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ABSTRACT

The use of cloud-base height data obtained from a ground-based microwave radiometer in the estimation of total cloud amount has been studied by Chan and Li (2009). The present paper extends the study by considering the performance of the total cloud amount estimation algorithm in different seasons and different years. It is found that the algorithm works generally well in different periods by comparison with the human observations of the cloud amount at the Hong Kong International Airport (HKIA). The major challenge to the methodology is the occurrence of isolated cumuli in the summer time, especially those developing over the mountains nearby HKIA. It is because such cumuli may just stay nearby the mountains and are outside the observation region of the radiometer, which is basically the column of the troposphere right above the instrument.

The radiometer has also been equipped with an azimuthal positioner to make observations in different directions. As a result, a 2D map of integrated water vapour (IWV) is obtained every hour. This IWV map shows the potential of making cloud observations over nearly the whole sky dome, which is an improvement over the conventional zenith observation of the radiometer in terms of the sampling volume. Some examples of the observations of cloud movement and clearance from the 2D IWV maps would be presented in the paper.

Index Terms— radiometer, cloud observation, IWV

1. INTRODUCTION

The ground-based, multi-channel microwave radiometer is mainly used for measuring the temperature and humidity profiles of the troposphere. When equipped with an infra-red radiometer, it could also be used to measure the temperature of the cloud base, and thus the cloud base height (in combination with the measured tropospheric temperature profile). As such, the radiometer may also be used as a ceilometer. By processing the time series of the cloud base height, the total cloud amount and the cloud amount of the first layer of clouds could be determined from the radiometer data, in a way similar to the processing of the laser ceilometer data.

Compared with human observation, the radiometer has a number of limitations in the estimation of cloud amount. First of all, for zenith measurement (the most common mode of operation of the radiometer), the measurement sample is just the column of the atmosphere above the equipment only. The radiometer may be used to see the whole sky dome if it has been equipped with an azimuthal scanning (the so-called "azimuthal positioner") and a rotating mirror (observing different elevation angles above the horizon). Secondly, for thin clouds, the cloud base temperature may be contaminated by the microwave radiation of the background atmosphere, and thus it may be under-estimated (i.e. it tends to be cooler and the cloud base height is higher than reality). In Chan and Li (2009), the latter issue was tackled by adopting an optimal threshold of radiometer-measured cloud base height by comparing the total cloud amount estimated from the radiometer with that provided by the human observer.

The present paper extends the results from the previous study by Chan and Li (2009) in a couple of aspects:

(a) to study the seasonal variation of the performance of radiometer-based cloud amount estimates, instead of considering the behaviour of the whole year only as in the previous study, in order to identify the possible limitations of the radiometer-based method; and

(b) to present some initial results of using 2-dimensional (2D) scans of integrated water vapour (IWV) in the monitoring of the movement of clouds in a couple of case studies.

2. EQUIPMENT

The equipment in use is the same as that reported in Chan and Li (2009). The radiometer uses 7 oxygen channels and 7 water vapour channels in the measurement of tropospheric profiles of temperature and humidity respectively. It also includes an infra-red radiometer to measure cloud base height.

Starting from April 2009, the radiometer has been installed with an azimuthal positioner to measure the microwave radiation emitted by water vapour in the whole sky dome. Since the radiometer is used to make a number of scans (zenith scans for temperature and humidity profiles, elevation scans for boundary layer temperature measurements, as well as 2D scans) and it takes quite some time for completing each 2D scan (at least 10 minutes), the sky dome measurements are made every hour only, which limits the application of such scans in monitoring the evolution of clouds/water vapour (in terms of the temporal resolution). The 2D scan is configured to have 24 azimuthal directions (i.e. each extending over an angle of 15 degrees) and 6 elevation angles.

The radiometer was set up inside the meteorological garden near the centre of the Hong Kong International Airport (HKIA) up to the end of July 2009 (location in Figure 1). Afterwards it went through repair at the factory. It has been working again since early October 2009, but it has been moved to the shoreline anemometer station near the eastern coast of the airport island (Figure 1).

