Comparison of Satellite and Ship Observations for Total Cloud Amount

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ABSTRACT

The data series of monthly clouldiness over global ocean from COADS was compared with that of from satellite Nimbus–7 during April 1979 to March 1985. The correspondence between them is good. Both the two methods of observation can provide useful information of the distribution of cloudiness and the two data sets can be mutually complementary.

I. INTRODUCTION

Cloud in the atmosphere is obviously very important for the climate system. It is closely related with some major diabatic heating components in the earth–atmospheric system. The cloud properties such as cloud form, depth, and height should modify the earth radiation budget, thus affecting the main energy source of climate system. Through the processes of latent heat release and evaporation, clouds also affect the dynamic and hydrologic climate processes. Thus a well description of worldwide cloud cover is useful for the studying of the earth radiation budget and the atmospheric dynamic processes, then further for the improvement of numerical models.

The observation of cloud cover in the atmosphere mainly depends on two methods: the conventional surface observation and the satellites observation. In the land areas, the surface observation is done at meteorological stations; and in the marine region, the observation is made at the ships on their voyages. The surface observations either in the land areas or in the marine areas have accumulated more than hundred years historical data. The Comprehensive Oceanic and Atmospheric Data Set has already collected and edited global marine meteorological reports primarily observed by ships during 1854–1985. This data set also contains monthly mean total cloud amount of each year for each geographical $2^\circ \times 2^\circ$ latitude–longitude box in the world wide marine regions. The satellite observation for cloud had already been carried on for more than 30 years. The informations of cloud cover amount, cloud forms and the height of cloud top are from the visible picture or the infrared radiation measurment.

It is obvious that a data set having more than 100 year length in time is more suitable for the climate research. However, the shortage of surface observation data is apparent. The data series are usually not homogeneous in spatical and temporal distribution, especially for the marine meteorological data, because most ships on which the meteorological observation is done travel along the oceanic routes; there are fewer or even no meteorological report in those marine areas which are far away from the routes. Additionally, the weather observer is only able to record cloud cover observations accurately over an circle area with a radius of tens km with the observater at the center. Thus the data set of surface observation is only referred to the cloud cover in many discrete points over the earth.

The satellite observations are the only means of getting reliable data of cloud cover over the oceans as well as both over the oceans and continents at night. They show the areal distributuon of clouds. However, the satellite observations are shorter in history. Furthermore, as the observation instruments differ from one satellite to another, it is difficult to edit a long enongh data series of satellite observation for climate studies. Thus, both the surface–based and satellite–based observations of cloud have their strong and weak points, they are complementary. It is a fundamental task to compare and assess the two data sets and find a correction method to improve them.

In this report, we have analysed and discussed the differences between the cloud cover data measured by the two observation methods over the marine areas in the Pacific, Atlantic and Indian Oceans. The surface observation data is obtained from COADS and the satellite data is from Nimbus–7. The monthly cloud data of ISCCP in July 1984 and January 1983 is also used to compare with both the cloud data of COADS and Nimbus–7.

II. DATA

The following data sets are used in the comparison: 1. The satellite observation data is Nimbus–7 THIR global monthly mean total cloud amount for a six year period (April 1979 to March 1985). The monthly mean value is derived from the daily value which had twice daily observation during ascending 1 / 2 of orbrt and descending 1 / 2 of orbrt (1). A geographical box of $4.5^\circ \times 4.5^\circ$ latitide and longitude (approximately 500×500 km) is used in which the cloud amount is determined for each grid area as the fraction amount of the total cloud cover (percent of the grid area).

