THE REPRESENTATIVENESS OF VARIOUS CLOUDS AS TRACERS OF THE FLOW

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Abstract

High level cloud motion winds (CMW) are classified according to their cloud patterns and individually compared with collocated radiosonde winds to confirm the representativeness of various clouds as tracers of the flow. As a result, the relationship between cloud characteristics and their ability to trace the flow is obtained.

Case studies show that thin cirrus in clear shape traces the flow at a single level as exactly as a radiosonde even in jet stream areas. Such cirrus often traces the jet stream axis. If height assignment error and tracking error do not exist, no significant difference occur in either wind speed or direction between the CMWs obtained from suitable tracer clouds and radiosonde winds. Therefore a negative speed bise of CMWs and speed dependency of the bias found in the statistical comparison between CMWs and radiosonde winds are not consistent features pertinent to all CMWs. Rogue CMWs obtained from tracers of thick clouds mainly cause the negative speed bias. Cloud texture analysis and thinness of cloud can provide information on the quality of a tracer.

1. Introduction

CMW is an important consideration with respect to numerical weather prediction performance, especially over the oceans where limited wind data are available from other observation systems. However, the use of high level CMWs (< 400 hPa) as initial data of numerical weather prediction has been under debate, because "statistical" comparisons with either collocated rediosonde winds or those in the first-guess wind fields show that CMWs tend to underestimate the wind speed, especially in jet stream areas. Moreover, a negative speed bias of CMWs have generally been reported to be proportional to the wind speed (e.g., Kållberg and Delsol, 1987; Woick, 1991).

This "negative speed bias" problem has been common to high level CMWs generated

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by three satellite operators [the National Environmental Satellite Data and Information Service (NESDIS), the Japan Meteorological Satellite Center (JMSC), and the European Space Operations Centre (ESOC)], although details of the technique vary among the three satellite data producers. The bias has a negative impact on the analysis/forecast systems. Hence, the European Centre for Medium Range Weather Forecasts (ECMWF) decided not to use high level CMWs over land in 1987. The possibility of unrepresentativeness of CMWs is, however, not excluded over oceans either.

Several reasons for the negative speed bias may be suggested as follows.

(a) unrepresentativeness of clouds as tracers
(b) height assignment error
(c) cloud tracking error

For instance, ESOC has modified the operational system for extracting CMWs from METEOSAT images; i.e., IR radiance slicing before tracking (1987), water vapor calilbration (1987), use ECMWF forecast to start the automatic tracking (1989), cloud filtering based on spatial coherence method (1990). These modifications to eliminate height assignment error and cloud tracking error brought improvements. However, the negative speed bias of CMWs is still found in statistical comparisons (e.g., Woick, 1991). This fact implies that the representativeness of various clouds as tracers should be examined to understand the cause of the negative speed bias.

If no cloud exactly traces the flow at a single level, it is impossible to completely remove the bias of CMWs. However, if the bias is mainly caused by selecting unsuitable clouds for the tracers, it is possible to remove the bias by rejecting those poor quality CMWs.

The starting point of production of CMWs is the premise that certain of clouds drift with the flow at a single level. In fact, however, the premise has not adequately confirmed. It is the intention of this paper to investigate the representativeness of various clouds as tracers of the flow. Moreover the relationship between cloud characteristics and the quality of CMWs will be discussed.

2. Comparison of high level CMWs with collocated rediosonde winds

Morgan (1985) stated that the quality of CMWs is bound to vary under different atmospheric conditions because of the variability of the tracer clouds. Thus case studies are useful to establish the precise error budget in

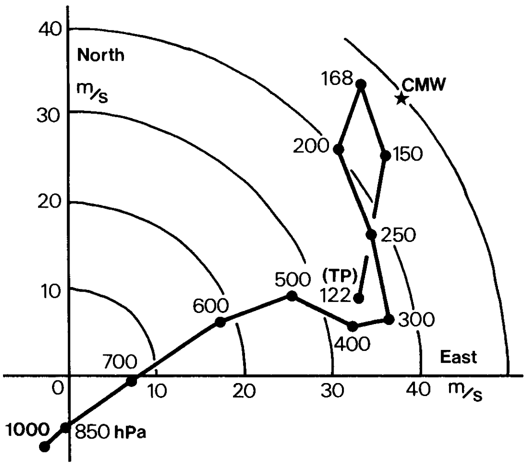

Fig. 2 Wind hodograph for Minamidaitojima on 01 December 1989 at 0000 UTC.

