SATELLITE REMOTE SENSING OF METEOROLOGICAL FACTORS IN EAST ASIA

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1. INTRODUCTION

On the basis of the real-time receiving and preprocessing of TOVS/HIRS, MSU and GMS-4 data, the paper mainly focuses on the retrieval of temperature, cloud parameters, tropopause height and total atmospheric ozone content. On the other hand, Sea Surface temperature was retrieved by using GMS-4 and TOVS data, and a RMS 1.06°C is obtained. The Study of monitoring drought and precipitation by using MSU are also underway.

2. ATMOSPHERIC TEMPERATURE

By combining the characteristics of statistical and physical method, a new retrieval method, i.e., the Statistical-Physical Retrieval Method (STPRM) has been developed. We choose retrieval values (temperature) and retrieval factors (HIRS, MSU), set up a corresponding bank by construct retrieval coefficient matrix by statistical method. A brightness temperature (T_B) range distribution along a given TIROS-N satellite track for the different HIRS/MSU channels is shown in Fig.1. Several points at same latitude are selected to remove the effects of meridional variation and the associated T_B range spectrum for these points is shown in Fig.2. From these diagrams, the relationship between TOVS channels and cloud can obtained.

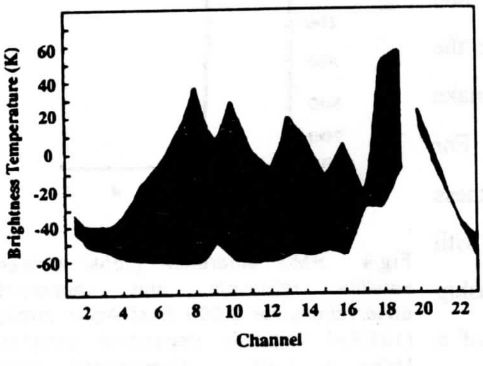

Fig.1 Brightness temperature range spectrum of TOVS channels for different points along a TIROS-N track (June 6, 1985). Abscissa positions 1-19 represent HIRS channels 1-19; position 20-23 represent MSU channels 1-4

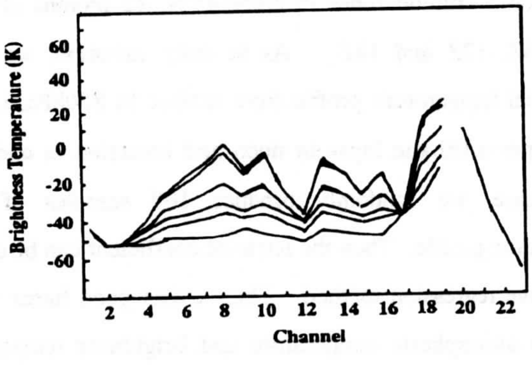

Fig.2 Brightness temperature range spectrum of TOVS channels for different points along same latitude (June 6, 1985). Abscissa convention is same as for Fig.1

2.1 Channels selection

On the basis of radiation transfer equation, the simulation calculation will be carried on in order to find the sensitivity channel for retrieval temperature and non-cloud effect channel. The amplitude of brightness-temperature change reveals the degree of cloud effect. The cloud effect on radiance is small in following channels: microwave channels, HIRS-1 and HIRS-17. Because the peak of weighting function of HIRS-17 is so high(~

5hPa), it is not suitable for retrieval factor. Four non-cloud effect channels, i.e., HIRS-1, MSU-2, MSU-3 and MSU-4 are taken to carry out the retrieval of atmospheric temperature profile. In order to promote the resolution of temperature profile, three combined channels are added:

$$\text{NEW-1} = (\text{MSU-2}) + 0.5(\text{MSU-3})$$

$$\text{NEW-2} = (\text{MSU-2}) + 1.5(\text{MSU-3})$$

$$\text{NEW-3} = (\text{MSU-3}) + 0.4(\text{MSU-4}) \quad (1)$$

The height-dependent channel weighting functions are shown in Fig.3. The temperature profiles are therefore retrieved with the 4 original channels minimally impacted by cloudiness, plus the three new combinations of MSU channels 2, 3 and 4. The retrieval tests show the combined channels improves the average retrieval accuracy by 0.21°C.

