TRANSPORT OF OXYGEN, NUTRIENTS AND CARBONATES BY THE KUROSHIO CURRENT

C. T. A. Chen
(*Institute of Marine Geology, National Sun Yat-Sen University, Kaohsiung, Taiwan*)
C. T. Liu and S. C. Pai
(*Institute of Oceanography, National Taiwan University, Taipei, Taiwan*)

Received Sep. 1, 1993

Abstract

Measured concentrations of dissolved oxygen, phosphate, silicate, total alkalinity and calculated total CO_2 in a section between 121° E and 125° E across the Kuroshio near 22° N off Taiwan and the geostrophic velocity were used to estimate the gross transport of oxygen, nutrients and carbonates.

The flux of dissolved oxygen is 6.7×10^6 mol/s northward and 0.9×10^6 mol/s southward. The net flux equals 5.8×10^6 mol/s down-stream. The northward flux of phosphate is 22.6×10^3 mol/s; the southward flux is 1.4×10^3 mol/s. The net phosphate flux is 21.2×10^3 mol/s northward. The flux of silicate is 967×10^3 northward and 59×10^3 mol/s southward; the net transport is 908×10^3 mol/s down-stream. The flux of alkalinity is 75.5×10^6 mol/s northward, and 10.8×10^6 mol/s southward, the net flux is 64.7×10^6 mol/s northward. For total CO_2 the transport is 73.4×10^6 mol/s northward and 10.8×10^6 mol/s southward, or a net transport of 62.6×10^6 mol/s northward.

Key words: transport, oxygen, nutrient, carbonates, Kuroshio Current

INTRODUCTION

The Kuroshio, like the Gulf Stream of the North Atlantic Ocean, is the strongest western boundary current of the North Pacific Ocean. It is generally considered to be originated from the area southeast of Taiwan and east of the Bashi Strait. The Kuroshio is characterized by its high speed, narrow width and great depth. It brings a large quantity of warm equatorial seawater while traveling northward along the east coast of Taiwan (Pai et al., 1987). Because of its characteristic high temperature and salinity, it has important impacts both on the local climate and the marine biological resources. Our interest is to quantitatively estimate the material fluxes carried by the Kuroshio.

The first quantitative estimates of nutrient fluxes are apparently those of Wunsch et al. (1983) for the Pacific. In the Atlantic, the first calculation of nutrient fluxes seems to be that of Brewer and Dyrssen (1987). They multiplied the average values by the net meridional transport in each depth class to find the net flux across 24° N. Brewer et al. (1989), Csanady (1990) and Rintoul and Wunsch (1991) further extended the flux calculation in the North Atlantic Ocean to include nutrients, oxygen and CO_2. We are not aware of similar work in the North Pacific.

The first cruise of the Cooperative Hydrographic Investigation of the Philippine Sea (CHIPS−1) was carried out southeast of Taiwan, (Liu et al., 1986, 1987; Pai et al., 1987). In this note, we shall make use of these data to estimate both the flux-density (velocity times concentration), and the gross transport of dissolved oxygen, phosphate, silicate, alkalinity and total CO_2.

SOURCE OF DATA

The hydrographic data used in this note were cited from the data report of CHIPS – 1 (Liu et al., 1987). Of the 27 CTD stations in Fig. 1 only 21 stations were chosen for chemical analysis. The analytical procedures in determining the dissolved oxygen, phosphate, silicate and total alkalinity were described in Pai et al. (1987).

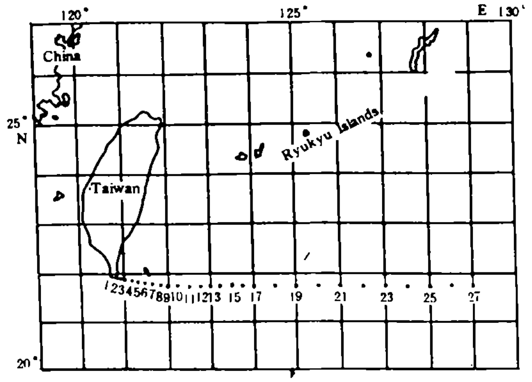

Fig. 1 Station location

The highest dissolved oxygen concentration(4.4 ml/L to 4.9 ml/L, near saturation) was found in the surface layer. The minimum was 1.6 ml/L at 1000 m. The phosphate concentration increased with depth, ranging from 0.3 μmol/L near the surface to a maximum of about 3.0 μmol/L. The distribution of silicate concentration was similar to that of phosphate, low in the surface layer and high in deep water, up to about 150 μmol/L. The total alkalinity of surface seawater ranged from 2.3 to 2.4 mmol/L and increased with depth to a maximum of 2.5 mmol/L between 2000 – 3000 m (Pai et al., 1987). The distribution of total CO_2(calculated from pH and alkalinity; Chen, 1984) was similar to that of alkalinity, with concentrations ranging from 2.0 to 2.6 mmol/L. The geostrophic velocity (Fig. 2) was based on the 1000 dB surface as the reference level. (Liu et al., 1986)

