Some Aspects of the Cloud Formation and the Airmass Modification over the Japan Sea in Winter Revealed by TIROS Observation (Part II)

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Abstract

The aspects of the cloud formation over the Japan Sea during the three day period from Feb. 10 to Feb. 12, 1962 was analysed by using T.V. data and channel 2 radiation data of TIROS IV in the author's previous report.

In this report, the distribution of the albedo over the Japan Sea and her neighbourhood during the period mentioned above is obtained by using channel 3 radiation data. The bright areas in channel 3, which indicate solid overcast, are very well correlated to low equivalent black body temperatures in channel 2. The estimations of cloud cover and cloud height over the Japan Sea are tried by coordinating the albedo and equivalent black body temperature. It is shown that, under the winter monsoon situation, cloud cover increases rapidly 2-300 km off the shore of the Japan Islands and that the cloud exists mainly under the inversion layer.

1. Introduction

Several works have shown that the distribution of effective temperatures measured by infrared channels and also that of reflected solar radiation measured by solar channels have a close correlation with the cloud cover (HANEL and STROUD 1961, FRITZ and WINSTON 1962, NORDBERG *et al* 1962, RASOAL 1964). It is well known that channel 2, the so called atmospheric window channel ($8-12\mu$), gives us the equivalent black body temperature of the earth's surface and/or dense cloud surface. Almost all the parts of the reflected solar radiation are covered by channel 3 radiometer ($0.2-6.0\mu$) of TIROS IV. Hence the albedo of cloud and/or the earth's surface is easily obtained.

In his previous paper (Part I, 1966), the author discussed the aspects of cloud formation over the Japan Sea under the typical winter weather situation during the three-day period from Feb. 10 to Feb. 12, 1962, by using T.V. data and channel 2 radiation data.

In this paper, the distribution of albedo over the Japan Sea and her neighbour-

hood will be discussed in Section 2 for the period under consideration. Comparisons between the distribution of albedo, that of equivalent black body temperature (which is obtained in Part I) and the synoptic cloud data are next made in Section 3. Combining these values of albedo and black body temperature, the cloud cover and the height of cloud over the Japan Sea under the winter monsoon situation will be estimated in the last section.

2. Estimation of albedo

The channel 3 ($0.2\text{--}6.0\mu$) radiation data of TIROS IV orbit 0021, 0035 and 0049 printed out in the listings of the Final Meteorological Radiation Tape (FMRT) are used as the basic data in this report.

It is necessary first to refer to TIROS IV Radiation Data Catalog and User's Manual (NASA 1964) about the degradation of the channel 3 radiometer. The post-launch degradation has been observed as the decrease in the value of the quasi-global albedo. The quasi-global albedo A^i of channel 3 is obtained as a function of orbit number (Fig. 1) by NASA. The figure indicates that A^i decreased rapidly during the

Fig. 1. The quasi-global albedo of channel 3 (solid line) and the corrected quasi-global albedo (broken line) (after Staff Members of NASA (1963)).

first week after the launch. After orbit 600, the curve levels off, indicating that the instrumental response has stabilized. The radiometer, similar to the one carried on TIROS IV, was flown on a balloon over South Dakota on 2 June 1962. Radiation data from the same area were obtained by the TIROS IV radiometer on orbit 1642 at 21^h43^m GMT of the same day. The comparison indicates that the balloon measurement of channel 3 shows higher values than the satellite measurement by a factor of about 1.84. Thus the corrected channel 3 value of A^i at orbit 1642 becomes

$$A^i_{\text{cor}} = 1.84 \times 16.5 = 30.4\%$$

(Staff Members of NASA, 1963)

Also, the quasi-global albedo value of 30.7% is obtained by the quasi-global (55°N–55°S) radiative energy budget (Staff Members of NASA, 1963). As the quasiglobal albedo is expected to be almost constant, the value of α

$$\alpha = 30.5/A^i$$

is adopted as the correction factor for the reflected solar energy measured on each orbit.

