Total Precipitable Water estimated from Split-Window techniques using meteorological satellite data

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Abstract: Total precipitable water has been retrieved from two different split-window techniques, the Split-Window Logarithm Ratio (SWLR) technique and the Physical Split-Window (PSW) technique, using brightness temperature data of the Geostationary Meteorological Satellite (GMS-5) imager. Retrieval has been conducted for the East-Asia region, and results are compared with TPW from a numerical prediction model, Regional Data Assimilation and Prediction System (RDAPS). Both techniques give spatial distribution of TPW similar to that of RDAPS. However, the SWLR technique reveals large horizontal gradients near clouds. Results from the PSW technique are in good agreement with those of RDAPS.
Keywords: Total Precipitable Water (TPW), Split-Window, Split-Window Logarithm Ratio (SWLR), Physical Split-Window (PSW)

1. Introduction

Total Precipitable Water (TPW), the total amount of water vapor in the air column, is an important parameter for hydrometeorology, numerical weather prediction model, and radiative transfer calculation. Temporally and spatially high resolution data of water vapor are needed to improve the results. Satellites provide data in relatively good quality with much better coverage in the space and time domain than the conventional Balloon Borne Sounding System (BBSS) network. Split-window techniques were utilized to exploit the difference in the water vapor absorption between the channels at 11 and 12 μm from the satellite measurements (see Fig. 1).

In this study, two split-window techniques to retrieve total precipitable water are employed, and calculated results using Geostationary Meteorological Satellite (GMS-5) infrared measurements are compared. The Split-Window Logarithm Ratio (SWLR) technique (Chesters et al., 1987) utilizes parameterized transmittances for a single atmospheric layer. The Physical Split-Window (PSW) technique (Jedlovec, 1987; Guillory et al., 1993), on the other hand, utlizes a priori information on the atmospheric condition to improve TPW estimation. TPW is retrieved from these two techniques, and compared with TPW of a numerical weather prediction.model The Korean meteorological satellite will be launched in 2008, and the same techniques will be employed to retrieve TPW when the satellite gets imager data.

2. Split-Window techniques

2.1 Split-Window Logarithm Ratio technique

The split-window channel at 11 and 12 μm has different absorption by water vapor. Fig. 1 shows variation of brightness temperatures of the two channels with water vapor amount; the 12 μm channel is more sensitive than the 11 μm channel. Ratio (or difference) of the brightness temperatures of the split-window channel tends to increase with TPW. This characteristic of the split-window channel is used in the Split-Window Logarithm Ratio (SWLR) technique. The brightness temperature T^*_λ observed from the satellite and the transmittance τ_λ for the zenith angle of θ of a single atmospheric layer can be defined by the following equations (Chesters et al., 1987):

$$T^*_\lambda = T_{sfc}\tau_\lambda + T_{air}(1-\tau_\lambda) \tag{1}$$

$$\tau_\lambda = \exp\left[-\left(\kappa_\lambda + \alpha_\lambda U + \beta_\lambda U^2\right)\sec\theta\right] \tag{2}$$

where T_{sfc} and T_{air} are the surface and the air temperatures, respectively. Variable τ is the transmittance for the single layer and λ represents 11 or 12 μm. Variables κ, α, and β represent the model coefficients. To eliminate the surface contribution, Eqs. (1) and (2) are applied to each of the 11 and 12 μm channels. Then assuming small β (Chesters et al., 1987), the total precipitable water can be determined from

$$U = \frac{1}{\Delta\alpha}\left\{\frac{1}{\sec\theta}\ln\left[\frac{T^*_{11} - T_{air}}{T^*_{12} - T_{air}}\right] - \Delta\kappa\right\}. \tag{3}$$

where $\Delta\alpha=\alpha_{12}-\alpha_{11}$ and $\Delta\kappa=\kappa_{12}-\kappa_{11}$. Chesters et al. (1987) determined optimized values of $\Delta\kappa$, $\Delta\alpha$, and T_{air} from the least-square minimization procedure.

