Volcanism as a Trigger for Onset of the Little Ice Age

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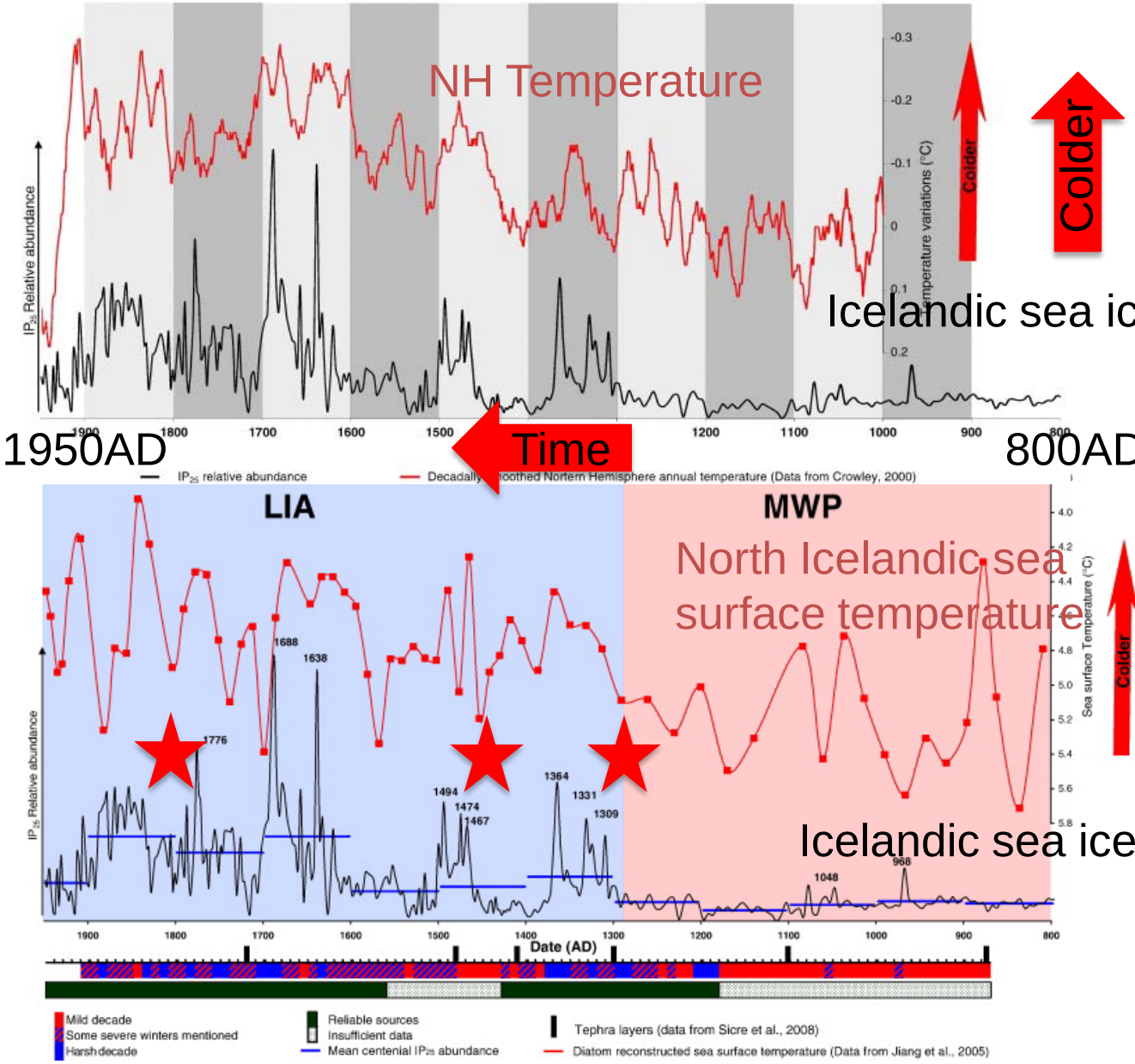
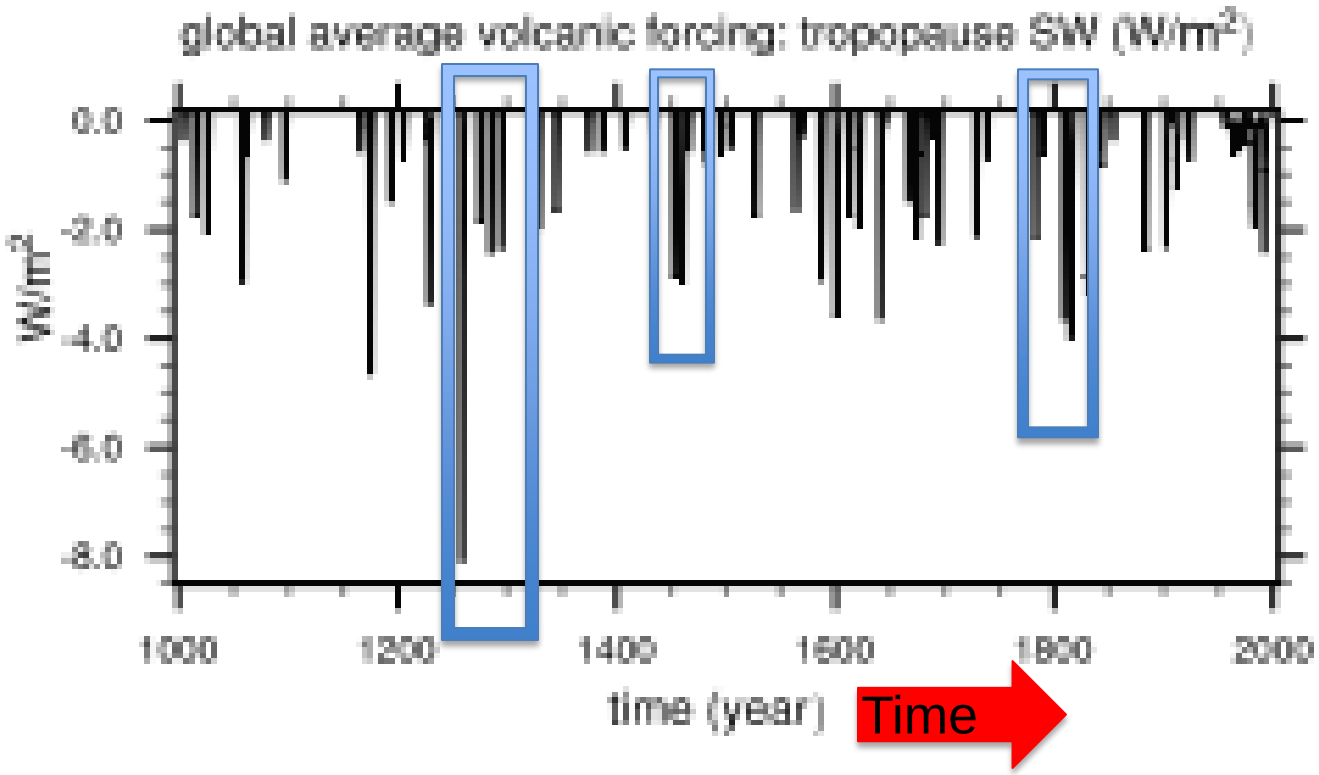
Medieval Warm Period to the Little Ice Age



Step-changes at 1250-1300AD,~1450AD and ~1800AD

Masse et al. (2008)

Volcanic aerosol forcing



Climate step-changes correspond with strong volcanism

Goal

To test whether the explosive volcanism could have caused a step-change in climate state that triggers the onset of the Little Ice Age.

Challenges/questions

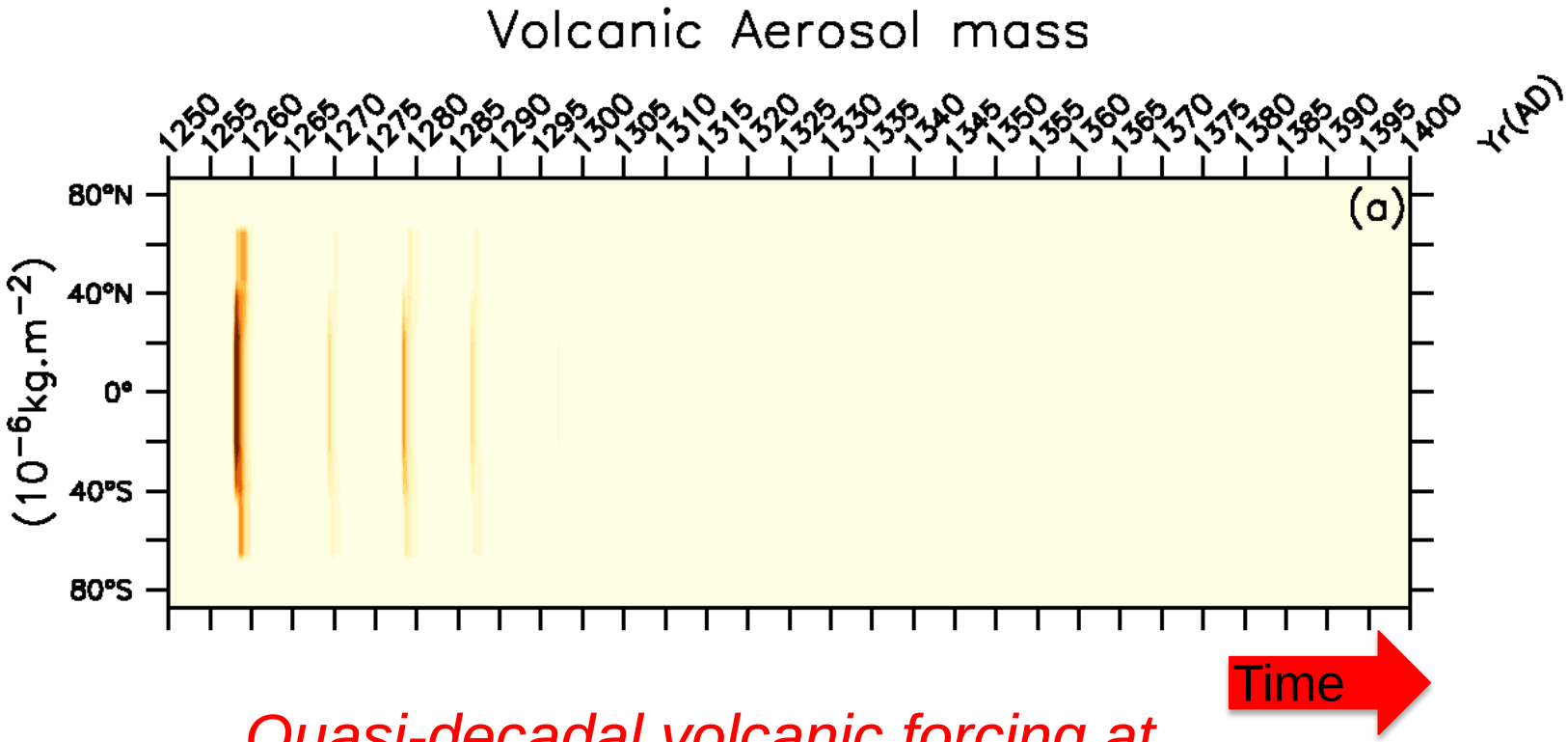
How could short-lived volcanic forcing induce long-lasting climatic responses? The role of slow-evolving ocean?

