Atmospheric transmittance calculation of InfRared Atmospheric Sounder of FY-3A meteorological satellite

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ABSTRACT

Fast transmittance coefficients of IRAS (**I**nf**R**ared **A**tmospheric **S**ounder) were calculated and verified bases on the characteristics and spectral response function of the primary IRAS sounding channels and GENLN2 line-by-line spectral transmittance database. The channel transmittances and weighting functions of atmospheric profiles were also calculated and compared with those of **Hi**gh **R**esolution Infrared **S**ounder (**HIRS**). It is shown that the IRAS' transmittance coefficients is satisfying , the channel transmittance and weighting function curves are reasonable, they have little differences from that of HIRS ,can indicate the contribution of each atmospheric layer make to the upwelling radiance from the whole atmosphere. The levels of peak energy contribution were mostly consistent with the propositional target, although some channels' peak-levels are a little rise from the design object, the variety trend is consistent with HIRS/3 instrument.

INTRODUCTION

FY-3 meteoroligical satellite is the second generation of polar-orbit meteoroligical satellite in China, it will carry **I**nf**R**ared **A**tmospheric **S**ounder (**IRAS**)、Microwave Atmospheric Sounder、Microwave Atmospheric Humidity Sounder for the first time. In order to provide some helpful information to the designer of IRAS, much simulation should be done to verify the characteristics of IRAS so that the satellite can be in good working state and the satellite data can be useful. IRAS is the primary remote sensor, it will provide real-time and valuable atmospheric data for numerical weather prediction. There are 26 spectral channels onboard IRAS, and can retrieve more than ten kinds of synoptic, climatic and environmental products.

This study only performs forward simulation of infrared channels those concern with atmospheric temperature retrieval. The object is to verify the spectral channel characteristics and the according designed parameters. The way of obtaining this is on the base of fast radiative transfer model RTTOV-7 and the channel characteristics and spectral response function of IRAS, calculates fast transmittance coefficients and channel fast transmittance of IRAS, as well as the weighting function. So can validate the coefficients and the designed instrument indexes.

CALCULATION OF THE FAST TRANSMITTANCE COEFFICIENT

(a) Spectral channel characteristics of IRAS and HIRS/3

Table 1. shows spectral channel characteristics of IRAS, most of those channels are almost same with HIRS/3 except for channel 11 of IRAS, whose central wavenumber locates in 1345 cm^{-1} that HIRS/3 doesn't include. The channel 18 of IRAS (expects mainly use to detect CO_2 concentration) is different from that according channel 17 of HIRS/3, their central wavenumbers are 2388 cm^{-1} and 2420 cm^{-1} respectively.

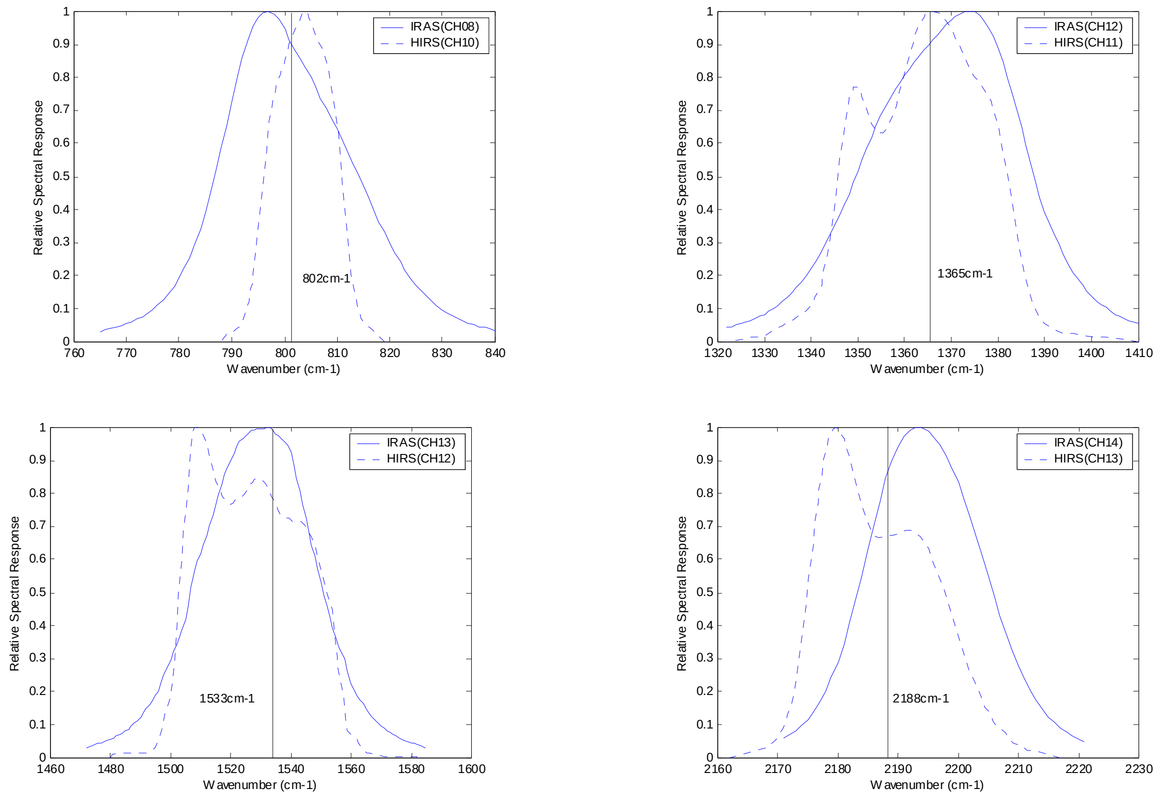
Table 1. Characteristics of IRAS sounding channels

