

# **Ice-ocean interactions in the context of future ice-sheet/ocean coupled models**

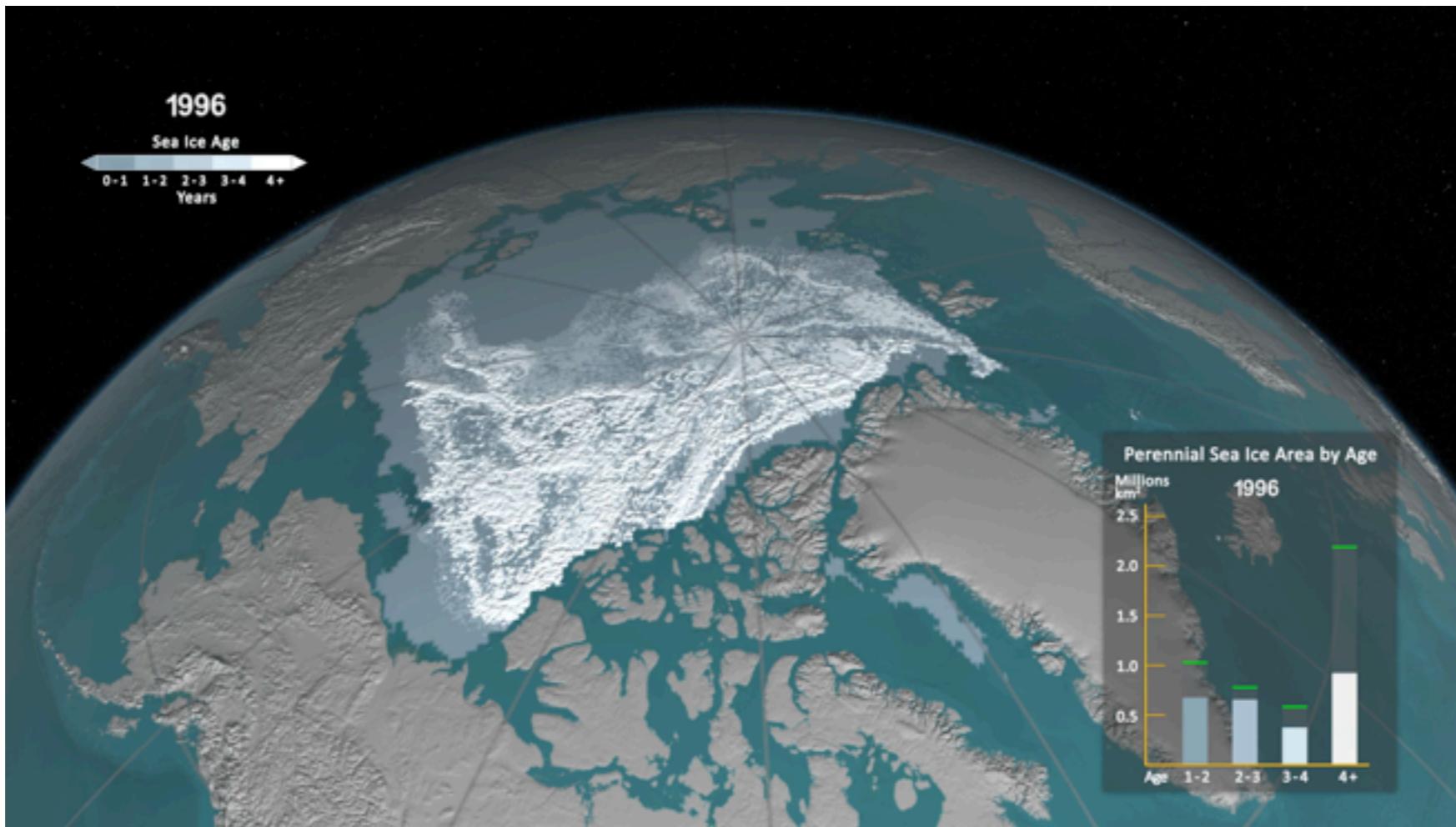
**Grenoble 2-Dec-2016**  
**by Nacho Merino**

**Supervised by:**  
**Gaël Durand**  
**Julien Le Sommer**



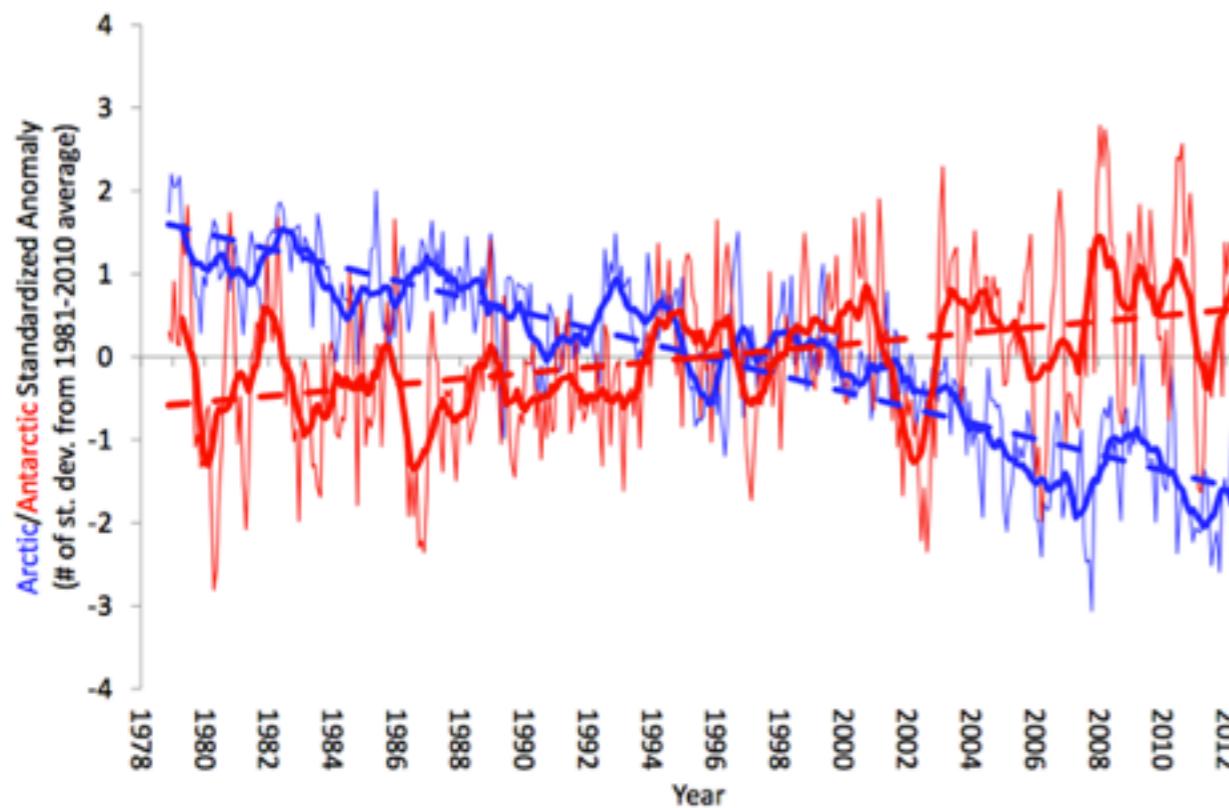
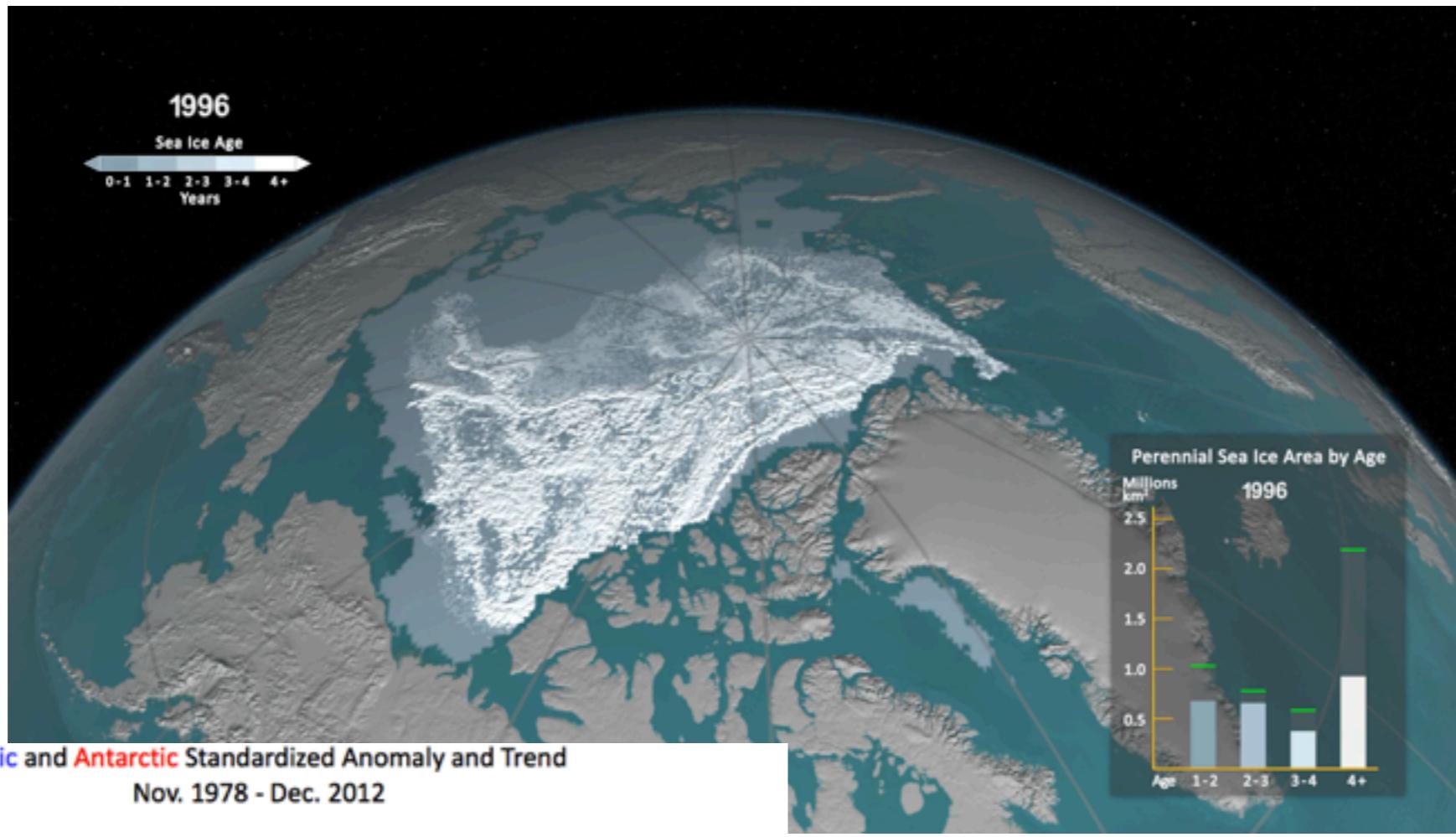
**Jury composition:**  
**Michel Fily**  
**Gilles Reverdin (R)**  
**Jean-Baptiste Sallée (R)**  
**Marie-Noëlle Houssais**  
**Xylar Asay-Davis**

# Sea ice concentration trends: inter-hemispheric contrast



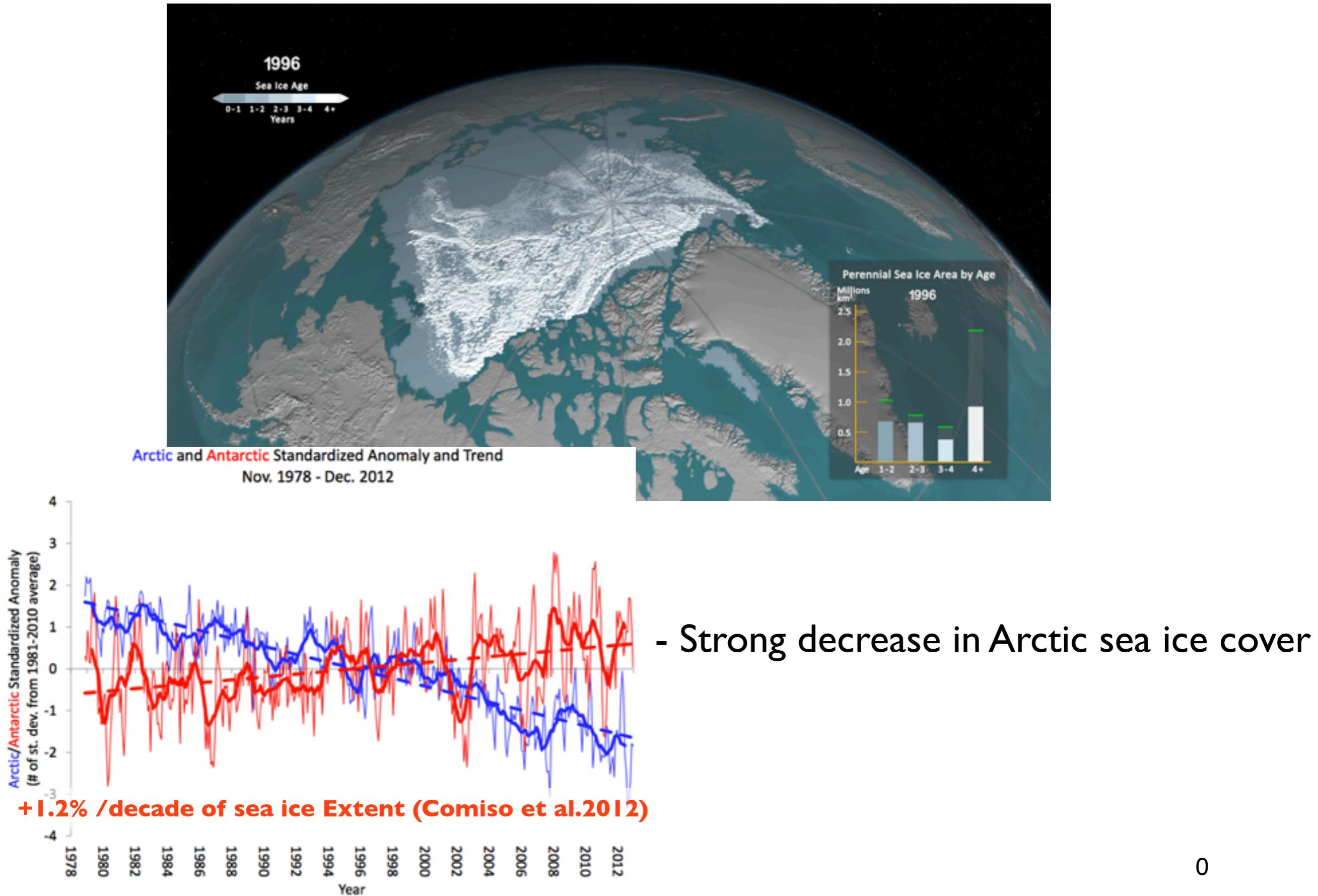
- Strong decrease in Arctic sea ice cover

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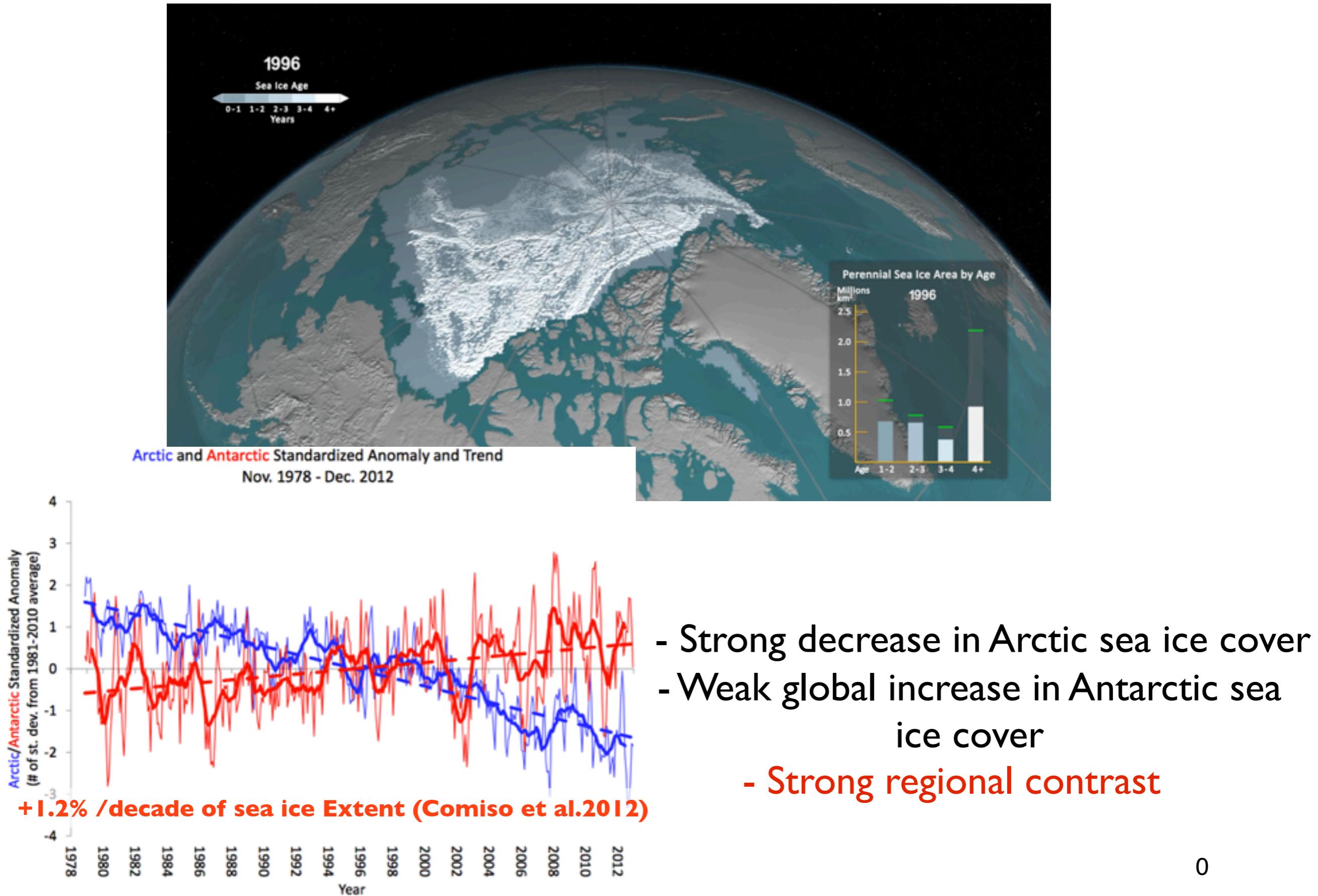


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(Oceans south  $30^{\circ}$ S)

75% excess heat uptake

40 % anthropogenic CO<sub>2</sub> uptake

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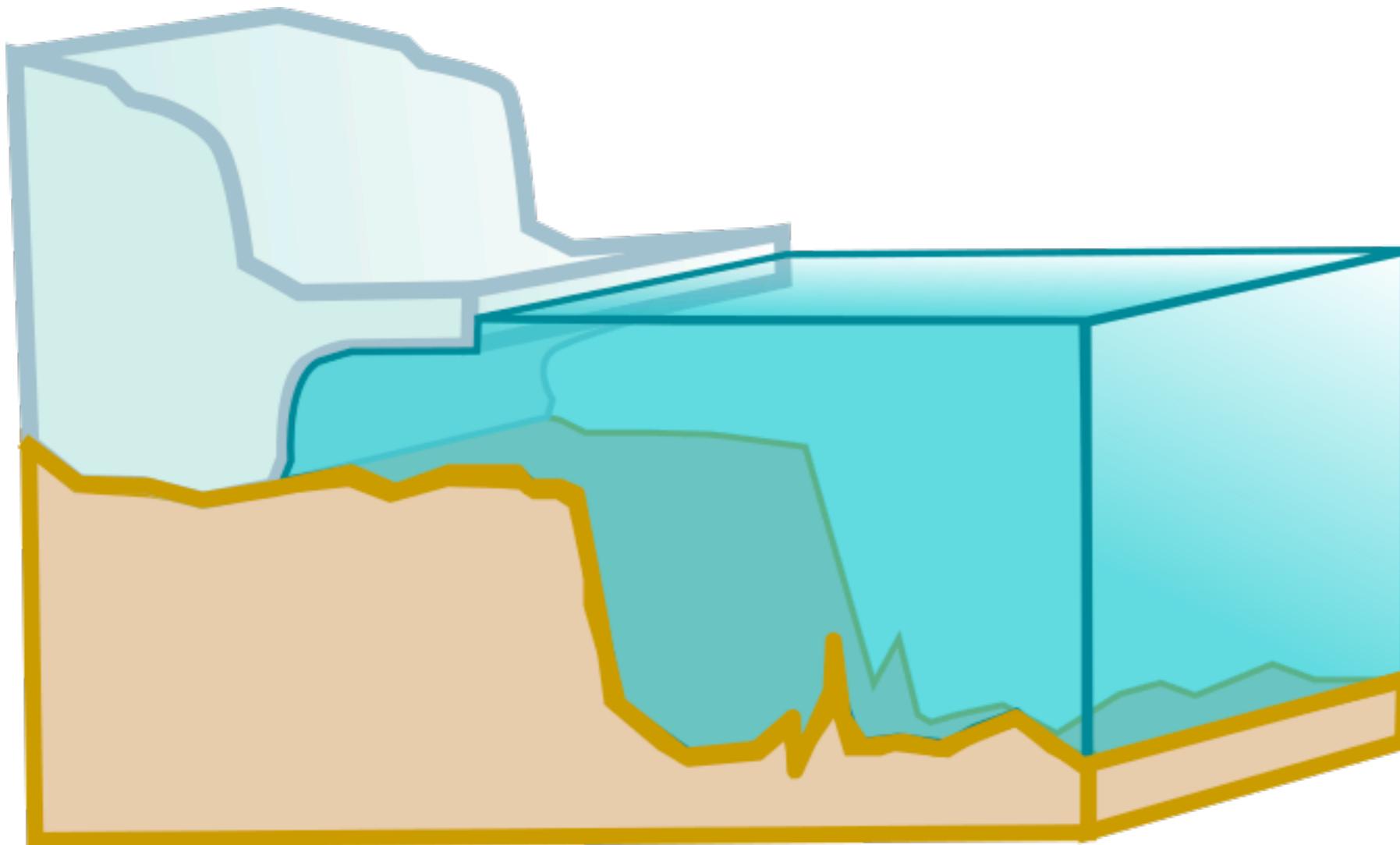
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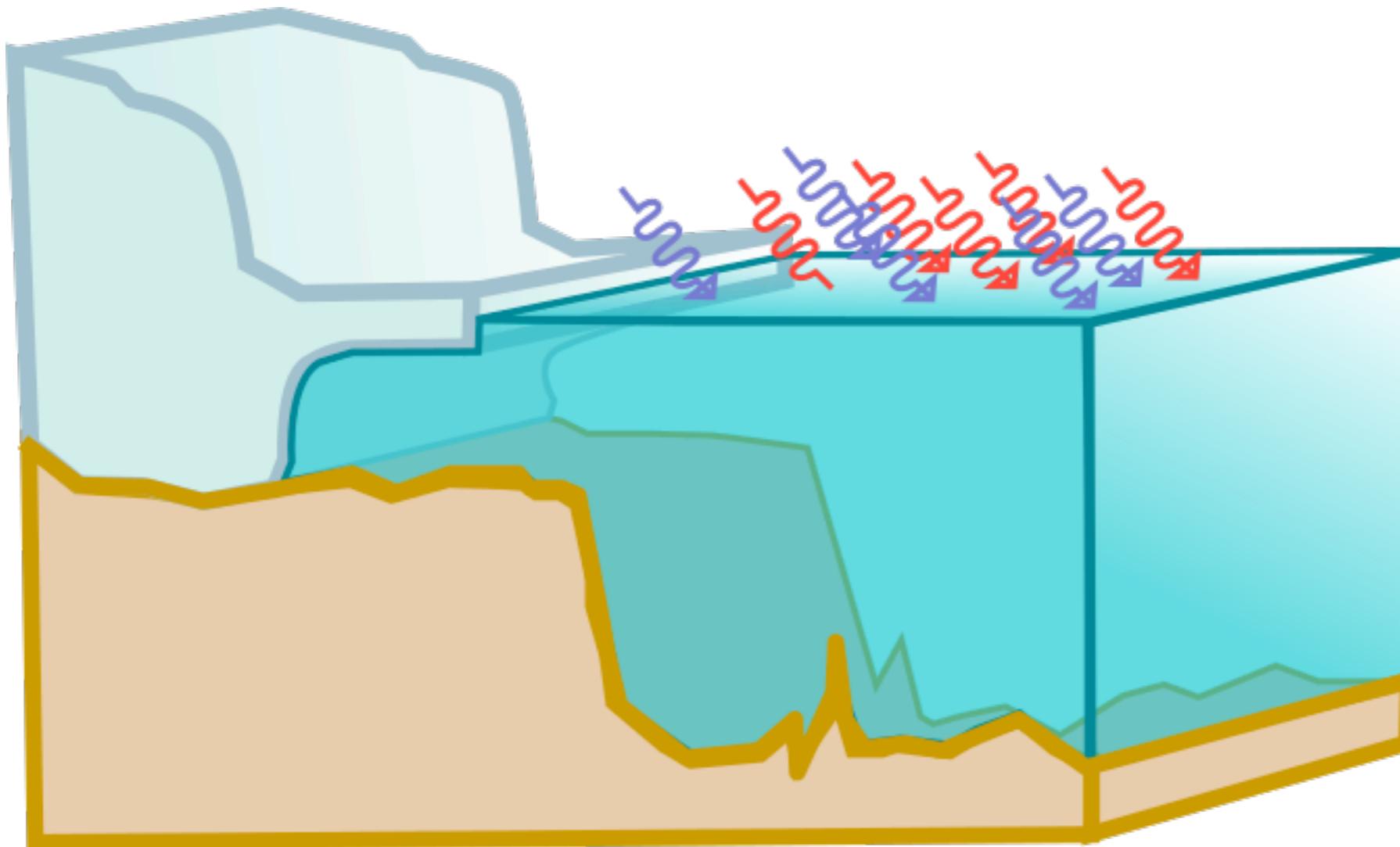
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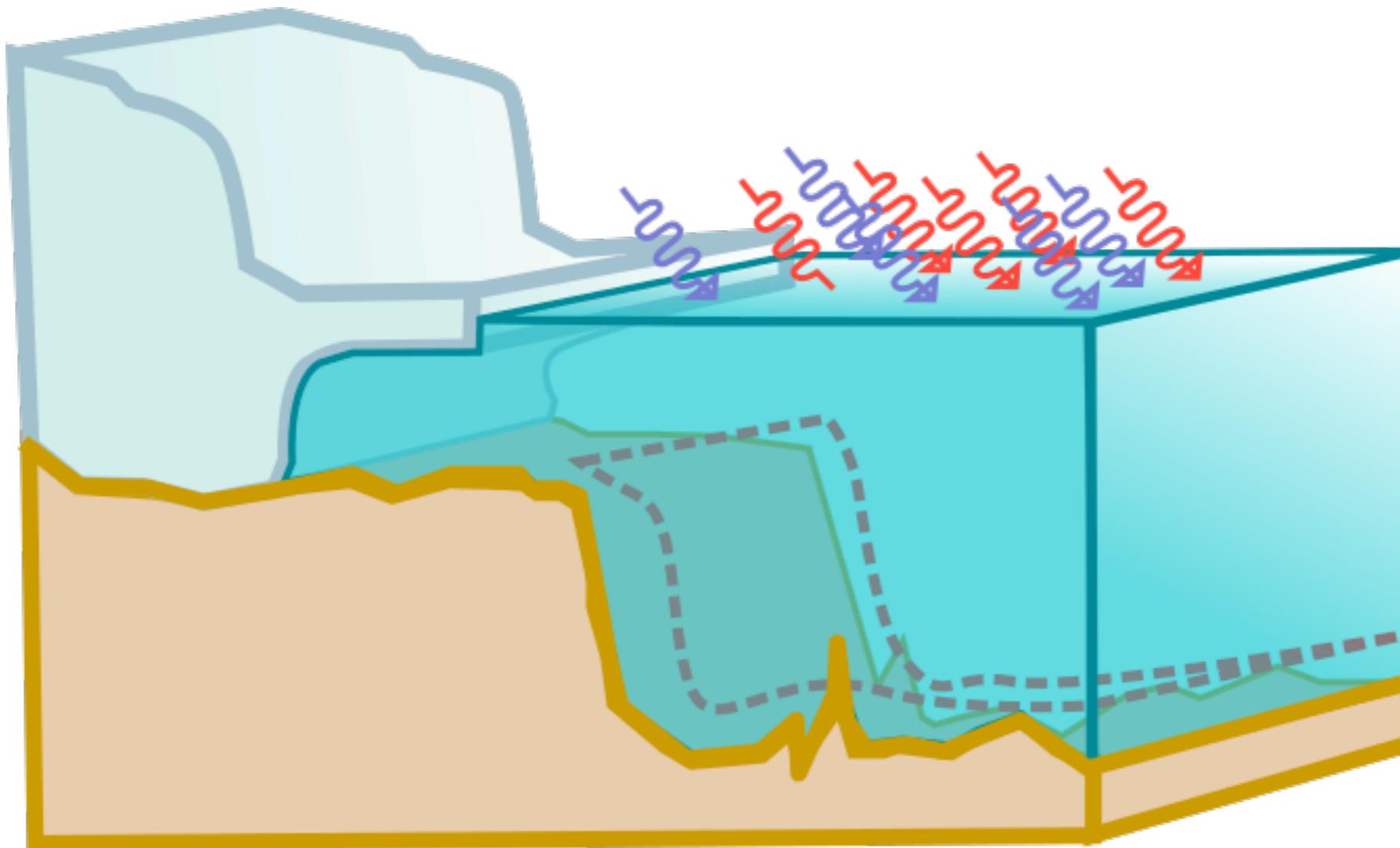
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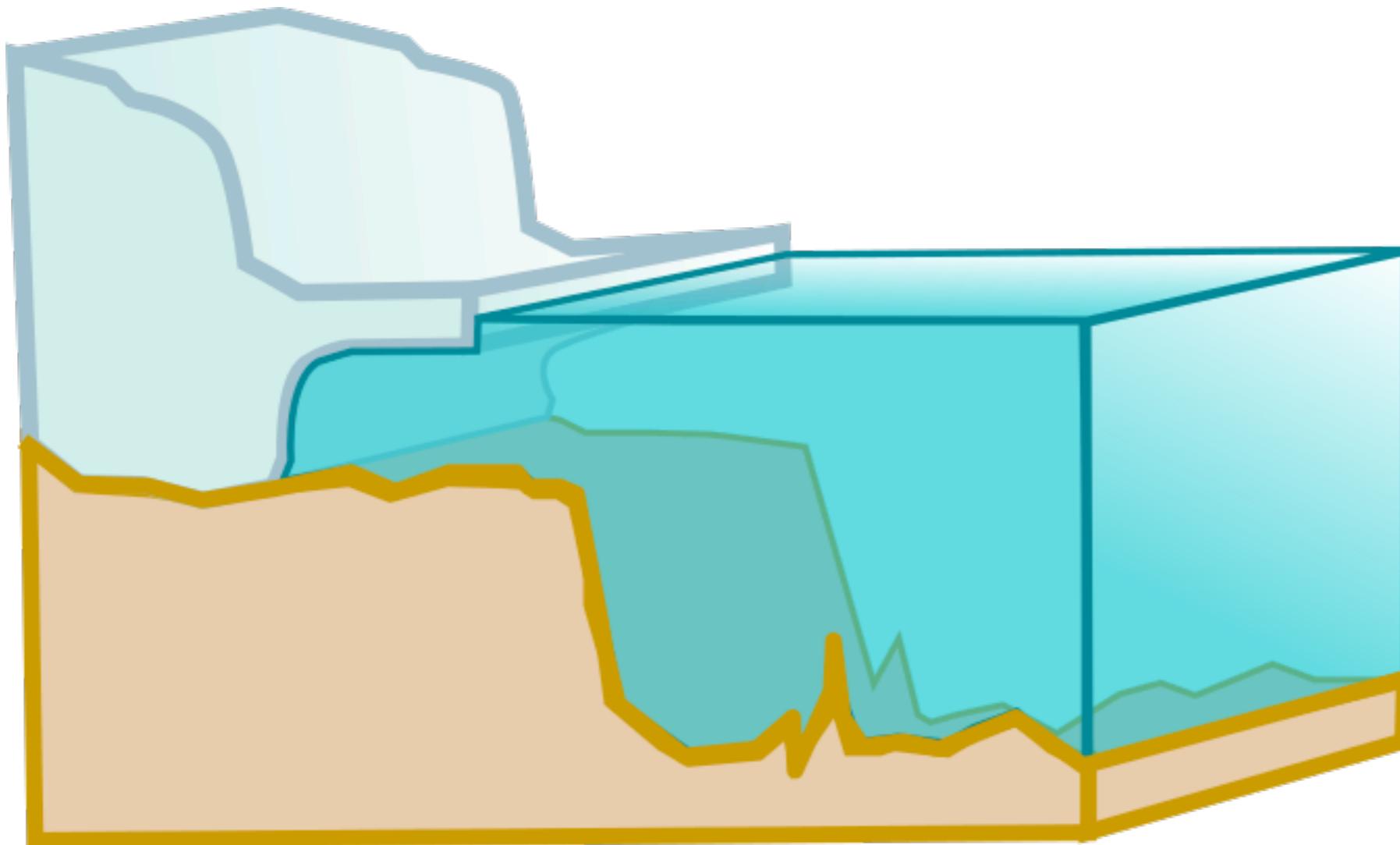
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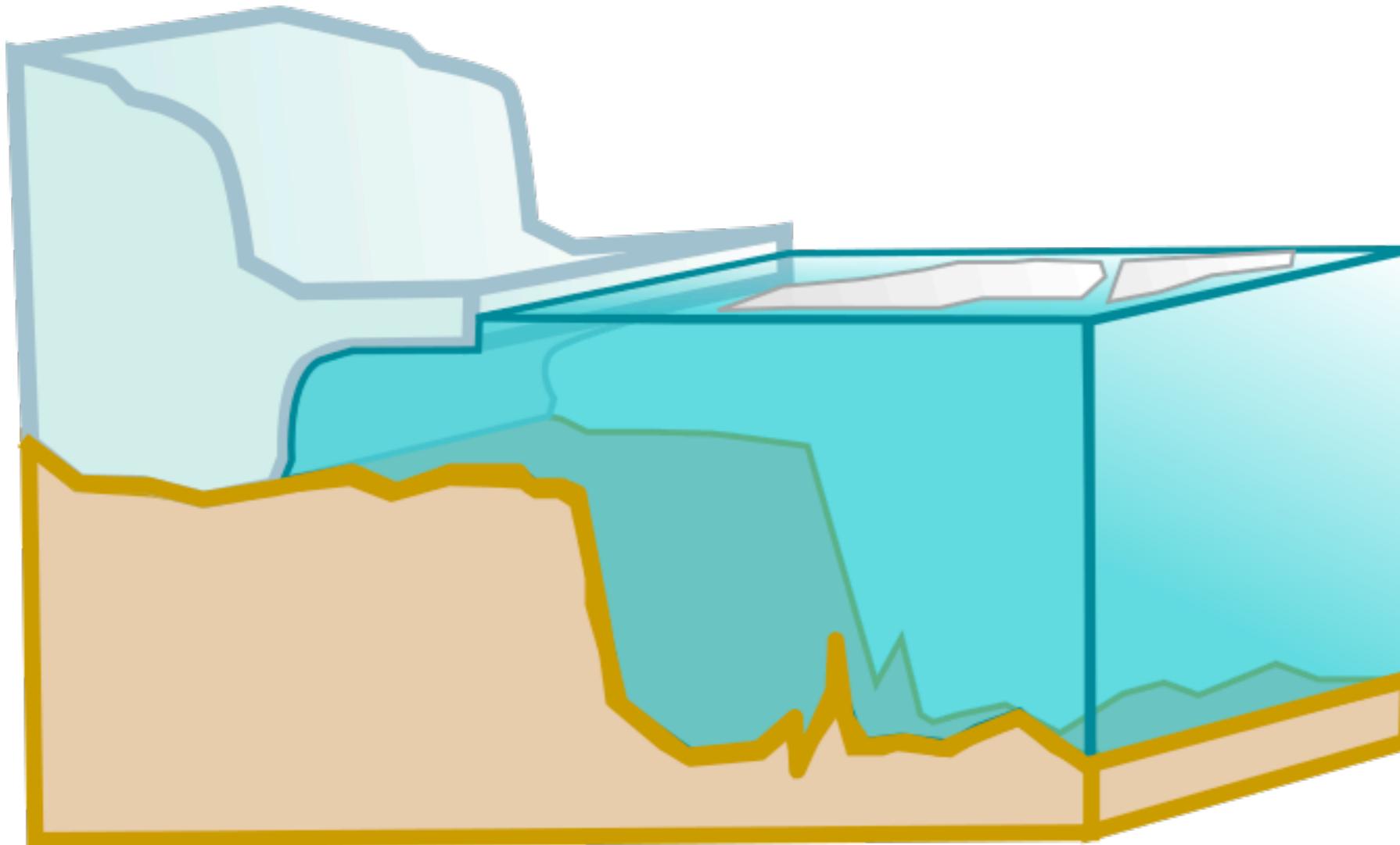
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Physical barrier to exchanges (lid)

Buoyancy fluxes (heat, freshwater)

Example: High Salinity Shelf Waters



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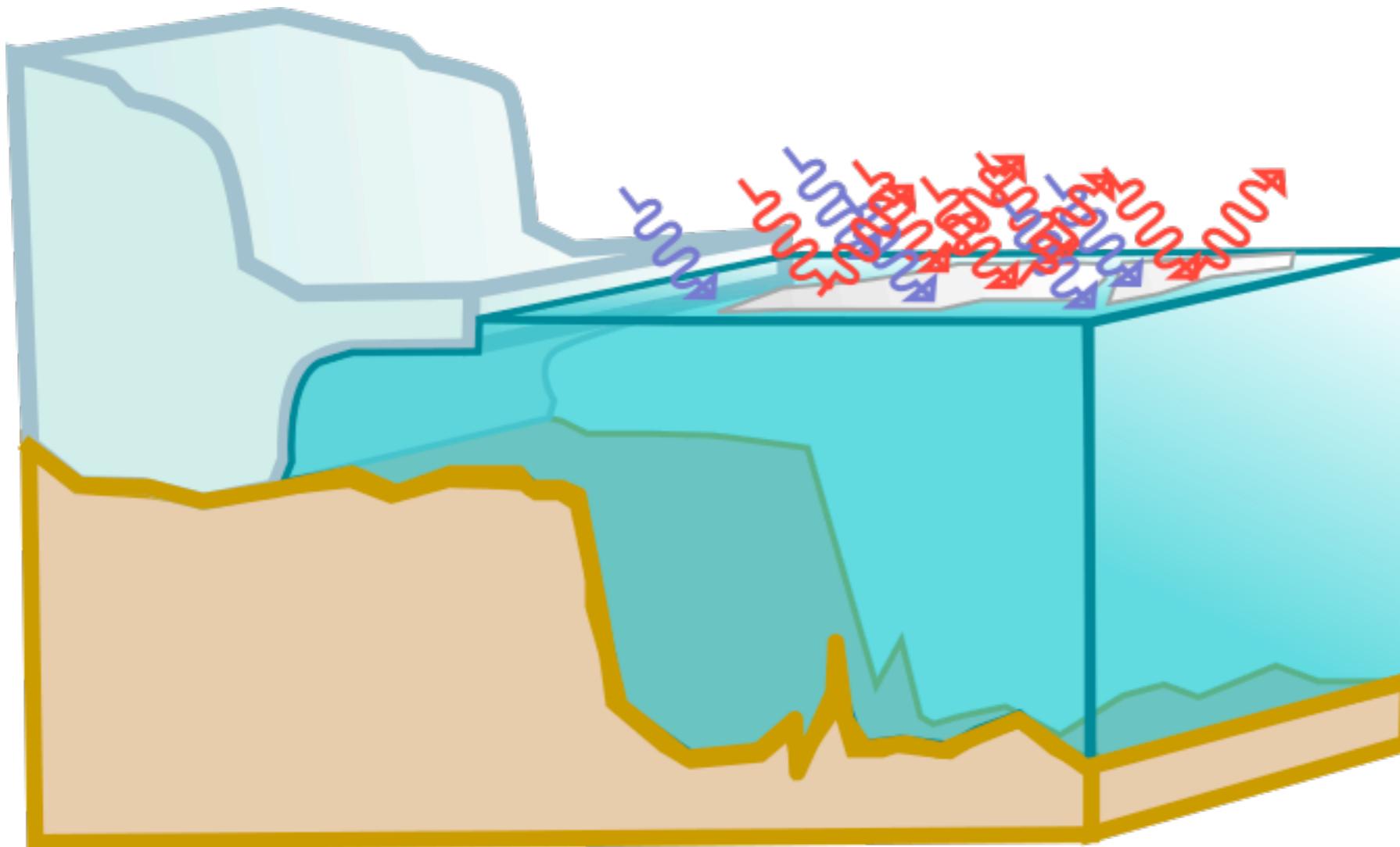
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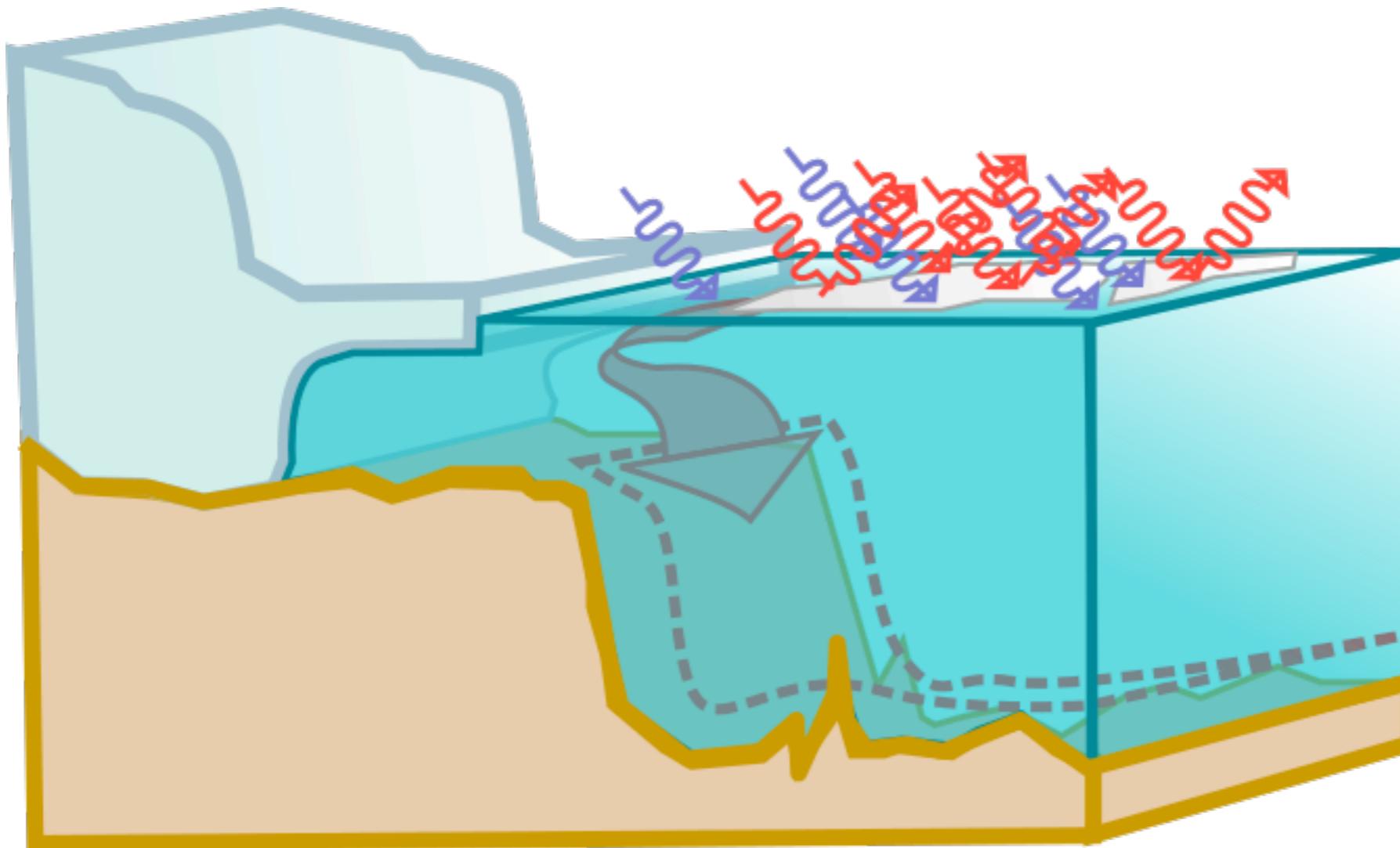
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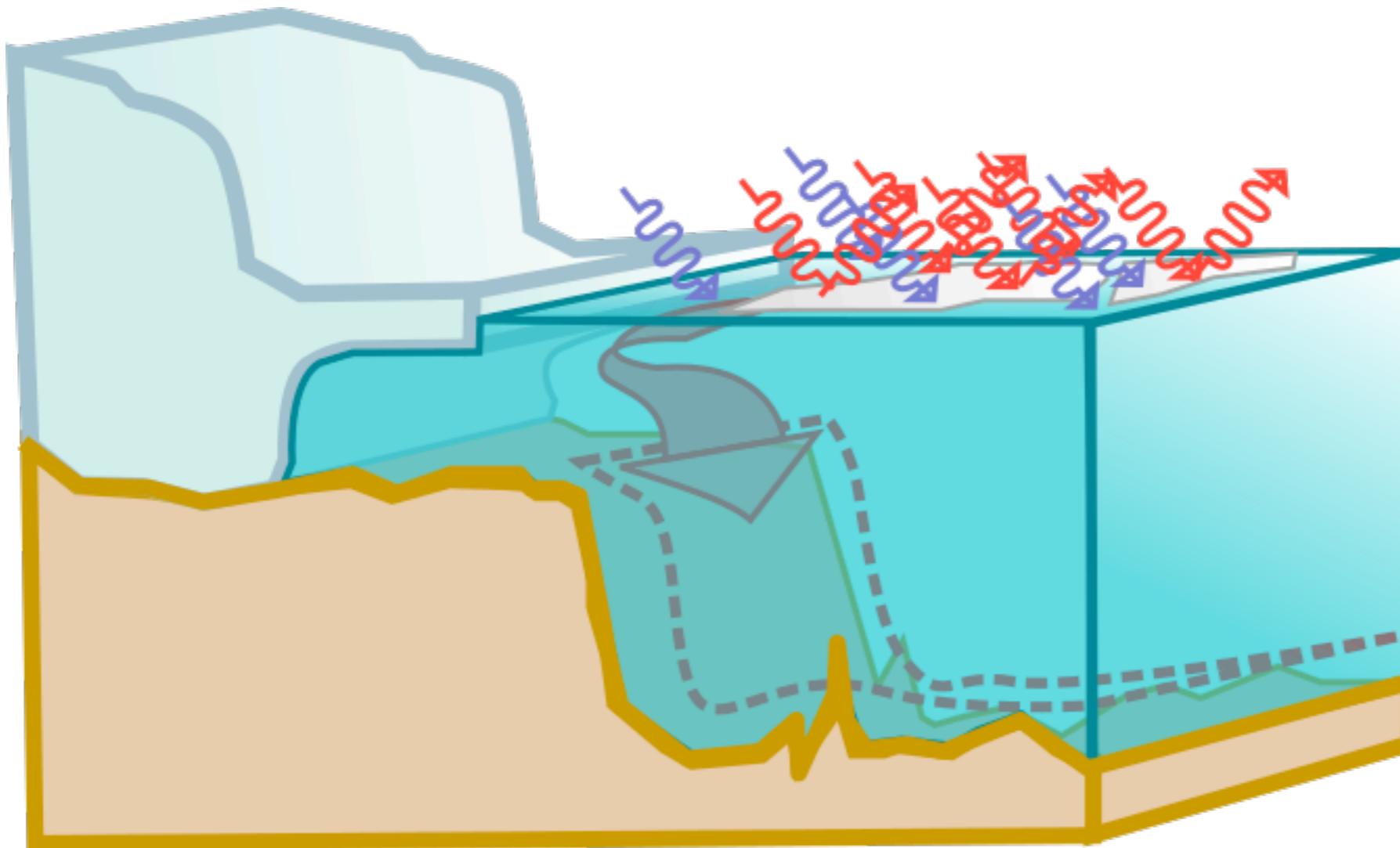
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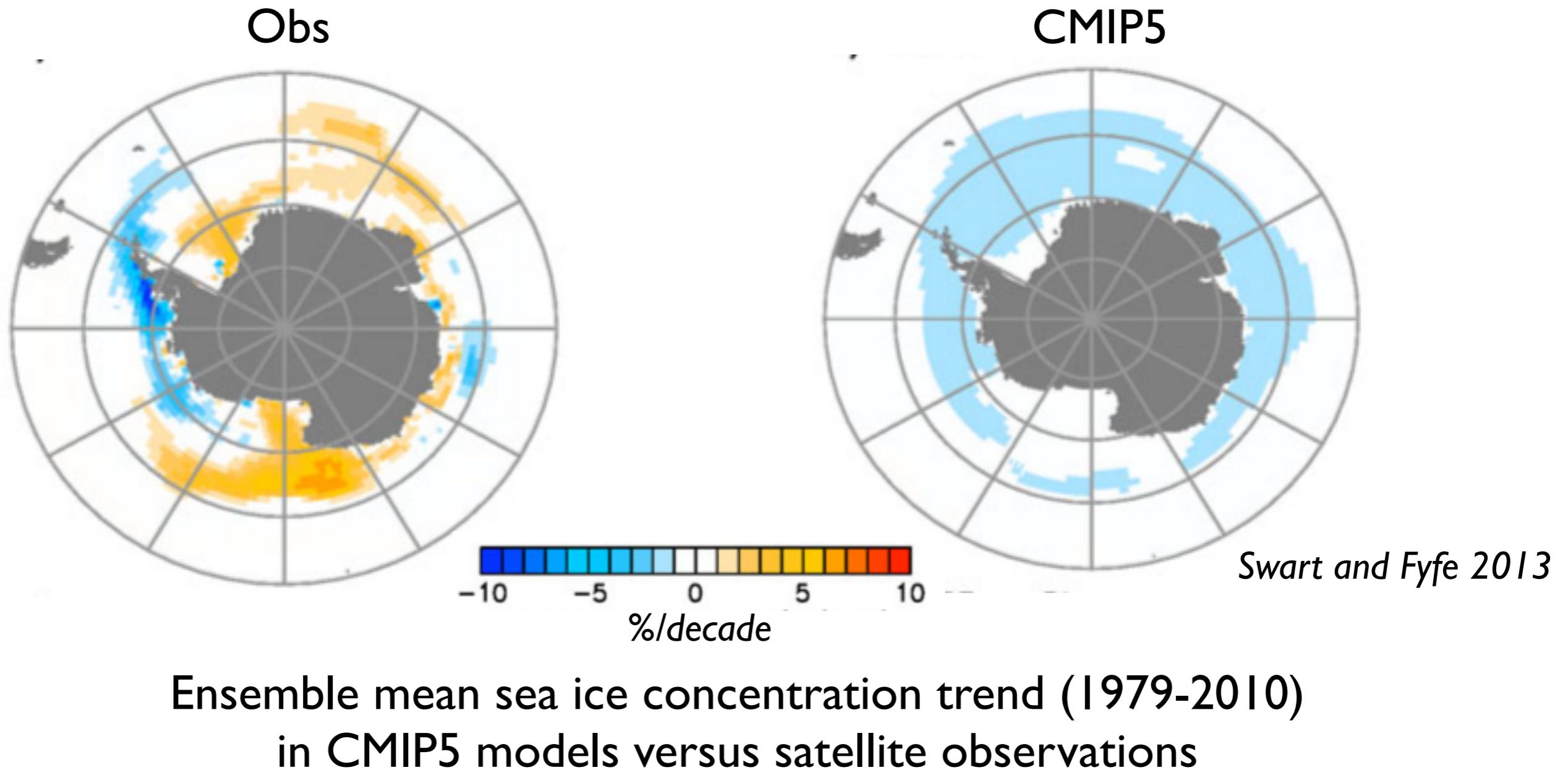
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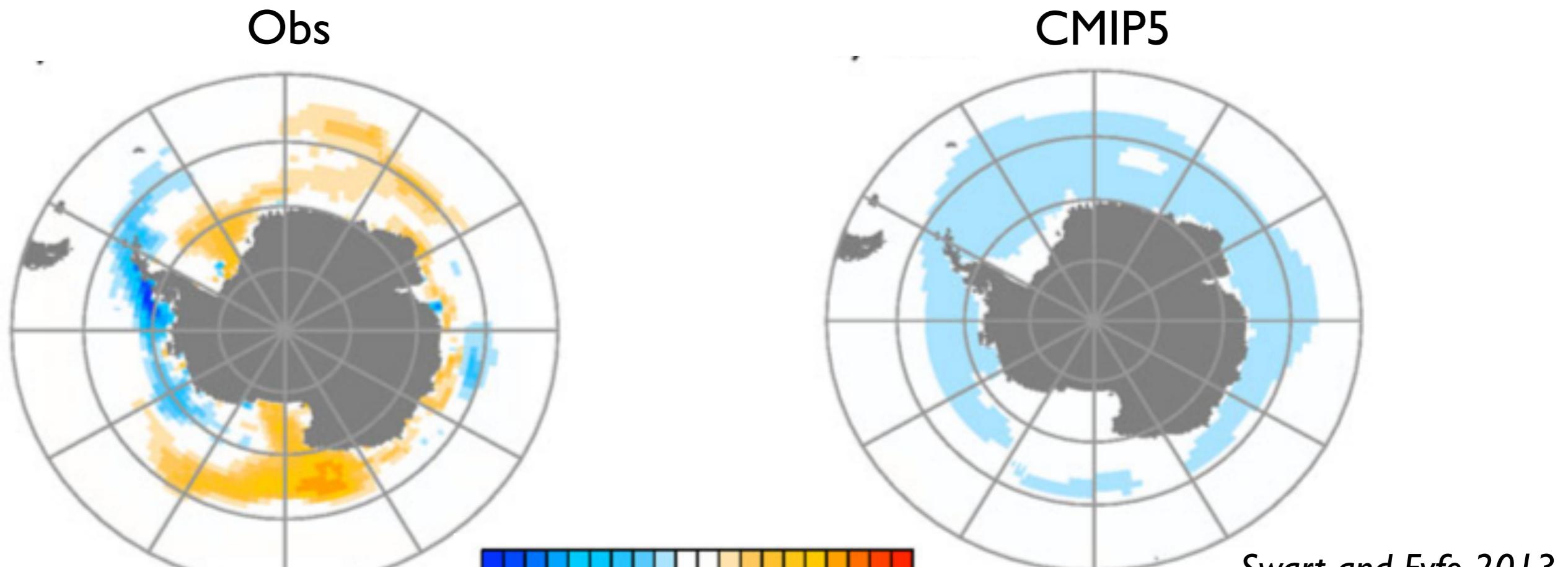
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# Antarctic sea ice trends in CMIP5 models



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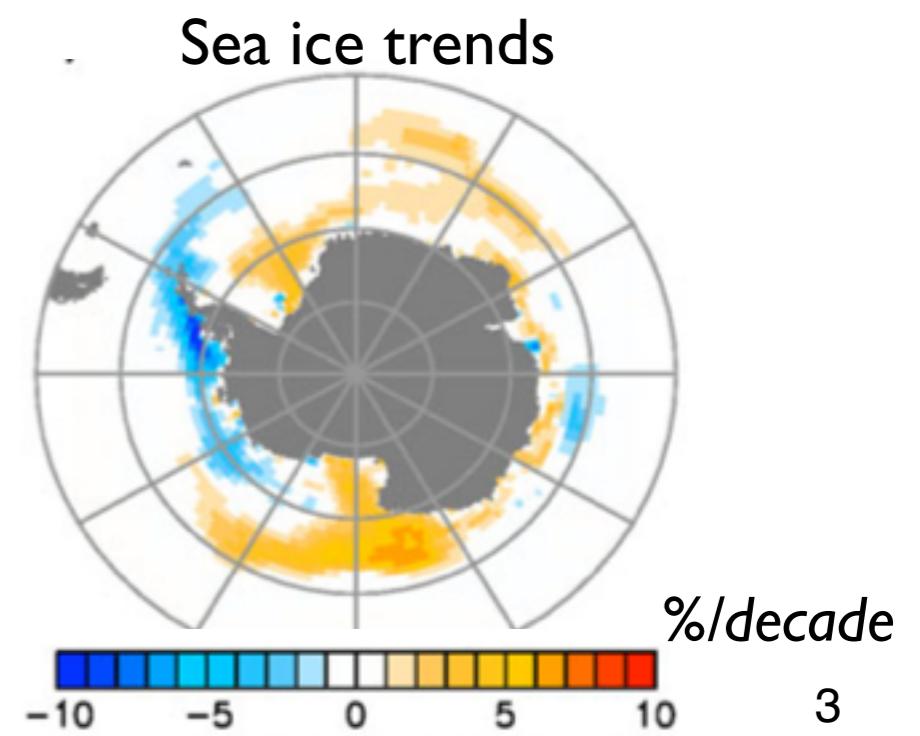


Ensemble mean sea ice concentration trend (1979-2010)  
in CMIP5 models versus satellite observations

**Current generation of climate models fail in  
reproducing Antarctic sea ice trends**

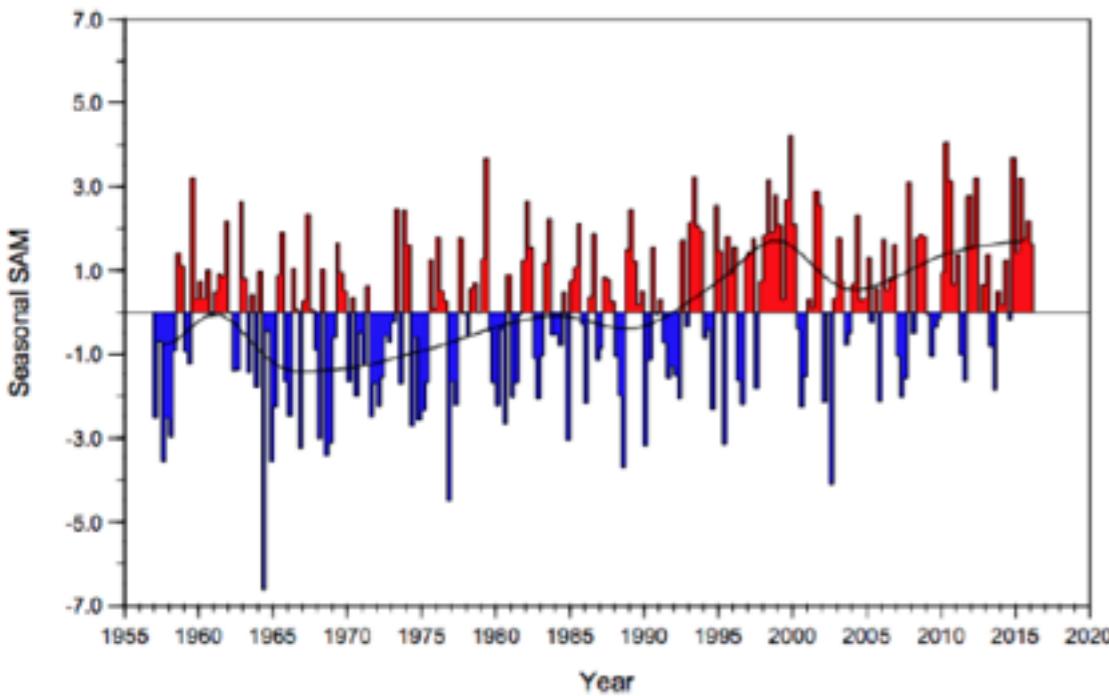
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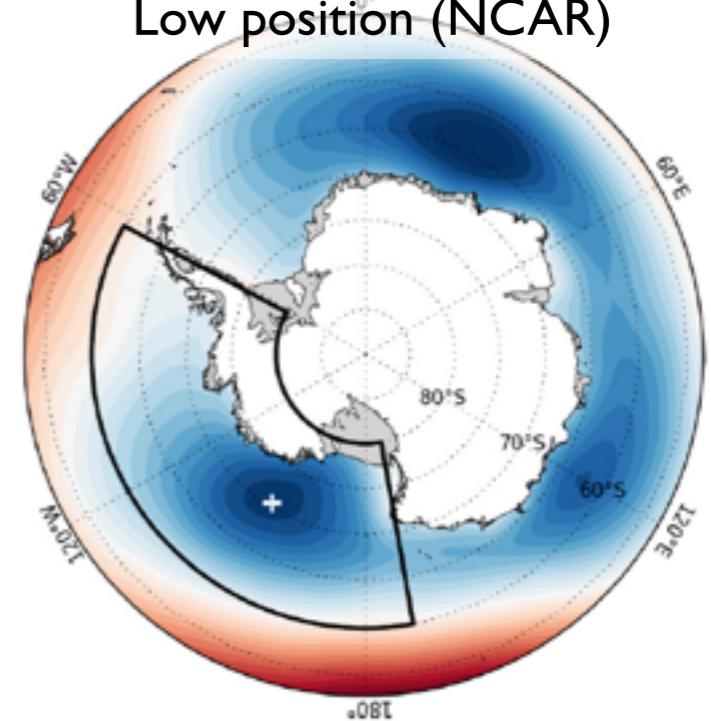
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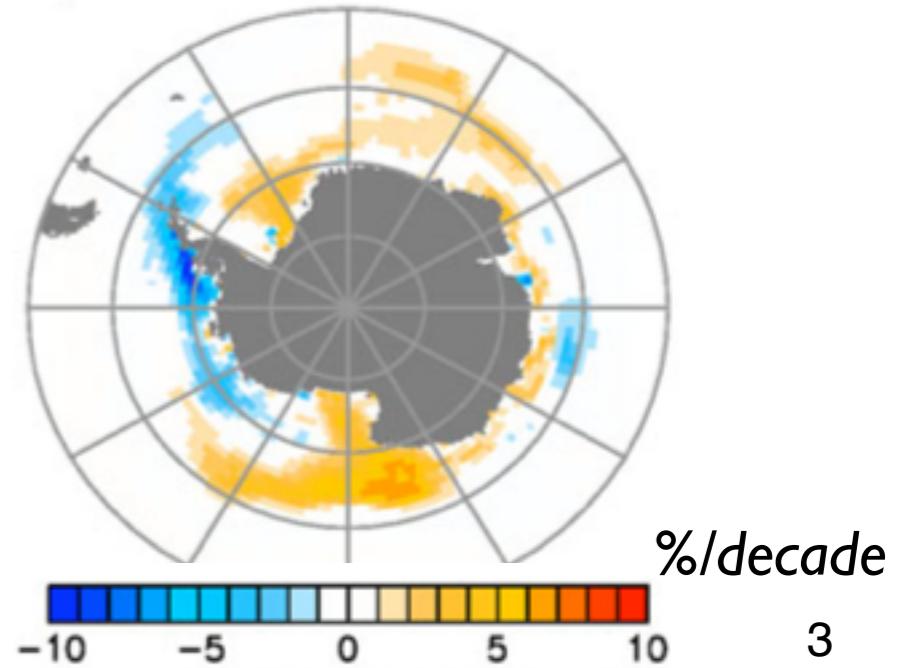
Increase in westerlies over the Southern Ocean

Average sea level pressure and Amundsen Low position (NCAR)



