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of a Ground-based Microwave Radiometer

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# THE USE OF NEURAL NETWORK RETRIEVAL FOR THERMODYNAMIC PROFILES OF A GROUND-BASED MICROWAVE RADIOMETER

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## ABSTRACT

A ground-based microwave radiometer is used to retrieve the temperature and humidity profiles of the troposphere based on brightness temperature observations and climatological data of the observation site. At present, there are two major methods to include the climatological data in the retrieval algorithm, namely, regression-based method and neural network. Both methods are employed for the radiometer at the Hong Kong International Airport (HKIA) for over a year and their performance is compared. It turns out that the neural network approach is far more robust and gives much more realistic humidity profiles of the troposphere in comparison with the radiosonde data, particularly in rainy weather. On the other hand, the regression method fails to provide realistic humidity profiles in rain, even in light rain condition.

The neural network approach is used to generate liquid water profile of the troposphere. The liquid water profile is useful in the monitoring of heavy rain. However, using the brightness temperatures from the zenith observations alone, the liquid water amounts at certain altitudes may become unrealistically large. The retrieval method could be improved by considering the brightness temperature observations in elevation scans. Some examples of such liquid water profiles would be discussed in the paper.

*Index Terms*— radiometer, regression, neural network

## 1. INTRODUCTION

A ground-based, multi-channel microwave radiometer (model: HATPRO) has been used at the Hong Kong International Airport (HKIA) since May 2008. It employs 7 oxygen channels and 7 water vapour channels to measure the temperature, humidity and liquid water profiles up to 10 km above ground in zenith model. It also uses 7 elevation angles at the 58 GHz frequency channel to measure the boundary-layer temperature profile (up to 2 km above ground). Furthermore, a two-dimensional scan is made every hour to obtain a “map” of integrated water vapour and liquid water path over the sky dome.

Given the above scan strategy of the radiometer, a number of methods could be tried out in the retrieval of the thermodynamic quantities of the troposphere. One possible thing to change is the statistical method used to determine the retrieval algorithm for the thermodynamic profiles. In the retrieval process, reference has to be made to the past upper-air ascent data of the site. Such climatological information is then used to build the statistical model on the correlation between the measured brightness temperatures and the vertical profiles of the thermodynamic quantities. Two common approaches are the regression-based method and the neural network method. Both methods have been applied to the brightness temperature data obtained from the radiometer at HKIA. It turns out that the results from the two methods are comparable with each other in non-raining and light rain situation. However, their performance in moderate to heavy rain situations could be different. This paper presents some preliminary observations of the retrieved profiles using the two methods.

Another thing that could be tried out in the retrieval is the inclusion of brightness temperature data obtained in elevation scans. It is well known that the use of elevation mode, compared to the use of zenith mode alone, could improve the quality of the retrieved temperature profiles within the boundary layer, such as the resolution of isothermal or temperature inversion close to the ground. Concerning the retrieval of liquid water profile, it has been shown that the use of zenith mode data alone would not be possible (Crewell et al., 2009). The paper also discusses the use of brightness temperatures obtained in elevation mode as well to retrieve liquid water profile and the observation in a heavy rain case.

## 2. RETRIEVAL METHODS FOR TEMPERATURE AND HUMIDITY PROFILES

The retrieval methods, which are statistical methods in nature, are based on the climatological upper-air ascent data in Hong Kong. Radiosondes in Hong Kong are launched at 00 and 12 UTC every day at King’s Park, a station of about 25 km east of HKIA. The finest available data, namely, 2-second data are considered, i.e. data are updated every 2

seconds, which correspond to an ascent of the weather balloon of about 10 m in the lower troposphere. Radiosonde data over a period of about 7 years is used. Surface observations from the radiometer have not been considered in the retrieval algorithms.