Channel Number	Central Wavenumber (cm^{-1})	Central Wavelength (μm)	Principal Absorbing Constituents	NEΔN (mW/m^2-Sr-cm^{-1})	Level of Peak Energy Contribution (hPa)
1	669	14.95	CO_2	4.00	30
2	680	14.71	CO_2	0.80	60
3	690	14.49	CO_2	0.60	100
4	703	14.22	CO_2	0.35	400
5	716	13.97	CO_2	0.32	600
6	733	13.84	CO_2/H_2O	0.36	800
7	749	13.35	CO_2/H_2O	0.30	900
8	802	12.47	Window	0.20	Surface
9	900	11.11	Window	0.15	Surface
10	1030	9.71	O_3	0.20	25
11	1345	7.43	H_2O	0.23	800
12	1365	7.33	H_2O	0.30	700
13	1533	6.52	H_2O	0.30	500
14	2188	4.57	N_2O	0.009	1000
15	2210	4.52	N_2O	0.004	950
16	2235	4.47	CO_2/N_2O	0.006	700
17	2245	4.45	CO_2/N_2O	0.006	400
18	2388	4.19	CO_2	0.003	Atmosphere
19	2515	3.98	Window	0.003	Surface
20	2660	3.76	Window	0.002	Surface
21	14500	0.69	Window	0.10%A	Cloud
22	11299	0.885	Window	0.10%A	Surface
23	10638	0.94	H_2O	0.10%A	Surface
24	10638	0.94	H_2O	0.10%A	Surface
25	8065	1.24	H_2O	0.10%A	Surface
26	6098	1.64	H_2O	0.10%A	Surface

Satellite detecting instrument can only response the radiance of some spectral interval, one optimal instrument can absorb all the radiance that rips into it, but the physical characteristics of filter determine the radiance response isn't consistent with its wavenumber, is the function of its wavenumber, we call this function Spectral Response Function (SRF, Weinreb and Fleming, 1981). In order to shows the weighting of spectral response in each wavenumber more explicitly, the SRF is normalized commonly.

Fig1. is the comparison of the normalized SRF of IRAS and HIRS/3, in which the dashed lines represent the SRF of HIRS/3 and solid ones represent that of IRAS, vertical lines are channel central wavenumber. The response characteristics of the former six channels are very similar (not shown). However the central location of channel 12, 14, 15,19 of IRAS is a little right-floated, while that of HIRS/3 is a little left-floated. Central wavenumber of channel 8 of IRAS floats toward left and that of HIRS/3 toward right. Exclude this mentioned above, the shapes of SRF of channel 11, 12, 13, 16, 17 of HIRS/3 arise two peaks those possess of different altitude. Further more, the shape of SRF of channel 19 of HIRS/3 has even three peaks. These shapes of SRF have potential effects on atmospheric transmittance and retrieval calculation.

