Ice Sheet - Ocean Interactions and Sea-Level Change: Prospects for Predictability

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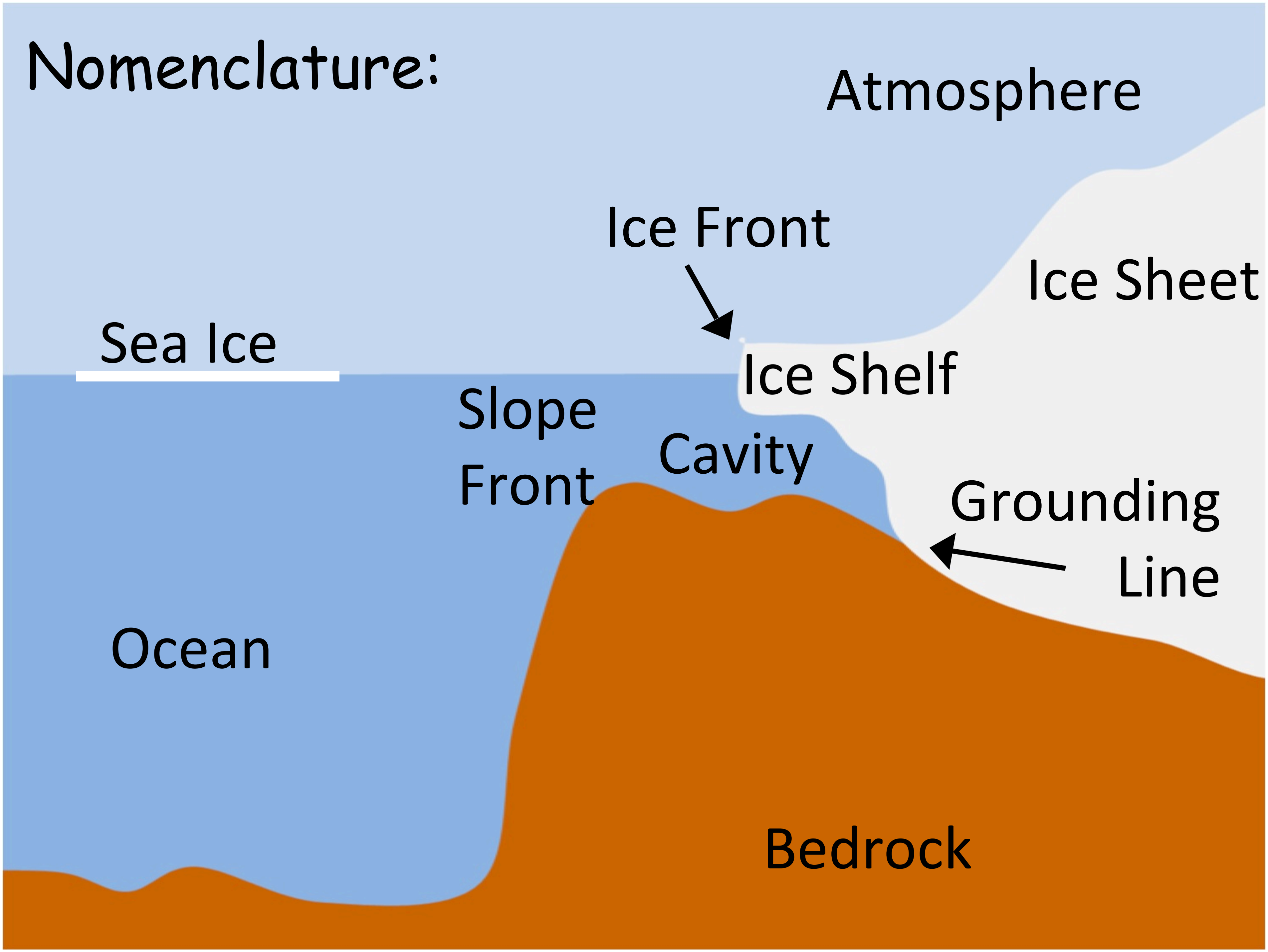
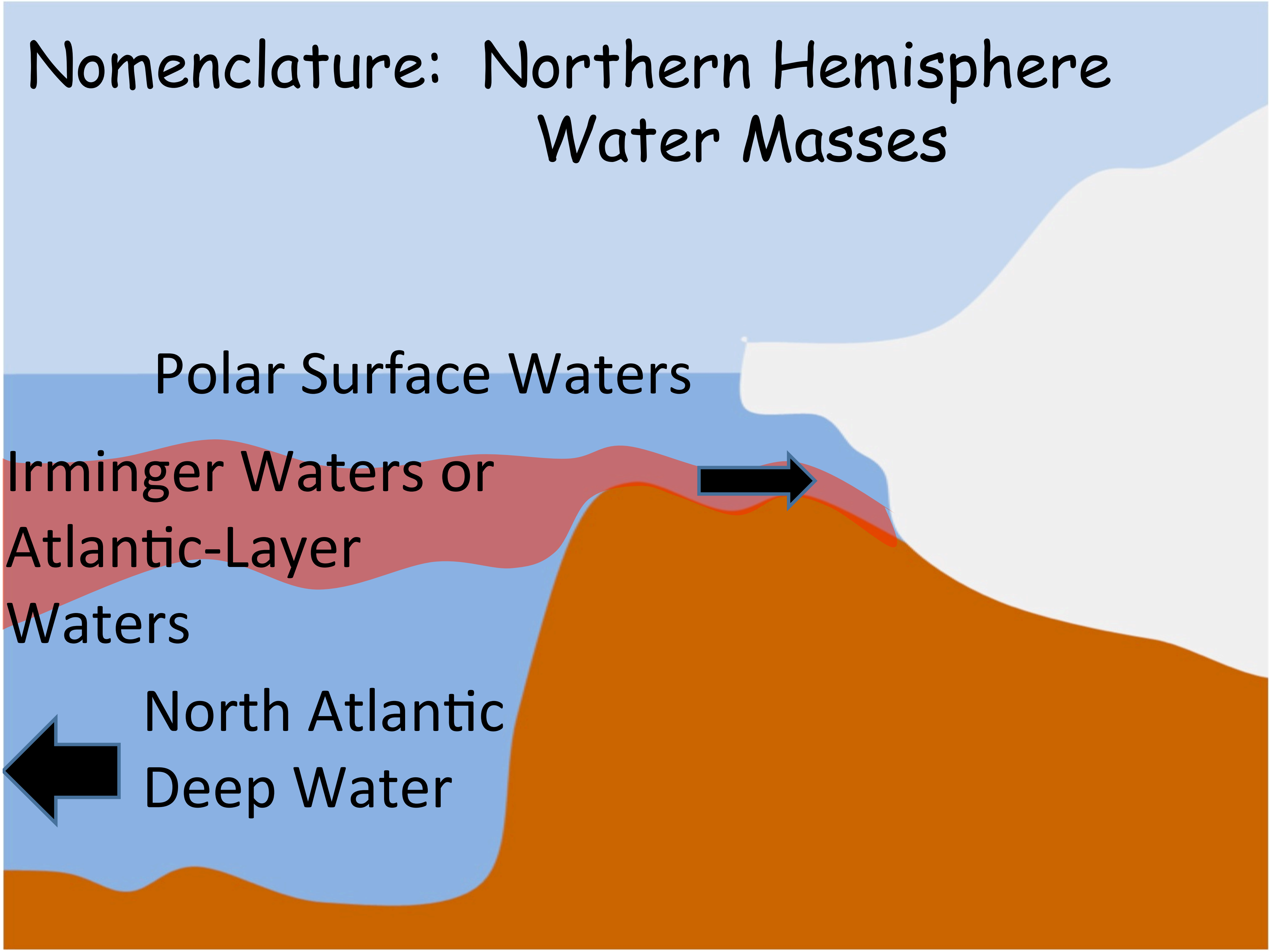
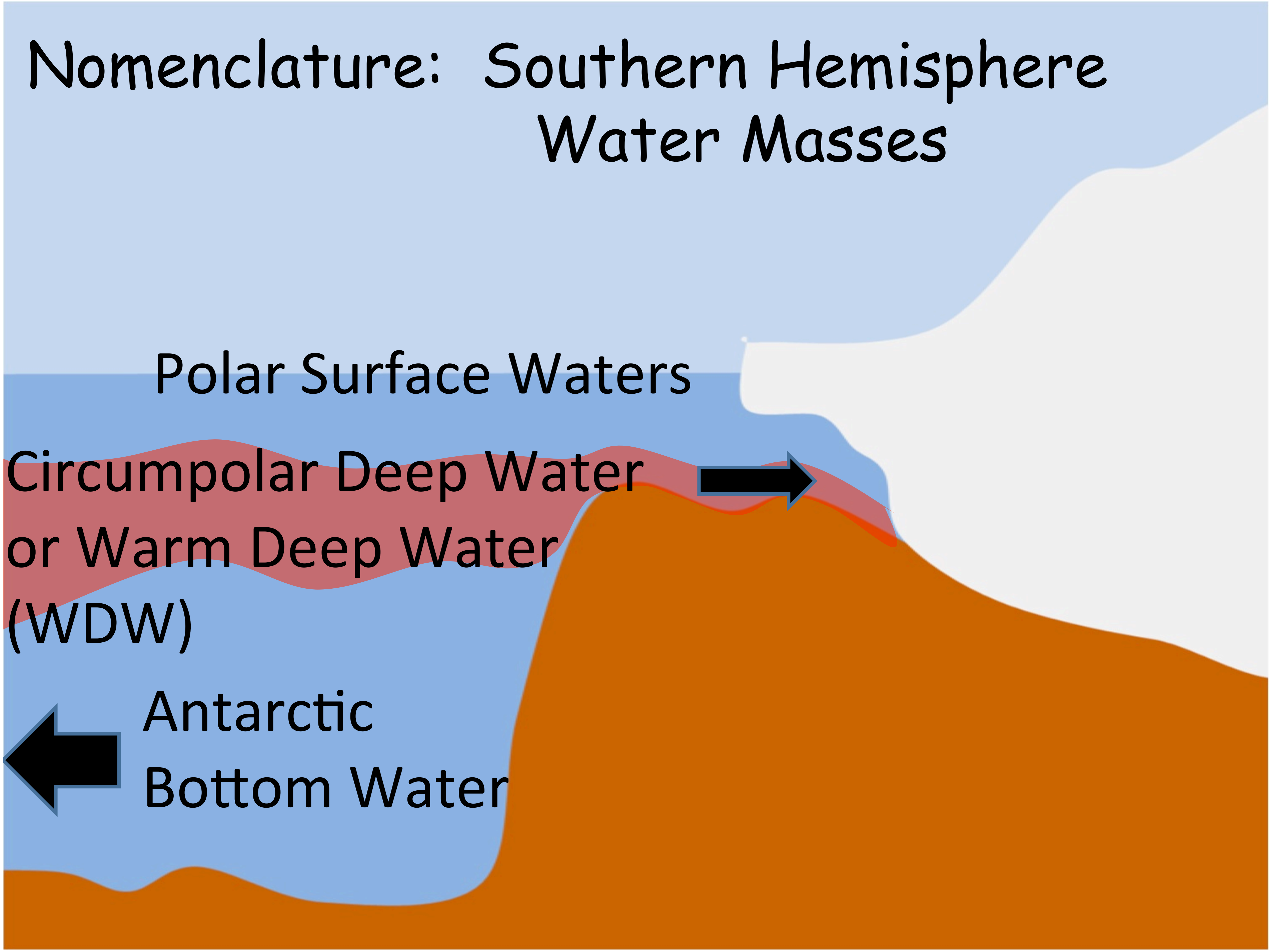
Courant Institute
New York University
USA

WCRP Workshop on
Seasonal to Multidecadal
Predictability of
Polar Climate
October 26, 2010

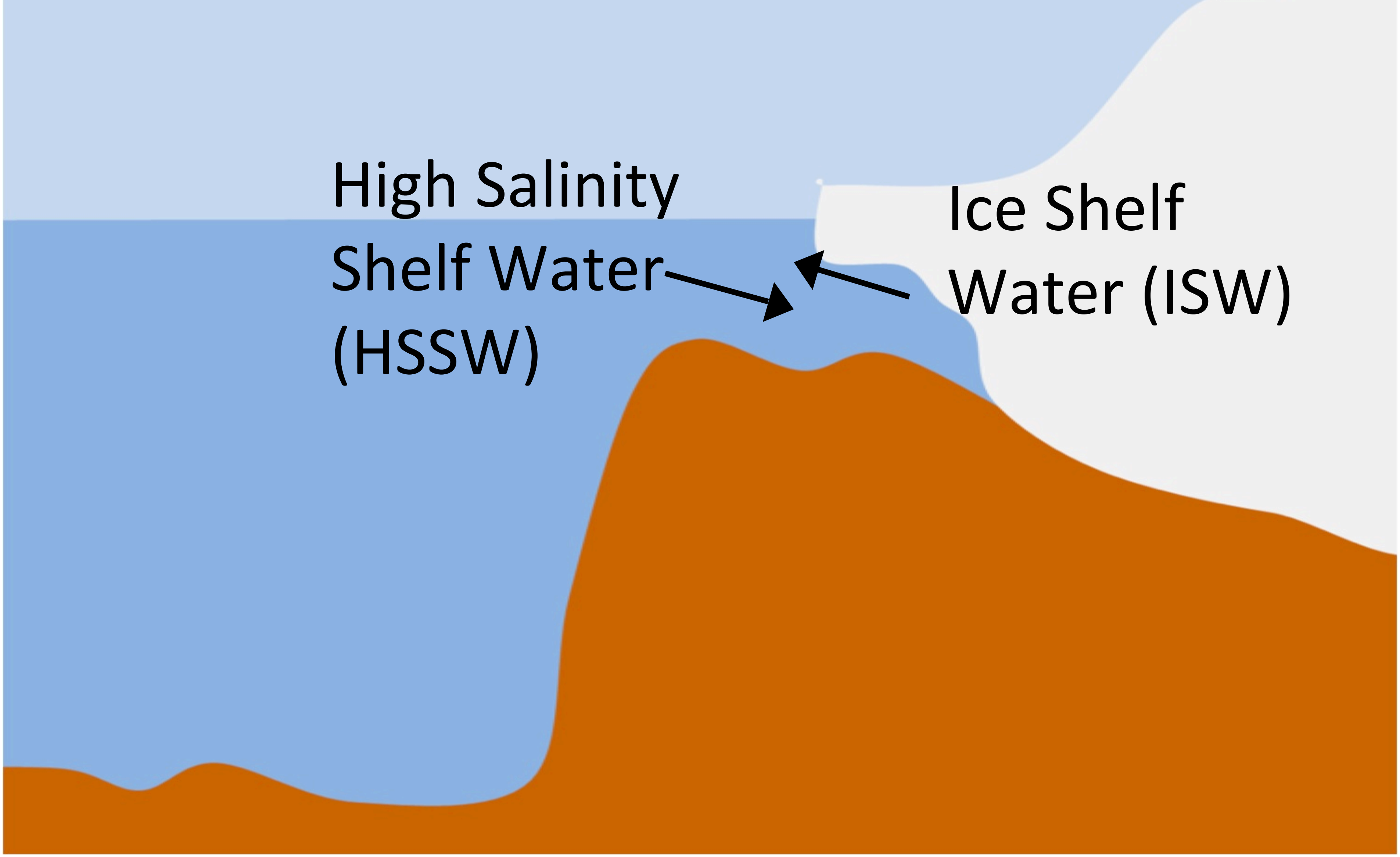

Nomenclature:
Atmosphere
Ice Front
Ice Sheet
Sea Ice
Ice Shelf
Slope
Front
Cavity
Grounding
Line
Ocean
Bedrock



