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FORECASTING MARINE AIR INTRUSIONS INTO THE SACRAMENTO VALLEY

Mike Staudenmaier, Jr. - NWSO Sacramento

Abstract

Significant intrusions of marine air into the Sacramento Valley are usually not forecast well by model guidance. Many times this marine intrusion is not forecast and suddenly develops by late afternoon causing strong southerly winds over 20 mph and rapid temperature falls. Occasionally, this marine intrusion lasts through the night bringing stratus into the Sacramento Valley by morning. This usually results in lower maximum temperatures, and IFR conditions at the local airports. This paper will discuss this feature and address ways to improve the methods used in forecasting the intrusion.

Introduction

Summertime weather forecasting in the southern Sacramento Valley is usually a fairly routine procedure. Normally, the sky is clear, the temperature high, and the relative humidity low. During most evenings, the winds will switch to the south and slightly cooler marine air will flow into the Sacramento area, but not much further north. Occasionally, however, a strong penetration of deep, cool, moist marine air moves through San Francisco Bay, the Carquinez Strait, through the river delta, and finally into the Sacramento Valley and progresses northward. Such intrusions can cause the maximum temperature to fall 25°F or more and the relative humidity to increase by 30 percent over a 24-hour period. In addition, these intrusions are accompanied by strong, gusty winds in its initial stages.

Several studies have been conducted on the nature of marine penetrations in coastal valleys. These include investigations by Lowry (1959), Fosberg and Schroeder (1966), Schultz (1961), and Savage (1967). All of these investigations have led to a better understanding of this phenomena and its influences upon agriculture and forestry. This paper utilizes these investigations, and combines them with other techniques for forecasting marine intrusions into the Sacramento Valley.

General Discussion of the Sea Breeze

The sea breeze circulation occurs along many coasts of the world. Because of differential heating between the land and the water, a circulation develops which tries to offset the horizontal pressure gradient force due to the differential heating. Upward movement of the overland air due to buoyant forces upon it produces a pressure gradient aloft directed from land to sea resulting in upper-level seaward movement of the air. According to Riehl (1954), in response to this mass divergence of air in the upper levels, low-level pressures begin to fall establishing a horizontal low-level pressure gradient from sea to land. Cooler, more dense, marine air responds to this gradient by moving onshore, and the sea breeze circulation becomes established.

The sea breeze is, in a sense, self-regulatory. As the sea breeze becomes stronger, more marine air is advected inland. This reduces the difference in temperature and density between the land and sea air. As the contrast is reduced, so is the horizontal pressure gradient, and the sea breeze winds gradually begin to decrease, eventually dying out altogether.

Forecasting Marine Intrusions

Strong delta intrusions into the Sacramento Valley occur as the eastern portion of the Pacific high pressure cell nears its maximum seaward displacement, while inland, a general area of low pressure exists over Oregon and Nevada, with low pressure at the northern end of the Sacramento Valley. With the high pressure cell located offshore, subsidence associated with the eastern portion of the high is at a minimum lifting the subsidence inversion that normally traps the marine air west of the Coastal Mountain range. This deeper layer of cooler, and more dense, marine air flows through San Francisco and into the Sacramento Valley.

The low pressure area located to the north and east results in a northward directed pressure gradient in the valley, while a tight pressure gradient associated with the sub-tropical high pressure system over the ocean to the west causes a well-developed onshore gradient. The result is a strong gusty southwesterly wind in Sacramento. Unlike the winds normally associated with the typical sea breeze circulation, which arise due to surface heating (in the afternoon) and end with cessation of that heating (at sunset), these strong marine penetrations can begin at any time when the synoptic situation is favorable and may continue throughout day or night. The intensity of the marine air penetration is, in large part, dependent upon the depth of the marine layer and the intensity of the south to north pressure gradient.

The marine penetration may be a brief, one day, occurrence or it may continue for several days. Usually, the initial penetration, accompanied by strong, gusty winds, will fill the Sacramento Valley with marine air. On succeeding days, the temperature will remain below the seasonal normal, but the winds will be much lighter from the southwest, or quite often from the northwest. While it may be thought that northwest winds would lead to a rapid warming and drying of the airmass, that is not the case. The flow is a result of the mixing of northerly winds from aloft continuing the cooling effect. The winds advect cold air southward from the northern latitudes, and do not result in warming but instead prolong the cooling trend in the valley. Hence, the lowest maximum temperatures may be found, not on the day of the initial penetration, but on the day after.