In addition, in calculation of channel transmittance the SRF should be interpolated to have a same spectral resolution with monochromatic transmittance, while the spectral response testing number of IRAS is less than that of HIRS/3 so maybe it will bring greater error than HIRS/3 in the simulation of radiative transfer.



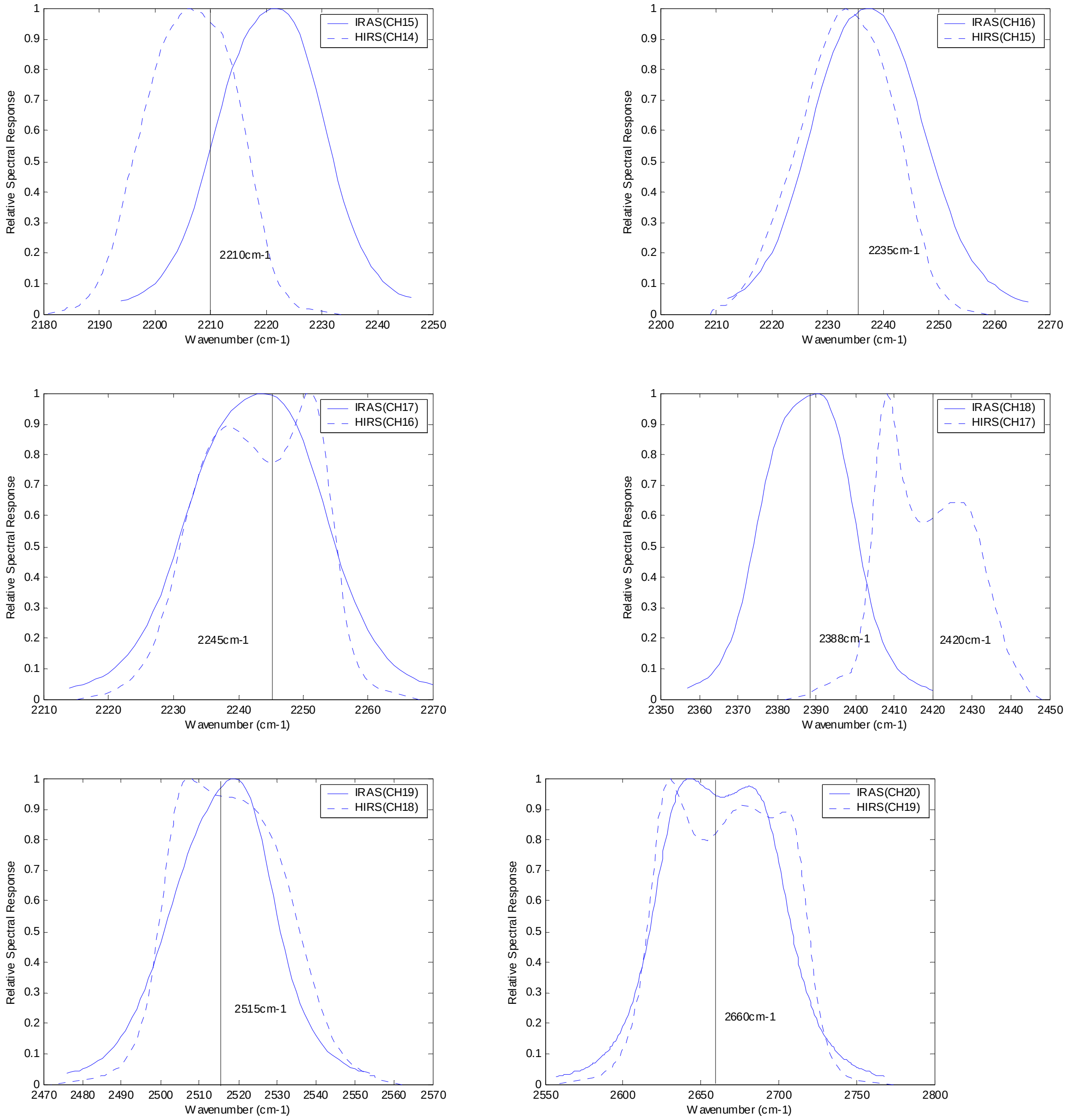


Fig.1 comparison of the normalized SRF of IRAS and HIRS/3

(b) Fast transmittance coefficient calculation of IRAS

RTTOV-7 export package contains nearly all the RT coefficient files of instruments and platforms that launched before May 2002 (Roger Saunders, 2002). So before we simulate FY-3A IRAS transmittance and radiance firstly we should calculate the RT coefficient of IRAS by ourselves.

