A New Method for Tracking Ocean Dynamics

The Kuroshio Current transports large amounts of warm and salty water from the tropics northward, whereas the Oyashio Current transports cold and fresh water from the Bering Sea and the Sea of Okhotsk southward. Where they meet in the western North Pacific, they form the Kuroshio Extension and the Oyashio Front, a region of very complicated currents and eddies. Large decadal variations that strongly affect Pacific climate have been found in the area. What happens in these currents is, therefore, of particular interest for climate study and climate prediction.

It is difficult in this region to chart in any detail mesoscale features that evolve over several weeks, and information about them has been sparse. This lack of observations has been an obstacle to gaining an understanding of how such features might determine or affect Pacific Ocean climate. Now **Max Yaremchuk, Konstantin Lebedev,** and **Humio Mitsudera** at the IPRC have developed a method that makes the detection and tracking of significant features easier, not only for this region, but also for the rest of the world's oceans.

Figure 4 illustrates the kinds of information that can be obtained by applying their method, showing the evolutions of mean transport velocity (contours) and temperature anomalies (color) in the Kuroshio Extension at a depth of 236 m, every nine days from July 20 to September 21, 1997. The sharp temperature difference between the warm Kuroshio (red shades) and the subarctic ocean (blue shades) is clearly visible in the figure and as large as 12˚C in some places. The sequence of eight panels shows intense eddy activity. A cold meander (yellow shades) at the Kuroshio Extension front is present in the top, left panel at 150–152˚E and 32–33˚N. This meander turns into a mid-sized cold-core eddy as it moves westward at a speed of 4 cm/s. Anomalously warm water reaches the latitude of 35˚N by the end of August and interacts with the cold eddy. The warm anomaly detaches itself in the second half of September at 34˚N, 151˚E, forming an eddy with a warm core. Both the temperature and streamfunction fields show this event. The detachment of the eddy from the western warm-water tongue was possibly triggered by the cold core anomaly further south at 30–32˚N, 147–148˚E. Qualitative analyses of the flow dynamics beyond those shown above reveal a current that sometimes exceeds 1.2 m/s (nearly 3 miles per hour) and that advects density anomalies.

These results were obtained by assimilating five variables into a numerical model: sea surface height data from the satellite TOPEX/Poseidon (solid slanted lines); acoustic travel-times observed along the ray paths connecting five autonomous acoustic transducers at a depth of 1075 m (positioned at the stars); differential acoustic travel-time observations (differences between direct and reciprocal travel-time, which contain information about currents); and hydrographic temperature and velocity measurements obtained during deployment and recovery of the transducers (arrows denote observed velocity).

Using acoustic travel-time as an indirect measure of water temperature in numerical models would be very helpful in studying the evolution of mesoscale ocean processes, but has not been very feasible, as the travel-times cannot be easily incorporated into models. The new strategy adopted here has dealt with this problem by assimilating the travel-times using a variational data algorithm. Since the model solution depends on both the initial and the boundary conditions, the evolution of an event changes when the values of these conditions are changed. The variational data assimilation procedure can find "best-fit" initial and boundary conditions, those that produce a model solution that is as close as possible to all the data measured during the time of model integration.

The graph in Figure 5 illustrates the large error reduction after assimilation: The straight horizontal line shows the mean error of acoustic travel-time measurements; the upper curve represents travel-time errors in a model solution without assimilation, while the lower curve shows the deviations of the model solution from measured data after assimilation. The deviations obtained with the assimilated data fall well below the measurement error, indicating how much this technique improves the usefulness of acoustic travel-times as a measure of ocean temperature.

This method for assimilating acoustic travel-times into an ocean model greatly facilitates charting week-long ocean processes that occur over large distances. The present data sets together with the dynamical information provided by the model are sufficient to detect and track how eddies form and decay. The evolution of eddies such as those seen in the panels is particularly important in estimating the ocean's heat and salinity budgets—the controlling forces in ocean circulation and its impacts on global climate.