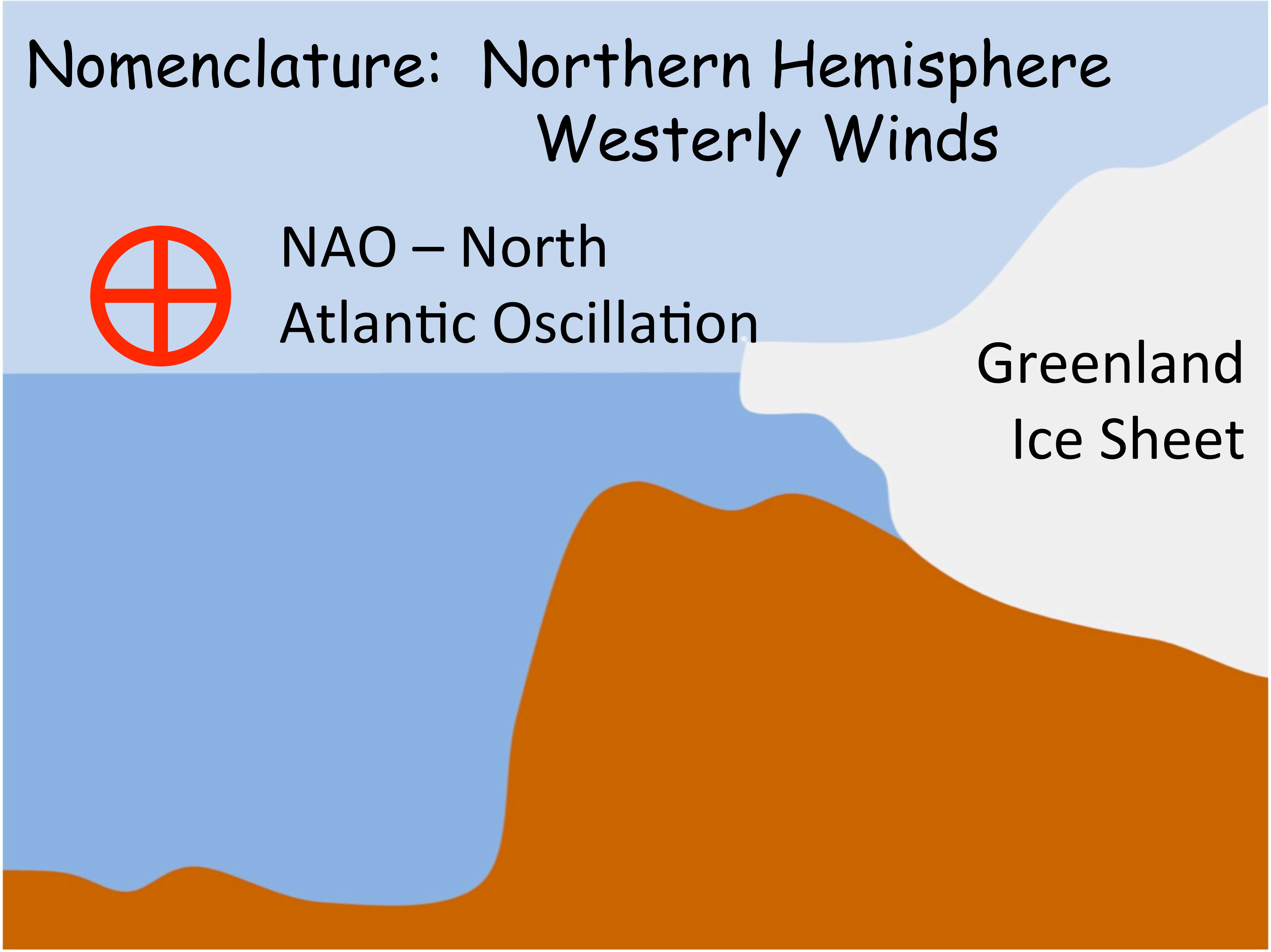
Nomenclature: Northern Hemisphere
Water Masses
Polar Surface Waters
Irminger Waters or
Atlantic-Layer
Waters
North Atlantic
Deep Water

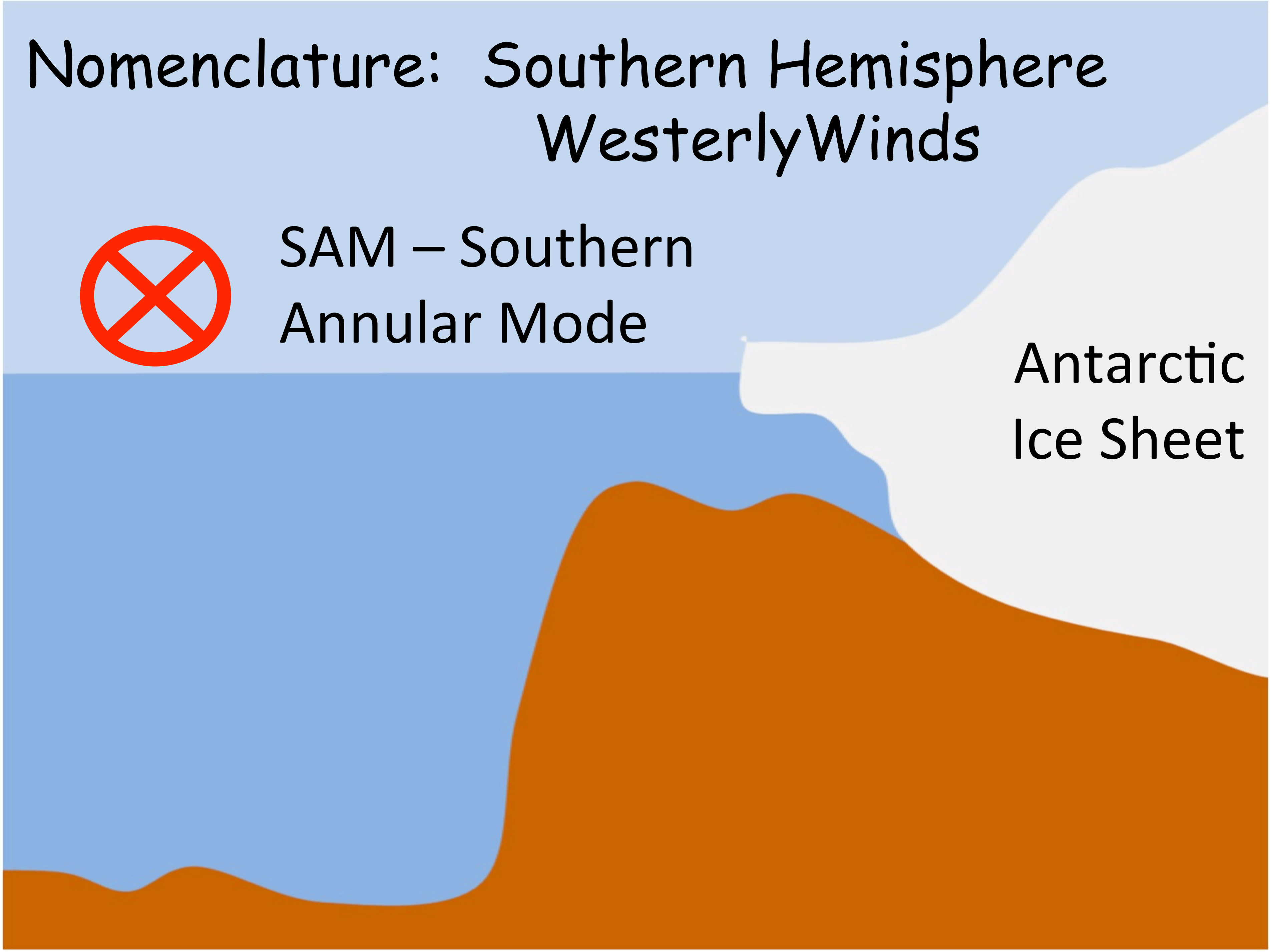

Nomenclature: Southern Hemisphere Water Masses
Polar Surface Waters
Circumpolar Deep Water or Warm Deep Water (WDW)
Antarctic Bottom Water

Nomenclature: Continental Shelf Water Masses

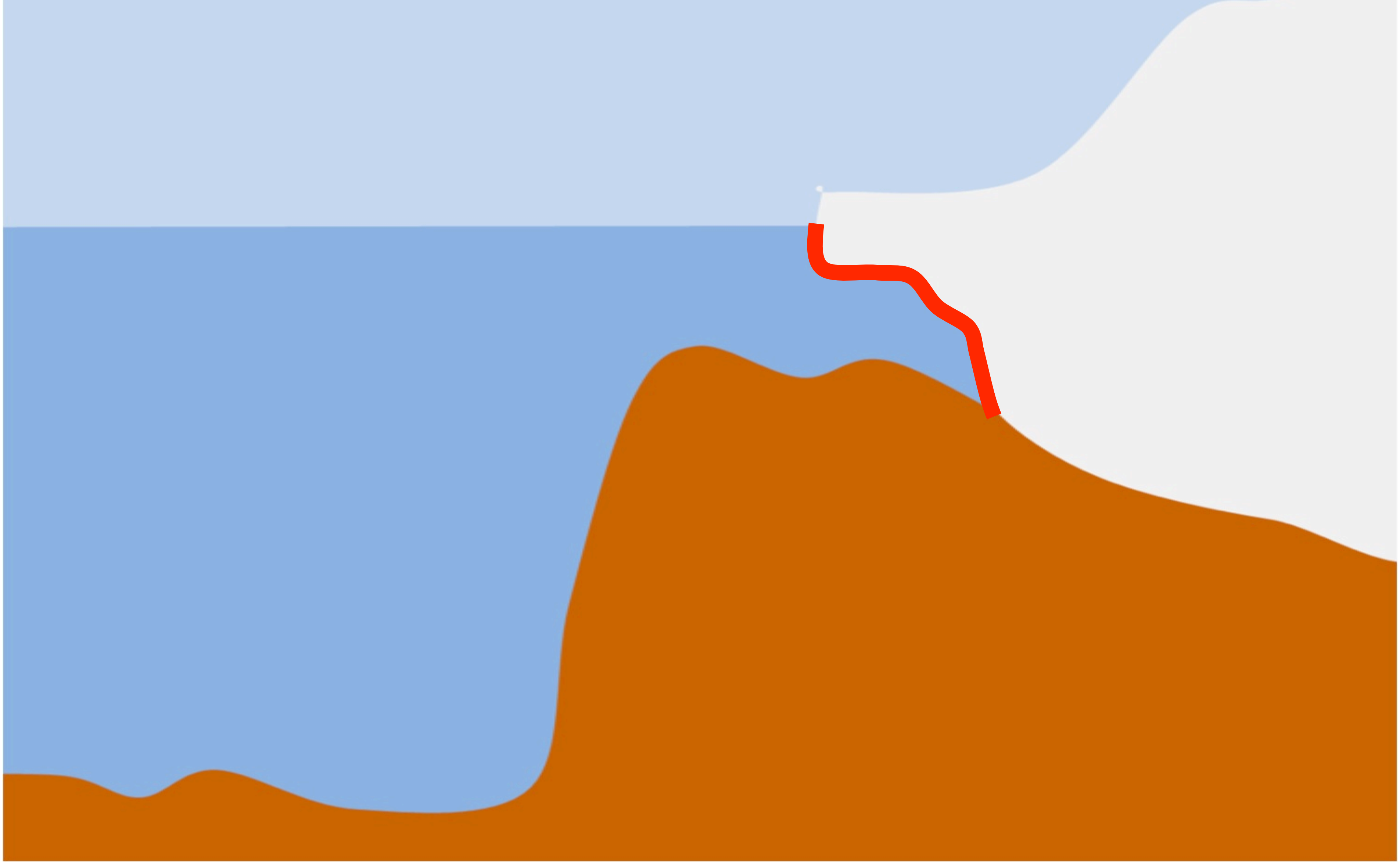


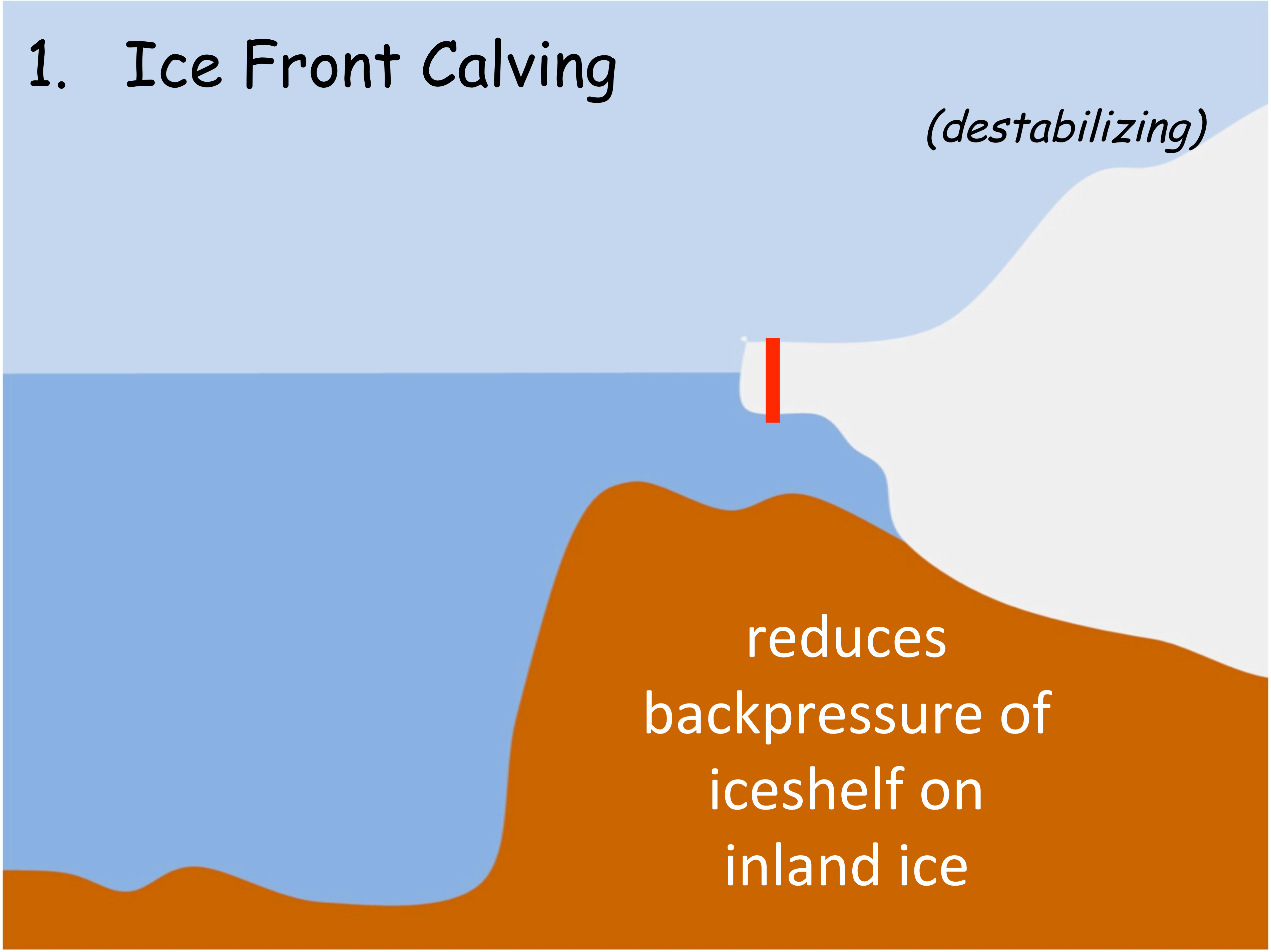
Nomenclature: Northern Hemisphere Westerly Winds