CCSM3 Experiment design

Control run: Standard simulation of 1000AD climate with orbital forcing at 950AD and Greenhouse Gas levels at 1000AD (280.6ppm CO_2, 684.3ppb CH_4, and 264.5 ppb N_2O).

Volcanism experiment: Branched off the control run and forced with volcanic aerosols in stratosphere as reconstructed for the second half of 13^{th} century. Tropical origins are assumed for the volcanism.

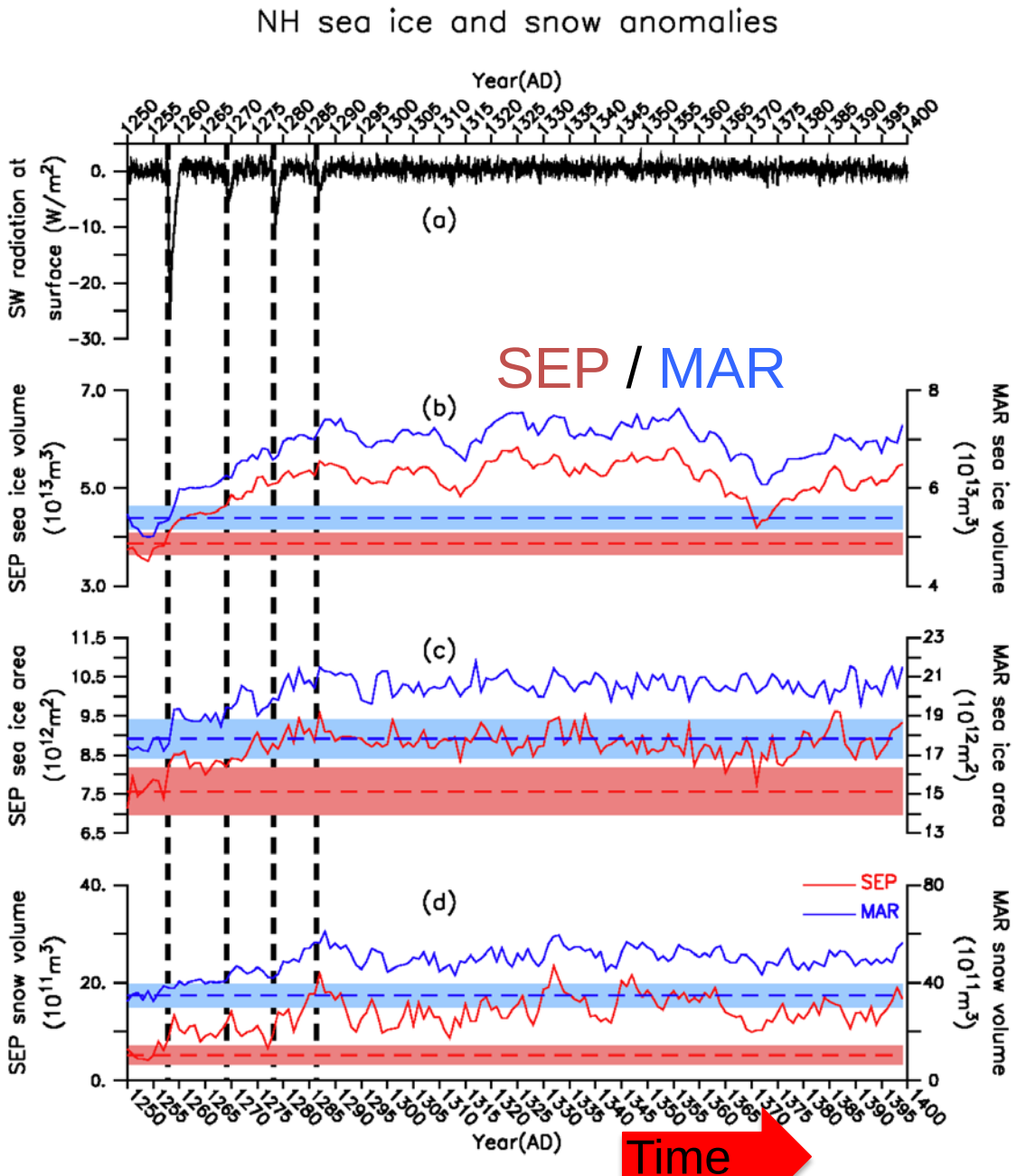
Volcanic aerosol imposed



Quasi-decadal volcanic forcing at 1258, 1269, 1278 and 1286

Ammann et al. (2007)

