Development of ocean general circulation model to understand an aquaplanet climate and preliminary numerical experiment

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1. Introduction

- **Exploring diversities of planetary climates**
  - As a number of extrasolar planets (exoplanets) have been discovered, their climates attract attention from more planetary atmospheric scientists. By numerical experiments, the distinctive futures is becoming(for example, Showman et al., 2009). On exoplanet, if it has atmosphere and ocean, it is highly probable that their heat transports are important for determining and maintaining their climates. However, it is difficult to understand how they have an impact on planetary climates.
- **Aquaplanet experiment**
  - In order to help us the role of atmosphere and ocean, some numerical experiments of climates on an idealized planet, such as a planet globally covered ocean (aquaplanet), have been performed.

Figure1: Schematic of aquaplanet (http://aressia.wikia.com/wiki/Wrobel)

- **Previous studies of aquaplanet climates**
  - Smith et al. (2006) is a first study of an aquaplanet climate with coupled atmosphere-ocean-sea ice model, and discussed the characteristics. Enderton et al.(2009) and Rose(2015) investigated solar constant dependence of the aquaplanet climate. However, in order to confirm the robustness of climate features they found, futher studies(for example, resolution dependence or intercompariosn of results from different models) are required.
- **This study**
  - Our research group (GFD-DENNOU club) has been developing atmospheric and ocean general circulation models, and sea ice thermodynamics model to simulate planetary climates. The author is mainly in charge of developing ocean and sea ice models, and coupling three models.
  - In the near future, we plan to examine solar constant dependence of aquaplanet climates in our developing coupled model, and to consider the role of the atmosphere and ocean circulation on the climate.
  - Here ocean general circulation in an aquaplanet configuration calculated with our ocean model is shown as preliminary result.

2. Description of model

- **Dynamical core**
  - Boussinesq primitive equations with a spectral Eulerian method
- **Parameterization of sub-grid scale processes**
  - Convective adjustment scheme (Marotzke, 1991)
  - Mesoscale eddy mixing scheme (Redi, 1982; Gent and McWilliams, 1990)
- **Sea ice processes**
  - Three layer thermodynamics model (Winton, 2000)

