GROUND-BASED MICROWAVE RADIOMETER'S REMOTE SENSING APPLICATION IN CLOUD DETECTION

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Abstract: In this paper, the advantage of radiometer is firstly introduced relative to radio sonde, weather radar and metrological satellite. Radiometer is mainly used for sounding of atmospheric profile, research of cloud and precipitation，guidance of weather modification operation and forecasting of precipitation. Cloud base height and temperature of low cloud, and thickness of fog can be computed by radiometer data. Icing potential can be calculated from atmospheric profile from radiometer and icing algorithm. A case is introduced that radiometer and cloud radar jointly detect icing potential. Lastly, some problems and suggestions about radiometer's application in aviation meteorological support are proposed.

INTRODUCTION

Ground-based multi-channel microwave-radiometer is one of passive ground-based microwave remote sensing equipment. Compared with optical and infrared remote sensing, microwave radiometer can work at all time, and not be impacted by cloud and fog.

Currently, Ground-based multi-channel microwave-radiometer is mainly used for atmospheric sounding, inversion of temperature profile，humidity profile，and liquid water，experiment and research of weather modification.

Radio sonde, weather radar and metrological satellite is commonly used for aviation meteorological monitoring and sounding. Routine radiosonde is operated at 8 and 20 o'clock, and radiosonde stations is usually far away from each other. Weather radar is often used for detecting precipitation and convective cloud. Meteorological satellite can continuously cover a large area. It's horizontal resolution is better than vertical resolution. When it is used for remote sensing upper atmosphere, the accuracy is better.

Ground-based multi-channel microwave-radiometer can work by self at all weather. It can retrieve of atmospheric profile, including temperature，humidity and liquid water，cloud base height, instability index and icing region, etc.

REMOTE SENSING POTENTIAL OF GROUND-BASED MULTI-CHANNEL MICROWAVE-RADIO METER

By microwave-radiometer data, many products can be retrieved, including path and profile of vapor and liquid water.

The antenna of microwave radiometers accepts the signal reflected and scattered by air and cloud drops. When cloud base temperature and height, surface temperature, humidity, and pressure are known, the path of vapor and liquid water, and the profile of temperature, humidity, vapor and liquid water can be retrieved.

Liu compared retrieval products from radiometers with radio sonde data from May 2006 to March 2008 (Liu, 2010a). According to different sky conditions, quantified error analysis is made. The radiometer is TP_WVP3000 ground-based 12-channel microwave-radiometer, which is made in Radiometrics Co.Ltd, USA. But for 12 microwave channels, the equipment can also measure surface temperature, relative humidity, pressure, precipitation, cloud base temperature and height. The precision of the radiometer's bright temperature is 1K.

By neuron network algorithm, total vapor and liquid water, and profile of temperature, relative humidity, vapor and liquid water are be retrieved. Figure 1 shows the products above.

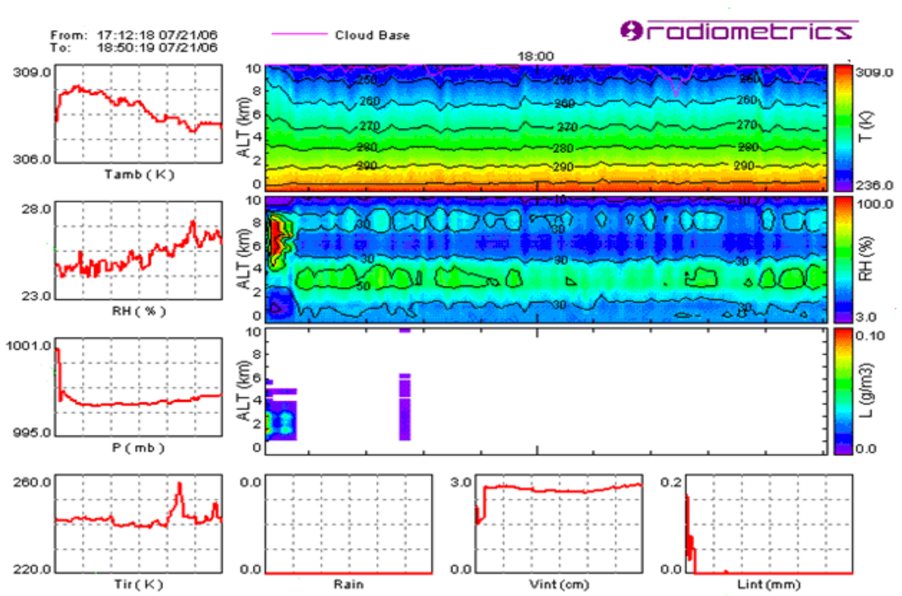

Figure 1: TP-WVP 3000 microwave radiometer products

CMAA institute of desert metrology bought a MP-3000 radiometer in 2008, the radiometer has 35 channels, and it covers 0 to 10km, it's vertical resolution is 250m, it's time resolution is 2min. The equipment can monitor the evolution of atmospheric condition, detect temperature and humidity profile, and guide weather modification operation. Zhao compared radiometer data with radiosonde data in June, 2008 (Zhao, 2010). The result shows that the temperature agrees with each other, and the humidity has same trend.