In plotting the reflected solar energy given by the FMRT listing, the value obtained by the scan spot whose nadir angle exceeds 60° is omitted. The distributions of reflected solar energy Q_r , thus obtained at 2358–0008 Z Feb. 9–10, 2321–2331 Z, Feb. 10 and 2244–2254 Z Feb. 11, 1962 are presented in Fig. 2 by solid lines.

Next the incoming solar energy per unit horizontal area at the top of the atmosphere, Q_0 , is obtained for the time of the three orbit mentioned above. If ζ is the zenith distance of the sun, and the solar constant is assumed to be $1400 \text{ wat} \cdot \text{m}^{-2}$ ($=2 \text{ ly} \cdot \text{min}^{-1}$), then Q_0 is written as

$$Q_0 = 1400 \cos \zeta.$$

The zenith distance of the sun ζ is given as

$$\cos \zeta = \sin \varphi \cdot \sin \varphi_s + \cos \varphi \cdot \cos \varphi_s \cdot \cos(\lambda - \lambda_s),$$

where (φ, λ) and (φ_s, λ_s) are the latitude and longitude of the point on which Q_0 is to be obtained and these of the sub-solar point respectively. The isolines of Q_0 thus obtained are shown by thin broken lines in Fig. 2.

From the distribution of both reflected solar energy and the incoming solar energy, the albedo a , defined by

$$a = Q_r/Q_0$$

is obtained. The distributions of albedo at the same times as in Fig. 2 are presented in Fig. 3. The albedo varies from about 70%, which is observed to the south of the Japan Islands at 2250 Z Feb. 11, to a few percent, which is found over the northern Japan Sea at 2250 Z Feb. 11, 1962.

3. Distribution of albedo and equivalent black body temperature in relation to the cloud systems

The relations among the distribution of albedo, equivalent black body temperature of channel 2, which obtained in Part I of this paper, and the cloud system will be discussed in this section.

It is necessary to begin with the explanation of the synoptic weather situation during the analysed period in order to interpret the radiation data. The surface weather maps at 00Z, Feb. 10, 11 and 12, 1962 are presented in Fig. 4. (Also see, Figs. 2 and

Fig. 2. The distribution of the reflected solar energy (solid line) and the incoming solar energy per unit horizontal area (thin broken line) at 2358-0008Z Feb. 9-10, 2321-2331Z Feb. 10 and 2244-2254Z Feb. 11, 1962. (unit is $\text{Watt} \cdot \text{m}^{-2}$).

Fig. 3. The distribution of albedo at 2358-0008Z Feb. 9-10, 2321-2331Z Feb. 10 and 2244-2254Z Feb. 11 1962. (unit is %)

Fig. 4. The surface weather maps at 0000Z, Feb., 10, 11 and 12, 1962.

3 of Part I, concerning the upper lever charts and the meridional cross sections).

At 0000Z Feb. 10, 1962, a cyclone which developed in front of the upper westerly trough is located to the west of the Korea Peninsula, and another occluded cyclone is located on the northwestern Pacific. Areas of solid overcast are observed over the northeastern China, the Korea Peninsula and the western part of the Japan Islands. Clear weather was found around the northeastern Japan Sea, where the ridge aloft was located.

At 0000Z Feb. 11, the cyclone, which developed rapidly during its passage over the Japan Sea, was located on the west coast of Hokkaido and a cold front was extending along the Japan Sea coast line. Solid overcast and snowy weather were found over Hokkaido, Saghalien and the northeastern Japan Sea.

At 0000Z Feb. 12, the cyclone moved farther east to the northwestern Pacific and a remarkable cold air outbreak was taking place. Areas of overcast are observed over the cyclone and the cold front to the south of the Japan Islands. The strong temperature gradient over the Japan Sea leads us to infer a remarkable modification of the air mass. The solid overcast and snow shower are observed actually over the Japan Sea coastal region, while the area of clear weather extends over the continent.

Fig. 5. The variations of albedo and the equivalent black body temperature along 40°N latitudinal circle.

It is easily recognized by comparing the surface weather maps (Fig. 4) with the maps of albedo distribution (Fig. 3) that the bright area in channel 3 or, in other words, the area of high albedo indicates solid overcast.

