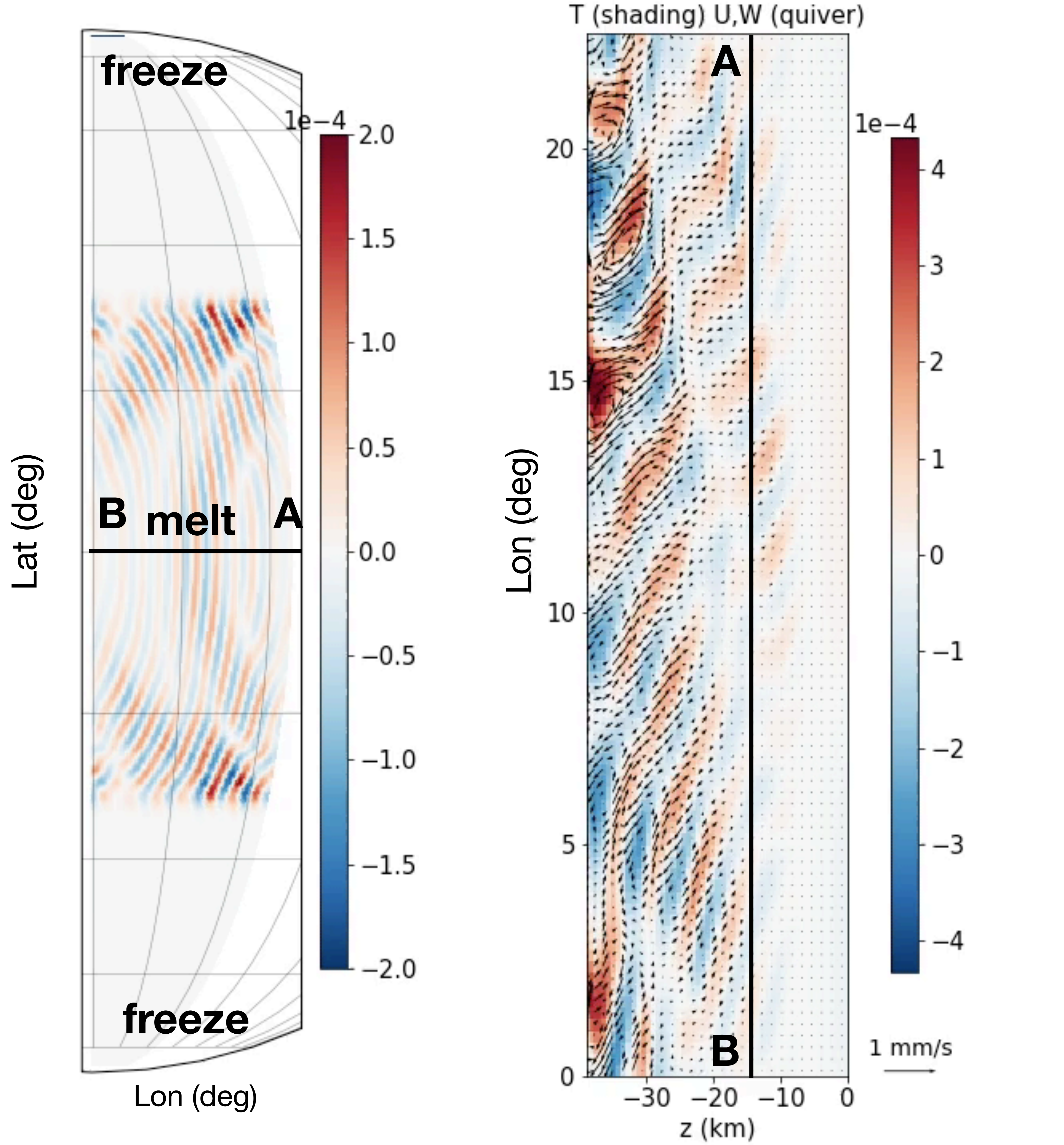
High-resolution oceananigans simulations done by *Ali Ramadhan, Suyash Bire and PJ Tuckman*

Bire et al. 2021 (in prep)

