Changes of Sea Level and Poleward Ocean Heat Transport as Potential Causes for the Late Ordovician Glaciation

Achim D. Herrmann and Mark E. Patzkowsky
Department of Geosciences, Penn State

Dave Pollard, Bernd J. Haupt, and Dan Seidov
EMS Environment Institute, Penn State

Objectives

- Using an Atmospheric General Circulation Model to
  - Evaluate the sensitivity of the Late Ordovician climate to different paleogeographies, atmospheric pCO_2 values, sea levels, and poleward ocean heat transport.
- Using an Ice Sheet Model to
  - Investigate the threshold that led to the formation of ice sheets.
- Using a Ocean General Circulation Model to
  - Evaluate the impact of paleogeographic changes, atmospheric pCO_2 values, and sea level changes on global poleward ocean heat transport and the initiation of ice sheets during the Late Ordovician.

Methods - 1

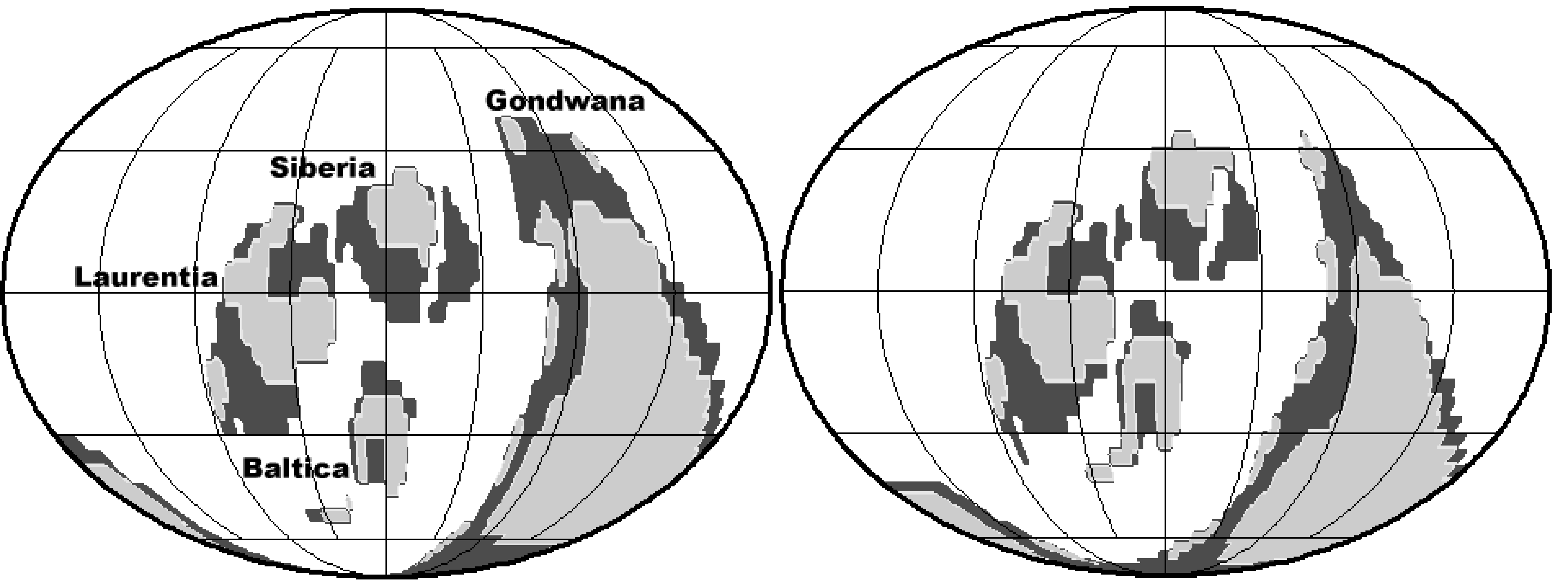
- General Atmospheric Circulation Model – GENESIS v.2.0
- T31 spectral resolution (~400 km) for atmosphere
- 2º x 2º surface resolution
- 50-m slab ocean, dynamic sea ice model
- 40-year runs