To the knowledge of the author, the regression method originally adopted for the model of the radiometer in use is based on linear regression between the radiosonde profiles and the computed brightness temperature from a radiative transfer model. All kinds of data have been included – no distinction has been made to rainy and non-rainy situations, and no consideration has been made to the intensity of the rainfall. However, separate regression-based coefficients for the retrieval have been established for different seasons. It turns out that the seasonal variation of the coefficients is significant for the retrieval of vertical humidity profile. To make use of the data obtained from the elevation scans which provides better resolution of the temperature profile within the boundary layer, a “composite” temperature profile is used in the retrieval: for heights above 2 km, only zenith data are used; for heights below 1.25 km, the elevation scan data are used; and then a cubic-spline interpolation is made between 1.25 and 2 km.

For the neural network based method, the statistical relationship between the radiosonde profiles and the brightness temperature (computed from the radiosonde profiles using a radiative transfer model) is established using artificial neural network. All the radiosonde data over the 7-year period are included in the training of the neural network in one-go: no distinction has been made to the weather conditions, and no seasonal variation has been considered. It should be noted that a limitation to the neural network algorithm is that it can only be applied to the range of atmospheric conditions included in the training dataset. When extrapolations beyond the states included in the algorithm development are made, the behaviour of the neural network would be unknown. It is thus assumed that, for the actual measurements made by the radiometer, the atmospheric condition encountered in the training radiosonde data would be repeated. For this assumption to be valid over a wider range of atmospheric condition, the training radiosonde data would be expanded with the accumulation of more data over the years.

### 3. RETRIEVAL OF TEMPERATURE AND HUMIDITY PROFILES IN RAIN

Two examples will be discussed in the present section, including a case of lighter rain and another case of heavier rain, to compare the performance of the retrieval of temperature and humidity profiles by the methods described in Section 2.

The lighter rain case occurred on 27 – 28 December 2009 when a cold front over southern China moved

southwards across the coastal area. According to the rainfall record at HKIA, the highest hourly rainfall was about 1.8 mm. An example of the vertical profiles of temperature and relative humidity obtained from the two retrieval methods is shown in Figure 1, viz. at about 17:10 UTC, 27 December 2009 (Hong Kong time = UTC + 8 hours). Between 17 and 18 UTC of 27 December, the hourly rainfall was about 1.0 mm. It could be seen that, in general, the profiles obtained from the two methods are similar to each other. There are two observations:

- (i) Though the shapes of the temperature profiles from the two methods are broadly similar, there are some discrepancies in the fine features, e.g. the height of the temperature inversion below 2 km. This may be due to the use of different scanning modes in the two retrieval methods (elevation mode for regression method vs. zenith mode in neural network method).
- (ii) In general, the time evolution of the relative humidity profiles from the regression method is relatively more erratic, whilst that from the neural network method is smoother, particularly during the raining periods. It appears that the neural network method is more stable in the generation of the relative humidity profiles.

The profiles retrieved from both methods are compared with radiosonde measurements at 12 UTC, 27 December 2009 in Figures 1(c) and (d).

The heavier rain case occurred on 25 April 2009. On that day, a trough of low pressure along the south China coastal area brought rainy weather to the region. According to the rain record at HKIA, the rain was the heaviest between 02 and 03 UTC, 25 April, with the hourly rainfall of 33 mm. The temperature and relative humidity profiles retrieved from the two methods at about 02:30 UTC, 25 April are shown in Figure 2. It could be seen that the retrieval results from the regression method do not seem reasonable meteorologically because:

- (i) There was a temperature inversion of more than 20 degrees Celsius between 2 and 3.5 km above ground. It also occurred at 00 UTC on that day, and such a temperature inversion is not observed from the upper-air ascent measurement at that time.
- (ii) In the relative humidity profile, the regression method gives 0% between around 2.3 and 5 km above ground, which should be unreasonable.

On the other hand, the temperature and relative humidity profiles from neural network method look more reasonable. The profiles at 00 UTC, 25 April are generally consistent with those obtained from the upper-air ascent (Figures 2(c) and (d)). The rainfall between 23 UTC, 25 April and 00 UTC, 25 April was 2.5 mm at HKIA. As such, it appears that the neural network method is more robust in the retrieval, and has more stable performance in both raining and non-raining periods.

