

A Case Study of the Interaction of the Summertime Coastal Jet with the California Topography

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ABSTRACT

Coast-parallel low-level jets are commonplace in the marine boundary layer off the west coast of the United States during summer. A field study was conducted in early summer of 1997 to document the forcing of boundary layer winds in the near-coastal environment off California. On 8 June 1997 the Wyoming King Air collected data along a 350-km stretch of coastal margin from Cape Mendocino to San Francisco in order to examine the interaction between the coastal topography and the low-level jet. During the course of the flight, 32 soundings were conducted. The maximum speed of the coastal jet was found near the top of the marine boundary layer at altitudes from 200 to 600 m. Analysis of the data revealed a westward increase in the height of the marine boundary layer and maximum jet wind speeds. Strongest jet winds were observed southwest of Cape Mendocino with a maximum speed of 28 m s^{-1} . The coastal jet was characterized by a broad horizontal extent. Wind maxima were found at distances approximately 30 km to more than 100 km offshore.

Hydraulic features such as jumps and expansion fans have previously been observed downwind of coastal capes and points along the California coast. The flow upwind of Cape Mendocino and Point Arena was found to be supercritical, but the King Air data showed that accelerations associated with possible expansion fan phenomena were minimal. It is proposed that the sloping inversion at the top of the marine boundary layer and attendant coastal jet are fundamentally the result of a geostrophic adjustment process arising because of the horizontal temperature contrast between the cool ocean and warm continent. This view emphasizes that the coastal jet is a ubiquitous, large-scale feature of the summertime coastal environment. Terrain-induced wind speed variations associated with expansion fans and hydraulic jumps only modulate the primary jet structure.

1. Introduction

During late spring and summer a northerly low-level jet frequently occurs over the Pacific Ocean along the west coast of the United States from Oregon to California. Wind maxima within the jet in excess of 25 m s^{-1} have been observed (Zemba and Friehe 1987; Beardsley et al. 1987; Rogers et al. 1998). This coastal jet (CJ) generally parallels the orientation of the coastline. The synoptic situation is controlled by the broad Pacific high situated some 1000 km west of the coastline that produces a general northerly flow in the lower atmosphere. The local pressure gradient force (PGF) is further enhanced by the thermal contrast between the Pacific Ocean and the desert regions of California and the southwestern United States (e.g., Burk and Thompson 1996).

The CJ is found near the top of the well-mixed marine boundary layer (MBL), which varies between 300 m or

less at the coast to greater than 500 m about 100 km from the coastline (Neiburger et al. 1961; Bridger et al. 1993). A temperature inversion on the order of 5° – 10°C caps the MBL, the result of subsidence induced by the Pacific high. A sloping MBL implies that significant horizontal temperature gradients exist, hence, a thermal wind (Zemba and Friehe 1987; Gerber et al. 1989). This thermal wind vector is directed from south to north, opposite in direction to the predominantly north winds in the MBL associated with the CJ. The northerly geostrophic wind component must decrease with height above the MBL due to the thermal wind. The jet profile displayed by the CJ is thus the dual result of frictional retardation in the near-surface layer and rapid decrease in the PGF associated with the thermal wind above the MBL (e.g., Zemba and Friehe 1987).

This paper will focus on the local forcing of the CJ by the California coastal terrain on 8 June 1997. As shown in Fig. 1 the Pacific coast north of San Francisco runs generally at a heading of 330° with numerous capes and points protruding into the Pacific Ocean. During CJ events, observations and modeling work have shown that wind speed maxima are often found in the lee of these points (e.g., Winant et al. 1988; Samelson 1992; Burk and Thompson 1996; Holt 1996; Cui et al. 1998;

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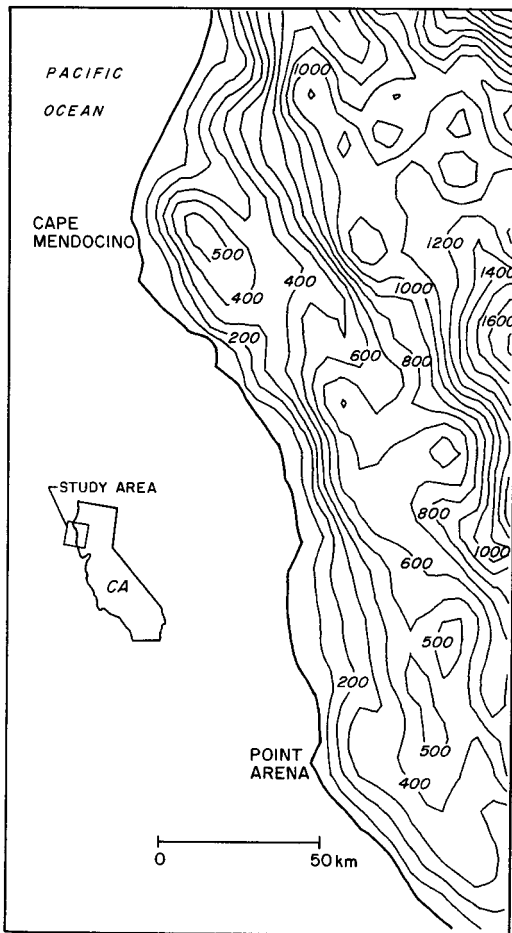


FIG. 1. Topography of coastal California. Contours plotted every 100 m.

Rogerson 1999; Burk et al. 1999). Cape Mendocino and Point Arena are two such topographic features (Fig. 1). With the CJ oriented between 320° and 360° , it is apparent that both of these terrain features can act to block or redirect the general flow near the coast. The coastal terrain along the western United States is quite complex with mountainous topography rising quickly from the ocean. A nearly continuous stretch of elevated coastal terrain at least 300 m in elevation is present from Oregon southward to nearly the Mexican border. Since this height is often above the top of the MBL at the coast, the coastal topography is an effective barrier to the eastward motion of stable air from the Pacific Ocean.

