Meteorological Satellite TIROS–N TOVS Remote Sensing of Atmospheric Property and Cloud

Zhao Bolin (赵柏林), *Zhu Yuanjing* (朱元竞), *Zhang Chengxiang* (张呈祥)
Zhen Jinming (甄进明) and *Zhang Wenjan* (张文建)
Department of Geophysics, Peking University, Beijing 100871
Received June 8, 1992; revised April 5, 1993

ABSTRACT

In this paper, a new retrieval method, i.e., the Statistical–Physical Retrieval Method (STPRM) has been developed. It is a combination of both statistical and physical method. On this basis, a retrieval system of temperature–humidity profiles and cloud parameters has been developed. By use of the developed TOVS STPRM the distribution of atmospheric temperature, humidity and geopotential height on isobaric surface can be obtained. In comparison with the statistical method and physical method, the TOVS STPRM system not only has the advantage of convenience in use, quickness in data processing and accuracy in retrieval result, but also can display cloud evolution on screen.

Key words: TOVS, Satellite remote sensing

I. INTRODUCTION

There are two kinds of retrieval methods for meteorological satellite TIROS–N TOVS, one is statistical method and the other is physical method (Lauritson et al., 1979; Smith et al., 1983; Weinreb et al., 1981). A combination of both statistical and physical method has been developed, and we name it the Statistical–Physical Retrieval Method (STPRM).

II. TOVS STATISTICAL–PHYSICAL RETRIEVAL METHOD AND TEMPERATURE RETRIEVAL

By combining the characteristics of statistical and physical method, a new method, i.e., Statistical–Physical Retrieval Method, is founded here. We choose retrieval value and retrieval factor, set up the corresponding bank by calculation with radiative transfer equation and construct retrieval coefficient matrix by statistical method, which will be used in real time retrieval.

1. *To Choose Retrieval Factor*

By radiative transfer equation (1), the simulation calculation will be carried on in order to find the best retrieval factor for the retrieval value.

$$I_i = \chi_i B(T_s)\tau_i(p_s) - \int_0^{p_s} B_i(T)\frac{\partial \tau_i}{\partial p}\,dp, \tag{1}$$

where I_i is observed radiance, p is pressure, p_s is surface pressure, χ_i is surface emissivity, τ_i is transmittance, B_i is Planck function, T_s is surface temperature.

At first, we discuss cloud effect on TOVS channel radiances. 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 MSU 1 is used to determine surface microwave emissivity and the peak of weighting function of HIRS 17 (~ 5 hPa) is too high, they are not suitable for retrieval factor. We take 4 non-cloud effect channels, i.e., HIRS 1, MSU 2, MSU 3 and MSU 4 to carry out the retrieval of atmospheric temperature profile.

2. Channels for Temperature Retrieval

There exist some errors from model of radiative transfer equation and observation of satellite instruments. In order to eliminate the errors, we check the observed satellitic data on calculated value with radiative transfer equation. The samples on plain in clear sky are chosen. In comparison the upward radiance with calculated radiosonde data, the correction may be carried out. By statistical regression, we have

$$T_b^{obs} = aT_b^{cal} + b, \tag{2}$$

where T_b^{obs} and T_b^{cal} are brightness temperature which is observed by satellite and calculated from radiosonde data with radiative transfer equation, respectively, a and b are parameters, dependent on different channels. By correction, the errors may be eliminated. Then the retrieval process can be carried on. We take HIRS 1, MSU 2, MSU 3 and MSU 4 as retrieval channels for temperature profile. In order to promote the resolution of temperature profile, we add several combined channels NEW 1, MSU 2+0.5MSU 1; NEW 2, MSU 2+1.5MSU 3 and NEW 3, MSU 3+0.4MSU 4. From above channel radiances, the retrieval formulae of temperature profile can be constructed.

Let sensitivity criterion K be

$$K = \partial T_{bi} / \partial T_j, \tag{3}$$
$$i = 1,2,\cdots m,\ j = 1,2,\cdots n,$$

where T_{bi} is the ith channel brightness temperature, T_j is the j^{th} layer temperature.

We choose retrieval factor of the j^{th} the layer by sensitivity criterion, and retrieval formulae of atmospheric temperature can be obtained by successive regression method.

3. Construction of Temperature Bank

We take the average temperature profile in clear sky as the referential temperature profile. Around the referential temperature profile, several small values will be randomly added in to produce a set of new temperature profiles. 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 850 hPa, i.e., to make near super-adiabatic lapse in noon and inversion in mid night. For every case, we randomly produce 100 samples of brightness temperature against temperature profile. Then the retrieval coefficient can be derived with successive regression method. There exists good linear relationship between atmospheric temperature and brightness temperature. The correlation coefficient is 0.75 on surface layer and >0.9 on the layers above 780 hPa.

