Ensemble of Trajectories in the Southern Ocean Circulation System

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Long-distance transport of mass, heat and salt in the ocean is one of the primary mechanisms determining the evolution of the thermohaline structure and of climate variability. To reveal peculiar properties of mass transport and of related mixing processes in the Southern Ocean circulation system, ensemble of trajectories of liquid particles (LPs), or markers, was computed for different LPs initial positions.

Varying with time three dimensional field of ocean currents required to plot the trajectories was derived from numerical experiments with an ocean general circulation model (OGCM) based on primitive equations (*Resnyansky and Zelenko, 1999*; *Zelenko and Resnyansky, 2007*). A global OGCM version was used with computational domain over the whole World Ocean excepting part of the Arctic Basin northward of 80.3° N and with horizontal resolution 2°×2° in the Southern Ocean. The vertical structure was approximated by 32 unevenly spaced z-levels with finer resolution in the upper ocean.

The NCEP 6-hour reanalysis data on heat/fresh water fluxes and wind stress over 1979–2002 were used to specify boundary conditions at the water surface.

The ensembles were formed by a set of initial LPs positions allocated in nodes of regular 5×5×4 mesh occupying a volume $\Delta\lambda\times\Delta\varphi\times\Delta z$ = 2°×2°×20 m. The area of horizontal projection of the water volume with initial markers distributed within it coincides with the size of OGCM computational cell (about 110×220 km^2 at φ = 60°). The vertical size matches the depth of the upper computational layer.

Some of the pictures illustrating the trajectories behavior are shown in Figs. 1–3. It is seen that three-dimensional time-dependent circulation in the Southern Ocean reveals the properties inherent in chaotic advection (e.g. *Liu and Yang H., 1994*). The trajectories become chaotic, and the LPs initially distributed within a compact volume are randomly distributed with time over vast areas (Fig. 1).

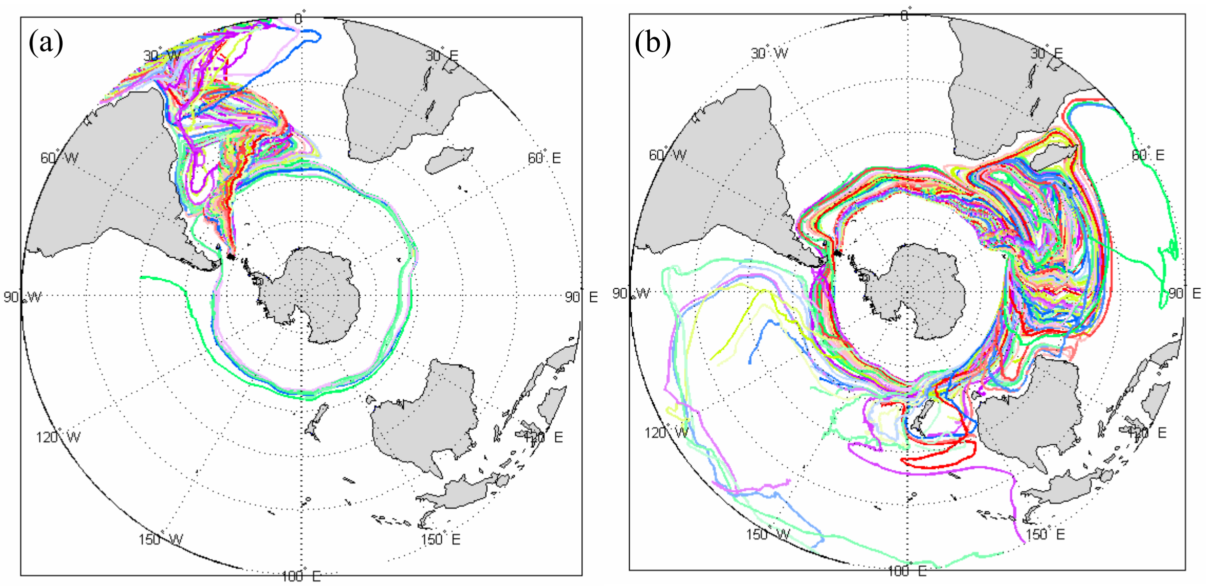

Fig. 1. Horizontal projections of LPs trajectories ensembles derived from model large scale ocean currents over 1979–2002 with starting position at different depths z_{p0} in the Drake Passage.
(a) – z_{p0} =10 m; (b) – z_{p0} =100 m.

The transport of LPs from the upper layer of the Southern Ocean takes place predominantly under the influence of Ekman currents. In the Southern Ocean with prevailing west winds the meridional component of Ekman currents is directed from the pole to the equator. As a consequence, all the LPs ensembles examined in the experiments traveled equatorwards, and therewith intensive mixing appeared being localized in different places depending on initial position of the control volume (Fig. 1a).