As noted by Rogers et al. (1998), only a few observational studies on the effects of topographic forcing of the CJ have been conducted. During June 1997 a field study was conducted to study the boundary layer wind field off the California coast. The Wyoming King Air (K/A) research aircraft was the primary observation platform. Among the goals of the research project was to study the dynamical forcing mechanisms in the MBL associated with the CJ as well as to capture episodes of

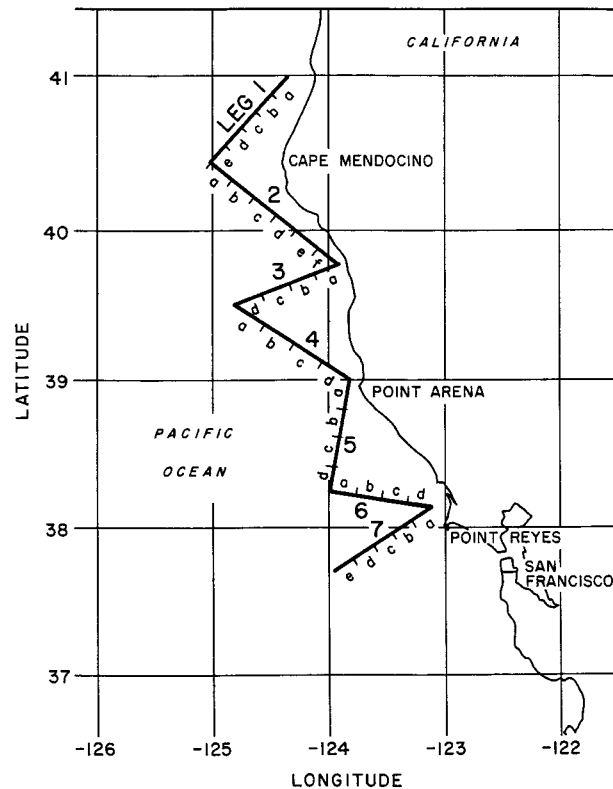


FIG. 2. Flight track of the King Air on 8 Jun 1997. Numbers shown identify each leg in chronological order; hatch marks indicate start and stop distances of sawtooth maneuvers. Letters represent location of soundings along each flight leg.

southerly wind reversals known as coastally trapped disturbances. This paper examines a case study of the CJ along the California coast on 8 June 1997. Emphasis is placed on the dataset collected by the K/A. This particular case study flight was designed specifically to examine the spatial variations in the CJ structure in relationship to the coastal terrain.

2. The 8 June 1997 coastal jet case study

At 2200 UTC 8 June 1997 the Wyoming King Air departed Monterey, California, to investigate spatial variations in the CJ off the California coast. Clear sky conditions prevailed for the duration of the flight throughout the entire area of study. The flight strategy was based on previous observations (e.g., Winant et al. 1988) and modeling results (Burk and Thompson 1996) of the spatial variability of the CJ. The K/A mission consisted of seven legs over the Pacific Ocean (Fig. 2) between 2305 UTC 8 June and 0120 UTC 9 June in a zigzag pattern, alternating in heading away from and toward the coast. Flight legs were arranged to sample key locations adjacent to Cape Mendocino and Point Arena along the California coast. Previous studies (Beardsley et al. 1987; Winant et al. 1988; Rogers et al. 1998) show wind maxima close to shore to the lee

side of coastal protrusions such as Cape Mendocino. The modeling study of Burk and Thompson (1996) also indicates a maximum south of Cape Mendocino (see their Fig. 15b). It has been proposed that such wind maxima are the result of supercritical flow in the MBL and associated expansion fan phenomena. The K/A flight track covers an area just north of Cape Mendocino (near 41°N, 124°W) to Point Reyes (near 38°N, 123°W), and from the coastline to a maximum distance about 100 km offshore. A series of slow rise ascents and descents in a sawtooth pattern were conducted along the flight legs, covering altitudes between 100 and 1400 m above sea level. Such a pattern enables the K/A to sample a large volume of the CJ environment. As can be seen in Fig. 2, between four and seven vertical soundings were conducted along each leg. During the entire case study 32 soundings were conducted. Due to the horizontal progress of the aircraft during sawtooth maneuvers, individual soundings span a horizontal distance of about 20 km. These data provide a unique and detailed set of measurements of the structure and spatial variation of the CJ.

According to the National Centers for Environmental Prediction Eta Model initialization at 0000 UTC 8 and 9 June 1997, synoptic conditions at the surface consisted of a thermal low in the San Joaquin Valley of California, and the broad Pacific high (Fig. 3). A strong PGF can be seen off the northern California coast in the area covered by the K/A flight track. It is not known whether such a pattern reflects the influence of topography on the ambient PGF, or simply is indicative of the synoptic setting associated with this specific case study. However, there is indirect support for the former. Other K/A flights examining the CJ during the June 1997 field study revealed a consistently stronger CJ to the north of Monterey Bay. In addition, the Coastal Ocean Dynamics Experiment (CODE) observations (Beardsley et al. 1987) suggested a stronger CJ north of Point Reyes. Numerical simulations by Burk and Thompson (1996) also indicated stronger winds north of Point Reyes. It is probably the case that both thermal contrasts and the orientation of the coastline to the north of approximately 38°N act to enhance the prevailing synoptic PGF. Furthermore, such a sea level pressure pattern as shown in Fig. 3 is considered a characteristic pattern off the California coast. The large-scale pressure pattern is representative of the climatological warm season sea level pressure analyses shown in Mass and Bond (1996) and also is similar to pattern 3 in Winant et al. (1988). It was noted that a structured MBL and strong CJ were associated with pattern 3, and there appeared to be strong topographic influence on the boundary layer winds. Winant et al. (1988) showed that the surface wind was influenced by the coastal topography; hydraulic features were present in the MBL in their study. The intensity of the CJ as shown in Winant et al. (1988) appeared to display a high degree of spatial variation in close to the shoreline during pattern 3.

