Current Measurements along the Shelf Break in the Gulf of Alaska

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ABSTRACT

Data from current moorings at four sites near the shelf break in the Gulf of Alaska are used to present information on the flow, to examine the effects of local winds, and especially to investigate momentum transfer between the offshore and inshore circulation. Net flow at the shelf break in the central and western Gulf appears to be similar through the year, but it intensifies appreciably in winter in the northeast Gulf. Only records in the northeast Gulf suggest significant effects on flow by local winds. The eddy fluxes of momentum at the shelf break were extremely small. Although the offshore Alaskan Stream was previously found to transfer momentum toward shore, this flux apparently does not reach the shelf break and influence shelf waters. It appears rather that the gradients of heat and salt observed near the shelf edge result from offshore effects of the coastal flow.

1. Introduction

The upper ocean in the Gulf of Alaska is influenced by a circulation system consisting of varied, multiple flows (Fig. 1). On the south side of the Gulf the weak, broad Subarctic Current flows eastward and provides the source waters for the northward flow on its eastern side. This flow then narrows and intensifies as it leaves the head of the Gulf and forms the Alaskan Stream. On the inner portions of the continental shelf, an additional baroclinic flow is present. This latter feature (the Alaska Coastal Current; Royer, 1981) is continuous along much of the coastline to 165°W, where it flows into the Bering Sea; especially along the Kenai Peninsula, there is a large seasonal change in speed as a result of a maximum in freshwater discharge in fall. Finally, on the outer continental shelf, complex flows occur in the vicinity of banks and troughs.

At present, it is not clear if or how the Alaskan Stream and the Alaska Coastal Current influence or are linked to each other over the region of the outer continental shelf–inner continental slope. Reed et al. (1980) presented evidence for an eddylike feature in the Alaskan Stream near Kodiak Island, which appeared to intensify and possibly move shoreward. Furthermore, Reed and Schumacher (1984) analyzed records from two ten-month current moorings in the Stream. Onshore eddy fluxes of momentum were obtained (at 200–300 m in 700–1700 m water depth) which, coupled with the horizontal velocity shear, gave a negative energy flux or a transfer from the mean flow to smaller scales. Thus available data suggest that eddylike processes at the edge of the Stream may affect inshore waters. The eddy fluxes derived, however, were small in magnitude, and the current meters were rather far offshore and deep for confident extrapolation of results to the shelf edge. There is a need to examine data between the Stream and the inshore coastal current in water depths of perhaps 150–200 m. A limited dataset for such an analysis does exist and is the subject of this study. The data are described and presented, time scales and wind effects are examined, and eddy fluxes are investigated in terms of coupling between offshore and inshore flow and properties.

2. Data and methods

During 1974–78, data were obtained over the open shelf–slope region from 57 current moorings that had records of approximately two months or longer. No comprehensive analysis of these data exists; the net flows and variances from the records are listed in Reed and Schumacher (1986), however, and the few other studies with small numbers of records are cited. For this analysis, we have chosen moorings along the inner edge of the continental slope that extend across the entire region (Fig. 1). In general, these sites also had data from which time series of five months or longer could be generated.

All of the data here (see Table 1 for details) were obtained with Aanderaa RCM-4 rotor/vane current meters on taut-wire moorings with floats just above the upper meter. The meters also contained temperature, conductivity and pressure sensors. The data records were checked for errors, and the time series were passed through a 35-hour half-power point low-pass filter to derive daily net vectors, which are used in the following presentations and analyses. In order to create