To forecast marine intrusions, one must consider the following: 1) The 500 mb ridge axis should be located east of Sacramento. 2) An area of surface low pressure should be developing over the Nevada/Oregon/Idaho region. If both of these are apparent, then a weak to moderate delta breeze should be forecast within the next 12-24 hours. If pressures at Redding fall to below that of Sacramento, this weak to moderate delta breeze will go all the way up the valley, otherwise it will likely only make it as far north as Marysville which is located half way up the valley. 3) A westward displacement of the Pacific high pressure cell, from its normal position, and north-south oriented isobars over the western portion of the state enhances the sea breeze which will already develop due to the previous two criteria. This third criteria will produce a moderate to strong delta breeze through the Sacramento area. Tied with the position of the Pacific high pressure cell is the depth of the marine layer. 4) If the top of the marine layer is located above 910 mb, marine air will flow right over the coastal mountain range and flood the valley with cooler air. This, along with the first three criteria, when found together, will cause a strong marine intrusion into the valley.

Forecasting Stratus Formation and Dissipation at Sacramento

Forecasting stratus intrusions into the Sacramento area has always been a major problem for local forecasters. This is due to the fact that stratus does not always accompany a strong marine penetration into the valley. Some criteria have been developed which will aid the forecaster in determining the possibility of a stratus intrusion into the valley. These have been put in the form of a flow chart so that each criteria may be examined individually before going on to the next one (Fig 6).

If the forecaster decides that stratus may advect into the region during the night, the following information may help the forecaster determine the formation and dissipation times of the fog.

Time of Stratus Formation

- Take the average wind speed (SFC-2000') using the San Francisco (SFO) 1800 LST surface observation and the 0000 GMT OAK upper air observation.
- Divide this average wind speed into 100 (the approximate distance between SFO and SAC).
- Add the quotient (which is expressed in hours) to 1800 LST. Thus 3.5 would mean 3.5 hours after 1800 LST, which would be 2130 LST.

Time of Stratus Dissipation

- Add 1 hour to sunrise time per 1000' cloud height.

- If the Sacramento Executive Airport (SAC) windspeed > 5 kts at sunrise, delay dissipation time 20 minutes for each 3 kts.

The 1 June 1995 Case

On 1 June 1995, a significant marine intrusion developed in the Sacramento Valley. This marine intrusion followed four days of afternoon high temperatures running 5-10 degrees above climatological normals. Model guidance had forecast two days earlier that the synoptic conditions would support a marine intrusion, however, no intrusion materialized. Forecasters had given up hope that a significant intrusion would develop even though a low pressure trough was located offshore of California. This system was forecast to move south of the Sacramento Valley, preventing the strong pressure gradients, which are necessary to create significant marine intrusions, from developing.

Winds were light and variable throughout the early afternoon as only a weak onshore gradient existed across the area. As solar insolation continued, pressures began to fall across the Sacramento Valley and in the mountains. Thunderstorms also began to form in the Sierra Nevada Mountains as the thermal trough began to move eastward. By 1800 UTC, pressure falls of 1-2 mb/3 hrs were occurring over all of Nevada and also over the northern Sacramento Valley (Fig 1). Meanwhile pressures at San Francisco were slowly rising. An area of low pressure was beginning to develop between Redding and Sacramento causing winds at Sacramento to become light southerly and winds at Redding to become light northerly.

By 2100 UTC, pressures continued to fall across Nevada with falls of 2-3 mb/3 hrs commonplace (Fig 2). Over the northern Sacramento Valley, pressures also continued to fall generally between 1-2 mb/3 hrs. Meanwhile, in San Francisco, pressures had risen 1.5 mb/3 hrs. At the 300 mb pressure level, mass flux divergence was occurring over northern California/Nevada/and Arizona (not shown). This divergence aloft, along with ample solar insolation, likely contributed to these large pressure falls at the surface. However, over central and southern California, convergence was occurring aloft, likely contributing to higher pressures high along the central and southern California coast.

