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FORECASTING THE TIME OF FORMATION OF STRATUS CLOUD CEILING AT OAKLAND, CALIFORNIA AIRPORT

by
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INTRODUCTION

The purpose of this paper is to outline the development and use of a method for forecasting the time of formation of summer stratus clouds with ceiling of 2000 feet or less at Oakland Airport (California) between the hours of 4:30 P.M. and 6:30 A.M. In the development of this method special consideration has been given to the need for a procedure which can be used by forecasters who are new to the area under consideration and can benefit by a "formula" for forecasting the summer stratus, thereby eliminating the personal equation until such time as their experience in this area will justify the introduction of variations based on personal observations and studies.

Recognizing that every forecast is in a sense an expression of probability, an attempt has been made not only to provide a means of arriving at the most logical forecast, but also of saying to what extent the forecast may be depended upon.

DERIVATION OF THE METHOD

Stratus clouds of sufficient extent to constitute a "ceiling" occur at Oakland Airport approximately 63 out of one hundred summer nights. The stratus may be regarded as an extension of the summer sea fog of the California coast (1). Although sea fog usually forms at the ocean surface, it becomes elevated over San Francisco Bay and adjacent areas because the condensation level is raised as the air is warmed while passing over the San Francisco Peninsula and the warmer surface water of the Bay.

It is at once apparent that a sea breeze is a prerequisite condition for formation of the cloud. It is also apparent that the pressure distribution must be such as to cause an onshore component of wind strong enough to counteract the tendency for a land breeze during the night, since otherwise the cloud would not occur during the night. Thus, we should expect that the time of formation of the cloud will be, in some degree, a func-

(1) Byers, H.R., Synoptic and Aeronautical Meteorology pp188-189.

tion of the southeast-northwest pressure gradient, since such a gradient would produce the required onshore component of wind. Hence:

$$t = f_1 \ (\Delta P/\Delta x), \qquad 1.$$

which states that t, the time the stratus ceiling will form, is a function of the pressure gradient, measured in this case from southeast to northwest.

It is well known that the cloud under consideration forms when the condensation level is lower than the temperature inversion.(2),(3). The condensation level rises and falls in phase with the diurnal temperature curve provided the specific humidity remains constant, a condition approximately fulfilled in most cases. For this purpose the height of the condensation level in feet may be computed as a constant (220) times the depression of the dew-point. For example, if the depression of the dew-point were 10°F, the condensation level would be 2200 feet. If the base of the temperature inversion were at 1600 feet, the temperature would have to fall 3° F in order to reduce the condensation level to less than 1600 feet and permit the cloud to form. It follows that the time of formation of the cloud is a function of the depression of the dew-point, Δ Ts. Hence:

$$t = f2 \ (\Delta T_s). \qquad 2.$$

From the preceding, it is clear that the time at which the cloud forms will also be a function of the height of the inversion. However, the records available for this study did not include data on the height of the inversion in late afternoon. For this reason it was decided to try another element which would be related to the vertical temperature gradient and perhaps in some degree to the height of the inversion. The temperature difference between Oakland and Mt. Hamilton (Elev. 4212 feet) was selected and the assumed relationship between it and the time of cloud formation was expressed by:

$$t = f_3 \ (\Delta T/\Delta Z). \qquad 3.$$

Combining equations 1., 2., and 3.;

$$t = f \left(\frac{\Delta P}{\Delta X}, \Delta T_s, \frac{\Delta T}{\Delta Z}\right). \qquad 4.$$

(2) Petterssen, S. On the Causes and the Forecasting of the California Fog. Bull. Am. Met. Soc., Vol. 19, No. 2, 1938.
(3) Vernon, E.M., The Diurnal Variation in Ceiling Height Beneath Stratus Clouds. Monthly Weather Review, Vol. 64, No. 1, 1936.

Using records compiled during the years 1934 through 1940, scatter diagrams were constructed to test for the nature of the relationship between the time of ceiling formation and each of the independent variables in equation 4. In each case it was found that for practical purposes the relationship could be regarded as linear, suggesting the following regression equation:

$$t = k_1 + k_2 \left(\frac{\Delta P}{\Delta X}\right) + k_3 (\Delta T_s) + k_4 \left(\frac{\Delta T}{\Delta Z}\right). \qquad 5.$$

in which the k's are the regression constants. The time t is measured in hours after 12:30 p.m., P.S.T.

The next problem was to obtain values for the k's so that equation 5 could be used as a formula. Time was not available for determining the values for each month of the summer sea fog season, so it was planned to determine them for April, July, and September and then interpolate for intermediate months. However, upon considering the validity of such a procedure, attention was brought to the unusual nature of the seasonal march of temperatures in the San Francisco Bay Region.