3. SEASONAL VARIATION OF CLOUD AMOUNT ESTIMATION

Following Chan and Li (2009), the cloud base height threshold of 7500 m is adopted for the radiometer results presented in this section. No further attempt has been made to adjust the threshold, e.g. using a season-dependent threshold.

The results of total cloud amount estimation from the radiometer as compared with human observations are shown in Table 1. As in Chan and Li (2009), we mainly focus on the "band 2" results, i.e. the total cloud amount difference (between the radiometer-based estimates and the human observations) within 2 categories (2 oktas of cloud amount). The performance is the best in spring and winter, with the band 2 percentage exceeding 80%. On the other hand, in autumn, the band 2 percentage is the lowest (just 66%), and the amount of missed cases is comparable with that of false cases (both in the region of 16 – 18%). Though the amount of data considered is limited (just one year only), the results may suggest that the clouds are more extensive in winter and spring, so that the limited measurement volume of the zenith scan of the radiometer may not be a big issue. On the other hand, the clouds are more scattered in summer and early autumn. There could also be cumuli developing at the mountains nearby HKIA and do not drift over the radiometer. As such, the representativeness of the measurement volume of the radiometer becomes a bigger issue and the total cloud amount so estimated has bigger difference with that based on human observations (which consider the whole sky dome).

The results of the lowest cloud base height are shown in Table 2. Again, considering band 2 percentages, the performance of radiometer-derived cloud base height appears to be quite good in winter and spring. This percentage is the lowest in the summer, which may be related to the occurrence of isolated cumuli that are not well sampled by the radiometer. Moreover, it is noted that, for three seasons (spring, summer and autumn), the percentages of false cases are much higher than those of missed cases. In other words, the lowest cloud base height tends to be over-estimated by the radiometer. Apart from the limited measurement volume of the radiometer, the contamination by the microwave radiation of the background atmosphere (as discussed in the Introduction section above) could be a possible cause. As such, the cloud base height data from the radiometer should be interpreted with caution by considering the possibility for this instrument to "see through" clouds (vs. a laser ceilometer, in which the laser beam tends to be attenuated rapidly in the cloud liquid/vapour of sufficient depth).

4. USE OF 2D SCANS OF IWV

The amount of data collected by 2D scans of the radiometer is still rather limited at the time of writing so that a comprehensive comparison between the 2D IWV data and the total cloud amount in the sky has not been carried out. However, a couple of case studies have been conducted to illustrate the application of the 2D images in the monitoring of the evolution of the clouds in the atmosphere.

Figure 2 shows the radiometer data for the case on 15 May 2009. In the evening on that day, the cloud band associated with a westerly wave in the middle troposphere (as at 700 and 500 hPa levels, not shown) moved eastwards along the south China coastal area towards Hong Kong. Based on the human observation at HKIA, there was just one okta of cloud around midnight of 16 May 2009 (=16 UTC, 5 May 2009, with Hong Kong time = UTC + 8 hours). The sky became cloudier gradually in the next several hours, with the cloud amount increasing to 7 oktas around dawn (~23 UTC, 5 May 2009). As shown in Figure 2, between about 16:30 and 21:30 UTC of 15 May 2009, areas of higher IWV appeared on the southwestern part of the sky dome and spread towards the east. The increasing trend of IWV and the eastward spreading of the areas of higher IWV are consistent with the movement of the clouds from satellite pictures (not shown) and the increasing cloudiness from human observations.

