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EXAMINATION OF THE WIND FLOW IN THE WESTERN SIERRA NEVADA FOOTHILLS UNDER NORTHERLY FLOW ALOFT

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Introduction

During the spring and fall months, northerly winds typically develop as high pressure builds across the Pacific Northwest. Under the correct synoptic configuration, a northerly barrier jet develops along the west side of the Sacramento Valley (Staudenmaier, 1994). Northerly flow dominates much of the Sacramento Valley, however along the eastern portion of the valley, in the western Sierra Nevada foothills, the wind flow has a much different character with southwest to west flow dominating this region. Due to snow cover in the Sierra Nevada mountains, easterly flow may develop over the Sacramento Valley as cold stable air sinks down the mountains and hits the upslope winds in the foothills creating an easterly jet across the valley. These different wind regimes have possible ramifications in agriculture, fire weather, and aviation. All of these wind regimes will be examined in further detail.

Northerly Wind Flow

The development of northerly wind flow in the Sacramento Valley has been investigated through the use of composite mapping (Staudenmaier, 1995) and through case studies (Staudenmaier, 1994). It was found that two different synoptic patterns can cause north winds to develop in the Sacramento Valley. One of these, the cold air advection case, develops as high pressure builds in behind synoptic low pressure. Low pressure typically deepens over Nevada and Utah as high pressure builds over Washington and Oregon. Cold air advection (CAA) occurs as cold air from the high pressure system is driven southward across the Sacramento Valley behind the surface cold front sometimes leading to the development of a northerly barrier jet in the Sacramento Valley.

The second scenario for north winds is the warming and drying north wind situation. This is a late spring-early fall pattern as high pressure builds into the Pacific Northwest with no synoptic low pressure system ahead of it. The thermal low which develops in southern California enhances the north-south pressure gradient over the state, sometimes leading to the development of a northerly barrier jet across the Sacramento Valley.

The main emphasis of the investigation of this northerly barrier jet (Staudenmaier, 1994) was along the west side of the Sacramento Valley where the strong winds develop. Little attention was paid to the eastern portion of the valley although a peculiar wind pattern was noted at some locations. Upon further investigation, it was found that west-southwest winds develop along the lower portions of the Sierra Nevada foothills under northerly wind flow across the rest of the Sacramento Valley. This southwest wind flow will be examined more closely in the next section.

Wind Flow Along the Lower Sierra Nevada Foothills

Fifteen examples of northerly wind flow in the valley were examined to verify the production of southwest winds in the lower Sierra Nevada foothills. Of these, one situation will be presented which exemplify these conditions. This case occurred on 2 April 1995 as an area of high pressure built into the Pacific Northwest behind a moderate cold front.

Six sites along the western portion of the Sierra Nevada foothills will be examined to determine how and where these west-southwest winds develop. Lincoln (LCN) is located at 200 ft ASL, Chico (CHI) is at 230 ft ASL, Bangor (BGR) is at 840 ft ASL, Pilot Hill (PIH) is at 1200 ft ASL, Ben Bolt (BLT) is at 1500 ft, and Cohasset (CST) is at 1670 ft ASL (Fig. 1).

Lincoln and Chico are located almost on the valley floor so both of these stations should not deviate significantly with the winds on the valley floor. Indeed, this is what happens, as both sites show northwesterly winds between 290-330 degrees which develop around 0700 LST and last until about 1900 LST (Fig. 2). These winds are generally just as strong as the winds occurring on the valley floor. Of significance is that although northwest winds continue to blow across the western portions of the valley, both of these sites experience downslope drainage winds during the night with directions switching from northwesterly to northeasterly very rapidly, generally under an hour near sunrise and sunset. Relative humidities change rapidly at this time as well typically increasing 15-30 percent in the hour of the windshift.

Bangor is the next site which will be examined. The winds here are slightly more westerly than those at lower elevations typically between 260-300 degrees and somewhat slower (Fig. 2) The northwest winds typically develop at around 0700 LST and last until about 1900 LST. At this time, northeasterly winds rapidly develop and continue through the night, becoming lighter toward morning. Relative humidity values here typically do not lower as rapidly as those at lower elevations.

Pilot Hill, located at the 1200 ft level, shows a significant windshift, occurring slightly later in the day at around 0900 LST and 2000 LST. During the night, light northwesterly winds develop, (although southeasterly winds are also sometimes possible) switching to west-southwesterly during the daytime (230-290 degrees) (Fig. 2). These southwest winds are typically less than 15 mph sustained with gusts of 20-25 mph observed during peak afternoon heating.

