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CONTINENTAL SHELF RESEARCH

Author's reply to Comments on "Artifacts introduced into the calculation of the mixing ratios of seawater end-members using *T*–*S* properties"

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It has been widely recognized for many years that the Kuroshio upwells into the East China Sea (ECS), yet early attempts to discuss its distribution have mostly been qualitative. For instance, Liu et al. (1992) divided the waters near the ECS shelf break into I, II, III and K-types. However, none of these water types has a discernable *T* and *S* characteristics. Further, the sharp boundaries between these water types do not correspond to any oceanic feature, such as a front, a thermocline or a chemocline, and they have no physical meaning.

Chen et al. (1995) made an attempt to divide the waters into four components with clear *T* and *S* characteristics: the Kuroshio Surface Water (SW), with high temperature and high salinity; the Kuroshio Tropical Water (TW), with a salinity maximum; the Kuroshio Intermediate Water (IW), with a salinity minimum; and the Surface Shelf Water (SSW), with relatively lower temperature and salinity compared to the SW. The mixing percentages of these 'end-members' were then calculated for the waters at a cross-section perpendicular to the shelf break northeast of Taiwan. The conclusion was reached that in September 1988 the bottom waters on the shelf contained only 10% of the original SSW with the rest coming from the SW (10%), TW (50%) and the IW (30%). In contrast, in December 1989, the original shelf water was almost non-existent near the bottom where the SW (30–50%), TW (30%) and IW (10–30%) dominated. These percentages were mainly based on *T*–*S* data, but calculations based on NO_3^-–*S*, PO_4^{-3}–*S* and pH–*S* pairs yielded similar results.

Liu et al. (1998) correctly pointed out that, because of a sealing problem, an artifact existed in the method used by these authors. Therefore, this makes it necessary to take

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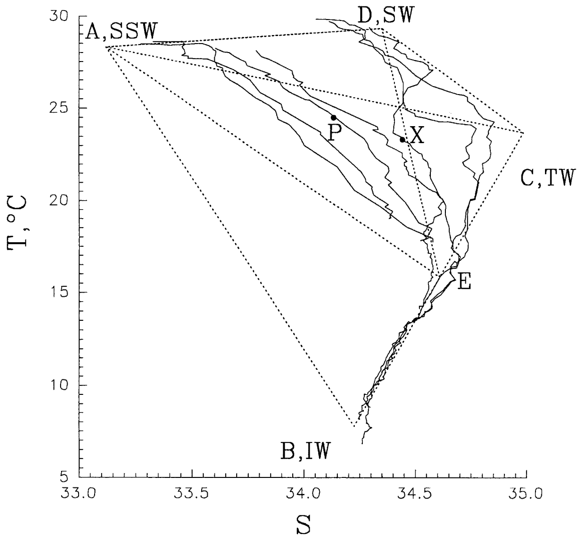

Fig. 1.

Table 1
Mixing ratios based on *T*–*S* for the September 1988 cruise

Method	1				2				3				4			
Sta.10																
Depth (m)	SSW	SW	TW	IW	SSW	SW	TW	IW	SSW	SW	TW	IW	SSW	SW	TW	IW
50	—	—	—	—	1	58	21	20	—	—	—	—	29[a]	0[a]	68[a]	3[a]
75	0	40	34	26	—	—	—	—	—	—	—	—	18	0	68	14
100	0	15	54	31	—	—	—	—	—	—	—	—	6	0	67	27
150	0	0	53	47	—	—	—	—	—	—	—	—	0	0	53	47
200	0	0	41	59	—	—	—	—	—	—	—	—	0	0	41	59
400	0	0	7	93	—	—	—	—	—	—	—	—	0	0	7	93
Sta. 12																
50	0	87	10	3	—	—	—	—	6	73	21	0	—	—	—	—
75	0	64	22	14	—	—	—	—	23	15	62	0	—	—	—	—
100	0	25	65	10	—	—	—	—	—	—	—	—	12	0	86	2
200	0	0	54	46	—	—	—	—	—	—	—	—	0	0	54	46
400	0	0	5	95	—	—	—	—	—	—	—	—	0	0	5	95
Sta. 13																
50	0	87	9	4	—	—	—	—	6	72	22	0	—	—	—	—
75	0	55	36	9	—	—	—	—	6	41	53	0	—	—	—	—
100	0	19	80	1	—	—	—	—	2	16	82	0	—	—	—	—
200	0	0	63	37	—	—	—	—	—	—	—	—	0	0	63	37
400	0	0	10	90	—	—	—	—	—	—	—	—	0	0	10	90

a different approach to calculate the mixing percentages when four end members are involved. Again the September 1988 CTD data are taken as an example (Fig. 1). It is clear that the *T–S* curves converge at point E which is a mixture of both TW and IW. Warmer, shallower waters are then mixtures of A (SSW), D (SW), C (TW) and E.