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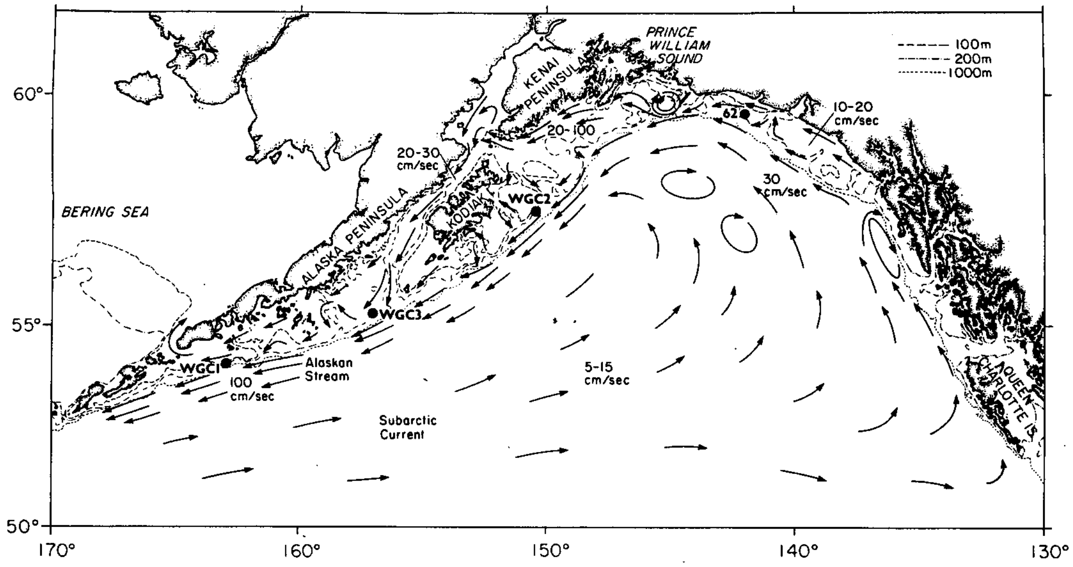

FIG. 1. Map of the Gulf of Alaska with a schematic representation of the major currents (speeds in cm s^{-1}) from Reed and Schumacher (1986). The depth contours are in meters from International Hydrographic Office Chart 5.03. Locations of current moorings used here are shown by the dots.

time series of long duration, records from individual moorings at the same sites and approximately the same depths were joined (and filled with the overall means) when the data gap did not exceed two days. At each site, flow was resolved into u and v components; the v component was taken in the direction of maximum velocity variance, which agreed closely with the direction of net flow and the general trend of the isobaths. Temperature and salinity data were similarly checked for errors and filtered, and average daily values were computed. The conductivity sensors often exhibited noticeable drift, and the data needed corrections (as indicated by hydrocasts during deployment and recovery); they were not used when salinity errors greater than 0.1‰ seemed possible.

Wind time series were computed by Fleet Numerical Oceanography Center from 6-hour synoptic surface pressure maps, using a 3° grid with interpolation to locations within 100 km of each of the current moorings shown in Fig. 1. The surface wind velocities were estimated by rotating computed geostrophic winds by 15° to the left and reducing them in magnitude by 30% (Bakun, 1973). The wind time series were then passed through a 35-hour filter to derive daily net vectors, which were used for the same time periods as the nearby current time series.

3. Net flow and energy levels

Table 1 presents the net flow and energy levels derived from the time series at the sites shown in Fig. 1.

TABLE 1. Information on current moorings in the Gulf of Alaska. The letters in parentheses in the mooring names identify various time series at approximately the same sites. $\overline{KE}$ is the kinetic energy of the mean flow per unit mass [$\overline{KE} = \frac{1}{2}(\bar{u}^2 + \bar{v}^2)$], and KE' is the eddy kinetic energy per unit mass [$KE' = \frac{1}{2}(\sigma_u^2 + \sigma_v^2)$]. The velocity components u and v are approximately cross-stream and alongstream as stated above; the variances of the u and v components are σ_u^2 and σ_v^2.

Mooring	Location (N, W)	Water depth (m)	Meter depth (m)	Start time	Length (days)	Net flow (cm s^{-1}/deg T)	Energy per unit mass (cm^2 s^{-2})	
							$\overline{KE}$	KE'
WGC1 (A–B)	54°01′, 163°00′	190	20	9 Sep 75	162	18/254	162	142
WGC1 (A–B)	54°01′, 163°00′	190	102	9 Sep 75	109	19/262	180	131
WGC3 (B–C)	55°12′, 156°58′	112	24	15 Jun 76	260	21/253	220	103
WGC2 (C)	57°27′, 150°29′	185	24	14 Mar 76	82	22/227	242	88
62 (G–H)	59°36′, 142°06′	184	20	10 Mar 76	160	10/318	50	126
62 (G–H)	59°36′, 142°06′	184	50	10 Mar 76	160	9/315	40	82
62 (J–K–L)	59°38′, 142°06′	189	54	26 Oct 76	312	28/302	392	130
62 (J–K)	59°38′, 142°06′	186	100	26 Oct 76	204	21/301	220	80
62 (K–L)	59°38′, 142°06′	191	181	21 Mar 77	170	4/316	8	20