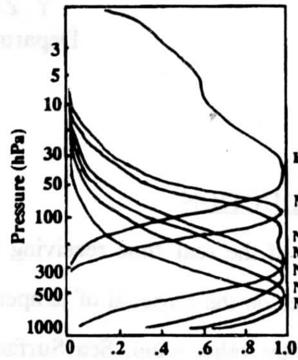

Fig.3 Weighting function profiles for HIRS-1, MSU-2 to 4 and NEW-1 to 3, where: NEW-1=(MSU-2)+0.5(MSU-3), NEW-2=(MSU-2)+1.5(MSU-3), and NEW-3=(MSU-3)+0.4(MSU-4)

2.2 Construction of the temperature bank

The average temperature profile in clear sky are taken as the referential temperature profile. Around the referential temperature, several small values will be randomly added in order to produce a set of new temperature profile. In order to improve the retrieval accuracy, we divide 5 latitude zones in 20°N-45°N, 12 months of a year and 00Z, 06Z, 12Z and 18Z. As to daily variation, we change the referential temperature profile from surface to 850hPa, i.e., to make near super-adiabatic lapse in noon and inversion in midnight. For every case, we randomly produce 100 samples of brightness temperature profile. Then the retrieval coefficient can be derived with successive regression method. There exists good linear relationship between atmospheric temperature and brightness temperature of a channel most closely associated to a given layer(Zhao, 1990). The correlation coefficients are approximately 0.75 for the near-surface layer (700hPa) and ⩾0.9 for layers higher than 780hPa.

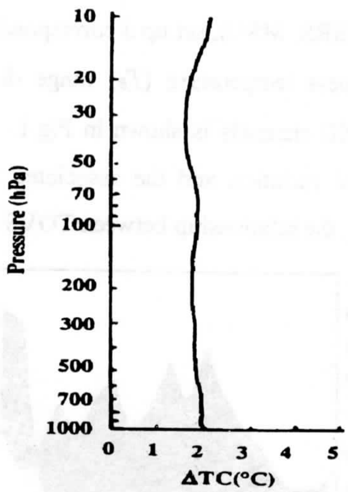

Fig.4 RMS difference profile between satellite retrievals and radiosonde observations for 8,089 East Asian profiles (108,494 vertically dependent samples). Mean is 1.8°C. Comparison period includes July, August, 1986; December 1988; January, May, July, August, October, 1989

2.3 Validation

Data of 64 radiosonde stations in the area 105°E-155°E and 15°N-45°N have been used for comparison with satellite retrieval results. Satellite data of NOAA-9,10 in eight months of 1986-1989 have been taken in practical test(July, August, 1986; December 1988; January, May, July, August, October, 1989). The comparison involved 8,089 separate profiles. Considering all profiles, the mean RMS deviation between the retrieval results of satellite observation and that of radiosonde data is 1.8°C with 108,494 vertically dependent samples which is nearly invariant with height, is shown in fig.4.

3. CLOUD AMOUNT AND HEIGHT

Two method presented here have been used to retrieve cloud parameters, including cloud amount and height.

3.1 Cross method

The cloud amount and height have been derived with HIRS-4~HIRS-7 data. Suppose cloud top pressure is P_c and that cloud amount is N^*, the radiance of satellite observation B_{obs} is:

$$B_{obs} = B_{cle} - N^*(B_{cle} - B_{cld}) \tag{2}$$

where B_{cle} is radiance in clear sky, B_{cld} radiance of cloud, subscript 1 and 2 stand for channel 1 and channel 2, respectively.

