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Study of the Simultaneous Physical Retrieval Method for Meteorological Parameters over the Continental Plateau of China①

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ABSTRACT

It is common knowledge that continental retrieval especially for Qinghai-Xizang Plateau has not been solved to date. In order to explore applicable inverse model and method for continent including the plateau, in this study authors use an improved simultaneous physical retrieval method hereafter referred to as the ISPRM, for computing meteorological parameters from NOAA-10 satellite TOVS data. The retrieval results verified by nearby radiosondes show that the ISPRM is more applicable for the continental plateau.

Key words: Retrieval method, Optimum first guess, Self-consistence, Forward Computation, Ground truth verification

I. INTRODUCTION

Qinghai-Xizang Plateau is the world's highest and largest one, which has the most complex and unique geographical feature, and it covers probably a quarter of the continent of China. Its existence has influence on weather and climate not only over the East Asia but also over the world. Lack of radiosonde stations makes weather forecast, numerical prediction and climate study extremely difficult. For the reasons above, the weather analysis technique for the plateau area of China has not yet been solved. Along with the rapid advances of space and computer technique, theory of atmospheric radiation and quantitative spectroscopy, this problem seems to be solved only by the combined techniques of satellite (or satellite platforms) remote sensing and retrieval method, as well as in-situ ground truth verification.

The simultaneous physical retrieval method (simply called SPRM) developed by Smith et al., (1983) is essentially different from usual single parameter retrieval methods. It has many advantages and is a more powerful and potential method. However, if this algorithm is adopted in operational practice for processing satellite data from the East-Asia continent including Qinghai-Xizang Plateau much work has to be done to it.

In order to realize the simultaneous retrieval algorithm, we started with ill-posedness of retrieval problem and did some theoretical analysis as well as comparison studies on the important factors causing retrieval errors in the SPRM (see Li et al., 1987, 1990, 1991; Wu et al., 1990; Zhang et al., 1992). Then we did some modifications to SPRM to improve the retrieval accuracy over China's continent. The modified SPRM is called ISPRM (i.e. improved SPRM). The improvement tests include: (1) deriving self-consistent simultaneous physical

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retrieval model instead of the inconsistent model; (2) choosing Barnes′ analysis technique (Barnes, 1973) to get three–dimensional temperature and moisture initial guess fields based on the nature of continental geography and dense radiosonde data over China region; (3) using the analysis fields to modify forward computed brightness temperature. The experiments show that the above three points can reduce effect of retrieval uncertainty; (4) performing an optimum selection of retrieval channels, for example, using HIRS / 2 channel 14 kernel function instead of the channel 7′s in SPRM and using channel 7′s ~~instead of channel~~ 10′s in SPRM as arbitrary pressure function of different retrieval solution; (5) reasonably determining surface pressure p_s reflecting effect of surface elevation. Our tests show that the last two points can improve retrieval accuracy near earth surface and particularly at the middle and lower tropospheric layers; (6) using three pairs of HIRS channels (channel 5 / 7, channel 5 / 6 and channel 6 / 7) instead of one pair (channel 5 / 7) in SPRM to do cloud parameter retrievals, which is similar to that described by Menzel et al., (1989).

The retrieval results verified by nearby radiosondes prove that the ISPRM is applicable for the continental plateau through 11 days 33 overpasses of NOAA–10 TOVS data processing. Further details of the results of comparison experiments between SPRM and ISPRM are available in the references (Li et al., 1991, Dong et al., 1991, Li et al., 1992).

II. SUITABILITY OF THE ISPRM FOR THE CONTINENT OF CHINA

In this section the basic aspects of ISPRM are simply introduced.

1. *Retrieval Model*

In the usual way, the non–scattering multispectral cloudless atmosphere remote sensing equation can be written in the perturbation form:

$$R - R^0 = B(p_s)\tau(p_s) - B^0(p_s)\tau^0(p_s) - \int_0^{p_s} B(p)d\tau(p) + \int_0^{p_s} B^0(p)d\tau^0(p) \ , \qquad (1)$$

where R, B and τ are radiance, Planck radiance and transmittance, respectively, in which the superscript ‘0’ indicates a priori condition and subscript ‘s’ indicates surface condition, R^0 is calculated by forward remote sensing equation, R is satellite measured radiance. All variables in Eq.(1) are pressure dependent. p_s indicating a natural surface pressure (e.g. land, ocean and cloud) is very important for retrievals over continental plateau. Because of the physical and optical effect from surface and contribution of elevation introduced in Eq.(1) through the p_s, the forward computation or the realization of inverse problem by Eq.(1) is related to accuracy of the determined p_s. Dependence of variables on wavenumber and dependence of R on instantaneous field of view (FOV) angle θ, and the spectral response function Φ_L as well as surface emissivity ε_ν in the boundary term in Eq.(1) have been suppressed to simplify the representation.