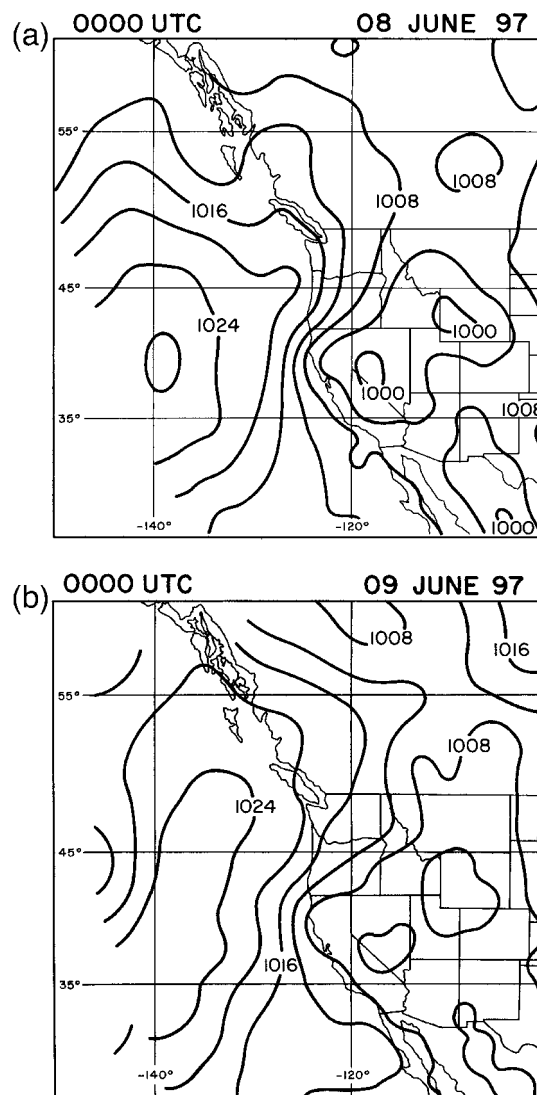


FIG. 3. Sea level pressure (hPa) from Eta Model initialization 0000 UTC 8 and 9 Jun 1997.

3. Topographic forcing of the wind field

Topography has been proposed as a potentially important forcing mechanism for the CJ wind speed variability along the west coast of the United States. Much of the early work on the CJ was stimulated by the observations conducted during CODE (e.g., Beardsley et al. 1987; Zemba and Friehe 1987), which clearly show the jet structure and suggest spatial variations along the coast. Ample observational evidence exists to suggest that the coastal topography plays a key role in establishment of CJ local wind maxima. In particular, maxima were observed near capes and points. For example, Winant et al. (1988) noted an acceleration of more than 5 m s^{-1} in the lee of Point Arena, with the speed maximum also very close to the coast (also see Samuelson 1992; Rogerson 1999; Burk et al. 1999). Modeling work by

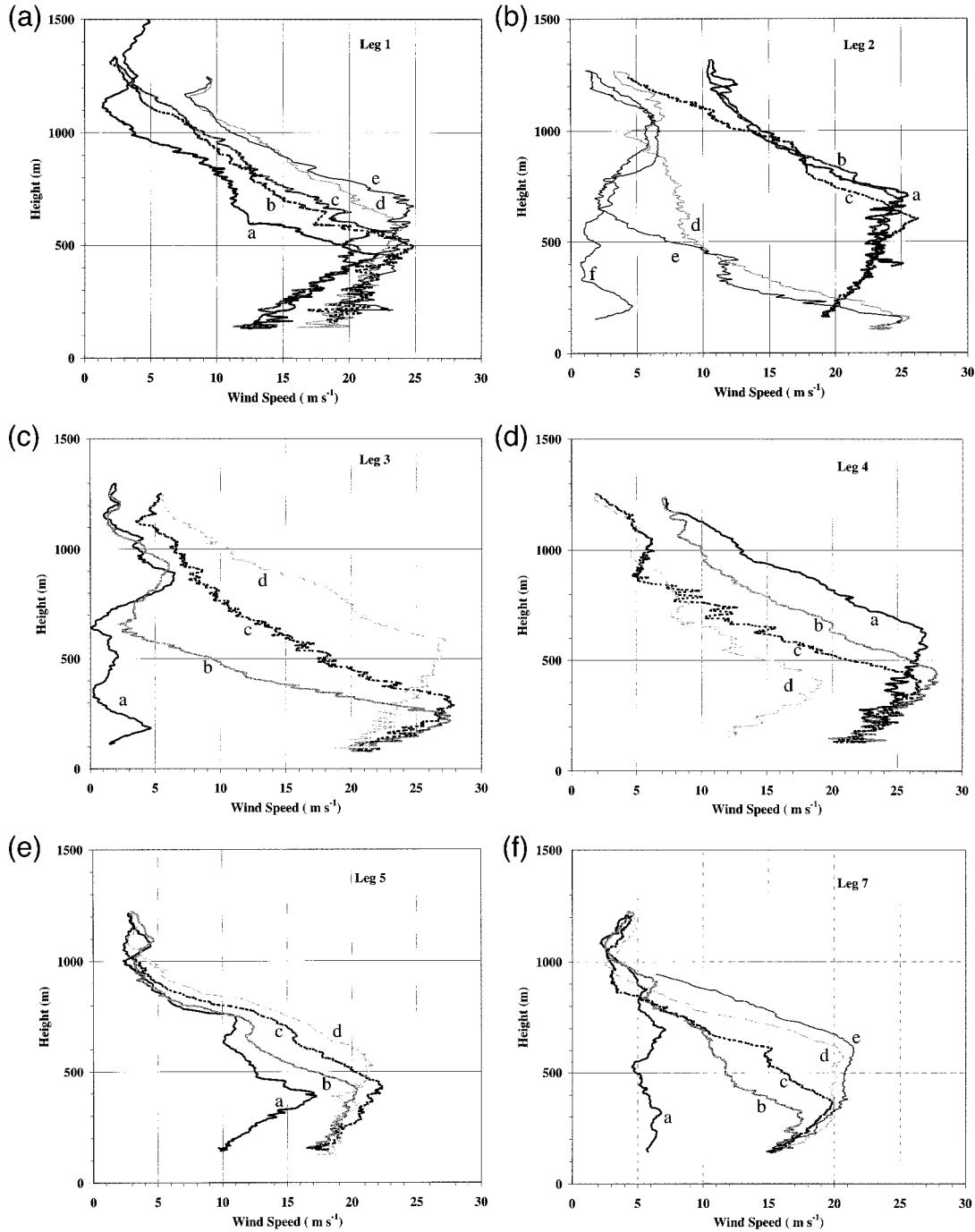


FIG. 4. Vertical profiles of wind speed (m s^{-1}) for flight legs in Fig. 2. Letters within panels indicate position of soundings shown in Fig. 2.