Boundary Conditions

Boundary Conditions	How varied
Land-Sea distribution	Paleogeography of Scotese and McKerrow (1991); shoreline position after Scotese (1997)
Topography	250 m for coastal grid points and 500m for all other land grid points
Orbital parameters	“Cold-Summer Orbit” eccentricity: 0.06 obliquity: 22. precession: 270. perihelion to N.H. vernal equinox
Solar luminosity	4.5% reduction of present day
Vegetation and soil type	No vegetation with intermediate soil color values
Atmospheric pCO_2	5040 ppm (18x PAL); 4200 ppm (15x PAL); 3360 ppm (12x PAL); 2800 ppm (10x PAL); 2240 ppm (8x PAL)

Paleogeographic Changes

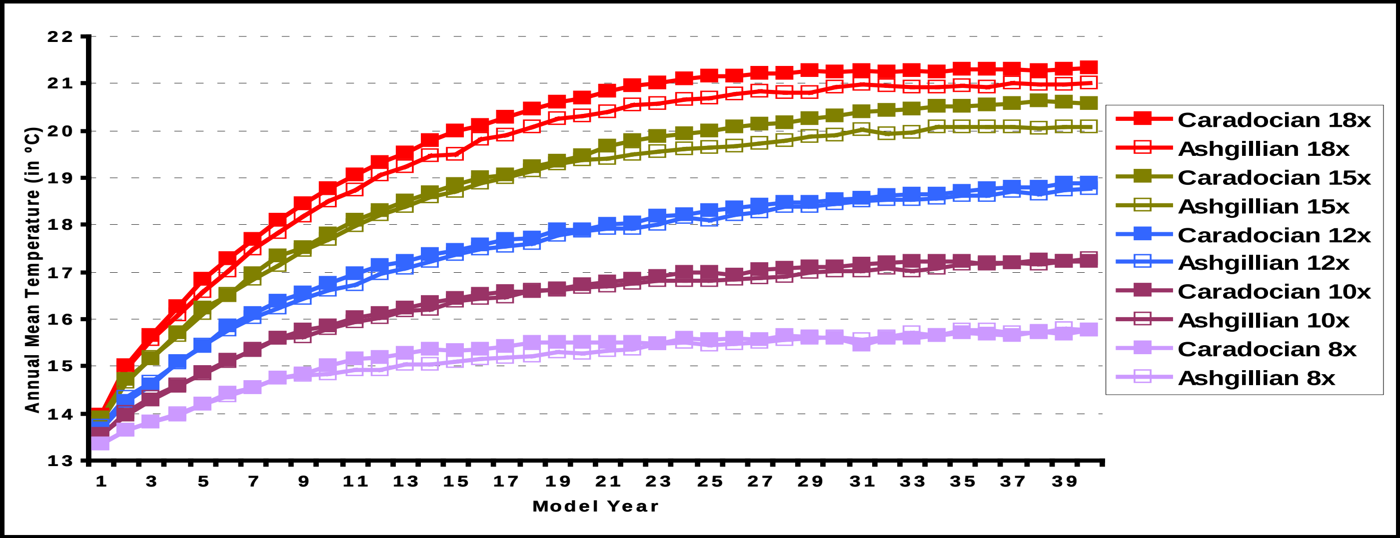
Caradocian (454 Ma) Ashgillian (446 Ma)



(after Scotese and McKerrow 1990, 1991; Scotese 1997)