Thermally driven Rossby wave near the equator

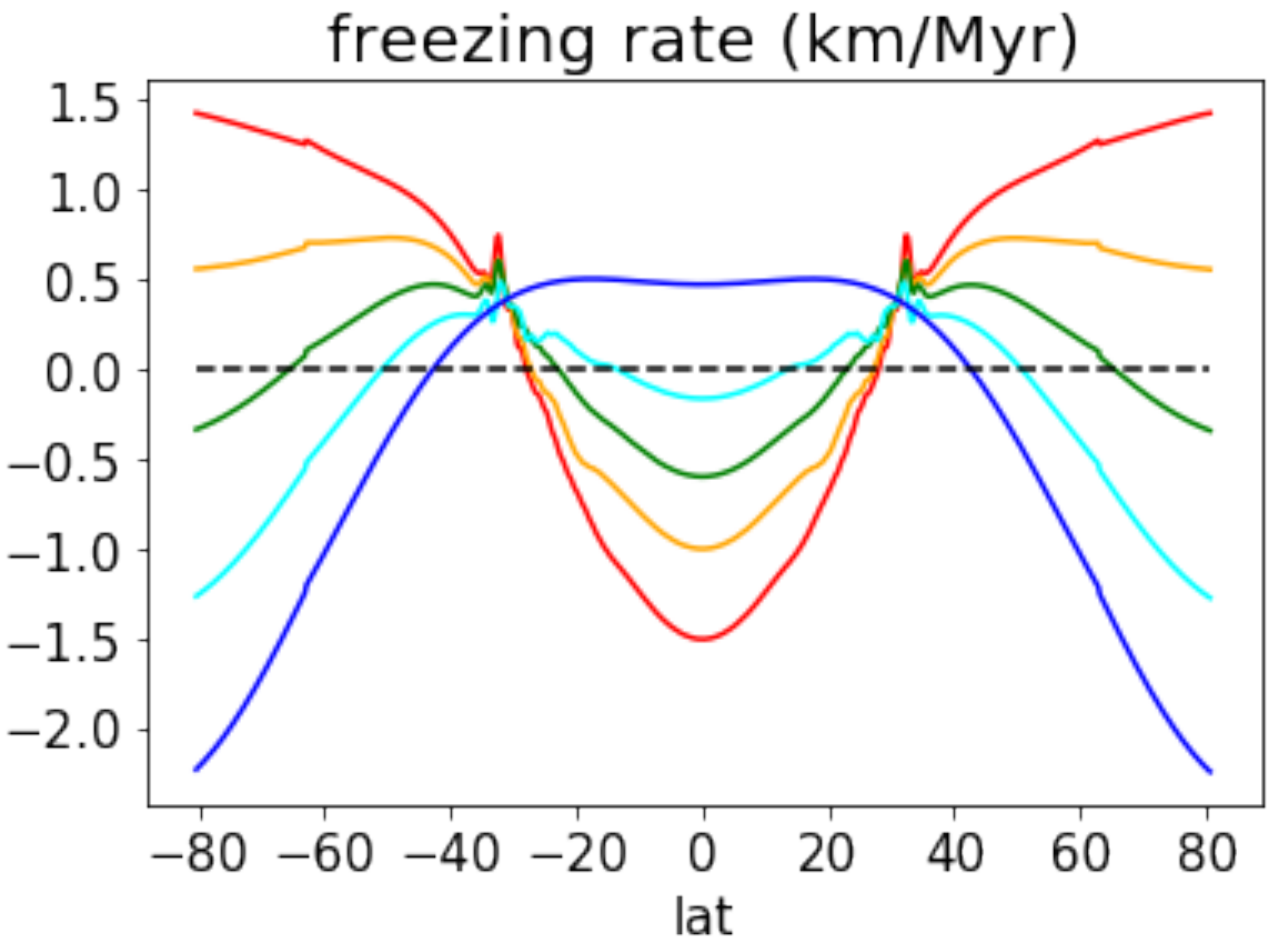
(Dormy et al. 2003, Cardin and Olson 1994)

Kang et al. 2021 (under revision)



