Journal of the Korean Society of Remote Sensing, Vol. 14, No.4, 1998, pp.315~324

Total Precipitable Water Fields of Typhoons WALT(9407) & FAYE(9503) Derived from TOVS and SSM/I

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TOVS 자료로 도출한 태풍(WALT(9407)과 FAYE(9503))에 동반된 총가강수량장

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Abstract

The total precipitable water fields derived from HIRS(High Resolution Infrared Radiometer Sounder) and MSU (Microwave Sounding Unit) measurements of TOVS and brightness temperature of SSM/I were used to investigate the evolution of moisture fields for the Typhoon WALT(9407) which after landing in Japan it became tropical depression in Korea-Japan Strait, and FAYE(9503) which was the first tropical storm of 1995 to become a typhoon, respectively. The total precipitable water derived from TOVS observations is delineated according to the evolutions of WALT and FAYE movements because total precipitable water fields of TY WALT(9407) and FAYE(9503) were largely controlled by horizontal transport of water vapor over the Northwest Pacific Ocean which dominantly plays an important role in maintaining and accelerating their intensities toward Korea and Japan. These fields demonstrated that two major bands, which imply the rain bands, were locally well-organized and similar to the thick convective cloud features over Japan and the Korean peninsula while WALT and FAYE were approaching away and to. But the values of derived TOVS total precipitable water have shown the underestimate of those of SSM/I total comparatively for two typhoons.

Received 7 August 1998 ; Accepted 20 December 1998.

요 약

TOVS에 탑재된 마이크로파 센서(MSU)와 고감도 적외복사계(HIRS)로부터 도출한 총가강수량과 SSM/I 관측으로 계산한 총가강수량으로 일본에 상륙 후, 한일해협에서 열대성 저기압으로 약화된 태풍 월트(9407)와 1995년 처음 태풍으로 발달한 태풍 페이(9503)의 운동기간 중의 수증기장 변화를 조사하는데 사용하였는데, 이들로 태풍의 운동변화에 따른 수증기장 변화를 나타낼 수 있었다. 태풍 월트와 페이의 전가강수량장은 주로 한국과 일본을 향하여 다가옴에 따라, 그들의 강도를 유지하고 강화하는데 아주 중요한 역할을 하는 북서태평양 상에 수증기의 수평수송에 주로 좌우된다. 도출된 수증기장은 두 주요구름대가 월트와 페이가 다가오고 지나가는 동안 한반도와 일본상공의 강우대 임을 나타내는 두터운 대류운 형태와 유사함을 보였다. 그러나 도출된 TOVS 전가강수량의 값은 SSM/I 값과 비교할 때 상대적으로 과소평가되었음을 나타내었다.

1. Introduction

Meteorological satellite observations can provide much needed information on global and regional moisture distribution at higher temporal and spatial resolution. These calculations of moisture fields from satellite observations like TOVS except for ITPP(International TOVS Processing Package), although promising in many aspects, have yet to be developed fully. In particular, IR estimates currently do not have sufficient accuracy for numerical weather predictions (Le Marshall, 1988).

Total precipitable water(TPW) derived from TOVS observations appears very useful for various studies of the hydrological cycle (Cadet and Greco, 1987), as well as for the initialization of numerical weather models (Bengtsson and Shukla, 1988). The estimated PW in the atmosphere can be retrieved from linear combinations of the individual satellite channel Brightness Temperature (BT) observations in IR (Aoki and Inoue, 1982; Chester et al., 1987; Lipton et al., 1986; Tjemkes and Stephens, 1990) and in microwave bands (Alishouse et al., 1990; Wang et al., 1989; Wilheit, 1990). A better understanding based on more accurate analysis of moisture fields retrieved from satellite observations is needed to improve the analysis and prediction of tropical weather features and oceanic weather phenomena on the spatial and temporal synoptic scale (McGuirk et al., 1985; Smith, 1989).

The purpose of this study only presents preliminary result to derive the TPW used by regression algorithm of TOVS observations in the Far East Asia region and then shows the evolution of sequential moisture fields accompanied by the typhoons. Intercomparisons of calculated TPW developed by the regression algorithms were made among the regressive processed SSM/I(Special Sensor Microwave/Image) TPW fields over the Ocean accompanied with typhoon WALT(9407) from 0000UTC 24 to 1200UTC 27 July 1994 and FAYE(9503) from 0000UTC 21 to 1200UTC 24 July 1995, respectively. The WALT brought 100-150 mm rain in south-west of Korea with no casualty loss on July 25, 1994(Typhoon Committee Annual Review, 1994). And also the FAYE formed around 300 nm(550 km) south-southeast of Guam on 14 July 1995 and made landfall on the south coast of Korea with an intensity of 95 knots(49 m/sec) on 06UTC 23 July 1995.