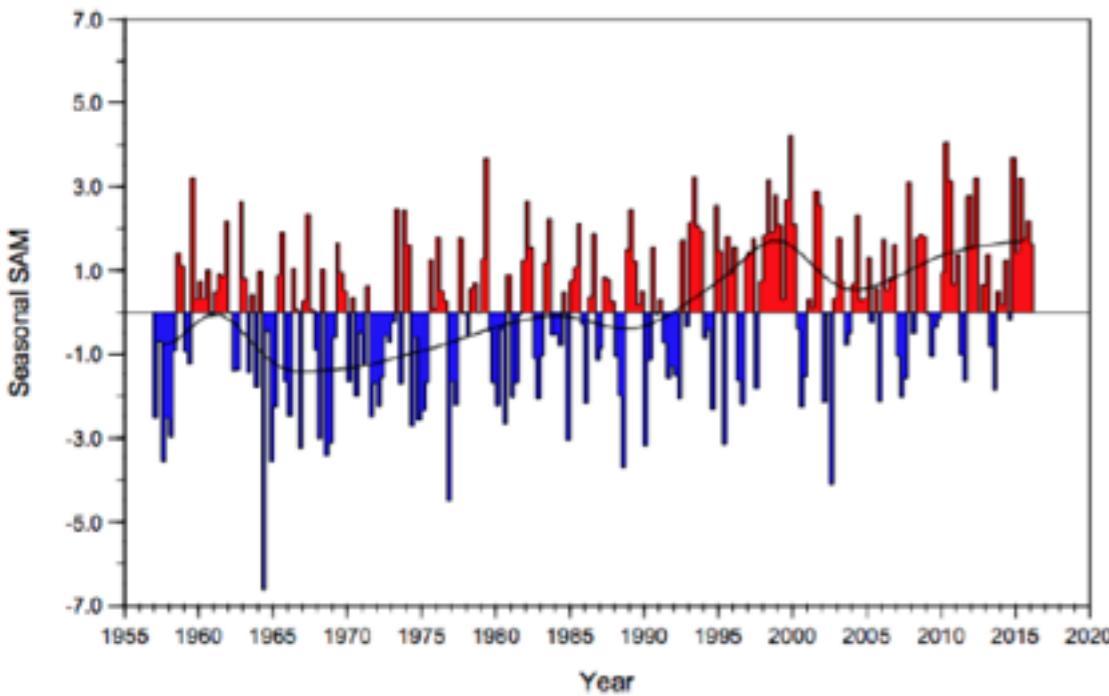
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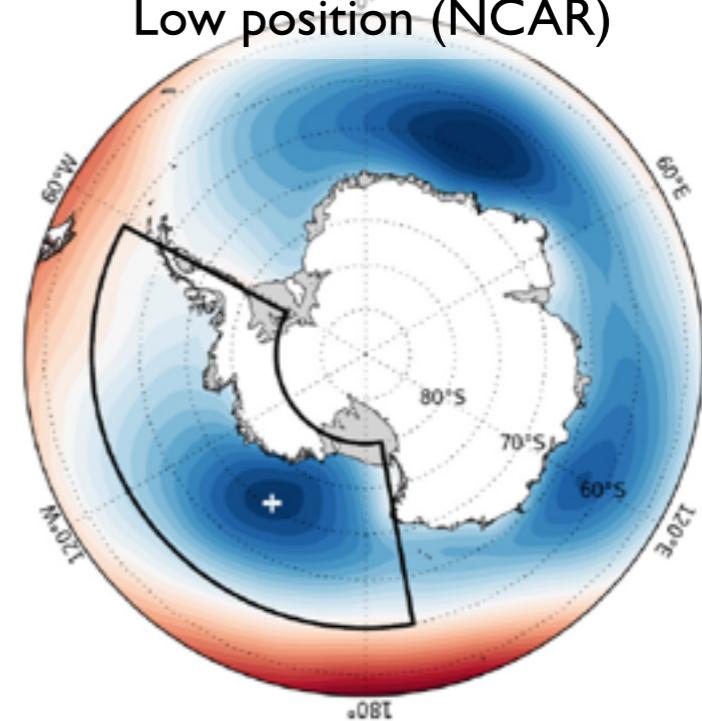
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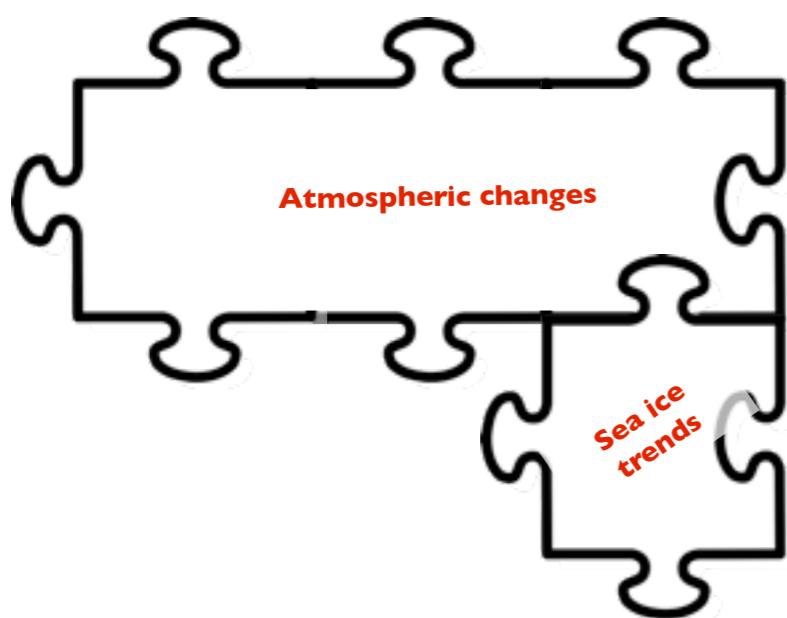


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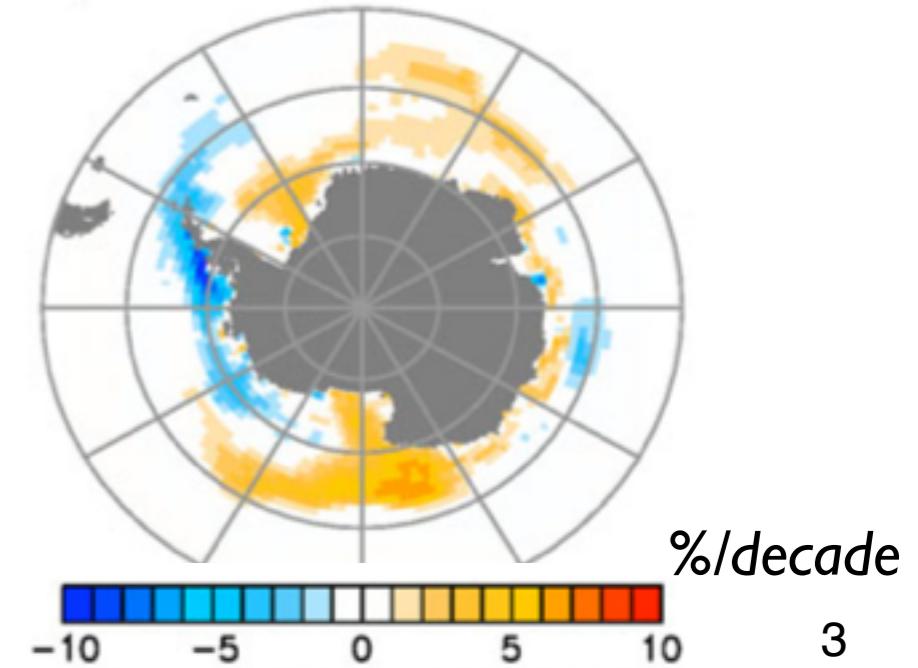
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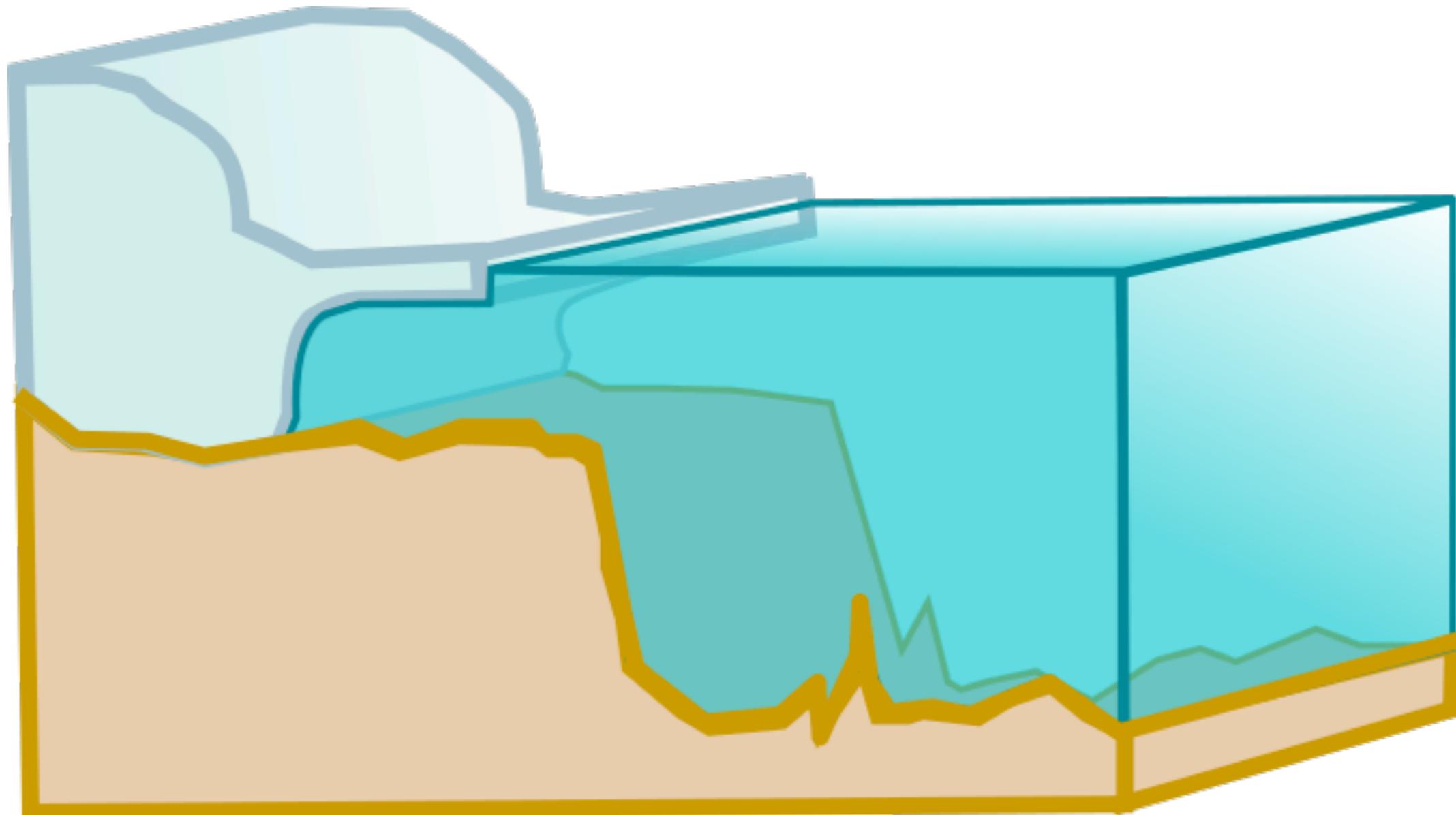
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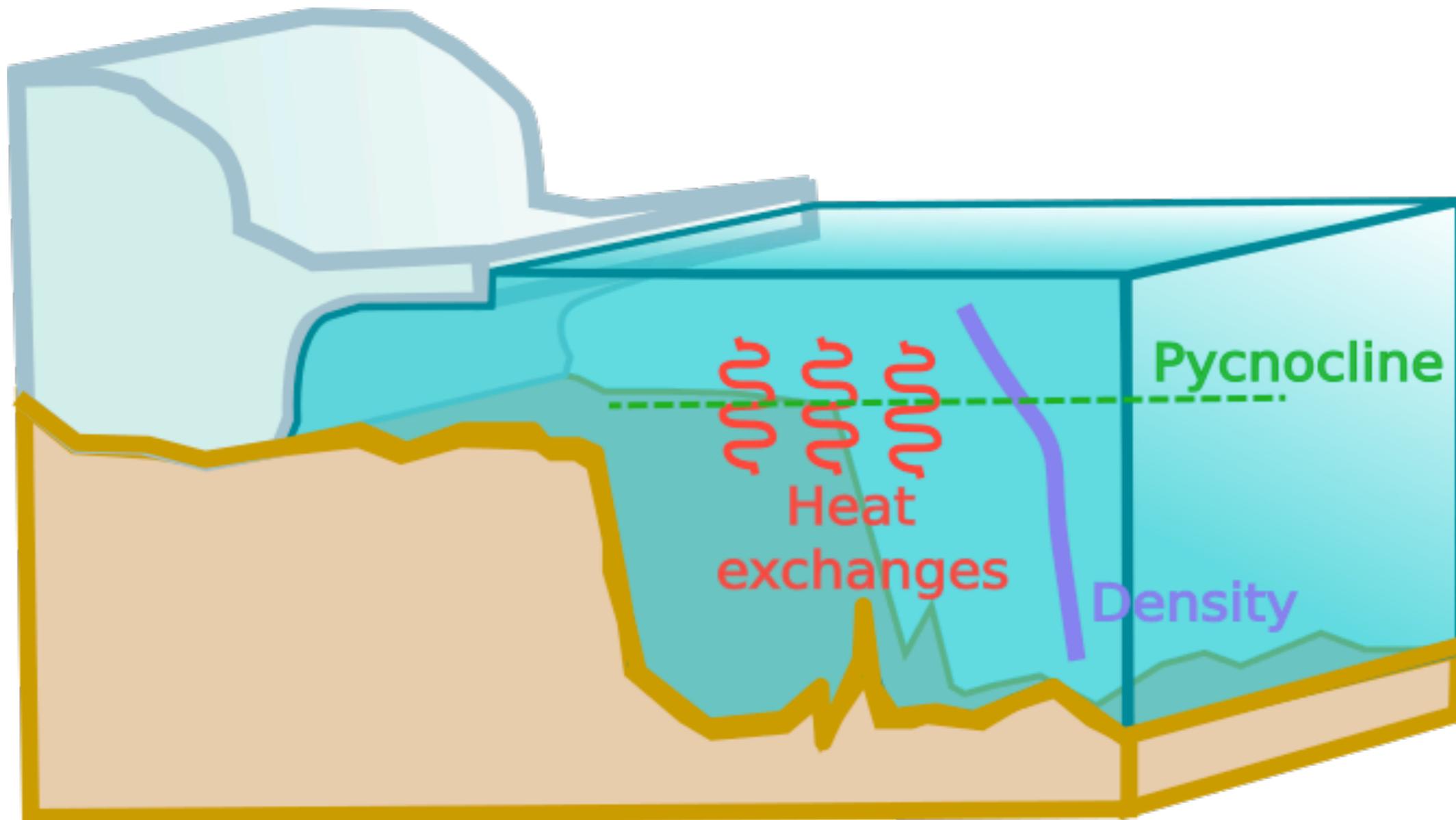


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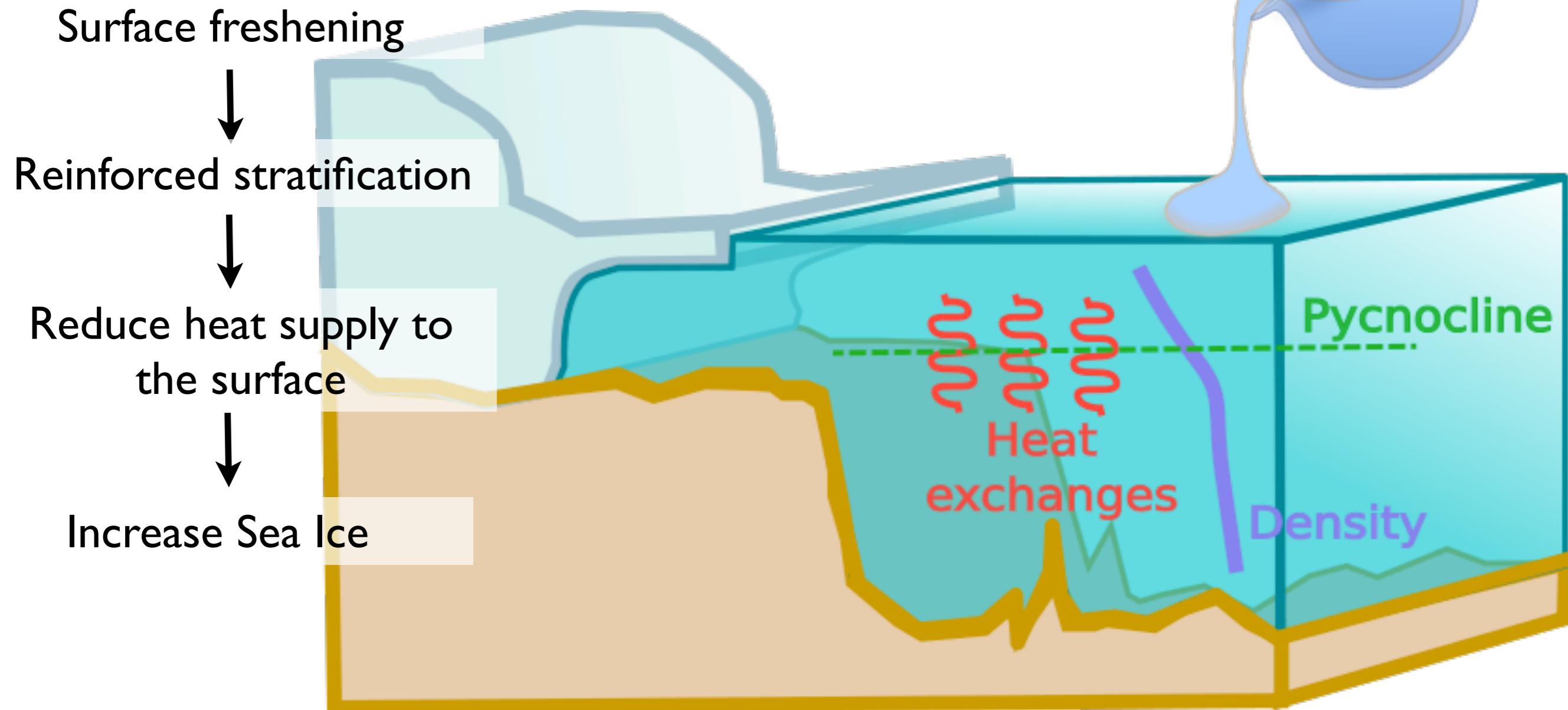
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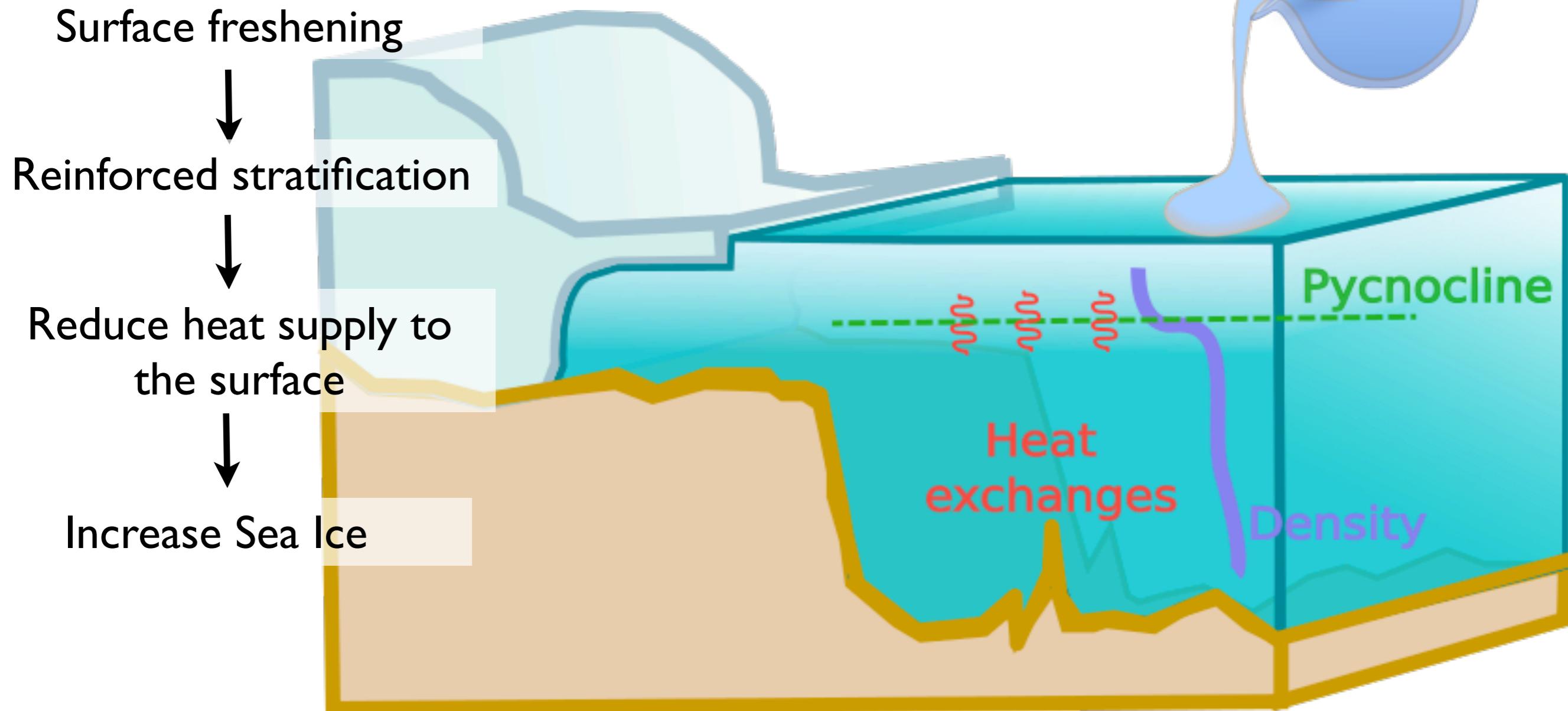
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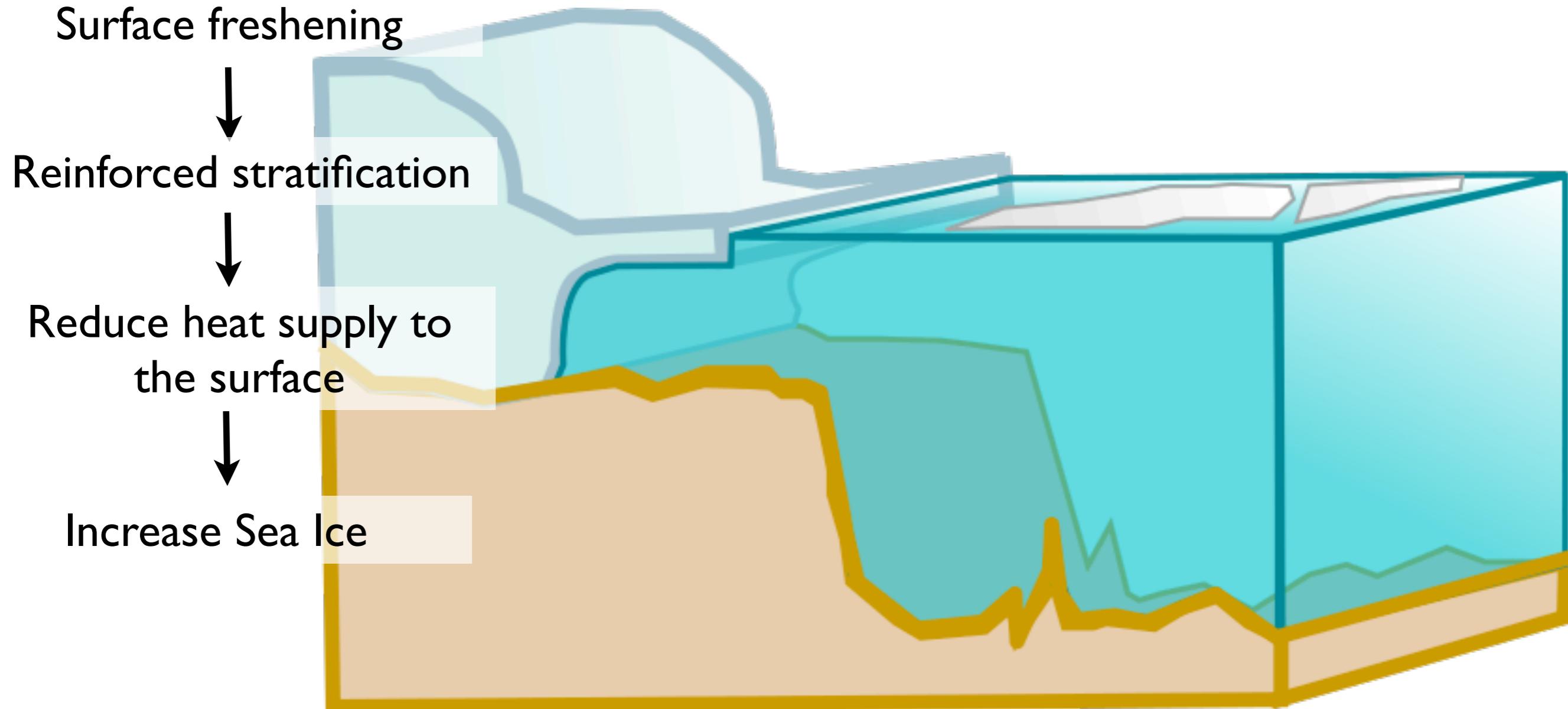
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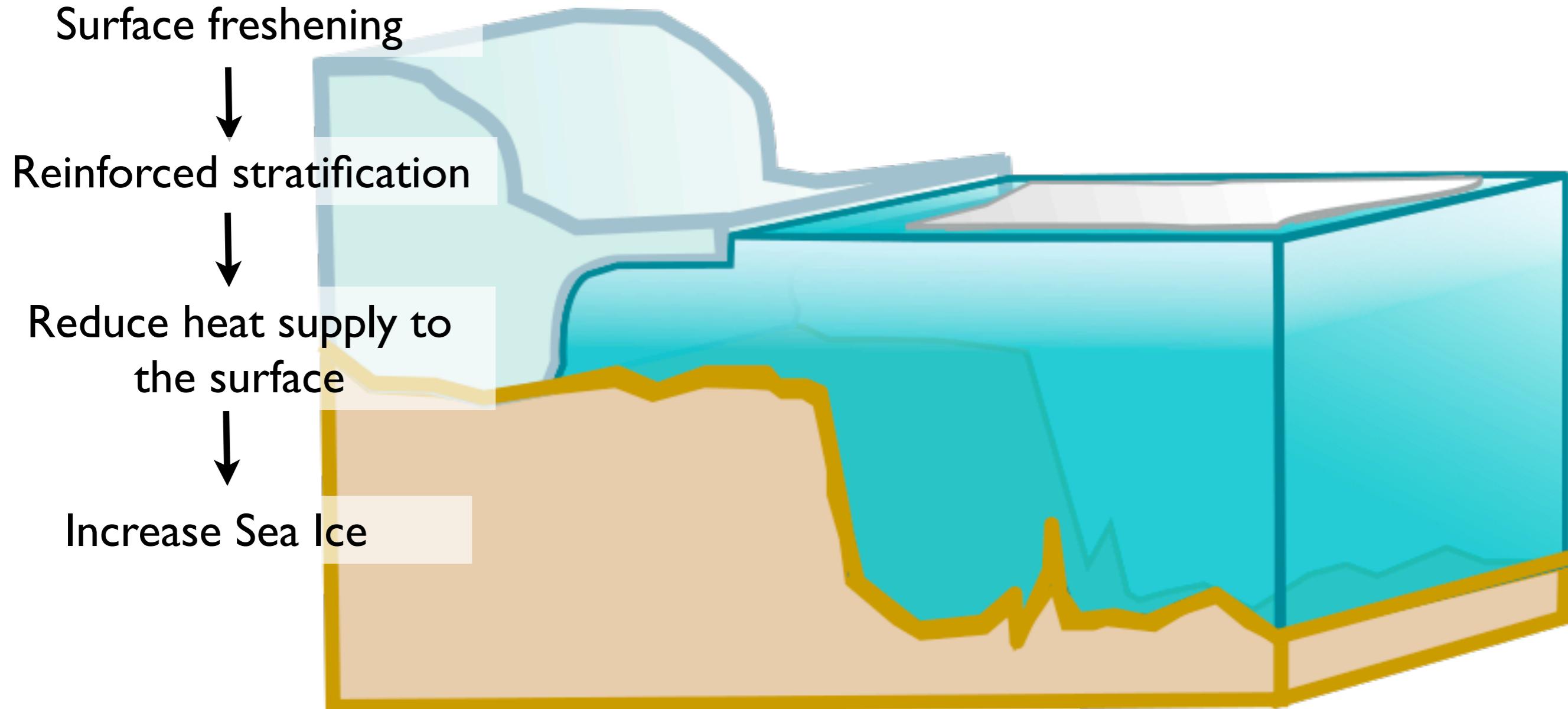
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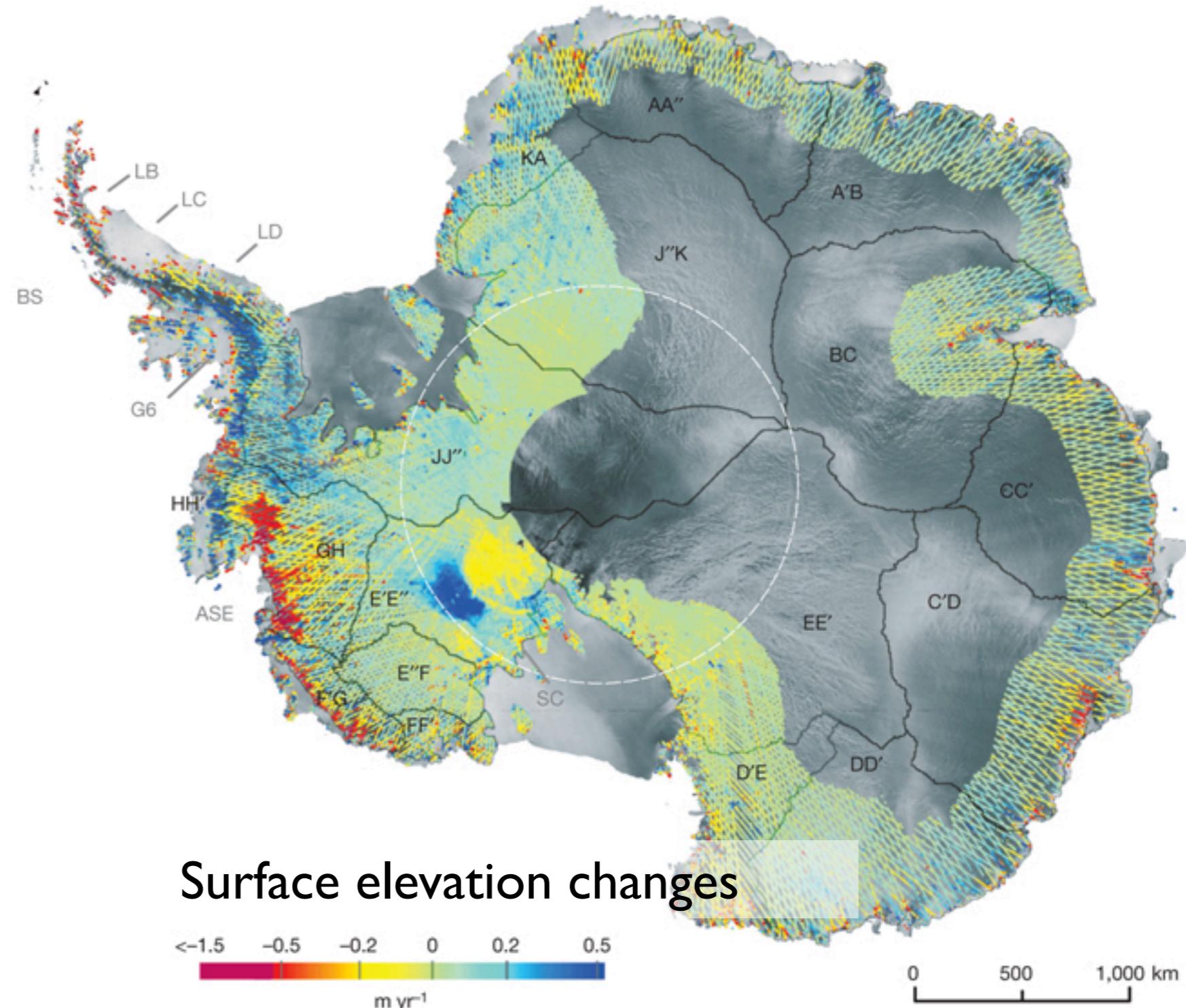
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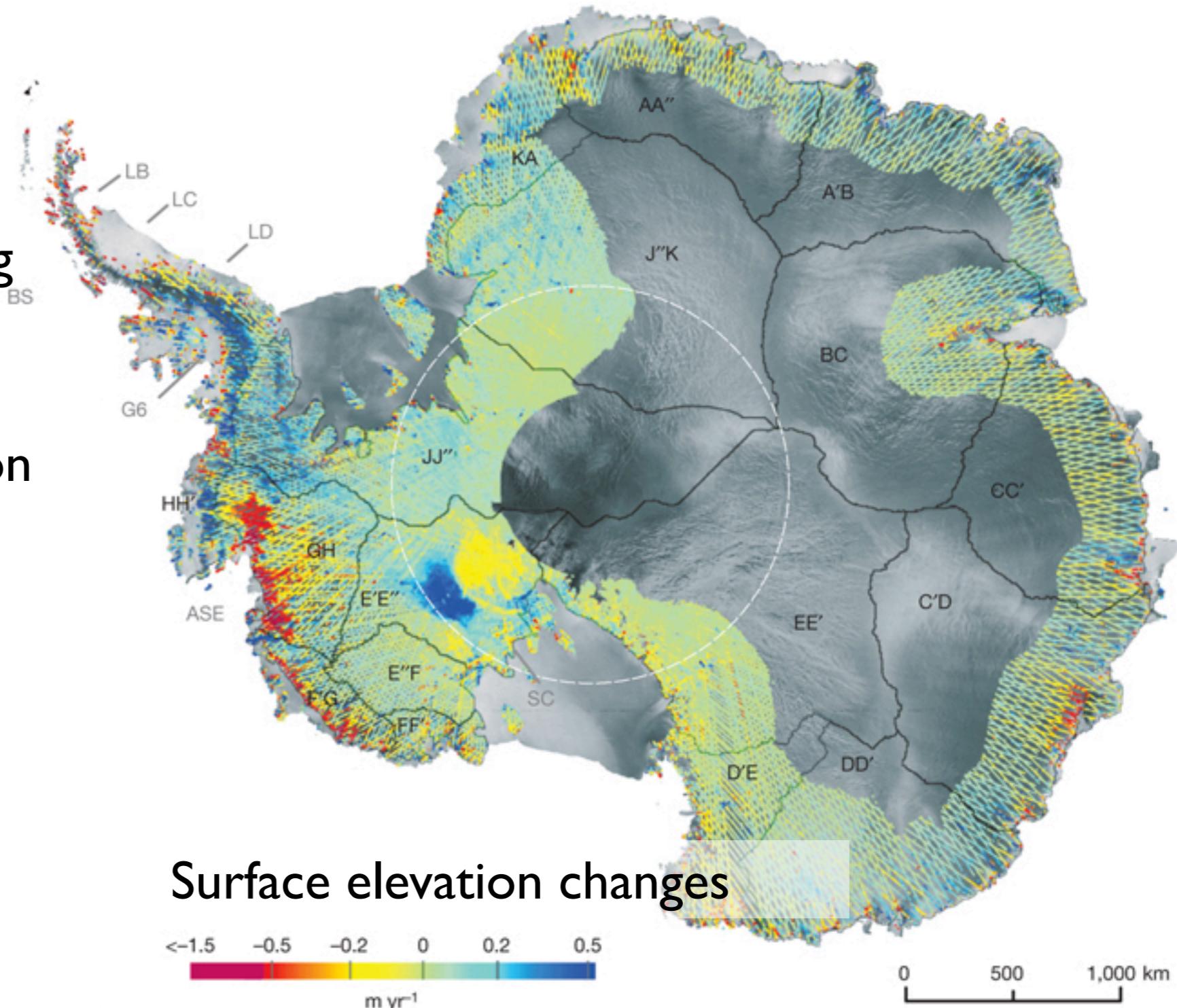
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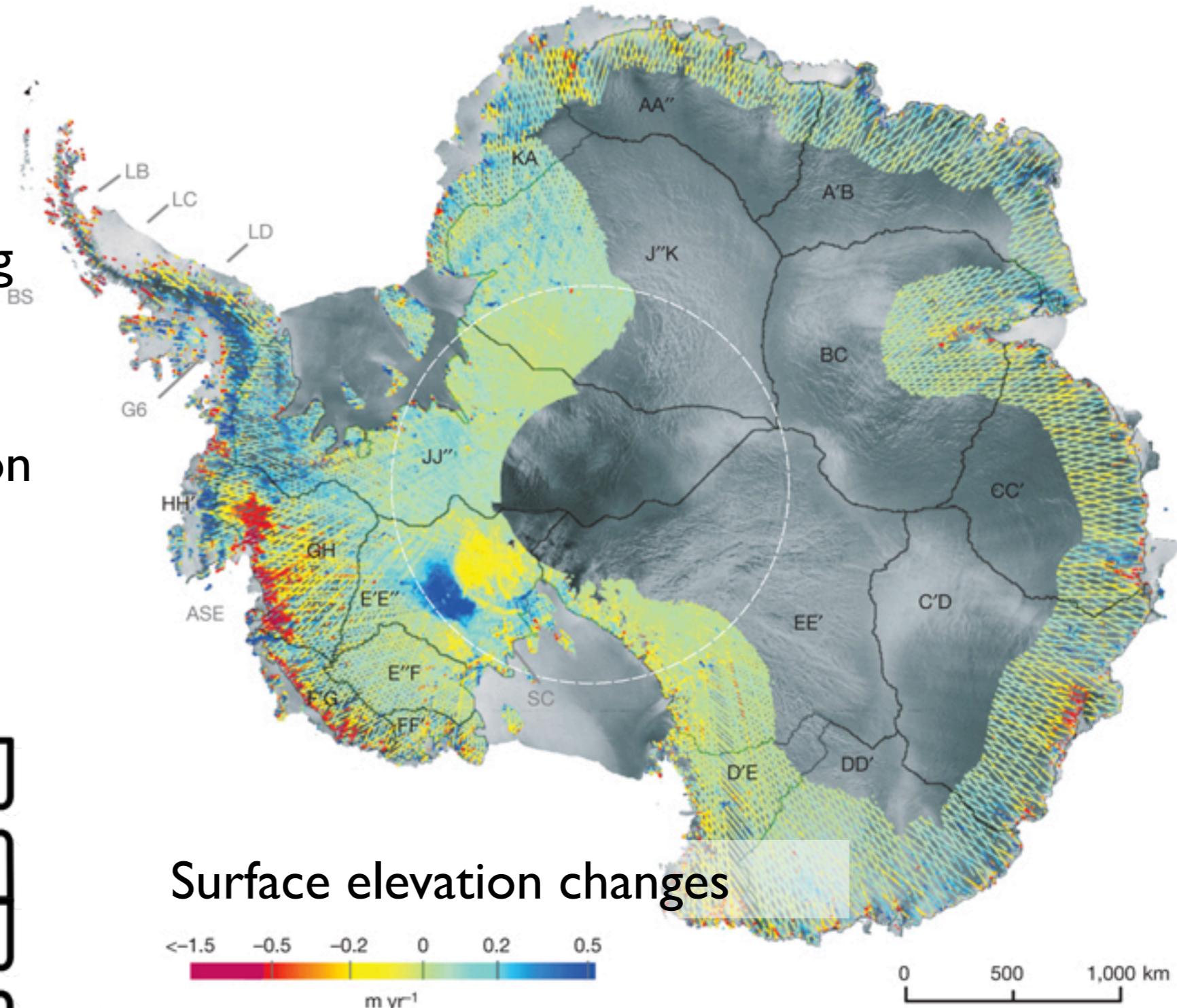
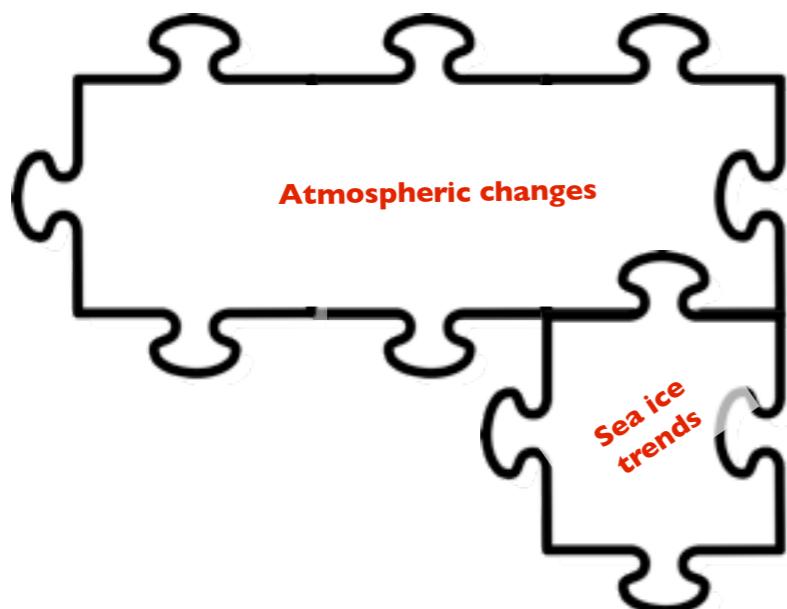
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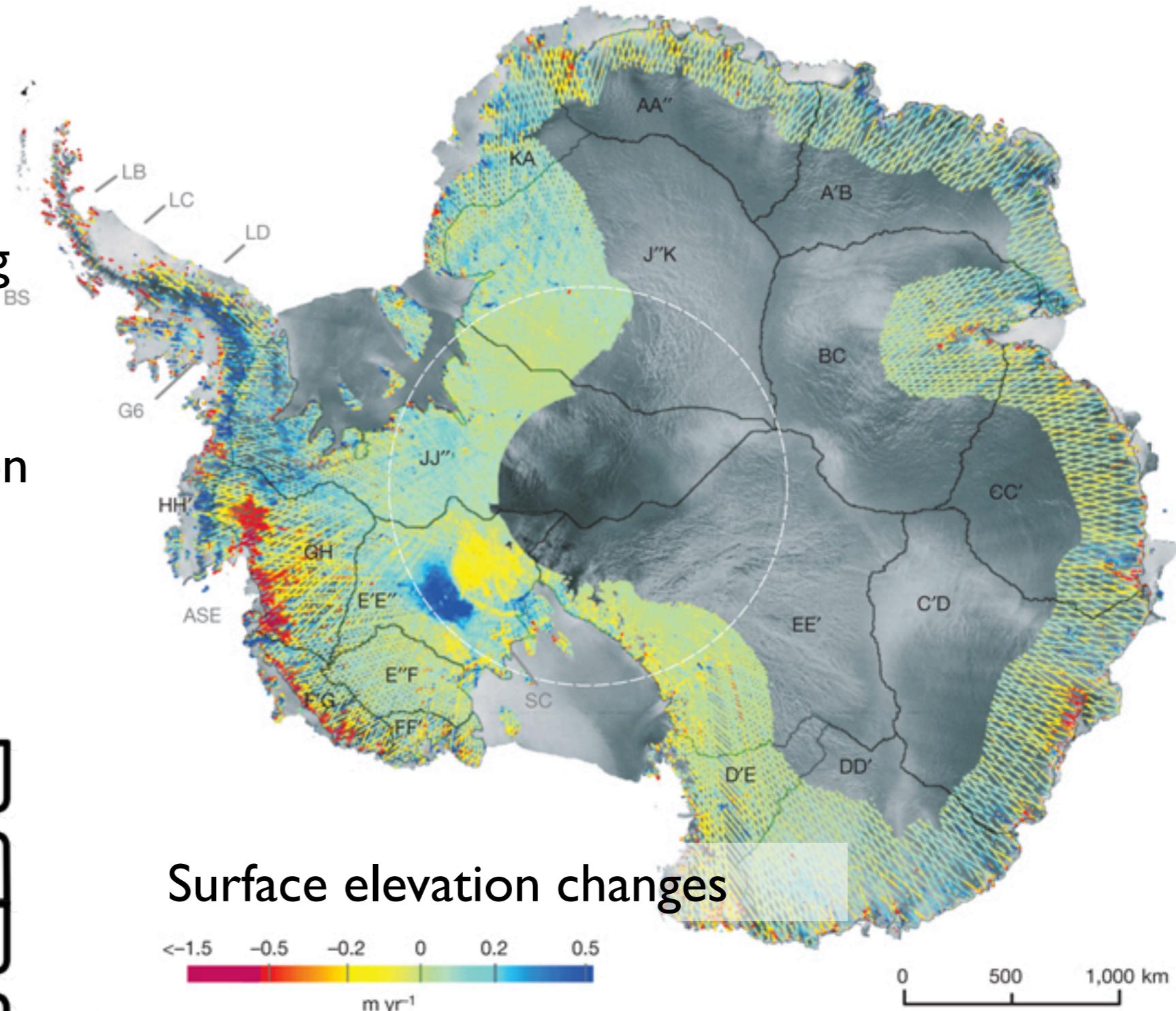
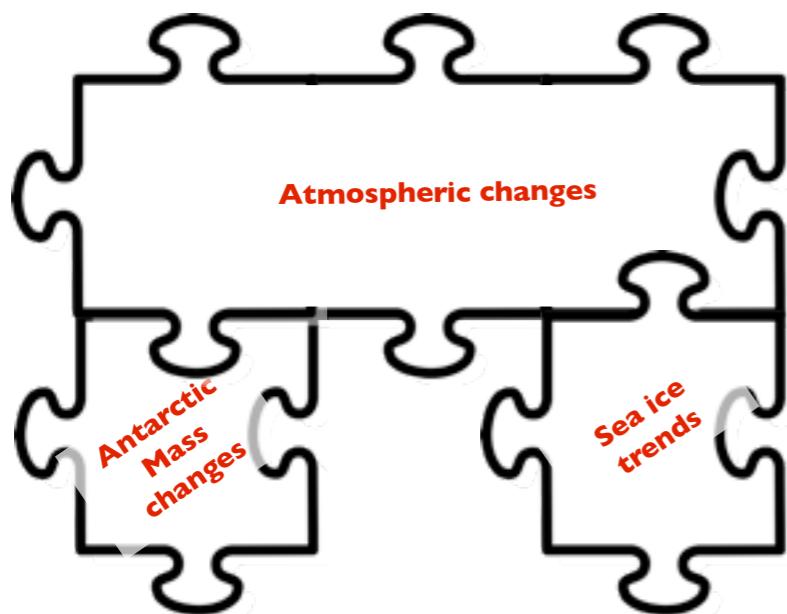
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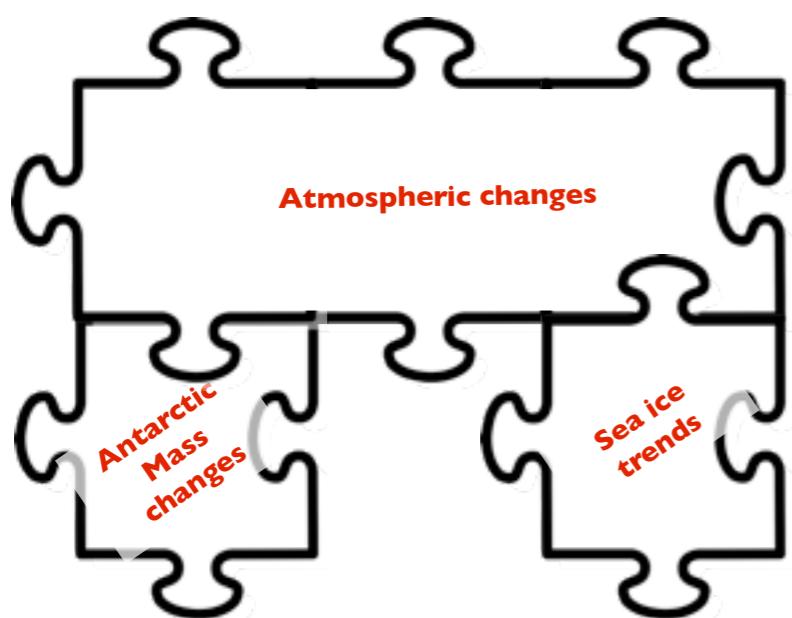
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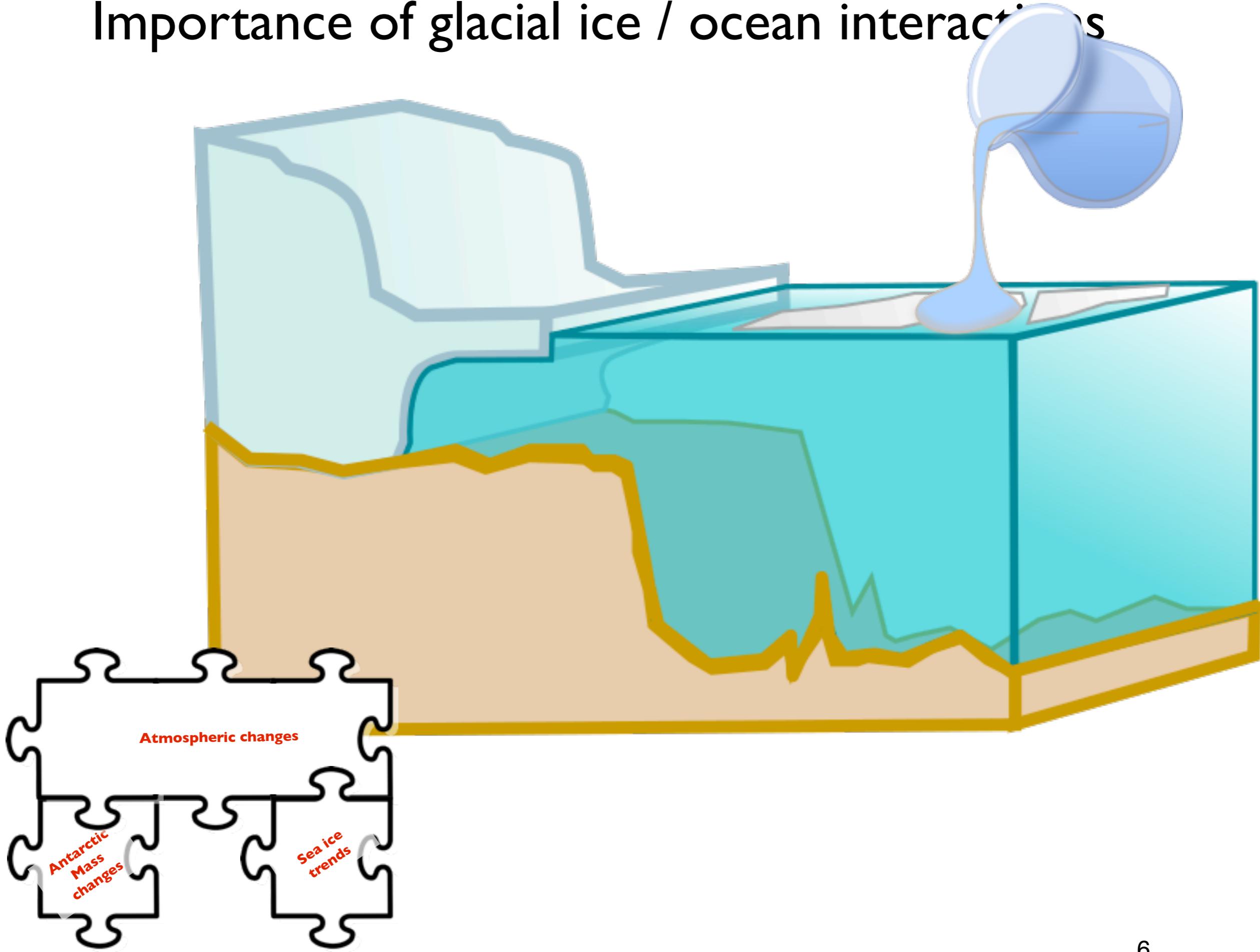


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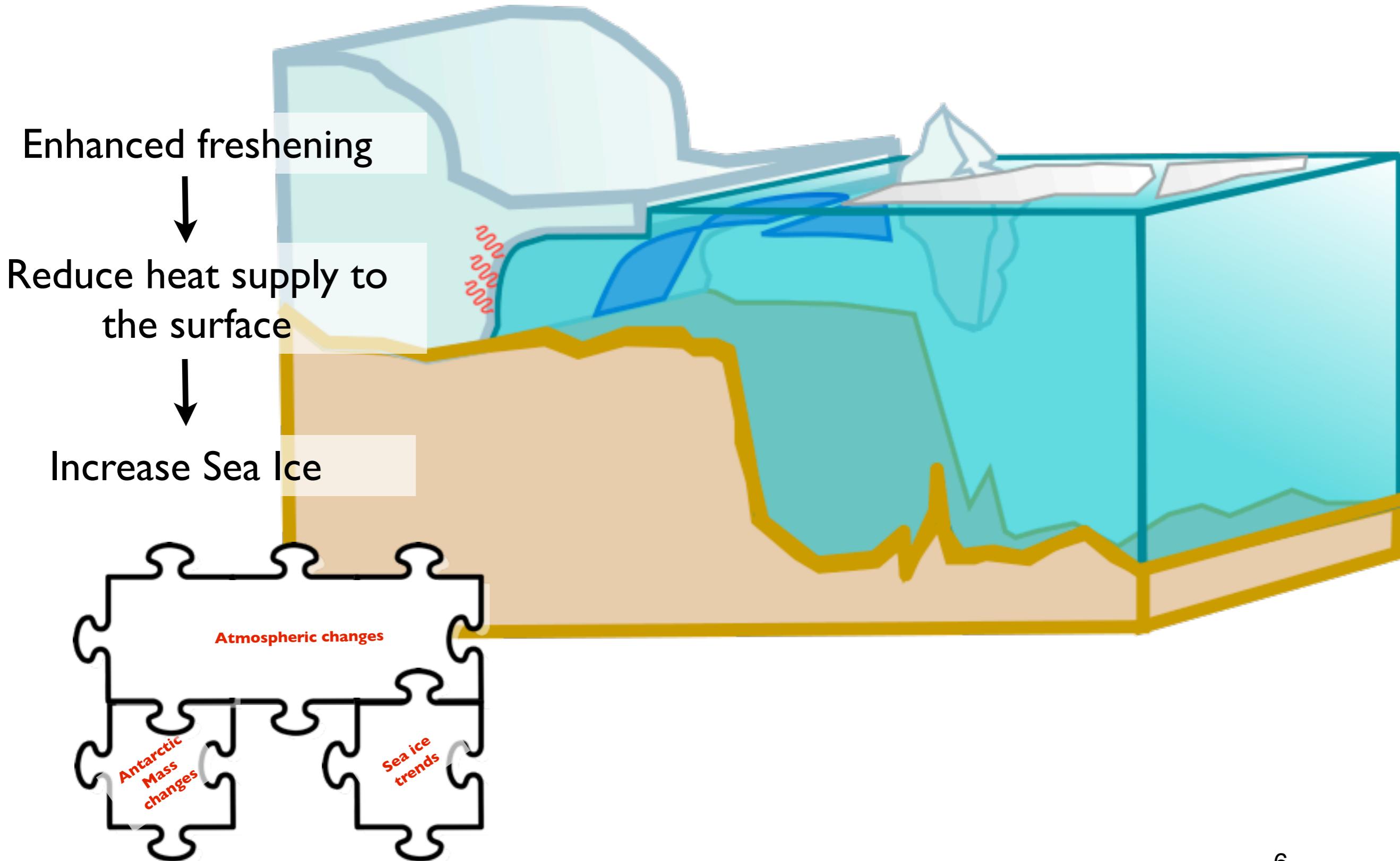
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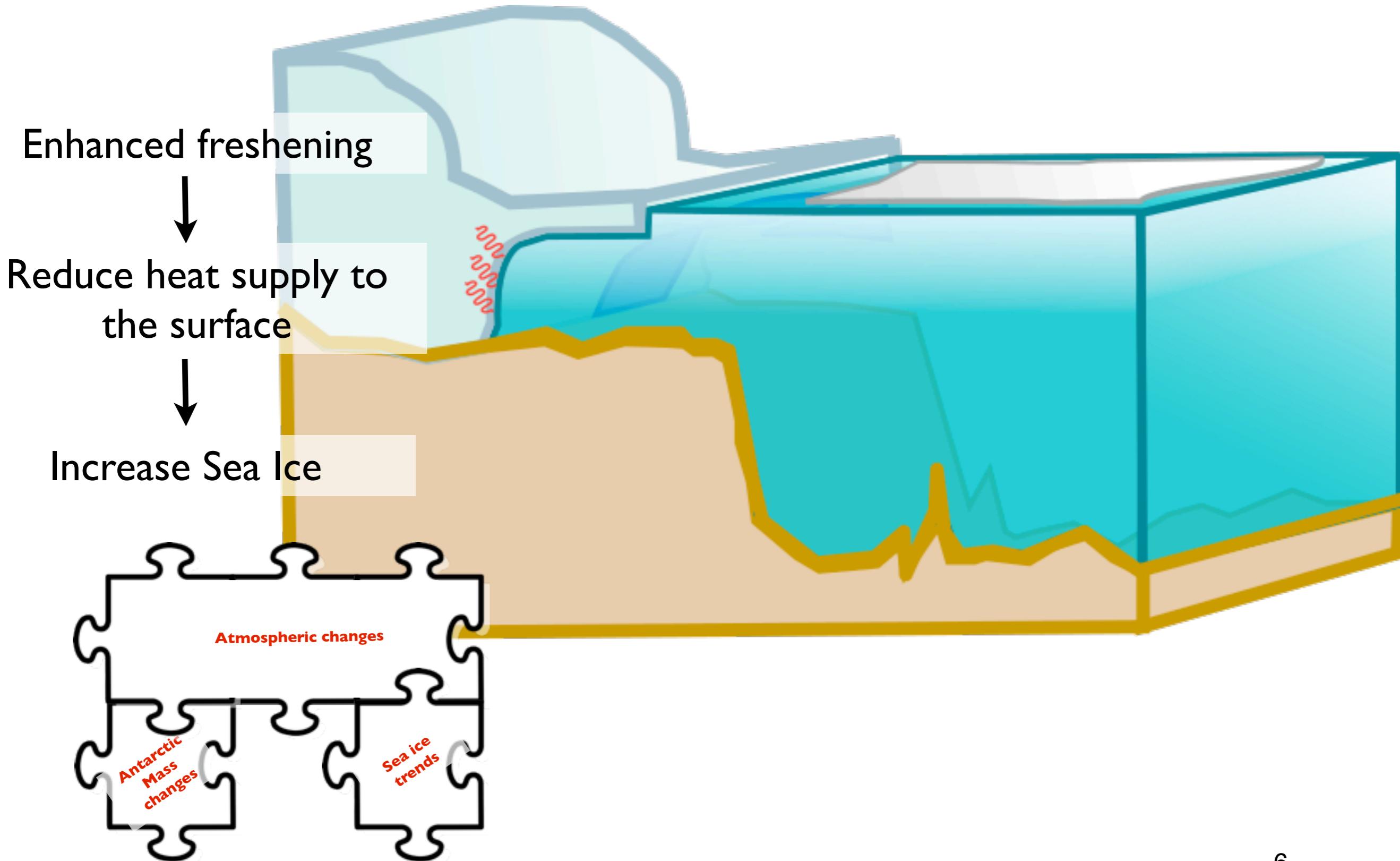
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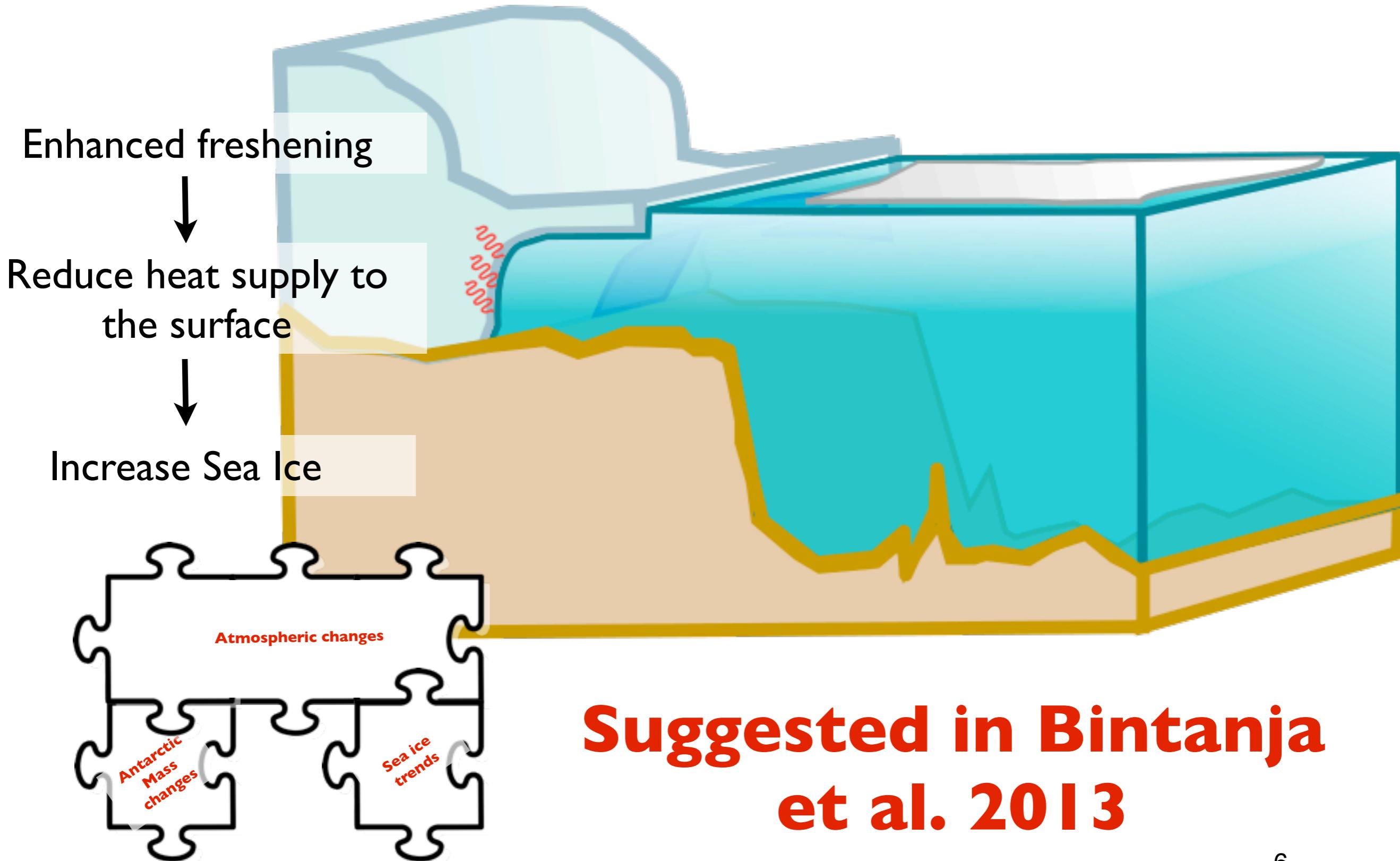
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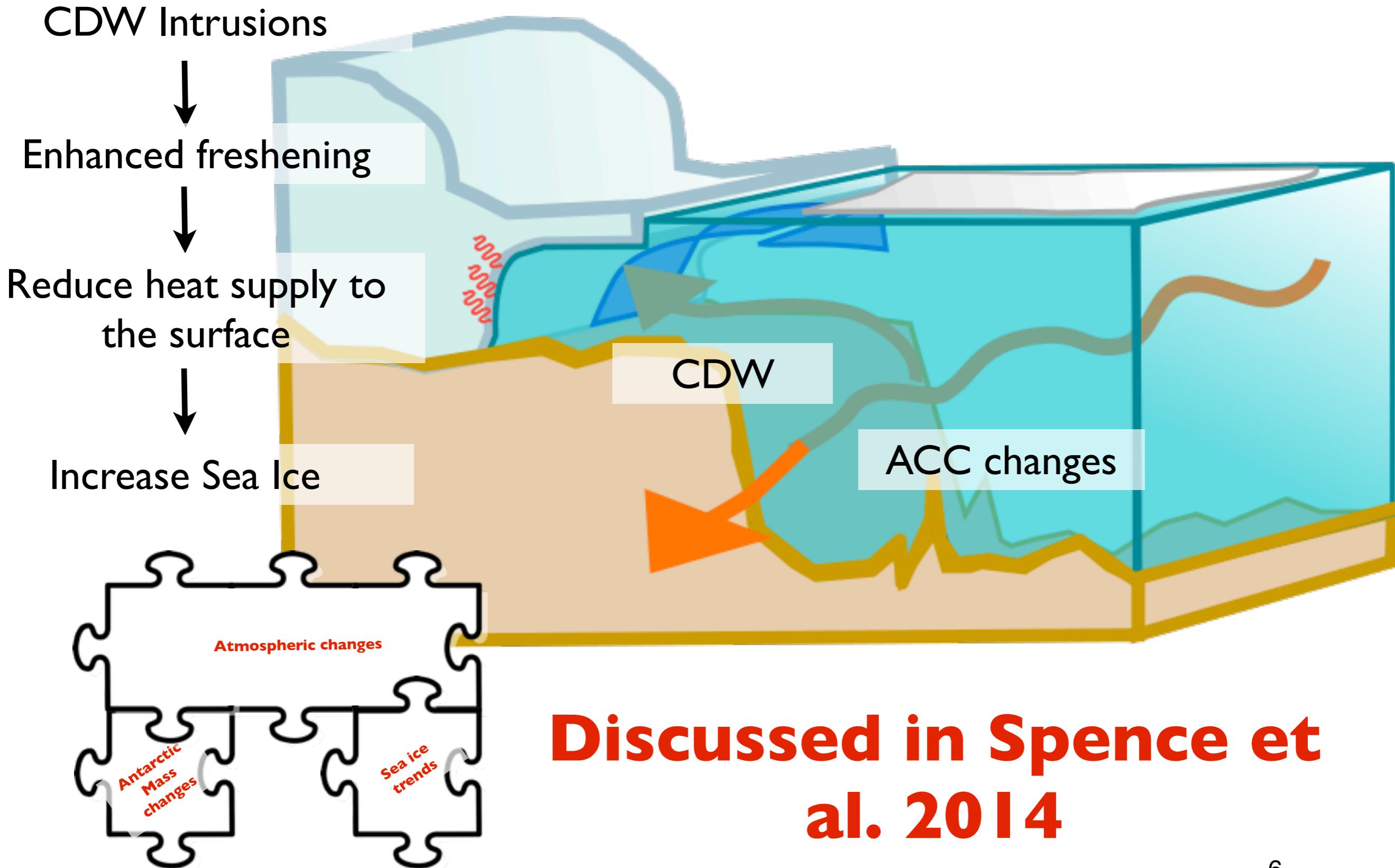
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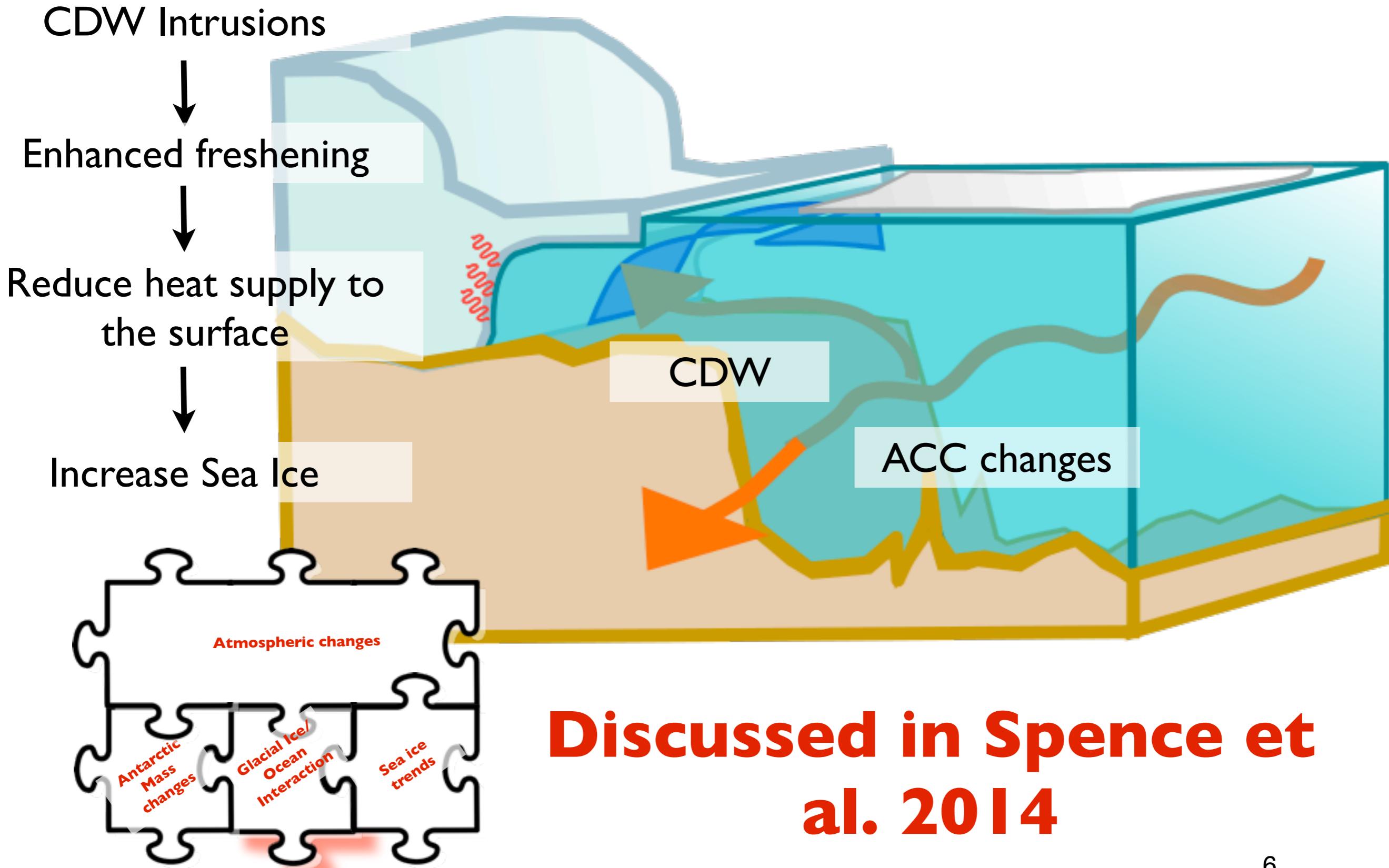
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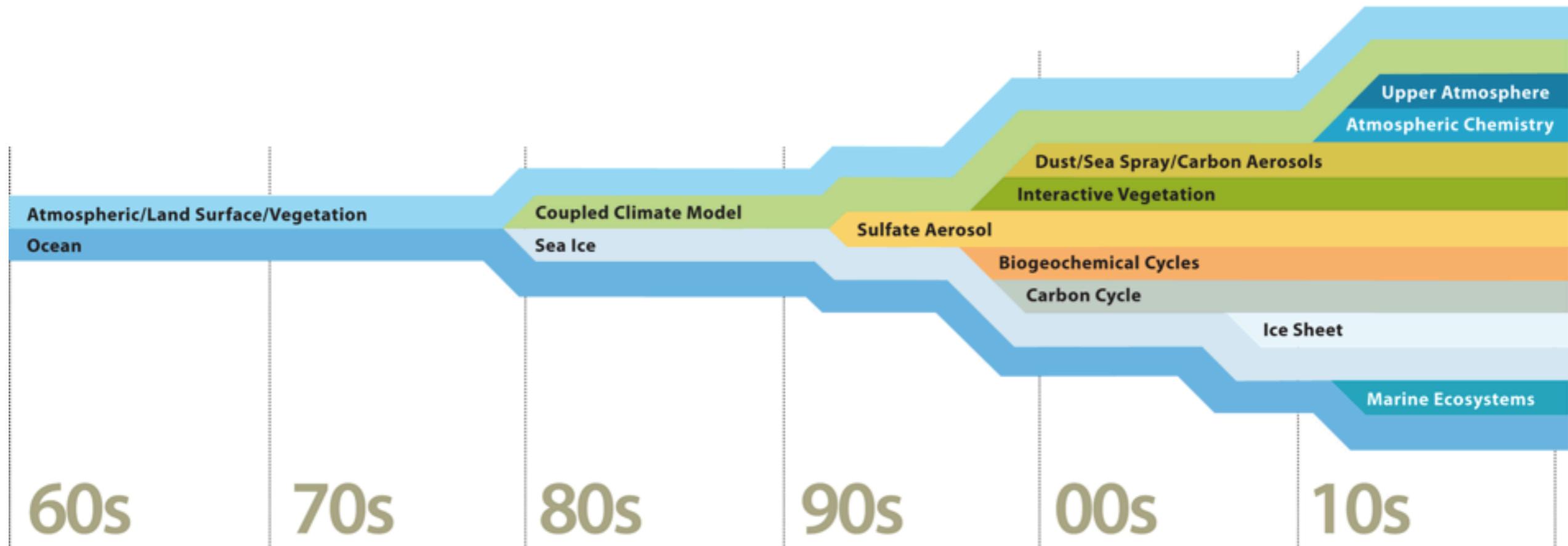
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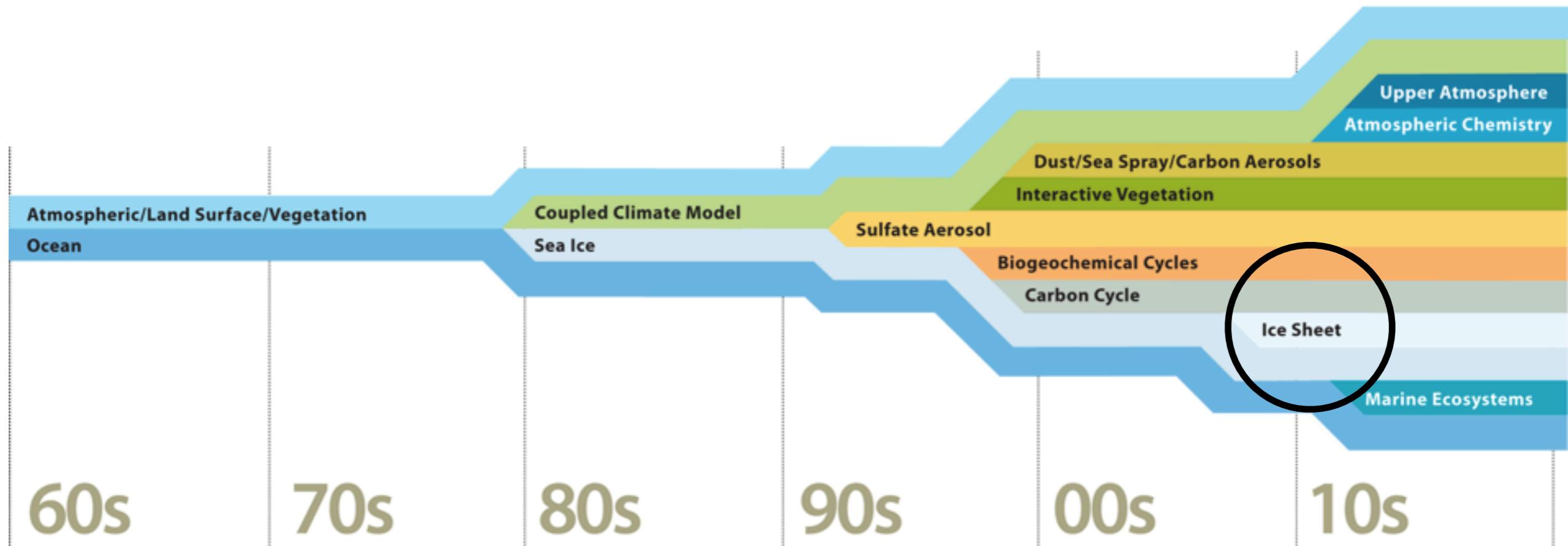