Ben Bolt also shows the same tendency in wind directions and speeds as Pilot Hill with a slightly more southerly component (typically from 210-270 degrees) (Fig. 2). During the night, northwesterly winds develop but typically remain less than 10 mph.

Cohasset has a slightly more westerly component during the afternoon than Ben Bolt (typically 220-290 degrees) (Fig. 2). The afternoon windshift from southwesterly to northeasterly typically occurs around 2100 LST, likely due to the sun setting later in the evening at this elevation. After sunset, the winds rapidly become easterly as drainage winds develop typically staying in the 5-10 mph range all night long.

From this data, it appears that the west-southwest wind flow in the lower Sierra Nevada foothills is driven by solar insolation. As the sun shines on the foothills, the wind begins to blow upslope as the air heats up and rises. However, the northwest flow over the Sacramento Valley should overwhelm this upslope flow. Why doesn't it?

The answer to this question lies in the topography of the eastern side of the Sacramento Valley. A broad area of higher mountains extends to the northeast of Chico while the Sierra Nevada range take on a distinct northwest to southeast orientation from Chico to just east of Sacramento. This orientation with high mountains to the north and a southwest facing slope, minimizes northerly flow over this region; allowing the thermal circulation which develops into upslope winds to dominate the low-level flow in the Sierra foothills. Thus, this region experiences a significant windshift at sunrise and sunset when the upslope winds die down, allowing either northwesterly synoptic-scale winds, or drainage east winds to develop.

Easterly Winds Over the Sacramento Valley

Unfortunately there is a data gap between 2000 and 5000 feet in the Sierra Nevada Mountains. Above this level, at 5280 ft, Blue Canyon (BCN) showed easterly winds of 10-20 mph for both of these cases. The WSR-88D from Sacramento indicated easterly flow from around the 5000 ft level to the 8000 ft level (Fig. 3). Speeds as high as 25 mph were recorded during these events which creates significant low-level wind shear (LLWS) in the 3000-5000 foot layer. This easterly wind extended across the entire Sacramento Valley and was even seen in the wind profile from the Monterey WSR-88D. Although there are no sources of data in the Coastal Range, it is likely that easterly winds were found here as well above the 4500 ft level.

This phenomenon poses two questions: How can easterly winds develop over the Sierra Nevada mountains, and how does this layer of easterly winds move over the valley? Again, the answers lie in the topography. Most of the Sierra Nevada mountains in northern California have rivers which run down the crest of the Sierra and into the valley. These rivers, and the canyons which they carve out, typically run east to west. Thus, wind flowing over the mountains are forced to blow easterly or westerly depending on the synoptic wind flow. Under north-northeast wind flow, easterly winds will develop over the west side of the Sierra Nevada mountains due to colder air from the mountain snowpack sinking down the mountainside.

As these easterly winds migrate westward down the mountain canyons and valleys during the morning hours, the southwest winds in the lower foothills develop. As heating continues in the lower elevations, the thermally driven upslope winds mix vertically up the mountains, eroding the downslope easterlies upwards. During the two cases which were examined closely, the upslope winds mixed to about the 4500 ft level (according to the WSR-88D VAD Wind Profile). The easterly wind, which represents a secondary circulation in the Central Valley, occurs at the level where both the upslope and downslope winds merge. Once this level becomes quasi-stationary, the easterly flow moves westward across the Sacramento Valley. The level where the merging occurs is typically determined by the amount of insolation, but in this case, heavy snow (greater than 20 inches) which had fallen the week before created an artificially low mixing barrier at the 4500 ft level. Upslope flow could only occur up to this level, while cold downslope flow could continue to occur even during the daytime above this level.

During the summer months, upslope flow develops along the entire western face of the Sierra Nevada, which explains why easterly winds are not very prevalent in summer and why this circulation has never been noticed until this spring. However, in the late fall-early spring period, this phenomena may occur frequently, especially when strong thermal contrasts can develop over the mountains.

Consequences of this Wind Pattern

Low-level wind shear is defined as a change of 30° in a vector field in any direction in space. During these easterly flow regimes, significant changes in the vector field occur especially in the 3000-5000 ft level. Due to the location of Sacramento Metropolitan Airport, a pilot may get a report of strong northerly winds at the airport, while unknown to the pilot, a 2000-4000 ft layer of easterly winds with speeds of 10-25 mph exist above this. To further complicate matters, northerly winds exist above this layer in the free atmosphere. Thus, an airplane may encounter a switch from a headwind to a tailwind as the pilot flies in or out of the Sacramento Valley. Knowledge of this wind pattern could prevent an accident from occurring.

