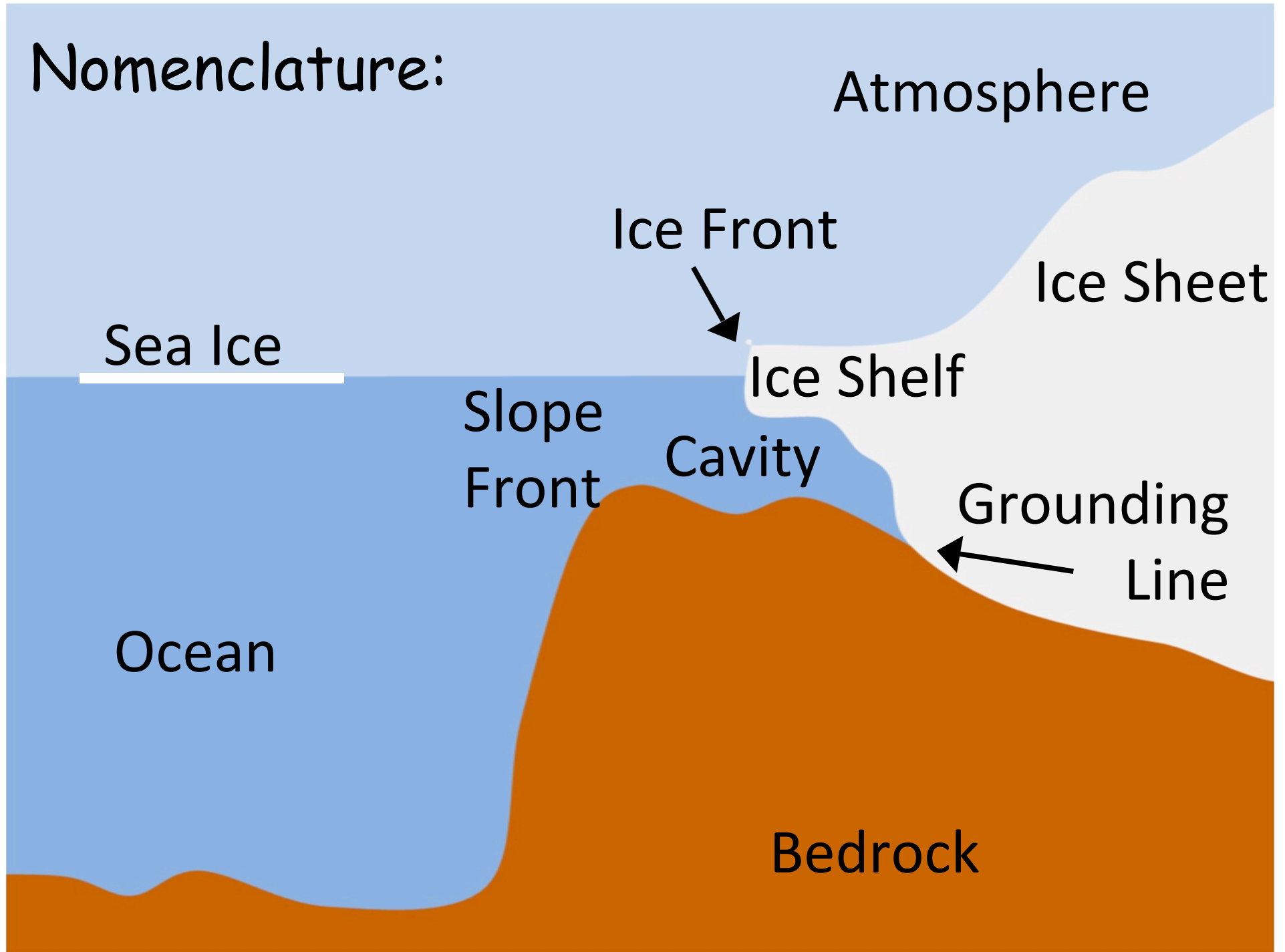


Ice Sheet - Ocean Interactions and Sea-Level Change: Prospects for Predictability

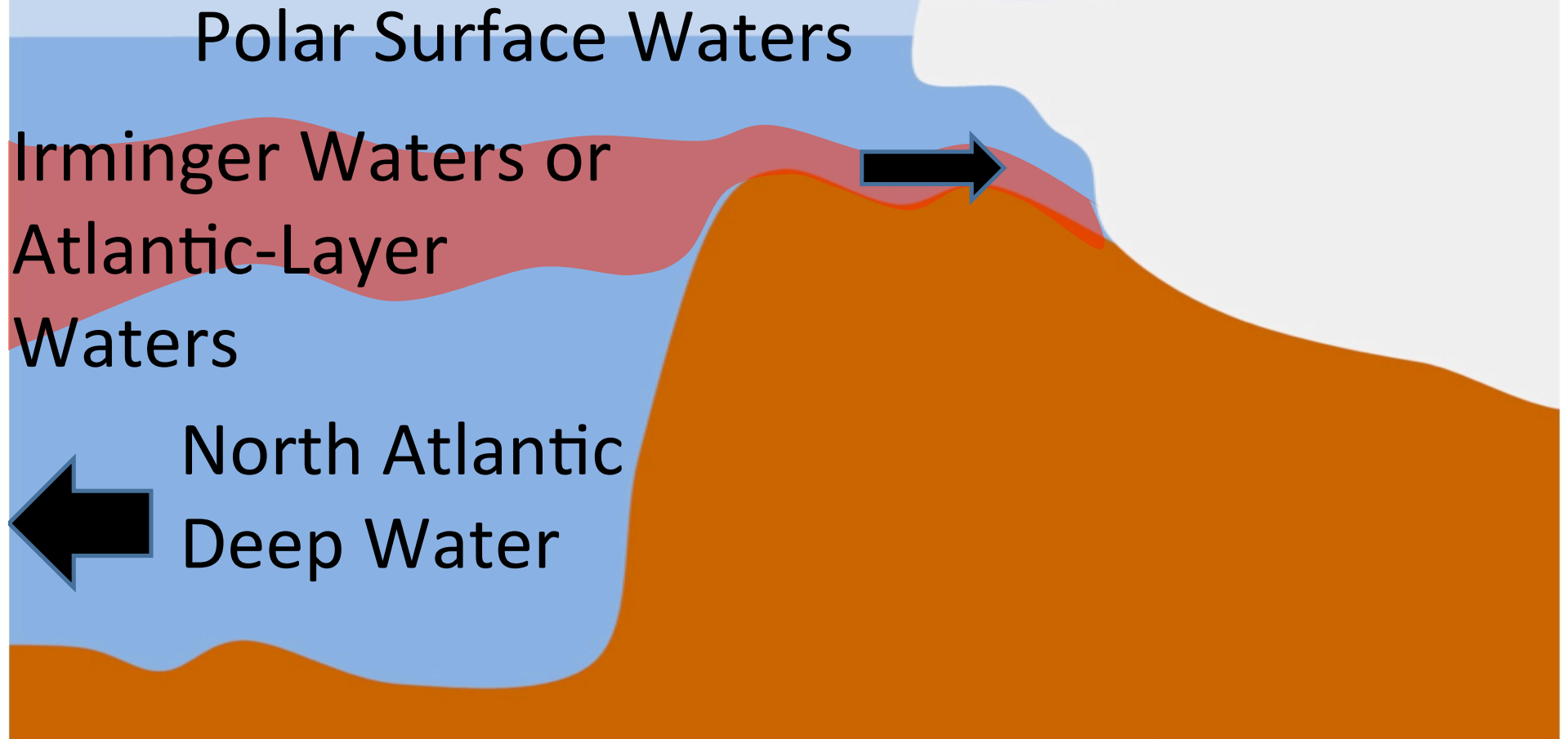
David Holland
Courant Institute
New York University
USA

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

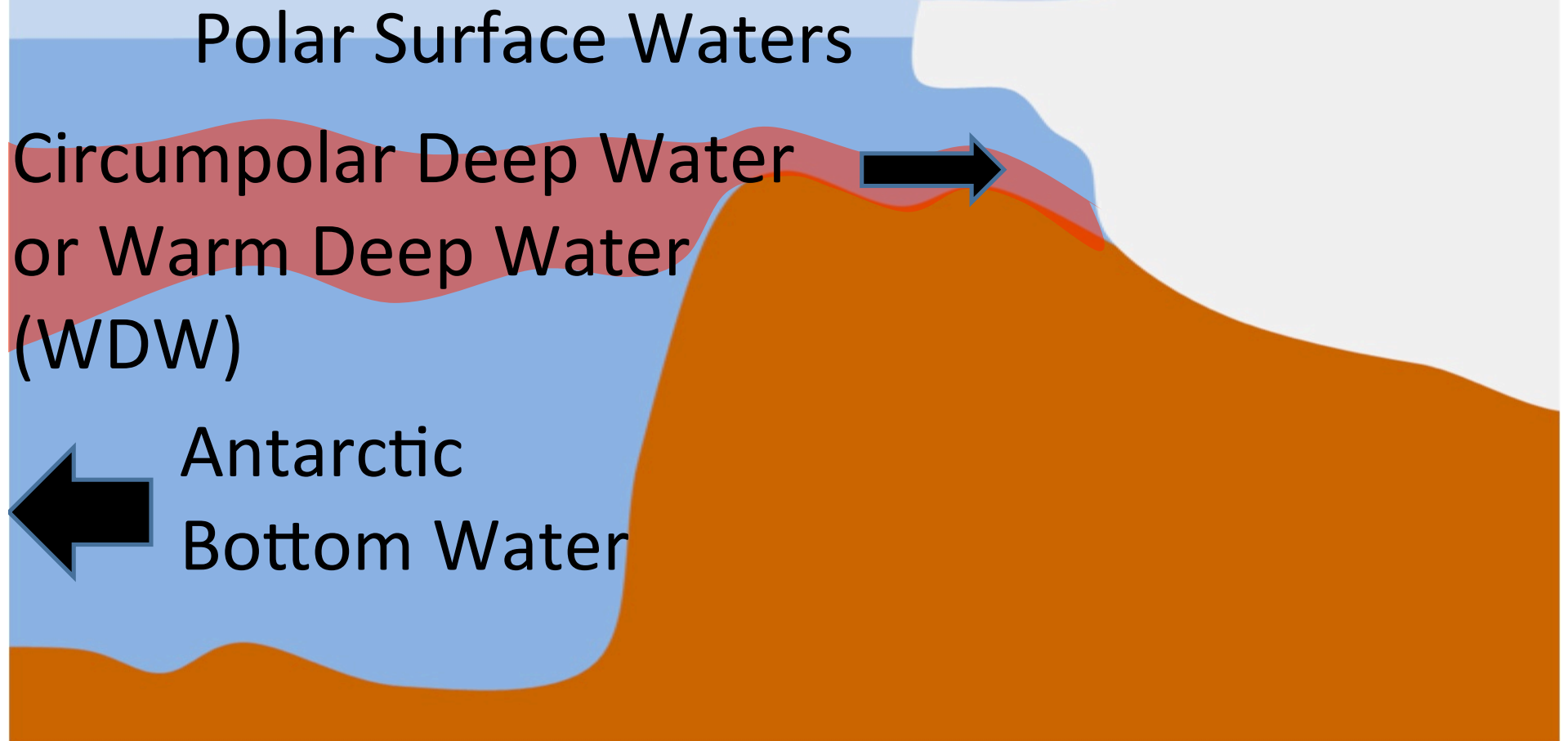
Nomenclature:



Nomenclature: Northern Hemisphere Water Masses



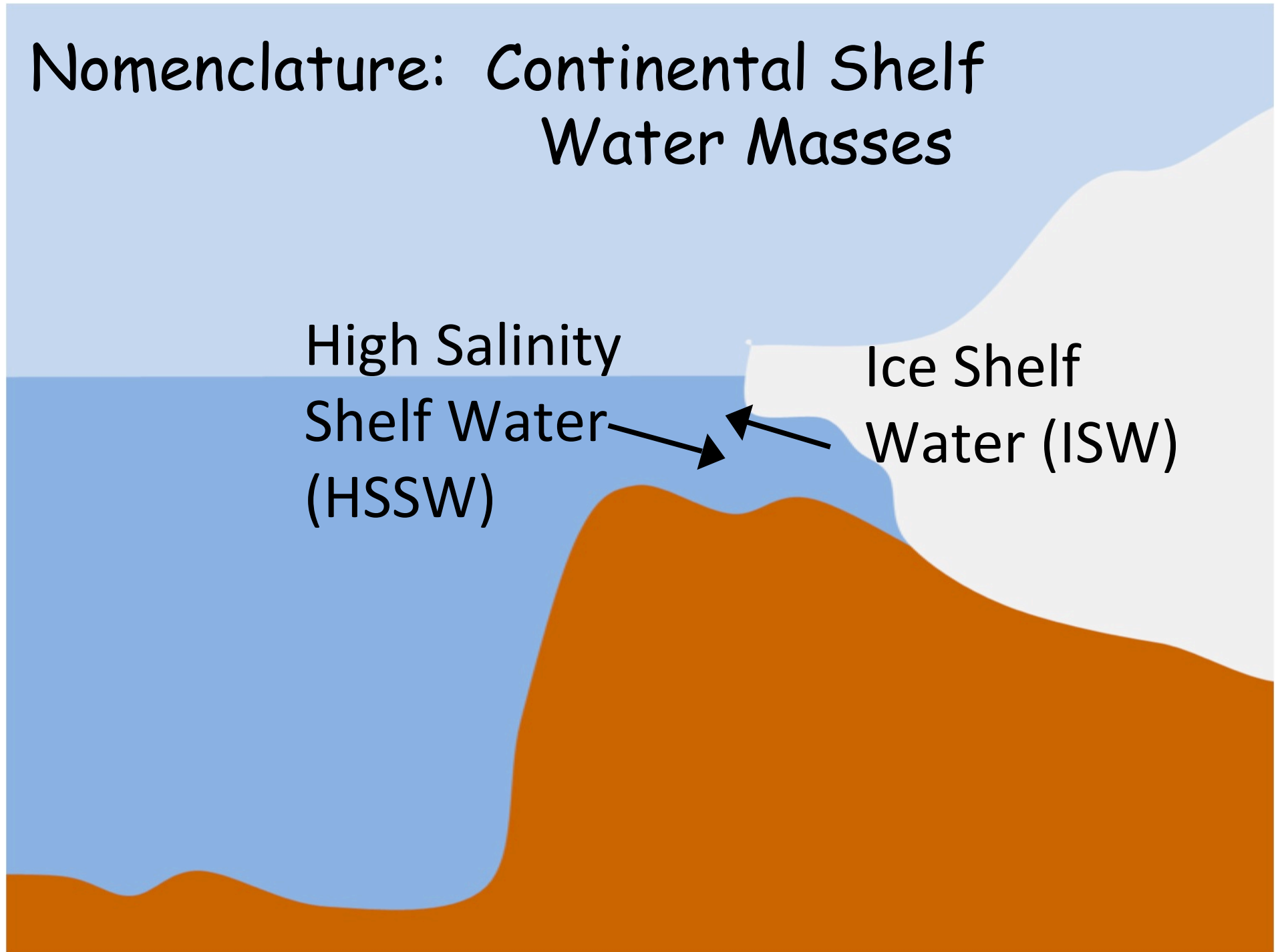
Nomenclature: Southern Hemisphere Water Masses