For a comparison between the distribution of albedo and that of equivalent black body temperature which is obtained by using channel 2 observation (see Fig. 6 in Part I of this report), the distributions of these value along the 40°N latitudinal circle are presented in Fig. 5. As seen in the figure, the high albedo is very well correlated to low equivalent black body temperature and vice versa.

At 0000Z Feb. 10, 1962, areas of high albedo are found over 130°E and 150°E, where the low T_{BB} (equivalent black body temperature is written as T_{BB} hereafter for convenience) is also observed. The former corresponds to the cloudy area in front of the cyclone to the east of the Korea Peninsula and the latter to the cloudy zone over the cold front extending from an occluded cyclone over the Kamchatka Peninsula. An area of notable high albedo and low T_{BB} is found over 145°E in front of the rapidly developing cyclone at 0000Z Feb. 11.

The figure for 0000Z Feb. 12 shows the cloud distribution in the polar air mass which breaks out from the continent as the winter monsoon. As the air mass flows over the relatively warm Japan Sea, the cloud amount increases and the maximum of albedo and the minimum of T_{BB} is found over the Japan Sea coastal area (139°E). The low albedo and high T_{BB} over 141–142°E indicates the clear weather which appears usually over the lee side of the Japan Islands under a winter monsoon situation. The albedo increases again as the air mass flows over the warm Pacific.

The T_{BB} in the regions of overcast cloudiness is to be related to the temperature, and hence to the height, of the cloud top. As isotherms are drawn on each standard pressure map, the contours of cloud top height are easily obtained (see Fig. 7 of Part I). To see the relation between the height of the cloud top and its albedo, the distributions of both height and albedo are shown in the composite maps (Fig. 6).

The region of overcast cloudiness in front of the cyclone at an early stage of its development is characterized with a high cloud top (about 500 mb) and fairly high albedo (20–30%). The observation station in the region mentioned above reports a thick altostratus or nimbostratus. The albedo increases to 30–50% as the cyclone gets at the occluded stage (23Z Feb. 10).

When the cold front is analysed over the Japan Sea (2300 Z Feb. 10) by using the synoptic weather report, no evidence of its existence is given by the albedo or T_{BB} . On the contrary, when the cold front moved over the Pacific (2300 Z Feb. 11), a very low T_{BB} (the top of cloud is estimated to reach 400 mb) and a very high albedo of 60–70% are reported. The vertical cross section along 140°E meridian shows that a deep moist layer exceeding 400 mb exists over the cold front (see Fig. 3 of Part I). It could be said that both mixing ratio of water vapour and air temperature were too low over the Japan Sea for convective clouds associated with the cold front to develop sufficiently.

The existence of convective cloud is reported by each observation station along the Japan Sea coastal area under the situation of cold air outbreak (2300 Z Feb. 11).

Fig. 6. The composite maps to show the relation between the albedo and the height of the cloud top which is estimated from T_{BB} .

Although fairly high albedo (30%) is found over the area above mentioned, the rather high T_{BB} indicates that the elevation of the cloud top is not so high. The detailed discussions about cumulus formation and its relation to the inversion layer in the polar airmass will be made in the next section.

4. Some aspects of cloud formation over the Japan Sea under the situation of a winter monsoon.

The height of the cloud top over the Japan Sea was estimated very roughly in Part 1 of this report, by using the value of T_{BB} only. Here, more reasonable estimation is to be tried by coordinating the values of both albedo and T_{BB} .

As mentioned in Section 3, the values of T_{BB} in the regions of overcast cloudiness are to be related to the temperatures, and hence to the height of the cloud top. In regions of broken and/or scattered clouds, the situation is more complex, because both cloudiness and height are unknown parameters. The values of T_{BB} and the corresponding cloud top height in this case are more difficult to interpret.

