DAYTIME DOWN-CANYON FLOWS IN THE EASTERN SIERRA NEVADA, CALIFORNIA

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Abstract: Climatological analyses have been conducted to determine the characteristics of frequently occuring daytime down-canyon flows during summer in the lee of the Sierra Nevada. While these flows have been documented in a historical context, very little is known on the mechanisms that drive these flows. Analyses using longterm climtotogical data from sites in the lee of the Sierra Nevada, suggest that these westerly flows are thermally driven due to regional pressure differences rather than the downward mixing of upper-level momentum.

Keywords *– Sierra Nevada, Thermally-Driven Flows*

1. INTRODUCTION

Thermally-driven wind systems are a common phenomenon found in mountainous regions throughout the world. These wind systems, along with the structure of the atmospheric boundary layer, are important for understanding the distribution and transport of atmospheric pollutants in mountainous areas, forest fire control, thunderstorm and precipitation, and wind energy potential (Furger et al. 2000). Typically, thermally-driven circulations in mountainous terrain blow up slope, and up valley during the day and down slope and down valley at night. Over the eastern slopes of the Sierra Nevada located in eastern California (Fig. 1), however, a daytime, downslope or down-canyon flow occurs regularly during the summer season which goes against the local pressure gradient force resulting from the differential heating of the slope and the atmosphere adjacemt to the slope. This daytime downslope/down-canyon flow is known historically as Washoe Zephyr following author Samuel Clemens. The flow is usually originated at the mountain crest and is generally strong in magnitude with peak speeds occurring in the afternoon or early evening. Strong winds associated this downslope/down canyon flow have been linked to dust storms in Carson City, NV (Twain, 1871) as well as some of the convective activities occurring to the east of the Sierra crest (Hill 1980). More recently, observations were made (Clements 1999) to investigate valley flows in an eastern Sierra valley. This study, which took place in Lee Vining Canyon (LVC) (Fig. 1) during both summer and winter seasons, concluded that daytime down-canyon winds were a regular feature of this canyon and had a distinct vertical structure. Furthermore, Kingsmill (2000) used a doppler sodar to investigate the vertical structure of this flow phenomena over a two-month period in Reno, Nevada.

Although a frequent phenomenon, little is known regarding what mechanisms are responsible for the formation of the Washoe Zephyr. Two hypotheses have been proposed to explain the formation of this daytime downslope/down-canyon flow. The first hypothesis is that the flow is a result of the pressure difference between the mesoscale thermal low in the interior of Nevada and the high pressure over the coast of California (Hill, 1980). The pressure difference, which usually peaks in the afternoon, will draw the air from west of Sierra crest down to the eastern slope, bringing more polluted air from the coastal region or from the Central Valley to areas on the eastern slope of in the Great Basin east of Sierra Nevada. The second hypothesis is that the surface downslope wind may be a result of downward mixing of momentum from the westerly winds aloft as the convective boundary layer over the eastern slope of Sierra grows high in the afternoon into a generally westerly flow layer aloft (Banta 1984; King 1997). Since the westerly flow aloft would not be sheltered from the surface emissions by the existence of subsidence inversion, the downslope flows on the eastern slope resulting from mixing down of the westerly flow would bring air with background concentration to the surface.

2. CLIMATOLOGICAL ANALYSES

In order to help determine the primary mechanism for this phenomenon, we have carried out climatological data analyses using wind data from several surface stations on the eastern slope of Sierra. The surface stations are part of an air quality monitoring network operated by the Great Basin Air Quality Control District (Bishop, CA) and the observations include the typical suite of meteorological variables. Figure 2 shows the frequency of occurrence of westerly downslope wind at Lee Vining for June, July, and August at each hour of the day for a 20-year period from 1985-2004. This site is located at the entrance of Lee Vining Canyon near the southwest shore of Mono Lake. The figure shows a pronounced frequency maximum between 1500 and 1900 LST. Over

50% of time a down-canyon flow occurred during this period when the local pressure gradient associated with the heating of the slopes and the canyon walls should produce a upslope and up-canyon flow. Similar afternoon peak frequency of westerly downslope flows are also observed at other stations.

To determine how the daytime down-canyon flow is related to upper level conditions, rawinsonde soundings from Reno, Nevada are analyzed. Figure 3 shows 700-mb wind speed, wind direction, and geopotential height from the Reno sounding at 0000 UTC (1600 LST) for the days in the summer of 2004 and the corresponding wind speed of the westerly down-canyon winds for each hour of the day for the same time period. Although the winds at 700 mb were dominated by westerly winds, the wind speed varied considerably from one day to another ranging from very weak winds of 1 m s^{-1} to strong winds nearly 15 m s^{-1}. Over 50% of the days, the winds at 700 mb were weak at less than 5 m s^{-1}, but yet on most of these days a surface down-canyon flow of over 5 m s^{-1} was observed which normally occurred between 1500 and 2000 LST. On a number of days when the 700-mb winds were from the north, westerly surface flow still occurred in the afternoon. This rejects the hypothesis that the downward westerly momentum transfer is the primary mechanism for the regular occurrence of the afternoon down-canyon flow. It is interesting, however, to note that near the end of the time period there is an event when the 700-mb winds increased from below 5 m s^{-1} to nearly 15 m s^{-1} when a trough passed over the region as indicated by the drop in the geopotential height fields. At the surface, relatively strong westerly winds occurred most of the day, suggesting a coupling of low and upper-level winds and a downward momentum transfer.