4. Retrieval Result of Atmospheric Temperature Profile

Data of 64 radiosonde stations in the area 105°–155°E and 15°–45°N have been used for comparison with satellitic retrieval results. Satellite data of NOAA 9, 10 in eight months of 1986–1989 have been taken in practical test. The mean deviation between the retrieval result of satellitic observation and that of radiosonde data is ΔT = 1.8K (Data: radiosonde temperature profile 8089 and sample 108494). The results of 1989 are shown in Table 1.

Table 1. Deviation of Temperature Retrieved by TOVS in Comparison with Radiosonde Data (1989)

P hPa	January		May		July		August		October		Average
	ΔT K	sample	ΔT K	sample	ΔT K	sample	ΔT K	sample	ΔT K	sample	ΔT K
1000	2.64	907	2.29	1525	1.81	857	1.43	962	1.97	1948	2.02
850	2.49	1085	2.10	2035	1.66	1341	1.43	1626	2.32	2310	2.00
700	2.44	1085	2.23	2033	1.89	1342	1.28	1622	2.41	2305	2.25
500	2.37	1083	1.85	2031	1.69	1337	0.97	1627	1.99	2328	1.77
400	2.27	1085	1.89	2020	1.74	1334	1.17	1616	2.00	2328	1.81
300	2.31	1083	1.88	2012	1.87	1330	1.43	1606	1.78	2335	1.85
250	2.30	1084	1.75	2002	1.57	1319	1.29	1606	1.97	2312	1.79
200	1.86	1080	2.31	1983	1.41	1308	1.49	1591	1.78	2288	1.73
150	1.67	1079	2.24	1969	2.12	1294	1.30	1572	1.46	2288	1.79
100	2.11	1076	1.92	1914	2.39	1256	1.49	1537	1.85	2197	1.87
70	2.21	1007	1.68	1753	2.04	1133	1.30	1456	1.83	2070	1.82
50	2.02	961	1.86	1636	1.60	1075	1.37	1402	1.55	2018	1.68
30	1.64	833	1.53	1369	1.49	897	1.43	1194	1.37	1803	1.49
20	1.84	629	1.68	977	1.57	649	1.56	845	1.49	1382	1.62
10	2.21	59	2.34	102	2.16	67	2.59	92	1.91	221	2.24
Average	2.16		1.97		1.80		1.43		1.85		1.84

III. HUMIDITY

In the TOVS channels for remote sensing of humidity, there exists cloud effect. Before retrieval, transmission of radiance into equivalent clear column radiance has to be carried out and the CO_2 slice method (see IV) has been used to eliminate the cloud effect on radiance. In the TOVS humidity retrieval channel, there exists the important information of atmospheric temperature. While carrying on remote sensing of atmospheric humidity, we take not only TOVS humidity sensitive channels but also TOVS temperature sensitive channels, which are used to correct temperature effect of humidity retrieval. As the same as temperature retrieval, the average historical humidity has been taken as reference profile. We put random value into reference humidity profile to obtain a set of new humidity profiles. We choose channels with sensitivity criterion of humidity K'

$$K' = \partial T_{bi} / \partial W_j \tag{4}$$

$$i = 1, 2, \cdots m, \; j = 1, 2, \cdots,$$

where W_j is mixing ratio (g / kg). The relationship of retrieval factor and retrieval value can be found by successive regression method. We divide 5 latitude zones and 12 months in a year to form a set of regression formulae on each latitude zone and each month. The humidity retrieval 10 channels are from HIRS 4 to HIRS 13. In practical retrieval, they are recorded as NOAA 10, January, May, July, August and October 1989 in East Asia.

The total water vapor content and layer vapor content, i.e., the deviation between retrieval of satellitic observation and that of radiosonde are listed in Table 2.

The total water vapor content (1000–400 hPa) RMS deviation is 22%.

In summary, the TOVS system of Peking University. has following advantages: high accuracy, computer time saving and convenience for operation. With TOVS system of Peking University, the distribution of temperature, humidity and geopotential height on different pressure surfaces can be obtained conveniently (Fig.1).

