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Supplement of

Statistical analysis of Lagrangian transport of subtropical waters in the Japan Sea based on AVISO altimetry data

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Main geographic features and bathymetry of the Japan Sea

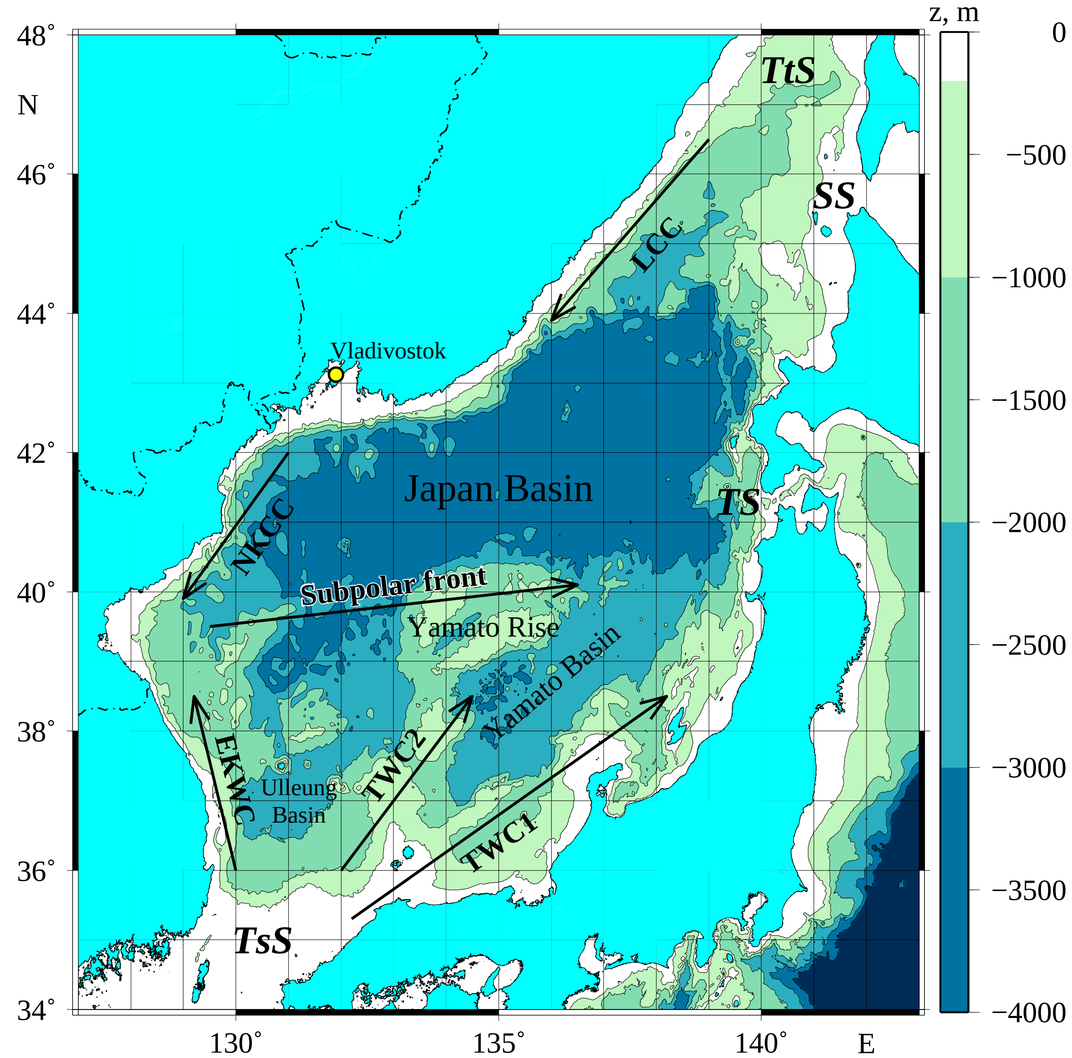

Figure 1: Main geographic features and bathymetry of the Japan Sea where z is depth in m. Abbreviations are the following: TsS (Tsushima or Korean Strait), TS (Tsugaru Strait), SS (Soya or La Perouse Strait), TtS (Tatarsky Strait), EKWC (East Korean Warm Current), NKCC (North Korean Cold Current), LCC (Liman Cold Current), TWC1 and TWC2 (the first and second branches of the Tsushima Warm Current).

