On the Diurnal Variation in the Reported Heights of Isobaric Surfaces, Temperatures and Winds in the Troposphere

By Y. Kurihara

Meteorological Research Institute

(Manuscript received 15 May 1962)

Abstract

By using six-hourly upper air observations made at 97 stations in the northern hemisphere for ten-day period in September, 1958, the diurnal variations in height of isobaric surfaces, temperatures and winds in the troposphere except the boundary layer were investigated. The prominent features of the diurnal variation in height of isobaric surfaces are negative deviation from the daily mean at about 07 local time for each level, positive one at about 13 LT, and the existence of two maxima and two minima at 850 mb level. The average deviation of temperature for the air column, from 300 mb to 850 mb, is remarkably negative at about 07 LT and positive in the afternoon.

1. Introduction

In order to make a good analysis of synoptic chart and also to carry out a significant numerical analysis of some meteorological quantities, we should know about the quality of the reported upper air data. In the reported data, there may exist diurnal variations more or less. They have errors, both systematic and random, too. In this paper, mean diurnal variations over the northern hemisphere of the reported heights of isobaric surfaces, temperatures and winds are described. The results of the analyses show that the mean diurnal variations of those elements are fairly small, and the magnitudes are less than the probable errors of the present upper air observations. However, these do not mean the small diurnal variations at any locality, because the regional specialities such as latitude or the influence of the distribution of land and sea and so on are reduced to some extent in our analyses by taking the average for the whole selected stations in the hemisphere.

2. Data and process of analysis

The source data for the analysis are obtained from the micro-cards which were compiled by the WMO and contain the upper air data in the International Geophysical Year. The period we chose is ten days, 13 through 22, September, 1958. This period includes the autumnal equinox, and the special observations, i.e. six-hourly observations at many stations, have been carried out in it. Fig. 1 shows the stations we selected. In the figure, the large marks, double circle for Japan, black circle for USA, cross mark in a circle for Gt. Britain, circle for USSR and dot in a circle for other countries, indicate the stations where observations have been made at 00, 06, 12 and 18 GCT. The total number of these stations are 97. Other 87 stations, where observations have been made twice a day, give the supplementary data for the analysis and shown by dots in Fig. 1.

In this study, we used the reported values for four standard levels, i.e. 850, 700, 500 and 300 mb levels. Therefore, roughly speaking, our analysis can reveal the diurnal variations of heights of isobaric surfaces, temperatures and winds in the troposphere excluding the boundary layer.

Now, we will mention about the procedure of analysis. At first, the six-hourly data for a certain level for each station were averaged over the before mentioned ten-day period to obtain the mean value for each observation
time. By subtracting the over-all mean value for the station from the mean value thus computed, we got the mean departure at each time from the daily mean value. Then, considering the longitude of the station, we can convert the departure at each time into the deviation at a local time. For example, if the longitude of the station is 45 degree east, the departures at 00, 06, 12 and 18 GMT correspond to those at 03, 09, 15 and 21 LT (local time), respectively. By making use of the deviations for all the stations, we can get the figures which show the relation between the local time and the departure from the daily mean. Fig. 2 and Fig. 3 are the figures of this kind. In these figures, the local time is shown in the abscissa and the departure of 850 mb height and that of temperature on 850 mb level are shown in the ordinate. The scattering marks in the figures are plotted according to the departure at the local time at each station. In order to estimate the mean magnitude for the northern hemisphere of the diurnal variations, the running two-hour mean of the deviations in the figure was taken. In taking the average, we excluded the largest six deviations in each two-hour range so as to avoid the influence of the large departures which are not the diurnal variations essentially and might have been caused by the synoptic situation such as a passing of the intense cyclone. The continuous lines in Fig. 2 and 3 show the mean diurnal variation which are obtained in the above way. It is seen that the lines in the figures represent the general aspect of the
variations fairly well. We can also say that the scattering of the marks in the figures suggest that the diurnal variations at some stations may be much larger than the mean variations for the hemisphere.

The estimation of the mean diurnal variations of several meteorological elements was made for each level of 850, 700, 500 and 300 mb. From these, Figs. 4, 6, 8, 9 and 10 are obtained, in which the departure from the daily mean value is shown as a function of the local time and pressure. In the following sections, considerations on the diurnal variation of each element shall be made based upon these figures.