HATPRO is a 14-channel radiometer made in Germany. In addition to atmospheric profile, it has convective stability index, such as TTI, KI, CAPE, SI, LI, Showalter.

In China, microwave-radiometer is mainly used for sounding of atmospheric profile (Huang, 2010), research of cloud and precipitation (Li, 2005; Liu, 2009), guidance of weather modification operation (Wang, 2007), and forecasting of precipitation. In the future, radiometer is probably used for monitoring aviation dangerous weather such as low cloud and dense fog, aircraft icing.

MICROWAVE RADIOMETER'S APPLICATION IN CLOUD AND ICING DETECTION

Monitoring Low Cloud and Dense Fog

Low cloud and dense fog seriously impacts on take-off, landing, and low altitude flight. When aircraft lands in fog or low cloud, the pilot has little time to find object and could make incorrect decision (Zhao, 1994). Cloud base height and temperature of low cloud, and thickness of fog can be computed by profile of temperature, humidity, vapor and liquid water.

He compared and studied the area of fog's region, temperature, humidity, wind speed and liquid water content in the boundary by many methods (He, 2009). The result shows that there is inversion layer and LWC decreased quickly at top of the fog.

Liu also studied the evolution and distribution of meteorological elements in boundary when it's foggy (Liu, 2010b). It's found that, when fog appears, the lower humidity is large, and the upper humidity is small, and the maintaining of fog mainly depends on increase of boundary. After an hour, liquid water appears at 100m, and then expands down and up. Before weather system arrives, there is largest liquid water content at 100m.

Lou monitored a winter fog in 2006 with radiometer (Lou, 2007), the result shows that, vapor density is almost saturated and there is liquid water in the fog, vapor density decreases suddenly at top of fog, and there's no liquid water above fog.

Monitoring Icing Potential

Aircraft icing is the phenomenon that ice clusters somewhere at the surface of aircraft. the phenomenon usually occurs in cloud, fog, sleet, and wet snow. Aircraft icing can affect aircraft's dynamic, security and handling (Zhou, 2011).
Icing potential can be calculated from atmospheric profile and icing algorithm, such as RAOB icing algorithm and ICAO's icing algorithm (Wang, 2003).

RAOB icing algorithm defines the type and intensity of icing by temperature，dew point deficit, and temperature lapse rate. Eight classes of icing intensity are defined: 0-no icing, 1-TRC-RIM, 2-LGT MXD 3-LGT RIM, 4-MDT-MXD, 6-MDT-RIM, 7-MDT-CLR, as form 1 shows:

Table 1: RAOB icing algorithm

Temperature in humidity layer℃	$-8°C < T \le 0°C$				$-16°C < T \le -8°C$				$-22°C < T \le -16°C$
$T - T_d = ddp$	$ddp \le 1$		$1 < ddp \le 2$		$ddp \le 1$		$1 < ddp \le 3$		$ddp \le 4$
Lapse rate ($°C/305m$)	stable <=2	unstable >2	stable <=2	unstable >2	stable <=2	unstable >2	stable <=2	unstable >2	N/A
Icing type intensity	LGT-RIM 3	MDT-CLR 7	TRC-RIM 1	LGT-CLR 4	MDT-RIM 6	MDT-MXD 5	LGT-RIM 3	LGT-MXD 2	LGT- RIM 3

ICAO’s icing algorithm is based on the profile of temperature and relative humidity from radiometer, the formula of icing index is:

$$I1=2(f-50)T[(T+14)/(-40)]/10$$

f represents relative humidity, and T represents temperature, when f is between 50 and 100, icing index increase linearly from 0 to 100. $I1<0$ represents no icing, $0\leq I1<5$ represents light icing, $5\leq I1<8$ represents moderate icing, $I1>8$ represents serious icing.

NCAR's icing severity index is relative to three parameters: atmospheric temperature(T), super cooled water content(L), and medium volume diameter(MVD). The index is an integer between 0 and 10. 0 presents no icing, and 10 represents most serious icing. The relation between T, L, MVD and icing severity index is demonstrated by a matrix (Wang, 2003).