Nomenclature: Southern Hemisphere WesterlyWinds
SAM – Southern Annular Mode
Antarctic Ice Sheet

Primary Objective:
Position of the Ice-Ocean Interface

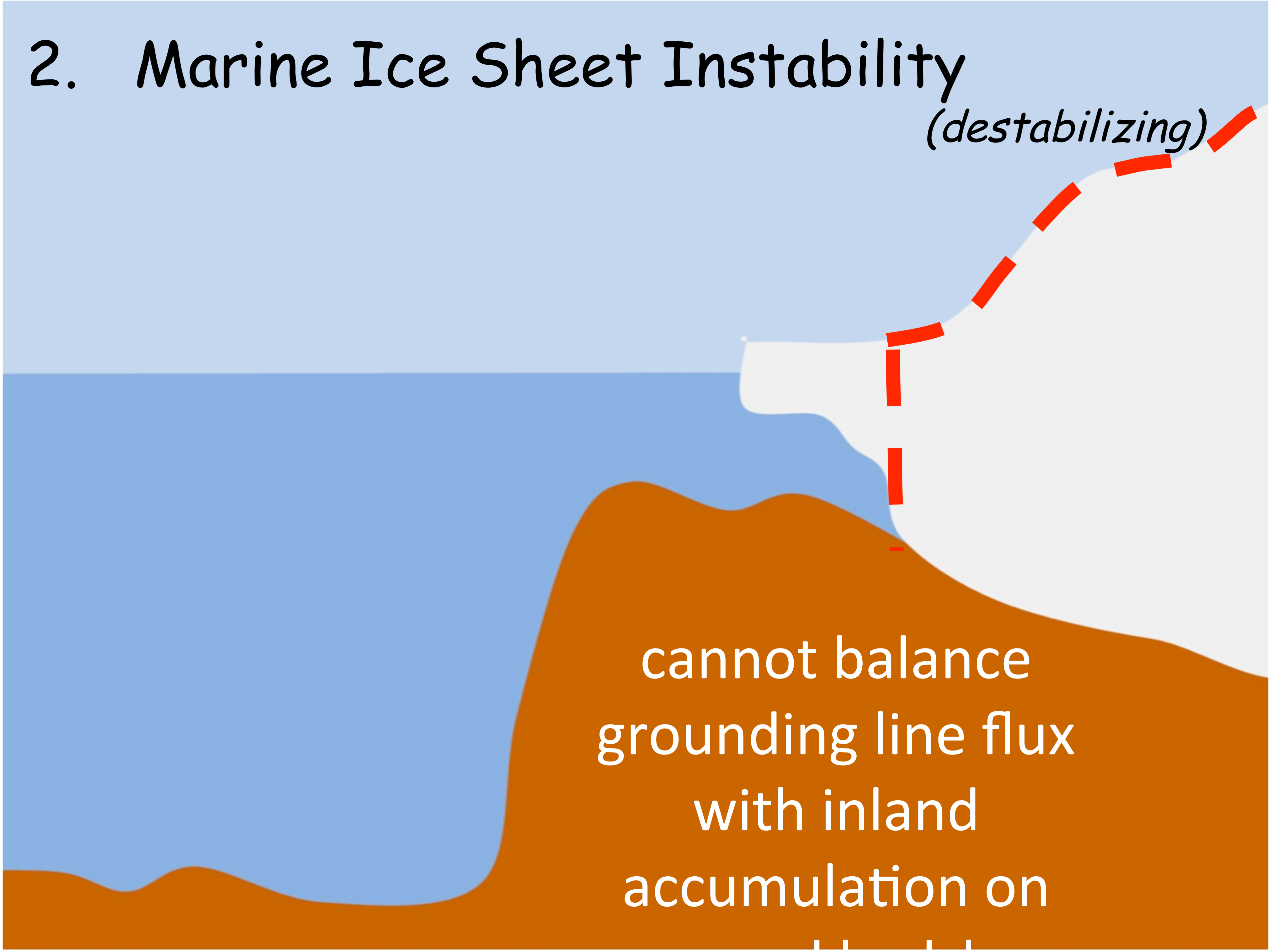


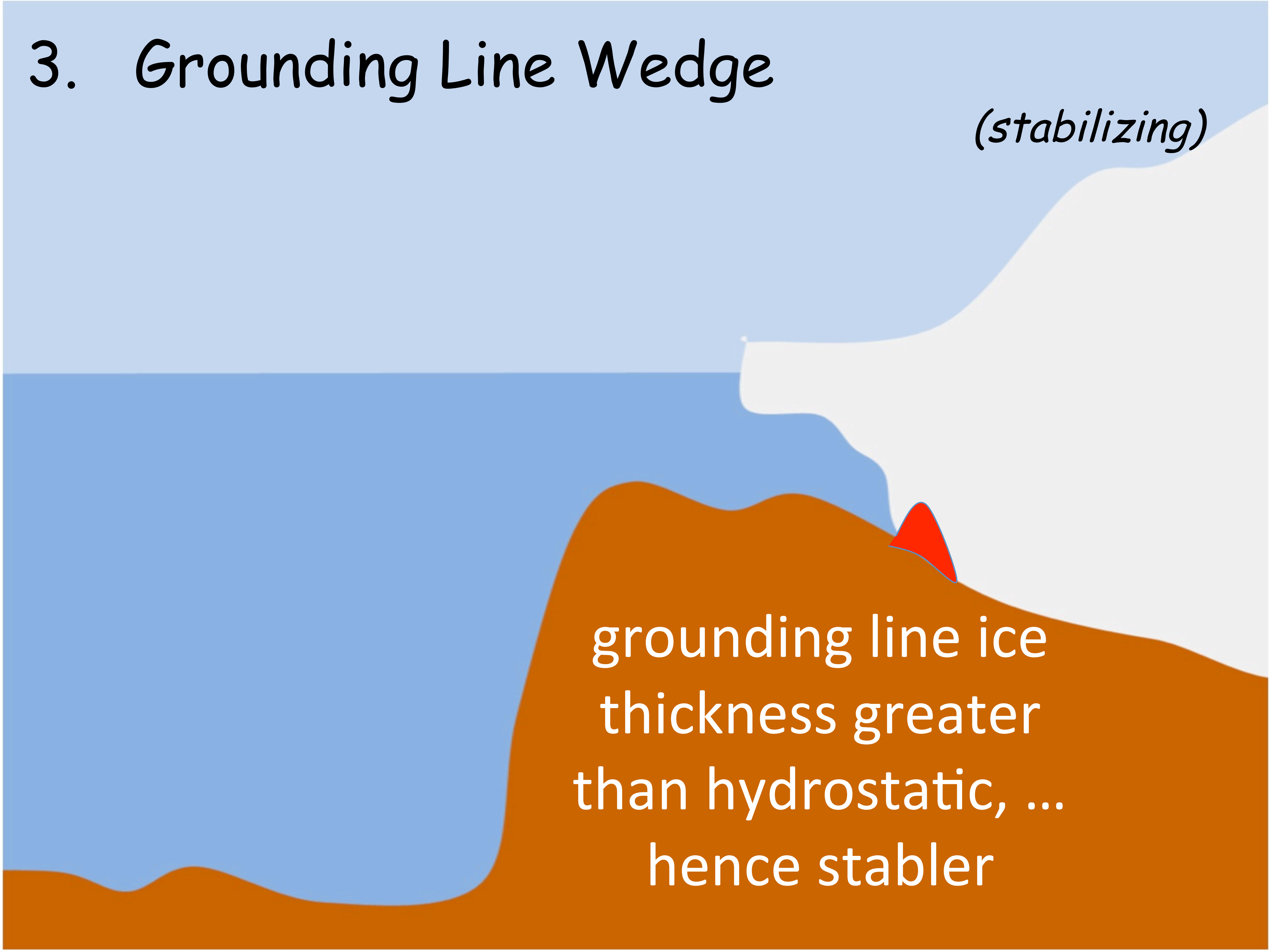

1. Ice Front Calving
(destabilizing)
reduces backpressure of iceshelf on inland ice

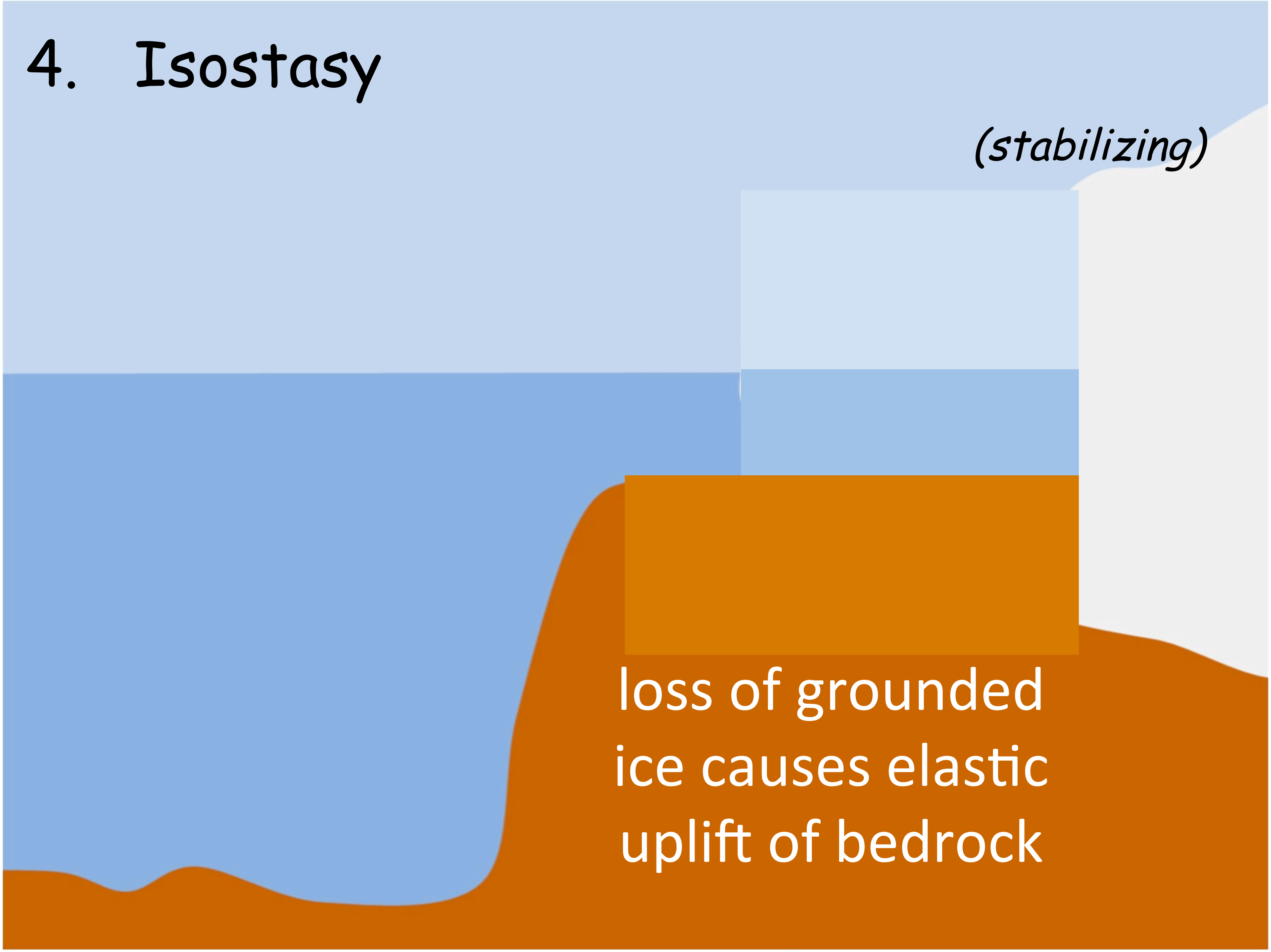
1. Ice Front Calving: Theoretical Description Lacking

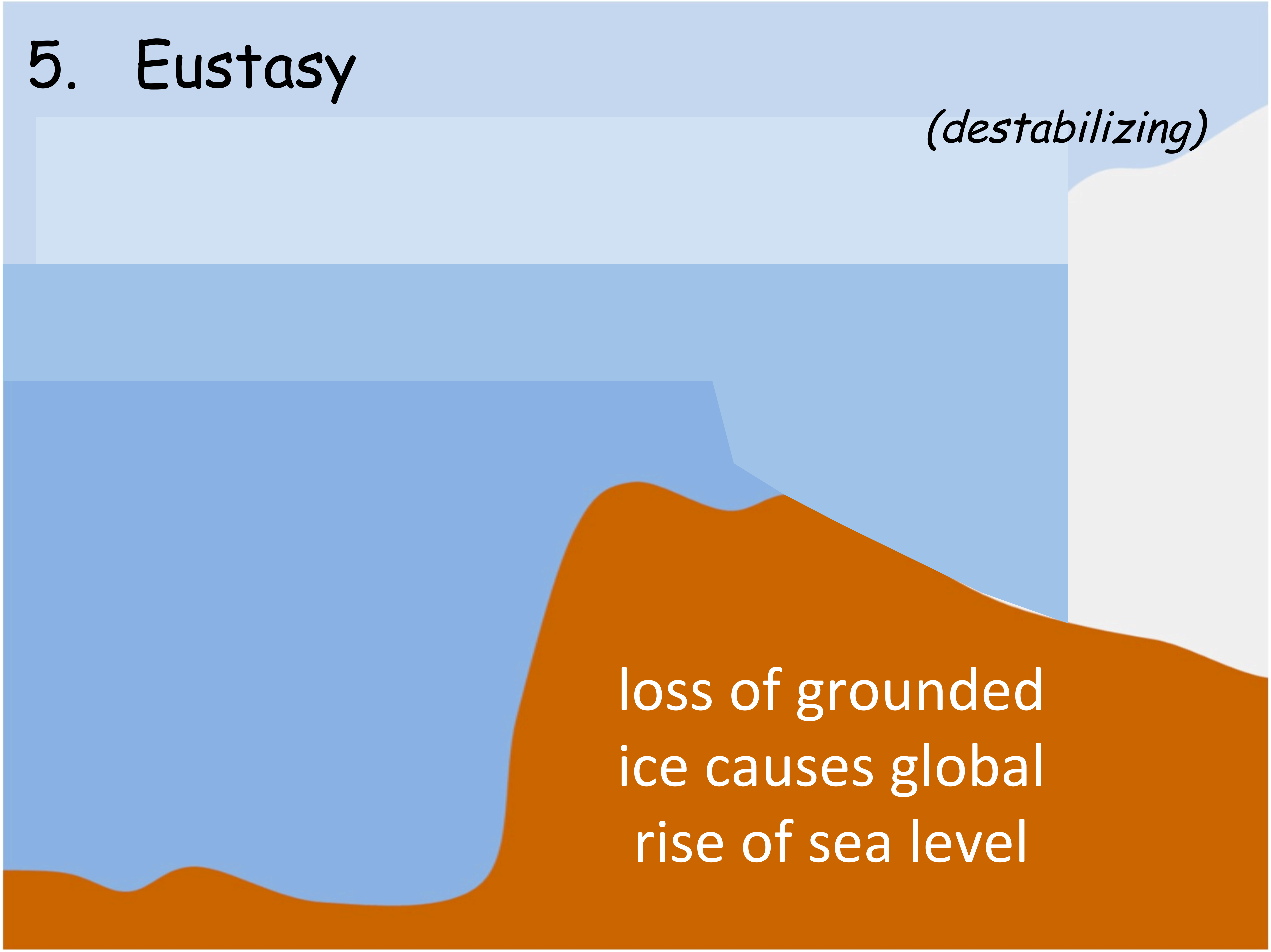
Jakobshavn Isbræ, West Greenland
5 June 2007
14:10 - 14:28 UTC