Nomenclature: Continental Shelf Water Masses

High Salinity
Shelf Water
(HSSW)

Ice Shelf
Water (ISW)

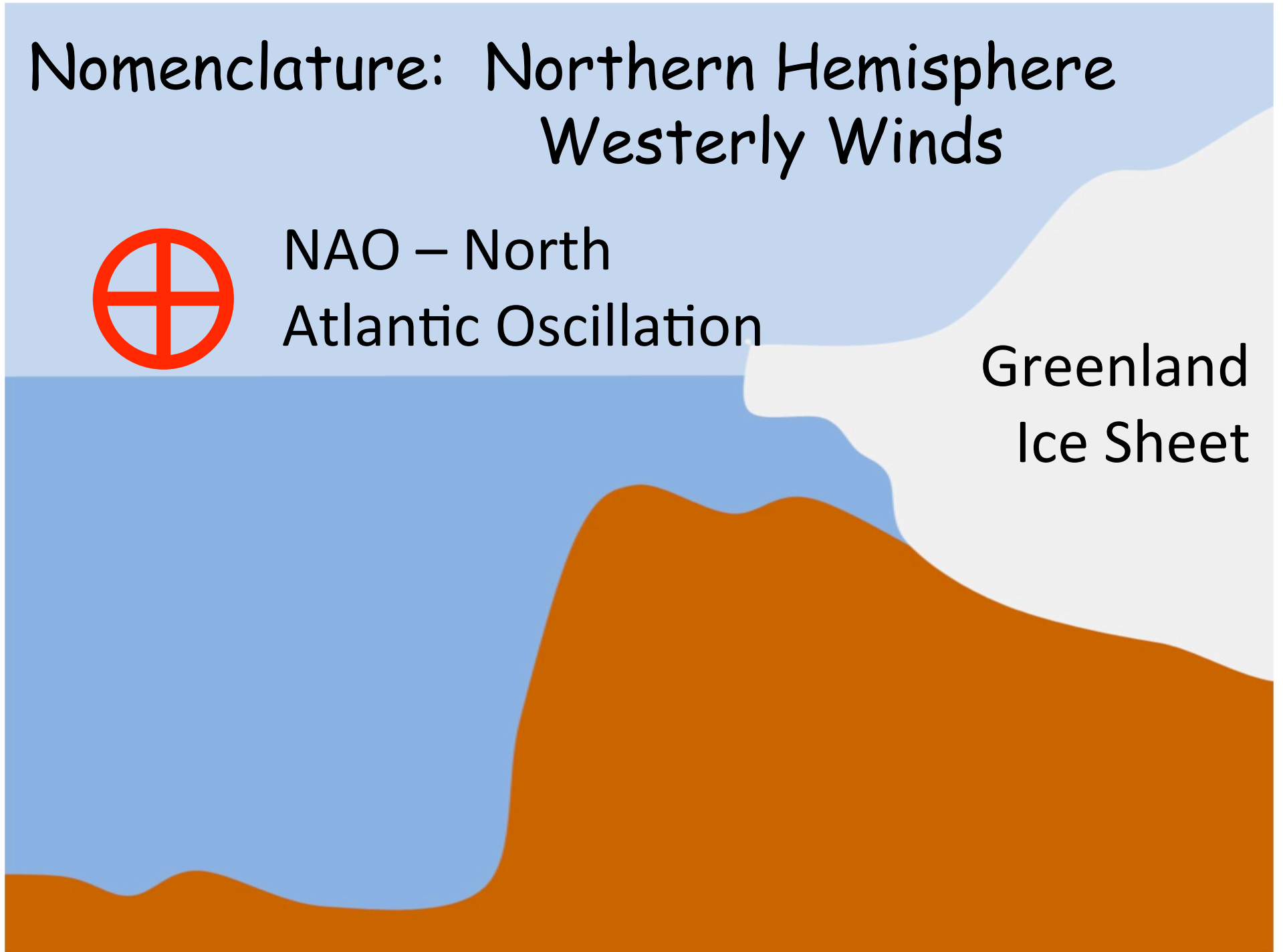


Nomenclature: Northern Hemisphere Westerly Winds



NAO – North
Atlantic Oscillation

Greenland
Ice Sheet

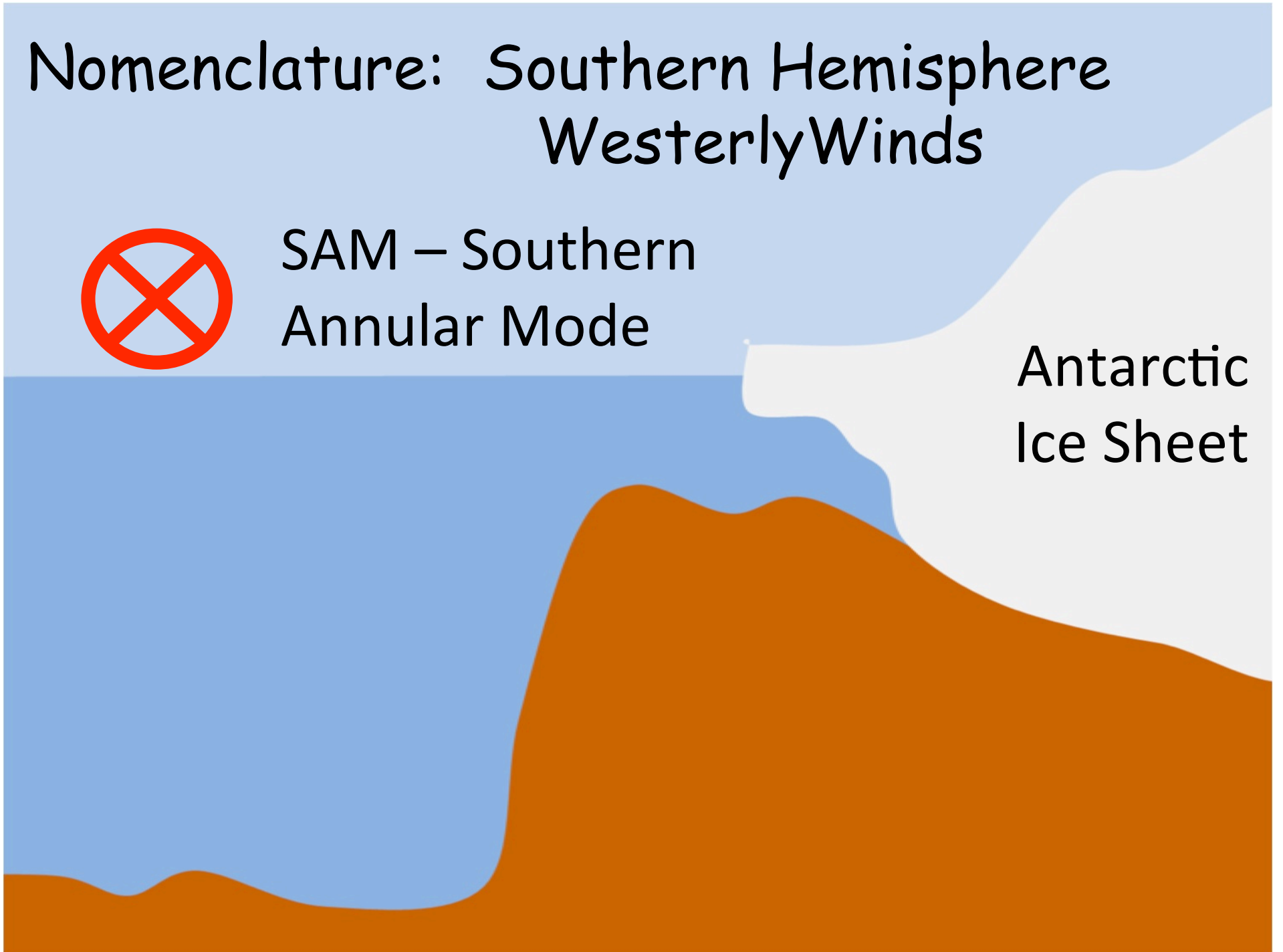


Nomenclature: Southern Hemisphere Westerly Winds

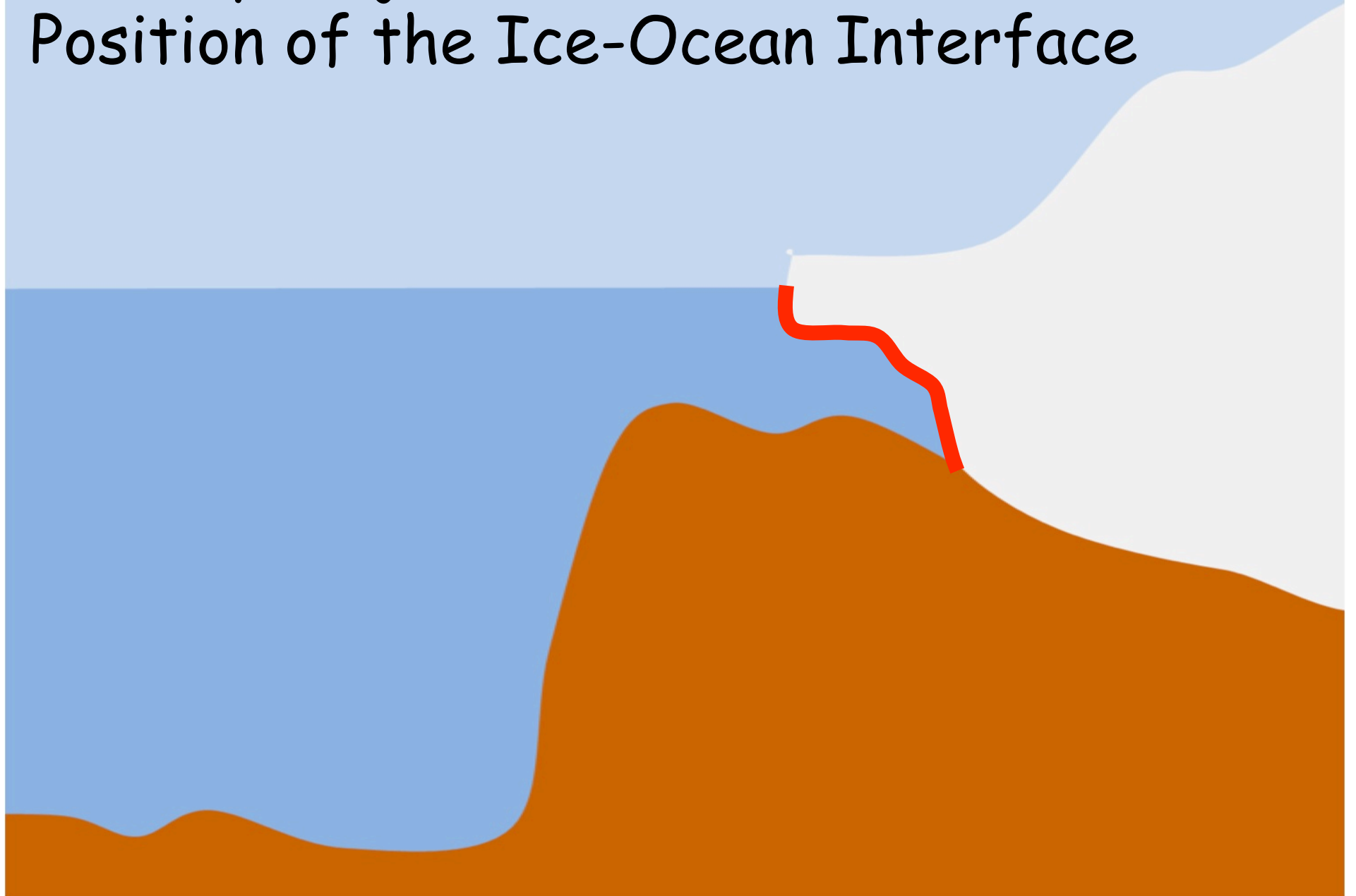


SAM – Southern
Annular Mode

Antarctic
Ice Sheet

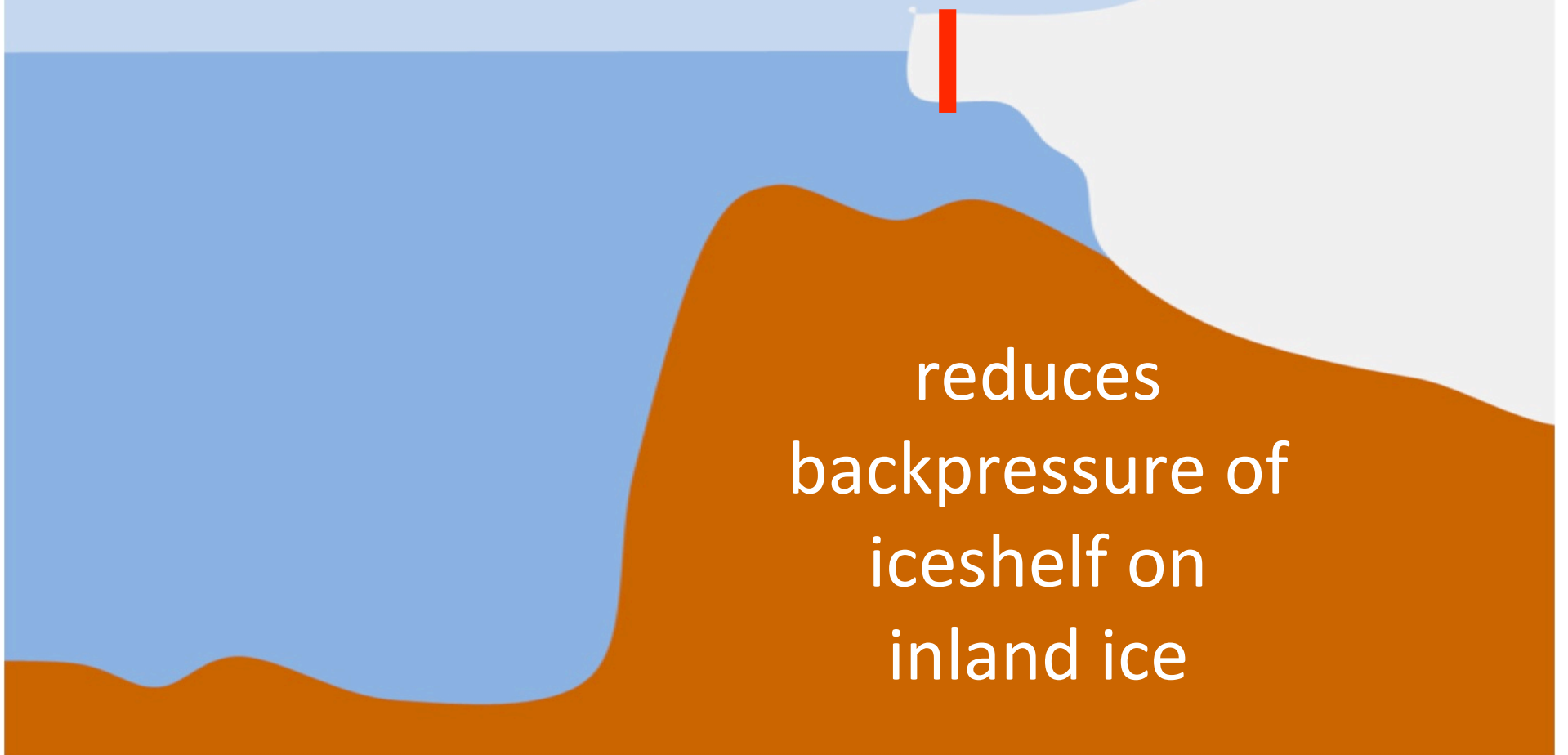


Primary Objective: Position of the Ice-Ocean Interface



1. Ice Front Calving

(destabilizing)



reduces
backpressure of
iceshelf on
inland ice

1. Ice Front Calving: Theoretical Description Lacking

Jakobshavn Isbræ, West Greenland

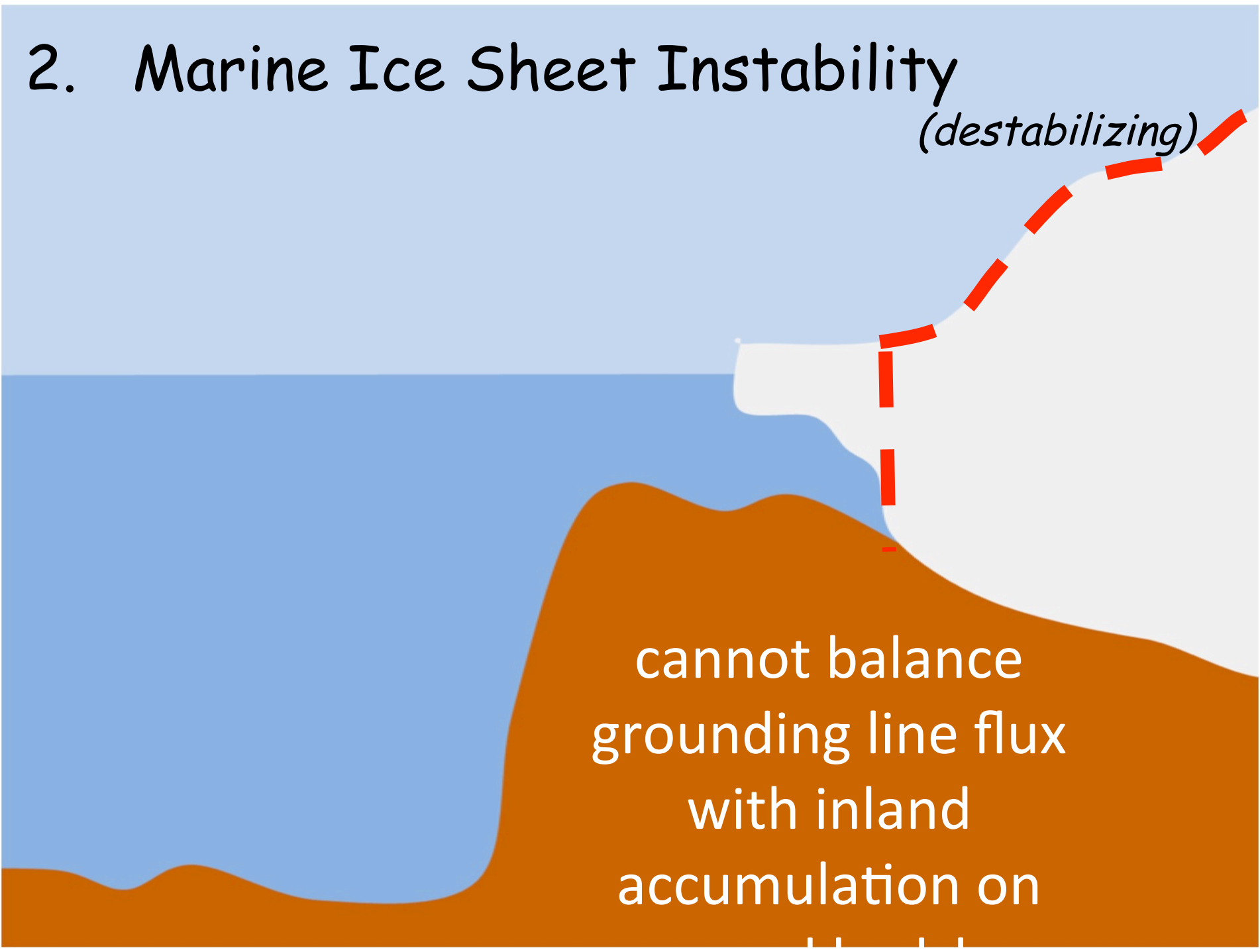
5 June 2007