In order to get fast RT coefficient, first of all should prepare a set of profiles that extensively cover the earth, than calculate monochromatic accurate transmittances of from each model level to space with line-by-line transmittance model (e.g. GENLN2). Secondly the line-by-line transmittances are convolved with channel spectral response to get channel transmittances $\tau_{\upsilon,j}$, eq.1, F_v is the spectral response function, $\hat{\tau}_{\upsilon,j}$ is monochromatic transmittances.

$$\tau_{\nu,j} = \frac{\int \hat{\tau}_{\nu,j} \cdot F_\nu \cdot d\nu}{\int F_\nu \cdot d\nu} \tag{1}$$

Thirdly convert channel transmittances to optical depth according to eq.2, $\sigma_{\nu,j}$ is the channel optical depth of each model layer to space.

$$y_{\nu,j} = -\ln(\frac{\tau_{\nu,j}}{\tau_{\nu,j-1}}) = \sigma_{\nu,j} - \sigma_{\nu,j-1} \tag{2}$$

Finally performs regression in terms of layer optical depth to obtain a set of RT coefficients.

$$\sigma_{\nu,j} - \sigma_{\nu,j-1} = \sum_{k=1}^{M} a_{\nu,j,k} \cdot X_{j,k} \tag{3}$$

Here $X_{j,k}$ are predictors that depend on profile variables and $a_{\nu,j,k}$ are regression coefficients. The subscript ν, j, k represent the central wavenumber of channels, the *jth* layer and *kth* predictor.

For the temperature and water vapour profiles 42 were taken from the TIGR profile dataset that together the mean profile provided 43 profiles of temperature and specific humidity. To enable ozone to be included in the model as a variable gas, a separate dataset of 34 profiles of ozone (with temperature and water vapour) were selected from a set of 383 profiles to represent the global variability of ozone profiles. This study concerns setting 10 ozone profiles aside as independent dataset of validation, so only 23 ozone profiles were used to calculate ozone coefficient, 2 ozone profile hasn’t been used.

VALIDATION OF FAST RT COEFFICIENTS

(a) Validation of transmittance

Because of unavailability of GENLN2 line-by-line transmittance, this study only used the 10 independent profiles to validate RT coefficients of IRAS. The disadvantage of doing so is that these 10 profiles can only represent limited atmospheric state at the same time it’s still valuable.

Fig 2a to 2d are the rms of the transmittance differences from the Line-by-Line (LbL) transmittances. These statistics are for 6 different viewing angles in the range 0 to 63.6 deg. Fig 2a is the rms of the transmittance differences of the former 7 channels, the rms in all the altitude less than 0.002. Fig 2b is the rms of the transmittance differences of the channel 8 to 13, the errors of two window channels 8 and 9 are small, while that of the channel 10 is a little relatively large that is absorbed primarily by ozone. Fig 3c is the rms of the transmittance differences of the channel 14 to 17, this group of channels have the smallest rms of all the IRAS channels, all less than 0.001. The rms of channel 18, 19, 20 are shown as Fig 2d, these three channels have rms of less than 0.002.

