Evaporation from the Japan Sea in the winter

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雑誌名	Science reports of the Tohoku University. Ser. 5, Geophysics
巻	15
号	2
ページ	67-75
発行年	1964-03
URL	http://hdl.handle.net/10097/44649

Evaporation from the Japan Sea in the winter monsoon season

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(Received May 1, 1963)

Abstract

Evaporation from the Japan Sea was estimated by using the evaporation diagram which had been reported by the author, and the result was compared with the increased amount of water vapor at the lee ward. It was found that the amount of evaporation was somewhat larger than that of the increased amount of water vapor. The difference of these quantities may be explained as the precipitation over the sea.

The integral amount of snowfall over Hokuriku district was also estimated. It amounted to be about 40% of the evaporation from the sea.

1 Introduction

The monsoon is a prevailing feature of Japan in winter. In this season, the cold-dry Siberian airmass transforms into maritime air during the flowing out over the warmer Japan Sea. And the modified moist-airmass causes a heavy snowfall over Hokuriku district, (the north-west coast of the Japanese islands.)

The study on the modification of airmass over the Japan Sea has been made by several authors. For example, Manabe (1957) estimated the amounts of heat and water vapor supplied from the sea to the atmosphere, based on the divergences of water vapor and heat from the radiosonde data which were made at the surrounding observation stations, and on the horizontal distribution of the presumed precipitation over the Japan Sea.

On the other hand, Jacobs (1942) showed an empirical equation of evaporation from the ocean which was made based on the energy budget of the ocean water during the long period. This is

$$\frac{E}{\chi_s-\chi}=2.05\times10^{-3}\,u,\ (\text{C.G.S.})\,, \tag{1}$$

where E is the evaporation, χ is the water vapor concentration at the shipboard, χ_s is the water vapor concentration at the sea surface which is estimated to be 0.98 times the saturation vapor concentration corresponding to the sea surface temperature due to the salinity, and u is the wind velocity at the shipboard. Above equation applies to the mean evaporation of the large-scale during the long period.

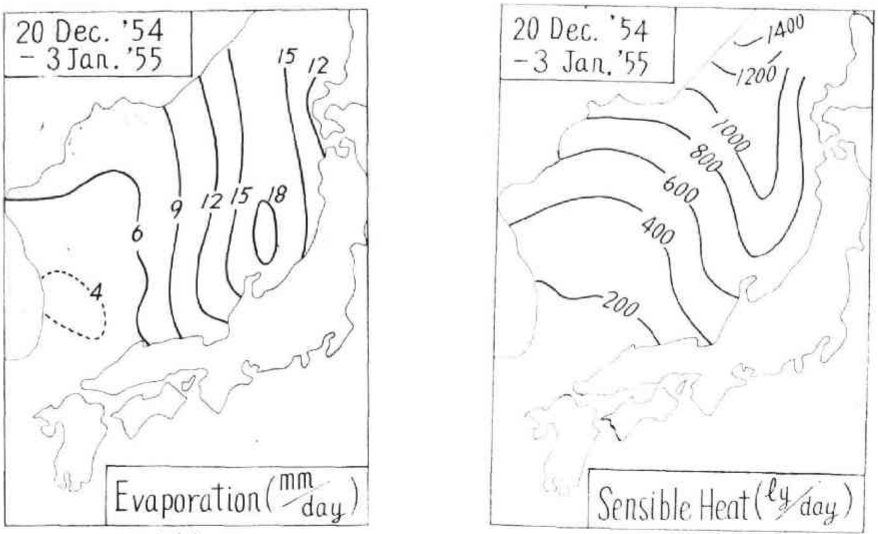
In the previous paper, Kondo (1962), the writer has presented an evaporation diagram. This was made based on the turbulent theory [Yamamoto (1959)], and the relations obtained by the observations. In comparing between Jacobs' equation and Kondo's evaporation diagram, the former leads to overestimation when the wind is mild and leads to underestimation when the wind is strong: for example, when $u<5$

m/s under nearly neutral conditions Jacobs' is about twice the evaporation of Kondo's, when $u \fallingdotseq 20$ m/s the former is 2/3 times of the latter and when $u \fallingdotseq 10$ m/s both are nearly same.

In the present paper the author estimates the evaporation from the Japan Sea by using the evaporation diagram, and he estimates the ratio of the evaporation to the amount of the snowfall over the north-west coast of Japanese islands.