To construct a simultaneous retrieval model which is valid for the continental area including Qinghai–Xizang Plateau, first, we did some algebraic manipulation to Eq. (1) using the following variable combination form as:

$$B^0(p_s)\tau(p_s) - \int_0^{p_s} B^0(p)d\tau(p) - B^0(p_s)\tau(p_s) + \int_0^{p_s} B^0(p)d\tau(p) \ , \qquad (1')$$

and got the form:

$$\delta R = \delta B(p_s)\tau(p_s) - \int_0^{p_s} \delta B(p) d\tau(p) + \int_0^{p_s} \delta\tau(p) dB^0(p) \ , \tag{2}$$

where $\delta R = R - R^0$, $\delta B(p) = B(p) - B^0(p)$, and $\delta\tau(p) = \tau(p) - \tau^0(p)$. Second, using the other variable combination form to do the similar algebraic manipulation to Eq.(1), we can obtain a form as:

$$\delta R = \delta B(p_s)\tau^0(p_s) + \int_0^{p_s} \delta\tau(p) dB(p) - \int_0^{p_s} \delta B(p) d\tau^0(p) \ . \tag{3}$$

Obviously, both Eqs.(2) and (3) are full nonlinear integral equations, because all variables are nonlinear, such as R and B are nonlinear functions of temperature, but transmittance is that of atmospheric constituents. Why do we call this kind of equation Fredholm integral equation of the first kind? Because the integral limitation is bounded, and its inversion solution is ill–posedness, i.e., there is no unique solution to it. The numerical solution is also unstable, that is, the small errors in satellite observations, particularly in the kernel function propagate into the solution very much amplified (Li et al., 1988 and Fleming et al., 1986). Furthermore, Eqs.(2) and (3) are self inconsistence, i.e., it confuses known with unknown variables.

To solve this problem we continue to do some manipulations to Eqs.(2) and (3) and then get the simultaneous physical retrieval equation in another form:

$$\delta R = \delta B(p_s)\tau^0(p_s) - \int_0^{p_s} \delta B(p) \frac{d\tau^0(p)}{dp} dp + \int_0^{p_s} \delta\tau(p) \frac{dB^0(p)}{dp} dp$$
$$+ \int_0^{p_s} \delta\tau(p) \frac{d(\delta B(p))}{dp} dp \ . \tag{4}$$

If we do not consider the effect of the two–order perturbation term or the variation of temperature field is very little during a short period time, the last term of Eq.(4) can be negligible. In this case the above equation can be simplified as a full–consistent–nonlinear and ill–posedness simultaneous inversion equation:

$$\delta R = \delta B(p_s)\tau^0(p_s) - \int_0^{p_s} \delta B(p) \frac{d\tau^0(p)}{dp} dp + \int_0^{p_s} \delta\tau(p) \frac{dB^0(p)}{dp} dp \ , \tag{5}$$

where R is the functional of brightness temperature T_B, but the non–linear functions only appear in unknown function to be solved. On the other hand, if the variation of temperature field is significant, $B(p)$ is not equal to $B^0(p)$, directly solving Eq.(4), some new information is hopefully obtained.

To linearize the Eq.(5), each perturbation variable is expanded by Taylor series about a respective guessed value and higher order terms are ignored. Therefore a linearized self–consistent simultaneous physical retrieval model can be gotten:

$$\delta T_B = f(T^0, T_B^0, p_s)\tau^0(p_s)\delta T(p_s) - \int_0^{p_s} f(\dot{T}^0, T_B^0, p)\delta T(p) \frac{d\tau^0(p)}{dp} dp$$
$$+ \int_0^{p_s} f(u^0, T_B^0, p)\delta u(p) \frac{dB^0(p)}{dp} dp \ , \tag{6}$$

where fs are some known parameters.

With the discretization of Eq.(6) and then using a regularized least square solution (Smith et al., 1983), we can simultaneously get surface skin temperature, atmospheric temperature and moisture profiles and so on.