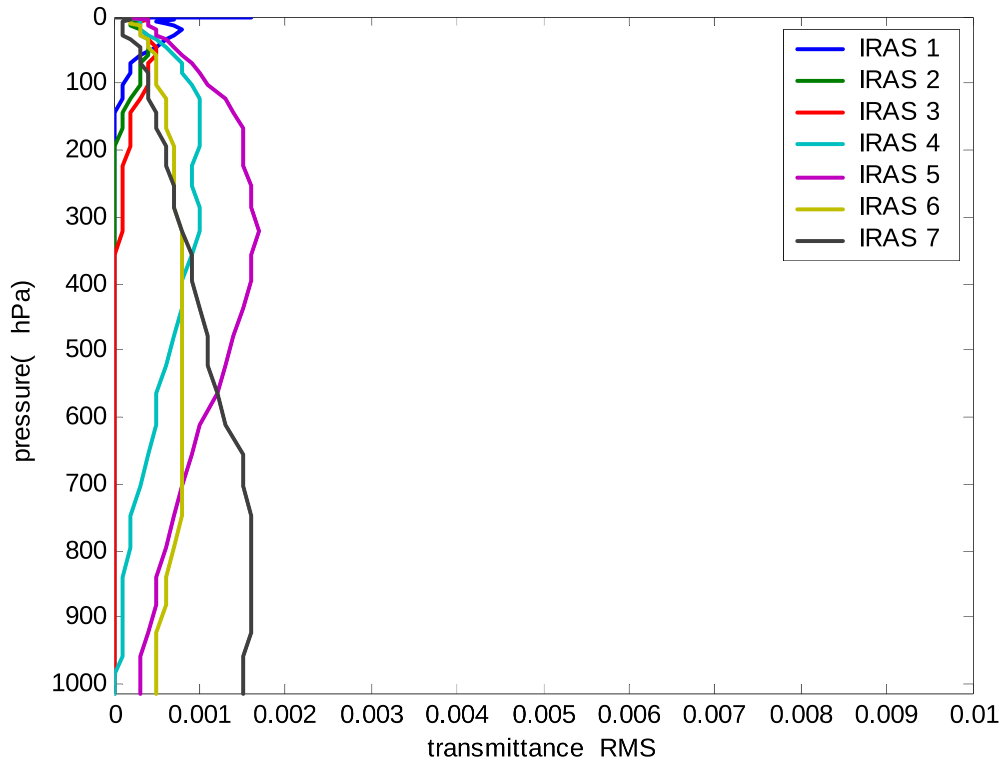


Figure 2a RMS of RTTOV-7 for FY-3A IRAS transmittance differences from GENLN2 LbL model for 10 independent profiles and 6 viewing angles.

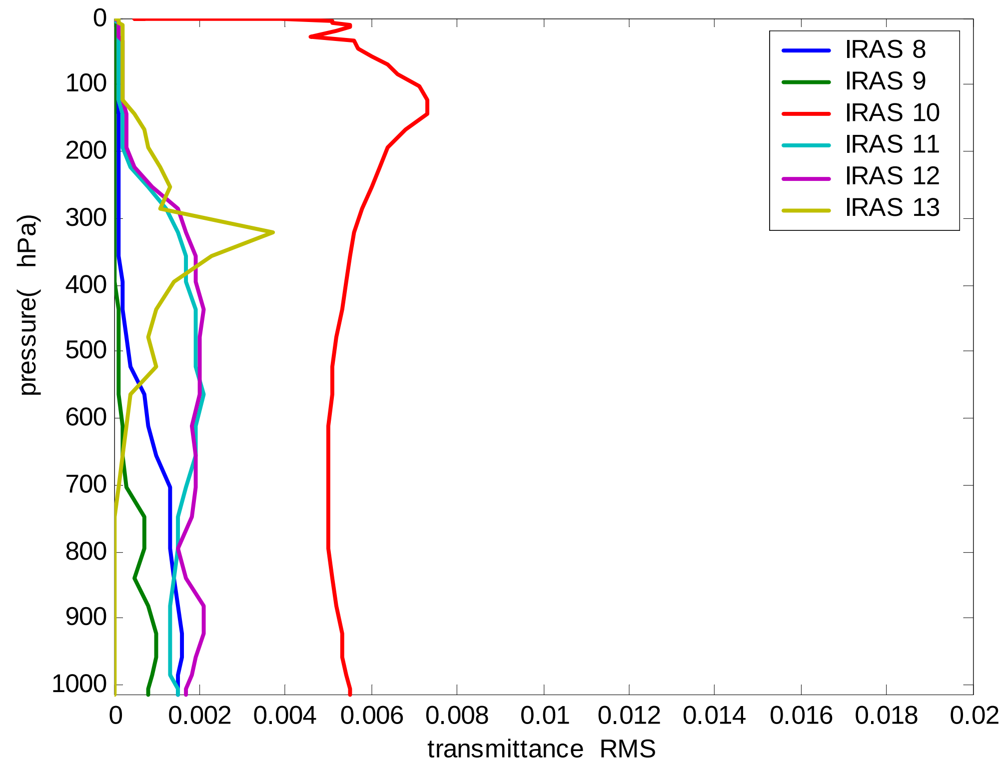


Figure 2b RMS of RTTOV-7 for FY-3A IRAS transmittance differences from GENLN2 LbL