2 Comparison between the result obtained by Manabe and that by present method

As stated in the preceding section MANABE (1957) estimated the amounts of heat and water vapor supplied from the sea to the atmosphere based on radiosonde data, and he concluded that the amount of supplied sensible heat was larger than that of supplied latent heat in spite of the fact that mean Bowen's ratio was nearly equal to unity. And he emphasized that the rate of energy exchange in sensible form seemed to exceed much that of energy exchange in latent form. However, it will be of some interest to estimate those quantities by a different method.



(A) (B)

Fig. 1. Distributions of evaporation (A), and sensible heat (B) estimated by KONDO's evaporation diagram

At the first step of the present study we will estimate the sensible heat and evaporation from the evaporation diagram by using the same data which have been compiled by MANABE (1957). The results are shown in Fig. 1, and the mean amounts are 620 ly/day and 10.2 mm/day respectively.

Instead of comparing the present results with Manabe's results directly, it will be more reasonable to make some correction to his results based on MANABE's second paper (1958) and compare with them. According to his second paper, errors of his estimation are as follows:

(1) overestimation caused by geostrophic approximation is about 13%,

(2) underestimation of the divergence of water vapor caused by the neglection of water content in the cloud is about 14%.

The comparison between the corrected MANABE's and the present results is shown in Fig. 2.

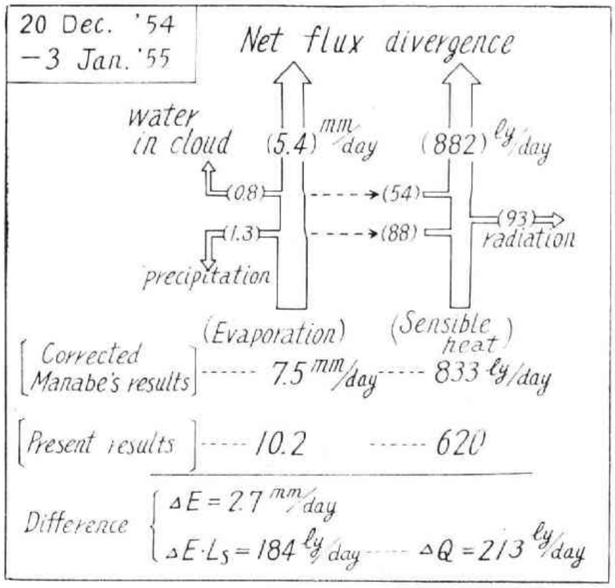


Fig. 2. Comparison between the corrected Manabe's and the present results. L_s=680 cal/gr; heat of sublimation

It will be seen in Fig. 2 that the present estimation of evaporation is larger than Manabe's while that of sensible heat is smaller than MANABE's. Based on MANABE's estimation the Bowen ratio becomes as large as about 1.9. In order to explain this unexpectedly large Bowen ratio, Manabe has suggested that the eddy diffusivity for heat might have exceeded that for vapor under unstable conditions such as those over the Japan Sea. On the other hand in the present estimation the Bowen ratio estimated from the average evaporation and sensible heat is about 1.0. This result is of course due to our assumption that the eddy diffusivity for heat and that for vapor are equal. It will not be reasonable to criticize MANABE's results, by reason of the difference of his results and the present ones. However, in examining his method it will be seen that his estimation of precipitation over the Japan Sea was based on the precipitation isopleths which were drawn daringly covering the Japan Sea where no observations exist generally. It might be possible to arrive at other estimations from the same data as used by him. From this stand point it is possible to reconsile his results with ours, if it is assumed that the precipitation over the Japan Sea in this period was greater than the estimated value by Manabe. The reasons which might support this assumption is as follows:

(a) Four successive cyclones have passed over the Japan Sea during the period from Dec. 20, 1954 to Jan. 3, 1955.

(b) Statistical data show that the area of the bad weather over the Japan Sea in winter extends from the north-west coast of the Japanese islands to the region at a distance of about 200–400 km from the continental coast.

(c) Manabe has omitted the precipitation data at Ullungdo island, by the reason that he considered the observed values of precipitation too much to be reasonable.

Now, by assuming the 4 mm/day precipitation instead of 1.3 mm/day, it will be seen from Fig. 2 that the estimated value of evaporation by Manabe's method becomes $5.4+0.8+4.0=10.2$ mm/day and the sensible heat becomes $882+93-54-0.4\times 680=649$ ly/day. The estimated value of evaporation agrees with the present one and that of sensible heat also agrees within a small difference of 29 ly/day with the present one. From this discussion it seems desirable that Manabe's method be applied on some other areas where reliable data on precipitation over the areas exist, in order to verify his suggestion that the eddy diffusivity for heat far exceeds that for vapor over a wide area.