There was a union sounding experiment with cloud radar and dual-channel microwave radiometer from March to July in 2007, as figure 2 shows. The cloud radar is a 45-degree slant linear depolarization radar. It works at 35GHz, and its resolution is 75m, the radiometer works at 23.8 and 31.65GHz, The observation manner of radiometer was same as the cloud radar. Figure 3 shows that radar reflectivity and depolarization ratio at 8 o’clock April 17th, 2007.

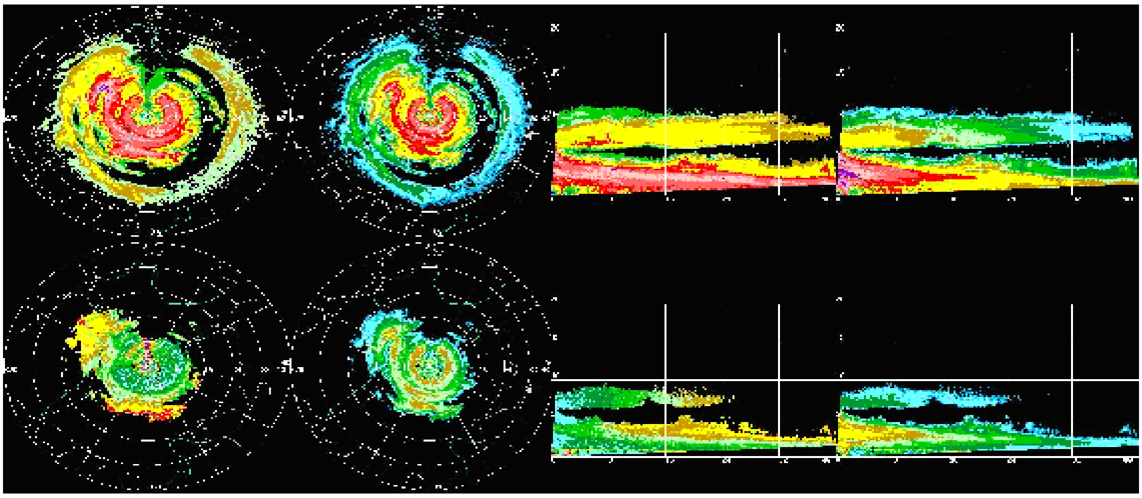

Figure 2: radar reflectivity and depolarization ratio at 8 o’clock April 17th 2007
(the left is PPI scanning, angle of elevation is 20°, the right is RHI scanning, angle of azimuth is 180°)

At 8 o’clock, the weather system was in front of 850hPa trough, and the cloud was thick. Surface temperature was 12.5℃, relative humidity is 48%, and cloud cover was: fracto nimbus 3 and stratocumulus 7, the cloud base height was 270m and 1500m, the visibility was 12km. According figure 3, it can be inferred that the height of zero layer is 1817m, the dew point deficit is less than 4 between 0 layer and 500hPa, so icing layer should be between 1800m and 4000m.

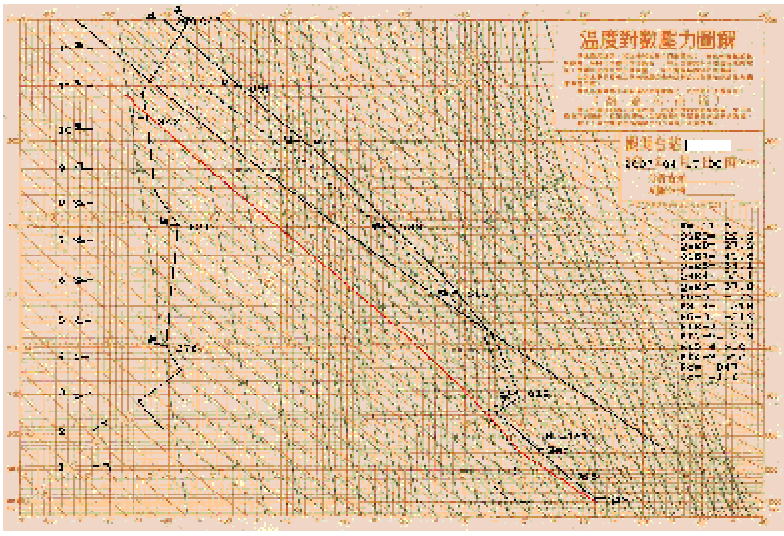

Figure 3: T-lnP figure at 8 o'clock April 17th 2007

Water drop in cloud would remain polarization state of incident wave, but ice crystal would lead to a vertical polarization scattering component. So, cloud phase can be differentiated by depolarization information of back scattering. In this paper, cloud phase is inferred by fuzzy logic algorithm. There are three variables, radar reflectivity, linear depolarization ratio and temperature. The left in figure 4 shows cloud phase over the station.

