SUMMERTIME COASTAL AIR FLOW IN NORTHERN CALIFORNIA

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During the past few years, several articles have been published on ocean-air interactions and coastal air flow. Many dealt with the interaction of summertime upwelling with the land-sea breeze system. The basic nature of this circulation and its resultant hodograph shape have been described by Haurwitz and by Staley. The monsoonal component of the air motion along the west coast of the United States was described by Schroeder et al. Other influences such as diurnal strength of the inversion and its height fluctuations on the transgressions of marine air have been outlined by Meitin and Stuart, and Simon. Thus, coastal areas are zones of complex geophysical interactions.

Other research interests in the coastal environment have been concerned with explaining precipitation mechanisms or the lack of them. Bryson and Kuhn have examined the effect of coastal topography and orientation on zones of subsidence, while Azevedo and Morgan measured the amount of fog precipitation (fog drip) associated with the penetration of summer stratus in coastal forests. Simon, using weather satellite photography, identified four regions of different low cloud formations off the west coast of the United States. Others have described the penetration of fog in coastal areas. Lastly, researchers such as Mahrer and Pielke have employed numerical models to analyze the interaction of the sea and land breezes with local topography and the mountain wind systems. They have described the diurnal changes in the coastal flow brought about by the interaction of both the mountain and sea breeze circulation in a two dimensional numerical model.

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Study Area and Objectives

Northern California was chosen as the study site because of the presence of cold, upwelled water along the coast during the summer and its possible effect on the regional air flow. Furthermore, very few people have examined mesoscale surface air flow in this region of complex topography. The area around Eureka is generally quite flat while to the south several transverse ridge systems lie adjacent to the coast. This change in topography should logically modify the basic land-sea breeze system. A better understanding of the modification brought about by the topography on the air circulation would aid numerical modelers and also help researchers interpret the effect of climate on the vegetational patterns in a coastal area.

To examine the general air flow in the Cape Mendocino area, nine wind sampling locations were used to depict the characteristics of the summertime atmospheric motion from July 8 to August 17, 1970. (Figure 1) Standard wind instruments were lent by the National Center for Atmospheric Research, Boulder, Colorado. The Blunt's Reef Light Ship data was obtained from the National Climatic Data Center, Asheville, North Carolina. The nine sampling locations were classified as low level (Navy, Ocean House, Blunt's Reef, and Trinidad Head), intermediate in elevation (Walker-George) and ridge top (Windy Nip, Mount Pierce, Bunker Hill and Mazzepa). The ensuing discussion of each station's wind characteristics will proceed in this paper according to this categorization.

The data were extracted at hourly intervals from a continuous record to determine the characteristics of the average (vector) resultant wind field, the major objective of this paper. The mathematical basis for the calculation of a resultant wind is described by Pant. The three hour weather information taken aboard the Blunt's Reef Light Ship was included in this analysis to illustrate the nature of the offshore flow.

Resultant Wind Field

Figure 2 depicts the nature of the hourly resultant wind field at the low level and intermediate locations. All stations generally display the classical afternoon vector rotation through time. For example, the vectors for Navy rotate clockwise from 1400 to 2000 PDT. The influence of the Pacific High pressure system on the surface wind is indicated by the frequency of northerly
CAPE MENDOCINO AREA, NORTHERN CALIFORNIA

Figure 1
winds at all hours. Trinidad Head is the only site that had an offshore flow during this study period. This implies that Trinidad Head is subject to more late evening and early morning air drainage and land breeze flow than the other locations. The difference in physical characteristics between the Cape Mendocino area and the Trinidad Head location probably causes the variation in the flow structure at each site. The larger Cape headland exerts greater frictional and thermal effects on the wind field than does the smaller Trinidad headland. The Trinidad Head station occupies a more leeward location on a headland than does either Navy or Ocean House. This leeward location on a headland might be influenced by atmospheric eddy structures that would favor an offshore flow. The existence of eddy structures in this area had been borne out by observation of the local zones of stratus dissipation near Trinidad Head.

Another factor that would likely influence the general lack of offshore flow in the Cape Mendocino area is the effect of atmospheric wave activity and subsidence in this locale. Subsiding air or dense marine air could "scour out" any nighttime down-valley flow. Dense marine air flowing down the leeward slope in the late evening hours, observed, could logically be expected to modify the offshore flow. Mountain ridges at right angles to the general northerly flow could induce formation of atmospheric waves and under proper conditions could eliminate or strongly modify through subsidence the offshore motion. The existence of waves activity in this area is mentioned by Marotz, Hannes, and Lahey.  