# Ice Sheet representation in Earth system models



source: UCAR

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**Oncoming climate models will solve explicitly ice sheet dynamics and ice-sheet/ocean coupling**

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PUBLISHED ONLINE: 31 MARCH 2013 | DOI:10.1038/NGEO1767

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GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 4328–4332, doi:10.1002/grl.50820, 2013

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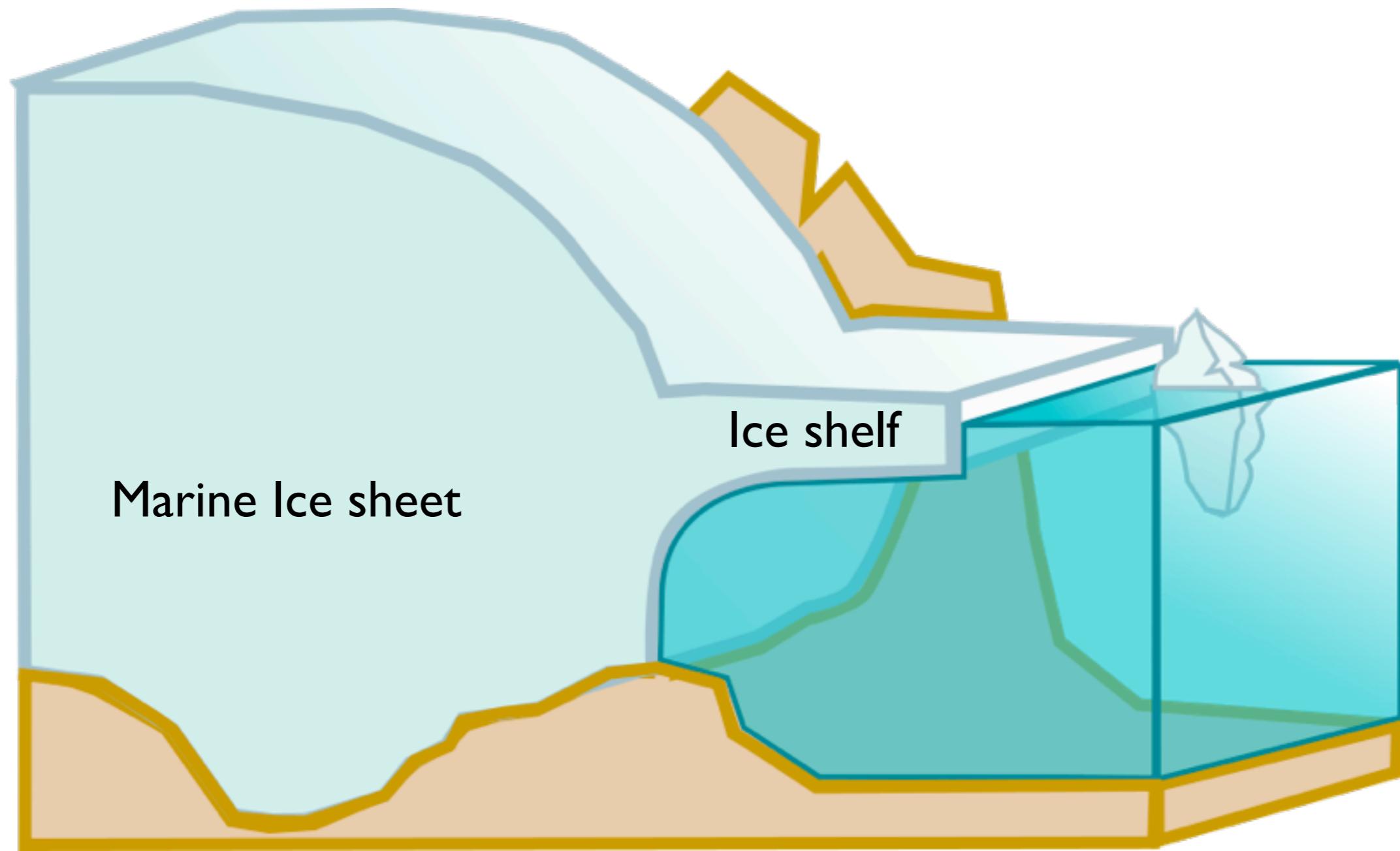
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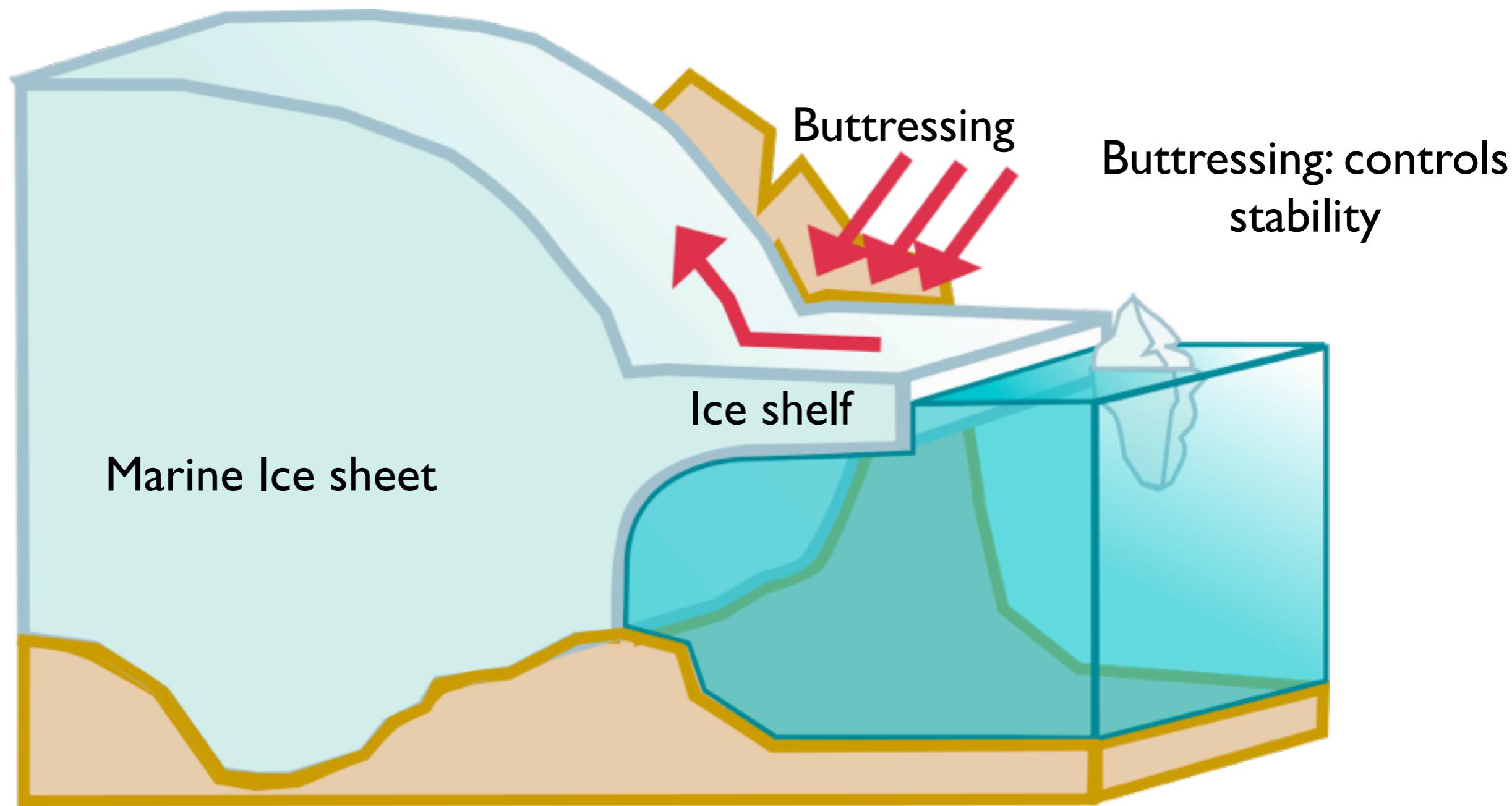
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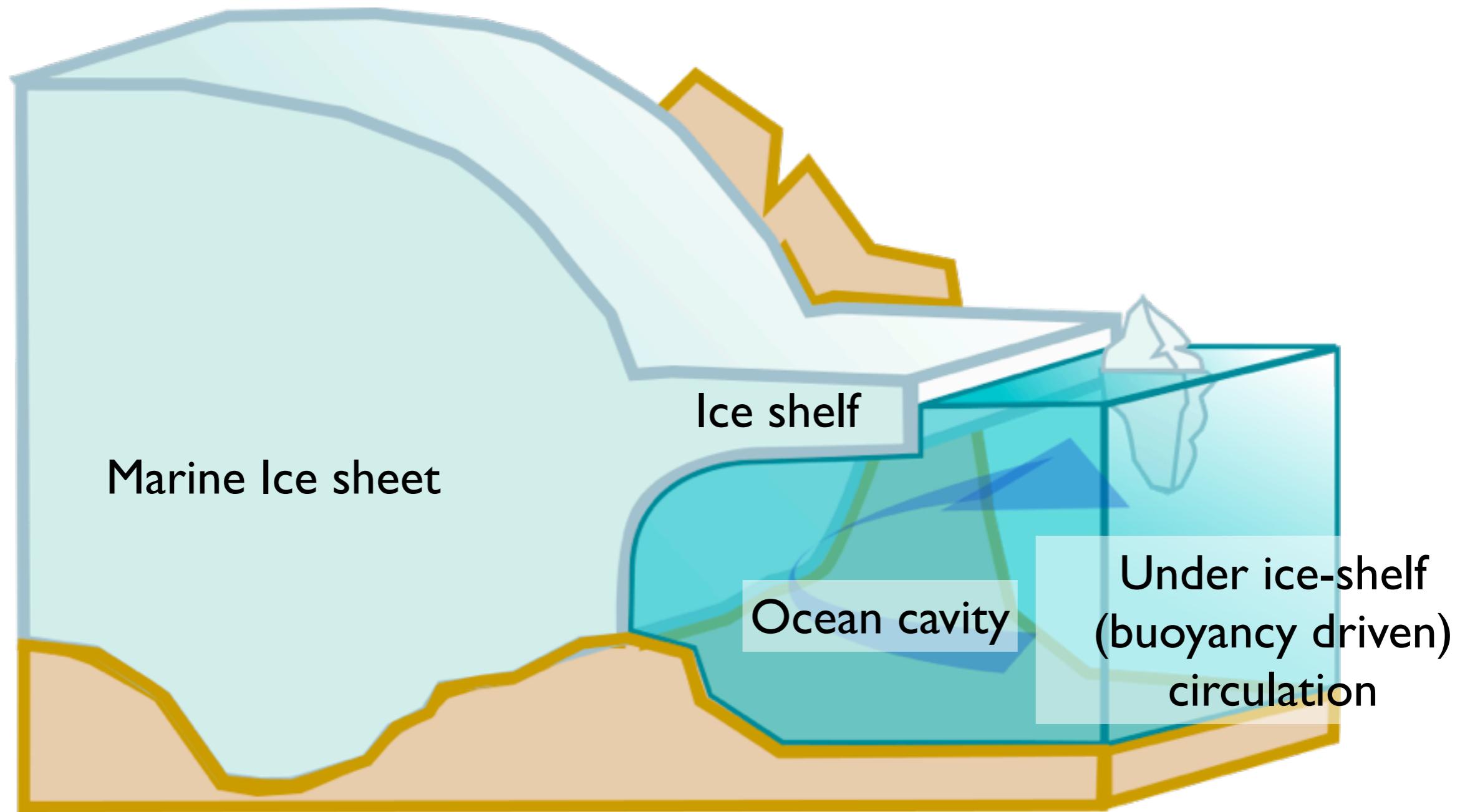
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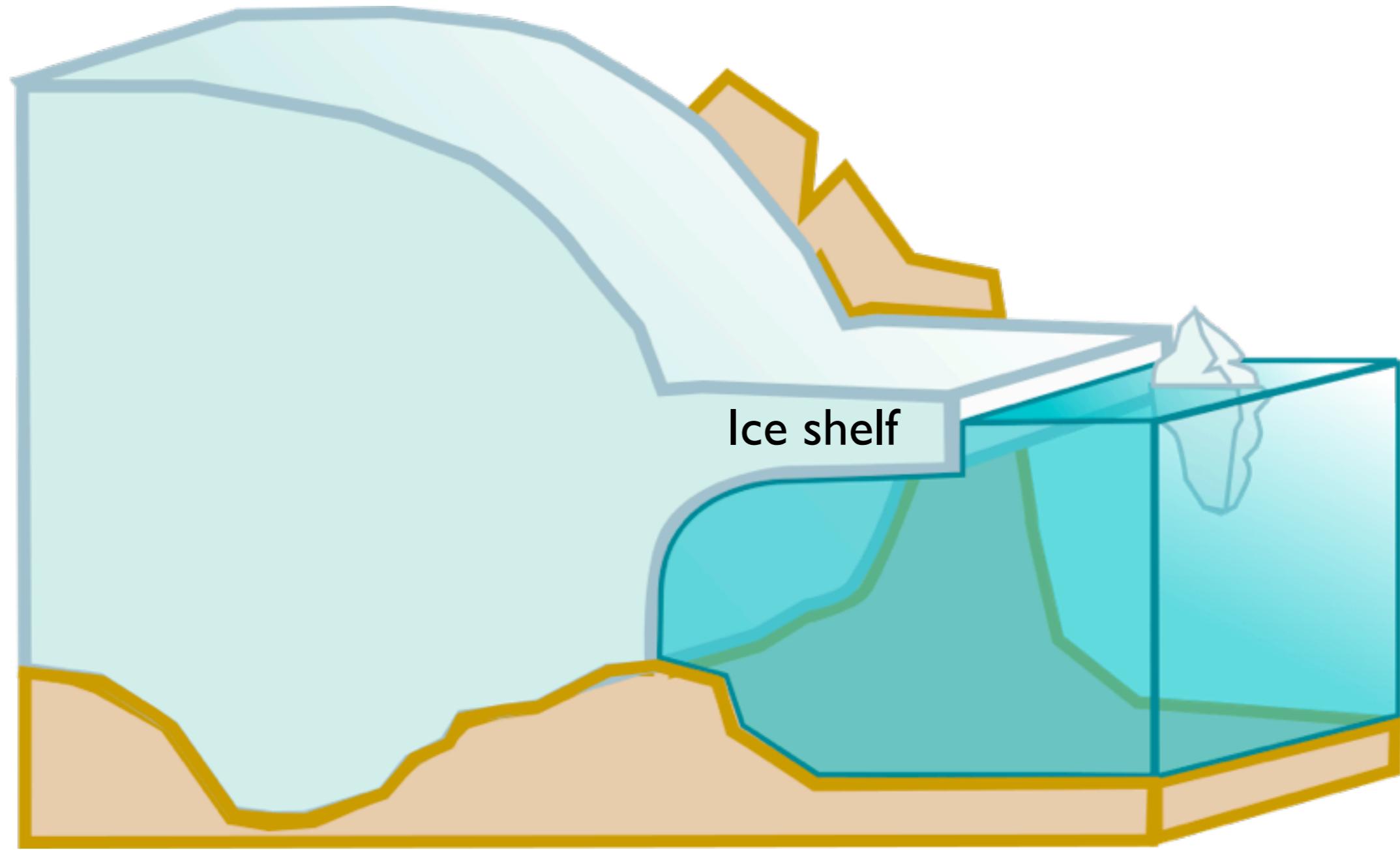
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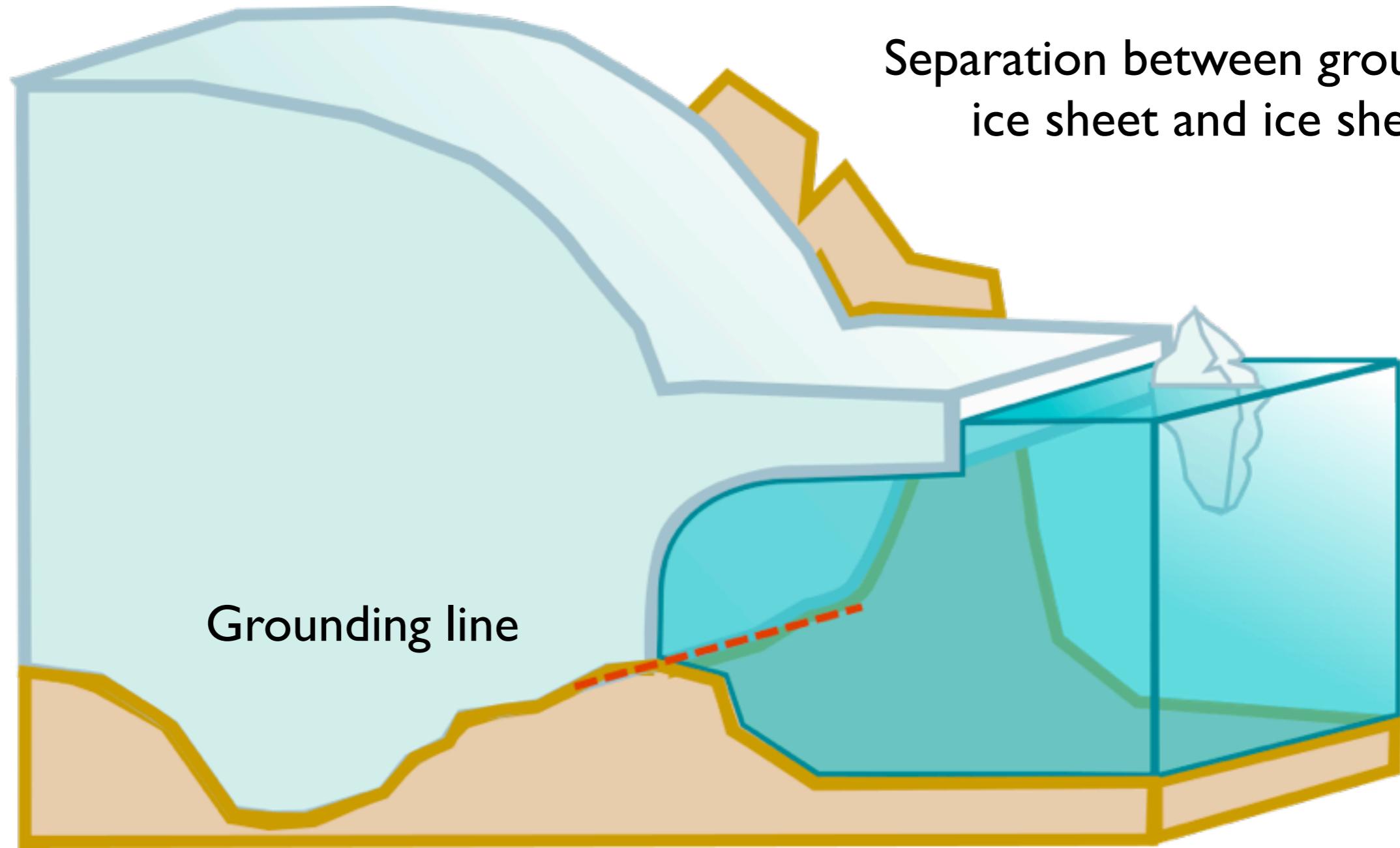
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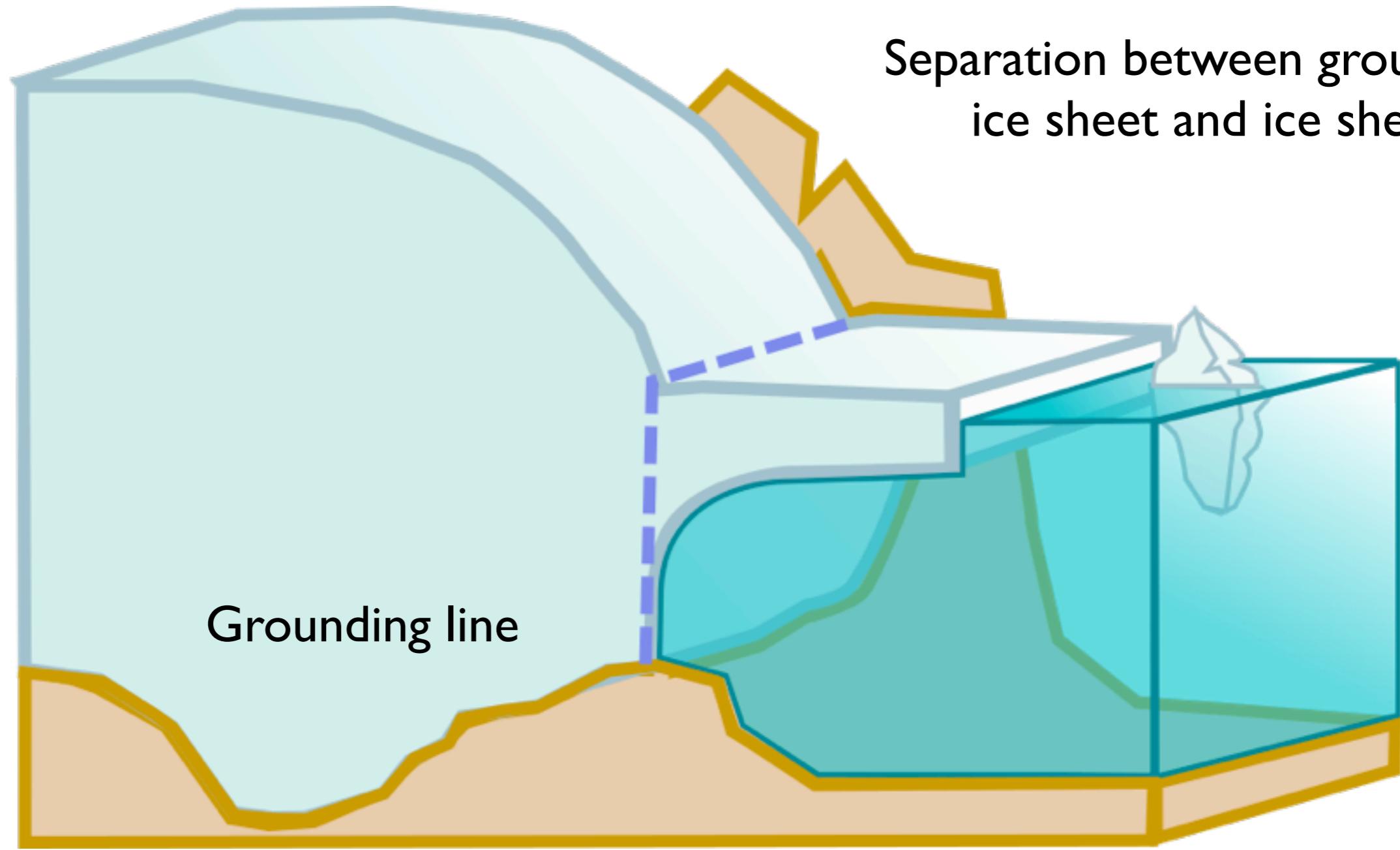
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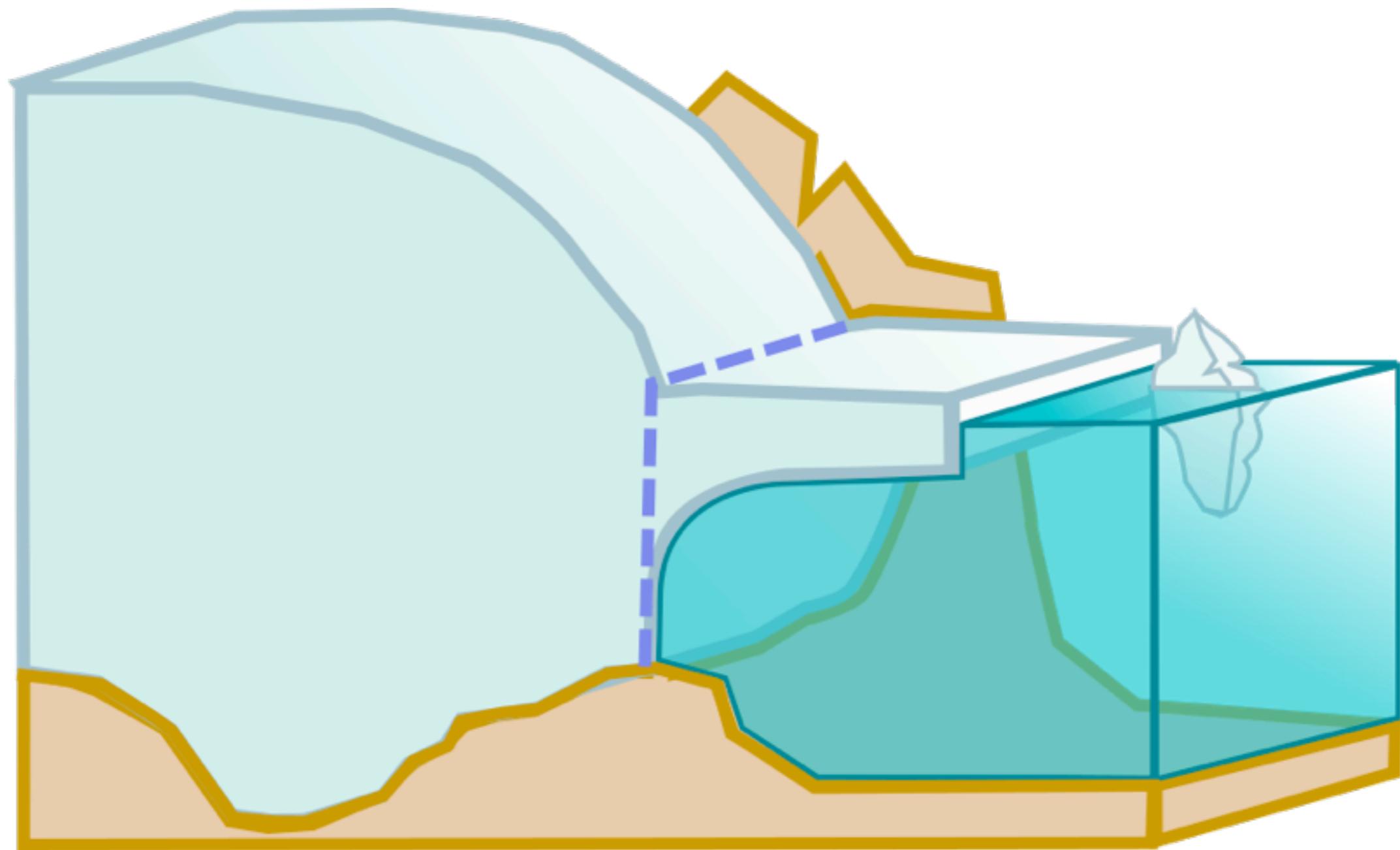


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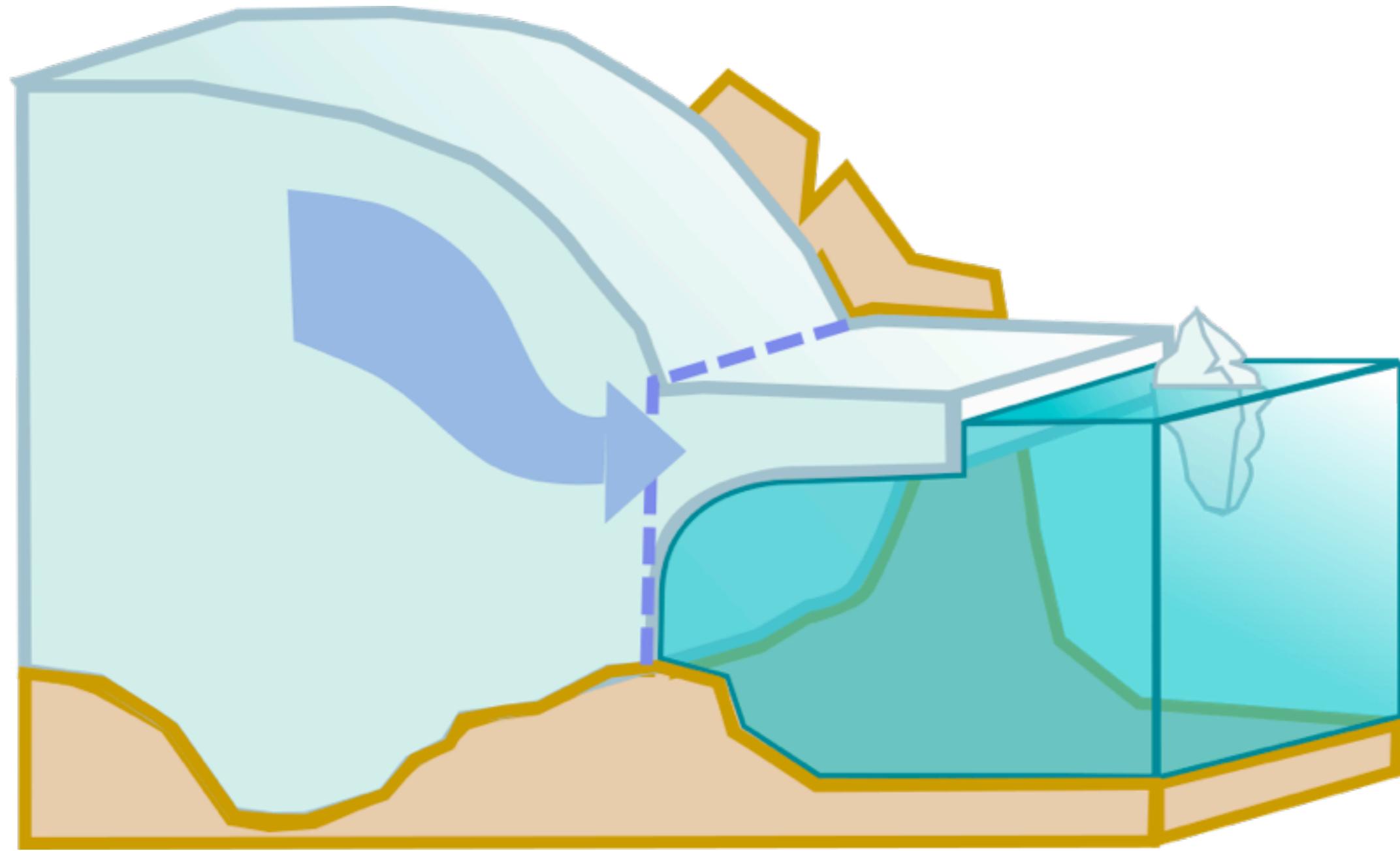
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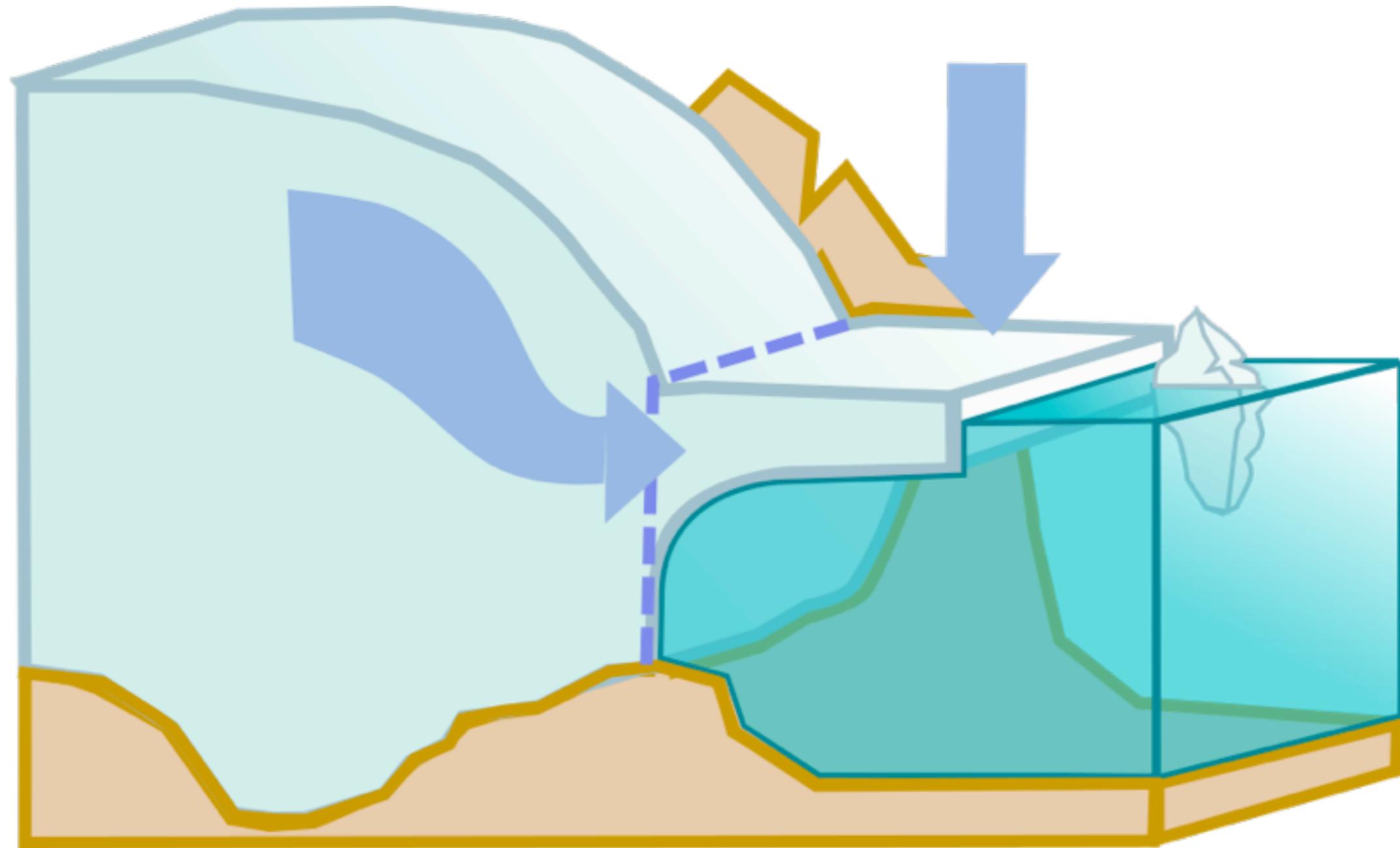


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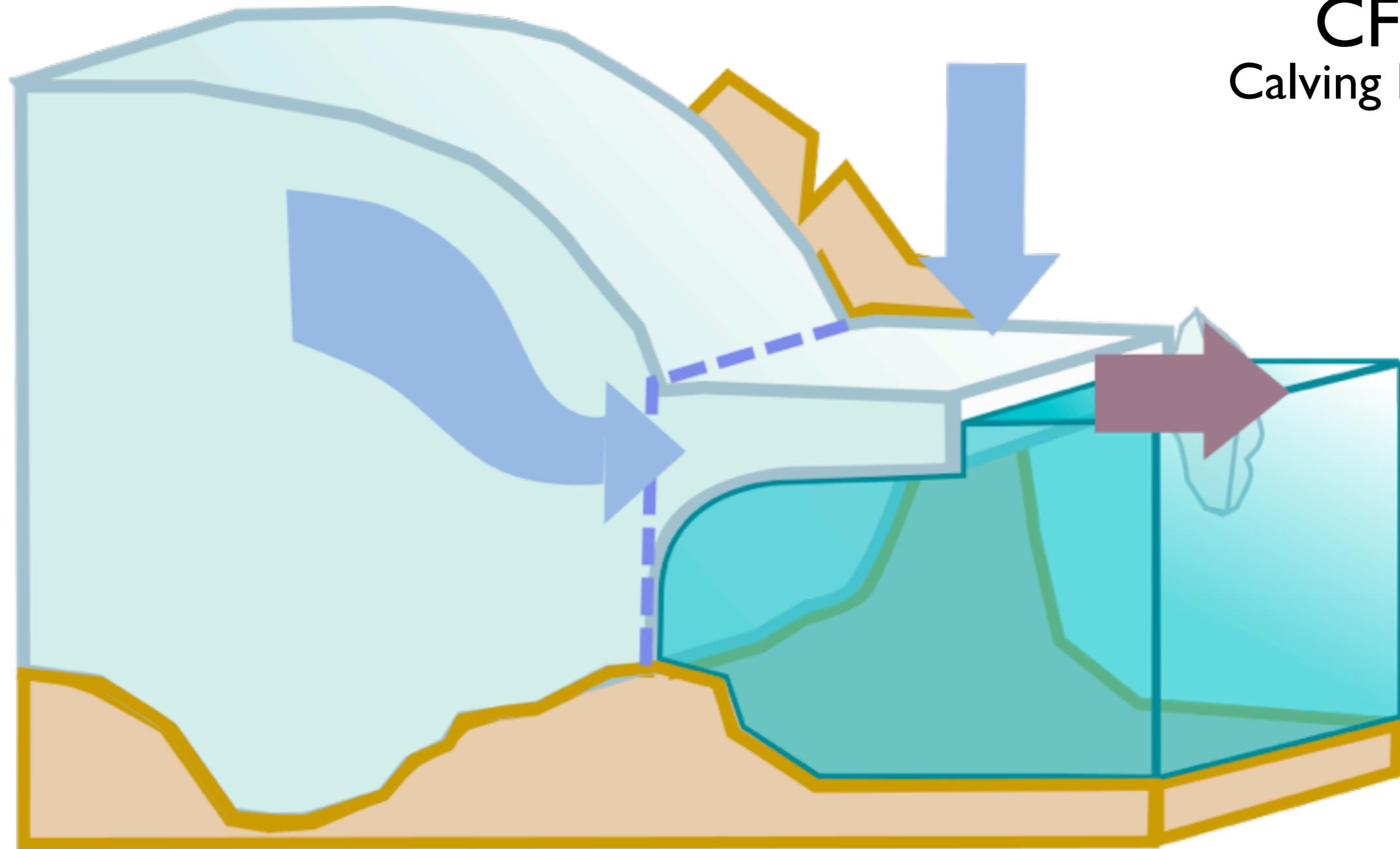
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Calving Flux



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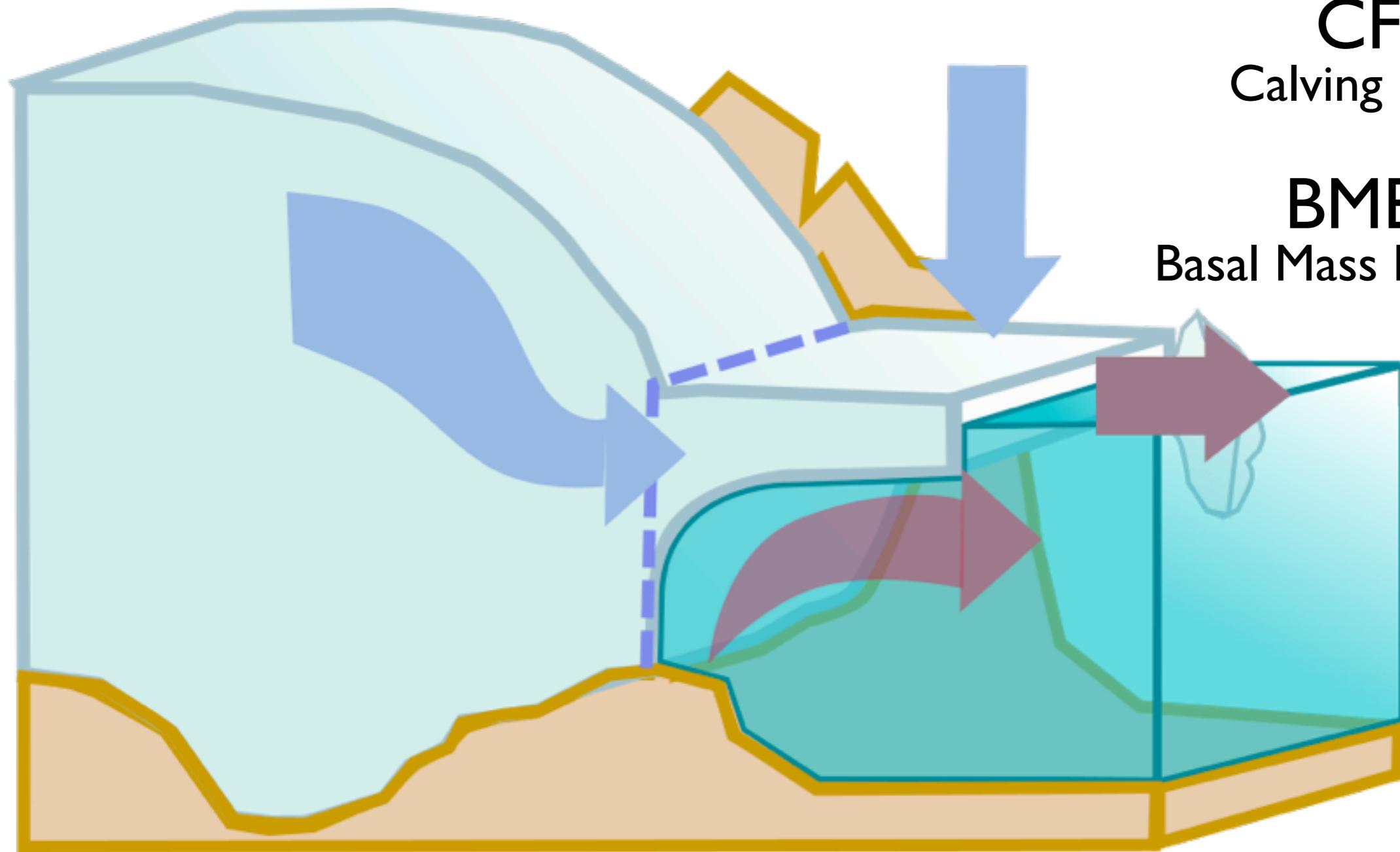
Surface Mass Balance

**CF**

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Basal Mass Balance



# Some definitions ...

**GLF**

Grounding line Flux

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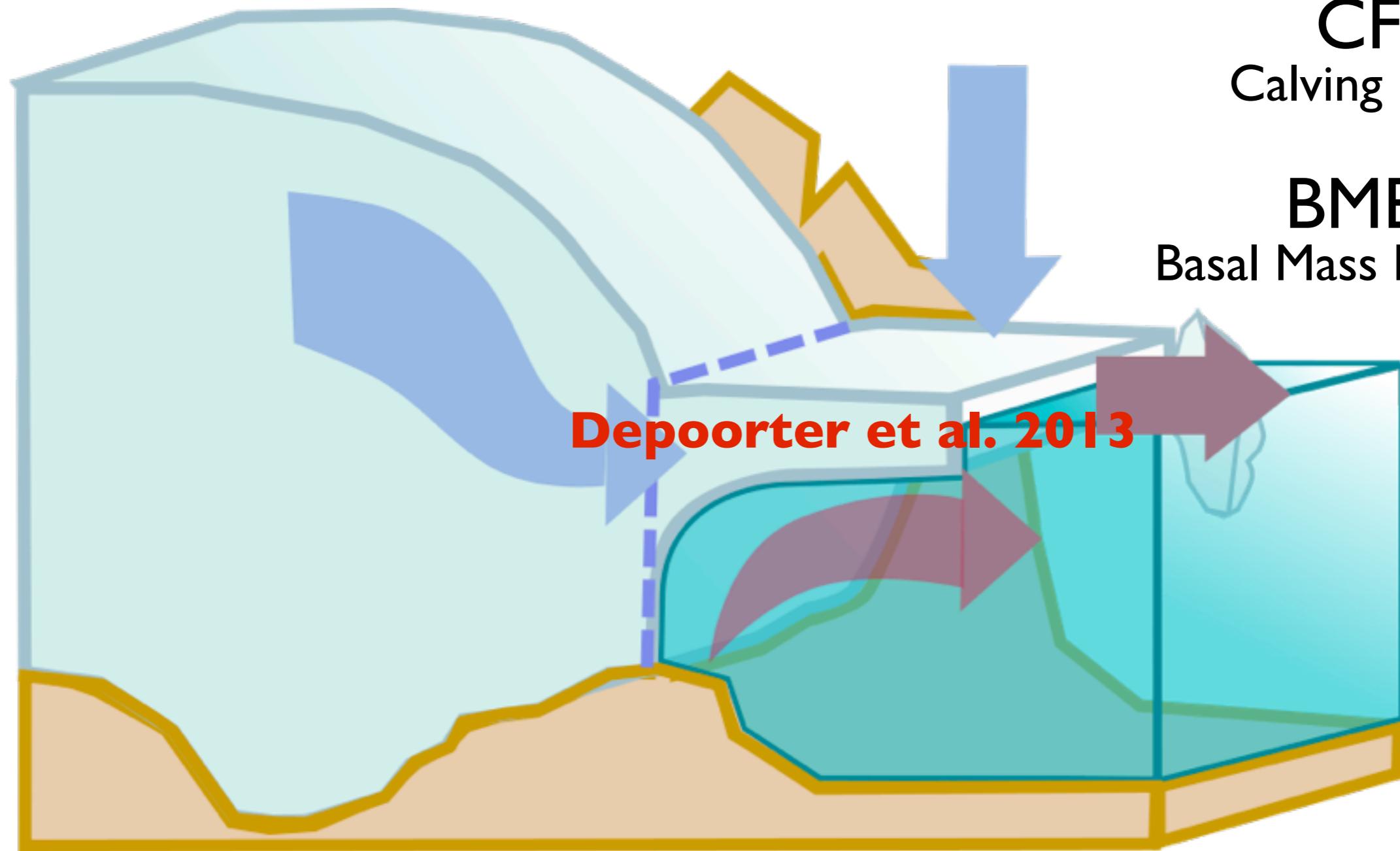
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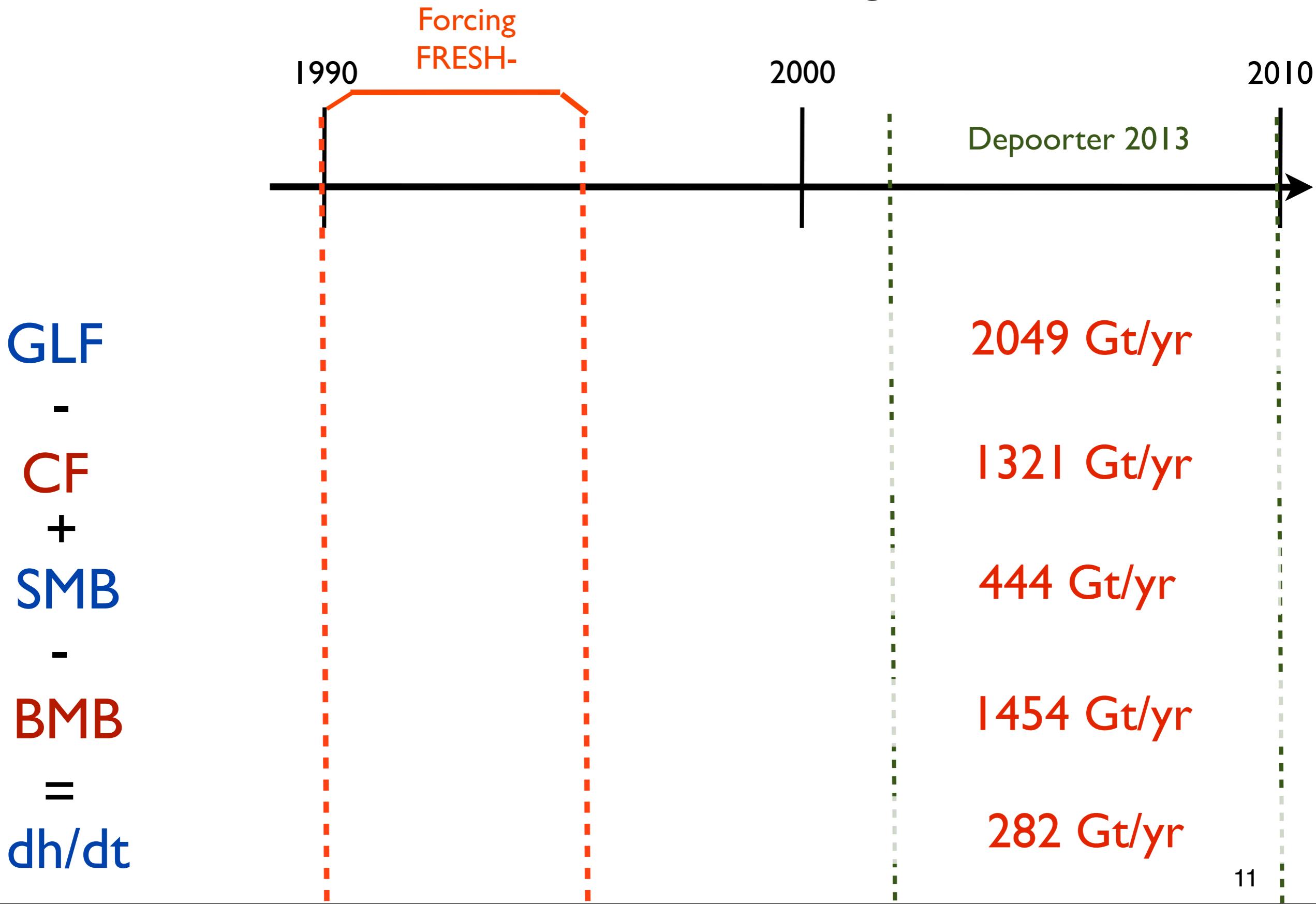
#|