photos by Jason Amundson
Geophysical Institute, University of Alaska Fairbanks

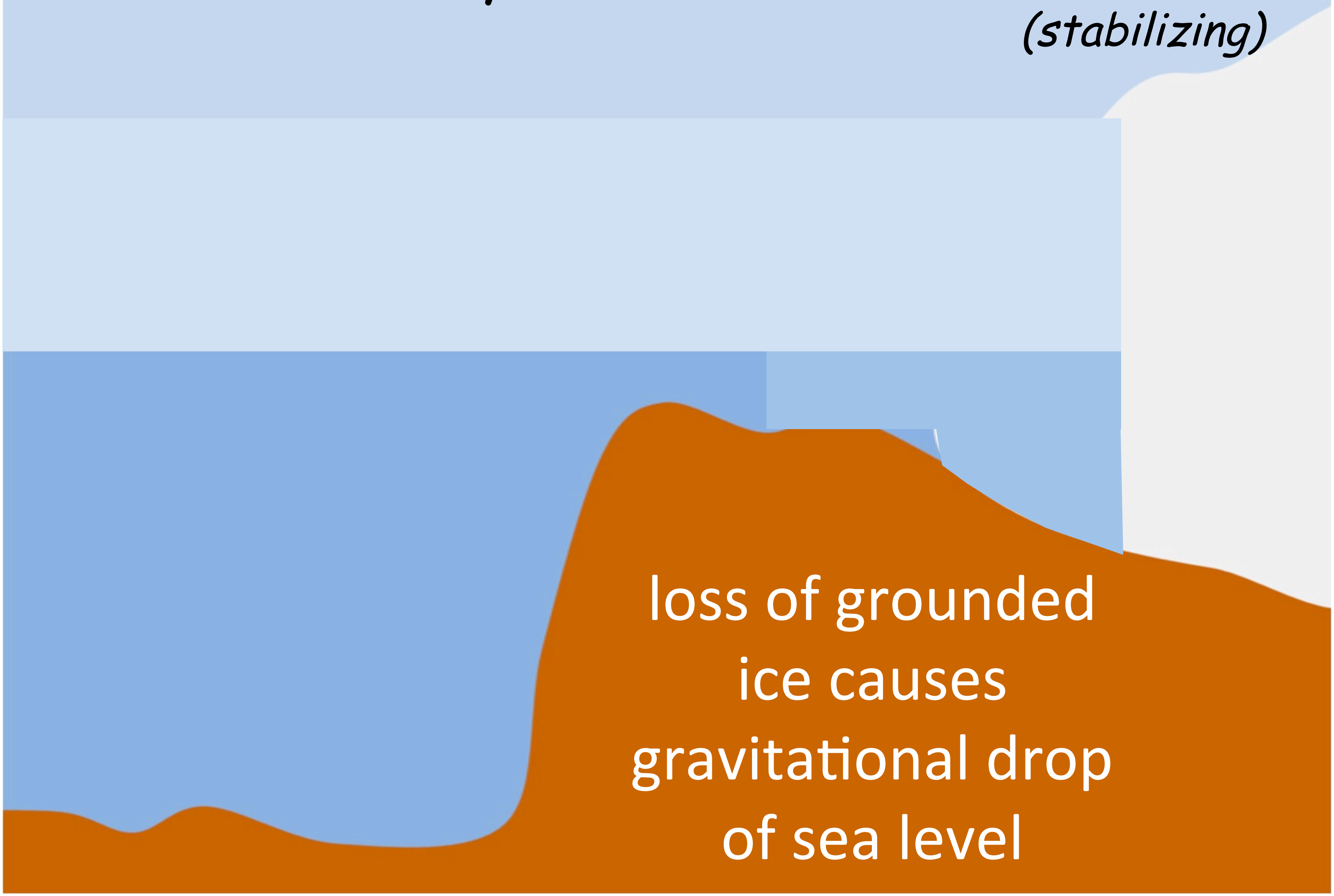

2. Marine Ice Sheet Instability
(destabilizing)
cannot balance
grounding line flux
with inland
accumulation on


3. Grounding Line Wedge
(stabilizing)
grounding line ice
thickness greater
than hydrostatic, …
… hence stabler

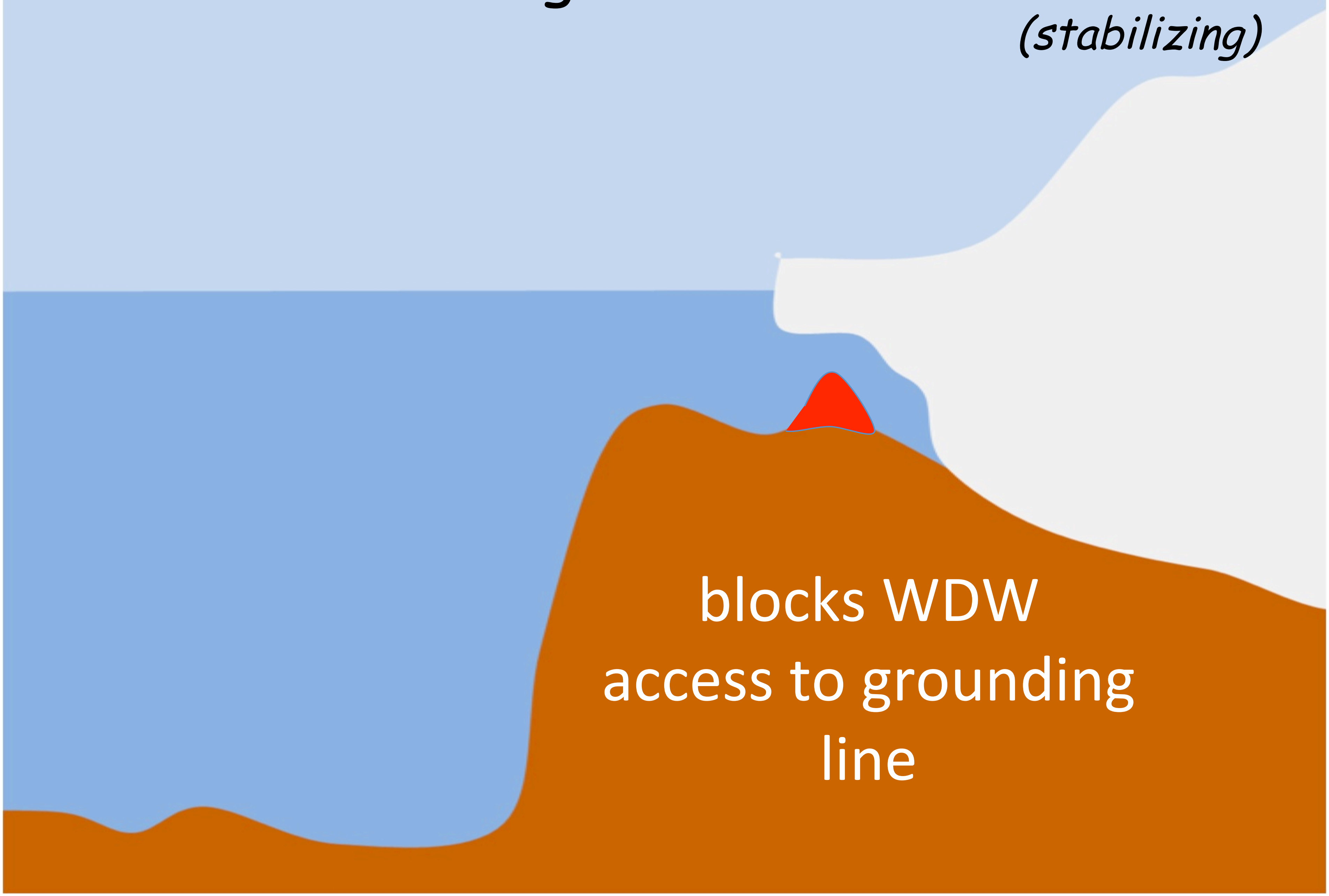

4. Isostasy
(stabilizing)
loss of grounded ice causes elastic uplift of bedrock


5. Eustasy
(destabilizing)
loss of grounded ice causes global rise of sea level

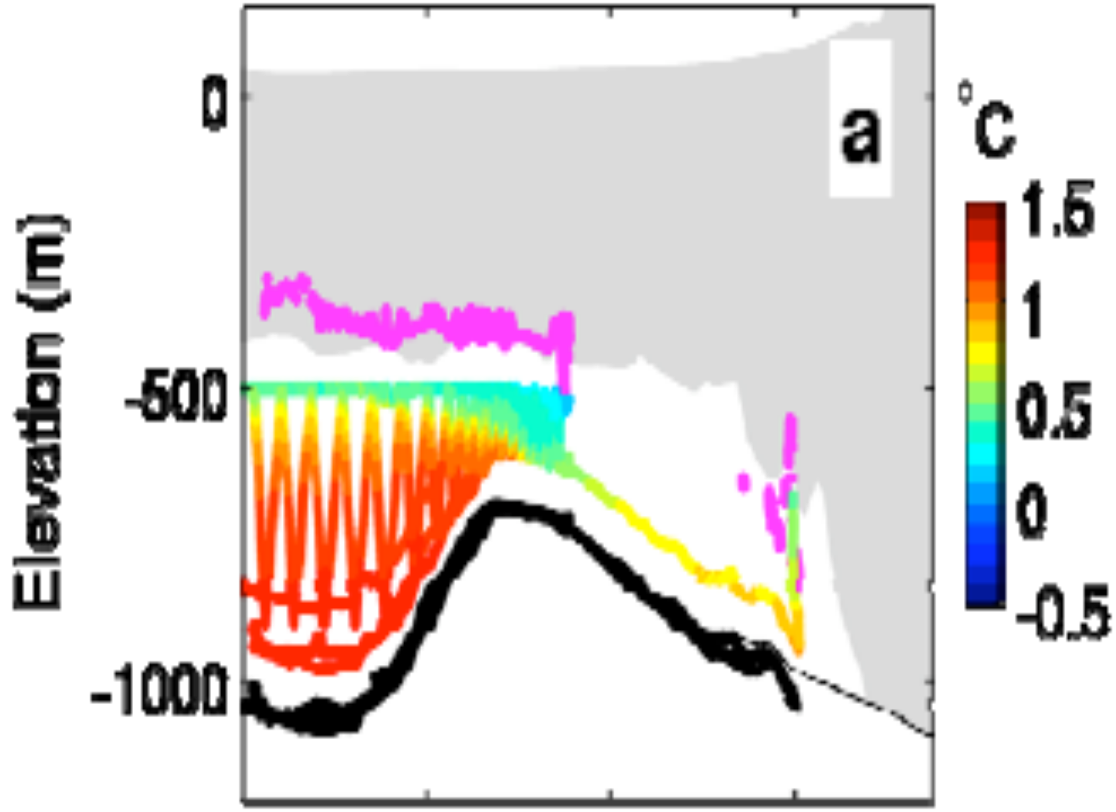