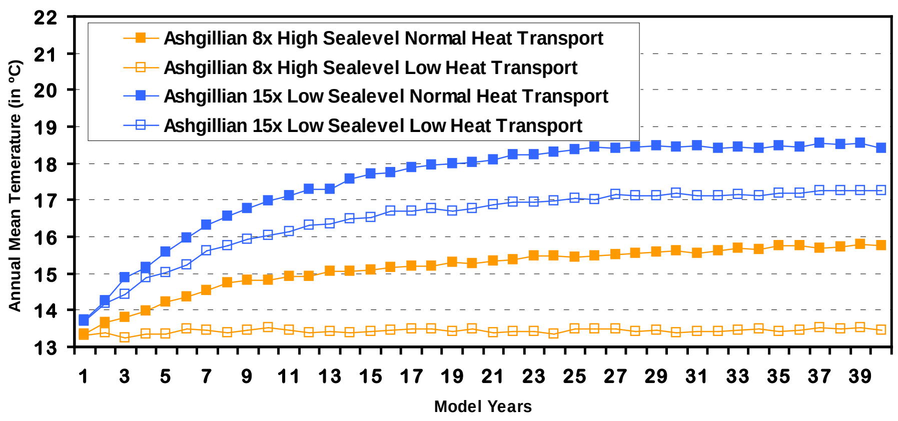
Annual Mean Temperatures

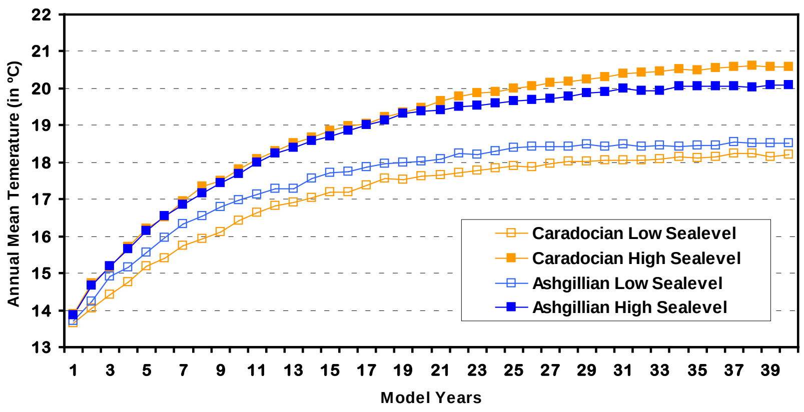
Paleogeography and pCO_2



Poleward heat transport

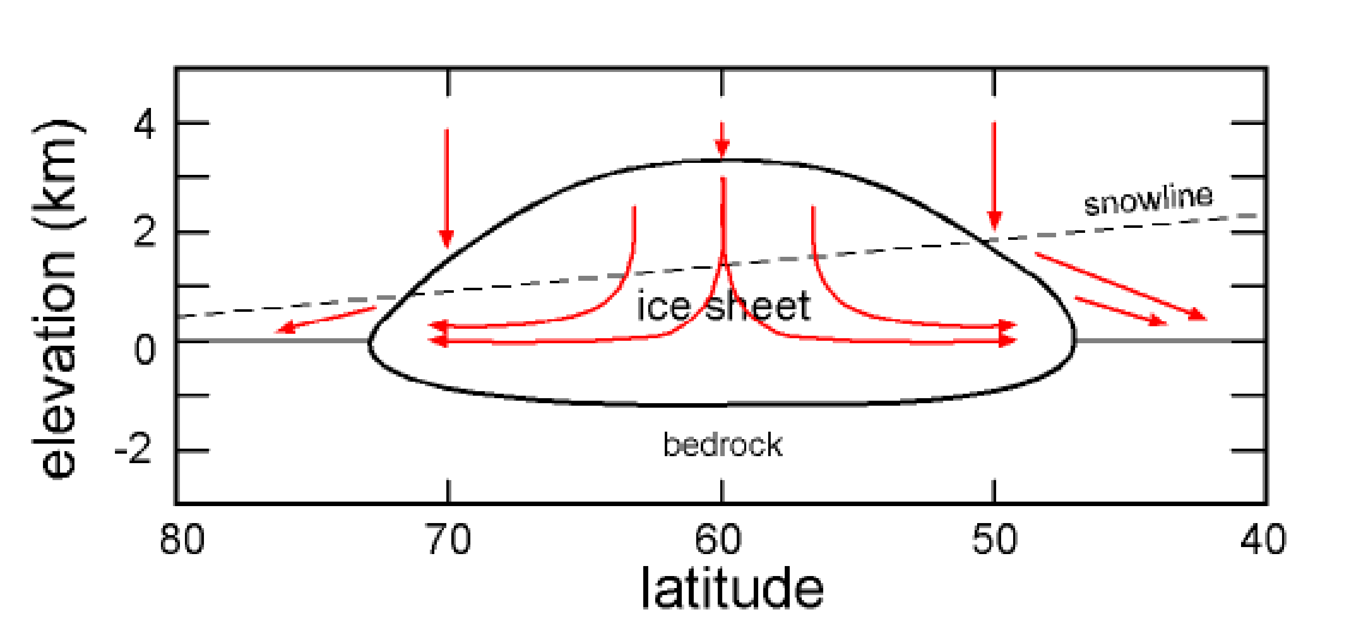
Sea level





Methods 2 - Ice Sheet Model

- 3-dimensional model
- 1º x 1º longitude-latitude grid
- Surface mass balance: Degree-day
- 2-km bedrock with vertical heat diffusion