2. *First Guess Solution from Objective Analysis Field*

Due to the ill–posedness of retrieval problem, choice of method of constructing optimum first guess field is very important as a priori restriction in order to obtain stabilized and regularized solutions. Currently there are three kinds of methods for finding first guess solution. One is to use pattern recognition technique, that is, first, to set up a data base with matchups between radiosondes and satellite observations in space and time from a large number of data, for example, TIGR (TOVS Initial Guess Retrieval) data set used in 3I (Improved Initialization Inversion) developed by Chedin et al., (1985) then use the minimum variance principle according to satellite measurements and other auxiliary data in the TIGR data set to find the corresponding first guess solution. This method can improve retrieval accuracy, but the shortcoming is that it requires much computation time for finding an initial guess solution on–line and not valid for operational use; in addition sometimes there is a large departure between the first guess solutions for the same criterion due to the ill–posedness of Eq. (5). The second one is to directly use numerical prediction fields as first guess for retrieval. Since it may be closer to real atmospheric condition than climate data, its retrieval accuracy can be better than that using climate data. But it has a disadvantage of lower vertical resolution of the current prediction fields from the National Meteorological Center of China, especially over the East Asia region where the prediction fields have some obvious uncertainty due to the difficulty of processing the boundary condition. The third one is to use climate profiles as first guess of retrieval leading to an obviously lower retrieval accuracy.

In order to avoid these disadvantages mentioned above, we decide to use objective analysis fields of radiosonde data received by the Satellite Meteorology Center (SMC) of China as initial guess values in this experimental study. The specific steps are: 1) to select radiosonde stations according to the region appointed in advance which covers 70°E through 150°E longitude and 10°N through 70°N latitude; 2) to apply the fast Barnes' method to the selected radiosonde data over the region for objective analyzing and then get first guess fields with average fine grid of three–dimension on 0.5×0.5 latitude / longitude in size. Each grid has 13 pressure levels from 30 hPa to 1000 hPa for temperature, 10 pressure levels from 100 hPa to 1000 hPa for moisture, 10 pressure levels from 100 hPa to 1000 hPa for geopotential height; 3) to find the corresponding grid and get the first guess profile according to the retrieval box of a 3×3 array of scan spots, and then interpolate the temperature profile with 13 pressure levels to 40 TOVS pressure levels, in which the first guess above 30 hPa is determined by a combination of extrapolation and climatic value for lack of radiosonde data. First guess profiles of moisture with the 10 pressure levels are interpolated to the lower 20 TOVS retrieval levels. Up to now we have determined the first guess profiles required by the retrieval model.

3. *Modification to Error in Forward Computed Brightness Temperature*

The procedure of directly computing radiance (or brightness temperature) through remote sensing equations using a set of radiosonde temperature or moisture profiles is called forward computation. Since any physical retrieval starts with it, it's very important to perform forward computation. But currently due to some important physical parameters, such as surface emissivity ε_v and transmittance $\tau_v(p_s)$, etc., can not be determined accurately, as well as the effect of empirical correction to transmittance is not notable (Li et al.,1991 and Parikh, 1985). Therefore, more reasonable technique may be applied to estimate the statistic deviation of forward computed radiance from the associated satellite observed radiance and add this deviation directly to the computed brightness temperature to implement the correction to forward computed brightness temperature.

The specific steps are: 1) to find cloudless area with dense radiosondes and uniform physical topography according to cloud picture and synoptic chart during polar orbiting satellite overpass; 2) the radiosonde data over the area involved are objectively analyzed and interpolated to the 40 TOVS pressure levels, and up to 100 hPa for water vapor mixing ratio; 3) to match the satellite observations with radiosonde data from the objective analysis fields, and to compute each channel brightness temperature by forward model using the matched radiosonde data. But surface skin temperature is defined by split window method. When computing brightness temperature, cloud clearing is necessary (cloudy FOV is not used for this purpose); 4) to make statistic computation and obtain deviation (unit K) of measured channel brightness temperature from the computed one, as an example shown in Table 1 for NOAA-10 TOVS instrument.

This procedure is more convenient for using in operational retrieval system over the transmittance empirical correction technique. In order to eliminate seasonal influence, the statistic deviation needs to be updated routinely (Zhang et al., 1992).

Table 1. Biases between Observed and Calculated Brightness Temperature for NOAA-10 TOVS Instrument (unit K)

HIRS / 2 Channel	BIAS
1	-2.82
2	-1.21
3	-1.93
4	-0.52
5	-0.43
6	-0.13
7	-0.35
8	0.31
10	0.90
11	2.36
12	4.18
13	1.65
14	-0.87
15	-2.84
MSU-2	-0.70
MSU-3	-1.46
MSU-4	-1.05

4. *Determination of Surface Pressure p_s*

The importance of reasonably determining surface pressure has been pointed out in the previous section because surface elevation and surface thermal state are introduced into remote sensing equation through surface pressure, as well as both the forward and inversion are all related to reliability of determined p_s. Using the polytropic atmosphere pressure-height formula, p_s can be presented as

$$p_s = p_0 \exp\left\{-\frac{g}{R_d}\int_{Z_0}^{Z_s}\frac{dZ}{T_0 - r_T(Z - Z_0)}\right\}, \tag{7}$$

where z is elevation above sea level for scan spot, p_0 and T_0 indicate pressure and atmospheric temperature at Z_0, respectively, r_T is lapse rate of temperature, g and R_d are gravity acceleration and dry air constant, respectively.