6. Self Gravity



7. Sea Floor Ridges

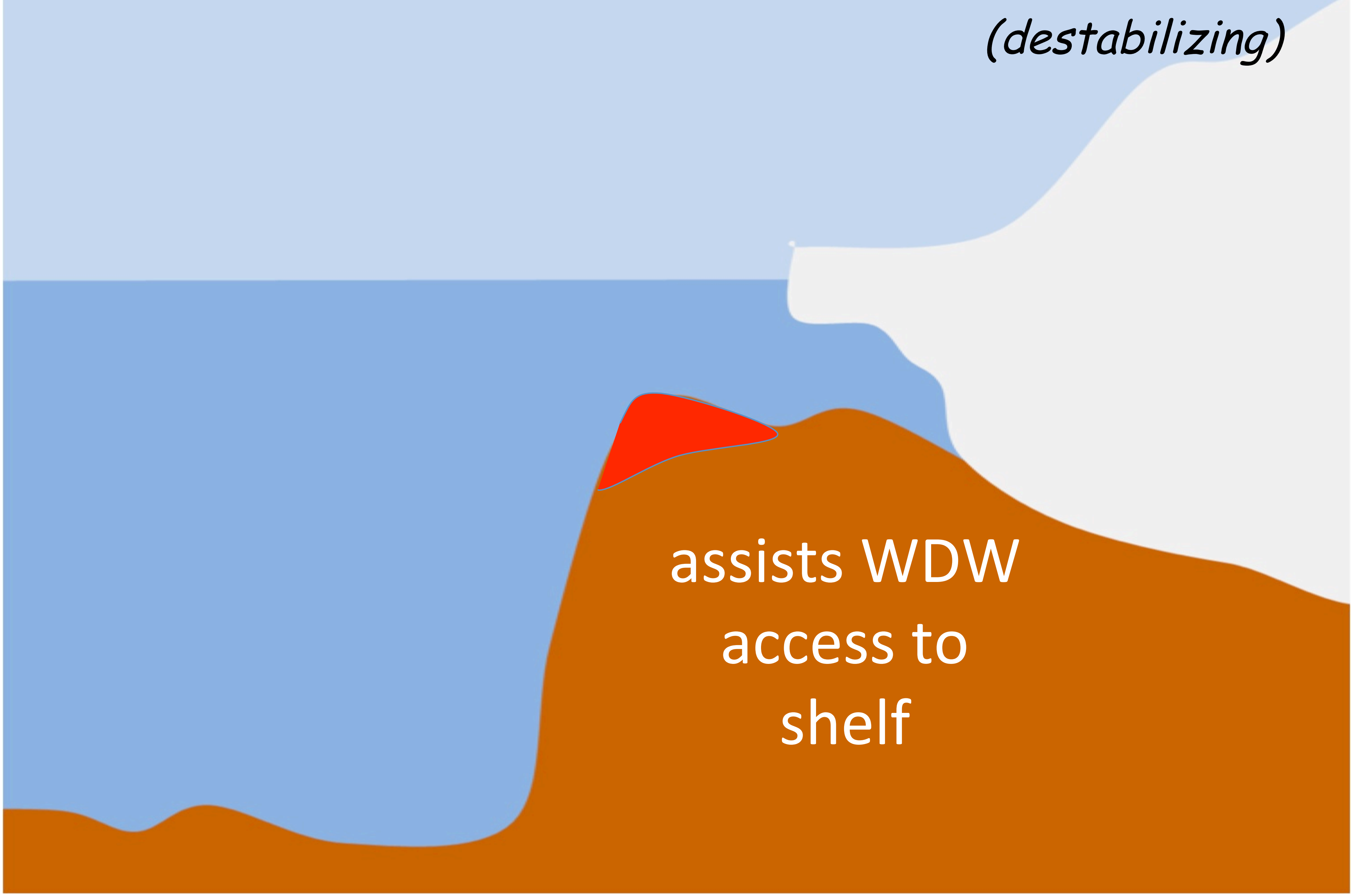


7. Sea Floor Ridges
Autosub @ PIG, Jan 2010

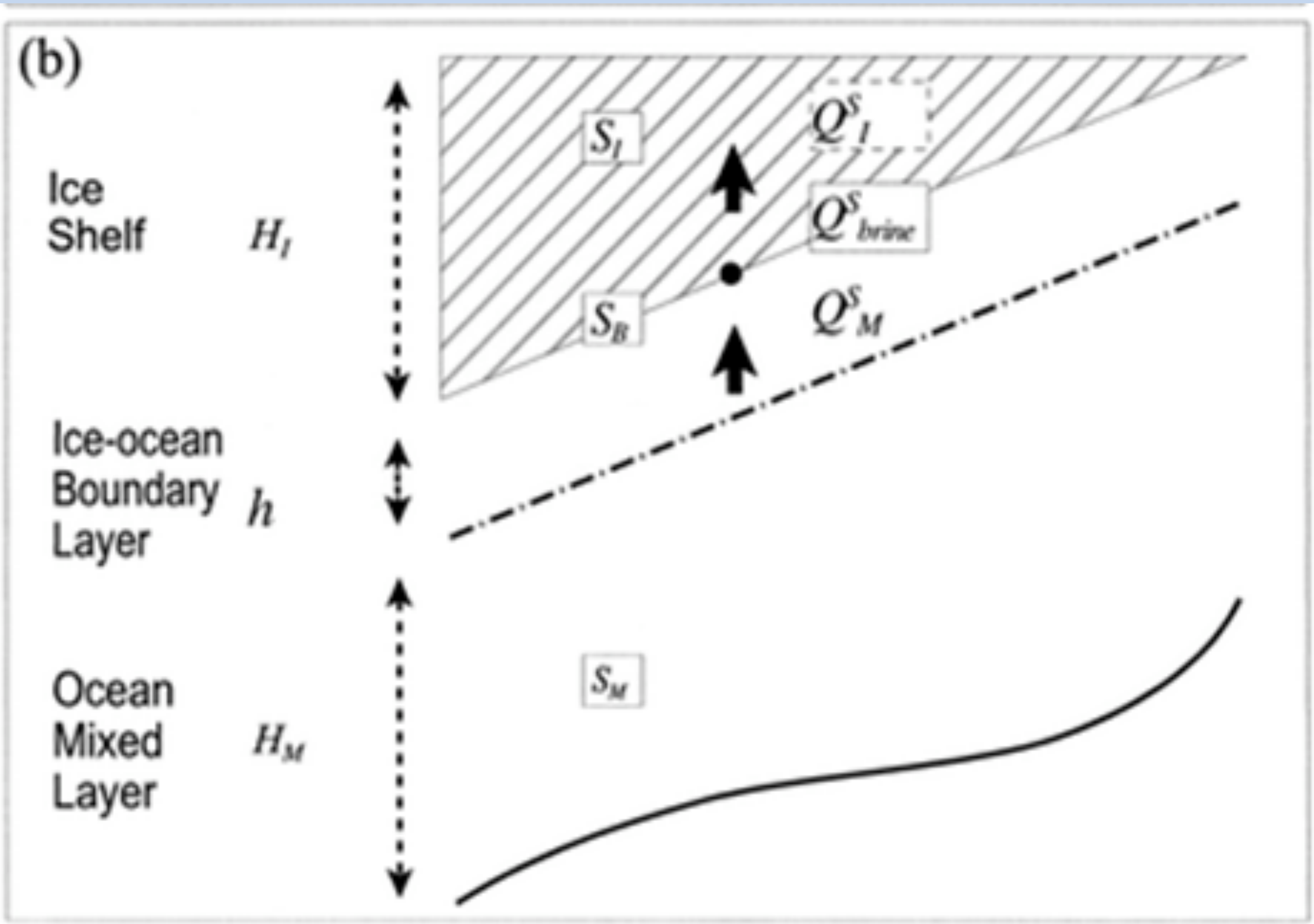


Jenkins et al.,
Nat. Geosci., 2010

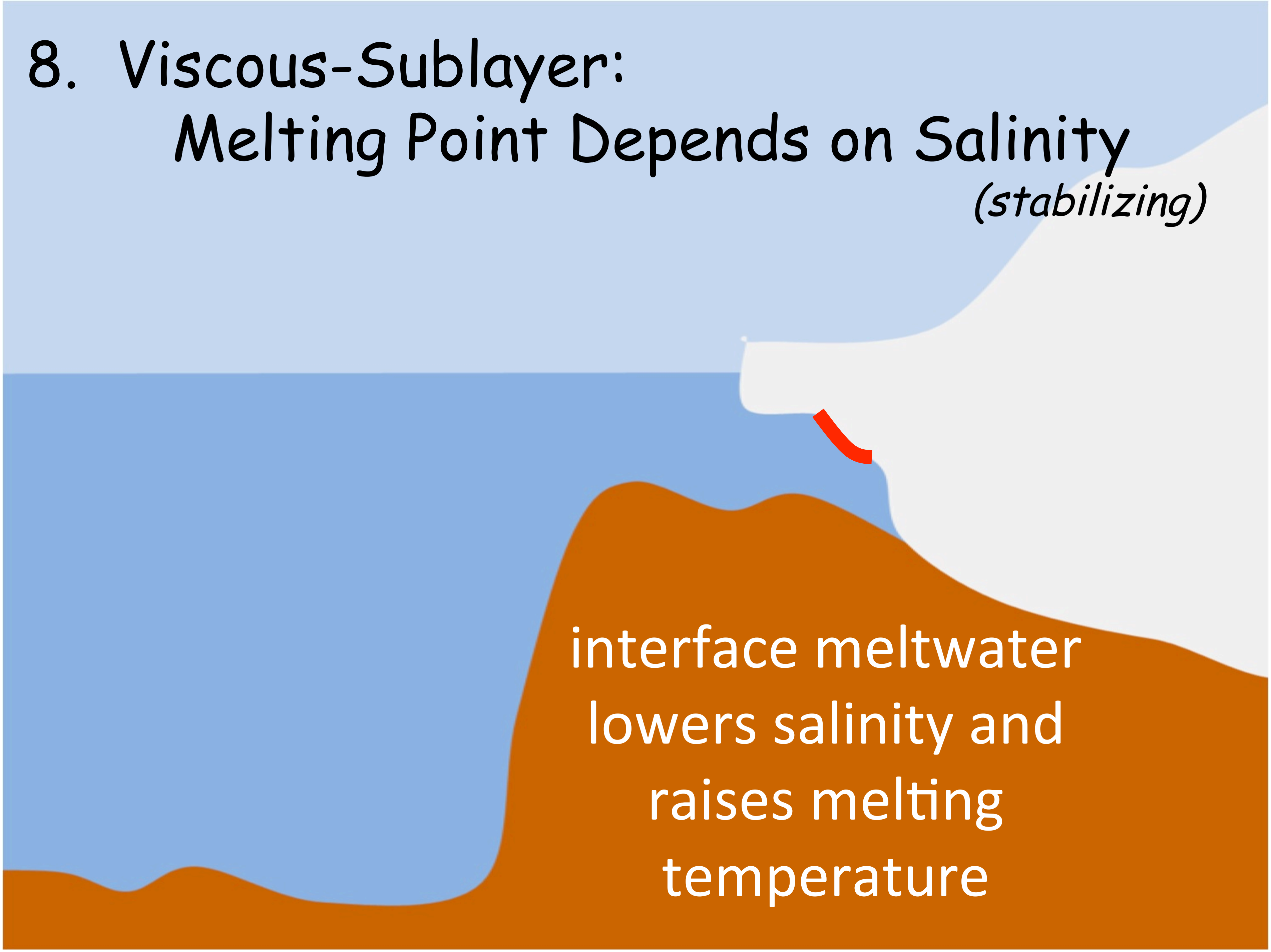
7. Shelf Break Troughs

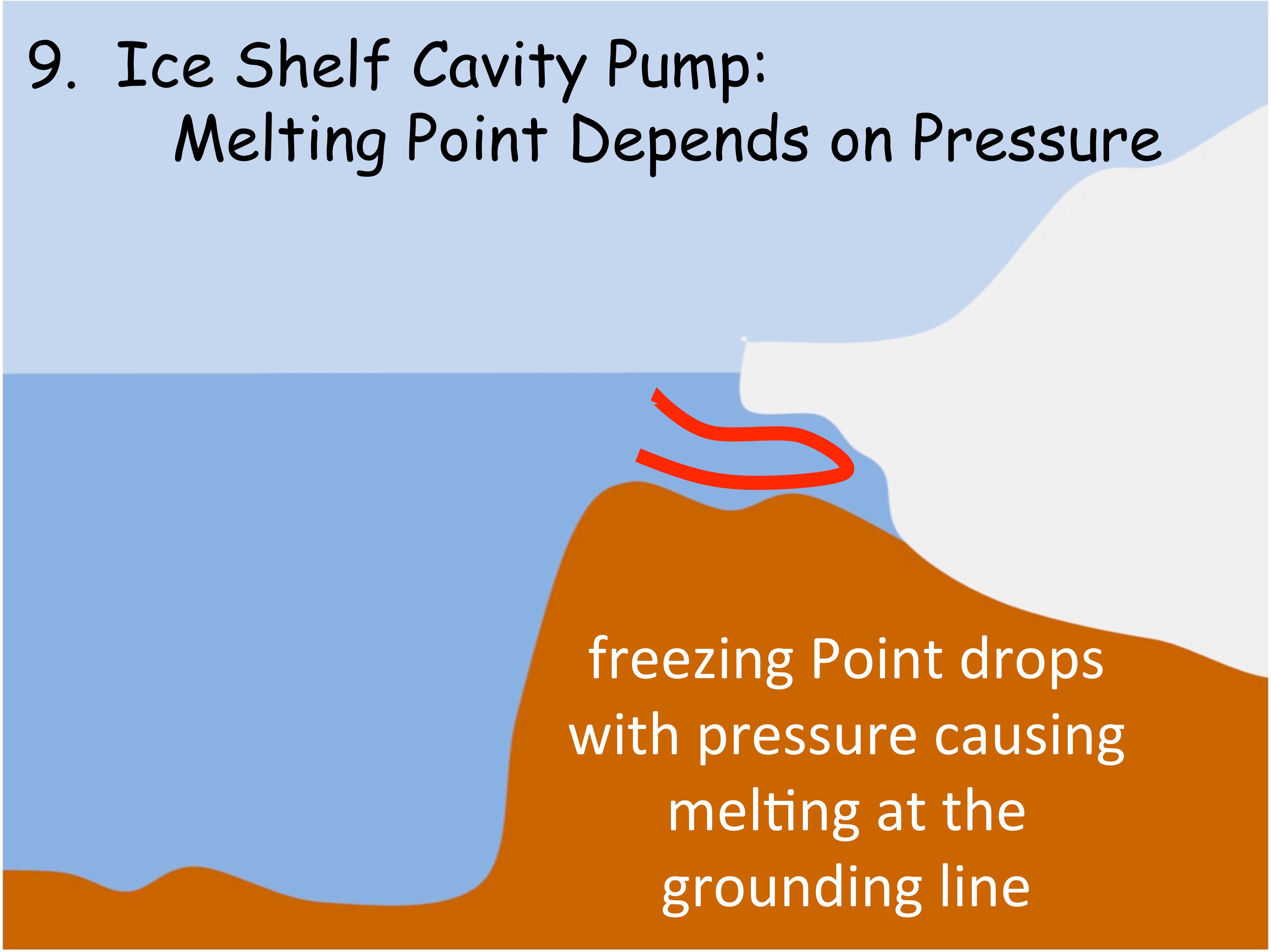


8. Viscous-Sublayer: Molecular Exchange Rules



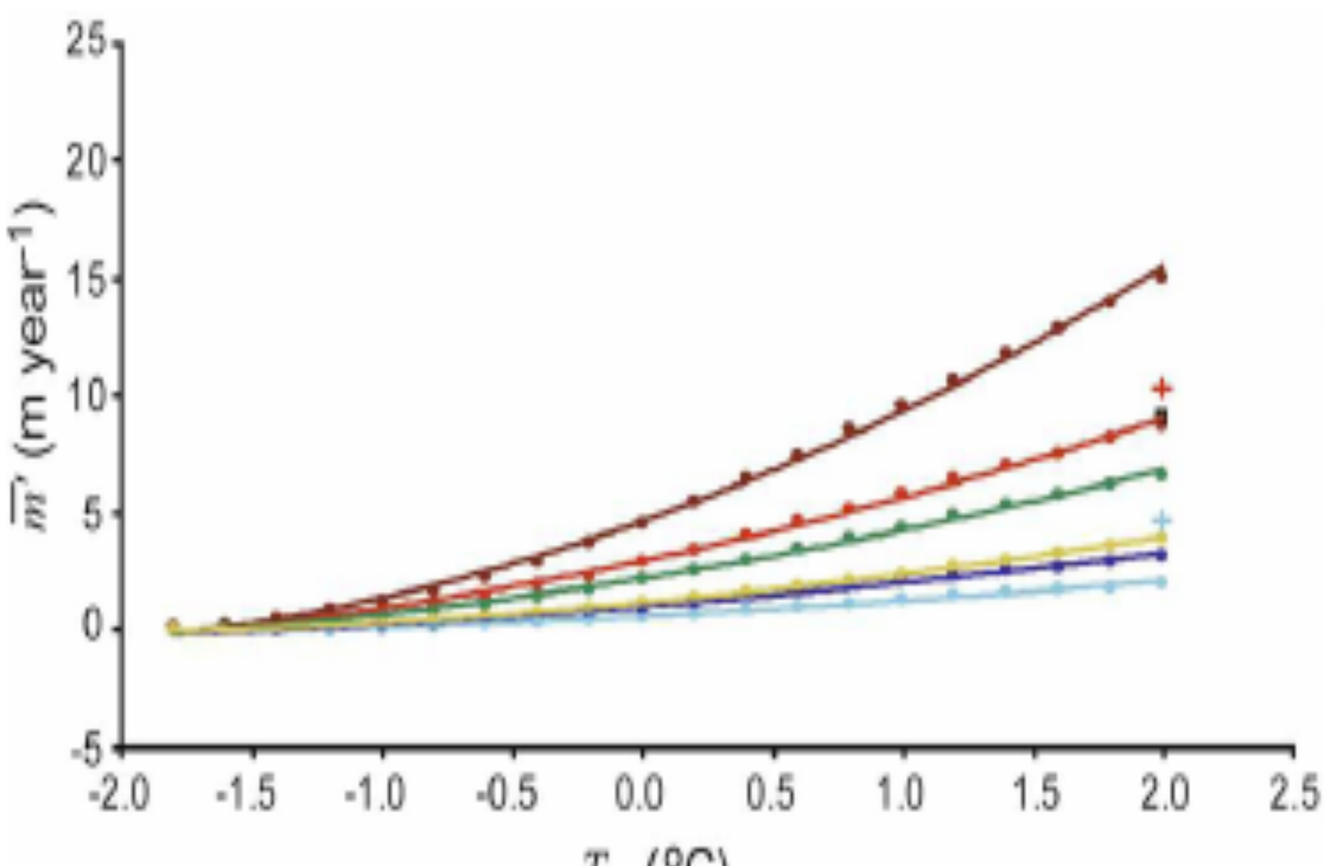
Holland & Jenkins, JPO, 1999


8. Viscous-Sublayer:
Melting Point Depends on Salinity
(stabilizing)
interface meltwater lowers salinity and raises melting temperature