The criterion δ_{12} reads

$$\delta_{12} = | \, TM_1 - TM_2 \, | \tag{3}$$

where,

$$\begin{aligned} TM_1 &= (B_{obs1} - B_{cle1})(B_{cle2} - B_{cld2}) \\ TM_2 &= (B_{obs2} - B_{cle2})(B_{cle1} - B_{cld1}) \end{aligned} \tag{4}$$

We choose cloud sensitive channels as HIRS-5, HIRS-6, and HIRS-7, the criterion of cloud height δ is

$$\delta_{12} = \delta_{5,6} + \delta_{6,7} + \delta_{5,7} \tag{5}$$

where $\delta_{i,j}$ is the deviation of HIRS-i and HIRS-j. Setting δ at its minimum to get cloud height P_c, then cloud amount N^* can be written as

$$N^* = -\frac{1}{3}\sum_{i=5}^{7} [(B_{obsi} - B_{clei})/(B_{clei} - B_{cldi})] \tag{6}$$

3.2 Statistical Method

Another method to retrieval cloud amount by satellite TIROS-N TOVS observation is as follows. The i-channel radiance of cloudy sky I_i can be expressed as:

$$I_i = (1 - N^*) B_{icle} + N^* B_{icld}(T_c) \tag{7}$$

where B_{icle} is radiance of clear sky, B_{icld} radiance of cloud, and T_c the top cloud temperature.

According to simulation result of channels HIRS-4, HIRS-5, HIRS-6 and HIRS-7, we have

$$A_4 B_{4cld}(T_c) + A_5 B_{5cld}(T_c) + A_6 B_{6cld}(T_c) + A_7 B_{7cld}(T_c) = A_0 \tag{8}$$

where A_0, A_4, A_5, A_6, and A_7 are the regression coefficients. For this expression, the correlation coefficient is 0.999996, with a variance of 0.06 square radiance units.

From a set of Eqs.(7) and (8), we can solve

$$N^* = \left(\sum_{i=4}^{7} A_i B_{icle} - \sum_{i=4}^{7} A_i I_i\right) \Big/ \left(\sum_{i=4}^{7} A_i B_{icle} + A_0\right) \quad (9)$$

The cloud amount by satellite observation is similar to cloud amount by surface meteorological observation, but the satellite value N^* is smaller than that of surface meteorological value N. The relationship between N^* and N is given by:

$$N^* = 0.066 + 0.7N \quad (10)$$

Then cloud height will be obtained by solving radiation transfer equation through N calculated from N^*.

3.3 Example

A example by the cross method is shown in here. A distribution of satellite derived cloud amount N^* (given in %) along with station–based surface observed cloud amount N (given in %/10) are shown Fig.5. A cloud height distribution field derived from TOVS in comparison with various independent retrievals from Japanese GMS satellite measurements is shown in Fig.6. The coincident points are seen to be consistent with each other.

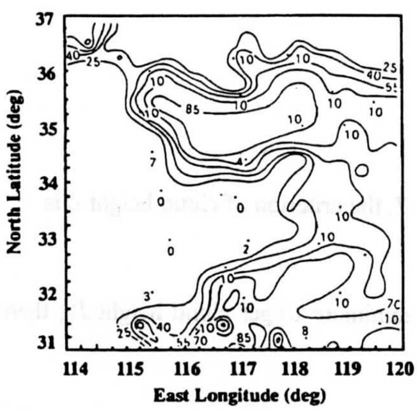

Fig.5 Distribution of satellite-derived cloud amount(%) along with surface-observed cloud amount (%/10) on July 12, 1986 (0626 GMT). Contours represent the TOVS retrieved quantities using a 15% contour interval. Numeric values situated next to periods represent the surface observations

