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The Application of Upper Level Heights in Diagnosing and Forecasting San Joaquin Valley Dense Fog Episodes

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Introduction

a. Background and Motivation. The San Joaquin Valley of California, rimmed by the Coast ranges to the west, Tehachapi mountains to the south, and the Sierra Nevada to the east, provides an ideal topographic environment for the restriction of atmospheric mixing and resultant air stagnation. During the cooler months of the year, when longer nights team with sufficient boundary layer moisture, widespread dense fog becomes a perennial problem, adversely impacting travel on California's major arterial highways and subsequently serving as a foremost contributor to many vehicular-related injuries and fatalities.

Forecasters often rely on inspection of low level winds, the presence of a large-scale anticyclone aloft, initially clear skies, damp surface conditions, and climatology to gauge the potential for dense fog in the San Joaquin Valley. However, many of these methods are quite subjective in nature and/or are overly reliant on model guidance, as opposed to observational data. Thus, this study seeks to objectively examine one parameter, upper level heights derived from radiosonde data, and correlate its effectiveness in diagnosing and predicting dense fog across the central San Joaquin Valley.

b. Data. 00Z and 12Z radiosonde observations were archived from Oakland, California, approximately 153 miles upstream of Fresno, the largest city in the San Joaquin Valley and one of two anchor points for which surface ASOS observations were compiled (FCC 2003). The other anchor point, Hanford, is situated 31 miles south of Fresno (FCC 2003). Hanford was selected not only due to representative and reliable ASOS observations, but also as a more rural counterpart to Fresno surface observations. These data were recorded from November 1, 2002 through February 28, 2003, inclusive. It should also be noted that the first measurable rainfall of the cool season, which helps provide the requisite moisture in the boundary layer, didn't occur until November 7 at both locales. The termination time of the study was chosen as a modified continental polar airmass shifted into the region in early February, helping to disperse stagnant low level moisture, and multiple days of light rain followed through the middle of the month. These factors, along with the seasonal rapid increase in daylight, helped ensure the end of the examined fog "season."

ASOS sensors report horizontal visibility below 5/8 mile as fog; 1/4 mile or less horizontal visibility is denoted as heavy fog (NWS 1996). For the purposes of this study, only the latter threshold qualified as being dense fog, and only one such observation (even irregularly scheduled SPECI observations) was required for the day to count as being one with dense fog for a particular location. If one or both observing sites experienced this condition, the day was classed as being one with a "dense fog occurrence." When dense fog occurrences were limited to just those that produced dense fog at both locations, the event was considered "widespread." Of course, if neither site experienced such a severe degradation in visibility, then the day was labeled as a "non-event." The National Climatic Data Center provided the quality-controlled daily data for Fresno, with locally archived data constituting hourly surface observations and Hanford daily summaries. From the entire 00Z radiosonde set, only two observations were unavailable from the surface through 500 mb; five were unavailable at 300 mb. For the 12Z 500 mb set, eight observations were not available. In all cases, the average of the respective data sets' height available immediately preceding and immediately after the missing data was taken as proxy for missing observations.

In order to effectively determine the most appropriate pressure level for diagnosing, as well as predicting, dense fog, heights corresponding to those pressure levels were recorded along with a binary digit indicating whether there was a dense fog occurrence (Y=1) or a non-event (Y=0) for each surface location. This technique, utilizing point biserial correlations, has been successfully employed for similar comparisons, most notably between dew point temperature and fog frequency (Panofsky and Brier 1965). This correlation was computed for the totality of dense fog episodes for each pressure level; on occasions when both Fresno and Hanford registered dense fog (widespread dense fog occurrence), a subset of the former correlation was computed just for these more limited events, comprising yet another useful statistic. The specific formula used to calculate the correlations, depicted below, is a form of the standard Pearson correlation (Lowry 2003).

$$r = \frac{[(X_1 - X_0)][p(1-p)]^{1/2}}{S_x}$$

where

r is the point biserial correlation
X is the upper height level
Y is the digit indicating the presence (Y=1) or absence (Y=0) of dense fog
X_0 is the mean of X when Y=0
X_1 is the mean of X when Y=1
S_x is the standard deviation of X
p is the proportion of values where Y=1

Results

a. Prognostic and Diagnostic Sounding Data Versus Ground Truth. 00Z 500 mb height data were analyzed to determine its value in forecasting dense fog events for the immediately approaching night. 12Z sounding data were also utilized to determine usefulness in forecasting dense fog events prognostically for the next night, since these data would be the most timely available for deciding whether to issue advisories during the daytime operational shift. 12Z data were also examined diagnostically as dense fog events were occurring, since the local time corresponds to predawn hours at observed sites, when dense fog presence would normally be expected to be at a maximum.