However, there may not always be direct correspondence between the trend of IWV and the cloudiness. For example, for the case in Figure 3, IWV appeared to be decreasing between about 15:30 and 22:30 UTC of 3 May 2009 based on the radiometer observations. Moreover, areas of lower IWV spread to the southeast gradually. This is consistent from the upper-air analysis (not shown) that the humid area (relative humidity above 80%) spread southwards in association with the movement of an east-west oriented trough at 850 hPa and 700 hPa levels over the south China coastal areas, and the eastward movement of a westerly wave at 500 hPa level over the region. Following the movements of the trough/wave, the IWV generally decreased over the atmosphere, but there was still a thin layer of low clouds associated with the trough at the lower troposphere. As such, it remained cloudy at HKIA throughout the period under consideration in Figure 3, with 7 oktas of clouds observed at the airport. More 2D maps of IWV would need to be studied in order to establish any correlation between the IWV distributions and the observed cloudiness.

5. CONCLUSIONS

The seasonal variation of cloud amount and cloud base height estimated from the radiometer is studied in this paper. The performance is better in winter and spring. Moreover, sample 2D IWV maps from the radiometer are given with a review to evaluate their application in the monitoring of clouds. Such maps are found to be useful in capturing the evolution of water vapour and thus cloud distributions, at least for one case in late spring/early summer.

Table 1 Seasonal variation of the estimation of total cloud amount at HKIA based on the radiometer measurements.

Spring — Radiometer

Spring	CldAmt	NA	0	1	2	3	4	5	6	7	8	9	Sum
March	NA	0	0	0	0	0	0	0	0	0	0	0	0
to	0	13	0	0	0	0	0	0	0	0	0	0	13
May	1	106	26	1	0	0	1	0	0	0	0	0	134
	2	73	30	1	1	0	1	0	0	0	0	0	106
	3	64	68	12	5	1	3	5	2	2	5	0	167
HKA	4	59	23	9	3	5	3	2	2	0	7	0	113
	5	82	30	15	6	7	8	7	5	13	31	0	204
	6	71	6	9	6	11	4	9	15	21	97	0	249
	7	155	3	10	5	10	8	9	25	51	744	0	1020
	8	9	0	0	0	0	0	2	0	6	185	0	202
	9	0	0	0	0	0	0	0	0	0	0	0	0
	Sum	632	186	57	26	34	28	34	49	93	1069	0	2208
	Band 0 =	17%	Band 1 =	71%	Band 2 =	83%	Miss =	14%	False =	3%	Valid =	71%	

Summer — Radiometer

Summer	CldAmt	NA	0	1	2	3	4	5	6	7	8	9	Sum
June	NA	0	0	0	0	0	0	0	0	0	0	0	0
to	0	0	1	0	0	0	0	0	0	0	0	0	1
August	1	8	67	5	0	0	1	4	2	2	10	0	99
	2	86	93	15	1	1	1	1	1	2	51	0	252
	3	129	90	26	7	8	7	5	7	16	138	0	433
HKA	4	116	49	15	8	6	6	3	3	8	127	0	341
	5	151	54	31	14	9	15	6	4	17	177	0	478
	6	198	31	17	5	4	12	5	10	14	356	0	652
	7	428	13	7	8	5	7	8	10	19	1381	0	1886
	8	11	0	0	0	0	2	1	0	7	253	0	274
	9	0	0	0	0	0	0	0	0	0	0	0	0
	Sum	1127	398	116	43	33	51	33	37	85	2493	0	4416
	Band 0 =	9%	Band 1 =	56%	Band 2 =	73%	Miss =	11%	False =	17%	Valid =	74%	

Autumn — Radiometer

Autumn	CldAmt	NA	0	1	2	3	4	5	6	7	8	9	Sum
September	NA	0	0	0	0	0	0	0	0	0	0	0	0
to	0	48	63	2	0	1	0	0	0	0	0	0	114
November	1	209	336	23	2	0	1	4	1	1	17	0	594
	2	146	222	22	5	4	4	1	5	3	22	0	434
	3	199	191	42	11	13	6	6	5	9	59	0	541
HKA	4	146	75	27	7	7	7	7	7	10	50	0	343
	5	234	49	46	9	14	10	9	9	27	144	0	551
	6	225	14	19	7	12	9	17	16	28	210	0	557
	7	450	7	13	10	7	6	14	15	42	565	0	1129
	8	44	0	0	0	0	0	0	0	0	61	0	105
	9	0	0	0	0	0	0	0	0	0	0	0	0
	Sum	1701	957	194	51	58	43	58	58	120	1128	0	4368
	Band 0 =	9%	Band 1 =	48%	Band 2 =	69%	Miss =	18%	False =	12%	Valid =	61%	

