1.3. COMPARISON OF RADIOSONDE AND RUC MODEL

MEAN RADIATING TEMPERATURE OF THE ATMOSPHERE

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1. INTRODUCTION

In order to acquire measurements of precipitable water vapor (PWV) and precipitable liquid water (PLW) from a dual-frequency ground based microwave radiometer, an accurate statistical retrieval algorithm is required to convert raw brightness temperatures into PWV and PLW. These algorithms include a set of input parameters whose values vary according to location, season, and weather conditions (Westwater 1978). One of these input parameters, the mean radiating temperature of the atmosphere (\(T_{mr}\)), can be estimated using different techniques (Chiswell et al. 1994).

Over the last decade the resolution and accuracy of numerical weather prediction (NWP) models has continually improved. The accessibility of the model output has also significantly improved, to the point that the operational use of \(T_{mr}\) obtained from NWP models should now be considered, as a replacement for the current method of producing \(T_{mr}\) from seasonal or monthly averaged climatological values from radiosonde measurements.

The main objective of this study is to examine the use of the ‘real-time’ NWP \(T_{mr}\) in microwave radiometer statistical retrievals rather than seasonal averaged climatological \(T_{mr}\) values from radiosonde measurements, and to assess differences in accuracy.

2. ACCURACY OF THE STATISTICAL RETRIEVAL

The Radiometrics WVR-1000 microwave radiometer measures sky brightness temperature \(T_b\) at two frequencies: 23.8 GHz (“vapor” channel) and 31.4 GHz (“liquid” channel). Because \(T_b\) is not a linear function of PWV and PLW, the linear quantity opacity \(\tau\), is derived.

\[
\tau = \ln \left( \frac{T_{mr} - 2.75}{T_{mr} - T_b} \right) \quad (1)
\]

In (1), \(T_b\) is a measured quantity and \(T_{mr}\) is estimated.

From (1) we find that the error in opacity \(\delta\tau\) is proportional to the errors in \(T_{mr}\) and \(T_a\):

\[
\frac{\delta\tau}{\tau} \approx \frac{\delta T_{mr}}{T_{mr}} + \frac{\delta T_a}{T_a} \quad (2)
\]

This indicates that an improvement in the estimation of \(T_{mr}\) leads to a better estimation of opacity, and consequently more accurate PWL and PLW retrievals.

3. DATA AND METHODOLOGY

One full year (2003) of radiosonde and the Rapid Update Cycle (RUC) model data, (Benjamin et al. 2004), were analyzed for Maniwaki, Ontario radiosonde site location for two standard times: 0h and 12h UTC.

The RUC model used has 20 km horizontal resolution (RUC20) and 50 computation levels. Only a reduced amount of RUC model data was available during the summer period. \(T_{mr}\) for 23.8 and 31.4 GHz were derived from both the radiosonde and RUC model vertical profiles, using the same algorithm used by the Radiometric Corporation for the WVR-1100 retrievals (Fredrick Solheim private correspondence).
The data from four RUC forecast times (3h, 6h, 9h, and 12h) were used in the comparison with the radiosonde data.

4. DATA ANALYSIS AND COMPARISONS

The radiosonde and RUC time series of $T_{mr}$ are shown in Figure 1. Plots of $T_{mr}$ for 23.8 and 31.4 GHz are shown on the left and right sides of the figure respectively. The forecast time increases from the top to the bottom.

From Figure 1 it can be seen that the RUC $T_{mr}$ was consistently higher than the corresponding radiosonde values. The differences became greater in warmer periods. A possible explanation for this could be increasing differences in model predictions and observed profiles of relative humidity with increasing convective dynamics in the warmer periods (Benjamin et al. 2004). Further analysis would be required to validate this suggestion.

The scatter diagrams of the radiosonde-RUC $T_{mr}$ values (Fig. 2) show a linear correlation. In Table 1 the corresponding correlation coefficients range from .92 to 0.97 (Table 1). The correlation was the strongest for the 3 h forecast, for the 31.8 GHz frequency, and become weaker as the forecast times increased. Therefore the corresponding rms was quite high, at -13 and 8 K respectively, which leads to unacceptable errors in the operational estimate of $T_{mr}$ using the RUC model.

Since a strong correlation exists between the radiosonde and RUC $T_{mr}$, it is possible to make a simple adjustment to the RUC $T_{mr}$ based on the radiosonde-RUC regressions. This new RUC $T_{mr}$ data set is referred to as the corrected RUC $T_{mr}$ ($T_{mr}^-$):

$$T_{mr}^- = T_{mr} - \frac{b}{a},$$

where $a$ is the slope and $b$ is the intercept of the linear correlation between radiosonde and the RUC $T_{mr}$.

From the time series and the scatter diagrams of the corrected RUC model $T_{mr}^-$ (Figs. 3 and 4.) it can be seen that, as expected, the corrected set of RUC $T_{mr}$ fits well with the radiosonde $T_{mr}$ and the correlation coefficients were in the same range as for uncorrected $T_{mr}$. More importantly the rms had much lower values, in the range of 2.7 to 4.2 K, when compared to the pre-corrected values.