Long-term growth in NH sea ice and snow



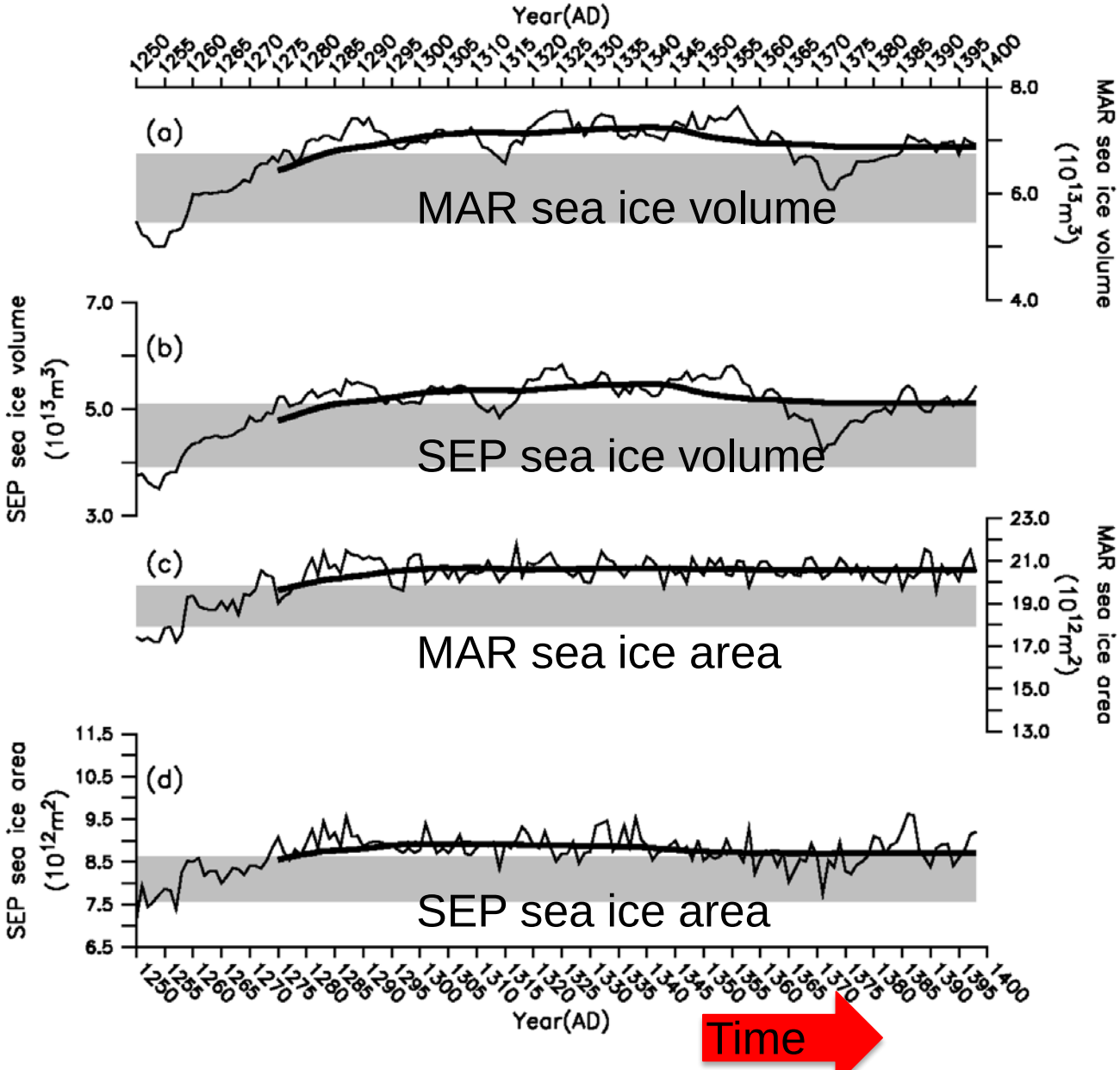
SW

Sea ice volume

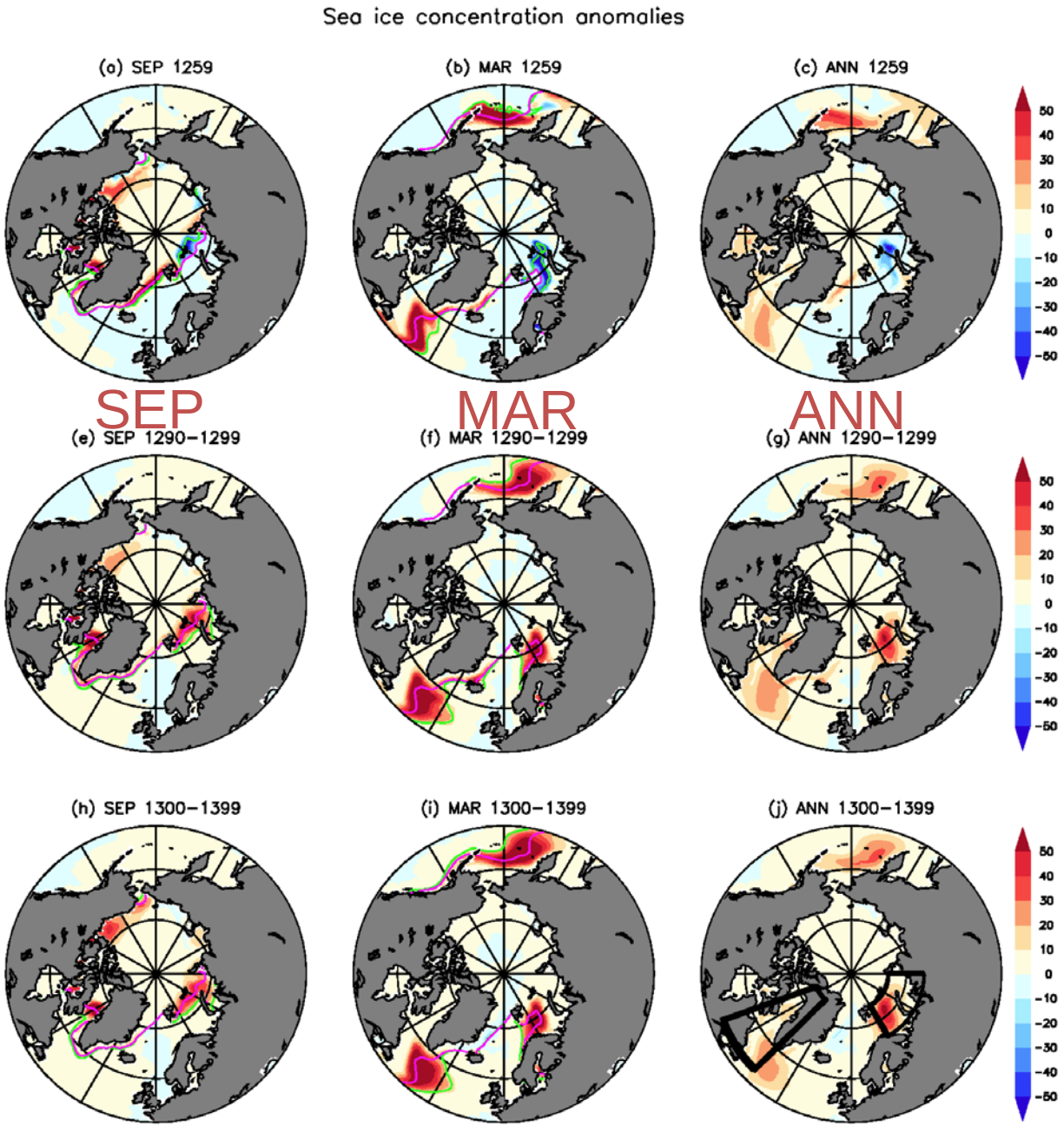
Sea ice area

Snow volume

Step-change in NH sea ice



Sea ice concentration anomalies

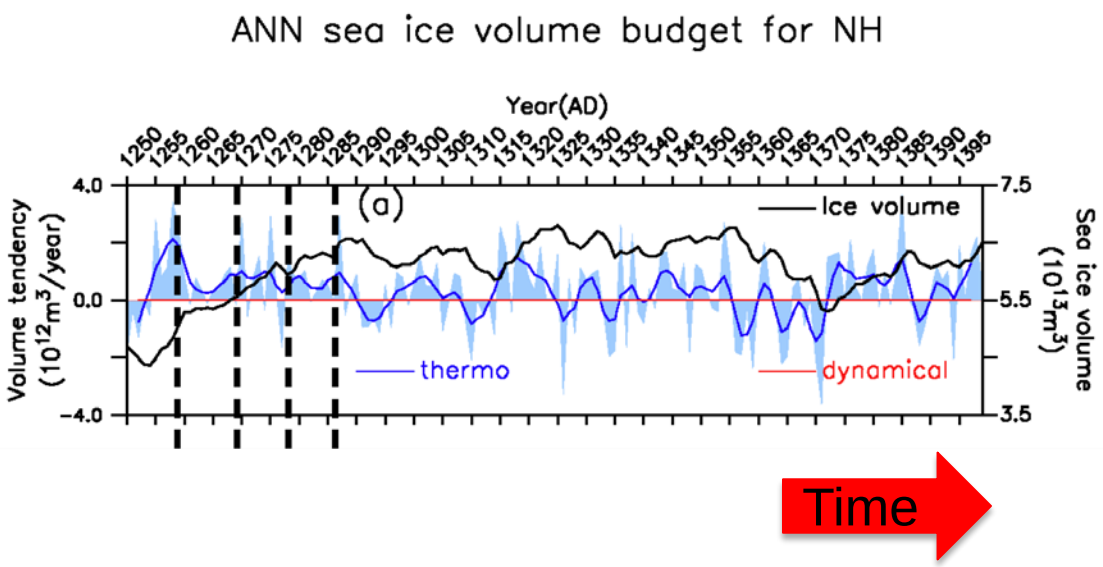


1259AD

1290-1299AD

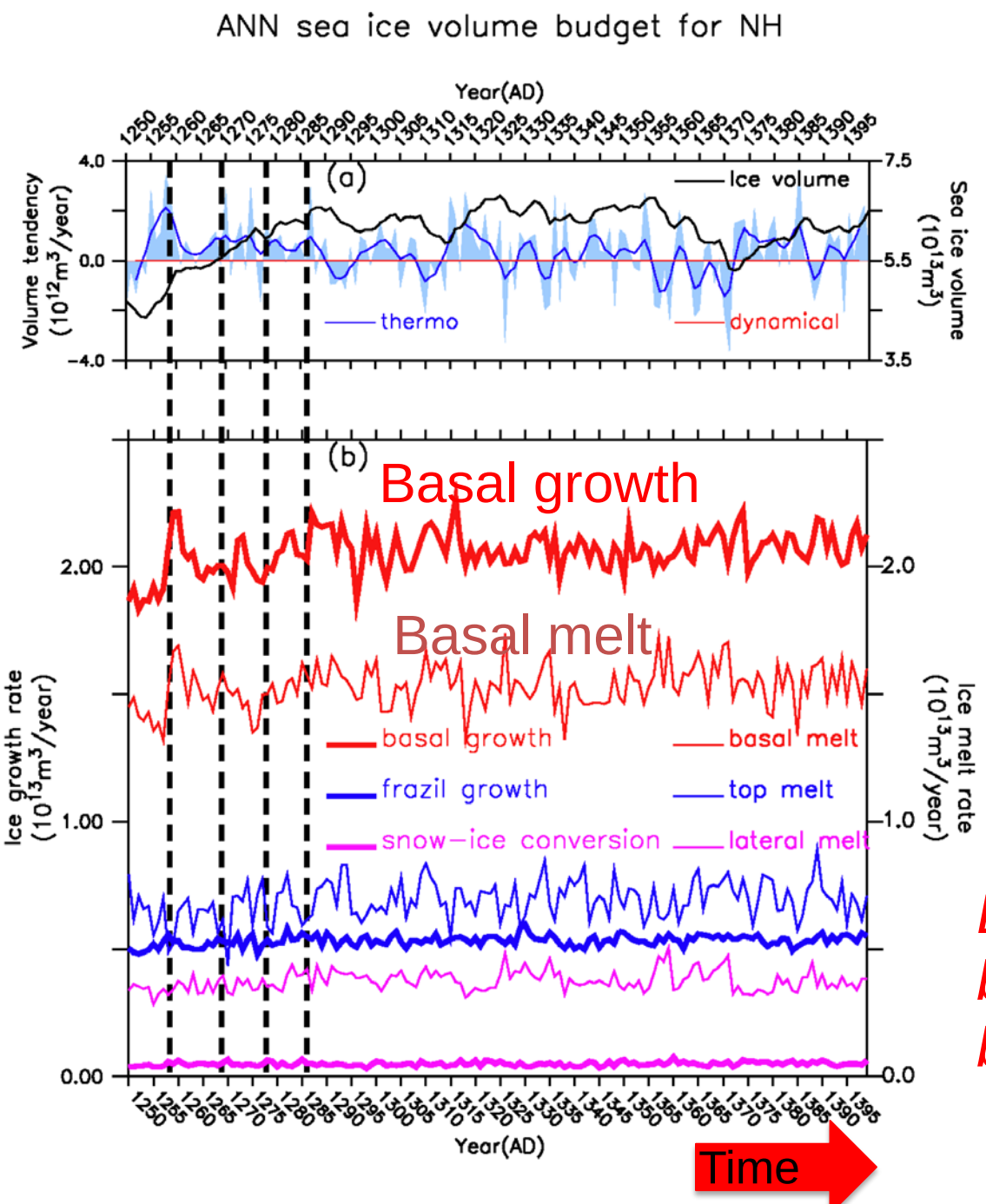
1300-1399AD

Mass budget of ANN NH sea ice



dynamical / thermo

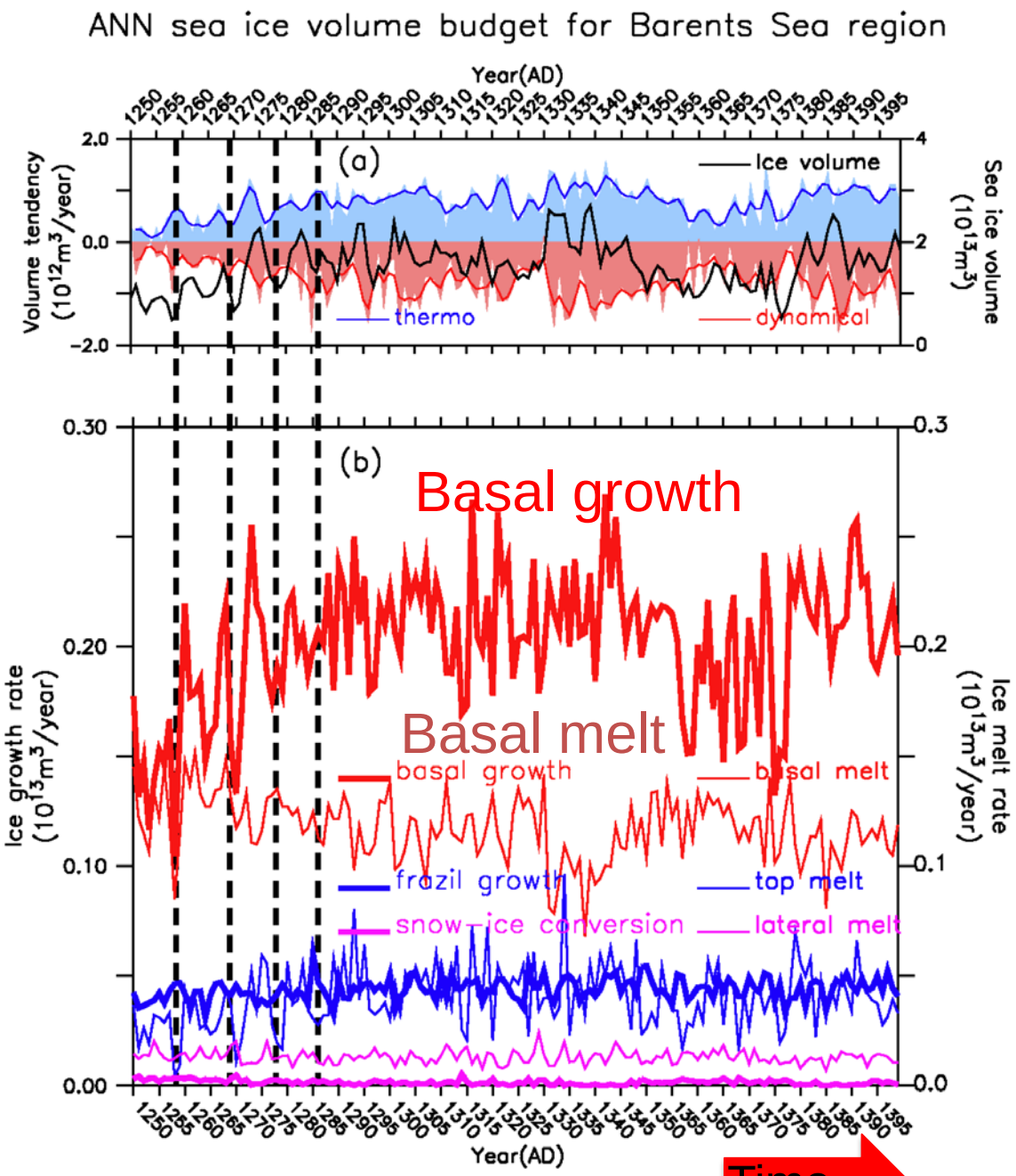
Mass budget of ANN NH sea ice



dynamical / thermo

Driven primarily by increased basal growth

