ON THE CAUSES OF UNSUSTAINABLE EVENING TRANSITION TEMPERATURE FALLS IN VALLEYS

C. David Whiteman¹, Sebastian W. Hoch¹, Maura Hahnenberger¹, and Greg Poulos²

¹ University of Utah, Salt Lake City, UT, USA
² National Center for Atmospheric Research, Boulder, CO, USA
E-mail: whiteman@met.utah.edu

Abstract: Unsustainable evening transition temperature falls are an occasional feature of the meteorology of the Owens Valley as observed in the March/April 2006 Terrain-induced Rotor Experiment in California's Owens Valley. These unusual features are investigated using meteorological data from the T-REX program.

Keywords: ICAM, T-REX, mountain meteorology, temperature oscillations, stable boundary layer, evening transition, Owens Valley, California

1. INTRODUCTION

As part of the Terrain-Induced Rotor Experiment (T-REX) of Mar/Apr 2006 (Grubisic and Doyle 2006), temperature data loggers were installed on lines oriented along and across the axis of the deep Owens Valley on the east side of the Sierra Nevada (Fig. 1). Temperature time series from these loggers exhibited abrupt temperature falls after sunset on many days. In many instances the temperature falls were unsustainable and the temperature would rise again before beginning a more general nighttime decline. These temperature falls and subsequent rises produced evening "notches" in the temperature time series. The purpose of this paper is to investigate these unsustainable temperature falls by characterizing the notches and their distributions in time and space. A case study of one notch event using data from three heavily instrumented meteorological towers allows us to formulate some initial hypotheses concerning their origin.

1.1 The Owens Valley

Owens Valley, located between the NNW-to-SSE-oriented Sierra Nevada and Inyo-White mountain chains, is one of the deepest valleys in the United States. Between Lone Pine and Bishop, California, where our instruments were located, the Sierras on the west side of the valley have a largely uninterrupted mountain ridgeline with a mean elevation of 4000 m MSL. The Inyo-White Mountains to the east have a mean elevation of 3000 m MSL. The valley floor between these mountain chains has a mean elevation of 1200 m. The west side of the valley floor is sandy with sagebrush bushes; the east side is rocky and steep, with little vegetation.

1.2 The HOBO lines and Towers

Temperature data loggers (HOBO® Pro Temp/Ext Temp, Onset Computer Co., Bourne, Massachusetts) were placed at 51 sites on the lines indicated in Fig.1. Whiteman et al. (2000) described the characteristics of these loggers and their suitability of use in meteorological research programs. The thermistor temperature
sensors used in these loggers were installed on steel fenceposts in un-aspirated 6-plate radiation shields at heights of 1.3 m AGL. Temperature data were sampled and stored in the loggers at 5-min intervals during the 2-month-long experiment. One line ran up the valley floor from Lone Pine to Bishop. The instruments on this line were numbered V01 through V11. A second line ran perpendicular to the valley axis through Independence, California. The instruments on this line ran up the west (Sierra) and east (Inyo-White) slopes of the valley and were numbered W01 through W13 and E01 through E14. A third line, perpendicular to the valley, ran up the west (Sierra) slope of the valley through Manzanar, California. Sites on this line were numbered M01 through M13. This line was installed in a segment of the valley where there was no major pass to the west (Kearsarge Pass was located west of the Independence line). Meteorological data from three 30-m NCAR flux towers (Central, West and South; Fig. 1) was used to observe notches at different heights above the ground and to investigate the causes of the notches.

1.3 Objective method for identifying notches

Oscillations in nighttime temperature traces in both flat and complex terrain are thought to be produced by a variety of meteorological processes. Temperature notches in the Owens Valley, however, are unusual for their singularity (i.e., they are typically a single deep notch that occurs in the few hours following sunset. Their timing and characteristics are rather repeatable on days when they form. As a first step in investigating the phenomenon, a computer program was written to identify the times and sites where notches were present in the observational period. The program began by identifying relative temperature minima and maxima in the time period from 1700-2140 PST. The program then searched for notches each day in three time windows, 1700-2010, 1700-2055, and 1700-2140 PST. For each time window, the absolute minimum was selected from the relative minima (a in Fig. 2) and the largest relative maximum occurring after the absolute minimum (b in Fig. 2) was then identified. The temperature of this absolute maximum was then projected backward in time to determine the time when the absolute maximum first occurred in the time window (c in Fig. 2). The largest notch in the three time windows was then selected and the characteristics of the notch so identified were then determined including the depth of the notch (ΔT, in °C), the width of the notch (Δt = cb, in hours h), and the area of the notch (A, in °C-h) as determined by integration. By identifying and characterizing the notches in this way at all the Owens Valley HOBO sites we determined the dates when notches formed, and further details of their distributions in time and space.

2. NOTCH CHARACTERISTICS

The period of record for the 51 data loggers used in our analysis was the 67 days from 23 Feb through 30 Apr 2006. This was a period when there were many passing synoptic scale disturbances and high wind events, with few clear-sky, quiescent periods.

2.1 Frequency of occurrence and characteristics of notches

Figure 2: Temperature notch at site W01 on 28 Apr 2006.