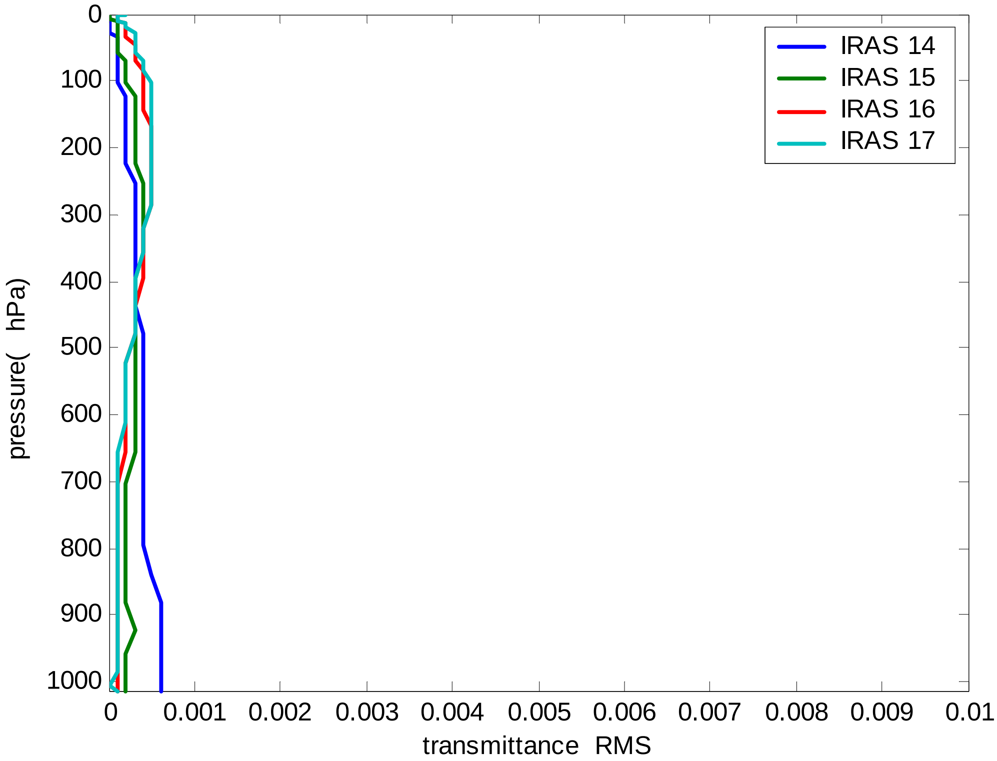


Figure 2c RMS of RTTOV-7 for FY-3A IRAS transmittance differences from GENLN2 LbL model for 10 independent profiles and 6 viewing angles.

