Statistical Relationship between ISCCP Cloud Type and Vertical Relative Humidity Profile

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Abstract

The statistical relationship between ISCCP (International Satellite Cloud Climatology Project) cloud type, and the vertical relative humidity profile observed by radiosonde, was studied during the period from August, 1992 to July, 1994. The ISCCP-DX data of GMS (Geostationary Meteorological Satellite) were used to obtain cloud type information over the 1.5 degree grid area centered at the radiosonde station. To obtain the reliable cloud type classification, the data at 00 UTC—when the visible data were available—were used. The radiosonde observations when the 1.5 degree grid area is covered by single cloud type were used to compare the vertical relative humidity profile. Four cloud types of low-level, middle-level, cirrus-type and cumulonimbus-type cloud, and cloud-free case were selected for the comparison.

As was expected, the mean relative humidity was largest at all levels when the cumulonimbus-type cloud existed, and was smallest at all levels when no cloud existed. The relative humidity was larger than that of a cloud-free case at middle- and low-level (low-level) when middle-cloud (low-cloud) existed. When cirrus cloud existed, the high level relative humidity was larger than that when low- and middle-cloud existed, and showed local maximum at 400–500 hPa.

The feasibility for the use of the statistical relationship in this study in estimating relative humidity profile was shown as a case study by comparing with the current JMA statistical relationship derived from the GMS single infrared data. Cirrus clouds are difficult to be identified objectively from single infrared measurement and are often misclassified as middle- or low-level cloud. The misclassification between cirrus-type cloud and middle-/low- level cloud leads to a different vertical profile of water vapor. However, cirrus-type cloud is reasonably identified in the ISCCP with the use of visible and infrared measurements.

1. Introduction

The presence of clouds influences the energetics of the atmosphere in two ways—the atmospheric water cycle, and the radiation budget. In numerical weather prediction models, cloud amount is one of the important quantities to determine radiative fluxes (Saito and Baba 1988). The ascent of damp air can lead to condensation, and cloud is formed. During the ascent, although the mixing ratio of water vapor remains constant, the relative humidity increases and may reach 100% when condensation occurs, while cloud will disappear when the cloud goes into drier air. Therefore, cloud is closely related with relative humidity at the level where cloud exists. The study of the relationship between cloud and relative humidity is important in two ways, to estimate the relative humidity from the cloud information, and to estimate the cloud information from the relative humidity.

The vertical moisture profiles have been estimated from GMS cloud data and used in moisture analysis in the numerical weather prediction system at the Japan Meteorological Agency, since the moisture data has not been provided routinely except for radiosonde data. The algorithm was statistically derived from the comparison between cloud data, and moisture field, observed by radiosonde. Baba (1987, 1995) improved the algorithm using.
cloud data by considering cloud amount, mean infrared brightness temperature (TBB) of GMS and standard deviation (S.D.) of TBB within a 1 degree latitude/longitude area. Cloud conditions are classified into 32 categories considering the above parameters. With the combination of present weather observed at synoptic observation stations, 141 vertical profiles of moisture fields were used in the routine moisture analysis at JMA. Saito and Baba (1988) also studied the effect of cloud amount on relative humidity profile from the statistical relationship between cloud amount using GMS infrared measurement, and relative humidity data from aerological observations.

The former studies were based on single infrared measurement, which tends to misclassify thin cirrus cloud as middle- or low-level cloud. The ISCCP (Rossow and Shiffer 1999) provides nine cloud types according to cloud height and optical thickness. In the cloud analysis, radiances are converted into cloud parameters with the help of a radiative transfer model and auxiliary data like temperature profiles derived from TOVS (TIROS-N Operational Vertical Sounder) and ozone information, etc.

In this study, the statistical relationship between cloud types and the vertical relative humidity profiles is surveyed using more reliable cloud information derived from the ISCCP. We also aim to study the feasibility of the use of the ISCCP cloud data in estimating moisture field, especially over the ocean area where moisture data is sparse.