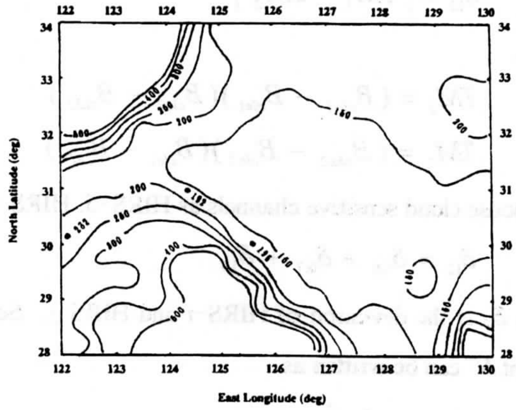

Fig.6 Distribution of satellite-derived cloud top heights(hPa) over ocean on July 11, 1986 (1905 GMT). Contour interval is 50 hPa. Solid dots are independent retrievals from Japanese GMS satellite measurements

4. TROPOPAUSE HEIGHT

The tropopause heights can be retrieved after the cloud correction procedure and clear brightness temperatures are obtained, (Zhao et al., 1993).

The tropopause height perturbations are introduced in a random fashion upon the reference profiles. A brightness temperature–tropopause height data bank is then generated from the RTE model. As with the temperature retrieval procedure, the data bank is divided into 5 latitude zones(for the latitude range 20°N–45°N) and for the 12 months of the year. The most sensitive channels(i.e., the largest K''s, where K'' is the sensitivity of channel,

$K'' = \partial T_{Bi} / \partial H_{Tp}$, H_{Tp} is tropopause height) are found to be HIRS-3, HIRS-4, HIRS-12, HIRS-16 and MSU-3. Because of a known relationship between tropopause height and ozone content, the HIRS ozone channel (HIRS-9) is also taken as a retrieval channel.

The tropopause height are then retrieved by a regression equation given by:

$$H_{Tp} = b_0 + \sum_{k=1}^{6} b_k T_{Bk} \tag{11}$$

where the b_k are regression coefficients, and k=1, 2, 3, 4, 5 and 6 denotes the 6 TOVS channels selected for the retrieval procedure(HIRS-3, 4, 9, 12, 16 and MSU-3).

Tropopause height results, derived from 3 months of satellite measurements (January/July 1989, January 1990) and compared to radiosonde observations, give an RMS deviation of 0.4km. As an example, the distribution of tropopause height for July 1989 is shown in Fig. 7. The results demonstrate a tropopause height gradient of approximately 0.073km deg^{-1} over the East Asian region.

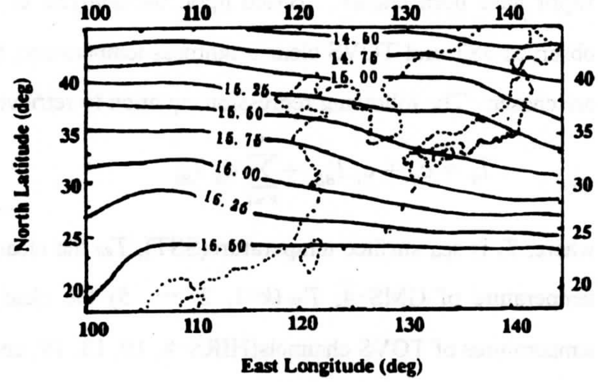

Fig.7 Satellite-retrieved distribution of monthly mean tropopause height (km) for July, 1989. Contour interval is 0.25 km

5. ATMOSPHERIC OZONE CONTENT

Using HIRS channels 1-4 and channels 8-9, the retrieval of total ozone content has been carried out for the East-Asian sector. Comparison with surface observations suggest that at least qualitatively, the retrieved fields are representative of the ozone distribution over East Asia. The iterative retrieval methods of Ma et al.(1984), Ma and Zhang(1986), and Smith(1970, 1983) are used. Cloud effects are eliminated using the HIRS procedure described in Section 3. First guess values of the ozone profile are obtained from radiances taken from HIRS channels 1-4 (Ma, and Zhang, 1986). An iterative procedure is then invoked using the HIRS-8 and HIRS-9 channel(Smith, 1970). The correlation coefficient between atmospheric ozone contents derived from the TOVS channels and ground-based Dobson spectrometer measurements taken in Beijing is 0.65 based on 34 samples. And an absolute deviation of 3.67% for retrieval is obtained. This intercomparison suggests the satellite retrievals are qualitatively

