Comparison of Total Cloud Amount Determined by a Ceilometer and a Microwave Radiometer

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ABSTRACT

Both the laser ceilometer and the ground-based microwave radiometer (equipped with infrared cloud radiometer) provide essentially point measurements of the cloud base height continuously. By using a sophisticated algorithm, it is possible to determine the total cloud amount based on the continuous record of cloud base height. In the present study, the operational algorithm of Royal Netherlands Meteorological Institute (KNMI) is considered and the total cloud amount so determined is compared with co-located actual observations by human observers. The laser ceilometer, having some difficulties in detecting the thin cirrus clouds, could underestimate the cloud amount when extensive cirrus clouds cover the observation area. On the contrary, the microwave radiometer may be more sensitive to high clouds, though it may not be able to distinguish between very thin cirrus and totally clear sky. This paper demonstrates that, by choosing a suitable threshold for the cloud base height determined by the radiometer, the total cloud amount estimated by the radiometer is more consistent with human observations compared with the cloud amount provided by the laser ceilometer. This opens up a potential application of using the microwave radiometer in automatic observation of the total cloud amount.

1. INTRODUCTION

Cloud amount is one of the weather elements to be reported in the synoptic weather observations. Automatic determination of cloud amount has been tried out using the continuous cloud base height measurements from laser ceilometers at some airports in the world [1]. At the Hong Kong International Airport (HKIA), similar laser ceilometers have also been deployed by the Hong Kong Observatory (HKO), e.g. there is a ceilometer model LHX06 from Vaisala (formerly Impulsphysik) inside the meteorological garden (Figure 1) located near the centre of the airport. This ceilometer is mainly used for the detection of low to medium clouds which are important to aviation operation. Ceilometers of the latter model LD-40 are also set up at the runway ends. However, even with the upgrade of signal processors and filters, these ceilometers do not seem to be sensitive enough in the detection of thin cirrus clouds. As such, the total cloud amount provided by the ceilometers could be smaller than those reported by the human weather observers, which are stationed at the Airport Meteorological Office located close to the meteorological garden.

Since May 2008, a microwave radiometer has also been set up at HKIA (Figure 1). The primary purpose of this radiometer is the measurement of temperature and humidity profiles of the atmosphere up to about 10 km above ground. This instrument is equipped with an infrared cloud radiometer to measure the temperature at the cloud base. Together with the temperature profile, it is possible to estimate the cloud base height, which is updated frequently (every few seconds). The continuous availability of cloud base height from the radiometer may be useful in the determination of cloud amount using an algorithm similar to that adopted for the ceilometer data. To the knowledge of the author, this is the first time that the ground-based microwave radiometer is used to estimate the cloud amount using such an approach.

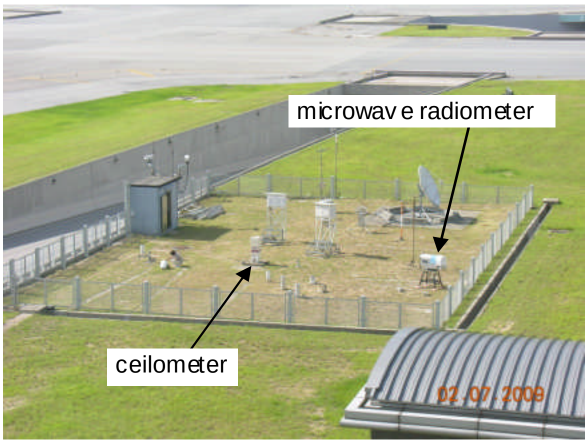

Figure 1 The meteorological garden at HKIA.

Compared to a laser ceilometer, a microwave radiometer may be more sensitive to the thin cirrus clouds. However, it may also have limitation in the detection of high clouds due to the background sky (the “background” effect leading to under-estimation of brightness temperature retrieval, [2]). As such, different thresholds of the cloud base height given by the radiometer is tried out to optimize the provision of total cloud amount from this instrument.

2. EQUIPMENT AND ALGORITHM

The ceilometer at the eastern end of the south runway of HKIA (location “R1E”) is used in the present study because it has been equipped with the latest version of signal processor and filter for this ceilometer model. It is a LD-40 ceilometer with double lenses. It measures cloud base height between 5 m and 13,000 m with a resolution of about 7.6 m (25 feet). Cloud base data are updated every 15 seconds.