As a rough measure of the statistical significance of the obtained result, the probable errors in the estimation for each level are shown at the right side of Figs. 4, 6 and 8. These are derived from assuming the random error in an individual observation. We can assume the magnitude of random error by using the result of the comparisons of the various types of radiosondes, as described in the author's previous paper\(^1\) (1961). In this study, the random errors of isobaric height and temperature were obtained from the information concerning the world comparisons of radiosondes made at Payerne in 1956\(^2\). As for the error in the winds-aloft data, the

<table>
<thead>
<tr>
<th>mb</th>
<th>height</th>
<th>temperature</th>
<th>wind speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>33 gpm</td>
<td>1.5°C</td>
<td>5.2 m/s</td>
</tr>
<tr>
<td>500</td>
<td>15</td>
<td>1.5</td>
<td>2.2</td>
</tr>
<tr>
<td>700</td>
<td>14</td>
<td>1.1</td>
<td>1.6</td>
</tr>
<tr>
<td>850</td>
<td>6</td>
<td>0.8</td>
<td>0.7</td>
</tr>
</tbody>
</table>

---

\(^1\) Author's previous paper (1961).
\(^2\) Comparisons of various types of radiosondes made at Payerne in 1956.

---

Vol. 40, No. 4, 1962
results of the study about it by the present author\textsuperscript{15} were adopted. Magnitudes of random errors in isobaric heights, temperatures and winds, which we assumed for a single observation, are tabulated in Table 1.

3. Diurnal variation of heights of isobaric surfaces

The departure of the height of isobaric surface from the daily mean height is shown in Fig. 4. The prominent feature of the figure is the negative deviation at 02 LT through 08 LT and the positive departure at 11 LT through about 15 LT. The minimum height occurs somewhat after 06 LT at 300, 500 and 700 mb level, while it does before 06 LT at 850 mb. The largest deviations at this time at 300, 500, 700 and 850 mb level are $-10.0\pm 3.1$, $-8.2\pm 1.4$, $-5.5\pm 1.3$ and $-2.7\pm 0.6$ gpm, respectively. The maximum values in the...
Fig. 4. The departure of height of isobaric surface from the daily mean as a function of local time (in abscissa) and pressure (in ordinate). The probable error in the estimation for each level is shown at the right side of the figure.

daytime for these levels are 7.0 ± 3.1, 6.3 ± 1.4, 4.9 ± 1.3 and 3.0 ± 0.6 gpm, respectively.

The small negative deviation at 18 LT at 300 mb level, which is seen in the figure, is not statistically significant. We may say that 300, 500 and 700 mb levels descend at about 07 LT and ascend somewhat after the noon. The deviation of these levels in the nighttime from the daily mean height are very small, if any. At 850 mb level, we notice the negative deviation at 15 LT through about 20 LT and the positive one at about 20 LT through 02 LT, other than the before mentioned departures. The minimum and the maximum values for these times are −1.4 ± 0.6 and 1.8 ± 0.6 gpm. Consequently, we can conclude that two maxima and two minima in the diurnal variation of 850 mb height are revealed in this analysis. It should be remarked here that the time of occurrence of these extremes

Fig. 5. The departure of the 850 mb height at 00 GCT from the daily mean (in gpm). The dotted line is used for the area with sparse data.
has time lag of three or four hours behind those in the diurnal variation of the surface pressure, i.e., about 09 and 21 LT for the maxima and about 03 and 15 LT for the minima.

The discussions made so far are based upon the average state for many stations. The diurnal variation at each station may be more complicated, though the characteristic we obtained is generally to be contained in it. As an example, Fig. 5 is represented, in which the departure of 850 mb height at 00 GCT from the daily mean is shown. There are two positive large areas, at the European region and the Pacific Ocean, and two negative areas, at the Asian and the American continents. These correspond to the before mentioned four extreme departures in the mean diurnal variation of 850 mb height. It seems that the amplitude of the variation at the middle latitude is larger than at the higher latitude. There are some places where the sign of departure is opposite to that of the average departure at the corresponding local time. This may be due to causes peculiar to the place.