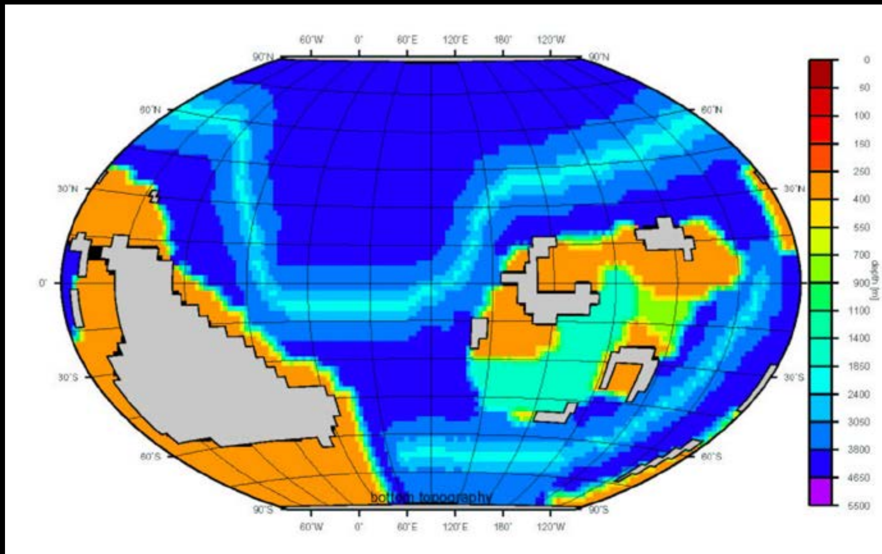
Ice Sheet Model

Simulation	Caradocian	Ashgillian
18x High Sealevel Normal Heat Transport	No glaciation	No glaciation
15x High Sealevel Normal Heat Transport	No glaciation	No glaciation
15x Low Sealevel Normal Heat Transport	No glaciation	No glaciation
15x Low Sealevel Low Heat Transport	Glaciation	No glaciation
12x High Sealevel Normal Heat Transport	No glaciation	No glaciation
10x High Sealevel Normal Heat Transport	No glaciation	No glaciation
8x High Sealevel Normal Heat Transport	No glaciation	No glaciation
8x Low Sealevel Normal Heat Transport	Glaciation	Glaciation
8x High Sealevel Low Heat Transport	Ice Sheets	Glaciation

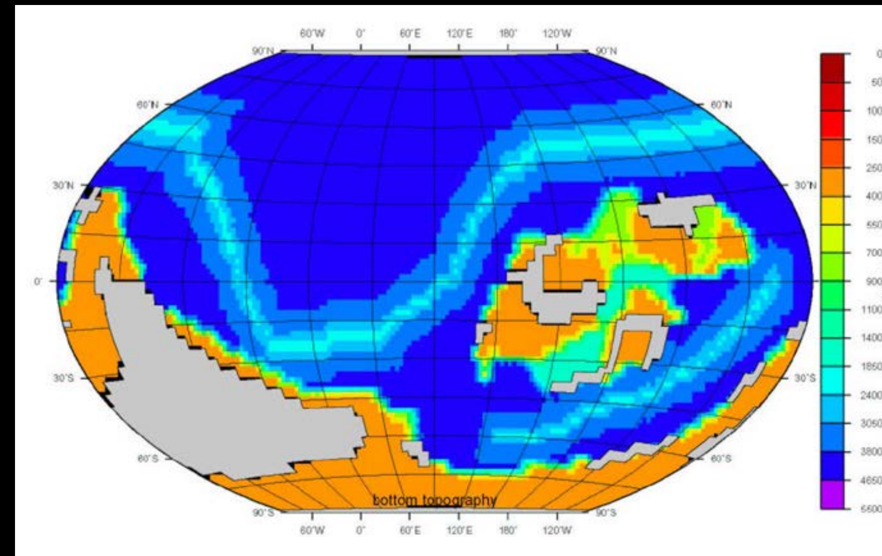
Methods 3 – Ocean Circulation Model

- Modular Ocean Model v.2.2
- 4º x 4º longitude-latitude grid and 16 unequally spaced vertical layers
- Atmospheric forcing from GENESIS simulations
- All runs are 2000 model years long, with five-fold acceleration in the deep layers (i.e., deep ocean is effectively run for 10000 yr).