The base velocity product from the WSR-88D indicated the development of a strong marine intrusion by 2226 UTC (Fig 3). The VAD wind profile indicated a 3000 foot deep layer of southwesterly flow moving past the radar site after 2200 UTC (Fig 4). As the winds began to increase in Sacramento, temperatures peaked and then began to slowly fall.

By 0000 UTC 2 June 1995, a center of low pressure had developed in the northern Sacramento Valley (Fig 5). A pressure gradient of 8.8 mb existed between Redding and San Francisco, with 5.0 mb between San Francisco and Sacramento. This was producing wind gusts over 35 mph in the delta region and over 25 mph in Sacramento.

After 0000 UTC, temperatures rapidly fell at Sacramento with most stations reporting temperature falls of 15 to 20 degrees from 0000 UTC to 0300 UTC as the cool marine air flowed rapidly northward. As the winds continued to gust over 35 mph in the delta, marine stratus began to propagate into the delta region. By 0600 UTC, this stratus was beginning to move into the Sacramento area, and by morning, overcast skies covered the Sacramento Valley from Sacramento northward to Redding.

Conclusion

Significant intrusions of marine air into the Sacramento Valley bring rapid change to the region in the form of significant cooling and strong gusty winds. Many times this marine intrusion develops without much notice and causes major forecast problems in the Sacramento Valley. Criteria have been developed which aid the forecaster in deciding if a significant marine intrusion is likely to develop and how strong it is likely to become. Occasionally a stratus deck advects into the valley and acts to suppress daytime heating and create IFR conditions at the local airports. A flow chart has been developed to assist the forecaster in deciding if a stratus intrusion is likely. These and other studies will hopefully help other coastal valley locations develop their own guidance to help in the forecasting of this important weather change. More local research is continuing to further refine this forecast problem.

Acknowledgements

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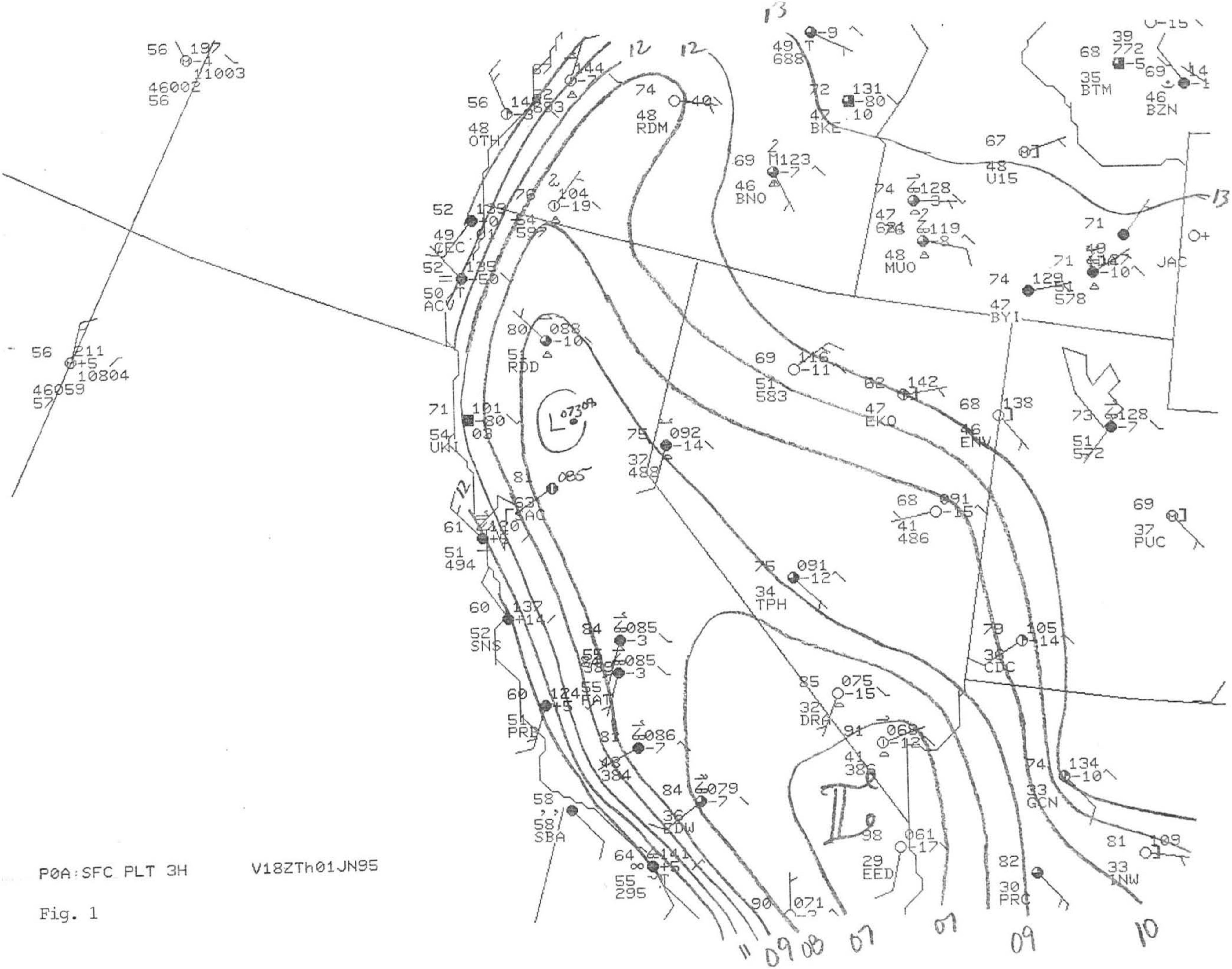

