FOEHN WINDS OF SOUTHERN CALIFORNIA.

By

Irving P. Krick,

California Institute of Technology, Pasadena (Calif.).

(With 3 figures.)

Zusammenfassung: Föhnwinde treten in Südkalifornien häufig während des Winters auf, und zwar machen sie sich besonders im „Los Angeles Basin" bemerkbar, das sich vom Pazifischen Ozean im Westen zu den San Bernardino-Mountains im Osten erstreckt und im Norden durch die vielfach über 2000 m hohen San Gabriel Mountains von den kalifornischen Steppen (desert) getrennt ist. Die Föhnwinde werden durch Luftmassen gespeist, die durch den im Nordosten des Gebietes in nordsüdlicher Richtung in etwa 1300 m Höhe verlaufenden Cajon-Paß [Profil in Fig. 1[1])] aus der Steppe abfließen und in das Bassin gelangen. Diese Föhnwinde wurden seit jeher als Wüstenwinde angesprochen, da sie sehr warm und trocken sind. Sie entstehen, wenn das Luftdruckgefälle von den „Great Basin"-Gebieten in den Staaten Utah und Nevada (mittlere Höhe etwa 1500 m) gegen die höchstens einige hundert Meter über Meereshöhe gelegenen Tiefländer in Südkalifornien gerichtet ist. Die ursprünglich schon trockene und ziemlich stabile Luft gelangt dann auf ihrem Wege aus den ariden Gebieten von Utah und Nevada in immer geringere Meereshöhe. Hierbei entstehen sowohl durch adiabatische Erwärmung wie durch nächtliche Ausstrahlung Temperaturinversionen in Höhen von der Größenordnung 100 m über dem Boden. Die stabilen Luftmassen, und zwar nicht die kältere Bodenluft, sondern die darüberliegende warme Luft strömt nun an der tiefsten Stelle des Gebirgswalls durch den Cajon-Paß in das Los Angeles Basin ab, wobei sie bereits die ganze auf dem Wege erzeugte adiabatische Wärme mit sich führt. Schon vorher war sie so trocken, daß selbst beim Aufsteigen kein Niederschlag fällt. Bei außergewöhnlich steilen Gradienten überquert sie sogar die Gebirge und erzeugt dann in der genannten Ebene Sandstürme, bei denen gelegentlich Luftfeuchtigkeiten bis zu 3% gemessen wurden.

Die Untersuchungen, von denen hier zunächst nur ein kleines Teilergebnis veröffentlicht wird, zeigen, daß der hier behandelte Föhn so häufig auftritt, daß er als Winter-Monsun angesprochen werden kann. Er bewirkt die milden Winter in Südkalifornien, durch die sich dieses von den entsprechend gelegenen Tälern in Nordkalifornien unterscheidet.

One of the characteristic weather phenomena of southern California is a wind of the foehn type known locally as the Santa Ana. Unseasonably

[1]) Eine Karte des Gebietes befindet sich in dieser Zeitschrift, Bd. 35, S. 11, 1932. Der Cajon-Paß liegt etwa 30 km nördlich von Riverside.

high temperatures and very low humidities are associated with its occurence. The maximum effects of this wind are felt in the region south of Cajon Pass at the eastern extremity of the Los Angeles Basin. The latter area, extending eastward from the sea to the San Bernardino Mountains, is ordinarily protected from continental influences by the rather high San Gabriel Mountains to the north. Cajon Pass, trending roughly north and south between the San Gabriel Mountains to the west and the San Bernardino Mountains to the east, opens to the north upon the Mohave Desert and to the south upon the alluvial plain of the Los Angeles Basin.

These winds, originating in the desert regions to the north, blow out upon the Los Angeles Basin from the southern entrance to Cajon Pass. In previous descriptions the writers have used such titles as "The Santa Ana or Desert Winds"[1]) and "Desert Winds in Southern California"[2]). Such titles lead the reader to believe that the desiccating effect of these winds and their high temperatures are entirely due to the fact that they blow off the desert to the north. This idea has also become prevalent among the residents of southern California; descriptions having heretofore stressed the fact that the winds are of desert origin and only mentioning in a general way that the air in passing down from the Great Basin regions to the north is dynamically heated during its journey from these high level areas to the lowlands of southern California.