14:10 - 14:28 UTC

photos by Jason Amundson
Geophysical Institute, University of Alaska Fairbanks

2. Marine Ice Sheet Instability

(destabilizing)



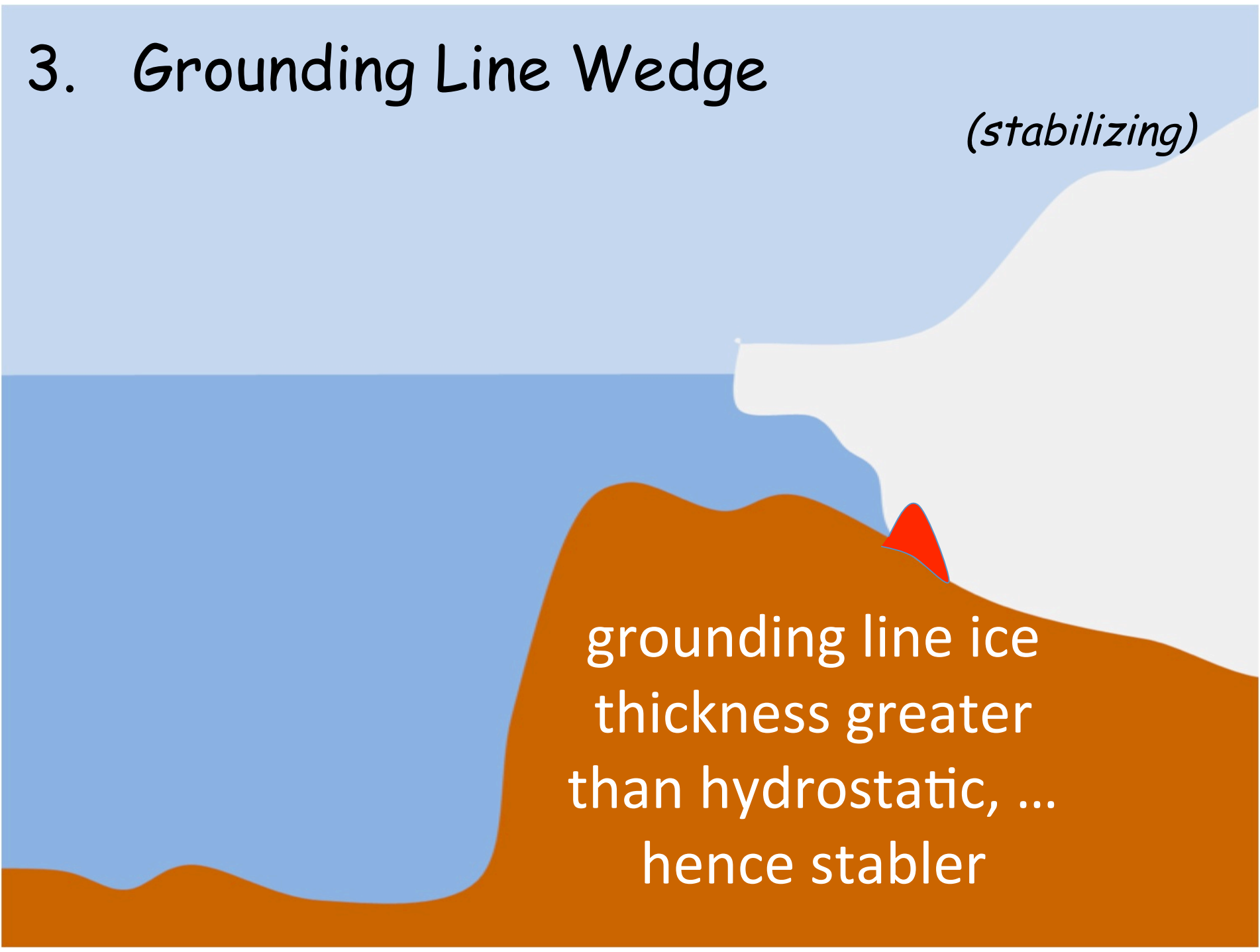
The diagram illustrates a cross-section of a marine ice sheet. On the left, a blue ocean extends to a white ice shelf. A red dashed line marks the grounding line where the ice meets the ocean floor. To the right of this line, the ice flows over a brown landmass. The text 'cannot balance grounding line flux with inland accumulation on' is written in white on the brown landmass. The top right of the diagram is labeled '(destabilizing)' in black italicized text.

cannot balance
grounding line flux
with inland
accumulation on

3. Grounding Line Wedge

(stabilizing)