2. The surface observatipn data over the oceans is from the COADS for the same period as that of Nimbus–7. The cloud amount is determined for each box of $2^\circ \times 2^\circ$ latitude–longitude box as value of octant (2). In order to compare with the satellite data, the COADS data have to be transformed into the same geographical box and the same unit as that of satllite data. First, the cloud amount in $2^\circ \times 2^\circ$ degree box is transformed into the value in $4^\circ \times 4^\circ$ degree box which is the algebric mean of four $2^\circ \times 2^\circ$ degree boxes. Then, the cloud amount in $4.5^\circ \times 4.5^\circ$ degree box is derived from the value of $4^\circ \times 4^\circ$ degree box using the linear interpolation method. Finally, multiplying by 0.125, the value of cloud amount in octant is transformed into percentage of the box area. Because there are fewer observation in the Arctic and southern higher latitude regions, the comparison of two data series in this report is confined in the areas 70°N–45°S. Fig.1 shows mean daily surface observation numbers which the COADS contained in each $4^\circ \times 4^\circ$ degree box during April 1979 to March 1985. In the Northern Hemisphere, most of the boxes in the oceans south of 60°N have at least one report a day on the average, however, the observations significantly decrease to 0.4 times per day in the tropical central and eastern Pacific ocean, i.e., there are only less than 12 reports a month in each box. In some boxes, it drops to less than 0.2 times per day (i.e., 6 reports in a month). In the Southern Hemisphere, the observations are fewer in the southern Pacific Ocean. South of 40°S, the mean observations are less than 0.2 times a day in each box.

3. The monthly mean total cloudiness from ISCCP for July 1983 and January 1984, which is composed of the measurement of five satellites (3), is also used to be compared with the cloud amount data of Nimbus–7 and COADS.

III. COMPARISON OF THE TOTAL CLOUD AMOUNT

1. The maps of distribution pattern of cloudiness of July 1983 and January 1984 obtained from ISCCP, Nimbus and COADS data are compared (figures are not shown). The maps of

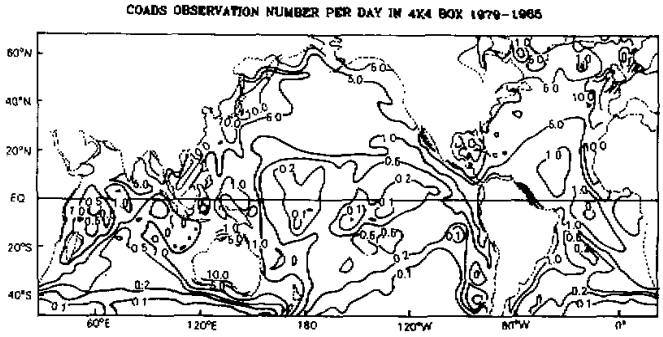

Fig.1. Mean daily numbers of COADS cloud observation reports in 4° × 4° longitude–latitude box during April 1979 to March 1985.

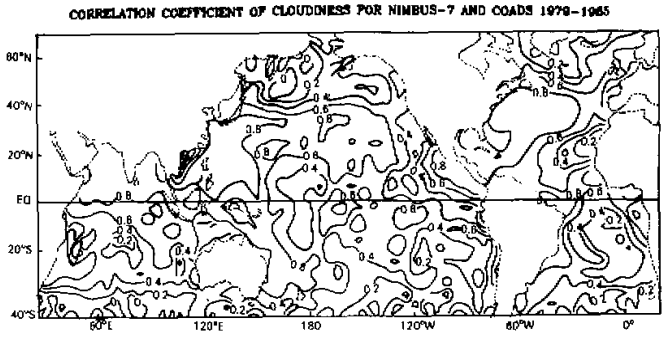

Fig.2. Map of correlation coefficients between the monthly cloudiness measured by Nimbus–7 and COADS during the period from April 1979 to March 1985.

Nimbus–7 match better with that of ISCCP even in many details, however, the Nimbus data are generally lower than ISCCP data. The Nimbus THIR cloud is about 0.8 of ISCCP cloud in general. The pattern of COADS cloud amount has the same large scale feature as the satellite cloud coverage, although it seems rather scattered. This may be caused by the inhomogeneity of data coverage. Futhermore, the spatial variance is smaller for the COADS cloud amount than for that of the satellite cloud amount.