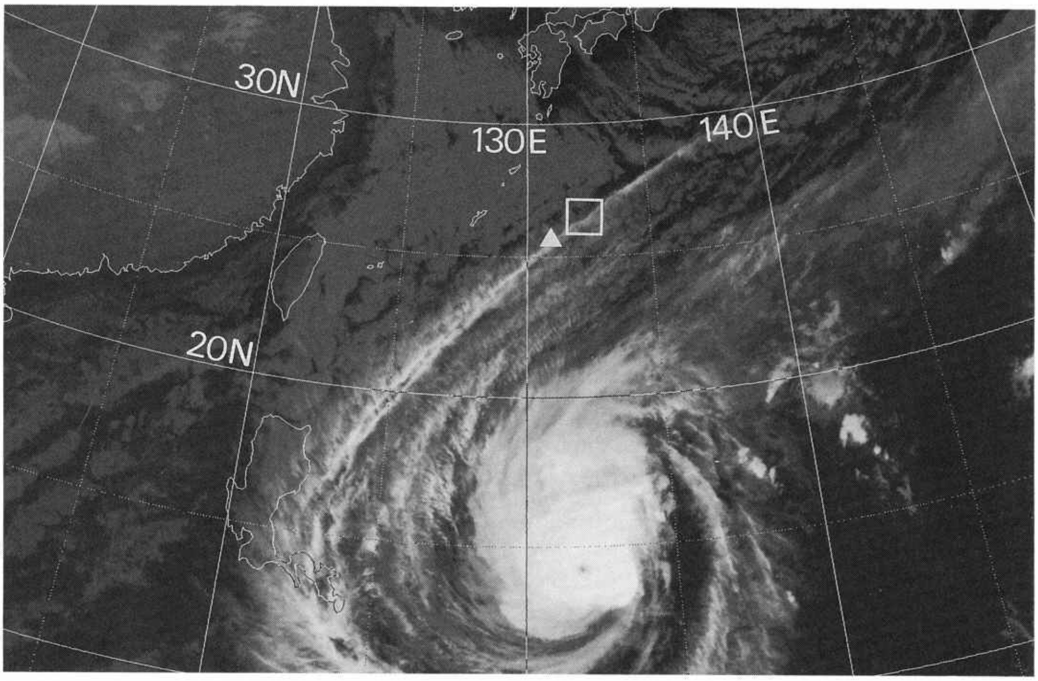

Fig.1a　GMS IR image on 01 December 1989 at 0000 UTC.　The target area is indicated dy a box.
The triangle shows Minamidaitojima (131.2°E, 25.8°N).

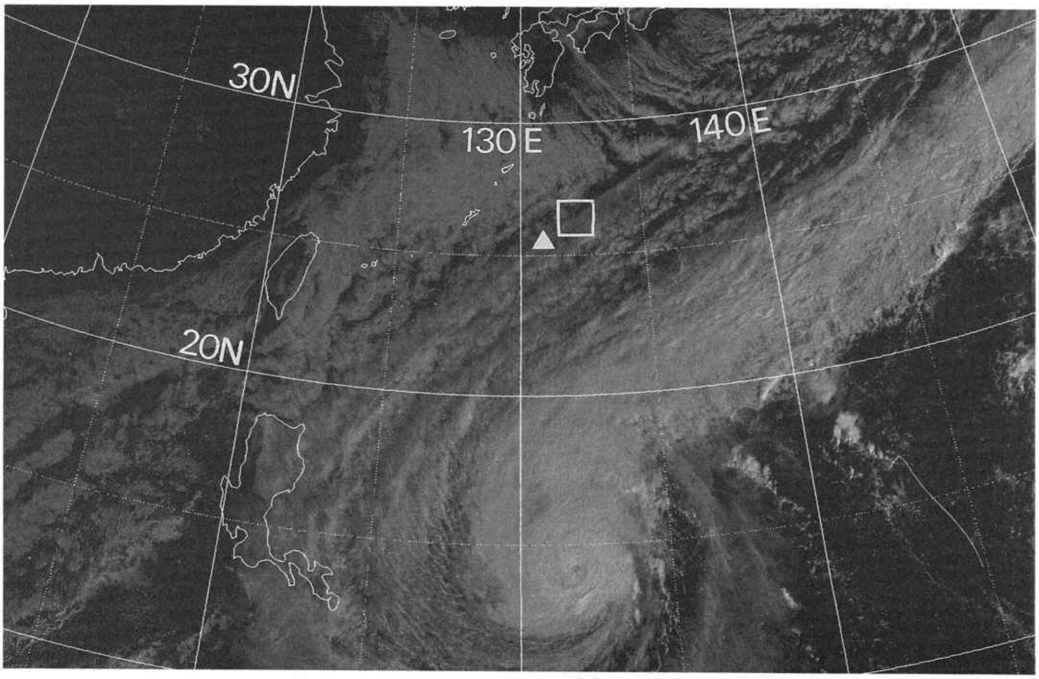

Fig.1b　As Fig.1a, but VIS image.