It is interesting to note that in other regions of the earth also where the Foehn has been observed it usually has been attributed first to the heat of some adjacent desert, as in the present case, and later recognized as a Foehn. Indeed, foehn winds as initially observed years ago in the Swiss Alps were first thought to be air currents originating in the Sahara Desert far to the south, but then the same phenomenon was observed on the west coast of Greenland, a region obviously too far removed from any desert areas to be effected by them. Hann in 1885 first gave a comprehensive explanation of the phenomenon in terms of the compressional heating of an air current as it rapidly descends the leeward slopes of a mountain. This explains the dryness of the wind, as well as the high temperature, since the dynamical heating in raising

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1) Archibald Campbell, The Santa Ana or Desert Winds, Monthly Weather Review, Vol. 34, p. 465. 1906.

2) D. Young, Desert Winds in Southern California, Monthly Weather Review, Vol. 59, No. 11. Nov. 1931.

the temperature increases the capacity of the air for water vapor which it, however, does not receive. This remains today the generally accepted explanation. Even farther from the truth was the early explanation of the Zonda, a hot, dry wind of the Argentine Republic occurring at the eastern base of the Andes. This wind was attributed to volcanic activity in the lofty Andes to the west until shown to be a foehn type wind by DAVIS[1]). Thus it is not unnatural that many people in southern California still believe the Santa Ana to be merely a hot wind blowing off the desert to the north.

It is the object of this paper to show that these Santa Ana winds owe their properties to compressional heating rather than to the fact that they originate in desert areas, and are therefore truly foehn type winds. It is further to be pointed out that the foehn characteristics of this air current do not become apparent at the surface during its long journey from the high level regions of Utah and Nevada to the lowlands of southern California until with a final rush down Cajon Pass it reaches the Los Angeles Basin. It will be shown also that the temperatures prevailing in the desert during the occurrence of a Foehn are actually lower than those ordinarily recorded.

The U. S. Department of Commerce maintains throughout the country a network of weather reporting stations placed at intervals along the principal airways. The records from two of these stations located in southern California will be used in the present discussion, since these stations are admirably located for such a study. One station, Baldy Mesa, is located on the desert side of Cajon Pass about 2 miles north of the summit at an elevation of about 3700 feet and the other station, Fontana, is located on the western side of the southern entrance to the pass at an elevation of approximately 1700 feet. Fig. 1 represents a profile through Cajon Pass between these two stations. Hourly observations of temperatures, dew points, wind directions and velocities are available from these two stations. Of the many examples of Santa Ana winds noted while examining the records from these stations a typical one of recent date has been chosen for discussion here.

The Santa Ana winds occur almost exclusively during the fall and winter seasons when the barometric gradients are frequently directed across the San Gabriel Mountains causing a flow of air southward from the desert down into the Los Angeles Basin. The air has come

[1]) W. M. DAVIS, The Foehn in the Andes. The American Meteorological Journal. March 1887.

down from the high level areas of the Great Basin. It is a transitional type of air mass which has obtained its initial properties in the polar regions of the Pacific Ocean. It passes over the mountains of Washington and Oregon in the lee of a cyclonic disturbance and in so doing loses a part of its moisture before reaching the Great Basin region. If the barometric gradients are favorable, as is frequently the case, this air will then begin its journey southward over the arid regions of Utah, Nevada and eastern California. As it travels southward a very stable lapse rate ordinarily with marked temperature inversions near the surface will be established in this air mass both by active nocturnal