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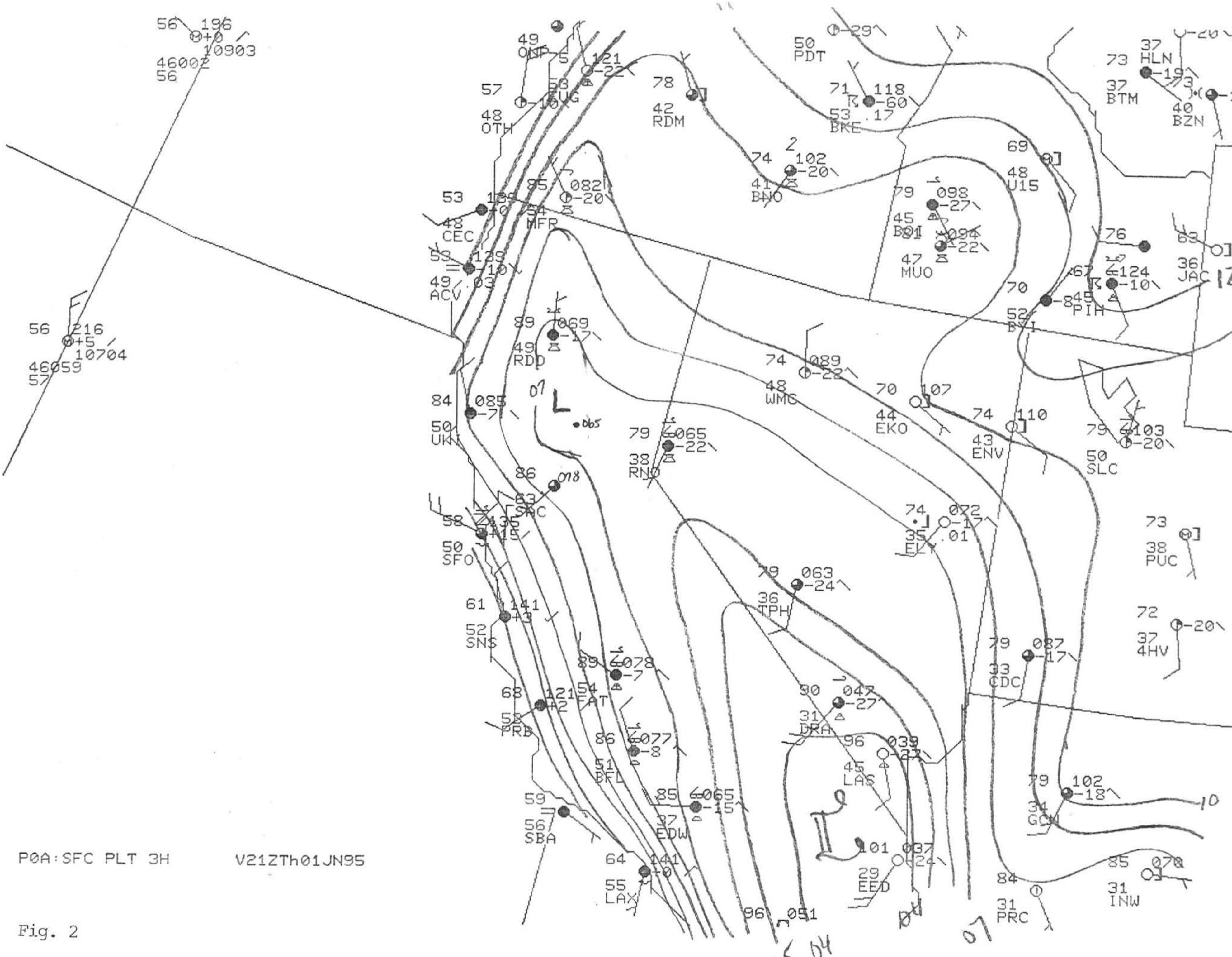
Fig. 1