2.2 Physical-Split Window technique

The radiance I_λ at the satellite can be calculated from the integral form of the radiative transfer equation, when the emissivity of the surface is 1, as

$$I_\lambda = B_\lambda(T_{sfc})\tau_{sfc} - \int_0^{p_s} B_\lambda(T_p)\frac{d\tau}{dp}dp\ . \tag{4}$$

where B_λ is the Black-body function. The retrieval equation is derived from a perturbation form of Eq. (4), that is further simplified through parameterization of the transmittance for the single atmospheric layer. This retrieval technique requires a priori information on air temperature and moisture distribution, total precipitable water, and surface temperature. The information is used in a forward radiative transfer calculation to obtain the transmittances and brightness temperatures for each split channel. The results are used in derivation of the retrieval equation. The TPW retrieval equation can be written by the following equation (Guillory et al., 1993).

$$\delta T_\lambda^* = \delta T_{sfc} C_\lambda + \frac{\delta U}{U_0} D_\lambda \qquad (5)$$

where C and D are the model coefficients and δT_λ^* is the difference between the brightness temperatures observed by the satellite and simulated by the forward radiative transfer model. Subscript 0 denotes a priori information. Variables δU and δT_{sfc} are the perturbations from the priori values and retrieved quantities.

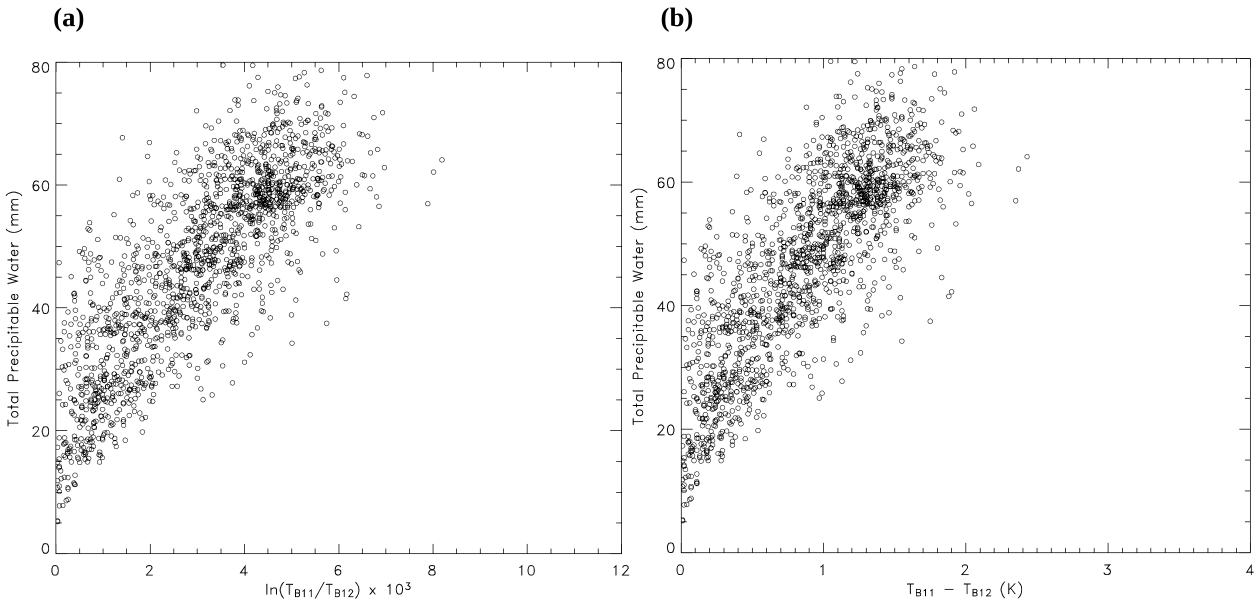


Fig. 1. (a) Total precipitable water vs ratio of the brightness temperatures of the split-window channel, and (b) difference of the brightness temperatures.