9. Ice Shelf Cavity Pump:
Melting Point Depends on Pressure
freezing Point drops with pressure causing melting at the grounding line

9. Ice Shelf Cavity Pump: Quadratic Melting

(destabilizing)



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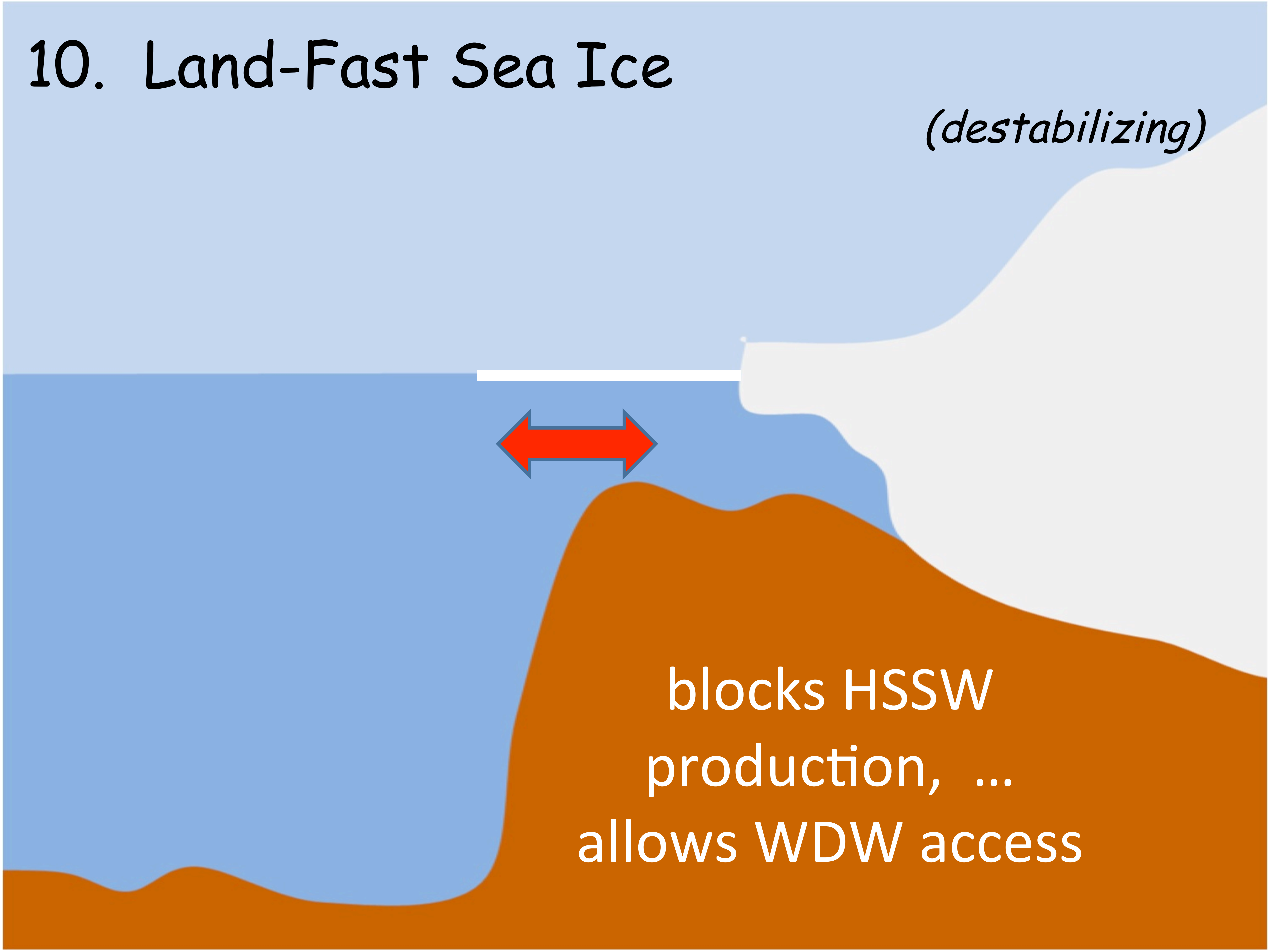
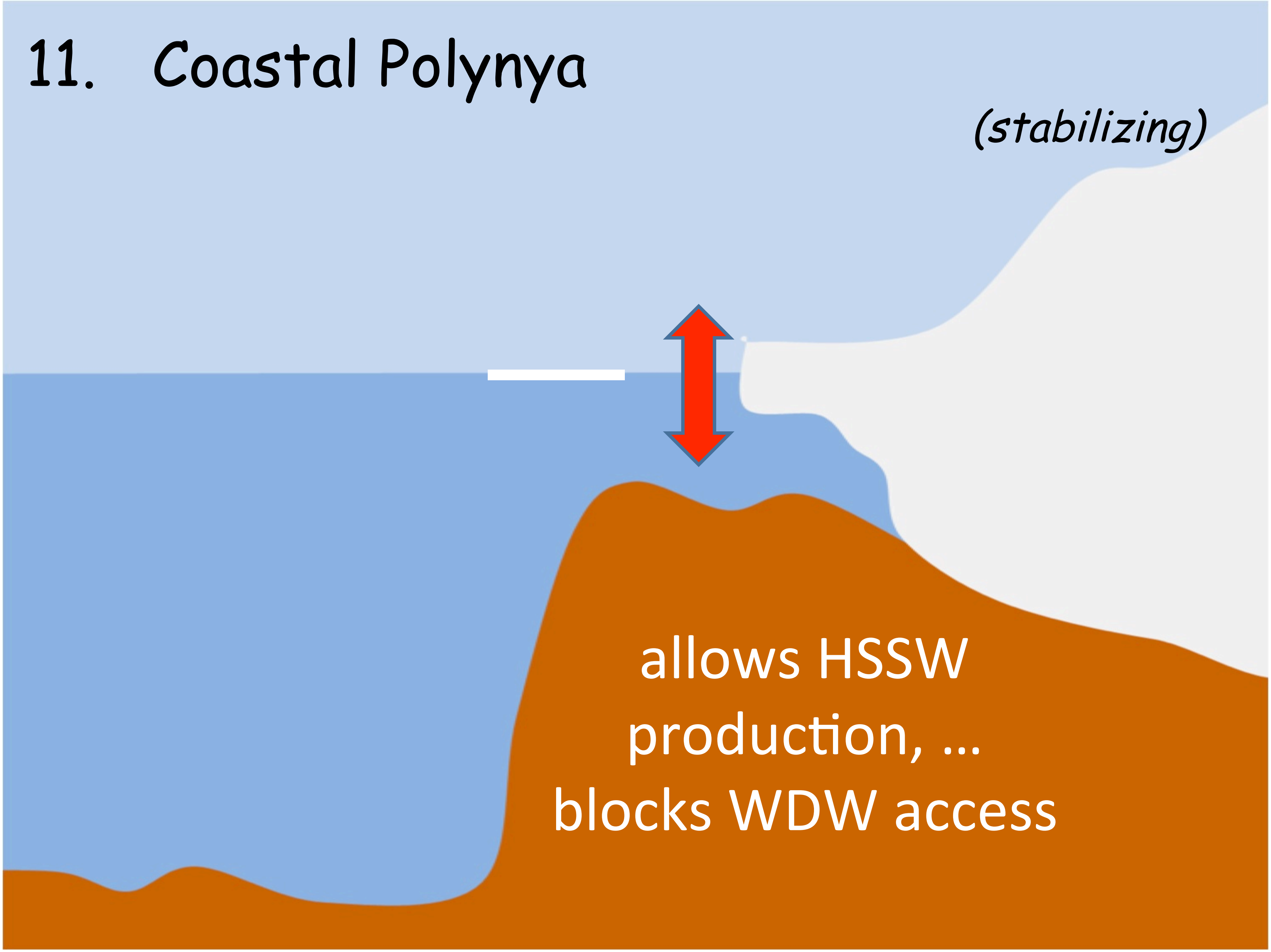
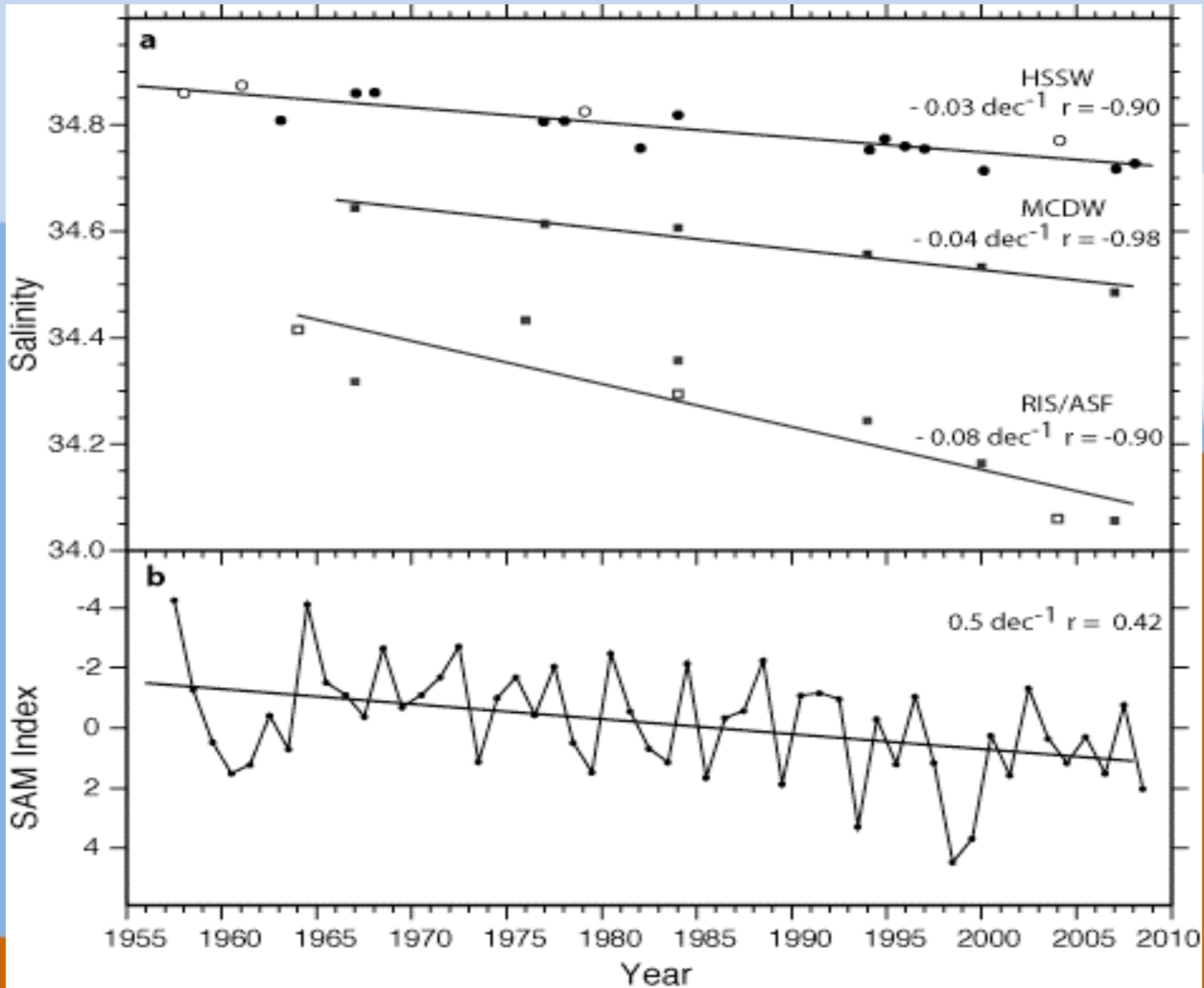
P. Holland et al., *J. Climate,* 2008


10. Land-Fast Sea Ice
(destabilizing)
blocks HSSW
production, …
allows WDW access


11. Coastal Polynya
(stabilizing)
allows HSSW
production, ...
blocks WDW access

12. Mean Density Structure over Continental Shelf

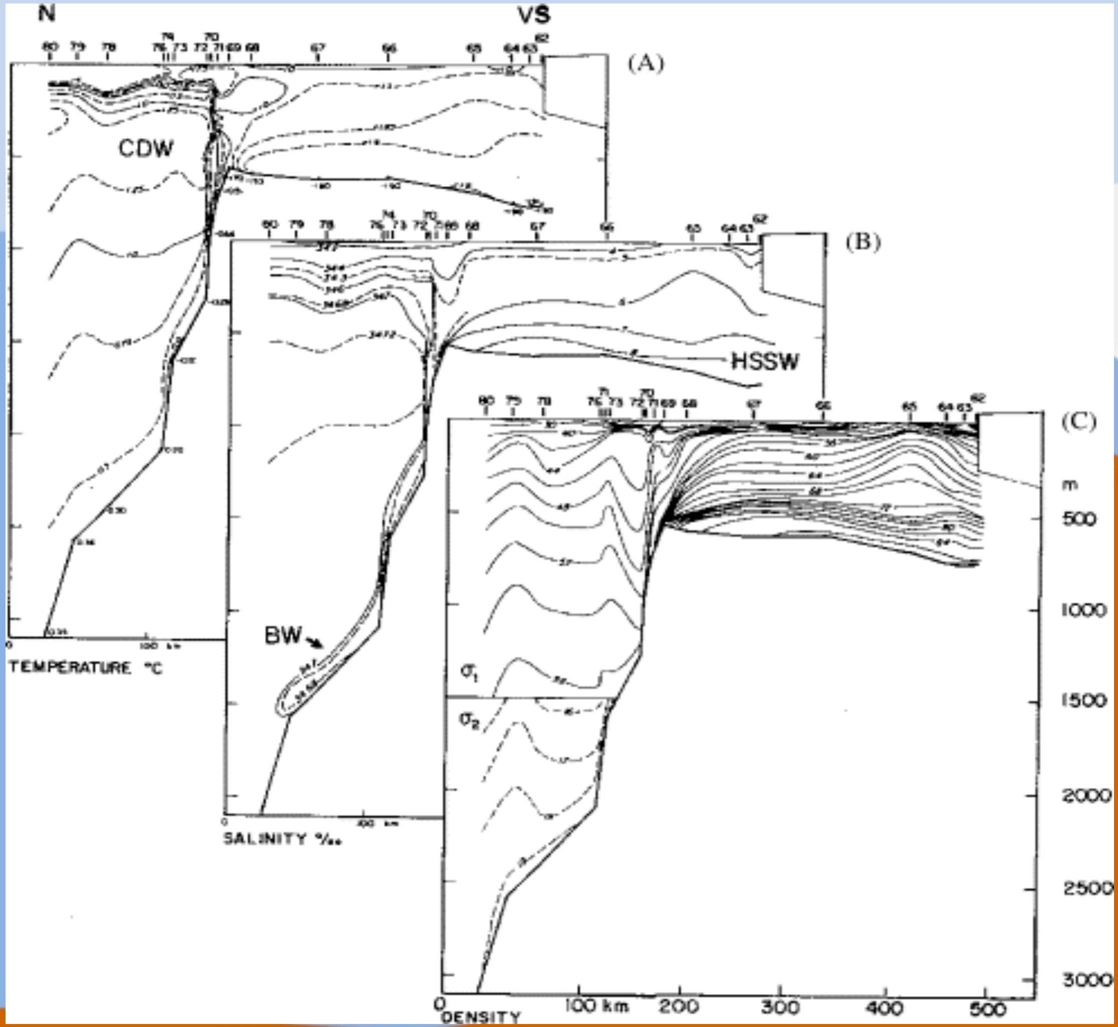
(de/stabilizing)



