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COASTAL FOG FORECASTING AT MONTEREY, CALIFORNIA; AN OPEN-ENDED, OBJECTIVE, 3 TO 6 DAY APPROACH

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1. PREVIEW

To make a visibility forecast for specific times at the Monterey Airport, California using the approach to be described herein, first make a forecast of whether or not the air at any elevation in the early morning will be warmer than the adjacent ocean. If not, forecast no restriction to visibility other than expected frontal activity. If coastal presence of air warmer than the sea is forecast, then make a forecast of the expected height of the inversion base on a day to day basis for the early morning verification. Use this predicted once daily height of the inversion base to determine, from a table of frequencies, the probability of each of three different ranges of reduced visibility occurring on each day, the time of day upon which any expected period of reduced visibility is likely to be centered, and the probable duration of each period of expected reduced visibility.

2. OBJECTIVE

The objective is to determine for this site the most probable restricted visibility range which is likely to occur at any given time in the next several days, and also the probability that any more (or less) limited range of visibility might occur. It is sought to do this upon the basis of an acceptable physical model, using simplifications for practical use by the forecaster and commonly observed sequences of day to day changes in the height of the inversion base over this coastal region.

3. THE PHYSICAL MODEL

The model is similar to that first described for San Diego by the author (1948) and later reviewed for an air pollution application (1968). It deals with a combination of synoptic events which may occur along segments of the West Coast from Baja California to as far north as central Oregon. The most important such events are the upwelling of cold water along the coast and the occasional extension inland of the Pacific anticyclone, leading to offshore airflow and subsequent development of over-all atmospheric stability over the cold water region. The model is based upon the observation that, after a strong intrusion of the warm, dry continental air resulting from the downslope and offshore flow, there occurs in sequence the formation of a low inversion, the development of a mixed layer, and a gradual increase in the thickness of the layer. The range of thickness which is related to dense surface fog is that from zero to 400m. The shallowest layers within this range are associated with dense, patchy fog--often just off the coast during the day. The deeper layers below 400m are associated with overcast near the coast lowering to fog during the early mornings. The layers thicker than 400m have almost no associated fog but have low stratus overcast with some restriction to visibility. Analysis of data for Monterey Airport accordingly led to categorization of the synoptic development by ranges of inversion height: 0m, 1 to 250m, 251 to 400m, 401 to 800m, and higher or no inversion.

4. AIR TEMPERATURE FORECAST

The most common and possibly the only way in which the early morning air temperature at levels below 400m can become significantly warmer than the sea on the west coast is to have offshore flow (usually downslope) of air which has subsided inland due to the inland extension of the normally offshore positioned Pacific anticyclone. High maximum temperatures inland, at stations such as Fresno, and a definite but often weak offshore gradient for geostrophic flow are indicators of this situation. The early morning has the strongest tendency for the land breeze and coastal raobs at that time are best measures of the progress and extent of this type of warming.

In many cases, the excess of air temperature over sea temperature will increase over a period several days and the warm air will increase its vertical extent at the coast, often until it reaches from the surface to 1000m or so. When this heating ceases, the sequence of events described above in the section on the physical model may be expected to occur. Thus, the prediction or observation of the cessation of heating is a critical step in the forecast procedure. By the time heating ceases, air temperatures at some elevation will often exceed sea surface temperature by 10C or so.

Since the sea-air temperature difference is of primary significance in determining the overall vertical stability or the strength of the so-called subsidence inversion, it is the general level of the sea surface temperature over an area of tens of kilometers, and not the point value at a fixed time, which is important. A running curve of monthly averages or a reading from the biweekly fisheries charts provide appropriate values for this use.

The absolute air temperature rather than the potential temperature is used for this application since it is desired to have a value representative of the initial conditions which started the sequence at the coast rather than any value which would be used primarily for consideration of vertical motions.

5. FORECASTING INVERSION HEIGHT

The height of the inversion base is not an element of present synoptic forecasts. However, its importance in radio, radar, and light propagation, its utilization in air pollution predictions, its relation to diurnal range of temperature and its indicated value in forecasting west coast visibilities all give support for increasing the attention on this type of forecasting.

The Leipper (1948) model describes for the San Diego area a day to day gradual rise in the height of the inversion base following a given set of initial warming conditions. Such an expected sequence is useful in forecasting. The same rising trend in height of the inversion after a period of strong coastal warming has been observed in the Monterey area. Whereas such periods of warming are most significant in the winter in the San Diego area, farther north as at Monterey they are most noticed in the spring, summer and fall. This is due to the northward shift of the Pacific anticyclone when winter ends.

The author (1980) discusses some of the factors affecting inversion height and shows that they vary in space and time in a manner which gives hope of predictability. For example, the temperature of the air above the inversion is almost directly proportional, in the inverse, to the height of the inversion for several cases studied. Also, he recalls the data of Blake showing that maximum air temperatures at inland stations were directly related to inversion height at the coast. Then, Rosenthal, et al., (1980) showed that selected pressure differences between pairs of stations varied in time in a fashion quite similar to the inversion height in the CEWCOM experiment, giving evidence of another possible approach to forecasting height of the coastal and offshore inversion height and its synoptic variations.