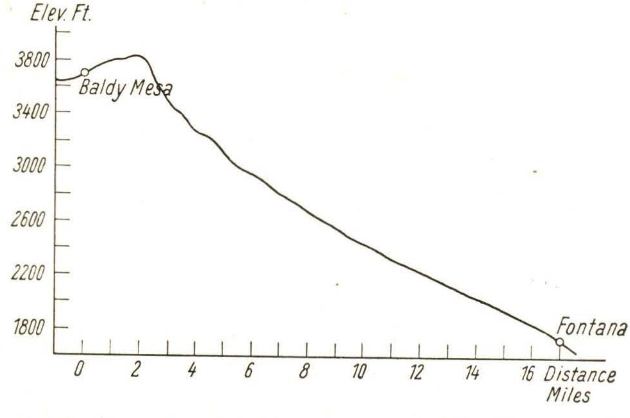

Fig. 1. Profile through Cajon Pass between Baldy Mesa and Fontana. 1 mile = 1.61 km., 1000 feet = 305 m.

radiation and by compressional heating as it passes progressively to lower levels. The stability of this air upon its arrival at the northern slopes of the San Gabriel Mountains accounts for the fact that its passage over the mountains under moderate pressure gradients is limited to the passes, notably Cajon Pass. Due to the crowding of the stream-lines as it flows through Cajon Pass high velocities are attained by the current.

It is worth noting at this point that under similar conditions in summer intense heating of the surface layers of this air as it passes over these arid regions north of the San Gabriel Mountains renders it unstable and it usually passes out over the San Gabriel Mountains without reaching the surface of the Los Angeles Basin below. It is further prevented from reaching the surface due to the fact that during the summer months the Los Angeles Basin is continually occupied by cool, moist, stable air which moves in from the Pacific Ocean a short distance to the west. The warm air aloft is thus obliged to merely slide out over the cooler air below, not being able to displace it at the surface.

In order to show that the Santa Ana is a foehn type wind and does not owe its characteristic properties to desert influences it will be shown that for the duration of the phenomenon the same air mass is present both at Baldy Mesa, the desert station, and at Fontana, the station to the south of the San Gabriel Mountains, and that the relative humidity at the former station is higher and the temperature lower than the relative humidity and temperature at the latter.

The Foehn which I have chosen for discussion here occurred during

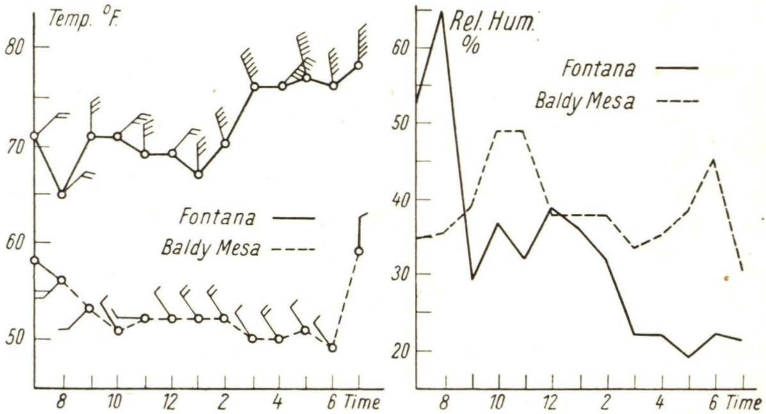

Fig. 2. Temperature, relative humidity and wind (see text) at Baldy Mesa and Fontana (profile in Fig. 1) during the night of October 10—11, 1932.

the night of October 10—11, 1932, and was initiated by conditions similar to those described above as necessary for its genesis. We shall examine here the records of the two stations, Baldy Mesa and Fontana, for that night using the observations from 7.00 PM., October 10th, to 7.00 AM., October 11th. Fig. 2 shows a plot of the temperatures and relative humidities recorded at the two stations for this period with the wind directions and velocities indicated for each hour during the period, each barb representing a wind velocity of 4 miles per hour.