Plots for the dates and longitudes when and where subtropical tracers cross the zonal lines 40° N and 42° N for the whole integration period

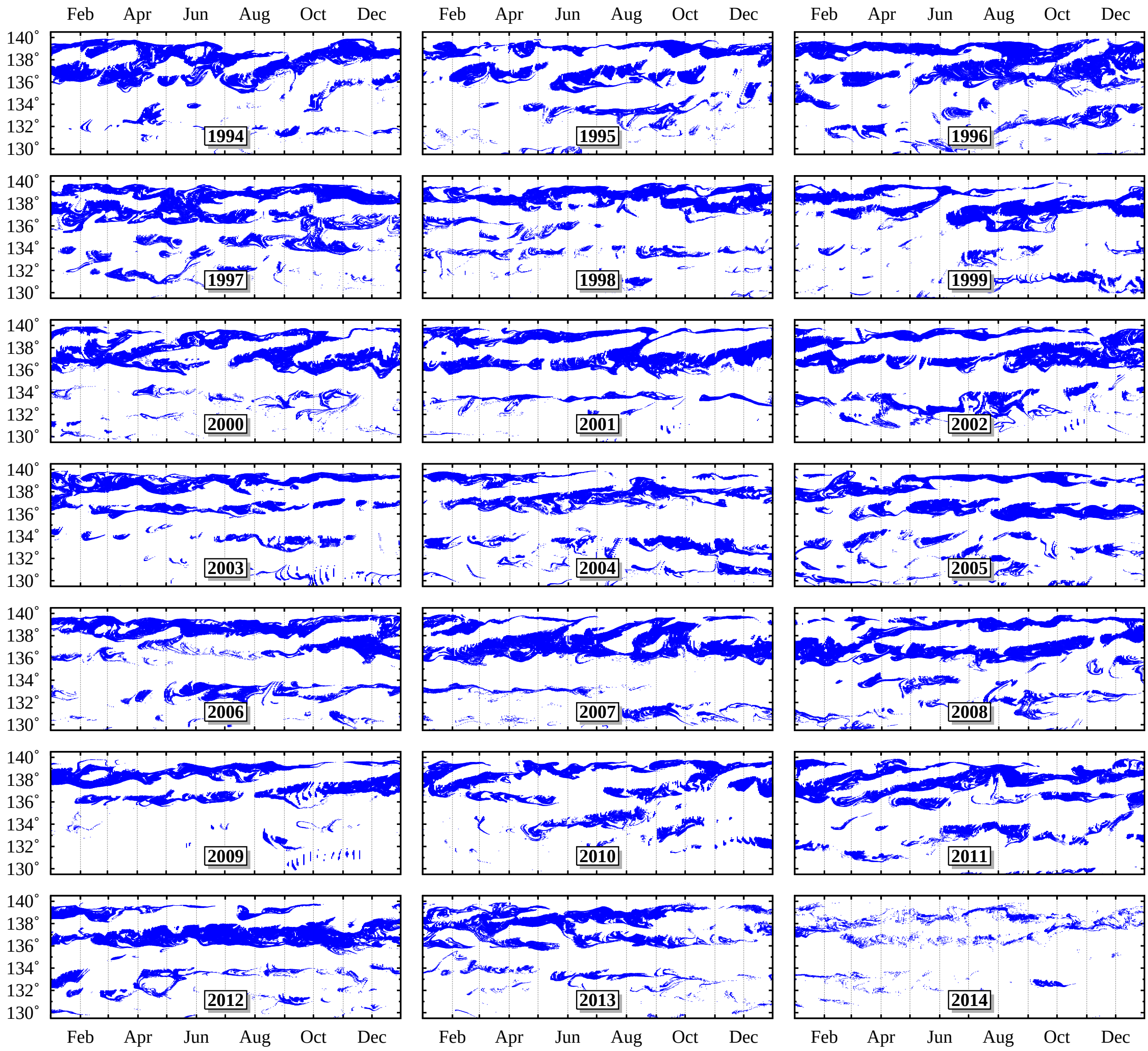

Figure 2: The $T-\lambda_f$ plot shows when and at which longitudes the tracers, launched at the zonal line 37° N, crossed eventually the zonal line 40° N in the period from January 1, 1994 to January 1, 2015.

