A Statistical Study on the Relation between Cloud Amount and Supply from the Japan Sea Surface in January

by

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(Received August 24, 1968)

Abstract

Basing on ship observations over the Japan Sea area, the relations are investigated statistically between cloud amount and heat or moisture supply estimated by the bulk method for the January situation of the 5 year period 1963-1967. A significant positive correlation is found particularly over the central part of the Japan Sea area where cumulus clouds start to form and develop. The relation seems to be clear under a north to northwesterly monsoon situation.

1. Introduction

It has long been noticed empirically that the weather over the ocean is likely to be influenced by the sea surface temperature. According to the pioneering observations made by ISHIHARA et al. (1947) across the Japan Sea in mid-winter, zones of cumulus development were found over regions of pretty warm sea surface which is undoubtedly caused by the Tsushima warm sea current.

Recently, MATSUMOTO and NINOMIYA (1966) pointed out from an aerial photographic observation that the cloud amount distribution seems to respond quite sensitively to the evaporation from the sea surface. Since then quantitative discussions on the convective heat and moisture transport have come to occupy a more and more important place in budget analyses with regard to airmass modification and precipitation (MATSUMOTO, 1967 a, b). Above all NINOMIYA (1966, 1967 and 1968) made extensive studies on cloud formation and airmass modification over the Japan Sea area in winter.

Many works have been published concerning the airmass modification over oceans; the Japan Sea particularly under the influence of winter monsoon may be considered to serve as an excellent natural laboratory (MIYAZAKI, 1952; ALDOUSHNA, 1957; MANABE, 1957 and 1958; KAWASAKI, 1959; GOTO, 1959; MATSUMOTO, ASAI and NINOMIYA, 1963; NINOMIYA, 1964a, b; KONDO, 1964; FUJITA and HONDA, 1965).

It should be emphasized that the cloud observations would provide us with a large amount of information as to the cumulus activity which directly indicates the energy redistribution process in the atmosphere on one hand and, on the other, as
to an indispensable ingredient for discussing the water budget which is related to the precipitation phenomena. Satellite observation and aerial photographic observation are becoming available for these kinds of discussion but, at the present stage, they have certain limitations, i.e. the former is not fit for quantitative discussions and the latter is obtainable only in a limited area. In recent years there are a lot of meteorological reports from ships from almost all over the Japan Sea area. Ship observation has the merit that it gives surface meteorological as well as cloud conditions, although it may be somewhat wanting in precision.

In this paper are dealt with the ship observations during the mid-winter season statistically to ascertain the close relationship between cumulus development and heat and moisture supply from the underlying sea surface.

2. Source of data

Observations by Russian vessels in the Far East area are broadcasted from Khavalovsk in the international code. In order to see the climatological situation of mid winter, we collected the data for the 20-day period from January 11 to 30 for the five years from 1963 to 1967. During this period, the Heavy Snow Storm Research Project was carried out by the Japan Meteorological Agency, in which the observing vessels “Ryofu-maru”, “Seifu-maru” and “Kofu-maru” participated for about 10 days as listed below, covering mostly the southeastern quadrant of the area particularly off the coast of Hokuriku District.

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Furthermore the vessels of Defence Force cruising the coastal area made supplementary observations for the periods January 11~12, 1964, January 14~21, 1965 and January 25, 1967 and the data are also collected.

Since the observations made by non meteorological vessels may contain certain errors including those that derive from tele-communication process, it may be better to exclude them if any of the reported elements deviate largely from the average values. Thus the total number of observations used for the analysis is 1826 and about 98% of the collected data. The percentages of the numbers of the data used are

- USSR ship reports 79%
- Observing vessels, J.M.A. 16%
- Vessels, J.D.F. 5%

for each data source.

Statistical computations are made for each of the subdivided areas of 2 degrees in longitude and latitude as shown in Fig. 1, where the numerals indicate the numbers of observations obtained within 100 days during 5 years' winter.

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Fig. 1. Divided areas over the Japan Sea in which statistical analysis are made. Numerals are the total numbers of collected observations within 100 days in the mid winter 1963~1967.

3. 5-year mean field for the 20-day period January 11—30

In order to see the climatological character of the mid-winter situation, the mean values are computed for each 2° lat. × 2° long. area shown in Fig. 1. Let us in the following use the term “mean” or “5-year mean” for the simple arithmetic mean values thus obtained of the collected data for the 20-day period January 11-30 and denote them by bars.

