

Basic Principles of the Balloon Bomb*

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Abstract

The height of 10~12 km has been selected as an appropriate level for drifting of balloon bombs, for this level is the well-defined isopycnic level with maximum westerly currents. During the winter of 1944~1945, 9,000 balloons were sent out to the United States from Japan, for the winter season is characterized by heavy baroclinicity in middle latitudes and hence the greatest strength of the westerlies is found. Two or three days will be enough to send balloons through the upper troposphere if the conditions are favourable.

During the Great War II, the Japanese Army tried to attack the United States by means of the so-called Balloon Bomb. Because of the shortage of long distance aeroplanes, bombs were loaded on large constant-level balloons and sent out at about 10~12 km level where the middle-latitude westerlies are very well developed.

During my stay at Rabaul in the late autumn of 1942 as a sick traveller, I suffered the severe bombings of the Allied Air Forces. Then I dreamed of the attack against the United States by means of unmanned balloons. Soon after coming back to Japan, I advised to the Japanese Army and Navy through the late Dr. S. FUJIWHARA, then the director of the Central Meteorological Observatory, Tokyo.

Meanwhile, about ten months elapsed. During this period the Japanese Army and Navy almost gave up the hope for victory over the Allied Forces. To recover from the discouraging situation, the Japanese Army took up the plan of balloon bombs, and requested me to study the following unsolved problems: What level should be selected for the drifting of balloon bombs? What seasons will be the most favourable to release the balloon bombs? How many days will they take to reach the central zone of the United States after the release from Japan? How about the diffusion of the constant-level balloons over North America?

At the end of the war, I burned almost all the data concerning the balloon bombs by the suggestion of the Japanese Army. So I have only a few data left on this problem, but I think they will be of interest for the meteorologists studying the general circulation of the atmosphere.

At first, I checked the wind data of the Aerological Observatory at Tateno

* Reference should be made to the same article abstracted in "Meteorological Abstracts and Bibliography", published by the American Meteorological Society, Vol. 5, 5 E-126, 1954.

(International index number 646) reported by W. OISHI [1]. The most interesting fact is that the monthly mean wind speed over Tateno at 10 km level is tremendously great as seen from Table 1. For instance, the mean wind speed at 10 km level for February was reported to be 76.1 m/sec from the west.

Table 1. Annual change of wind at the level of 10 km, from the data reported by W. OISHI (1930).

	Wind direction (°)	Wind speed (m/sec)
Jan.	288	62.3
Feb.	266	76.1
March	278	54.0
April	296	34.7
May	307	38.1
June	280	35.3
July	302	15.8
Aug.	328	12.4
Sep.	244	26.0
Oct.	264	42.1
Nov.	276	49.0
Dec.	264	66.3
Spring	299	42.3
Summer	308	21.2
Autumn	262	39.0
Winter	273	68.2
Year	282	39.6

For the sake of comparison, the mean wind speeds at 10 and 12 km levels over the United States were referred from the source materials (Monthly Weather Review Supplement). The mean wind speeds less than ca. 25 m/sec appeared to be underestimated, partly due to the fact that the pilot balloons were sent only on such conditions of fair, calm weather.

To inquire into the realness of the tremendous mean wind speed as much as 76 m/sec over Tateno, I treated the problem from a purely dynamical point of view. In 1942, there were seven radiosonde stations in Japan, i.e., Sendai (International index number 590), Niigata (604), Wajima (600), Yonago (744), Fukuoka (807), Shionomisaki (778) and Oshima (675). The monthly mean values at each radiosonde station were plotted on an aerogram and the monthly mean temperature-height curves were drawn for the seven stations. All the mean temperature-height curves intersect at a common point at the level of about 200-mb (i.e., about 12 km level). Since the original data were lost, I would like to quote from a recent paper by H. YAMADA and S. MATSUHASHI [2]. Fig. 1 represents the mean temperature-height curves for January and July, 1950, in which we can see how the curves intersect at a common point approximately at the 200-mb level. In Fig. 1, the temperature-height curves stand for the following stations (Internatio-

