Snowball oceanography—Ocean circulation under snowball earth conditions

Preliminary results!!

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Abstract

The dynamics of ocean circulation under Snowball conditions is still largely unexplored. Here we study oceanic circulation under a complete ice cover using the MIT oceanic general circulation model. We use idealized aqua-planet conditions with meridionally variable sea glacier depth and surface temperature, and spatially constant geothermal heating. We examine convection and meridional circulation developing due to brine rejection associated with ice production and freezing temperature variations, due to the dependence of freezing temperature on pressure and thus on the ice thickness. We show that variable freezing temperature and salinity have a crucial role on ocean circulation. These two factors may therefore have a significant effect on sea glacier dynamics as the heat flux at the bottom of the ice, and hence ice melting, is strongly affected by ocean circulation.

Background

There are indications of several episodes of global (or almost global) ice and snow, between 750Ma to 620Ma. Ice and atmosphere dynamics under such extreme climate conditions have been studied in the past. However, ocean dynamics under snowball conditions had received little attention. Here we show that in fact ocean dynamics may have significant role on ice dynamics.

The models

Ocean: MITgcm using the shelf-ice package. We use the shaved cell of MITgcm.

Shelf-ice: Basically one layer and three variables: the mass flux between ocean/ice, freezing temperature and salinity. Ice can span several vertical levels.

Sea-glacier model: Tziperman et al. (almost accept, JGR). 1D model version:

$$0=\left[\frac{1}{\sin\theta}\partial_\theta\left(B\sin\theta\partial_\theta v\right)+\partial_\theta\left(B\frac{1}{\sin\theta}\partial_\theta(v\sin\theta)\right)\right.$$
$$\left.-\cot^2\theta Bv\right]-g\rho_I(1-\mu)hh_\theta$$
$$B=\frac{1}{r}h\langle A(T)^{-\frac{1}{3}}\rangle\dot\epsilon^{\frac{1}{3}-1}$$
$$\dot\epsilon^2=\dot\epsilon^2_{\phi\phi}+\dot\epsilon^2_{\theta\theta}+\dot\epsilon^2_{zz}$$
$$\dot\epsilon_{zz}=-(\dot\epsilon_{\phi\phi}+\dot\epsilon_{\theta\theta})$$
$$h_t+\frac{1}{r\sin\theta}\partial_\theta(\sin\theta vh)=\kappa\nabla^2h+S(\theta).$$

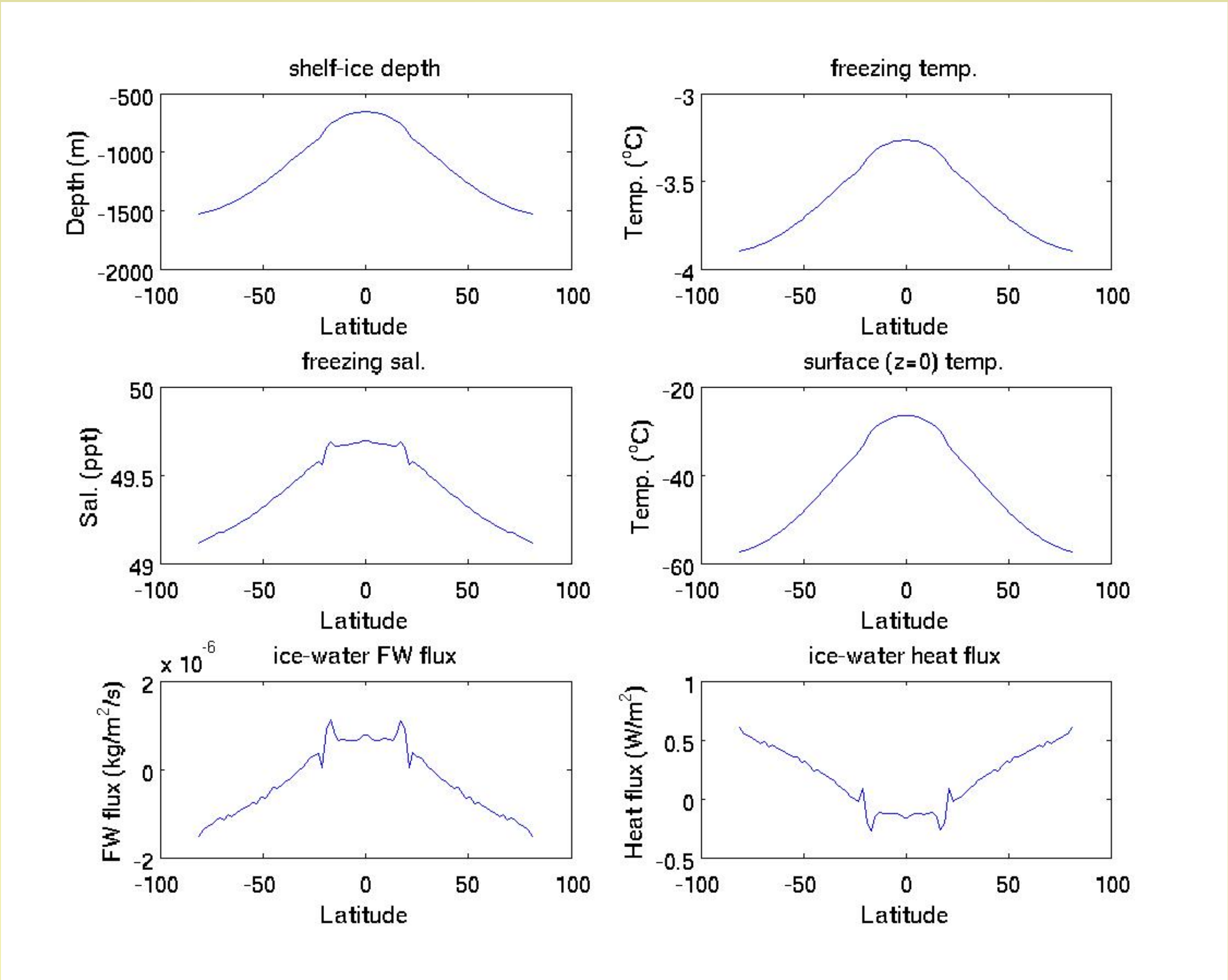
Configuration & numerical strategy:

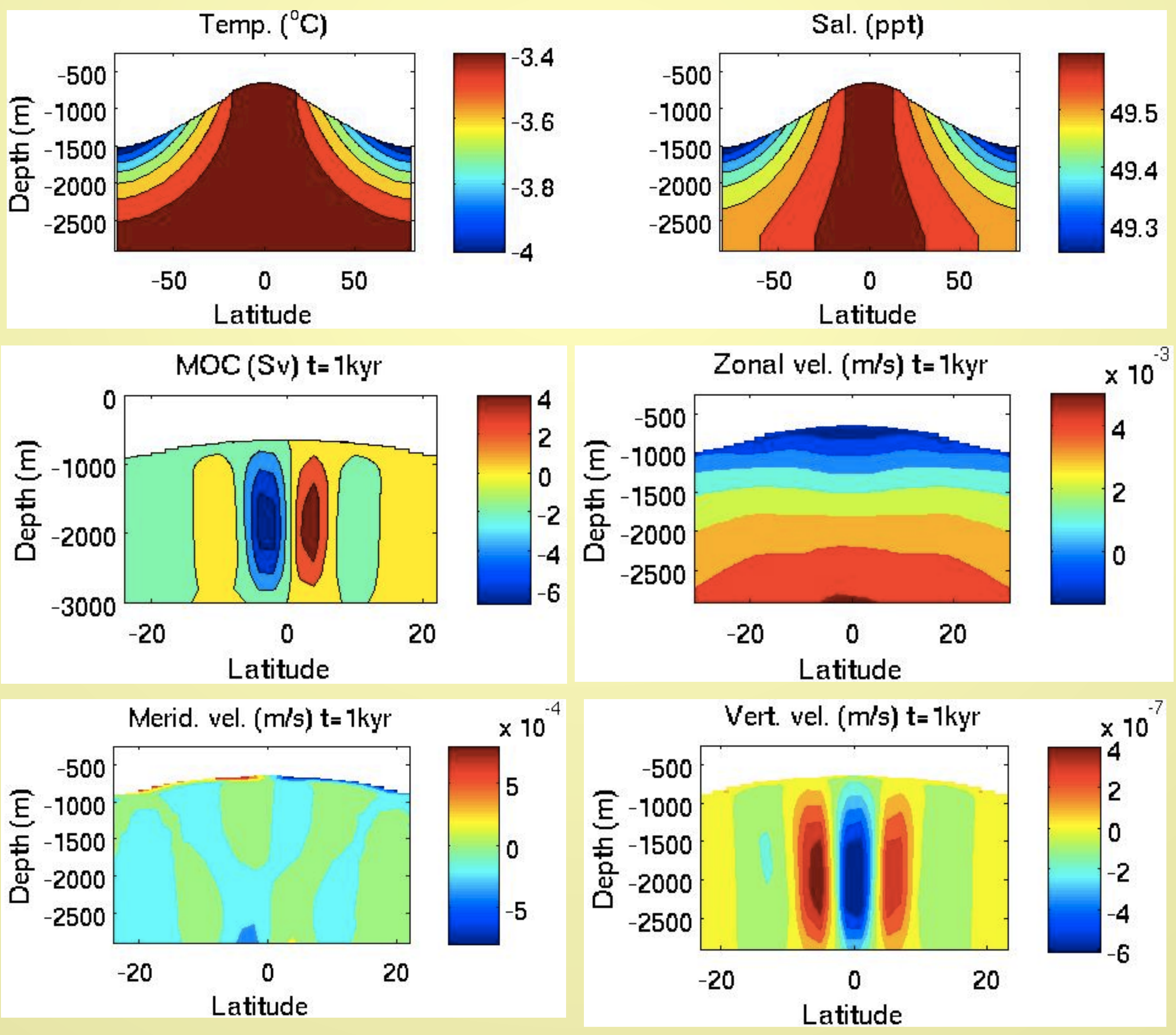
120 vertical levels. 10m resolution in the vicinity of the ice and 200m for the deep ocean. Zonally symmetric configuration with 2 degree resolution from 82S to 82N. Aqua-planet conditions. Uniform geothermal heating of 0.1 mW/m^2, meridionally variable surface temperature, and meridionally variable net precipitation (Pallard and Kasting, 2005).