All the plots in Figs. 2S and 3S show the eastern gates VIII and VII (see Fig. 4 in the paper) through which the subtropical tracers cross the corresponding latitudes. The locations of the central and western gates fluctuate in time, and some gates may be even closed for a while to the northward transport. The patchiness in the plots means that subtropical tracers prefer to cross the zonal lines in the specific places (note the peaks in Fig. 4 in the paper) and during specific time intervals. Any patch with a large number of tracers somewhere, say, at the central meridional gate means that a water mass proportional to the size of this patch passed through the central gate across a given latitude during the period of time proportional to its zonal size. Thus, the northward transport of subtropical water across the SF occurs by a portion-like manner. Specific oceanographic conditions may arise in a given area and at a given time which produce a large-scale intrusion of subtropical water to the north by means of mesoscale eddies to be present there.

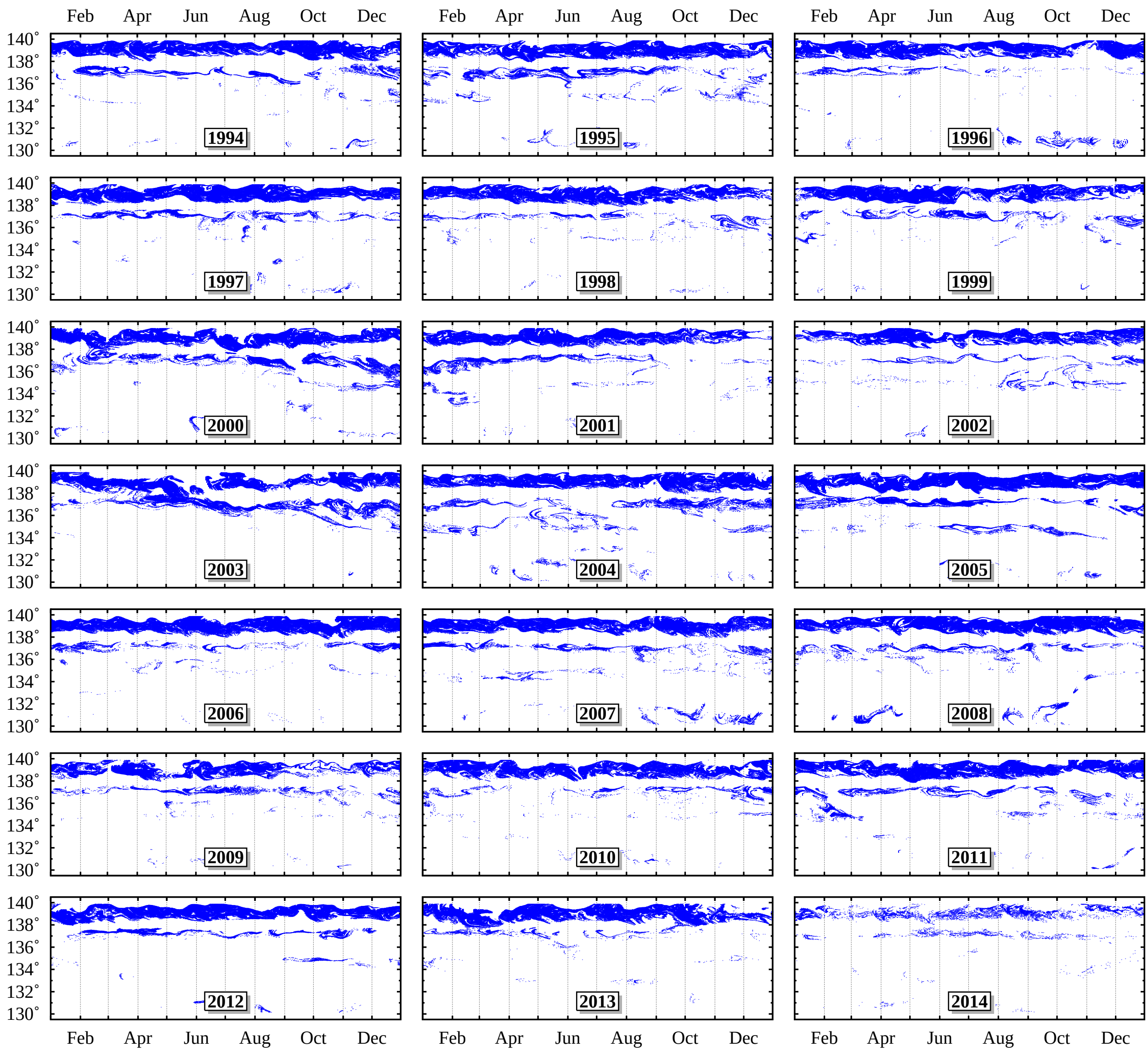

Figure 3: The same as in Fig. 2S but for the zonal line 42° N.

Transport pathways of subtropical water in the central Japan Sea