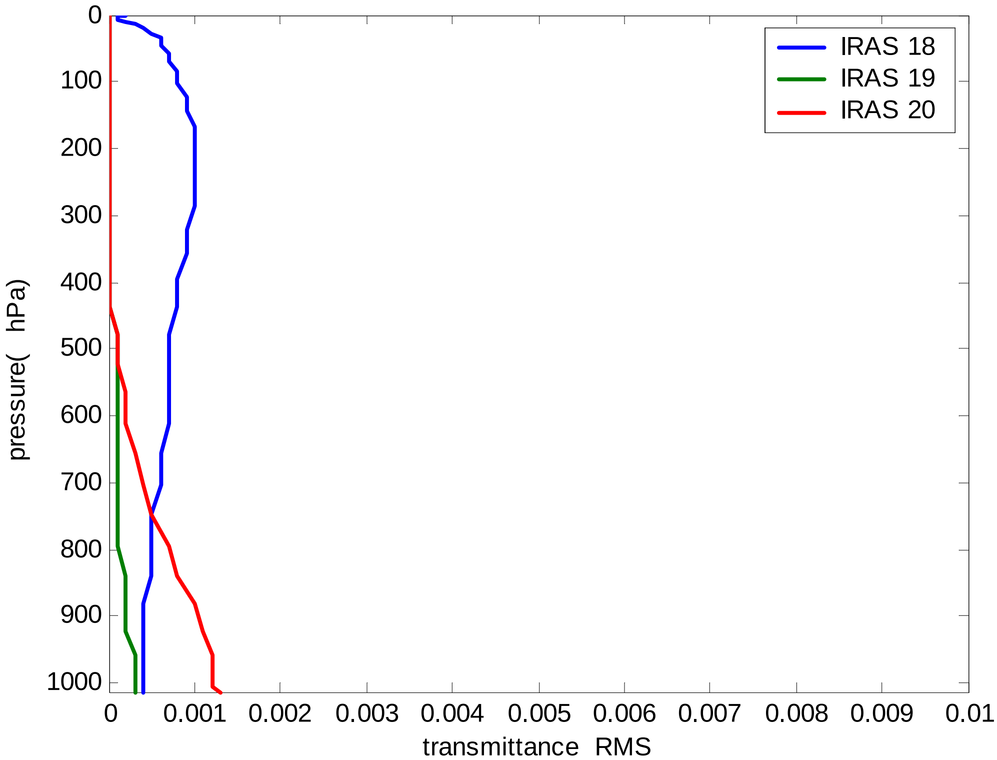


Figure 2d RMS of RTTOV-7 for FY-3A IRAS transmittance differences from GENLN2 LbL model for 10 independent profiles and 6 viewing angles.

(b) Comparison of weighting functions of IRAS and HIRS/3

The transmittance weighting function (WF, $d\tau / d \ln p$) of satellite instrument can reveal the weights of radiance contribution of each atmospheric layer to the radiance that instrument receive from the whole atmosphere, in the other word is that which layer atmosphere contribute most to the upward radiance. Peak of a WF curve represents the vertical altitude of the radiance-contributed most layer.

Fig 3a is the transmittance weighting functions of IRAS and 3b is that of HIRS/3 (Jun Li, 2000), select U.S 1976 standard profile as input profile. It's shown the weighting function curves of IRAS are reasonable, they have little differences from that of HIRS, can indicate the contribution of each atmospheric layer make to the upwelling radiance from the whole atmosphere. The spectral band of channel 8, 9, 19, 20 (corresponding channel 8, 18, 19 of HIRS/3) are window channels, the peak of WF curves arrive surface. Channel 10 of IRAS whose central wavelength is 9.7 μm, is a spectral band that gas absorption mainly by ozone, there is a peak of WF in altitude of between 50 and 20 hPa, this is because the ozone mainly exist in stratosphere. The channel 11, 12, 13 of IRAS locate in spectral band of 6.3 μm that water vapour strongly absorbed, water vapour primarily existing in troposphere, the rapidly reduction of water vapour in the top of troposphere leads to the rapidly enlargement of transmittance, so peaks of WF curves arise here.