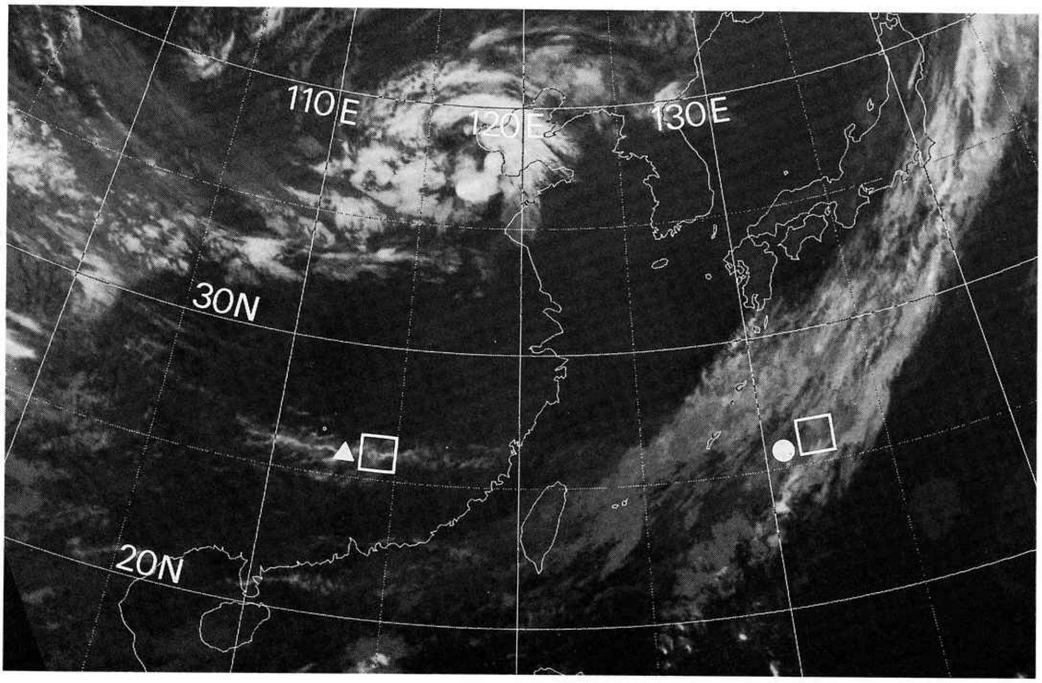

Fig.3 As Fig. 1a, on 05 May 1990 at 1200 UTC. The triangle shows Chenzhou (113.0°E, 25.8°N). The cicle shows Minamidaitojima (131.2°E, 25.8°N).

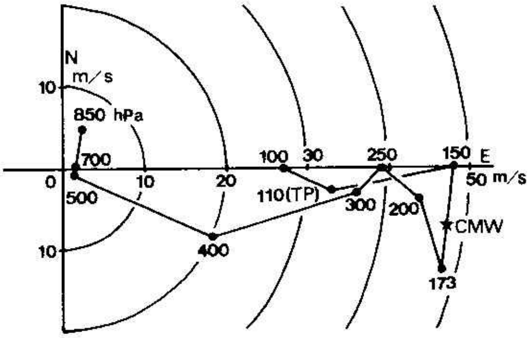

Fig.4 As Fig.2, but for Chenzhou on 05 May 1990 at 1200 UTC.

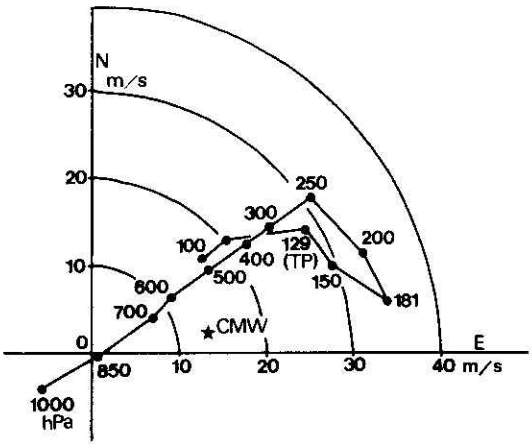

Fig. 5 As Fig.2, but for Minamidaitojima on 05 May 1990 at 1200 UTC.

individual situation and are therefore essential for studies into possible ways of improving the product. Here, CMWs are classified according to their cloud patterns and individually compared with collocated radiosonde winds. Five typical examples containing both suitable and unsuitable tracer clouds will be discussed below. In following examples, manual quality control ensured that no tracking error existed and each cloud pattern remained unchanged during cloud tracking (1 hour).

It should be noted that the Root Mean Square (RMS) values of the vector difference at zero separation and at a separation of 100 km are respectively 5 m/s and 8 m/s for high level radiosonde - radiosonde comparison (Morgan, 1985). Furthermore errors inherent in the CMW and radiosonde observations must also be recognized as occurring.

Case 1 — Thin cirrus shaped like a streak

Fig. 1 shows a tracer cloud used in this example. It is thin cirrus shaped like a streak. This cirrus traced the upper divergence flow around a developed typhoon over the ocean, being automatically tracked by a cross-correlation method. The CMW speed is 49.5 m/s. A corresponding hodograph (Fig.2) observed at Minamidaitojima (131.2°E, 25.8°N) shows the wind profile at a separation of about 40 km from the CMW.