The T.V. cloud photograph, Frame 31 of orbit 0038, taken at 0445Z Feb. 11, 1962 and the map showing the distribution of albedo and T_{BB} for 2326Z Feb. 10 (orbit 0035) drawn in the same scale as Frame 31 are presented in Fig. 7. It is noticeable that the area of low albedo is observed just over the clear area near the continent. This fact means the possibility of relating albedo to the cloudiness. The cloudiness can be measured, of course, if the T.V. cloud photograph is available. The T.V. observation, however, is not always made simultaneously with radiation observations, and thus, it is necessary to estimate both cloudiness and cloud height by using radiation data only.

Fig. 7. T.V. cloud photograph Frame 31, orbit 0038 taken at 0445 Z Feb. 11, 1962 and the distribution of albedo (solid line) and T_{BB} (broken line) for 2326 Z Feb. 10, drawn in the same scale as in Frame 31.

It should be noted that the scan spot on the earth viewed by the radiometer of TIROS IV has a diameter of about 70 km. In other words, the value of albedo and T_{BB} mentioned above are the mean values over a radiometer scan spot whose diameter is about 70 km. Thus the following relations on the albedo and T_{BB} are expected;

$$a = na_c + (1-n)a_s$$

$$T_{BB}^4 = nT_c^4 + (1-n)T_s^4$$

where, a and T_{BB} are the albedo and equivalent black body temperature obtained by radiometer over a scan spot, n , a_c , a_s , T_c and T_s are the cloudiness, albedoes of the cloud and sea surface, temperatures of cloud top and sea surface respectively.

The distribution of a and T_{BB} along the airmass trajectory over the Japan Sea under the winter monsoon are shown in Fig. 8. Also the evaporation and sensible heat supply from the sea surface estimated by Jacobs' formula are presented in the figure.

Fig. 8. The variations of heat (Q_s) and moisture (E) supply from the sea surface obtained by Jacobs' formula along the airmass trajectory over the Japan Sea (upper figure). The variations of albedo T_{BB} and temperature at standard pressure levels along the airmass trajectory (lower figure).

It is assumed that the value of a_c (i.e. albedo of cloud) is constant, as the situation of cloud would be rather uniform over the Japan Sea, at least over its coastal area. Just over the coastal area of the Hokuriku district, where synoptic stations report cumulus and/or strato cumulus overcast. (i.e. $n=1.0$), the observed value of a is 0.30. Therefore the value of a_c is considered as 0.30. This value should not be considered as the albedo of cumulus itself. It is known by aerial photographic ob-

servation that the cumulus top is rather flat and also stratified cloud like stratocumulus coexists with cumulus under the inversion layer when the winter monsoon predominates (MATSUMOTO and NINOMIYA, 1966 *a* and 1966 *b*). Thus the albedo of 0.30 is to be understood as the mean albedo of cumulus and stratocumulus.

The albedo of developed cumulus would be larger and its cloudiness would be smaller, even an overcast situation is reported by the synoptic weather station. The albedo of the sea surface is decided to be 0.05 by a comparison between the T.V. cloud photograph and the albedo distribution (Fig. 7). Thus the cloudiness n is obtained as

$$n = \frac{a - a_s}{a_c - a_s}$$

Then the temperature at the cloud top T_c is written as

$$T_c^4 = \frac{T_{BB}^4 - (1-n)T_s^4}{n}$$

Fig. 9. The upper figure: the cumulative amount of sensible heat and water vapor which are gained in the air column after the airmass goes away from the continent. The lower figures: The variations of cloudiness and the height of the cloud top along the airmass trajectory.

The estimated distributions of n and T_c are presented in Fig. 9. The cloudiness begins to increase remarkably about 200–250 km off the shore of the Japan Sea coastal line, while the temperature of the cloud top is rather uniform, i.e. -15° — -12°C . The height of the cloud top is estimated by comparing T_c with the temperature on each standard pressure level. The result is that the height of cloud top is 850 mb about 250 km off the shore and increases only gradually to 800–750 mb.

The soundings at Wajima and Akita for 0000Z Feb. 12, 1962 are presented in Fig. 10. It is notable that a well developed inversion layer exists in the lower troposphere and that humidity rapidly decreases above the lower boundary of the inversion, and almost saturated moist air is only observed in the sub inversion layer. Thus it would be concluded that the estimated cloud height by using TIROS radiation data corresponds with the humidity sounding. Similar situations are also analysed by MATSUMOTO and NINOMIYA (1966 *a* and 1966 *b*) by using the aerial photographic observation of cloud and also the drop sonde observation over the Japan Sea.