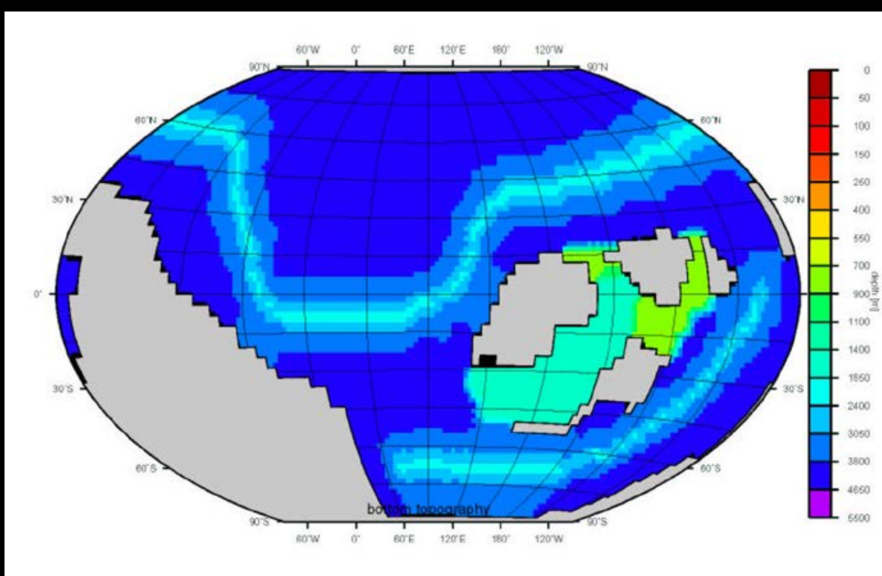
Bathymetry



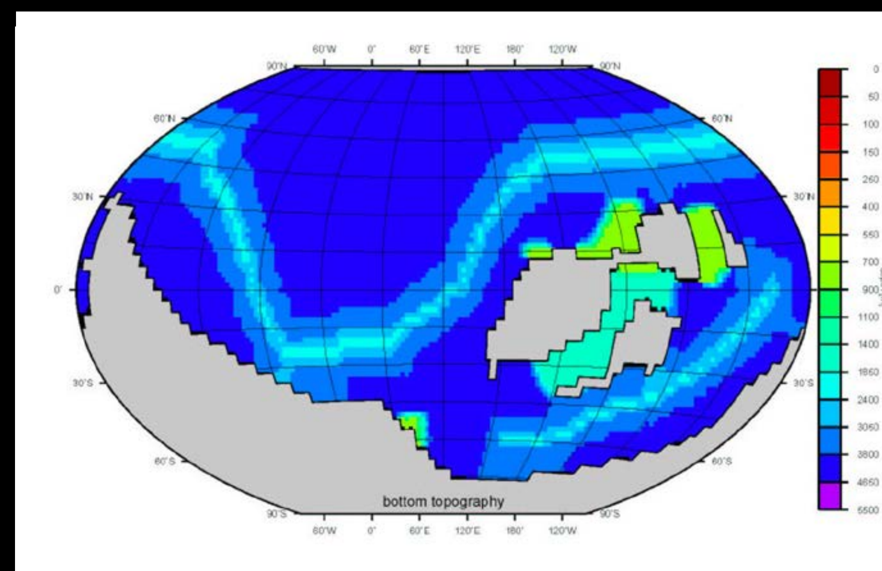
Caradocian High Sea Level



Ashgillian High Sea Level

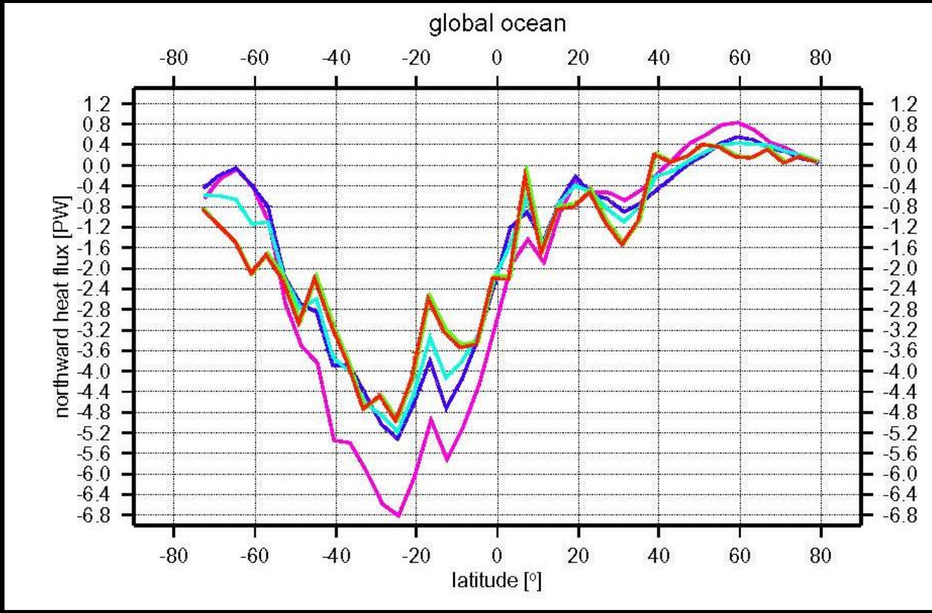


Caradocian Low Sea Level

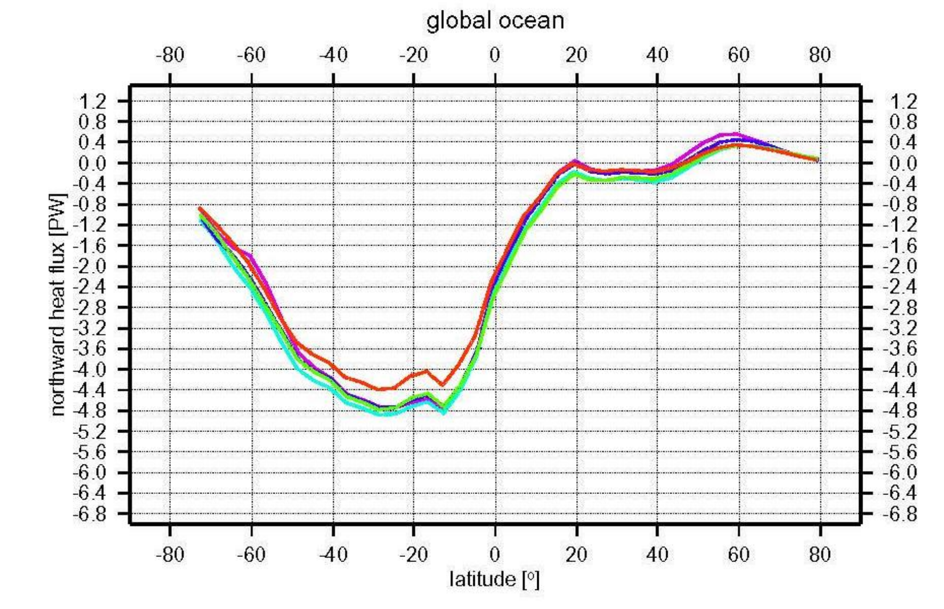