Burk and Thompson (1996) suggests a 5 m s^{-1} acceleration in the lee of Cape Mendocino and a maximum speed only a few kilometers off the coast at the lowest levels for their July 1992 case (also Chao 1985). Holt (1996) also suggested that the role of the mountains is important to the structure of the CJ. Most recently, the Coastal Waves 1996 experiment was conducted to sam-

ple the marine environment off of the California coast. The National Center for Atmospheric Research C-130 Hercules and the University of North Carolina Piper Seneca III gathered field data between the altitudes of 30 and 1000 m (Rogers et al. 1998). In addition, several dropsondes were used. An increase in horizontal wind speed of 6 m s^{-1} around Cape Mendocino was observed.

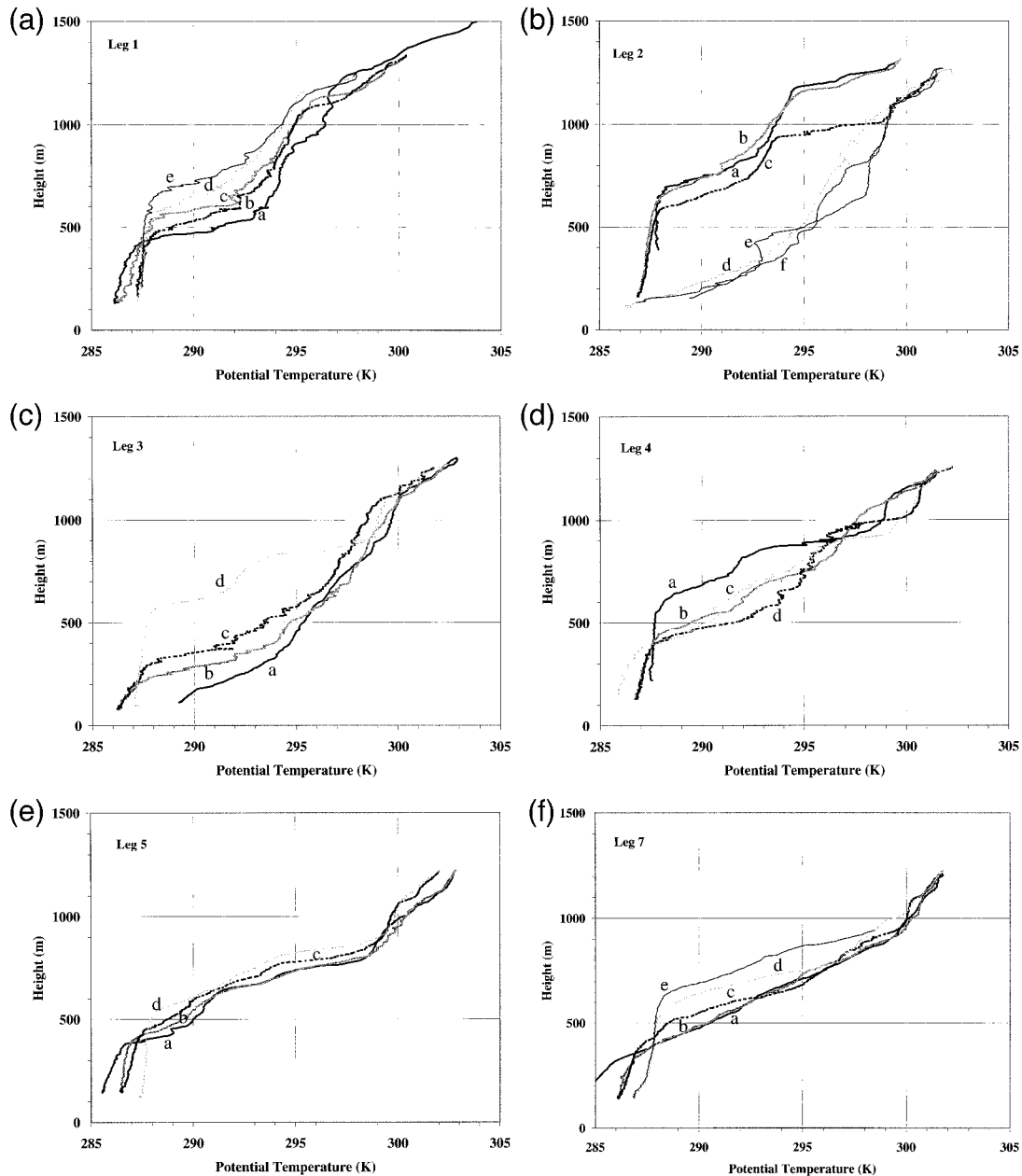


FIG. 5. Vertical profiles of potential temperature (K) for flight legs in Fig. 2. Letters within panels indicate position of soundings shown in Fig. 2.

In the case of the CJ, it has been noted that the flow encountering Cape Mendocino is often supercritical and the analogies with channel flow hydraulics have been noted (Winant et al. 1988; Burk and Thompson 1996; Rogers et al. 1998). Changes in the geometry of the coastline can then result in expansion fans, forcing a low-level acceleration in the lee of capes and points (Beardsley et al. 1987). The result of an expansion fan is a decrease in the depth of the flow and an increase in the speed of the flow as a result of the change in coastline geometry. Supercritical flow could also result

in fluid flowing over a barrier resulting in similar leeside accelerations (Burk and Thompson 1996). As more data have been acquired in the vicinity of the California CJ, evidence of expansion fans in the lee of Cape Mendocino and Point Arena has been found (e.g., Winant et al. 1988). Almost all field data in the MBL indicates that supercritical flow normally exists upwind of these two features during a CJ event. The 8 June 1997 case study provides another detailed set of observations of the structure and forcing of the CJ.