From data at hand and completed analyses, it is clear that there is a pattern of change in height of the inversion which is consistent from day to day and relatively uniform over distances of hundreds of kilometers. This pattern is related to synoptic weather features which can be forecast. The observed height is a measure of the progress of related synoptic events to date and the continuing trend in height may be forecast using what is known about normal sequences of change following heating periods, and from association with other mesoscale variables which receive considerable attention in standard forecasts, such as maximum temperatures and horizontal pressure gradients.

At this time, a study of 34 fog related sequences at Monterey indicates that a lowering inversion may best be predicted by relating it to subsidence as expressed by high maximum temperatures inland and advection of the warm air offshore as indicated by slight offshore geostrophic gradients. Once the warm air has arrived over the sea and the offshore flow has terminated, it appears that the mixed layer deepens in a relatively systematic manner and that inversion height may be predicted for several days by assuming that this normal sequence will occur.

A sequence as used above is a period of days when the inversion first gradually lowers with upper air heating and then gradually rises as the marine layer again grows in thickness at a given location.

Average behavior is one useful guide in making day to day predictions. The following averages represent the 34 sequences observed in 1973 using the Oakland early morning raobs, which were the closest dependable observations to the Monterey Airport. The mid day of the period when the inversion was at its lowest level is taken as day zero, with prior days indicated by minus signs and following days by plus.

Table 1
Average Height of the Base of the Early Morning Inversion at Oakland during fog related sequences (1973)

Day	Height (m)	No. Obs.	Day	Height (m)	No. Obs.
-4	782	6	0	65	34
-3	570	27	1	199	34
-2	393	31	2	389	31
-1	235	34	3	436	21
			4	537	14
			5	594	7

In 29 of the 34 sequences, the inversion base did come down to zero. (It is important to note here that any time the early morning raob shows the air temperature at any elevation to be higher than the sea temperature, an inversion will exist when that air moves over the ocean; thus, these situations were listed as an inversion of zero height. Forecasters must become more conscious of this situation.)

From the table it can be seen that, at least on the average, there are periods of some seven to ten days when the inversion height goes through a systematic change--a period of lowering followed by a period of rising. On the average the inversion is below 400m, and thus in the range where dense surface fog is possible, for four or five days.

For practical three to six day forecasting of daily inversion heights once the period of heating and lowering inversion is at an end, the forecaster may assume that the ground inversion will last two to three days and that the base will rise at a rate such that it will be one day in the 0 to 250m category, one in the

Table II

Visibility Frequencies versus Height of the Base of the Inversion,
Air warmer than the sea, Monterey Airport, California, 1973,
April through November

No. Days	Ht. of BI (m)	Percent of days with vsby 0 to ½ mi.	0 to 3	0 to 7	Mid-time of occurring fogs 0 to ½ mi.	0 to 3	0 to 7	Avg. Duration (hours) 0 to ½ mi.	0 to 3	0 to 7
69	0	26 (19)*	36 (26)	82 (59)	03-04	00-12	any time	5.1	8.6	12.8
17	1-250	59 (10)	94 (16)	100 (17)	02-03	00-04	any time	6.1	12.	20.
35	251-400	34 (12)	71 (25)	97 (34)	01-08 04-06#	01-09 04-05	any time	3.5	7.6	19.5
53	401-800	6 (3)	40 (21)	89 (47)	02-09	21-10 00-06	any time	4.7**	8.3	15.6
79	No. Inv.	3 (2)	6 (5)	27 (21)						

*Number of days it occurred
#Most occurrences were in this interval
**This very seldom occurs (3 times)

251 to 400m category, and three days in the 400 to 800m category. He may then determine expected visibilities for these days as in the following section

6. VISIBILITY DETERMINATION

When it has been forecast that the early morning air temperature will be warmer than the sea for a given day and when the height of the early morning inversion for the same day has been predicted, then the probability of occurrence of different reduced visibility ranges may be read off from Table II. Likewise, the mid time of occurrence of each period of reduced visibility as well as the average duration of each may be determined. Used together, these quantities make it possible to tell for each hour of the day the lowest reduced visibility range to be expected and its probability, as well as the probability that less reduced visibilities will occur at that hour.

Table II is based upon only one year of data. Hourly visibilities were from the Monterey Airport and height of the inversion base was obtained from the Oakland raob. A better table could be prepared by lengthening the time over which averages were determined and by having the radiosonde observation made at the same location as the visibility observations. However, the good indications obtained, despite the fact that the present data sources were some 90 miles apart, supports the mesoscale character and consistency of the phenomena involved. On the other hand, it is fairly obvious that suitable allowance for the differences in location would improve the relationships indicated here.

Inspecting Table II, dense fog (0 to ½ mi.) is most probable with an inversion base between 0 and 250m. Moderate fog (0 to 3 mi.) and light fog (0 to 7 mi.) are also most probable in this range. With inversions 400 to 800m high, few dense fogs occur but 40% of the days had visibility reductions to less than three miles.

When the inversion is based at the surface, atmospheric heating may still be occurring and the offshore drift will prevent the fog from moving to the coast and inland. If the offshore drift has stopped, fog is more likely.

7. VERIFICATION

Efforts have been initiated to verify forecasts of the height of the inversion made using the sequential timing described in the last paragraph of the section above on forecasting inversion height. It is hoped to test these forecasts against the climatology of the inversion height and against persistence. However, considerable work needs yet to be done along this line.

8. REFERENCES

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