2. Data

2.1 ISCCP–DX data

The ISCCP was established in 1982 and provided cloud information analyzed by combining satellite-measured radiances with TOVS atmospheric temperature-humidity profile data. The first version of ISCCP products is called the C-series and the revised version of products is called the D-series. The DX data consists of pixel by pixel analysis performed for satellite radiance data, which are sampled every 30 km and 3 hours. Here we use the ISCCP–DX data of GMS observed at 00 UTC during the two year period from August, 1992 to July, 1994.

In the ISCCP, visible (daytime only) and infrared data are used to retrieve cloud parameters. During daytime, the optical thickness of cloud is determined from visible reflectance data. The cloud top temperature is corrected for transmitted radiation as a function of optical thickness for transparent cirrus clouds. In the ISCCP–DX data, ice crystals with 30 μm effective radius are used to compute the optical thickness of clouds which are colder than 260 K. Therefore, the ISCCP–DX data of daytime provides more reliable cloud parameters by combining visible and infrared data than by using single infrared data.

Based on these cloud optical thickness and heights, each cloudy pixel is classified into one of nine cloud types according to three cloud top pressure categories (divided at 440 and 680 hPa), and three visible optical thickness categories (divided at 3.6 and 23). In this study, we select four cloud types for simplicity in the comparison between cloud and radiosonde observation, instead of nine cloud types in the ISCCP. High-level cloud is classified as cirrus-type cloud, with an optical thickness smaller than 23, and cumulonimbus-type cloud, with an optical thickness greater than 23. The three cloud types at middle-level (low-level) are combined into one cloud type as middle-level (low-level) cloud. We also consider the cloud-free case as another category.

The cloud type in this study is derived just from satellite observation considering the cloud top height and cloud optical thickness. The reader should note that the cloud type names in this study are different from the ten cloud genera defined by WMO (World Meteorological Organization), although we hope the cloud type by satellite is similar to the cloud type by WMO.

Since the ISCCP–DX data are sampled every 30 km, although the original spatial resolution of 5 km is restored, we construct a 0.5 degree latitude/longitude grid map of cloud parameters over the GMS coverage of 50°N–50°S, and 110°E–180°E. The 00 UTC data are only used for comparison between cloud types and radiosonde observations, because the visible data of GMS is available at 00 UTC.

The cloud data, when only single cloud type exists over the 3 by 3 grids (1.5 degree latitude/longitude area) centered at the grid of the radiosonde station, are used to compare the relative humidity profile.

2.2 Radiosonde

We use the 00 UTC radiosonde data, which coincide with the cloud observation by the GMS. We only use the standard level data of air temperature and dew point temperature at 1000, 925, 850, 700, 500, 400, 300 and 250 hPa for computation of
the relative humidity. Therefore, some fine vertical structures of moisture profiles are neglected. The reader should note that the relative humidity above 300 hPa is less accurate than the other levels.

The mean relative humidity, and the difference between air temperature and dew point temperature (T-Td) at each level, are computed from the dataset by discarding the exceptional data. The exceptional data is defined as the data which is beyond the 1.8 times of S.D. from the mean (Baba 1987). We repeated this quality control process until no exceptional data existed in the new dataset, and there remained only typical data.

Generally, the relative humidity over the tropics is higher than that over the subtropics. We compare the cloud information with radiosonde observation over the three regions, the northern subtropics (23.5°N–50°N), tropics (23.5°N–23.5°S) and southern subtropics (23.5°S–50°S).

Figure 1 shows an example of the position of radiosonde stations used in this study, during July, 1994. The radiosonde stations are selected considering the effectiveness of the visible image at 00 UTC during winter. The radiosonde stations are mostly selected near coasts or islands because we aim to study the relationship between cloud type and vertical relative humidity profile over the ocean where conventional radiosonde observations are sparse.

In the study area, there are many kinds of radiosonde types made by a variety of manufacturers. Comparison of radiosonde observation by several instruments was summarized in the WMO Report (1996). It reported that there was a large difference in relative humidity observation depending on the types of instruments. In this study, no quality control is done for the difference of radiosonde type. As stated above, we discard the exceptional data and select the typical values by considering the mean, and the 1.8 times of S.D. in the dataset.