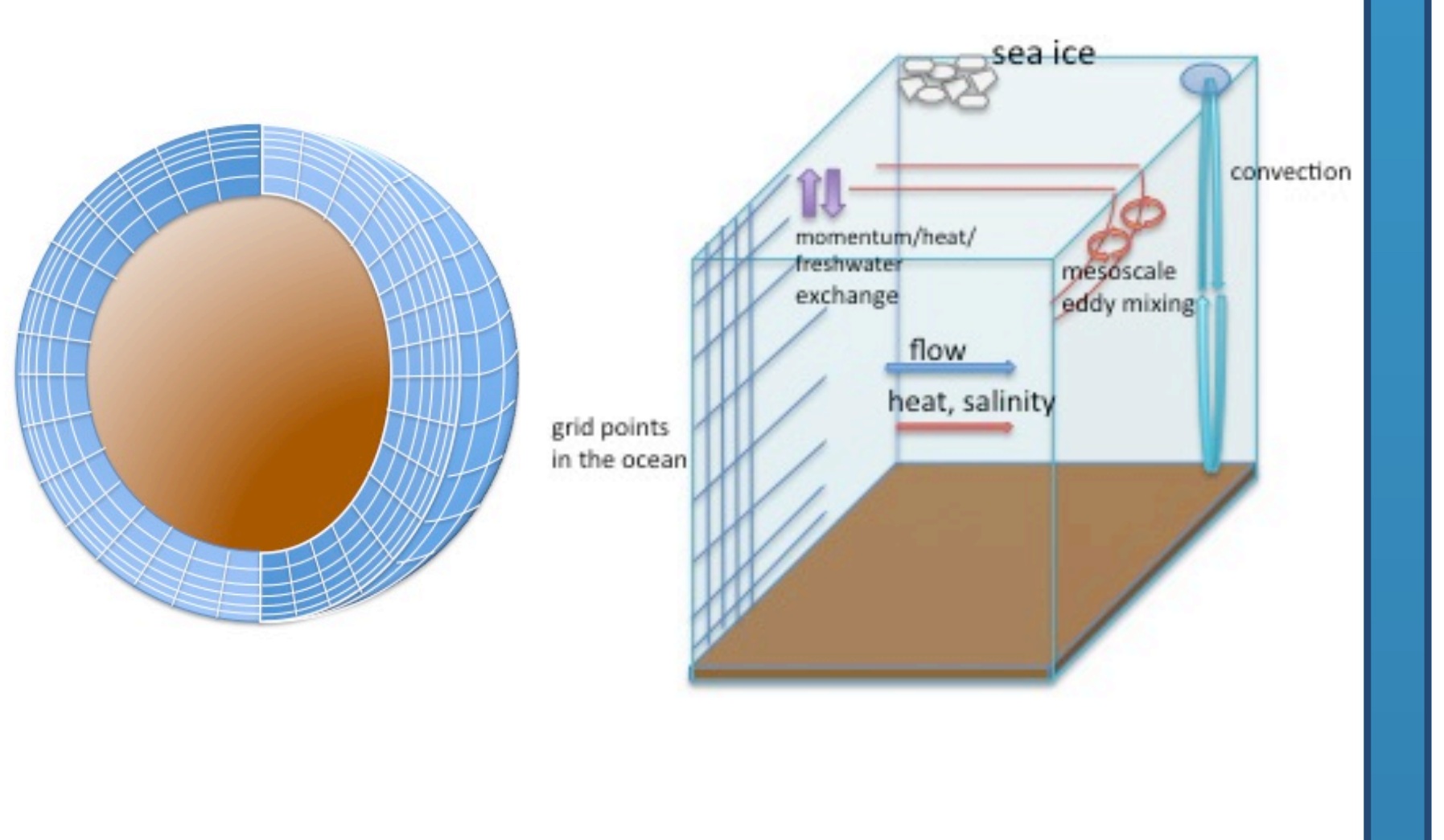

Figure 2: Schematic figure for (left) a model grid, and (right) processes included in the model.

3. Experiment design

Numerical experiments of zonal symmetric (independent of longitude) general circulation is performed.

- **Purpose**
  - To validate our developing ocean model
  - To understand fundamental features of ocean general circulation on an aquaplanet
  - To evaluate the effects of sub-grid scale parameterizations
- **Set-up**
  - The computation domain is a meridional cross section whose bottom is flat, and the depth is 5.2 km. The grid interval is about 300 km horizontally, and 90 m vertically.
  - The values of planetary radius and rotation rate are same as present Earth's one.
  - Boundary conditions
    - At the sea surface, surface stress, temperature and salinity obtained from previous study of aquaplanet experiment (Marshall et al., 2007) are imposed(See right figures).
    - At the bottom, no-slip condition for flow and no flux condition for both of heat and salinity are imposed.
  - Experiment series

name	remarks
control	a standard case for comparison
const-dens	The density field always has a reference value everywhere.
noSGSParam	without convective adjustment and mesoscale eddy mixing scheme
convOnly	only convective adjustment scheme

- For all four cases, the ocean model is integrated to equilibrium state.