Table 2 shows the rms, relative rms, the average $T_{mr}$ of the atmosphere, and the total number of points for the following five periods: a full year (2003), December - February, March – May, Jun – August, and September – November, for computed for both frequencies from radiosonde and RUC data.

For the radiosonde, rms was calculated relative to the mean value of radiosonde $T_{mr}$, while for the RUC rms was calculated with respect to the corresponding radiosonde $T_{mr}$ value. In other words, radiosonde rms values quantify the dispersion of $T_{mr}$ from the mean value for the selected period, while the RUC rms quantifies the difference between radiosonde and RUC $T_{mr}$.

The rms differences between the radiosonde and RUC $T_{mr}$ values were in the range of 2.5 to 5.2 K (0.9-2.0 %), which was much better than the radiosonde differences of 3.5 to 8.0 K (1.3-3.0 %) from it's averaged $T_{mr}$ values, for the same seasonal periods.

Table 1. Summary of the root-mean-square (rms), relative rms, slope $a$, intercept $b$, and correlation coefficient of a linear correlation between RUC and Maniwaki radiosonde mean radiating temperature $T_{mr}$, and the number of radiosonde - RUC points for two frequencies, 23.8 and 31.4 GHz, for 3, 6, 9, and 12 h RUC forecast durations.
Fig. 1. Time history of $T_m$ for 23.8 GHz (left) and 31.4 GHz (right) for 3, 6, 9, and 12h forecast durations (from top to bottom).
Fig. 2. Scatter diagrams of $T_{mr}$ for 23.8 GHz (left) and 31.4 GHz (right) for 3, 6, 9, and 12h forecast durations (from top to bottom).
Fig. 3. Time history of corrected $T_{mr}$ for 23.8 GHz (left) and 31.4 GHz (right) for 3, 6, 9, and 12h forecast durations (from top to bottom).
Fig. 4. Scatter diagrams of corrected $T_{mr}$ for 23.8 GHz (left) and 31.4 GHz (right) for 3, 6, 9, and 12h forecast durations (from top to bottom).
The data presented in Table 3 and Figure 5 show that if the adjusted RUC Tmr is used instead of a constant average seasonal Tmr from historical radiosonde data, in about ¼ of the instances (from a cumulative relative frequency) the relative error decreased by more than 5%.

The Jun-Aug period was incomplete and thus the Relative Frequency to Relative Error for Maniwaki (WMW).

Table 2. Summary of the rms, relative rms, averaged Tmr, and total number of P for the five periods (2003 full year, and 4 seasons: Dec-Feb, Mar-May, Jun-Aug, Sep-Nov) for 23.8 and 31.4 GHz frequencies.

Table 3. Summary of the changing relative frequency (r.fr.), relative error (r.err. = ΔTmr / avTmr), and the total number of RUC output hours during the season (N), versus the absolute differences between the average seasonal radiosonde 31.4 GHz Tmr and the RUC model 3 h forecast 31.4 GHz Tmr (ΔTmr). Data are shown for the four seasons (Dec-Feb, Mar-May, Jun-Aug, Sep-Nov) for Maniwaki (WMW).

Fig. 5. The relative frequency of the relative error if it used seasonal averaged Tmr instead of the RUC 3 h forecast Tmr for the 31.4 GHz frequency.
dependency is slightly different than that of the other seasons.

4. SUMMARY AND CONCLUSIONS

From a one year data set of Maniwaki radiosonde and RUC data, the mean radiating temperature ($T_{mr}$) values for 23.8 and 31.4 GHz were calculated. The data were linearly correlated, but with a slope in a range of 1.2 – 1.3 (RUC being the dependent variable), and with rms values in a range of 8 – 13 $^\circ$K.

After an adjustment based on this regression was applied to the RUC $T_{mr}$, the new data set naturally had a 1:1 linear correlation. For the five periods including the full year of 2003, Dec-Feb, Mar-May, Jun-Aug, and Sep-Nov, the rms difference between the radiometer and the adjusted RUC $T_{mr}$ values was in the range of 2.5 to 5.2 $^\circ$K, which was much better than the, 3.5 to 10.0 $^\circ$K radiosonde rms difference from its averaged $T_{mr}$ values for the same periods.

When using seasonal averaged radiosonde-derived values of $T_{mr}$ in PWV and PLW retrievals, greater error is generated than if the corrected forecasted RUC $T_{mr}$ values were used.

Three main points regarding to use of $T_{mr}$ in radiometric retrievals can be concluded from this study:

a) The $T_{mr}$ calculated from the RUC model forecasts can be successfully substituted for $T_{mr}$ derived from historical radiosonde data. In this study the linear correlation increased from 0.92 for 12 h forecast (23.8 GHz) to 0.97 for a 3 h forecast (31.4 GHz).

b) The use of RUC model $T_{mr}$ can often result in improved accuracy of $T_{mr}$ relative to historical radiosonde-derived values. In this study, it was shown that the improvement was > 5% in about 25% of the cases. Maximum improvement was 8%.

c) The use of the RUC model forecast data may also reduce errors in regions where radiosonde historical data are not available.

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REFERENCES