Net flow in all instances is essentially parallel to the isobaths and directed toward southwest to northwest (that is, in the same general direction as both the Alaskan Stream and the Alaska Coastal Current). Speeds at WGC1, WGC2 and WGC3 were all nearly 20 cm s^{-1}, but there is considerable variability at station 62. During series G–H, speeds were only about 10 cm s^{-1}; on the other hand, results for J–K–L and J–K were in excess of 20 cm s^{-1}, but K–L only had a flow of 4 cm s^{-1}, perhaps because it was only 10 m off the bottom. The larger speeds at station 62 probably occurred because these two series extended over late fall and winter, and the others did not. Earlier, Lagerloef et al. (1981) concluded that flow at this site almost doubled from summer to winter. No such seasonal trend, however, is suggested at the three western sites.

The eddy kinetic energy (per unit mass) in the western Gulf (Table 1) is relatively constant, and the $KE'/\overline{KE}$ ratios are all <1. The results are in fact quite similar to those for the upper part of the Alaskan Stream (Reed and Schumacher, 1984). At station 62 the eddy energies, except for the series at 181 m, are also similar to those to the west and those in the Alaskan Stream. Results for the two series near 50 m support the conclusion of Lagerloef et al. (1981) that total kinetic energy increases in winter. The $KE'/\overline{KE}$ ratio did not, however, because of the relatively greater winter increase of $\overline{KE}$ over KE'. Thus the major characteristic of flow here is that the net flow increases from summer to winter.

4. Time scales

Figures 2 and 3 present spectra of the flow variability in an energy preserving form. The confidence interval is large, which suggests that several realizations would be needed to derive reliable statistics; on the other hand, current vector plots were in general agreement with the variability (or lack of it) in the spectra at intermediate and higher frequencies. The distributions show numerous differences, but most of them have the greatest energy at the lowest frequency. In fact, some spectra [WGC1 and 62 (G–H)] are quite like those from the Alaskan Stream (Reed and Schumacher, 1984). On the other hand, the results at WGC3, WGC2 and 62 (J–K–L) indicate considerable energy at intermediate frequencies. These results do not really suggest any clear regional or seasonal trends in the spectra.

Figure 4 presents vertical coherence functions between alongstream (as defined in Table 1) velocities at stations WGC1 and 62, where the time series have been truncated where necessary to make them coincident. The plot at WGC1 shows only one value at the 95% significance level, but it may only be among the 5% expected to reach this value by chance. Thus motions at 20 and 102 m at this site were not coherent. At station 62 motions in the lower frequency bands, as well as at several intermediate frequencies, were coherent at a significance level of 95% between 20 and 50 m and between 54 and 100 m, but they were not coherent between 54 and 181 m. The coherent motions also are essentially in phase. This comparison is based