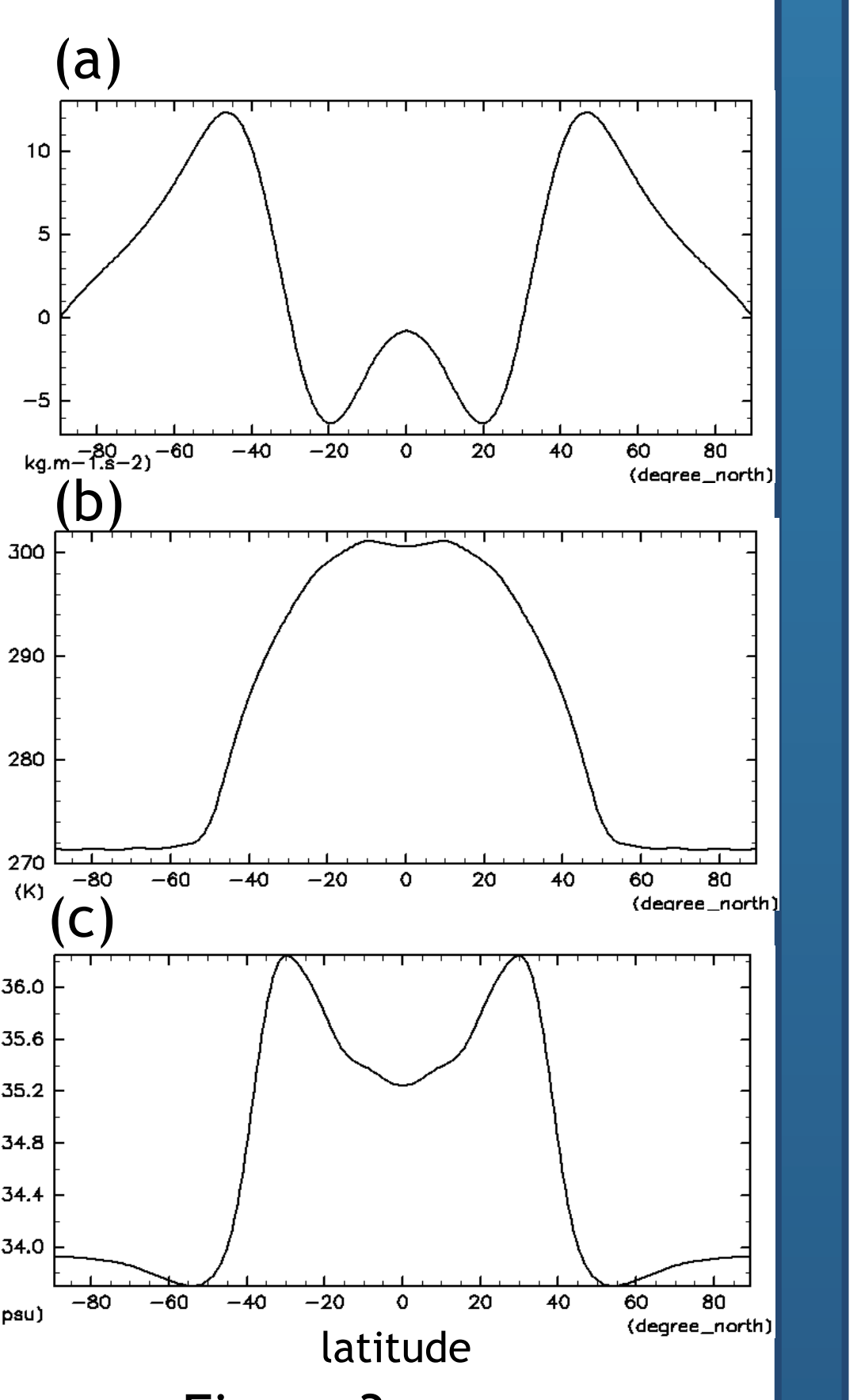

Figure 3: Meridional distribution of surface (a)stress (in N/m^2), (b)temperature (in K) and (c)salinity (in psu).

➢ Summary

- ➢ The author has been developing ocean and sea ice models to explore aquaplanet climates, and couping these model to atmosphere model.
- ➢ Some fundamental features of ocean general circulation on an aquaplanet and the effects of sub-grid scale parameterization are investigated with the ocean model.
- ➢ In the near future future, we plan to examine solar constant dependence of aquaplanet climates in our developing coupled model.