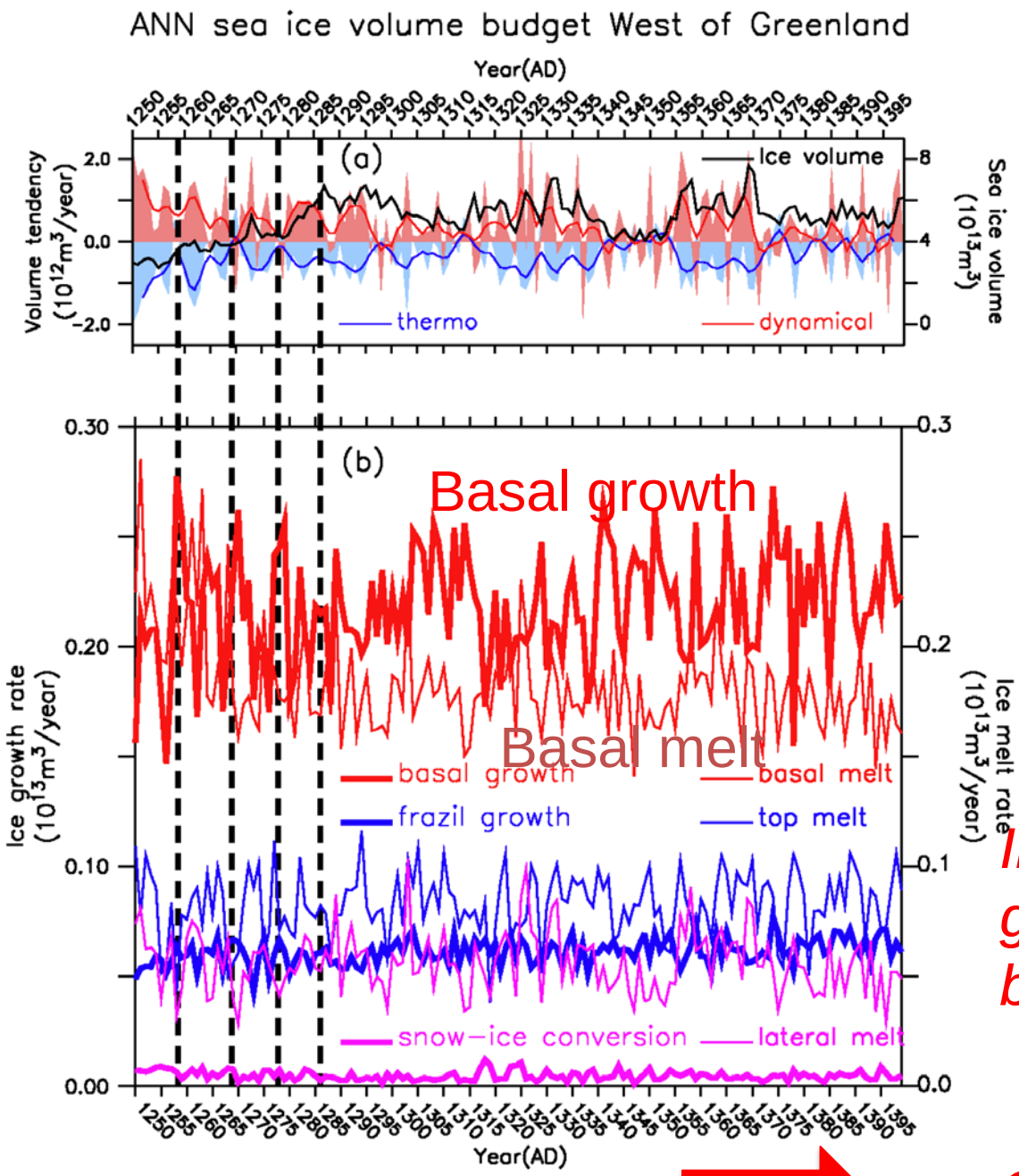
Ice mass budget for Barents Sea region



dynamical / thermo

Increased basal growth & reduced basal melt

Ice mass budget west of Greenland

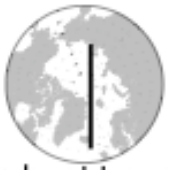


dynamical / thermo

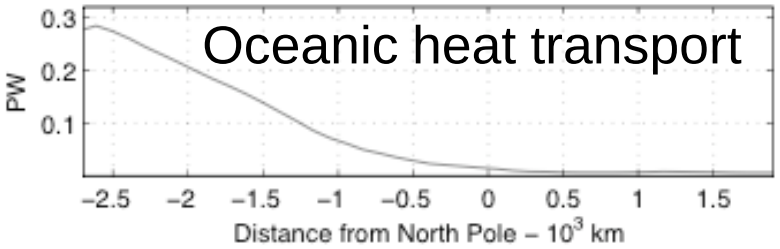
Increased basal growth & reduced basal melt

Colder water beneath

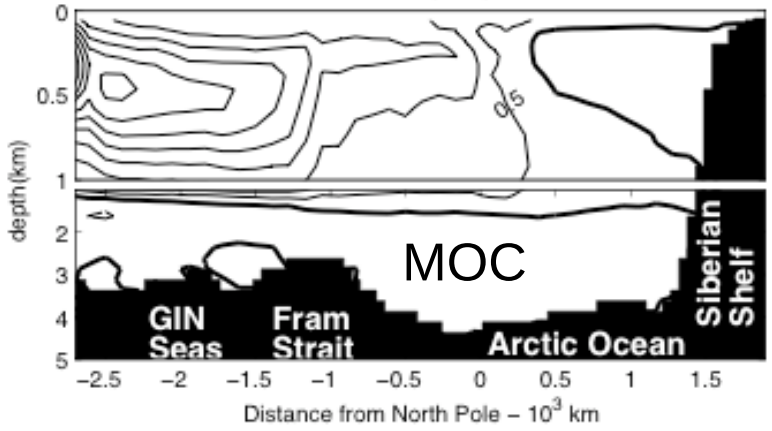
Reduced oceanic heat transport into the Arctic



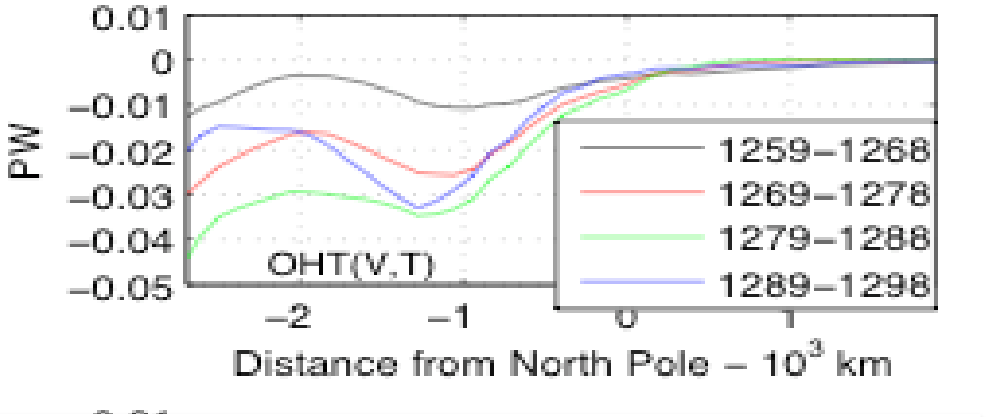
Oceanic heat transport



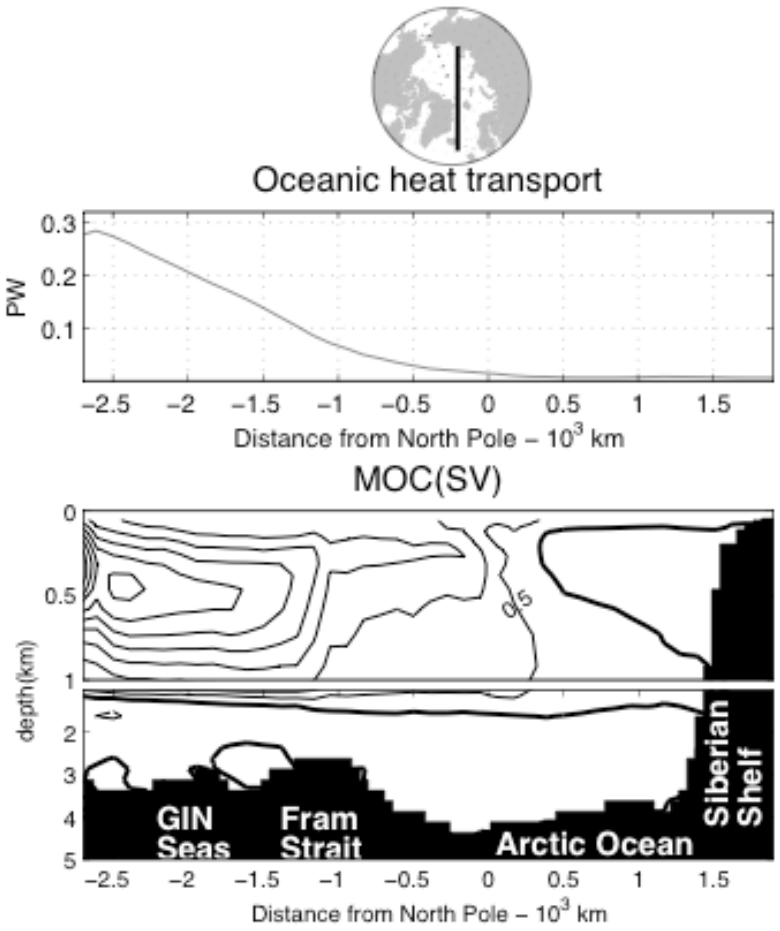
MOC(SV)