2. Data and Methodology

Descriptions of the observing systems and summaries of satellite data collected can be found in the NOAA Polar Orbiter Data User's Guide and Smith et al. (1979) for TOVS. The NESDIS TOVS data formatted to the Condensed TOVS Data(CTD) was used by converting sounding data. The values of TPW are retrieved from TOVS infrared and microwave channel brightness temperatures which are chosen within 1 degree radii and 6hrs interval compared with RAOB(RAdiosonde OBservation) by means of stepwise linear regression(Chung, 1994). Generally, the most skillful predictors were boundary layer brightness temperatures of TOVS channels. Regression models which used some TOVS observations, surface observations calculated from RAOB, were the most successful. The best of these explained 87.5% of the variance, but the regression selected almost no TOVS channels, relying instead on RAOB and surface observations. TPW_{TOVS} above each bulk pressure layer is expressed by an equation of the form related to McGuirk's algorithm(1994) as

$$TPW_{TOVS} = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + ... + B_nX_n \quad (1)$$

where B_n are the regression coefficients, X_n are the selected variables names, which are prespecified by predictors, n is the number of variables, TPW_{TOVS} represents the vertical distributions of TPWs from TOVS BTs.

SSM/I observing systems and summaries of satellite data collected can be found in Katsaros(1990). The values of TPW are retrieved from brightness temperature of SSM/I which is chosen within 1 degree radii and 6 hrs interval compared with RAOB by means of stepwise linear regression(Sohn, 1998). $TPW_{SSM/I}$ is expressed by an equation of the form as

$$TPW_{SSM/I} = C_0 + C_1*\ln(286-Tb_{19V}) - C_2*\ln(286-Tb_{22V}) + C_3*\ln(286-Tb_{37H}) \quad (2)$$

where Tb is the brightness temperature of SSM/I and C_i is the regression coefficients.

Figure 1 shows three scatter plots of TPW_{TOVS} and $TPW_{SSM/I}$ against TPW_{RAOB} collocated within 1 degree radii and 6hrs interval and the value of Cloud Liquid Water(CLW) greater than

0.1 g/cm2 for June, July and Aug. 1995, respectively(Sohn et al., 1998). There shows the agreement of TPW_{TOVS} with $TPW_{SSM/I}$ for July and August, 1995, but for June TPW_{TOVS} has more outliers than those of $TPW_{SSM/I}$. The other result of the residuals versus predicted TPW_{TOVS} within the 1 degree radii shows with a rms error of 0.916 g/cm2 and a correlation coefficient of 0.72. But there