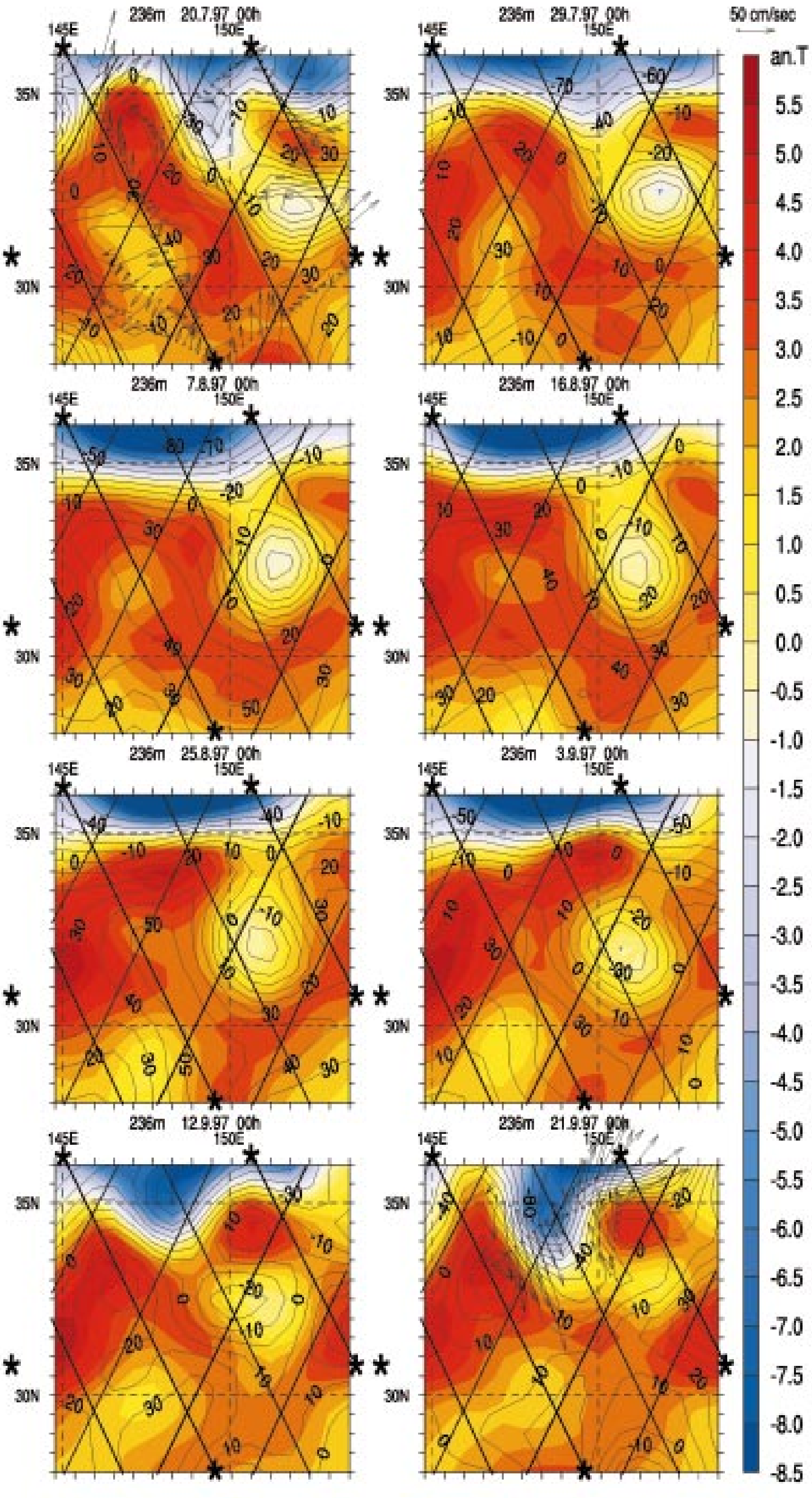

Figure 4: *Evolution of the optimized stream-function (contours) and temperature anomalies (color) at 236 m depth retrieved by means of four-dimensional variational data assimilation technique. Positions of the acoustic transceivers are denoted by stars, satellite tracks by solid slanted lines. Results of the acoustic Doppler current profiler measurements are shown by arrows (first and last panels).*

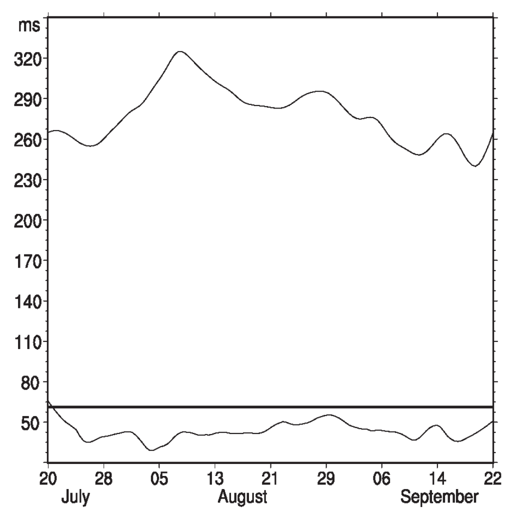

Figure 5: *Evolution with time of data misfits in the tomography model. Upper curve shows the errors of the "first-guess" solution (i.e., before assimilation); lower curve shows the errors after assimilation. The horizontal line represents the observational error variance level.*