To visualize the transport paths by which subtropical tracers reach the northern SF area we compute so-called tracking maps in Fig. 4S showing where the subtropical tracers, which crossed eventually the zonal line 42° N, wandered for the whole integration period. Each panel shows the tracks of those tracers which crossed that line through the corresponding interval indicated by the black strip at the top. These are the same intervals as in Figs. 4b and c (in the paper).

The subtropical tracers, crossed eventually the latitude 42° N through the western gate 130° E – 132.5° E, have been found during their travel to the north mainly in the western part of the Sea (Figs. 4Sa and b). Those ones, that crossed it through the gate 132.5° E – 133.8° E, have travelled mainly in the western and central parts of the Sea (Figs. 4Sc and d). The subtropical tracers, crossed the latitude 42° N through the central gate 133.8° E – 136.5° E, have been found during their travel in an enlarged area (Figs. 4Se and f). Those ones, which crossed the latitude 42° N through the eastern gate 136.5° E – 140.2° E, have been found during their travel over the the whole basin (Figs. 4Sg and h) being well mixed. It is another manifestation of the fact established before in Fig. 4 (in the paper), that the Tsushima Warm Current contains water parcels with cardinally distinct "stories".

The data, collected in Figs. 4 (in the paper) and 4S, allow to make the conclusion that the