3. Data and Methodology

To apply the two retrieval techniques, the infrared measurement data of the GMS-5 imager are used. Results on June 6 and July 1, 2002 are presented here. Sampled European Centre for Medium–Range Weather Forecasts (ECMWF) Thermodynamic Initial Guess Retrieval database (TIGR; Chevallier, 2001) in June are used to determine model coefficients of the SWLR technique. The model coefficients for the PSW technique has been determined using the brightness temperatures for the GMS-5 split-window channels, which are calculated from the Radiative Transfer for Tiros Operational Vertical Sounder fast radiative transfer model (RTTOV-8: Eyre et al., 1993), and TPW values on June 6 and July 1, 2002 from Regional Data Assimilation and Prediction System (RDAPS) of the Korea Meteorological Administration (KMA). Fig. 2(a) shows TPW of ECMWF TIGR vs $\ln[(T_{11}-T_{air})/(T_{12}-T_{air})]$, which is on right hand side of Eq. (3), to determine the models coefficients ($\Delta\alpha$, $\Delta\kappa$) and T_{air} of the SWLR technique (afterward refered to as SWLR-1 method). Fig. 2(b) shows TPW of ECMWF TIGR vs TPW retrieved from the SWLR technique. The root-mean-square error (RMSE) is 7.94 mm, and the correlation coefficient is 0.85. Similar works have been done to determine $\Delta\alpha$ and $\Delta\kappa$, but using T_{air} from ECMWF TIGR data at 600 hPa (afterward refered to as SWLR-2 method).