The ground-based microwave radiometer uses 14 frequency channels in the region of 20 to 60 GHz to measure thermodynamic profiles of the troposphere. The infrared radiometer gives cloud base height up to 10 km above ground with a resolution of 1 m. Cloud base data are updated every few seconds.

Details of the cloud amount algorithm could be found in [1]. Only the main features of the algorithm are described here. It uses the cloud base height data of the three cloud layers C1, C2 and C3 (from the lowest to the highest) from the laser ceilometer. In case of the microwave radiometer, only C1 would be available. The cloud amount is determined at the end of each hour in order to compare directly with the synoptic weather observations. The cloud base height data in the last 10 minutes of the hour are given double weight in the determination of cloud amount.

The time series of cloud base height data is considered in determining the total cloud amount by taking the correspondence between the temporal continuity in the occurrence of the clouds and the spatial distribution of the clouds. The number of entries corresponding to each octa region is then determined by taking into account the weight of the entries. Note that 0 and 8 octa correspond to no cloud hit and nothing but cloud hits, respectively. The lowest cloud hit C1 is the cloud base and the total weight of cloud hits of C1 determines the total cloud cover. As such, the algorithm outputs the following: the total cloud amount, the amount of the first layer of clouds, and the height of the first layer of clouds.

The study period of this paper spans over one whole year, namely, June 2008 to May 2009. The performance statistics of the algorithm as applied to ceilometer and microwave radiometer (in comparison to human observations) is considered for the whole year. Future study would look at seasonal variation of the performance statistics.

3. COMPARISON BETWEEN CEILOMETER AND HUMAN OBSERVATIONS

The comparison between ceilometer data and human observations is given in Table 1. In all comparisons, band 2 would be considered, namely, the difference in cloud amount within 2 okta of clouds or cloud base height within 2 height categories (following the categories in [1]).

For total cloud amount, band 2 is achieved at 66% only. The miss cases (26%) are many more than those of false cases (8%). This is consistent with our understanding that the laser ceilometer may miss the high and thin cirrus clouds due to the weak signal of the laser return.

For the first cloud layer, the cloud amount is within 2 bands for 69% of the cases and the cloud base height is within 2 height categories for 72%. There are many more cases in which the cloud base height given by the ceilometer is much higher than that reported by the human observers. This may be due to (a) limited sampling of the laser ceilometer, which is essentially a spot overhead, and (b) occurrence of low clouds at the mountains nearby HKIA, which do not drift and come over the ceilometer's measuring volume.

4. COMPARISON BETWEEN RADIOMETER AND HUMAN OBSERVATIONS

First of all, an "optimum" threshold for cloud base height is determined for the cloud data output from the microwave radiometer. This is the threshold above which the cloud base data would be ignored, i.e. clouds with heights exceeding the threshold are not considered to be present. Such an approach is to address the under-estimation of brightness temperature of the clouds due to "background" effect. By considering the band 2 percentages of the total cloud cover from the microwave radiometer in comparison with that obtained by human observations, it turns out that a height threshold of 7,500 – 8,000 m would have the best performance (Figure 2). It also turns out that, if no threshold is adopted, namely, a height threshold of 10 km (the maximum cloud base height from the radiometer) is adopted, the band 2 percentage drops to about 60% in comparison with 76% for the optimum height threshold values.

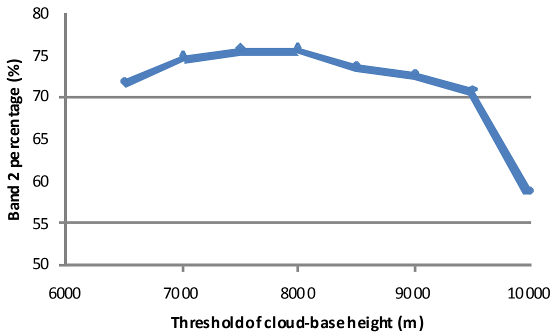

Figure 2 Band 2 percentage of total cloud cover from the radiometer as a function of height threshold.