4. Ocean ciruculation on an aquaplanet represented in the model

- **Control experiment**

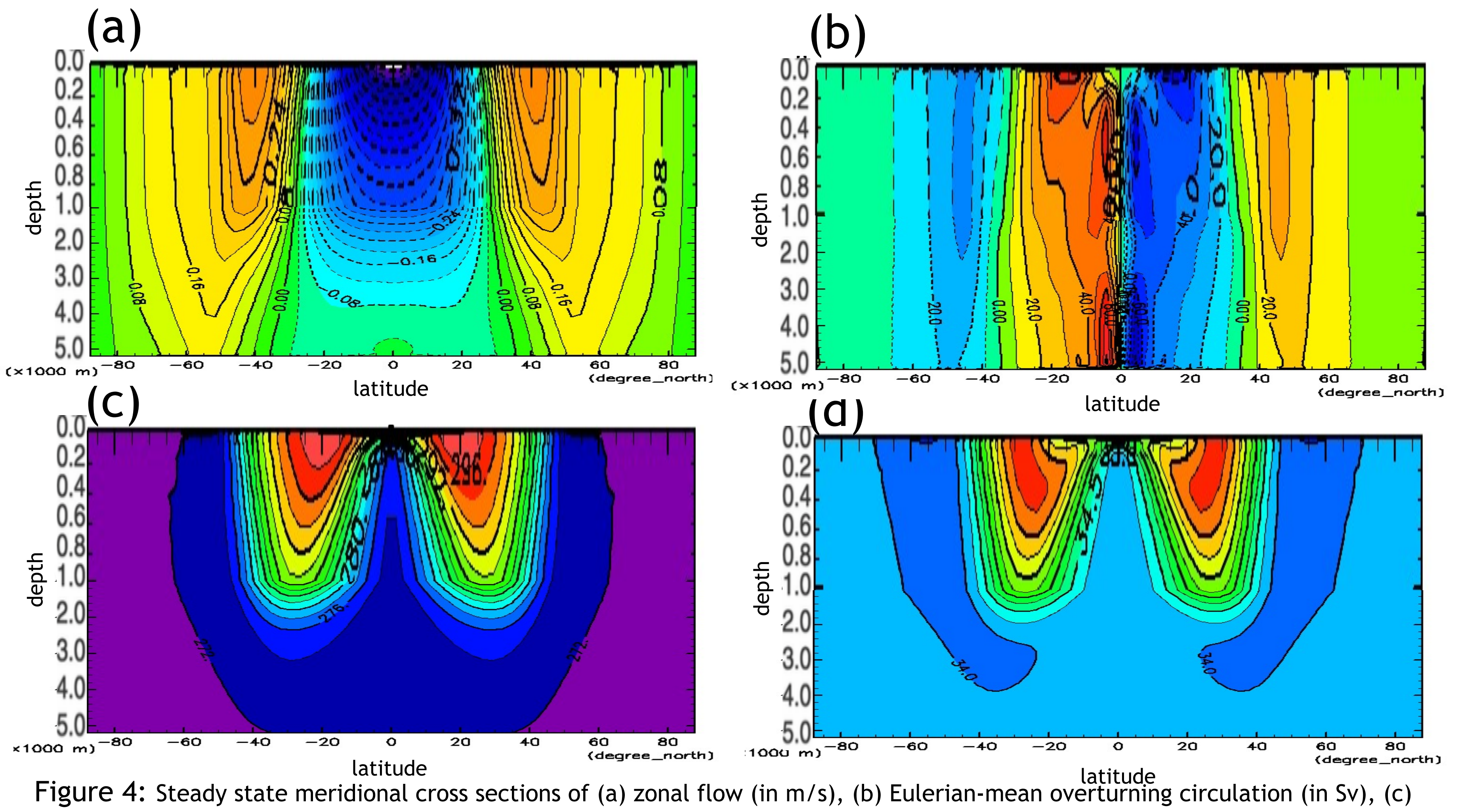

Figure 4: Steady state meridional cross sections of (a) zonal flow (in m/s), (b) Eulerian-mean overturning circulation (in Sv), (c) potential temperature (in K) and (d) salinity (in psu).

- Strong zonal flow and weak meridional overturning circulation are found.
- Thermocline and halocline are deeper than the ocean which has shores.
- These are fundamental features of ocean general circulation on an aquaplanet found by previous studies (Smith et al., 2006; Marshall et al. 2007).