Instead of following the usual form, which would mean a rise from April to July followed by a fall through the later summer and autumn months, the San Francisco temperature curve rises from April until the last decade of June and then falls slightly until the last decade of July, after which it rises until the end of September. Fresno, California, which is located in a valley far removed from the sea breeze, has a mean temperature curve of the type which we should expect of San Francisco were it not for the effect of the sea breeze on the latter. The two curves are compared in the Figure. The differences between them are related to the strength of the sea breeze and therefore to the stratus cloud. From this it is reasoned that there is some justification for interpolating between k's derived for the whole month of April, the last decade of June, the last decade of July, and the whole month of September to find values for the intervening periods.

This course was decided upon and by means of multiple correlation the k's were determined from seven years of record, using only cases in which stratus cloud formed. The k's are given in Table 1, the use of which will be explained later.

Coefficients of multiple correlation were computed for April, June (last decade), and July (last decade)(4) and found to be .85, .90, and .87 respectively. The standard error of estimate of the time of stratus formation for the same months was derived as 1.6, 2.8, and 2.1 hours. Assuming normal distribution, Table 2 was prepared from the standard errors to show what degree of confidence could be placed in forecasts based on the regression equation. The use of this table will become apparent in an example to be given.

(4) This study did not extend beyond the month of July due to the fact that detailed data for August and September had been loaned out for another research project.

Values for substitution in equation 5 are determined from 4:30 p.m., P.S.T. data as follows:

P_{eu} = Barometric pressure at Eureka in mb.
P_{rg} = Barometric pressure at Redding in mb.
P_{oa} = Barometric pressure at Oakland in mb.
T_{oa} = Temperature at Oakland in °F.
T_{mh} = Temperature at Mt. Hamilton in °F.

$$\frac{\Delta P}{\Delta X} = \frac{P_{eu} + P_{rg}}{2} - P_{oa}$$

ΔT_s = Depression of dew point at Oakland at 4:30 p.m., P.S.T.

$$\frac{\Delta T}{\Delta Z} = (T_{oa} - T_{mh})$$

Substitution of these values in equation 5 yields t, an estimate of the time in hours after 12:30 p.m., P.S.T., at which stratus cloudiness may be expected to form a ceiling at Oakland Airport. If t is later than 6:30 a.m., of the following day, stratus cloudiness should not be expected to occur in sufficient amount to form a ceiling. Hence, when t is greater than 18.5, the prognosis is that the stratus ceiling will <u>not</u> form.

EXAMPLE OF THE USE OF THE FORECASTING EQUATION

Given that

P_{eu}	Barometric pressure at Eureka	=	1018.2 mb.
P_{rg}	Barometric pressure at Redding	=	1011.3 mb.
P_{oa}	Barometric pressure at Oakland	=	1014.3 mb.
T_{oa}	Temperature at Oakland	=	71° F.
T_{mh}	Temperature at Mt. Hamilton	=	67° F.
ΔT_s	Depression of dew-point at Oakland	=	15° F.

then from the above,

$\frac{\Delta P}{\Delta X}$ is computed to be 0.5

$\Delta T/\Delta Z$ is computed to be +4.0

while from Table 1 we obtain the values of the appropriate regression constants as follows, assuming that the date under consideration is July 20th:

k_1 = -9.17
k_2 = 1.00
k_3 = 1.50
k_4 = -.12

Substituting in equation 5 gives t = 13.4 hours. Hence, the stratus cloudiness may be expected to form in sufficient amount to constitute a ceiling about 13.4 hours after 12:30 p.m., or at 1:55 a.m.

The question now arises as to what accuracy may be expected of this forecast. For example, we may wish to know what the odds are against a ceiling forming by 11:00 p.m., P.S.T. If the ceiling forms within 2.9 hours of the time forecast by the formula, it will not form until after 11:00 p.m. In the hypothetical example just computed, we assumed that the date was July 20th. By referring to Table 2 we see that the ceiling may be expected to form within 2.9 hours of the time forecast by the equation about 84 times out of 100 cases. This reduces theodds to about 11 to 1 that the ceiling will not form by 11:00 p.m., since in approximately half of the misses it would form later rather than earlier than the forecast time.

TEST OF THE FORMULA DURING 1942.

The formula was tested during June and July, 1942 and the results are given in condensed form in Table 3 which may be summarized as follows: In June the formula was correct 26 times out of 30 in indicating whether or not a stratus ceiling would form. In July the score was 30 times out of 31. In the two months there were 5 cases in which a stratus ceiling was forecast and not observed. However, in 3 of these cases the forecast time was 5:30 a.m. or later and the forecast could be considered correct to the extent that it indicated virtually the entire night would be free of stratus ceiling.