3 Precipitation over the Japan Sea when no cyclone passes through over the sea

As stated above, MANABE's method of the evaluation of evaporation is only applicable over an area where the reliable data on precipitation are available. However, it may be possible to evaluate the amount of precipitation over the area where no precipitation data are available, by applying both MANABE's and the present methods simultaneously. In this section we will estimate the precipitation over the central region of the Japan Sea when no cyclone passes through over the sea. The period from 21st to 31st Jan. 1962 was selected for the purpose.

Sea-surface temperature

The sea-surface temperature near the central region of the Japan sea—from the Bay of Peter the Great to the north-west coast of Central Japan—is obtained by the extraporation from the observations made in Feb. 1962, and from the tendency of the seasonal variation of surface temperature in the past. This is shown in Fig. 3. (H) and (L) represents the higher and the lower extrapolations, respectively.

Wind velocity

It is known empirically that the wind velocity on shipboard is 2/3 times of the geostrophic wind speed, [PETTERSSEN (1956)]. Dash-dotted curve in Fig. 3 shows the wind speed which was obtained by the empirical relation, from the distance of isobars on the surface pressure map. The trend of the distribution of wind speed in Fig. 3 is also detected in the statistical data (A).

Air temperature and dew-point temperature

The distributions of air temperature and dew-point temperature are obtained by the interpolation from the observations at the surrounding stations, [refer also to the statistical data (A) and (B)]. These are shown in Fig. 4.

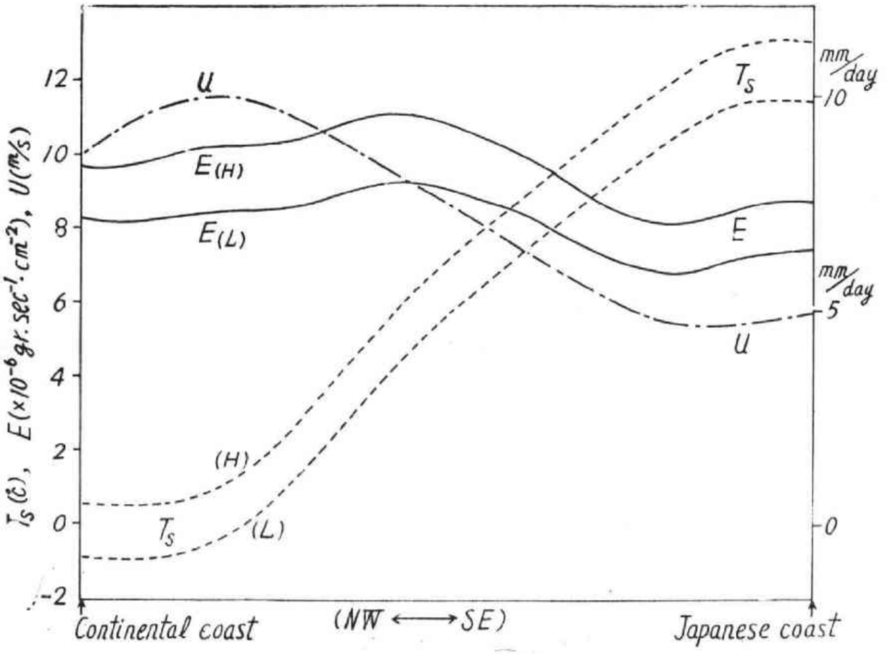


Fig. 3. NW-SE cross-section of the sea surface temperature T_s, the surface wind speed u, and the evaporation E for 21–31 Jan. 1962.

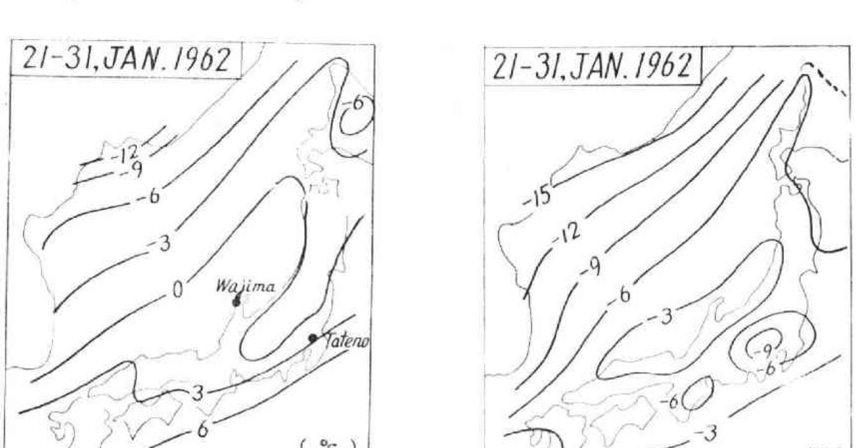


Fig. 4. Distributions of the air temperature (A) and the dew-point temperature (B).