Ashgillian Low Sea Level

Ocean Heat Transport and atmospheric pCO_2



Caradocian

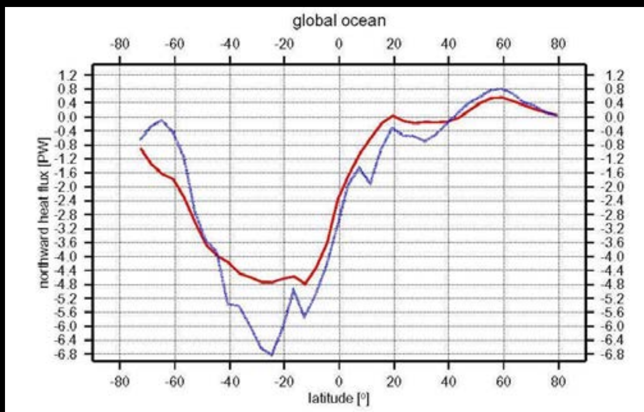


Ashgillian

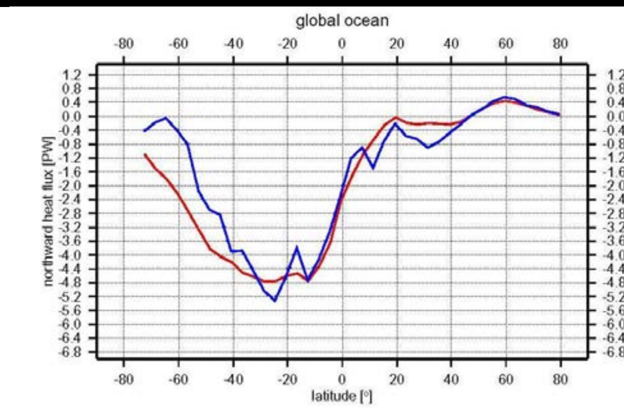
8x PAL   10x PAL   12x PAL   15x PAL   18x PAL