The CMW is only in good agreement with the rediosonde wind at 168 hpa, where the maximum wind speed (46.8 m/s) was observed by the rediosonde. The vector and speed differences between the CMW and the rediosonde wind at 168 hPa are respectively 5.6 m/s and 2.7 m/s. These differences are negligible (Morgan, 1985). If the cloud did not drift exactly at the same height as the flow occurring at the maximum wind speed level, such good agreement would be improbable. Therefore it is concluded that this cirrus traces the maximum speed flow as accurately as the radiosonde even in the jet stream area.

Hence the correct cloud height is certainly 168 hPa. In practice, however, a 300 hPa height was assigned to the CMW using the climatological method. At this height the vector and speed differences between the CMW and the radiosonde wind are respectively 24.9 m/s and 12.5 m/s; thus height assignment errors significantly result in large differences because of a strong vertical wind shear near the jet stream in spite of correct tracking. The climatological height assignment was a contributory cause of the poor quality of GMS high level CMWs, as metioned by Radford (1989). However, it is noted that the negative speed bias of CMWs would not coour, even if incorrect height is assigned to clouds tracing the maximum speed flow.

The cloud's minimum equivalent black body temperature (T_{BB}) in the IR window is 242 K, and corresponds to the temperature at about 300 hPa. The temperature at 168 hPa is about 215 K, which is the actual cloud temperature. The observed cloud T_{BB} (242 K) was estimated as being higher than the actual cloud temperature (215 K) by 27 K, because the cloud was semitransparent cirrus. It is difficult to accurately determine the cloud height from only T_{BB}. This difficulty led to JMSC using the climatological height assignment.

Case 2 − Thin cirrus shaped like feather

Fig. 3 shows the tracer cloud used in this example. It is cirrus shaped like feather. There is no cloud under the cirrus. The CMW speed is 47.3m/s, with the tracking method being the same as in Case 1. Its corresponding hodograph (Fig. 4) observed at Chenzhou (113.0°E, 25.8°N) shows the wind profile at a separation of about 20km from the CMW.

The CMW is only in good agreement with the radiosonde wind at 173 hPa. The vector and speed differences between the CMW and the radiosonde wind are respectively 6.4 m/s and 0.7 m/s at 173 hPa, where the maximum wind speed (48.0 m/s) was observed by the radiosonde. Similar to Case 1, these differences are negligible. Hence, this cirrus certainly traces the maximum speed flow as accurately as the radiosonde even in the jet stream area and over land, although ECMWF decided not to use CMWs over land. The important issue to identify rogue CMWs is not whether a tracer cloud is over land.

The cloud's minimum T_{BB} is 232 K and corresponds to the temperature at 250 hPa. The temperature at the correct cloud height of 173 hPa is about 210 K, which is most probably the actual cloud temperature. In this case, the effective emissivity of the semitransparent cirrus in the target area can be approximately calculated from the difference between the actual cloud temperature and the cloud's T_{BB} (see Appendix A). The effective emissivity (e) is

$$0.45 < e < 0.85.$$

Since the cirrus's emissivity is less than unity by an unknown and variable amount, the cirrus's T_{BB} is higher than the actual cloud temperature.

Case 3 − Midlatitude cloud system

Case 3a: Thick clouds in a cloud band

Fig. 3 shows the tracer cloud used in this example. The target area contains thick clouds in a cloud band, not only cirrus. It was tracked by a cross-correlation method. The CMW speed is 13.4m/s. Its corresponding hogograph (Fig. 5) observed at Minamidaito-jima (131.2°E, 25.8°N) shows the wind profile at a separation of about 40km from the CMW. The values of the minimum vector and minimum speed differences between the CMW and the radiosonde wind are respectively 5.6 m/s and 1.6 m/s at 600 hPa. However, is the CMW representative of the flow at 600 hPa?

The observed cloud's minimum T_{BB} is 234 K, which corresponds to the temperature at about 250 hPa. Since the observed cloud T_{BB} should always be greater than its actual temperature, the cloud top height is considered to be higher than 250 hPa. In the upper layer, however, the CMW speed is much less than the radiosonde wind speed and their vector and speed differences increase to about 20 m/s.

This indicates that this cloud-pattern motion does not correlate with the actual wind at any level. Even if the cloud temperature could be estimated correctly, the CMW would have