Evaporation from the sea

Using the evaporation diagram and the meteorological values obtained above, we can estimate the evaporation from the cross-section at the central region of the sea. This is shown in Fig. 3, $E_{(H)}$ and $E_{(L)}$ represents the evaporations when the surface temperature is (H) and (L), respectively. The mean values of $E_{(H)}$ and $E_{(L)}$ is 9.7×10^{-6} gr/sec.cm^2 (8.4 mm/day) and 8.1×10^{-6} gr/sec.cm^2 (7.0 mm/day) respectively.

Increase of water vapor at the lee ward

The evaporation causes the increase of the water vapor in the air. The equation of conservation of water vapor content, from the continental coast (c. coast) to Wajima (Waj.), under the steady state in a stream-tube, which is assumed to have a unit-lateral width at any height at Wajima, is given by

$$\int_0^{z_1}\{\Delta(z)\,\chi(z)\,u(z)\}_{Waj.}\,dz-\int_0^{z_1}\{\Delta(z)\,\chi(z)\,u(z)\}_{c.coast}\cdot dz$$

$$=\int_{c.coast}^{Wajima}\Delta(0)\,E\,dx-\int_{c.coast}^{Wajima}\Delta(0)\,P_r\,dx \qquad (2)$$

where χ is the water vapor concentration, u is the wind velocity, P_r is the precipitation, x is the distance from the continental coast along the wind direction, Δ is the interval of isobars and z_1 indicates the height at which $\chi_{\mathrm{waj.}}(z_1)=\chi_{\mathrm{c.coast}}(z_1)$ is to be satisfied, (in practice, the pressure at z_1 is about 500mb). This equation holds when the lateral uniformity (normal to the wind direction) of the atmospheric condition is assumed. With use of the continuity relation:

$$u(z)\,\Delta(z)=\{u(z)\,\Delta(z)\}_{Waj.}=\{u(z)\,\Delta(z)\}_{c.coast} \qquad (3)$$

Eq. (2) is transformed into

$$\int_0^{z_1}u_{Waj.}(z)\,\{\chi_{Waj.}(z)-\chi_{c.coast}(z)\}\,dz=\int_{c.coast}^{Waj.}\frac{u_{Waj.}(0)}{u(0)}\,E\,dx-\int_{c.coast}^{Waj.}\frac{u_{Waj.}(0)}{u(0)}\,P_r\,dx \qquad (4)$$

where $u(0)$ represents the surface wind (in Fig. 3). In Fig. 5 the vertical profiles of water vapor-pressure at Wajima and at the continental coast are shown. The increased amount of water vapor from 1000mb to 500mb (the left hand side of Eq. (4)) is 400±60 gr·sec^{-1} per cm of lateral width of Wajima. The first term of the right hand side of Eq. (4) can be calculated from the values given in Fig. 3. This is 495±55 gr·sec^{-1} per cm of lateral width at Wajima. With use of these two values we can evaluate from (4) the precipitation over the sea. In the present example the mean precipitation over the sea is found to be about 1.5 mm/day. This value is somewhat smaller than that obtained in the preceding section.

4 Comparison between the total amount of snowfalls over Hokuriku district and that of evaporation from the sea

Hokuriku district is the region with considerable snowfall in Japan since the airmass which flows towards this district takes the longest pass over the Japan Sea.