Winter — Radiometer

Winter	CldAmt	NA	0	1	2	3	4	5	6	7	8	9	Sum
December	NA	0	0	0	0	0	0	0	0	0	0	0	0
to	0	191	138	0	0	0	0	0	0	0	0	0	329
February	1	196	431	5	2	0	0	0	0	0	0	0	634
	2	34	134	10	3	1	0	1	1	0	1	0	185
	3	43	100	29	6	8	3	4	2	1	9	0	205
HKA	4	25	26	20	7	5	7	1	2	4	4	0	101
	5	62	37	33	14	8	9	13	9	14	17	0	216
	6	86	11	19	12	11	18	19	24	31	31	0	262
	7	153	7	7	4	6	15	15	19	69	609	0	904
	8	6	0	0	1	0	0	1	0	0	54	0	62
	9	0	1	1	2	1	0	0	0	0	0	0	5
	Sum	796	885	124	51	40	52	54	57	119	725	0	2903
	Band 0 =	15%	Band 1 =	70%	Band 2 =	82%	Miss =	16%	False =	2%	Valid =	73%	

[1] P.W. Chan and C.M. Li, "Comparison of Total Cloud Amount Determined by a Ceilometer and a Microwave Radiometer," *8th International Symposium on Tropospheric Profiling: Integration of Needs, Technologies and Applications*, 19 - 23 October 2009, Delft, The Netherlands.

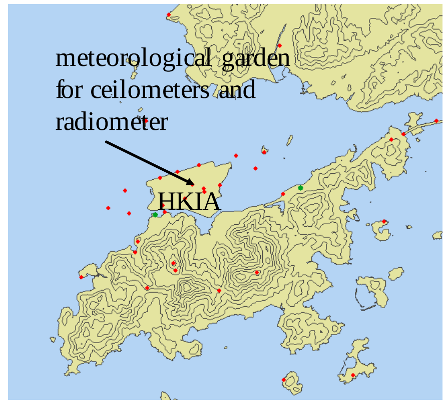

Figure 1 The location of the radiometer and the geographical setup of HKIA. Height contours in 100 m

Spring

			Radiometer											
		Height	NA or n=9	50	100	200	300	600	1000	1500	2000	2500	≧ or n=0	Sum
March		NA or n=9	0	0	0	0	0	0	0	0	0	0	0	0
to		50	0	0	0	0	0	0	0	0	0	0	0	0
May		100	0	0	0	0	0	0	0	0	0	0	0	0
		200	85	9	4	4	2	5	0	0	0	0	0	109
		300	137	3	0	3	8	7	0	0	0	0	0	158
	HKA	600	876	2	0	3	4	32	12	2	0	1	9	941
		1000	495	0	0	0	1	8	16	3	0	1	15	539
		1500	266	0	0	0	0	3	10	4	0	0	14	297
		2000	4	0	0	0	0	0	0	0	0	0	0	4
		2500	5	0	0	0	0	0	0	0	0	0	7	12
		≧ or n=0	110	0	0	0	0	0	0	0	0	0	38	148
		Sum	1978	14	4	10	15	55	38	9	0	2	83	2208
		Band 0 =	44%	Band 1 =	70%	Band 2 =	80%	Miss =	2%	False =	17%	Valid =	10%	