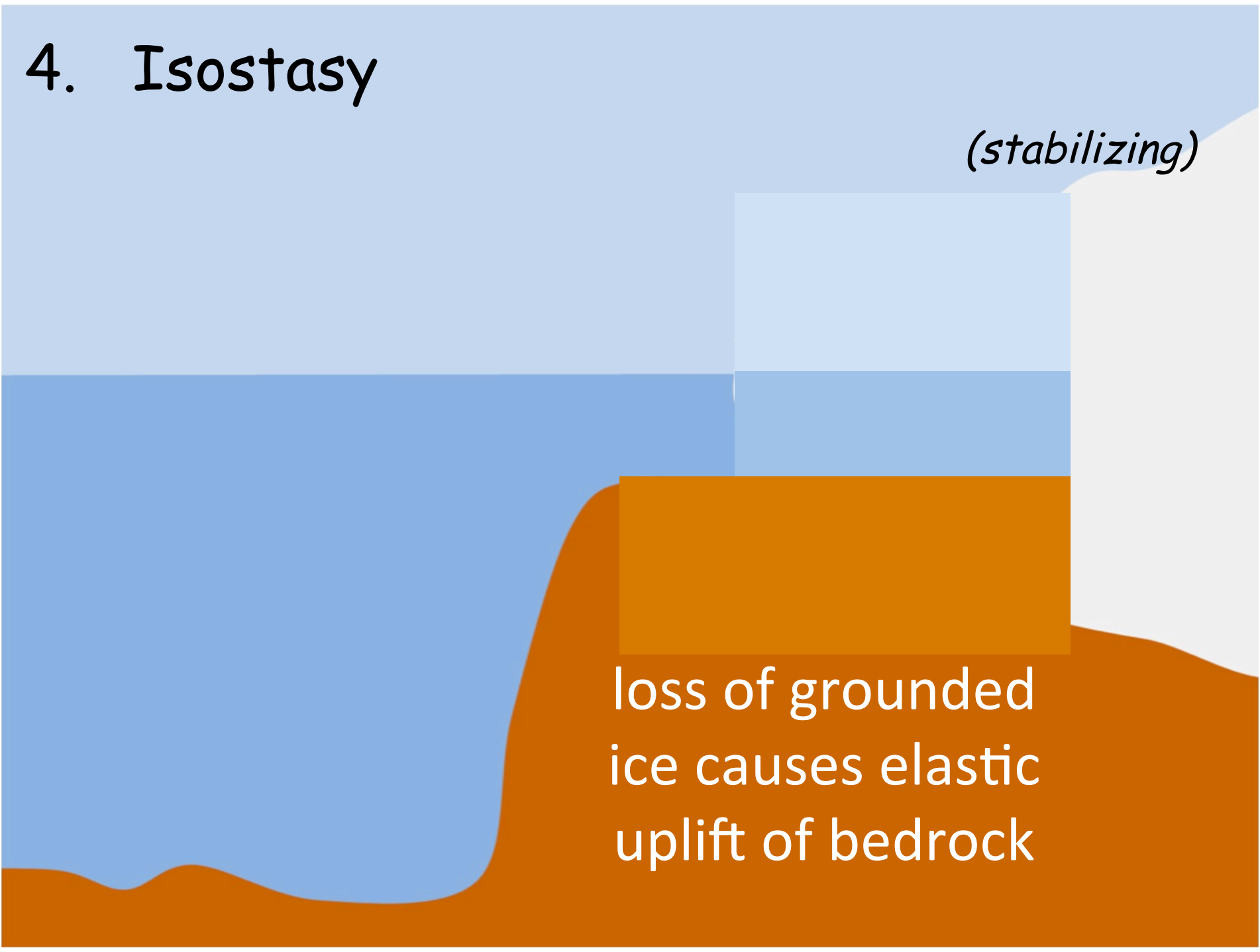
grounding line ice
thickness greater
than hydrostatic, ...
hence stabler

A cross-sectional diagram of an ice shelf. The top part is a light blue sky. Below it is a white ice shelf. The shelf is grounded on a brown, irregularly shaped landmass. The ice thickness is shown to be greater than the water depth, creating a 'wedge' of ice. A small red triangle is at the point where the ice meets the land. The text 'grounding line ice thickness greater than hydrostatic, ... hence stabler' is written in white on the brown landmass. The text '(stabilizing)' is written in black in the sky area.

4. Isostasy

(stabilizing)

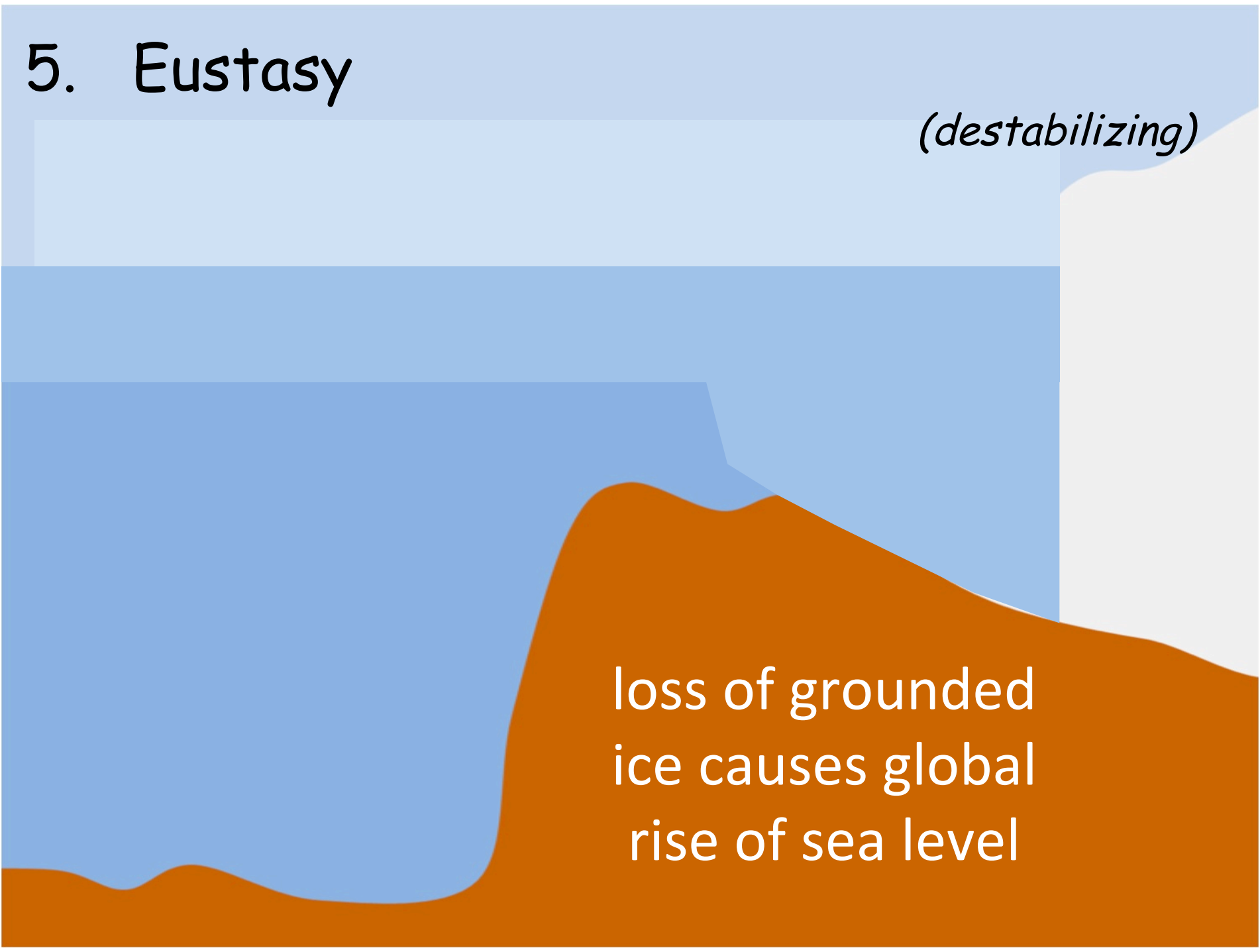
loss of grounded
ice causes elastic
uplift of bedrock

A cross-sectional diagram illustrating isostasy. The top part of the image is a light blue sky. Below it is a darker blue ocean. The bottom part is a brownish-orange landmass. On the left, the land is low and flat. On the right, the land is elevated into a plateau. A vertical line separates the two states. To the right of this line, the land is higher, and the ocean level is lower. A white rectangular box is overlaid on the right side of the diagram, containing the text '(stabilizing)'. Below this box, on the brown landmass, is the text 'loss of grounded ice causes elastic uplift of bedrock'.

5. Eustasy

(destabilizing)

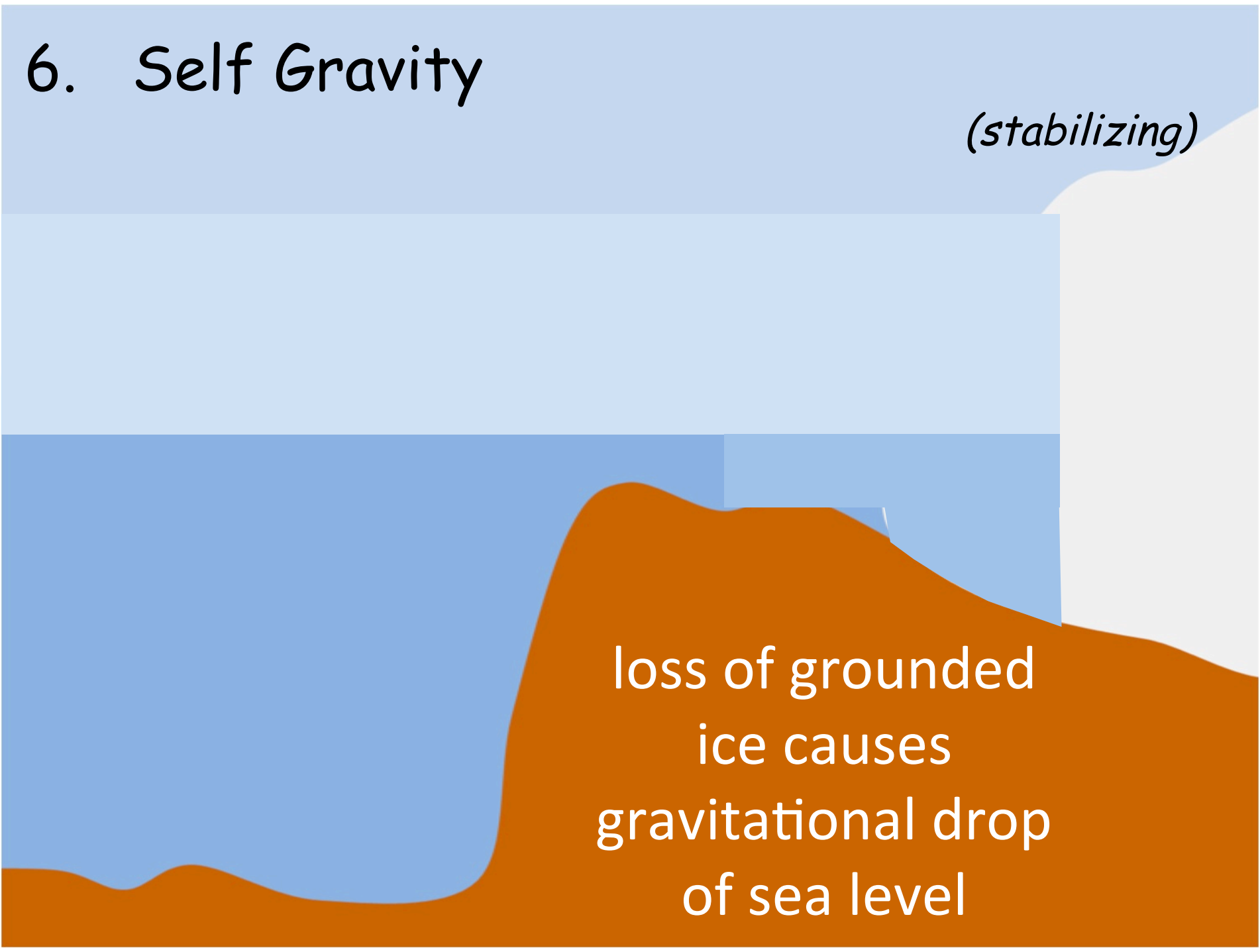
loss of grounded
ice causes global
rise of sea level



6. Self Gravity

(stabilizing)

loss of grounded
ice causes
gravitational drop
of sea level

A cross-sectional diagram showing a brown landmass on the left and a white ice sheet on the right. The sea level is represented by a blue line. On the left, the sea level is higher, with a vertical line extending to the top of the frame. On the right, the sea level is lower, with a vertical line extending to the top of the frame. The text 'loss of grounded ice causes gravitational drop of sea level' is written in white on the brown landmass. The text '(stabilizing)' is written in black in the top right corner.

7. Sea Floor Ridges

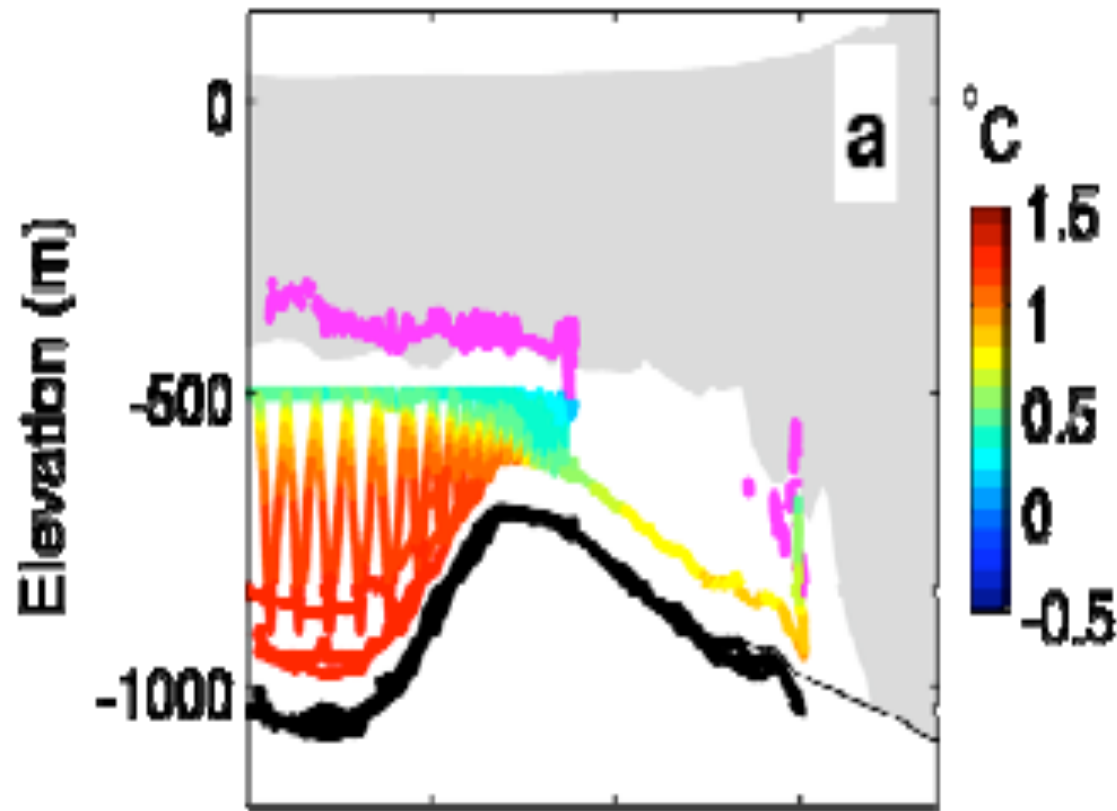
(stabilizing)

blocks WDW
access to grounding
line

A cross-sectional diagram of a sea floor ridge. The ridge is a large, brown, rounded mound. On top of the ridge, a small red triangle represents a West Drift Wedge (WDW). To the right of the ridge, a white, irregular shape represents a glacier. The text "(stabilizing)" is written in italics above the glacier. The text "blocks WDW access to grounding line" is written in white on the brown ridge. The background is a light blue sky and a darker blue sea.