Wind speed profiles collected by the K/A along the

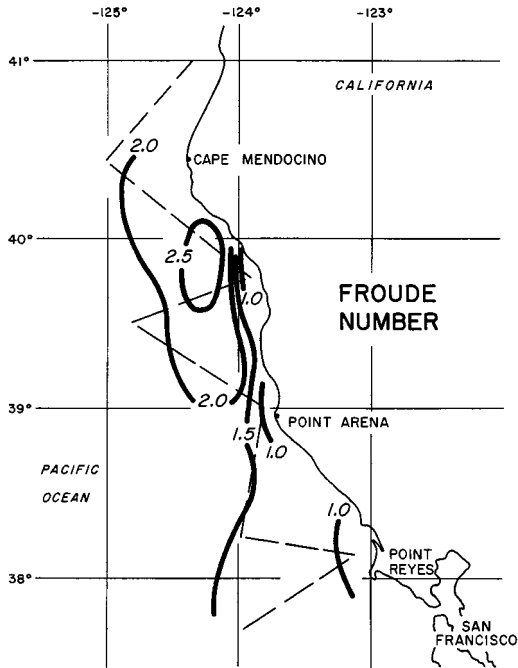


FIG. 6. Estimates of Froude numbers of the MBL based on K/A soundings.

flight legs shown in Fig. 2 are illustrated in Fig. 4. The soundings along leg 6 are very similar to those obtained along leg 7 and only the latter are shown. In contrast to previous observations, the 8 June 1997 CJ intensity was not a maximum near the shore. Wind speeds within 20 km of the coast were weak throughout the entire flight region. In addition, only marginal terrain induced wind speed structure is apparent. Inspection of Fig. 4 reveals that the CJ in general increases away from the California coast for each leg. Maximum CJ wind speeds are typically 25 m s^{-1} with the strongest winds observed along the western end of leg 4 in excess of 28 m s^{-1} . The CJ winds are stronger to the north in agreement with the general synoptic pattern shown in Fig. 3.

Strong CJ winds are apparent upwind of Cape Mendocino along leg 1. As the K/A progressed southwest along leg 1, the maximum CJ winds increased only slightly although the height of the wind maximum increased by approximately 250 m. The increase in the height of the maximum CJ winds away from the coast was seen for every leg. Legs 2 and 3 are the two most critical components of the flight. They encompass a large region to the south of Cape Mendocino, a key area for the development of expansion fans and hydraulic jumps (Rodgers et al. 1998; Burk and Thompson 1996). Significant local accelerations have been observed

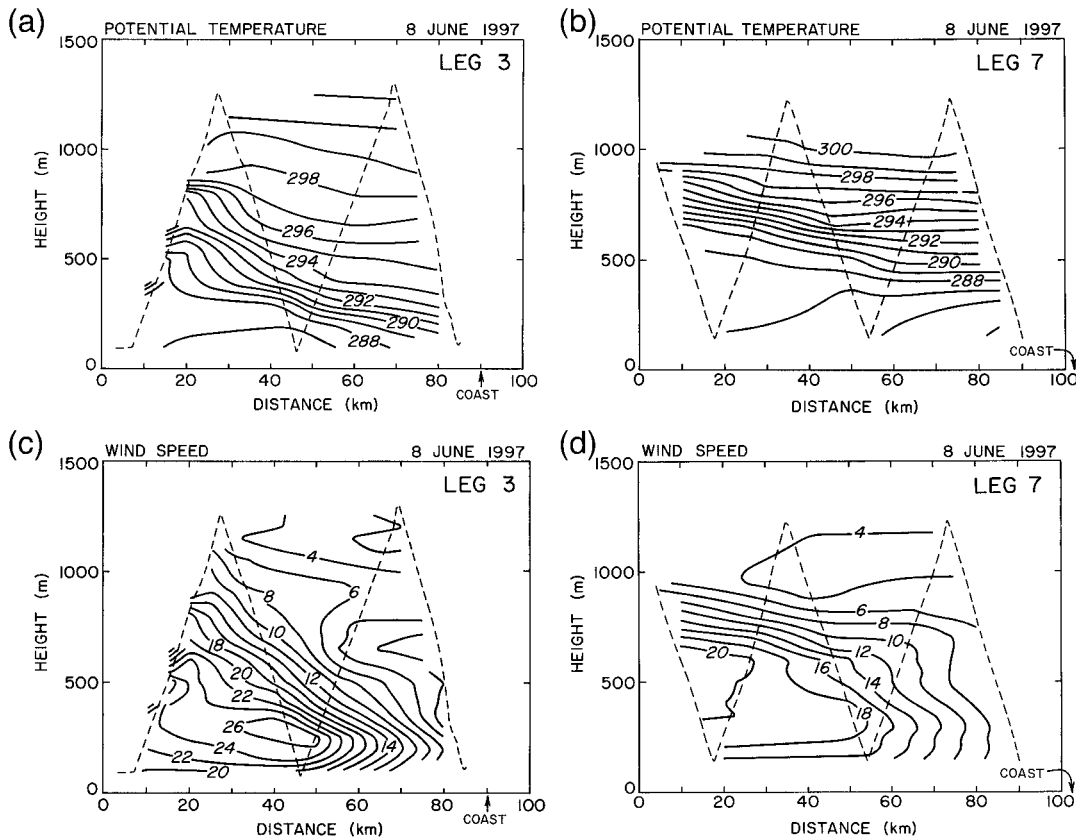


FIG. 7. Cross sections of potential temperature (K) and wind speed (m s^{-1}) for legs 3 and 7. East is to the right in each case.