Fifteen stations (St. 2 – 19) between 121 °E and 125 °E were chosen for flux estimations. Currents further east were too low for accurate flux estimations.

RESULTS AND DISCUSSION

The calculated geostrophic velocity was based on a level of no motion at 1000 dB. (Fig.2) The results agree with that obtained by Nitani (1972). There were two northward current bands and a weak southward current (from 124 °E to 125 °E). The flux densities of oxygen, nutrients and carbonates were calculated by multiplying velocity by concentration. Integrating these data gives the total fluxes shown in Table 1.

Oxygen:

Fig. 3 shows the flux-density of dissolved oxygen ranging from – 104 to 260 mmol/m²s (positive sign indicates northward flow), with a maximum at St. 5. Since the flux-density is dominated by concentraion and velocity, and both decrease with depth, the flux-density structure of dissolved oxygen was similar to the velocity structure. The gross flux of oxygen at this 400 km wide section was 6.7×10^6 mol/s northward and

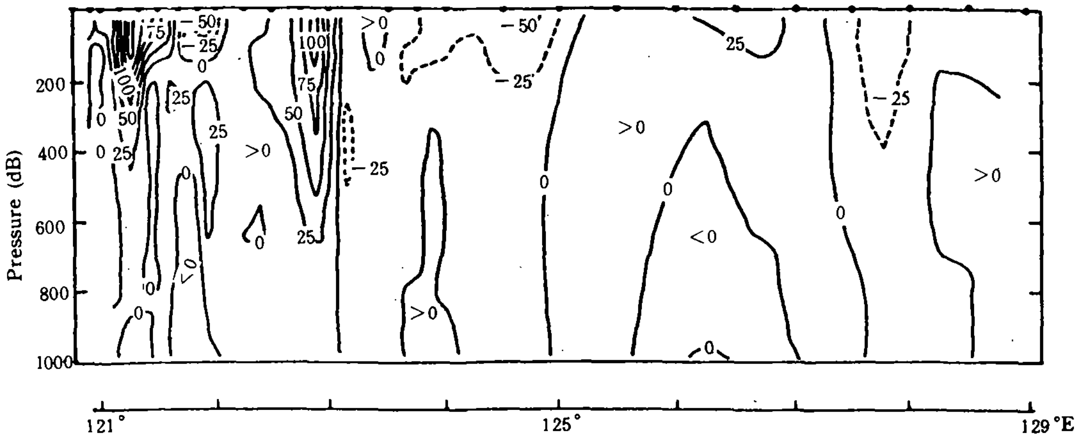

Fig. 2 Geostrophic velocity at the section near 22° N, contours are in centimeter per second and the positive sign indicates northward flow (Data from Liu et al., 1986)

