The Temporal Changes of Vertical Temperature Differences after Sunrise

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1. Introduction

A casual reading of any one of three important micro-meteorological references (Geiger, 1950, p. 86; Prandtl and Tietjens, 1934, p. 43; U. S. Weather Bureau, 1955, p. 28) may give the impression that soon after sunrise nocturnal surface inversions are eliminated as a super-adiabatic lapse rate is established at the surface and steadily deepens. Evidence has been presented, however, that the air within nocturnal inversions with bases within 5 to 10 ft of the ground may be heated through a relatively great depth without the immediate establishment of a superadiabatic lapse rate in these layers just above the surface; such observations are given in a report (Crozier, 1953) issued more than a decade ago and several more recent reports (Appleby and Ohmsted, 1963; Cleeves *et al.*, 1964; Edinger and Myrup, 1962; Munn, 1962). These reports have had limited distribution, and most do not place any significance in the temporal change of vertical temperature differences after sunrise. Plots of the relevant soundings and a brief discussion of the sites, sounding techniques, and important features of the soundings are included in this

note. The assembled data lead one to believe that the phenomenon is not so rare that its occurrence should be overlooked or disregarded in making evaluation of the temporal change of vertical temperature differences after sunrise.

2. Gila Bend, Arizona—February 1946

At six sites along a 46-mi stretch to the west of Gila Bend, Ariz., the Naval Electronics Laboratory took hourly vertical temperature soundings on various days in February 1946. Since the principal purpose was to study anomalous propagation of tropospheric radio waves, little attention was given to the significance of the meteorological data *per se*. Detailed meteorological data are listed for more than 500 soundings in the report (Crozier, 1953).

The area to the west of Gila Bend is flat desert. Humidity data obtained on the days of the temperature soundings show that the humidity was low. As one might expect with intense nocturnal inversions, the winds were light in the morning, probably a southeast drainage flow (slope 40 ft per mile or less at the individual sites). At three of the sites wiresonde devices were attached to tethered blimps; at the other three sites

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autosondes (devices incorporating a ceramic thermistor rod) were raised on wires alongside of towers. Data for three mornings, selected as representative, are shown in Figs. 1 through 3.

On the morning of 6 February 1946 (Fig. 1) data from all six stations showed the maintenance of an inversion immediately above 10 feet while heating occurred through layers of various thickness. It was not until 0900 (MST) that a low-level superadiabatic layer was observed at the stations. Even then some increased heat-

ing occurred through layers aloft, in which a temperature inversion was maintained. Another interesting occurrence was the low-level warming accompanied by upper-level cooling from one observation to the next (e.g., the Gila Bend station with each change of time).

Until 0800 MST on 14 February (Fig. 2), most hour-to-hour changes showed that heating occurred through a layer immediately above 10 ft while an inversion was maintained. By 0900 MST a very shallow superadiabatic layer above 10 ft was observed at five of the sta-

FIG. 1. Variation of temperature with height and time for six locations near Gila Bend, Ariz., 6 February 1946.

tions. Again, alternate layers of warming and cooling were observed from one hour to the next.

On 28 February (Fig. 3) heating through a low-level layer from one time to the next without the establishment of a superadiabatic layer was observed. Superadiabatic lapse rates became established at most sites at low levels by 0900 MST.

3. Gila Bend, Arizona—24 September to 18 October 1956

The Army Electronics Research and Development Activity of Fort Huachuca, making use of three of the same stations as the Naval Electronics Laboratory but with different instrumentation, conducted a detailed investigation into vertical temperature gradients (Ap-

FIG. 2. Variation of temperature with height and time for six locations near Gila Bend, Ariz., 14 February 1946.

FIG. 3. Variation of temperature with height and time for six locations near Gila Bend, Ariz., 28 February 1946.

pleby and Ohmstede, 1963). The stations used were Gila Bend, Sentinel, and Dateland; the latter two were situated, respectively, 27 and 45 mi west of the Gila Bend station. The towers used in this study were of much heavier construction than those used in the former; the temperature sensors were mounted on the landings of the stairwells, which, in turn, were mounted on the sides of the towers. The temperature sensors were thermocouples. Skies were generally clear, diurnal temperature variations were large, and very little precipitation occurred during the period investigated. Wind data from Gila Bend indicate that the winds in the early morning were light and from the southeast.

Data showing the mean vertical temperature differences for 24 or 25 days at 0600 and 0700 MST in the fall are shown in Fig. 4. Note that even these mean values indicate the heating of a surface inversion layer

without the establishment of a superadiabatic lapse rate.

The authors include a simplified hypothetical model having statistical characteristics that are qualitatively consistent with their observations of upward heat flux against the potential temperature gradient. In developing the hypothesis, which places emphasis on buoyant elements, the authors include a very extensive and complete review of related theory. However, in spite of the fact that the works of Priestly and Swinbank (1947) Priestly (1953, 1954, 1959), Morton *et al.* (1956) and Deardorff (1956) are taken into account in the development, the model is too primitive for quantitative evaluation. The hypothesis is basically similar to that offered below by Myrup and Edinger and assumes that heat flux against the gradient occurs only when the wind speed is light.