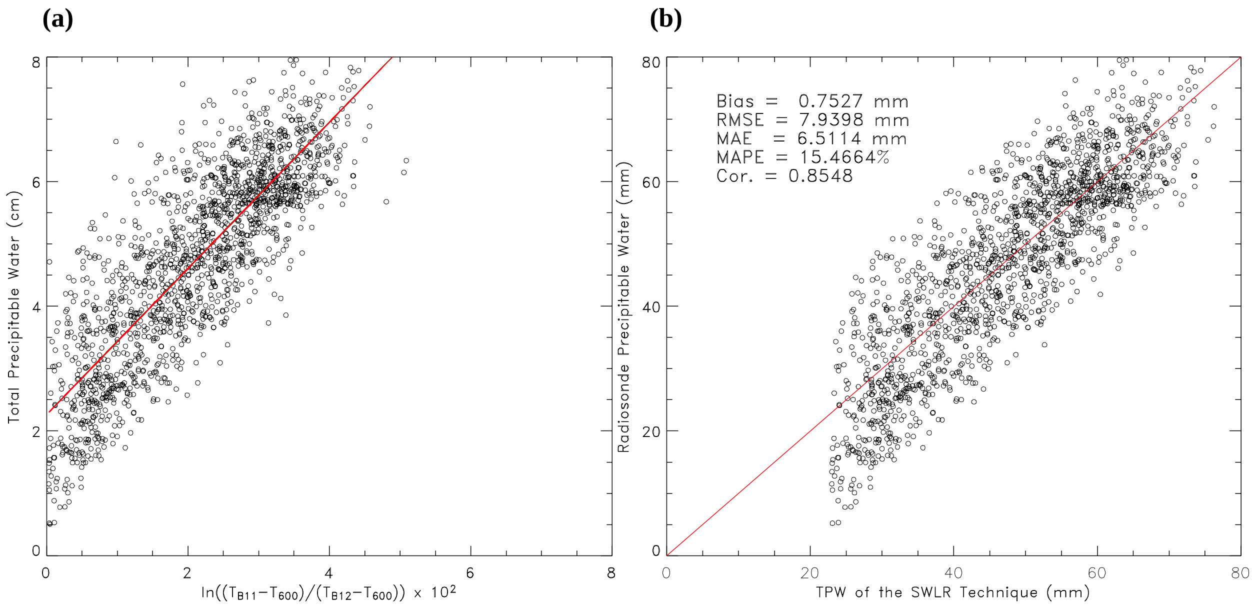


Fig. 2. (a) TPW of ECMWF TIGR vs $\ln[(T_{11}-T_{air})/(T_{12}-T_{air})]$, vs $\ln[(T_{11}-T_{air})/(T_{12}-T_{air})]$ and (b) TPW of ECMWF TIGR vs TPW retrieved from the SWLR-1 method.

4. Results

The two techniques are used to determine TPW using the brightness temperatures of the GMS-5 split-window channels on June 6 and July 1, 2002. The results for each case are described below.

4.1 Case I (June 6, 2002)

Fig. 3 shows GMS-5 imager data at 0000 UTC on June 6: data of (a) the visible (0.55~0.9 μm) channel, (b) the water vapor (6.5~7.0 μm) channel, (c) the infrared 1 channel (10.5~11.5 μm), and (d) the infrared 2 (11.5~12.5 μm) channel. Fig. 4 shows retrieved values of TPW, along with TPW of the RDAPS for comparison. White area indicates region where clouds exist. Figs. 4(a)-(b) show TPW retrieved from the SWLR-1 method and the SWLR-2 method, respectively. Fig. 4(c) shows TPW retrieved from the PSW technique, and 4(d) shows TPW of the RDAPS. The retrieved values of TPW from the SWLR technique are similar to those of RDAPS. In general, the SWLR-2 method gives a better comparison in the region with high TPW value than the SWLR-1 method. However, both methods reveal very large spatial gradients, for instance, in the southern part of China, and near clouds. Furthermore, they tend to overestimate in the region of small and large values of TPW. On the other hand, results from the PSW technique shown in Fig. 4(c) are in good agreement with TPW of the RDAPS. Only small difference can be found in the ocean. Fig. 5 shows comparison of retrieved TPW with that of RDAPS for clear sky region: (a) retrieved TPW from the SWLR-2 method, and (b) retrieved TPW from the PSW technique. The RMSE of the SWLR-2 method is 9.12 mm, while the RMSE of the PSW technique is 1.1 mm. The correlation of the PSW technique is almost 1, much better than the SWLR-2 method.