During the fire season, specific forecasts are made for areas which are experiencing wildfires. Without knowing about these southwesterly winds in the lower foothills, an inexperienced forecaster would predict northwesterly winds through the whole area, thus endangering both the fire fighters and the property which they are trying to save. Based on this study, southwesterly winds develop in the lower foothills of the Sierra Nevada mountains between the 1000-2500 ft elevations almost year round under these conditions. More work is needed to see what wind regime occurs between the 2500-4000 ft level and how this flow changes seasonally. During the late spring-early fall months, the wind flow above 4000 ft tends to be more northwesterly as the ambient wind flow overwhelms the thermal upslope pattern.

Agriculture is becoming a very large business in the foothills. The wind regime becomes important when addressing concerns such as evaporation rates, irrigation, and crop spraying. Important decisions such as when to irrigate or spray are dependant on accurate wind forecasts. Thus, knowing these mesoscale details of wind flow in the Sierra Nevada foothills is very important.

Conclusions

Although northerly winds are the predominant wind flow as high pressure builds over the Pacific Northwest, some areas of the Sierra Nevada foothills experience significantly different winds. Thermally driven upslope flow develops along the east side of the valley due to the topography and from the blockage of northerly synoptic-scale flow. This southwest flow continues upward until it becomes quasi-stationary at the level of an equally strong downslope circulation which is occurring. In the two cases examined, heavy snow down to 4500 ft prevented the upslope from moving any higher causing an artificially low convergence zone. As the easterly downslope winds collided with the southwesterly upslope winds, a layer of easterly flow formed which moved across the Sacramento Valley. This easterly wind flow created an area of LLWS over the valley with both this flow and the southwesterly foothill winds presenting potential weather problems in aviation, fire weather, and agriculture. More studies of this type need to be done in order to discover those mesoscale circulations which can cause a deviation in the "normal" weather patterns.

Acknowledgements

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References

Staudenmaier, M.J., 1994: WSR-88D evidence of a northerly barrier jet in the Sacramento Valley. Western Region Technical Attachment No. 94-36.

Staudenmaier, M.J., 1995: Composite maps of meteorologically significant events in Sacramento. in house.