Usually, p_0 is taken to be 1000 hPa, Z_0 and T_0 are taken to be geopotential height and climate average value of atmospheric temperature at 1000 hPa, respectively; r_T is taken to be 0.65 K / 100 m. In this case, the computed surface pressure is much different from the real surface pressure and further will cause significant errors in the computed brightness temperature, retrieved temperature and computed geopotential height, particularly, over the Qinghai–Xizang Plateau.

In the ISPRM, determination of p_s is based on the initial guess analysis fields. First, we find the surface elevation Z_s from the topography data set with high spatial resolution of 10 × 10 minutes in size by the location of retrieval box; second, we determine the retrieval pressure level (TOVS level) which is the nearest one to the elevation Z_s and then to get the parameters at the determined level from the analysis field profile as near real values of Z_0, p_0, T_0; r_T value is determined by interpolation of the values of two adjacent pressure levels. Experiment studies show that the accuracy of the determined p_s has an obvious improvement.

5. *Optimum Selection of Channels for Retrieving Atmospheric Parameters*

The SPRM chose to use the kernel functions of MSU channels 2 through 4 and HIRS / 2 channels 1,3 and 7 as the arbitrary pressure functions for NOAA–10 temperature retrieval. The reason for this selection is that the MSU channels are largely not inhibited by clouds and water vapor; the peaks of weighting functions of HIRS / 2 channels 1, 3 and 7 represent the thermal radiation contribution from upper, middle and lower atmosphere layers in vertical direction, respectively. But the channel 7 is very sensitive to water vapor from our numerical test, thus the use of channel 7 could make large error of temperature in lower atmosphere due to the error from the first guess of moisture profiles. The maximum value of the kernel function of channel 14 is near the 1000 hPa and sensitive to temperature radiation in the lower troposphere, also the disturbance caused by water vapor for channel 14 is less. Neuendorffer (1985) confirmed that the radiance of channel 14 is more sensitive to the change of temperature in the lower troposphere using standard step by step regression for radiosonde matchups under the clear skies. So the kernel function of the channel 14 instead of channel 7's is chosen for temperature retrieval in the lower troposphere and that of the channel 7 instead of channel 10's is appropriate for water vapor retrieval in this study.

6. *Determination of Cloud Parameters*

The HIRS / 2 radiometer has four channels (4–7) affected by cloud. In the ISPRM, the three of the channels (5–7) and the longwave infrared window channel are selected to calculate cloud parameters. Using the ratios of radiances of the selected channels, three cloud top pressure and three effective cloud amount determinations can be made. But the most representative cloud height p_{cld} and amount ($N\varepsilon$) are those that best satisfy the following equation:

$$R_{obs}(\nu_i) - R_{CLR}(\nu_i) - N_k \varepsilon_i \int_{p_s}^{p_{cld,k}} \tau(\nu_i, p) \frac{dB}{dp} dp = M_{i,k} \quad , \tag{8}$$

where $i = 5, 6, 7$, $k = 1, 2, 3$ for three sets of cloud parameters. The set which makes the minimum value of $\sum_{i=5}^{7} M_{i,k}^2$ is chosen. Concerned with retrieved results of cloud parameters(such as cloud pressure, cloud top temperature) may be seen from Dong et al. (1992).

III. COMPARISONS OF RETRIEVALS WITH RADIOSONDES

Strictly speaking, there is no objective and reasonable standard method for verifying the results of retrieval so far. Usually, the radiosondes are used as the criterion. Because the principle and technology of these two observing systems are completely different and have different inherent uncertainty themselves, there is only relative meaning for evaluation of retrieval results.

In order to realize the accuracy of retrieval results, first, to match the retrieval results with the radiosonde data in space and time and then calculate the statistical rms errors. Second, to analyze the retrieval results from the region of 70°E–150°E and 10°N–70°N using Barnes′ method. Furthermore, to use the same analyzing method to the corresponding radiosondes to the grids with the same size of the retrievals.

1. *Statistical Accuracy of Retrieval Results*

Tables 2–4 show mean rms errors of satellite temperature profile, thickness and mixing ratio profile compared with the matched radiosonde data for 11 days 33 overpasses in total over the period of January and February in 1990. Sometimes Beijing HRPT ground receiving station can obtain three contiguous orbits (A, B and C) covering most part of the East Asia: Orbit A covers the north–east part of China′s coastal and West Pacific Ocean; orbit B and orbit C cover the middle and west parts of China, respectively. In Tables 2–4, NO and RMS are the number of statistic sample and root–mean–square error of retrieval results, respectively. Comparing the results from the three orbits, it is clearly on the overall concept as the following:

The accuracies of temperature and thickness from orbit A are a little better generally than those from B at the same pressure levels. The main reason is the different complex degree of topography, in which the other conditions are completely identical. The accuracy of B is a little better than those of C. The retrieval accuracy decreases slowly from east to west at most of the pressure levels. It shows clearly that the contribution to retrieval errors is from the effect of surface radiation. In addition, there are a few radiosonde stations in the areas covered by orbits A and C. Although there are a large number of retrievals the available matchups are not so many, especially in Tibet Plateau for lack of radiosondes.