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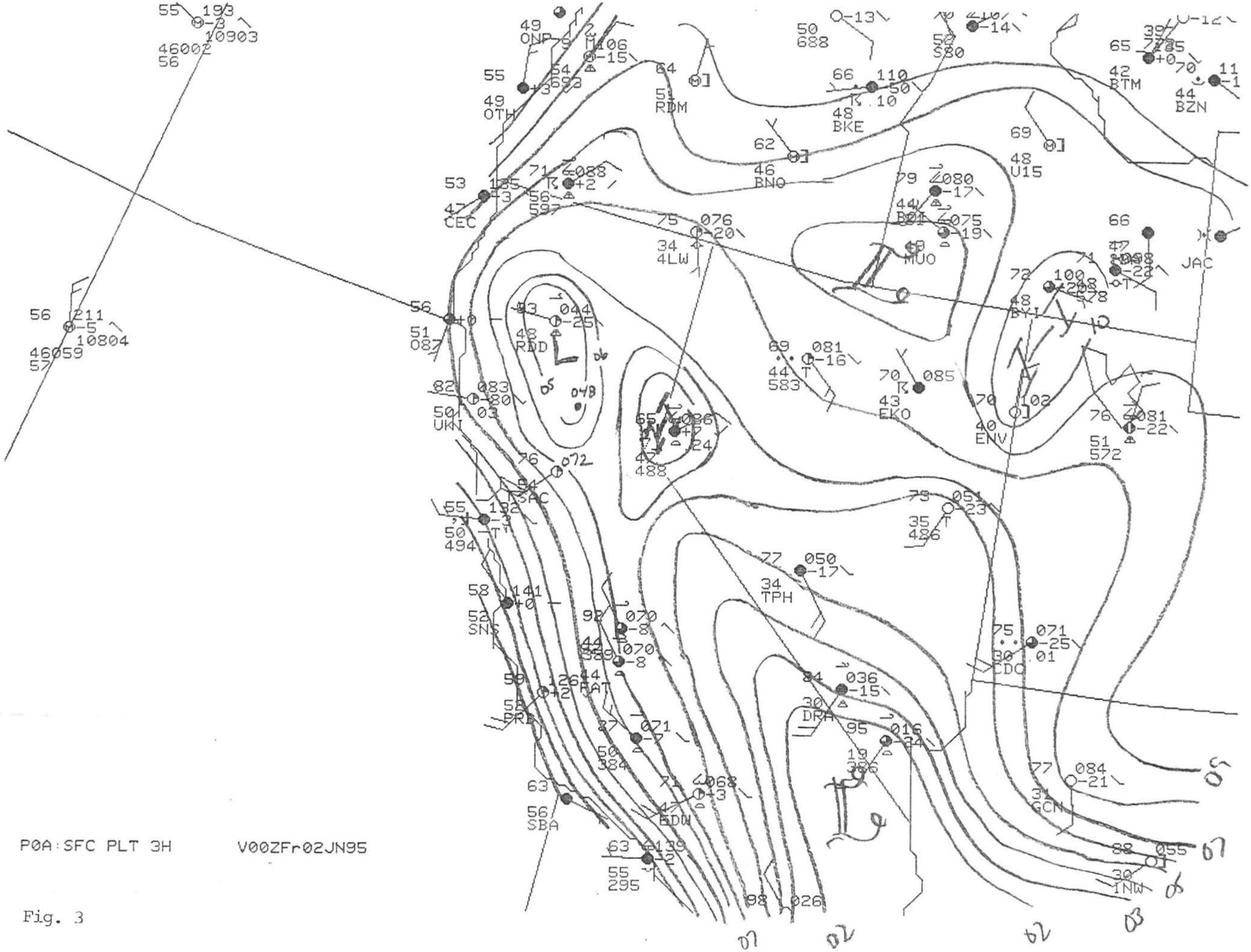