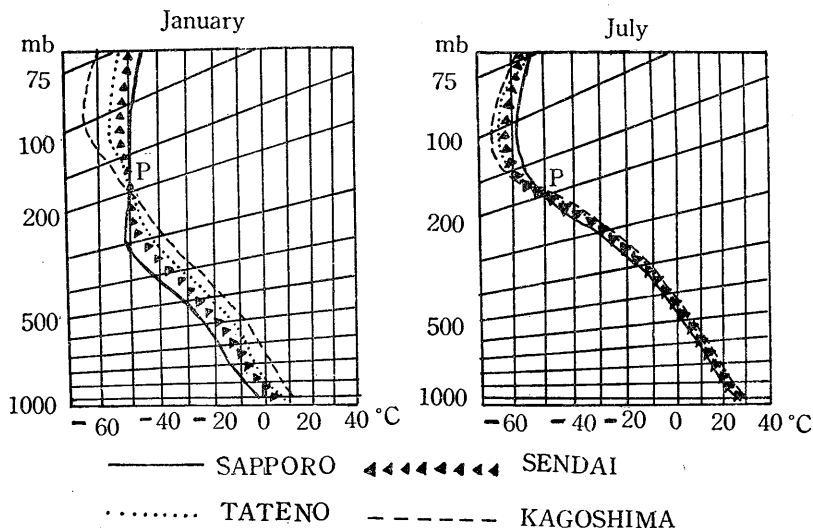


Fig. 1. Mean temperature-height curves; left for Jan. 1950, right for July, 1950.

nal index number in parentheses): Sapporo (412), Sendai (590), Tateno (646) and Kagoshima (827).

In view of the importance of baroclinicity for the dynamics of westerlies, I have intended to evaluate the solenoid $N = \oint dp/\rho$, where ρ is the density, and p the atmospheric pressure. If the solenoid in a vertical NS-cross section is to be computed, a convenient path of integration would consist of two isobars and two vertical lines connecting these isobars. In order to compute the intensity of the solenoid in the NS-cross section, one might choose the two isobars p_0 (standard pressure) and p_1 , and two verticals a_s and a_n connecting these isobars at southern and northern stations. Integration along the isobars gives zero. From the hydrostatic equation it follows that $-dp/\rho = g dz = d\phi$, where g is the acceleration of gravity, z the height, and ϕ the geopotential. Thus, along the curves a_s and a_n the height differences between two principal isobars can be integrated so that $N = (\phi_s^{p_1} - \phi_n^{p_1}) - (\phi_s^{p_0} - \phi_n^{p_0})$.

The number of solenoids may be evaluated by means of the log- p - T -diagram graphically as

$$(1) \quad N = - \oint dp/\rho = -R \oint T d(\log p),$$

where T is the air temperature in absolute scale, and R the gas constant for dry air. So the density of the solenoid field can be represented readily by the area closed by two isobars and two temperature-height curves in the log p - T -diagram.

Assuming the geostrophic wind, we have the expression for the westerly current u_1 at right angles to the isobar p_1 as: $u_1 = (\phi_s^{p_1} - \phi_n^{p_1})/2 \omega \sin \phi \cdot \Delta y$, where ω is the angular velocity of the earth's rotation, ϕ the latitude, and Δy the meridional distance between two stations. Thus the velocity difference, $u_1 - u_0$, must be expressed by the equation

$$(2) \quad u_1 - u_0 = N/2 \omega \sin \phi \cdot \Delta y,$$

where u_0 is the westerly current at right angles to the isobar p_0 and must be written as $u_0 = (\psi_s^{p_0} - \psi_n^{p_0}) / 2 \omega \sin \phi \cdot \Delta y$. The formula (2) is well-known as SANDSTRÖM = HELLAND-HANSEN'S theorem in oceanography, which holds for general upper-air current for it does not necessarily assume to take the NS-cross section. N can be evaluated from the diagram shown in Fig. 1. YAMADA and MATSUHASHI [2] got the following result for the number of solenoids N by evaluating the area closed by the surface-level and two mean temperature-height curves for Sapporo and Kagoshima up to the isopycnic level through the common point P . The corresponding geostrophic velocities are also listed below.