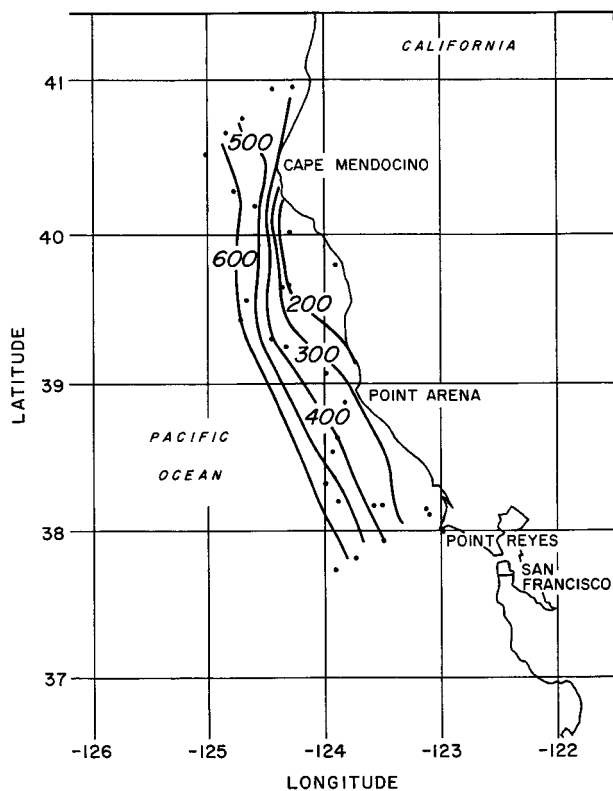


FIG. 8. Height of the MBL (m) taken from K/A observations. Dots indicate location of actual data points.

(Rodgers et al. 1998) and numerically simulated (Burk and Thompson 1996) in the lee of Cape Mendocino. Inspection of the soundings along leg 2 shows a pronounced lowering of the height of the CJ maximum along the eastern end of legs 2 and 3 (cf. soundings 2a, 2b, 2c, 3d, and 2c with 2d, 2e, 3b, and 3c). This dramatic change in the height of the maximum CJ from 600 m at the west end of the leg to about 100 m south of Cape Mendocino at the east end is consistent with expansion fan phenomena from previous studies. Maximum speeds of the CJ, however, remain fairly constant throughout the course of the entire leg with the exception of the near-tranquil winds associated with sounding 2f. If an expansion fan were solely responsible for the thinning of the CJ layer, significant acceleration of the flow would be expected. It appears that the maximum winds observed for soundings 2d and 2e are about the same as those conducted previously along leg 2 as well as seen upwind from Cape Mendocino in leg 1. Similar trends in the heights and intensity of the maximum CJ wind speeds are seen along leg 3. It appears as though the MBL collapses within 20 km off the coast for both legs 2 and 3. No jet profile could be identified from the soundings closest to the shoreline downwind from Cape Mendocino (soundings 2f, 3a).

Leg 4 is situated in excess of 100 km to the south of Cape Mendocino and is thought to be outside the influ-

ence of expansion fan dynamics (e.g., Burk and Thompson, Fig. 15b). Wind speed profiles display the same trend as observed in the previous legs with the level of the maximum wind decreasing from approximately 650 m at the westernmost sounding to approximately 375 m nearest the coast. Wind speeds are in excess of 25 m s^{-1} throughout the course of the leg with the exception of the weaker winds of sounding 4d, which is only 25 km from the coast.

Profiles of the wind speed for legs 5–7 are also similar to the previous legs in that the height and intensity of the CJ increases away from the coast. Maximum CJ speeds are about 5 m s^{-1} less than seen to the north although the lowering of the CJ level is much the same as seen elsewhere, dropping from near 600 m at the western end of each leg to approximately 300 m at the sounding nearest the coast.

Vertical profiles of potential temperature are depicted in Fig. 5. The 8 June 1997 MBL is well mixed in all soundings except those nearest the coast along legs 2 and 3. Potential temperature profiles resemble pattern 2 in Winant et al. (1988). Comparison of Figs. 4 and 5 reveals that the CJ maximum and the top of the MBL are nearly collocated. Detailed inspection of the individual profiles suggests that the CJ maximum is 10–50 m higher than the temperature minimum on all of the soundings where a well-defined jet can be identified. This is consistent with previous observations (e.g., Zemba and Friehe 1987). As noted by Winant et al. (1988), a well-developed MBL can be interpreted as a material surface. Strong frictional decoupling occurs at the inversion interface. The maximum CJ can be expected just above the inversion since friction becomes reduced significantly, yet the horizontal pressure gradient is still large. With increasing distance above the inversion, the integrated effects of the thermal wind reduce the horizontal PGF and the CJ intensity decreases. The inversion at the top of the MBL appears strongest along the eastern half of legs 2 and 3, in agreement with the observed strong shear associated with the CJ in soundings 2e, 2d, and 3b.

Without exception, the MBL thickness increases toward the west for each leg and reaches a maximum in excess of 600 m about 70 km offshore. Legs 2 and 3 reveal dramatic changes in the height of the MBL. Over a distance about 30 km in leg 2, the MBL thickness decreases eastward from 600 m to less than 100 m. Leg 3 displays similar although not as dramatic spatial changes in the MBL. Legs 4–7 suggest somewhat less pronounced spatial changes in the MBL depths, although the terminal eastern points are not as close to the coast as seen in legs 2 and 3.