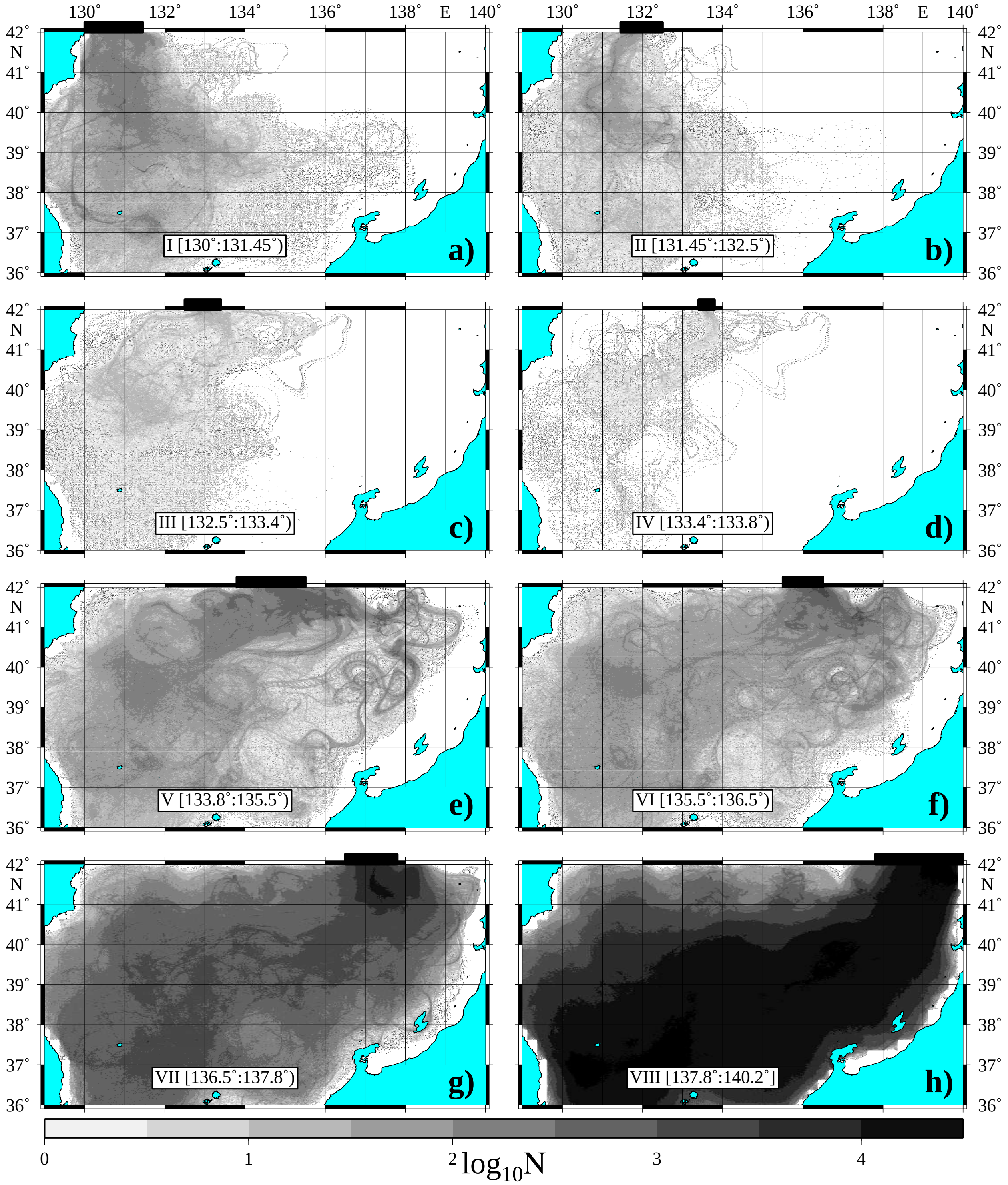

Figure 4: Tracking maps show where the subtropical tracers, launched initially at the zonal line 37° N and crossed eventually the zonal line 42° N, wandered for the whole integration period. Each panel shows the tracks of those tracers which passed through the corresponding gates indicated by black strips at the top.

northward transport of subtropical water does not depend on initial spatial and temporal conditions (tracers "forget" fast their initial coordinates and launch dates) except for transport provided by the strong Tsushima and East Korean Warm currents. Therefore, it is expected that an oceanographic survey of the main outflow of the Tsushima Warm Current through the Tsugaru Strait would detect at the same place "fresh" subtropical water, delivered by the shortest route, and modified subtropical water travelling in the central basin for a long time. From the ecological point of view, wherever a polluter would be situated in the central part of the JS it is expected to find that pollution in the Tsugaru Strait.

It is interesting that there is a “hub” through which those subtropical waters pass which contribute to all the peaks in the meridional tracer distribution along the latitude 42° N to the north off the SF (Fig. 4c in the paper). This “hub” is the area with coordinates at about 39° N – 41° N and 130° E – 132° E with increased density of points in all the panels in Fig. 4S. The existence of that hub is probably caused by two reasons, the presence of the quasi-permanent mesoscale Wonsan Eddy (WE in Fig. 1 in the paper) with the center at about 39° N, 130° E and separation of the East Korean Warm Current from the coast to the east at about 39° N with formation of the frontal jet.