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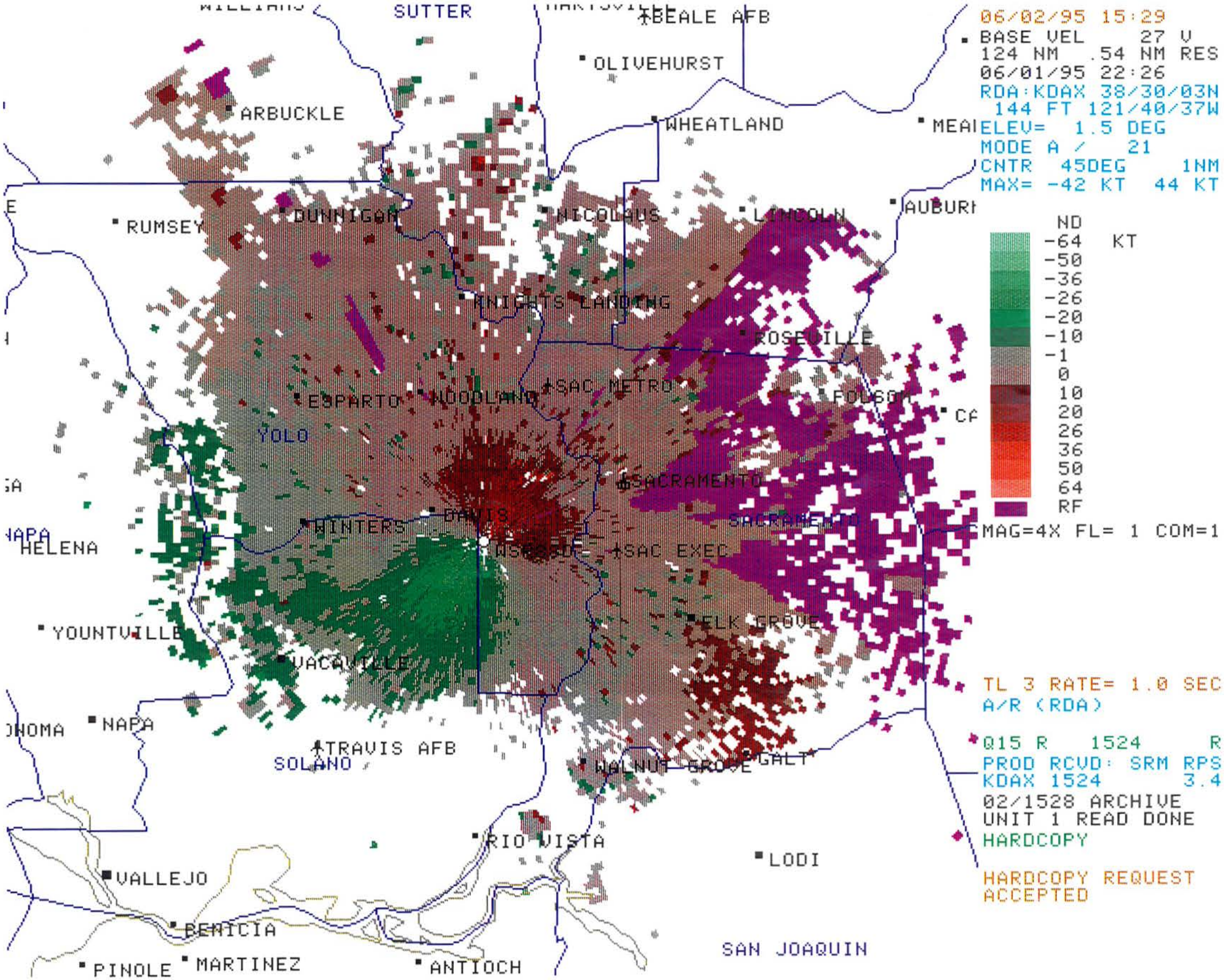
Fig. 3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ROSEVILLE
ESPARTO
WOODLAND
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FOLSOM
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WINTERS
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ELK GROVE
NAPA
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SOLANO
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Fig. 4