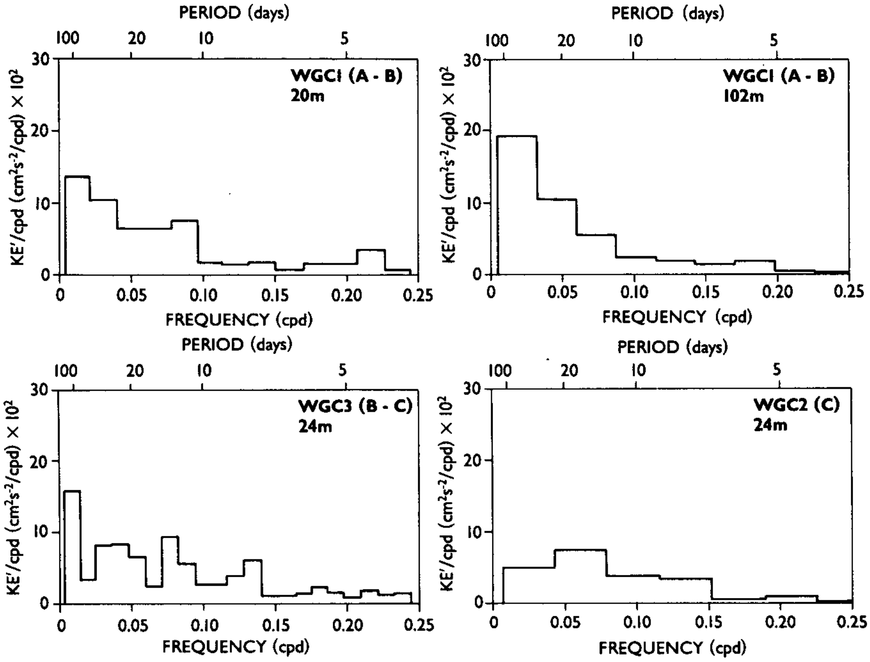

FIG. 2. Spectra of the total eddy kinetic energy (KE') at stations WGC1, WGC3 and WGC2 in the central and western Gulf of Alaska. The log 95% confidence limits are −0.38 and 0.69, based on six degrees of freedom.

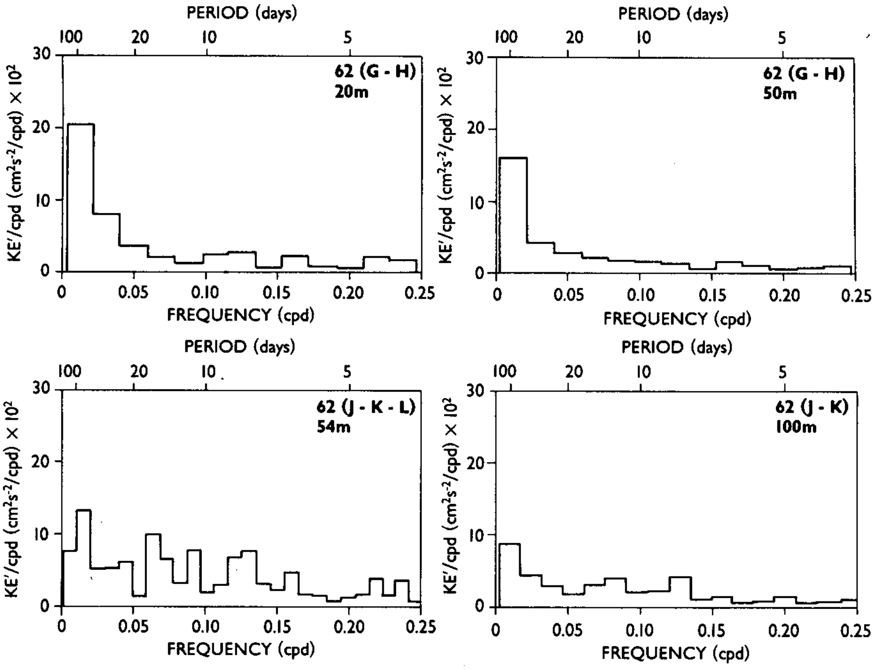

FIG. 3. Spectra of the total eddy kinetic energy (*KE'*) at station 62 in the northeast Gulf of Alaska. The series K–L is not shown because of very low levels of *KE'*.

on limited data, however, and it is not clear if there is a regional difference in vertical coherence or if the differences are temporal or result from differences in vertical separation of the data. Examination of the individual, shorter records at all four sites do not support the existence of a regional difference.