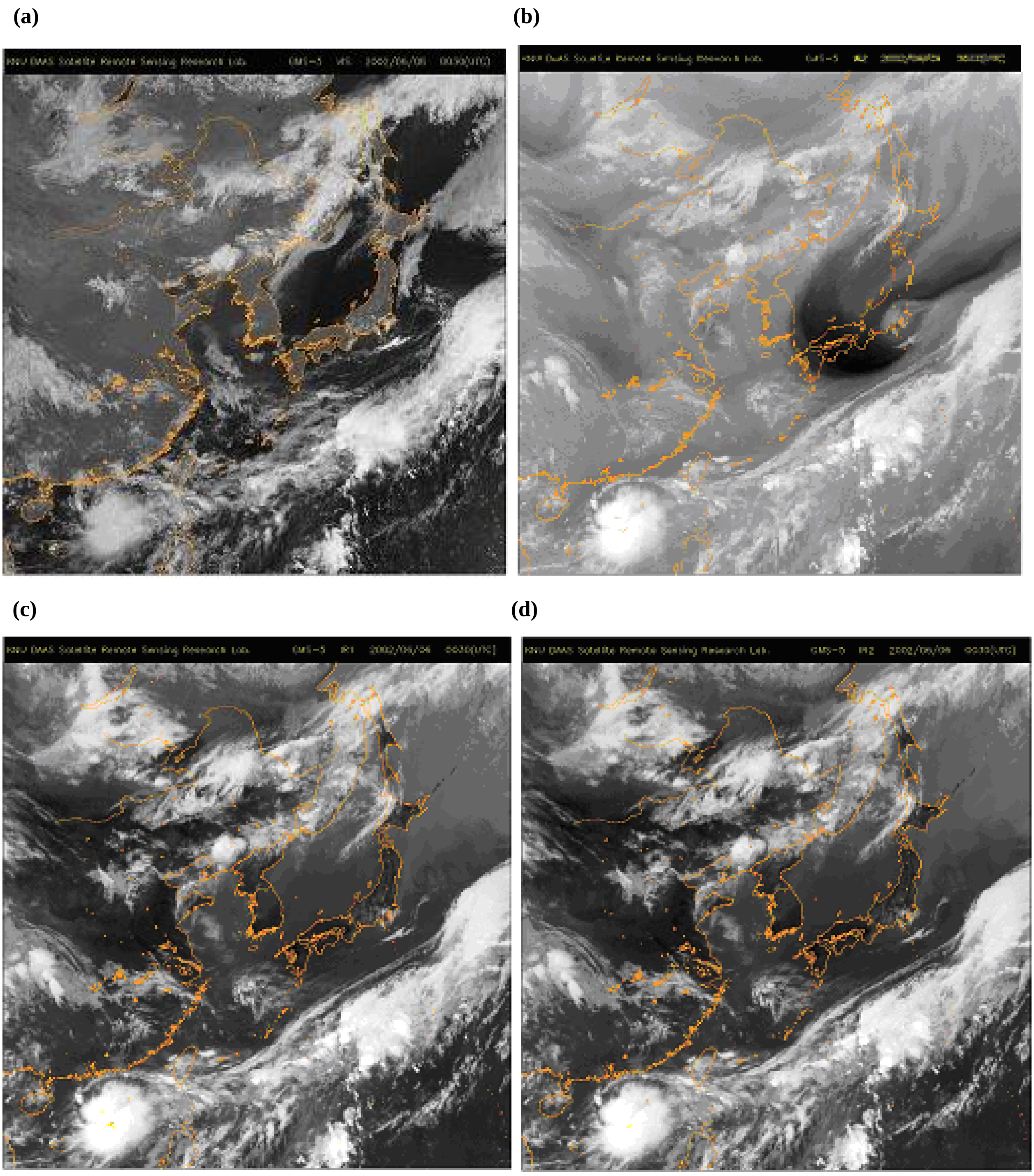
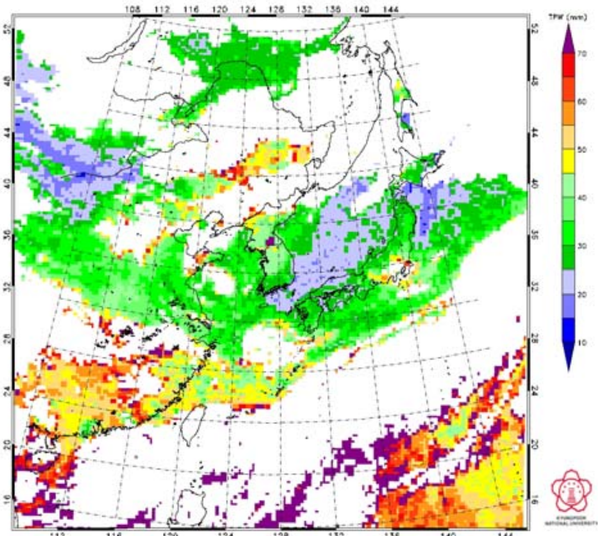
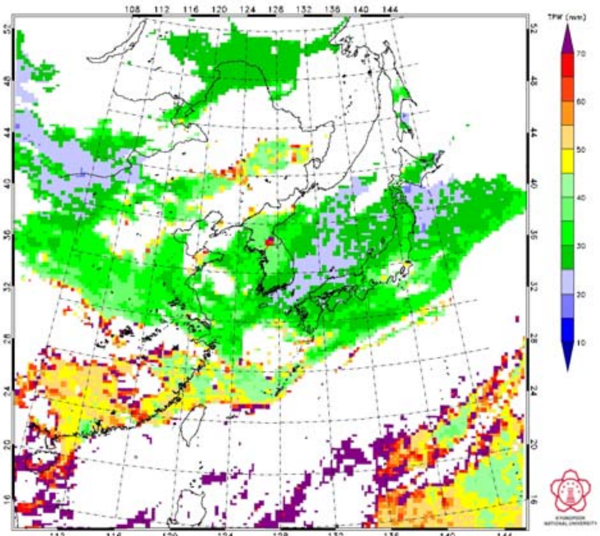