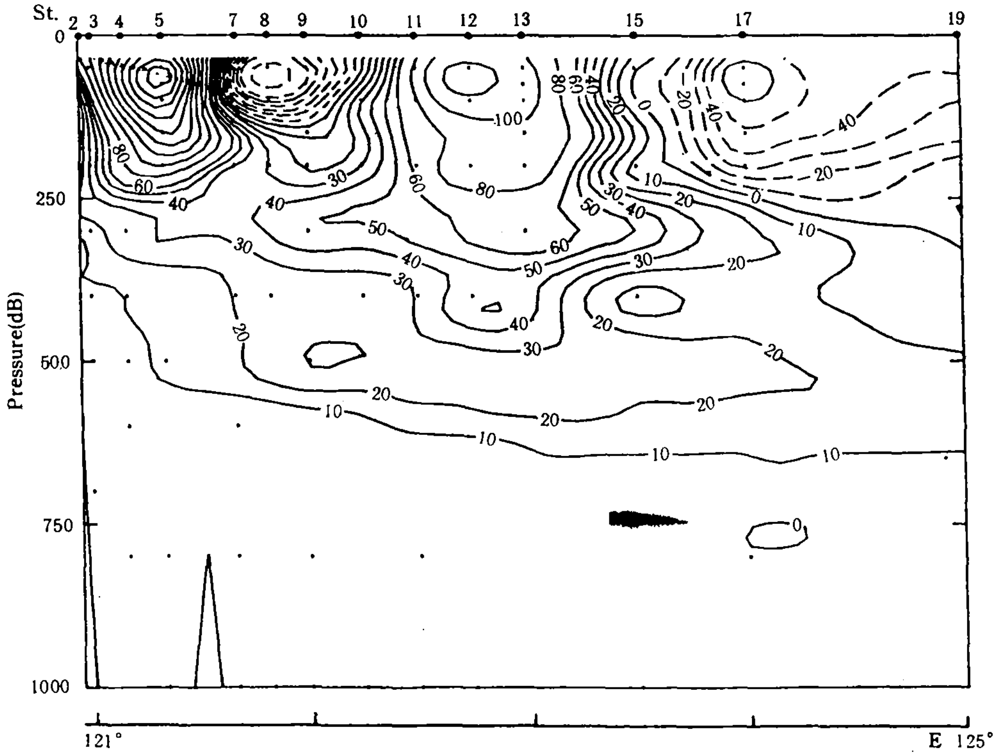

Fig. 3 Along-stream flux-density of dissolved oxygen (mmol/m²s) at a section near 22° N

0.9×10^6 mol/s southward, yielding a net flux 5.8×10^6 mol/s down-stream, or contributing 183×10^{12} moles for this section per year.

Phosphate:

The distribution of flux-density for phosphate is shown in Fig. 4. The values ranged from -125.4 to 450.3 μmol/m²s with a maximum at 500 m at St. 9. There was a maximum core located at 500 m, just below the high velocity core of the Kuroshio. The Gulf Stream shows a similar pattern (Csanady, 1990). The total flux of phosphate across this section was 22 639 mol/s northward and 1 462 mol/s southward, yielding a northward net flux of about 21 177 mol/s. This amounts to a phosphate transport of 668×10^9 moles per year.

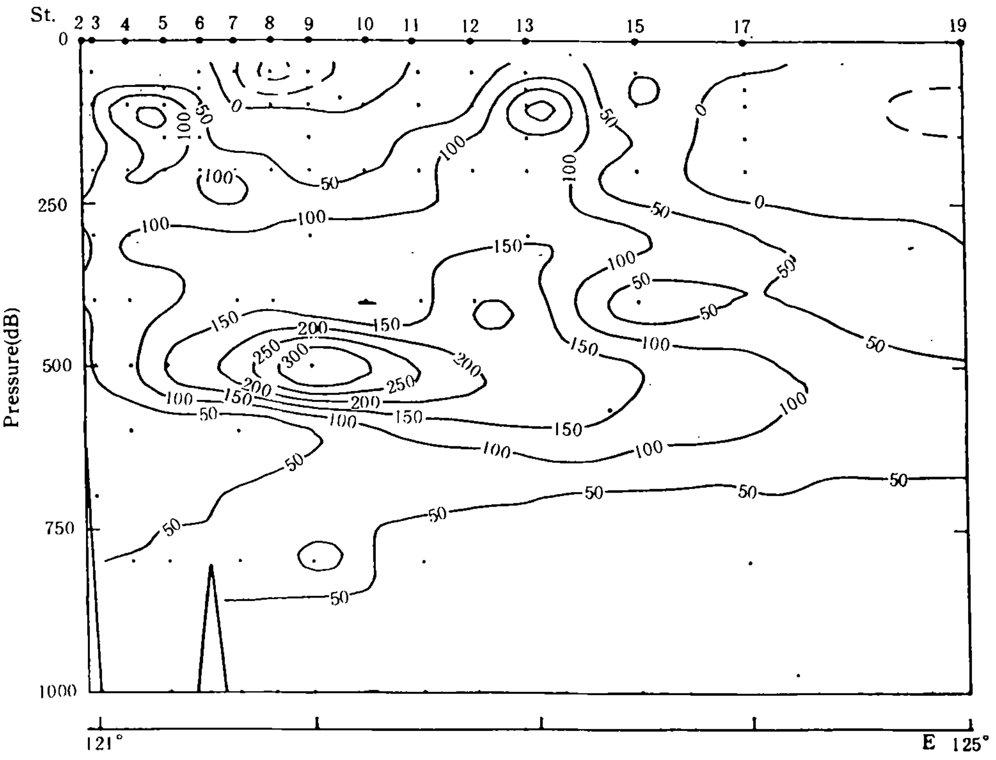

Fig. 4 Along-stream flux-density of phosphate (mmol/m²s) at a section near 22° N

Silicate:

The flux-density of silicate ranging from -3.66 to 17.76 mmol/m²s is shown in Fig.5 showing a silicate stream core at about 500 m below the high velocity core. The negative values, at St. 8–10 and St. 17–19, indicate the southward transport of currents. The silicate flux was 967×10^3 mol/s northward and 59×10^3 mol/s southward. The net northward flux of silicate was 908×10^3 mol/s or 28.6×10^{12} moles per year, some forty times the net phosphate flux. For nutrients, the northward transport was about sixteen times the southward transport.

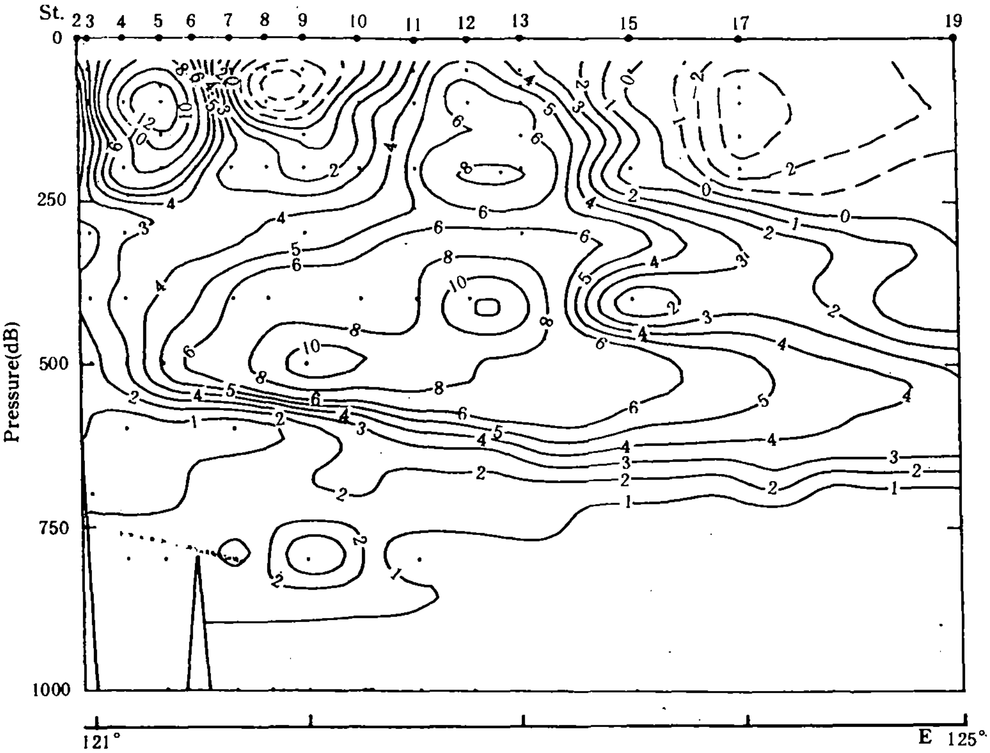

Fig. 5 Along-stream flux-density of silicate (mmol/m²s) at a section near 22° N

Alkalinity:

The inferred alkalinity flux-density (Fig.6) had band structures similar to that of the geostrophic velocity (Fig. 2). The down-stream maximum transport of alkalinity by the Kuroshio at this latitude was 3029 mmol/m²s in the western part close to the coast. The southward maximum flow was -1150 mmol/m²s at St. 8 at about 50 m. The inferred alkalinity flux (Table 1) transported by the Kuroshio was 75.5×10^6 mol/s northward. The southward transport was 10.8×10^6 mol/s; thus the net alkalinity flux was 64.7×10^6 mol/s or 2.04×10^{15} mol/a northward.