2. Fig.2 is the map of correlation coefficients between the cloudiness data sets of Nimbus–7 and COADS. The correlation coefficients are generally above 0.6 south of 40°N in the Northern Hemisphere and above 0.4 north of 30°S in the Southern Hemisphere. They are higher than 0.8 in the North Indian Ocean and western part of both North Pacific and North Atlantic. The higher coefficients indicate that the correspondence between the two data sets is considerable within the 40°N–30°S belt except off the west coast of the continents. The two data sets have greater differences in higher latitudes in the two hemispheres where the correlation coefficients drop to less than 0.2.

3. Differences between the monthly mean cloud amount of Nimbus–7 and COADS are produced at each 4.5° × 4.5° latitude–longitude box in the global marine areas (included the areas in north of 70°N and south of 45°S) through April 1979 to March 1985. The differences are divided into 4 classes and summarized in Table 1. It may be seen that there are 30–40%

boxes having the differences within 0.10 of cloud amount in absolute values and 62–76% boxes having the value within 0.20. The remaining one third boxes have differences of cloud amount greater than 0.20. The greater differences of the two cloud data sets are found in June, July and August, as for July, they are more than 0.20 in 38% of the boxes. The correspondence is found to be better in the transitional seasons, as there are 76% of boxes with differences lower than 0.20 in April and 75% in October and November.

4. Fig.3 shows the annual variation of zonal mean differences of Nimbus–7 and COADS cloud cover data in the oceanic regions. The cloud amount of Nimbus–7 is generally lower than the cloud amount of COADS, except within the equatorial zone from 10°N to 10°S. Besides, the cloud amounts of Nimbus–7 are also greater than those of COADS in the marine areas north of 80°N and near the 60°S zone during the winter half year.

The zonal mean differences show considerable seasonal variation as follows:

(a) The area with positive value of differences along the equatorial zone moves southward and northward with the progress of seasons. It is at the southern location during February to April and moves out of the Southern Hemisphere in May. From July to September, the positive area moves northward from the equator, and the difference values become greater than those in other seasons, while in November it returns to southward. The seasonal movement of the poistive area seems to coincide with the movement of the intertropical convergence zone (ITCZ) near the equatorial zone.

(b) In 10°–30° latitude zone of tropical and subtropical regions of the two hemispheres, the correspondence of the two data sets is better in summer. In winter the differences become greater with the satellite cloud amount being 0.10 lower than the surface–observed cloud

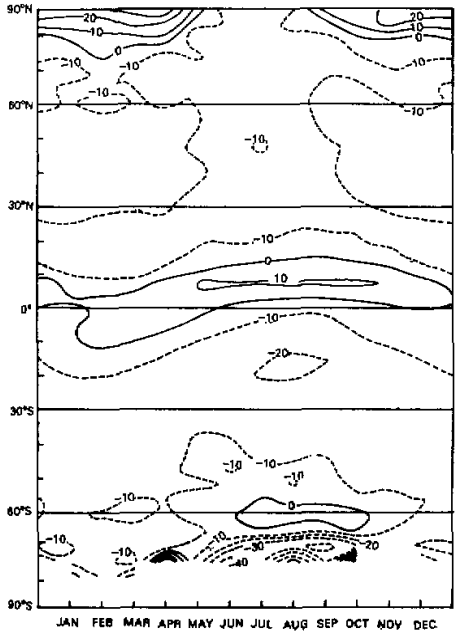

Fig.3. Annual variation of zonal mean differences between the monthly cloudiness of Nimbus–7 and COADS (unit: percent in 4.5° × 4.5° box).

Table 1. Occurrence of 4 Classes of Difference between the Monthly Cloudiness of Nimbus–7 and COADS in Percentage of Boxes for the Worldwide Oceans

	Percentage of values in each catalogue			
Months	0.0–0.10	0.11–0.20	0.21–0.30	>0.31
1	0.39	0.32	0.19	0.10
2	0.38	0.33	0.19	0.10
3	0.38	0.34	0.20	0.08
4	0.41	0.35	0.16	0.08
5	0.37	0.37	0.17	0.09
6	0.32	0.36	0.21	0.11
7	0.29	0.33	0.24	0.14
8	0.29	0.37	0.22	0.12
9	0.34	0.37	0.19	0.10
10	0.41	0.34	0.17	0.08
11	0.44	0.31	0.17	0.08
12	0.41	0.31	0.18	0.10

amount. During the southern winter of August and September, the zonal mean difference near 20°S reaches −0.20.