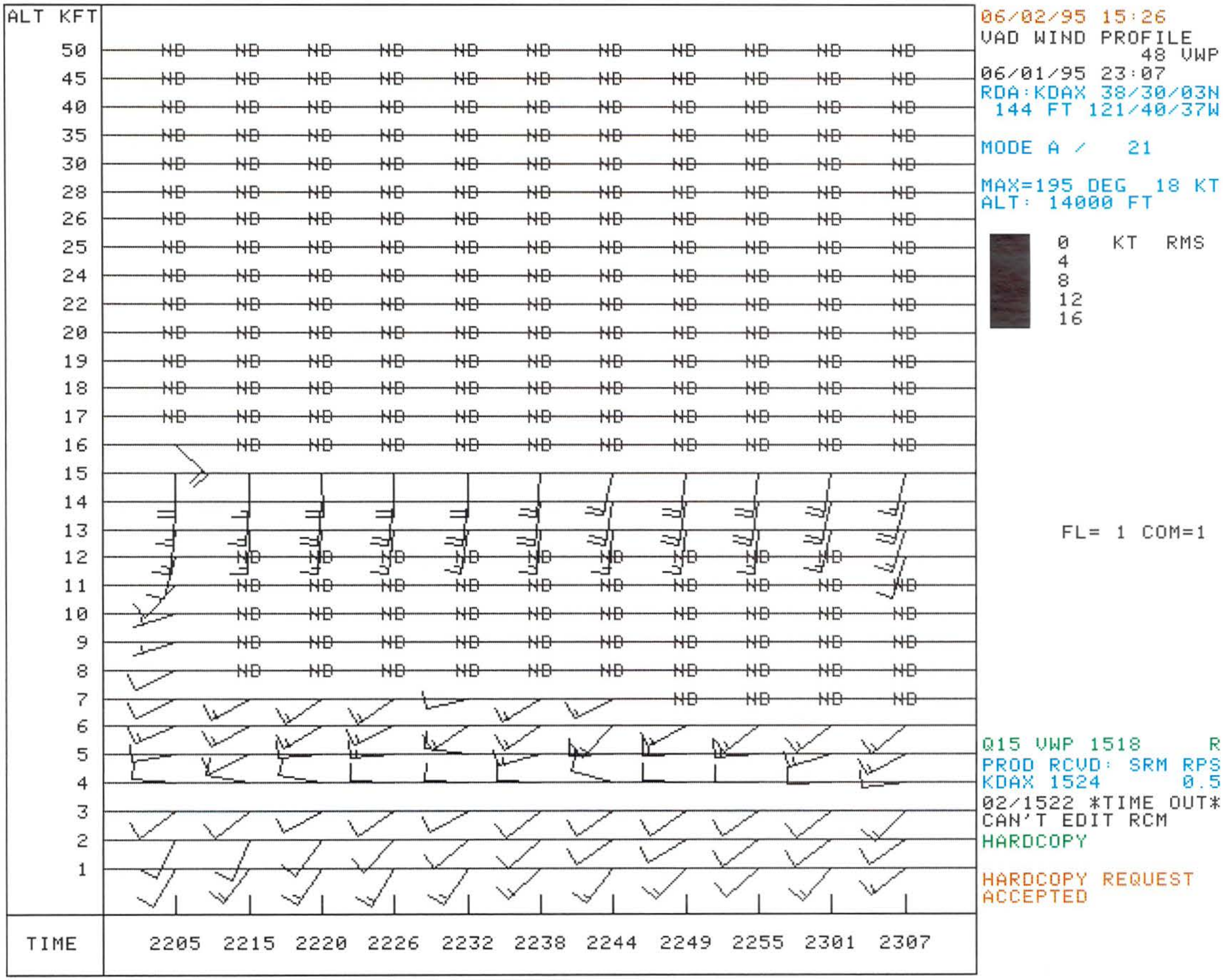
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Fig. 5