Fig. 10. The sounding of temperature and humidity at Wajima (solid line) and Akita (broken line), for 0000 Z Feb. 12, 1962.

As cumulus formation is highly correlated with the modification of the airmass, it is necessary to compare the increase of cloudiness mentioned above with the sensible heat and water vapor supplied to the airmass. The accumulative amounts of the sensible heat and the water vapor which are gained in a unit air column after the airmass goes away from the Continent, calculated along the airmass trajectory, are shown in Fig. 9. The result shows that the cloud formation is remarkably intensified when or after the air column gets 200 ly of sensible heat and $0.4 \text{ gr}\cdot\text{cm}^{-2}$ of water vapor during its passage over the Japan Sea surface. It can also be said that the early supply of $0.4 \text{ gr}\cdot\text{cm}^{-2}$ of water vapor works mostly to moisten the dry airmass and a considerable part of the additional supply thereafter is consumed to generate cloud or as the precipitation.

5. Conclusion

The results of Part II of the present report, the analysis of cloud formation over the Japan Sea in winter by using TIROS IV channel 3 radiation data, are summarized as follows:

1. The areas of high albedo, which indicate solid overcast are very well correlated to low equivalent black body temperatures obtained by channel 2 radiation measurement.
2. The albedo of 30% is observed on the cumulus overcast over the down stream side of the Japan Sea under the winter monsoon situation. The albedo of sea surface is known to be 5%.
3. The cloudiness is estimated by using the albedo distribution, then the cloud height is estimated in both overcast and broken area by using channel 2 radiation data. The results of this estimation coincide with the data of synoptic cloud observation.
4. The cloudiness increases rapidly after the air mass gets $0.4 \text{ gr} \cdot \text{cm}^{-2}$ of water vapor during its passage over the Japan Sea.
5. The height of the cloud top is rather uniform, about 800 mb over the coastal area. This height coincides with the height of inversion base.

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TIROS 資料による冬期日本海上における雲の発生と 気団変質の解析 (第2報)

二 宮 洸 三

1962年2月10日朝鮮半島西岸に位置した低気圧は、11日発達しつつ日本海上を通過し、ひきつづき12日には寒気の吹出がみられた。第1報ではこの冬期の典型的な気象状態のみられた3日間について、主として TIROS IV の channel 2 輻射資料をもちいて日本海上での雲の分布・発生状況を調べたが、この報告ではさらに channel 3 ($0.2-6.0\mu$) 輻射資料をもちいて albedo の分布を求め、前報の結果とあわせて、季節風下における日本海海上での積雲の発生状況をより詳しく解析する事を試みた。その結果は次の様に要約される。

1. albedo, channel 2 equivalent black body temperature (T_{BB}) および雲量分布の間には非常に高い相関が見出された。
2. 寒気吹出の状態で日本海域でみられる最大の albedo は積雲の overcast 域の30%であつた。また T.V 写真との比較によつて海面の albedo は 5%である事が知られた。
3. albedo 分布から雲量を推定し、ついで T_{BB} から雲頂高度の推定を行なつた。この推定は雲量10以下の部分においても行なわれ得るが、その結果は他の観測事実ともよく一致した。
4. 雲量は日本海沿岸沖 250 km 附近から急速に増加しはじめる。気団の変質と比較すると気団が大陸をはなれてからのち、海面から $0.4 \text{ gr} \cdot \text{cm}^{-2}$ 程度の水蒸気補給を受けた前後から雲量が急に増加している。
5. 雲頂高度の増加はゆるやかで、250~300km 沖あいで 850 mb 程度、沿岸部分で 800~750mb 程度である。この高さは、この日、寒気団内部に存在した顕著な逆転層下面の高さと一致していた。

この報告は気象研究所・北陸豪雪特別研究の一部となされたものである。