Supercritical flow is necessary for the existence of an expansion fan and has been observed in conjunction with the CJ in previous investigations. The Froude number was computed for each of the 32 vertical soundings conducted during this case study mission. The Froude number, F , can be expressed as follows:

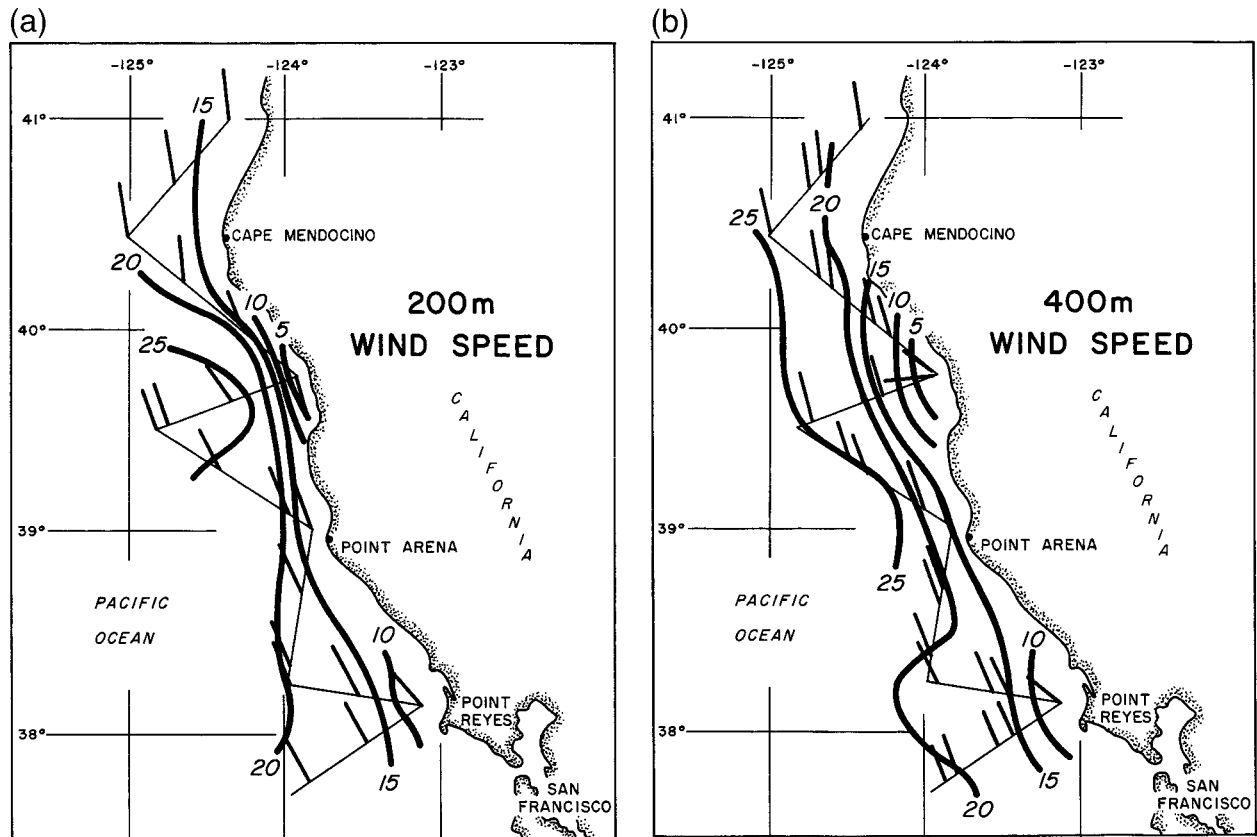


FIG. 9. Wind speeds (m s^{-1}) at the 200- and 400-m levels from the King Air observations. Wind directions indicated by short, solid bars along flight track.

$$F = \frac{u}{\sqrt{g'H}}$$

where u is the average wind speed in the MBL, g' is the value of reduced gravity, and H is the height of the MBL. The reduced gravity term, g' , was computed by multiplying the acceleration due to gravity by the difference in potential temperature across the inversion interface, and dividing the results by the mean potential temperature in the MBL. The height of the MBL was determined by locating the altitude of minimum temperature and the mean potential temperature was determined by taking the potential temperature at the 150-m level. The greatest uncertainty in the Froude number calculation was calculation of the reduced gravity term. Often the potential temperatures showed a gradual transition above the top of the MBL such as shown in the soundings of Fig. 5 and specification of the appropriate inversion strength was difficult. However, the calculations (Fig. 6) clearly show that supercritical flow exists throughout the study region. The largest Froude numbers were found along legs 2 and 3 to the south of Cape Mendocino owing to the large wind speeds and shallow MBL depth. Froude numbers less than 1.0 were observed only for soundings 2f, 3a, 6d, and 7a, which are nearest the coastline.

From Fig. 6, conditions are appropriate for the development of supercritical channel flow features such as expansion fans and hydraulic jumps in the MBL. Wind and temperature data collected by the K/A during the flight legs show the broad nature of the CJ and the tendency for the MBL to slope downward toward the coast. Enhanced shallowing of the MBL layer is evident along legs 2 and 3 (soundings 2d, 2e, and 3b) to the south of Cape Mendocino and is consistent with either expansion fan dynamics or flow directly over the topography. Wind speeds, however, are not significantly different from elsewhere, such as along legs 4 and 5 where expansion fan dynamics should not be present. Sounding 2c, situated approximately 30 km from sounding 2d, has wind speeds at the 600-m level that are as strong as those seen at 175 m for soundings 2d and 2e. If the thinning of the MBL at the eastern portion of legs 2 and 3 was solely due to an expansion fan, significantly greater wind speeds should be present in soundings 2d, 2e, and 3b than are observed in Fig. 4. Although it seems clear that the Cape Mendocino topography does influence the MBL structure immediately downwind along legs 2 and 3, such effects are only secondary to the large-scale trends in both wind and temperature fields. Lowering of the CJ is a common feature throughout the region and is simply enhanced downwind of the cape.

Therefore, it is proposed that the slope of the inversion at the top of the MBL along the California coast is not the result of supercritical channel flow interactions with the terrain. Fundamentally, it is the horizontal temperature contrast between the cool ocean and warm continent that is responsible for the observed trends in the MBL and attendant CJ. The slope of the inversion at the top of the MBL is consistent with a simple geostrophic adjustment of a thermally direct circulation arising due to the marked horizontal temperature contrast between ocean and continent. This will be discussed later.