Ocean Heat Transport and Paleogeography

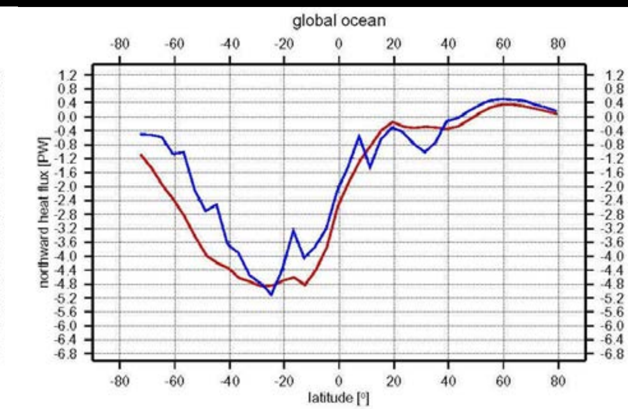
8x PAL



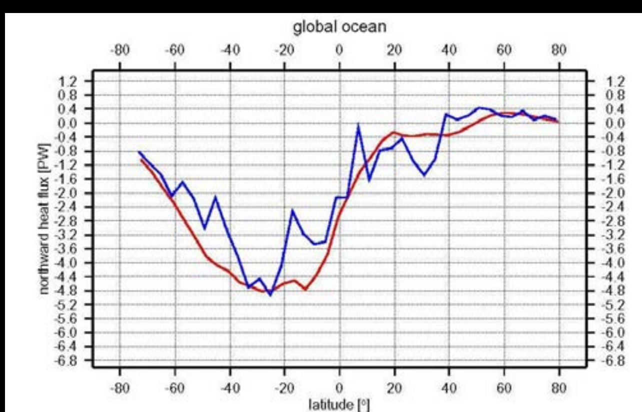
10x PAL



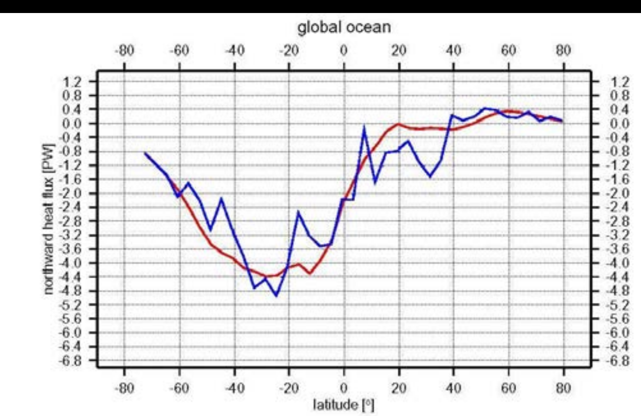
12x PAL



15x PAL



18x PAL

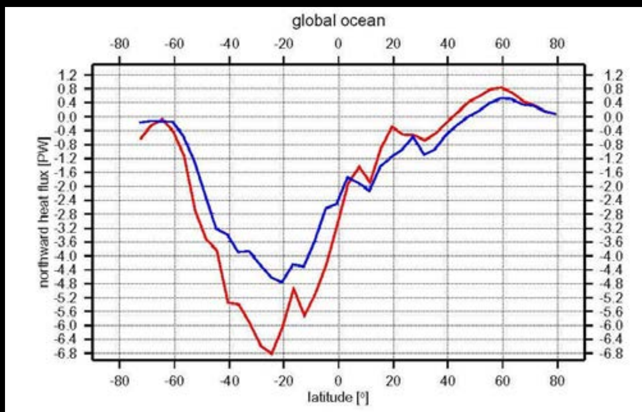


Caradocian

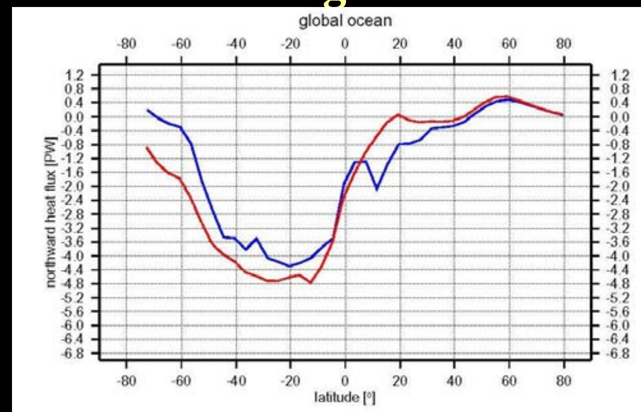
Ashgillian

Ocean Heat Transport and Sea Level

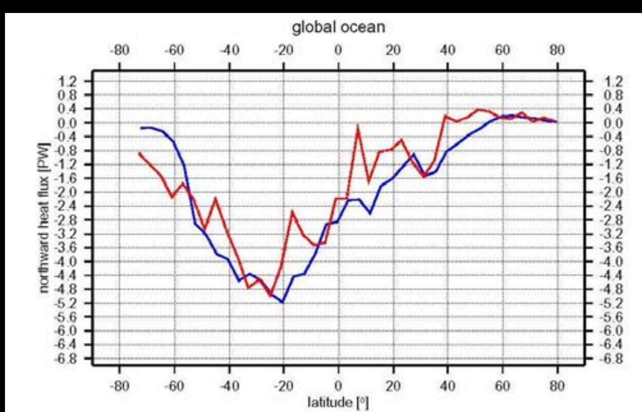
8x Caradocian



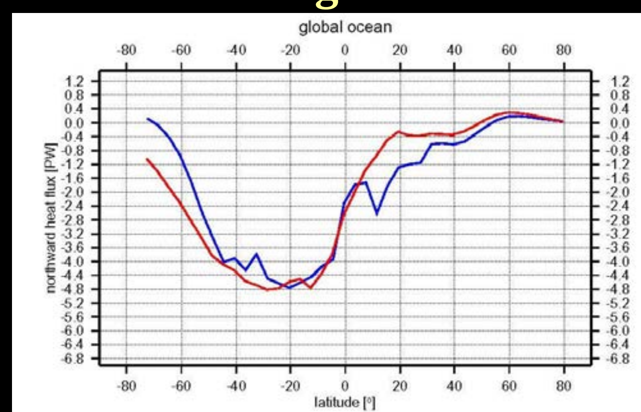
8x Ashgillian



15x Caradocian



15x Ashgillian



Low Sea Level

High Sea Level

Main Outcomes - Ocean (1)

Our primarily results indicate that:

- in the Caradocian, a decrease in atmospheric pCO_2 leads to an increase in poleward ocean heat transport;
- in the Ashgillian, there is no change in in poleward ocean heat transport between 15x and 8x PAL

→ therefore, a decrease in atmospheric pCO_2 levels would not lead to a positive feedback favoring glaciation

Main Outcomes - Ocean (2)

- With atmospheric pCO_2 values above 8x PAL, the Ashgillian paleogeography leads to a higher ocean heat transport in the Southern Hemisphere.
- Only in the simulation with 8x PAL does the paleogeographic change lead to a lower heat transport in lower Southern latitudes during the Ashgillian

Main Outcomes - Ocean (3)

- at 8x and 10x PAL, low sea level simulations have a lower southward ocean heat transport → a drop in sea level in the Ashgillian at low atmospheric pCO_2 levels could have lead to a positive feedback favoring glaciation by reducing the southward ocean heat transport in addition to the ice-albedo feedback of the exposed shelves

Acknowledgements

- Dr. E. Barron, and the Penn State Earth and Mineral Sciences Environmental Institute
- Financial support from NSF (EAR-??????), Penn State Astrobiology Research Center, ExxonMobil Fellowship