7. Sea Floor Ridges

Autosub @ PIG, Jan 2010

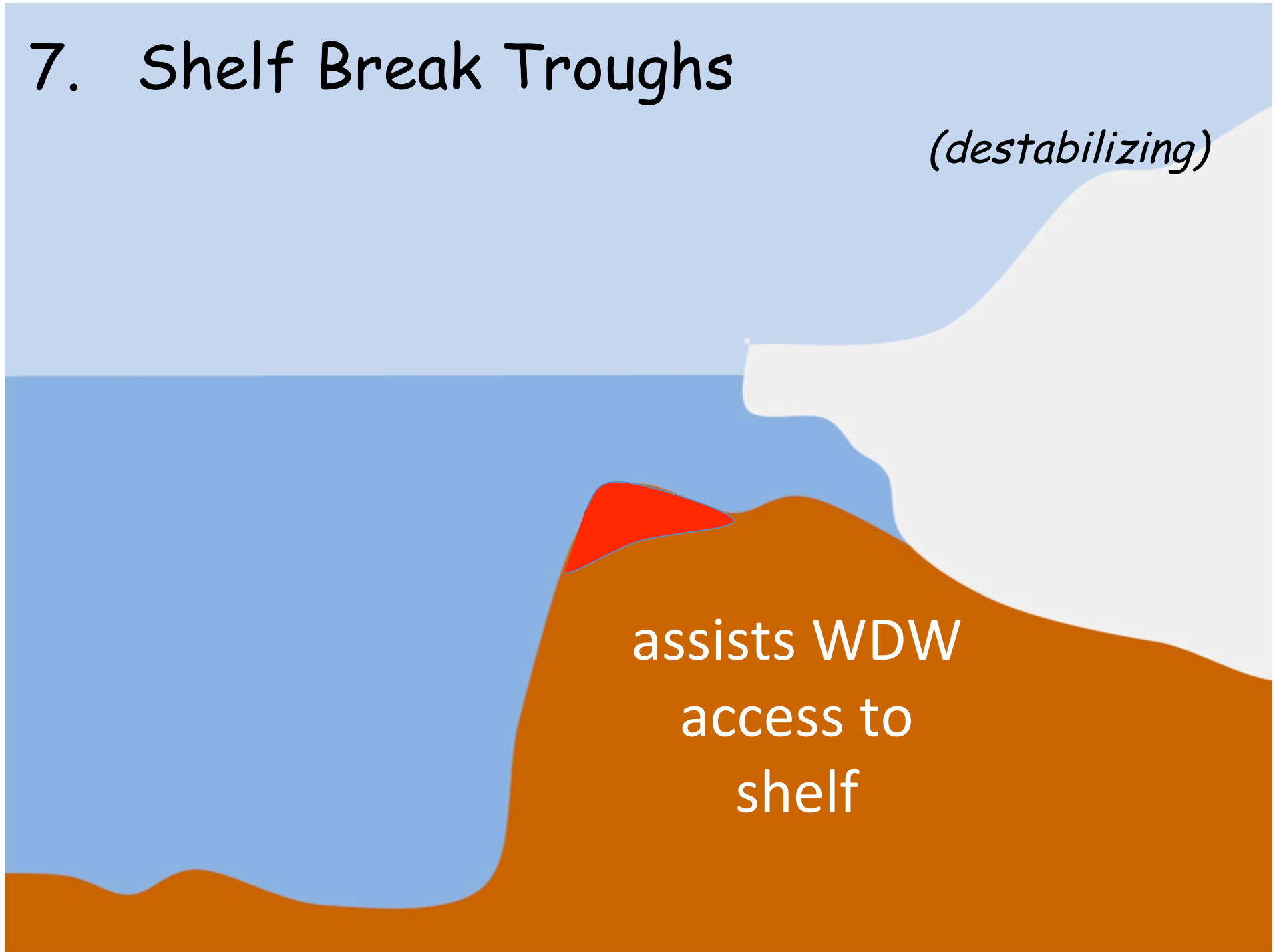


Jenkins et al.,
Nat. Geosci., 2010

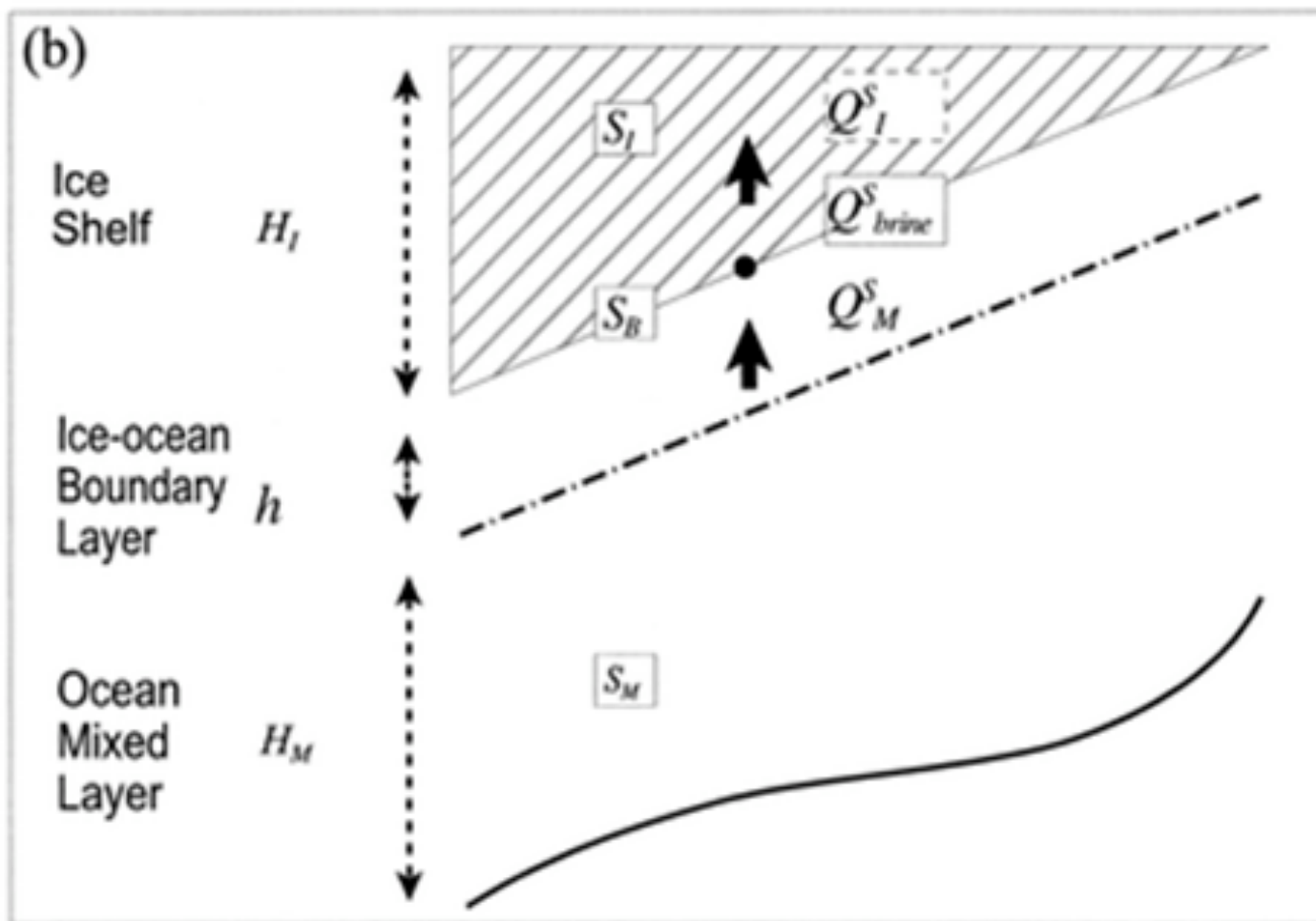
7. Shelf Break Troughs

(destabilizing)

assists WDW
access to
shelf



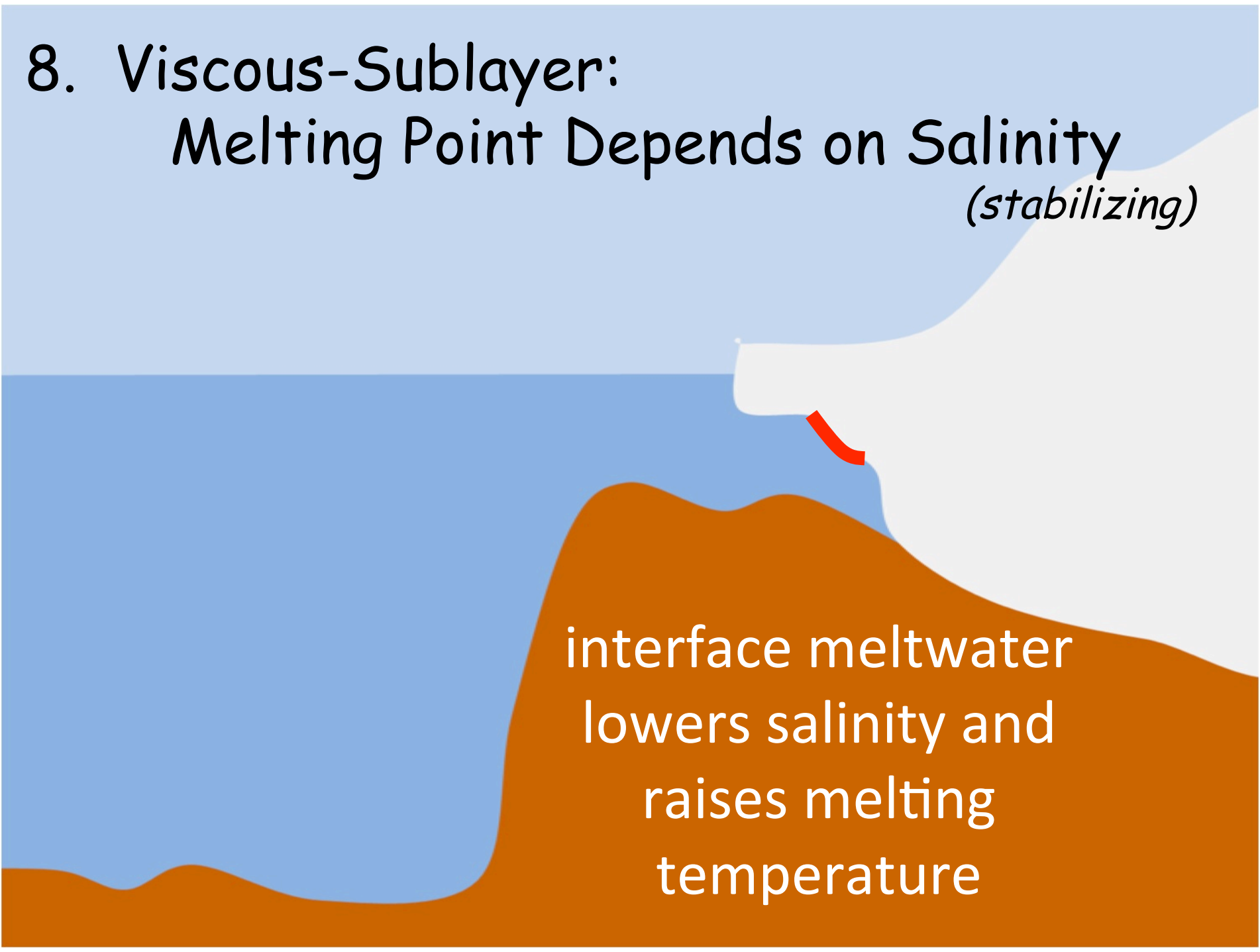
8. Viscous-Sublayer: Molecular Exchange Rules