In order to determine the identity of air masses present at the wo stations some conservative property of an air mass must be used tasa criterion. One of the most conservative properties of any air mass when no precipitation or evaporation is involved is the specific humidity. In computing the specific humidities of the air masses present at Baldy Mesa and at Fontana at the beginning of the period under consideration it is found that the specific humidity at Fontana is 9 g./kg. while that at Baldy Mesa is only 4 g./kg., a fact which indicates that the same air mass is not present at both stations at this time. A specific humidity of 9 g./kg. at Fontana indicates that the moist air from the adjacent Pacific Ocean usually occupying the Los Angeles Basin is still present at Fontana since this value of the specific humidity closely approximates the characteristic value for this air mass at this time of year. On the other hand the air at Baldy Mesa is the Transitional Polar Pacific air referred to above which has made its way southward from the Great Basin, because the specific humidity of this air mass is known to have a value of about 4 g./kg. at this season. At 9.00 PM. the specific humidity of the air at Fontana is 5 g./kg. which shows that the same air is now present at both stations, the moist air formerly occupying Fontana having moved out in response to the prevailing pressure gradient allowing the dryer Transitional Polar Pacific air air to replace it. The difference in the values of the specific humidities at Baldy Mesa and Fontana is due to the difference in elevation of the two stations. For the remainder of the period under discussion these values remain the same respectively for the two stations.

The temperature difference between the two stations during the first hour of the period is due to the difference in the air masses present. The dry Transitional Polar Pacific air present at Baldy Mesa being intrinsically a colder air mass at the surface than the moist air at Fontana and subject to wider diurnal variations in temperature by virtue of its dryness. At 8.00 PM. the difference in temperature between the two stations amounts to 9° F. while at 9.00 PM. after the moist air at Fontana has been replaced by the drier air this difference amounts to 18° F. The same air mass is now present at both stations, however, the air now at Fontana could not have come from the surface at Baldy Mesa. If the surface air at Baldy Mesa were to rush down Cajon Pass to Fontana losing no heat by radiation cooling and being heated by compression during the descent it could only gain an increase in temperature of 11° F. since the difference in elevation between the two stations is 2000 feet. Furthermore in this case there is opportunity for radiation cooling during the descent from Baldy Mesa to Fontana as indicated by the low wind velocities at Fontana at this time. It is seen from Fig. 2 that with similar wind velocities radiation cooling continues at Fontana between 9.00 PM. and 1.00 AM. We can therefore not infer that the increase in temperature between 8.00 PM. and 9.00 PM.

is due primarily to a foehn effect, since during the Foehn velocities of the current are high enough to prevent radiation cooling, thus bringing out the maximum effect of the compressional heating undergone during the descent. The temperature increase during this period is then due almost entirely to the change of air that takes place at Fontana during this interval and since we have shown that the new air could not possibly have come from the surface at Baldy Mesa we are obliged to look to the temperature inversions known to exist in this air mass at levels short distances above the surface as the source of this new warm air at Fontana. This warmer air aloft at Baldy Mesa slides out over the cool surface air below at elevations approximating the altitude of the summit of Cajon Pass and flows down the pass toward Fontana.

After 1.00 AM. the true Foehn begins, the wind velocities having been increased sufficiently to overcome radiation cooling as the air descends the Cajon Pass. Between 1.00 AM. and 3.00 AM. the wind velocities at Fontana increase from 12 miles per hour to 25 miles per hour with a temperature increase of 9° F. in the interval. During this time the temperatures at Baldy Mesa are continually decreasing by radiation cooling. From 3.00 AM. until sunrise the temperatures and wind velocities at Fontana remain practically constant the wind having a direction which parallels the longitudinal axis of Cajon Pass since, due to its stability, the current is restricted to the pass. Just before sunrise the temperature at Fontana is 76° F. while at Baldy Mesa it is 49° F., a difference of 27° F. Normally the temperature at both stations at this time of the morning during this season is around 53° F., as will be shown below. During the Foehn the relative humidity at Fontana dropped to 19 % while at Baldy Mesa values as high as 45 % were recorded. This is the more remarkable when one considers the difference in elevation between the two stations.