Lagrangian intrusions of subtropical water via the eastern gate

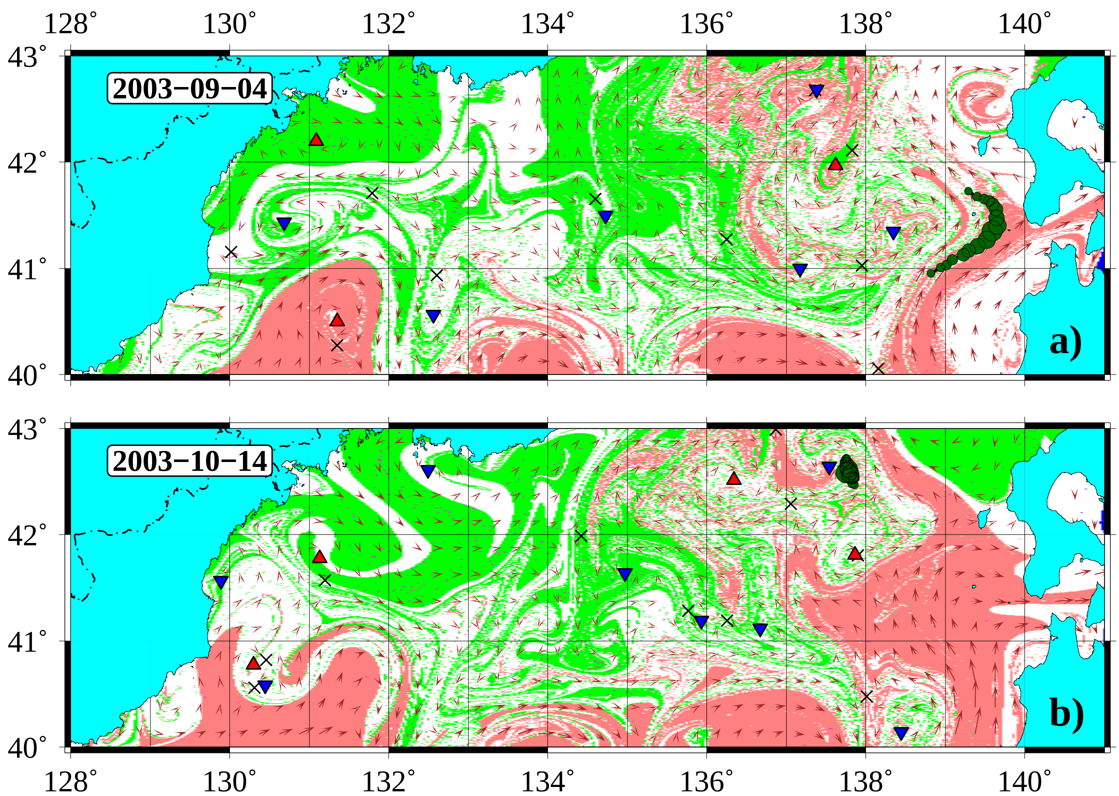

Figure 5: a) The backward-in-time drift maps in September – October, 2003 document a propulsion of subtropical tracers to the northwest (the dispersed red patch) with the help of the vortex pair consisting of the anticyclone with the center at 42° N, 137.7° E and the cyclone at 41.25° N, 138.35° E. Track of the drifter No. 35660 is shown by full circles for two days before and after the day indicated.

As to the transport of subtropical waters through the eastern gate no. VII (see Fig. 4 in the paper), it occurs mainly due to existence of a quasi-permanent vortex pair labelled as AC-C in the mean field in Fig. 1 in the paper. It provides a propulsion of some subtropical tracers to the northwest whereas most of them,propagating along the eastward frontal jet, join to the Tsushima Warm Current and flows out to the Pacific through the Tsugaru Strait. The maps in Fig. 5S document the typical situation with a propulsion of subtropical water to the northwest in September – October, 2003. The browsing and analysis of Lagrangian drift maps, computed for the whole observation period, have shown that frontal eddies used to facilitate the northward transport of subtropical water across the SF via the central and eastern gates.