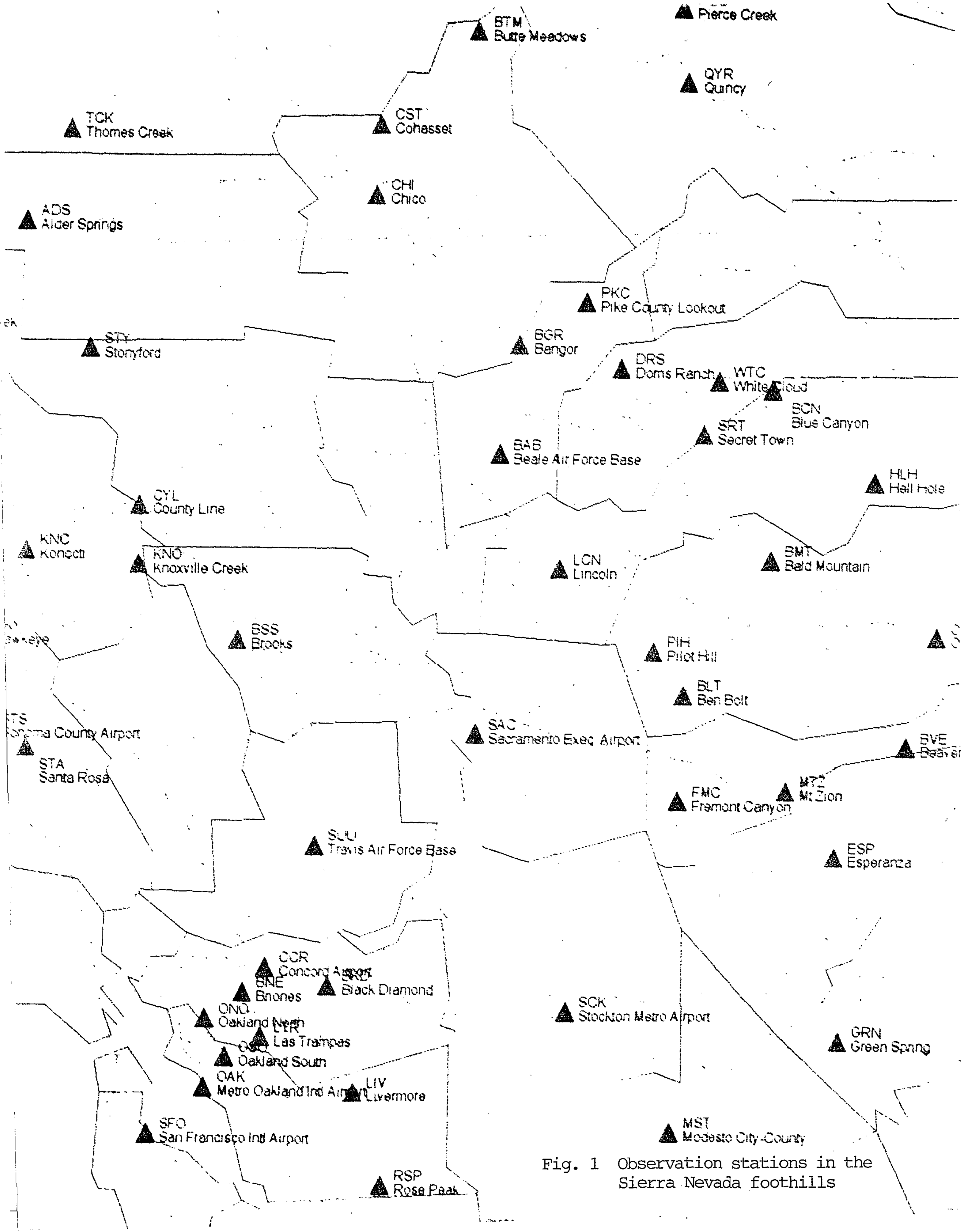

Fig. 1 Observation stations in the Sierra Nevada foothills

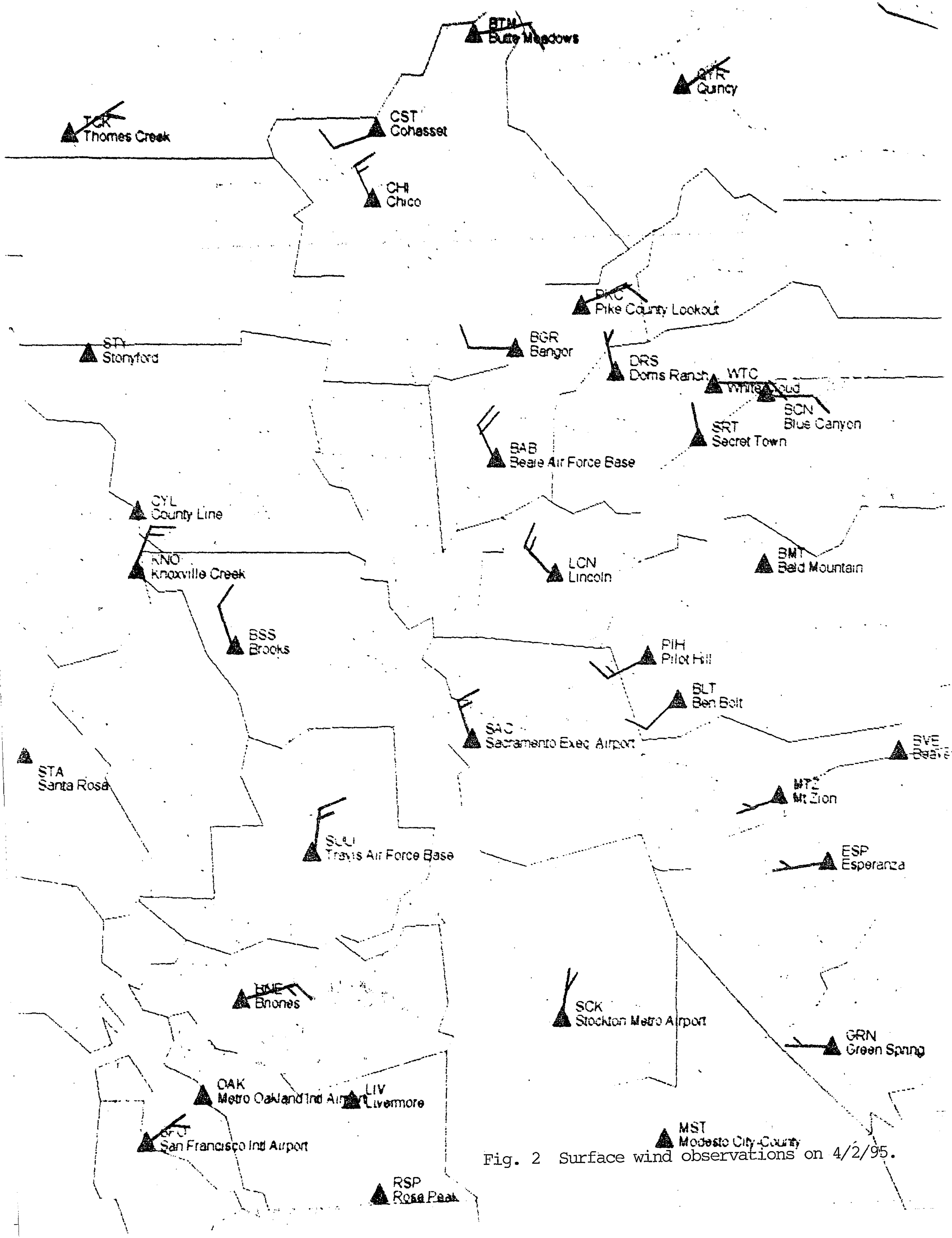

Fig. 2 Surface wind observations on 4/2/95.