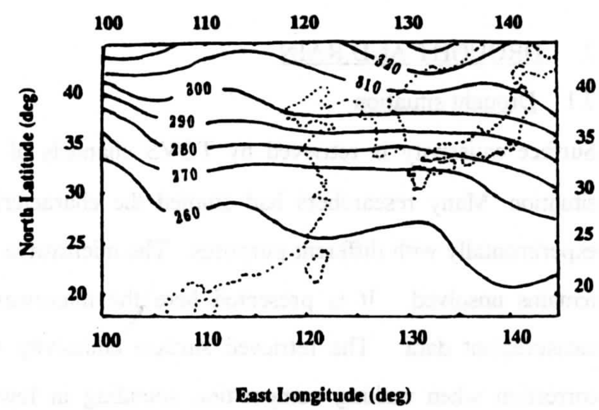

Fig.8 Satellite-derived distribution of monthly mean total ozone content (Dosbsons) for July, 1989. Contour interval is 10 Dobsons

representative. A spatial distribution field of atmospheric ozone over East Asia for July 1989, derived from the TOVS retrievals, is then shown in Fig. 8. The results are in general agreement with those of Bowman(1984).

6. SEA SURFACE TEMPERATURE

Sea surface temperature has been retrieved by TOVS and GMS data when the clear brightness temperatures of TOVS channels and GMS infrared channel are obtained(Li et al, 1997).

Considering the affection of water vapor absorption to SST retrieval, TOVS channels which are sensitive to water vapor have been chosen. Based upon the analysis of the correlation coefficients between the real Buoy-ship observed SST and TOVS clear brightness temperature, HIRS-8, 10, 18, 19, MSU-1, and GMS window channel are chosen. The following regression equation to retrieve the SST is obtained:

$$T_S = c_0 + c_1 T_{BB} + \sum_{k=1}^{5} a_k T_{Bk} \qquad (12)$$

where, T_S is sea surface temperature(SST), T_{BB} the clear brightness temperature of GMS-4, T_{Bk} (k=1, 2, ···, 5) the clear brightness temperatures of TOVS channels(HIRS-8, 10, 18, 19, and MSU-1), c_0, c_1 and a_k(k=1, 2, ···, 5) the regression coefficients.

The RMS deviation between the retrieval results of satellite observation and that of Buoy-ship data is 1.06°C with 379 samples. The correlation coefficient is 0.93. The precision is matched with that of other current multi-channel statistical models. A spatial distribution field of SST in the northwestern Pacific ocean for August 1993, derived from the TOVS and GMS retrievals, is shown in Fig. 9. The results are in general agreement with those of sea surface based measurements(JMA, 1993).

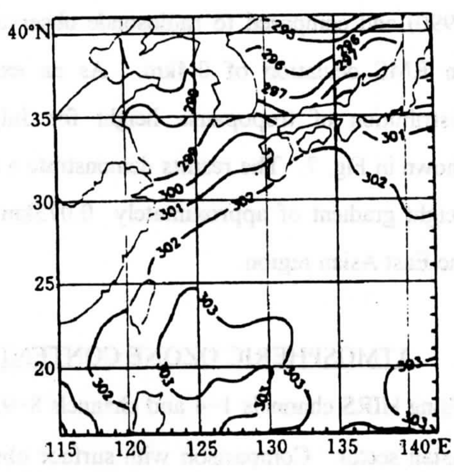

Fig.9 Satellite-derived distribution of monthly mean SST (K) for August, 1993. Contour interval is 1K