(c) In the belt of 30°–60° latitude, the differences of negative value are smaller in winter and in the transition seasons, however, they become greater in summer.

(d) In the northern higher latitude, the satellite cloud cover is less than the surface cloud amount in winter, while in summer the situation isreverse. In the southern higher latitude, the observation reports are fewer so the monthly surface cloud data are not reliable in comparison with the satellite data.

(5)Fig.4 and Fig.5 show the patterns of mean difference between the cloud amount observed by satellite and ocean ships in January and July, respectively. These two maps show that the distribution of differences has some seasonal and geographical characters. It implies that the difference between the two data sets are not induced by occasional or random factors, but by the different properties of the two observation methods and their own shortcomings.

In generally, correspondence between the two data sets is better in the winter hemisphere, especially for the Northern Hemisphere in January. In most areas, the cloud amounts measured by Nimbus–7 are less than those reported by the surface observations. The major positive difference area (i.e., satellite cloudiness more than surface cloud amount) occurs along the equatorial zone from Indian Ocean to the central Pacific. This area has considerable seasonal variation corresponding with the seasonal variation of intertropical convergence zone and the summer monsoon activities. In January, the positive center moves to the south side of the equator with its axis parallel to the South Pacific Convergence Zone. In July, Nimbus–7 measures more cloud amount in the broad areas north of the equator from the eastern Arabian Sea to the western Pacific, where the SW summer monsoon and the intertropical convergence zone are active in this season. Over the tropical eastern Pacific and the Atlantic Ocean, the positive differences also occur along the ITCZ. The positive belts also show seasonal variation in south–north movement. Additionally, in January, the differences are also

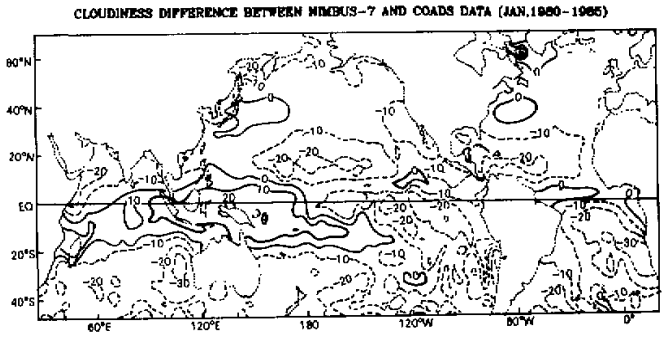

Fig.4. Map of mean differences between monthly cloudiness of Nimbus-7 and COADS in January 1980–1985 (unit: as in Fig.3).

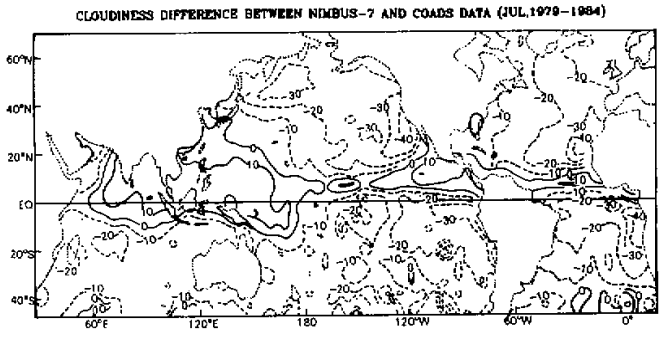

Fig.5. The same as Fig.4 but for July 1979–1984.

positive over the core area of Kuroshio current and Gulf stream, but in July, no positive differences appear there at all.