The arithmetic mean from the Tables 2–4 is calculated as follows: retrieval accuracy (rms) of temperature is 2.33 K for the orbit A; 2.46 K for the orbit B; 2.82 K for the orbit C (see Table 2). The accuracy (rms) of thickness is 26.0, 26.14, and 31.21 geopotential meters for orbits A, B, C, respectively (see Table 3); The average rms error of water vapor mixing ratio for orbit C is smaller than the other two orbits due to the facts that the content of water vapor over the plateau is relatively less and the atmosphere is cleaner (see Table 4). The orbit B has an accuracy of 0.678 g / kg and orbit A has an accuracy of 0.523 g / kg. It shows clearly that the quality of the whole retrieval profiles of ISPRM is much better than the SPRM′s through

Table 2. Mean Temperature RMS Errors (K) Compared to Radiosondes

P	A		B		C	
(hPa)	NO	RMS	NO	RMS	NO	RMS
1000	186	1.37	281	1.76	80	2.18
850	213	1.83	664	2.09	313	2.35
700	212	1.99	694	1.91	398	2.14
500	212	2.02	695	1.77	426	2.17
400	*218*	*1.93*	*677*	*1.83*	*415*	*2.13*
300	214	1.96	665	2.04	407	2.33
250	210	2.06	670	2.10	401	2.23
200	212	2.11	652	2.29	388	2.75
150	202	2.36	620	2.76	321	3.14
100	184	2.84	489	3.16	226	3.44
70	203	2.86	682	2.71	230	2.81
50	159	2.85	596	2.59	177	3.28
30	137	2.78	483	2.65	112	3.66
20	100	2.98	297	3.24	75	3.67
10	37	3.04	50	4.06	18	4.07

Table 3. Mean Layer Thickness Errors (Geopotential Meter) Compared to Radiosondes

P	A		B		C	
hPa	NO	RMS	NO	RMS	NO	RMS
850	191	14	287	11	96	24
700	218	12	660	18	317	23
500	219	22	697	21	395	23
400	221	15	689	16	435	16
300	210	18	677	20	421	20
250	211	12	679	14	413	16
200	218	18	675	17	401	20
150	205	16	647	21	379	26
100	194	22	605	23	365	26
70	53	34	281	30	109	46
50	207	41	679	34	247	33
30	150	49	499	43	124	53
20	148	45	390	40	96	48
10	33	47	39	58	11	63

Table 4. Mean Water Vapor Mixing Ratio Errors (g / kg) Compared to Radiosondes

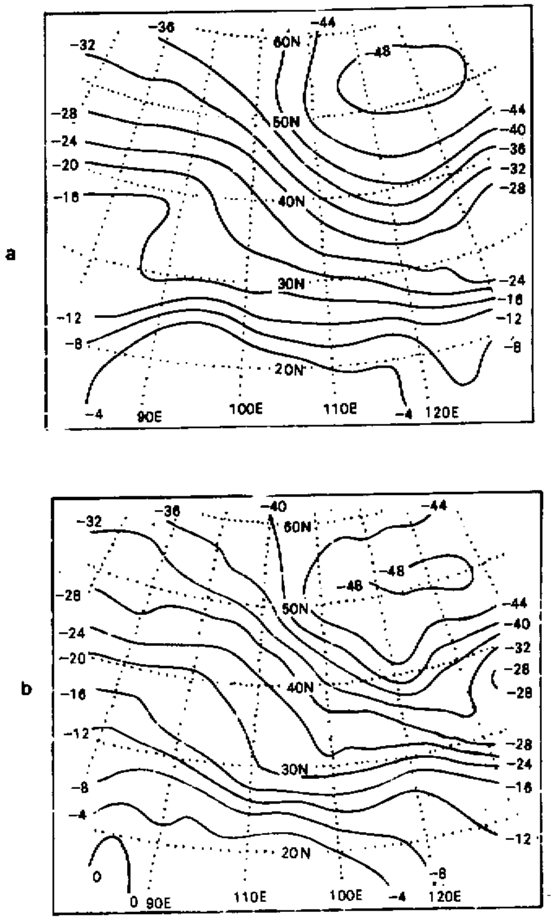
P	A		B		C	
hPa	NO	RMS	NO	RMS	NO	RMS
1000	195	0.593	280	1.026	81	0.265
850	220	0.901	669	0.954	324	0.616
700	218	0.785	694	0.995	404	0.493
500	180	0.509	586	0.616	388	0.184
400	149	0.257	483	0.345	260	0.078
300	58	0.076	474	0.130	229	0.034

analysis and comparison(Li et al., 1992, 1993). Especially, ISPRM's accuracy has been improved much more than retrieved accuracy of MVSPRM (Fleming et al., 1988) in the lower troposphere and near the surface.

