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WEST COAST FOG AND STRATUS EVENTS AT AIR TERMINALS AND RELATED WEATHER SUMMARIES

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1. INTRODUCTION

The fog/stratus events discussed below are those events described in the LIBS (Leipper Inversion Base Statistics) synoptic sequence first noted by Leipper (1948, 1968) and later applied at Monterey Airport, California (MRY) (Leipper 1994, 1995, 1996). They represent only new and developing fog/stratus cases. They occur from Baja California northward along the west coast to British Columbia. They usually occur about two times each summer month north of Los Angeles and each winter month south of there. They are also noted in other parts of the world having similar coastlines, coastal mountains and cool adjacent oceans. A brief review of the LIBS method will indicate the nature of the observational information needed in the data summaries.

2. THE LIBS SYNOPTIC METHOD

The term fog/stratus is used because California fog and stratus are closely related and because there is often fog at sea when there is stratus at shore terminals. The LIBS new fog/stratus synoptic events start with the advection of hot dry air, more than 5°C warmer than the sea surface, over the cool ocean. This brings about a very strong near surface inversion over the sea which is followed by the development of a shallow fog. The fog creates a mixed layer. The layer grows in depth from day-to-day due to radiational cooling from the fog top and heating of the cold fog by the underlying ocean. (Koracin and Rogers 1990, Leipper and Koracin 1998). The fog layer grows until it reaches approximately 400 m in depth when it lifts from the surface to become stratus. The sequence usually takes about five days. It often has trapped coastal disturbances associated with its growth after it reaches an inversion height of approximately 200 m (Ralph et al. 1998).

When the LIBS sequence terminates and at other times there may be continuing fog/stratus which may be called "mature" fog/stratus. The prediction of the fog/stratus on these occasions depends more upon diurnal variation and less on synoptic changes than does LIBS.

In making a summary, one must face the fact that there are multitudinous sources of data and information and that careful selection of representative observations must be made. In LIBS the early morning observations are selected to show the day-to-day changes. Of these, for MRY and San Francisco Airport (SFO), the (12Z) Oakland (OAK) RAOB is chosen as the representative observation. The height of the inversion base (BI) and a temperature index are taken as the key elements of that observation. The hours between early morning RAOBs on successive days are analyzed by categorized synoptic climatology. Categorization is by ranges of BI.

The BI is assumed to indicate the top of the stratus cloud. Since the 1930's, tests have shown the OAK RAOB to be applicable at MRY as well as at SFO.

Given a LIBS forecast of the day to day synoptic situation, the hour to hour forecast of fog/stratus for a particular terminal may be made from a forecast aid developed for that station. See Figure 2 for an example at MRY.

An indication of the operational usefulness of the LIBS approach may be gained from a statement by Maux Barnes, a retiring Lead Forecaster at Monterey who had made use of LIBS in the 1996 season and wrote on November 20, 1996:

> *" --we have been using your LIBS West Coast Fog and Stratus Forecasting Method for the past six months and have found it to be very useful for forecasting : 1. The onset of-, 2. The changing of -, and 3. The duration of -- - Fog and Stratus along the Northern and Central California Coast. ---it appears to be the best and the most practical method of forecasting fog and stratus that is available at this time."*

After a very clear cut set of initial conditions are observed, (see Table 1), and especially when the offshore winds are strong and the lower air column at the coast is more than 5°C warmer than the sea, the LIBS synoptic sequence of fog/stratus events may be expected to occur over the coming week.

2.1. Initial conditions for a LIBS synoptic sequence

An example of the required initial conditions occurs with the well known Santa Ana wind. These conditions usually are observed one or more days before the LIBS synoptic sequence begins. A difficulty in forecasting is to know just when the initial conditions will weaken and the synoptic sequence will begin. A temperature index gives some indication of this. From this time onward, the phases of an undisturbed sequence development may be briefly described by the following synoptic categories, Since these categories or phases may be expected to follow a good set of initial conditions, they constitute the basis for a forecast for the coming days. The categories are listed on the data summary forms. The conceptual model described here is being investigated thoroughly in coastal modeling and climatological studies.