7. DROUGHT AND RAIN

7.1 Drought situation

Surface emissivity is retrieved by TOVS channels of MSU-1 and MSU-2 in order to monitor the drought situation. Many researchers had studied the characteristics of surface microwave emissivity theoretically or experimentally with different purposes. The microwave emissivity to composition sounding in lower atmosphere remains unsolved. It is presented here the microwave emissivity retrievals to different surface by actual measurement data. The retrieved surface emissivity can be used in the microwave brightness temperature correction when making composition sounding in lower atmosphere. It can also be used in surface type recognition and classification.

The microwave transfer equation is as following,

$$T_B = \varepsilon\,\tau(P_S)T_S + \int_{P_S}^{0}(1-\varepsilon)\left[\frac{\tau(P_S)}{\tau(P)}\right]^2 T(P)\frac{\partial\tau(P)}{\partial P}dP + \int_{P_S}^{0}T(P)\frac{\partial\tau(P)}{\partial P}dP \quad (13)$$

where, T_B is brightness temperature (K), ε the surface emissivity, P_S and P the surface and atmospheric pressure, T_S the surface temperature, $\tau(P_S)$, $\tau(P)$ the transmittance from top atmosphere to position P_S, P, and $T(P)$ atmospheric temperature at P (hPa).

The microwave emissivity calculated from channel MSU-1 is

$$\varepsilon = \{T_{B1} - \int_{P_S}^{0}T(P)\frac{\partial\tau(P)}{\partial P}dP - \int_{P_S}^{0}\left[\frac{\tau(P_S)}{\tau(P)}\right]^2 T(P)\frac{\partial\tau(P)}{\partial P}dP\} \Big/ \{\tau(P_S)T_S - \int_{P_S}^{0}\left[\frac{\tau(P_S)}{\tau(P)}\right]^2 T(P)\frac{\partial\tau(P)}{\partial P}dP\} \quad (14)$$

where T_{B1} is the brightness temperature measured by MSU-1 channel. According to the result of simulation calculation, it shows that the brightness temperature T_{B2} measured by MSU-2 channel is attributed mainly from troposphere. The influence of surface is small. As such, based on the simulation data set, regression analysis are made between T_{B2} and quantities pertaining to up, down direct radiation of T_{B1}. And from the up and down direct radiation calculated from the brightness temperature T_{B2} measured by MSU-2, along with the brightness temperature T_{B1} measured by MSU-1, the surface emissivity can be obtained. Fig.10 gives a distribution of monthly mean surface emissivity for October, 1989 in East Asian sector. It is well known, the emissivity of earth changes from 0.9 (very dry soil) to about 0.6 (wet soil). Fig.10 shows the emissivity in north of China is large and that is small in south of China, excluding the high plateau area. Fig.11 is drought distribution of China in autumn 1989. In Fig.11, the closed line for ε=90% located in Guangdong and Guangxi area, indicate the drought situation of south China in October. The drought tongue of ε=95% extended down to 35°N, 115°E shows the severe drought in Shandong Province. ε=100%, centered at 150°E, 45°N corresponding to the drought location and range in northeast of China. Based on the discussion above, it demonstrates the microwave emissivity can be used to show the soil moisture distribution, and indicates all the severe drought areas. It is a new method to monitor the agriculture climate, intensity and ranges of drought by satellite microwave window channels.

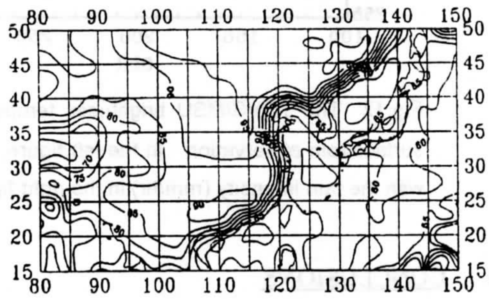

Fig.10 Satellite-derived distribution of monthly mean surface emissivity (%) for October, 1989. Contour interval is 5 (%)

Fig.11 Drought distribution of China in autumn 1989. The shadow lines demote the drought situation

7.2 RAINFALL

Rainfall in China has been studied by using TOVS/MSU brightness temperature T_B(MSU2) and outgoing longwave radiation OLR.