2. *Analysis Fields*

Graphing of TOVS retrieval data is the key part for applying retrieved products to the weather analysis forecasting, climate studying and numerical prediction.

For instance, the temperatures and geopotential height are analyzed at the standard levels using the Barnes analysis scheme. The retrieved and radiosonde temperature fields at 500 hPa and associated with retrieved and radiosonde height fields at about 00 GMT 19 January 1990 are shown in Fig. 1(a–d), respectively. By comparing Fig. 1(a) with Fig. 1(b) and Fig. 1(c) with Fig.1(d) it may be seen that the configuration of temperature and height trough and ridge is reasonable; the weaker temperature fields of west part of continent are also very similar.



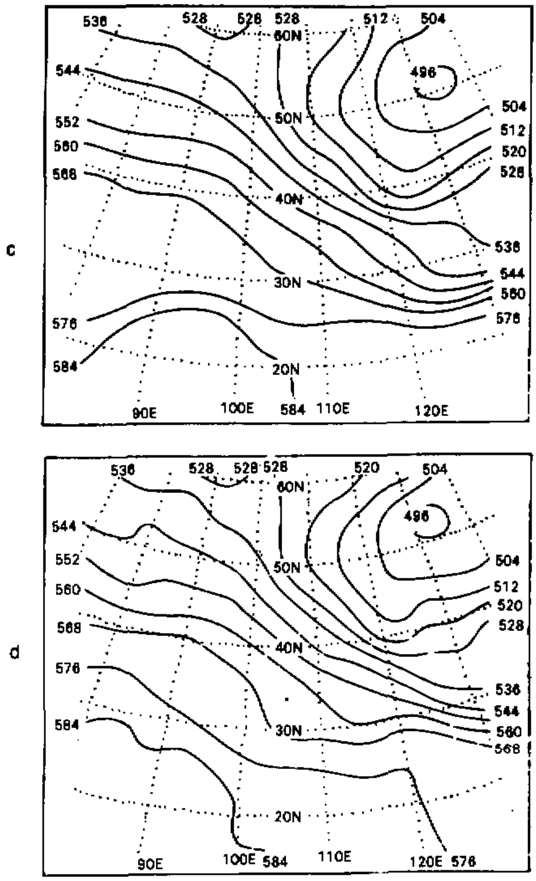


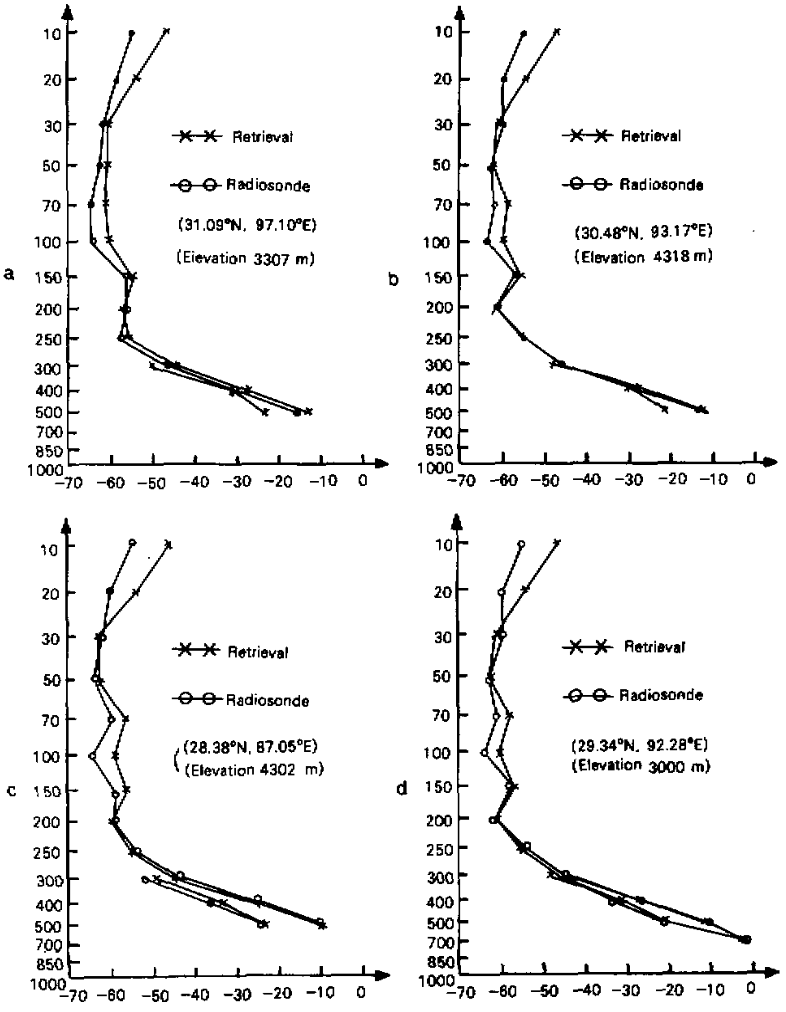
Fig. 1. Retrieved $T(P_{500})$ and Radiosonde $T(P_{500})$ analysis fields; retrieved $H(P_{500})$ and Radiosonde $H(P_{500})$ analysis fields.