<u>FORECASTING STRATUS FORMATION & DISSIPATION AT SAC</u>

<u>Using 5 p.m. LST obs:</u>

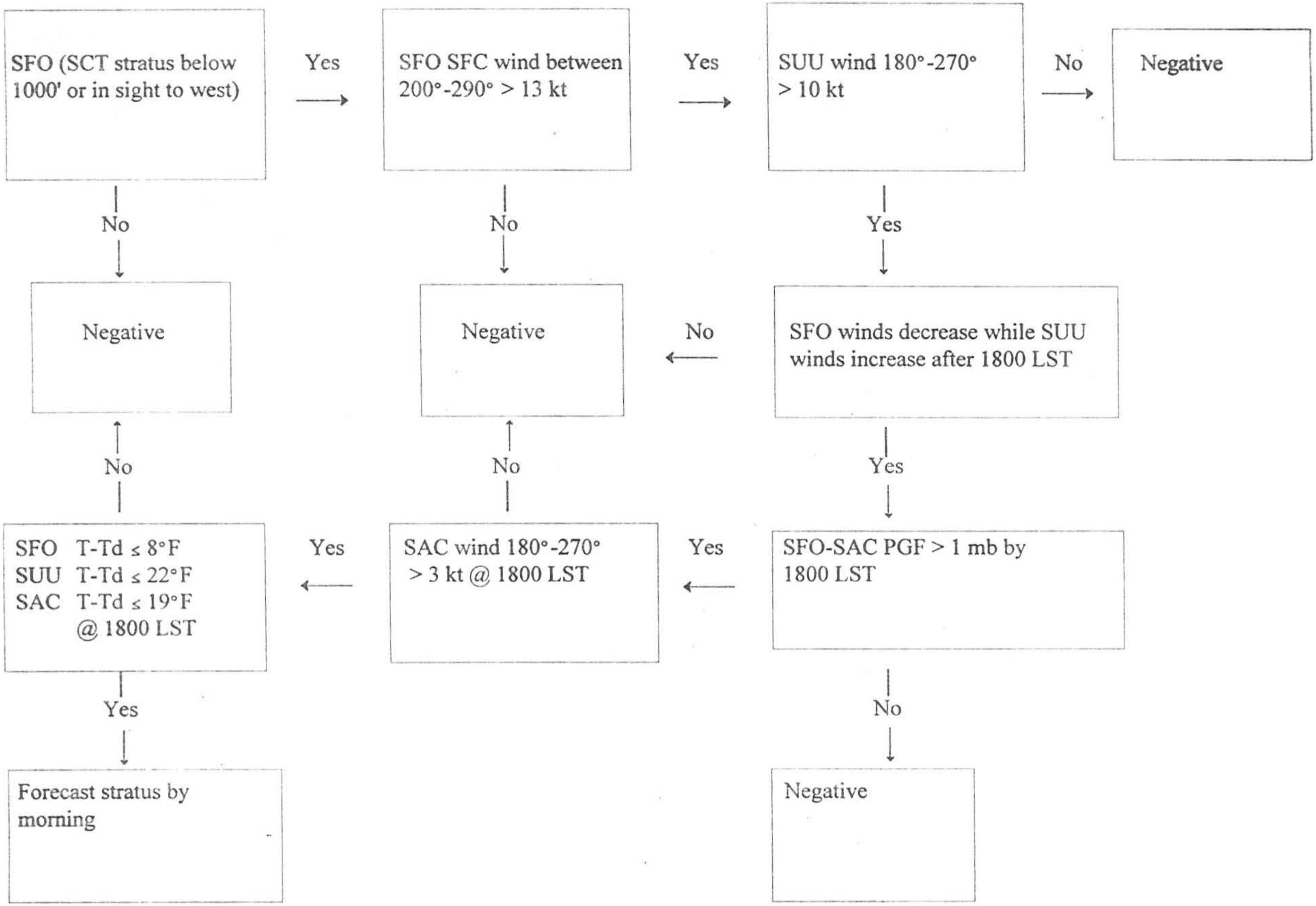

Fig. 6

May 1995