Summer

			Radiometer											
		Height	NA or n=9	<50m	<100m	<200m	<300m	<600m	<1000m	<1500m	<2000m	<2500m	≧ or n=0	Sum
June		NA or n=9	0	0	0	0	0	0	0	0	0	0	0	0
to		<50m	1	0	0	0	0	0	0	0	0	0	0	1
August		<100m	0	0	0	0	0	0	0	0	0	0	0	0
		<200m	50	18	7	1	2	10	8	1	0	0	0	97
		<300m	68	2	2	2	2	15	16	3	0	1	0	111
	HKA	<600m	1054	2	1	1	3	16	19	9	0	3	19	1127
		<1000m	675	0	0	1	1	4	28	8	1	3	78	799
		<1500m	546	0	1	0	0	6	1	0	0	0	7	561
		<2000m	522	0	0	0	0	3	0	0	0	0	4	529
		<2500m	395	0	1	0	1	5	3	2	1	1	5	414
		≧ or n=0	698	1	0	1	0	3	11	7	1	3	52	777
		Sum	4009	23	12	6	9	62	86	30	3	11	165	4416
		Band 0 =	25%	Band 1 =	42%	Band 2 =	59%	Miss =	11%	False =	30%	Valid =	9%	

Autumn

			Radiometer											
		Height	NA or n=9	<50m	<100m	<200m	<300m	<600m	<1000m	<1500m	<2000m	<2500m	≧ or n=0	Sum
September		NA or n=9	0	0	0	0	0	0	0	0	0	0	0	0
to		<50m	18	0	0	0	0	0	0	0	0	0	0	18
November		<100m	0	0	0	0	0	0	0	0	0	0	0	0
		<200m	3	0	0	0	0	0	0	0	0	0	0	3
		<300m	7	0	0	0	0	3	0	0	0	0	0	10
	HKA	<600m	318	0	1	2	0	26	7	0	0	0	4	358
		<1000m	915	0	0	2	0	9	44	15	1	2	47	1035
		<1500m	471	0	0	2	5	13	23	16	3	0	40	573
		<2000m	235	0	2	0	0	5	1	1	0	0	3	247
		<2500m	257	1	1	0	0	4	2	1	0	0	4	270
		≧ or n=0	1621	2	2	3	1	5	5	3	0	3	209	1854
		Sum	3845	3	6	9	6	65	82	36	4	5	307	4368
		Band 0 =	56%	Band 1 =	69%	Band 2 =	73%	Miss =	9%	False =	18%	Valid =	12%	

Winter

			Radiometer											
		Height	NA or n=9	<50m	<100m	<200m	<300m	<600m	<1000m	<1500m	<2000m	<2500m	≧ or n=0	Sum
December		NA or n=9	0	0	0	0	0	0	0	0	0	0	0	0
to		<50m	26	0	0	0	0	0	0	0	0	0	0	26
February		<100m	0	0	0	0	0	0	1	0	0	0	0	1
		<200m	26	0	0	2	0	1	5	0	0	0	2	36
		<300m	106	0	0	4	0	1	3	0	0	0	2	116
	HKA	<600m	259	2	0	1	10	13	7	2	0	0	1	295
		<1000m	443	0	1	13	14	12	4	6	2	1	17	513
		<1500m	420	1	0	1	11	9	4	0	5	0	29	480
		<2000m	128	0	0	1	1	12	2	0	1	0	8	153
		<2500m	101	1	0	1	1	2	2	0	0	0	7	115
		≧ or n=0	1040	3	1	0	0	1	3	0	0	0	120	1168
		Sum	2549	7	2	23	37	51	31	8	8	1	186	2903
		Band 0 =	40%	Band 1 =	55%	Band 2 =	67%	Miss =	16%	False =	16%	Valid =	12%	

Table 2 Seasonal variation of the estimation of cloud base height at HKIA based on the radiometer measurements.