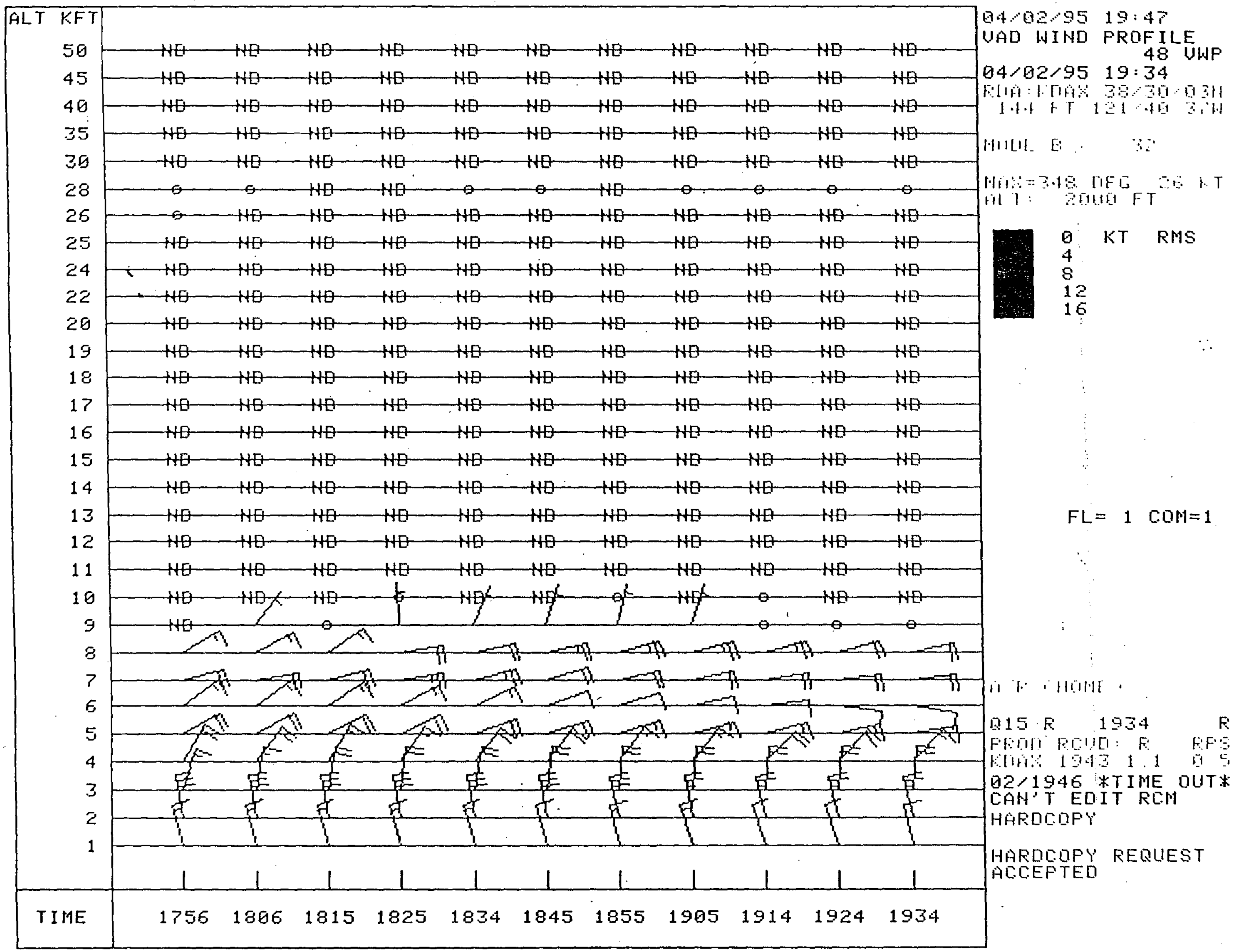

Fig. 3 VAD wind profile from Sacramento WSR-88D on 4/2/95 at 1935Z.