- **Constant-density experiment**

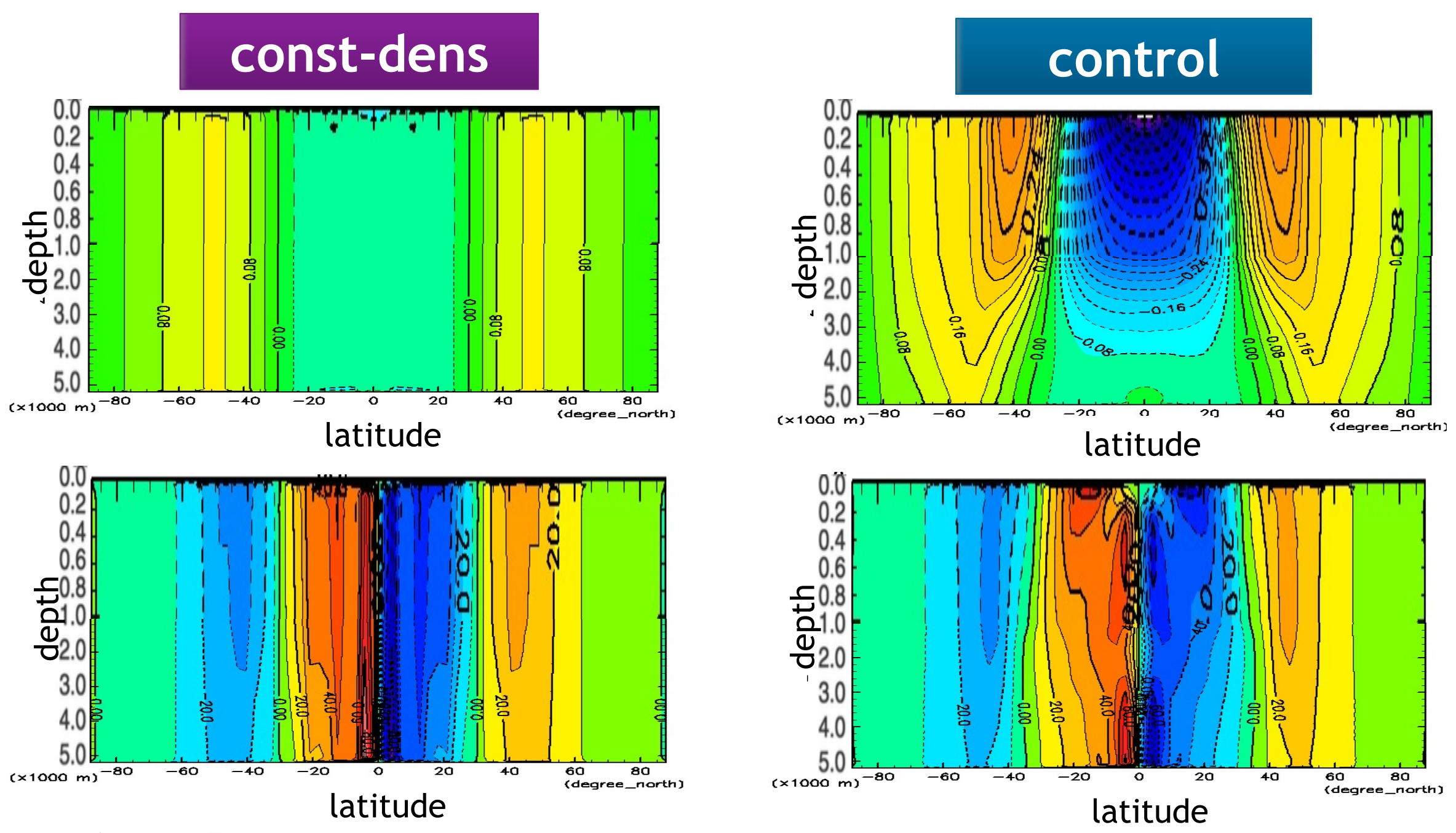

Figure 5: Steady state meridional cross sections of (upper panels) zonal flow (in m/s), (lower panels) Eulerian-mean overturning circulation (in Sv)

- The structure of zonal flow dependent on ocean depth relates to horizontal variation of density field.
- The density variation seems to influence the structure of meridional overtuning circulation in low latitude, but does not in midlatiude and high latitude.