4. Diurnal variation of temperatures

The upper part of Fig. 6 shows the mean departure of temperature at each level from the daily mean as a function of local time and pressure. In obtaining this figure, the diurnal variations of thicknesses between 300 and 500 mb levels, 500 and 700 mb levels and 700 and 850 mb levels, which could be estimated from Fig. 4, were considered, too. SR and SS in the figure indicate the approximate time of sunrise and sunset for the period we selected. It is seen that the remarkable drop in temperature occurs at all levels at the time a little after sunrise. This is particularly large below 700 mb level and the deviation reaches $-0.5 \pm 0.1^\circ\text{C}$ at 850 mb level. At 12 LT through about 15 LT, the deviation is positive at all levels. At about 19 LT, the deviation is positive below 700 mb, and becomes $0.35 \pm 0.1^\circ\text{C}$ at 850 mb level. Other departures seen in the figure, e.g. the negative deviation at 17 LT through 21 LT and the positive one at about 05 LT in the upper layer, are so small that they are not statistically significant. Summarizing what we
mentioned above, we may say that the characteristics of diurnal variation in temperature at 850 mb level are the drop below daily mean from midnight to noon, especially at the time somewhat later than sunrise, and the rise from noon to about midnight. While in the upper layer of the troposphere, the characteristics are the low temperature from sunrise to about 09 LT and the high temperature after 12 LT till 15 or 16 LT.

The lower part of Fig. 6 is obtained by taking the average of departure at each level from 300 to 850 mb. Therefore, it shows the average diurnal variation of temperature for the air column. It is clearly shown that the temperature as a whole becomes below the daily mean at 03 LT and 07 LT by $-0.11 \pm 0.05$ and $-0.26 \pm 0.05 ^\circ C$, respectively, and becomes above at 12 LT and 14 LT by $0.14 \pm 0.05$ and $0.12 \pm 0.05 ^\circ C$, respectively.

As it seems that there is a general tendency in the diurnal variation of temperature such as a gradual rise in the morning and a fall in the afternoon, the empirical relation between the departure of temperature from the daily mean and the elevation angle of the sun was tentatively obtained for each level. In Fig. 7, the departure at 700 mb level at each station is plotted against the elevation angle of the sun. The left and the right figures in Fig. 7 are those for morning and for afternoon, respectively. Denoting the departure by $\Delta T$ in °C and the elevation angle by $\theta$ in degree, we get the empirical formulae

\[
\begin{align*}
100 \cdot \Delta T &= 1.14\theta - 54 \quad \text{for} \ 850 \text{ mb}, \\
100 \cdot \Delta T &= 0.99\theta - 30 \quad \text{for} \ 700 \text{ mb}, \\
100 \cdot \Delta T &= 1.44\theta - 34 \quad \text{for} \ 500 \text{ mb}, \\
100 \cdot \Delta T &= 0.85\theta - 19 \quad \text{for} \ 300 \text{ mb}.
\end{align*}
\]

Those for afternoon are
\[
\begin{align*}
100 \cdot \Delta T &= -0.64\theta + 1 \quad \text{for} \ 850 \text{ mb}, \\
100 \cdot \Delta T &= -0.70\theta - 8 \quad \text{for} \ 700 \text{ mb}, \\
100 \cdot \Delta T &= -0.97\theta - 18 \quad \text{for} \ 500 \text{ mb}, \\
100 \cdot \Delta T &= -1.03\theta - 14 \quad \text{for} \ 300 \text{ mb}.
\end{align*}
\]

The plottings in Fig. 7 are made with different marks according to the classification of stations by latitude. However, it is difficult to find different features for different latitudes, so far as this study is concerned.