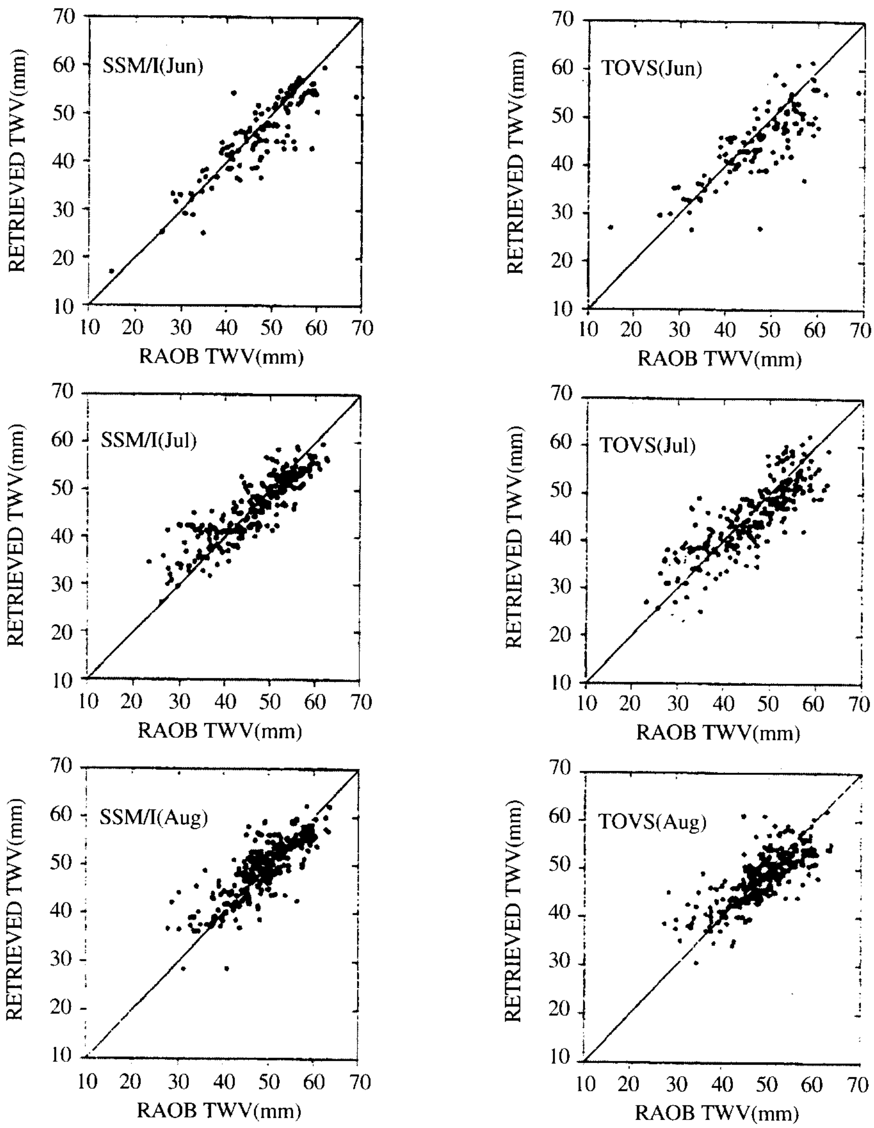

Fig. 1. Scatter diagrams of retrieved total water vapor a) SSM/I vs RAOB and b) TOVS vs RAOB when cloud liquid water is greater than 0.1 g/cm2 for June, July and August 1995, respectively.

are at least 3 outliers beyond $\pm 2\sigma$ when only about one is expected(Chung, 1994).

Figure 2 demonstrates the sequential locations of TY WALT(9407) and TY FAYE(9503), respectively. WALT(9407) deepened into a severe tropical storm in that afternoon as spiral cloudband structure became consolidated. With abundant supply of warm moist air over the open sea, WALT was able to strengthen rapidly into a typhoon in the next morning about the South China Sea.

Convective activity associated with the typhoon became subdued over cooler waters of south of Japan. It turned north-northeastwards on the early morning of July 24 as a result of erosion of the Pacific ridge near Japan and the approach of a westerly trough. As the westerly trough moved quickly eastwards, WALT failed to complete the process of recurvature. TY WALT moved disrupted by the terrain of Japan and it weakened into a tropical storm that night about 260 km norhteast of Kagoshima. As its organization further deteriorated, it was downgraded into a tropical depression on the afternoon July 26. It turned west-southwest the next day and

The track of Typhoon

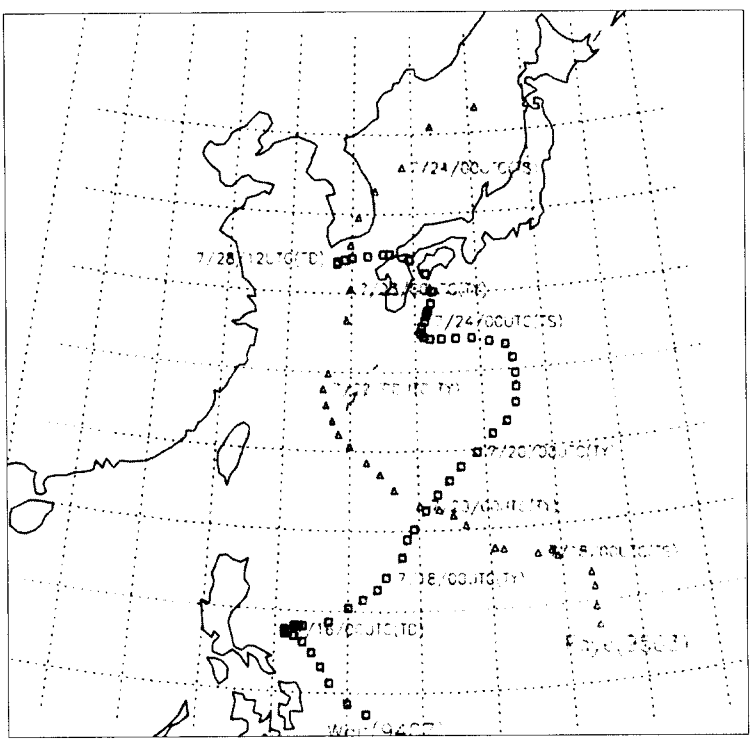

Fig. 2. The movements of TY WALT and TY FAYE during 0000UTC 21 July to 1200UTC 22 July 1995.

eventually dissipated over water after passing through the South Sea of Korean peninsula on July 27(ESCAP/WMO, 1994).