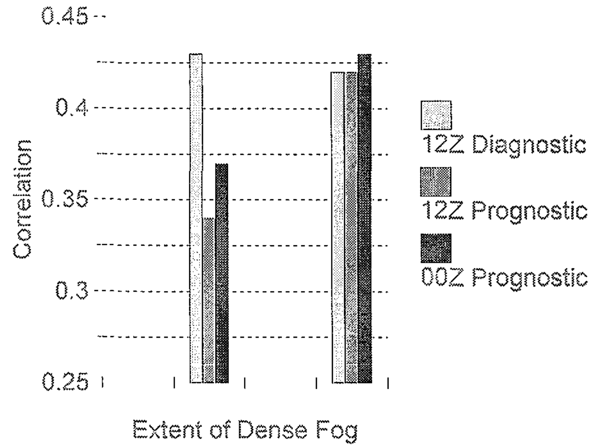


Figure 1. A comparison of Oakland 500 mb radiosonde observations and their correlation to San Joaquin Valley dense fog events. The cluster on the left represents all dense fog occurrences; the cluster on the right is limited to widespread dense fog events.

As Figure 1 indicates, the 12Z 500 mb diagnostic sounding correlates well to dense fog occurrences, including those limited to widespread episodes (r=+0.42 to +0.43). Using this same sounding to predict the next night's fog (the 12Z prognostic), the correlation between high 500 mb heights and widespread dense fog events remains essentially the same. However, a significant decline in prognostic ability was noted in using this sounding for the totality of dense fog occurrences (i.e., "patchy" and widespread coverage) for the subsequent night. Thus, in general, upper level heights are somewhat poorer predictors for "patchy" dense fog episodes than for more widespread events. Finally, the 00Z sounding, surprisingly, correlated just as well as the diagnostic 12Z sounding in predicting widespread dense fog coverage. For dense fog events as a whole, the prognostic 00Z sounding showed less skill than the diagnostic 12Z sounding, with the 12Z prognostic sounding for the following night showing the least correlation. Simply stated, the data suggest that soundings up to 24 hours old tend to show as good as skill in predicting widespread dense fog events as more recent data; "patchy" dense fog events require more timely data for accurate forecasts and are, in general, less predictable than more widespread occurrences.

b. Period of Consideration. Using 500 mb data, prognostic 00Z and 12Z soundings, as well as the diagnostic 12Z soundings, were examined for the entire period described above, with these correlations compared to those for other notable time periods. One such span, November 10, 2002 through February 2, 2003, inclusive, marked the beginning of the rainy season and the conclusion of a moist, stagnant airmass subsequently mixed out by a modified polar airmass, respectively. Another period, December 1 to January 12, was chosen primarily because these endpoints mark three weeks either side of the winter solstice, and as is quite well known, less daylight and low solar insolation are paramount for dense fog formation in this region. In these cases, correlations for segmented periods were worse than those for when the entire period was considered, especially for 12Z and 00Z prognostic data sets (represented in Figure 2). Possibly, sheer data quantity play a significant role in maintaining higher correlations for the longer periods, despite the fact that some of these data were gathered aside from "typical" dense fog formation conditions, as is the case when the boundary layer lacks sufficient moisture. Therefore, for all subsequent references in this study, only the entire period, November 1 to February 28, is considered. Additionally, since the 00Z data are the best correlated to upper heights out of the two prognostic measures, only this time will be utilized for further study.

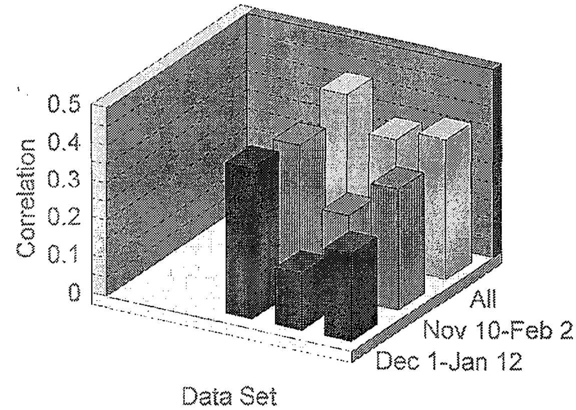


Figure 2. An analysis of 500 mb Oakland radiosonde data and its correlation to all dense fog occurrences in the San Joaquin Valley. The farthest left data (oriented diagonally) are the 12Z diagnostic set; middle data are the 12Z prognostic set; right data are the 00Z prognostic set.