#### 4. RETRIEVAL OF LIQUID WATER PROFILE

Again, the case of 25 April 2009 is used. The liquid water profile retrieved from zenith mode alone using neural network method is given in Figure 3(a). The liquid water amount reaches a value in excess of  $10 \text{ g/m}^3$  at about 7.2 km, at which the temperature should be well below 0 degree Celsius (Figure 2(b)). The existence of a large amount of supercooled liquid water is doubtful. The liquid water amount is even higher than that above 0 degree Celsius (below 7 km or so, where liquid rain begins to form). Though there is no separate measurement of the liquid water profile, the results in Figure 3(a) do not appear to be meteorologically reasonable.

Using the 30-degree elevation scan data in the retrieval, the liquid water profiles are shown in Figure 3(b). The maximum magnitude of the liquid water amount at the various altitudes becomes smaller – just several  $\text{g/m}^3$ . Moreover, the liquid water amount is higher below 2 km or so, where rain (in liquid form) should be present.

The above observations are also found in other convective rain events during the study period (summer time 2009). In general, the liquid water profiles obtained from the elevation scan data appear to be more reasonable meteorologically. It would be good to have an independent measurement of the liquid water profiles (e.g. from cloud radars) to double check the radiometer-based results.

#### 5. CONCLUSIONS

Among the two commonly used methods for retrieving temperature and humidity profiles using radiometer measurements, it appears that the neural network method performs better, especially in rain. Moreover, using elevation scan data, the neural network method seems to give reasonable profiles of liquid water within the troposphere.

[1] S. Crewell, K. Ebell, U. Löhnert and D. Turner, Can liquid water profiles be retrieved from passive microwave zenith observations?, *Geophysical Research Letters*, **36**, L06803.