FAYE(9503) developed to Tropical Storm at the Western Pacific on July 16, 1995. It moved to NNE direction with TY strength (940hPa) and landed at southern part of Korean Peninsula on July 23, 1995. In Fig. 2, FAYE continued to intensify as it moved northwestward Okinawa. It was upgraded to a typhoon on the warning valid at 1200UTC 19 July. After passing to the southwest of Okinawa on 21 July, FAYE reached its peak intensity of 105 knots(54 m/s) at 1200UTC 21 as it was moving northward. Now on a north-oriented track, FAYE maintained its intensity to 0000UTC 23 July 1995.

It began to weaken after 0000UTC 23, while accelerating toward Korea. Shortly after 0600UTC 23, FAYE made landfall on the south coast of Korea with an intensity of 95 knots(approximately 49 m/s). Weakening rapidly over the Korean peninsula, FAYE was downgraded to a tropical storm on the warning valid at 0000UTC 24(not shown here) after it had recurved and entered the East Sea.

In postanalysis it was downgraded to a tropical storm about nine hours earlier, while it was over the mountains of Korea. Wind maximum of TY FAYE near landing point, Yeosu (47168), was 33 m/s at the time of landing. Precipitation amount in Korea, especially in southern coast, showed large local variability (30 - 220 mm), but gust was very strong. As an overall review, FAYE was a small but intense typhoon, and damages were mostly due to winds rather than precipitation in Korea(ESCAP/WMO, 1995).

3. Case Results

1) TY WALT(9407) 24-27, July 1994

The satellite observations which are valuable in revealing atmospheric water vapor fields accompanied with typhoon provide wider coverage and high spatial resolution rather than the conventional observations. Then in this study the $TPW_{SSM/I}$ is composited by the several orbital observations with the gap of each swath.

Figure 3 shows TPW_{TOVS} fields for TY WALT to delineate the consequent evolution of total precipitable water fields according to the movement of TY WALT. The maximum area of TPWs moves toward the south coast of Korean peninsula with some white gaps to represent the overcast areas by clouds without calculation. The intercomparison illustrated that the location of maxima for TPW_{TOVS} and $TPW_{SSM/I}$ were in agreement, but though the magnitude of TPW_{TOVS} and

$TPW_{SSM/I}$ maxima were different from in this figure. As a consequence these fields were very useful for testing the location of potential rainband accompanied with typhoon. From qualitative satellite observations one can state that the derived TPW_{TOVS} and $TPW_{SSM/I}$ look reasonable and match well with dense cloud band in TOVS and SSM/I images(Katsaros, 1990).

2) TY FAYE(9503) 21-24, July 1995

Figure 4 shows TPW_{TOVS} fields for TY FAYE to delineate the consequent evolution