For the categories 4 through 7 in Table 2, forecast aids have been developed for MRY. These aids enable detailed forecasts of fog to be made for that site. One of these aids for BI between 250 and 400 m is shown here as Figure 2. The aid makes possible the prediction of the

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1. An inland extension of the Pacific anticyclone
2. Downslope offshore geostrophic winds over segments or all of the coast
3. Air temperatures in the lowest 1000 m column at the coast 5°C or more higher than the sea surface temperature
4. Coastal visibility of 20 to 55 miles
5. Clear area 100 to 200 km wide building outward from the coast.
6. A strong surface or near surface inversion offshore. (An inversion may not appear on the coastal RAOBs because of unusually high surface temperature on land.)
7. Western slope forest fires appearing quite often in the national news

Table 1: Initial conditions for a LIBS synoptic sequence

probability, duration and times of formation and breakup of dense, moderate and light fog at MRY,

The primary objective of the present FAA Grant is to extend the MRY aids into the BI range above 400 m, where troublesome stratus occurs, and to prepare similar climatological aids which will guide the short term (6 hours) prediction of the breakup time of stratus at SFO as the Monterey aids do for fog at MRY.

2.2. Categories for a LIBS synoptic fog/stratus forecast

The LIBS sequence for a particular fog/stratus event may differ from the above description by being cut short or by passing more or less rapidly through the various stages. There is evidence that such differences may be anticipated by the exact nature of the initial conditions. Some of the indications are variations in the north-south length of the coastal band involved, strength and duration of the initiating offshore wind, the value of the temperature index and the dimensions of the area cleared offshore.

3. DATA SUMMARIES

Although NWS stations at Monterey and Oakland provide many types of data presentations and forecast aids for the use of operational forecasters, they do not have means for recording sequences of synoptic weather events over periods long enough for the study of synoptic developments nor for the evaluation of forecasts. This has led to the active use of day-to-day summaries prepared by duty forecasters for monthly periods such as are discussed here. The first application of the summaries has been to the Monterey Airport (MRY). The categories listed above have been modified toward an SFO application.

There are two different data summaries introduced here. As well as can be done in a brief summary, both of them are intended to show key features of the day-to-day changes in the synoptic weather pattern. The first is a table of information from early morning RAOBs, surface observations and afternoon remote imaging. This table was first used for studying fog/stratus events at Monterey. The second summary presented here is a graphical one featuring representation of stratus periods for both Monterey and San Francisco Airports, surface pressures at each terminal with notations of fog, cloud cover and unusual synoptic events.

The forecasters at CWSU (Center Weather Service Unit at the at the Oakland Air Route Traffic Control Center) have for many years maintained daily logs of the elements they utilize in their forecasts made throughout the day. These logs summarize the hour-to-hour changes used in short term (zero to six hour) forecasts. They will not be discussed here.

4. THE TABULATED SUMMARY

As the tabulated summaries were used by DFL and DW over a two year period, the usefulness of the different elements was evaluated and changes were made accordingly. Working with Walter Strach, the senior meteorologist at the FAA Oakland Center, this summary is being modified for application to fog/stratus events at SFO. This application is in the preliminary stage. Each sheet of the summary contains one line for each day and holds 31 lines. Table 3 lists headings of the columns which make up this first data summary and gives a brief

1. FN - No initial conditions are observed. No LIBS sequence is in progress. No fog or stratus predicted in the next five days. This is an important forecast, especially in fog season. Although most forecasters have a feeling for it, LIBS gives some numbers to support the hunches.
2. FO - A strong offshore geostrophic wind indicating that the initial conditions for fog/stratus would develop; that there might be a fog/stratus sequence in the coming five days. A clear area is building outward along the coast.
3. FS - Some fog at sea in the formerly clear area.. The initial conditions for fog/stratus are present; TI >5°C , sometimes much greater. Fog/stratus is to be expected on the coast in the coming five days in the following phases.
4. Phase 1 of LIBS - BI near zero, TI > 5°C, easterly wind easing., some fog at MRY, no stratus at SFO
5. Phase 2; BI> 20 m, < 250 m, TI > 5°C - light winds., moderate or dense fog at MRY, still little stratus at SFO. There may be strong southerlies near shore.
6. Phase 3; BI 250 to <400 m, TI >5°C - Less MRY fog, May get surges, trapped waves. Fog at coast, Stratus at SFO. If any, watch for early breakup at SFO? See Fig. 2 for MRY forecast aid.
7. Phase 4; BI 400 to 600 m - low stratus forecast with small probabilities of reduced visibility. Late breakup at SFO?
8. stratus with BI > 600

Table 2: Categories for a LIBS synoptic fog/stratus forecast

definition of each. This list appears on the data summary form.