Fig. 3. GMS-5 data at 0000 UTC on June 6, 2002 (a) of the visible, (b) the water vapor, (c) the infrared 1, and (d) the infrared 2 channels, respectively.

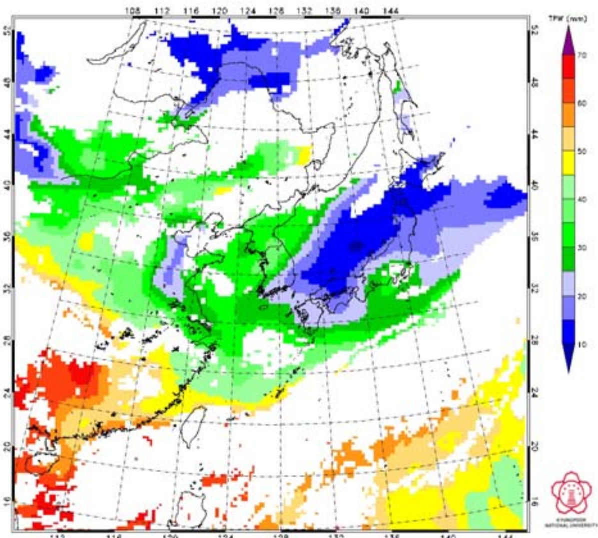
(a)



(b)



(c)



(d)

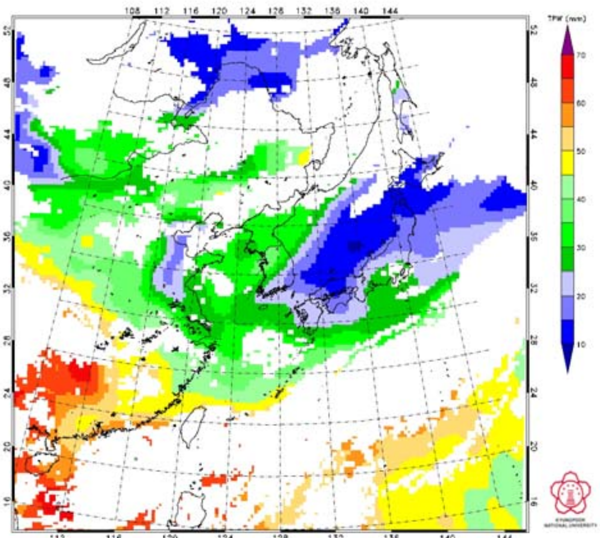


Fig. 4. Retrieved values of TPW and those of RDAPS at 0000 UTC on June 6, 2002. (a) TPW from the SWLR-1 method, (b) from the SWLR-2 method, (c) from the PSW technique, and (d) from the RDAPS.