The good correspondence between the two data sets is found in the extratropical areas in the winter hemisphere. In January, in most areas of 10°N–60°N the differences are within −0.10–0.10. In Southern Hemisphere, the differences are less in July than in January outside the tropical regions, however, as there are fewer surface reports in southern Pacific, the distribution of differences is in disorder. In the summer hemisphere, the greater differences are found in the middle and higher latitude regions, especially in the Northern Hemisphere. The differences exceed 0.20 in magnitude over the eastern part of the northern Pacific and northern Atlantic in July.

The negative centers of difference are mainly in several areas: (a) over the south side of the equator in the eastern Pacific and Atlantic, with their center located at 10°S in January and 5°S in July, (b) off the west coast of the continents. During the northern summer, the centers along California coast and off the northwest Africa coast reach −0.40, while in winter the center along northwest Africa becomes insignificant and the differences along California decrease to −0.20. In the Southern Hemisphere, the cloud cover amounts observed by Nimbus-7 during January are 0.30 less than those observed on ships off the west coast of South America, South Africa and Australian continents. In July, the correspondence is good

off the Australian coast, but off the south African and south American coast, the differences reach −0.40 and their centers move northward, (c) in January, along 10°−15°N zone where the subtropical high persists, the Nimbus−7 cloud covers are about 0.10−0.20 less than the surface cloud amounts.

IV. DISCUSSION

Surface−based and satellite−based cloud observation are quite different in the method of measurement. The satellite observation through the visible picture or the infrared radiometer determines the cloud coverage over the earth. The THIR in Nimbus−7 measures the radiation through the atmospheric window to determine the temperature of the earth surface or the top of cloud. From the temperature distribution measured, the global cloud coverage should be retrieved. Thus the measurement of cloud cover by Nimbus−7 is based on the resolution of THIR and cloud retrieval method. The surface observation cloud data are measured by the weather observer. Owing to the view field of the observer, the record is accurate only over an circle area with diameter of about tens miles. The monthly cloud data of COADS are averaged for the $2° \times 2°$ box. The representativeness of the COADS cloud data should be related to the cloud size. For the stratiform cloud, the cloud amount observed at one place can explain the cloud coverage in a large area as the cloud size is great. However for the cumuliform cloud, the cloud size is relatively smaller. The cumuliform clouds may usually gather to be cloud cluster with regular configuration and arrangement. The size of a cumulus cluster is about 3−10 miles across in general, the size of an isolated cumulonimbus is tens miles and for the cumulonimbus together with sheets of cirrus plume, its size can reach hundreds miles. The horizontal size of these clouds is smaller than the size of $2° \times 2°$ box. If there are only one observation report in a box, the cloud coverage of this box which is determined by the report may be overestimated or underestimated because the view field of the reporter is limited in tens miles. We have indicated that there are considerable differences between the satellite and surface observation cloud data. The reasons of these differences may be as follows:

1. The surface observation data coverage is inhomogeneous in space and time. For the boxes far away from the ship tracks, the representativeness of the surface cloud data is lower, and the difference between the satellite cloud and surface cloud is generally great. To comparison of the correlation coefficient of the two data sets (Fig.2) with Fig.1, a great amount of lower coefficients are usually in the regions where the marine reports are fewer.

2. In the maps of cloud differences between the Nimbus−7 and COADS data we have shown above, the positive areas generally scatter in the intertropical convergence zone, the summer monsoon area and along the warm current in winter. In all those regions, the thermal condition of underlying surface and the air flow convergence are in favor of intensive development in cumuliform cloud. The cumuliform cloud is rather small in time and space scale. The marine reports are confined with the ship tracks so they are inhomogeneity in time and space. The mismatch between the area of averaging box and the cloud size as well as between time interval of observation in a box and life cycle of the cloud leads to the incorrect estimate of the cloud amount in COADS. The positive differences in those areas should be due to the underestimate of cloud amounts in COADS. Fig.6 is a good indication of the positive differences associated with greater amount of cumuliform cloud coverage. It is well known that during the ENSO episode the pronounced vertical convection shifts eastward to the central tropical Pacific and brings abont enhancement of cumuliform cloud amount there. Meanwhile the cloud amounts in Indonesia and the Philippines decrease as the vertical convection weakened. Fig.6(a) is the map of differences during the El Nino poriod in January 1983 and