- **Effects of subgrid-scale parameterization**

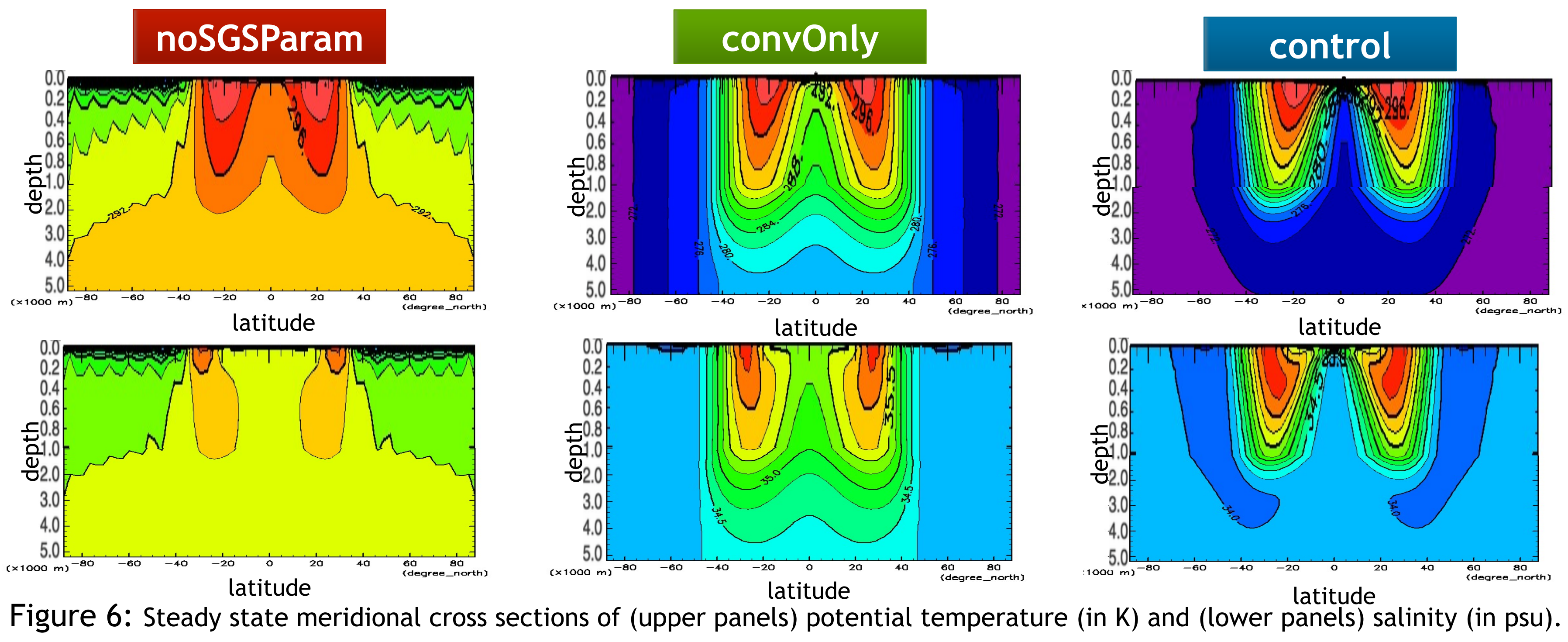

Figure 6: Steady state meridional cross sections of (upper panels) potential temperature (in K) and (lower panels) salinity (in psu).

- The comparison between noSGSParam and convOnly cases shows that convective adjustment scheme play a role in efficient vertical mixing due to convection in high latitude.
- The comparison between convOnly and control cases shows that mesoscale eddy mixing scheme maintains the sharp vertical gradients of thermocline and halocline.