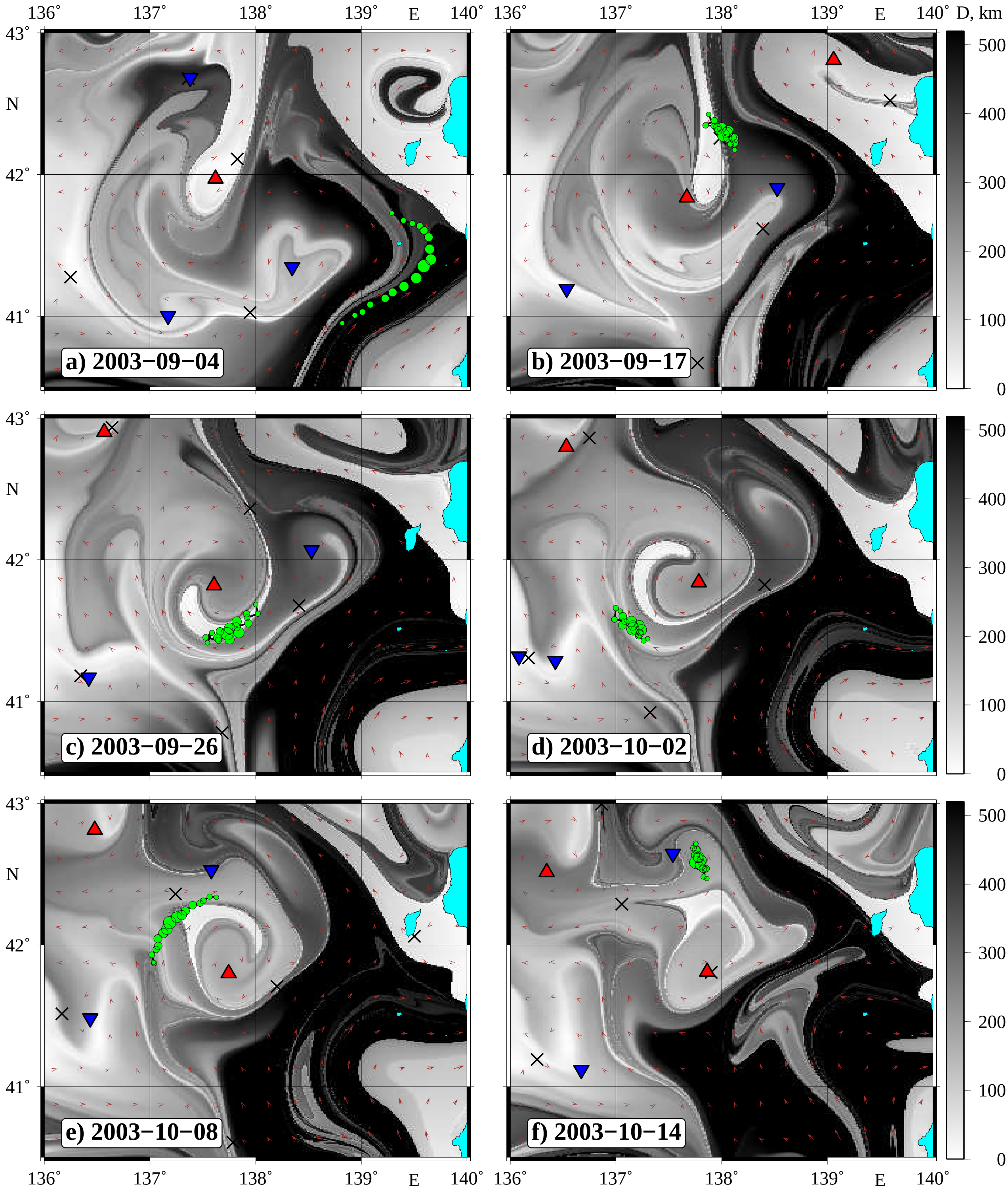

Figure 6: The D maps with snapshots of the drifter's track superimposed show how the vortex pair facilitates transport of subtropical tracers to the northwest through the eastern gate. The displacement of particles D in km, computed for a two months backward in time from the day indicated in each panel, are coded by shades of the grey color. Locations of the drifter No. 35660 are shown by full circles for two days before and after the day indicated.

To illustrate in more detail how this quasi-permanent vortex pair works we compute the backward-in-time D maps for September – October, 2003. The displacements D for tracers, distributed over the area in Fig. 6S, are computed for two months backward in time starting from the day indicated in each panel. The values of D in km are coded by shades of the grey color. So, the black tracers have displaced for the same time considerably as compared to the white ones. To validate our simulation we show in Fig. 6S positions of the drifter No. 35660 by full circles for two days before and after the date indicated with their size increasing in time. The entire track of that drifter, launched on May 2, 2003 at the point 34.925° N, 129.3° E, is shown in Fig. 7S.

In the beginning of September, 2003 (Fig. 6Sa) the vortex pair at the entrance to the gate VII consists of an anticyclone with the center at about 42° N, 137.7° E and a cyclone 41.25° N, 138.35° E. The cyclone winds some subtropical water from the eastward frontal jet round its northern periphery in a streamer-like manner (see the black tongue in Fig. 6Sa). Then this water is wound by the anticyclone round its southern periphery and is propulsed to the northwest (Figs. 6Sb–f). It is confirmed by snapshots of the track of the drifter No. 35660 for September–October, 2003. Being in the beginning of September in the main stream (Fig. 6Sa), it has drifted round the cyclone for the first half of September (Fig. 6Sb), then round the anticyclone for the second half of September (Fig. 6Sc) and in the beginning of October (Fig. 6Sd). Eventually the drifter No. 35660 crossed the latitude 42° N (Fig. 6Se) and moved to the north lugged by modified subtropical waters (Fig. 6Sf).