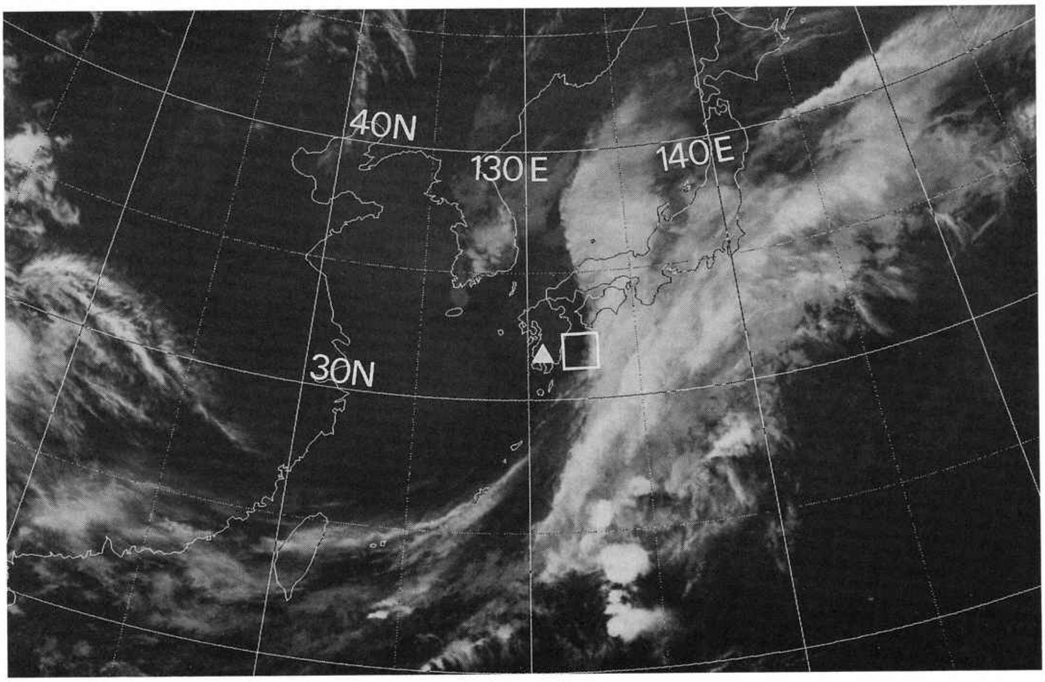

Fig. 6　As Fig.1a, but on 07 May 1990 at 1200 UTC; the triangle shows Kagoshima (130.6°E, 31.6°N).

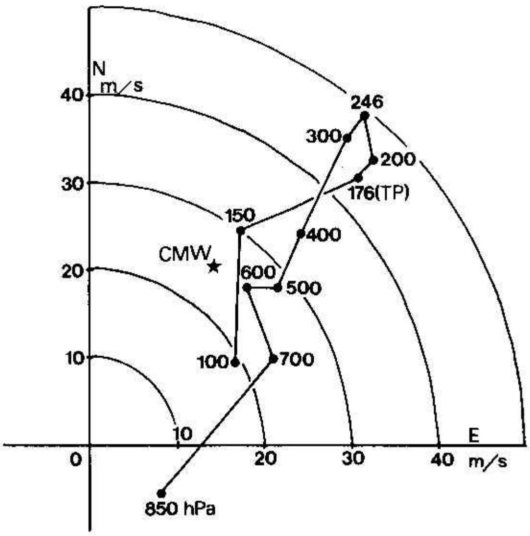

Fig. 7　As Fig.2, but for Kagoshima on 07 May 1990 at 1200 UTC.

lower velocity than the radiosonde wind' svelocity at the pressure level derived from cloud temperatuure. This target area is unsuitable for the tracer.

Case 3b: Thick cloud on the west edge of a cloud system

This case considers a CMW derived from the motion of thick cloud on the west edge of a cloud system (Fig. 6). The cloud was automatically tracked. The CMW speed is 24.8 m/s. Its corresponding hodograph (Fig. 7) observed at Kagoshima (130.6°E, 31.6°N) shows the wind profile at a separation of about 100km from the CMW. The values of the minimum vector and minimum speed differences between the CMW and the radio-