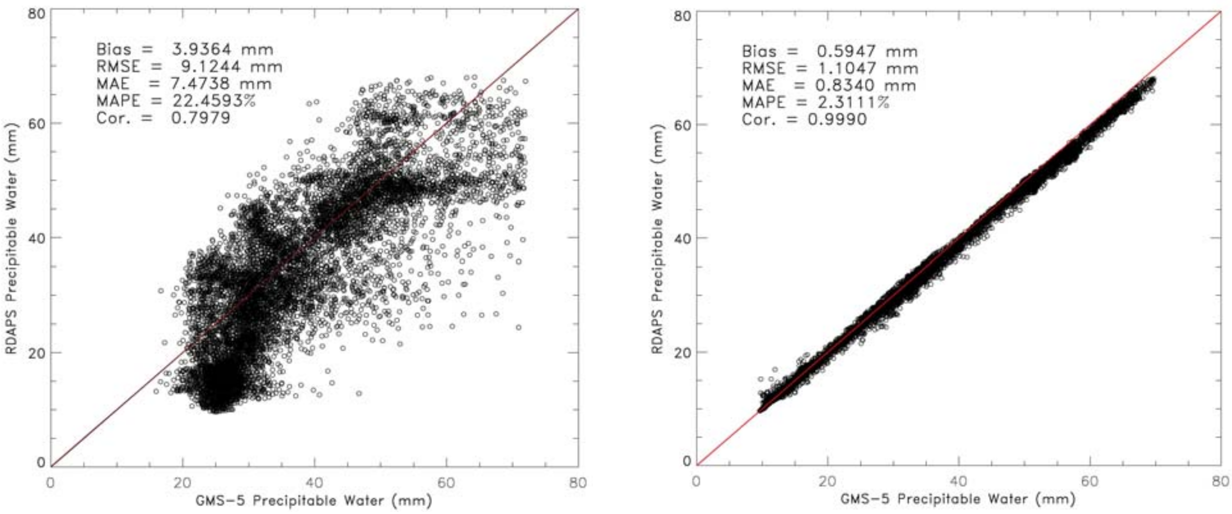
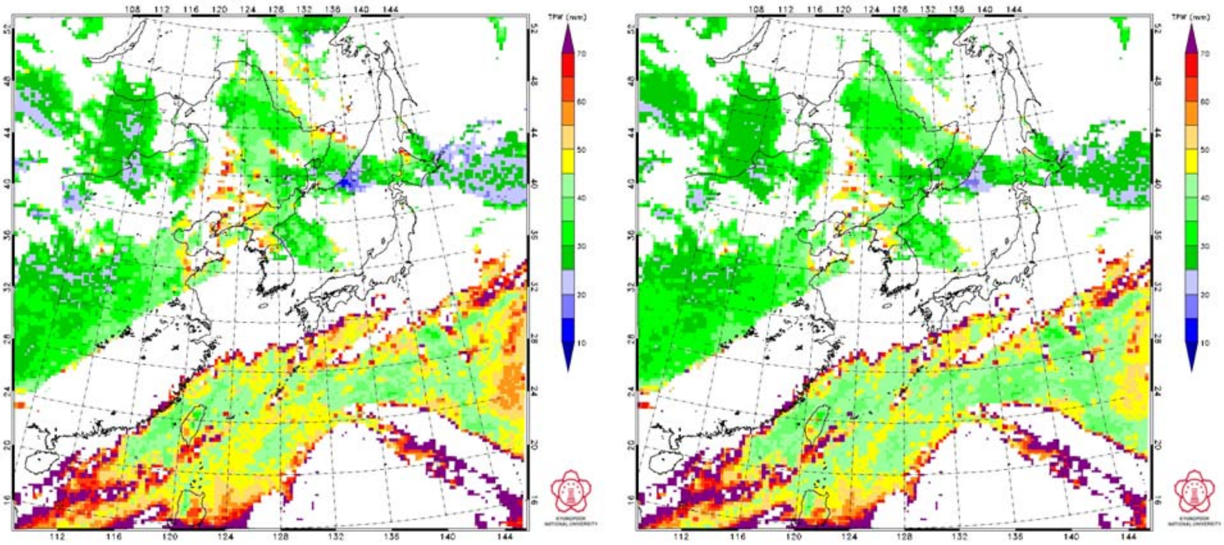
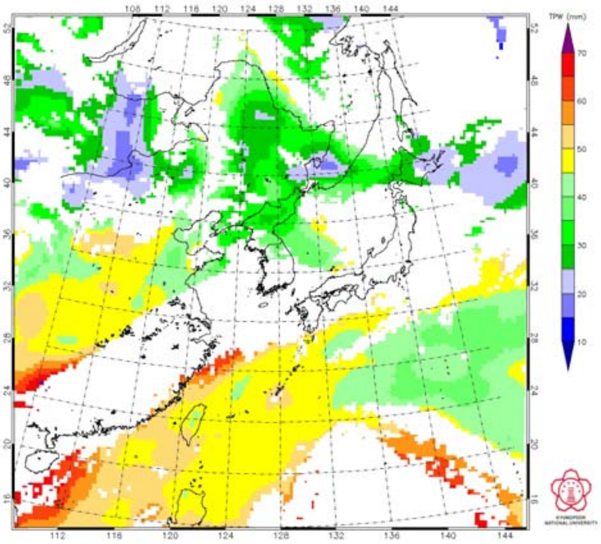