# Observationally-constrained perturbations of glacial freshwater forcing.



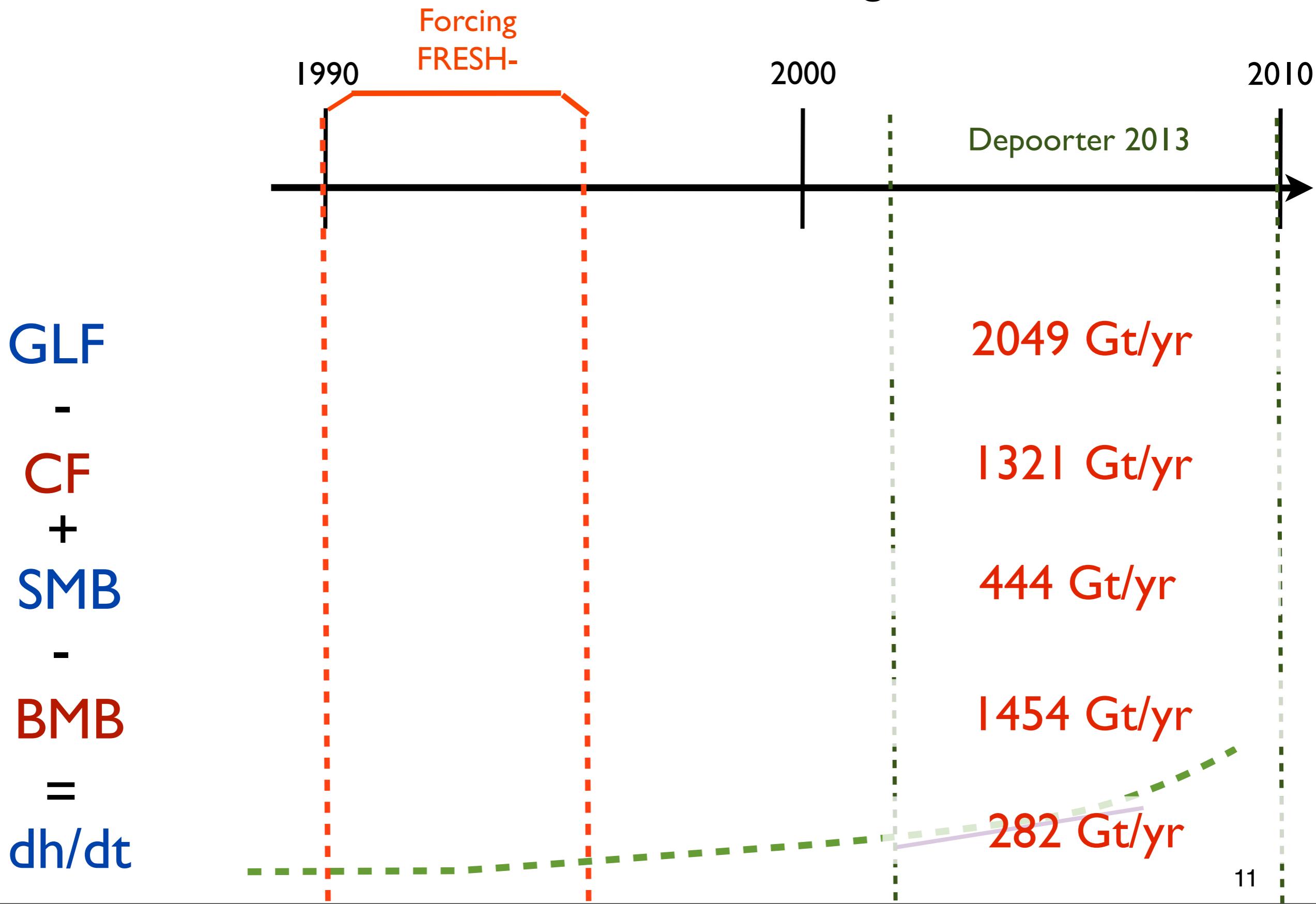
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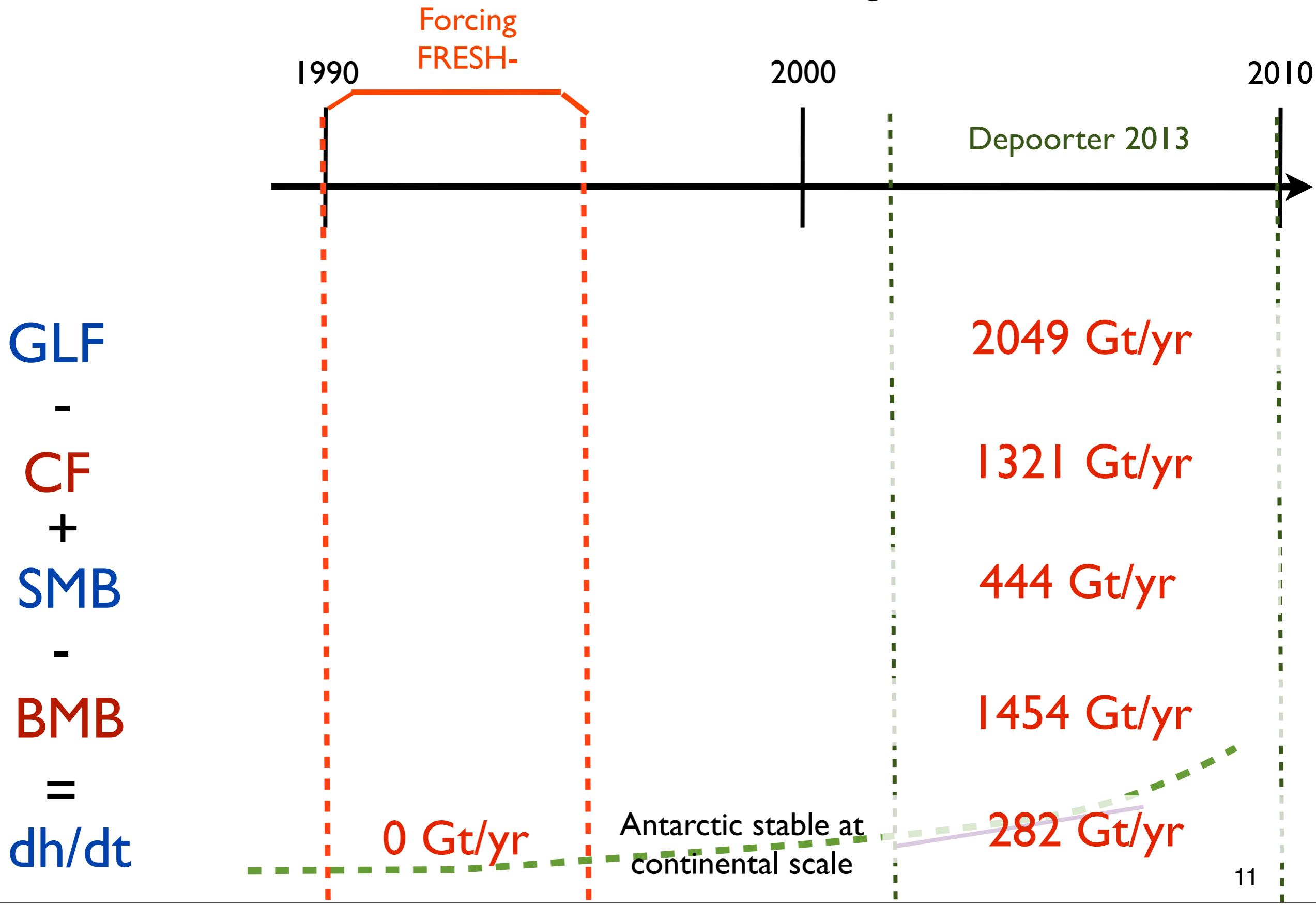
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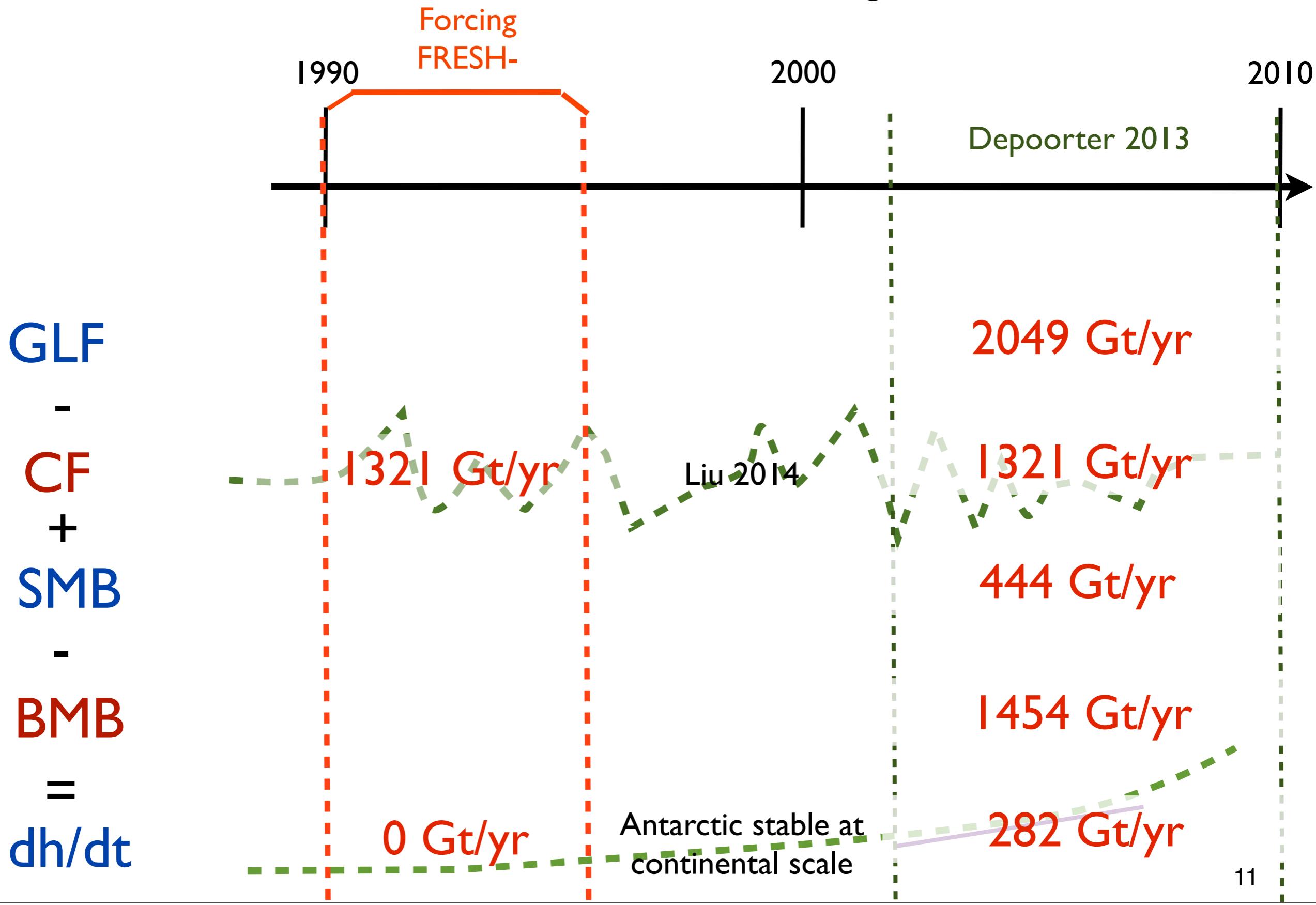
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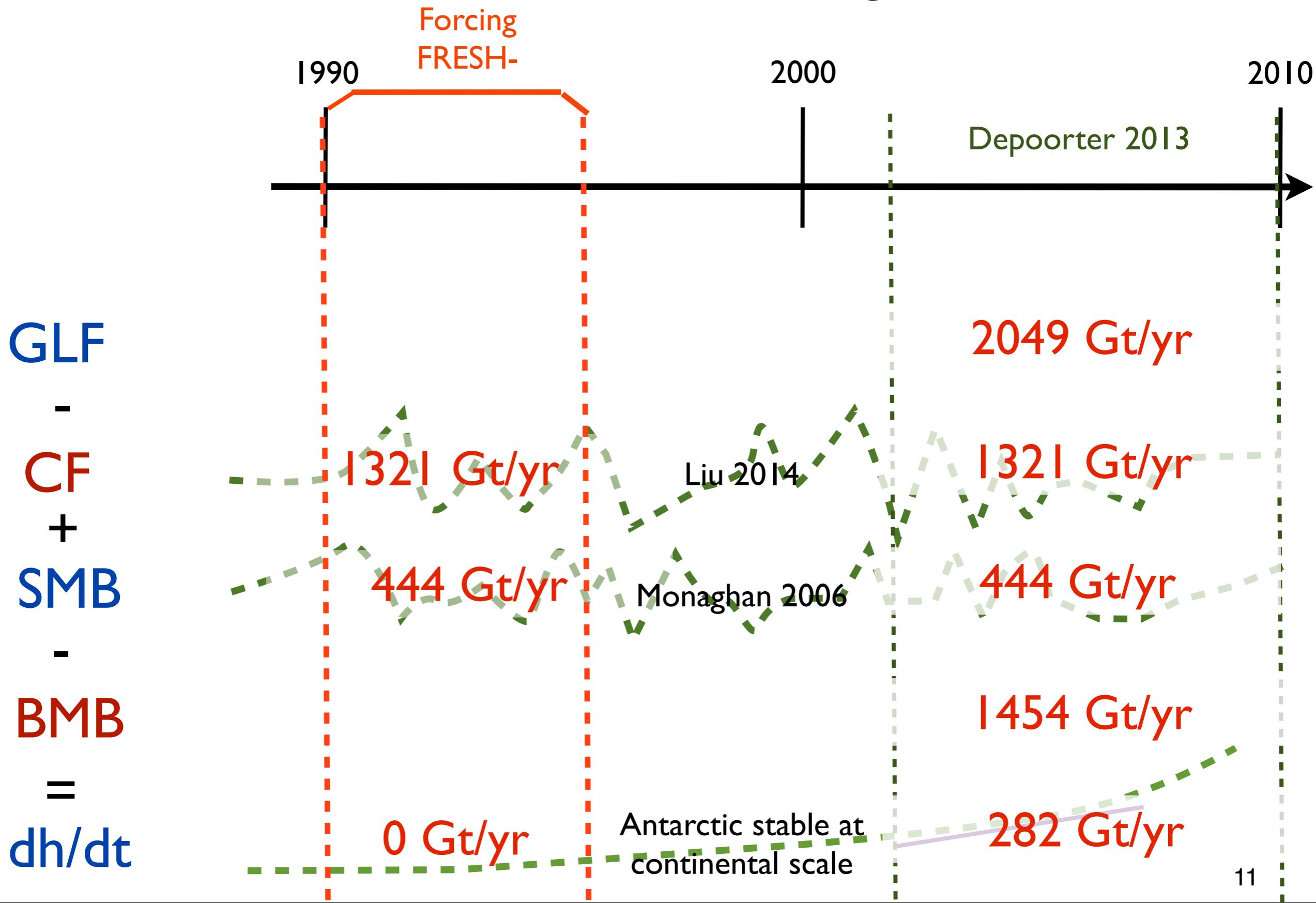
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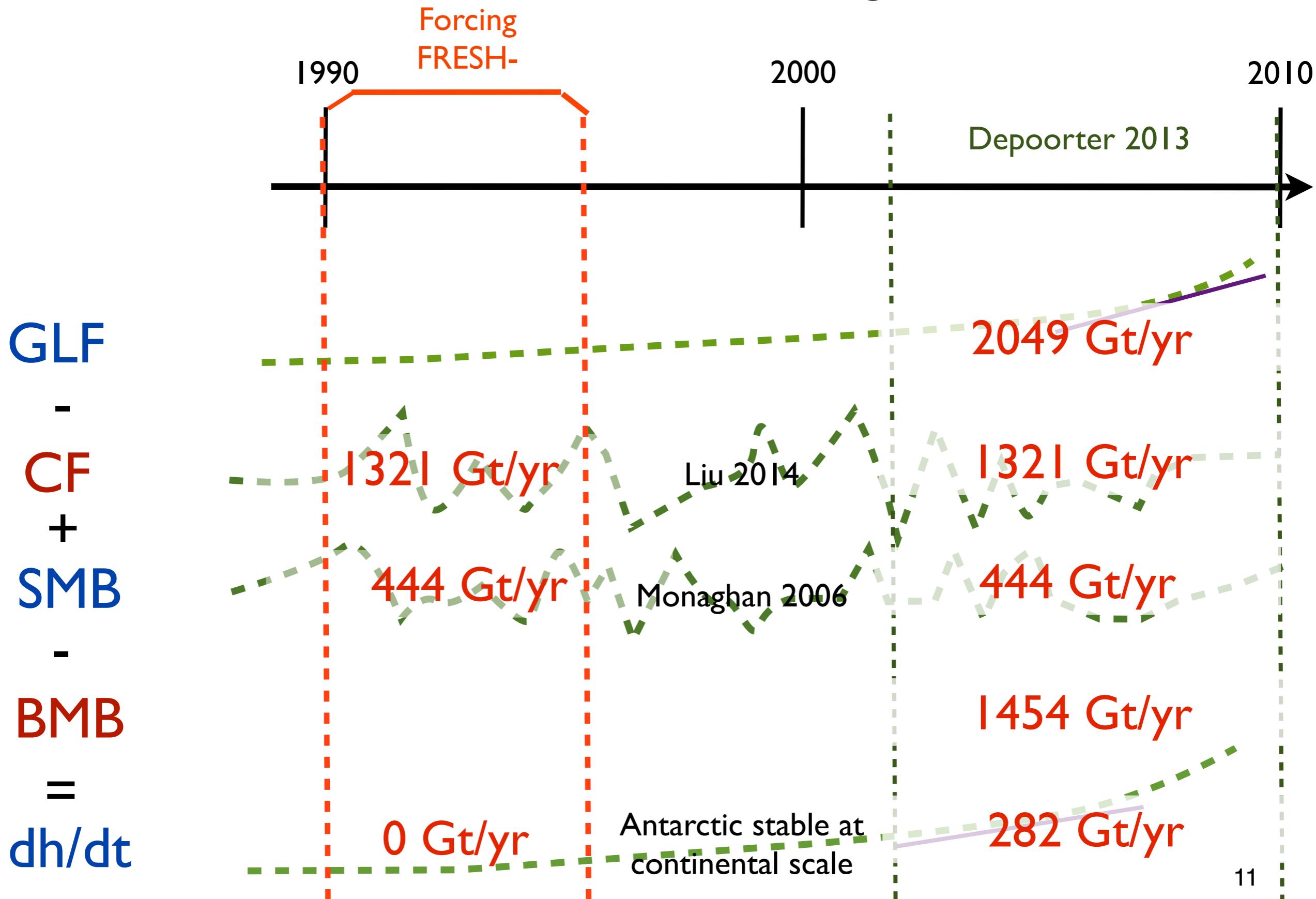
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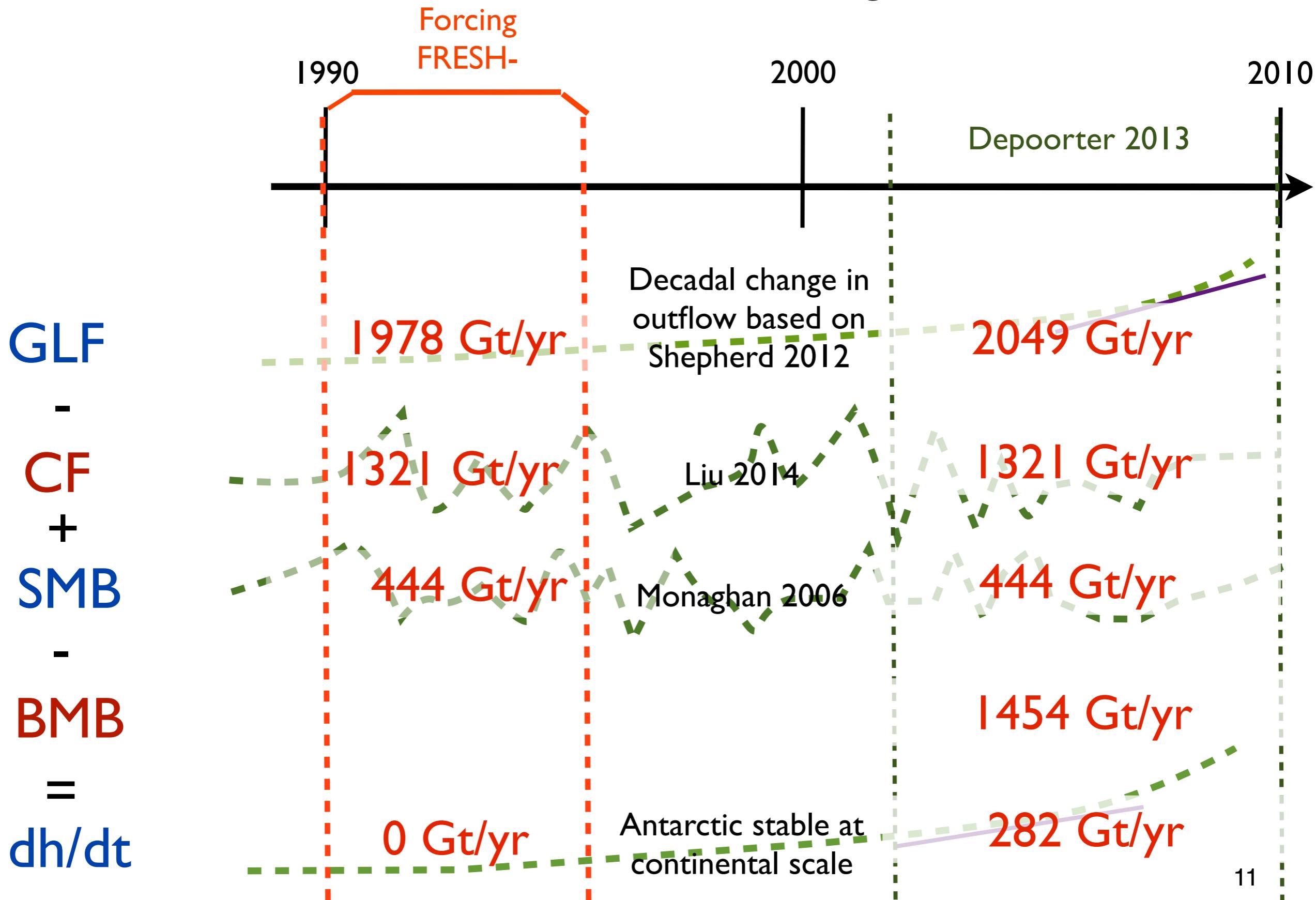
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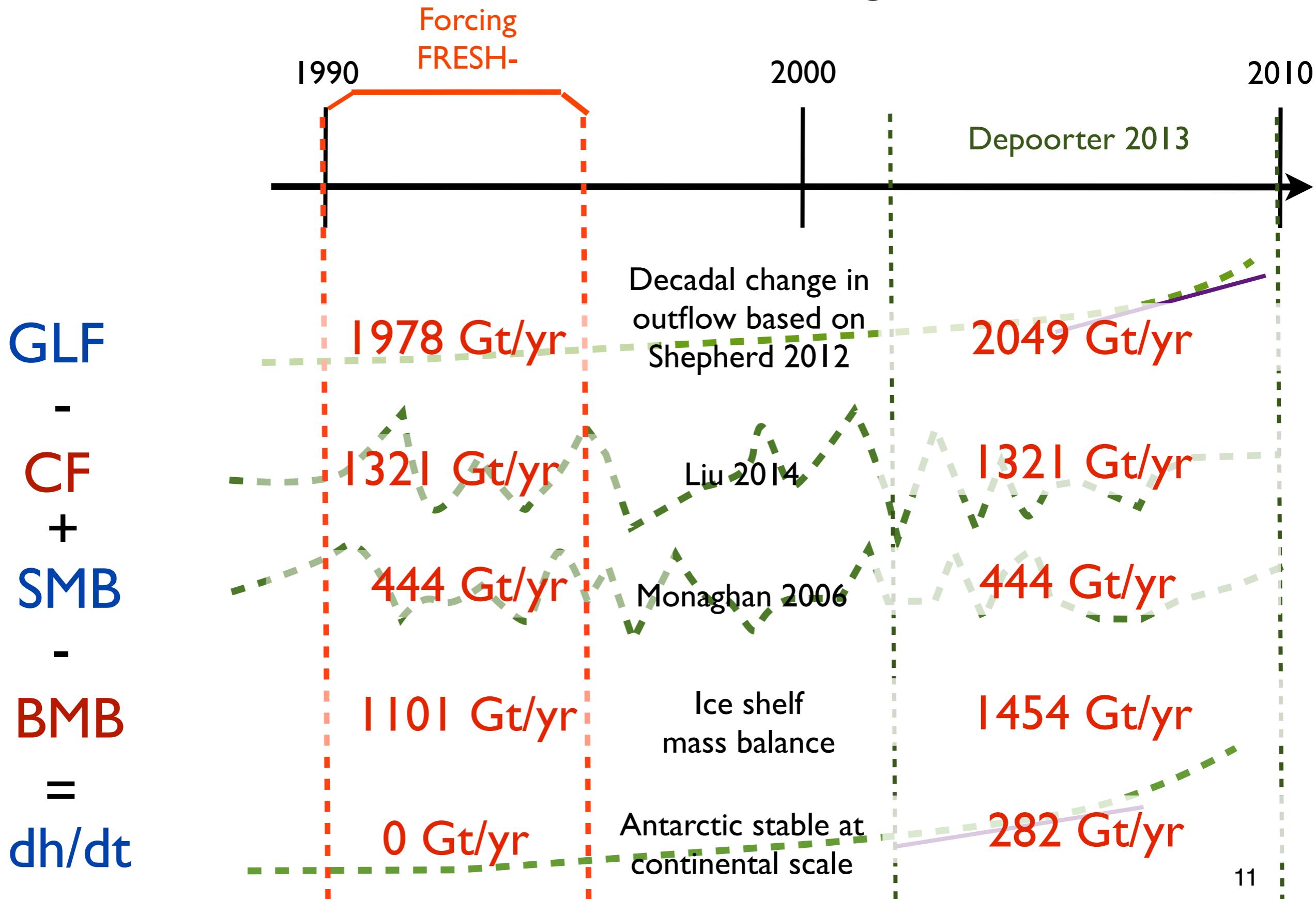
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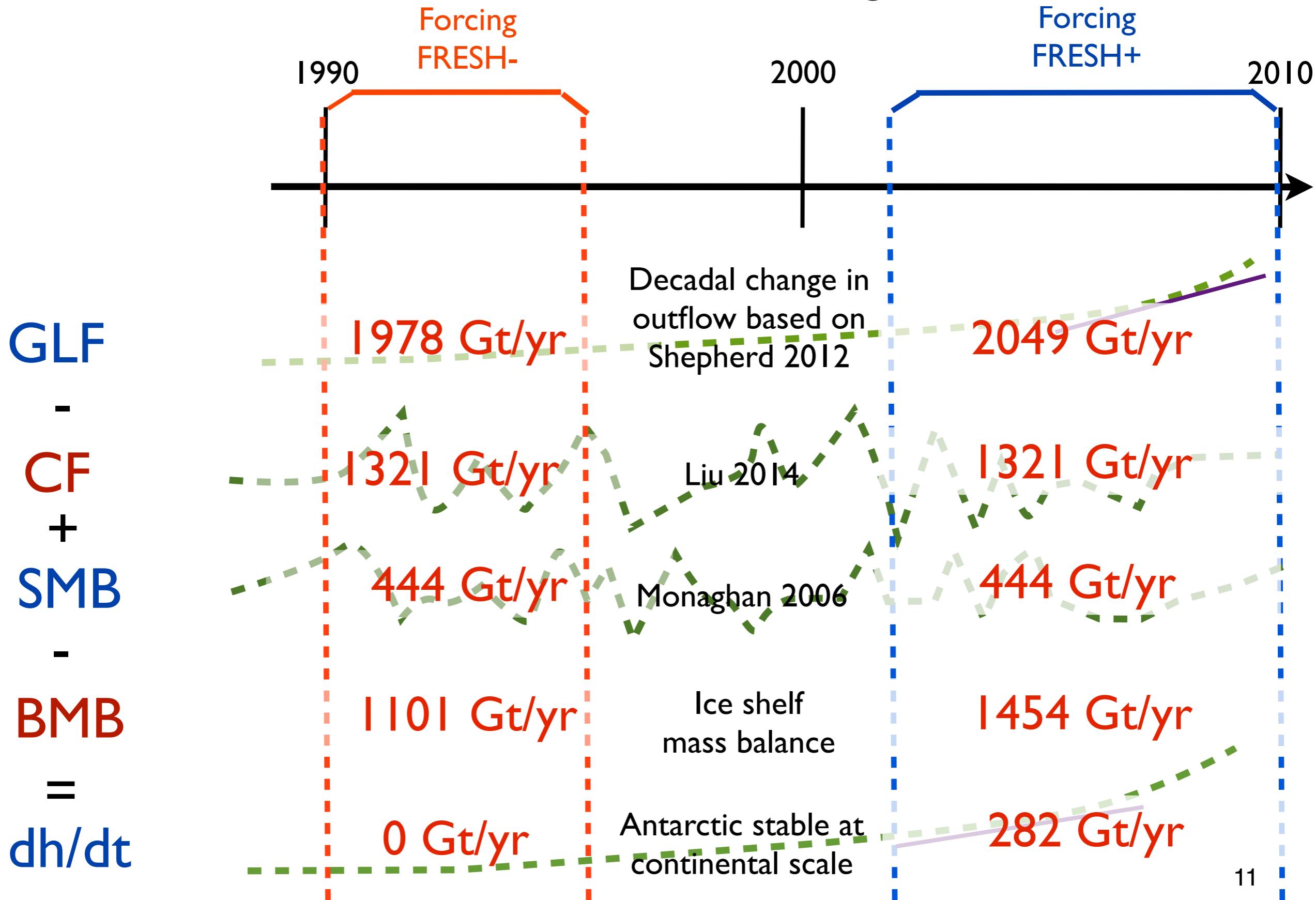
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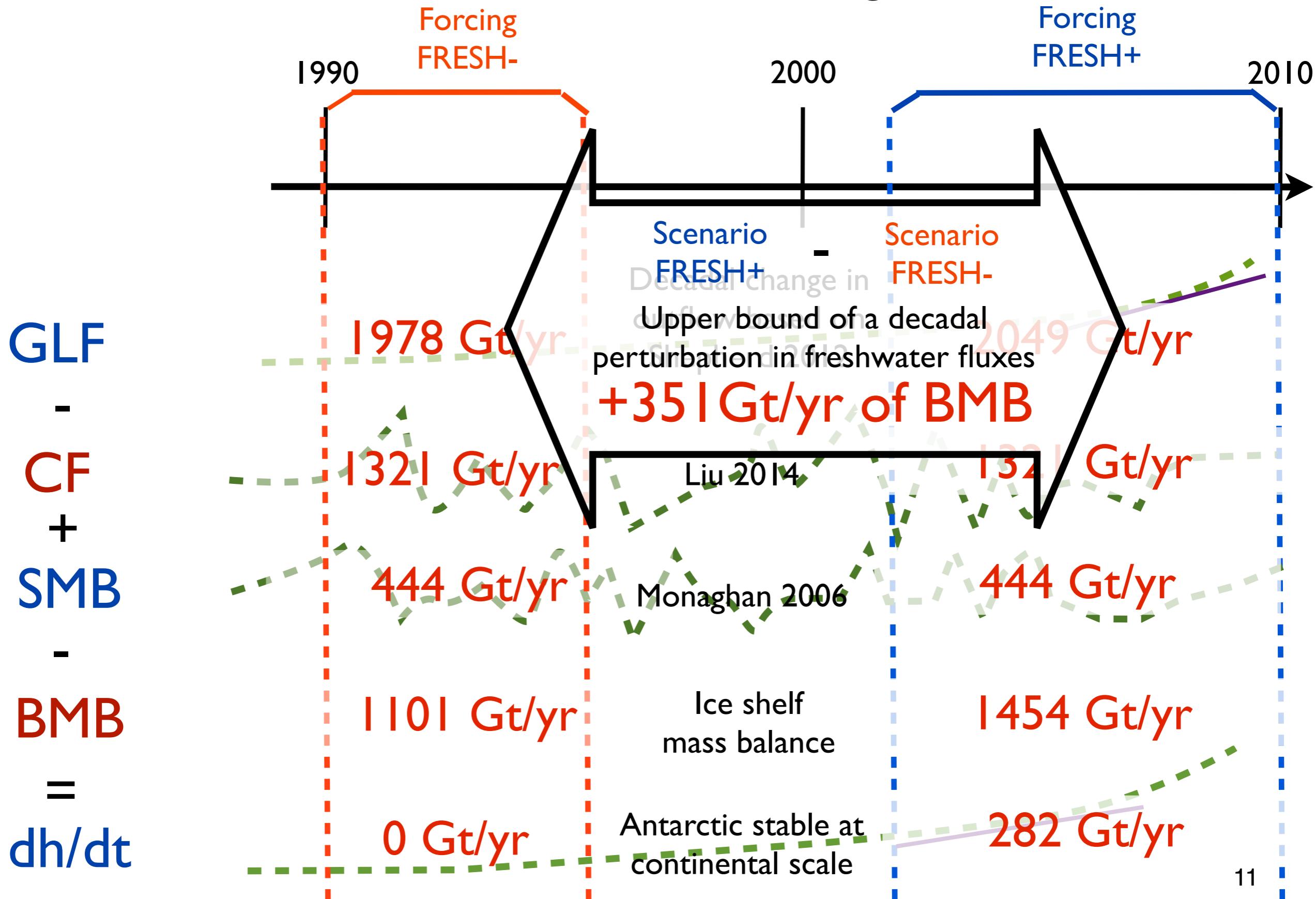
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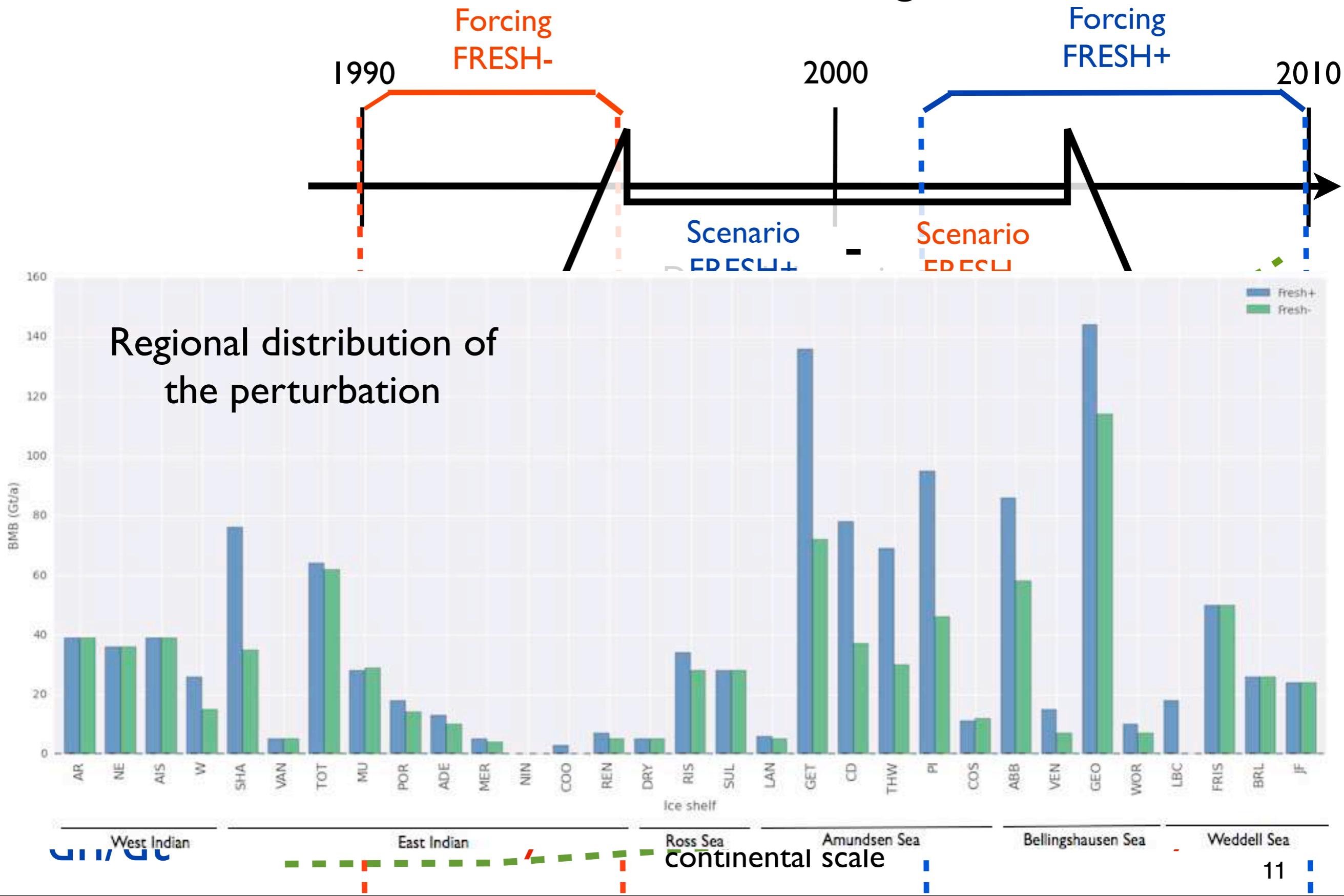


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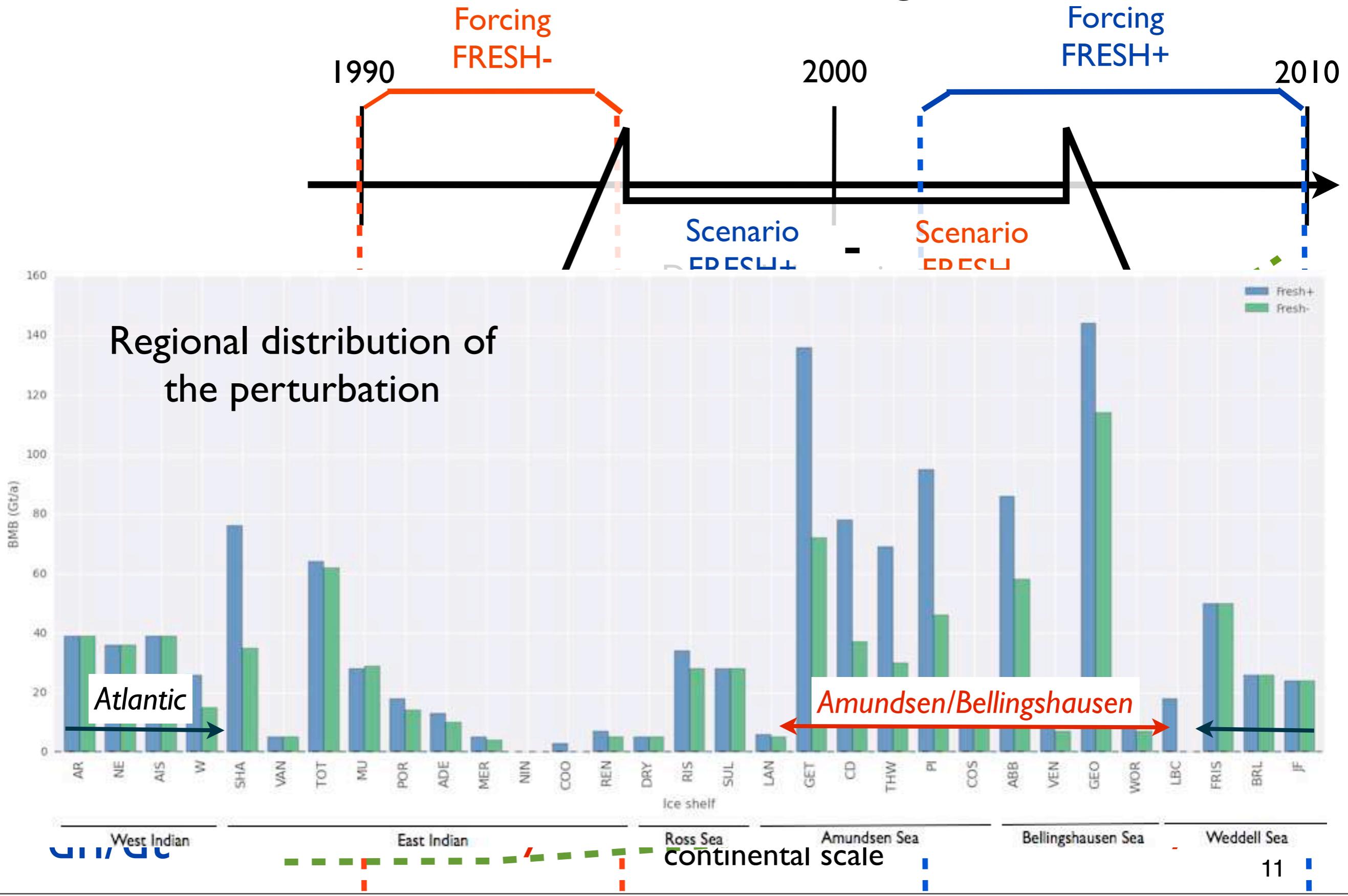
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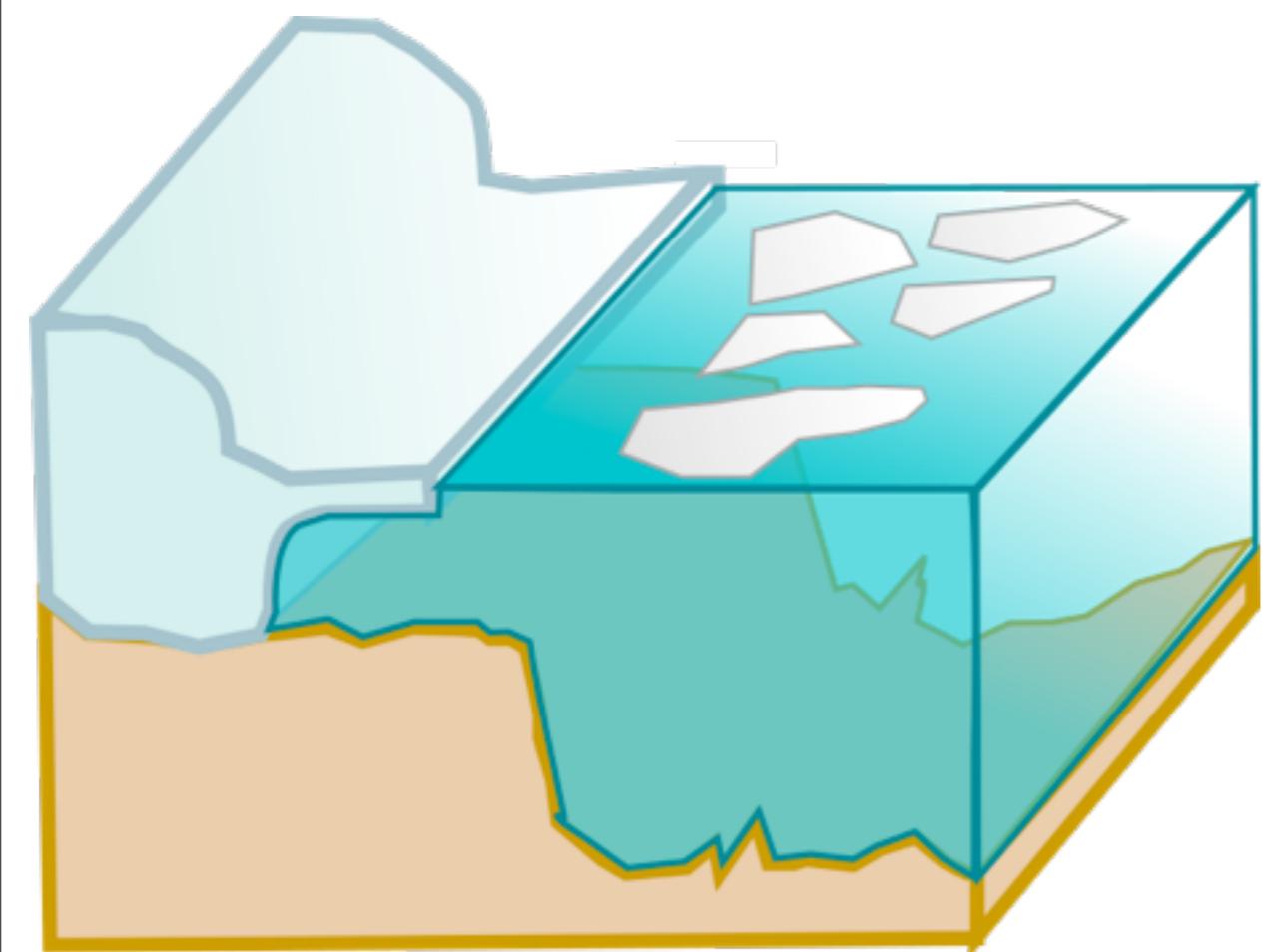
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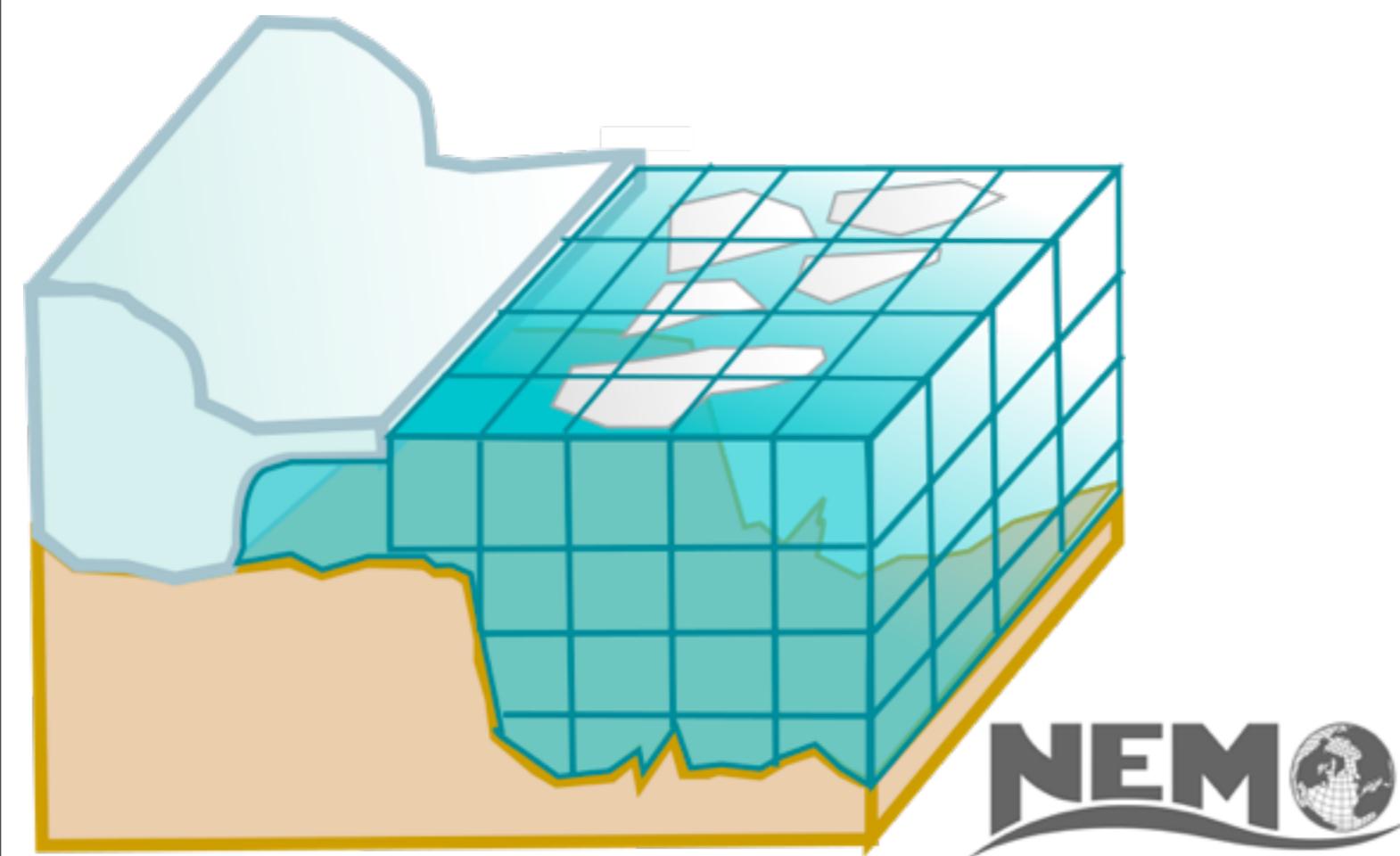
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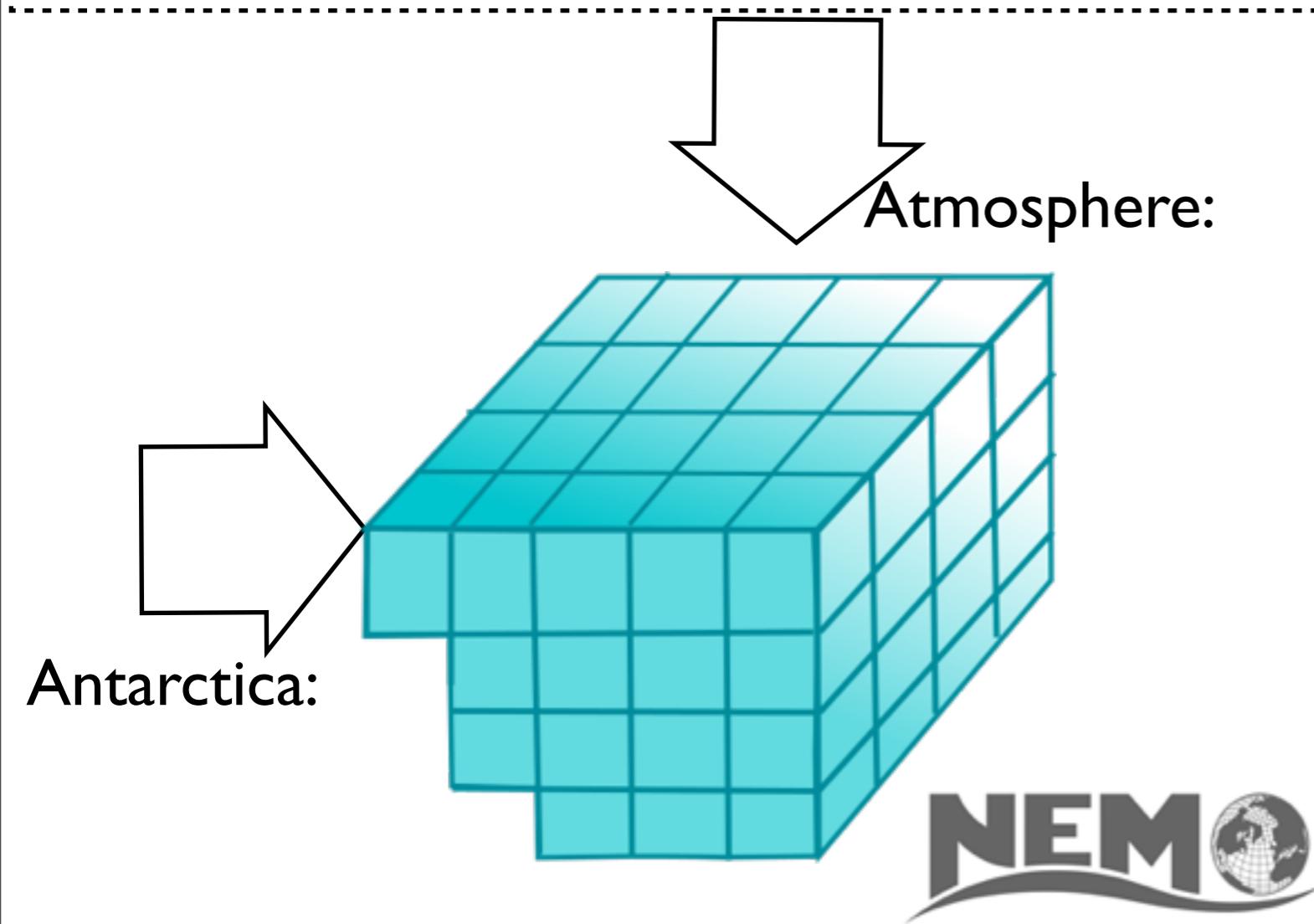
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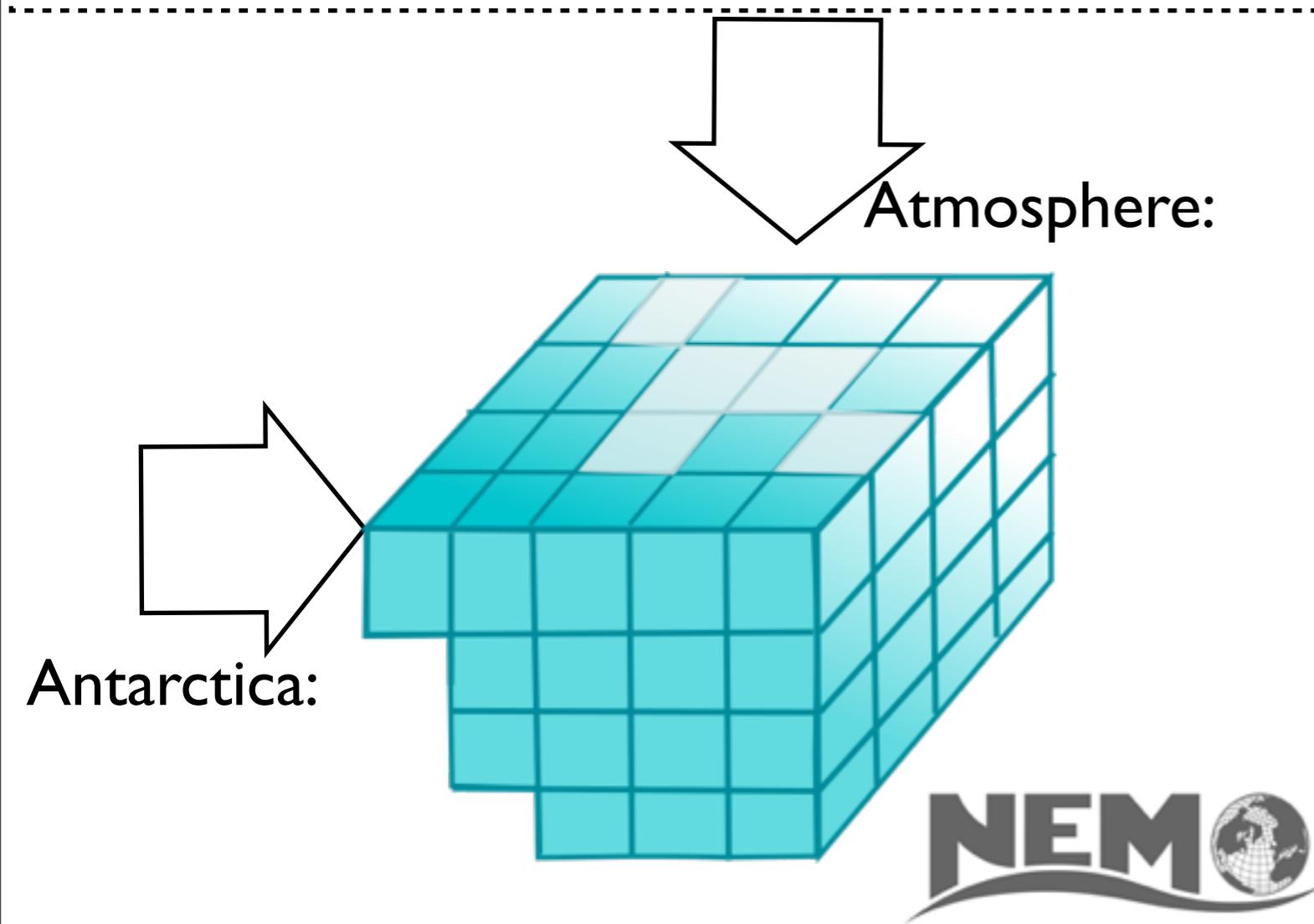
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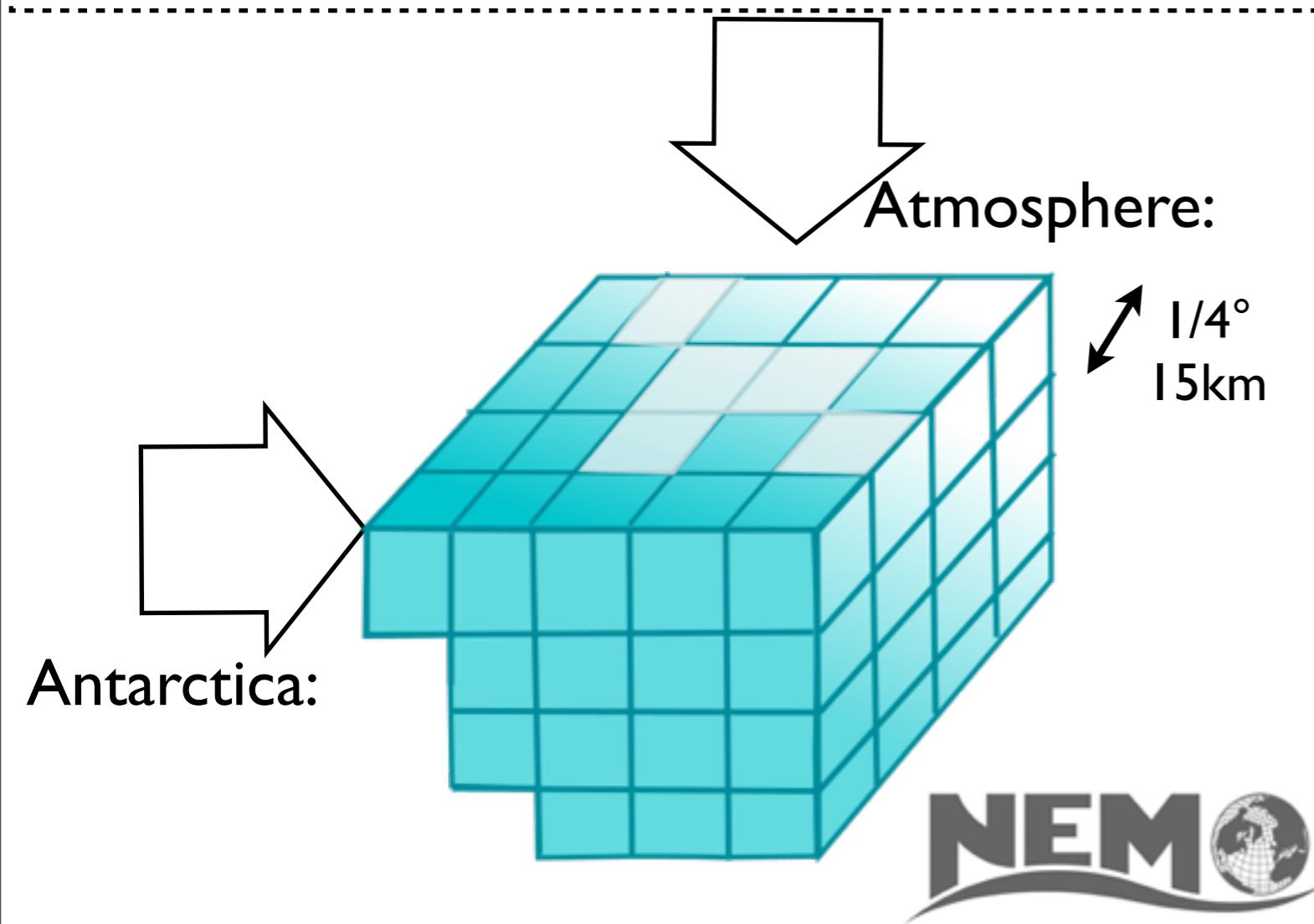
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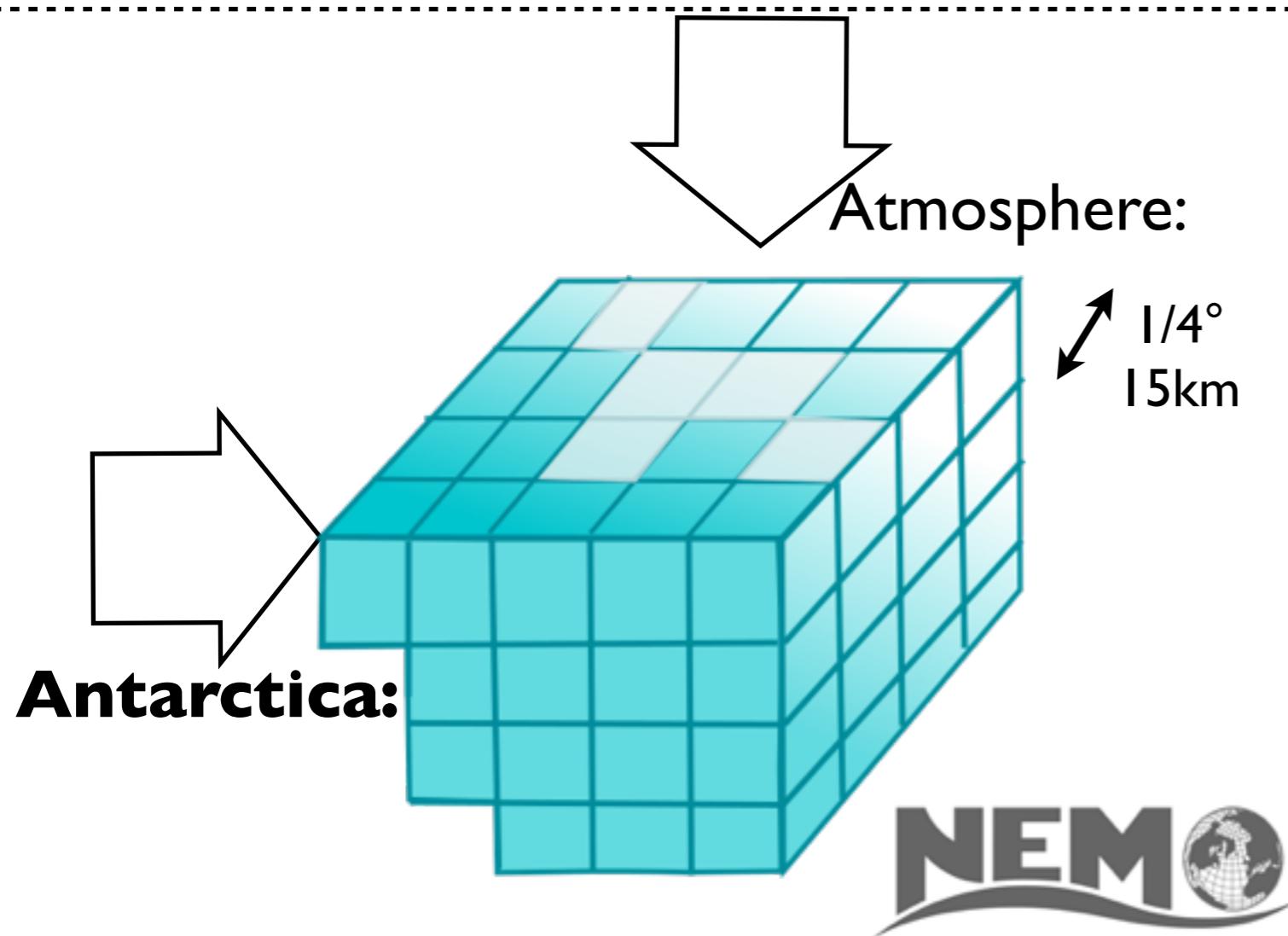
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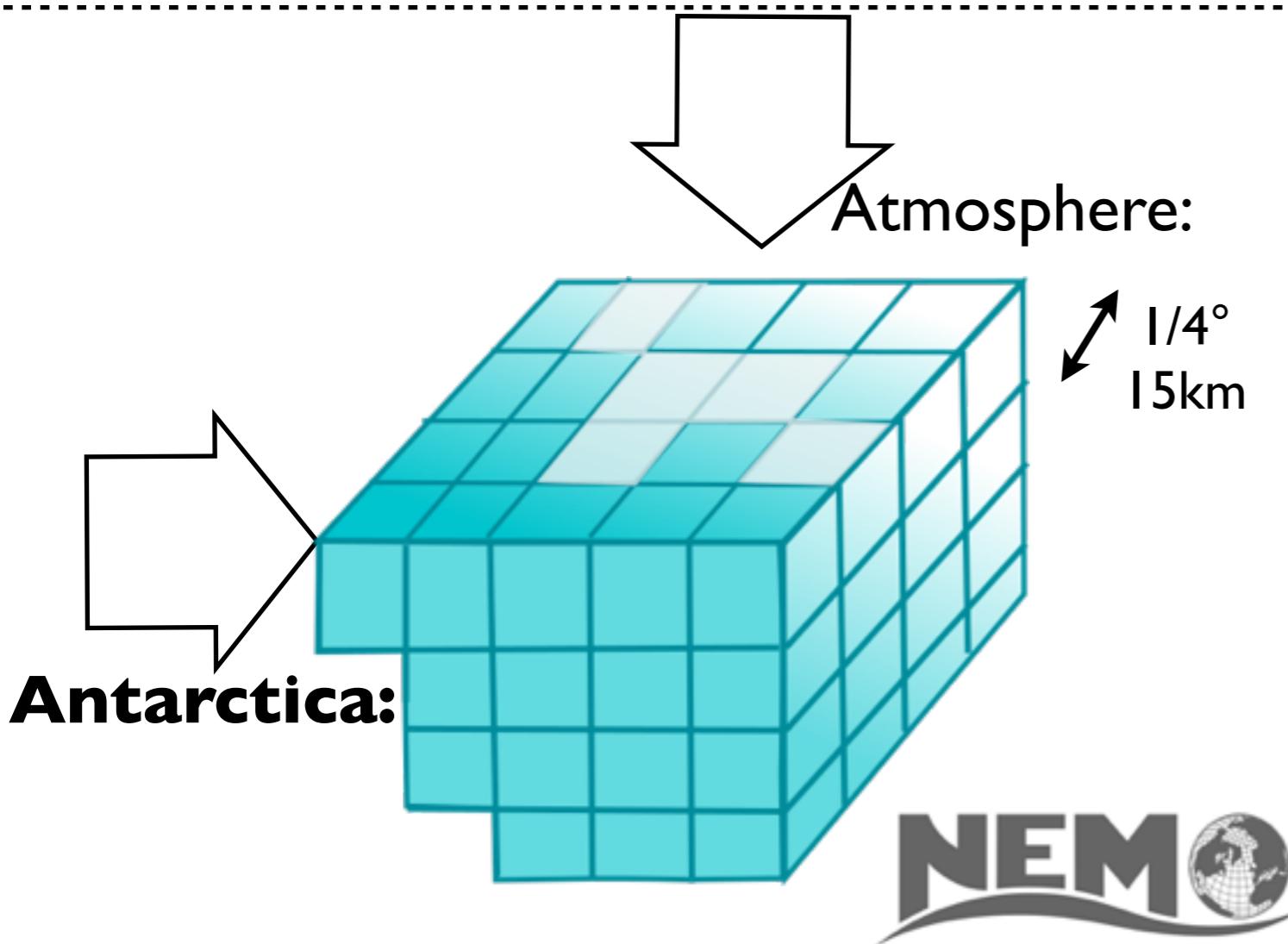


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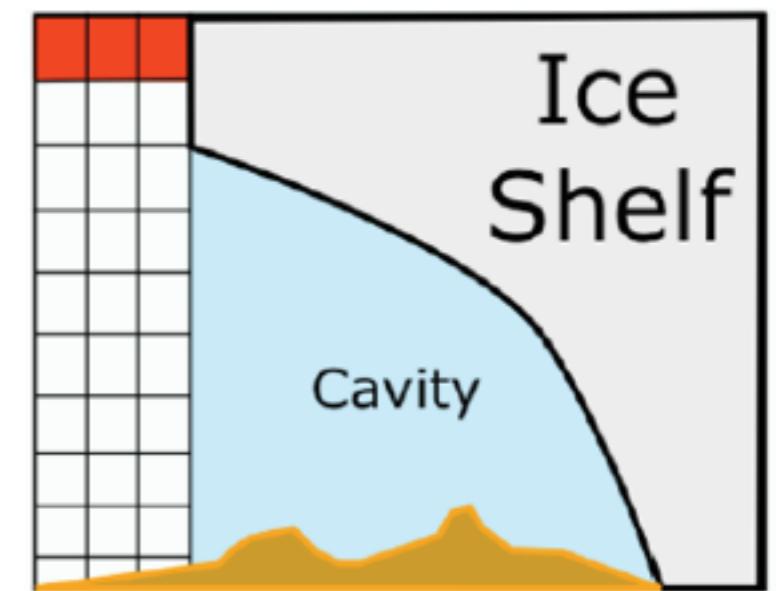
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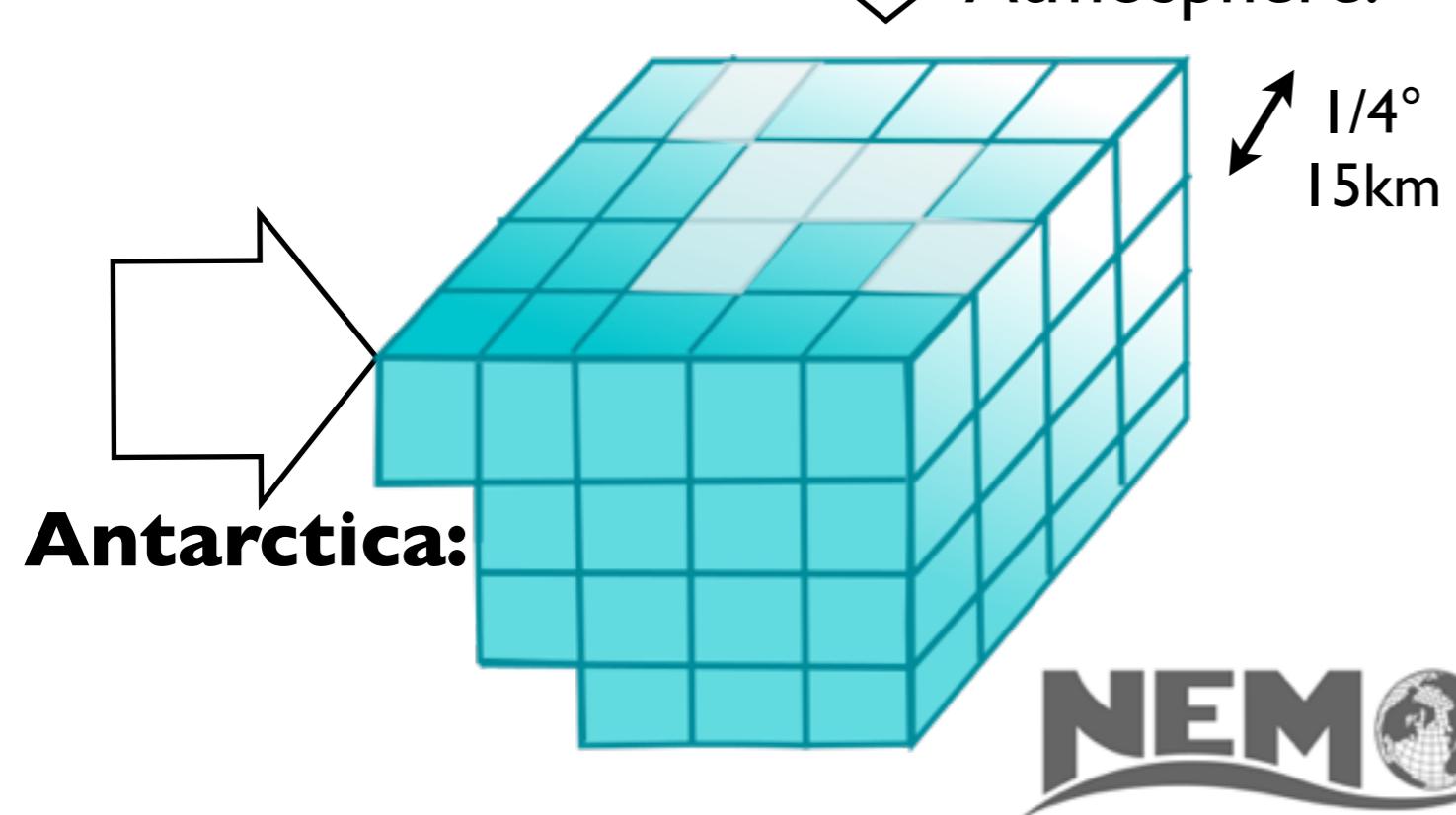
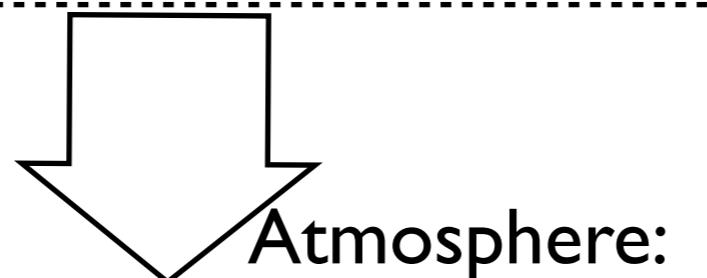