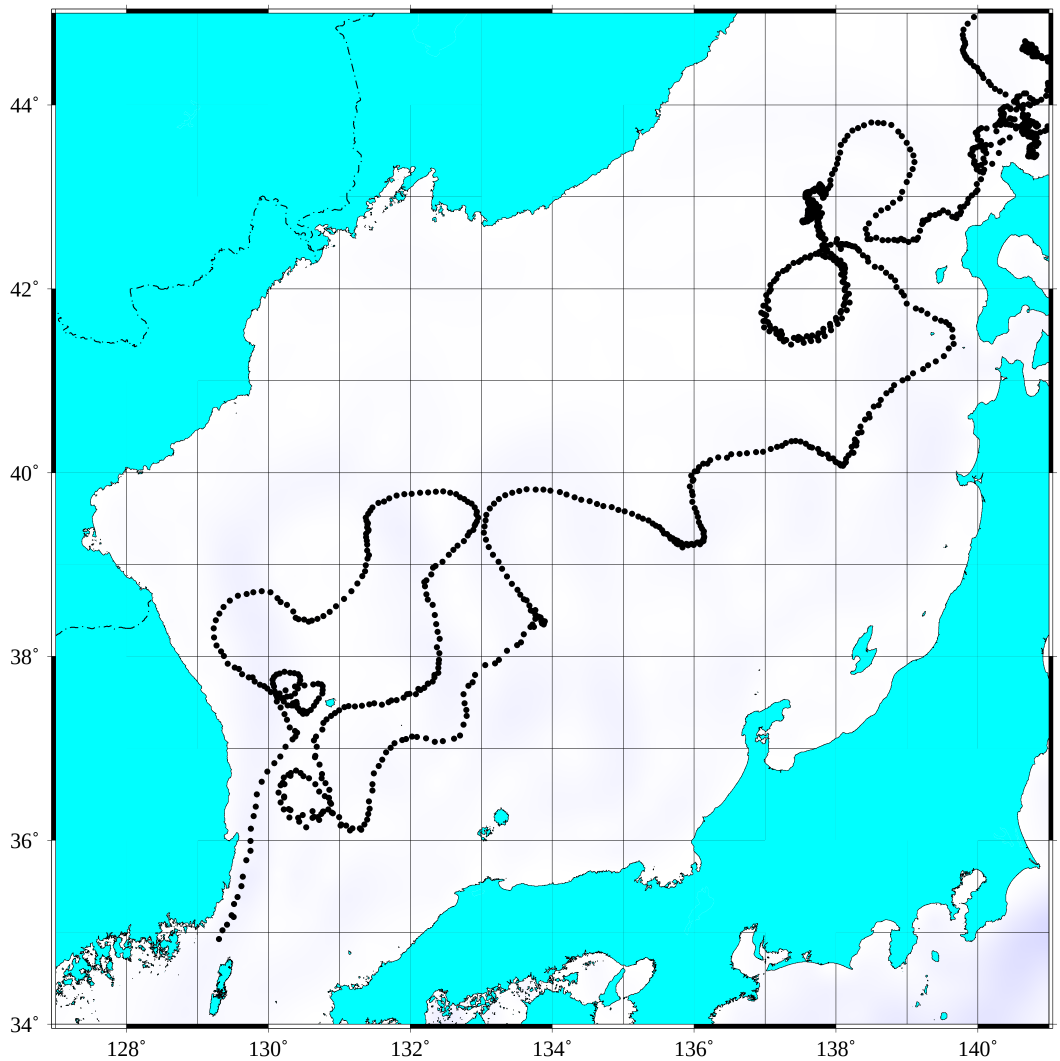

Figure 7: The track of the drfiter No. 35660 launched on May 2, 2003 at the point 34.925° N, 129.3° E.