Using a height threshold of 7,500 m, the performance of cloud cover and cloud base height data (in comparison with human observations) is given in Table 2. The total cloud cover has a band 2 percentage of 76%, which is 10% higher than that achieved by the laser ceilometer. In particular, the miss percentage drops from 26% for ceilometer to 15% for radiometer. This is consistent with our expectation that the radiometer is more sensitive in measuring the high cirrus clouds. The cloud cover for the first layer of clouds is within band 2 of human observations for 73% of the cases, which is 4% higher than that achieved by the ceilometer. On the other hand, the base height for the first layer of clouds has a band 2 percentage very similar to that from the ceilometer, i.e. about 71-72%. This may be expected in view of the limited sampling space of the radiometer and ceilometer (air column above the instrument vs. 360 degrees space observed by human) and the low clouds that are formed nearby the mountains and not observable by the instruments.

5. CONCLUSIONS

The present study uses the cloud base height data provided by the microwave radiometer and the ceilometer to estimate the cloud cover based on an operational algorithm of KNMI. It turns out that the radiometer achieves better measurement of total cloud cover and the cloud cover for the first cloud layer in comparison with the ceilometer. This may be due to higher sensitively of the infrared radiometer of the microwave radiometer in the observation of clouds, in comparison to the ceilometer (especially in the observation of high cirrus clouds). More research would be carried out to study the performance of the microwave radiometer in cloud observation in different seasons in an attempt to achieve automation of synoptic and METAR reports.

REFERENCES

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SYNOP observation (rows) vs. R1E ceilometer (columns)

	NA	0	1	2	3	4	5	6	7	8	9	Sum
NA	0	0	0	0	0	0	0	0	0	0	0	0
0	4	255	103	15	8	3	3	3	4	20	0	418
1	14	524	238	27	25	17	16	13	27	67	0	968
2	15	240	116	21	23	18	15	12	28	41	0	529
3	4	298	148	54	33	32	24	40	52	77	0	762
4	4	199	95	19	17	22	25	20	36	59	0	496
5	15	274	156	44	46	32	46	55	98	153	0	919
6	14	192	140	59	41	60	60	70	137	290	0	1063
7	40	189	191	86	114	104	148	199	572	1424	0	3067
8	0	8	4	3	3	7	8	17	94	394	0	538
9	0	0	0	0	0	0	0	0	0	0	0	0
Sum	110	2179	1191	328	310	295	345	429	1048	2525	0	8760
Band 0 =	19%	Band 1 =	53%	Band 2 =	66%	Miss =	26%	False =	8%	Valid =	99%	

(a)

SYNOP observation (rows) vs. R1E ceilometer (columns)

CldAmt	NA	0	1	2	3	4	5	6	7	8	9	Sum
NA	0	0	0	0	0	0	0	0	0	0	0	0
0	418	0	0	0	0	0	0	0	0	0	0	418
1	6923	0	0	0	0	0	0	0	0	0	0	6923
2	12	253	400	120	72	51	47	39	32	115	0	1141
3	0	57	29	14	5	7	2	4	7	18	0	143
4	0	17	7	0	1	4	1	2	5	14	0	51
5	0	24	14	4	4	1	1	1	2	2	0	53
6	0	18	7	3	1	0	1	0	0	1	0	31
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
Sum	7353	369	457	141	83	63	52	46	46	150	0	8760
Band 0 =	9%	Band 1 =	45%	Band 2 =	69%	Miss =	11%	False =	20%	Valid =	16%	

(b)

SYNOP observation (rows)

Height	NA or n=9	<50m	<100m	<200m	<300m	<600m	<1000m	<1500m	<2000m	<2500m	≧ or n=0	Sum
NA or n=9	0	0	0	0	0	0	0	0	0	0	0	0
<50m	0	0	0	0	0	0	0	0	0	0	0	0
<100m	0	0	0	0	0	1	0	0	0	0	0	1
<200m	158	0	0	12	11	36	17	3	1	1	6	245
<300m	316	3	0	0	7	38	14	7	3	0	7	395
<600m	2458	0	1	4	13	99	51	17	5	2	51	2701
<1000m	2289	0	0	4	5	50	114	55	19	16	161	2713
<1500m	994	0	0	0	0	13	22	60	20	12	77	1198
<2000m	36	0	0	0	0	0	0	1	1	3	12	53
<2500m	18	0	0	0	0	0	1	2	1	3	26	51
≧ or n=0	1084	0	0	0	0	5	12	15	18	8	261	1403
Sum	7353	3	1	20	36	242	231	160	68	45	601	8760
Band 0 =	40%	Band 1 =	61%	Band 2 =	72%	Miss =	3%	False =	25%	Valid =	16%	