c. Most Appropriate Upper Heights for Dense Fog Forecasting. The prognostic 00Z sounding data were then compiled in an effort to determine which height level correlated best to dense fog formation on the Valley floor for the upcoming night; 925 mb, 850 mb, 700 mb, 500 mb, and 300 mb levels were considered, as were all dense fog occurrences and those limited to widespread events. According to Figure 3, the 700 mb level provided superior correlation between height and dense fog episodes in the Valley. The correlation coefficient between widespread dense fog events at the selected sites and the 700 mb height stood at +0.46. This implies that approximately 21 % of all factors associated with widespread dense fog are also associated with 700 mb height level (coefficient of determination), regardless of the role of other variables. For dense fog events as a whole, the aforementioned correlation coefficient fell to +0.40. In both classes, the correlated 500 mb level was only slightly poorer, as was the 850 mb level. In contrast, both the 925 mb and 300 mb levels showed significant losses in correlation. Although there are many possible reasons for this outcome, perhaps the most plausible rests in the upper levels having relatively little influence on boundary layer conditions, while the lowest levels are impacted too greatly by terrain separating the radiosonde launch site and Valley, where mountains overcome the 925 mb level and local variations in atmospheric phenomena (wind, pressure, humidity) are often present and highly transient.

Figure 3. Correlation of widespread dense fog events (top line) and all dense fog occurrences (bottom line) to examined heights at selected pressure levels, using 00Z radiosonde data.

d. Application of the 700 mb Height for Dense Fog Forecasting. The 700 mb height for all 00Z soundings was further analyzed to determine trends and the significance of certain heights. For the 120 examined days, several descriptive statistics can be found in table 1.

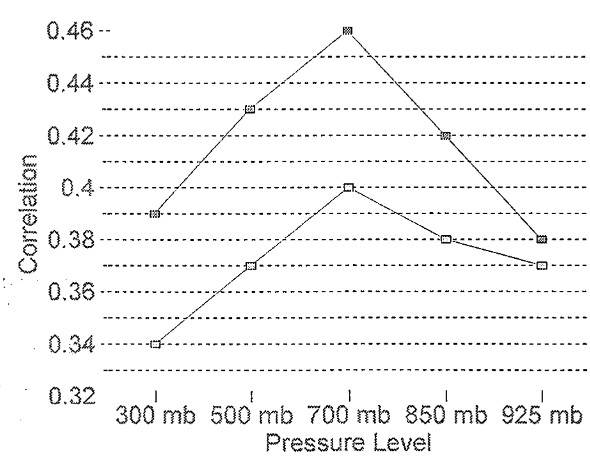
Table 1. Basic statistical information from Oakland, California 00Z radiosonde observations for November 1, 2002 through February 28, 2003, inclusive.

700 mb Descriptive Statistics (meters)

Minimum	2909
Mean	3088
Median	3094
Mode	3138
Maximum	3221
Standard Deviation	66.25

Figure 4 provides a summary of 700 mb height levels with corresponding dense fog occurrences. Particularly noteworthy is the finding that heights at or above 3190 meters always yielded at least some dense fog.

Figure 4. The relative abundance of 700 mb heights during the examined period. The lightly shaded portion of each bar represents the number of days with at least some dense fog.



In general, the proportion of days with at least some dense fog remained close to

50 % until 700 mb heights climbed above approximately 3100 meters, above which, the chances of dense fog increased sharply. If only widespread dense fog events are considered in relation to the total number of days with a specified range of heights, as detailed in figure 5, only a small proportion of days with 700 mb heights below around 3130 meters yielded widespread dense fog events. However, between approximately 3130 and 3160 meters, the proportion of days with widespread dense fog events rapidly increased to over half. Above 3160 meters, the percentage of days with widespread dense fog episodes continued to increase steadily, up to a maximum of 80 % as the highest 700 mb heights were observed.

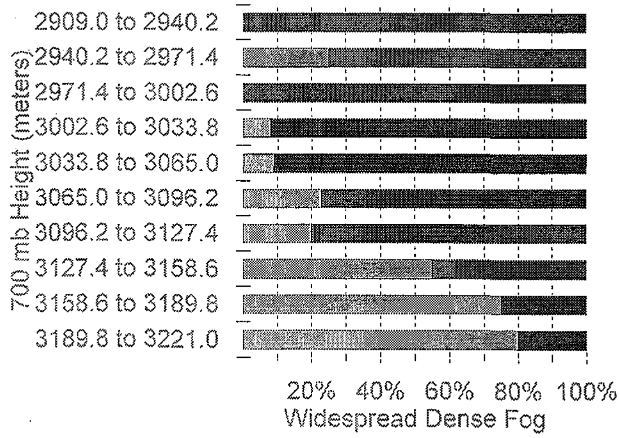


Figure 5. The percentage of widespread dense fog days in relation to the total number of days with observed 700 mb heights.