The likely heat partitions between core and ice

Starting from a flat ice sheet



Poleward thickening

100% heat from the core

75% heat from the core

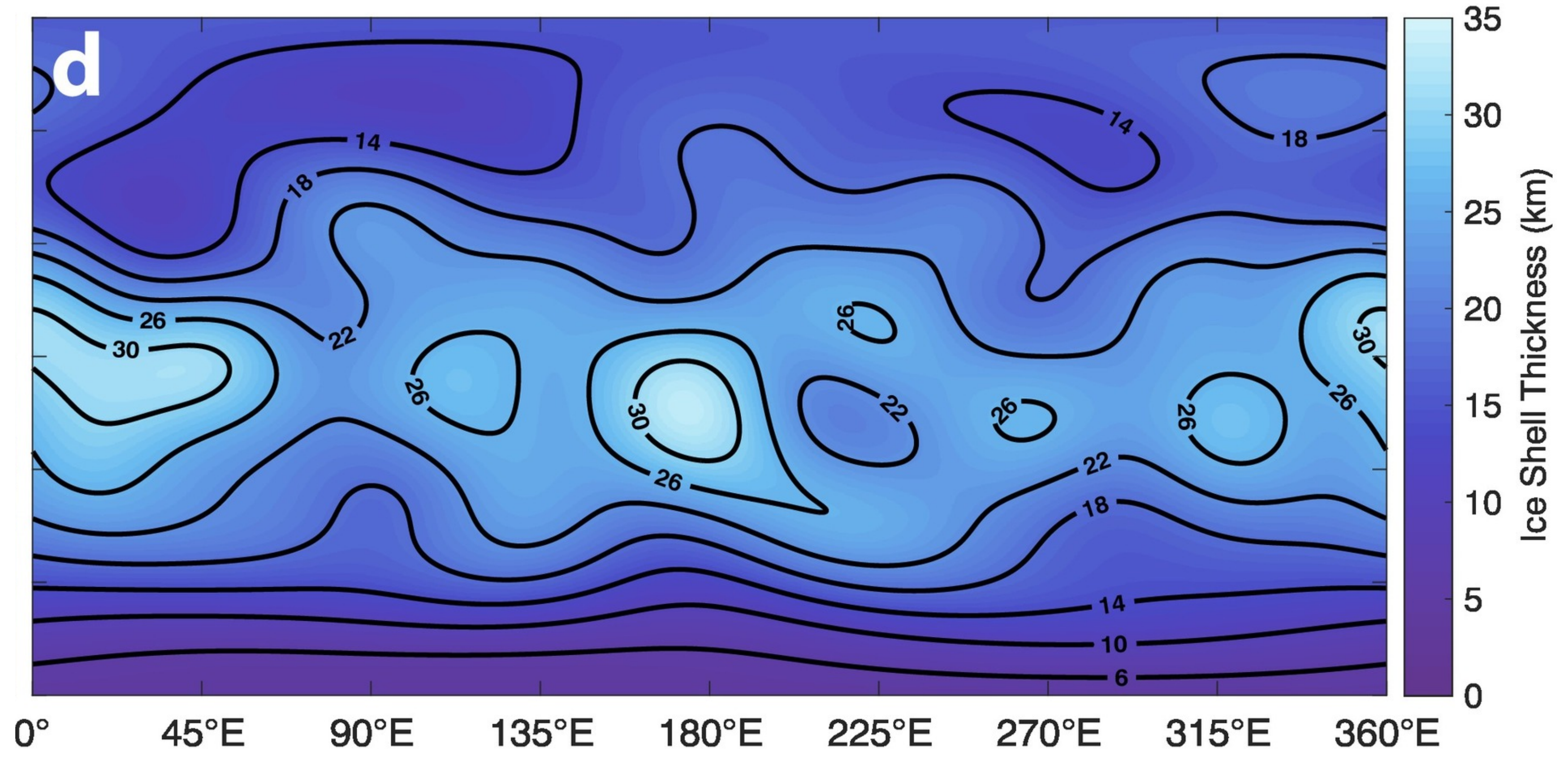
50% heat from the core

25% heat from the core

0% heat from the core

Poleward thinning

Ice shell thickness



Hemingway and Mittal 2019

Unlikely that the dynamics is dominated by a uniform bottom heating.

Kang et al. 2021, *Differing Enceladean ocean circulation and ice shell geometries driven by tidal heating in the ice versus the core,* ***Nature Communication (under revision)***