Ice
ar

Holland & Jenkins,
JPO, 1999

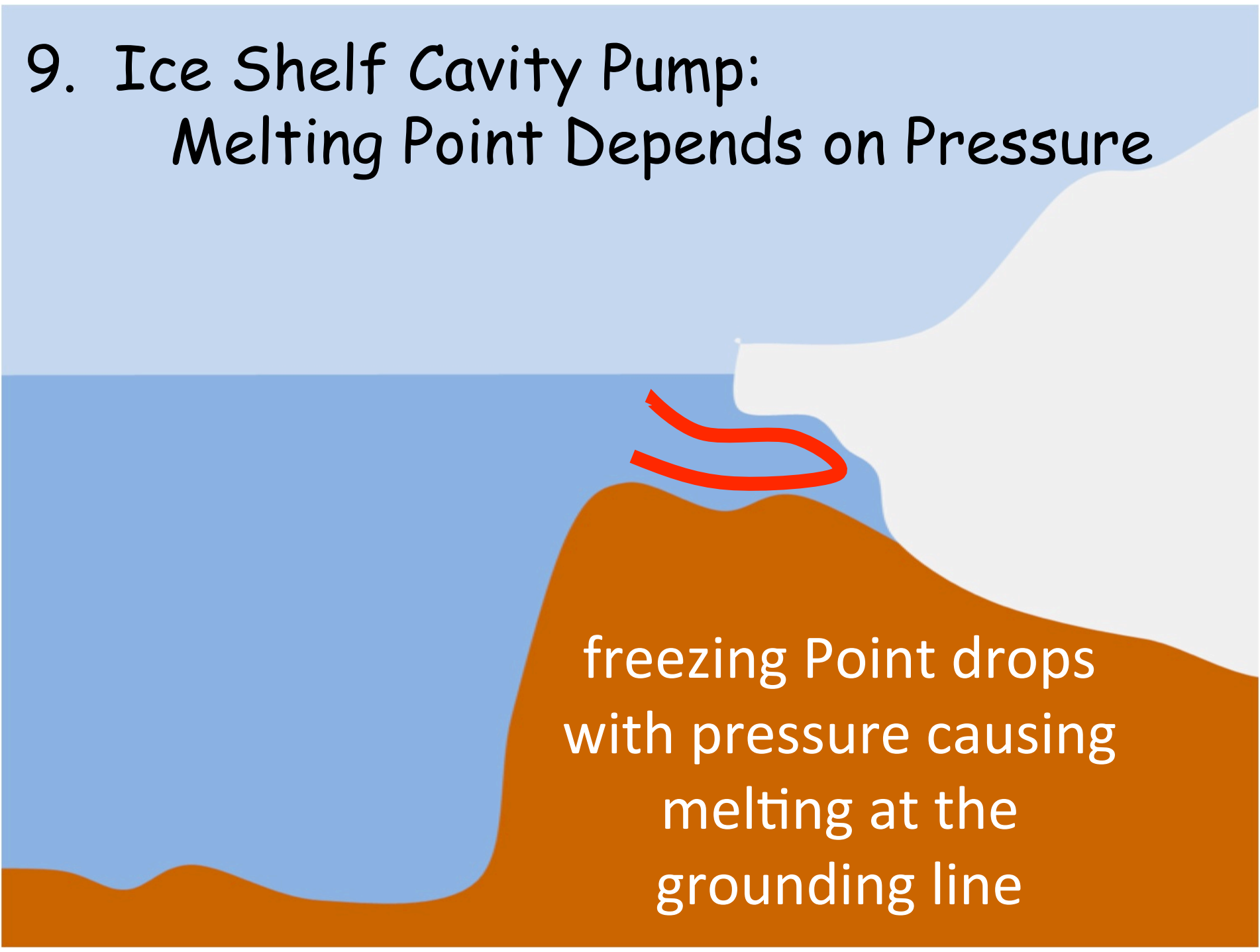
8. Viscous-Sublayer: Melting Point Depends on Salinity *(stabilizing)*



The diagram illustrates the viscous sublayer at the interface between meltwater and ice. The top portion is a light blue gradient, the middle is a darker blue representing the meltwater, and the bottom is a brownish-orange representing the ice. A red arrow points to the interface. The text 'interface meltwater lowers salinity and raises melting temperature' is written in white on the brownish-orange background.

interface meltwater
lowers salinity and
raises melting
temperature

9. Ice Shelf Cavity Pump: Melting Point Depends on Pressure

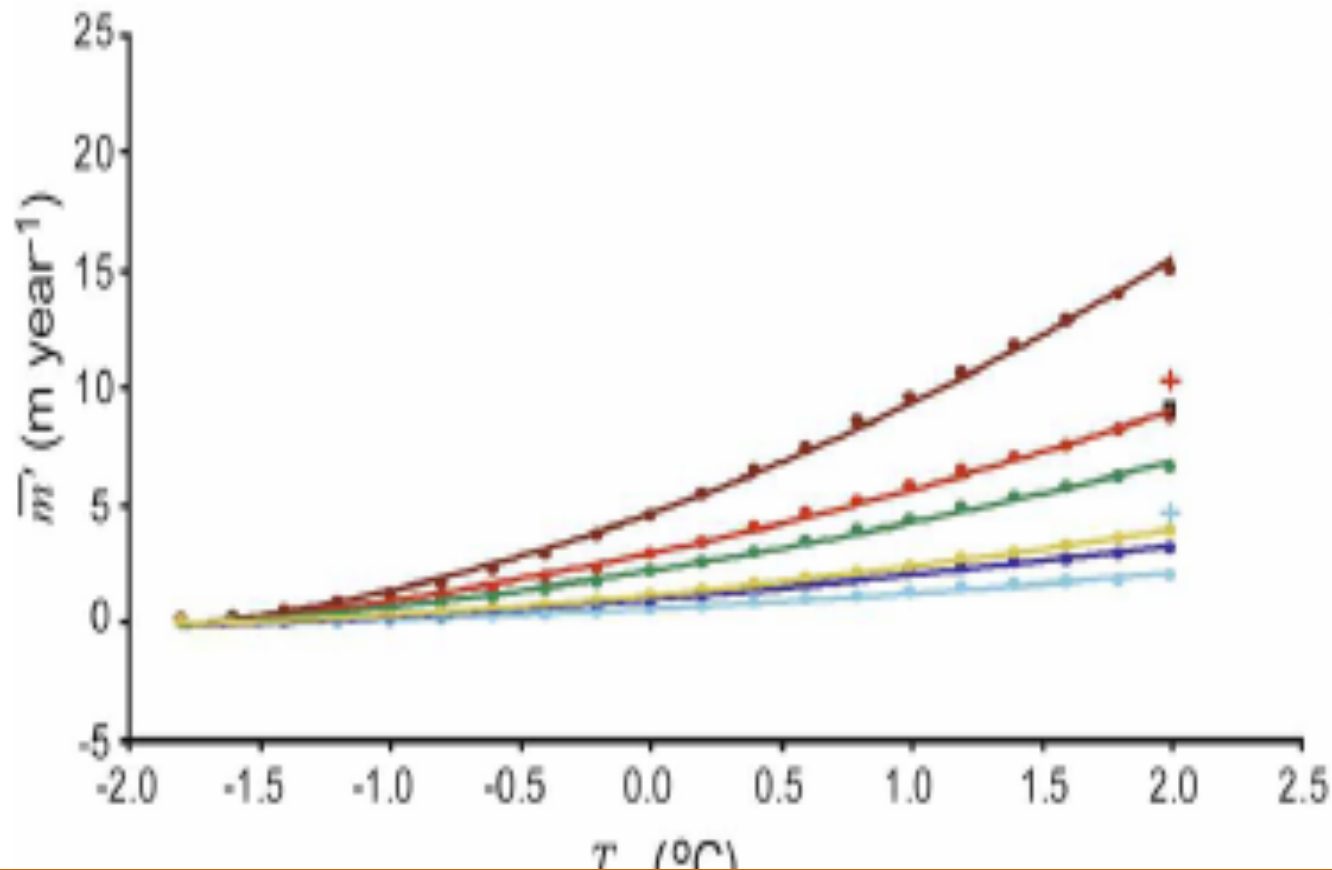


The diagram illustrates the 'ice shelf cavity pump' mechanism. It shows a cross-section of an ice shelf (white) overlying a subglacial cavity (blue). The cavity is formed by the ice shelf's weight, which depresses the ice surface. A red double-line arrow points to the leading edge of the ice shelf where it meets the cavity. Below the ice shelf is the grounding line (orange), which is the boundary between the ice shelf and the ice stream. The text explains that the freezing point of ice drops as pressure increases, causing melting at the grounding line.

freezing Point drops
with pressure causing
melting at the
grounding line

9. Ice Shelf Cavity Pump: Quadratic Melting

(destabilizing)



n

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

10. Land-Fast Sea Ice

(destabilizing)



blocks HSSW
production, ...
allows WDW access

11. Coastal Polynya

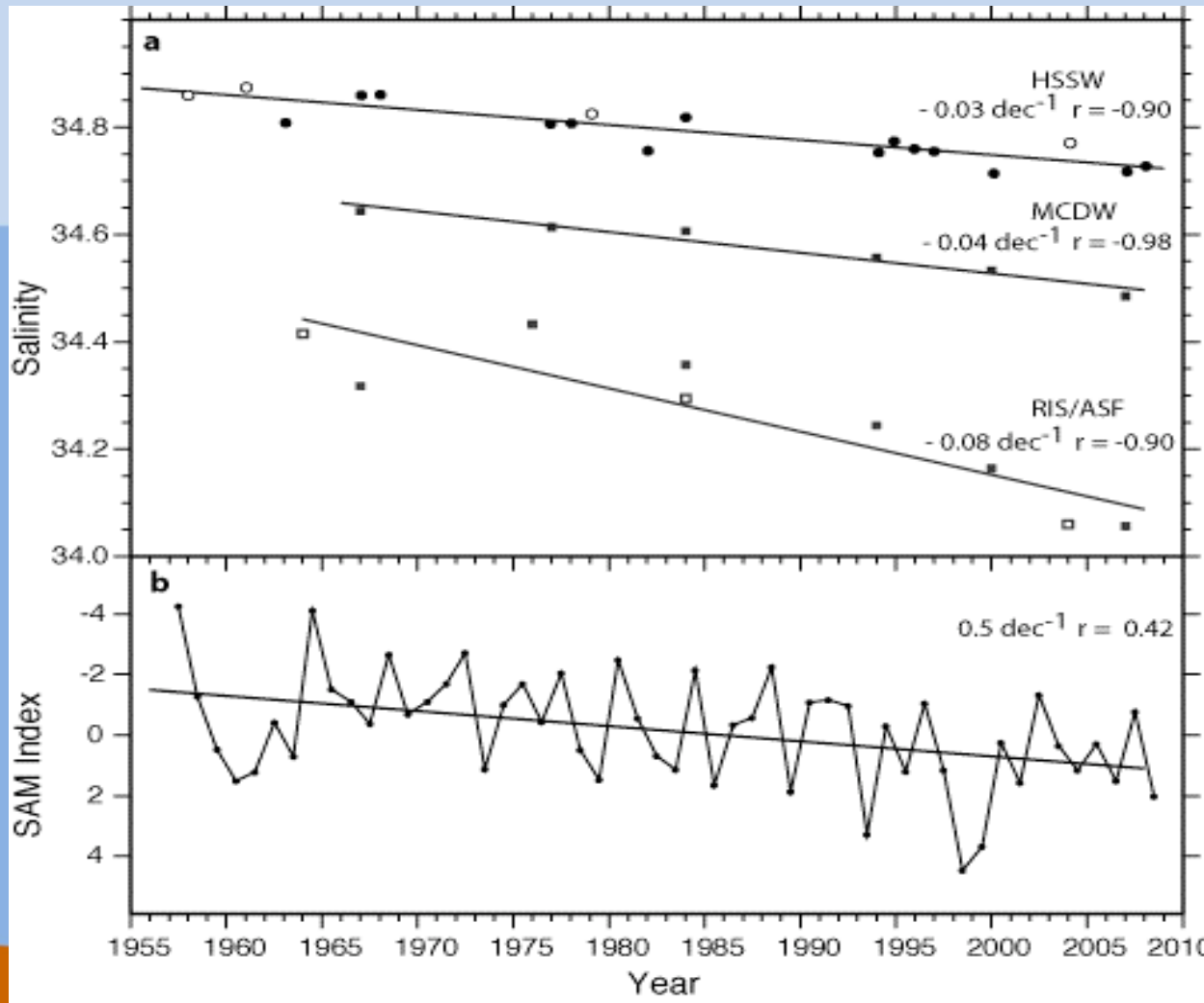
(stabilizing)