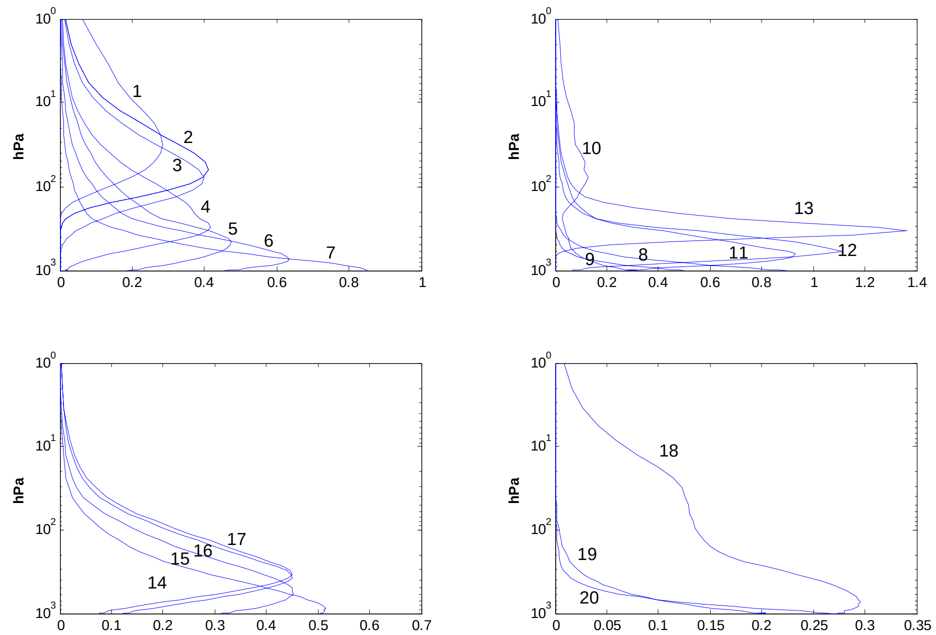


Fig.3a Channel weighting functions $d\tau / d \ln p$ of IRAS (U.S standard profile)

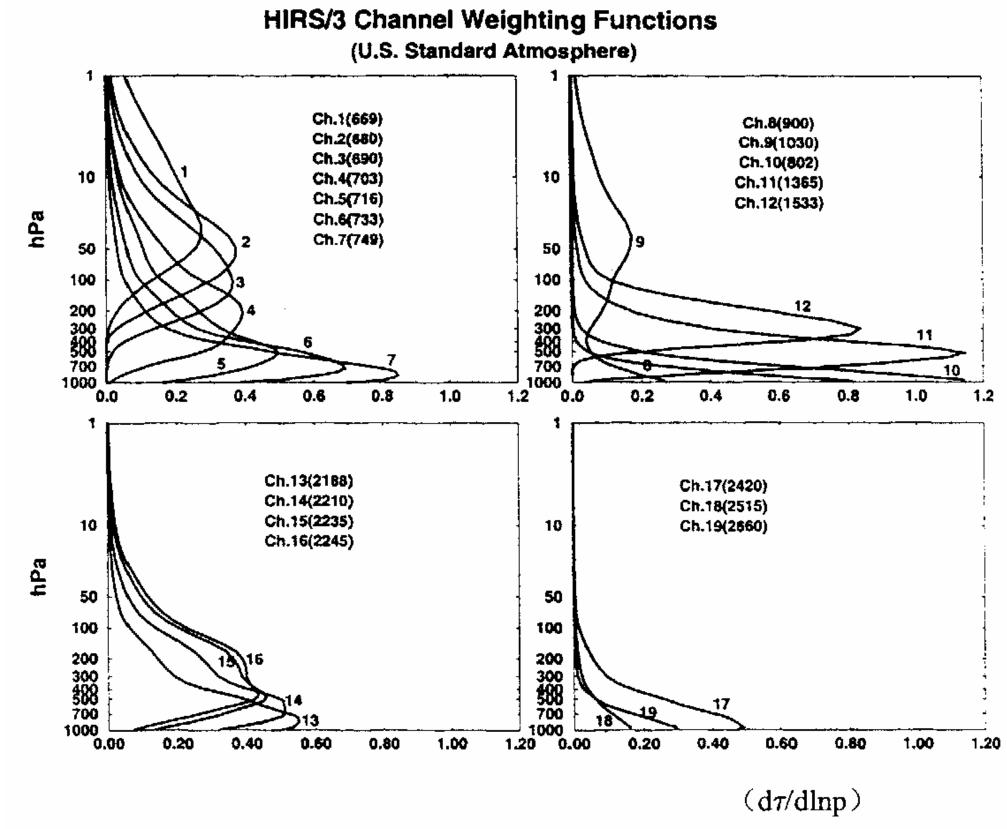


Fig.3b channel weighting functions $d\tau / d \ln p$ of HIRS/3 (Jun Li, 2000)

SUMMARY

Transmittance simulation performed and the results were compared with HIRS/3, the RT coefficient of IRAS can used to calculate the fast channel transmittance and do forward radiative transfer calculation, and obtain satisfying precision. The transmittance weighting function curves are reasonable.

References

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