IV. THE RETRIEVAL RESULTS OVER QINGHAI-XIZANG PLATEAU

There are no more than ten radiosonde stations in the plateau area, and the distribution of stations is not fit to the need of revealing weather system; as well as there is few radiosonde station in this area whose elevation is more than 3500 meters. Therefore the stations which can be matched for verification of retrievals are less, although we have lots of retrieval spots from satellite sounding data.

1. *Accuracy of Retrievals over Qinghai–Xizang Region*

As shown in Table 2, we can get the temperature accuracy of 2.8 K on the average by use of ISPRM in Qinghai–Xizang Plateau area (Orbit C) where they have varieties of geographic features including lower than 2,000 meters above sea level. But rms error over 3.5 K is retrieved by use of general physical retrieval method (see Li et al., 1990). This fact proves that ISPRM is applicable for obtaining the parameters of temperature and humidity over plateau area. Since the study of retrieval method for plateau is the most important part of this article, it is necessary to confirm the possibility of this retrieval method for the higher topographic areas. We selected the plateau region covering latitude from 40° to 25°N and longitude from 75° to 105°E, and matched retrievals with the radiosondes whose elevations are above 3,500 meters for six days, six orbits. As shown in Table 5, it can be seen that the rms errors of retrieval temperature (T) is 2.88 K at 500 hPa, 1.58 K from 400 hPa to 150 hPa, and 4.37 K near the tropopause (from 100 hPa to 70 hPa). This indicates that the level having the largest deviation in the plateau region is in the tropopause rather than in the surface. All of these indicate clearly that the low vertical resolution of current sounding unit is essential technical limit. In plateau area, the rms of geopotential thickness (H) calculated through retrieved temperature is 9 geopotential meters from 500 hPa to 400 hPa, 49 geopotential meters from 500 hPa to 70 hPa. The rms of water vapor mixing ratio (W) retrieved by use of ISPRM is 0.19 at 500 hPa, 0.109 g / kg at 400 hPa and 0.08 g / kg at 300 hPa.