3. Results

The ISCCP–DX data of GMS, which is sampled every 30 km, is mapped onto a 0.5 degree latitude/longitude grid map. Cloud type is determined at each grid from the visible optical thickness. Corrected cloud height is determined from infrared data. The cloud information over the 3 by 3 grids (1.5 degree latitude/longitude area) centered at the grid of the radiosonde station, is used for comparison with radiosonde observation. We selected the cases when the area is covered by only one cloud type. First, we introduce the vertical relative humidity profile in terms of cloud type, using the overcast area by one cloud type over the three regions of northern subtropics, tropics and southern subtropics. Then, a comparison of the relative humidity field between the JMA analysis, and our results, is demonstrated as a case study.

3.1 Vertical relative humidity profile for each cloud type over the northern subtropics

Figure 2a shows the vertical profiles of mean relative humidity (solid line) and S.D. (dotted line) derived from two years of data for cumulonimbus-type (circle), middle-level (square) and low-level (triangle) cloud classified by the ISCCP analysis over the northern subtropics. Figure 2b is the same figure as Fig. 2a except for cirrus-type cloud (circle), and the cloud free case (square).

When cumulonimbus-type cloud exists all over the 1.5 degree latitude/longitude area, the mean relative humidity indicates the largest value at all levels. This meteorological situation is considered as the radiosonde station being in the middle of some kind of meso-scale convective system. The S.D. is smaller than 12% at all levels.
Fig. 2a. The vertical profiles of mean (solid line) relative humidity, and S.D. (dotted line) derived from two year data corresponding to low-level (triangle), middle-level (square) and cumulonimbus-type (circle) cloud type derived from ISCCP analysis over the northern subtropics (23.5°N-50°N).

Fig. 2b. Same as Fig. 2a except for cirrus-type cloud (circle) and clear case (square).
When low-level cloud exists, the relative humidity at lower than 850 hPa is larger than the clear case, but as dry as the cloud free case at the levels higher than 700 hPa. The S.D. is smaller than 9% at all levels.

When middle-level cloud exists, the relative humidity is large at the levels lower than 700 hPa. The moist layer is thicker than the low-level cloud case, and the S.D. is very large at the 500 hPa level. This implies that 500 hPa is a critical level for middle-level cloud. Depending on the meteorological condition, middle-level cloud either exists at this level or does not.

When cirrus cloud exists, the vertical mean relative humidity profile shows a clear local maximum at the 500 hPa level and indicates larger values comparable to the cumulonimbus-type cloud case at higher levels. The mean relative humidity profile indicates a dip at the 700 hPa level, although the S.D. is very large at this level. We expect the local maximum of relative humidity at the higher levels, and lower relative humidity at lower levels, when we see cirrus cloud. However, in this study, the relative humidity at lower levels shows rather larger values than the cloud-free condition. Cirrus clouds often appear in front of the low pressure system over the mid-latitude and are often associated with lower clouds. In this multi-layered cloud case, the satellite cloud retrieval algorithm generally tends to classify them as cirrus-type cloud. This is one of the reasons for higher relative humidity at lower levels when cirrus cloud exists.

The relative humidity is lowest at all levels for the cloud-free case. The S.D. is very small at the levels higher than 700 hPa, but relatively large at the lower levels. This might reflect the seasonal variation of moisture condition at the lower levels when no cloud exists.

As is expected, the relative humidity is generally larger at the level where cloud exists. In this sense, the mean vertical profile of relative humidity for each cloud type in this study demonstrates the reasonability of cloud type classification by the ISCCP.

So far, we have studied the typical mean vertical profile of relative humidity in terms of cloud type. Now, we validate the cloud type appearance when the radiosonde station indicates the typical vertical profile of relative humidity over the northern subtropics. The validation should be done using independent datasets, however, we only have one independent dataset of July, 1992.

Table 1 shows the mean cloud amount of each cloud type within the area of the 3.5 degree latitude/longitude area when the radiosonde station observes the typical mean value allowing for the S.D. at all levels. Considering all the levels, the typical vertical profile for each cloud type is uniquely determined even allowing for the S.D. as seen in Fig. 2. This table shows reasonable results since the corresponding cloud type generally indicates the largest cloud amount, although other cloud types are contaminated in the area.