The TOVS/MSU brightness temperature T_B(MSU2) and outgoing longwave radiation OLR Vs surface rain observation shown in Fig.12. While high value of satellite brightness temperature T_B(MSU2) and high value of outgoing longwave radiation OLR shows no rain weather and while low satellite microwave brightness temperature and low value of outgoing longwave radiation is in response to rain weather.

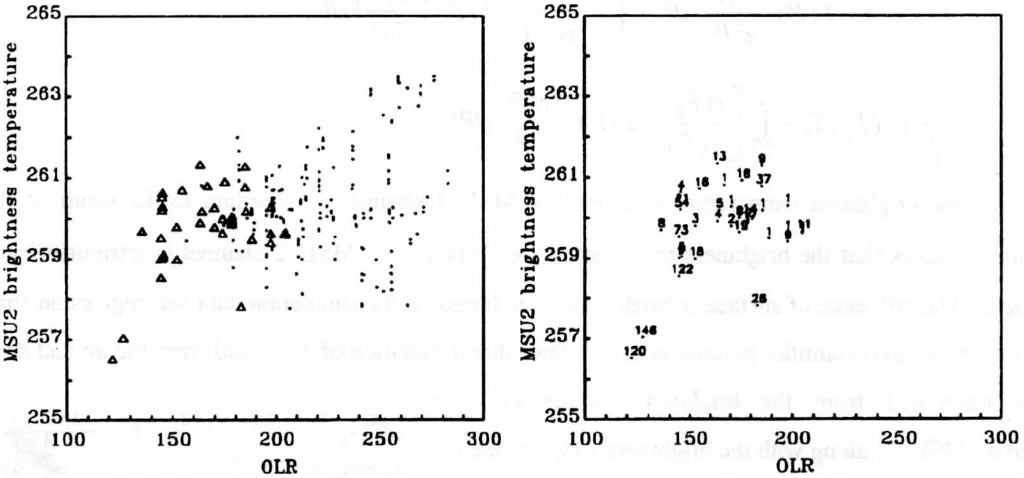

Fig.12 The TOVS/MSU brightness temperature *TB*(MSU2) and outgoing longwave radiation OLR Vs surface rain observation. In the left figure, the dots show no rain, and the triangles denote rain weather, with the rain intensity (mm/hr) in the right figure

8. CONCLUSIONS

The main results obtained from the TOVS data remote sensing over the East Asian region are as followsing:

(1) The use of one HIRS and three MSU channels minimally impacted by cloud, along with 3 new combinations of the MSU channels, provides the basis for an all-weather temperature retrieval procedure. The 8089 intercomparison between STPRM temperature retrievals and that of radiosonde observations gives an RMS difference of 1.8°C;

(2) Cloud parameters are directly obtainable from HIRS channels 4-7;

(3) Using the same cloud correction procedure, tropopause height can be retrieved from HIRS channels 3, 4, 9, 12, 16, and MSU channel 3. A retrieval case over the East Asian sector for July 1989 shows a north to south tropopause height gradient of 0.073km deg^{-1};

(4) Again, using the same cloud correction procedure, atmospheric ozone can be derived from HIRS channels 1, 2, 3, 4, 8 and 9 using an iterative method.

(5) SST can be retrieved from a multi-channel model using both TOVS and GMS data. The retrieval SST distribution retrieved by this model is in a good agreement with buoy-ship observation.

(6) Drought can be monitored by surface emissivity retrieval by window channels in MSU–1 and MSU–2. Also, rain can be monitored by MSU–2 and OLR.

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