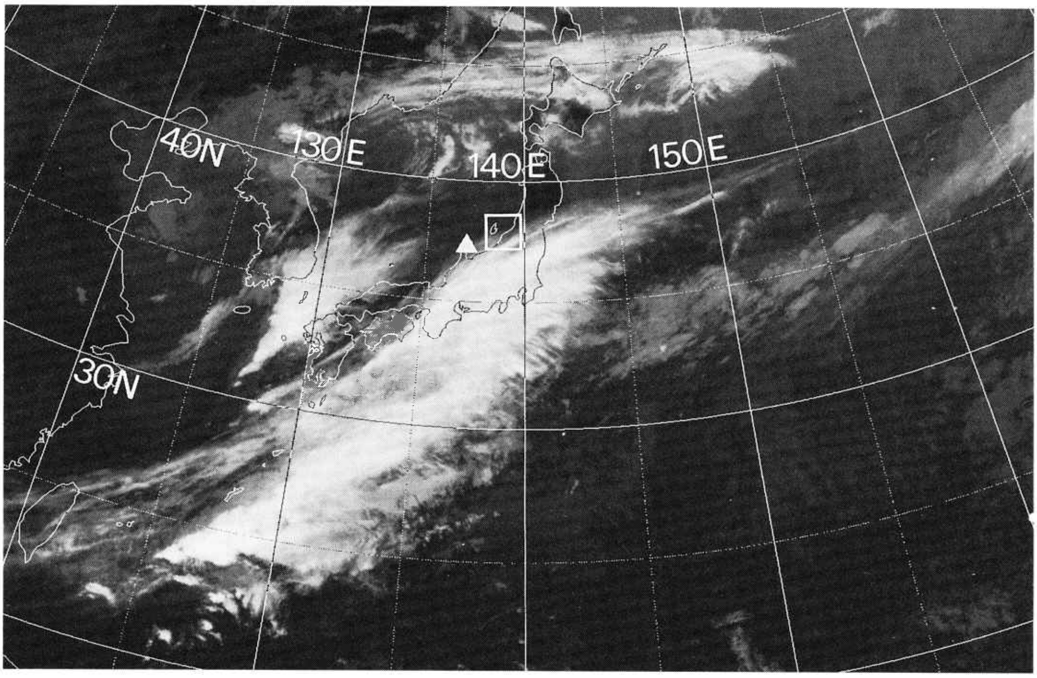

Fig.8a As Fig.1a, but on 07 May 1990 at 0000 UTC; the triangle shows Wajima (136.9°E, 37.4°N).

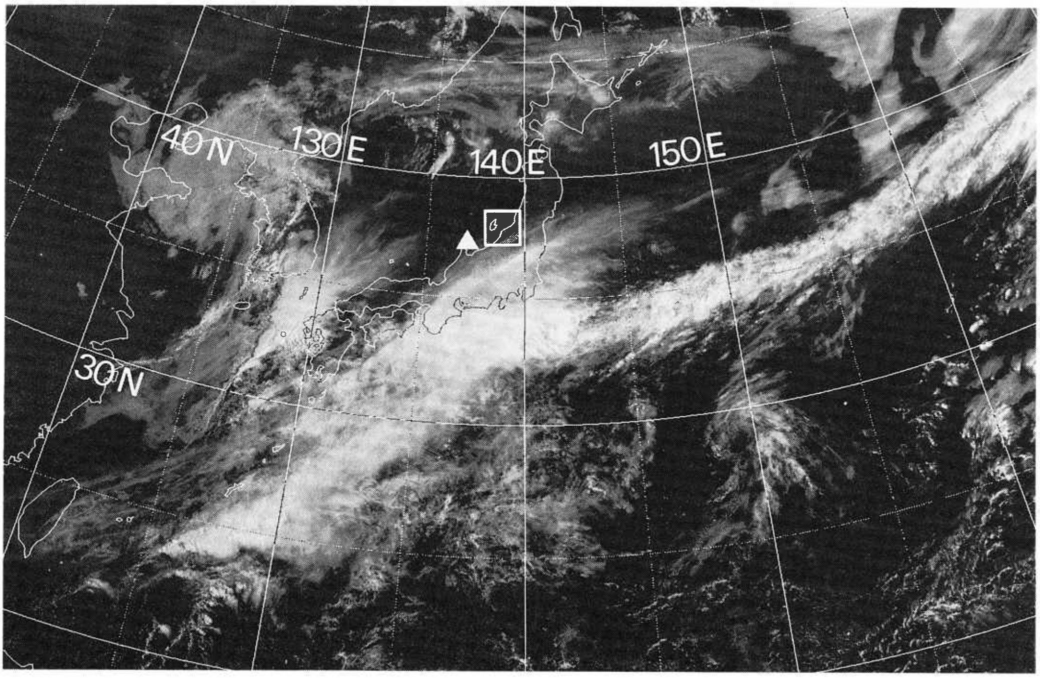

Fig.8b As Fig.8a, but VIS image.

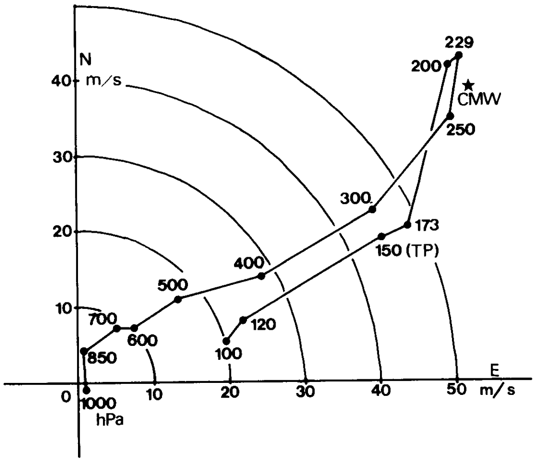

Fig. 9　As Fig. 2, but for Wajima on 07 May 1990 at 0000 UTC.

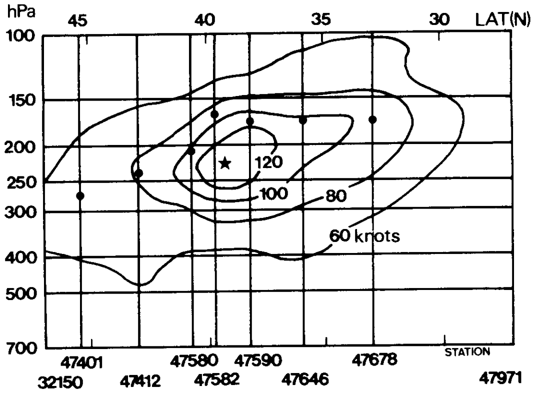

Fig. 10　Wind speed isolines in the meridional cross section chart along 140°E on 07 May 1990 at 0000 UTC. Tropopause height is indicated by dots. The star shows the CMW.

sonde wind are resepectively 4.2 m/s and 0.4 m/s at 600 hPa.