5. Diurnal variation of winds

The results of analyses concerning diurnal variations in west and south components of wind and in wind speed are shown by Figs. 8, 9 and 10, respectively. In each figure, the departure from the daily mean value is presented as a function of local time and pressure. The probable error in the estimation is written for each standard level at the right side of Fig. 8. Generally saying, the mean diurnal variations of these for the whole stations are fairly small. But, considering the probable error in the estimation, we can make remarks about the mean diurnal variation of winds as follows.
At 500 mb level, west component of wind becomes relatively small or east component large at about 06 LT through 10 LT, and it increases at about 15 LT. The mean departure of west component from the daily mean is \(-0.5\pm0.2\) m/sec at 07 LT and \(0.3\pm0.2\) m/sec at 15 LT or so. The mean deviation in south component at 06 LT through 09 LT is negative, the extreme value of which is \(-0.26\pm0.2\) m/sec, and the deviation at 18 LT through 21 LT is negative again with the minimum \(-0.24\pm0.2\) m/sec. As for wind speed, it is relatively large at 01 LT through 03 LT and also at 14 LT through about 15 LT. The deviation at the latter is estimated to be \(0.3\pm0.2\) m/sec.

At 700 mb level, the main feature of the variation in west component is similar to that for 500 mb. Namely the decrease of west component is seen at about 08 LT through 10 LT and the increase in the afternoon. In the variation of south component, the positive deviation at 12 LT through 14 LT with the maximum \(0.30\pm0.15\) m/sec, and the negative one at 15 LT through 18 LT with the minimum \(-0.38\pm0.15\) m/sec are remarkable. Significant departure in wind speed can not be found except the decrease at 19 LT through 22 LT.
Diurnal Variation in Heights, Temperatures and Winds in the Troposphere

with the extreme \(-0.23\pm0.15\) m/sec.

At 850 mb level, the type of diurnal variation in west component seems to be different to some degree from that above 700 mb. There exist two maxima and two minima in it, \(i.e., 0.23\pm0.07\) m/sec for the positive deviation at 02 LT through 05 LT, \(-0.30\pm0.07\) m/sec for the negative deviation at 06 LT through noon, \(0.21\pm0.07\) m/sec for the positive deviation at noon through 19 LT and \(-0.33\pm0.07\) m/sec for the negative deviation at 19 LT through 02 LT. South component on this level increases in the daytime and the deviation at 13 LT is \(0.12\pm0.07\) m/sec, and it decreases in the nighttime and the deviation at 05 LT is \(-0.14\pm0.07\) m/sec. Wind speed becomes a little larger than the daily mean at 02 LT through noon and at 16 LT through 20 LT. It shows a negative deviation at about 15 LT in a little degree and at 20 LT through 02 LT with the extreme \(-0.30\pm0.07\) m/sec.

It must be remarked here that the diurnal variation of wind at some places may differ largely from the above mentioned average variation for many stations. As an example, we shall refer to the study by Hering and Borden3) (1962). They investigated the diurnal variations in the summer wind field over the central United States. According to their results, there exist three oscillation regimes in the wind field, \(i.e., the low-level, the middle-layer and the upper oscillations. Comparing their results for the middle-layer with our estimations, we find that the magnitude of variation for the former is larger by one order than the latter, and even the sense of departure vector differs from each other in the case of south component of wind.

Acknowledgement

The author wishes to express his hearty thanks to Dr. H. Arakawa and Dr. S. Syōno for their encouragement throughout this study. He also wishes to thank the director-general of British Meteorological Office who gave him the information on the upper air data of his country. He is indebted to Mr. S. Nakamura, Japan Meteorological Agency, who arranged the IGY data for this study, to Miss T. Akiyama and Mr. I. Tabata who performed the laborious calculations and drafted the figures and also to Mrs. Y. Tsuneoka who typewrote the manuscript.

References

2. Information concerning the world comparison of radiosondes (Payerne, 1956). Recommendation 13 (CIMO-II) and Annex 7, WMO-No. 64. RP. 26.

対流圈内の等圧面高度、気温、風の観測値の日変化について

栗 原 宜 夫

（気 象 研 究 所）

北半球上 97 点における6時間毎の高層観測資料 (1958年9月中旬の10日間) を用いて、境界層を除く対流圈内の等圧面高度、気温、風の観測値に見られる日変化を調べた。等圧面高度は、各等圧面とも地方時7時頃に日平均に比べて負の偏差、13時頃に正の偏差を示し、850 mb 面は一日に2回の極大と2回の極小をもつ日変化を示すことがわかった。また 300 mb と 850 mb間の気柱全体について、日の出の少し後に気温は顕著に低くなり、午後は日平均よりも高温となる。

Vol. 40, No. 4, 1962