If hodographs were constructed for each site shown in Figure 2, each would be different. As mentioned by Staley, the shape of a hodograph is related to the local effects of friction, pressure gradient force, and Coriolis force. Furthermore, the stagnation points of vector rotation represent equilibrium points where some type of balance is achieved among the forces involved in producing the flow field. For example at Navy, stagnation periods occur between 1200 and 1300 PDT, and between 2100 and 2300 PDT. Ocean House, south of Navy, has a much more elongated hodograph shape than Navy. Elongation, according to Staley, generally indicates topographical constraints. Moreover, the difference between the two hodograph shapes could also be caused by diurnal pressure variations due to location. Ocean House occupies a leeward location, while Navy has a windward position with respect to the wind field. Myers has described local variations of the wind field along mountains with stable airflow, which may be similar in part to conditions occurring at these two Cape stations.
RESULTANT WINDS: July 8 to Aug 17 1970

Trinidad Head

Navy

Walker-George

Blunt's Reef

Ocean House

Figure 2
The hourly resultant winds for the ridge top locations are displayed in Figure 3. Mazzepa, Bunker Hill, and Mount Pierce are located at different elevations on the Bear River Ridge system. Windy Nip is south of the Bear River Ridge in general produces a shear zone between Mazzepa and Mount Pierce. For example, at 1800 and 1900 PDT the winds at Mazzepa are from the northeast and at Mount Pierce from the northwest. Bunker Hill, on the other hand, has an air flow from the north, intermediate to the other two stations. The shearing is likely caused by the land-water contrasts and the frictional effects of the ridge system. As mentioned by Bryson and Kuhn, a zone of horizontal divergence should occur if the land is towards the low pressure system. This seems to be the case in the summertime off the west coast of the United States, for the Pacific High is well developed offshore, while a thermal low is found in the Central Valley of California. This shear zone also extends south of the Bear River complex. The winds for this time interval (1800–1900) are northeasterly at Walker-George, northwesterly at Windy Nip.

Hodograph shapes of the low level sites are not as elongated as the upper level sites. (Figures 2 and 3) Again, elongation of shape usually implies some form of constraint on the ideal wind flow.

**Diurnal Wind Variation**

The diurnal wind velocity is quite variable spatially at the locations examined in this study. (Figure 4) However, the stations do exhibit certain similarities in the general nature of the summertime velocity distribution. The maximum resultant wind velocity at the ridge stations (Bunker Hill, Mazzepa, Mount Pierce and Windy Nip) comes during the late evening (1800 to 2100), while the minimum velocity generally occurs between 1000 and 1200 PDT (except at Mazzepa). In contrast to the ridge top sites, the low level sites (Ocean House, Navy, and Trinidad Head) all record maximum velocity at or before 1800 PDT, while the minimum value occurs at or before 0800 PDT. These local speed variations are in part related to the daily heating and cooling cycle of the Cape area. Hannes has described the diurnal temperature similarities that occur between the stations in this study area. Diurnally, all the sites do not heat and cool at the same rate; thus, each station's wind profile should vary throughout the day.
RESULTANT WINDS: July 8 to Aug 17 1970

Mount Pierce

Mazzepa

Windy Nip

Bunker Hill

Figure 3
The cause of the late evening maximum velocity, as opposed to the early morning minimum velocity, is probably related to a series of local factors modifying the classical sea breeze system. One such factor causing the morning minimum velocity (e.g., between 1000 and 12000 at Bunker Hill) is the effect of thermal turbulence. Turbulence could disrupt the morning horizontal flow field, while in the late evening hours a lack of vertical rising currents could enhance the horizontal flow over the ridges.

A second environmental factor that could modify the diurnal wind field is related to the changes in elevation of the inversion base. With late evening cooling of land or water, the inversion base could be lower, and thus cause the wind speeds to increase the Bernoulli effect. As described by Simon, the height of the inversion base varies along the California coast. This variation in height, coupled with the local topographic variations, would likely produce the strong winds at Bunker Hill and Mazzepa. No continuous or daily upper air soundings were taken during this study, but discontinuous soundings at Arcata, California by a United States Navy research team indicated an inversion base below 1200 meters in the early morning.

Hannes has described the breakdown of a low level wind maximum, a jet-like feature, over the Arcata area during the early morning. This velocity maximum is probably related to variations in the height of the inversion base and the frictional discontinuity between land and water. As described by Blackadar, the nocturnal inversion is often associated with wind shear at low levels. Furthermore, the diurnal wind diagram for Navy and Walker-George resemble the ideal shape of a hodograph influenced either by a low level wind maximum as described by Barad or an inertial oscillation as mentioned by Hoecker. The relationship between the inversion base and local wind maxima along the ridges can only be ascertained by further study of the diurnal nature of the upper level wind field.

Summary

In conclusion, this paper has described the general nature of the wind field in an area of complex terrain. The wind field at Trinidad Head, north of Cape Mendocino, exhibits the classical land-sea breeze flow, while the flow field over the Cape records a dominant northerly flow. Also, the lack of either a dominant nighttime land breeze or downvalley flow throughout the Cape area is thought to be related to modifying effects of subsiding air produced by the favorable onshore
Figure 4
pressure gradient between the Pacific High and an interior thermal low. As suggested in this article, the frictional and thermal effects of the Cape land mass cause many of these local variations in velocity and general hodograph shape. The shear zone that occurs along Bear River Ridge is thought to be related to frictional effects. The diurnal variations in velocity are a result of the changes in magnitude of the forces involved. As suggested by Lahey, the wind field is responding to temperature and pressure gradients produced by variations in the rate of upwelling along the coast. Further study in this area is needed to ascertain the exact nature of ocean-air interactions.
NOTES


18. Schroeder et al., op. cit. (Footnote 3), 802-808.