The initial ice depth is calculated using local geothermal balance. Each model is integrated, in turn, for 1000 years and then transfer fields to the other model. This procedure is repeated till convergence.

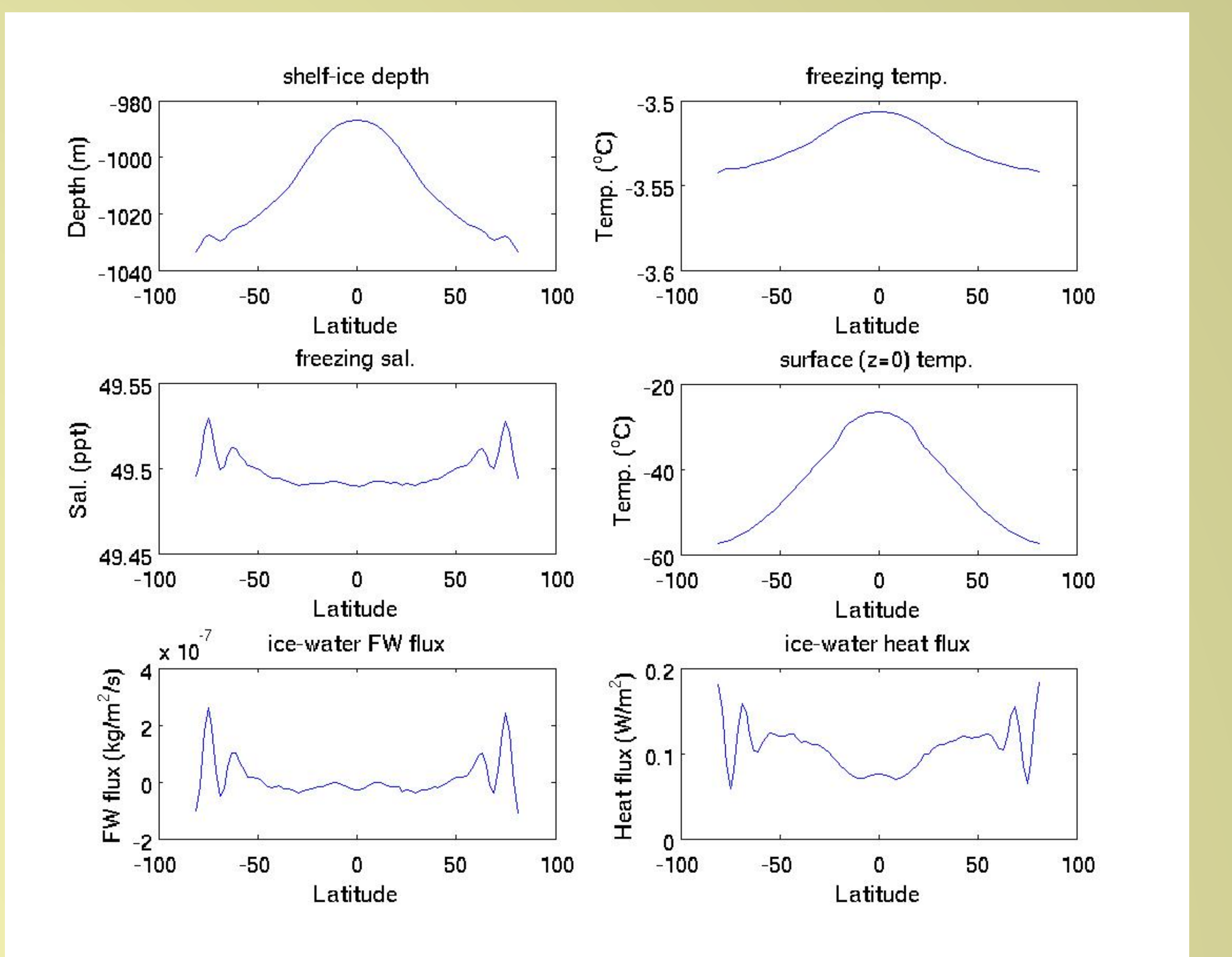
Results

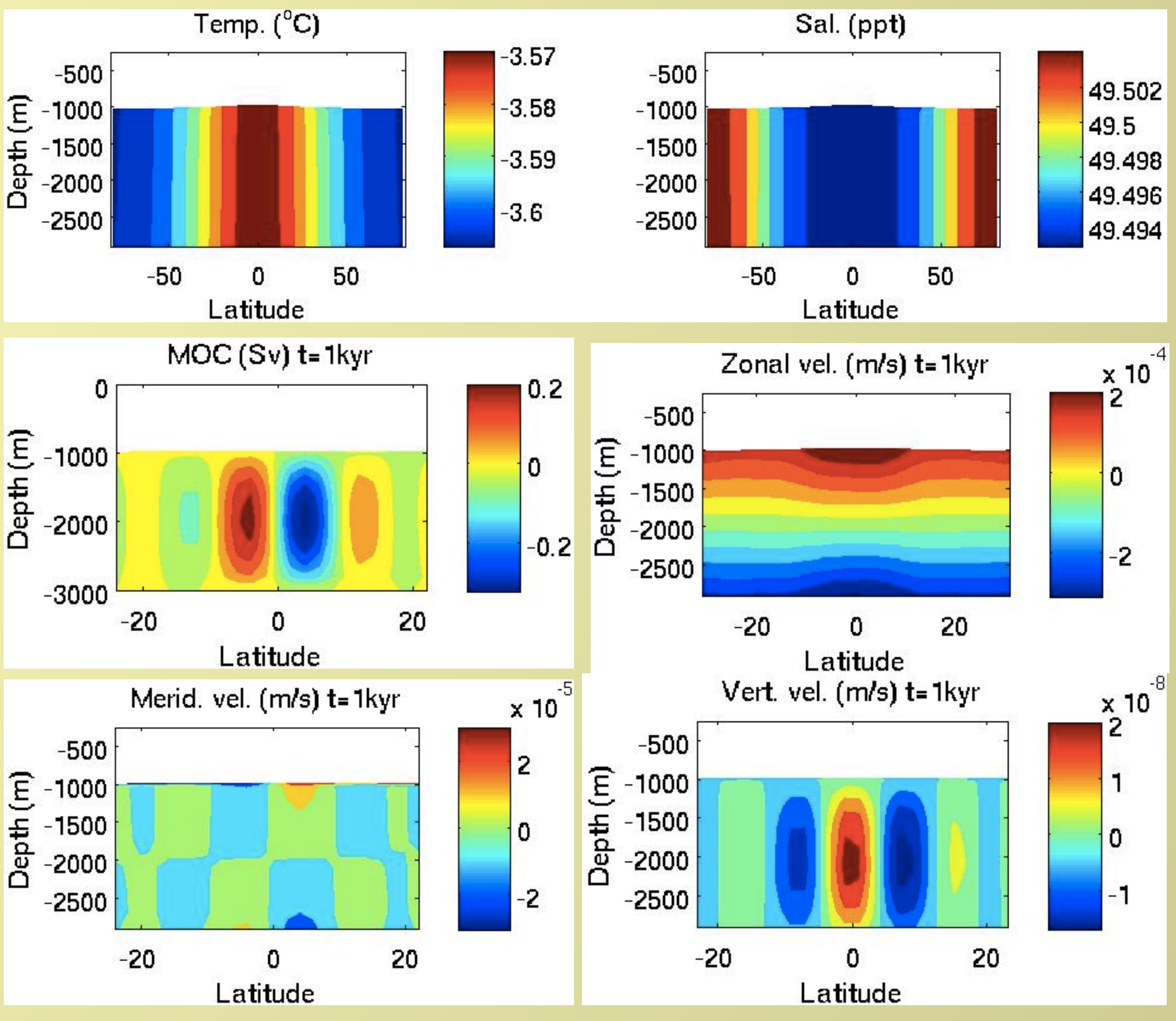
1st iteration





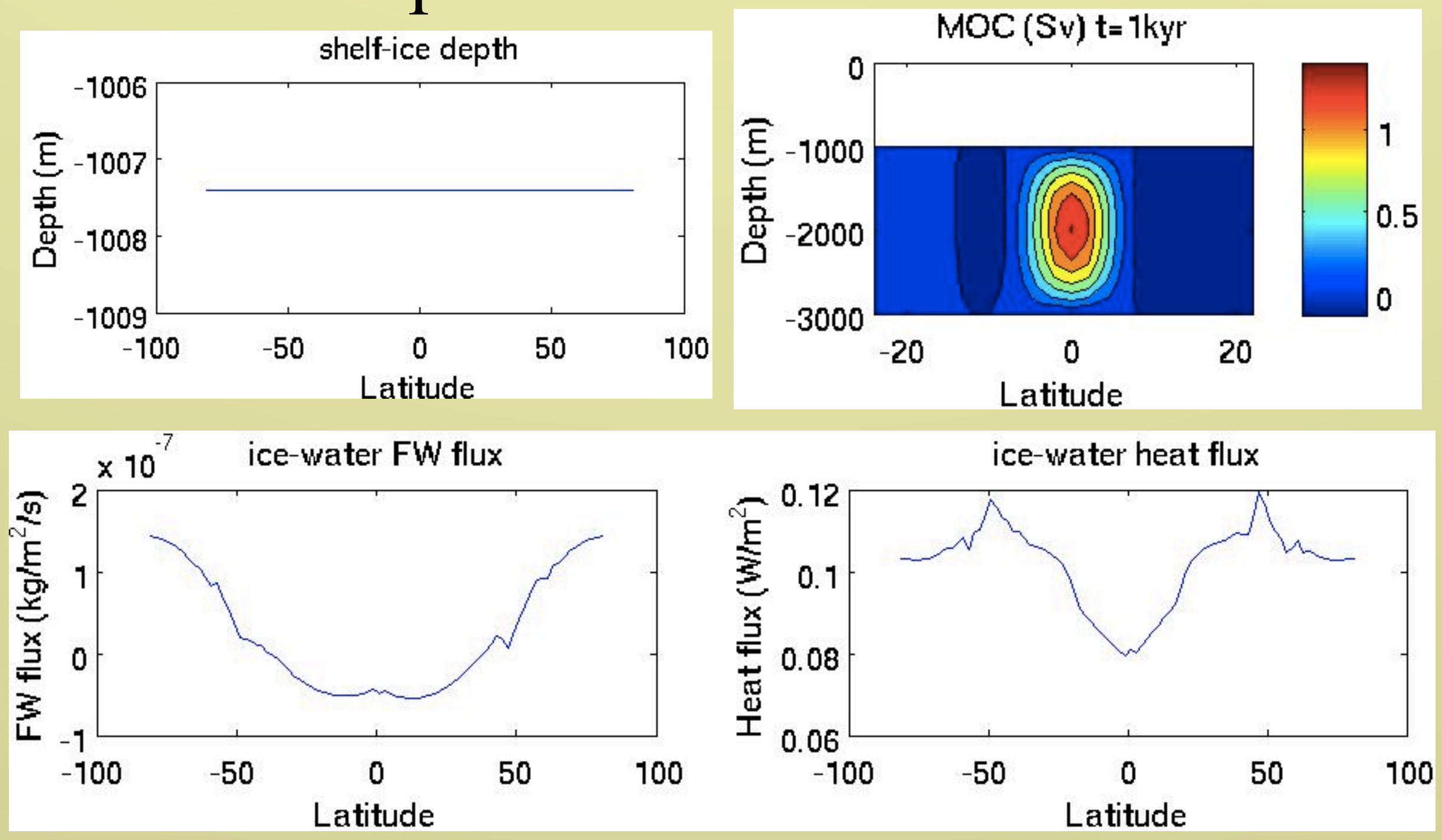
16st iteration



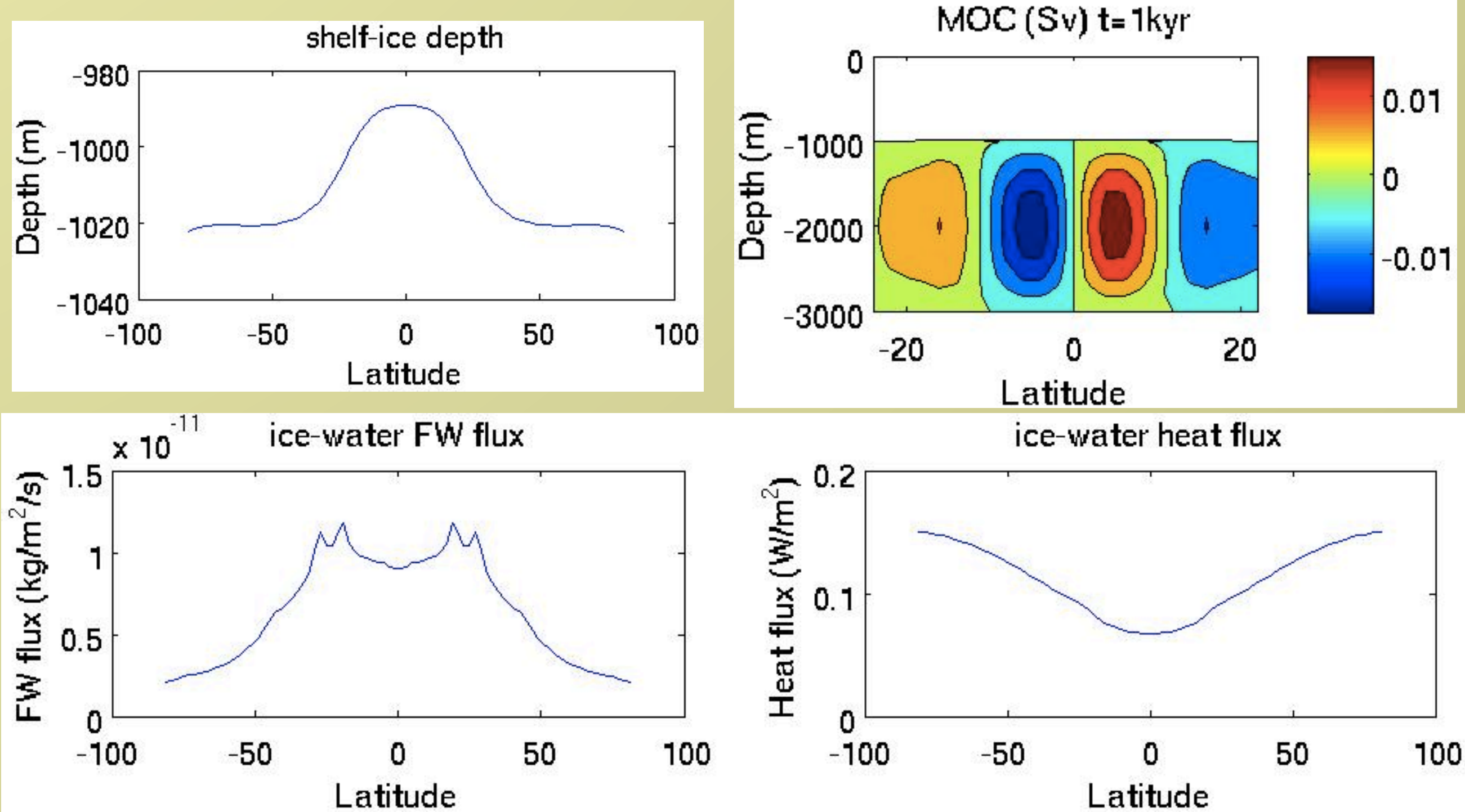