allows HSSW
production, ...
blocks WDW access

12. Mean Density Structure over Continental Shelf

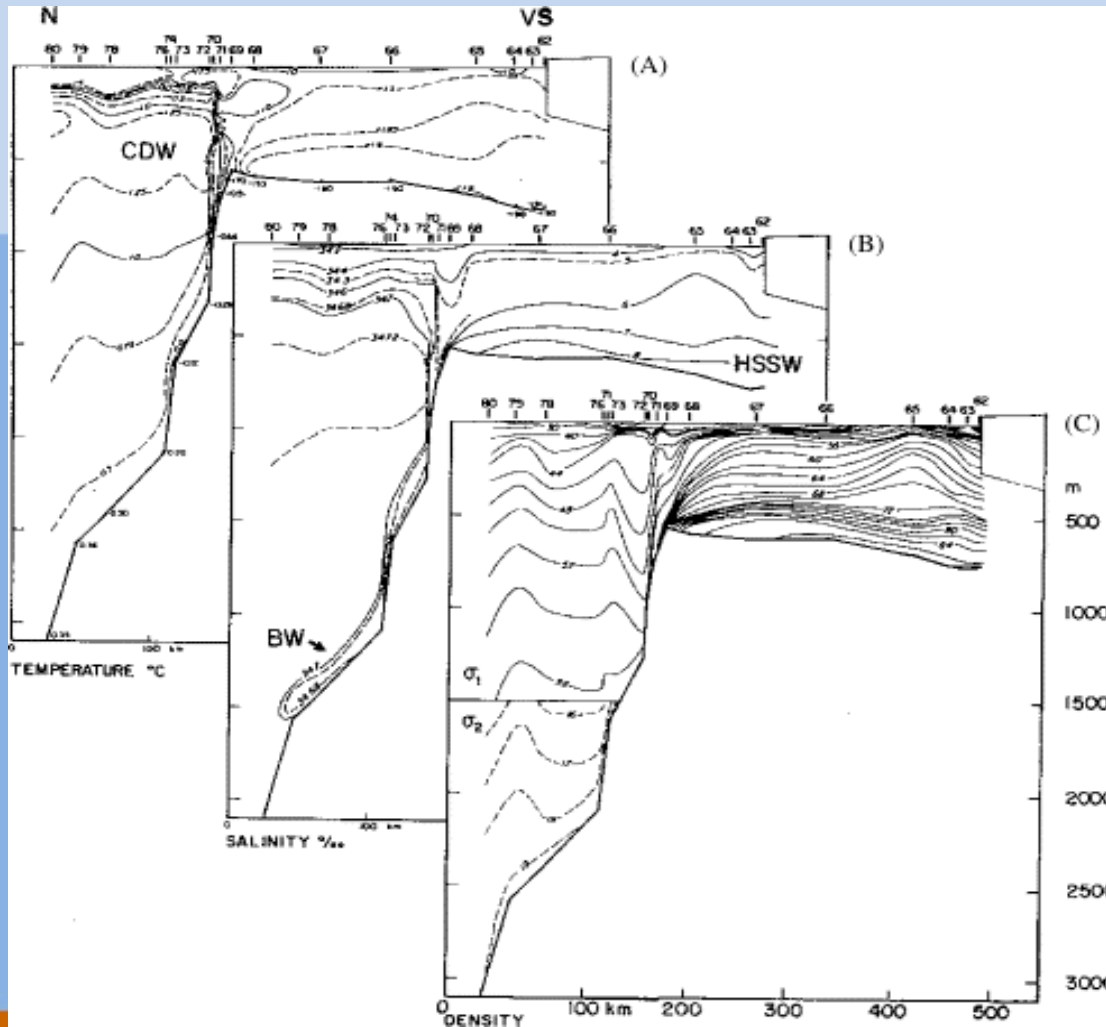
(de/stabilizing)



Jacobs & Giulivi,
J. Climate, 2010

13. Antarctic Slope Front: Dynamic Barrier

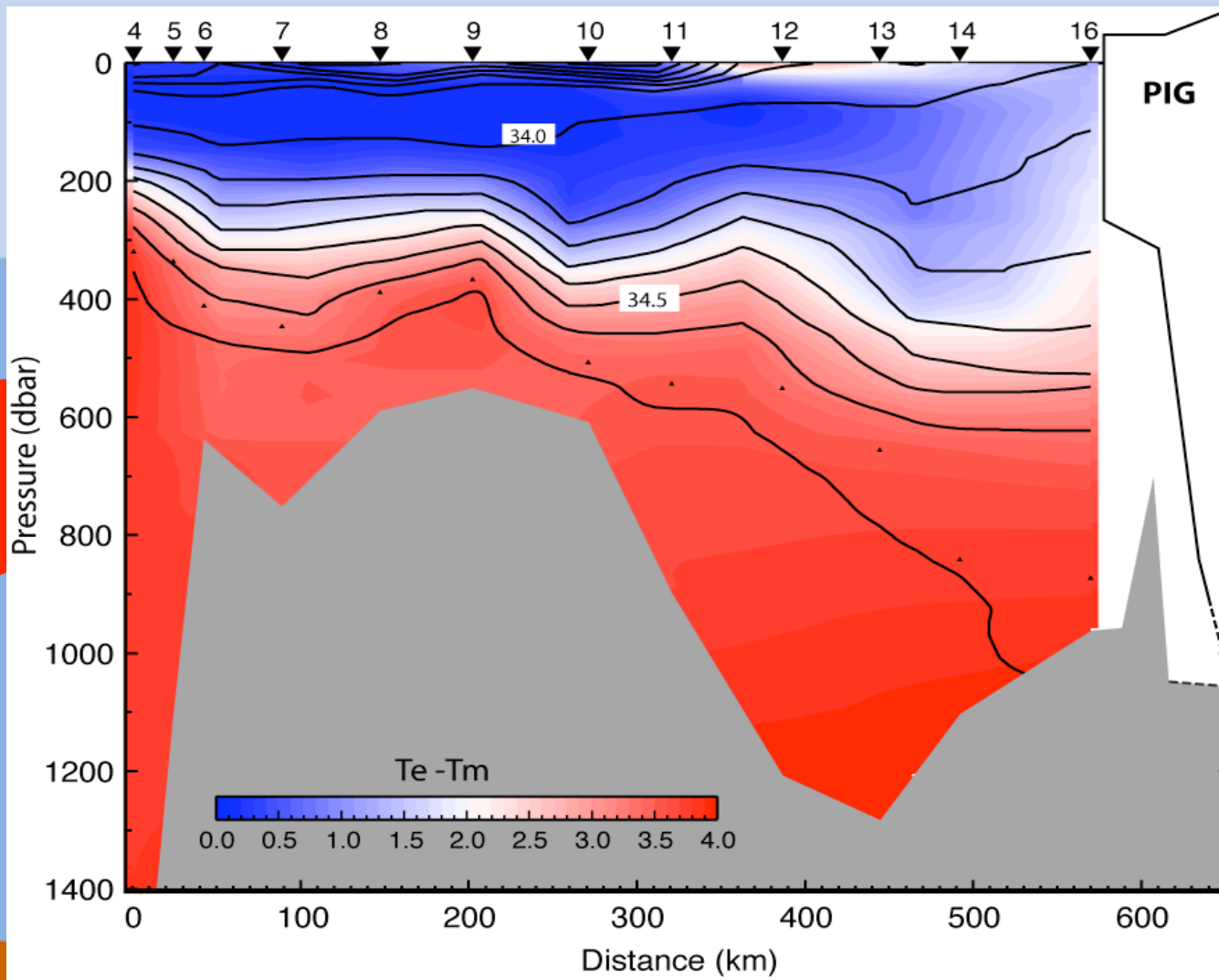
(stabilizing)



Jacobs
Mar. Chem., 1991

14. Warm Deep Water (WDW)

(destabilizing)



courtesy of
Stan Jacobs, LDEO

15. Westerlies (Strength/Position)

(destabilizing?)



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Science 3 October 2008: Vol. 322, no. 5898, p. 33
DOI: 10.1126/science.322.5898.33

NEWS OF THE WEEK

GLACIOLOGY:
Winds, Not Just Global Warming, Eating Away at the Ice Sheets
Richard A. Kerr

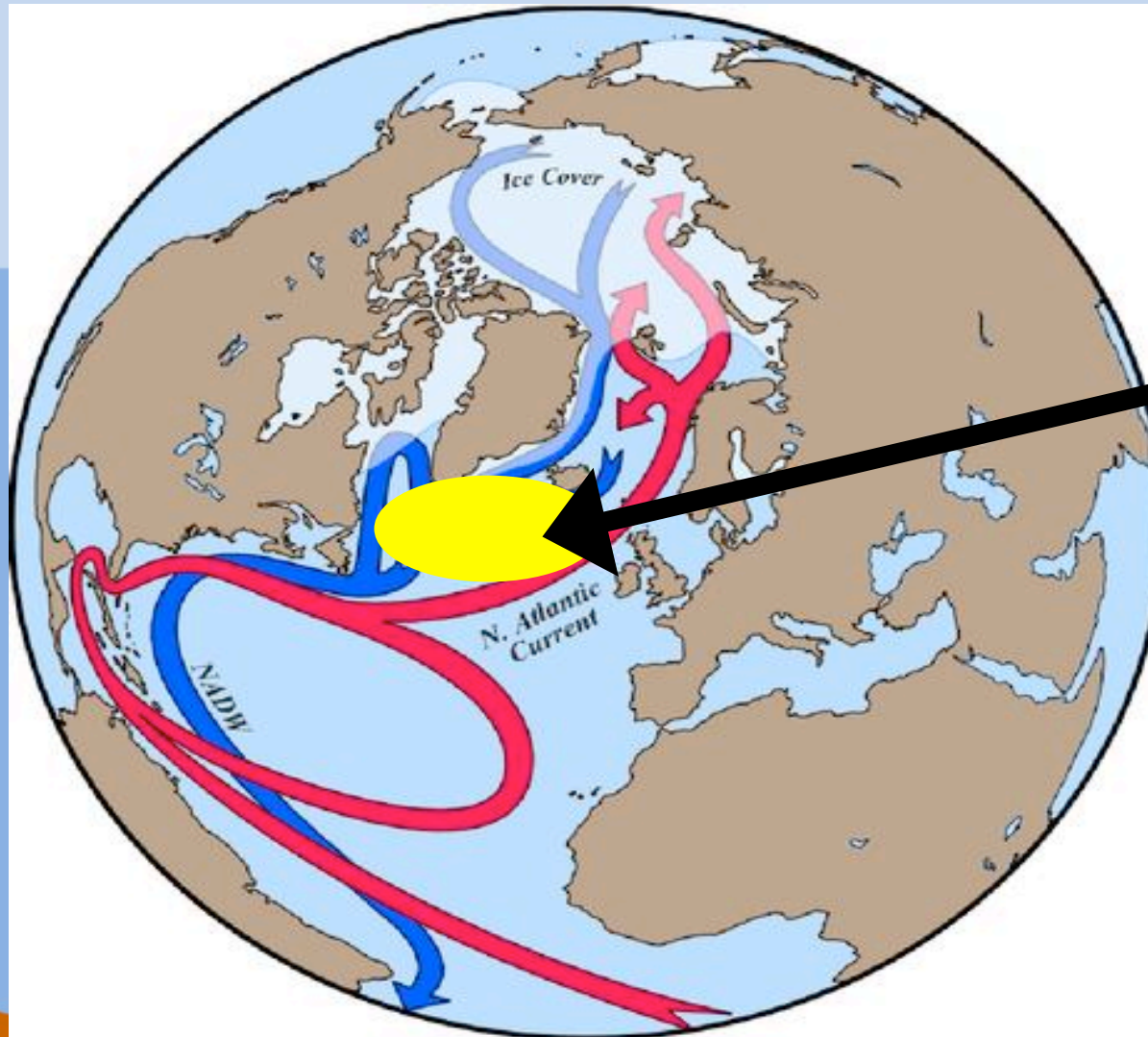


Too much. Ice coming off Jakobshavn Isbræ glacier surged after warm ocean water arrived.

CREDIT: BOB STRONG/REUTERS

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

(destabilizing)

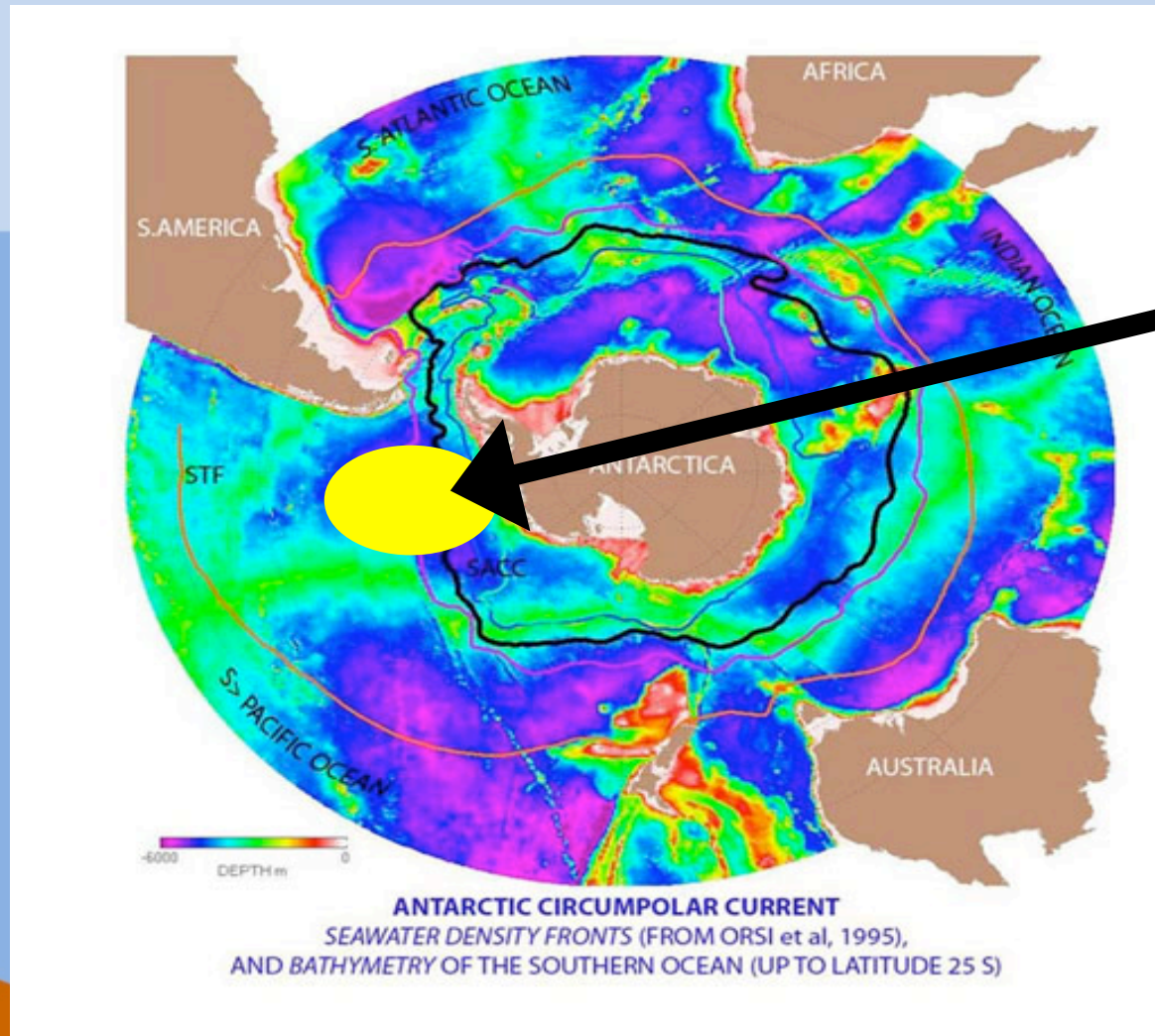


Observational
study:
Weaker
westerlies ...
Stronger ice
melt

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

(destabilizing?)