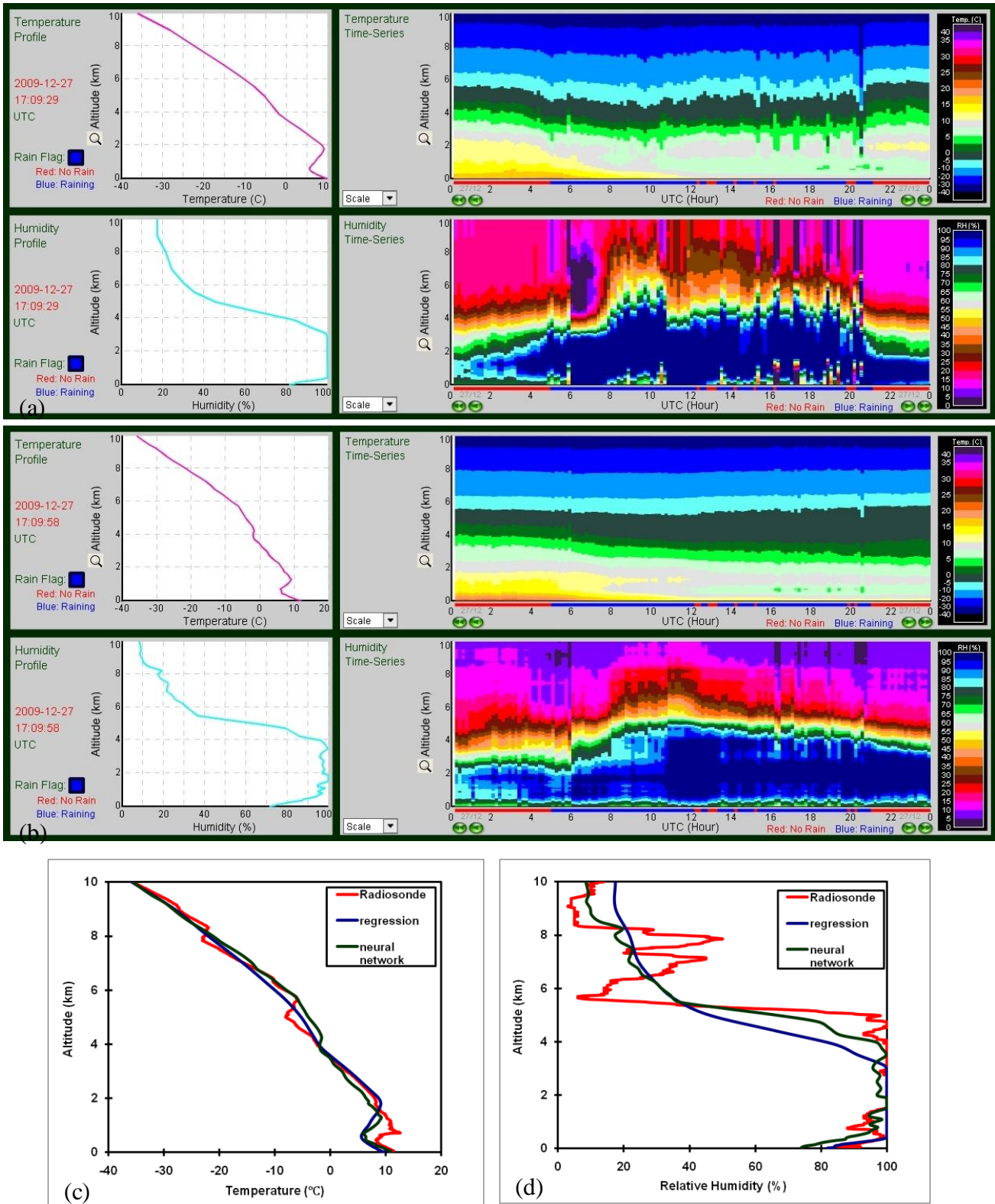


Figure 1 The lighter rain case of 27 – 28 December 2009: (a) and (b) are the temperature and humidity profiles retrieved from the regression-based method and the neural network method respectively, and (c) and (d) are the comparison of the radiometer-derived profiles with the radiosonde data at 12 UTC, 27 December 2009.