HOBO data were available for 3014 site-days. Notches were absent on 61 of the site-days, leaving 2953 site-days with notches. The depths, widths and areas of the notches tend to have log normal distributions (Fig.3a-c), with high frequencies of small depths, widths and areas. By restricting the analysis to A ≥ 1 °C-h
(a cut-off that better represents 'true' notches rather than low-amplitude, high-frequency temperature oscillations) the notch characteristics become more normally distributed (the black histograms in Fig. 3a-c). 735 site-days exhibited true notches. Mean temperature falls averaged over all site-days for true notches are 2.7°C, and widths are 1.9 h. These were seen at 10 or more sites on 34 of the 67 days. Twenty or more sites recorded true notches on 25 February, 02, 05, 10, 11, 15, 28 and 29 March, and 02 and 17 April. True notches were entirely absent at all sites on 26 and 27 February, and on 09, 17, 18 and 27 March. These can be generally characterized as disturbed, high-wind days.

2.2 Best days and sites for notches

The 2953 notches were distributed throughout the experimental period and were seen with varying frequencies at different HOBO sites. Mean values of A for each of the days of the experiment, as averaged over all HOBOs on that date, are shown in Fig. 4. Average areas exceeded 2°C·h on days 87, 92, and 107 (i.e., 28 March and 2 and 17 April). Fig. 5a shows mean values of A for each of the HOBO sites, as averaged over all experimental days and plotted against the HOBO elevations. Notches tend to be largest at the lower elevations on all lines. They are much weaker on the steeper East line than on the lower angle West and Manzanar lines, and on the Valley line. The notch areas decrease with height on the towers (Fig. 5b).

At mid-altitudes on the HOBO lines, temperature falls were greater on the Manzanar line than on the East line and greater on the West line than on the Manzanar line (not shown). Notch durations generally increased with elevation on all lines, but were much shorter on the East line than on the West, Manzanar and Valley lines (not shown). Temperature falls decreased with height on the towers, while notch durations showed little variation with height (not shown).

3. CASE STUDY OF 17 APRIL 2006

April 17 had the second-largest mean true notch area in the period of record, as averaged over all HOBOs. On this evening, notches greater than 1.7°C·h occurred on the West line below W10, with a notch of 6.4°C·h at W01. Small notches occurred on the East line, with the largest (2.8°C·h) at E01 and were found on the Manzanar line at and above M05. Notches ≥ 6°C·h were present in the southern valley (V01-V03), with smaller notches in the northern valley.

Data collected at the three NCAR towers (Center, West, South, Fig. 1) is used to determine the physical processes leading to the notches. These data, together with temperature time series from the nearby HOBOs are shown in Fig. 6.

Up until 1730 PST winds at all sites were blowing generally from the NNW, down the valley axis, at 4 m·s⁻¹. The down-valley winds decreased in the evening and a westerly down-slope breeze of 2 m·s⁻¹ began shortly after local sunset at 1730 PST at the West tower and at 1830 PST at the Central and East towers, initiating the overcooling. Net radiation decreased to its lowest values, but then increased slowly as longwave emission decreased as the surface temperature fell with the buildup of the surface-based inversion. Westerly downslope flows dominated the circulation until 2100. The South tower site was occasionally influenced by downslope flows from the eastern slope. At 2100, northerly down-valley winds became re-established at all three sites and the wind speed increased at the Central and South towers.
The down-valley flow initiation coincided with increasing temperatures, marking the end of the notches. At the Central tower (closest HOBO V03), the end of the notch was marked by a temperature increase of 5°C, a wind speed increase from 3 to 5 m s⁻¹ at the 5-m level, and a remarkable decrease in net radiation of 20 W m⁻². At V02, on the valley floor near the South tower, the end of the notch occurred when temperature increased by 7°C, wind speed increased to 4 m s⁻¹, and net radiation decreased by 10 W m⁻². At the West tower and at the nearby HOBO M08, no wind speed increase was observed at the end of the notch. Winds remained at 3 m s⁻¹ at the 5 m level, but the direction shifted from 290° to 325°. Increasing temperatures at the surface led to a decrease in net radiation at Central and South, indicating the break up of the inversion. At West, air temperatures increased slightly due to the cessation of the cooler down-slope flow, while the net radiation magnitude was unaffected. The weaker inversions over the more steeply sloping terrain are apparently continuously eroded by self-induced downslope flow (i.e., cold air descends down the slope).

It is not known whether the down-valley breeze that marked the end of the notch was a re-initiation of the synoptic-scale northerly flow seen in the afternoon or the start of the thermally driven down-valley wind.

4. CONCLUSIONS

Unsustainable evening transition temperature falls occur often in California’s Owens Valley and are seen at sites on the floor and both sidewalls of the valley. The distribution of the characteristic temperature traces in space and time was investigated using a temperature sensor network. A case study then used heavily instrumented towers to develop initial hypotheses regarding the excessive temperature falls and their subsequent recovery (i.e., temperature notches). The notches occur only when a stable boundary layer forms in the valley. A well-mixed atmosphere with strong winds is not effective in producing these features. The 17 April case study showed that the excessive temperature falls occurred with strong outgoing net radiation when the afternoon winds died and a down-slope flow began on the west sidewall. The temperature then warmed as winds shifted to down-valley and increased, producing downward mixing of warmer air from above the surface. Initial looks at several other case studies suggest that additional processes such as intermittent high winds or cloud cover can produce these events. In future, additional case studies will be used to test hypotheses.

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