4.1. Sample automated data summary for Monterey

Figure 1 is a sample of the automated output of elements of the tabled data summary. Each line represents one day. The program has run since June 18, 1997. It was worked out and maintained by coauthor DW.

4.2. Use of the tabulated summaries

1) general considerations

Since there is a line in the summary table focused on the 12Z weather each day, the summary makes it relatively easy to review the recent day-to-day changes in the synoptic situation, i.e. to determine synoptic trends without the complication of diurnal changes being involved. This is helpful for all types of forecasting. The tabulated summary may be supplemented by satellite images and a daily surface or upper air weather map.

To forecast fog/stratus synoptic sequences in operations, a watch is kept on the summary as entries are made, looking for an unusually high temperature index associated with a near surface inversion. When these are noticed, the other indications of a LIBS set of initial conditions, Table 1, are investigated. If these are favorable or if it is determined that such a sequence is already underway, a synoptic forecast can be made using the phases listed in Table 2.

2) a special case

In an experiment with such a synoptic forecast, favorable initial conditions were noticed on August 4, 1998. A real time forecast for SFO for five days was made and distributed that afternoon.

The nature of the forecast was determined by an important goal of the FAA program. This is to predict the breakup time at SFO and to do this in the morning briefing, about 1530Z, using the latest observations available at 12Z. Considering this, an effort was made in the five day forecast to forecast pertinent variables by the specific day and hour. This was expecting more detail than the LIBS forecast, Table 2, can provide. However, the distributed forecast did describe the succession of events which were to be expected in the coming days. They occurred on a schedule very close to that of the forecast. The BI did increase gradually as predicted from Table 2 with observed values being 2, 171, 215 , 431, and 565 m respectively on successive days.

For the specific operational briefings described above, it is not necessary to depend upon values predicted in the five day forecast. An observation is available just before the briefing. On the basis of the observed values, 2, 171 and 215 m, there would have been no stratus at SFO and therefore no breakup time for the first three days. This was as forecast.

BI = height of the inversion base in meters above MSL. This is the key index defining LIBS synoptic categories.

sta - surface air temperature on morning RAOB. Usually near sea surface temperature

ta = highest temperature in lowest thousand meters (3281 feet). Related to inversion strength..

sst = sea surface temperature

TI - inversion strength in degrees C. This is the excess of ta over sst and is the second index along with BI to synoptic changes not shown on synoptic maps

pw = precipitable water. Meant to indicate changes in long wave radiation. High moisture, lower chance of fog/stratus. Not practical so far.

dc = depth of calm, surface layer of sounding with < 5 km winds

gws = geostrophic wind speed

gwd = geostrophic wind direction. Wind at 1000 m usually taken. Some use 850 mb wind. The surface weather map has been found most useful.

p 12z = surface pressure at 12Z Indicator of synoptic change.

d 21z - surface dewpoint at 21 Z. The sea breeze at this time is an Indicator of relative humidity at sea. and the intrusion of marine air inland.

frm - observed formation time of fog or stratus

BU - observed breakup time at SFO. (Broken or overcast goes to scattered or clear).

sat = visible satellite view at 21z

MinV - minimum visibility during fog day (24 hours beginning at 00Z)

Cig - minimum ceiling during fog day.