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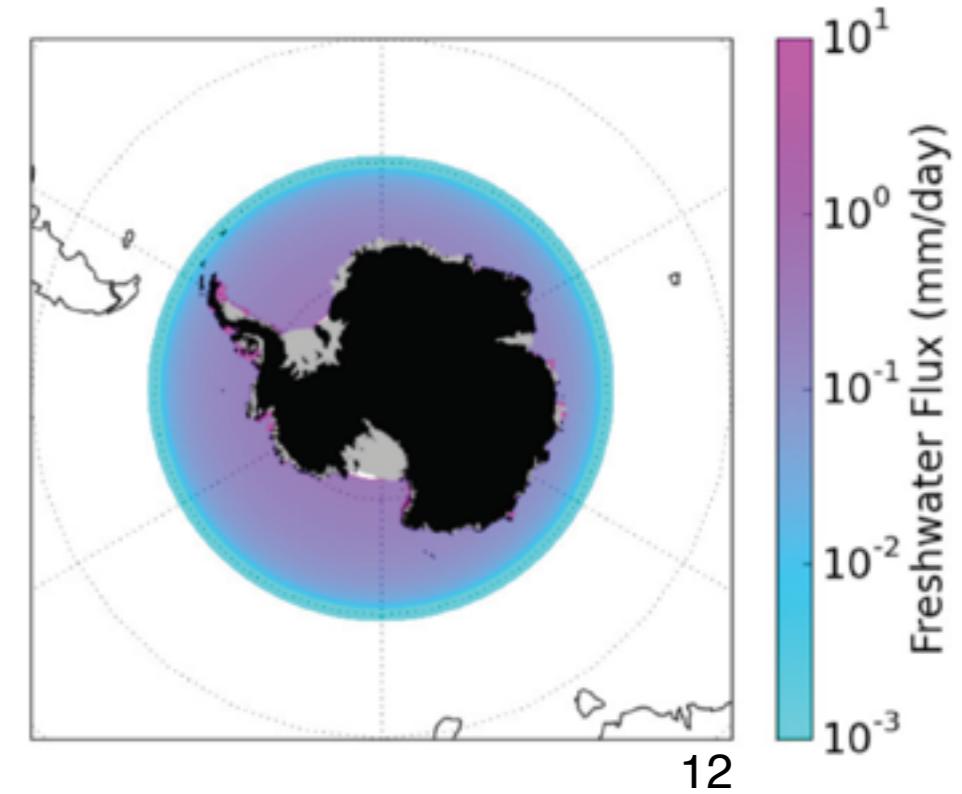
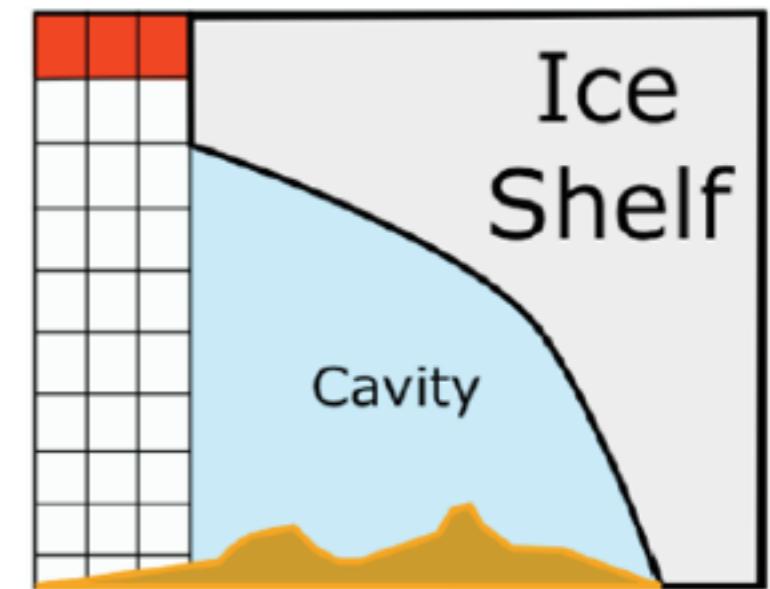
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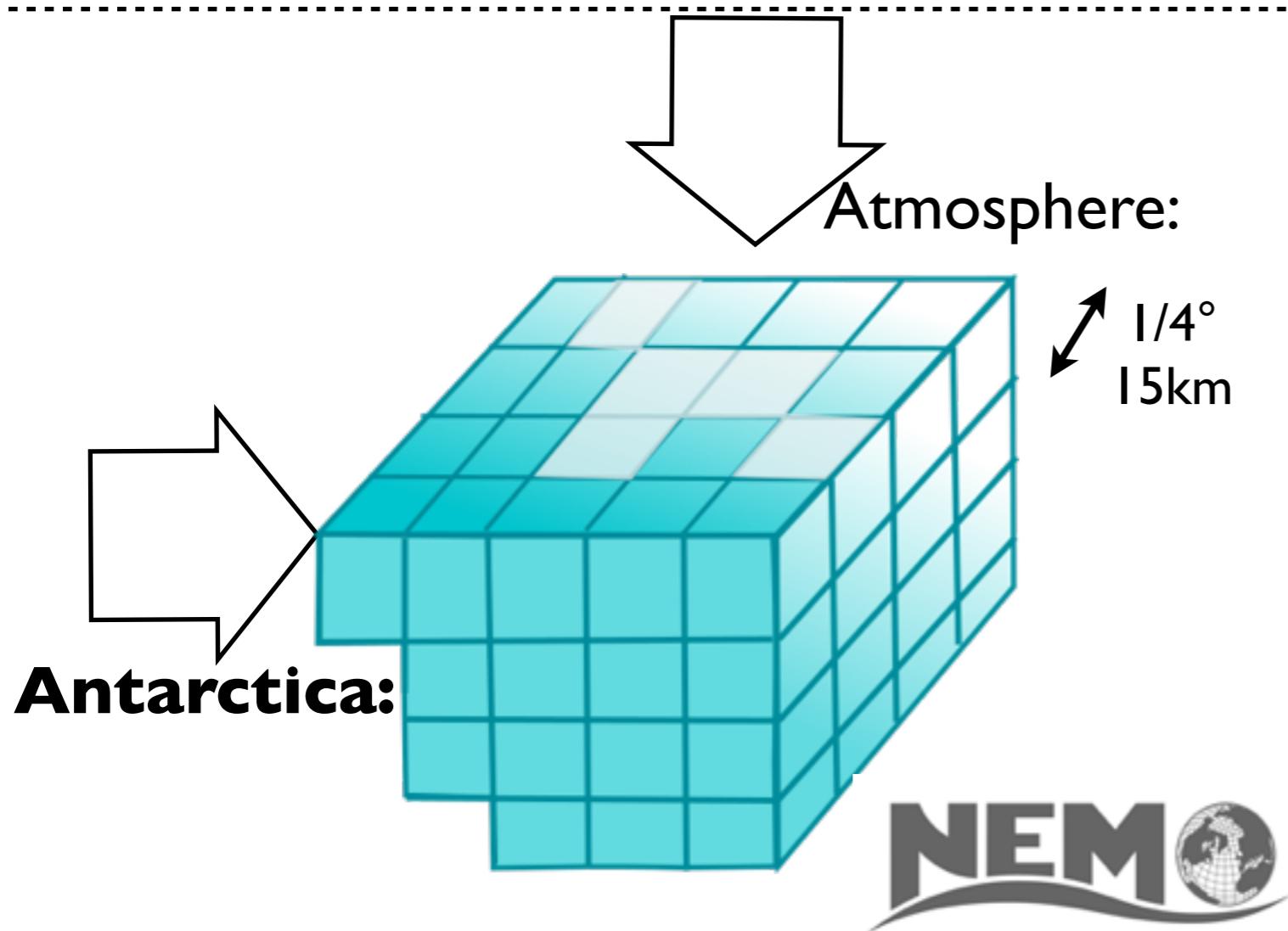


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- Ice shelf meltwater: Vertical distribution of ice shelf melt fluxes
- Split into ice shelf melt water and iceberg fluxes
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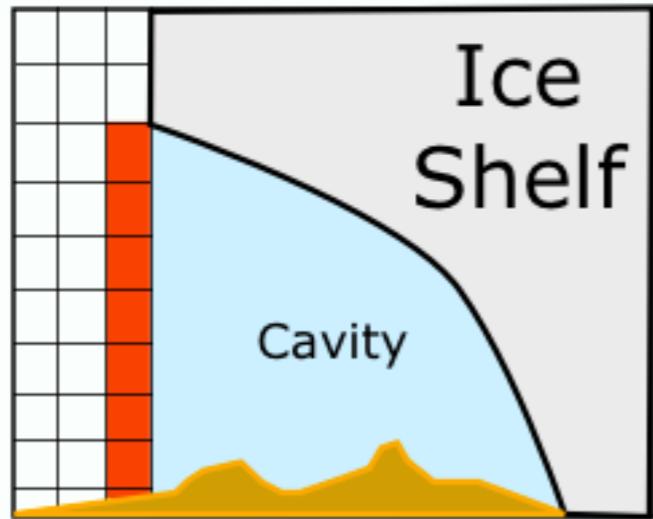
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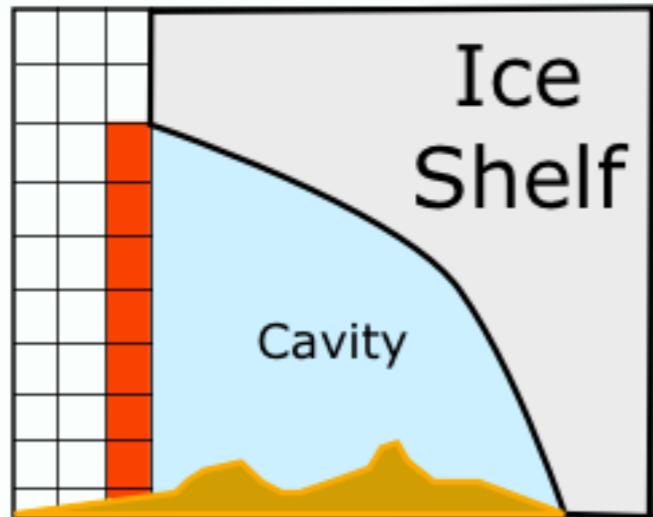
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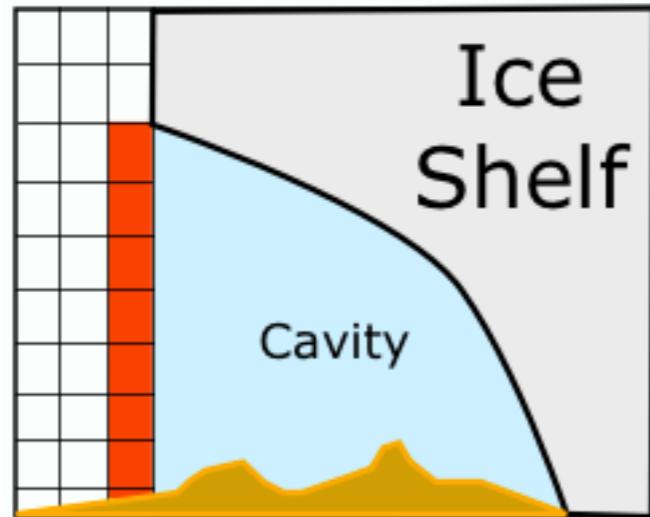
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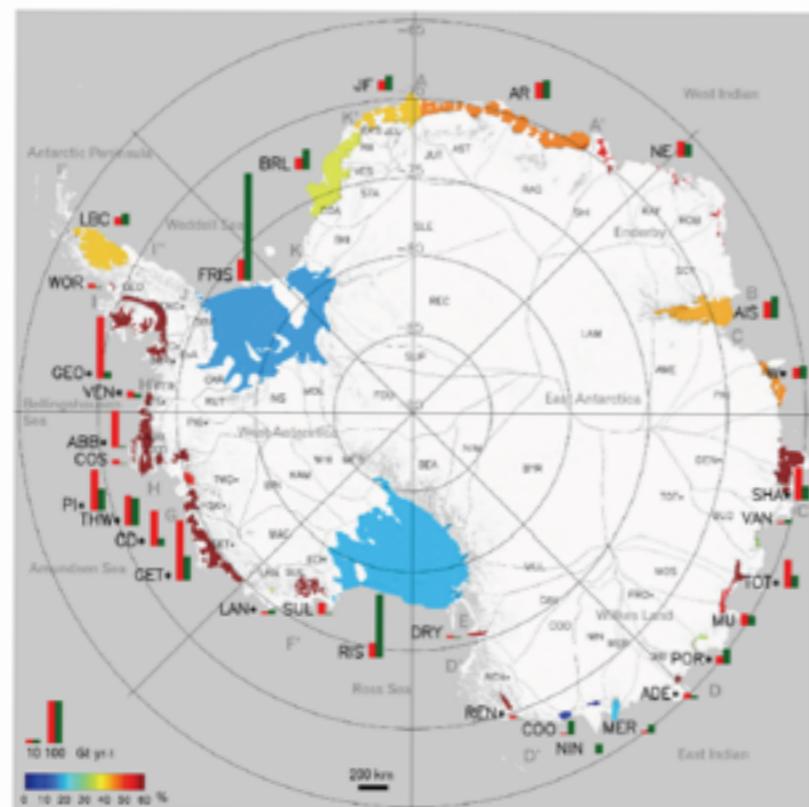
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Emulation of  
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Depoorter et al. 2013

Ice shelf melt:  
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Calving:  
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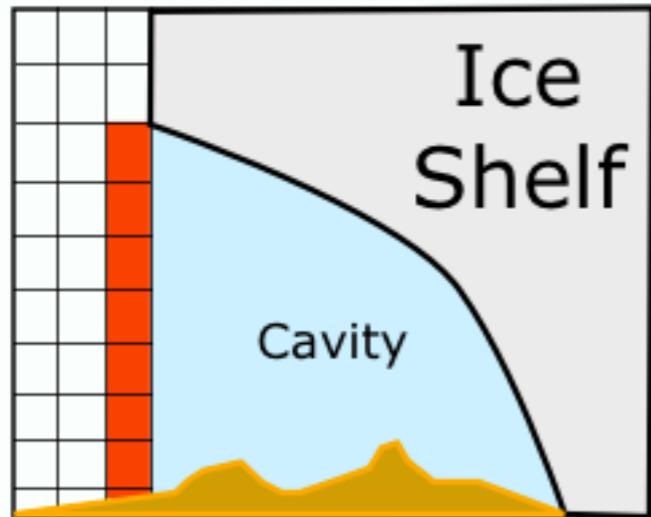
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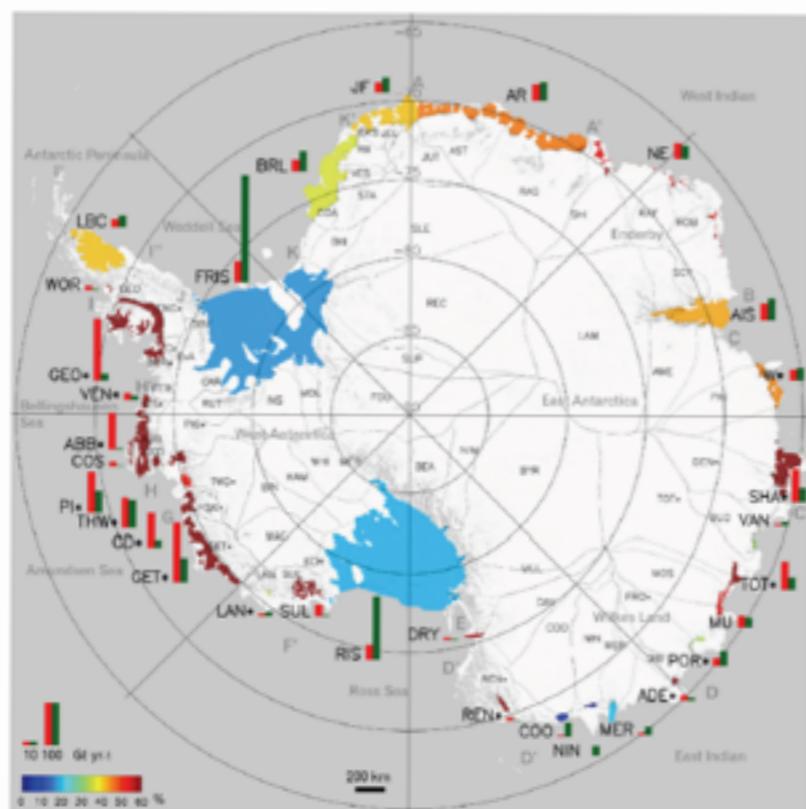
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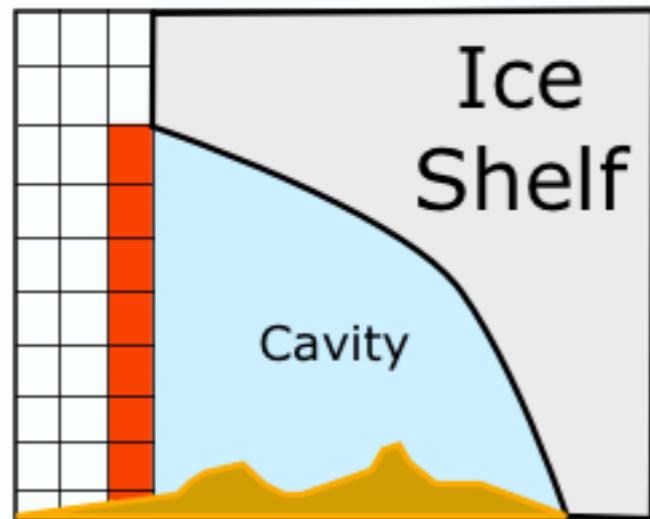
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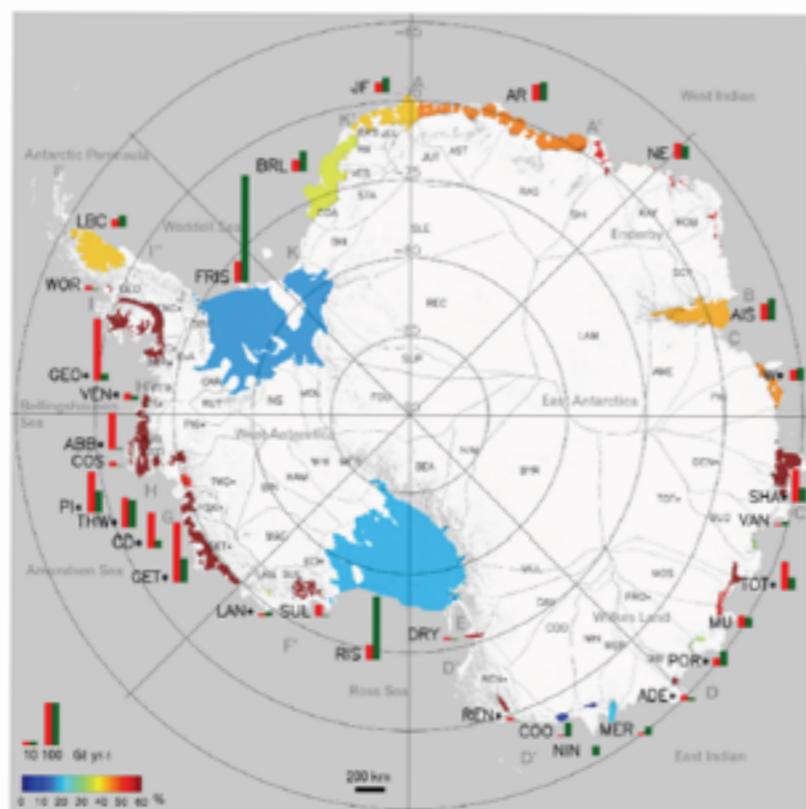
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# Emulation of ice shelf overturning



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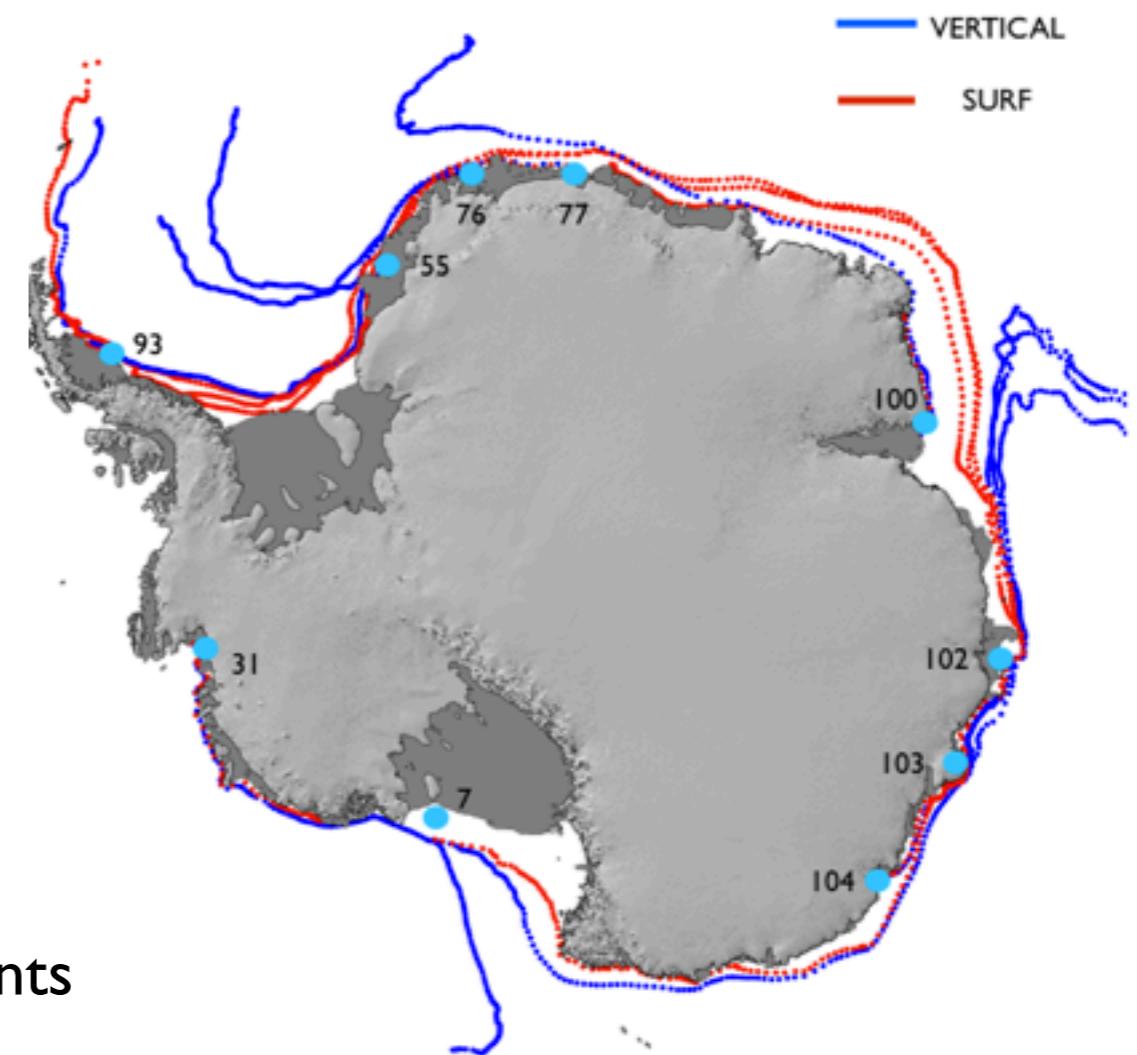
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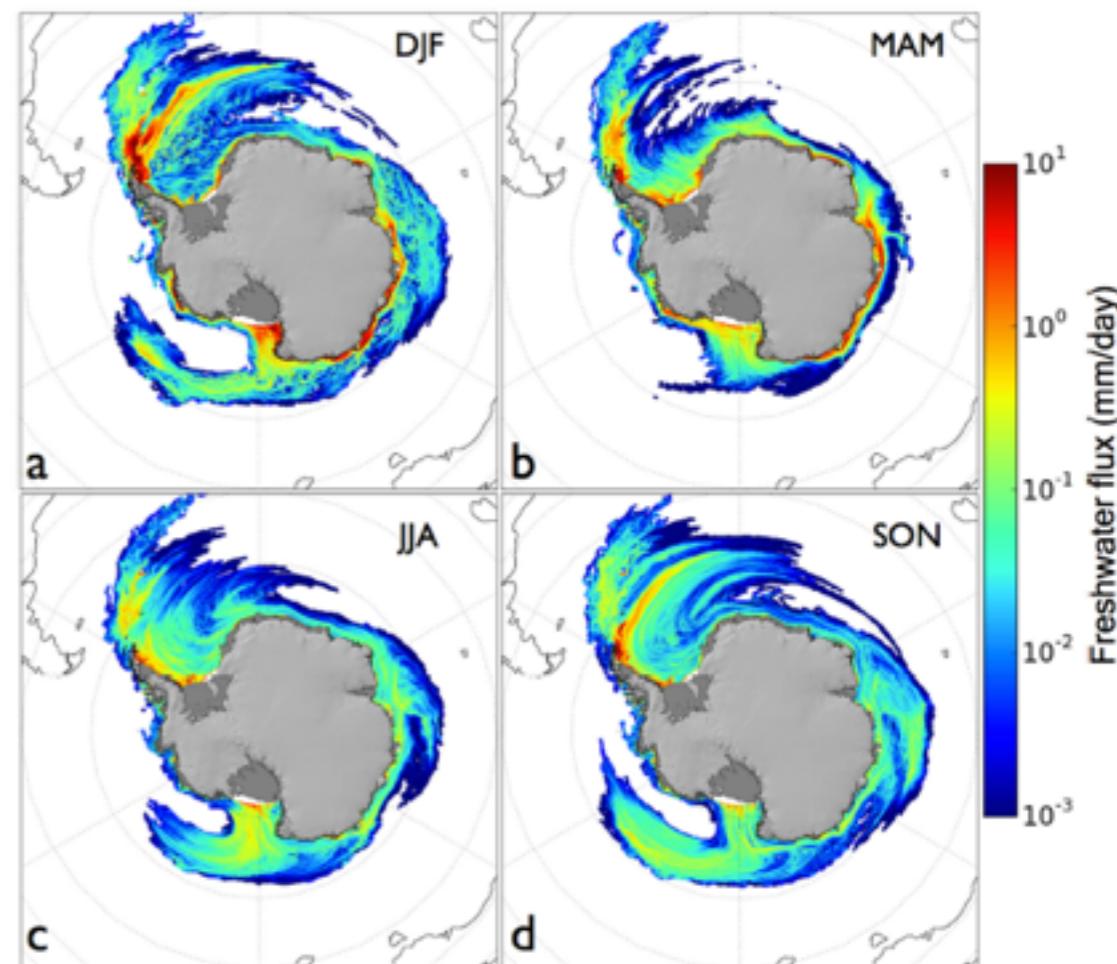
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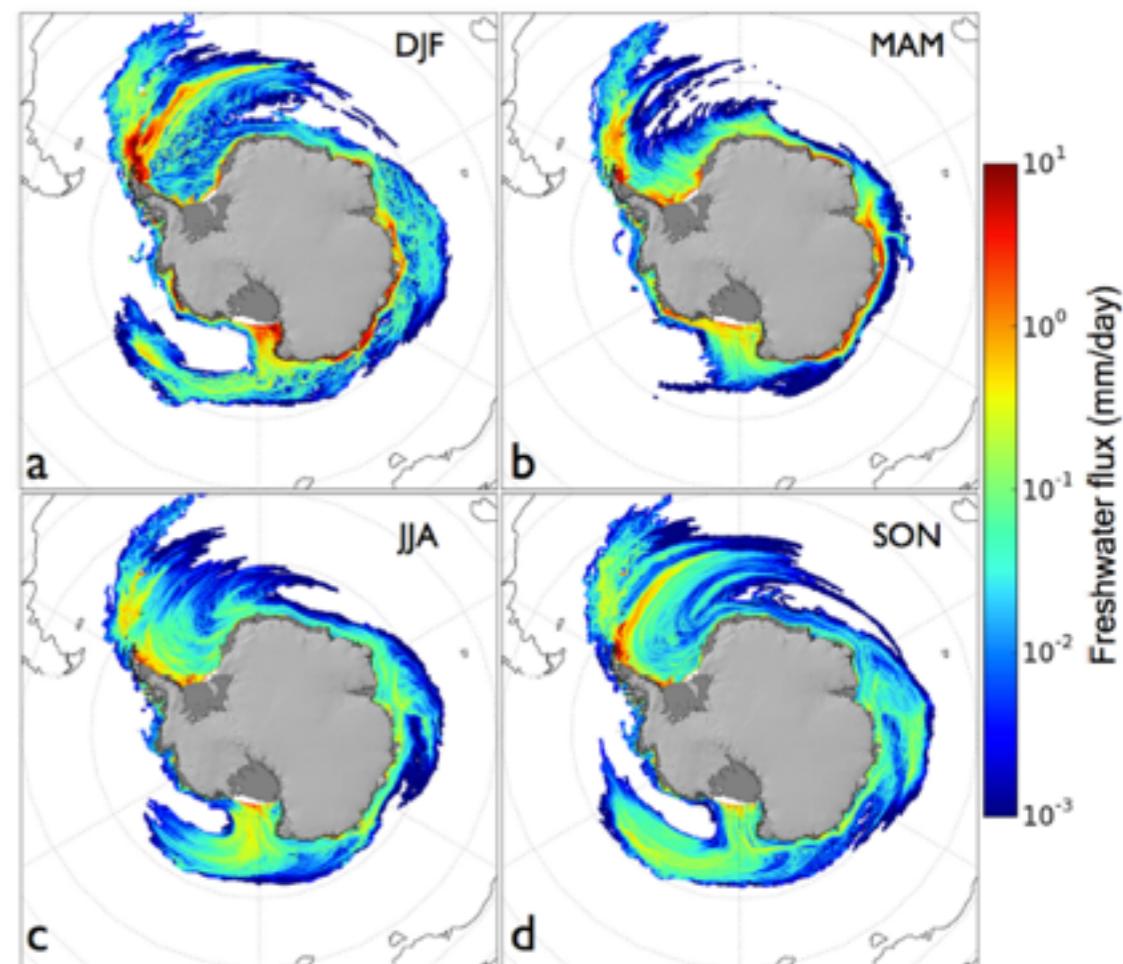
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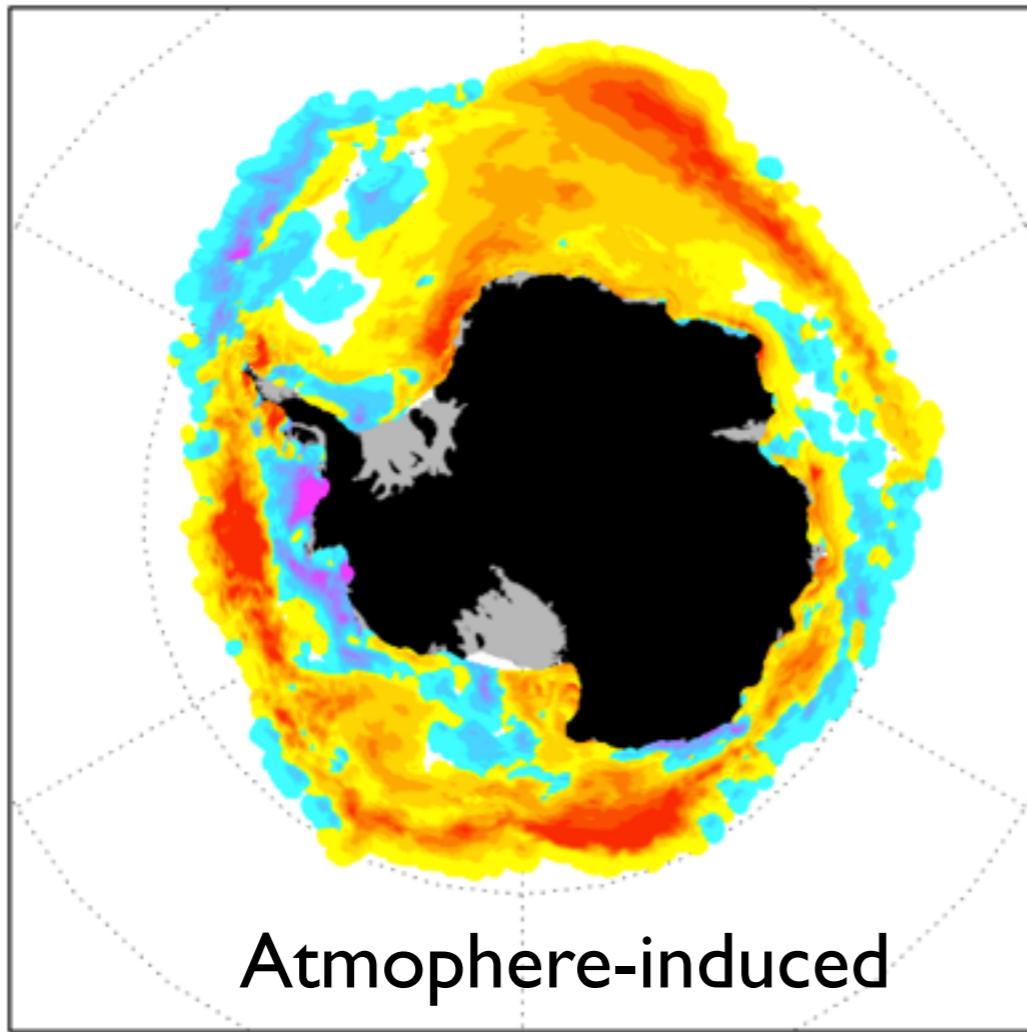
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**CTR vs FW-** Glacial-freshwater-induced changes

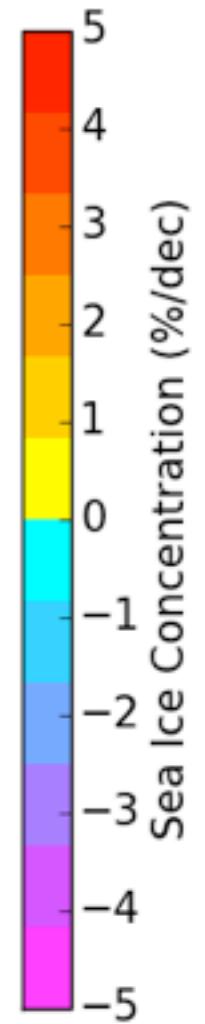
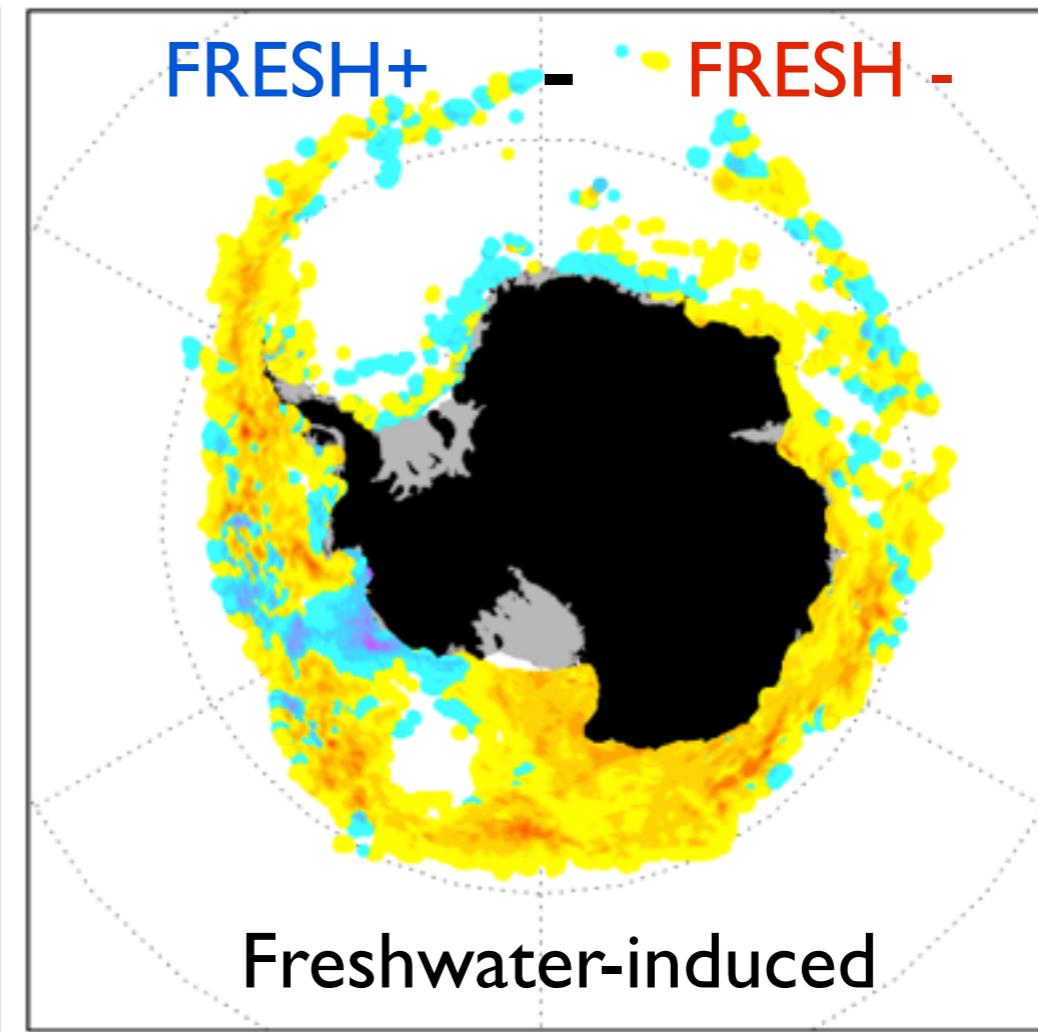
**FW- vs ATM-** Atmosphere-induced changes

# Sea ice concentration changes

**FW- vs ATM-**



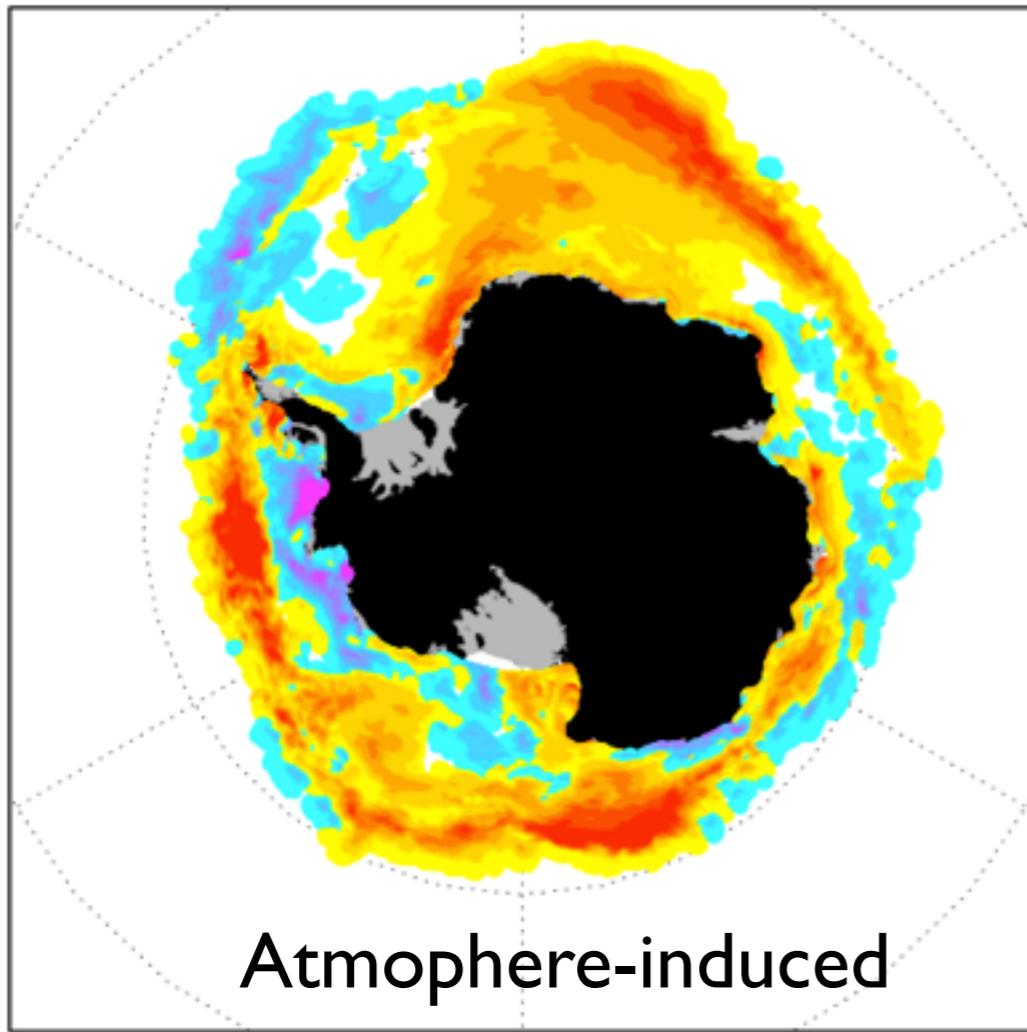
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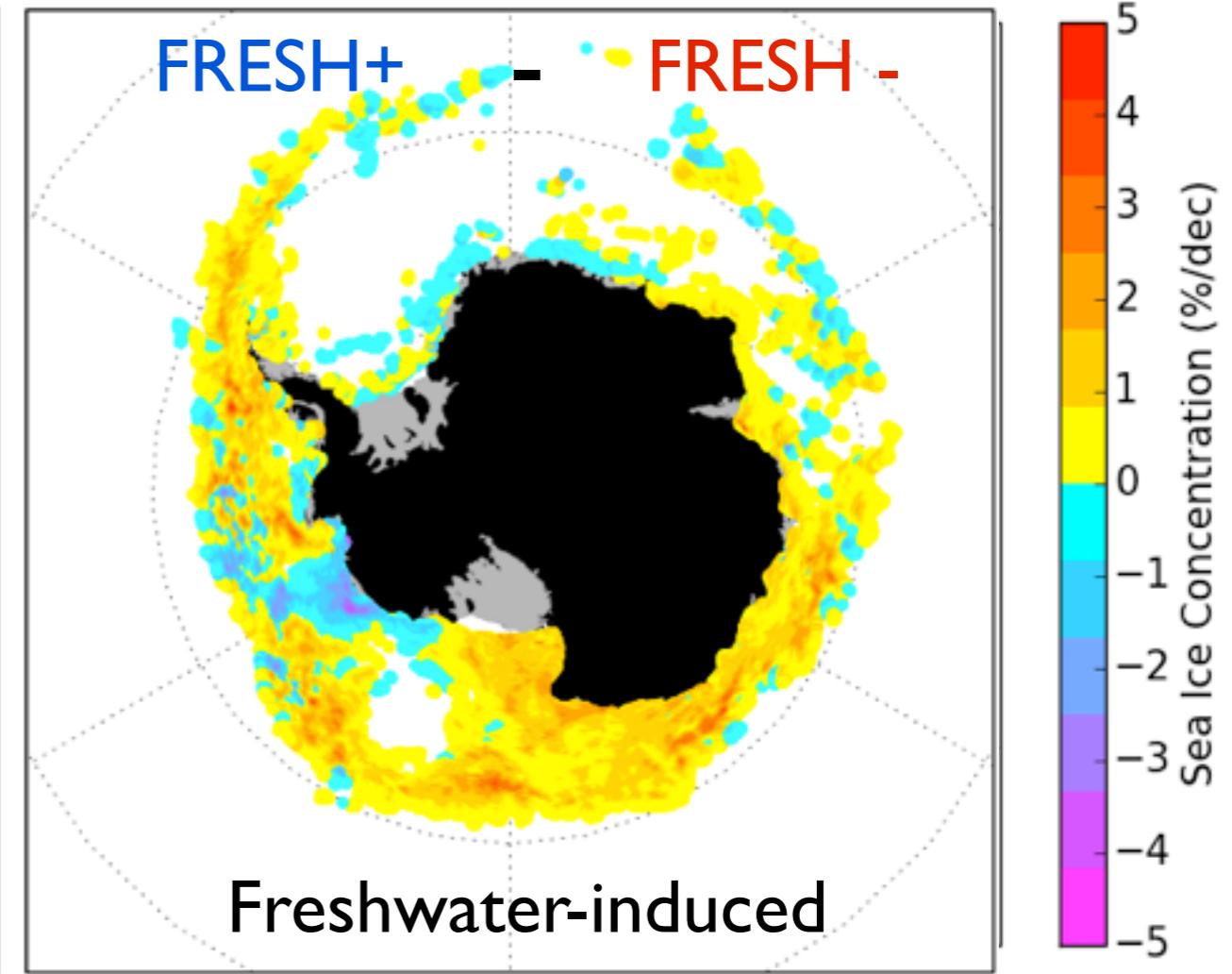
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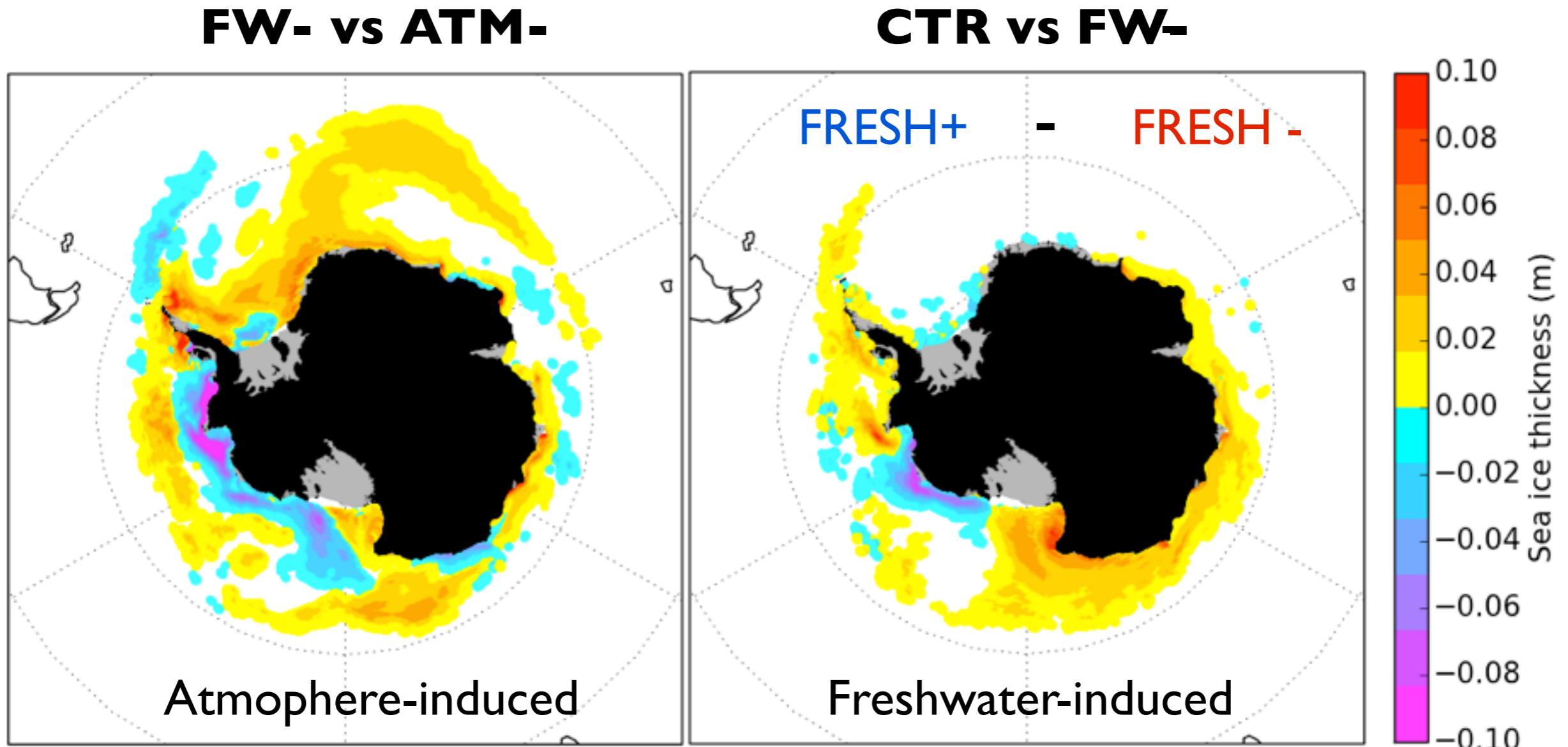
**CTR vs FW-**



Sea ice concentration changes dominated by atmospheric changes

**Freshwater induces 25% of global sea ice extent change**

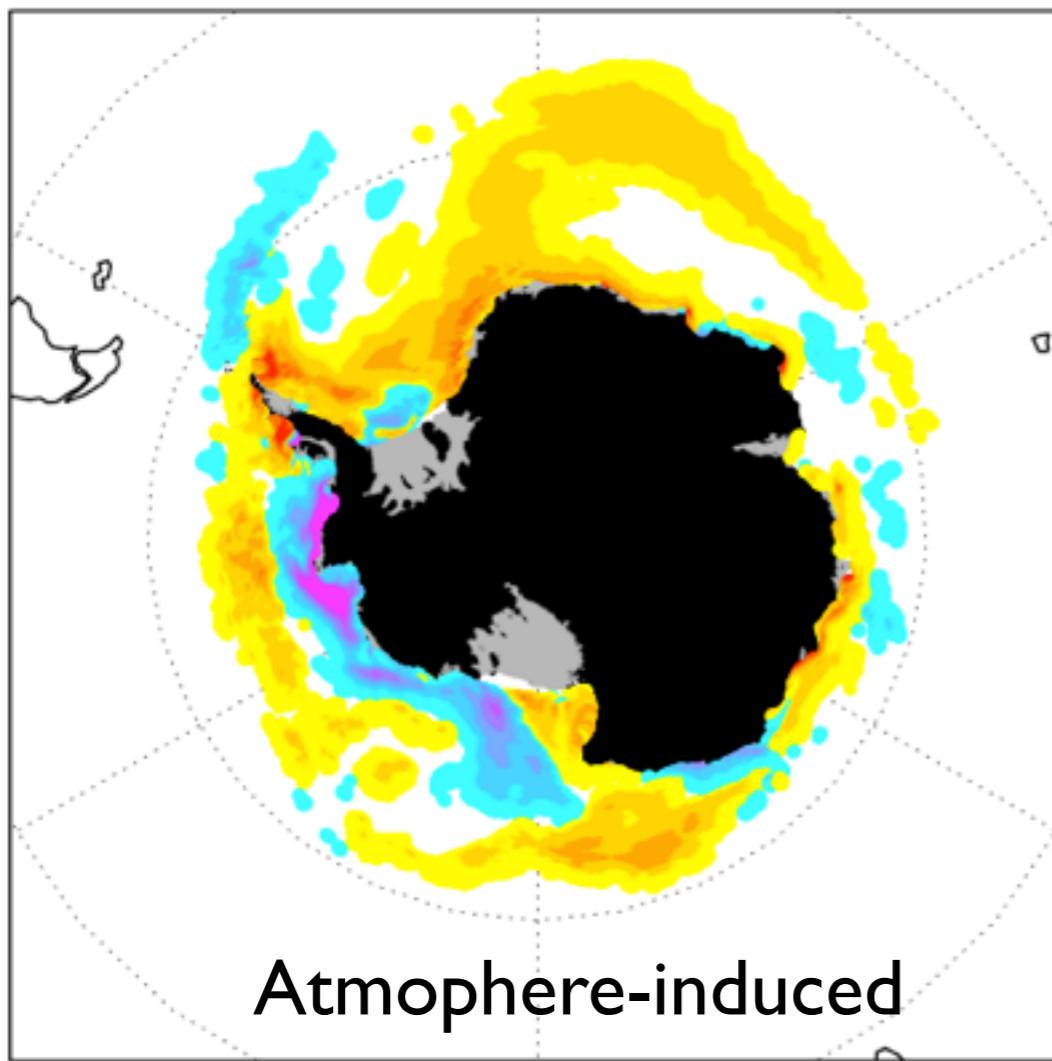
# Sea ice volume changes



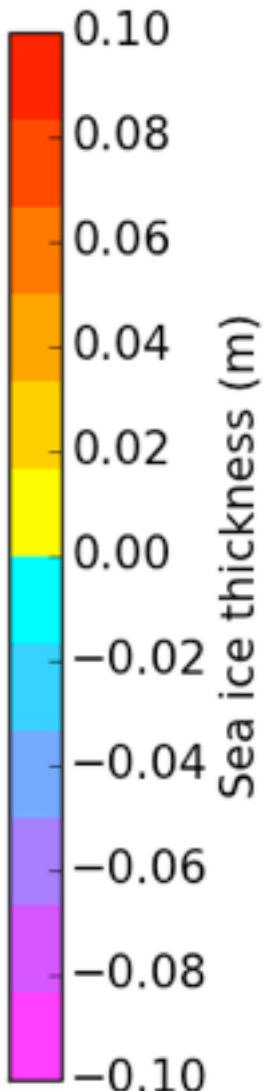
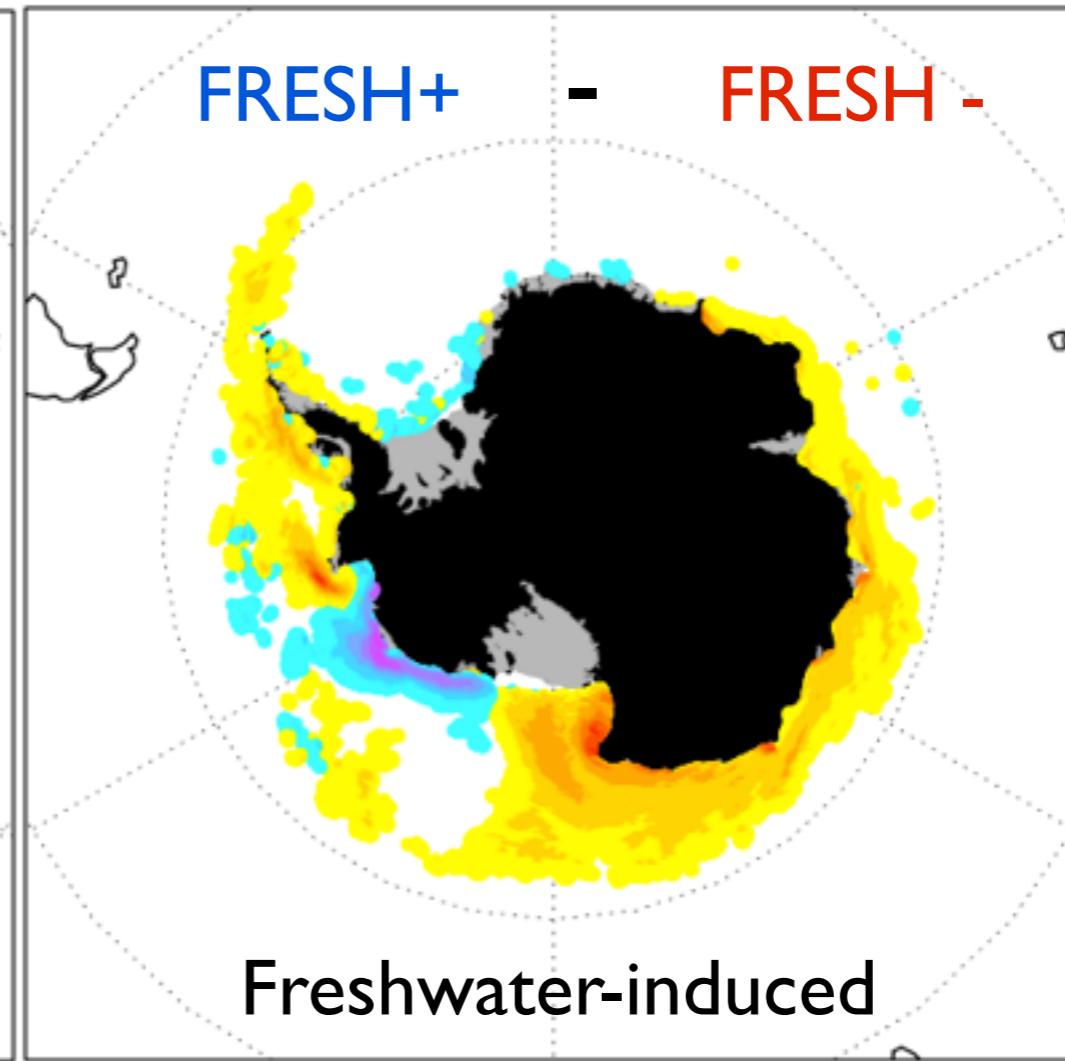
Freshwater induces significant regional changes in sea ice thickness

# Sea ice volume changes

**FW- vs ATM-**



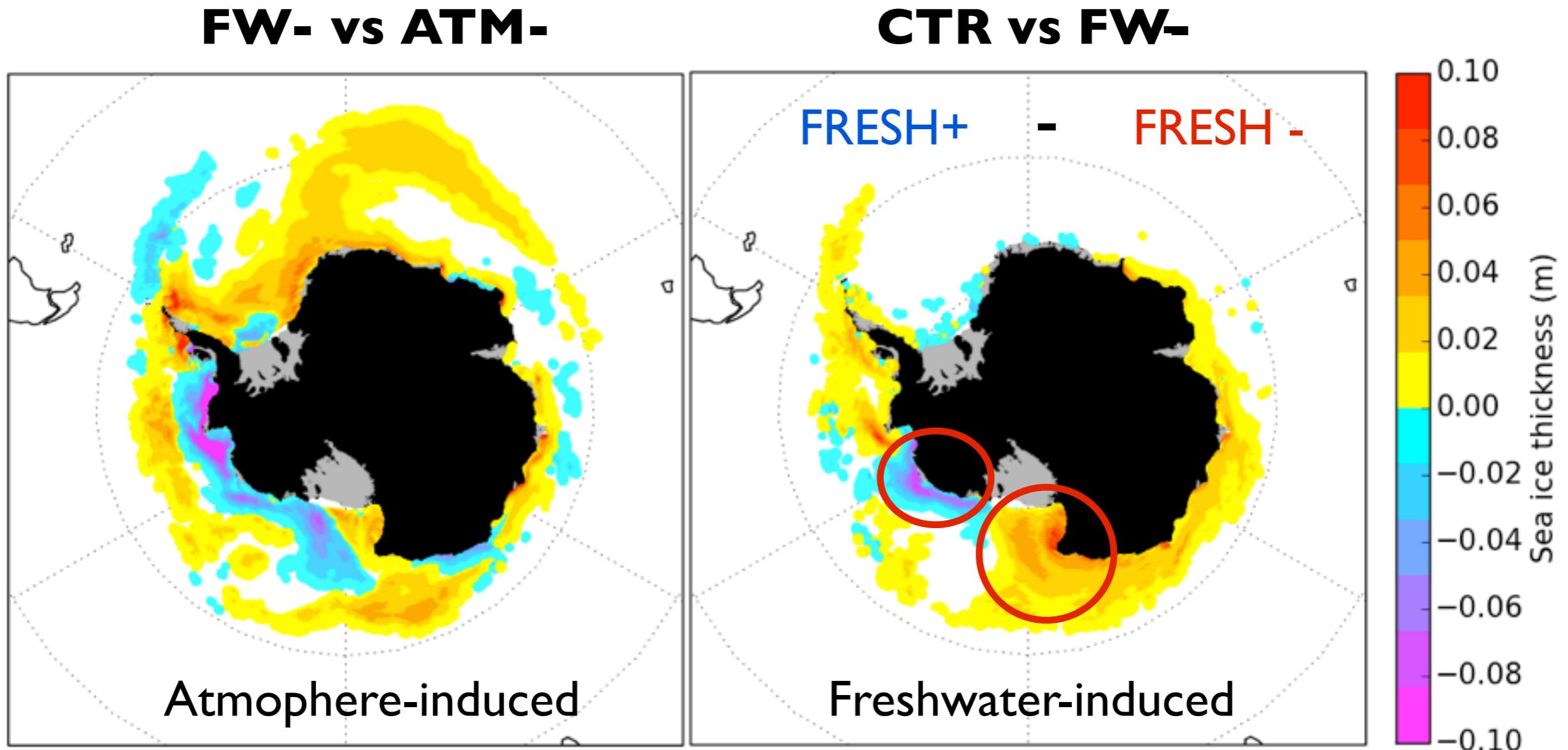
**CTR vs FW-**



Freshwater induces significant regional changes in sea ice thickness

**About 50% of global sea ice volume changes**

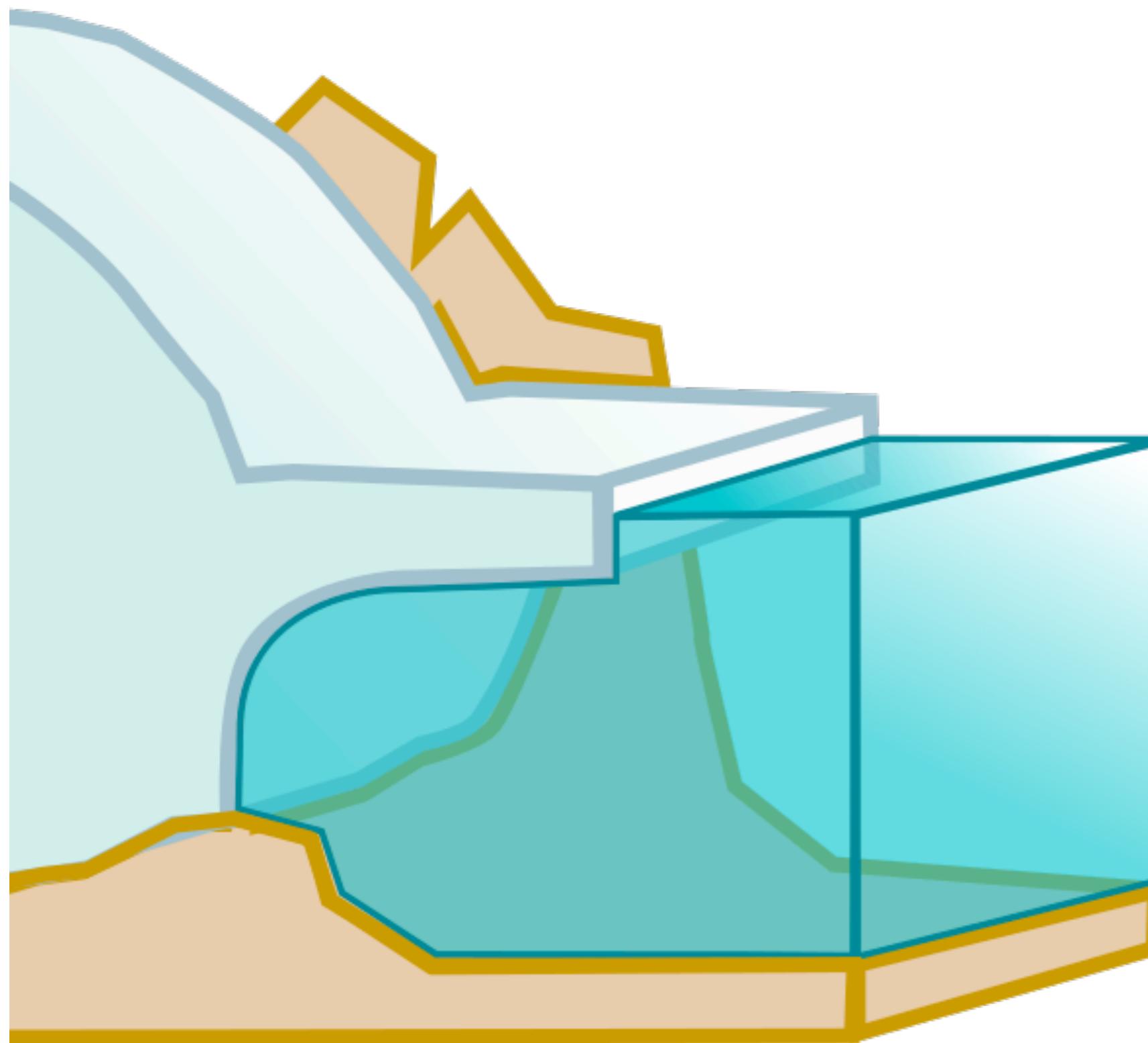
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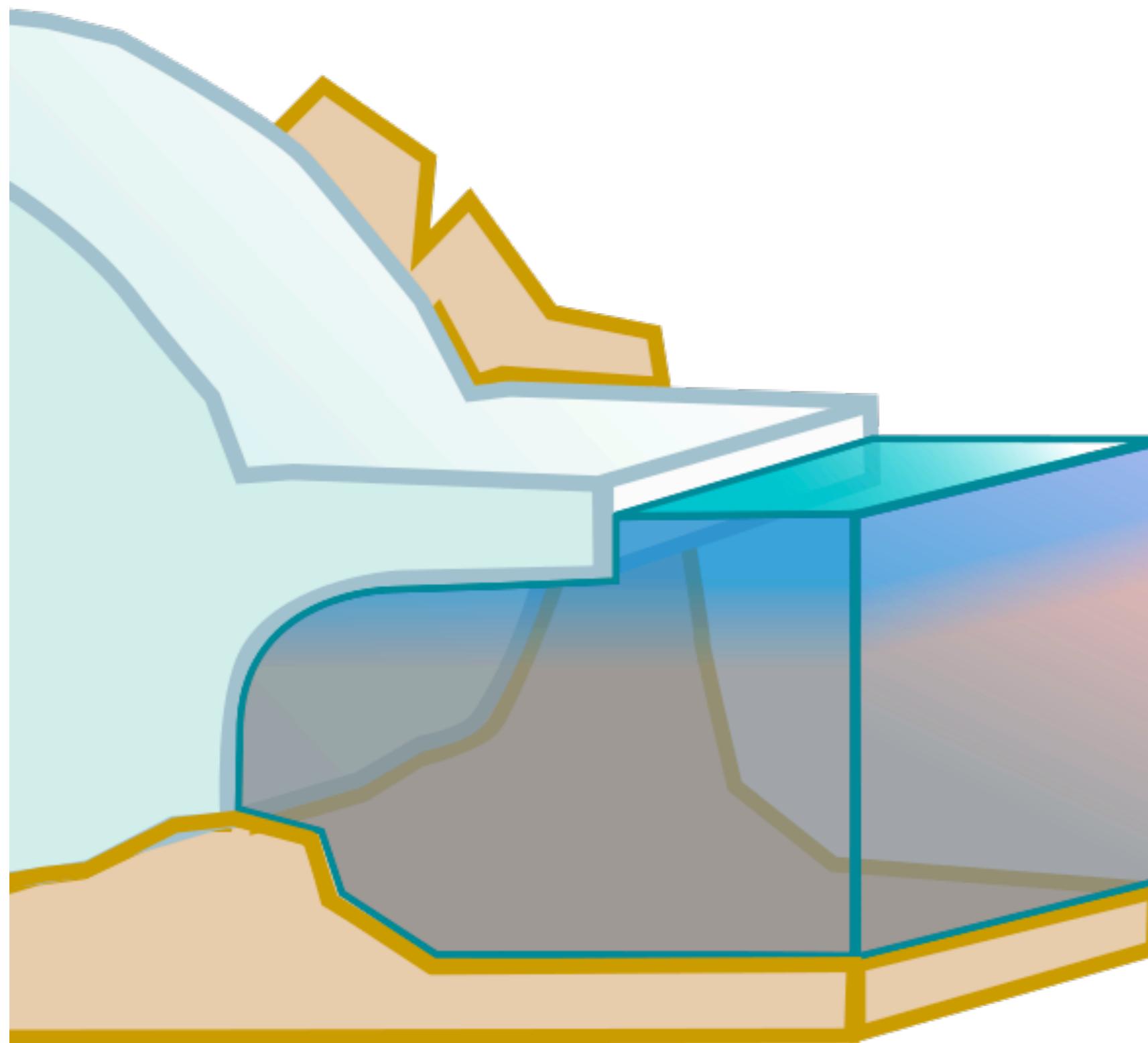
# Conjectured physical mechanisms explaining the response in Amundsen sea