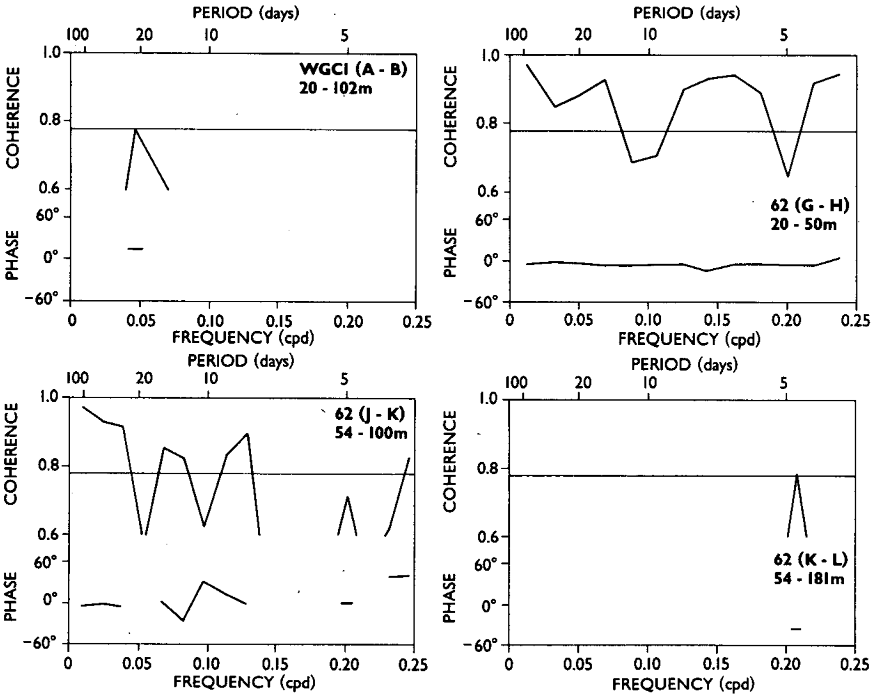

FIG. 4. Vertical coherence and phase estimates of the alongstream (*v*-component) velocities at stations WGC1 and 62. The 95% significance levels for coherence (all based on six degrees of freedom) are the horizontal lines.

5. Effects of local winds

To examine wind forcing, we computed lagged cross correlations for the coincident wind and current time series, using the same cross-stream and alongstream directions for wind and current. At stations WGC1, WGC3 and WGC2 there were correlations between wind and current components that reached the 95% significance level, but <12% of the variance of flow is accounted for by the winds, except curiously at WGC1 (A–B) at 102 m (r^2 = 17%). Thus we conclude that local wind forcing is not of major importance in the western Gulf. At station 62 (G–H) at 20 and 50 m and at 62 (J–K–L) at 54 m, 20–30% of the flow variance is linearly related to the winds; at the two deepest meters at station 62, however, the correlations were comparable to those in the western Gulf. In the northeast Gulf the largest correlations were positive and were between alongstream winds and alongstream currents; the current consistently lagged the wind, typically by 1–3 days. Since, as discussed, currents are greater in winter than summer, and winds are also (these data and Brower et al., 1977), we expect considerable wind influence then. It may be, of course, that some type of remote wind forcing (Battisti and Hickey, 1984), as well as local forcing, is important to the flow.

6. Eddy fluxes

Covariances have been computed from the time series and are listed in Table 2. The standard errors in the estimates were computed from the record variances and the integral time scales. (Note that u and v, as stated before, are approximately across and along the net flow direction.) The magnitudes of the mean momentum fluxes ($\overline{u'v'}$) are remarkably small; except for WGC2 (C), they are much smaller than the standard errors and are an order of magnitude less than such estimates at 200–300 m in the Alaskan Stream (Reed and Schumacher, 1984), which are themselves much smaller than values in the Kuroshio and Gulf Stream. The $\overline{u'v'}$ at WGC2 (C), however, is significant, but these data are not typical; of all 49 individual records, only this time series and a coincident one below it had values exceeding the standard errors. It is not known what mechanism caused the anomalous result at WGC2 (C), but the current vector plot showed relatively weak flow punctuated by a number of intense, "burstlike" events in agreement with the "mesoscale" spectral peak centered at 17 days in Fig. 2. Thus we must conclude that any significant onshore transfer of momentum is rare indeed. Although the Alaskan Stream did have onshore momentum flux (Reed and Schumacher, 1984), such transfer must not extend onto the shelf and affect the inshore current system.

Most of the eddy fluxes of heat and salt (Table 2) exceed the standard errors, however. Ignoring the result at WGC2 (C), the heat fluxes vary from essentially zero to 10.6 cm °C s^{-1}, and the significant salt fluxes range from 0.2 to 1.3 cm ‰ s^{-1}. In general, the magnitudes of the heat fluxes are greater near the surface than at the deeper meters. They are also an order of magnitude greater than our offshore estimates (Reed and Schumacher, 1984). They are comparable, however, to estimates at 200 m in the equatorial Indian Ocean (Luyten, 1982), to values at 600–800 m in the Gulf Stream recirculation region (Bryden, 1982), and to results off Oregon during coastal upwelling (Bryden et al., 1980). The vertical resolution of our data is inadequate to attempt a heat budget like that of Bryden and others, however.