Table 1 Estimates of northward oxygen, phosphate, silicate, alkalinity and total CO_2 fluxes at 22° N between 121° and 125° E

	Flux				
Depth	Dissolved oxygen (10^3 mol/s)	Phosphate (mol/s)	Silicate (mol/s)	Alkalinity (10^3 mol/s)	Total CO_2 (10^3 mol/s)
50–250 m	2 370	2 666	149 370	22031	19 768
251–500 m	2 445	8 480	425 994	28 577	30 247
501–750 m	940	7 674	286 026	10 987	9 658
751–1000 m	43	2 357	46 668	3 065	2 918
Total flux	5, 98	21 177	908 058	64 660	62 591

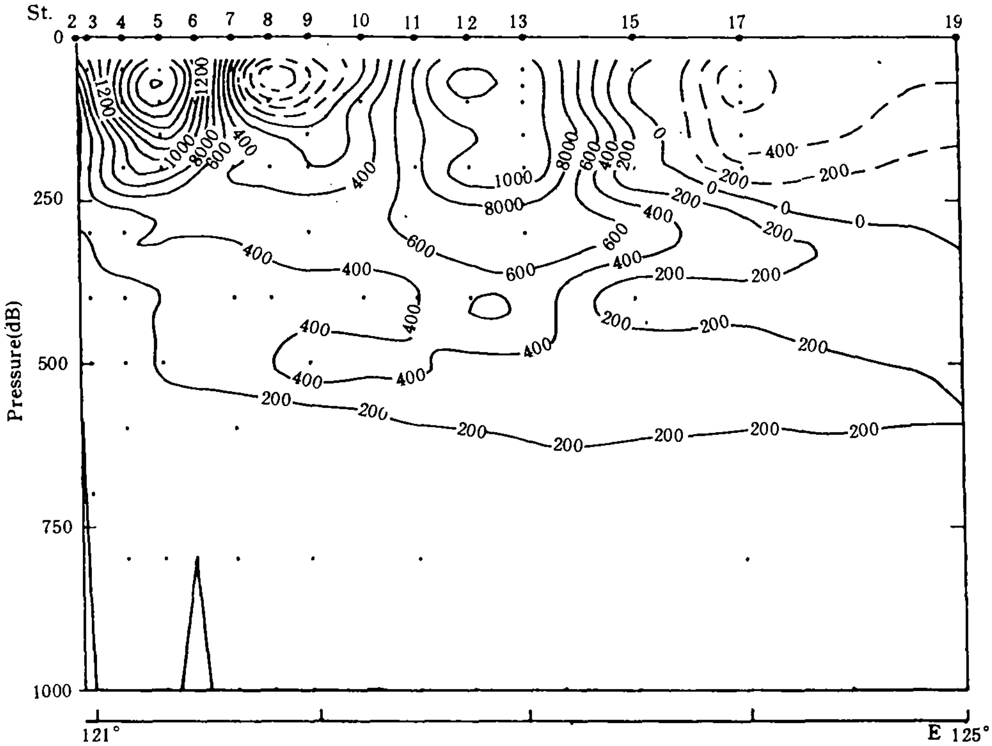

Fig. 6 Along-stream flux-density of total alkalinity (mmol/m²s) at a section near 22° N

Total CO_2:

Total CO_2 flux-density (Fig. 7), similar to that of alkalinity, also showed the band structure. Northward flow maximum of about 2 694 mmol/m²s located at St. 5 at 75 m, and southward maximum of 1 002 mmol/m²s located at St. 8 at 50 m. For total CO_2 the transports were 73.4×10^6 mol/s northward and 10.8×10^6 mol/s southward. These values yield a net northward flux of 62.6×10^6 mol/s, or 23.7×10^9 tons C per year. For both alkalinity and total CO_2, the northward flow transported some seven times the southward flow.