Table 2 shows another validation of the mean vertical relative humidity profile derived in this study for the data of January, 1993. This case also shows reasonable results except for the cumulonimbus-type case. When radiosonde observation fits the cumulonimbus-type profile derived in this study, cirrus-type cloud instead of cumulonimbus-type cloud occurs most frequently in this winter time dataset. This implies that the vertical relative humidity profile is different season by season. Another reason is that the difference

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of vertical profile between the cumulonimbus-type, and cirrus-type, is very small by allowing the S.D., since the S.D. at 700 hPa for cirrus-type is very large.

It is difficult to show the unique correspondence between cloud type and vertical relative humidity profile. One reason is the accuracy of observation for both cloud and relative humidity. Current satellites cannot observe the vertical structure of cloud distribution. Further, we use 0.5 degree latitude/longitude grid data that do not guarantee the cloud information for sub-grid scale. The radiosonde observation is a pin point observation along the ascending path. However, the results in this study give some insight into the relationship between cloud type and vertical relative humidity profile.

3.2 Regional characteristics of relative humidity profile

Figure 3 shows the vertical profile of mean relative humidity (pattern), and S.D. (whiskers) for the northern sub-tropics on the top, tropics in the middle, and southern sub-tropics at the bottom of the figure. Each figure is corresponding to cumulonimbus-type cloud (a); low-level cloud (b); clear (c); cirrus-type cloud (d), and middle-level cloud (e).

a. Cumulonimbus-type Cloud

The number of cases for constructing the figure is about 100 over the northern sub-tropics and tropics, and is only 20 over the southern sub-tropics. The vertical profile of relative humidity for the cumulonimbus-type case is similar over the three regions, although it is slightly drier over the southern sub-tropics at lower levels (Fig. 3a). The S.D. is generally smaller than 10% except at higher levels over the northern sub-tropics, and 850 hPa over the southern sub-tropics. The S.D. at the levels lower than 500 hPa is very small over the northern sub-tropics, while it is slightly larger at the levels of 700 and 850 hPa over the tropics. The relative humidity is larger at all levels in comparison with other cloud cases.

b. Low-level Cloud

The number of cases for constructing the figure is about 3000, 2000 and 1000 over the northern sub-tropics, tropics and sub-tropics, respectively. The features of the vertical relative humidity profile over the three regions are similar. The relative humidity drops very sharply between 850 and 700 hPa, and it is very small at levels higher than 700 hPa. However, it is slightly larger over the northern sub-tropics in comparison with the other regions. The relative humidity at the level of 850 hPa is the same over the three regions. However, it shows a slightly larger difference at the level of 1000 hPa. The S.D. is smaller than 10% at all levels and all regions.

A significant increase in relative humidity at levels lower than 700 hPa can be seen in comparison with the cloud-free case over the sub-tropics (Fig. 3c). However, over the tropics the vertical profile of relative humidity is similar to the cloud-free case, although the relative humidity at 850 hPa is about 10% larger, and at 700 hPa about 10% smaller.

c. Clear case

The number of cases for constructing the figure is about 1500, 1100 and 400 over the northern sub-tropics, tropics and southern sub-tropics, respectively. The salient features of larger relative humidity at lower than 850 hPa with the local maximum at 925 hPa can be seen over the tropics (Fig. 3c). The northern sub-tropics tend to be moist at the levels higher than 500 hPa in comparison with other areas. Over the southern sub-tropics, the vertical relative humidity profile at lower levels is similar to that of the northern sub-tropics, and it is rather similar to the tropics at levels higher than 500 hPa. The S.D. is largest at 700 hPa over the tropics, and largest at 850 hPa over the sub-tropics.

d. Cirrus-type Cloud

The number of cases for constructing the figure is about 600, 500 and 80 over the northern sub-tropics, tropics and southern sub-tropics, respectively. It is interesting to find a similar vertical profile of relative humidity with local maximum at higher levels, and smaller relative humidity at 700 hPa for the sub-tropics when cirrus-type cloud exists (Fig. 3d). The level of local maximum is 500 hPa over the northern sub-tropics and tropics, while it is 400 hPa over the southern sub-tropics. The dip at 700 hPa is largest over the southern sub-tropics, and smallest over the tropics. We can see the significant dry bias at all levels over the southern sub-tropics. The S.D. is larger than 20% at the levels of 850 and 500 hPa over the southern sub-tropics, and at 700 hPa over the northern sub-tropics. Whereas, it is relatively small over the tropics except at 500 hPa.