In Fig. 2 are given the mean fields of cloud amount N, sea surface temperature T_s and wind velocity V. We obtain a quite reasonable cloud amount distribution, that is, one that shows the increasing cumulus activity towards the lee of the northwesterly monsoon, which indicates the airmass modification process. The sea surface temperature distribution is characterized by the Tsushima warm current as is shown by many authors, and is naturally very similar to those given by Ninomiya (1968a) who prepared the maps for the years 1963, 1964 and 1965. In the mean wind field, there seem to be a little larger values in the central region where the frictional effect...
is smaller. It is noticed that the maximum wind velocity is located off the coast of Akita prefecture, the northern prefecture of the Mainland, where a secondary depression is quite often formed in the field of the northwesterly monsoon.

As to the root mean square deviation fields whose values are given in parentheses in Fig. 2, we can find large values of cloud amount, sea surface temperature and wind velocity along the zone of concentrated sea surface temperature gradient. Accordingly this tendency reflects in sensible heat supply, evaporation and air-sea temperature difference as is shown in Fig. 3. It may be quite reasonable that there is a large variability in the meteorological elements over the mid-Japan Sea where the sea surface temperature gradient is concentrated due to the Tsushima warm current.

Applying the bulk method given by Jacobs formulae (JACOBS, 1951) on individual observations, we can estimate the sensible heat supply $Q$ (in ly day$^{-1}$) and evaporation $E$ (in mm day$^{-1}$) from the sea surface as follows

\[
Q = 5.5 \times V \cdot (T_s - T_a), \tag{1}
\]

\[
E = 0.23 \times V \cdot (q_s - q_a), \tag{2}
\]

where $V$ is in m sec$^{-1}$, $T_s$ and the air temperature $T_a$ in °C and the specific humidity at the sea surface $q_s$ and that of the air $q_a$ in gr·kg$^{-1}$ respectively. The relative humidity observation required to obtain $q_a$ is not usually made in ordinary maritime meteorological observation and, therefore, it is assumed to have the climatological value of 75% which is known empirically (see for example NINOMIYA, 1968). Whereas $q_s$ is estimated by the saturation specific humidity at the sea surface temperature. We now obtain the 5-year mean sensible heat supply $\bar{Q}$ and evaporation $\bar{E}$ as given in Fig. 3.

\[
\bar{Q} = 5.5 \times \bar{V} \cdot (T_s - T_a), \tag{3}
\]

\[
\bar{E} = 0.23 \times \bar{V} \cdot (q_s - q_a), \tag{4}
\]

Fig. 3. 5-year mean fields of sensible heat supply $\bar{Q}$ (lethand figure), evaporation $\bar{E}$ (middle figure) and air-sea temperature difference $T_s - T_a$ (righthand figure). Numbers in parentheses are root mean square deviations. The fields of $Q^*$ and $E^*$ are also entered by broken lines.

Strictly speaking, the validity of Jacobs formulae (1) and (2) is established for climatological conceptions. Namely the climatological values of sensible heat transfer $Q^*$ and evaporation $E^*$ are to be given by
respectively and not necessarily by $\bar{Q}$ and $\bar{E}$. However the fields $\overline{Q}$ and $\overline{E}$ presented in Fig. 3 are quite reasonable and can be shown to be almost the same as the fields $Q^s$ and $E^s$ with a sufficient degree of approximation (see the fields given by broken lines in Fig. 3). This circumstance is considered to express the validity of the bulk method in estimating the boundary energy transfer physically and to show mathematically that $\overline{V^s}(T_s'-T_s)$ and $\overline{V^s}(q_s'-q_s)$ are ignored since $\bar{Q} \approx Q^s$ and $\bar{E} \approx E^s$. In other words, the wind velocity and the air-sea temperature difference are practically not correlated with each other.

4. Relationship between cloud amount and supply from the sea surface

During the winter time the water temperature of the Japan Sea is very high as compared with the air temperature and serves as a predominant energy source for the atmosphere. Consequently the prevailing cumulus activity takes place there and transports downstream a pretty large amount of condensed water vapor thus resulting in heavy snowfalls along the northwestern coast of the Japan Islands (MATSUMOTO, ASAI and NINOMIYA, 1963; NINOMIYA, 1964b).

MATSUMOTO and NINOMIYA (1966) found a cloud distribution closely related to the sea surface temperature distribution in such a way that there was a smaller amount of cumuli over the colder sea water pool. It was thus strongly suggested that cumuli are hardly developed unless sufficient water vapor is supplied from the subcloud layer. The authors (1967) emphasized that a predominant cumulus activity develops exclusively over a mesoscale convergence area characterized by the order of $10^{-4}$ sec$^{-1}$ of convergence. NINOMIYA (1968b) analysed a number of radar echo photographs covering the coastal area of the Hokuriku District and showed quantitatively the statistical relationship between echo density and supply of water vapor.