Other Considerations

a. Limitations. The 120 consecutive days were examined during a mild-moderate El Nino cycle, and therefore, overall synoptic patterns which may perceptibly influence San Joaquin Valley fog patterns may also deviate from what may be typically expected. Furthermore, as indicated earlier, only two locations were selected for surface observational data to confirm or refute the presence of dense fog. As is often the case, dense fog formation in the San Joaquin Valley changes spatially and temporally from one night to the next, with favored formation locales influenced by a host of factors. It is probable that on some days classed as "non-event" for purposes of this study, dense fog was observed at other Valley locations, aside from the two specifically considered. Additionally, upper air data used to calculate correlations were taken from a location removed from the San Joaquin Valley, introducing some degree of inconsistency. Finally, surface observations gathered to determine days with dense fog occurrences were assumed to occur in the predawn hours (not between sunset and midnight, local standard time); that is, no effort was made to differentiate between days where the dense fog occurred in the evening or in the morning of a particular day. Since this assumption was applied equally, and since on most days dense fog was experienced consecutively, no one statistic should be substantially impacted.

b. Value-Added Impacts. Despite the limitations mentioned above, examined correlations were still relatively high. And, of course, this negates the impact of forecaster judgment, which would serve to greatly improve the chances of successfully forecasting dense fog events. For instance, surface dewpoint depressions were not considered for this study; forecasters who can predict situations where upper heights are high, but dewpoint depressions are also high, could be assured of producing a forecast which dismisses fog development despite the upper height data suggesting otherwise. Further, since the obvious impact of cloud cover was also not considered, additional opportunity is presented for the forecaster to improve upon successfully forecasting fog events. In a cursory inspection, the 17 nights with 700 mb heights in the upper two categories (3158.6 meters and above) were further examined in an attempt to explain why four of these nights did not witness widespread dense fog (only one of these had no dense fog at all). Based on observer-augmented observations from the Fresno ASOS, ceilings at or below 20,000 feet AGL were observed some or all of the time between sunset and sunrise in every situation. In the one case where no dense fog was observed, a ceiling below 3,000 feet AGL persisted all night. Thus, when forecasters are reasonably confident of lingering overnight ceilings lower than those found with cirrus clouds, an additional forecast improvement over the stated correlations should be realized.

c. Other Variables. Surface gradients were also analyzed in order to ascertain their correlation to dense fog events. An observation time was chosen, 2 a.m. local standard time, and sea-level standardized surface pressures from Fresno and Bakersfield, located 100 miles south-southeast of Fresno, were tallied (FCC 2003). These locations were chosen due to ASOS reliability, the ability to locally archive these data, and to provide enough lateral distance to ensure routinely measurable surface gradients down the Valley. With only two observations unavailable during the entire study, dense fog occurrences at the Fresno and Hanford sites correlated to the strength of this gradient amounted to only +0.20; for widespread fog events, this correlation fell to +0.07. Analyzing the absolute value of this gradient yielded even lower correlations for both total and widespread dense fog events. Although the time chosen for comparison of surface pressures should accurately reflect favored times for dense fog development, significant differences in surface pressure on an hourly basis were noted, and given such a relatively short distance between observing sites, these changes, on a percentage basis, were occasionally quite large. Additionally, no surface gradient normal to the Fresno-Bakersfield set was analyzed with such rigor; synoptic charts were scrutinized on random days within this study to ascertain any obvious onshore/offshore gradients with respect to dense fog development. However, no pattern was easily recognizable.

d. Summary. Although it would be incorrect to assume that high upper level heights and the incidence of dense fog in the San Joaquin Valley constitute a "cause-and-effect" relationship, the evidence suggests that the former correlation is indeed surprisingly strong, especially when used in conjunction with acquired forecaster judgment. The exclusive use of observational data, rather than model data, to derive the findings presented herein should also help to eliminate some common biases and errors associated with determining probable dense fog environments. The data do support the expectation that higher upper level heights are well correlated to increasingly pronounced dense fog events on the Valley floor; however, correctly anticipating other important measures, such as boundary layer moisture, ambient cloudiness, and climatology, among others, provides for much greater skill and confidence in forecasting San Joaquin Valley dense fog events. With this in mind, the likely impact of resulting dense fog events can be more accurately gauged and subsequent implications on the populace can be assessed.

Acknowledgments

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