Point P serves as an example of this. It can be further divided into mixtures of AD and E. Once the percentage of E is determined, it is further divided into mixtures of C and B. P thus becomes a mixture of ADC, and B. Of course P could also be represented by ACE alone. In fact, without *a priori* information it cannot be determined which mixing scheme should be used; thus, the mean of the two schemes is normally taken.

Under certain circumstances, however, decisions could be based on mere judgement. To illustrate this, the sample at 50 m at Sta. 10, marked with an X in Fig. 1, is discussed. Since the section of the *T–S* curve above and below this point clearly suggests a mixing between D and E, any exclusion of D from the mixing (i.e. scheme 4 in Table 1) does not seem reasonable. In order not to base the calculations solely on scheme 2 for this case, the mixing percentages based on the mixing of DC and B (scheme 5) were also calculated. Other examples are given in Table 1 and show results comparable to those previously reported by these authors.

It is now important to look at errors. For waters below point E (roughly 200 m), there is essentially a two-component mixing; accordingly, the errors are small, while the mixing percentages remain the same as those reported by Chen et al. (1995). Waters above 200 m involve three or four component mixing, and the uncertainties become larger, especially for waters above 75 m. For waters above 200 m at Sta. 13,

5				Av.				Chen et al., 1995			
SSW	SW	TW	IW	SSW	SW	TW	IW	SSW	SW	TW	IW
0	61	17	22	1 ± 1[b]	59 ± 2[b]	19 ± 2[b]	21 ± 1[b]	13	71	15	1
—	—	—	—	9 ± 9	20 ± 20	52 ± 16	20 ± 6	7	44	38	11
—	—	—	—	3 ± 3	8 ± 7	60 ± 7	29 ± 2	2	18	66	14
—	—	—	—	0	0	53	47	0	0	55	45
—	—	—	—	0	0	41	59	0	0	41	59
—	—	—	—	0	0	7	93	0	0	7	93
—	—	—	—	3 ± 3	80 ± 7	16 ± 5	1 ± 2	0	82	18	0
—	—	—	—	12 ± 12	40 ± 25	41 ± 21	7 ± 7	6	50	34	10
—	—	—	—	6 ± 6	13 ± 13	75 ± 11	6 ± 4	0	20	66	14
—	—	—	—	0	0	54	46	0	0	54	46
—	—	—	—	0	0	5	95	0	0	5	95
—	—	—	—	3 ± 3	79 ± 7	16 ± 6	2 ± 2	0	78	22	0
—	—	—	—	3 ± 3	48 ± 7	44 ± 9	5 ± 5	0	48	52	0
—	—	—	—	1	17	81	1	0	0	100	0
—	—	—	—	0	0	63	37	0	0	58	42
—	—	—	—	0	0	10	90	0	0	10	90

Note: (1) Based on mixing DCE; (2) Based on mixing ADE; (3) Based on mixing ADC; (4) Based on mixing ACE; (5) Based on mixing DCB.

[a] Considered unreasonable, see text.

[b] Av. of 2 and 5.

the average mixing percentages are precise to $\pm$ 9% or better. These new results also agree with those reported by Chen et al. (1995) to generally 9% or better. For waters at 100 and 150 m at Stas. 10 and 12, the average mixing percentages are precise to generally 10% or better. In general, the new results also agree with those of Chen et al. (1995) to better than 10%. For waters at 50 and 75 m at Stas 10 and 12, the uncertainties are generally better than 20%.

To conclude, the authors agree with Liu (1998) that it takes at least n conservative tracers to determine the exact mixing ratios of $n + 1$ end-members. In their previous study, the present authors also used the NO_3^-–S, PO_4^{-3}–S and pH–S pairs to calculate the mixing percentages, but even so the scaling problem remains the same. The alternative approach presented above still does not give an exact solution to the four component mixing, but the uncertainties are most probably below 20% for waters above 100 m, and better than 10% for waters below 100 m. Chen et al. (1995) pointed out that neither T nor S is conservative near surface which means the above uncertainties have probably already reached the limit. With that in mind, the major conclusions of Chen et al. (1995), for example that the Kuroshio Intermediate Water contributes significantly to the cross-shelf mixing, remain intact. The previously reported mixing percentages also remain largely the same.

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