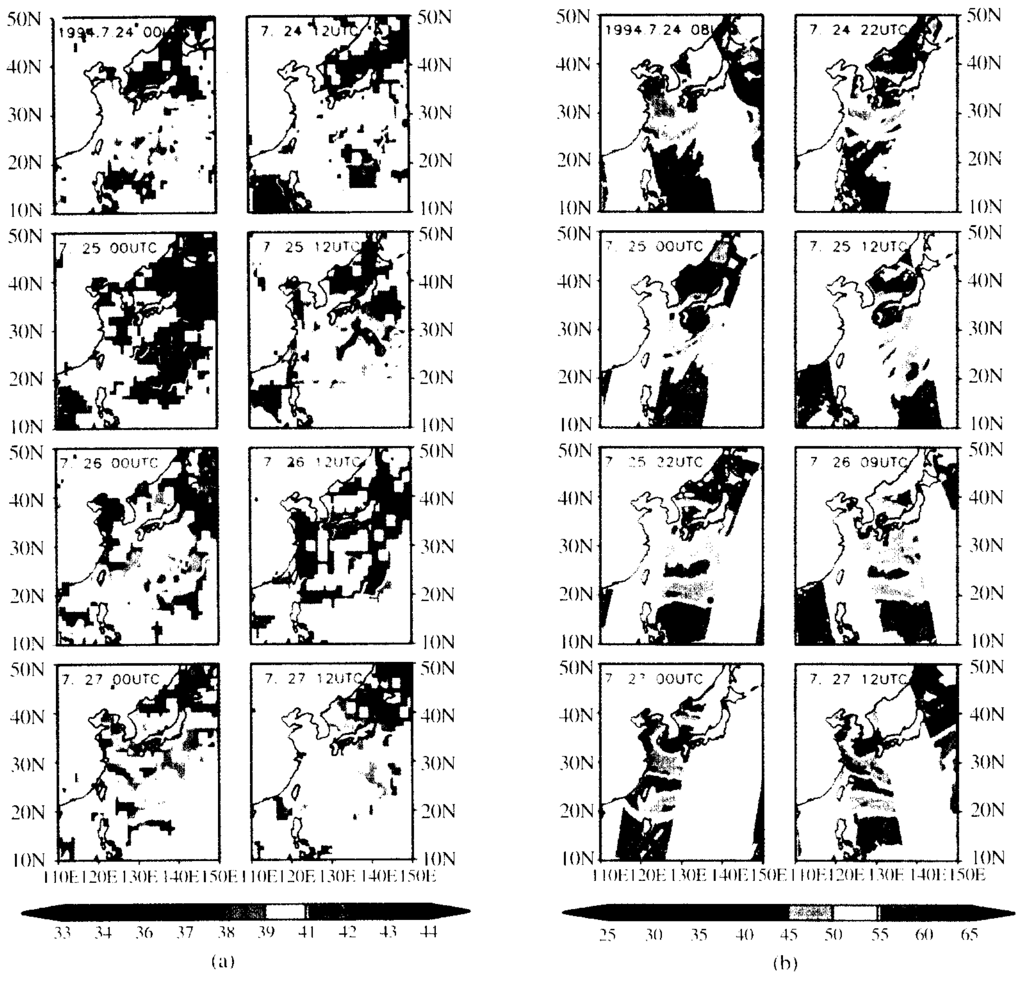

Fig. 3. The contour maps of total precipitable water for a) TPW_{TOVS}, b) $TPW_{SSM/I}$ of WALT(9407) from 0000UTC 24 July to 1200UTC 27 July 1994. The unit of color bar is mm.

according to the movement of TY FAYE. The procedure to construct these contour maps are similar to those described for Fig. 3. Obviously, a good agreement exists between TPW_{TOVS} and $TPW_{SSM/I}$ maxima but the value of TPW_{TOVS} shows less than that of $TPW_{SSM/I}$ in magnitude comparatively.

The maximum area of TPWs moves toward the south coast of Korean peninsula which is similar to $TPW_{SSM/I}$ to be composited by the several orbital observations with the gap of each swath according to the similar procedure as described for WALT.

On the contrast, the TPW_{TOVS} represents the partly cloudy or clear regions due to the cloud