Fig. 5. Comparison of retrieved TPW with that of RDAPS. (a) retrieved TPW from the SWLR-2 method, and (b) retrieved TPW from the PSW technique.

4.2 Case II (July 1, 2002)

Retrieval has been done using the split-window data of the GMS-5 at 0000 UTC on July 1, 2002. Fig. 6 shows retrieved values of TPW and those of RDAPS for comparison. Spatial distribution of the retrieved TPW is similar to that of RDAPS. However, like the results for Case I, both SWLR methods reveal a large horizontal variation near clouds. Results from the PSW technique are in good agreement with RDAPS. For both cases shown here, the PSW technique gives much better results than the SWLR technique.





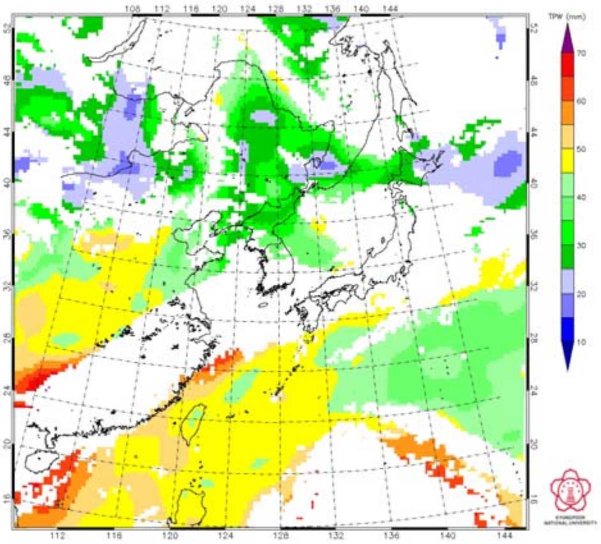


Fig. 6. Retrieved values of TPW and those of RDAPS at 0000 UTC on July 1, 2002. (a) TPW from the SWLR-1 method, (b) from the SWLR-2 method, (c) from the PSW technique, and (d) from the RDAPS.

5. Summary and Conclusion

Two split-window techniques, i.e., the SWLR and the PSW techniques, have been applied to retrieve TPW from GMS-5 data in the East-Asia region. Retrieved results are compared with TPW values of RDAPS for the same region. Comparison indicates that spatial distribution of TPW from both techniques is in good agreement with that of RDAPS. However, the SWLR technique reveal very large horizontal gradient near clouds, and tends to overestimate in the region of small and large TPW values. The PSW technique, compared to the SWLR technique, give a much better results. Magnitudes of TPW are close to those of RDAPS and horizontal gradients are in good agreement with RDAPS. The RMSE is 1.1 mm and the correlation is near 1.

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