The left of Fig. 6 shows the distribution of the total amount of precipitation (snowfall) in 21–31 Jan. 1962. The right of Fig. 6 shows the line-integral of precipitation from the dotted line (J) to the zero-precipitation line. This is about 190±50 gr·

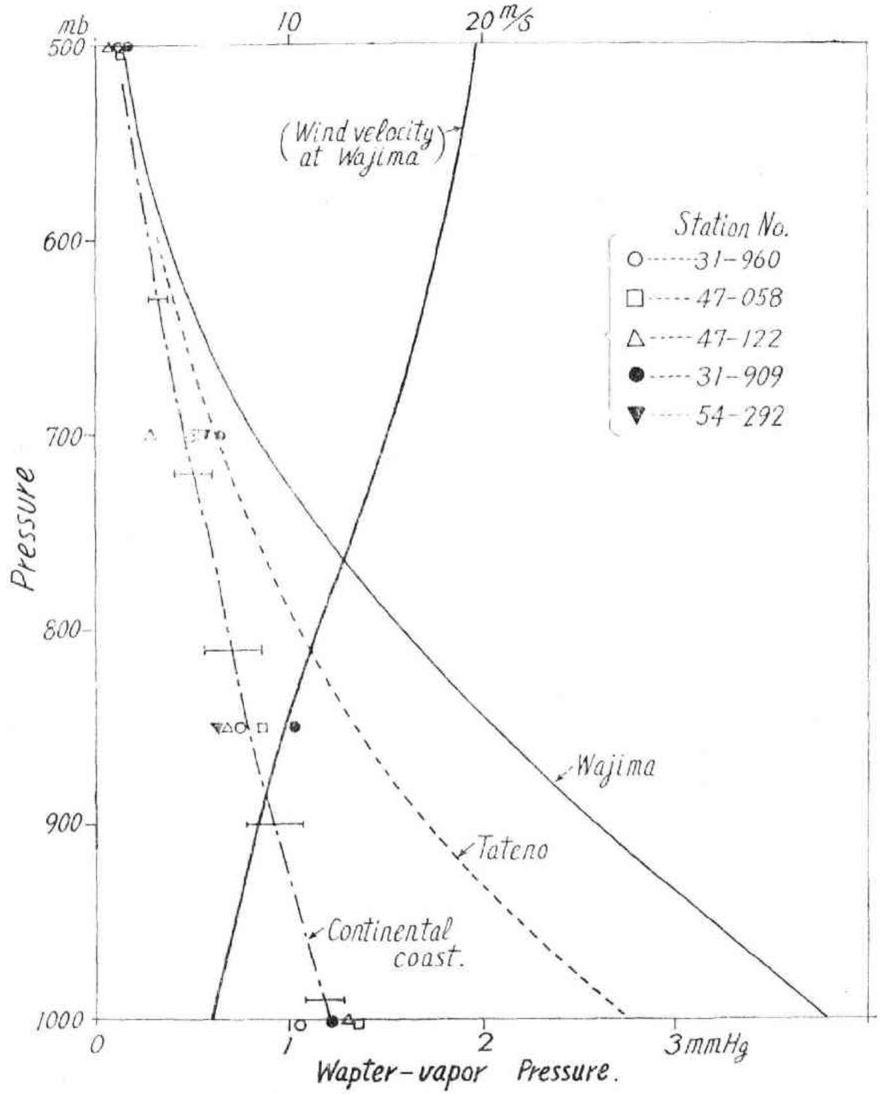


Fig. 5. The vertical profile of the wind velocity at Wajima, and the vertical profiles of the water vapor pressure at Tateno, Wajima and the continental coast. The horizontal bar denotes the error which yields are error of the transfer of the water vapor in the inflow air, owing to the variation of the wind direction. (21–31 Jan. 1962)

$\mathrm{sec}^{-1}\cdot\mathrm{cm}^{-1}$ (between Wajima and Tateno), which is about 40% of the evaporation from the sea.

One may expect the decreasing of water vapor at the Pacific side of the Japanese islands due to the snowfall. This is shown in Fig. 5. The difference of the transfers of water vapor at Wajima and Tateno is 205 $\mathrm{gr}\cdot\mathrm{sec}^{-1}\cdot\mathrm{cm}^{-1}$, which is comparable with the line-integral of precipitation.

