Tracing the Subarctic Circulation in the North Pacific

Given the role of atmospheric carbon dioxide (CO_2) in regulating global climate, recent observations on CO_2 exchange in the subarctic North Pacific are of significance. This region has areas where large quantities of CO_2 enter the atmosphere and other areas where large quantities of CO_2 enter the ocean. The exchange of CO_2 is regulated by the concentration of dissolved and suspended materials and is a function of the extent to which the mixed-layer mixes with the ocean interior. Little is known, however, about the subarctic North Pacific circulation, which affects this mixing.

A feature of the subarctic North Pacific is a shallow layer of cold water lying over a warm-water layer rather than the usual warmer water over colder water. This oceanic temperature inversion is called "mesothermal structure." Numerical experiments to investigate the ocean circulation in the North Pacific so far have not examined how the mesothermal structure forms because models fail to simulate a surface mixed layer that is deep enough to reproduce the structure.

IPRC researchers **Takahiro Endoh**, **Humio Mitsudera**, **Shang-Ping Xie**, and **Bo Qiu** (UH) have successfully reproduced the mesothermal structure using the Miami Isopycnic Coordinate Ocean Model (MICOM) that combines a bulk mixed-layer model and a 3-dimensional, primitive, isopycnic coordinate model of the oceanic interior. The most significant difference compared to previous numerical studies is that the model simulates in winter a surface mixed-layer deeper than 100 m in the western subarctic and the Alaskan gyres, leading to a more realistic simulation of the thermohaline structure in the subarctic North Pacific.

In the model, the cold-water layer originates from cold and low-salinity water formed locally in winter when strong cooling and wind-mixing deepen the surface mixed layer. During spring and summer, the seasonal thermocline develops over this cold water. In contrast, the warm-water layer, also called "mesothermal" water, originates as subtropical water that enters the North Pacific subarctic region. Figure 2 shows the annually averaged north-south overturning streamfunction. Analyzing the model output, Endoh and his colleagues found water in the density range of 26.8-27.0 σ_θ flowing from the subtropics into the subarctic region and forming the mesothermal water. In winter, the mesothermal water enters the surface mixed-layer by upward Ekman suction – weakened somewhat by water intruding sideways. Entrained into the surface mixed layer, the mesothermal water then flows out to the subtropics as low-density water by southward Ekman drift. The mesothermal water is thus a part of the shallow north-south overturning cell, the subpolar cell (SPC).

To show the pathway of this warm water in more detail, a passive tracer was continually injected, after a 50-year spin-up, into the 26.8 σ_θ layer of the model south of Japan in the gray region indicated by the arrows in Figure 3. This figure shows the annually averaged barotropic streamfunction in solid contours and the gyre boundary in dashed lines. The tracer path shows clearly that the source of the mesothermal water is the warm and saline water from the Kuroshio south of Japan. Kuroshio water that crosses the gyre boundary near the western boundary flows eastward along the gyre boundary in the Kuroshio-Oyashio Extension and, after 6 years, it has spread into the western subarctic gyre. The water then travels in the northern part of the North Pacific Current and after six more years, is found in the Alaskan gyre. Some Kuroshio water south of the gyre boundary enters the Alaskan gyre west of 150ºW after 18 years.

This numerical study is the first to show clearly the mesothermal structure in the subarctic North Pacific. Endoh and his colleagues are now planning to use MICOM to investigate the interannual-to-decadal variation of the water-mass exchange between the surface mixed layer and the oceanic interior in the subarctic North Pacific. Results from these studies are an important step toward understanding the pattern of CO_2 fluxes in this region.

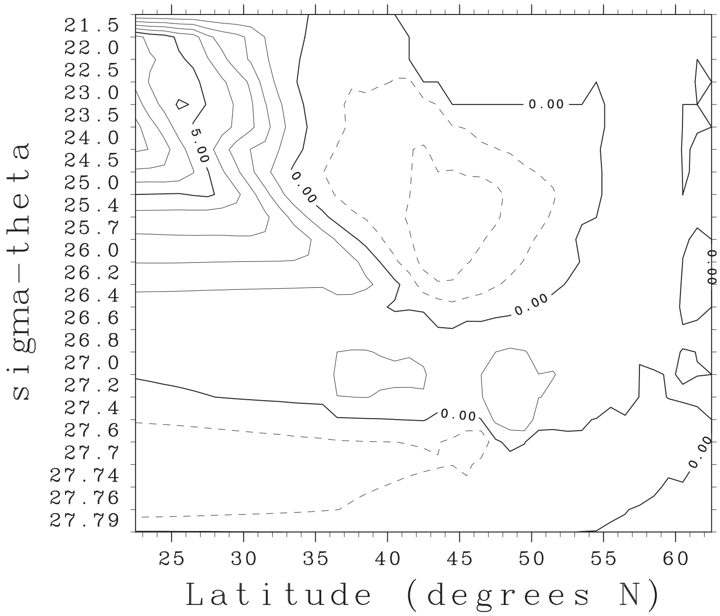

Figure 2. *The annually averaged meridional overturning streamfunction. Contour interval is 1 Sv (1 Sv = 10^6 m^3s^{-1}). Dashed contours are negative.*