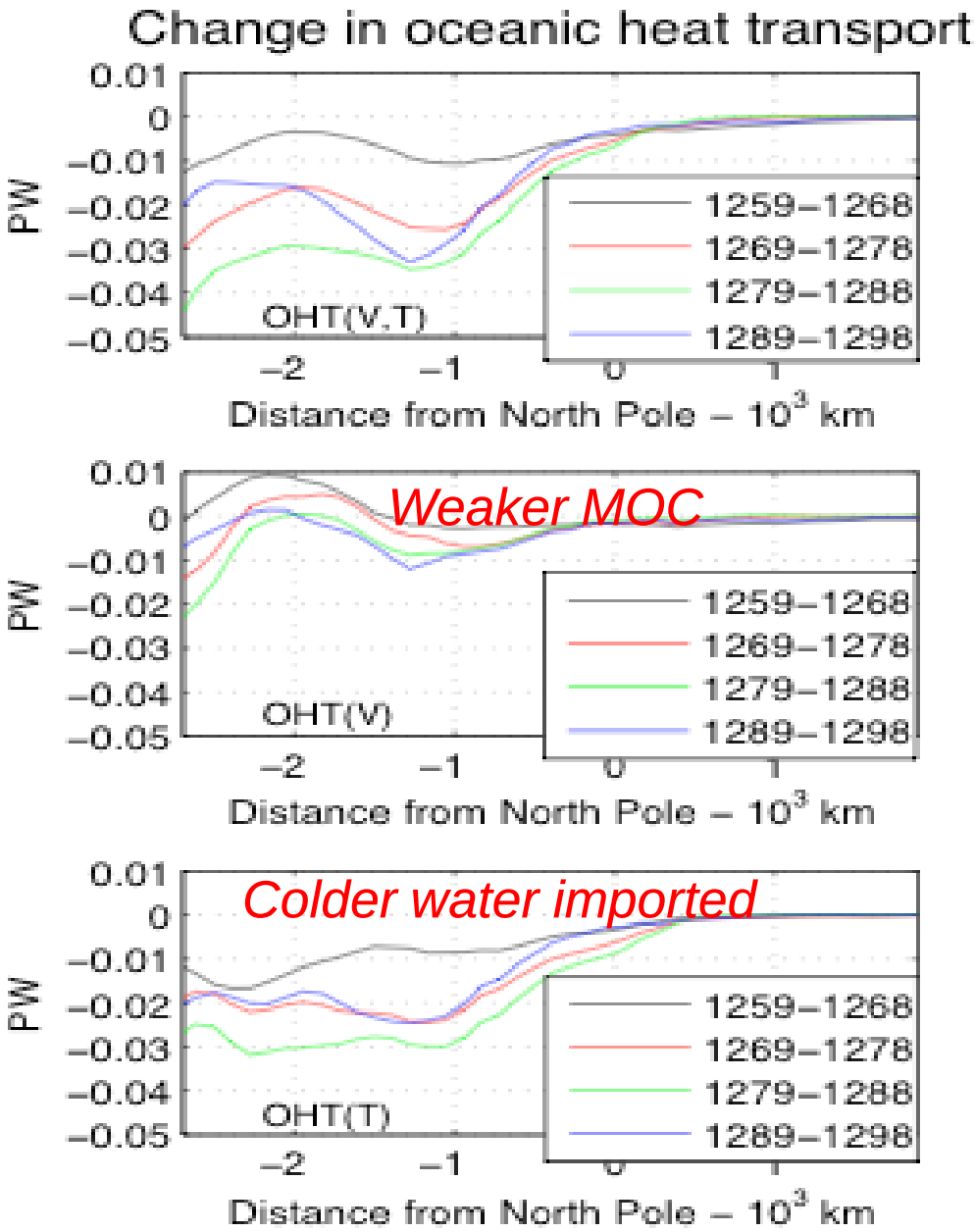


Change in oceanic heat transport

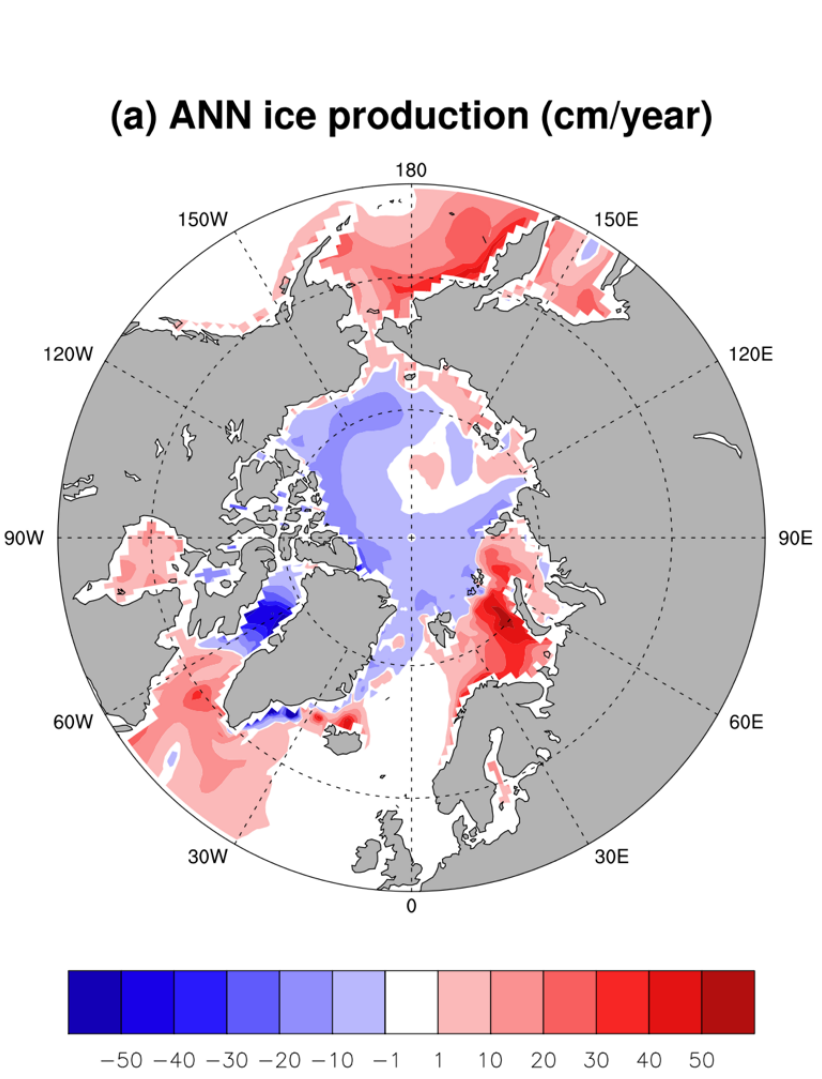


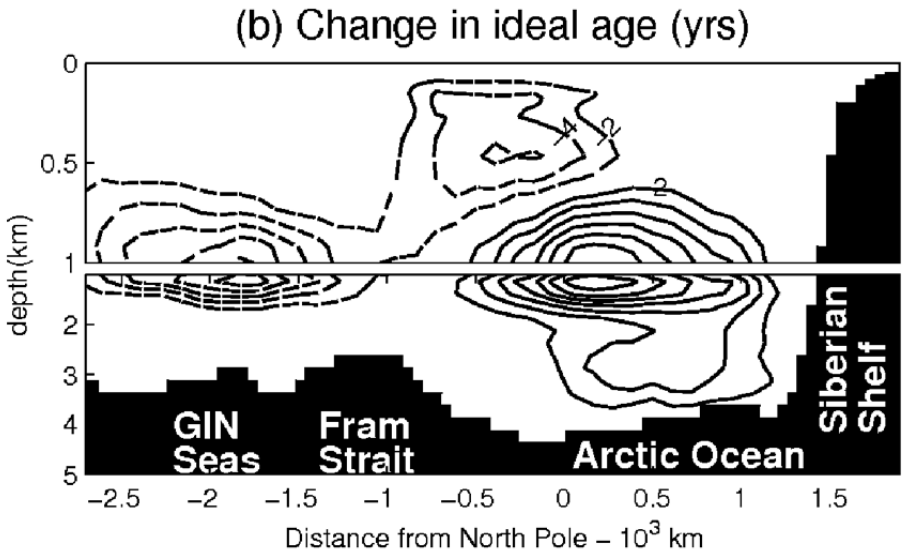
Reduced oceanic heat transport into the Arctic