	Jan., 1950	April, 1950	July, 1950	Oct., 1950
$N(10^6 \text{ ergs})$	57.8	37.4	13.7	41.6
$u_1 - u_0 \text{ (m/sec)}$	51.2	33.1	12.1	36.9

From this table, we can see that the intensity of westerlies over Japan is extremely pronounced in winter. Moreover, mean temperature-height curves for each month intersect approximately at the 200-mb level through a common point P in the aerogram (see Fig. 1), so that the greatest strength of the westerly wind will be found nearly at the 200-mb level all over Japan. For the number of solenoids N computed by integration expressed by equation (1) attains a maximum value when the upper isobar is chosen at about 200-mb level through the point P , so

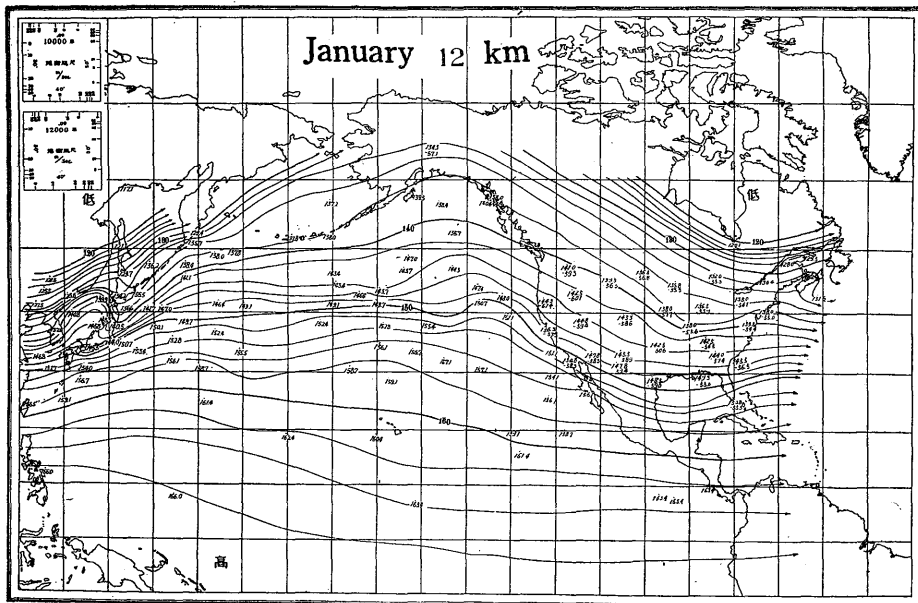


Fig. 2. Reproduction of the mean upper air chart for January (12 km level), made for the operation of balloon bombs. Upper left stands for the geostrophic wind scales.

that from formula (2), the greatest strength of the westerly wind will be found at isopycnic level all over Japan. For this reason, the existence of the well-defined isopycnic level with the greatest wind speed at about 200-mb, i.e., the jet stream level, has an important significance. So that the balloon bombs were sent from several stations on the east coasts of Japan, not from a single station.

Thus, we choose as the drifting level for the balloon bombs the isopycnic level with the greatest wind speed, or the level of 10~12 km. Also the seasonal variation of the westerly current was interpreted rather completely.

To follow the tracks of balloon bombs, I estimated the monthly mean pressures at 10 km and 12 km levels over the Pacific Ocean, using the surface pressure and temperature and assuming an appropriate temperature lapse-rate. Then I plotted them on charts and drew the isobars. Entering the wind data as much as possible, we obtained charts roughly showing the behaviour of the westerly current. Fig. 2 is a copy of the chart for January, at the level of 12 km. The striking feature of these charts for 12 km level is that the middle-latitude belt of westerlies generally appears as a rather narrow band of strong winds, embedded in relatively stagnant air masses to the south and north.

I also drew the daily historical maps for 10 and 12 km levels. Then I estimated the time interval might be required by the balloons for landing in the United States after releasing, and their dispersions. The most striking feature of these conclusions is, probably, that two or three days will be enough for the balloons to land in the central zone of the United States after the release from Japan.

Further details can be found in three following articles by the present author: Tenmon to kisho, Vol. 17, No. 11, 7-12 (1951); Journal of Geography, Vol. 60, No. 4, 167-172 (1951); Journal of the Japan Society of Aeronautical Engineering, Vol. 1 No. 2, 98-103 (1953); each in Japanese.

References

- [1] OISHI, W., 1930: Vento super Tateno, 2nd Note (in Japanese), Journal of the Aerological Observatory at Tateno, Japan, 1, No. 5, p. 1.
- [2] YAMADA, H. and MATSUHASHI, S., 1951: On the Winds Aloft Analysis by RAOB (in Japanese), Journal of the Aerological Observatory at Tateno, Japan, 5, p. 20.