Stratus ceiling formed on 43 nights, on 20 of which the formula forecast time was correct within $\pm$ 1 hour. On 25 nights it was correct within $\pm$ 2 hours, which is very close to the expectancy of 24 nights derived from Table 2; while on 10 nights the formula forecast time was in error by more than 4 hours as compared with an expectancy derived from Table 2 that this would occur on but 4 nights.

CONCLUSIONS

While the results of this study are not as good as had been hoped for, it is believed that the formula will be of some value to forecasters new to the San Francisco Bay Area provided it is applied only to conditions at the Oakland Airport. It is probable that it would work fairly well for Alameda (Naval Air Station) provided the depression of the dew point at that place is used in making the computations. It might also work for Hayward under similar conditions. After sufficient experience with local conditions the forecaster can modify the formula forecast on the basis of several helpful criteria.

For example:

1. If the formula time, t, indicates that a ceiling will form, correct t by adding 3 hours if the Tonopah, Nevada pressure is less than 1 mb. lower than Oakland; add 4 hours if the Tonopah pressure is more than 1 mb. higher than Oakland. (4:30 p.m., P.S.T. data).

2. When the Tonopah 4:30 p.m., pressure is higher than the Oakland pressure, the ceiling, if it forms at all, will probably be less than 500 feet.

3. When the Point Arguello pressure is as much as 1.5 mb. lower than Oakland, a stratus ceiling is not likely to form at Oakland, regardless of what other data may indicate.

4. When the Eureka, California pressure is lower than the Oakland pressure, the stratus is likely to be broken through most of the night rather than to form a solid layer over the Bay Region.

5. If the afternoon wind at Oakland reaches a velocity of 25 m.p.h. the stratus deck is likely to remain broken or scattered a large part of the night.

6. Frequently the isobars near the coast will form a loop by bending toward the sea and then back to the coast. If the loop is south of Oakland, stratus ceiling is not likely to form there. This rule holds for most of the California coast; stratus ceiling is not likely to form north of the loop but is quite likely to form to the south of it. The loop may be regarded as an eddy which, once formed, will usually move slowly northward causing the area covered by the stratus conditions to extend farther north on successive nights.

It is believed that this approach to the solution of local forecasting problems holds more promise than the degree of accuracy attained in this particular study indicates. It is apparent, from first hand study of the data, that better results could have been obtained had it been possible to use actual data on the height of the inversion rather than the value $\Delta T/\Delta Z$. Also, the pressure gradient function used does not define the pressure gradient with sufficient accuracy. In future studies of this nature it is suggested that two variables be used to define the pressure gradient, one for the direction and the other for the magnitude, and that these be determined by vector addition of the gradients between the project station and three or more other points.

TABLE 1.

Regression constants for use in forecasting by equation 5 .

Date		k_1	k_2	k_3	k_4
April	15	1.54	.16	.68	.09
	20	1.98	.37	.66	.09
	25	2.43	.58	.63	.09
	30	2.87	.80	.61	.10
May	5	3.32	1.01	.59	.10
	10	3.76	1.22	.57	.10
	15	4.20	1.44	.54	.11
	20	4.65	1.65	.52	.11
	25	5.10	1.86	.50	.11
	30	5.54	2.08	.48	.11
June	5	6.07	2.33	.45	.12
	10	6.52	2.54	.43	.12
	15	6.97	2.76	.40	.12
	20	7.41	2.97	.38	.13
	25	7.86	3.18	.36	.13
	30	4.45	2.75	.59	.08
July	5	1.05	2.31	.81	.03
	10	-2.36	1.87	1.04	-.02
	15	-5.76	1.43	1.27	-.07
	20	-9.17	1.00	1.50	-.12
	22	-10.53	.82	1.59	-.14

TABLE 2.