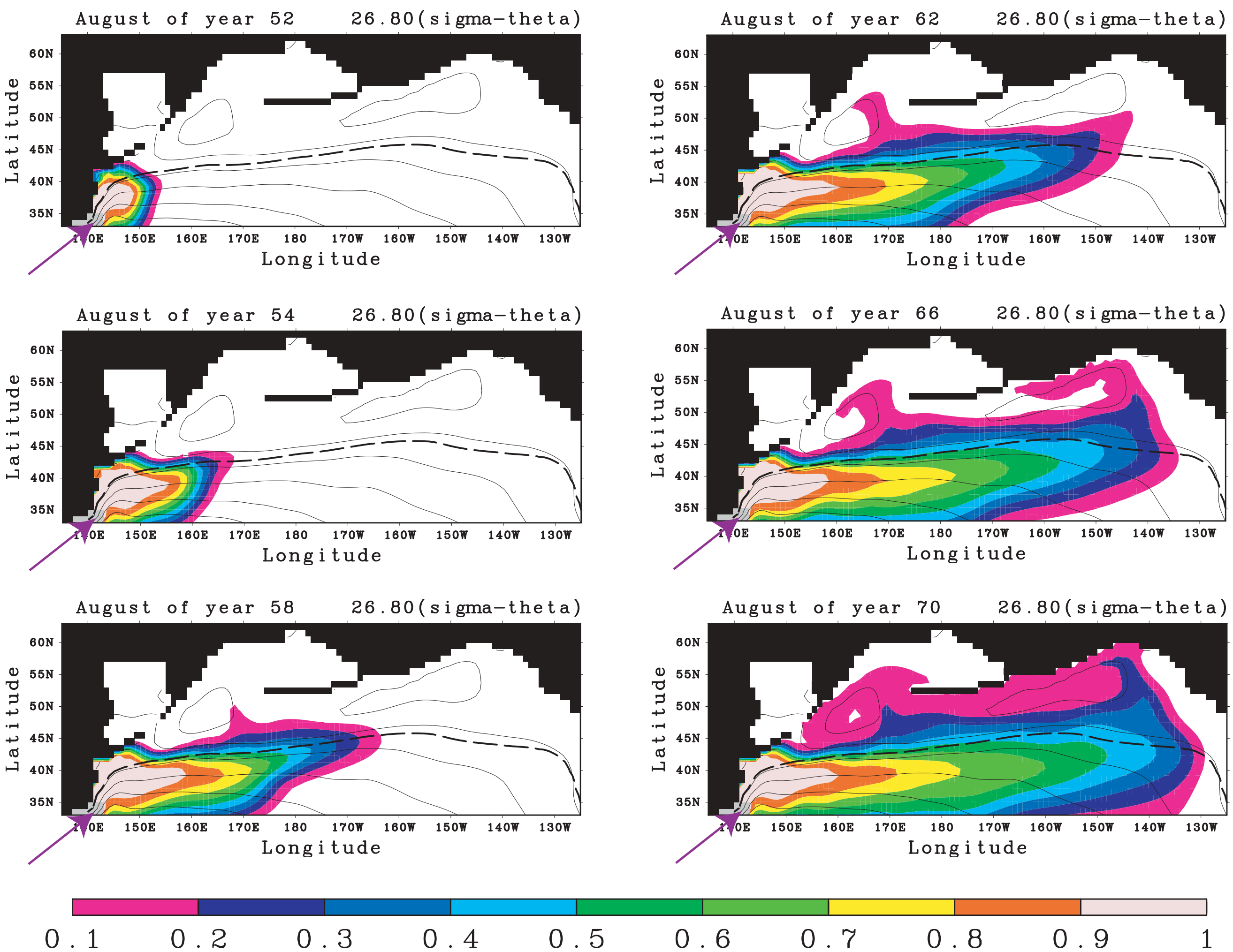

Figure 3. *Horizontal distribution of the passive tracer injected into the layer of 26.8 σ_θ, which is maintained at saturation in the gray shaded region (indicated by arrows) after year 50. Superimposed are the annually averaged barotropic streamfunction (solid contours; contour interval = 5 Sv) and the gyre boundary (dashed lines) derived by subtracting the annual mean Ekman transport from the annually averaged volume transport.*