We can now expect to find out some relationship between the cloud amount and the supply from the sea surface by the statistical treatment, since this may eliminate the effects originating from non-steady phenomena such as mesoscale disturbances.

![Fig. 4. Correlation coefficients between cloud amount and sensible heat supply $R(N, Q)$ (left hand figure), those between cloud amount and evaporation $R(N, E)$ (middle figure) and those between cloud amount and air-sea temperature difference $R(N, T_s - T_s)$ (right hand figure). Significant values on the level of 10% and 30% are hatched and stippled respectively.](image-url)
large scale horizontal advection and so on as well as errors inherent in ship observations. Basing on maritime meteorological observations as mentioned above (see Fig. 1), we obtain the correlation coefficients between cloud amount and parameters related to surface conditions such as $R(N, Q)$, $R(N, E)$ and $R(N, T_r - T_a)$ which are presented in Fig. 4. The numerals are correlation coefficients for the observations in $2^\circ$ lat. $\times 2^\circ$ long. regions, and the significant values with the levels of 10% and 30% are indicated by hatches and stiples respectively.

It is found that significantly positive correlation coefficients are distributed over the central part of the Japan Sea and the correlation becomes poorer towards up-stream and downstream boundaries. This circumstance may be postulated as follows. The mean cloud amount distribution given in Fig. 2 indicates that the mean cloudiness is less over the Siberian coastal regions where comparatively dry and extremely cold air is advected from the continent and therefore that the water vapor supplied from below is largely spent in moistening the lower layer of the atmosphere and does not necessarily contributes to increasing the cloudiness thereof. On the other hand plenty of cloud generated over the Japan Sea is advected towards the coastal regions of the Japan Islands, where it is almost always overcast. In this respect the dependence on the supply from below might well become poorer.

As was mentioned before, the evaporation $E$ is estimated under the assumption that the relative humidity of air is 75%. Therefore $E$ thus obtained is not quite independent of $Q$.

Next let us take up the dependence of cloud amount variation on two component parameters $T_r - T_a$ and $V$ which are related to $Q$ or $E$. The correlation coefficient $R(N, T_r - T_a)$ assumes about the same values and seems to be lowered as compared with $R(N, Q)$ or $R(N, E)$ over coastal regions where the situation is comparatively steady. (See the root mean square deviation field given in Fig. 3). The correlation coefficient $R(N, V)$ is given in Fig. 5. Here again the distribution does not change

![Fig. 5. Correlation coefficients between cloud amount and surface wind velocity $R(N, V)$. The lefthand figure is for the whole wind directions, the middle figure for the north to northwesterly winds (number of applied observations is given by small numerals) and the righthand figure is $R(N, E)$ for the north to northwesterly winds. Significant values on the level of 10% and 30% are hatched and stippled respectively.]
very much. However we obtain quite an interesting distribution of \( R(N, V) \) if the wind direction is taken into consideration. The middle figure of Fig. 5 is for winds from north or northwest representing the monsoon situation. Since the selection is made on the wind direction, the number of available observation becomes much smaller (given in Fig. 5 by small letters) and the lowering of reliability is inevitable. The most significant positive correlation is found in the windward side of the concentration zone of sea surface temperature gradient. In the lee side of it the level of significance diminishes. This may suggest the effect of advection of cumuli towards the downstream regions. The figure on the right of Fig. 5 shows \( R(N, E) \) under the same wind condition. It is quite natural that we have higher correlation coefficients.

Finally the distribution of Bowen's ratio is presented in Fig. 6 for the sake of convenience. Here Bowen's ratio is defined by \( \frac{Q}{E} \) and not by the climatological value \( Q^* / E^* \). However, both definitions of Bowen's ratio give practically the same value. The reason for this was discussed in section 3 above.

![Fig. 6. Distribution of Bowen's ratio defined by \( \frac{Q}{E} \).](image)

**Acknowledgements**—The authors would like to express hearty thanks to Dr. Magata for his encouragement and to the staff members of the Division of Maritime Meteorology, J.M.A. for participating in the project observations and providing us the collection of RDW teletype reports. Thanks are also due to Miss H. Imai and Mrs. Y. Tsuneoka who helped us in drafting the figures and typing the manuscript.

**References**


Kawasaki, N., 1959: The weather over the Japan Sea under monsoon situation. Maizuru
———, 1958: On the estimation of energy exchange between the Japan Sea and the atmosphere during winter based upon the energy budget of both the atmosphere and the sea. J. Met. Soc. Japan, 36, 123-134.
Miyazaki, M., 1949: The incoming and outgoing heat at the sea surface along the Tsushima warm current. Ocean. Mag., 1, 103-111.