Transport of Waters from a Deep Convection Region in the Labrador Sea: Sensitivity of Trajectories to Initial Position and to Atmospheric Forcing

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The concept of water masses holds an important place in classical oceanography. The characteristic feature of water masses is their homogeneity, produced and sustained by turbulent mixing. The building-up of water masses, including the deep-sea ones, according to Zubov (1938), takes place somewhere at the water surface, mainly due to winter vertical circulation. And then they are transported, preserving the acquired properties, to different regions by large scale sea currents. In adhering to this concept it is implicitly assumed that the integrity of large volumes of water is ensured in the course of their transportation; that is to say, water particles close to each other at some time remain such also at any subsequent instant. There are certain reasons for the concept of this sort. First of all, these are fairly steady T-S-properties. That steadiness, in essence, is generally used to subdivide the bulk of ocean waters into individual water masses.

At the same time, in modern studies on geophysical hydrodynamics deterministic models of ocean processes with manifestations of chaotic behavior are proposed and are actively developed (e.g., Yang 1996). The origination of chaotic behavior in a broad class of that sort of models pertains to the presence of strong instability of trajectories relative to their original position. Given such instability, initially close water particles after a lapse of time may be found far apart.

At the present time analysis of trajectories, i.e. Lagrange description of motion, is intensively used in studies of spreading of contaminants and of other water properties in the ocean. Here we will take a look at the transport of fluid particles with a starting position in the Labrador Sea. The tracing of water transport from this region is of particular interest due to the fact that the Labrador Sea is one of a few regions, in which the waters transformed near the surface are then mixed down to great depths under the action of intensive density convection and, being picked up by large scale flows, fill out the abyssal area at first of the North Atlantic and then, through the global conveyor belt, of the whole World Ocean (Gordon 1986; Broecker 1991; Koshlyakov et al. 2001).

The time-dependent ocean currents appropriate for plotting the trajectories were determined from numerical experiments with an ocean general circulation model (OGCM) based on primitive equations (Resnyansky and Zelenko 1999) The computations were performed in the global domain (excepting the Arctic Basin to the north of 80.3° N) with a horizontal resolution $\Delta\lambda = 2°$, $\Delta\varphi = 2°$ ($\Delta\varphi \sim \cos\varphi$ to the north of 40° N) and 32 unevenly spaced levels in the vertical. The OGCM runs in numerical experiments started from rest with climatological January distributions of sea water temperature and salinity specified from data of the WOA-2001 atlas (Conkright et al. 2002). The NCEP–DOE AMIP-II reanalysis data on the surface heat, fresh water and momentum fluxes (Kanamitsu et al. 2002) were used as atmospheric forcing (AF) with 6-hour data point interval in experiment ***BASE*** and monthly smoothed data in experiment ***SMON***. The length of both integrations was 24 years (1979–2002 according to the calendar associated with data on AF). The output fields on sea currents were archived for subsequent plotting of trajectories with 5 days intervals.

Fig. 1 shows the trajectories of fluid particles emitted from 500 m depth at three relatively close points in the Labrador Sea. Not going into details of individual trajectories, only from a general view of the figure it may be concluded that initially close particles after a lapse of time are found in positions separated by thousands of kilometers in the lateral direction and by thousands of meters in depth. And all this occurs over relatively short for oceanic measures time intervals of 24 years. It is clear that in model integrations over hundreds and thousands years, which are characteristic times for building-up of thermohaline structure in deep ocean, the scatter should be still larger. Thus, the advective transport in the OGCM, used to generate data on ocean currents for trajectories plotting, possesses properties inherent in chaotic advection (e.g. Kozlov and Koshel 2000).

From the comparison of trajectories plotted from data in experiment ***BASE*** with 6-hourly AF and in experiment ***SMON*** with monthly smoothed AF (blue and red curves in the figure) it is also apparent that long distance transport essentially depends not only on initial positions, but also on short-term perturbations of current speed vector superimposed onto large scale seasonally varying circulation. This dependence is another manifestation of trajectories instability having as a consequence a phenomenon of the chaotic advection kind.