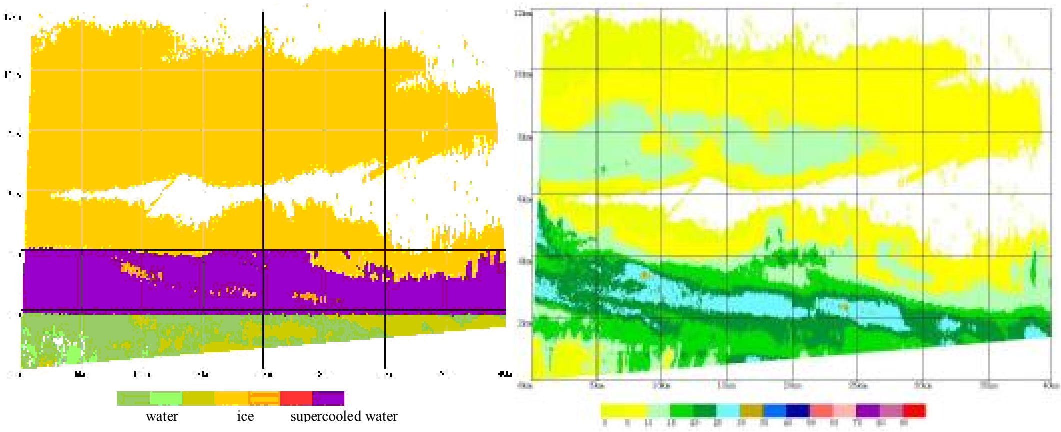

Figure 4: cloud phase(left) and effective radius(right) by jointly detecting(RHI scanning, angle of azimuth is 180°)

With the constraint that the droplet concentration and distribution spread is approximately constant, one can relate the reflectivity and microwave radiometer integrated liquid water to the cloud liquid water profile. If cloud droplet distribution is log-normal, the effective radius is proportional to Z^6. In fact, it's necessary that the relation between effective radius and reflectivity be modified.

In this paper, $R=aZ^b$, R represents effective radius, a and b are const. Effective radius of cloud drop is showed in figure 5(right).

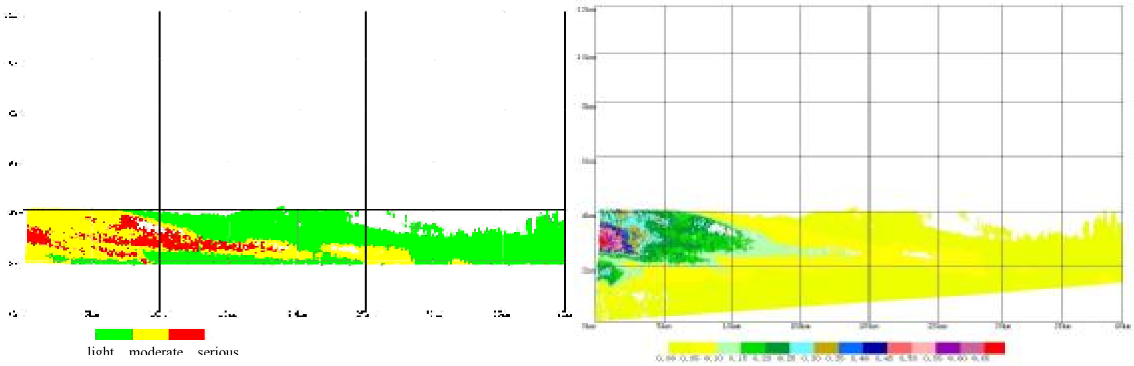

Figure 5: liquid water content(left) and icing intensity(right) by jointly detecting(RHI scanning, angle of azimuth is 180°

Since LWC is proportional to $Z^{1/2}$ (Frisch, 1998), LWP can be divided to every layer along the observation path. According LWC, temperature and effective radius, icing severity index can be calculated. The right in Figure 5 shows that thick icing layer is over the station, which is identical with figure 3(T-lnP).

PROBLEMS AND SUGGESTIONS

Microwave radiometer would be used widely. It is bright temperature that radiometer detects directly, so it would be verified whether the accuracy of product meet the aviation meteorological support. Some suggestions and problems are proposed.

(1) To improve retrieval, it is necessary that collect long term radio sonde data and build separately model according to different types of weather.

(2) There are many retrieval algorithms such as Monte Carlo, EOF, neuron network, and genetic algorithm. The accurate and efficient algorithm should be selected for aviation meteorological support.

(3) It would be more effective that the radiometer is used with other active sounding equipment, such as millimeter-wave radar, dual-polarized radar. The precision of monitoring icing would be better.

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