Sawtooth legs offer an opportunity to sample a cross section of the coastal environment. For the 8 June 1997 case, legs 3 and 7 display an orientation that is nearly perpendicular to the coast and so the structure of the atmosphere normal to the shoreline can be examined. Figure 7 illustrates cross sections of potential temperature and wind speed for both legs. The westward increase in the height of the inversion, and hence the MBL thickness, is present from the analysis of potential temperature in each leg and is most pronounced for leg 3. The potential temperature cross sections also suggest that the inversion at the top of the MBL is lower along leg 3 near the eastern end, corresponding to the near-coastal region south of Cape Mendocino. The wind speeds are greater along leg 3 and the CJ appears to be positioned closer to the shoreline than is seen for leg 7. For both legs, the broad extent of the CJ is evident, extending at least 60 km offshore, and for leg 7 perhaps 100 km. Additional CJ studies, such as the 13 June 1997 case (not shown), indicate that the maximum CJ can extend 200 km offshore.

Figure 8 illustrates the spatial patterns of the height of the MBL (and hence approximate height of the maximum wind speed) measured by the K/A for the entire flight. The thickness of the MBL increases rapidly away from the coast throughout the entire area sampled by the K/A. The deepest MBL was observed to be in excess of 600 m at the western end of the legs, some 50–75 km from the coast. The slope of the inversion at the top of the MBL is largest in the lee of Cape Mendocino. The MBL thickness decreases eastward along leg 2 by 400 m over a horizontal distance of 50 km, corresponding to a vertical change in the geostrophic wind of approximately 25 m s^{-1} over 500 m. This is consistent with the vertical shears observed in the soundings in Fig. 4.

A summary of the wind speeds and directions along the flight legs at the 200- and 400-m levels is shown in Fig. 9. The westward increase in the wind speed at both levels is seen with the strongest winds encountered at distances 50–100 km from the coast. Wind speeds at both levels also show the sheltering influence of Cape Mendocino and Point Arena along coastal sections downwind of these obstructions to the flow. Wind directions are uniform away from the coast, directed between 335° and 350° . There is some evidence of direc-

tional change of about 25° along legs 2 and 3, consistent with expansion fan spreading. Similar directional changes, however, are seen along legs 4, 6, and 7 without evidence of hydraulic mechanisms at work. Wind directions would suggest that expansion fan dynamics are not a dominant feature of the MBL on this day. Dramatic changes in the 200-m wind directions at the east end of leg 2 and the start of leg 3 represent the transition from the CJ to a tranquil wind environment and are, therefore, not considered significant.

Coastal jet events during the June 1997 field study were remarkably consistent in terms of jet position, strength, and MBL structure. Rather than tied closely to the terrain protrusions along the California coast, the CJ was best developed away from the coastal margin. The scale of the wind and temperature fields off the California coast during June 1997 suggest that the forcing of the CJ is fundamentally the result of geostrophic adjustment of a thermally direct circulation between the ocean and continent. The slope of the inversion at the top of the MBL within 100 km of the coast can thus be viewed as a quasigeostrophic frontal boundary arising from Coriolis influences acting on the thermally direct circulation. Lowering of the MBL near the coast need not imply expansion fan dynamics. It also can be viewed as a consequence of the adjustment of this secondary cross-coast circulation. The CJ resulting from such an adjustment is in a state of near-geostrophic balance. The thermal wind arising from the slope of the inversion at the top of the MBL will result in the characteristic decrease in wind speed above the MBL. The scale of the sloping MBL and attendant CJ, the persistence of the CJ throughout June 1997, and the position of the maximum winds each support the above inferences. The role of hydraulic processes was observed to be of secondary importance in the structure of the CJ on 8 June and other cases during the 1997 field study.

4. Summary

The 8 June 1997 CJ case displays characteristics similar to other cases that have been documented in the past. This includes a well-defined wind maximum near the top of the MBL, oriented in a coast-parallel direction. Yet, there also exist some differences between this and previous cases, which has prompted a slightly different view of the CJ. The most striking differences concern the scale and position of the maximum CJ, and the lack of obvious hydraulic influences associated with the coastal terrain. The K/A observations show that the strongest winds were situated at least 30 km from the shoreline and extending to 100 km and beyond. This feature was also observed during other CJ flights during June 1997. There is no evidence to suggest that the flight legs captured the maximum jet intensity for the 8 June 1997 case for several legs. It is likely that additional acceleration in the maximum CJ wind speeds exist to the west of the study area. In addition, little jet en-

hancement was observed downwind of the various capes and points. Supercritical flow consistent with previous observations was observed upwind of Cape Mendocino and Point Arena. The expansion fan, previously discussed by Winant et al. (1988) and Rogers et al. (1998) and numerically simulated by Burk and Thompson (1996), Rogerson (1999), and Burk et al. (1999), may have been present. Lowering of the MBL and CJ south of Cape Mendocino and directional changes in the air-flow at 200 m are consistent with expansion fan dynamics. Yet, CJ maximum wind speeds south of Cape Mendocino are comparable to speeds elsewhere. All legs show the same trends in MBL thickness and directional changes as seen along legs 2 and 3, suggesting that the expansion fan is not a dominant feature of the CJ in this case. The synoptic conditions on 8 June 1997 case study (Fig. 3) match those during the CODE case study described in the aforementioned works. The similarity of the observations made on 8 June 1997 with other case study flights of the CJ suggests that this case is representative of the marine environment during summertime.

Observations made during this case study and other flights during 1997 indicate that the CJ is a ubiquitous, large-scale feature of the marine environment of the California coast. *The sloping MBL and associated CJ are primarily the result of geostrophic adjustment of the thermally direct circulation between the cool ocean and heated continent.* The sloping inversion at the top of the MBL in the eastern Pacific then can be viewed as a quasigeostrophic frontal boundary arising due to the adjustment process. This view emphasizes the observed broad-scale nature of the CJ and suggests that local hydraulic interaction with the coastal topography may simply be perturbations to the general flow and are not prerequisite to a well-developed jet.

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