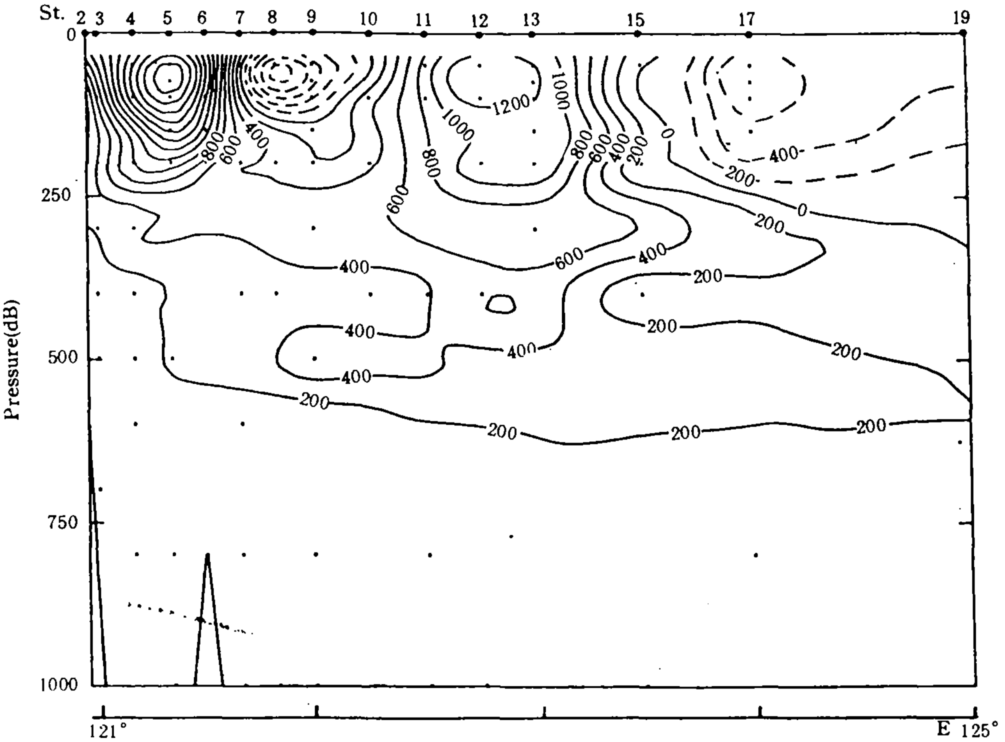

Fig. 7 Along-stream flux-density of total CO_2 (mmol/.m²s) at a section near 22° N

CONCLUSION

1. The flux-densities of phosphate and silicate by the Kuroshio at 22° N showed along-stream cores between 400 and 500 m, below the high-velocity core (between the surface and 200 m) of Kuroshio current.

2. The flux-density distributions of alkalinity and [redacted] CO_2 were similar to that of the velocity structure, indicating that both of them were dominated by the velocity field.

3. The gross northward fluxes of dissolved oxygen, phosphate, silicate, alkalinity and total CO_2 were 5.8×10^6 mol/s, 21.2×10^3 mol/s, 908×10^3 mol/s, 64.7×10^6 mol/s and 62.6×10^6 mol/s, respectively.

ACKNOWLEDGEMENTS

The National Science Council supported the research (NSC 82−0209−M−110−041). C. H. Wang provided assistance.

References

Brewer, P. G. and Dyrssen, D., 1987. Ocean chemical fluxes across 25° N in the Atlantic Ocean. Discussion paper prepared for the International GOFS meeting, Paris, 17–20, Feb. 1987, 25 pp.

Brewer, P. G., Goyet, C. and Dyrssen, D., 1989. Carbon dioxide transport by ocean currents at 25 °N latitude in the Atlantic Ocean. *Science* **246**: 477–479.

Chen, C. T., 1984. Carbonate chemistry of the Weddell Sea. Department of Energy Technical Report, DOE/EV/10611–4, 118 pp.

Csanady, G. T., 1990. Physical basis of coastal productivity. *EOS*. **71**(36): 1060–1065.

Liu, C. T., Liau, S. G., Pai, S. C. et al., 1986. Water masses in the Western Philippine Sea-physical aspects. *Acta Oceanographica Taiwanica* 17: 1–17.

Liu, C. T., Pai, S. C., Liau, S. G. et al., 1987, Data report of CHIPS– 1, Institute of Oceanography. National Taiwan University, 118 pp.

Nitani, H., 1972. Beginning of the Kuroshio. *In*: Kuroshio. University of Tokyo Press, Japan, pp. 129–163.

Pai, S. C., Liu, C. J., Wen, L. S. et al., 1987. Primary investigation of the Western Philippine Sea water-chemical data from the CHIPS–I expedition. *Yearly Journal of the National Taiwan College of Marine Science and Technology* **21**: 49–68.

Rintoul, S. R. and Wunsch, C., 1991. Mass, heat, oxygen and nutrient fluxes and budgets in the North Atlantic Ocean. *Deep-Sea Research* 38 (Suppl. 1): S355–S377.

Wunsch, C., Hu D. and Grant, B., 1983, Mass, heat and nutrient fluxes in the South Pacific Ocean. *Journal of Physical Oceanography* **13**: 725–753.