FIG. 4. Variation of temperature with height and time for Gila Bend Area (1956).

4. El Mirage, California—27 July 1961

The Meteorology Department of the University of California at Los Angeles (UCLA), using light aircraft and fast-response instrumentation, made detailed studies of the thermal structure over several areas in Southern California (Edinger and Myrup, 1962). One of the areas was El Mirage, which is a large, flat, dry lake bed 30 mi east of Palmdale in the Mojave Desert. For each observation period soundings consisted of a series of horizontal traverses at various altitudes, starting at 10 ft above the lake bed and reaching as high as 500 ft.

Fig. 5 shows three soundings made on the morning of 27 July 1961. During the periods between the three soundings heating through a low-level layer occurred with the maintenance of an inversion.

The authors include a detailed hypothesis to explain their findings. They reconstruct the process as follows:

(1) Buoyant elements originate either in a warm layer below the lowest layer of observation, or in local hot spots; (2) a rising motion of the hot elements is associated with a compensating descending motion in the environment, which heats the layer adiabatically; (3) simultaneously the buoyant elements are mixing with the environment and warming it by shedding air, which is eroded from the element; (4) above the layer in which

FIG. 5. Variation of temperature with height and time for El Mirage, Calif., 27 July 1961.

convection is occurring, there may be adiabatic warming due to subsidence compensating for up-slope motion along the nearby hillsides; (5) the process continues until the inversion layer is brought near an adiabatic lapse rate and the penetrating warm elements are then free to extend their influence to upper levels. Edinger and Myrup cite other investigations to support their idea of counter gradient (of potential temperature), buoyant heat flow.

5. Douglas Point, Ontario, Canada—17 August 1961

Douglas Point is on the east shore of Lake Huron about 10 mi north-northeast of Kincardine, Ontario. The land slopes gently upward from the lake, and there are no significant topographic features within 2 mi of the shore. During 13–18 August 1961, a period chosen to represent the “typical” synoptic situation of the season, a detailed micrometeorological study was undertaken by the Meteorological Service of Canada (Munn, 1962).

Fig. 6 shows a plot of temperature soundings made with a modified Canadian radiosonde attached to a tethered kytoon on 17 August 1961. Winds recorded at 20 and 80 ft at 0600 and 0700 Eastern Standard Time (EST) were about 1 mph or less and somewhat variable. Heating through a low-level layer (about 350 ft thick) with the maintenance of an inversion occurred between the 0604–0618 EST and 0630–0709 EST soundings. By the time of the third sounding a superadiabatic layer was observed at low levels.

FIG. 6. Variation of temperature with height and time for Douglas Point, Canada, 17 August 1961.

6. Gest Street, Cincinnati, Ohio—1–3 August 1962

The Weather Bureau Research Station in Cincinnati conducted an investigation at its Gest Street station in the summer of 1962 (Cleaves *et al.*, 1964). This station is situated in the Mill Creek Valley in the middle of an industrial area near downtown Cincinnati. The Ohio River is less than a mile to the south, and the Mill Creek is adjacent to the station to the east. Hills rise several hundred feet above the valley floor within a mile to the west. In no horizontal direction is there an unobstructed view for as much as 5 miles; tall buildings and hills encircle the area. Data on vertical temperature differences were obtained during this investigation with a modified radiosonde attached to a tethered blimp.

Data for the mornings of 1–3 August are shown in Fig. 7. Heating through a 900-ft surface layer without

the establishment of a superadiabatic lapse rate occurred each morning. During each period the winds were mostly north-northeast, averaging less than 5 mph, and the surface relative humidities averaged near 90 per cent.

7. Conclusion

As a result of the heat exchange accomplished primarily by hot buoyant elements rising through the atmosphere, the temporal change of vertical temperature differences for approximately an hour or two after sunrise may be such that inversion layers based at or near the surface will be heated through a relatively great depth and not readily eliminated. Postulations concerning the physical processes involved are presented in two reports (Appleby and Ohmstede, 1963; Edinger and Myrup, 1962) and have been summarized above. These postulations and the data in the reports cited in this note are mutually supporting. The occurrence of light winds (of the order of 3 mph or less) appears to be a most important feature when this phenomenon is observed. Observations of this type of temporal change have been obtained in desert areas in summer, fall, and winter; in a maritime area in summer; and in an urban area in summer; it appears, therefore, that such changes are not uncommon. Because the topographic features are dissimilar at these sites, it is assumed that the changes were not due to specific local topography. Since the winds were light during all of the observation periods, advection does not appear to be a cause. The overall indication is that the phenomenon of an inversion layer with a base within 5 to 10 ft of the surface persisting while being heated for a few hours after sunrise is not so rare that its occurrence should be overlooked in meteorological evaluations. Further, the generalization that there is practically no vertical exchange in inversions (U. S. Weather Bureau, 1955, p. 60), does not apply in these situations.

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FIG. 7. Variation of temperature with height and time for Gest St., Cincinnati, 1-3 August 1962.

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