The observed cloud's minimum T_{BB} is 243 K and corresponds to the temperature at the pressure level of about 350 hPa; thus the cloud top height is considered higher than 350 hPa. In the upper layer, however, the CMW speed is less than the radiosonde wind's and the difference increases to about 25 m/s. Although the actual shear of the wind between the two locations makes a substantial contribution to the observed diferences, the value of 25 m/s is too great to consider that the CMW is coincident with the radiosonde wind. Similar to Case 3a, this CMW does not correlate with the rediosonde wind at any level.

Case 3c: Thin cirrus on the north edge of a cloud system

Not every part of a midlatitude cloud system is unsuitable for use as a tracer, e.g., the thin cirrus on the north edge of a cloud system shown in Fig. 8 is a suitable tracer cloud. The VIS and IR images confirm that the cirrus is semitransparent and thin. The cloud was manually tracked and found to have a CMW speed of 64.9 m/s, being considerably high in comparison with the average of high level CMW speeds (about 25 m/s). Its corresponding hodograph (Fig. 9) observed at Wajima (136.9°E, 37.4°N) shows the wind profile at a separation of about 60km from the CMW.

The CMW is only in good agreement with the radiosonde wind at 229 hPa, where the maximum wind speed (65.8m/s) was observed by the rediosonde. The vector and speed differences between the CMW and the radiosonde wind are respectively 3.2 m/s and 0.9 m/s at 229 hPa. Similar to Case 1, these variations are negligible. Thus the correct cloud height is 229 hPa. This tracer cloud follows the wind at such a high wind speed, although Morgan (1985) noted the almost complete inability of the satellite winds to observe a wind greater than 50 m/s.

Schmetz and Nuret (1989) stated that the jet core itself is mostly cloud-free. However, a meridional cross section chart along 140°E (Fig. 10) and Fig. 8 show that the jet stream axis corresponds to the north edge of the cloud system. Hence, it is fortunately possible to obtain CMWs tracing the jet stream axis. Such CMWs potentially have a significant impact on numerical weather prediction performance.

3. Results and Discussion

3.1 The existence of clouds tracing the flow at a single level

It must be remembered that the clouds shown in Cases 1, 2 and 3c definitely trace the flow at a single level as exactly as a radiosonde even in jet stream areas. In addition, similar case studies offer evidence of the representativeness of thin cirrus clouds as tracers of the flow.

No significant difference will occur in either wind direction or speed between the CMWs obtained from suitable tracer clouds and collocated radiosonde winds, if height assignment error and tracking error do no exist. These CMWs must be realized to be correct and reliable. Therefore such CMWs must not be rejected, even though they are quite different from the forecast winds. The CMWs which are different from the forecast winds are most important as initial data of numerical weather prediction, because they have a substantial impact on the analysis/forecast system.

3.2 What is a primary contributor to the negative speed bias?

The examples in this paper show that the negative speed bias and its speed dependency found in the statistical comparison between high level CMWs and radiosonde winds is not a consistent feature pertinent to all high level CMWs. In particular, CMWs tracing the maximum speed flow will not cause the negative speed bias. If they are assigned an incorrect height, a positive speed bias will be caused. Nevertheless, why does the negative speed bias occur? Case 3a and 3b suggest the answer.

CMWs of Case 3a, 3b would have lower speeds than the radiosonde wind's at the level derived from the cloud temperature, even if the cloud temperature could be estimated correctly. In general, a motion of a thick cloud does not correlate with the actual flow at a single level. If many of poor quality CMWs obtained from such unsuitable tacer clouds are not rejected, they will cause the negative speed bias.

On the basis of these case studies, poor quality CMWs have been more intensively rejected since April 1991 ; in addition to revising JMSC's hight assignment method using the Japan Meteorological Agency (JMA) forecast and radiosonde winds. This can be achieved by a more selective manual quality control. As a result, recent verification data of GMS CMWs with collocated radiosonde winds show a reduction of the speed bias and the vector difference (e,g., Woick, 1991). The result proves that the main cause of the negative speed bias is to use unsuitable tracer clouds. It is not necessary to calibrate CMW speeds, but instead to identify poor quality CMWs.

Moreover, the negative speed bias of METEOSAT CMWs and GOES CMWs is probably the result of using unsuitable tracer clouds rather than cloud height assignment error, because cloud height information determined from METEOSAT and GOES data are more acurate than that of GMS data; the METEOSAT cloud height assignment is made using the water vapor calibration, whereas the GOES cloud height assignment by the carbon dioxide splitting technique.