The waters from subsurface layer (from depths of an order z_{p0} =100 m) are to a greater extent involved into circumpolar traveling, and the mixing zones also arise in the processes (Fig. 1b). In deeper layers (z_{p0} ~ 1000 m) the motion pattern appears as a rather tight bunch of trajectories, that is the mixing during the 24 years travel turns out here to be weak.

The ensemble mean depths $\bar{z}_p$ of LPs being traced, as a rule, increase with time for upper starting positions and decrease for deeper ones (Fig. 2). This indicates that the chaotic transport, arising in the field of time dependent three dimensional large scale currents in the Southern Ocean, contains quite a clear evidence of an efficient mechanism of vertical mass redistribution – the net submersion of waters from upper layers and their rising from deeper layers.

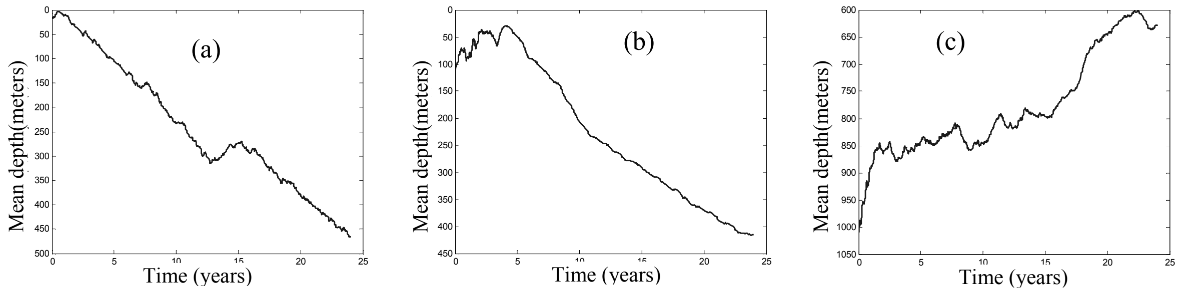

Fig. 2. Temporal changes of ensemble mean depths $\bar{z}_p$ of LPs transported by varying with time large scale ocean currents with starting position at different depths in the Drake Passage.
(a) – z_{p0} =10 m; (b) – z_{p0} =100 m; (c) – z_{p0} =1000 m.

The vertical redistribution of markers in the system of large scale circulation can be inferred from the diagrams presented in Fig.3. Markers starting at 10 m depth are redistributed with time down to 450–500 m (Fig. 3a). The noticeable mixing occurs in the Atlantic sector (Fig. 1), to which the most part of the LPs arrives. The meridional scattering amounts here to 45°, that is, about 5000 km (Fig. 3a). The passages through the meridional plane from the west to the east alternate with reverse intersections. The overall pattern of motion in the neighborhood of this meridian contains all the features of pronounced mixing of the originally compact set of LPs. For the ensemble with starting position in the Drake Passage at 100 m depth the mixing encompasses the layer down to 700 m (Fig. 3b) and occurs in Indian and Pacific sectors (Fig. 1b).

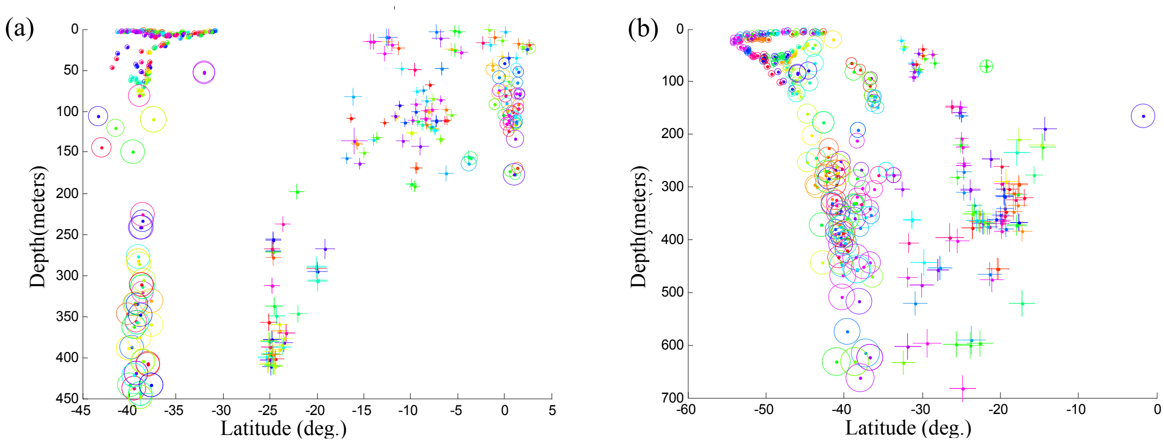

Fig. 3. Intersections of meridional planes by LPs for two starting depths in the Drake Passage. The intersections from the west to the east are marked by circles, from the east to the west – by crosses. The size of the marks is proportional to the logarithm of time elapsed from the trajectory start. Different colors correspond to individual trajectories of the ensemble. (a) – z_{p0} =10 m, intersection through λ=30° W; (b) – z_{p0} =100 m, intersection through λ=60° E.

References

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