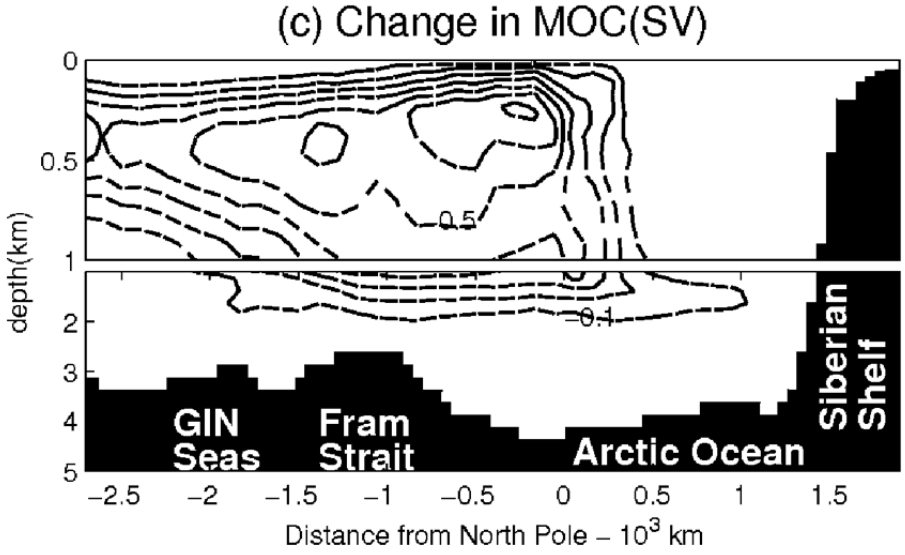




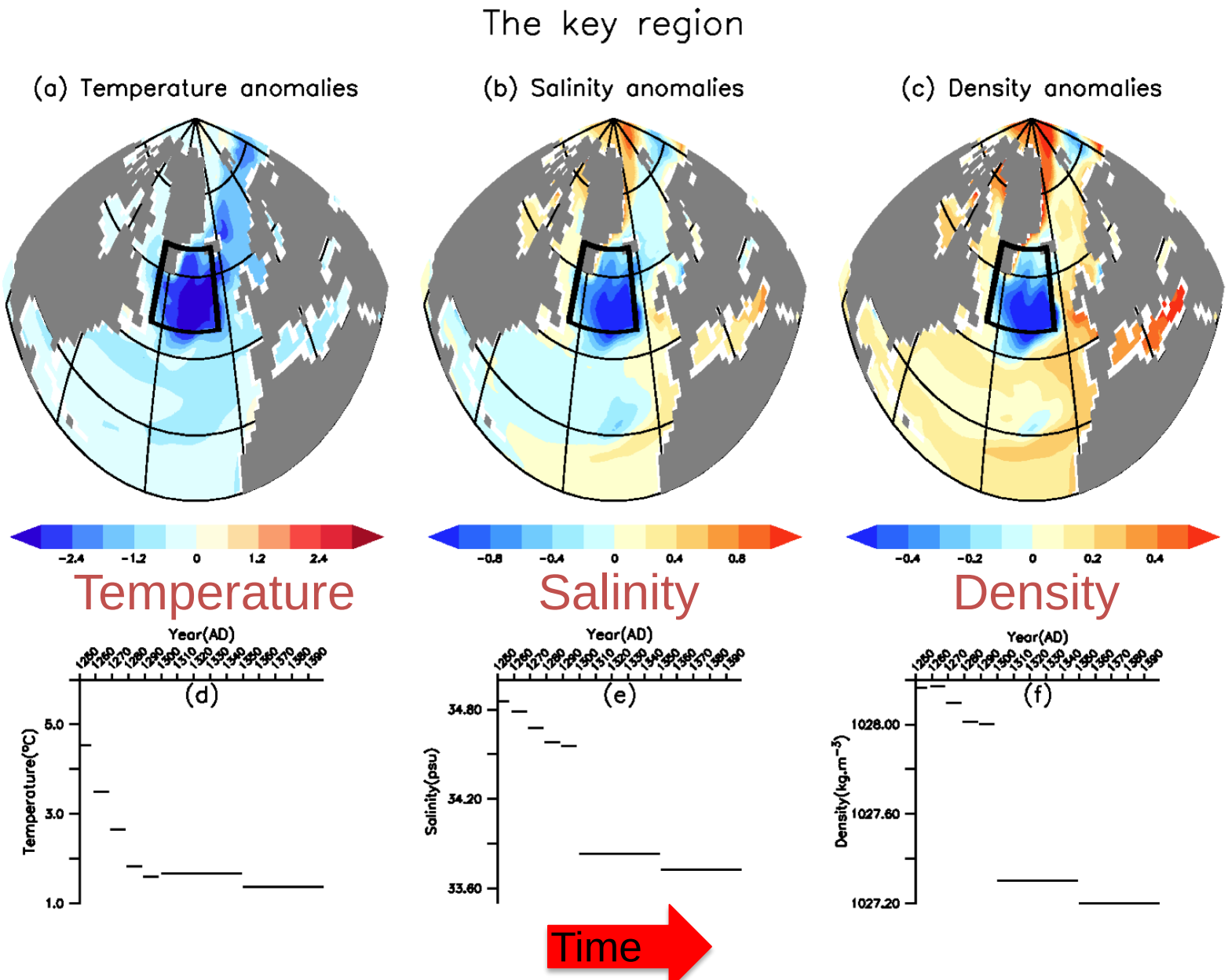
Weakened MOC in the Arctic



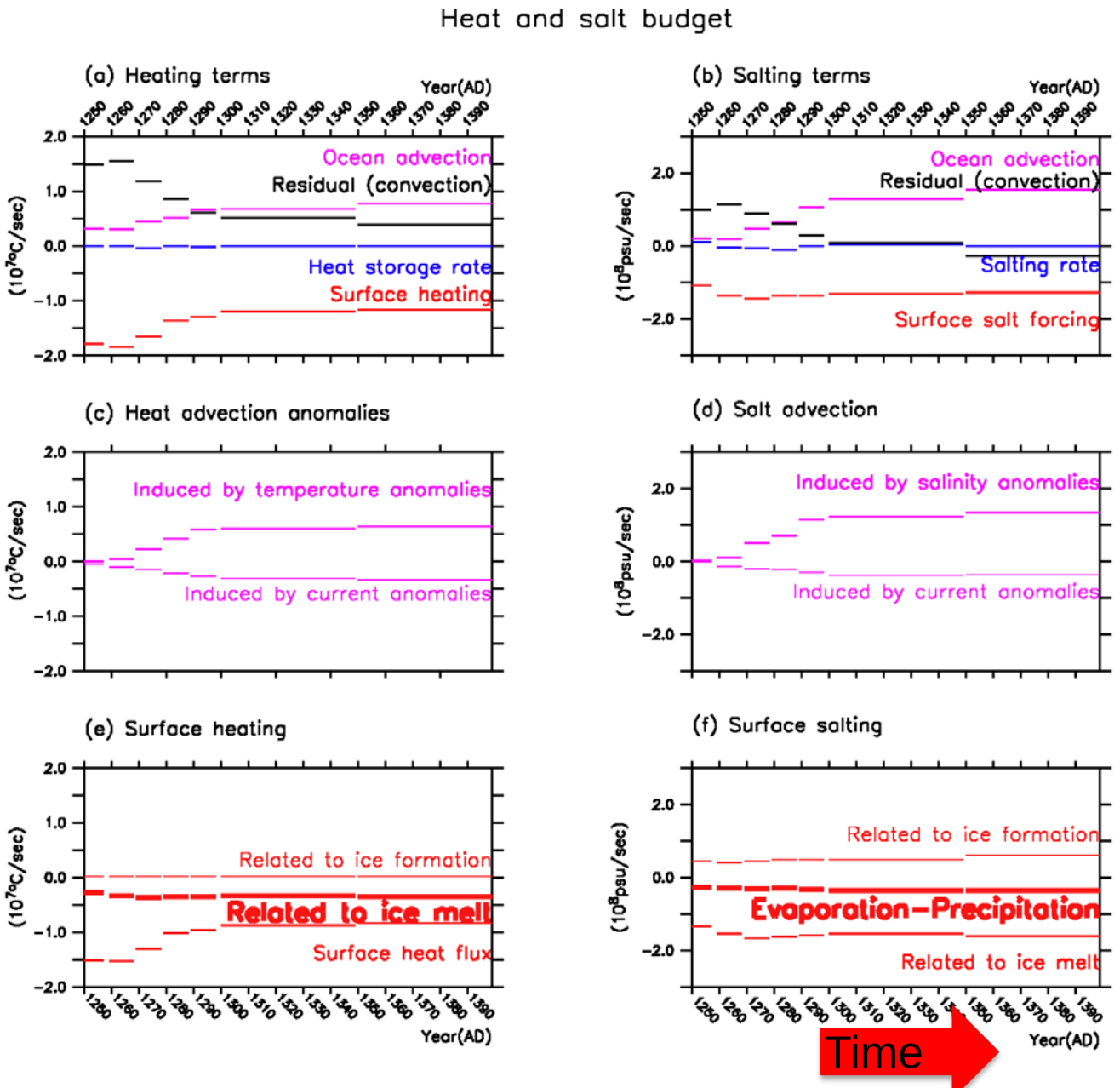


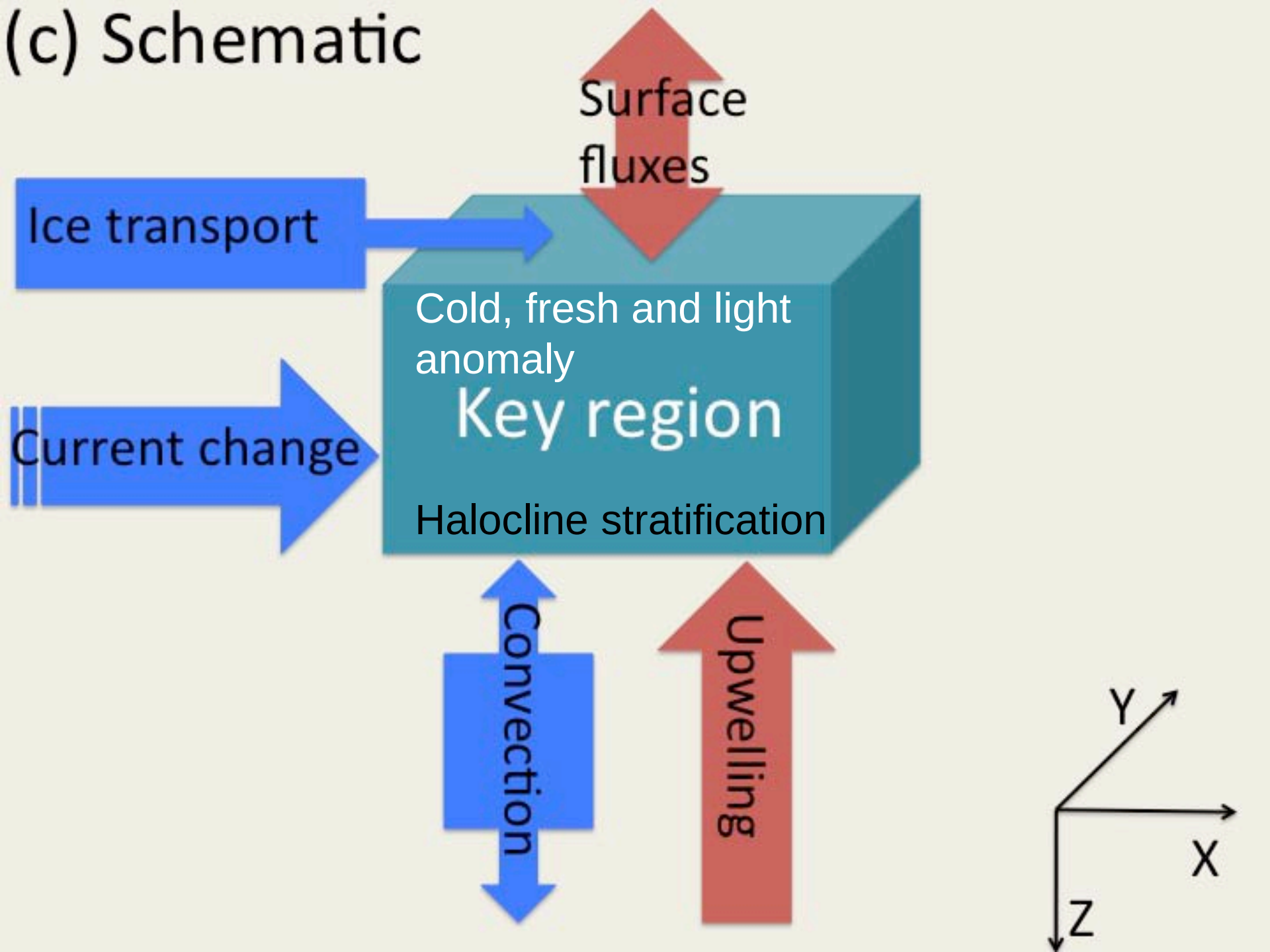


Colder surface water in northern North Atlantic

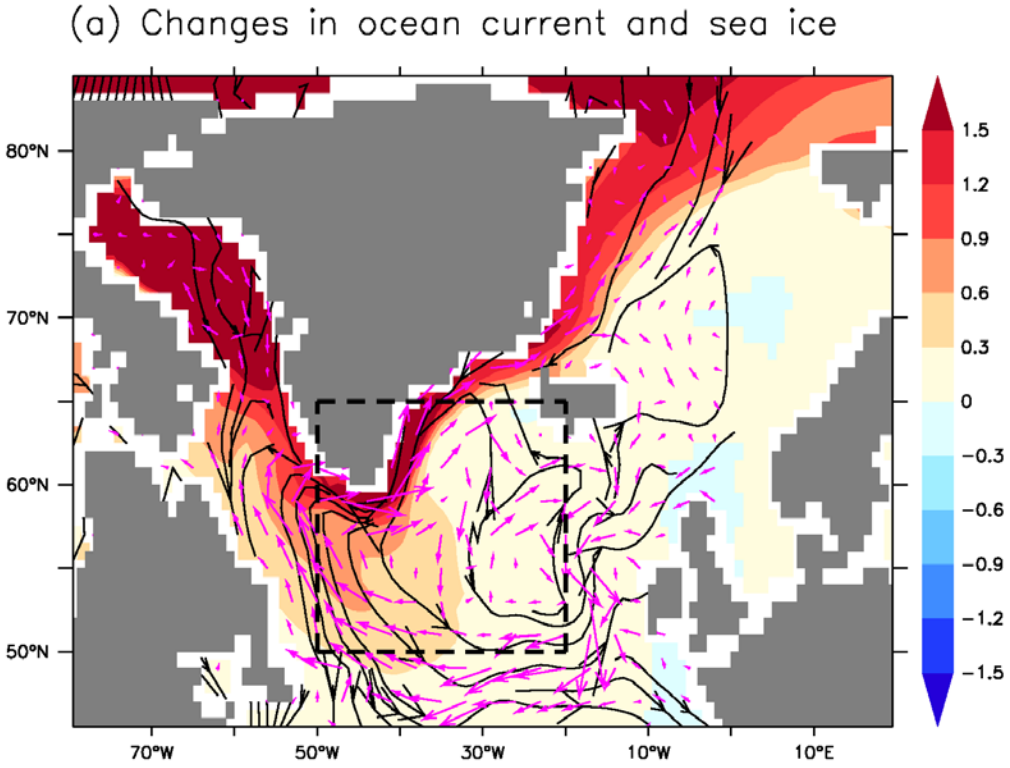


Heat and salt budget for the key region



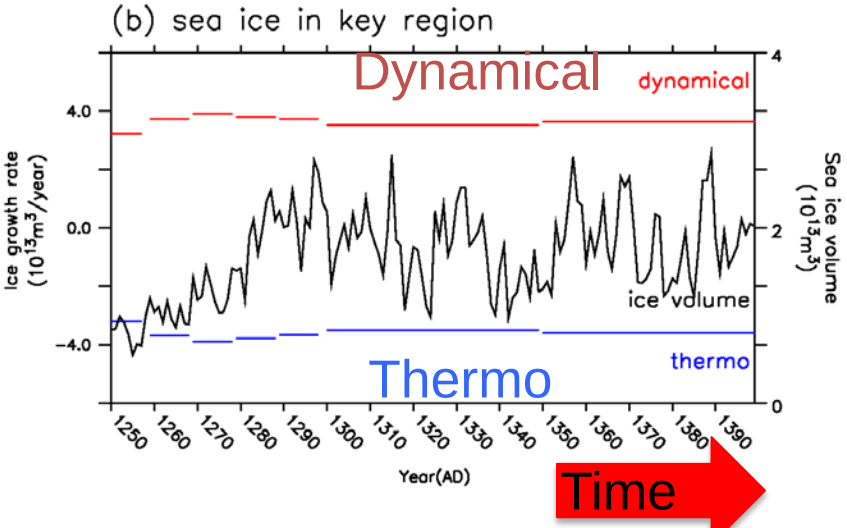

(c) Schematic
Surface fluxes
Ice transport
Cold, fresh and light anomaly
Key region
Current change
Halocline stratification
Convection
Upwelling
Y
X
Z

Changes in ocean current and sea ice

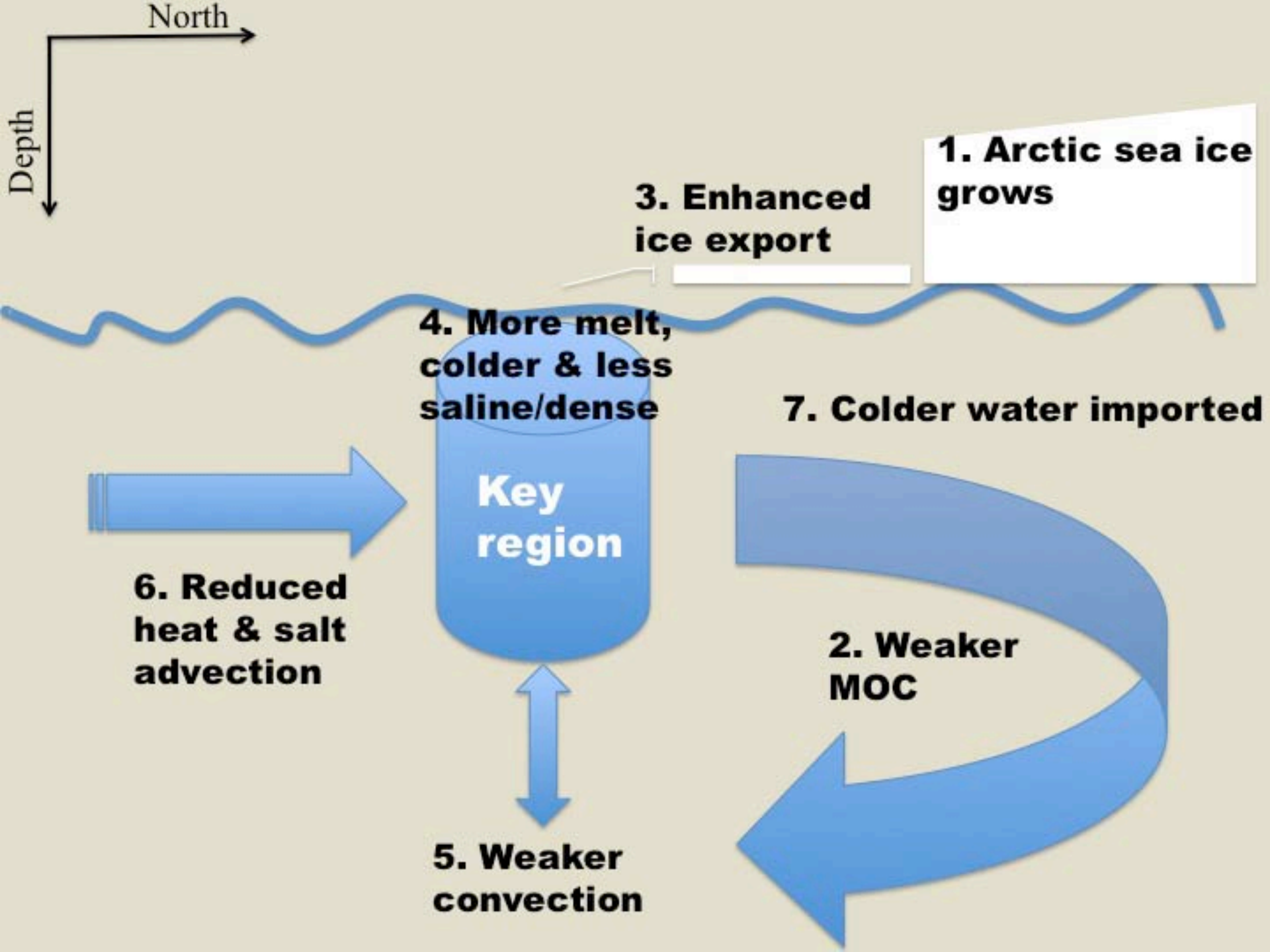


Relaxed oceanic circulation

Sea ice in key region



More sea ice transported to and melted in the key region


North
Depth
1. Arctic sea ice grows
3. Enhanced ice export
4. More melt, colder & less saline/dense
7. Colder water imported
Key region
6. Reduced heat & salt advection
2. Weaker MOC
5. Weaker convection

Mechanisms for long-term sea ice growth

Accumulated volcanic cooling effect and positive sea ice-ocean feedbacks

a. Arctic sea ice grows -> reduced ice production in central Arctic and Canadian Basin -> weaker MOC in the northern North Atlantic and Arctic -> less heat transport poleward -> sea ice grows.

b. Arctic sea ice grows -> increased ice export to and melt in the northern North Atlantic -> weaker convection and relaxed oceanic circulation -> colder surface water in the northern North Atlantic -> colder water transported to the Arctic -> sea ice grows.