In conclusion, Fig. 7 shows the water budget over the Japan Sea during NW-

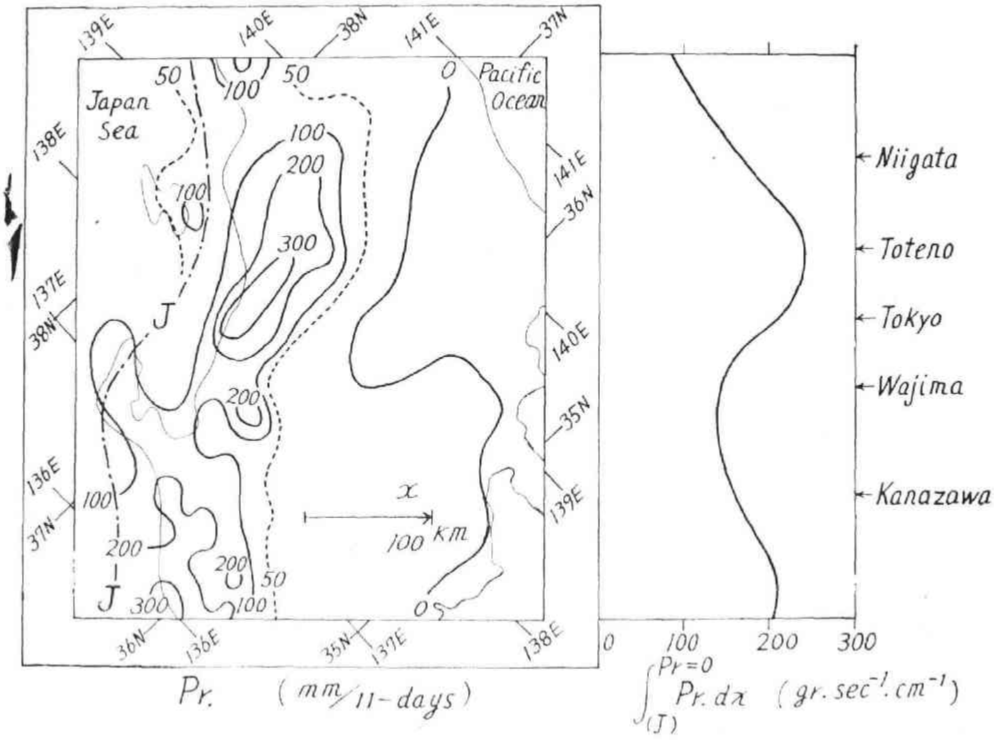


Fig. 6. The distribution of the total amount of the precipitation over Hokuriku district (left part), and the line-integral of the precipitation (right part) for 21–31 Jan. 1962.

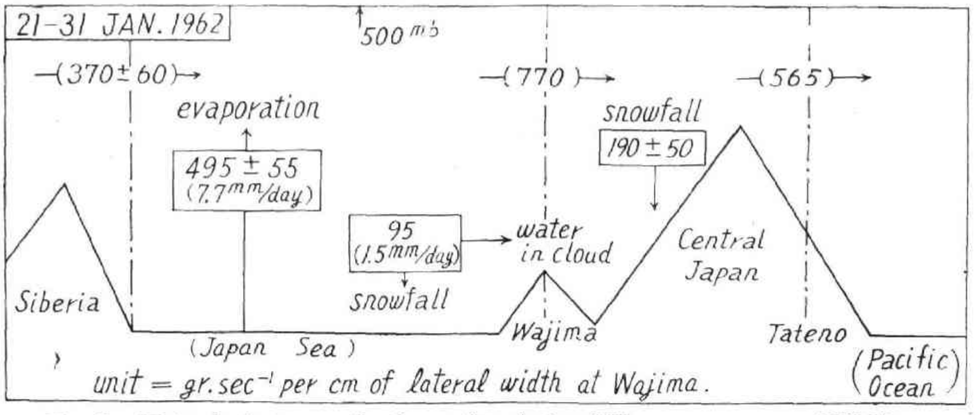


Fig. 7. Water budget over the Japan Sea during NW-monsoon season (NW-SE cross-section). Numbers are shown in unit of gr·sec^{-1} per cm of lateral width at Wajima

monsoon season.

Acknowledgement:

The author wishes to express his sincere thanks to Prof. G. YAMAMOTO for his kind guidance and encouragement throughout this work.

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Appendix

The following observation data and the statistical data were used for the present study.

(A) Memoris of monsoon in winter on San-in district: Maizuru Marine Observatory, Maizuru, Japan (1959)

(B) OKADA, T.; The climate of Japan: The Central Meteorological Observatory, Tokyo (1931)

(C) Daily weather maps with synoptic data tabulations: Japan Meteorological Agency, Tokyo

(D) Surface weather map: Sendai District Meteorological Observatory, Sendai, Japan

(E) Monthly report of the Japan Meteorological Agency, Meteorological observations for Jan. 1962:

(F) Ten days report of the Japan Meteorological Agency, Meteorological observations for Jan. 1962:

(G) Bulletin of the Aerological Observatory, Tateno, Japan

(H) The ten-day marine report, state of the sea adjacent to Japan: Japan Meteorological Agency, Tokyo

(I) Geophysical Review, 1941: The Central Meteorological Observatory, Tokyo