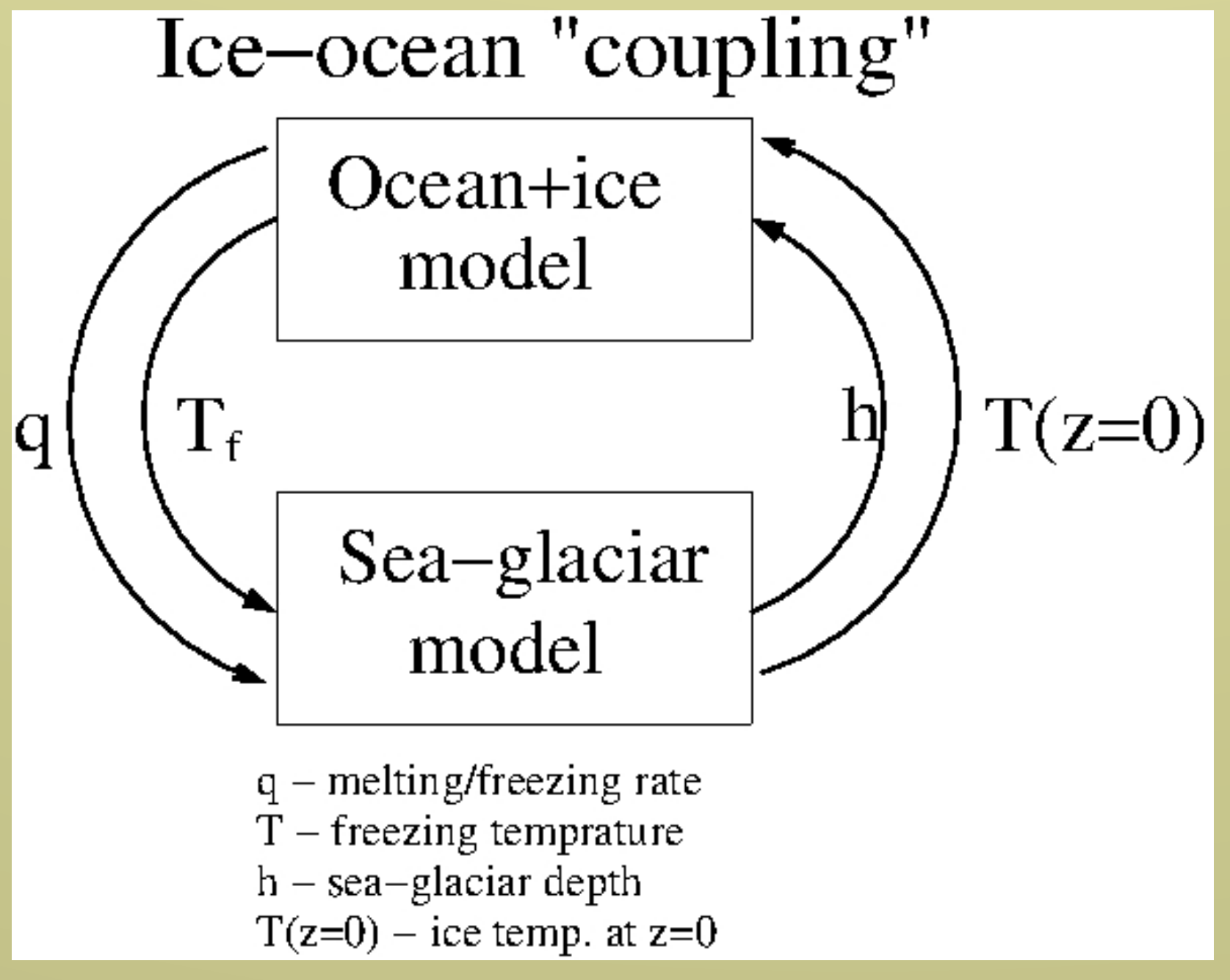
Additional numerical tests

Constant depth.



Fixed freezing temperature and salinity





q – melting/freezing rate
T – freezing temprature
h – sea−glaciar depth
T(z=0) – ice temp. at z=0

Conclusions:

- Ocean dynamics have significant role on ice dynamics.
- Spatial variations in ocean temperature and salinity are very small yet important for ocean circulation.
- Ocean circulation may enhance or suppress ice depth meridional gradient.
- There is convection from above and from below, leading to rising/sinking at the equatorial regions.

Ocean dynamics may not be ignored!