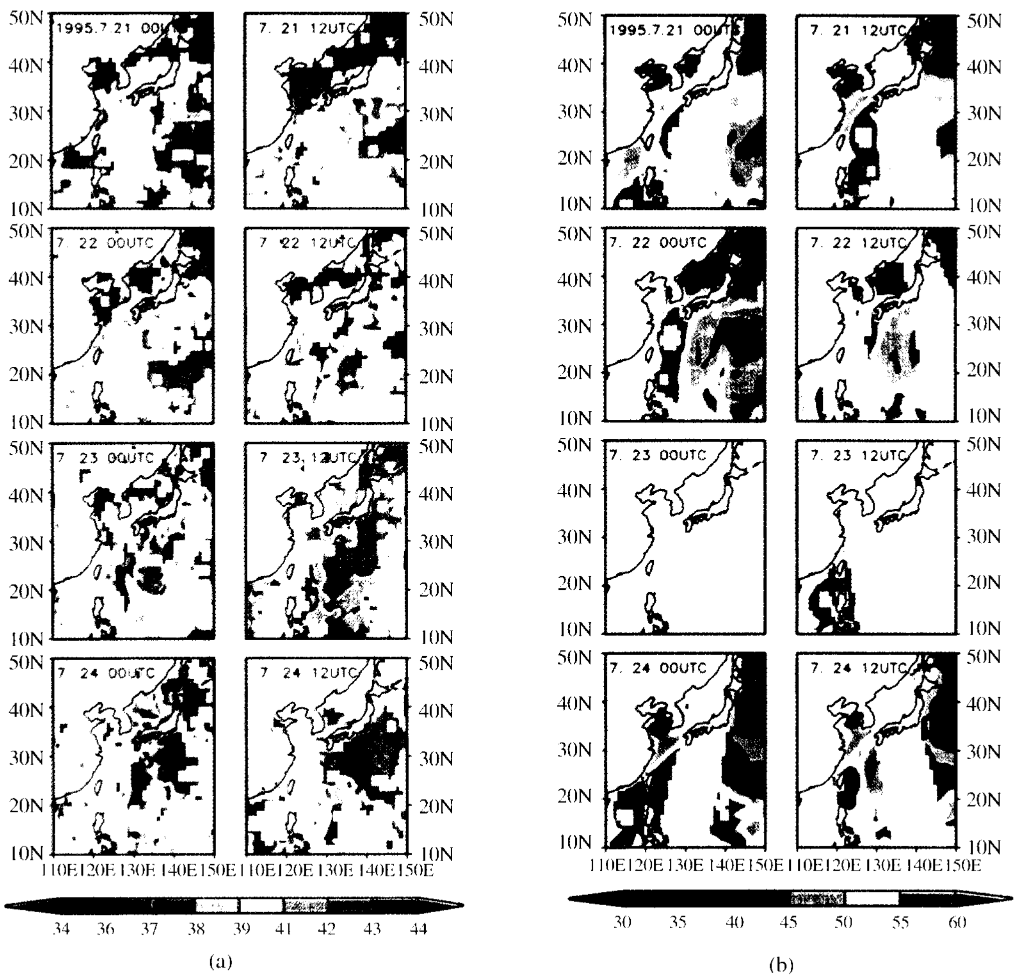

Fig. 4. The contour maps of total precipitable water for a) TPW_{TOVS}, b) $TPW_{SSM/I}$ of FAYE(9503) from 0000UTC 21 July to 1200UTC 24 July 1995. The unit of color bar is mm.

block. So the TPW_{TOVS} fields delineate the moisture surrounding to the FAYE. There exists the similarity of moisture feature corresponding to the sequential evolution of moving FAYE toward the south coast of Korean peninsula.

4. Summary

The total precipitable water fields derived from HIRS(High Resolution Infrared Radiometer Sounder) and MSU (Microwave Sounding Unit) measurements of TOVS and brightness temperature of SSM/I are used to investigate the evolution of moisture fields for the Typhoon WALT(9407) and FAYE(9503) can be delineated according to the evolutions of those movements. Even though the residuals versus predicted TPW_{TOVS} within the radius of 1.0o with a rms error of 0.916 g/cm^2 and a correlation coefficient of 0.72. But there are at least 3 outliers beyond $\pm 2\sigma$ when only about one is expected.

From qualitative satellite observations one can state that the derived TPW_{TOVS} and $TPW_{SSM/I}$ look reasonable and match well with dense cloud band in TOVS and SSM/I images(Katsaros, 1990). Total precipitable water fields of TY WALT(9407) and FAYE(9503) are largely controlled by horizontal transport of water vapor over the Northwest Pacific Ocean which dominantly plays an important role in maintaining and accelerating their intensities toward Japan and Korea. These fields show that two major bands, which imply the rain bands, are locally well-organized and similar to the thick convective cloud features over Japan and the Korean peninsula while WALT and FAYE are approaching away and to.

The values of derived TOVS total precipitable water show the underestimate of SSM/I total precipitable water comparatively for two typhoons. Due to two major problems inherent in all infrared moisture retrievals that tend to limit the dynamic range of the TOVS data, $TPW_{SSM/I}$ is higher in confidence level than TPW_{TOVS}: the inability to perform retrievals in areas of thick clouds can cause a dry bias(Wu et al. 1993) and the limitations in infrared radiative transfer theory can cause significant overestimation of water vapor in regions of large-scale subsidence(Stephen et al. 1994).

Acknowledgments

This research for estimating total precipitable water from TOVS observations has been supported by Korean Science Foundation(96-0703-04-01-3). Thanks are especially to Dr. J. McGuirk in Texas A&M University and to several satellite data and information services in the United States preparing for moisture analysis.

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