Fig.6(b) is during post El Nino period in January 1984. The patterns for these two months are quite different in the equatorial zone. In January 1983 (Fig.6(a)), the positive values in the area adjacent to Indonesia, Australia and the Philippines decrease and there are another pronounced positive center east of 180 degree longitude which is due to the change of thermal condition and the enhancement of cloud amount in the central and eastern Pacific during the ENSO event. The distribution of cloud amount differences along the equatorial zone in January 1984 is quite similar to the average pattern in Fig.4. The major positive center is in the equatorial western Pacific and Indian Ocean and there are no more considerable positive differences in the central Pacific as the longitudinal contrast of thermal condition restore to normal.

3. When the sea surface temperature is lower, and the thermal stratification in the lower troposphere is relatively stable, it is in favor of stratiform cloud overcasting the sea surface. The stratiform cloud is usually in a large scale of size, and is lower in the height of cloud top. The resolution of the height of cloud top and sea surface is based on the radiation contrast between them.

If the vertical lapse rate is small and the cloud top is not high enough, the temperature difference between the sea surface and the cloud top will not be great. It is difficult to detect the existence of cloud cover because the radiation contrast is under the resolution of radiometer in the satellite. For THIR of Nimbus–7, the temperature difference between the cloud top and the sea surface should be over 4°C for the resolution of cloud cover. Figs.7 (a) and (b) show differences of sea surface temperature and air temperature at 850 hPa in January and July of 1979. The vertical temperature contrasts are smaller in the extratropical ocean areas in winter. This may explain the greater differences of cloud amount between the two data sets found in winter as the THIR of Nimbus–7 fails to catch the existence of cloud which has rather smaller temperature contrast with the sea surface. Besides, the negative centers of difference along the cold tongue in the eastern equatorial Pacific and Atlantic should also be

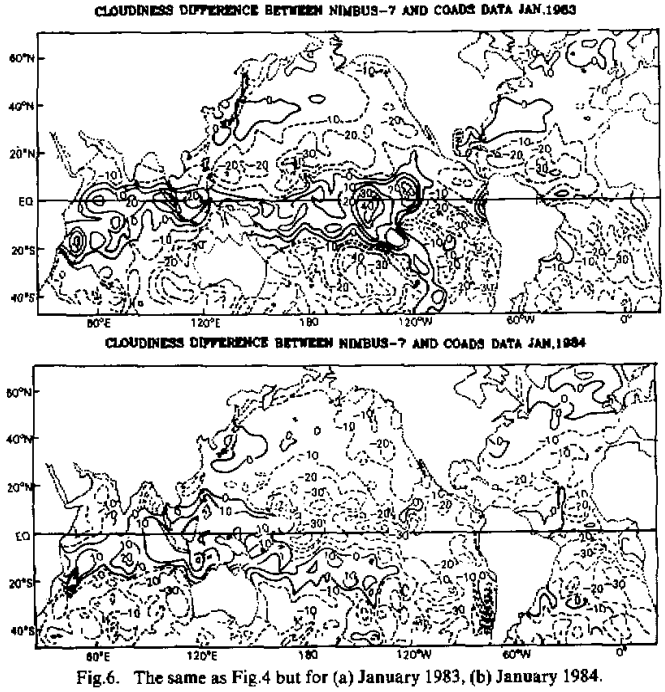

Fig.6. The same as Fig.4 but for (a) January 1983, (b) January 1984.