Increase meridional
temperature gradient, ...
increase westerlies

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. Shibata¹⁰

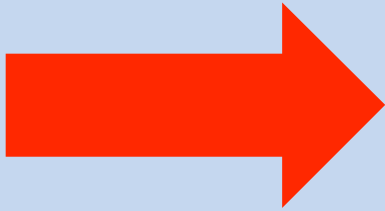
In the past several decades, the tropospheric westerly winds in the Southern Hemisphere have been observed to accelerate on the poleward side of the surface wind maximum. This has been attributed to the combined anthropogenic effects of increasing greenhouse gases and decreasing stratospheric ozone and 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

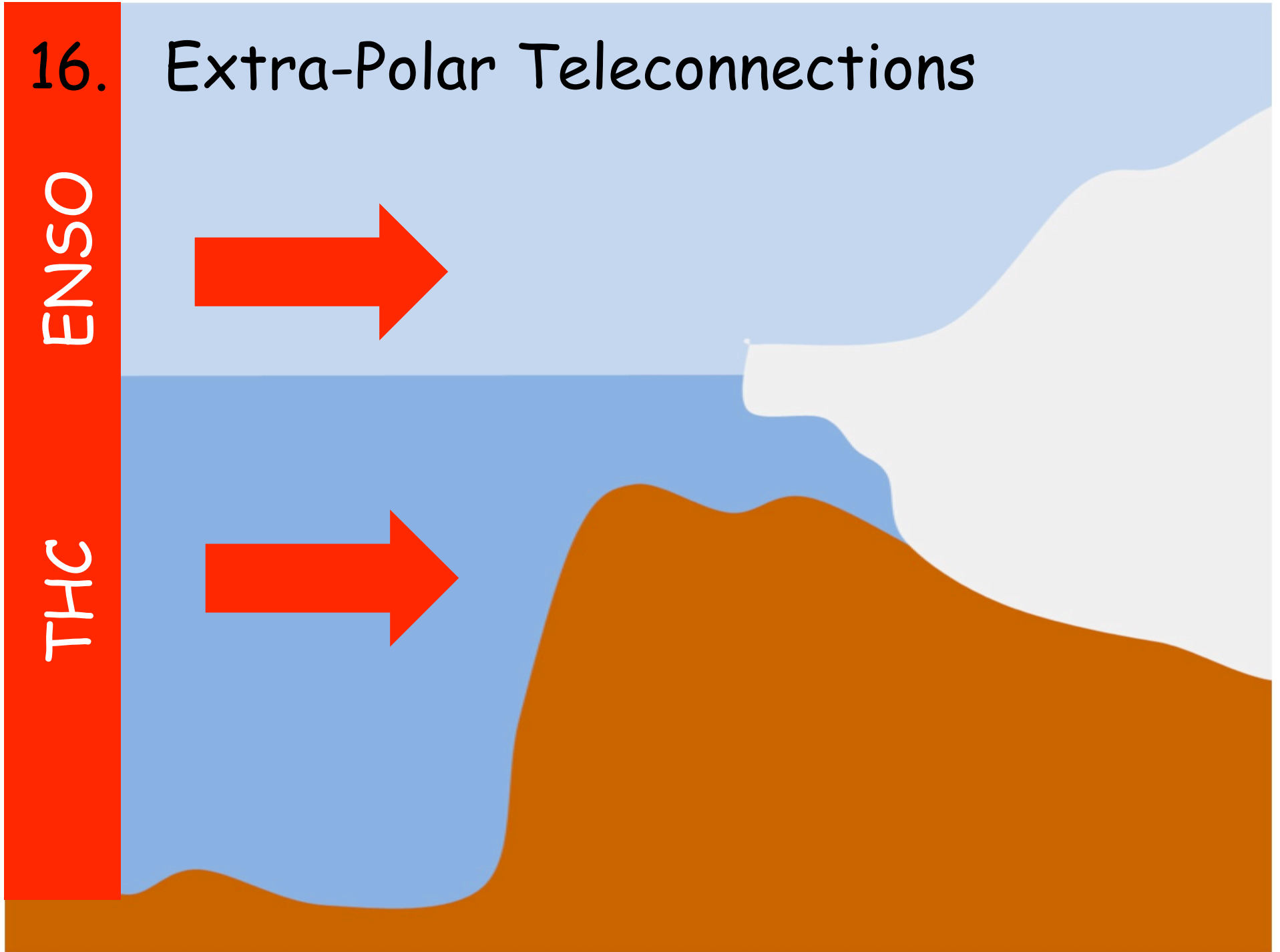
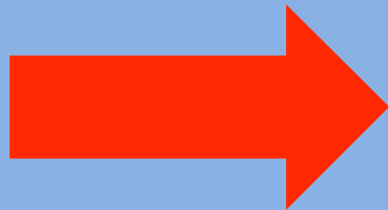
16.

Extra-Polar Teleconnections

ENSO

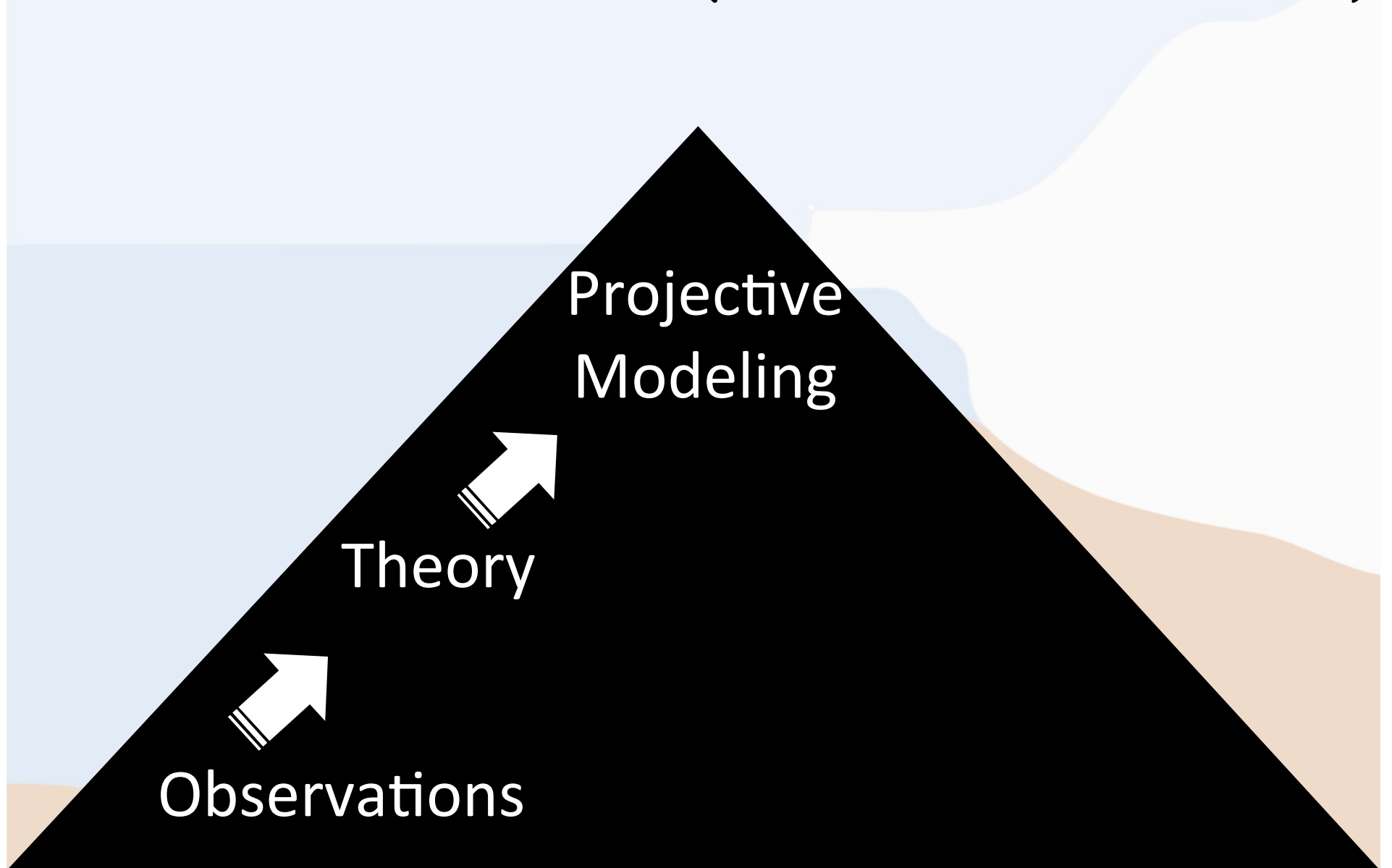


THC



Supposed Pathway Forward: AR5/Beyond

(ice-ocean interaction context)



Observations are going way tooo sloooow ... (ice-ocean interaction context)



Need to be Realistic: Present Resources *(ice-ocean interaction context)*



**Strong
Computational
Capability**

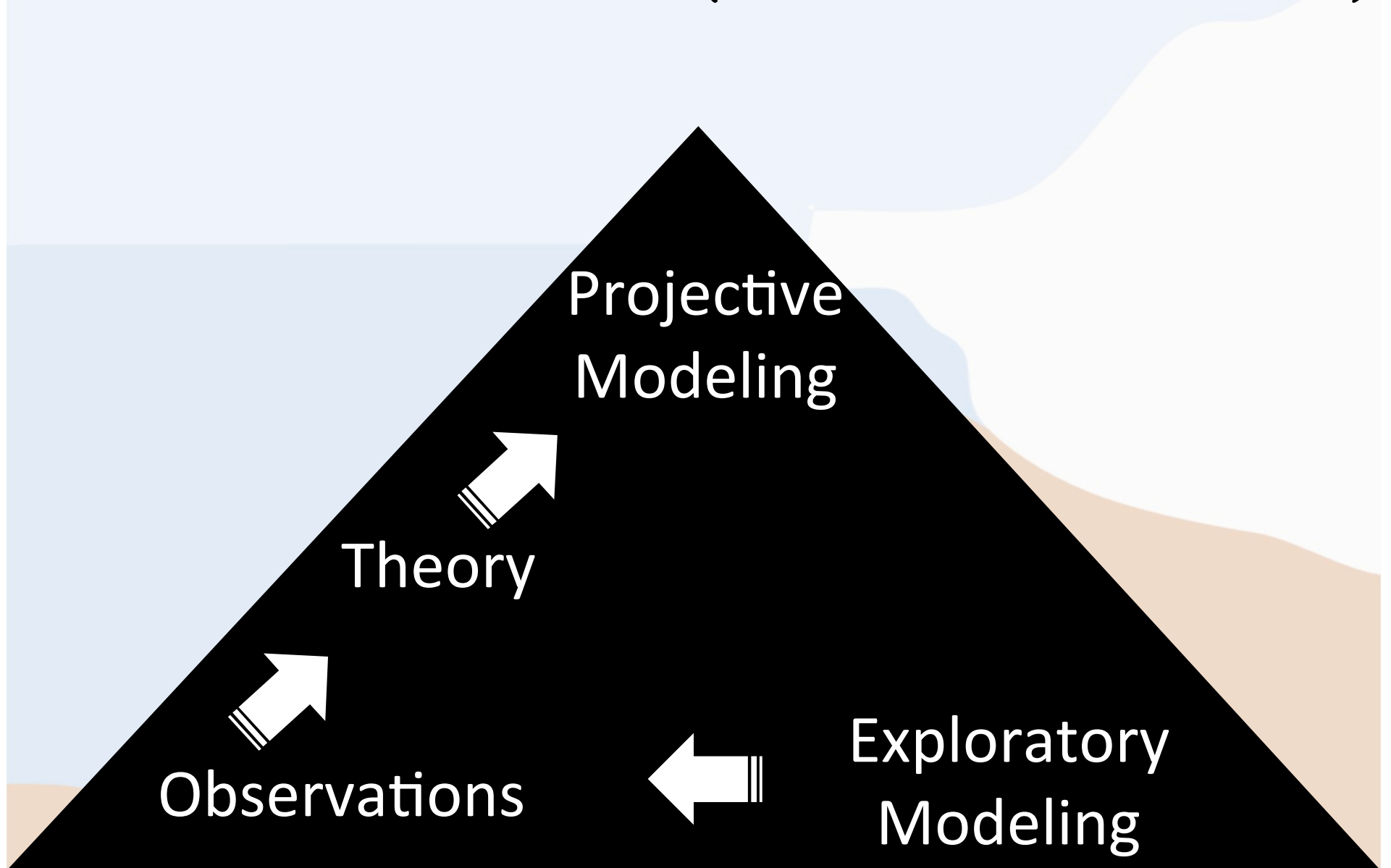


**Weak
Observational
Capability**

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