A significant result of the Foehn was that the day of its occurrence was the only day for a period of 42 days on which the Los Angeles Basin was entirely free from fog. During the Foehn the maritime air, in which the fog of the Los Angeles Basin forms, withdrew; the entire area being occupied by the warm dry air of the Foehn.

In order to further bring out the contrasting conditions at Baldy Mesa and Fontana during the Foehn let us look at records for a similar interval during an average day for this time of year. Fig. 3 shows a plot analagous to Fig. 2 with respect to the meteorological elements involved, compiled for the night of October 2—3, 1932. The wind velocities and directions have been omitted in this case as they are not significant. The specific humidities at Baldy Mesa and at Fontana for this period are 9 g./kg. and 10 g./kg. respectively indicating the presence at both stations of the moist air which we noted to be present the evening of October 10th at Fontana before being replaced by the drier air from the region to the north. The discrepancy between the two values is again due to the difference in altitude between the two stations. We see that during the night the temperatures at the two stations remain practically the same, indeed, within the limit of error

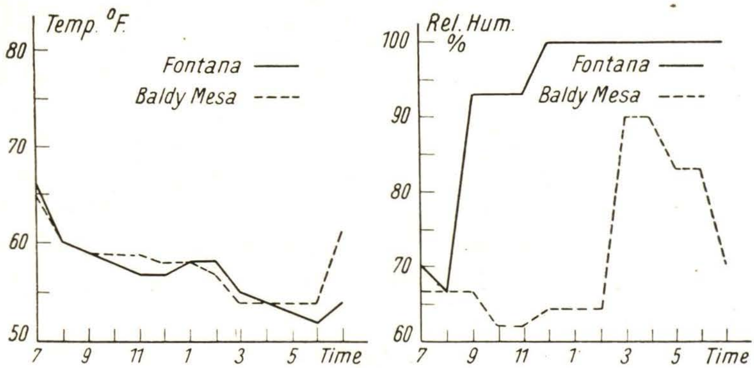

Fig. 3. Temperature and relative humidity at Baldy Mesa and Fontana (profile in fig. 1) during the night of October 2—3, 1932.

of the observations except in the case of the final reading at 7.00 AM. In this case the difference is due to the fact that at Fontana there is fog while at Baldy Mesa it is clear. The trend of the relative humidity curves would have been similar had not the relative humidity at Fontana reached 100% by midnight and remained at that value for the remainder of the period. It will be noted that in this case the relative humidities at Baldy Mesa are lower than those at Fontana while in the case of the Foehn they were higher. It will be seen in comparing Figs. 2 and 3 that temperatures at Baldy Mesa are consistently lower during the Foehn than under ordinary conditions, due to the dryness of the air mass present at the station in the former case.

When excessive pressure gradients exist over the San Gabriel Mountains the current may come directly over the mountains. In this case great clouds of dust are raised as the current strikes the surface of the Los Angeles Basin a few miles south of the mountains, and the air reaching the surface is from even higher levels than in the ordinary cases; relative humidities as low as 3 and 4 percent have been recorded. These extreme cases are, however, rather rare.

Foehn winds occur very often during fall and winter in southern California and influence the climate considerably. The mild winter of southern California is usually attributed to the proximity of the Pacific Ocean only, but during the foehn winds the temperatures are raised far above those prevalent when air from the Pacific is present, especially in the late fall and early winter before the Great Basin region becomes extremely cold. A glance at Figs. 2 and 3 shows this very clearly. These winds really represent a winter monsoon in southern California and will be treated in more detail in a later paper. They do not occur in northern California nearly as frequently due to the great barrier set up by the Sierra Nevada Mountains.

Hot dry winds occuring about 100 miles north of the Los Angeles area in the vicinity of Santa Barbara probably have the same origin since any air which reaches the California coast after passing down from the Great Basin area must be dynamically heated. In other regions true desert winds may occur occasionally, but probably at no point along the coast.