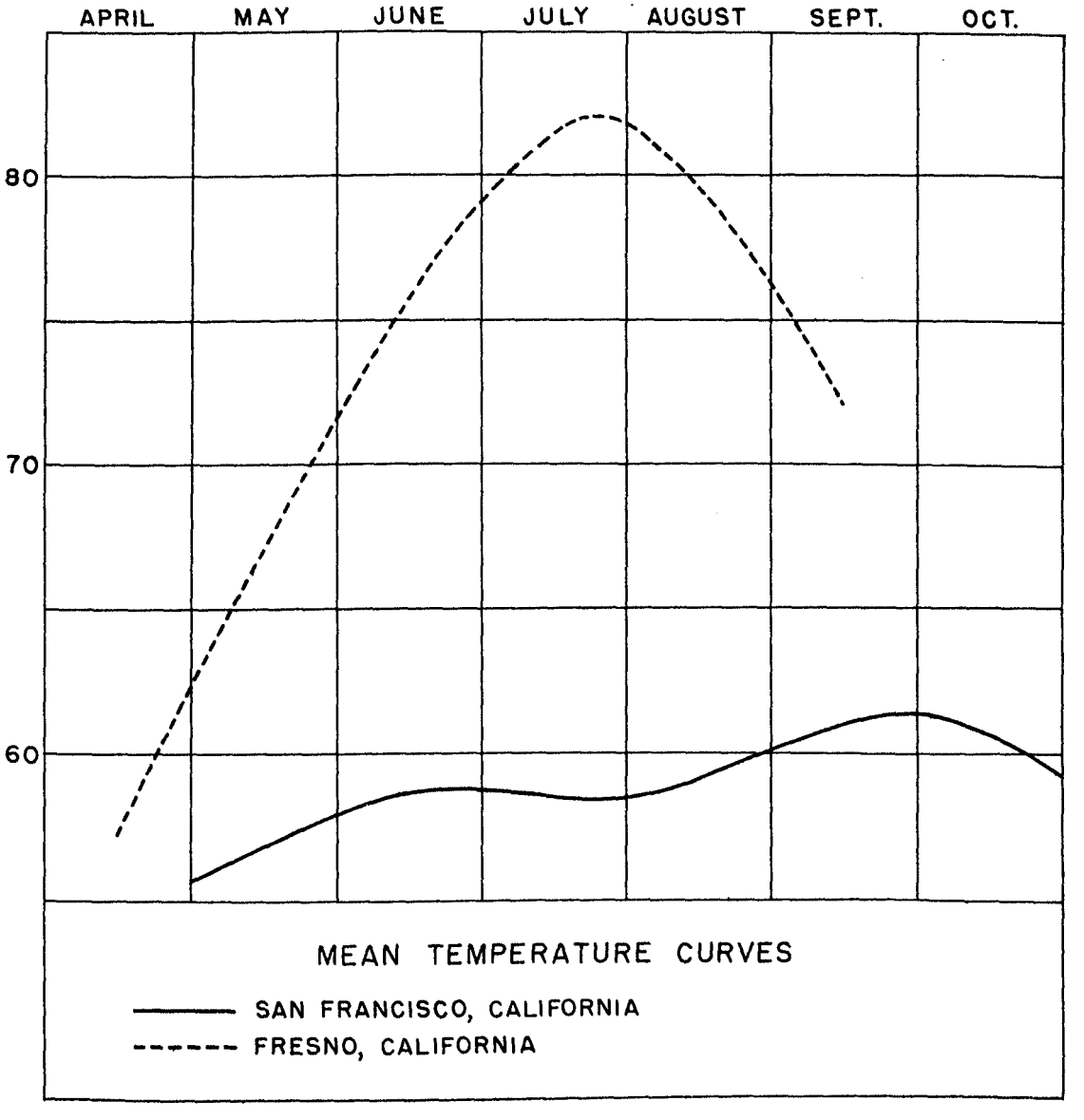
Tabular values give percentage of cases in which ceiling may be expected to form within the specified number of hours of the formula forecast time. This table has been computed theoretically from normal distribution. Cases in which ceiling is forecast but not observed make no contribution to the table, since the correlation was based only on cases in which ceiling occurred.

Hours ±	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0
April 15	58	77	88	93	97	98	99	
May 15	56	66	77	85	90	93	97	
June 15	52	56	66	76	83	87	95	
July 15	52	64	74	85	89	93	98	99

TABLE 3.

Comparison of Forecast and Observed Conditions in June and July, 1942.

Difference between forecast and observed time in 43 cases in which stratus ceiling formed.	Number of cases		
	June	July	Total
± 0 to 1 hour	7	13	20
±1-1/2 to 2 hours	1	4	5
±2-1/2 to 3 hours	0	2	2
±3-1/2 to 4 hours	2	4	6
±4-1/2 hours or more	4	6	10
Total cases	14	29	43
Stratus ceiling forecast and observed	14	29	43
Stratus ceiling not forecast and not observed	12	1	13
Stratus ceiling forecast and not observed	4	1	5
Stratus ceiling observed and not forecast	0	0	0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JUNE
JULY
AUGUST
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80
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MEAN TEMPERATURE CURVES
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