3.3 What is an useful parameter for identifying poor quality CMWs?

An operator can identify poor quality CMWs if he understands the relationship between cloud characteristics and their ability to trace the flow. In order to derive homogeneous-quality CMWs routinery, a method for identifying poor CMWs automatically should be developed, as suggested by Schmetz and Nuret (1989).

What is an useful parameter for identifying poor CMWs? First, cloud texture analysis can provide information on the quality of a tracer cloud, because the case studies show that there is a clear difference between cloud patterns of suitable tracers and ones of unsuitable tracer. Second, thinness of cloud could become an useful parameter for identifying poor CMWs, because the common character to clouds tracing the flow at a single level in jet stream areas is thinness; only thin cirrus can drift with a single level flow in a strong vertical shear.

4. Summary

Thin cirrus in clear shape traces the flow at a single level as exactly as a radiosonde even in jet stream areas. Rogue CMWs obtained from tracers of thick clouds mainly cause the negative speed bias. The analysis of cloud texture and thinness of cloud can provide information on the quality of a tracer.

5. Acknowledgements

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Appendix A

Approximate estimate of the effective emissivity of semitransparent cirrus

A method for estimating the effective emissivity of semitransparent cirrus at a single level is proposed based on the radiative transfer model, with assumptions being as follows;

(1) A plane-parallel atmosphere is in local thermodynamic equilibrium.

(2) The scattering arocess is negligilble.

(3) The cirrus temperature is homogeneous and equal to that of the environment.

(4) Ground temperature below the cloud is uniform in the area under computation.

For a given cirrus cloud element the observed radiation, I_{sa}, in the IR window can be written as

$$I_{sa} = (1-e)U + e \cdot I_{cl}$$

thus

$$e = (U - I_{sa}) / (U - I_{cl}) \qquad (*)$$

where e is the effective emissivity of the cloud, U is the clear sky radiation, and I_{cl} is the cloud radiation (see Fig. 11). The values of U and I_{sa} can be derived from satellite data, and I_{cl} can be derived from the actual cloud temperature.

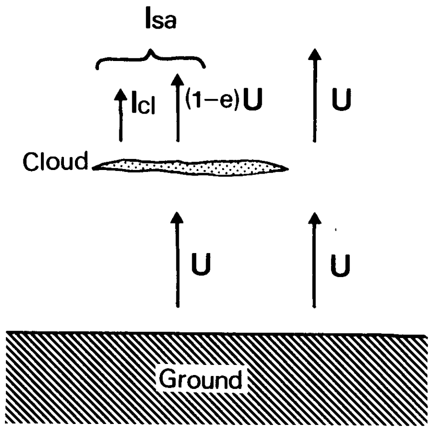

Fig. 11 Sketch illustrating IR radiation from semitransparent cirrus. Upward flux of the long wave radiation from the ground is U, satellite observed radiation is I_{sa}, and the cloud radiation is I_{cl}.

As a specific example, the effective emissivity of cirrus shown in Case 2 will be calculated. As discussed in Case 2, the actual cirrus temperature at 173 hPa is about 210K. Its corresponding radiation (I_{cl}) can be derived using the IR calibration table (not shown);

$$I_{cl}\ (210K) = 0.16\ [mW/cm/sr]$$

The cloud's T_{BB} ($T_{BB}c$) in the target area is in the range of 232 K to 275 K;

$$232 < T_{BB}c < 275\ [K].$$

These variations are due to the difference of cloud's emissivity. Their corresponding radiation (I_{sa}) can be derived using the IR calibration table;

$$0.26 < I_{sa} < 0.51\ [mW/cm/sr].$$

The ground T_{BB} is about 288 K. Its corresponding radiation (U) is

$$U\ (288K) = 0.80\ [mW/cm/sr]$$

Substituting these values (I_{cl}, I_{sa}, and U) into (*) gives the effective emissivity;

$$0.45 < e < 0.85.$$

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様々な雲のトレーサーとしての精度

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どのような雲がトレーサーとして適切であるのかを明らかにするために、雲の種類によって雲移動ベクトルを分類し、近傍のラジオゾンデデータと比較した。その結果、明瞭な形状を持つ薄い巻雲（Ciストリークや羽毛状の巻雲）は、ジェット気流付近の領域でも、ラジオゾンデと同程度の精度で流れをトレースしていることが判った。そのような巻雲はジェット気流の強風軸に位置することも多い。トレース雲が適切で、かつ、雲の高度推定と追跡が正確であるならば、雲移動ベクトルとラジオゾンデ観測から得られた風は、同質のデータとして扱うことが出来る。

上層の雲移動ベクトルとラジオゾンデデータを統計的に比較すると、雲移動ベクトルが負のスピードバイアスを示し、それが風速と共に増加することが今まで指摘されてきている。しかしこのことは、すべての雲移動ベクトルにあてはまる問題ではない。トレーサーとしては不適切な厚い雲の動きから算出された雲移動ベクトルが、負のスピードバイアスを引き起こしているのである。雲のパターンとその薄さを解析することが出るならば、トレーサーとして適切な雲を認識することが可能である。