OBU - Time that SFO cleared for sideby operation

Table 3: Column Definitions and notes for the tabulated data summary

Figure 1 - Automated Data Log

DATE	BASE	THKNS	Ta	SST	TI	PHASE	BASE2	THKNS2
970618	840	2397.8	21	12.9	8.1	3		
970619	9.8	341.2	25.4	12.6	12.8	1	798.5	2181.3
970620	9.8	344.5	21.8	12.8	9	1	1249	2265
970621	1185.3	427.8	18.8	13.4	5.4	3	2107.9	1401.3
970622	1465.1	576.2	16.2	14.1	2.1	4	2667	456.8
970622	1465.1	576.2	16.2	14.1	2.1	4	2667	456.8
970622	1465.1	576.2	16.2	14.1	2.1	4	2667	456.8
970625	9.8	195.7	25.2	14.1	11.1	1	765.7	1909.7

The day with 431 m BI occurred on August 7th. The five day forecast had predicted for August 6 or 7, "now the BI will have reached 400 m or more." This value of 431 was just outside the range when an early BU would be expected

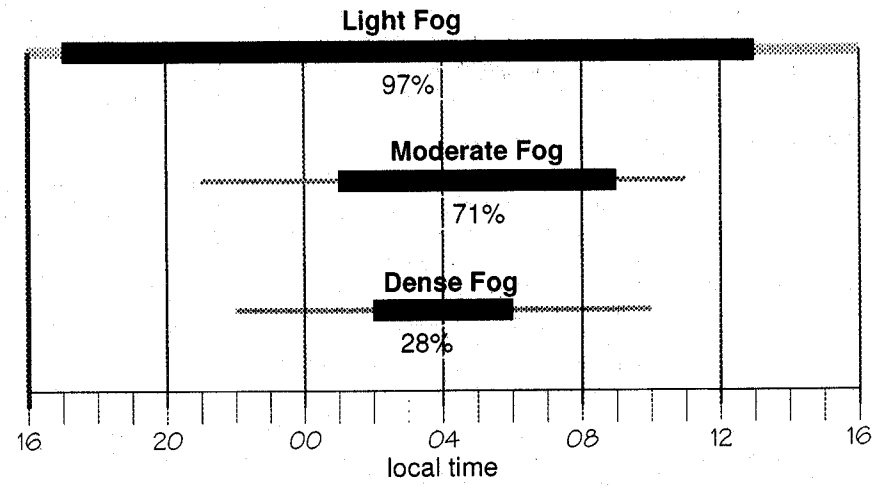
as predicted . One, which had been forecast, did not occur.

The 565 m BI day fits the BI range of 400 to 600 m (phase 4) of Table 2 when a late breakup at SFO is indicated. On that day, which was August 8, according to MRY forecaster Warren Blier, cloud cover went " --to overcast at 16Z, back to scattered at 20Z, and then to broken again at 22Z but only for 2 hours--". This should qualify as a late BU as was forecast.

The five day forecast made predictions not known to have been attempted in other approaches, i.e. the five day prediction of BI, the occurrence of fog at MRY and later stratus at SFO, and the occurrence of BU times for days ahead including a late BU.

Figure 2: Fog Forecast Worksheet

Monterey Airport 250m < BI <= 400m, Ta > Tw



The tabled data summary was invaluable for retracing the five day period for which the forecast was made and also for the period of days leading up to the initial conditions on August 4th, the date initial conditions were observed. This trial forecast review was only one example of the many ways in which a summary table is useful.

5. USE OF THE GRAPHICAL SUMMARIES

The second data summary, developed by JM, is a graphical representation showing the duration of fog/stratus events from day to day at both MRY and SFO and related observations. See Figure 3. As previously mentioned, It also features surface pressure trends.