*Amundsen*  
Warm sub-surface  
+  
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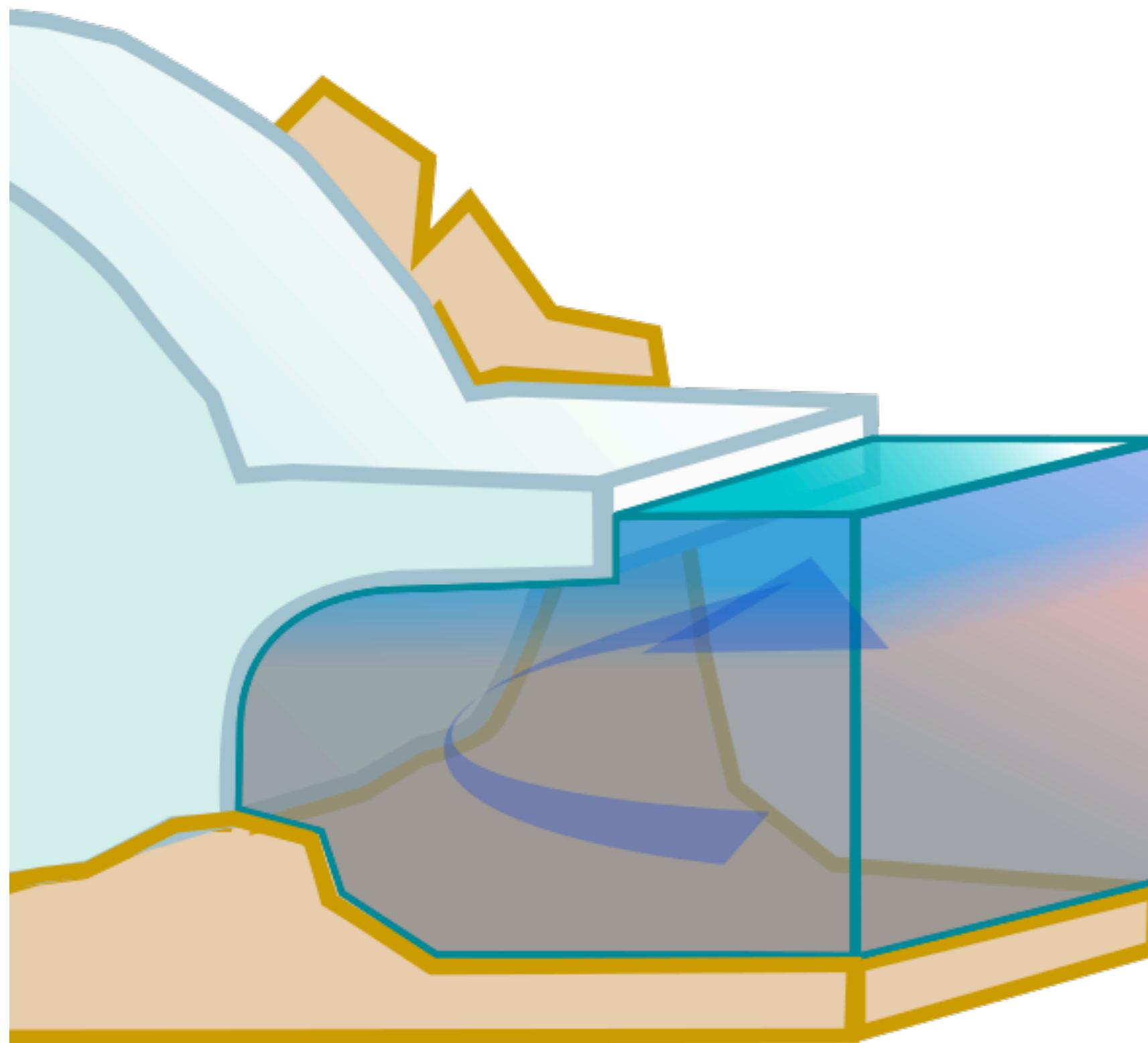
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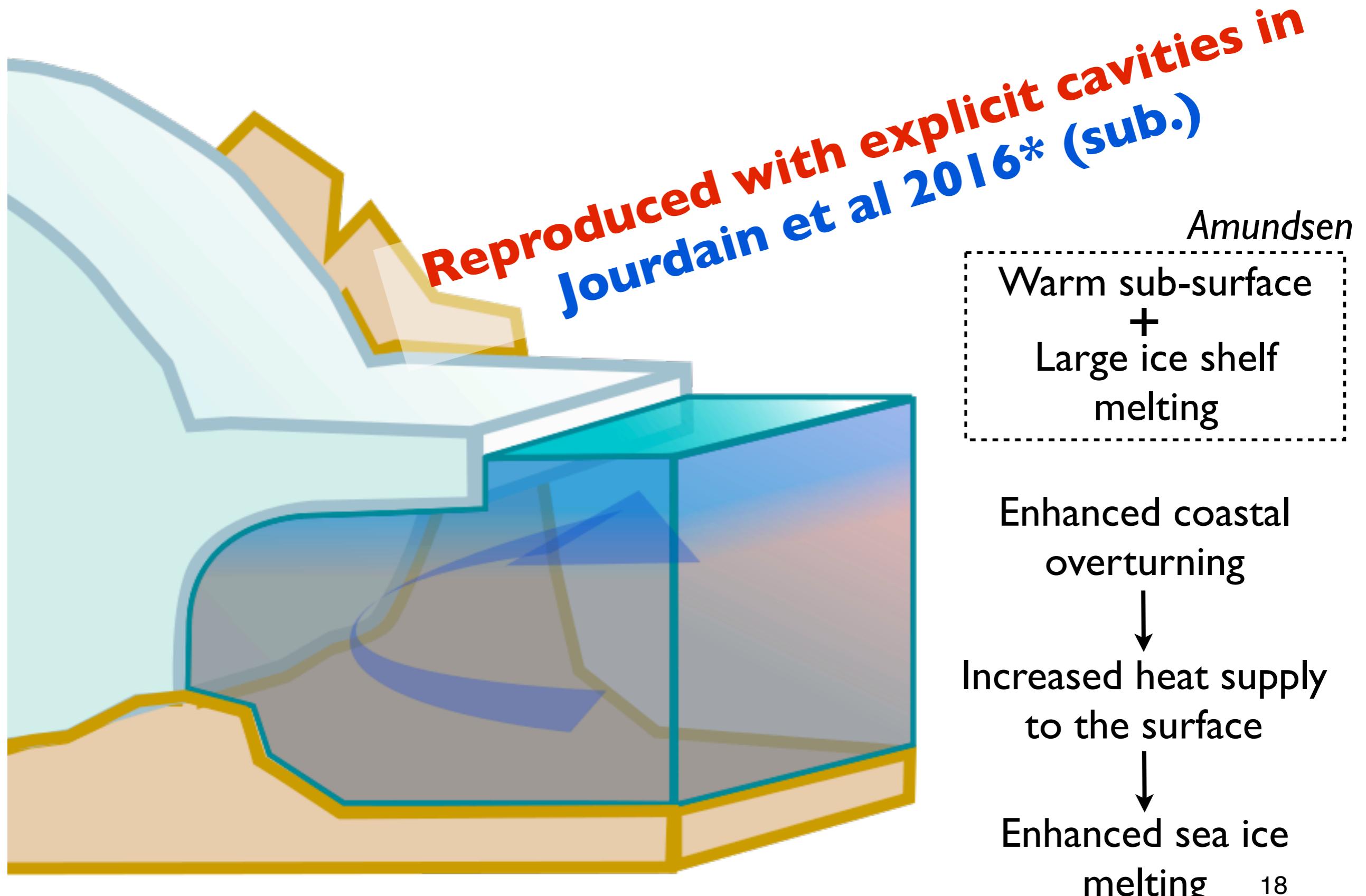
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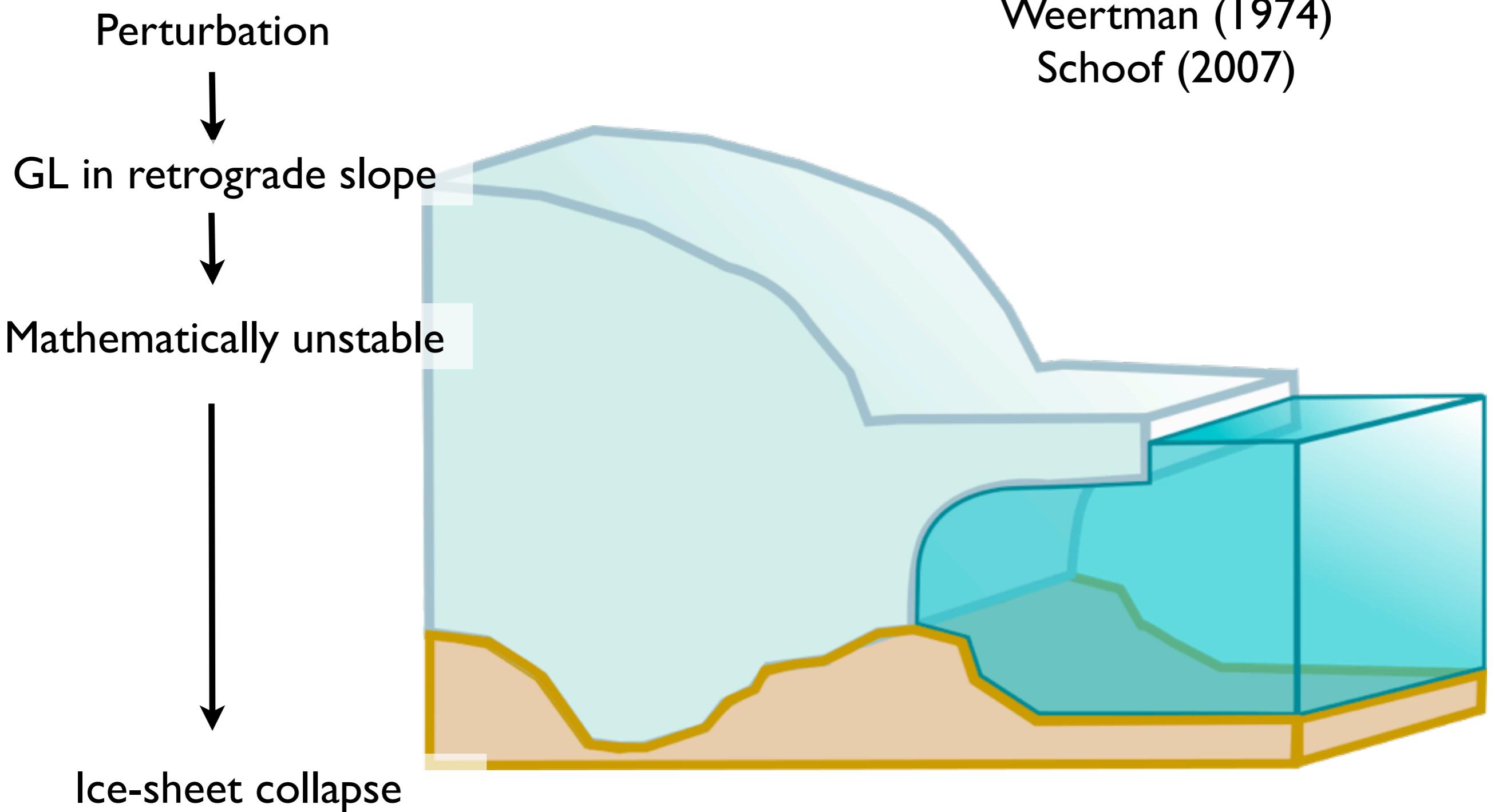
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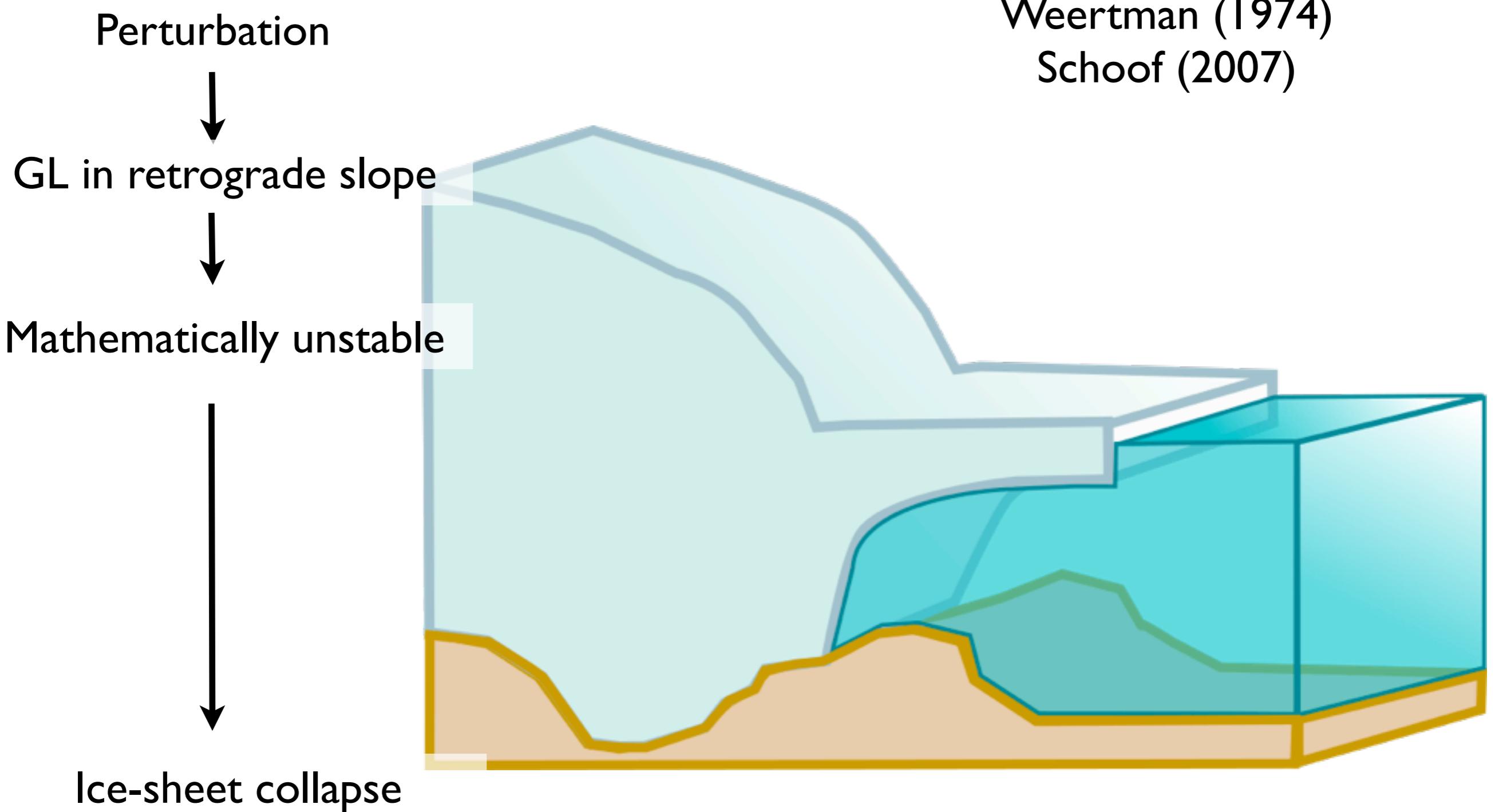
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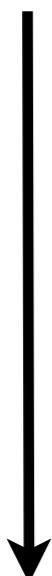
Perturbation



GL in retrograde slope

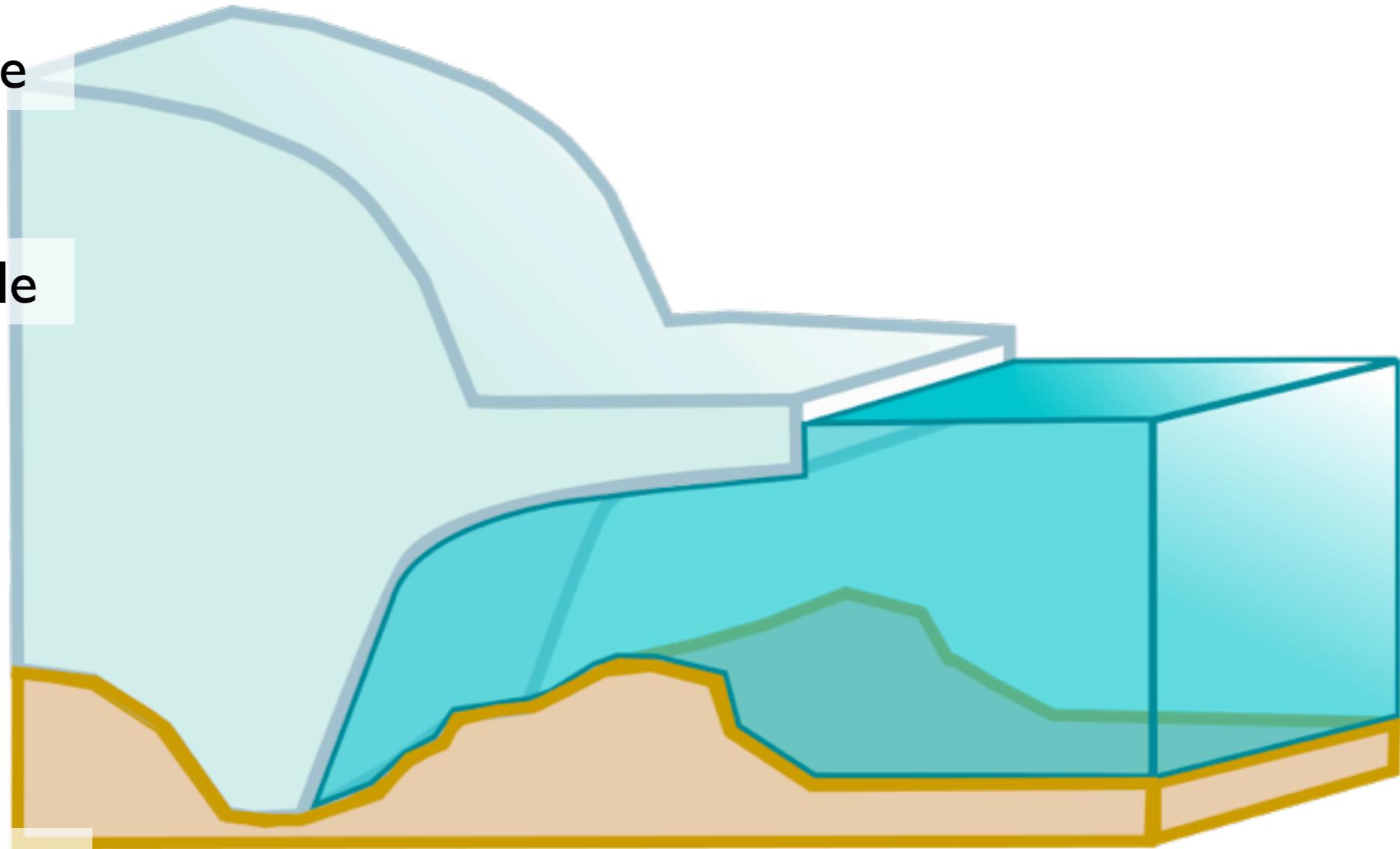


Mathematically unstable



Weertman (1974)

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Ice-sheet collapse

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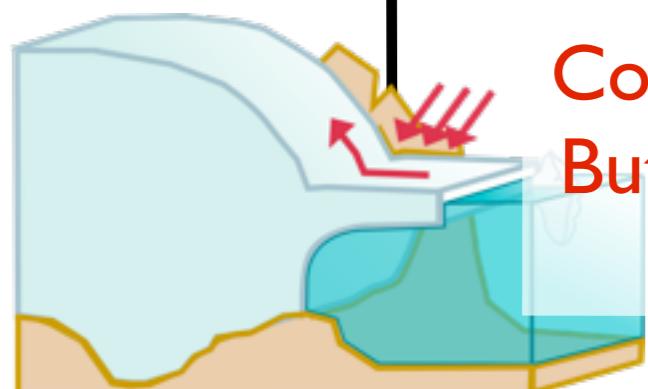


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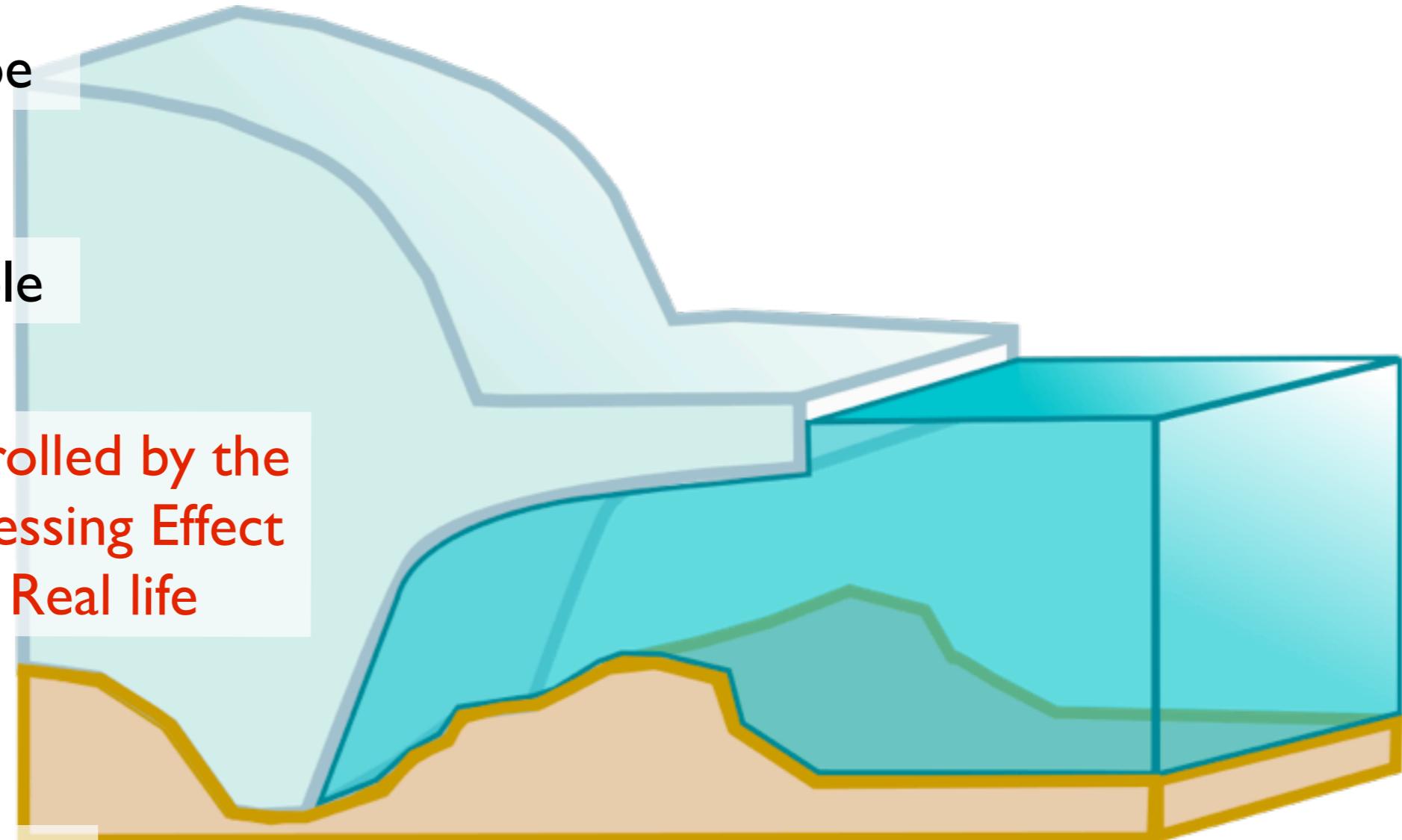
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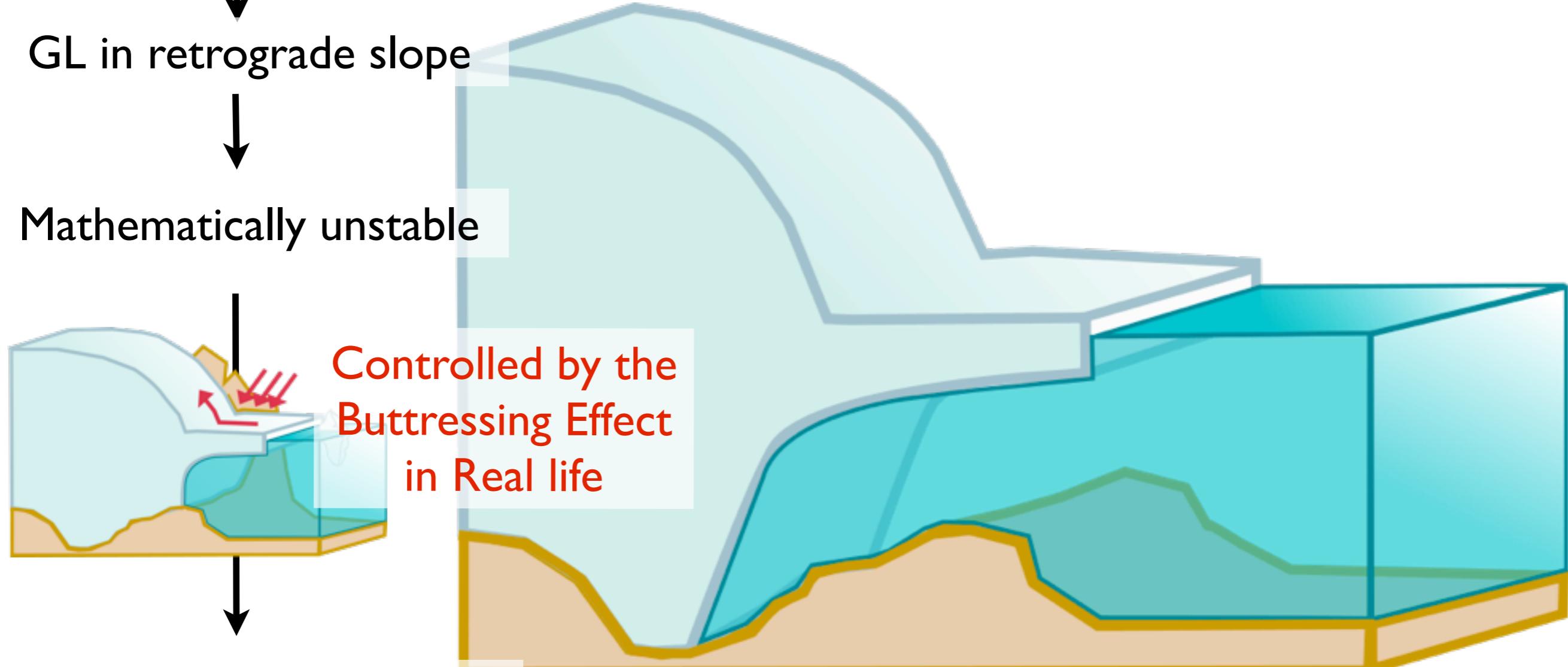
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**Critical for freshwater fluxes: Ice-sheet model uncertainties in MISI configurations**<sup>20</sup>

# Marine Ice Sheet Models

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## Fundamentals of ice-sheet models

(ex : ELMER/Ice)

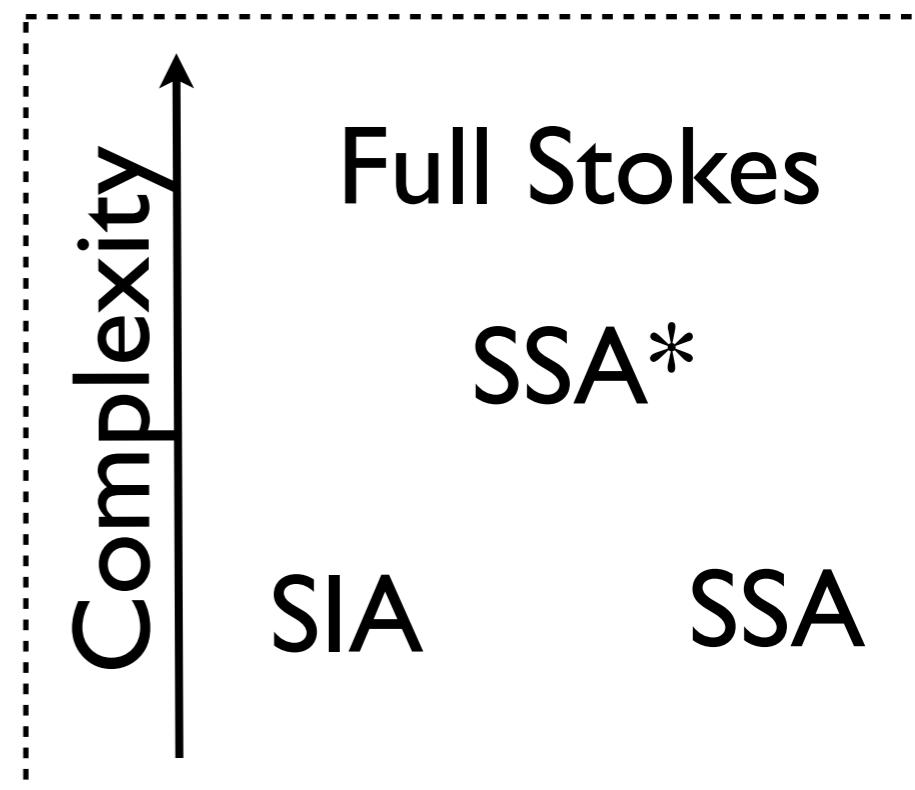
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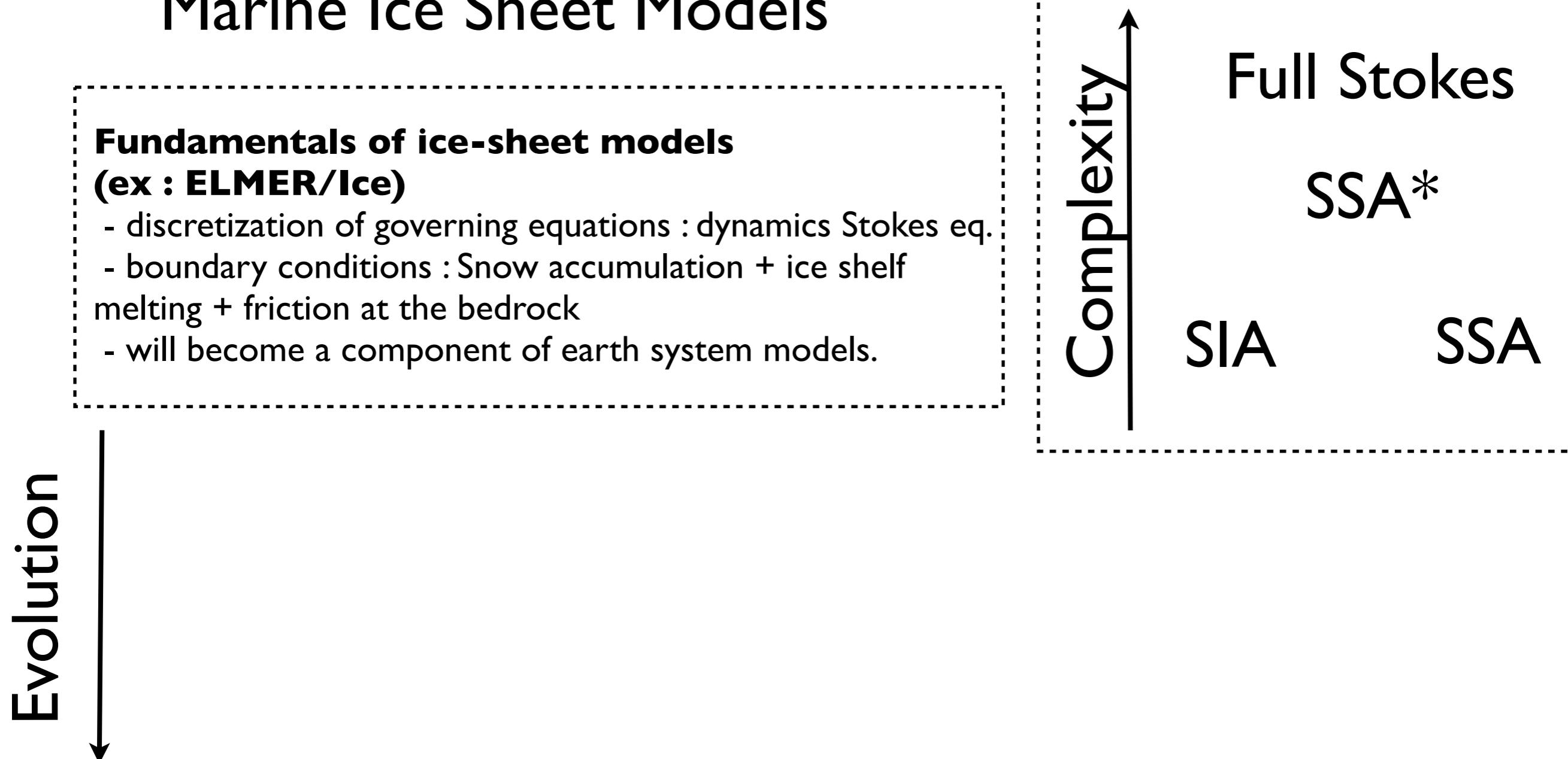
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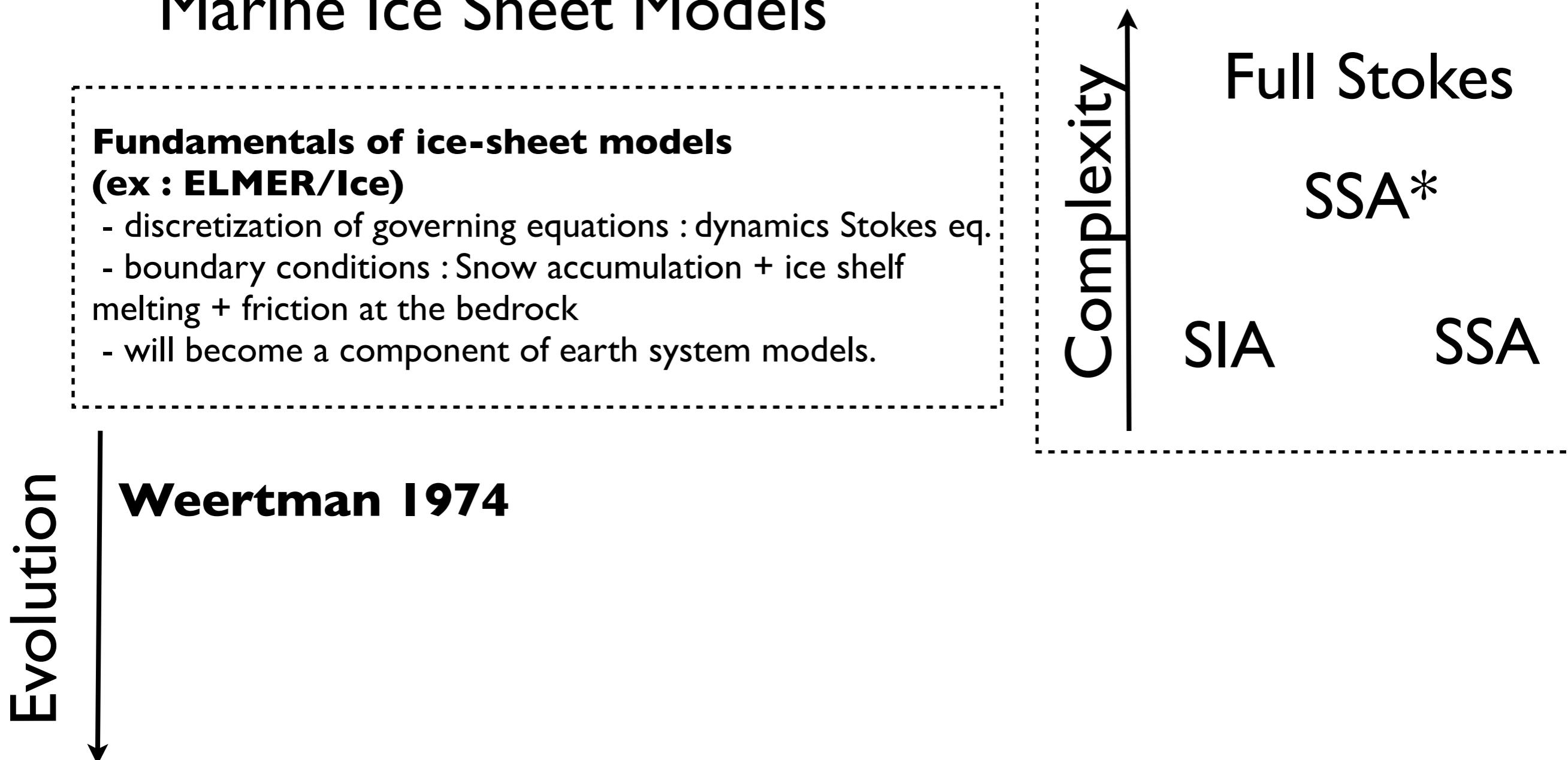
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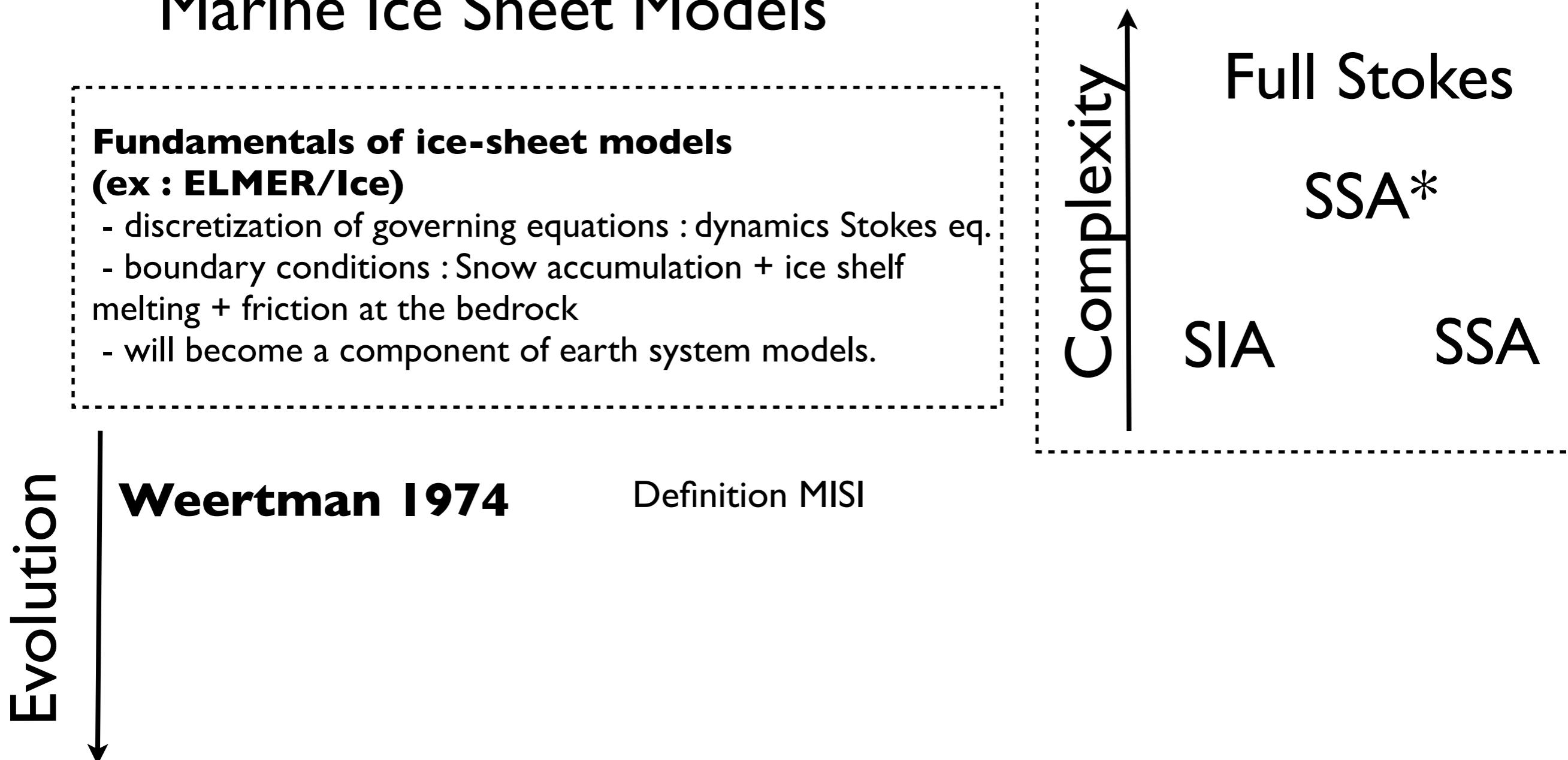
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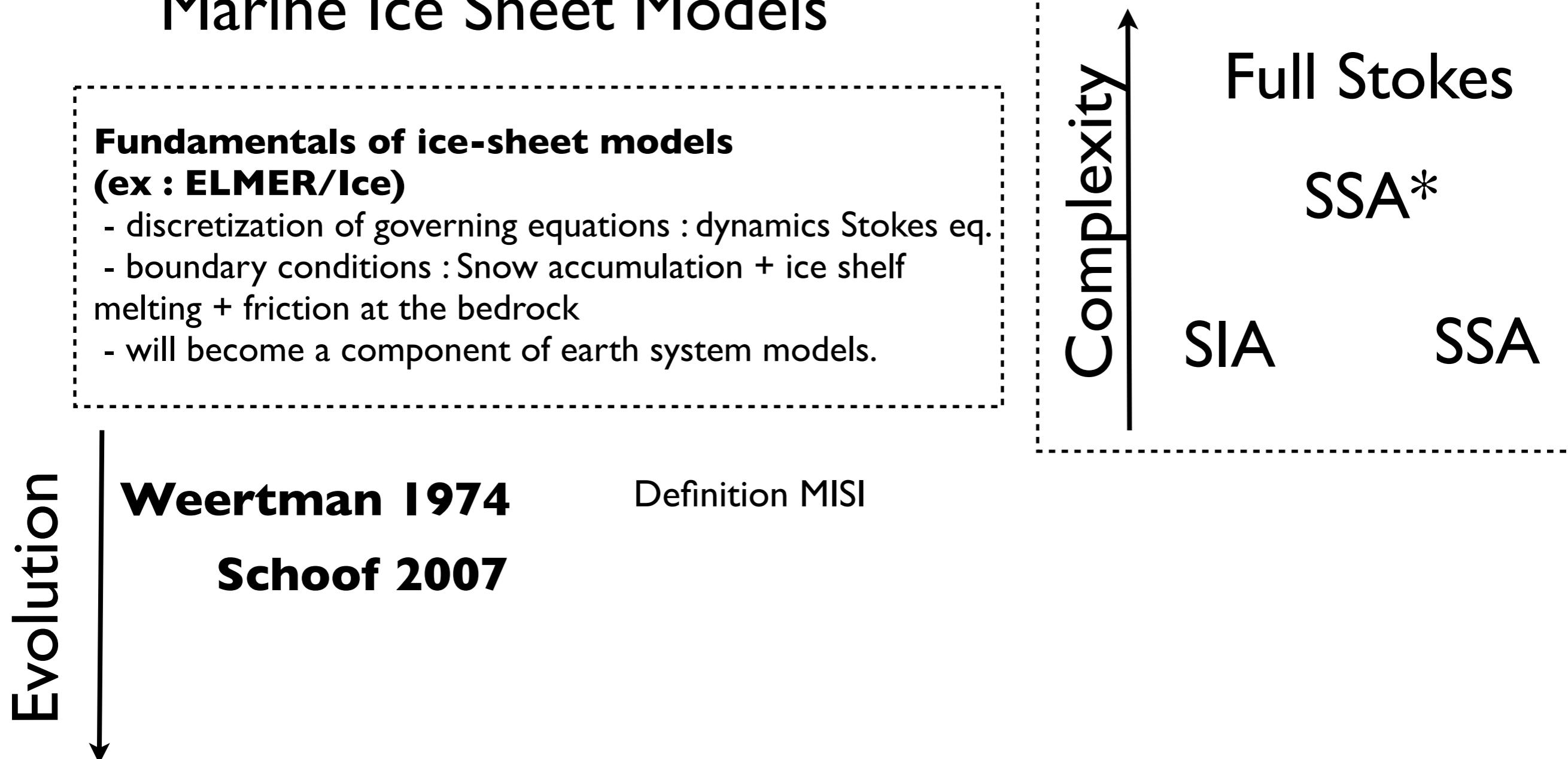
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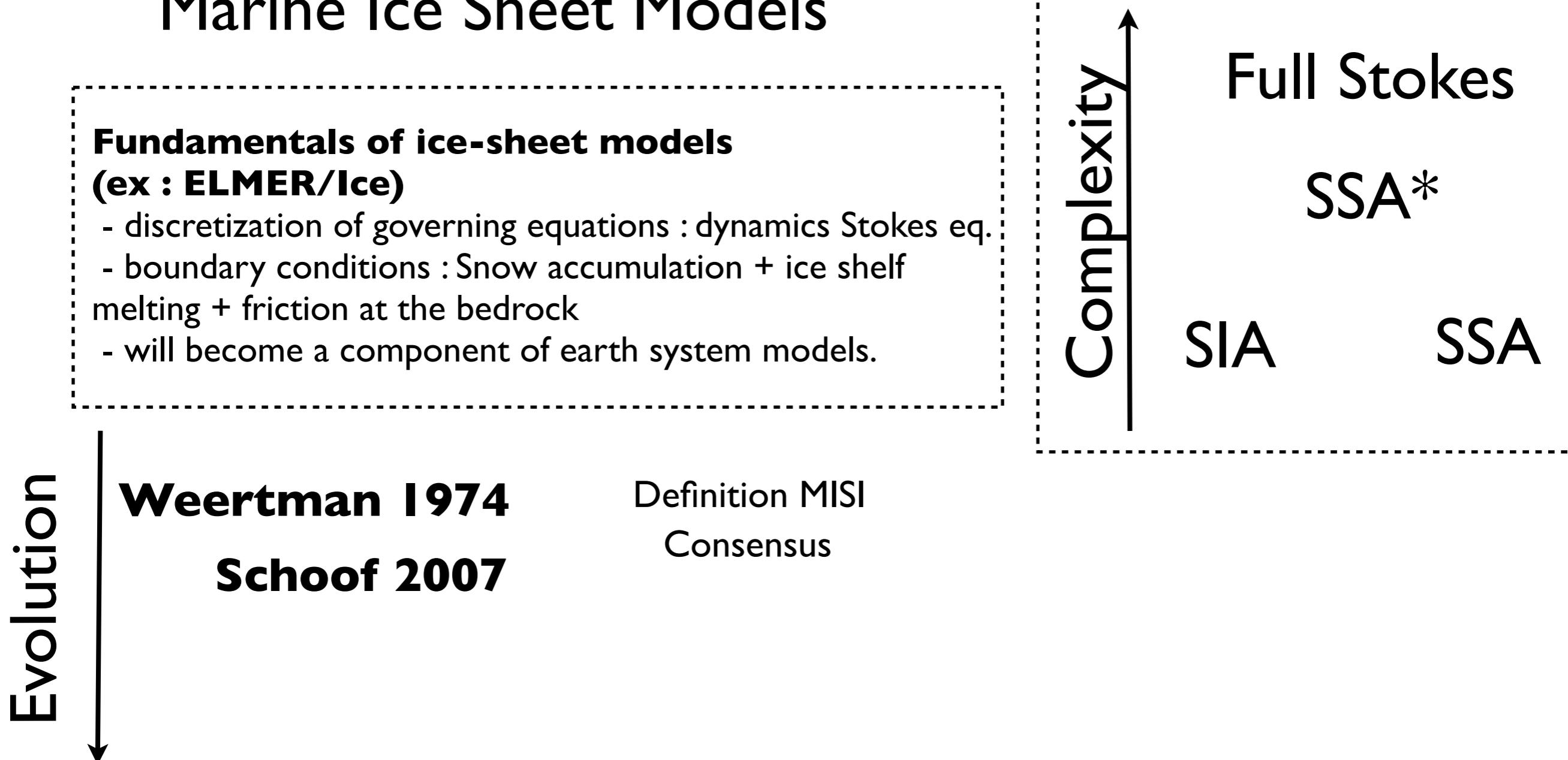
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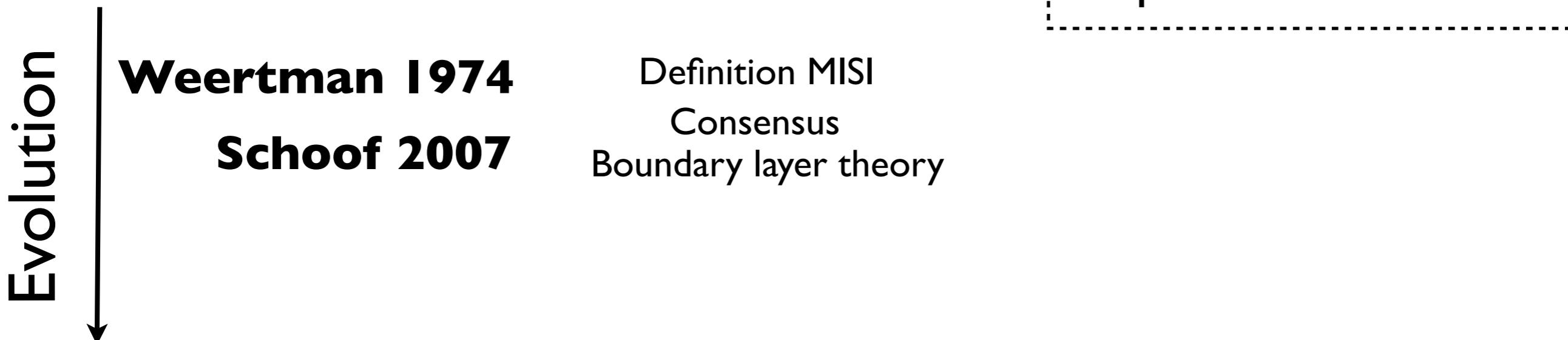


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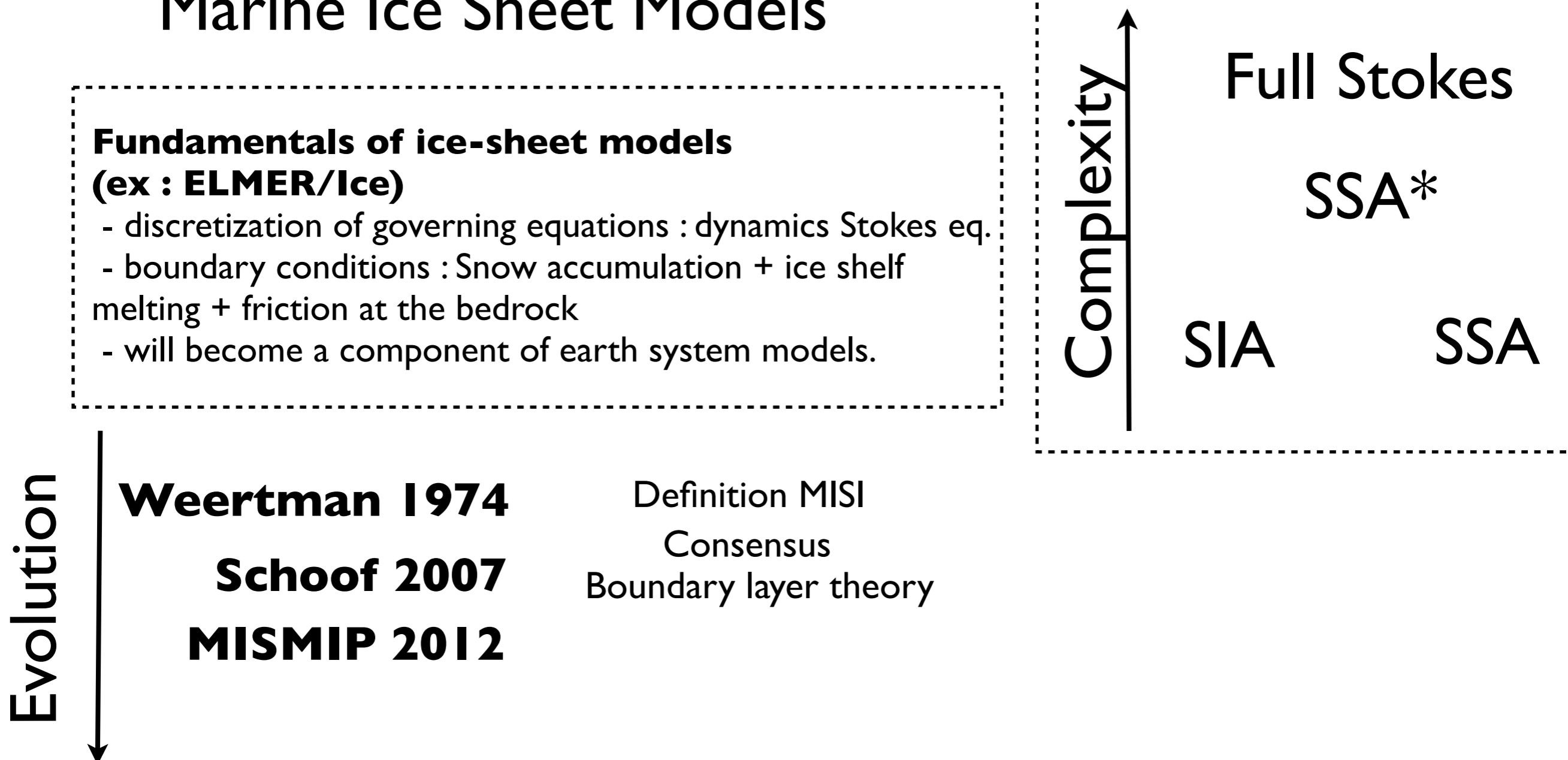
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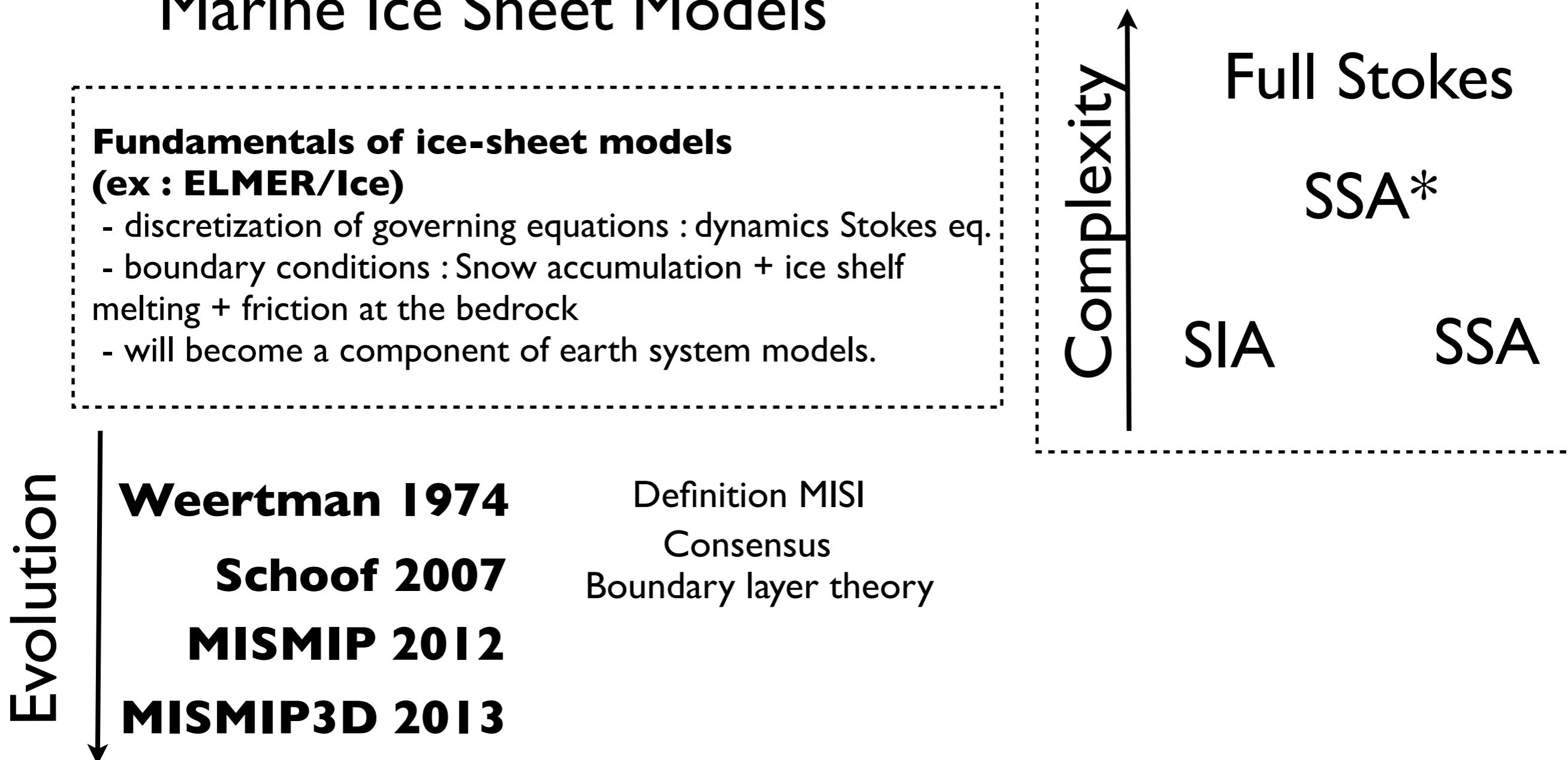
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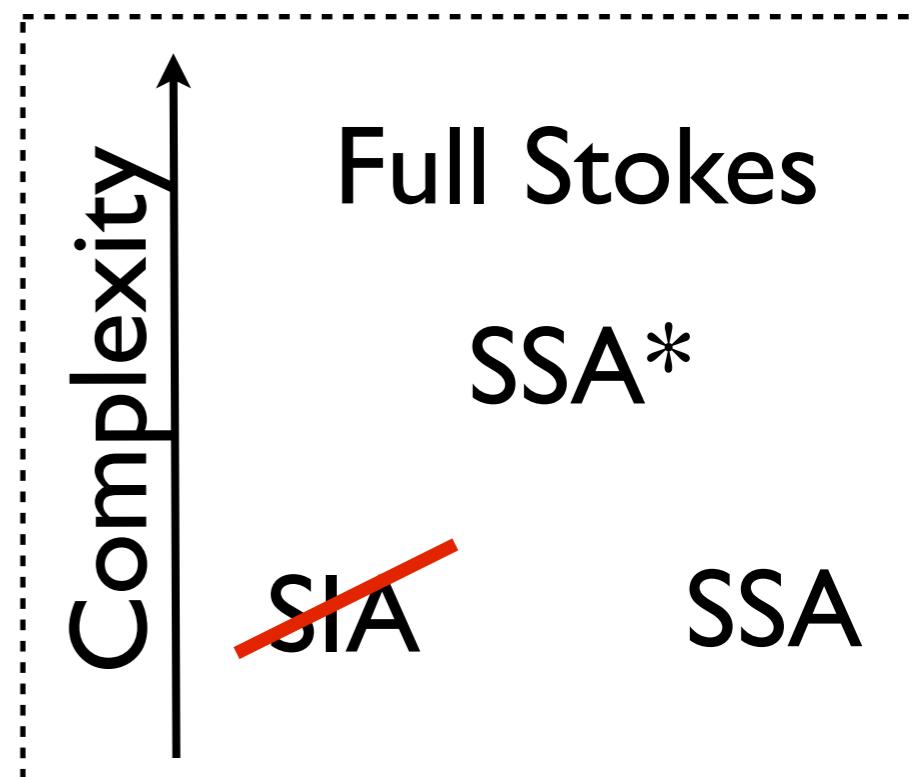
Evolution ↓

**Weertman 1974**  
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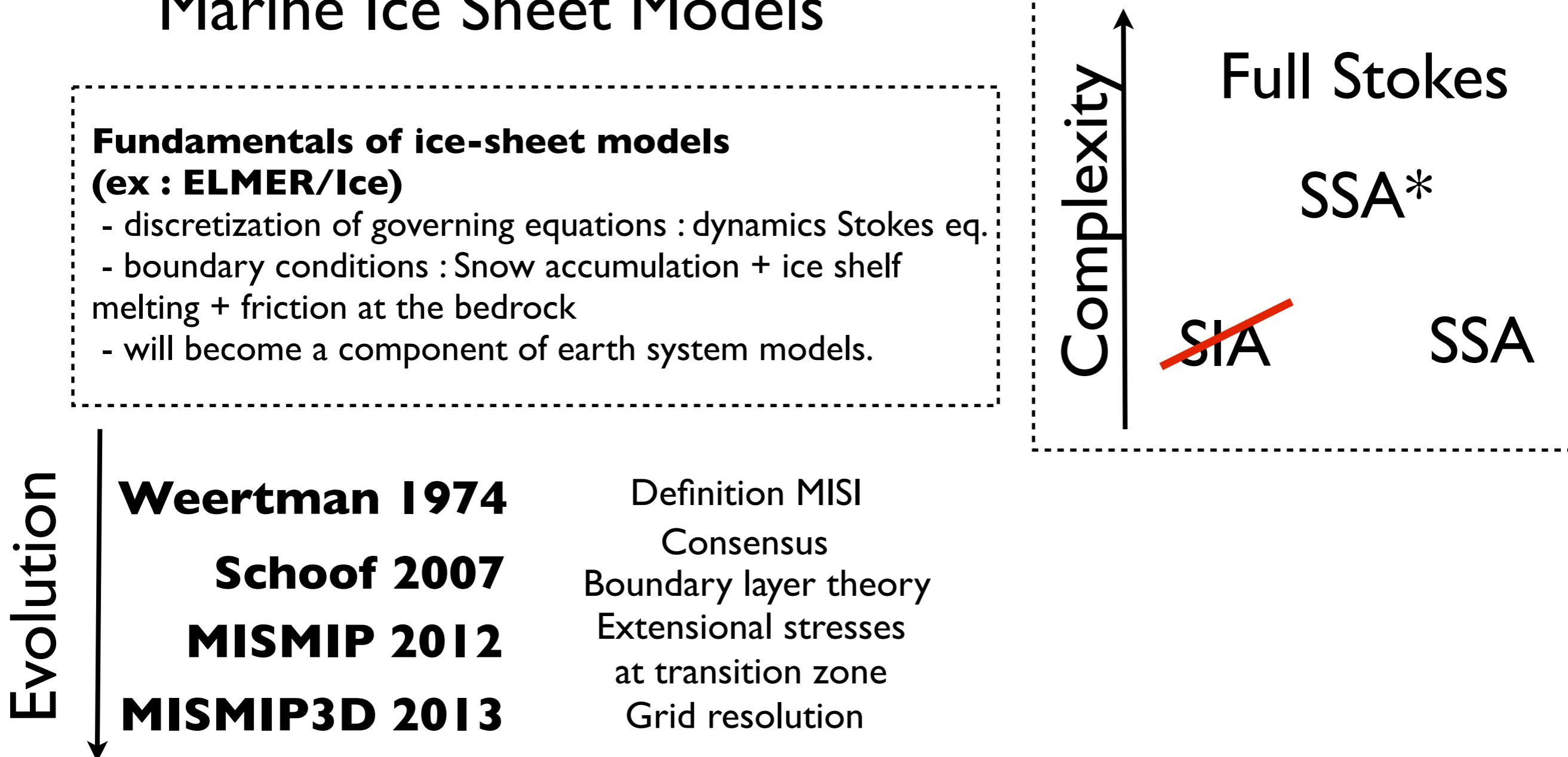
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Consensus  
Boundary layer theory  
Extensional stresses  
at transition zone  
Grid resolution