Table 2. Deviation of Water Vapor Content Derived by TOVS Retrieval in Comparison with Radiosonde Data (1989)

ΔQ: g / cm^2

P hPa	January			May			July			August			October			Average
	ΔQ	%	sample	ΔQ	%	sample	ΔQ	%	sample	ΔQ	%	sample	ΔQ	%	sample	%
1000 −850	.20	33	672	.19	19	1286	.21	18	687	.18	15	642	.19	22	1465	19
850 −700	.14	42	673	.16	27	1286	.18	18	673	.16	17	642	.15	29	1436	21
700 −500	.12	60	678	.16	38	1286	.18	24	673	.19	28	638	.14	32	1302	37

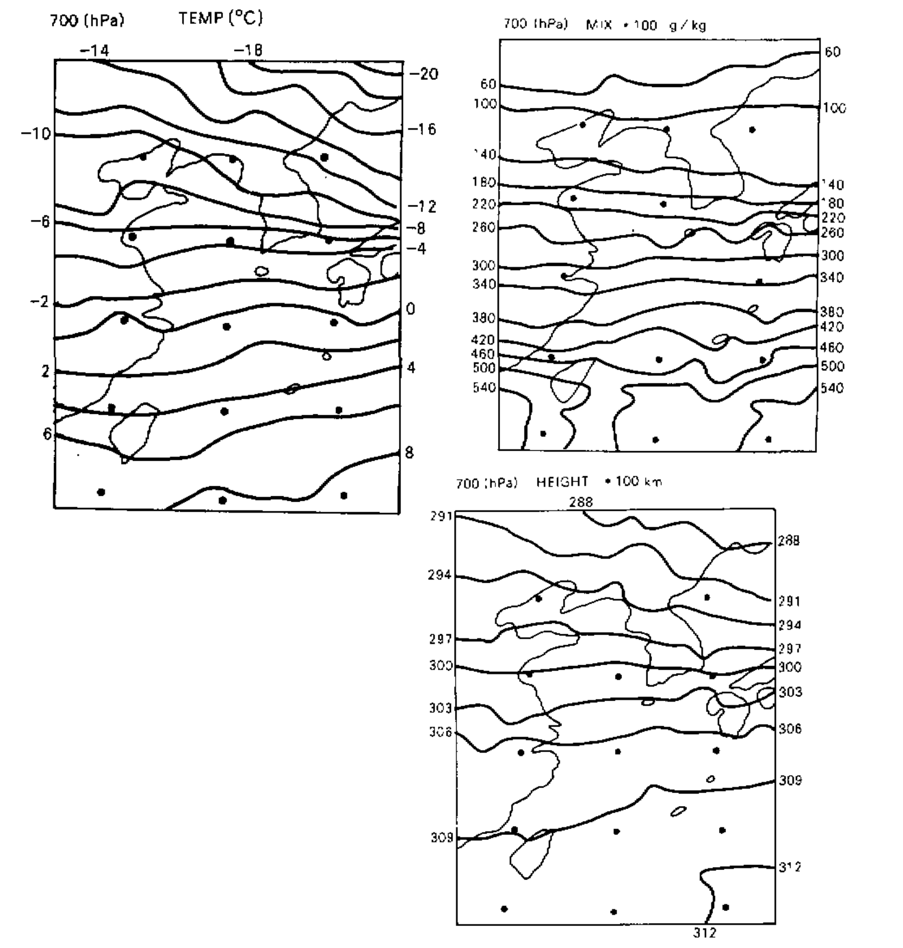

Fig.1. Temperature, humidity and geopotential height fields on 700 hPa pressure surface, TOVS retrieval, April 1, 1989, 231 GMT.

IV. CLOUD

Cloud parameters can be derived from TOVS infrared channels. Suppose cloud top pressure is P_c and that cloud amount is F_N, the radiance of satellite observation R_{obs} is

$$R_{obs} = R_{cle} - F_N(R_{cle} - R_{cld}), \tag{5}$$

where R_{cle} is radiance in clear sky, R_{cld} is radiance of cloud. According to Eq. (5), there exists a set of P_c–F_N solutions suitable for R_{obs} which can form a P_c–F_N curve. The P_c–F_N curves of different channels from HIRS 3 to HIRS 8 should cross at one point. Then the solution P_c and F_N can be obtained. Example of simulation results is shown in Fig.2. Now that there exist errors in observation and model calculation, their curves can not meet at one point. We choose two channels of them, i.e., Channel 1 and Channel 2. Taking their observed radiances as R_{obs1} and R_{obs}, the P_c–F_N solution can be derived from Eq.(5). We suppose TM1 and TM2 as follows:

$$TM1 = (R_{obs1} - R_{cle1})(R_{cle2} - R_{cld2}), \tag{6}$$

$$TM2 = (R_{obs2} - R_{cle2})(R_{cle1} - R_{cld1}), \tag{7}$$

where subscripts 1 and 2 stand for Channel 1 and Channel 2, respectively.