Jacobs & Giulivi,
J. Climate, 2010

13. Antarctic Slope Front: Dynamic Barrier

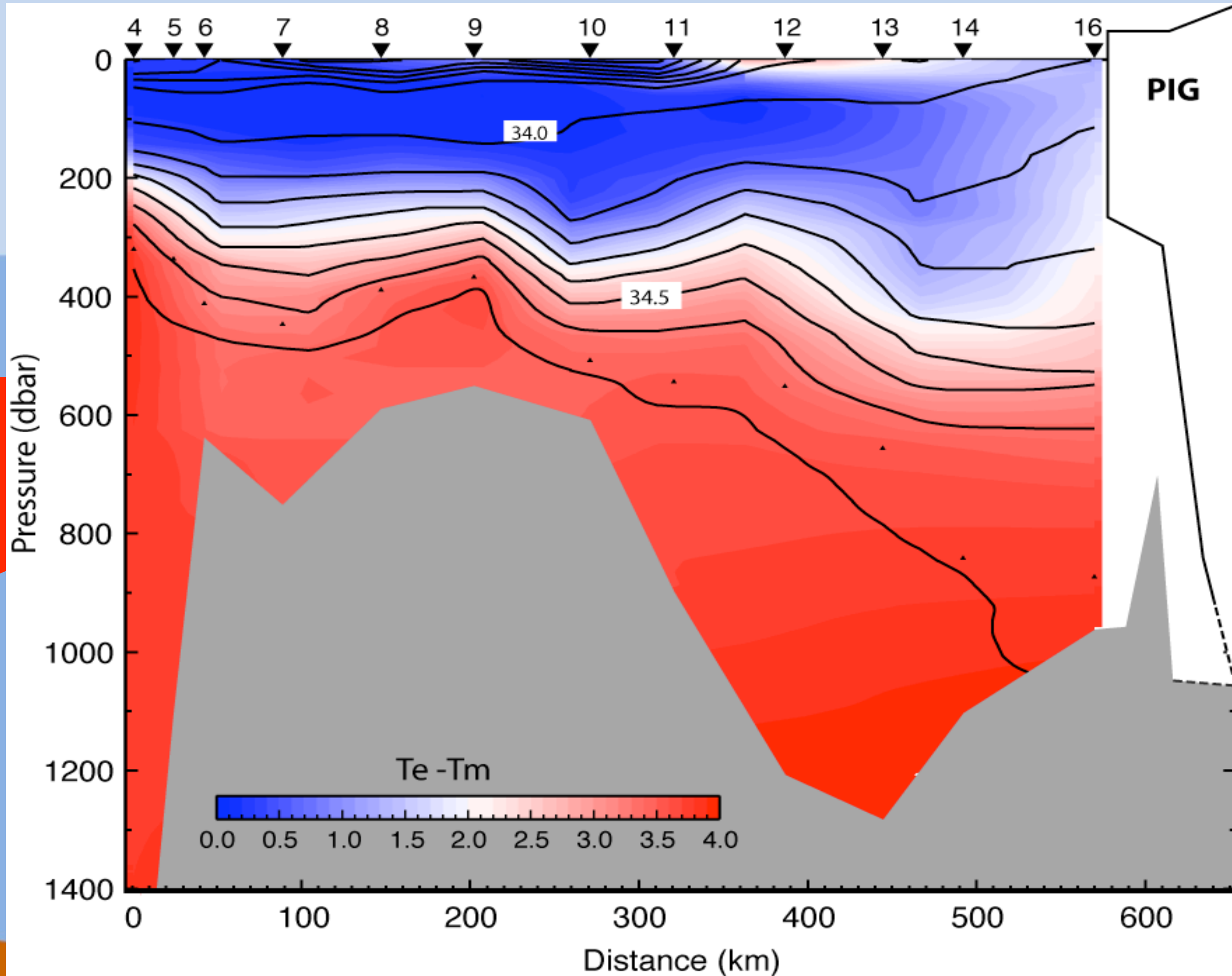
(stabilizing)



Jacobs
Mar. Chem., 1991

14. Warm Deep Water (WDW)

(destabilizing)



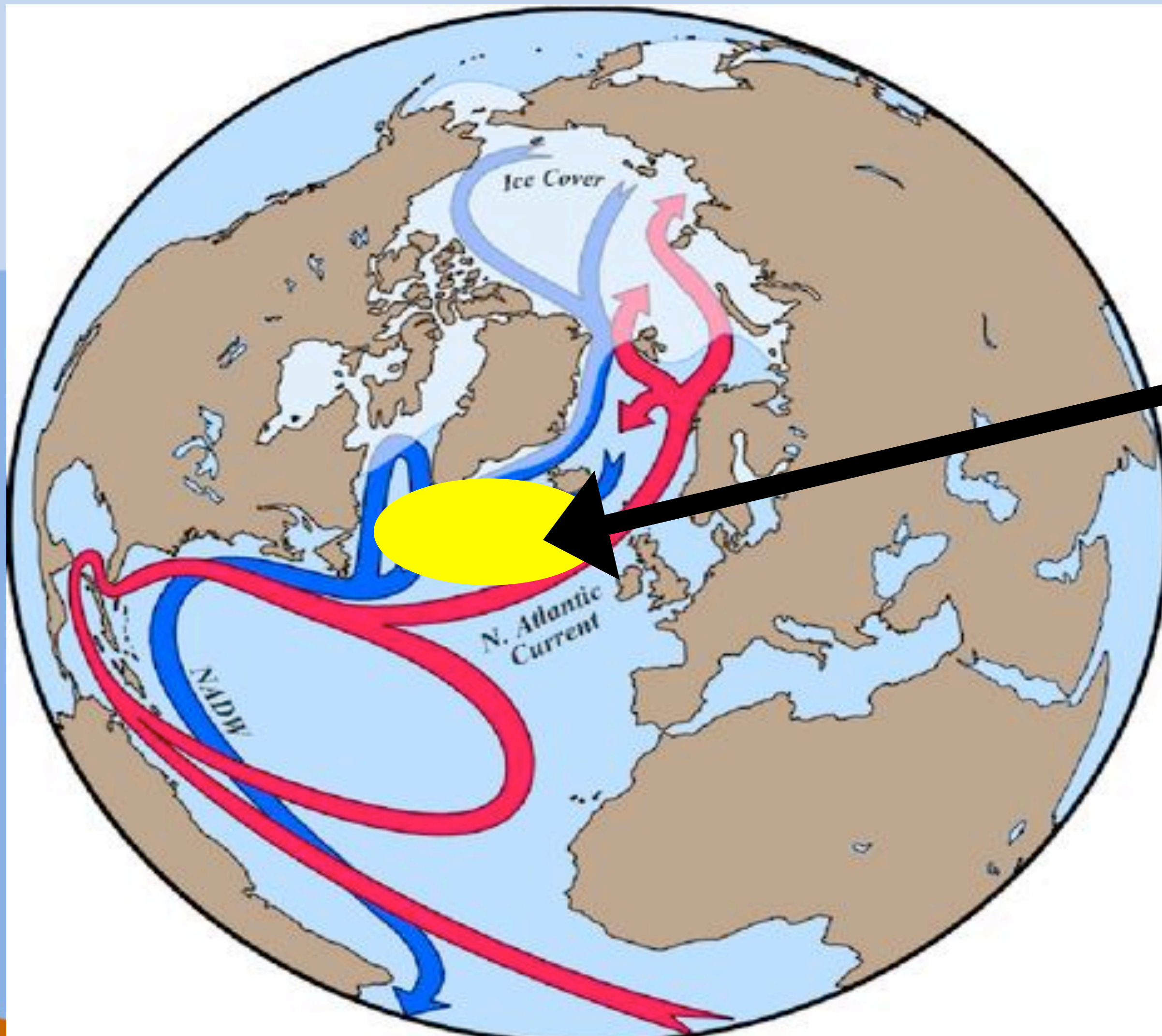
courtesy of
Stan Jacobs, LDEO

15. Westerlies (Strength/Position)

(destabilizing?)

15. Westerlies: Northern Hemisphere (NAO varied over the 1990s)

(destabilizing)

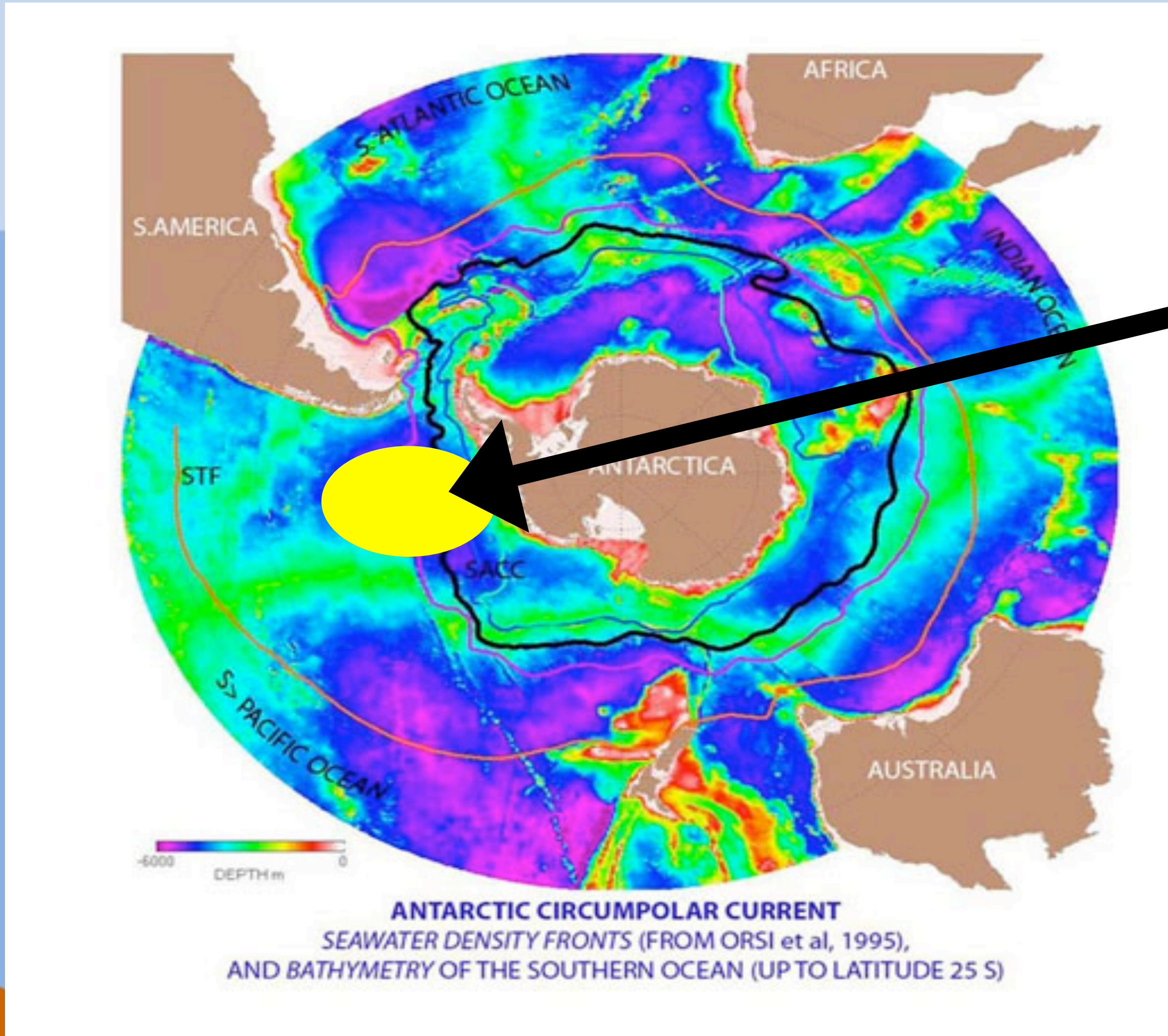


Observational study:
Weaker westerlies … Stronger ice melt

Holland et al., *Nat. Geosci*, 2008

15. Westerlies: Southern Hemisphere (Amundsen Sea Low varied over 1990s)

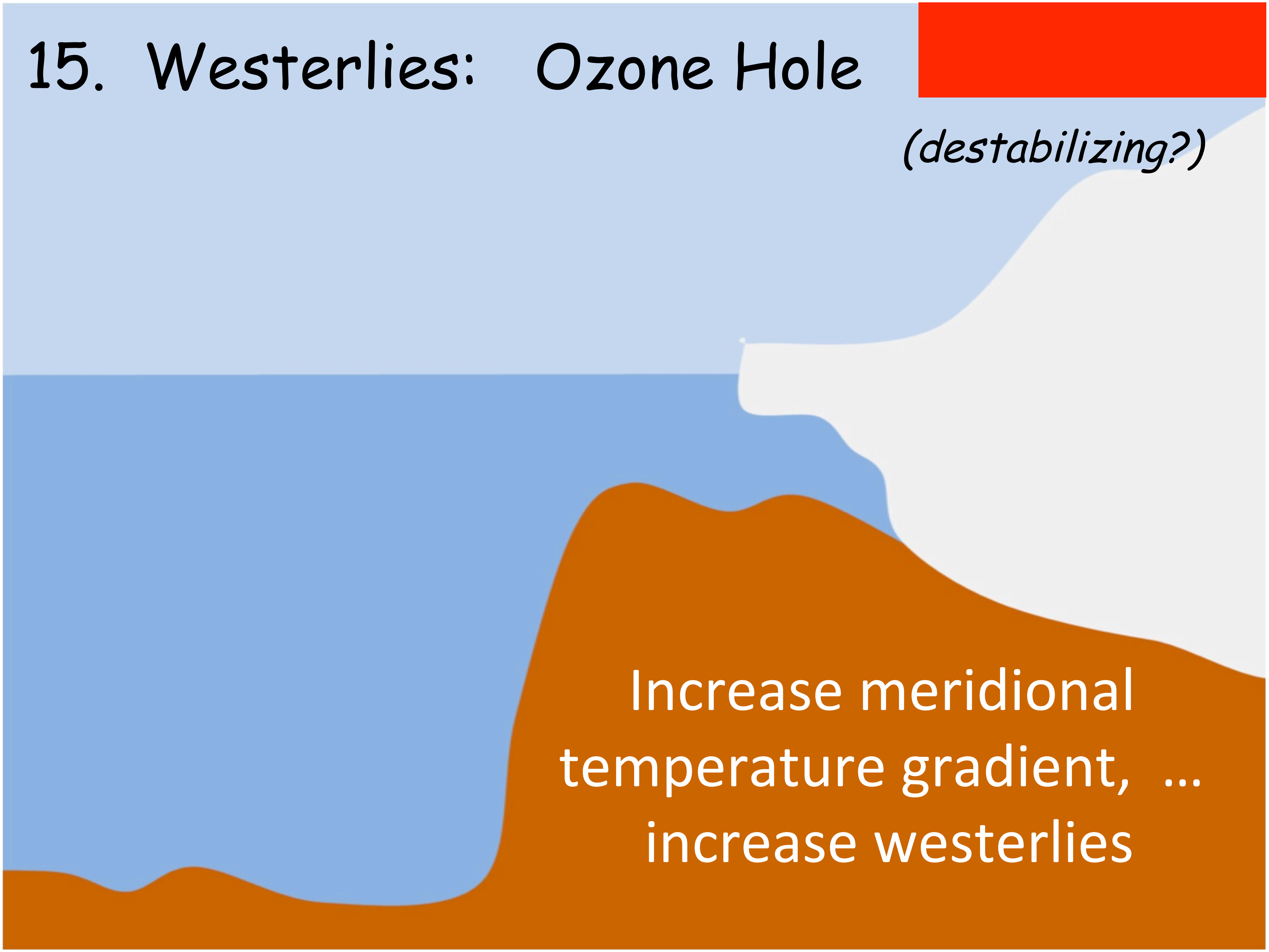
(destabilizing)



Modeling study: Stronger westerlies … Stronger ice melt

Thoma et al., *GRL*, 2008

15. Westerlies: Ozone Hole



15. Greenhouse Gases

(stabilizing?)