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**Debate and open questions following MISMIP and MISMIP3D:**

- Importance of realistic buttressing effect
- Importance of ocean-driven retreat perturbations
- Sensitivity to the approximation of Stokes equation
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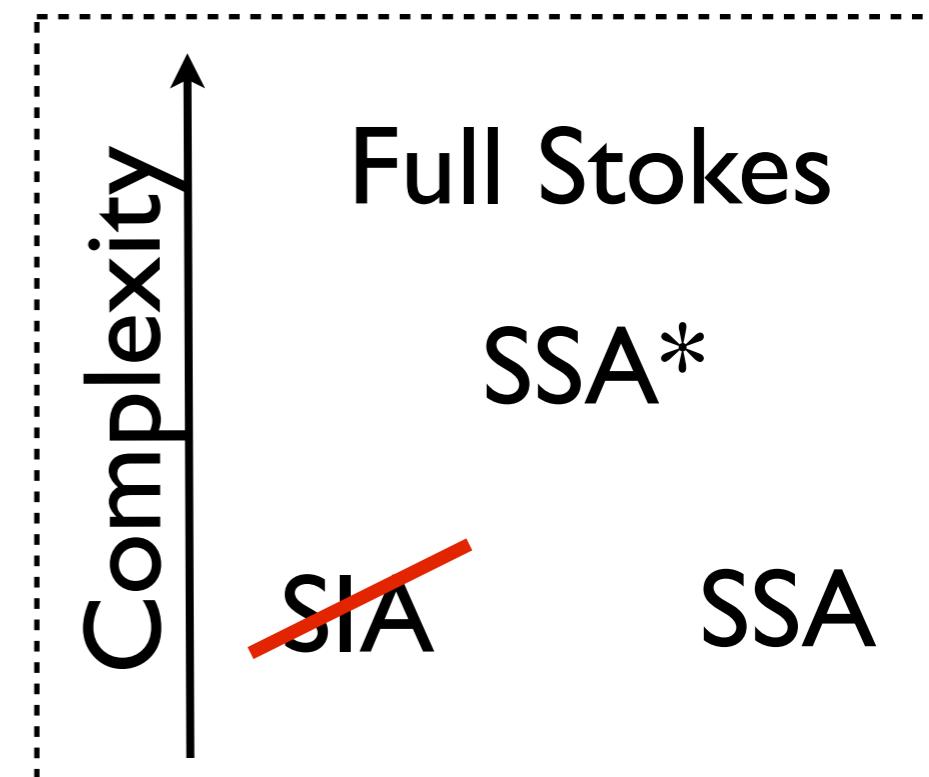
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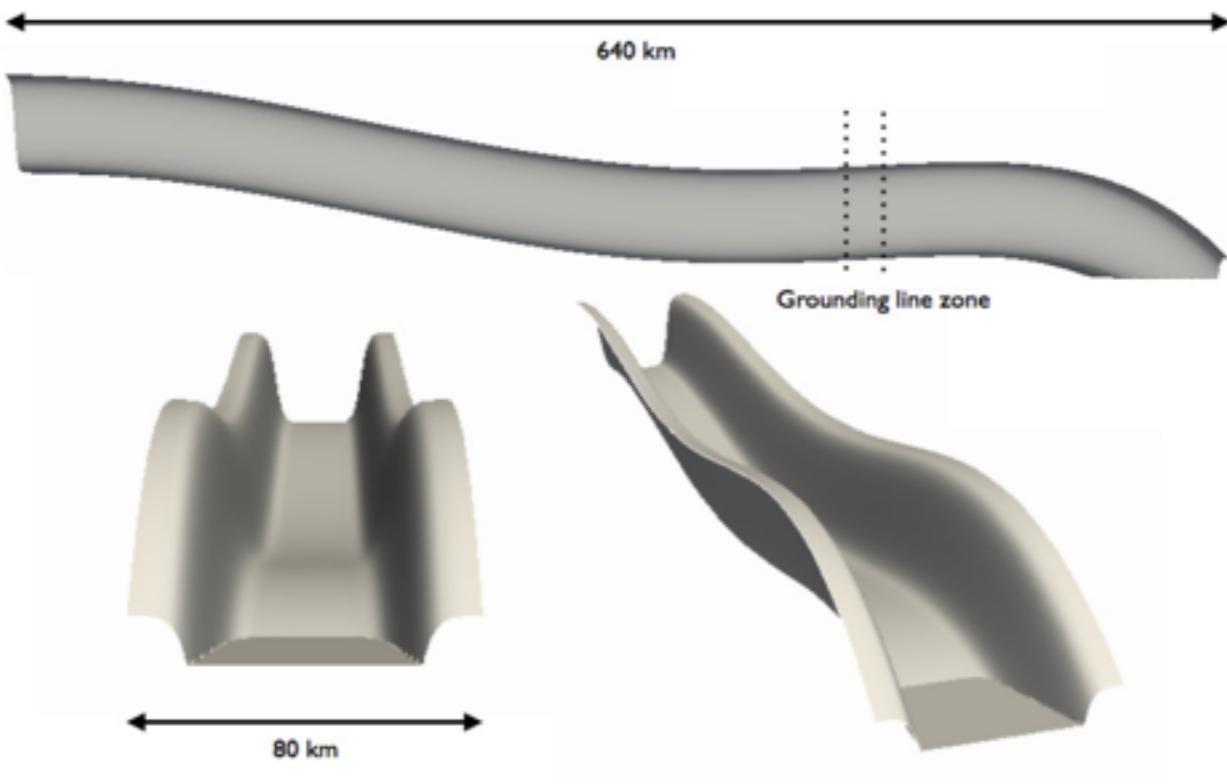
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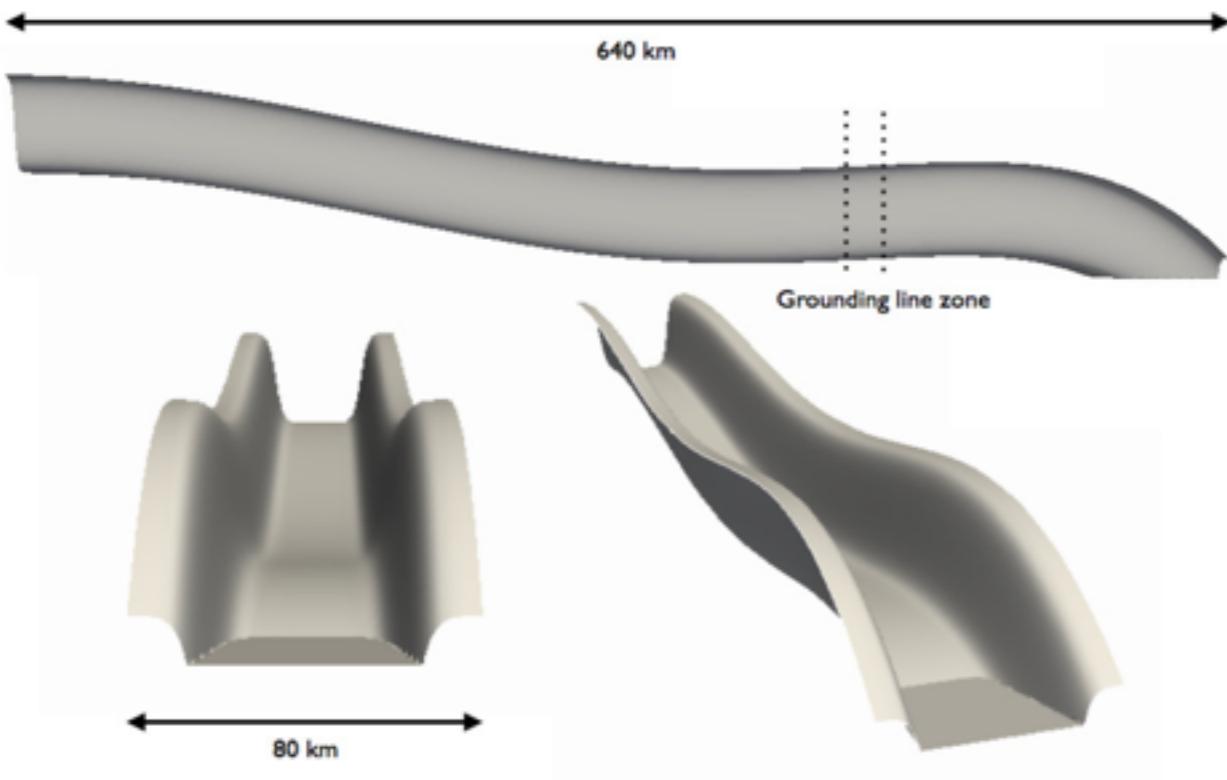
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MISI-sensitive geometry  
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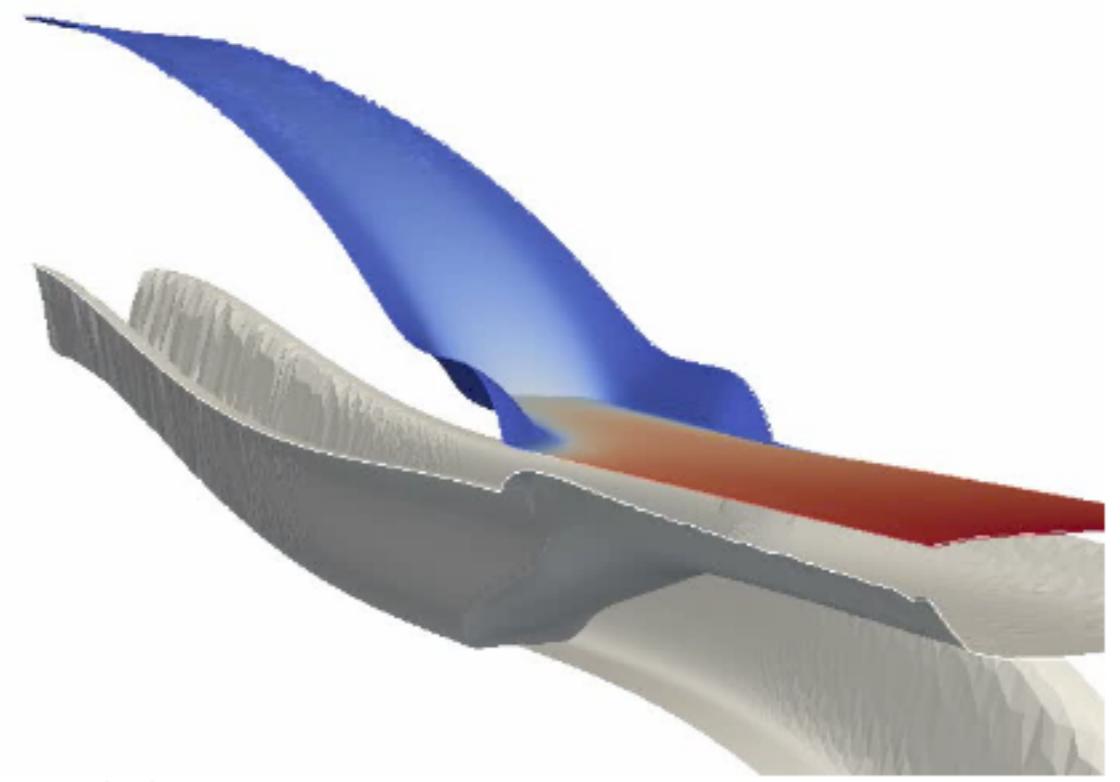
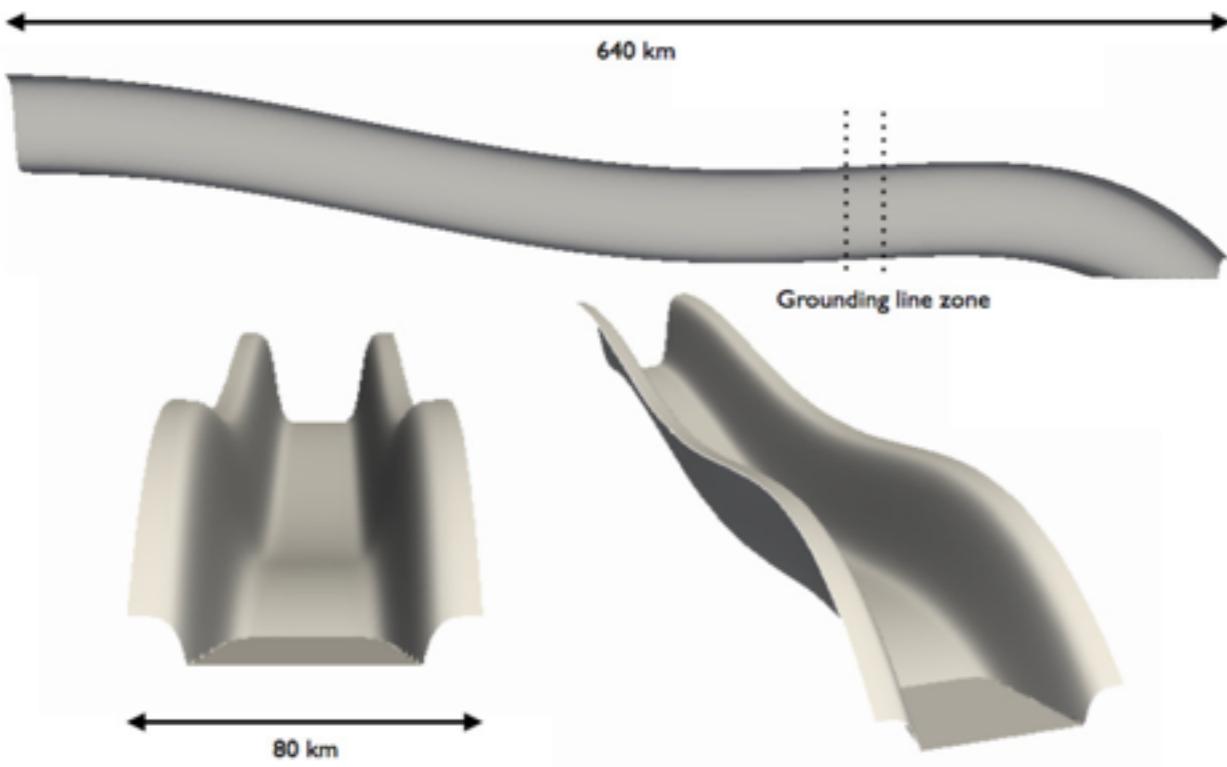


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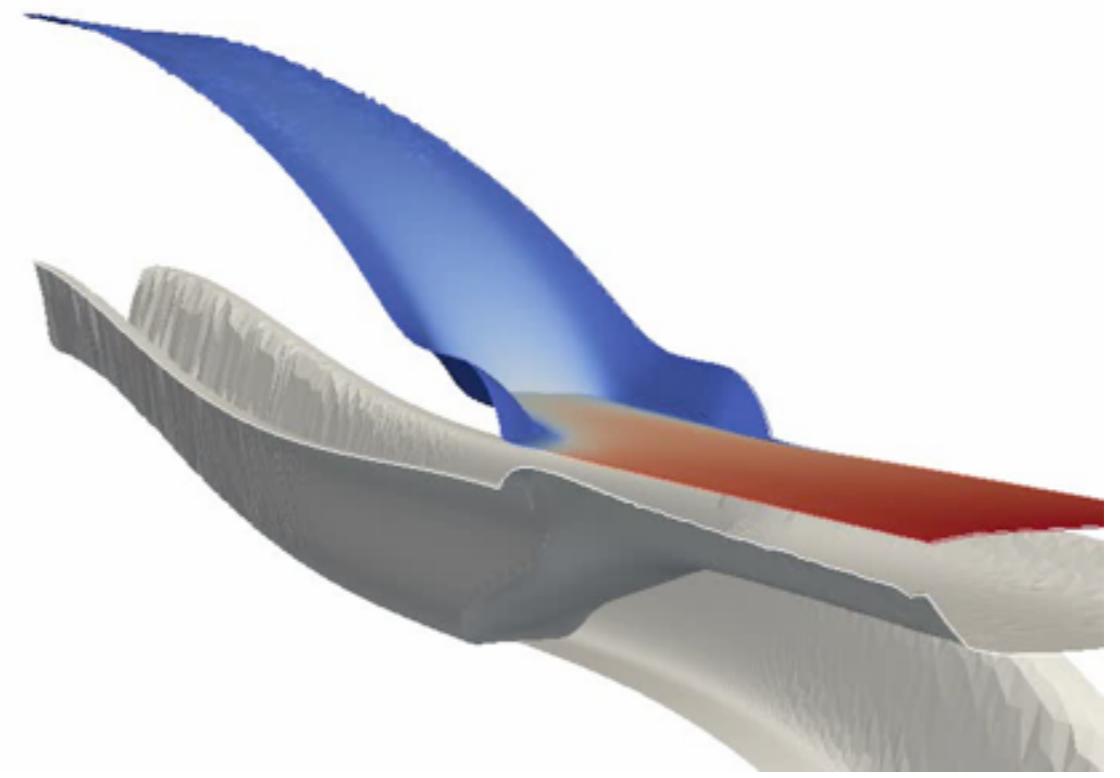
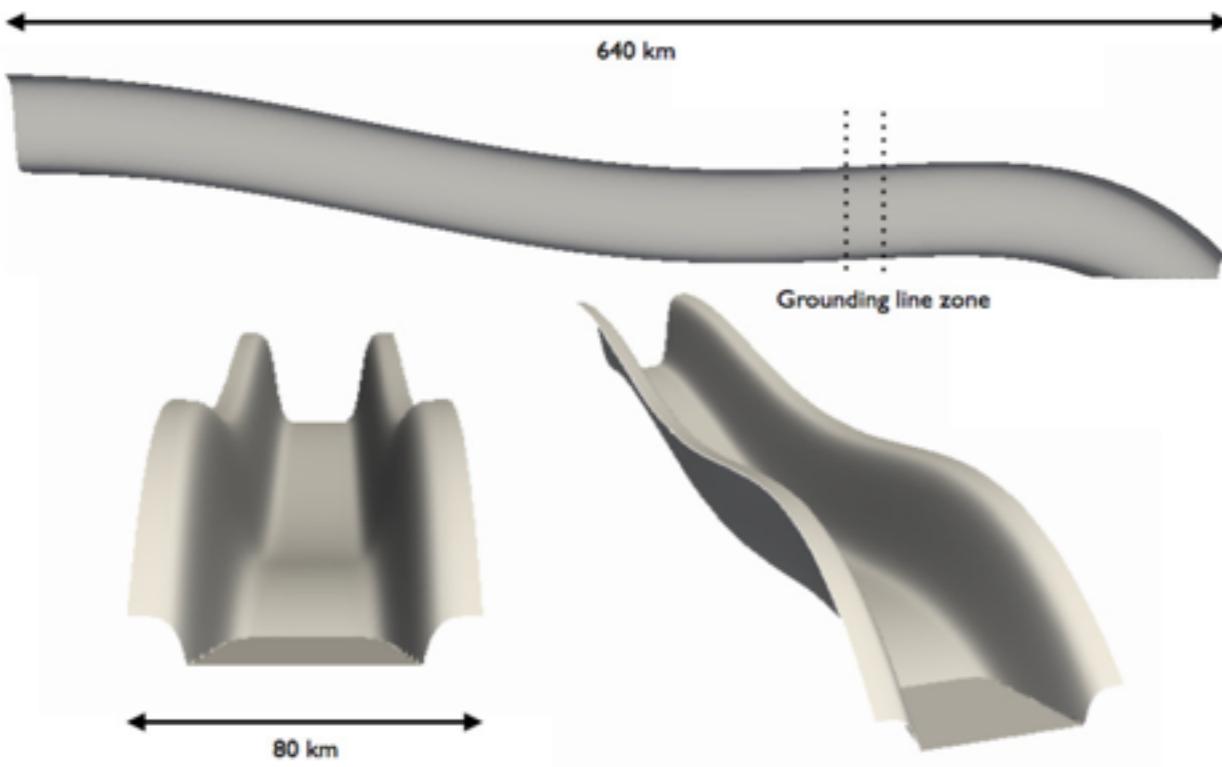


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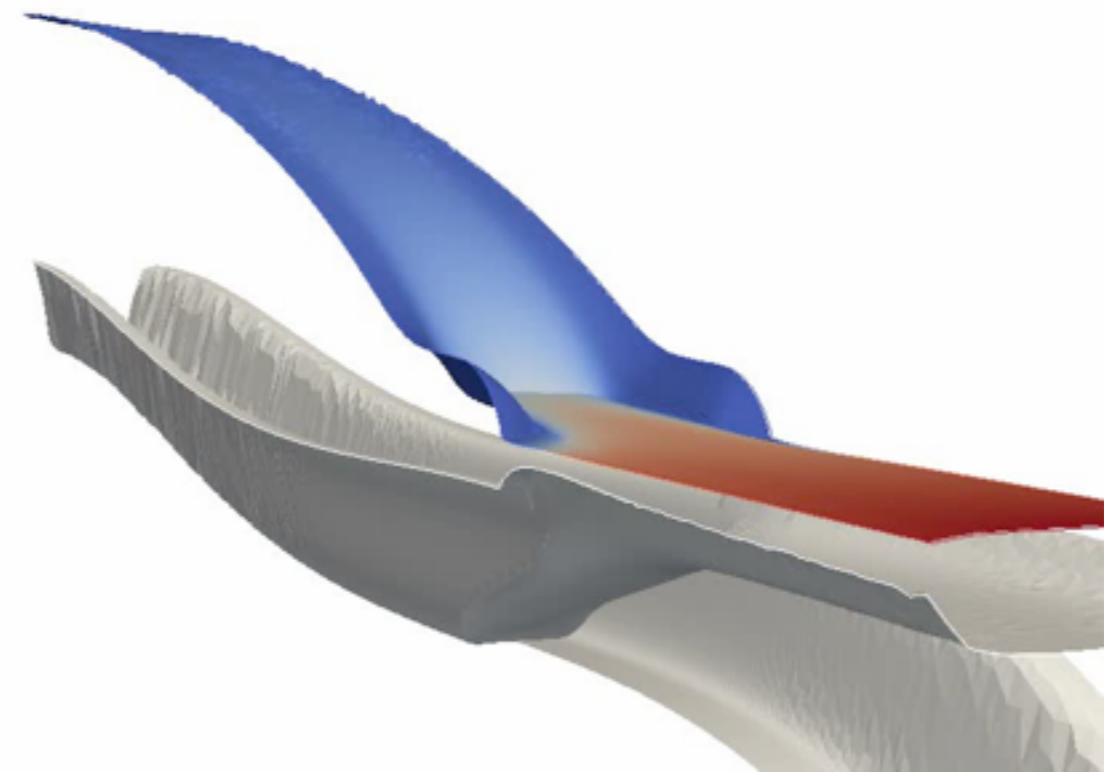
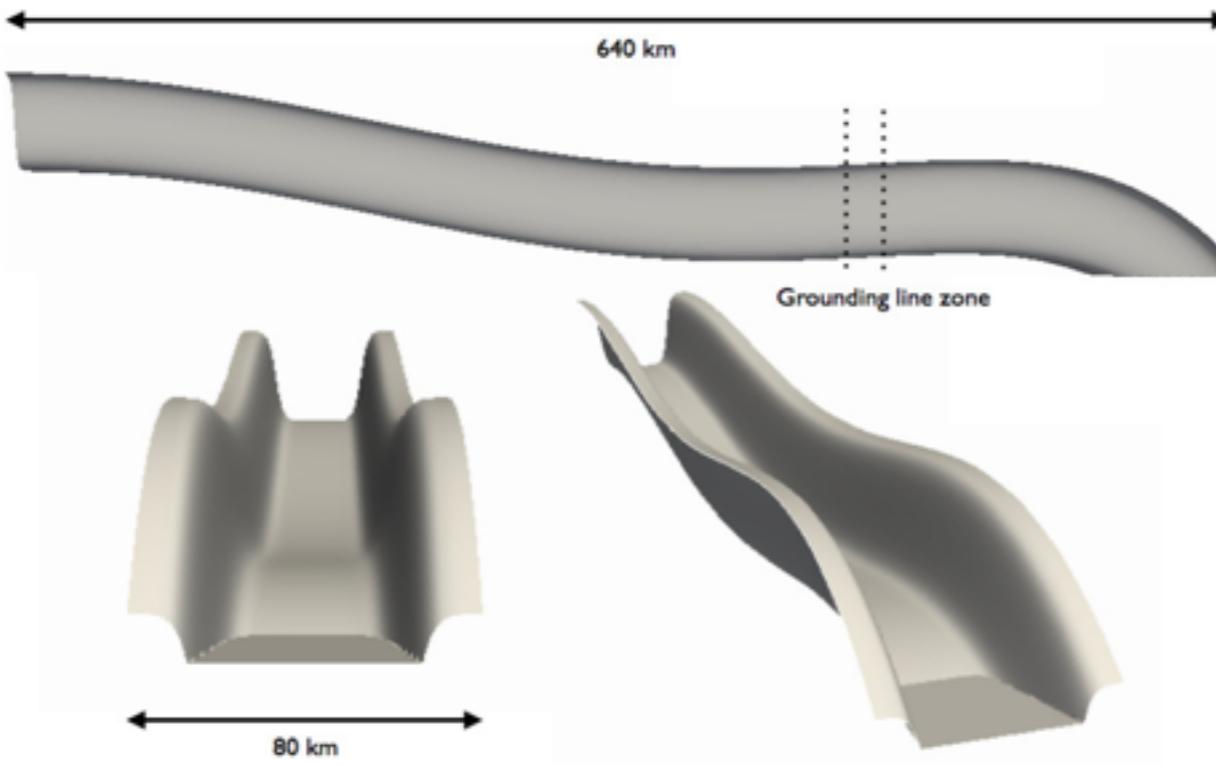


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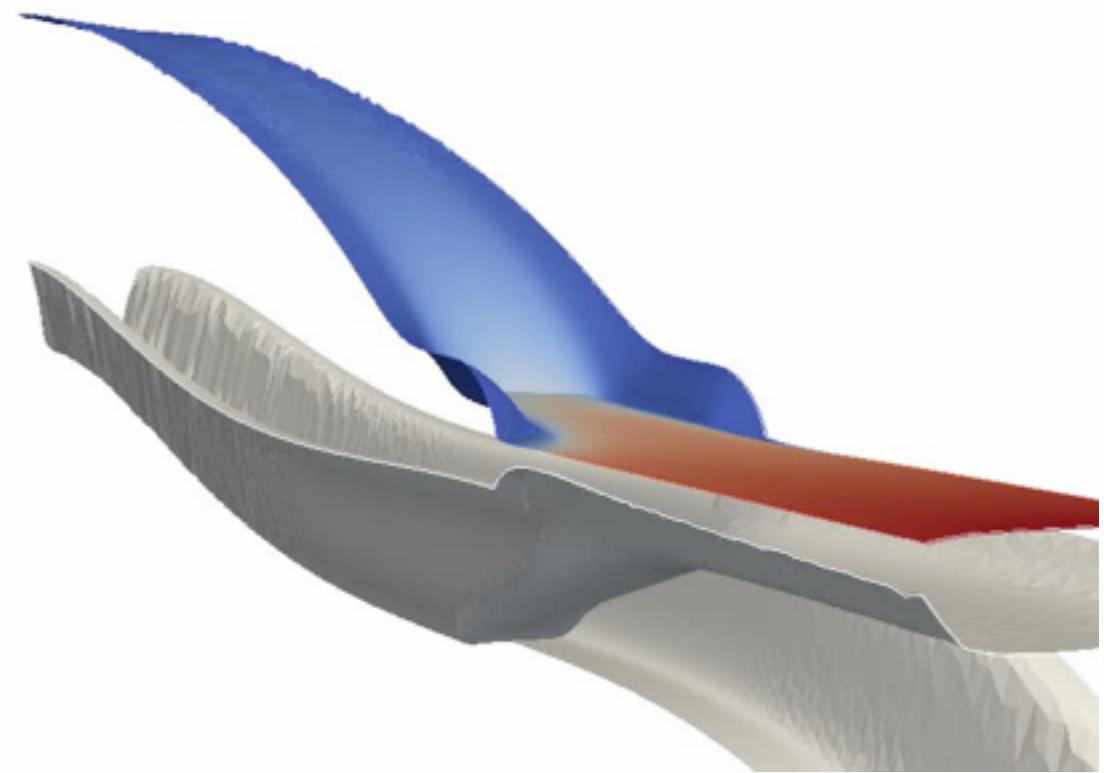
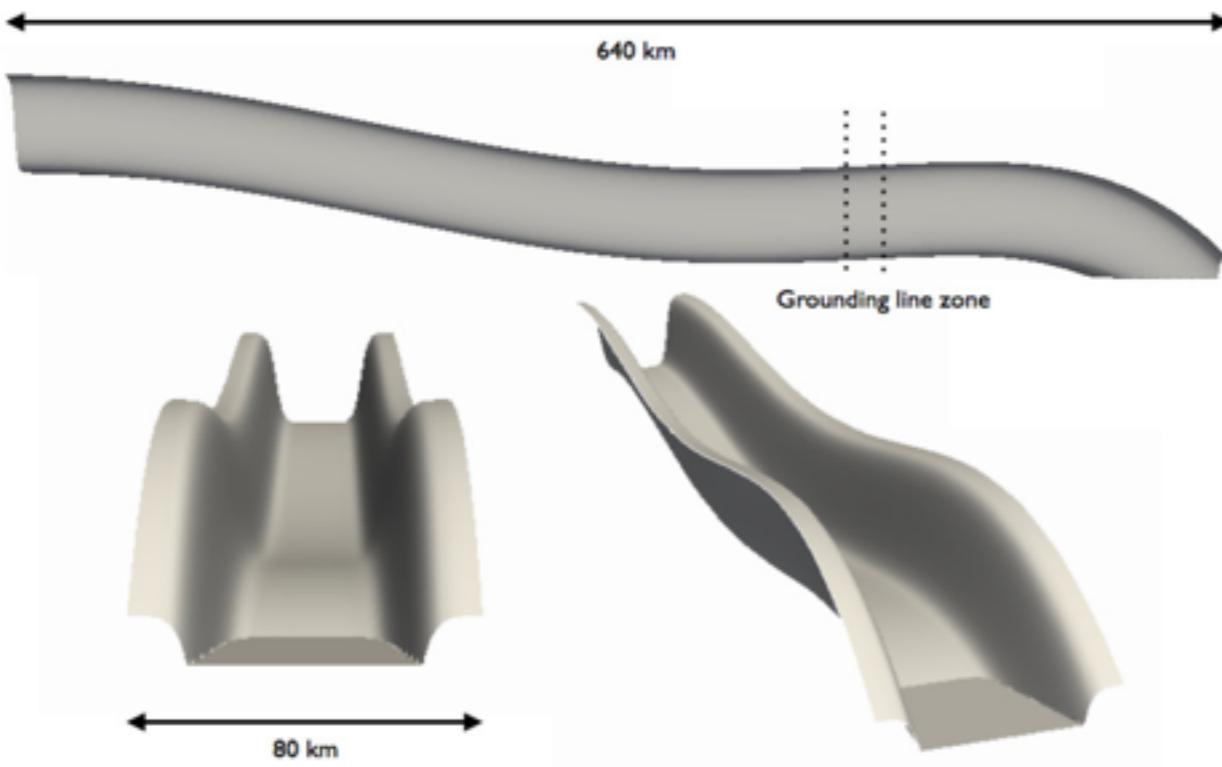
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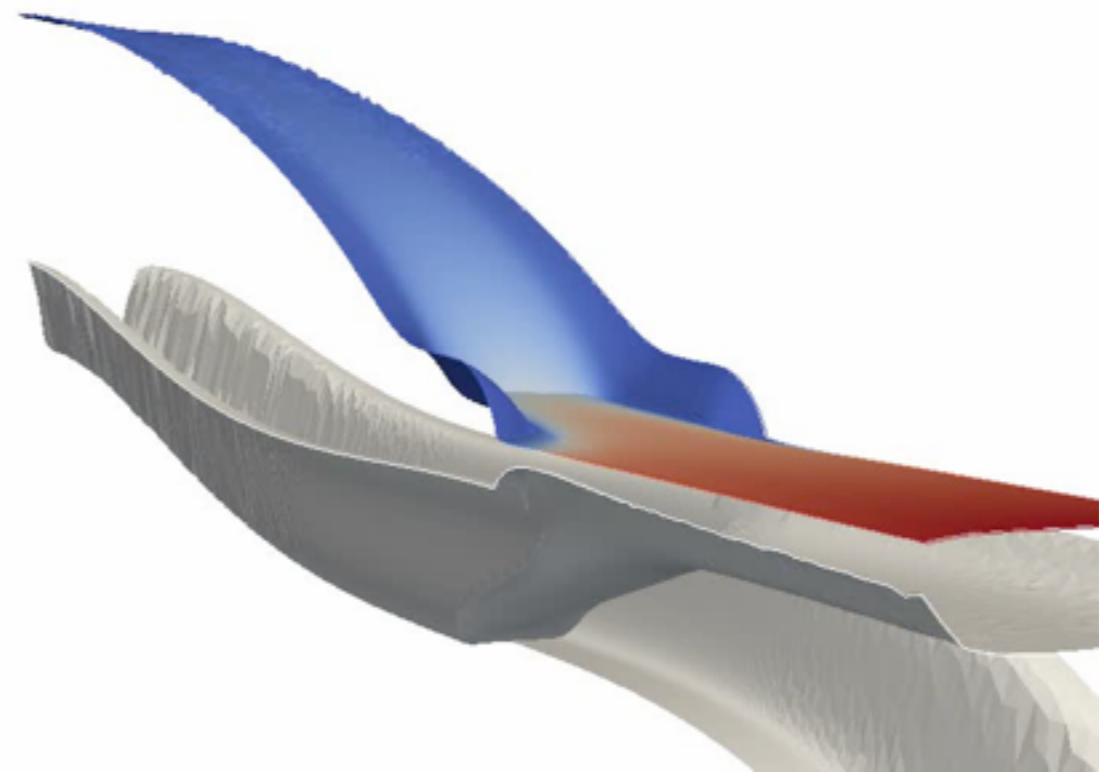
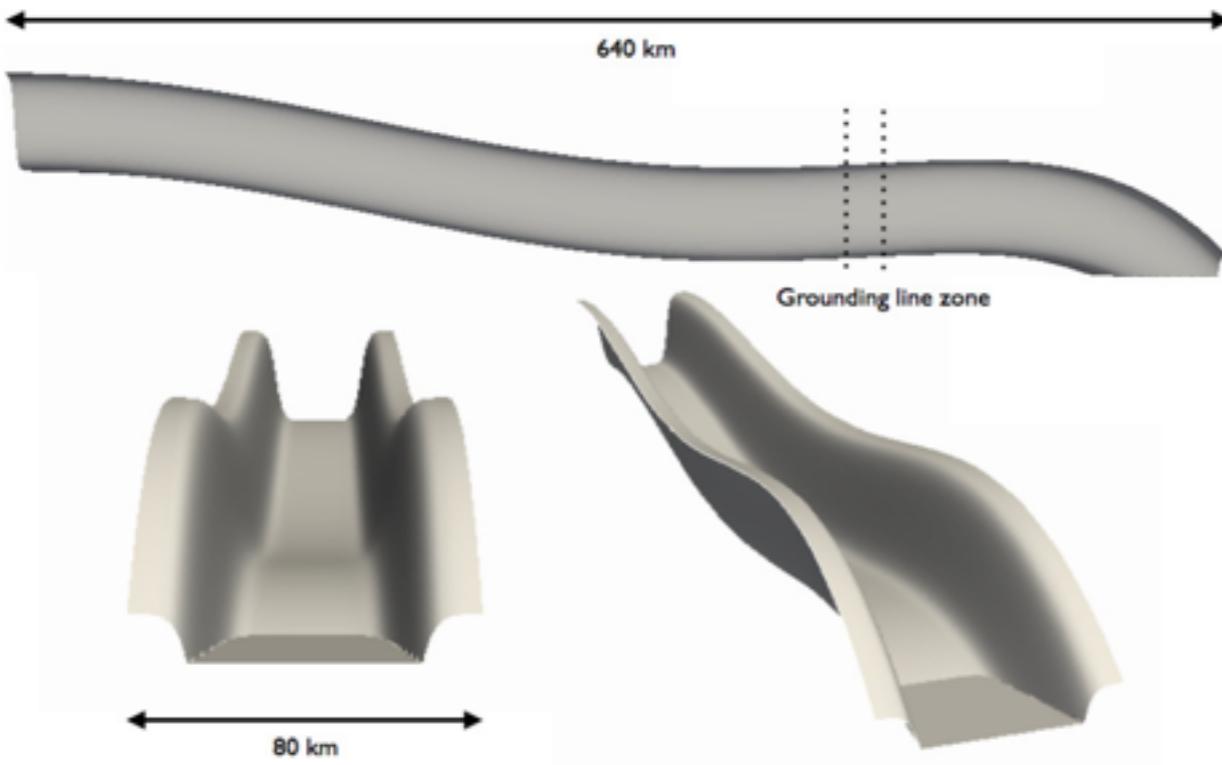
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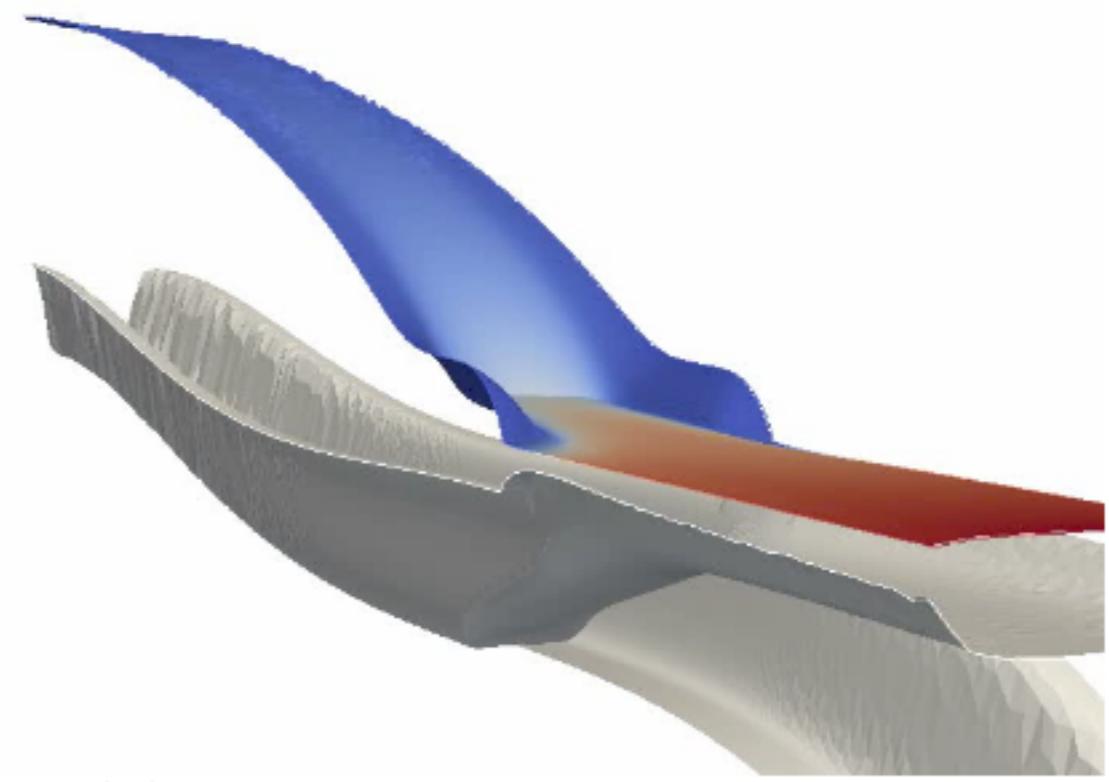
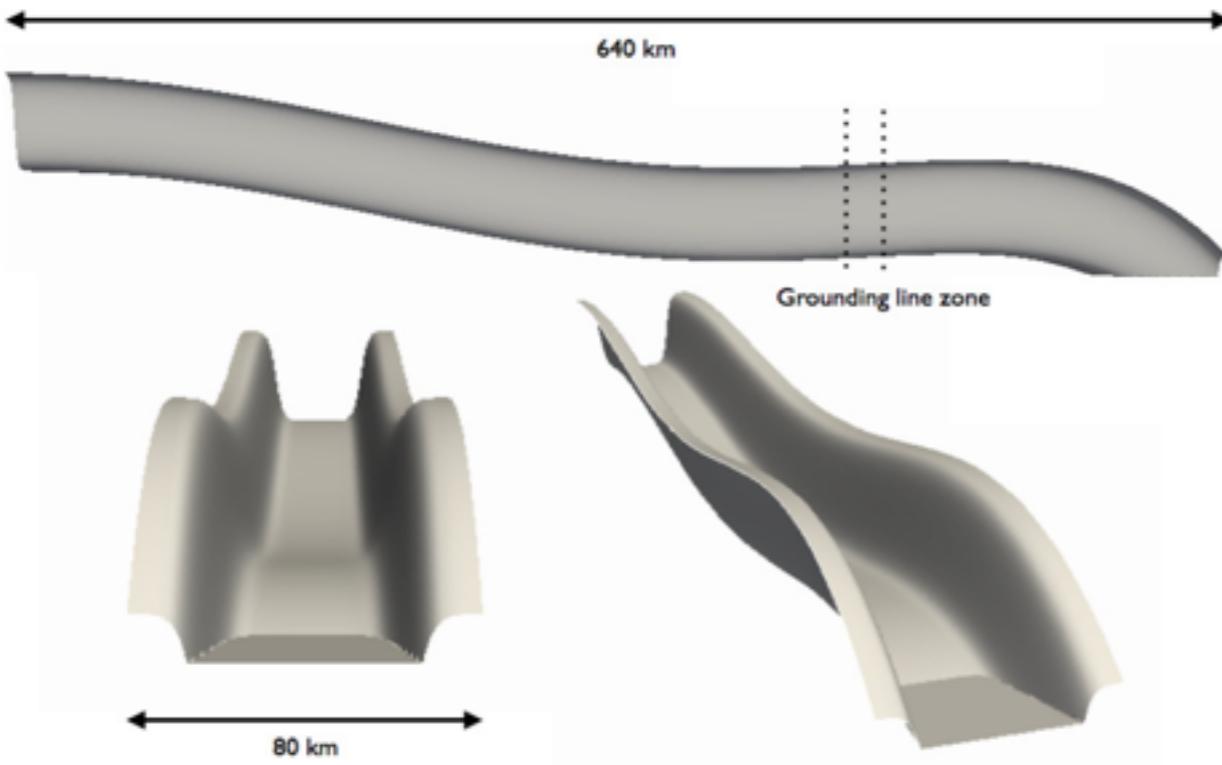
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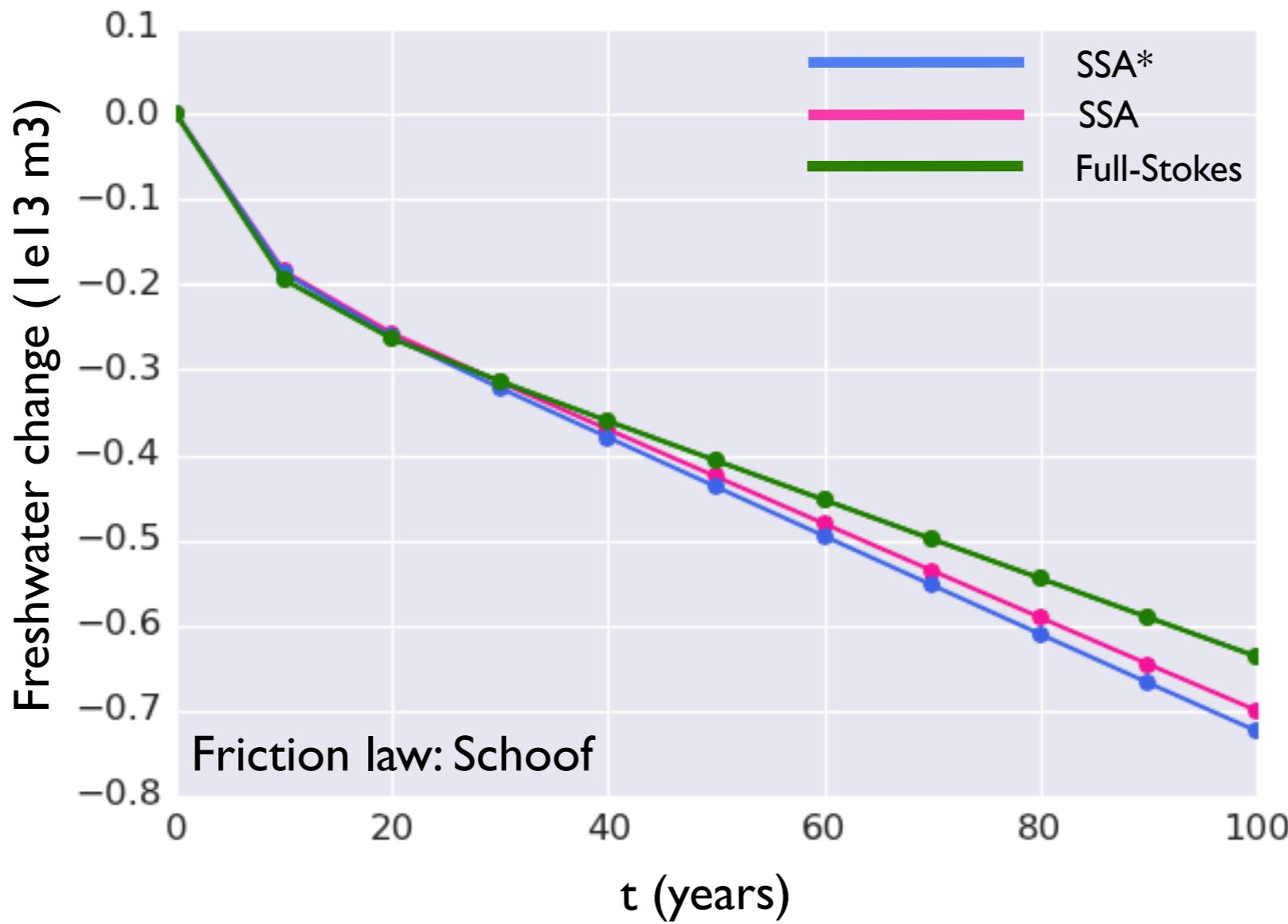
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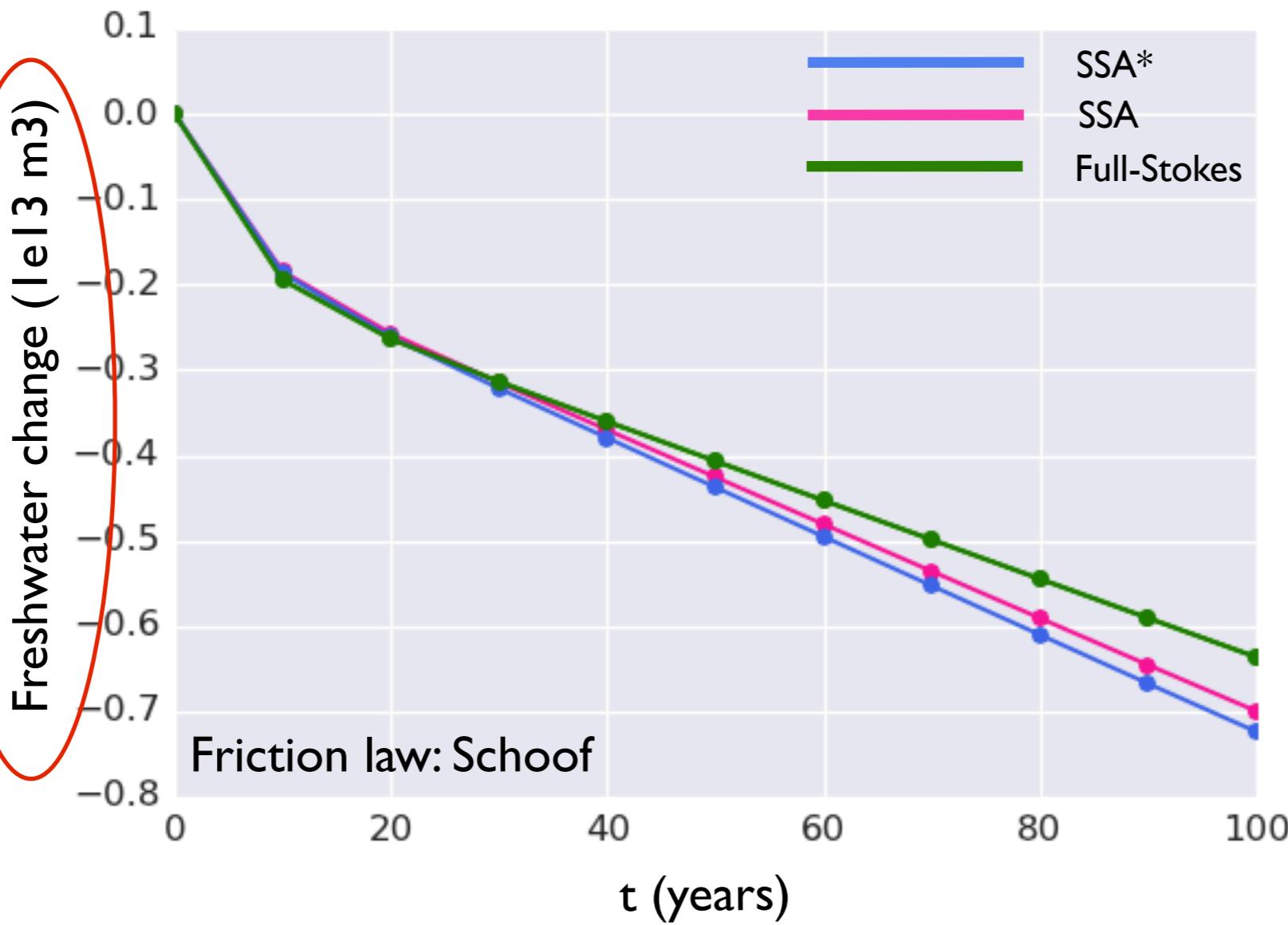
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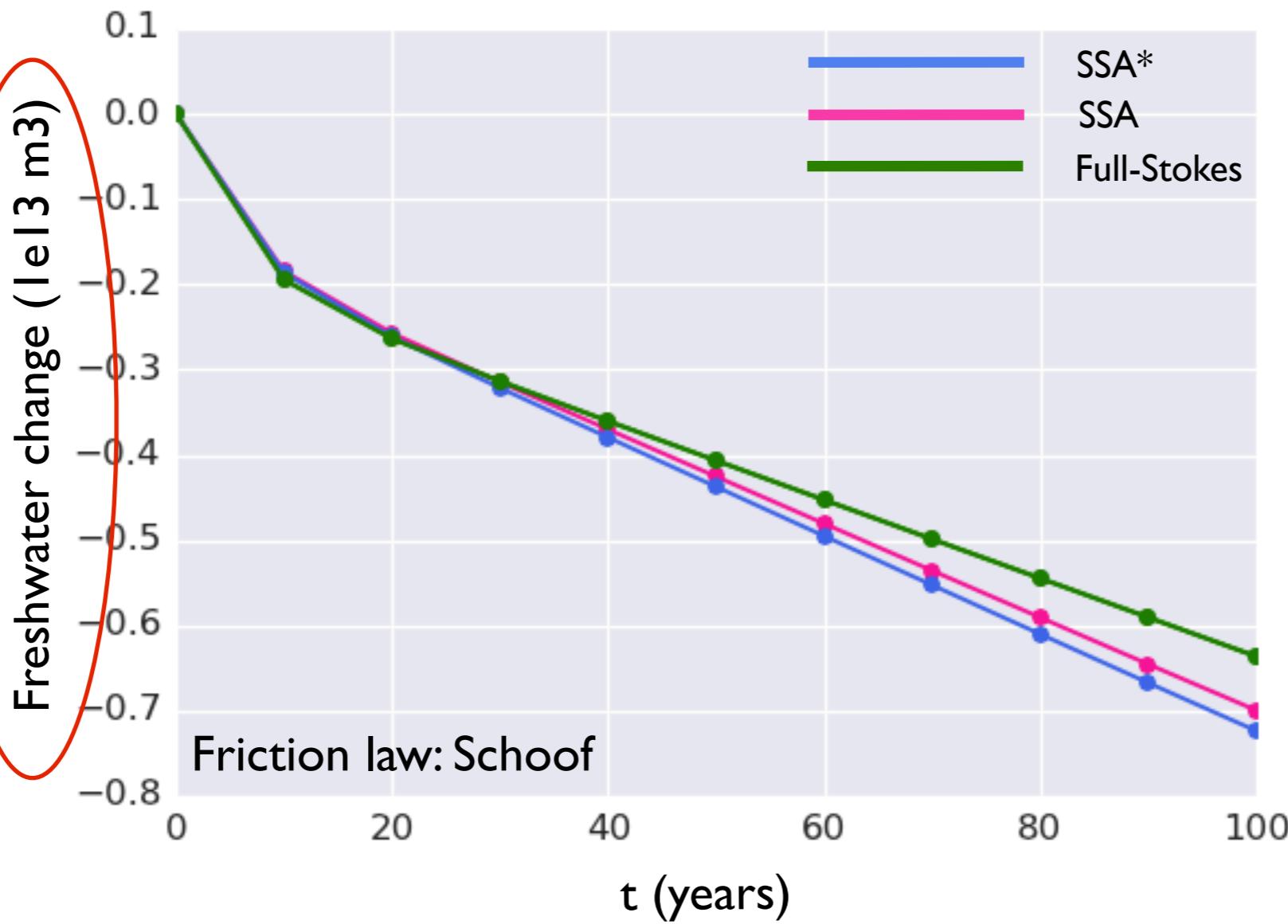
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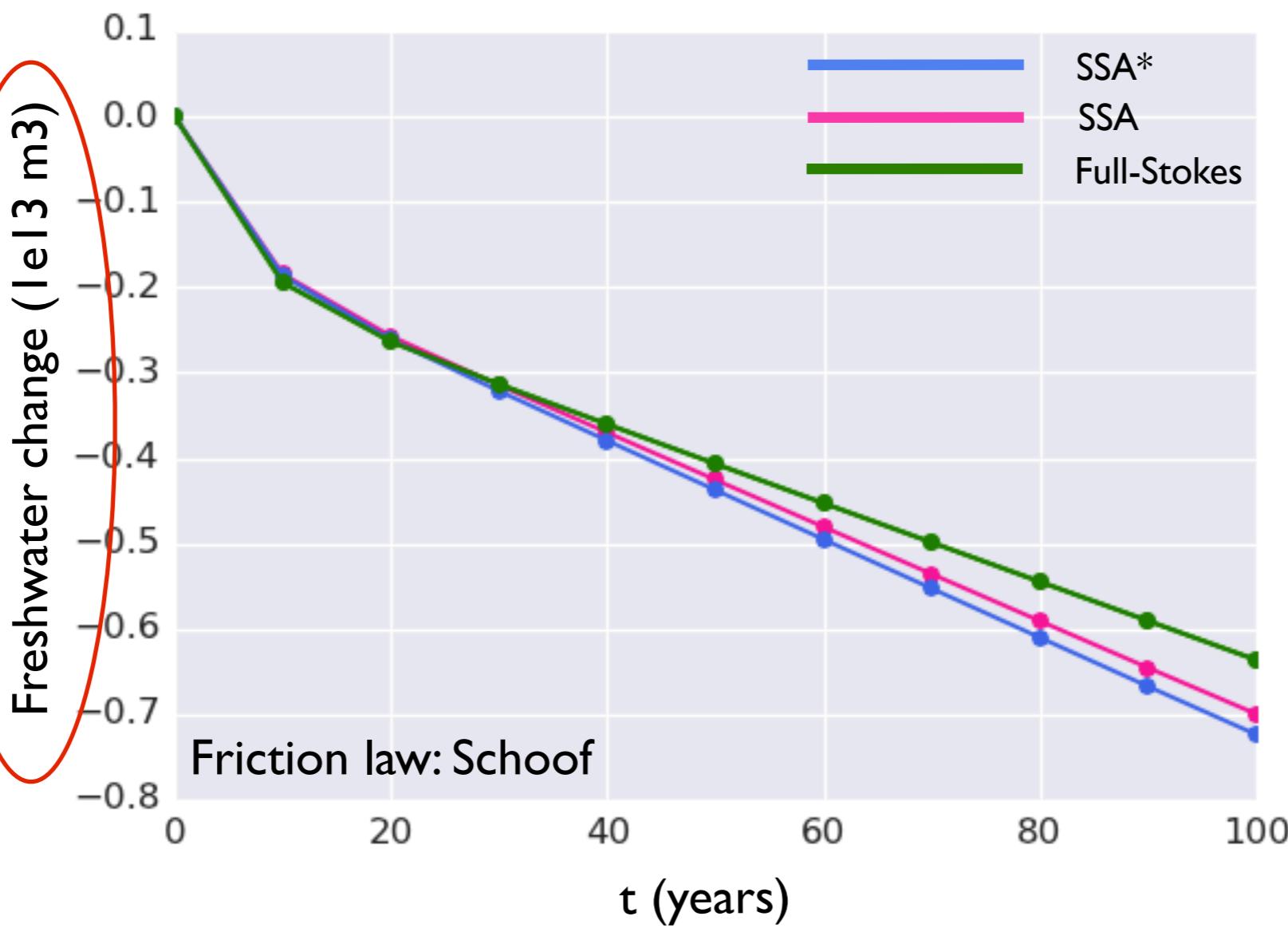


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SSA\* 12% more freshwater flux changes than Full-Stokes

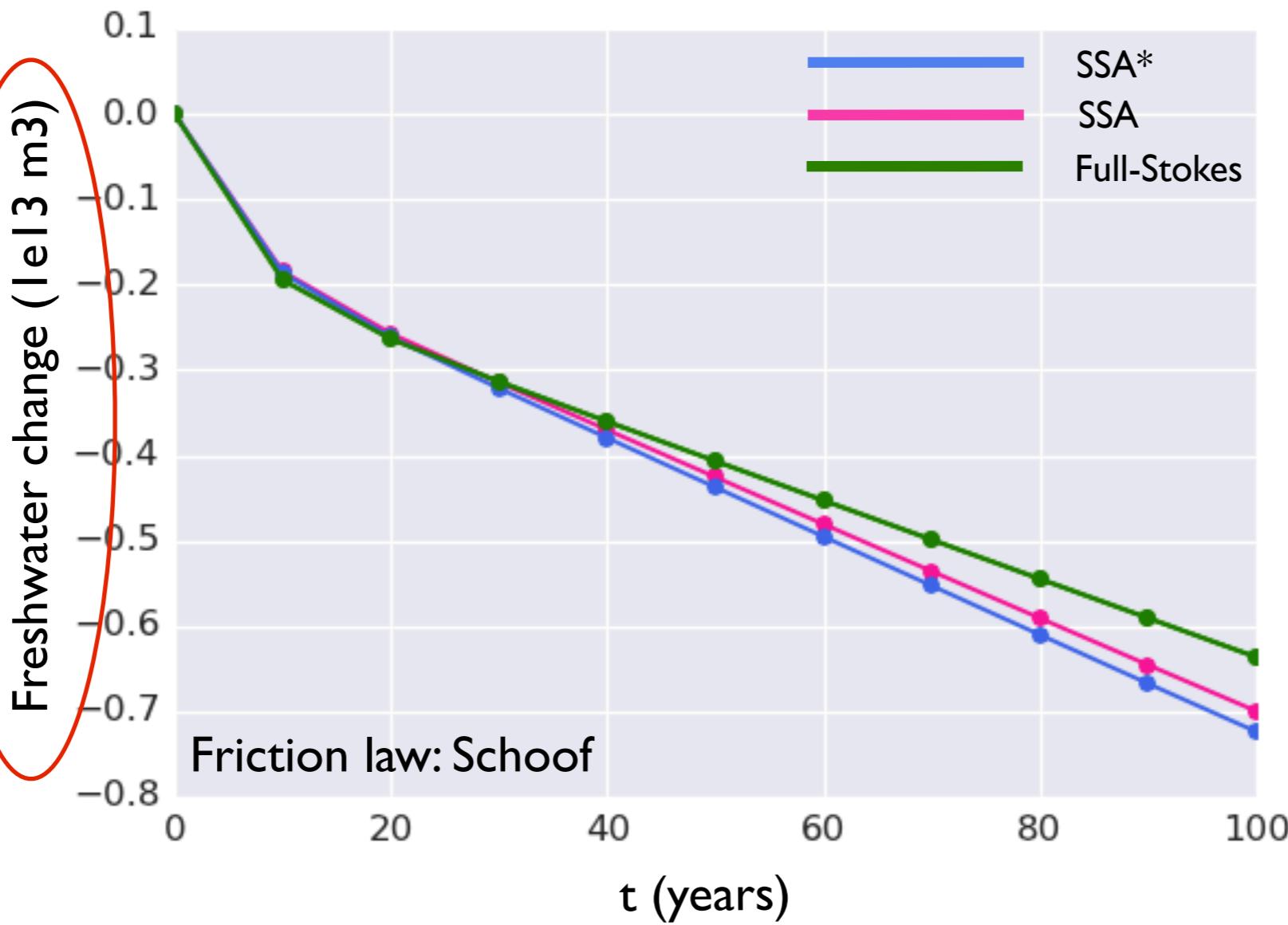
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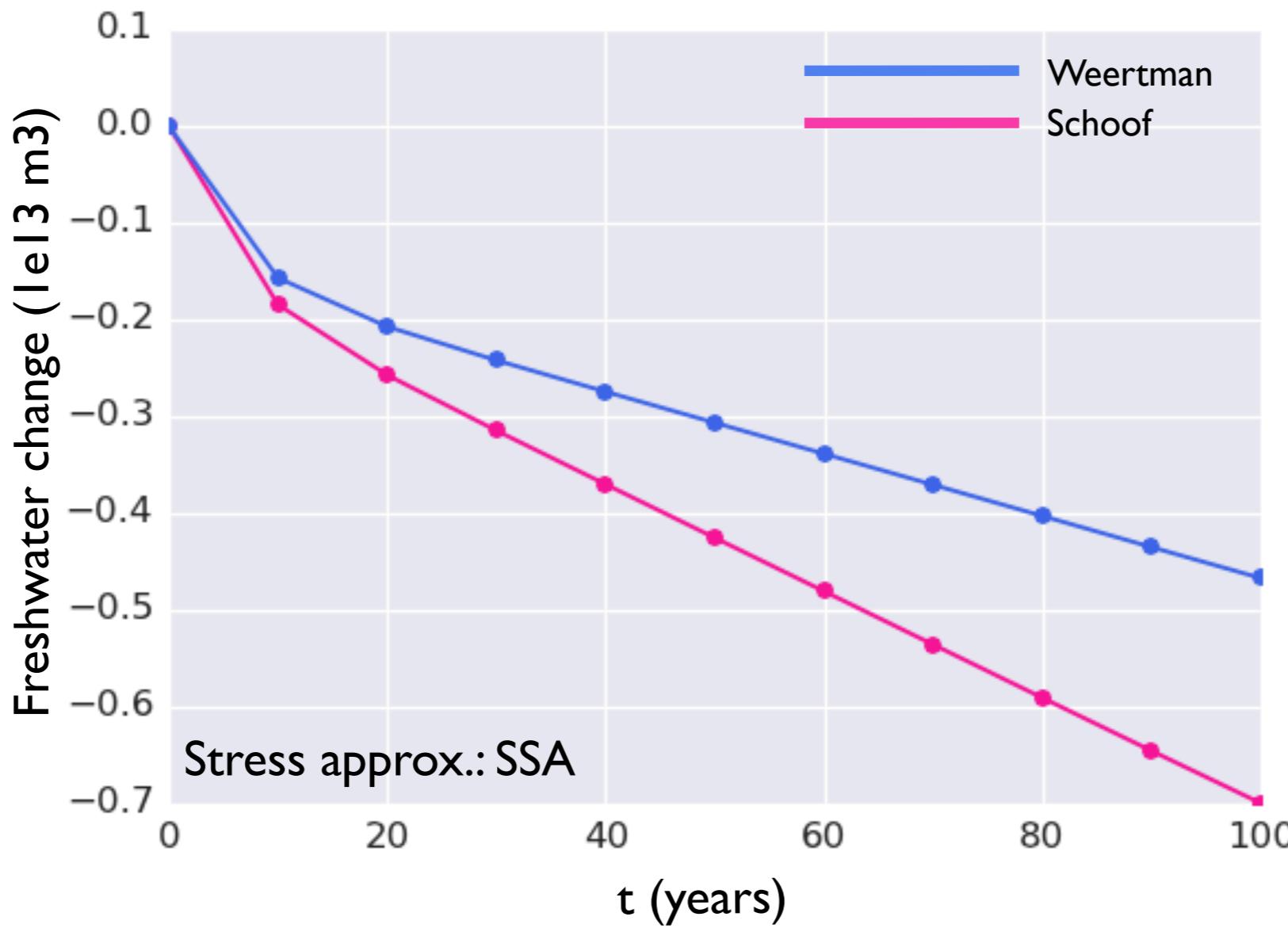