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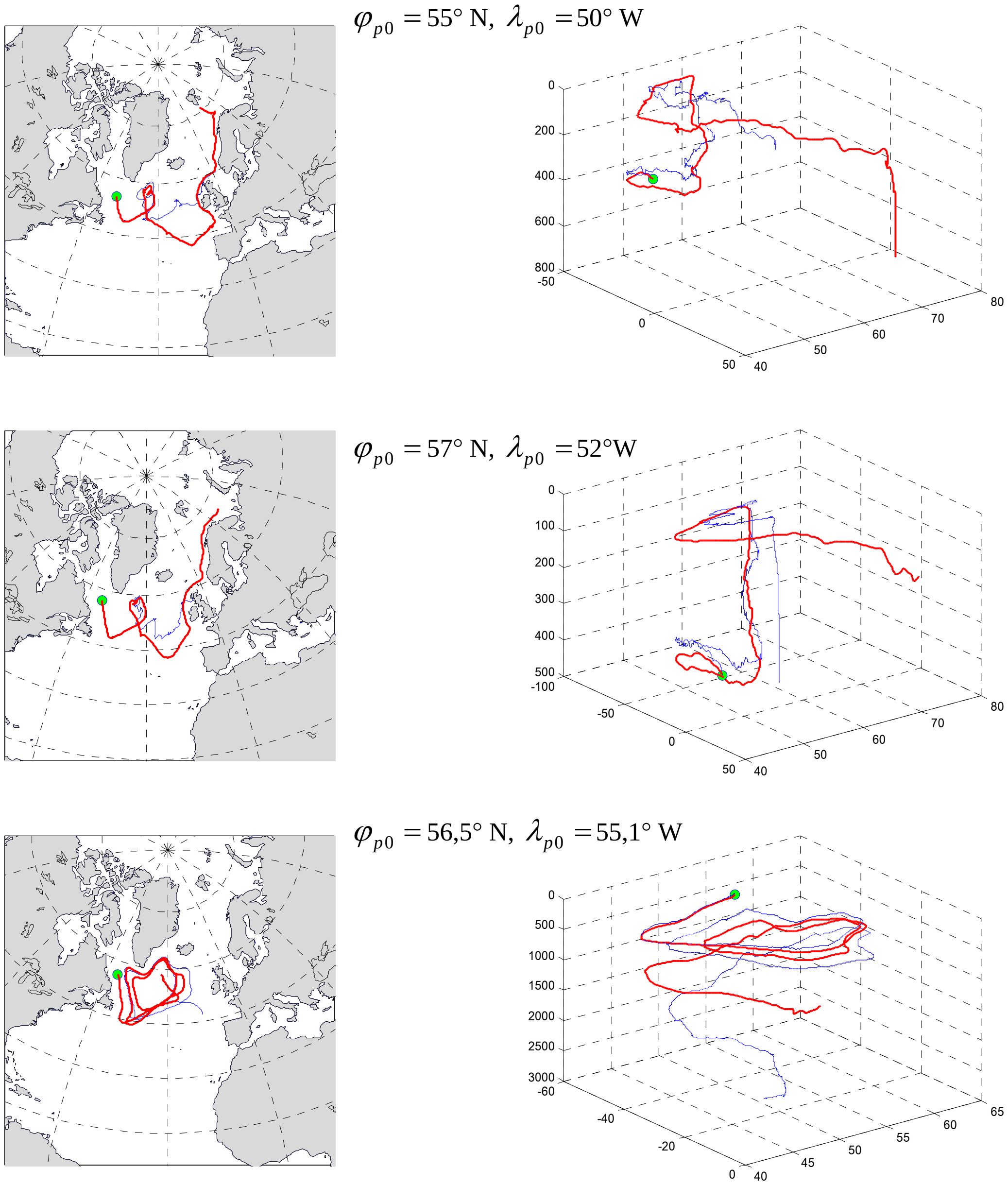

Fig. 1. Trajectories of liquid particles emitted from 500 m depth at three positions in the Labrador Sea. Left panels – horizontal projections of trajectories; right panels – their three-dimensional view. Computation using data on ocean currents from experiment ***BASE*** (6-hourly AF; blue thin lines) and from experiment ***SMON*** (monthly smoothed AF; red thick lines). The trajectories duration is 24 years (01.01.1979–31.12.2002). Green circles indicate initial position.