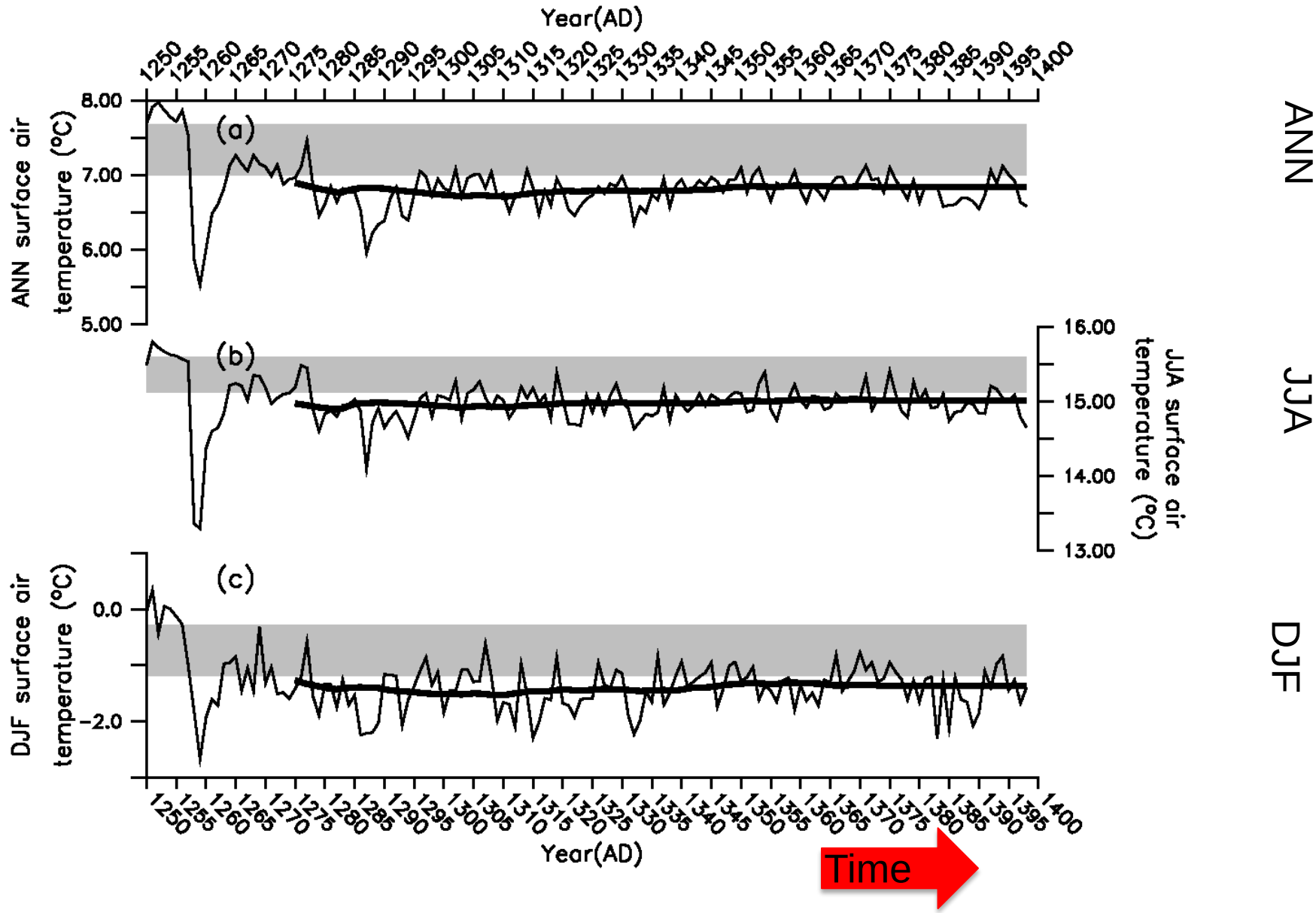
Summary

Our CCSM3 simulations show that the sequenced eruptions in the second half of 13th century are able to cause long-term growth in Arctic sea ice and snow cover.

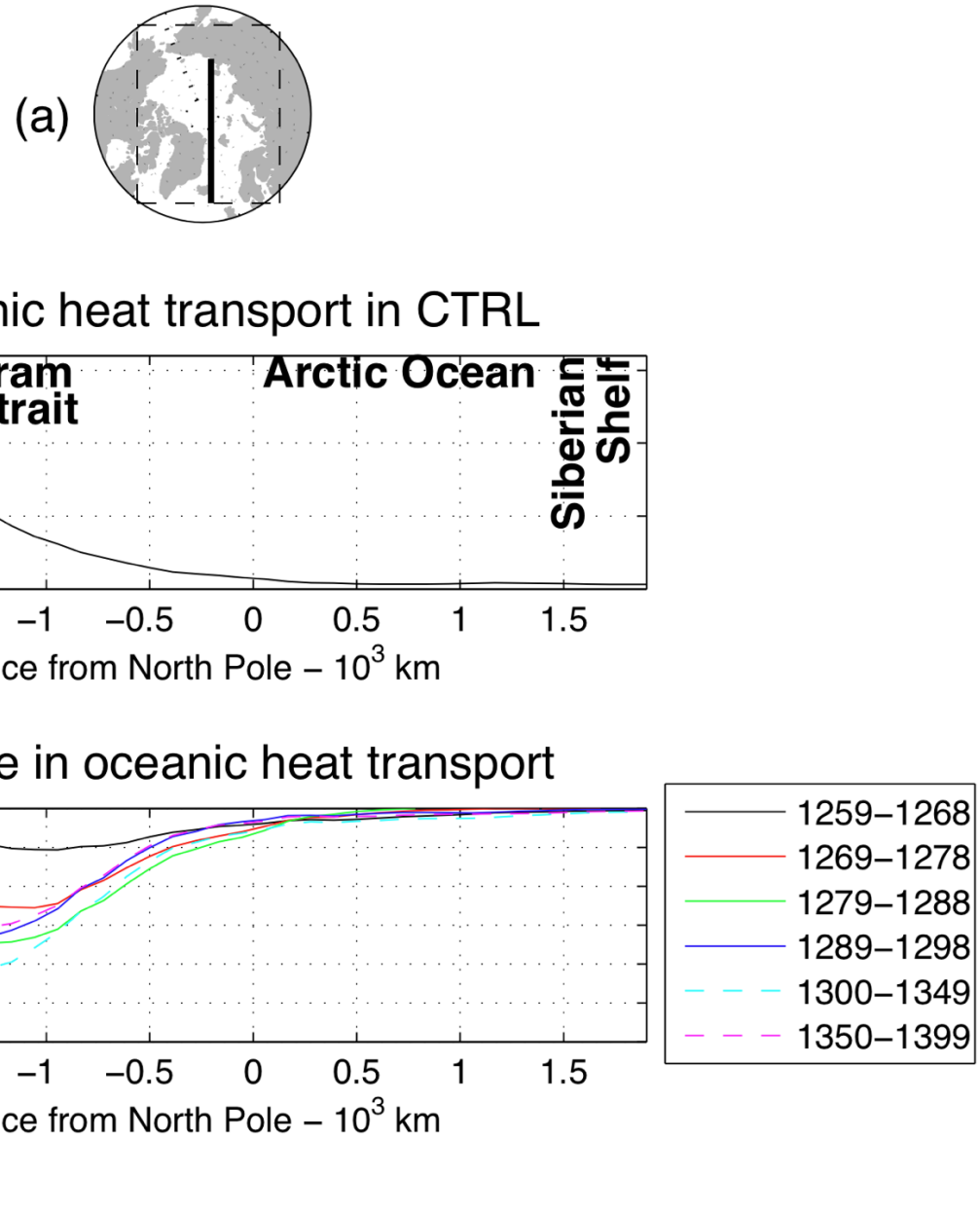
The long-term sea ice growth results from accumulated volcanic cooling effect and positive sea ice-ocean feedbacks.

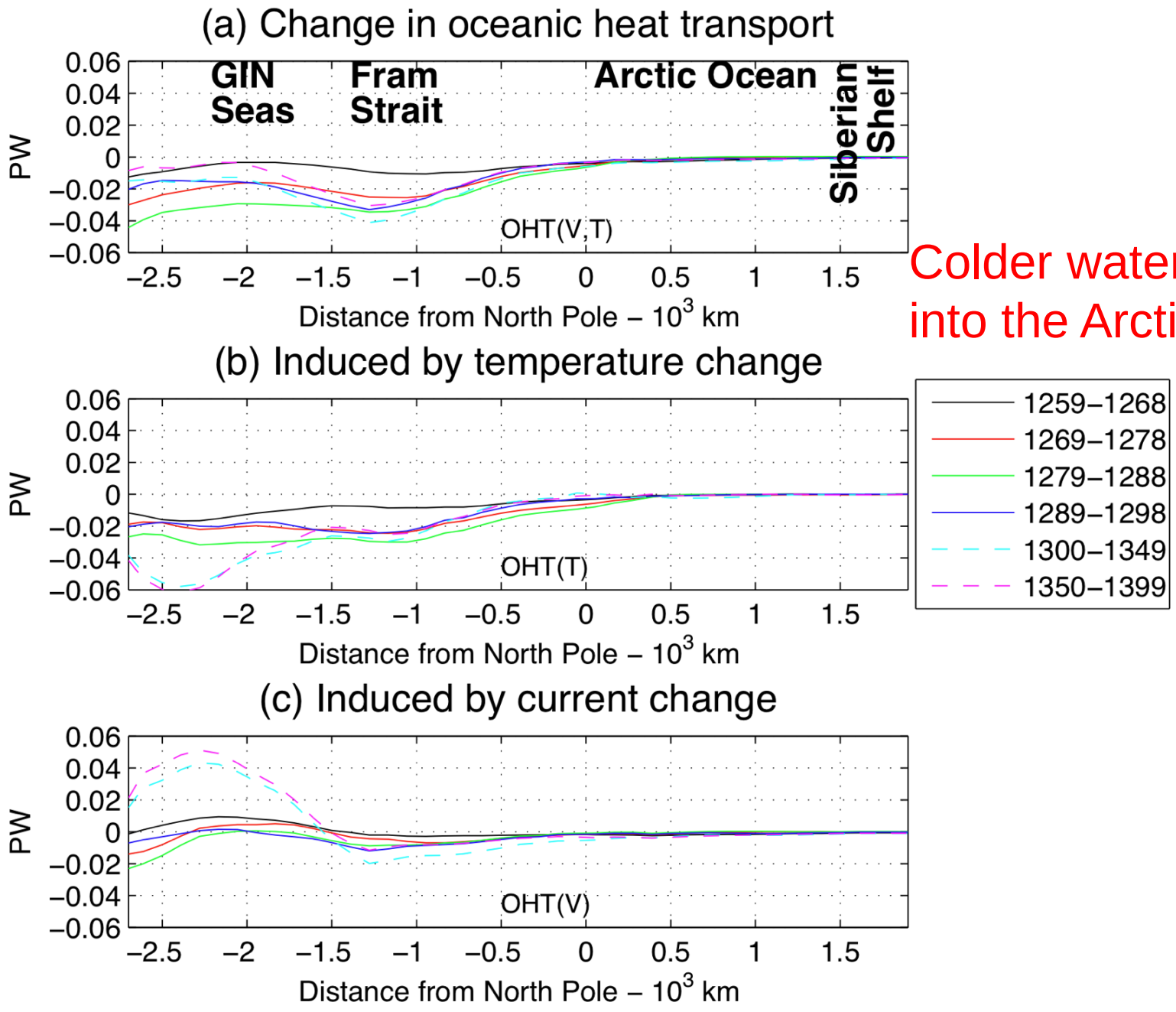
The volcanism could have triggered onset of the Little Ice Age via the proposed sea ice-ocean mechanism.

Step-change in NH air temperature



Reduced oceanic heat transport into the Arctic





Colder water transported into the Arctic