e. Middle-level Cloud

The number of cases for constructing the figure is about 900, 300 and 200 over the northern sub-trop-
Fig. 3. The mean vertical profile of relative humidity with S.D. for the northern subtropics (23.5°N–50°N), tropics (23.5°S–23.5°N) and southern subtropics (23.5°S–50°S) corresponding to cumulonimbus-type cloud (a), low-level cloud (b), clear case (c), cirrus-type cloud (d) and middle-level cloud (e).
ics, tropics and southern subtropics, respectively. The vertical profile of relative humidity over the northern subtropics is generally larger at all levels in comparison to the other two regions, especially at the 850–500 hPa levels (Fig. 3e). The relative humidity at 500 hPa over the northern subtropics is more than 20% larger than the other two regions, and the S.D. at the same level is larger than 25%. This implies that the mid-level cloud top varies around this level. The moist layer is just up to 700 hPa over the tropics, and southern subtropics. There is a dry bias over the southern subtropics, especially lower than 700 hPa, although the S.D. is very large.

4. Comparison of cloud type by single infrared method and ISCCP method

Baba (1987) developed a method to estimate the moisture data from GMS infrared data. He used the mean brightness temperature (TBB), cloud amount and standard deviation (S.D.) of the TBB within a 1 degree latitude/longitude area. The S.D. is used to classify the strati-form, and convective cloud for overcast areas. He used 4 K as the threshold to separate the cases and also used the present weather reported by the synoptic observation stations. The number of synoptic observation stations is sparse, especially over the ocean area, therefore the method depends on the effectiveness of the cloud type classification using the S.D. and TBB. In his paper, the relative humidity profile is not shown, and only the difference between air temperature and dew point temperature (T–Td) profile is available. Therefore, we use the T–Td information instead of relative humidity for the comparison of the methods in this section.

Figure 4 shows the vertical profile of T–Td derived by Baba (1987), where the S.D. is smaller than 4 K (a) and the S.D. is larger than 4 K (b) for high-level cloud. The figures are the cases over the subtropics with no synoptic present weather report. The S.D. is not effective in classifying strati-form/convective cloud, since there is only a small difference between the two profiles. Figure 5 shows the same T–Td profile with the present weather reported as clear. The T–Td at the level around 700 hPa in Fig. 5 is larger than in Fig. 4. Therefore, the T–Td vertical profile for cirrus-type cloud corresponds to Fig. 5. These figures imply the help of present weather from meteorological observation station inevitable for the single infrared method to classify the T–Td profile of cirrus-type cloud.

The vertical profiles of T–Td for cumulonimbus-type cloud (a) and cirrus-type cloud (b) over the northern subtropics derived in this study are shown in Fig. 6. The T–Td profile for cumulonimbus-type cloud in our study (Fig. 6a) shows very similar vertical profiles to Fig. 4. The T–Td profile for cirrus-type cloud in our study (Fig. 6b) shows similar vertical profiles to Fig. 5b. Without the present weather report, the S.D. seems ineffective in classifying strati-form/convective cloud, since there is not such a big difference in Fig. 4a, and Fig. 4b, as there is in Fig. 4a (Fig. 4b) and Fig. 5a (Fig. 5b).

On the other hand, Fig. 6a and Fig. 6b show some difference, especially at the middle level, although not as significant as Fig. 5. This suggests that the use of ISCCP cloud information is effective in classifying cirrus-type cloud, and cumulonimbus-type cloud without surface observation.

Figure 7 shows the the vertical profile of T–Td for low-level cloud (a) and middle-level cloud (b) over the subtropics by Baba (1987). Figure 8 shows the vertical profiles of low-level (a) and middle-level (b) cloud over the northern subtropics derived in this study. Figures 7 and 8 show similar vertical profiles of T–Td, although the T–Td is larger at higher levels, especially for the low-level cloud case, in our results. For the case of thin cirrus, the TBB is relatively warm and classified as middle- or low-level cloud by the single infrared method. This implies that the possibility of different assignments of vertical T–Td profile between the single infrared, and the method using the ISCCP cloud data.