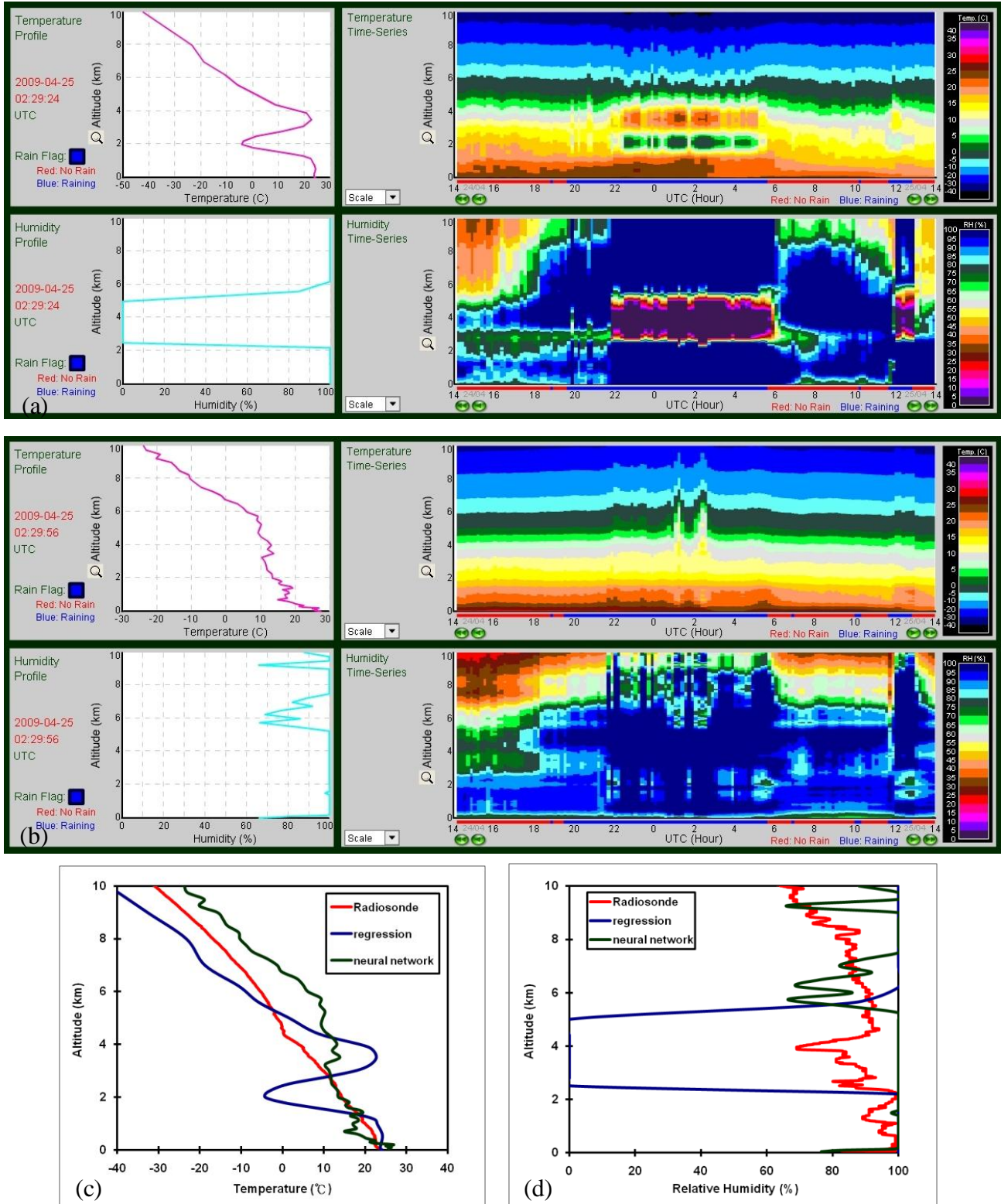
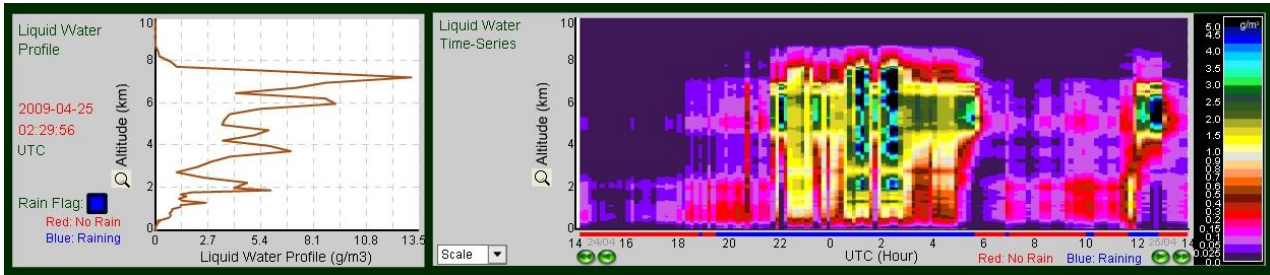
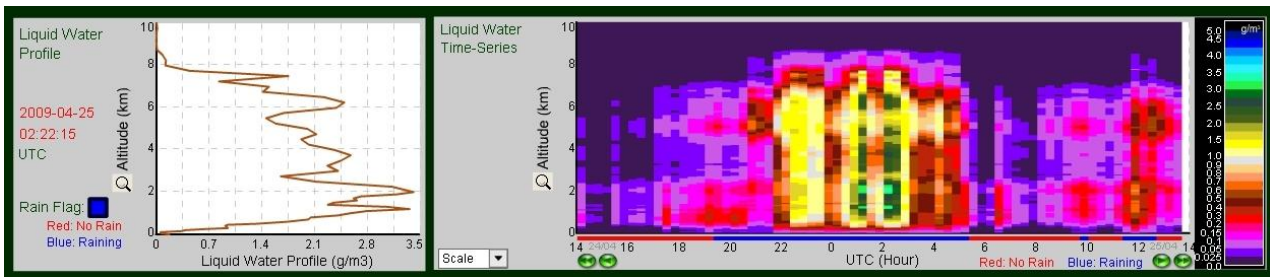


Figure 2 Same as Figure 1 but for the heavier rain case of 25 April 2009.





(a)



(b)

Figure 3 Liquid water profiles for the case of 25 April 2009:

- (a) Based on zenith scan data only; and
- (b) Using elevation scan data as well.