The criterion δ_{12}reads

$$\delta_{12} = |TM1 - TM2|. \tag{8}$$

By setting δ_{12} at its minimum, the solution P_c and F_N can be obtained.

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

$$\delta = \delta_{5,6} + \delta_{6,7} + \delta_{5,7}, \tag{9}$$

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 F_N can be written as

$$F_N = -\frac{1}{3}\sum_{i=5}^{7}\frac{R_{obsi} - R_{clei}}{R_{clei} - R_{cldi}}. \tag{10}$$

Examples are shown in Fig.3 and Fig.4. Solid lines are derived from TOVS, points in Fig.3 are cloud height derived from GMS. The distribution of TOVS brightness temperature can express cloud top height and degree of convection which can reveal the intensity of weather process.

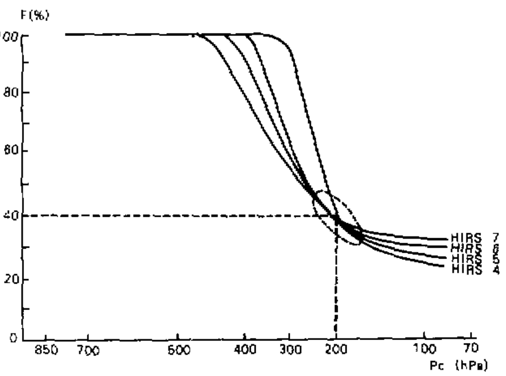

Fig.2. P_c–F_N curves of HIRS 4, HIRS 5, HIRS 6 and HIRS 7 at 19:05 on July 11, 1986.

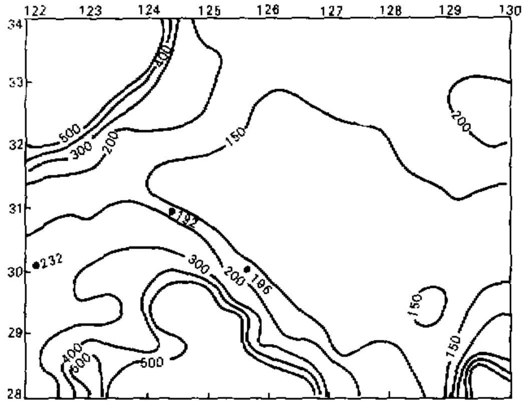

Fig.3. Cloud height P_c distribution ---TOVS • GMS, at 19:05 on July 11, 1986, unit: hPa.

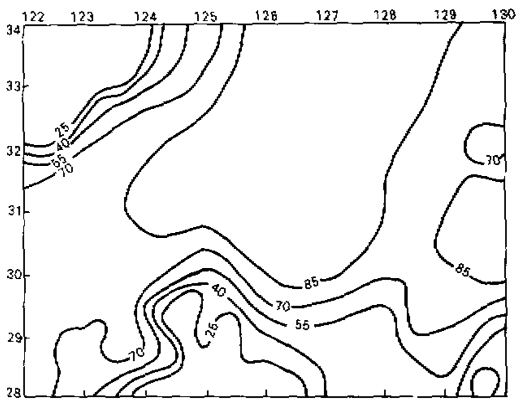

Fig.4. Cloud amount F_N distribution at 19:05 on July 11, 1986, unit: %.

V. CONCLUSION

In this paper, a Statistical–Physical Retrieval Method is developed. It presents a new idea in retrieval process. With TOVS Statistical–Physical Retrieval Method, the temperature–humidity profiles, distributions of temperature, humidity and geopotential height on pressure surface and cloud parameter can be derived. The TOVS Statistical–Physical Retrieval Method to deal with satellite data has the advantage of high accuracy. Owing to the short computation time it is useful for weather analysis and forecasting.

REFERENCES

Lauritson L., G.J. Nelson and F. W. Porto (1979), Data extraction and calibration of TIROS–N / NOAA radiometers, NOAA Technical Memorandum NESS 107, Washington D.C. 73pp.

Smith W.L., H.M. Woolf, C.M. Hayden, A.J. Schreiner and J. M. LeMarshall (1983), The physical retrieval TOVS export package. Tech. Proc. First TOVS Study Conf., Igls Austria, 227–261.

Weinreb W.P., H.F. Fleming, L.M. McMillin and A.C. Neuendorffer (1981), Transmittance for the TIROS Operational Vertical Sounder, NOAA Tech. Rep. NESS 85, 60pp.