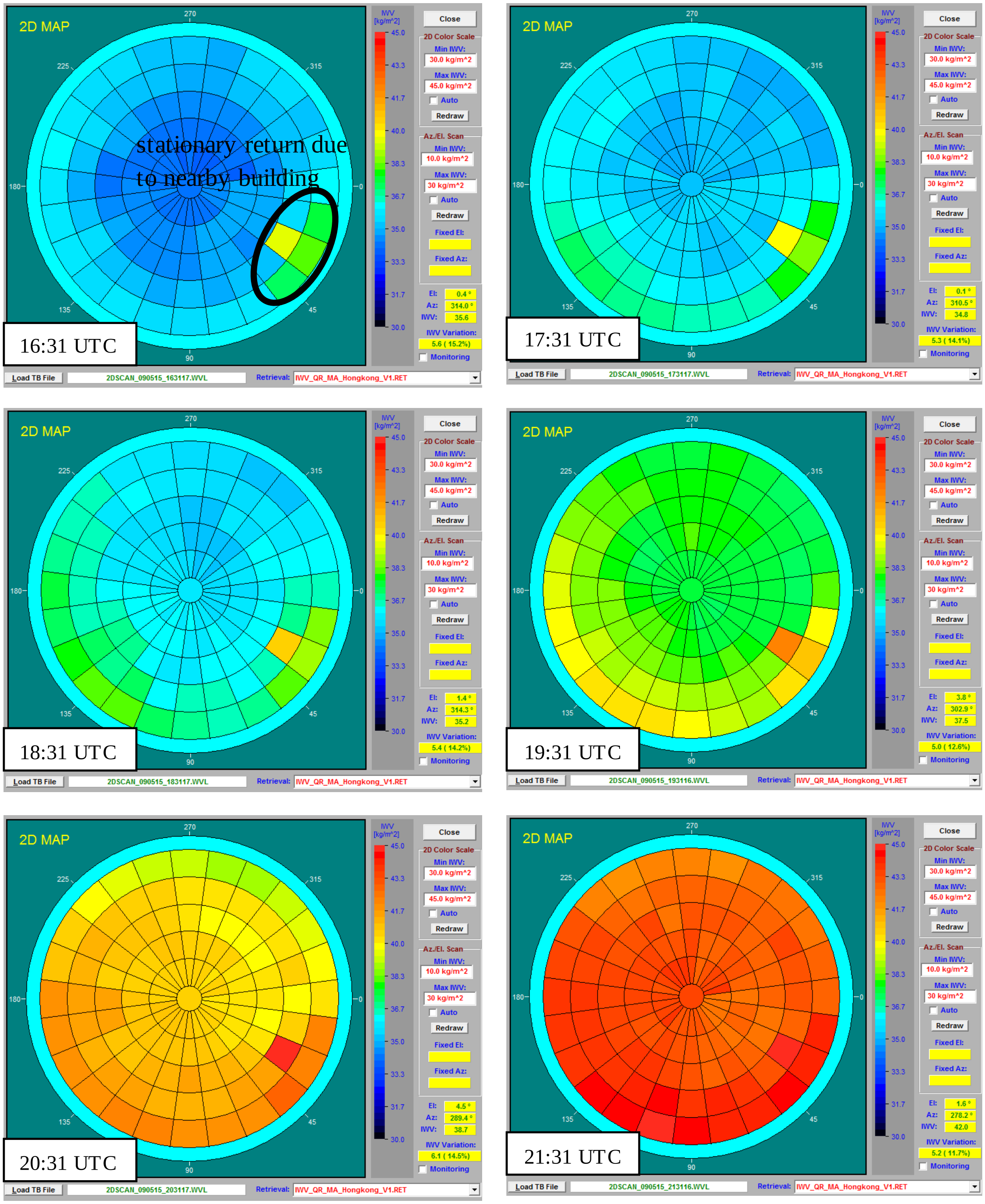

Figure 2 2D IWV maps from the radiometer for the case of 15-16 May 2009.