5. Case study

Figure 9 shows the visible (a) and infrared (b) images taken by GMS at 00 UTC July 21, 1998. Figure 10 shows the relative humidity estimation at the levels of 850, 700, 500 and 400 hPa analyzed by JMA using the GMS infrared data.

We selected typical JMA analysis grids that are covered by the four cloud types by inspecting the neph-analysis (not shown) reported by Meteorological Satellite Center (MSC), and GMS images (Fig. 9). The selected grids are marked as A to O in Fig. 10. From inspection of the GMS images, we judged that the selected grids of A–L were all overcast by cloud.

Table 3 shows the comparison of relative humidity between our estimate and JMA analysis, for cumulonimbus-type cloud areas of A, B and C. The relative humidity is very high for all the levels in all cases. The vertical profiles of relative humidity
Fig. 4. The vertical profile of T-Td shown in Baba (1987) for the high-level cloud case with the S.D. of TBB over the 1 degree latitude/longitude area is smaller than 4 K (a), and with the S.D. is larger than 4 K (b). The figures are the cases over the subtropics with no present weather reports from meteorological observation station.

Fig. 5. Same as Fig. 4, except for the present weather is reported as clear.

Fig. 6. The vertical profiles of T-Td for cumulonimbus-type cloud (a) and cirrus-type cloud (b) over the northern subtropics computed using the ISCCP cloud type.
Fig. 7. The vertical profile of T–Td for low-level cloud (a) and middle-level cloud (b) over the subtropics shown by Baba (1987).

Fig. 8. The vertical profiles of low-level (a) and middle-level (b) cloud over the northern subtropics computed using the ISCCP cloud type.

Fig. 9. The visible (a) and infrared (b) images taken by GMS on 00 UTC July 21, 1998 over the area of 20°N–50°N and 120°E–150°E.
Fig. 10. The relative humidity estimation at the levels of 850 hPa (a), 700 hPa (b), 500 hPa (c) and 400 hPa (d) analyzed by JMA using the GMS infrared data.
agree reasonably well with each other. However, there are slight dry biases at the levels of 700 and 850 hPa in the JMA analysis.

The relative humidity comparison for the low-level cloud areas of D, E and F are shown in Table 4. The low relative humidity at higher levels, and large relative humidity at 850 hPa, are estimated reasonably by the two methods. However, the JMA analysis is moist at 700 hPa and drier at 850 hPa than our estimate.

The relative humidity comparison for the middle-level cloud areas of G, H and I are shown in Table 5. The estimated relative humidity at higher levels agrees well but the JMA analysis is smaller at lower levels except for cloud area H that shows very good agreement at all levels. The S.D. may differ for the three cloud areas. However, the JMA analysis is much drier at 700 and 850 hPa.

Table 6 shows the comparison for the cirrus-type cloud area. Optically thicker cirrus-type cloud area (J) shows very good agreement, but optically thinner cirrus-type cloud areas (K and L) show very dry at higher levels in the JMA analysis. These cloud areas might be assigned as middle-level cloud in the JMA analysis.

There are some clear areas. Table 7 shows the comparison for clear cases. The relative humidity agrees well at 850 hPa level but is much larger at the higher levels of 700, 500 and 400 hPa in the JMA analysis.

We cannot compare the two methods directly, since coincident ISCCP data and JMA analysis data are not available. However, the JMA routine analysis shows a slightly different relative humid-

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ity profile from our results. The difference seems large for thin cirrus-type cloud area that might be misclassified as middle-level or low-level cloud area by the single infrared method.