(c)

Table 1 Performance statistics of R1E laser ceilometers in comparison with human observations (SYNOP): (a) total cloud cover, (b) cloud cover for the first layer of clouds, and (c) base height of the first layer of clouds.

	Radiometer											
		NA	0	1	2	3	4	5	6	7	8	9	Sum
SYNOP observation	NA	0	0	0	0	0	0	0	0	0	0	0
	0	242	175	0	0	1	0	0	0	0	0	418
	1	375	557	13	1	0	2	1	1	1	17	0	968
	2	157	297	30	5	2	4	1	3	1	29	0	529
	3	182	305	69	23	20	13	15	12	17	106	0	762
	4	142	116	49	21	18	20	12	12	14	92	0	496
	5	228	134	102	36	27	35	28	20	48	261	0	919
	6	215	58	50	21	29	35	41	49	75	490	0	1063
	7	398	28	31	24	24	26	36	57	139	2304	0	3067
	8	20	0	0	1	0	2	4	0	13	498	0	538
	9	0	0	0	0	0	0	0	0	0	0	0	0
	Sum	1959	1670	344	132	121	137	138	154	308	3797	0	8760
	Band 0 =	14%	Band 1 =	61%	Band 2 =	76%	Miss =	15%	False =	8%	Valid =	78%	

(a)

	Radiometer												
	CldAmt	NA	0	1	2	3	4	5	6	7	8	9	Sum
SYNOP observation	NA	0	0	0	0	0	0	0	0	0	0	0	0
	0	418	0	0	0	0	0	0	0	0	0	0	418
	1	6923	0	0	0	0	0	0	0	0	0	0	6923
	2	214	160	352	124	68	49	31	29	24	90	0	1141
	3	31	52	28	13	7	4	3	0	2	3	0	143
	4	18	11	11	4	1	1	0	2	0	3	0	51
	5	20	17	5	1	2	2	0	1	0	5	0	53
	6	16	4	6	1	2	0	0	0	1	1	0	31
	7	0	0	0	0	0	0	0	0	0	0	0	0
	8	0	0	0	0	0	0	0	0	0	0	0	0
	9	0	0	0	0	0	0	0	0	0	0	0	0
	Sum	7640	244	402	143	80	56	34	32	27	102	0	8760
	Band 0 =	12%	Band 1 =	51%	Band 2 =	73%	Miss =	10%	False =	17%	Valid =	13%	

(b)

	Height	NA or n=9	<50m	<100m	<200m	<300m	<600m	<1000m	<1500m	<2000m	<2500m	≧ or n=0	Sum
SYNOP observation	NA or n=9	0	0	0	0	0	0	0	0	0	0	0	0
	<50m	0	0	0	0	0	0	0	0	0	0	0	0
	<100m	0	0	0	0	0	0	1	0	0	0	0	1
	<200m	164	27	11	7	4	16	13	1	0	0	2	245
	<300m	318	5	2	9	10	26	19	3	0	1	2	395
	<600m	2489	4	2	7	17	87	45	13	0	4	33	2701
	<1000m	2375	0	0	5	8	33	92	32	4	7	157	2713
	<1500m	1041	0	0	0	0	10	35	20	7	0	85	1198
	<2000m	50	0	0	0	0	0	1	0	0	0	2	53
	<2500m	36	0	0	0	0	0	0	0	0	0	15	51
	≧ or n=0	1167	0	0	0	0	0	0	0	0	0	236	1403
	Sum	7640	36	15	28	39	172	206	69	11	12	532	8760
	Band 0 =	40%	Band 1 =	61%	Band 2 =	71%	Miss =	1%	False =	28%	Valid =	13%	

(c)

Table 2 Similar to Table 1, but for performance statistics of the microwave radiometer.