The data in Table 2 do reveal a systematic regional difference in the eddy fluxes of heat. In the western Gulf, the $\overline{u'T'}$ and $\overline{v'T'}$ values are positive, whereas they are negative in the northeast Gulf (except for one value at station 62). The signs agree, unless the eddy conductivities are negative, with the fact that offshore waters are warmer than shelf break waters along the Alaska Peninsula (Dodimead et al., 1963) but are cooler than inshore waters in the northeast Gulf (Royer and Muench, 1977). Likewise, salt fluxes are positive in agreement with more saline waters being offshore, except west of the Alaska Peninsula (Reed, 1984). Royer and Muench (1977), Royer (1981) and Royer (1983) have suggested that warm, fresh inshore waters may affect offshore waters, mainly through an injection of

TABLE 2. Estimates of the mean eddy fluxes of momentum, heat, and salt and the computed standard errors (see text) in the estimates. The u and v components are as defined in Table 1, and the locations are given in Table 1 and shown in Fig. 1.

Mooring	Meter depth (m)	Start time	Length (days)	$\overline{u'v'}$ (cm^2 s^{-2})	$\overline{u'T'}$ (cm °C s^{-1})	$\overline{v'T'}$ (cm °C s^{-1})	$\overline{u'S'}$ (cm ‰ s^{-1})	$\overline{v'S'}$ (cm ‰ s^{-1})
WGC1 (A–B)	20	9 Sep 75	162	0.6 ± 19.7	4.4 ± 1.5	10.6 ± 3.8	—	—
WGC1 (A–B)	102	9 Sep 75	109	−0.7 ± 12.7	1.0 ± 1.0	2.6 ± 1.8	—	—
WGC3 (B–C)	24	15 Jun 76	260	0.0 ± 10.3	2.2 ± 1.2	1.6 ± 1.8	—	—
WGC2 (C)	24	14 Mar 76	82	22.7 ± 5.2	1.4 ± 0.6	16.2 ± 16.5	−1.5 ± 1.5	40.5 ± 32.7
62 (G–H)	20	10 Mar 76	160	−0.8 ± 18.4	−2.1 ± 1.2	−6.7 ± 2.5	0.3 ± 0.2	0.8 ± 0.4
62 (G–H)	50	10 Mar 76	160	−0.3 ± 7.7	−0.6 ± 0.3	−2.1 ± 1.0	0.5 ± 0.3	1.3 ± 0.7
62 (J–K–L)	54	26 Oct 76	312	−0.5 ± 12.1	−0.9 ± 0.9	−0.3 ± 1.4	0.2 ± 0.2	0.3 ± 0.3
62 (J–K)	100	26 Oct 76	204	−0.5 ± 7.3	−1.8 ± 0.7	−0.5 ± 1.4	—	—
62 (K–L)	181	21 Mar 77	170	−0.2 ± 1.6	−0.2 ± 0.1	0.4 ± 0.2	0.2 ± 0.1	−0.1 ± 0.2

part of the coastal flow seaward in the permanent eddy west of Kayak Island (near 145°W; see Fig. 1). This could help explain the observed patterns and, coupled with negligible momentum flux elsewhere, suggests that the Alaska Coastal Current influences slope waters more than the Alaskan Stream affects shelf waters. Furthermore, the regional change in temperature gradient at the shelf break does not cause a flow reversal because the salinity gradient is not greatly altered, and it mainly controls the density gradient (Royer, 1981). Finally, recent temperature–salinity data that we obtained do suggest one exception to our generalization of no offshore effects on shelf waters; in deep troughs which cut across the shelf, waters below ~150 m do appear to be intrusions of slope water.

7. Conclusions

Our major finding is that onshore eddy fluxes of momentum are extremely small near the shelf break in the Gulf of Alaska. Thus the Alaskan Stream does not appear to be a source of mean momentum for inshore waters. Through consideration of the property fluxes and evidence presented by Royer, we have suggested that an important process is injection of coastal waters offshore in the permanent eddy near 145°W. Hence the inshore circulation appears to affect conditions offshore instead of the converse. Flow at the shelf break in the central and western Gulf did not seem to vary greatly nor did it appear to be influenced appreciably by local winds. In the northeast Gulf flow was strongest in winter (as are winds), and wind–current correlations were relatively high at levels above 100 m. Results from spectral analyses and vertical coherence of flow revealed considerable variability with no clear seasonal or regional trends.

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