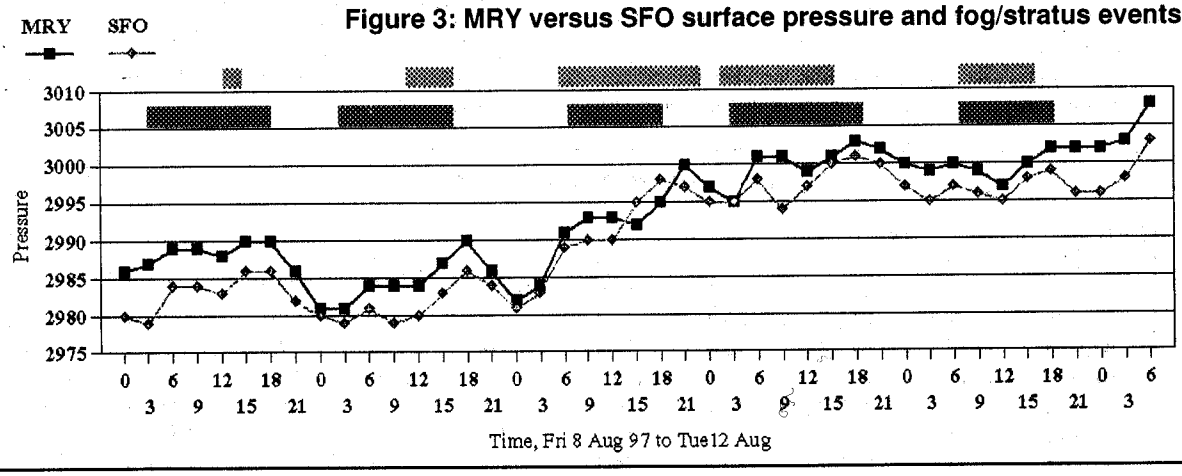
The working graphical summary represented by Figure 3 has a grid of one tenth inch to represent one three hour time interval. Thus, time may be read to the nearest hour, one third of a grid block. Also, along each curved line representing surface pressure, there is entered the weather every three hours: the cloud cover, and visibility in fog, if any fog. Miscellaneous notes are written in as desired.

Figure 3 is a representation of a segment of the graphical summary taken from an early version in August 1997. It may be seen that the duration bars for MRY and for SFO are different. Much of the difference is related to the differences in the coastline and the topographical settings. Monterey Airport, although somewhat protected, is more directly exposed to the open ocean than SFO

The period illustrated in Figure 3 follows two days, August 4th and 5th, on which some of the initial conditions for a LIBS new fog/stratus synoptic sequence were satisfied. The inversion base was at the surface and the temperature indices were 9.2 and 12.6 respectively. Dense fog occurred at MRY on the 6th, was gone the next day but light fog with a minimum of 3 miles returned on the 8th. (The fog data is not shown in Figure 3).

On August 8th there was only the slight restriction to visibility (3 Mi.) and stratus occurred at both MRY and SFO. Satellite imagery showed no clear area offshore for

Figure 3: MRY versus SFO surface pressure and fog/stratus events



new fog development. The sequence therefore progressed rapidly and there was stratus at MRY through this period. SFO, on the other hand, shows increasing stratus from the 8th through the 10th. Short segments of stratus as shown for SFO on the 8th and 9th are often associated with early breakups (BUs). In Figure 3 the BU at SFO on the 8th was 1600Z, an early BU, whereas on the 10th it did not occur until 2300Z and then reoccurred two hours later, a late BU.

Following the days shown in Figure 3, the stratus at SFO for August 12 through the 14th, settled into what has above been called "mature" stratus

5.1.some general considerations.

A study of the graphical summaries through the summer indicates that this succession of early and late breakups at SFO is often associated with the LIBS sequence .This may be explained by the fact that, when a growing fog reaches just the height to allow some of it to pass over the topographic protection afforded SFO, approximately 250 m, only a small amount passes over and this cannot persist very long. Then, when the heat index reaches a maximum, the associated strong westerly sea breeze above 250 m in the afternoon (Banta 1995) prevents the retreat of the stratus and leads to a late or no breakup at SFO. Forecasts of such occurrences are difficult to make and are of considerable importance.

The earliest uses of the graphical summary were in relating surface pressure variations to fog/stratus at MRY and SFO. These uses were based upon the principle that the larger the amount of marine air in the OAK lower air column, the more probability there is for fog or stratus. In the summer season there is often little activity in the upper air column. This allows changes in the lower 2000 m or so to be reflected in the surface pressure changes.

Figure 3 shows several cases where a decrease in MRY surface pressure was associated with the clearing of the stratus.

A problem with the graphical summaries is that they cannot readily nor conveniently be reproduced and distributed. One difficulty is the physical size of the summary. Also, the determination of times of formation and breakup, the cloud cover, the fog visibilities and other important parts of the summaries cannot readily be determined unless there are unusually good reproductions of the summaries.

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