6. Concluding Remarks

Using the reliable cloud information derived from ISCCP-DX, we studied the statistical relationship between cloud type and vertical relative humidity profile observed by radiosonde observation. The studied region was the GMS coverage area, and the studied period was the two year period from August 1, 1992 to July 31, 1994. The 00 UTC radiosonde observations were used for comparison with the cloud information from GMS/ISCCP-DX visible and infrared data taken at the same time. The spatial resolution of ISCCP-DX data is 5 km but sampled every 30 km. The satellite data were mapped onto 0.5 degree latitude/longitude grids. The cloud information was retrieved over the 1.5 degree latitude/longitude (3 by 3 grids) area centered at the radiosonde station. The five cloud types (including the cloud-free case) were classified from optical thickness and cloud height by ISCCP-DX data. They are low-level cloud, middle-level cloud, cirrus-type cloud and cumulonimbus-type cloud. The low-level and middle-level clouds are defined as cloud top lower than 600 hPa, and cloud top between 600 hPa and 440 hPa, respectively. The cirrus-type cloud is defined as cloud top higher than 440 hPa with visible optical thickness smaller than 23. The cumulonimbus-type cloud is defined as cloud top higher than 440 hPa with visible optical thickness larger than 23. The reader should note that the cloud type is defined only from satellite observations. Therefore, the cloud type name in this study is slightly different from the original cloud type name in the ISCCP, and the ten cloud genera defined by the WMO.

The radiosonde observation of relative humidity is used for comparison when the 1.5 degree latitude/longitude area is covered by a single cloud type. Since we used the 0.5 degree latitude/longitude grid point cloud data, there is no guarantee for cloud information between the 0.5 degree latitude/longitude grid. The mean relative humidity, and the difference between air temperature and dew point temperature (T–Td) at each level, are computed from the dataset by discarding the exceptional data. Then we can compute the typical value of relative humidity and corresponding S.D. as carried out by Baba (1987). Depending on the country, the radiosonde type is different. However, no quality control considering the radiosonde type was carried out in this study.

The characteristics of the vertical profile of relative humidity are statistically studied in terms of cloud type. As is expected, the vertical profile of relative humidity is largest at all levels when cumulonimbus-type cloud exists all over the 1.5 degree latitude/longitude area, which is associated with a meso-scale convective system, and is lowest at all levels when no cloud exists. The relative humidity is higher than that of the cloud-free case at middle- and low-level (low-level) when middle-cloud (low-cloud) exists.

When cirrus-type cloud exists, the vertical relative humidity profile shows a clear local maximum at the 500 hPa level and indicates larger values comparable to the cumulonimbus-type cloud case at higher levels. However, the relative humidity at lower levels is not as small as the cirrus case, although there is a dip at the 700 hPa level. Cirrus cloud is often associated with lower level clouds. In this multi-layer cloud case the satellite cloud retrieval algorithm tends to retrieve only higher cloud. This is one reason for the relatively higher relative humidity at middle- and low-level than in the cloud-free case.

We also studied the regional characteristics of vertical relative humidity in terms of cloud type by separating the latitudinal areas of the northern subtropics, tropics and southern subtropics. The relative humidity at high levels tends to be larger over the northern subtropics than over other regions. Generally, the relative humidity over the southern subtropics is smaller in comparison with the northern subtropics and tropics. It is well known that Vaisala and VIZ radiosonde showed a difference of about 10% as a mean for one month data during the Large-scale Biosphere Atmosphere Experiment (LBA) over Amazonia (Halverson, personal communication). The regional difference in this study seems slightly larger than the instrument dependency. Further study is required to understand whether these regional differences are caused by the difference of radiosonde type, or by regional climatological difference.

This study demonstrates the feasibility of better water vapor field analysis over the ocean areas, where neither radiosonde nor GPS (Global Positioning System) observations are available, than the method using the cloud information from single infrared data. However, more coincident data ac-
cumulation is required to refine the method. This kind of study using the split window (11 and 12 \(\mu\)m), which is effective in the classification of cirrus-type cloud (Inoue 1985; 1987), and is effective both day and night, is another way to increase the data and improve the statistical relationship between cloud type and water vapor field.

The total precipitable water estimation from SSM/I (Special Sensor of Microwave/Imager) and TMI (TRMM Microwave Imager) is widely accepted as reliable water vapor information. However, the estimation is just the total integrated water vapor amount, with no vertical profile information. With the help of cloud type information by multi-channel data, the vertical profile of water vapor analysis may be much improved.

We processed two years of data, but coincident data of satellite and radiosonde in terms of cloud type is not enough to study seasonal dependency and location dependency. Further study is required to establish a method that can be used in a routine numerical weather prediction model. However, we were able to demonstrate that the use of ISCCP cloud type is effective for analyzing the moisture field, especially for cirrus cloud area.

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References