3. CONCUSIONS

The primary analysis seems to suggest that daytime down-canyon flows in the eastern Sierra Nevada are thermally driven by regional pressure differences developed as a result of the formation of a thermal low by the heating in the interior of Nevada and the high pressure over the coast of California. Downward westerly momentum transfer occurs only when a synoptic low pressure system replaces the typical anticyclonic weather and breaks the elevated subsidence inversion. When downward momentum transfer occurs, the surface westerly down-canyon flows tend to occur over a longer period of time or all day long rather than only in the afternoon. More analyses need to be performed to further test the two hypotheses. Numerical modeling using RAMS will be performed to help identify the mechanisms and understand the sensitivity of the characteristics of this complex terrain phenomenon to synoptic and land surface conditions.

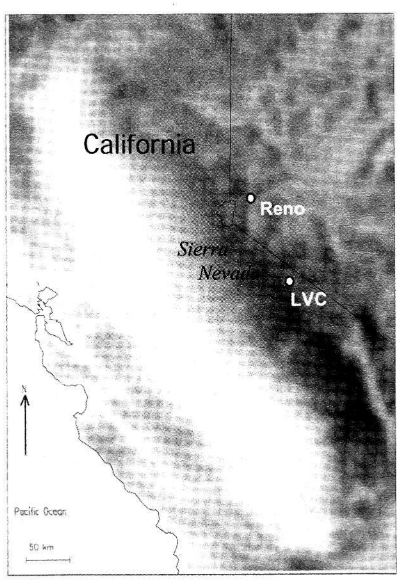

Figure 1. Map of California and the Sierra Nevada. Darker shading represents higher terrain.

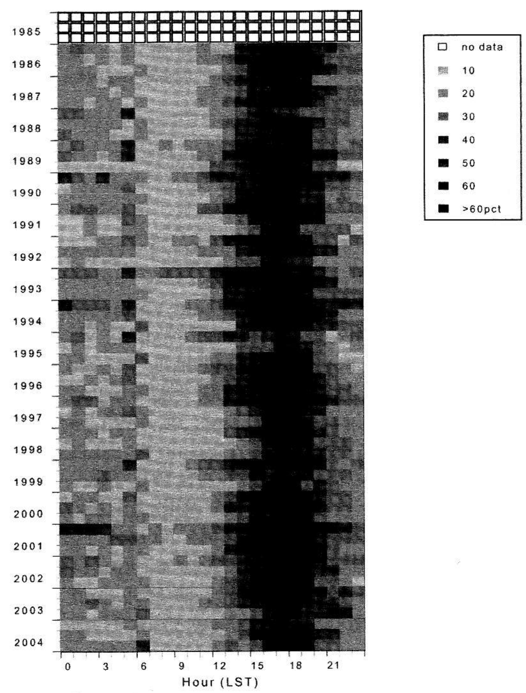

Figure 2. The averaged daily frequency distribution of westerly down-canyon flows at Lee Vining for June, July and August from 1985 to 2004.

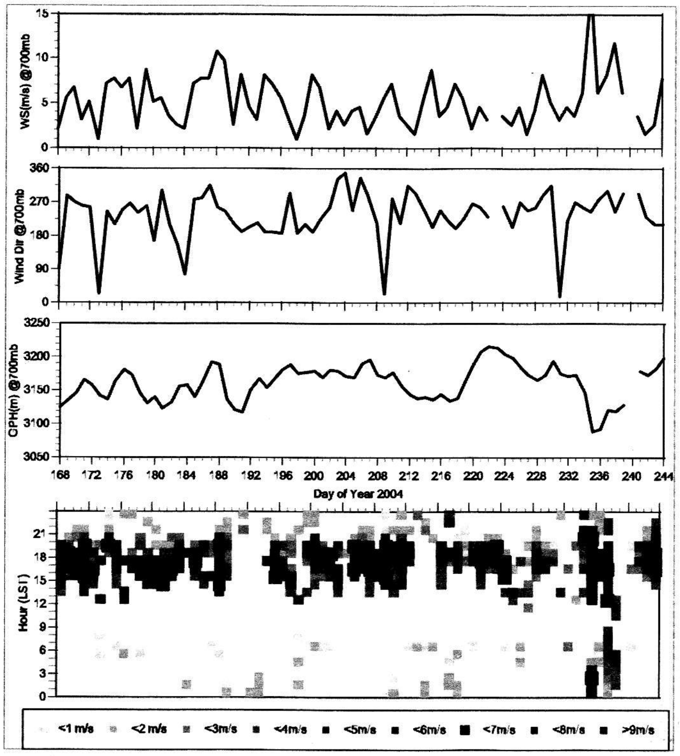

Figure 3. 700 mb wind speed , wind direction, geopotential height from 0000 UTC soundings at Reno and westerly down-canyon wind speed over each diurnal cycle at Lee

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