Science 13 June 2008:
Vol. 320. no. 5882, pp. 1486 - 1489
DOI: 10.1126/science.1155939

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REPORTS

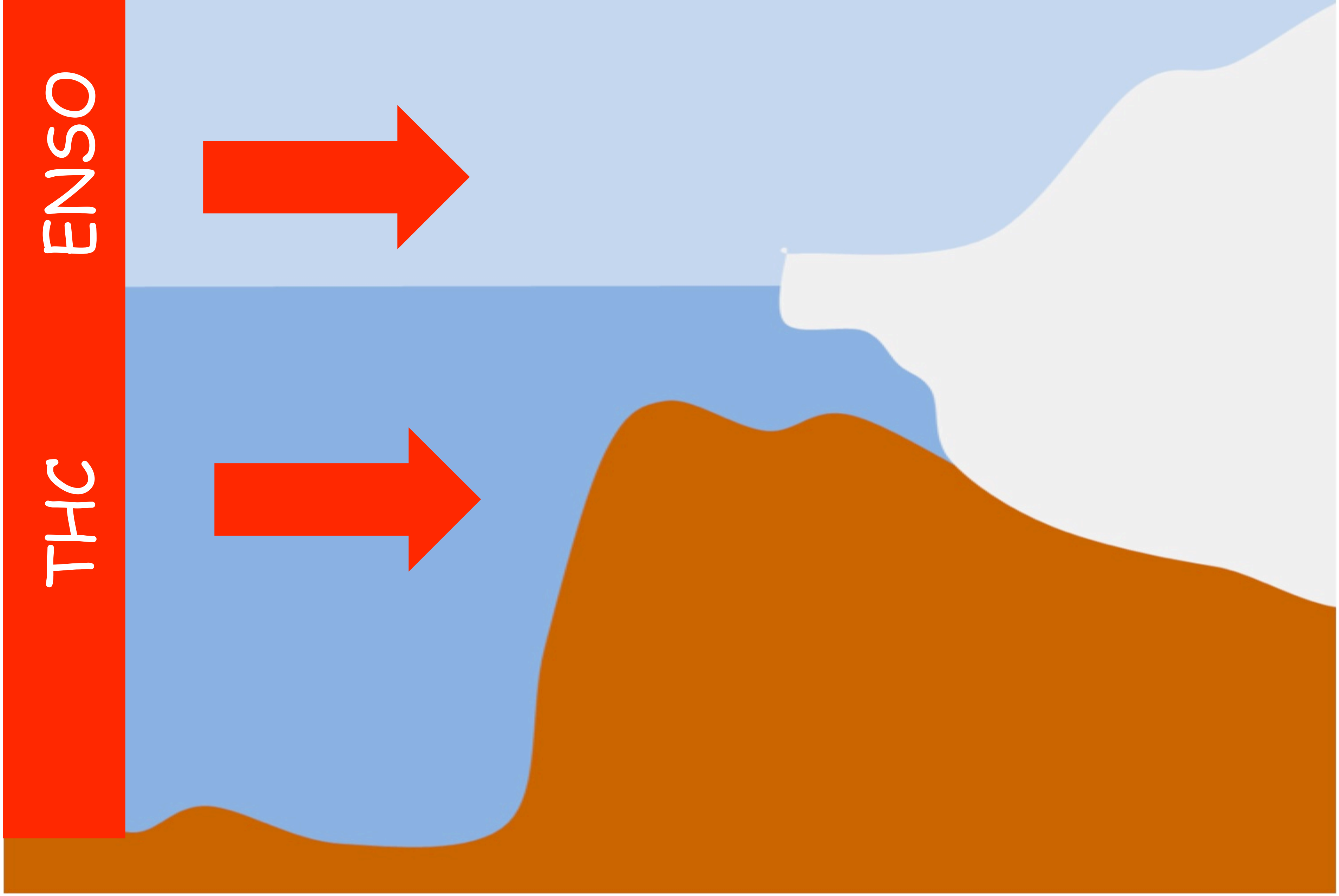
The Impact of Stratospheric Ozone Recovery on the Southern Hemisphere Westerly Jet

S.-W. Son,[1*] L. M. Polvani,[1,2] D. W. Waugh,[3] H. Akiyoshi,[4] R. Garcia,[5] D. Kinnison,[5] S. Pawson,[6] E. Rozanov,[7,8] T. G. Shepherd,[9] K. Shibata[10]

In the past several decades, the tropospheric westerly winds in the Southern Hemisphere have been observed to accelerate on the poleward side of the surface wind maximum. This has been attributed to the combined anthropogenic effects of increasing greenhouse gases and decreasing stratospheric ozone and is predicted to continue by the Intergovernmental Panel on Climate Change/Fourth Assessment Report (IPCC/AR4) models. In this paper, the predictions of the Chemistry-Climate Model Validation (CCMVal) models are examined: Unlike the AR4 models, the CCMVal models have a fully interactive stratospheric chemistry. Owing to the expected disappearance of the ozone hole in the first half of the 21st century, the CCMVal models predict that the tropospheric westerlies in Southern Hemisphere summer will be decelerated, on the poleward side, in contrast with the prediction of most IPCC/AR4 models.

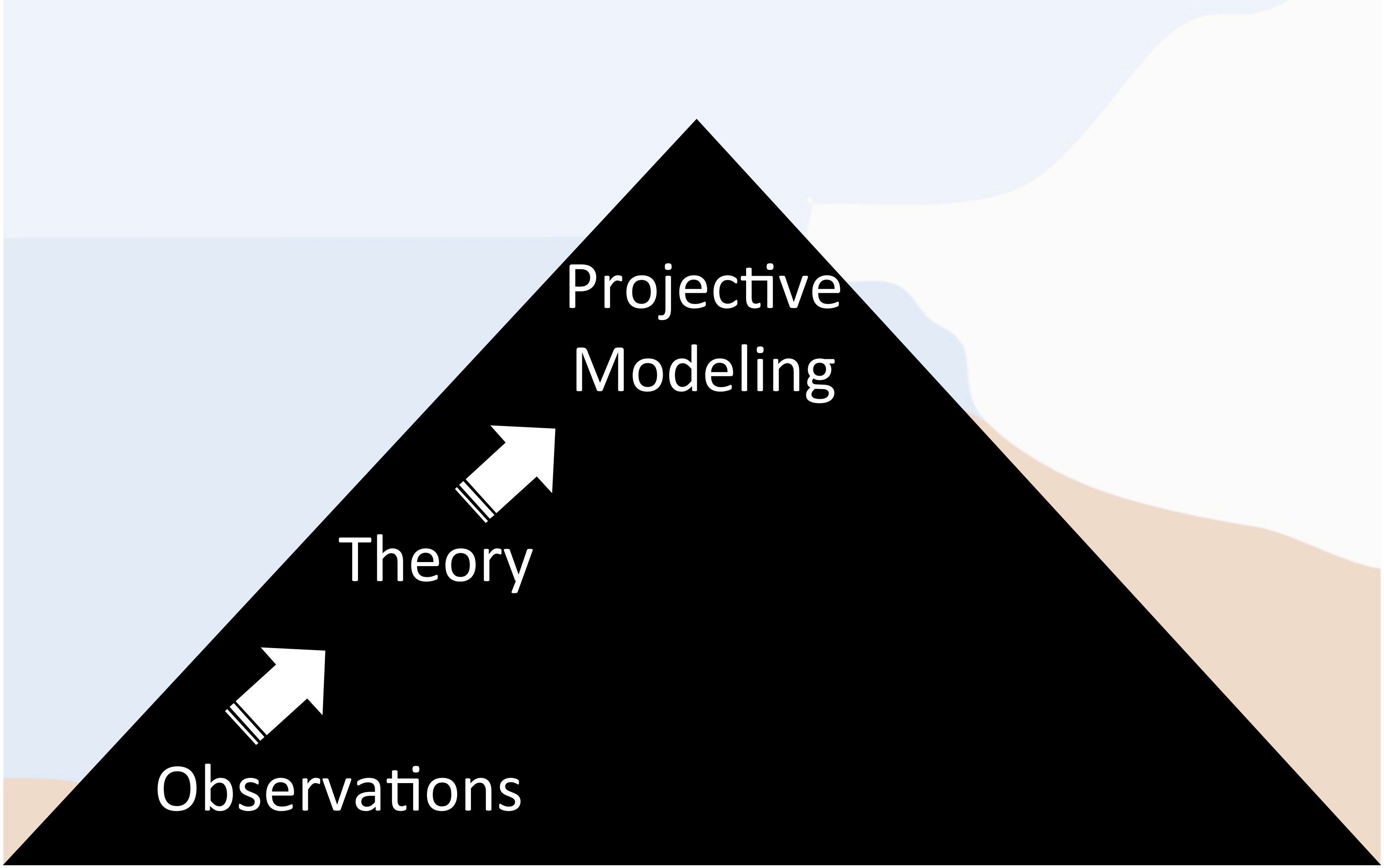
Decrease meridional temperature gradient, …
decrease westerlies

16. Extra-Polar Teleconnections



Supposed Pathway Forward: AR5/Beyond

(ice-ocean interaction context)



Observations are going way tooo slooow …

(ice-ocean interaction context)

Need to be Realistic: Present Resources

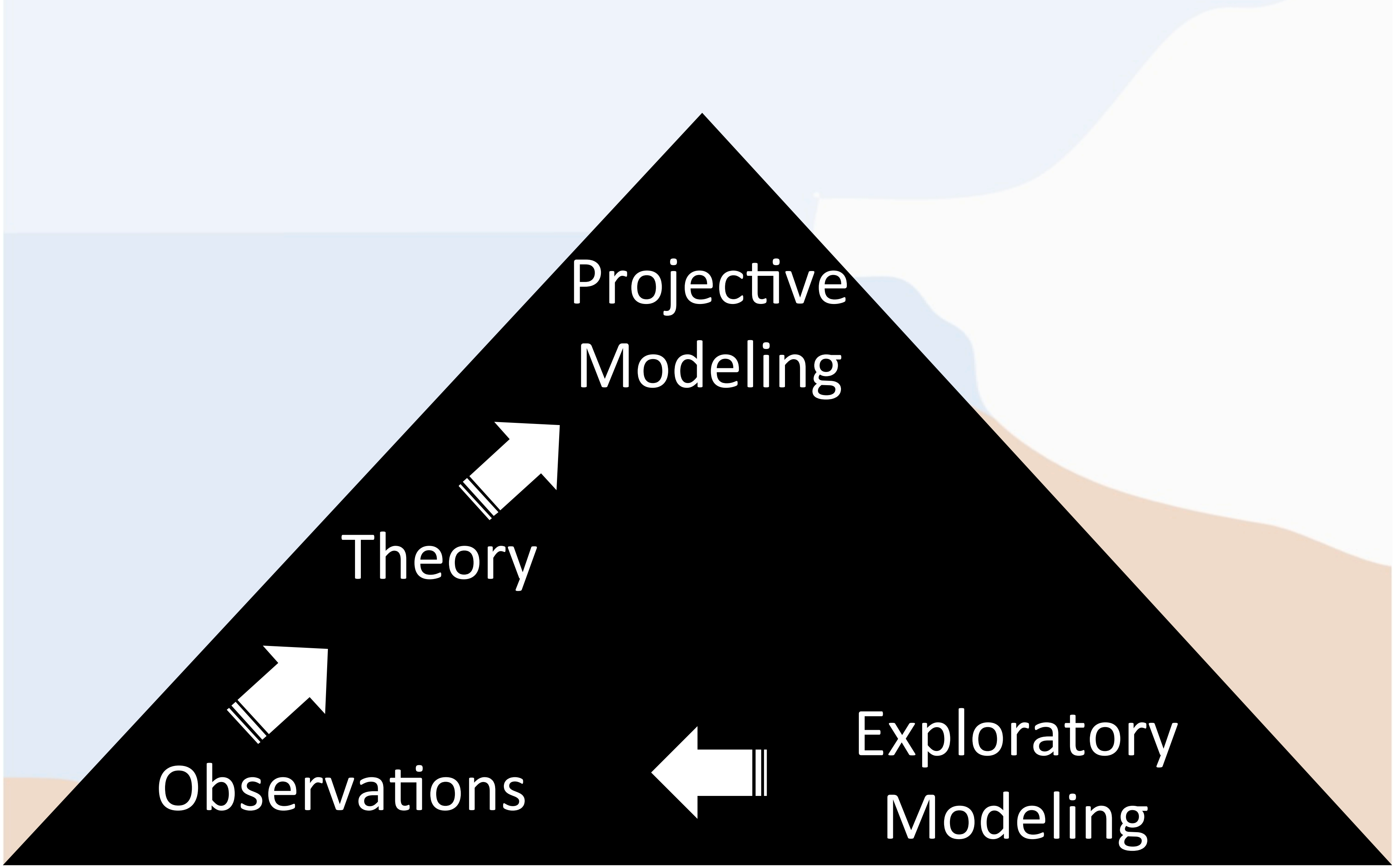
(ice-ocean interaction context)

Strong Computational Capability

Weak Observational Capability

Realistic Way Forward: AR5/beyond

(ice-ocean interaction context)



Present Challenges: Exploratory Modeling

- Atmospheric: Robust projection of SAM and NAO in the 21st Century

- Oceanic: models capable of advancing/retreating with ice sheet

- Glaciological: Higher-order ice sheet models with representation of ice shelves and ice streams

Present Challenges: Theory

- Extension of Marine Ice Sheet Instability theory to multi-dimensions
- Validation of viscous-sublayer model and quadratic melting

Present Challenges: Observational

- Long-term observations of ocean properties along periphery of ice sheets
- Detailed bathymetry