Salinity Minimum in the North Pacific

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Abstract—Analyzed is the variability of seasonal salinity in the North Pacific. It is demonstrated that the formation and disappearance of salinity minimum in subsurface layers depends on the freshwater budget variability of different time scales. In general, the salinity minimum is a temporary phenomenon formed during the negative phase of freshwater budget, when the evaporation exceeds the precipitation. Seasonal variability of fresh water budget leads to the seasonal formation of salinity minimum on the boundary between the climatic zones. The existence of salinity minimum at intermediate depths in the tropics is caused by the negative phase of long-period variability of freshwater budget.

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INTRODUCTION

The salinity minimum at intermediate depths in the North Pacific remains a riddle for the researchers. Attempts to interpret its origin within the framework of water mass conception were not successful. Contradictions in the ideas on the salinity minimum origin raise a question: is the salinity minimum the water mass or the phenomenon in the continuously varying vertical distribution of salinity? Is it associated with the processes of ocean–atmosphere interaction resulting in the salinity variability at different time scales?

In the present paper, an attempt is made to reveal the essence of salinity minimum in the water column within the framework of concepts on the changeable nature of the ocean (the Earth’s climate system). The objective is to study the seasonal variability of salinity and processes of formation and destruction of salinity minimum under the influence of seasonal variability of moisture budget on the boundary between the subarctic and subtropical climatic zones.

SOME PROBLEMS OF SALINITY MINIMUM ORIGIN

Nowadays, the salinity minimum is associated with the North Pacific intermediate waters (NPIW) and the process of its formation is often associated with the subarctic frontal zone [1–3, 15, 17, 18, 20, 30, 31, 35, 36]. The zone of interaction between the Kuroshio and Oyashio currents is considered the most probable area of salinity minimum formation [18, 30, 31, 34]. The ARGO data indicate that here it may disappear and be formed again; this causes the problems of its identification for the researchers and compels not to give the NPIW status to the newly formed minimum [17].

The main problem of traditional notions about the advective origin of the minimum is that the water density in the supposed sources is always lower than in the salinity minimum. This fact forces the researchers to assume that the given water mass can be formed as a result of processes of internal transformation [36]. Since the water density in the salinity minimum increases at first reaching maximum values in the tropics and then decreases towards the equator [30], this should presuppose the continuous increase [36, 40] and, afterwards, decrease in the density. The truth of this supposition is doubtful. Besides, the researchers do not have the common opinion about the density range within which NPIW should be considered (26.5–27.0σ, [31], 26.7–26.9σ, [30], 26.7–26.8σ, [40], 26.6–26.9σ, [17], and 26.4–27.2σ, [14]).

The salinity minimum \( S \) in NPIW has no temperature extreme, is not accompanied by the increased content of oxygen, and has no anomalies of other chemical elements [32, 37] that would indicate its origin or displacement.

It is considered that NPIW is situated at the depth of more than 300–500 m [38] and does not emerge to the ocean surface. However, it is known that there are salinity minima at lower depths along the northern, eastern, and southern peripheries of subtropical circulation [18, 30, 31, 39] which may disappear and appear
again [17, 23]. They are clearly observed on $T, S$-curves but do not have a status of water masses. They are called the shallow salinity minima and occupy a rather large water area of the Pacific (Fig. 1). In the continuous salinity minimum existing in the ocean, the researchers single out the deep minimum called the NPIW water mass and the shallow minimum which is not considered the water mass. No due attention is paid in literature to different interpretations of salinity minimum. In our opinion, the overcoming of this contradiction should enable to understand the essence of the minimum and to solve the problem of its origin.

It is considered that the coming of surface water to the intermediate depths takes place not permanently but mainly in winter, when the upper mixed layer has a maximum thickness [27, 28, 33]. This problem is of special importance for the North Pacific. Absence of tracers in the salinity minimum indicates that the “Stommel’s demon” [27, 33, 37] does not work here, and this prejudices the idea that surface water may come to intermediate depths. If the salinity minimum is not the water from the surface, it is not clear what it is and how it is formed in the water column.

The author of [15] supposed that the salinity minimum is not the water mass and is formed as a result of the inleakage of more salty subtropical water on the desalinated subarctic water acting as a boundary between the waters of different origin.

The observational data indicate that the salinity minima in the water column are associated with the freshwater budget variability, namely, they appear at near-surface and subsurface depths after showers [11], durable precipitation [9], and monsoon rains [19]. Their common feature is that they exist at those time moments, when the evaporation exceeds the precipitation. They also have a common reason for formation, namely, the varying moisture budget and the temporal variability of vertical salinity distribution caused by this budget. A wide range of scales of the Earth’s climate system variability (freshwater budget) [4, 5] presupposes that the salinity minima have different lifetime scales. In view of this, it is interesting to study a possibility of salinity minimum formation in the water column as a result of seasonal variability of freshwater budget, especially on the boundary between the climatic zones with different signs of freshwater budget associated with the shallow part of salinity minimum.

**DATA AND PROCESSING METHODS**

The oceanographic data from the World Ocean Data Base 2009 and from the data bank of Il’ichev Pacific Oceanological Institute of Far East Branch of the Russian Academy of Sciences and Far Eastern Research Hydrometeorological Institute were used for studying the seasonal variability of salinity in the North Pacific. The Ocean Data View software was used for the data processing [26].

All elements of the vertical salinity distribution as integral parts of the whole have been considered against the background of continuous variability of the whole profile at different time scales, and functional relationship between the salinity characteristics and the moisture budget have been taken into account. Using the available dataset for the whole observational period, the southern position of water structure without the salinity minimum was determined as well as the northern position of water structure with the salinity minimum at the depth of about 50 m. The salinity minimum observed at near-surface depths was registered in the subarctic zone.