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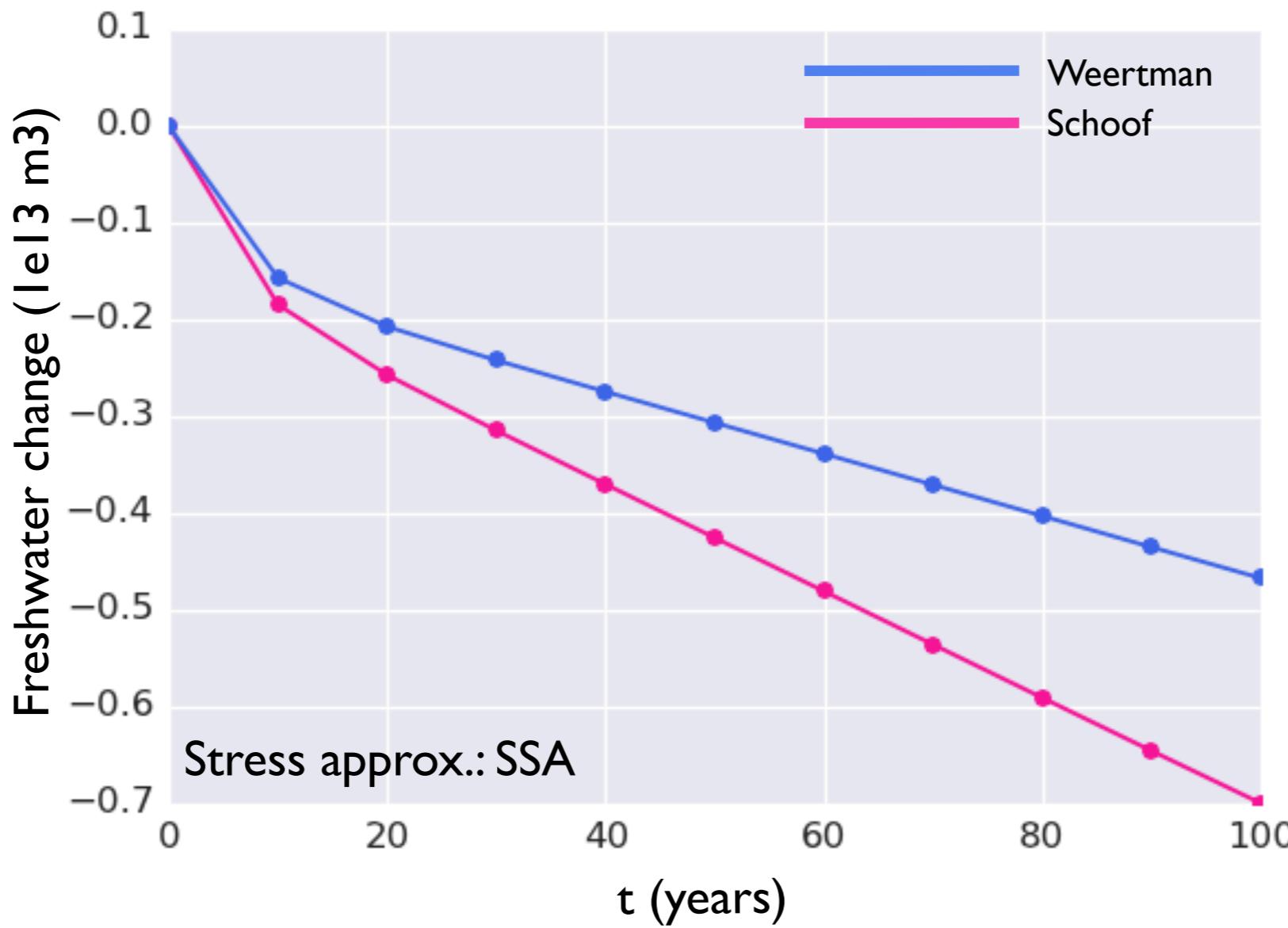
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**Glacier retreat almost unsensitive to englacial stress approximation**

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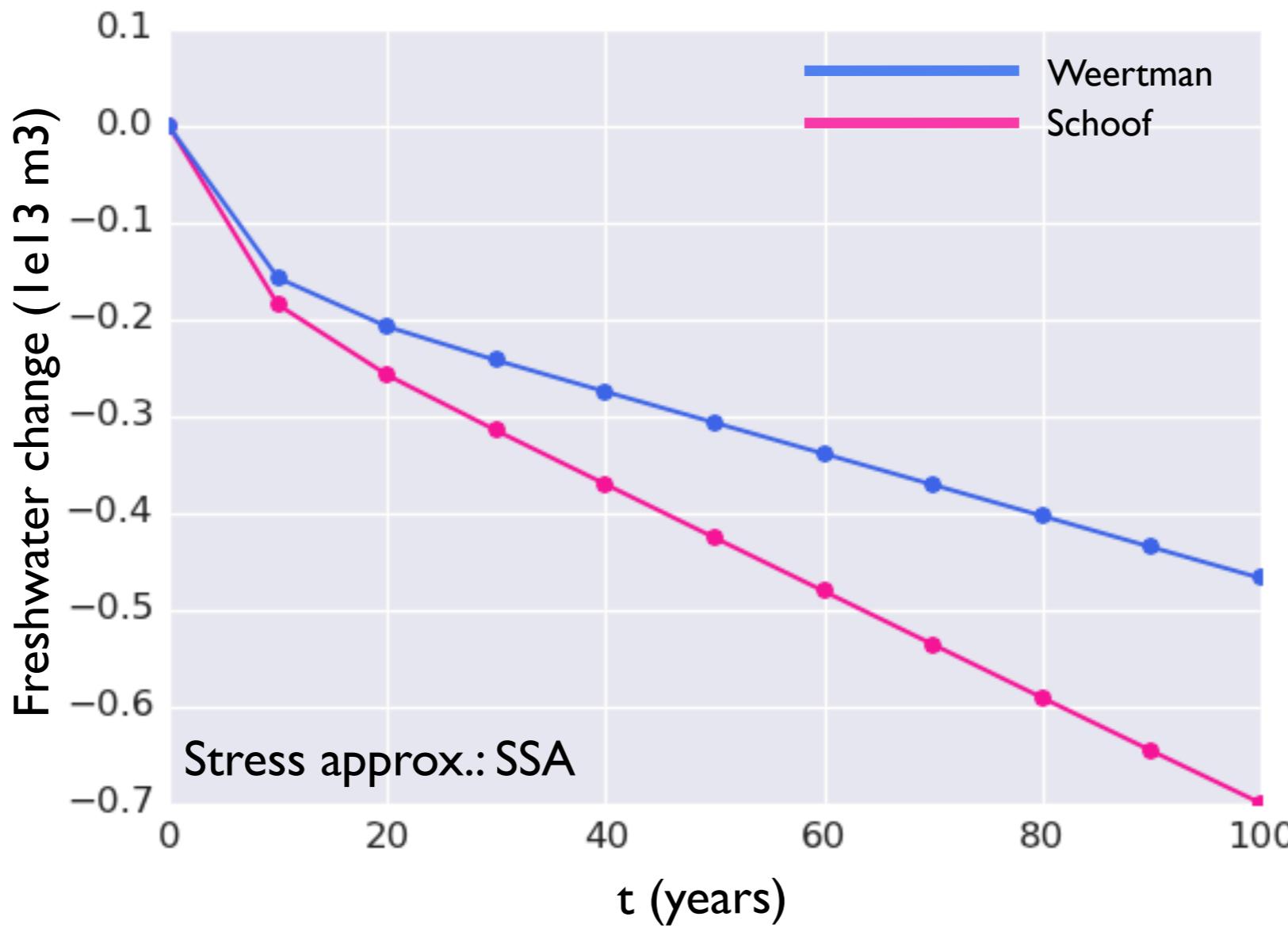


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Schoof 42% more freshwater flux changes than Weertman

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**Highly sensitive to friction law**

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**Yes, about 50% related to basal physics**

# Conclusion

# I-How sensitive is modeled sea ice to realistic changes in freshwater fluxes from Antarctic ice sheet?

## Approach

Sensitivity simulation with ORCA025 (ocean/sea-ice component CMIP6)

- Improve physical representation freshwater forcing
- Observationally based scenario of freshwater fluxes change

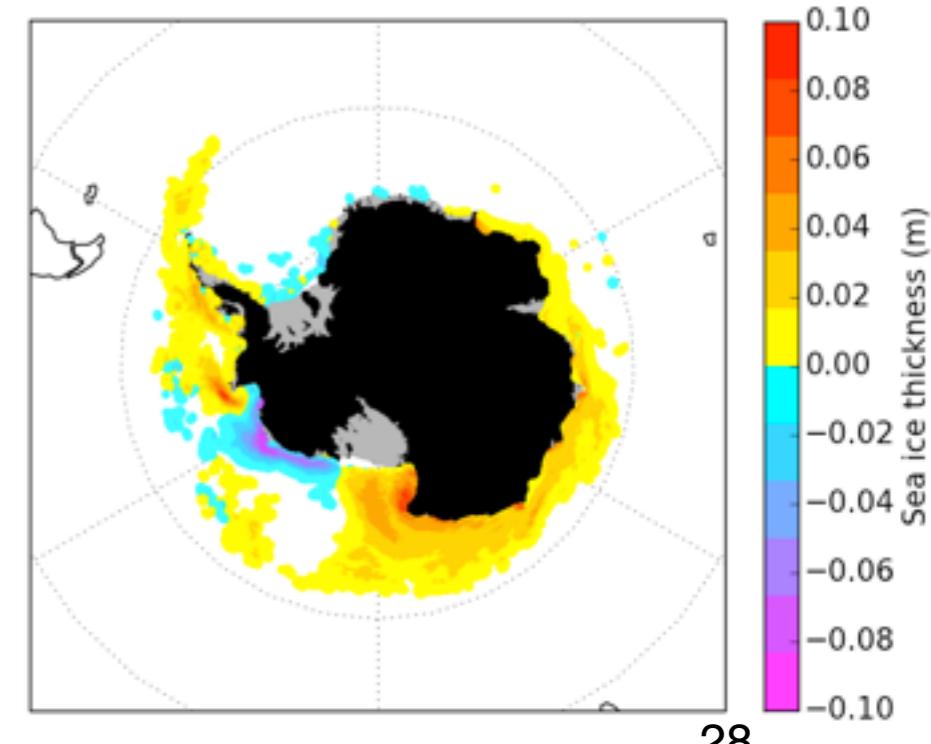


## Technical development

- Improvement of the freshwater forcing in NEMO-DRAKKAR configurations
- Improvements in physics of NEMO-ICB iceberg module
- Distribution of climatology iceberg melt to be used in OCMIP

## Scientific Results

- Concentration and thickness are significantly affected by observed changes in FW forcing
- The response to changes in freshwater forcing shows distinctive regional pattern
- Different physical mechanisms may drive the response depending on the location



# 2-Will uncertainties in the physics of ice sheet models affect projection of changes in freshwater fluxes?

## Approach

- Elmer/Ice simulation using MISMIP+ framework
- Evaluation of sensitivity to friction law and Stokes approximation

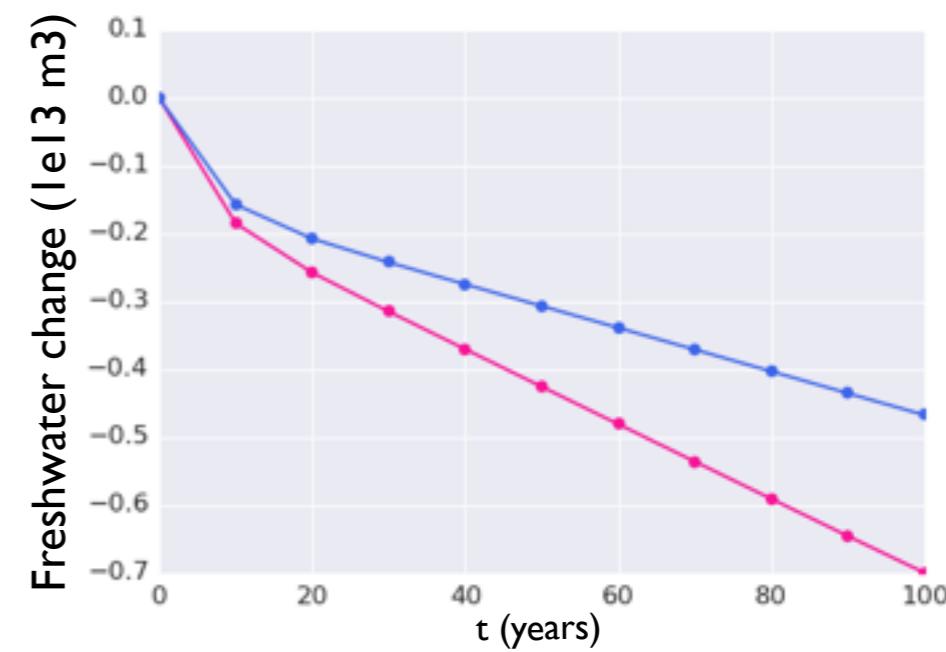


## Technical development

- Set up of MISMIP+ experiments with Elmer/Ice
- Automatic production chain for Elmer/Ice in the MISMIP+ set up

## Scientific Results

- Simulated freshwater release is much dependent on the chosen friction law



# Will forthcoming coupled ocean/ice-sheet models improve Antarctic sea ice projections?

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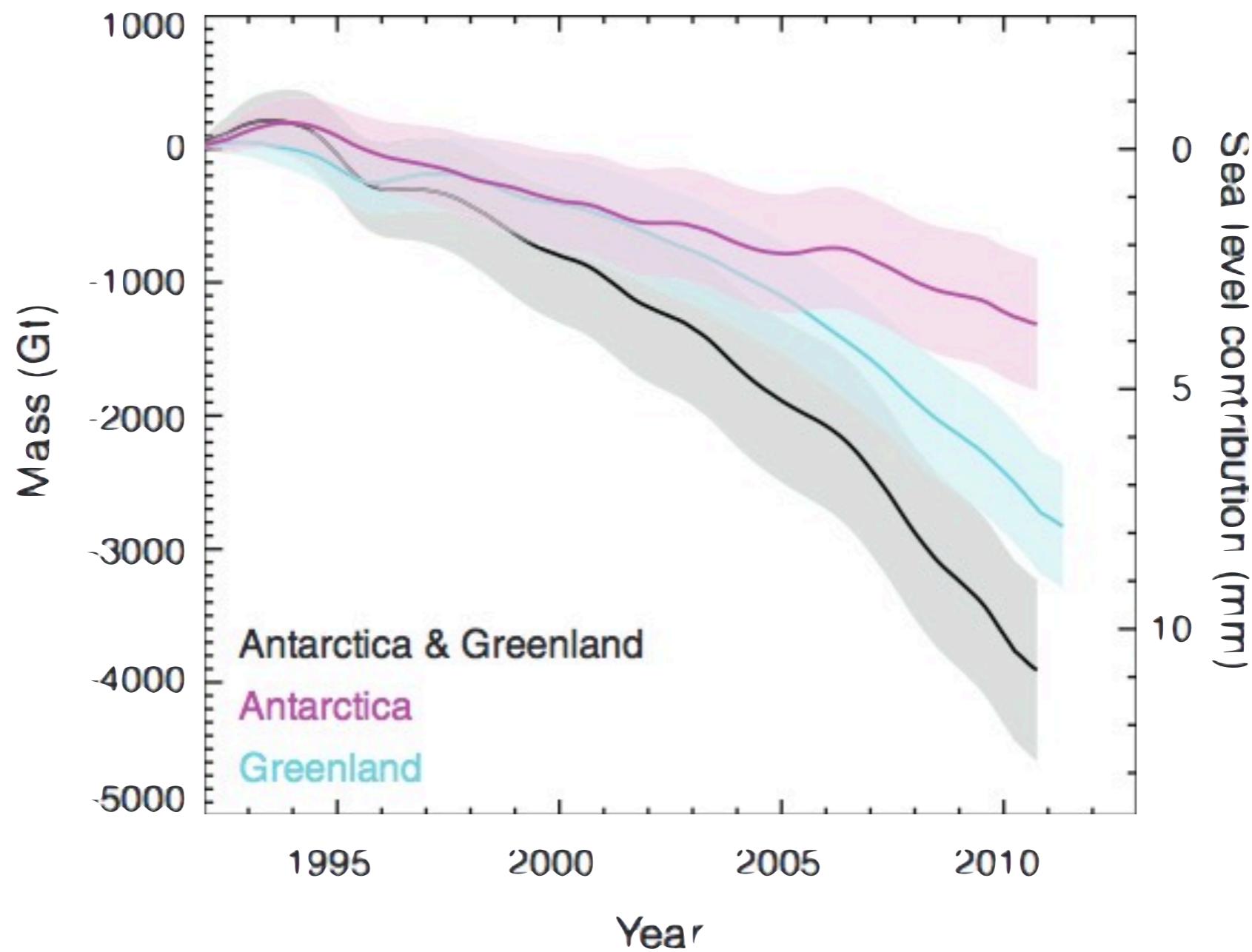
Only approach for investigating feedbacks between the two components

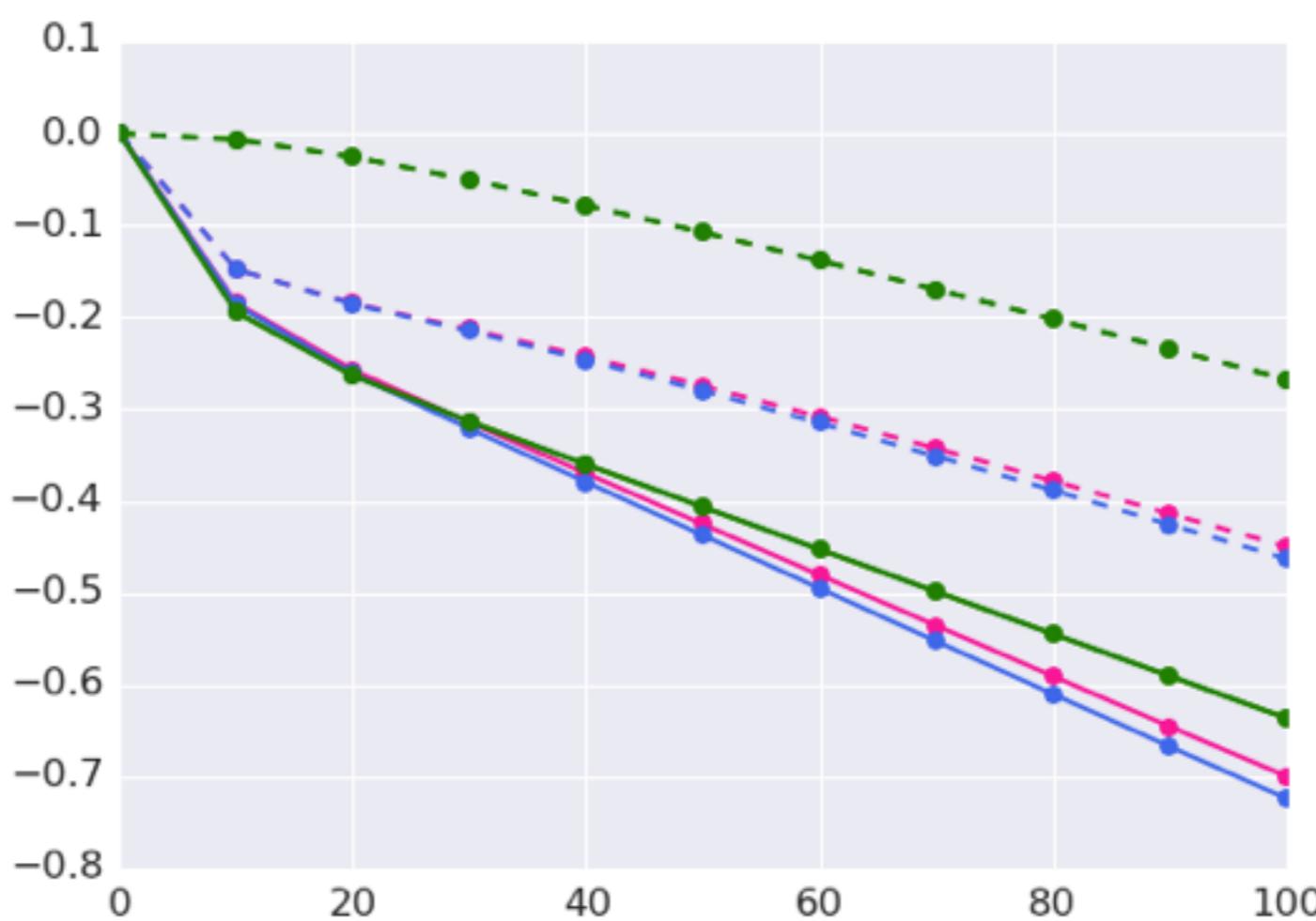
Model inter comparison projects and observations will eventually improve model physics and reliability

# Thanks

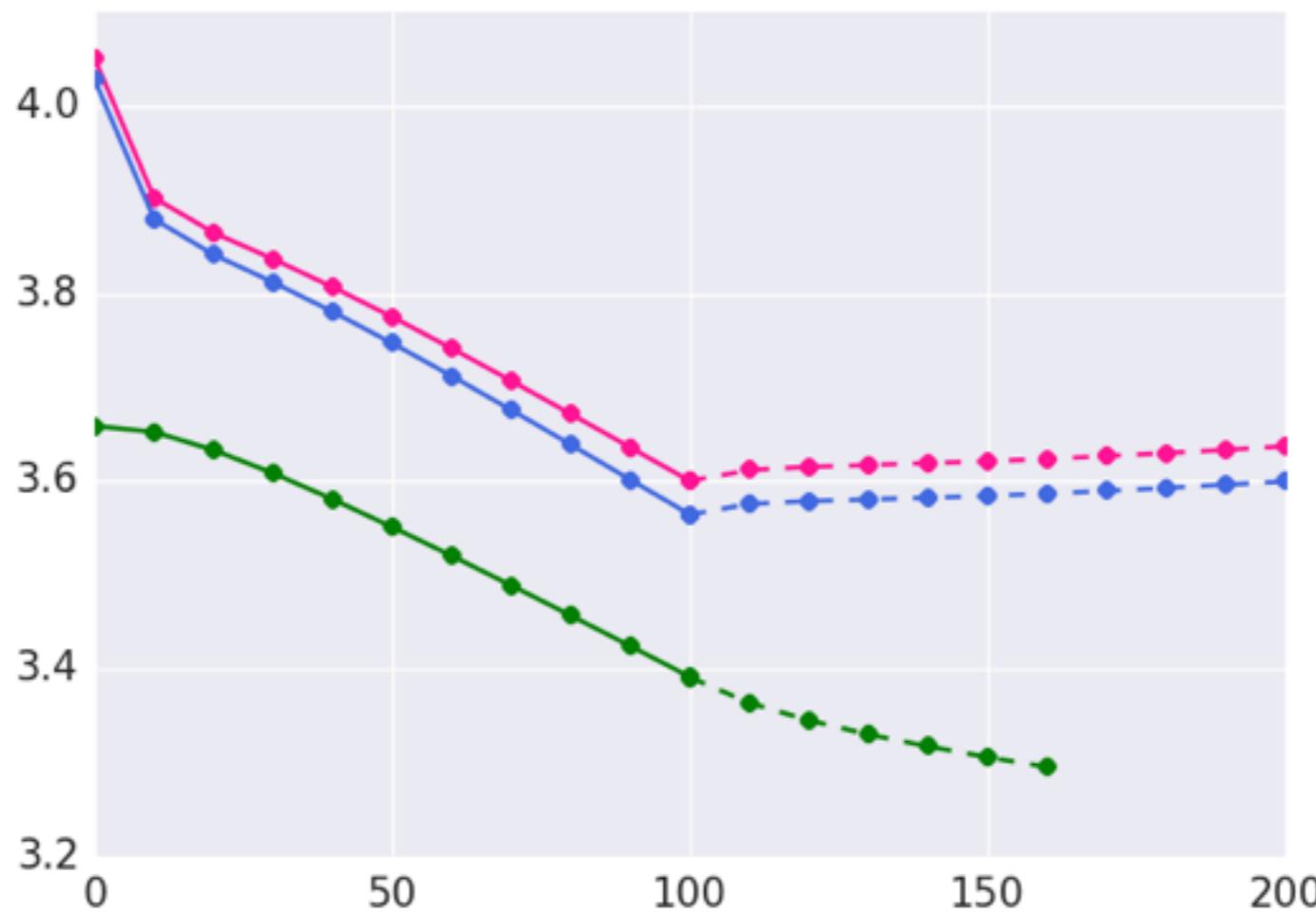


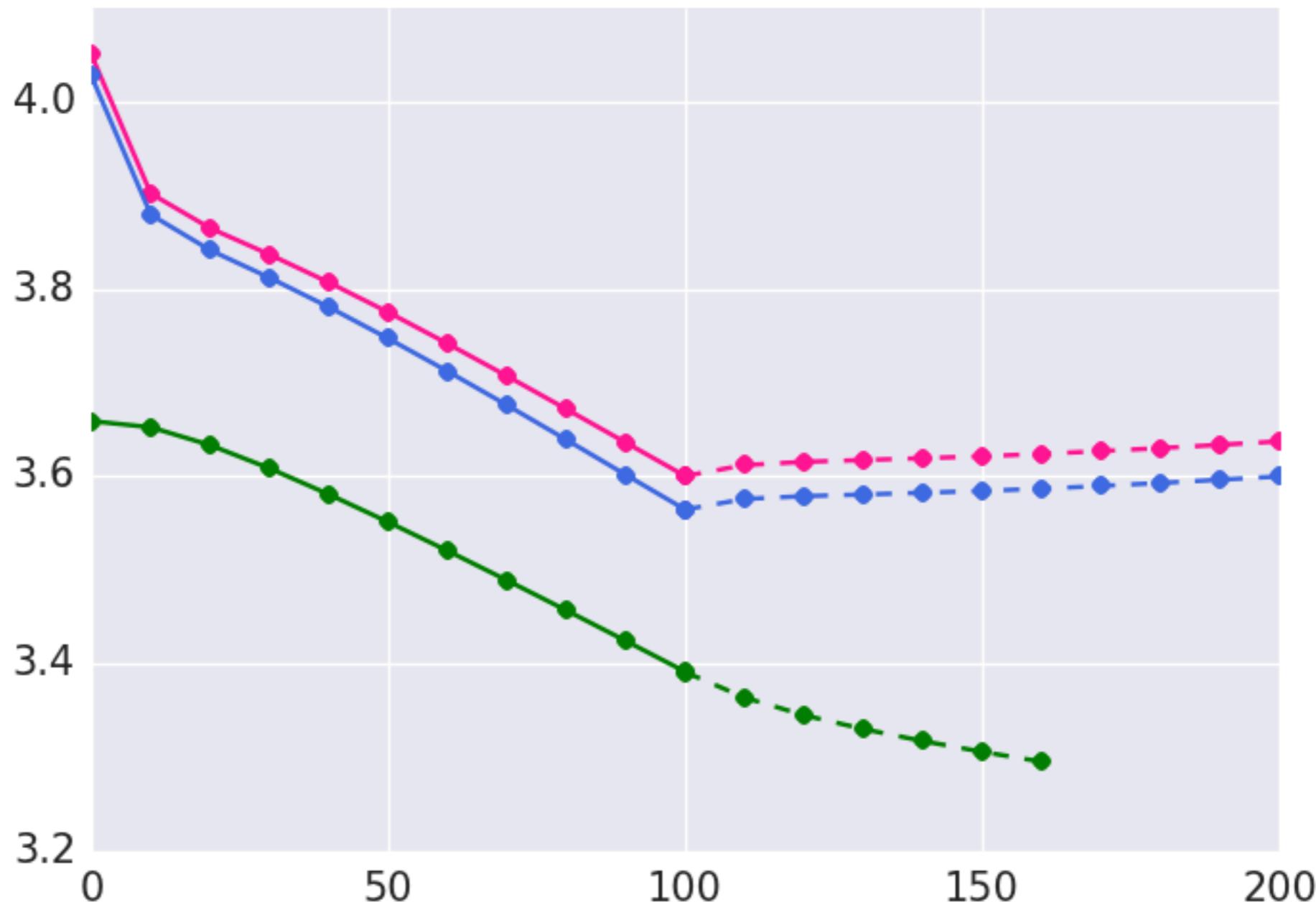


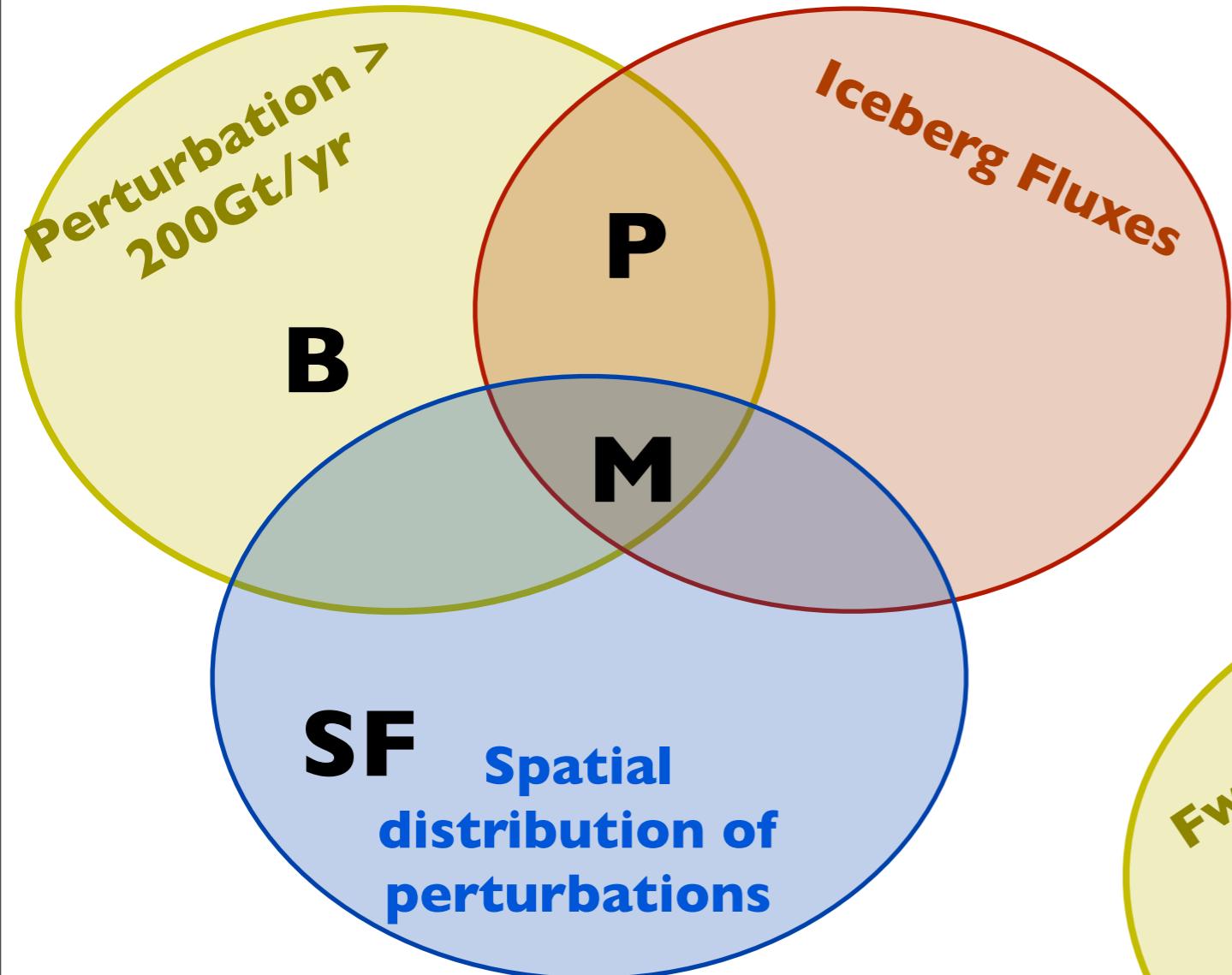




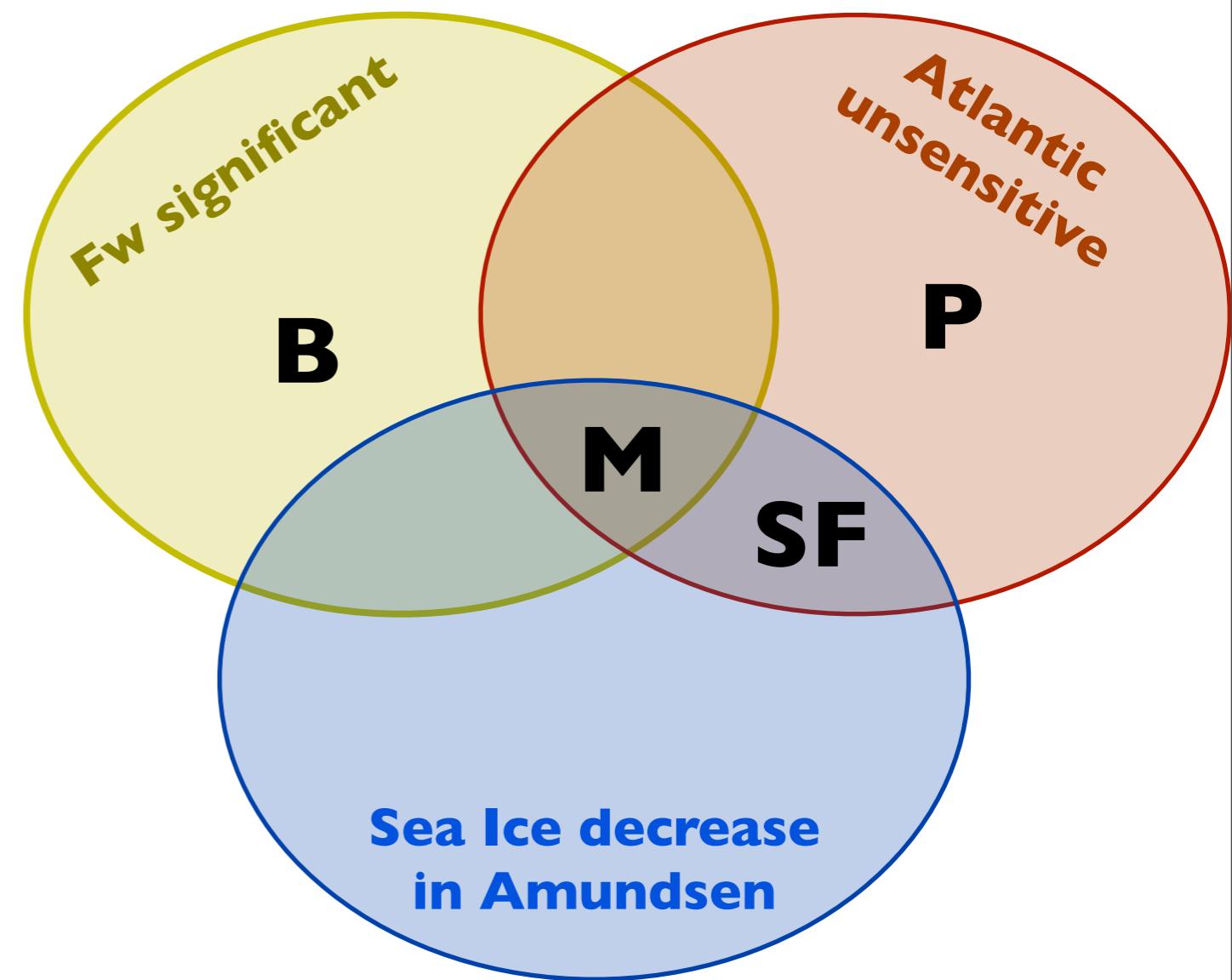
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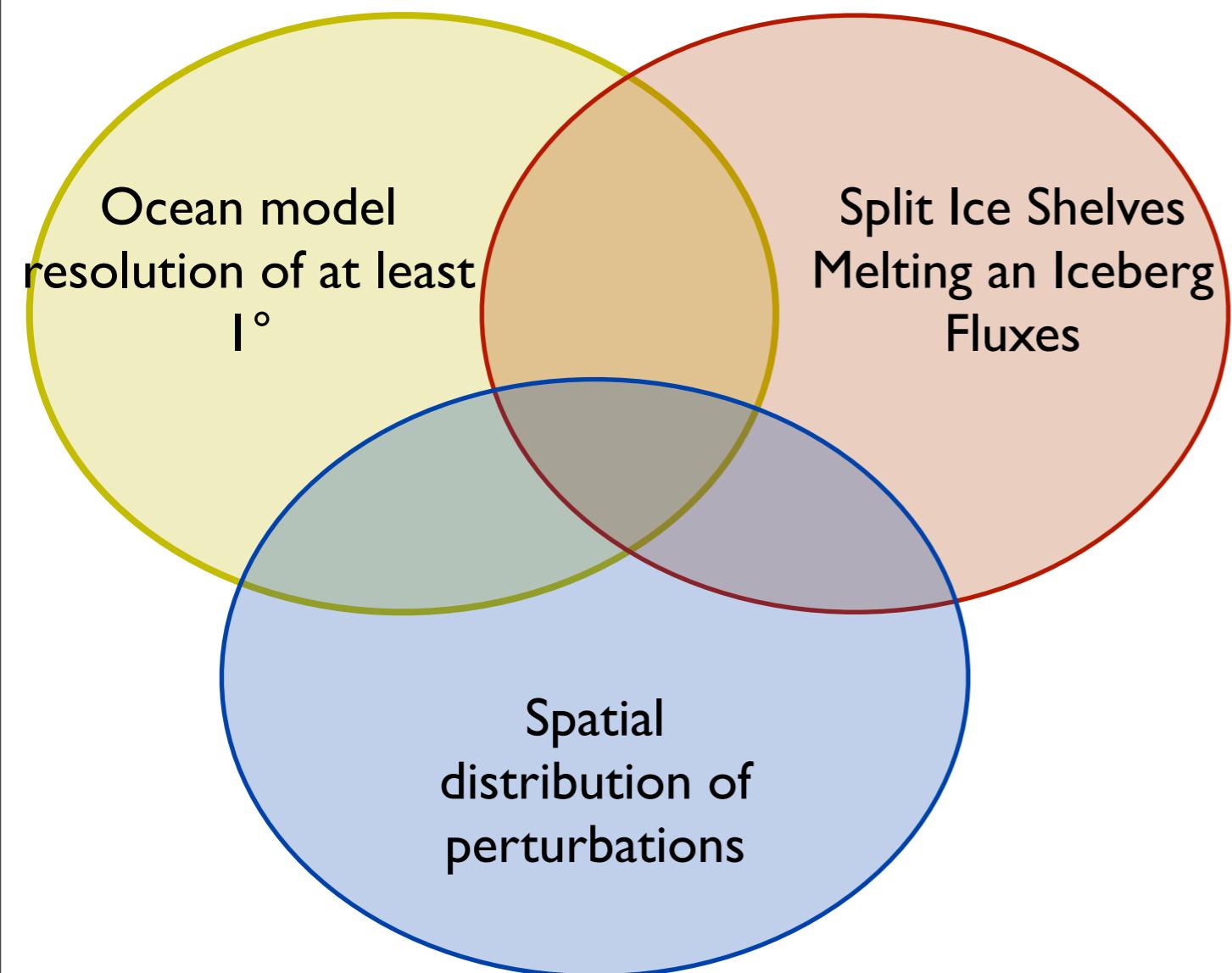




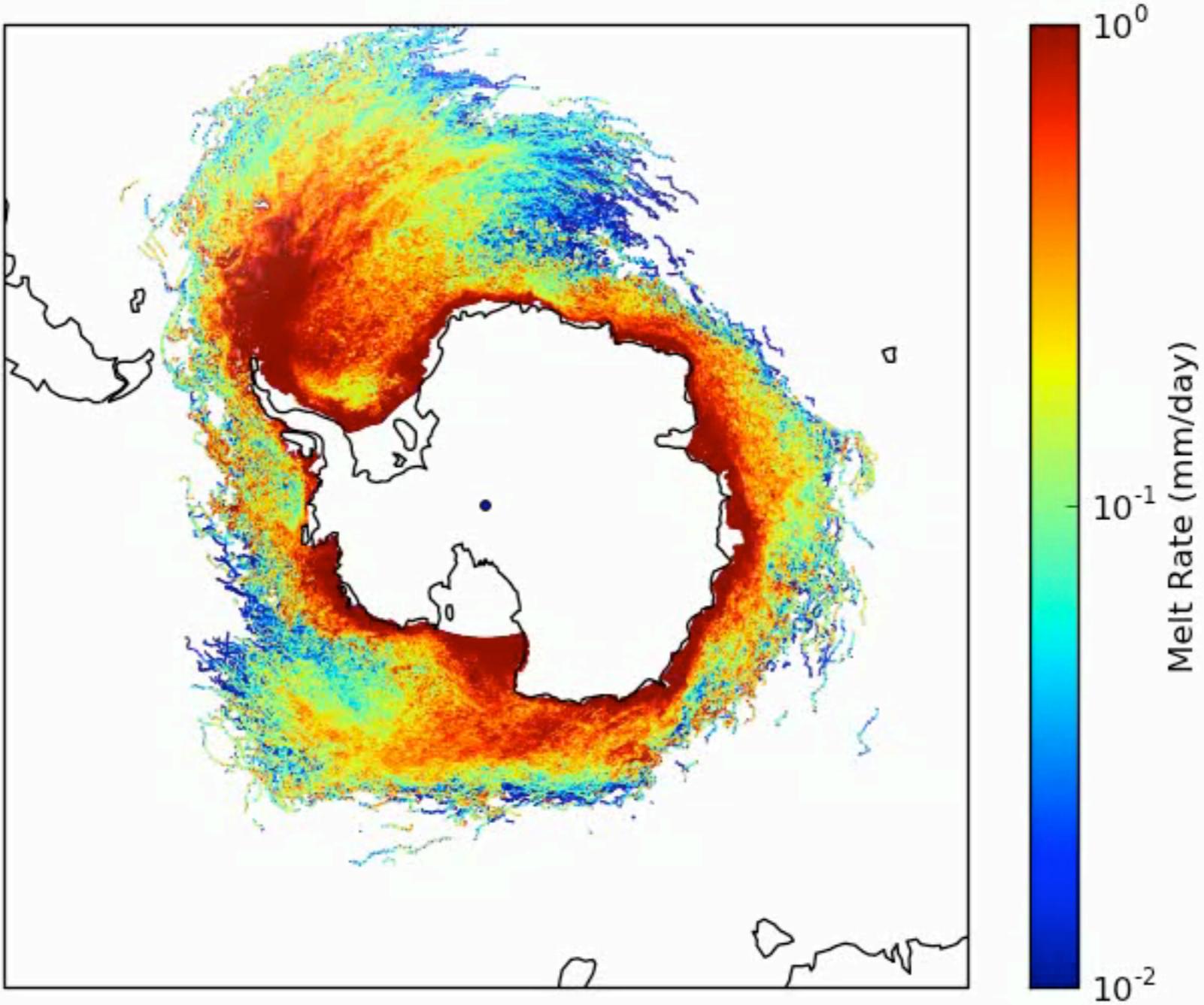
- |           |                      |
|-----------|----------------------|
| <b>B</b>  | Bintanja et al 2013  |
| <b>SF</b> | Swartz and Fyfe 2013 |
| <b>P</b>  | Pauling et al. 2016  |
| <b>M</b>  | Merino et al. 2016   |



**Spatial distribution of  
glacial freshwater  
changes required**



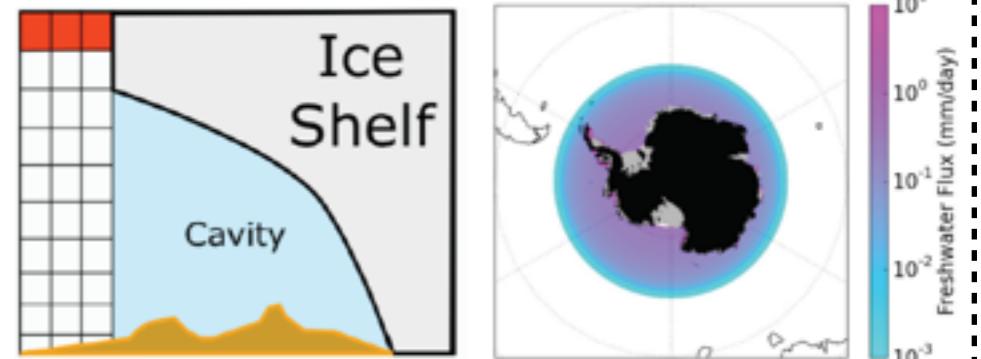
	Model Resolution	$F_w$ perturbation	Distribution of perturbations	Icebergs	Response Atlantic	Response Ross	Response Amundsen	Is the impact significant?
Bintanja et al 2013	1°	250 Gt/yr	Circumpolar	No.	Strong. +	No	No	Yes
Swartz and Fyfe 2013	1.8° x 3.6°	46-128Gt/yr	Amund	No.	Weak -.	Weak +	Weak -	No
Pauling et al. 2016	1°	120-3k Gt/yr	Circumpolar	Precip.	Weak - +	Weak +	Weak -	No
Merino et al. 2016	0.25°	353 Gt/yr	Observ.	Model.	No	Strong +	Strong -	Yes



# **Results and impact on iceberg trajectories and sea ice in Merino et al. 2016**

# But observational estimates says

Once upon a time...



## To do list

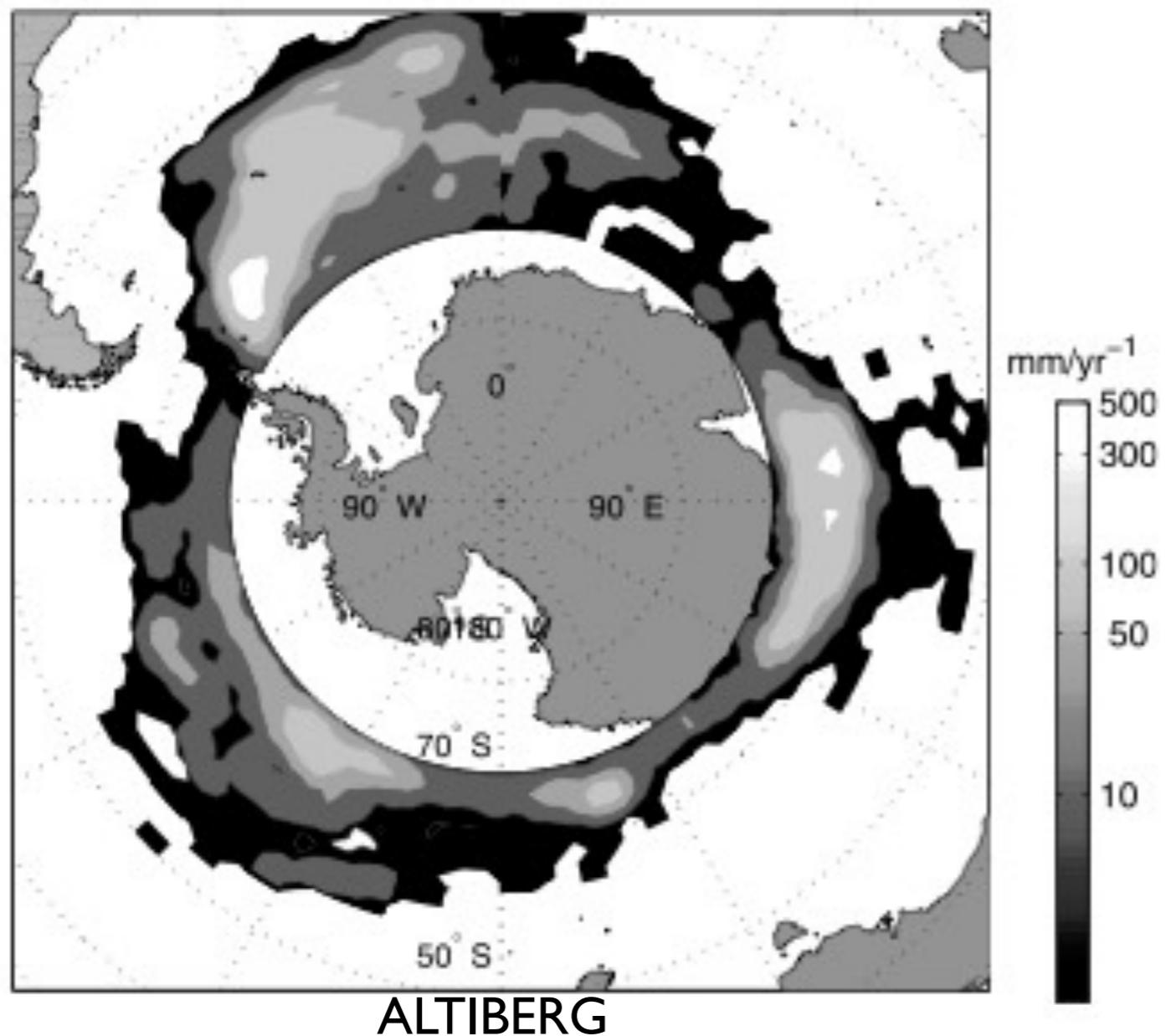
Identify relevant ice shelves location

Split into basal melt water and  
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I - Improve the glacial freshwater forcing in standalone ocean models

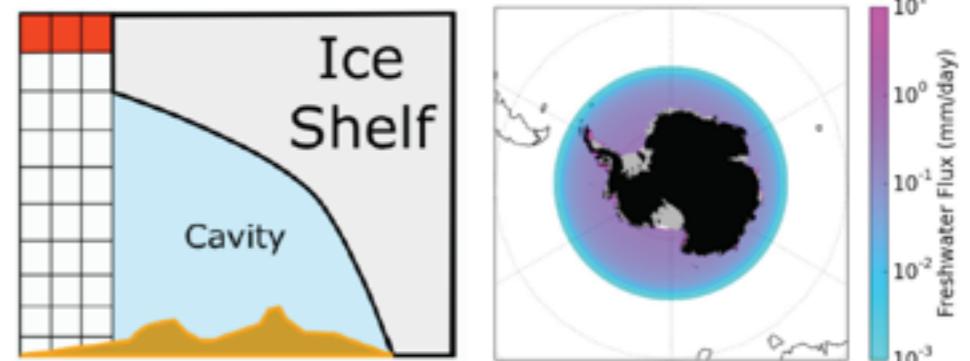
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Annual mean Iceberg meltwater fluxes



- Marked Iceberg melt water spatial distribution
- Strong seasonality
- Not observational estimate of melt rates seasonality
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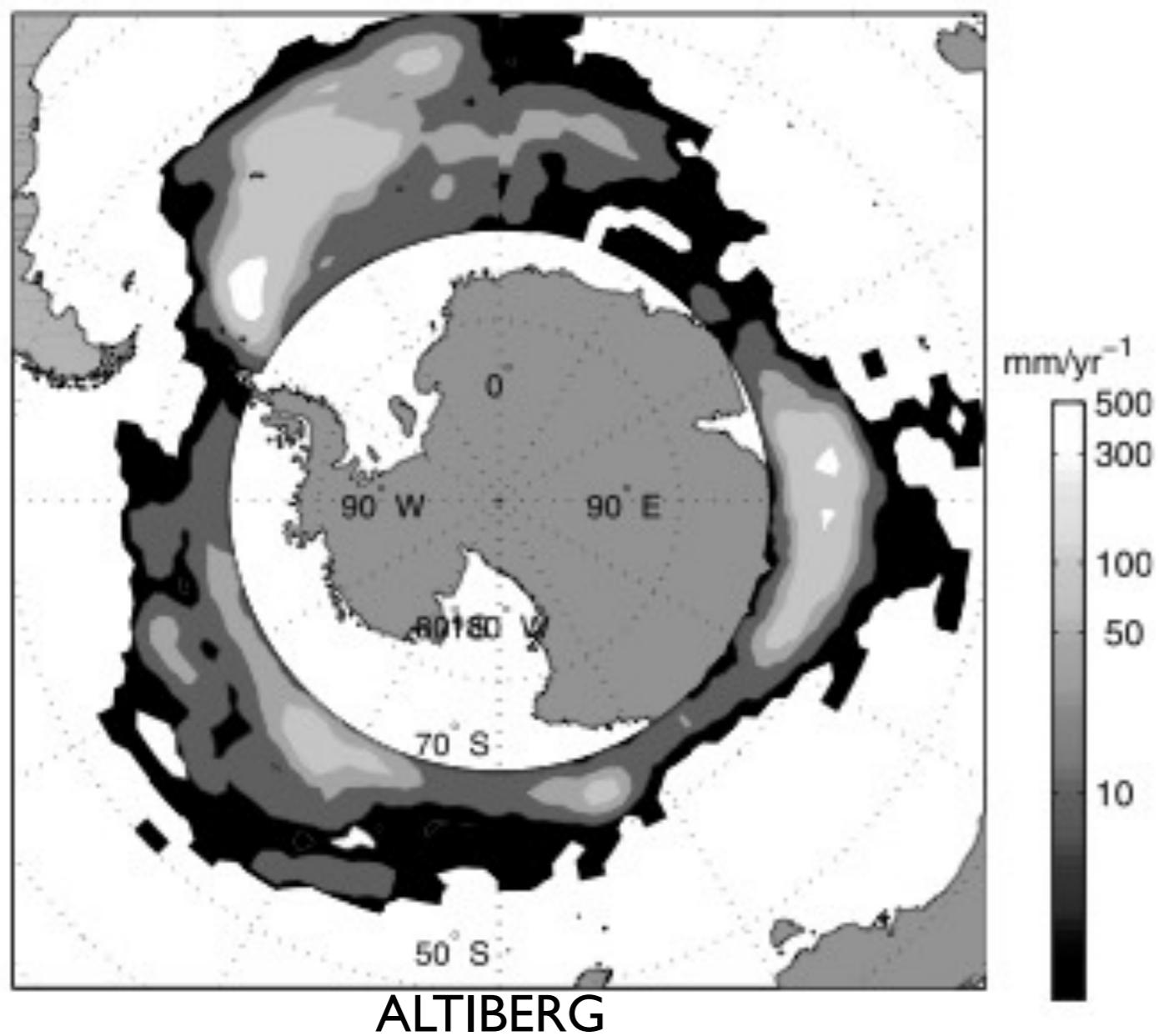
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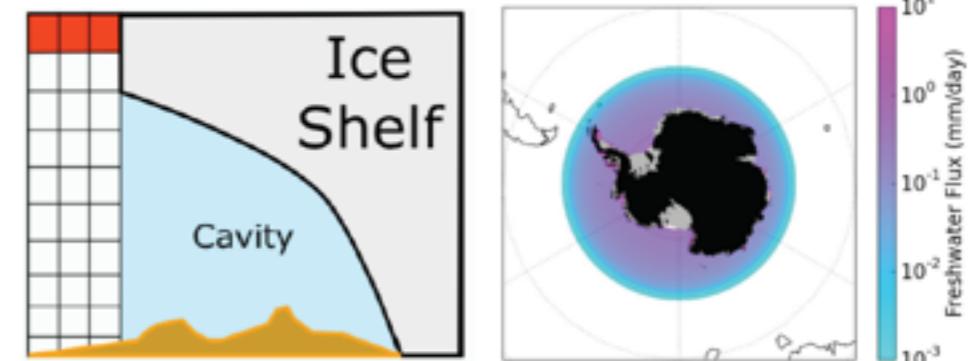
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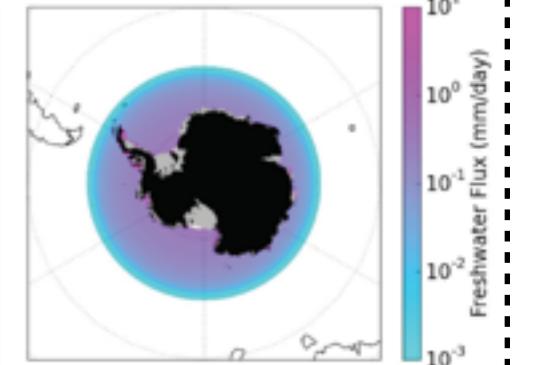
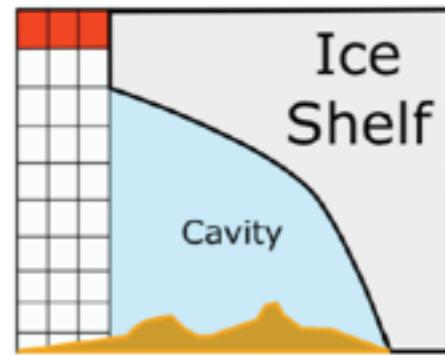
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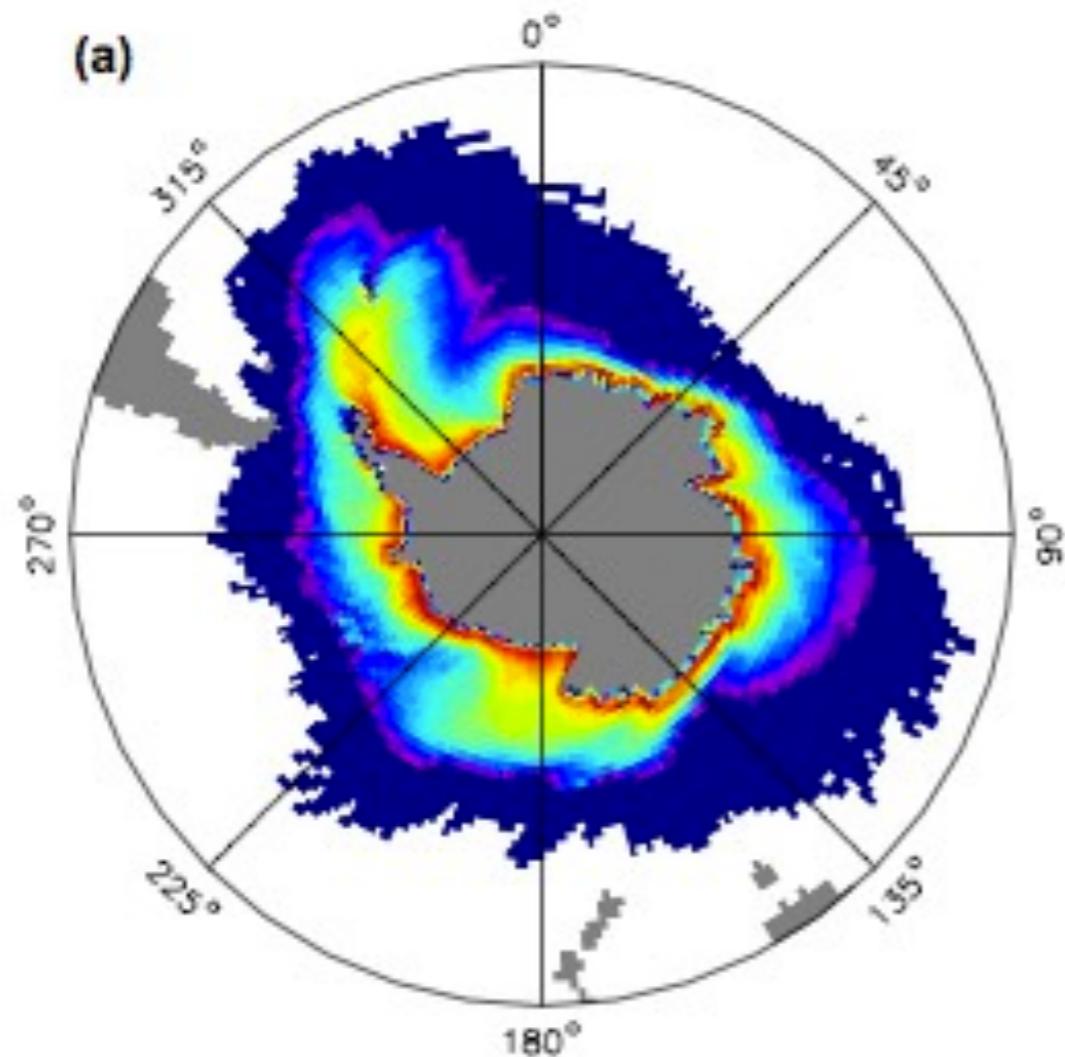
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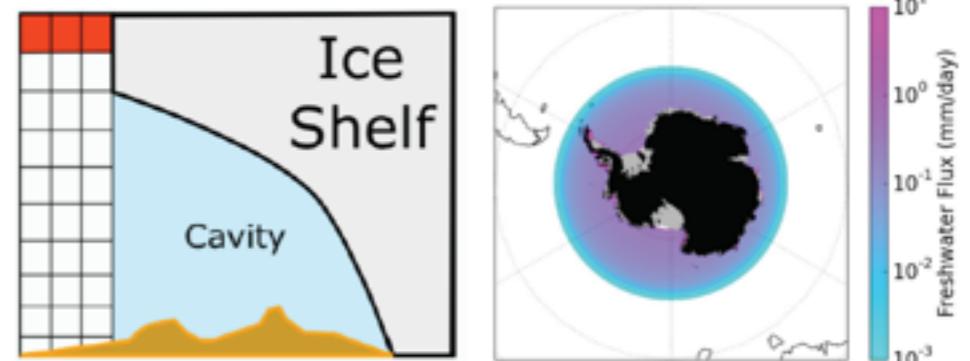
Modeled iceberg melt water



Martin and Adcroft 2010

- Too weak fluxes north of Weddell Gyre  
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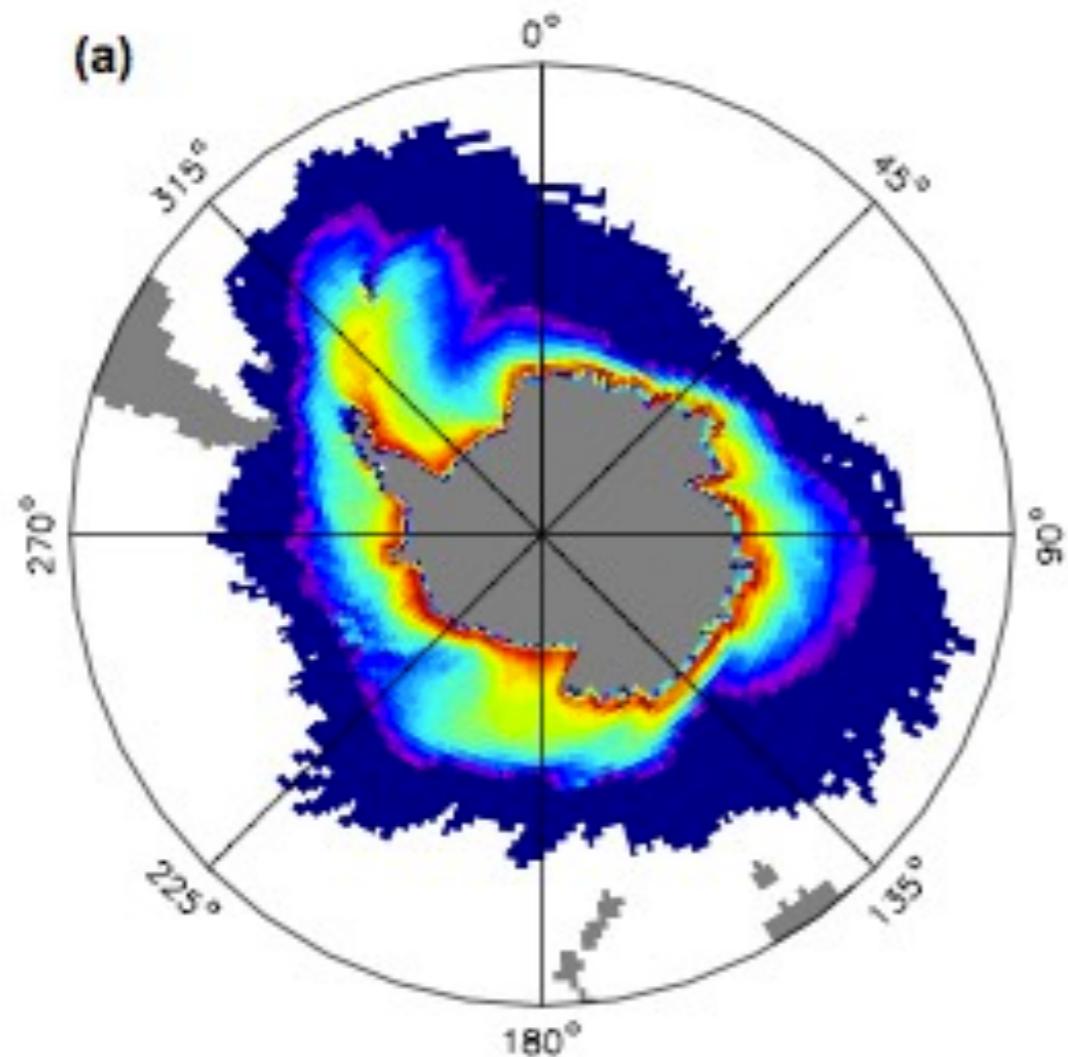
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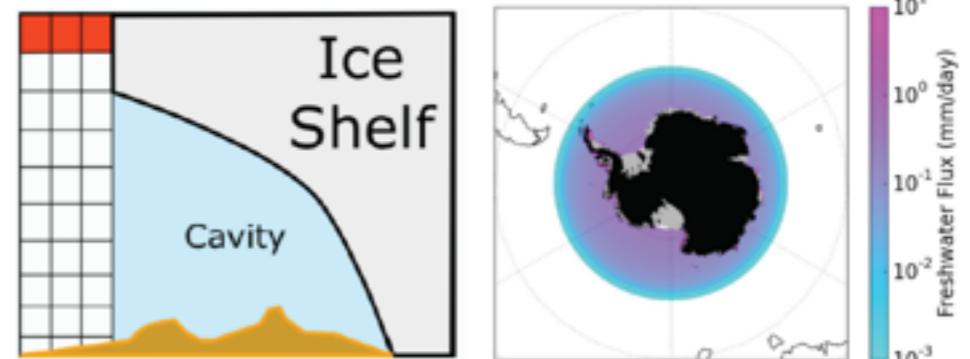
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### Temperature anomaly