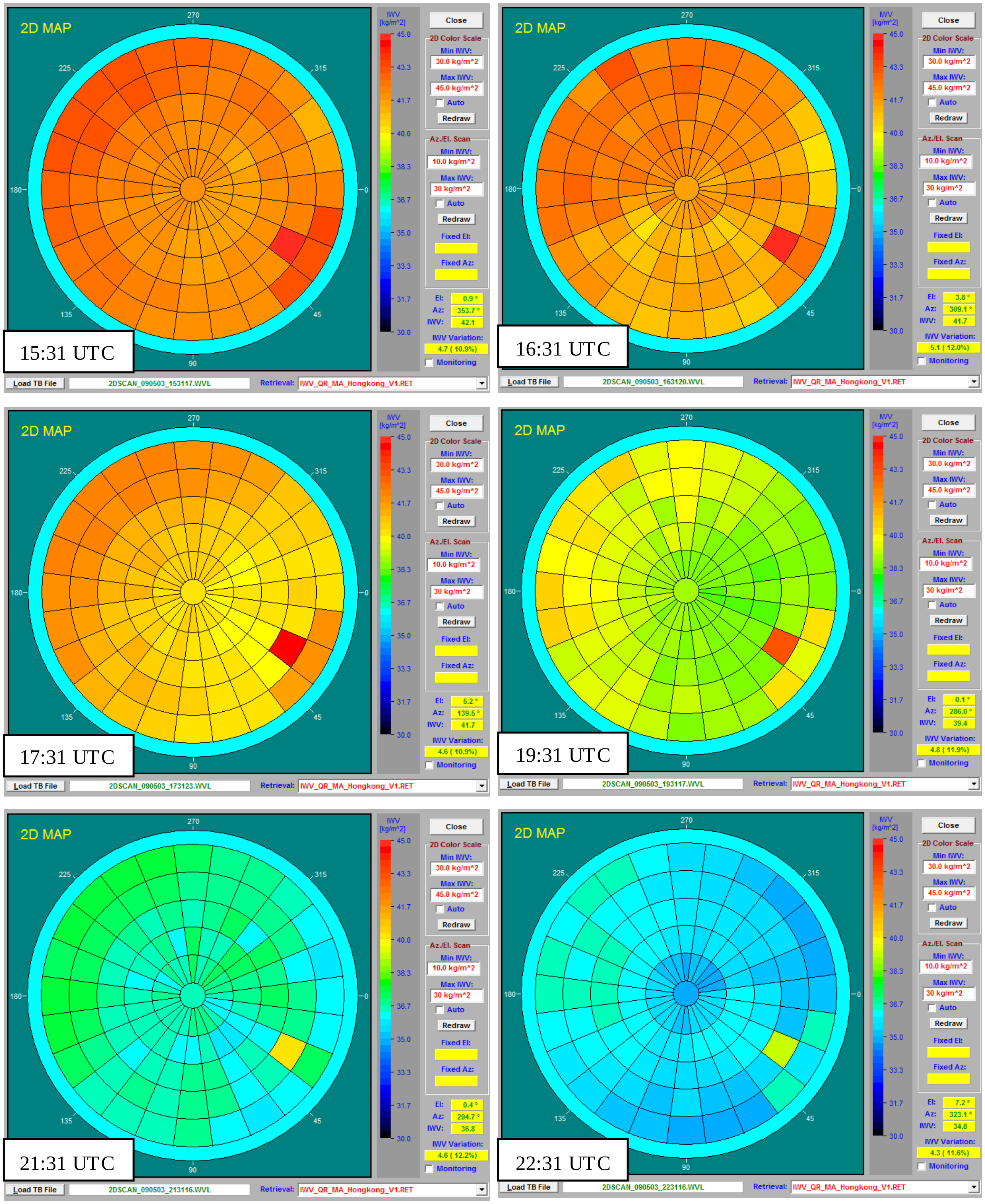

Figure 3 2D IWV maps from the radiometer for the case of 3-4 May 2009.