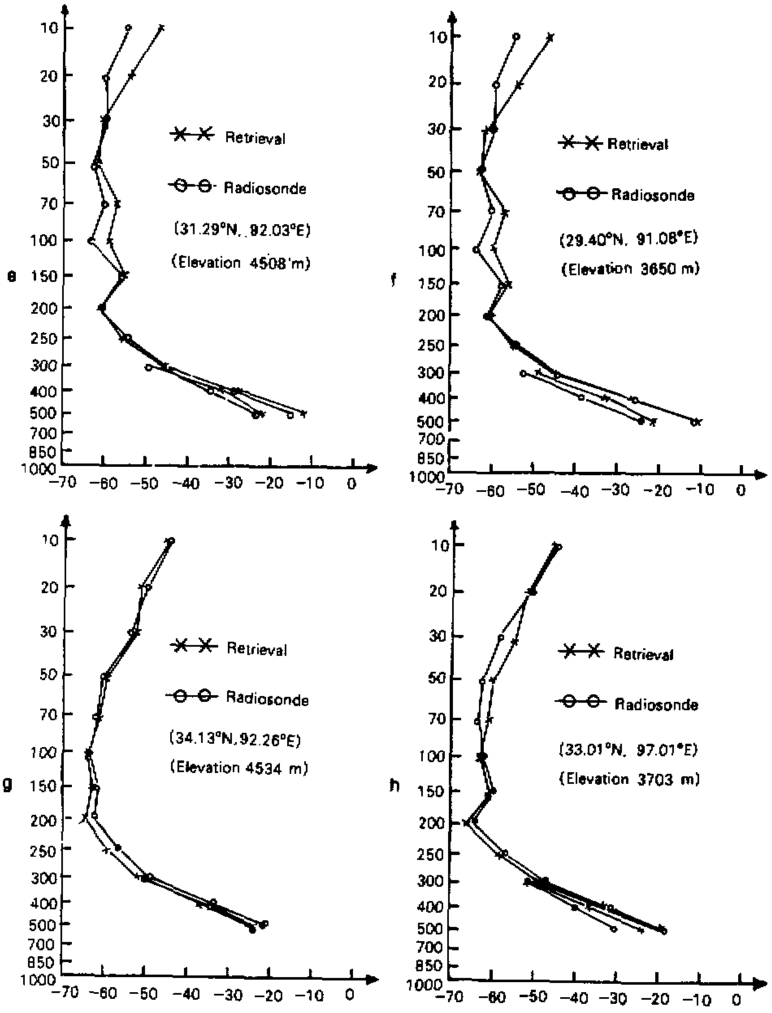


Fig. 2. Retrieved $T(p)$ and $T_d(p)$ and corresponding to the radiosonde profiles (18 Jan., 1990 00 GMT).

2. *Comparison of Retrieval Profiles with Radiosondes over Qinghai–Xizang Region*

In order to study further the retrieval capability of ISPRM over plateau area, we selected six retrieval profiles in January and February 1990 (see Figs. 2a–h) as follows: Changdu(a), Jiali(b), Dingre(c), Linzhi(d), Naqu(e), Lhasa(f), Tuotuohe(g), Yushu(h). Stations in Figs. 2a–f are located in Xizang area and the last four stations are located in Qinghai Province. To compare carefully the two sets of profiles from satellite and radiosonde, some suggestions are as follows:

(1) *Temperature profiles*

The surface temperatures retrieved by use of ISPRM are very close to the temperatures observed by radiosondes over the plateau area, the optimum retrieval levels occurred from surface to 150 hPa.

The most retrieval profiles have their minimum temperatures from 100 hPa to 70 hPa. The turning point of the minimum temperature of retrieval profiles coincides well with that of radiosondes.

Table 5. Mean RMS Errors Compared to Radiosondes for the Surface Elevation above 3500 Meters for 6 Days (only for Orbit C)

P	T		H		W	
hPa	NO	RMS	NO	RMS	NO	RMS
1000	0	0.00			0	0.000
850	0	0.00	0	0	0	0.000
700	0	0.00	0	0	0	0.000
500	31	2.88	0	0	31	0.190
400	31	1.55	31	9	31	0.109
300	31	1.23	31	16	31	0.080
250	31	1.47	31	6		
200	28	1.24	28	12		
150	17	2.42	17	12		
100	13	4.71	17	21		
70	15	4.02	12	59		
50	24	2.61	24	44		
30	13	1.56	13	32		
20	5	4.81	5	44		
10	0	0.00	0	0		

Based on the channel spectral characteristic, the higher the height above 20 hPa is, the worse the vertical resolution is, thus the greater the deviation between retrieval and radiosonde is.

ISPRM can obtain increase of temperature accuracy above 250 hPa over the plateau area.

(2) *Dewpoint temperature profiles*

The decreasing trend of the retrieved dewpoint temperature with altitude increasing is the same as one of radiosonde observation. Good coincidences occur under a few cases.

In plateau area, the error of the dewpoint is large when atmosphere is saturated (cloudy), whereas the accuracy is high when sky is clear. Through comparison analysis, obviously, retrievals of humidity have not yet been resolved well.

V. CONCLUSIONS AND FURTHER TASKS

Through the numerical experiment of retrieval method, some conclusions can be drawn as follows:

1. Based on the distribution of radiosonde stations over China region, we use objective analysis field of radiosonde temperature and humidity profiles as retrieval initial guess field rather than the numerical forecasting result. This choice founds the reasonable base for ISPRM and provides reliable initial guess data for forward problem.

2. Modifying the inconsistent in the retrieval model of SPRM, correcting the deviation of forward computed brightness temperature and selecting optimumly the retrieval channel in lower atmosphere, and accurate computation of ground pressure can make the ISPRM suitable to retrievals of the meteorological parameters over plateau area.

But some problems in this method still exist, for instance how to improve the retrieval accuracy further over plateau area. To solve these problems, perhaps we need:

1. To research a non-linear retrieval method and the corresponding theory based on solving the Eq.(4).

2. To construct a new model and fast algorithm for calculating the transmittances of atmosphere and surface in IR and microwave spectral regions.

3. To create a data base including emissivity, reflectivity etc. which can present surface characteristics, so as to put ISPRM into operational service.

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