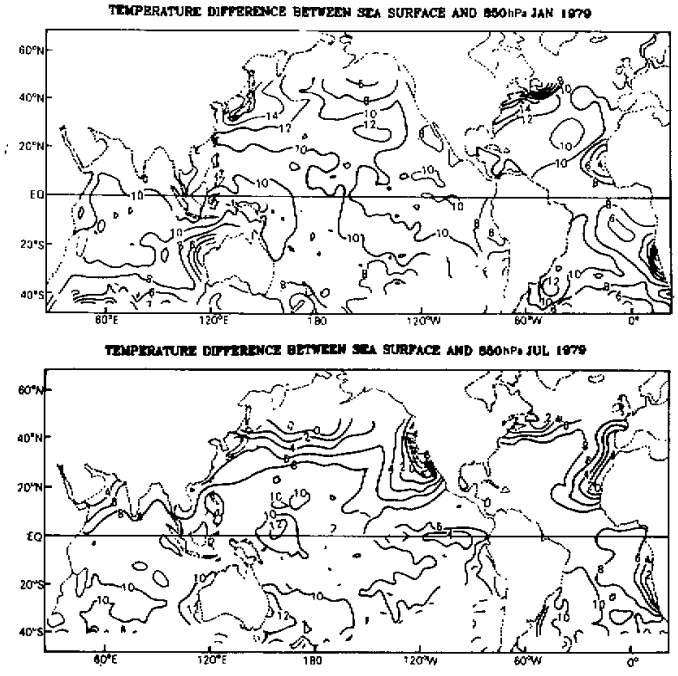

Fig.7. Map of differences between monthly sea surface temperature and monthly temperature at 850 hPa in (a) January 1979, (b) July 1979 (unit: °C).

an error in the detection of THIR in Nimbus–7. With comparison of Figs.7 (a), (b) and Fig.4, Fig.5, respectively, the negative centers of cloud difference along the west coast of the continents both in the two hemispheres are well corresponding with the smaller vertical temperature contrast in the lower troposphere. The good correspondence further explicates the limitation of cloud measurement of Nimbus–7 for the stratiform cloud.

V. CONCLUSION

We have compared the climatological cloud data of satellite–based and surface–based observation in the global marine areas. The following viewpoints are concluded.

1. The correspondence in the large scale pattern of monthly cloud amount is good between the satellite observations and marine ship reports, although the distribution of cloud amount in COADS is rather scattered due to the inhomogeneous in time and space of the marine reports and the monthly mean cloud amount is biased toward intermediate values.

2. The relationship between the cloud amount of Nimbus–7 and COADS are good in the broad ocean areas within the belt of 40°N–30°S. The better correspondences are in the western part of the oceans in the Northern Hemisphere, where the correlation coefficients of the two data sets are over 0.8. The correspondence is varied with different seasons. Generally, the differences between them are greater in absolute values in summer than in winter. Additionally, the insufficiency of marine reports in the most boxes of the higher latitudes, the equatorial Pacific and southern Pacific should cause the greater difference of satellite and surface cloud observation in those areas.

3. The differences between the two data sets are not occasional or random, as the patterns of difference show seasonal variation and geographical characteristic. Besides the insufficiency of the observation times in COADS, the cause of differences involved with the limitation of both the two observation methods.

4. The surface observation usually fails to give a correct estimate of cumuliform cloud coverage, thus in the ocean areas where the cumuliform cloud is in favor to develop, such as in the intertropical convergence zone, the difference occurs mainly due to the error of COADS.

The satellite observation usually has difficulty in resolution of the stratiform cloud and underestimates of the cloud coverage in the areas where the stratiform cloud prefers to form. The differences in these areas such as off the western coast of the continent, are mainly formed by the error of satellite observation. Both the two methods of observation can provide useful information of cloud cover. The two data sets can be mutually complementary and it is possible to improve the data sets after making correction.

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REFERENCES

Schiffer, R. A. and W. B. Rossow (1983), The International Satellite Cloud Project (ISCCP): The first project of the World Climate Research Programme Bulletin of the American Meteorological Society, **64**: 779–784.

Slutz, R. J. et al. (1984), Comprehensive Ocean–Atmosphere Data Set, Release 1, NOAA, Environment Research Laboratory, Boulder, Colorado, 268 pp.

Stowe, L. L. (1983), Validation of Nimbus–7 temperature–humidity infrared radiometer estimate of cloud type and amount, *Advance in Space Research* **2**: 15–19.