ANALYSIS OF THE ABILITY OF TOVS INFRARED WATER VAPOR CHANNEL FOR LOWER ATMOSPHERIC MOISTURE REMOTE SENSING

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1. INTRODUCTION

In numerical weather prediction and climate research, water vapor is an important atmospheric parameter. For satellite remote sensing of surface characteristics, water vapor is also a principal factor for atmospheric effects. In order to make atmospheric correction, one way is to combine the vertical sounding of moisture derived from satellite observation with radiative transfer model. At present, the accuracy of moisture retrieval of TOVS is not satisfactory. For water vapor profile remote sensing, the HIRS/2 aboard NOAA satellites uses three water vapor channels centered at 1484 cm^{-1}, 1364 cm^{-1} and 1217 cm^{-1}. The GOES I/M has also three water vapor channels, but their locations are different, their central frequencies are at 1535 cm^{-1}, 1425 cm^{-1} and 1345 cm^{-1}. Huang et al. (1992) have made analysis of the retrieval vertical resolution function for these two sets of water vapor channels. From their results, higher retrieval vertical resolution can be provided and better accuracy of water vapor profile retrieval might be obtained by water vapor channels aboard GOES I/M. That means the water vapor channels of GOES I/M contain more useful atmospheric moisture information than those of HIRS/2 on NOAA satellites. In this paper, we are going to make some analysis from another way to compare the water vapor remote sensing ability of these two sets of channels on board GOES and NOAA satellites. Because of the most atmospheric moisture is concentrated in the lower part of the atmosphere, our emphasis is on the analysis of the remote sensing ability of channels for low level moisture remote sensing, i.e. the 1217 cm^{-1} and 1345 cm^{-1} channels.

2. ANALYSIS

Generally, for a channel with stronger absorption, its suitable remote sensing layer is located in higher altitude than that for a channel with less absorption. But for low level atmospheric moisture remote sensing, not necessarily, the more transparent channel is more suitable. It is obvious that a channel with no absorption is of no use for low level atmospheric moisture remote sensing. Therefore, an optimal channel for lower atmospheric moisture remote sensing should be of certain extent absorption, that should be not too strong and not too weak.

For simplicity, the remote sensing equation of a water vapor channel can be expressed as

$$I = I_s \tau_s + \int_0^{\infty} B(T(z)) \frac{\partial \tau(z,\infty)}{\partial z} dz \quad (1)$$

here, $\tau(z,\infty)$ is the transmittance from level z to the top of the atmosphere along the path, I_s the surface upgoing radiance. Define the weighting function $W(z)$ as

$$W(z) = \frac{\partial \tau(z,\infty)}{\partial z},$$

which shows the contribution of a thin atmospheric layer at height z to the radiance measured in the channel from satellite. In the case of black body surface and the surface temperatureT_s=$T(0)$, Eq.(1) can be rewritten as

$$I = B(T(\infty)) - \int_0^{\infty} \tau(z,\infty) \frac{\partial B}{\partial z} dz, \quad (2)$$

From Eq. (2), the radiance change caused by water vapor variation, $\delta \ln q(z)$, in the atmosphere at height z can be expressed as

$$\delta I = - \int_0^{\infty} \frac{\partial B}{\partial z'} \frac{\partial \tau(z',\infty)}{\partial \ln q(z)} \delta \ln q(z) dz' \quad (3)$$

For the height higher than z ($z' \geq z$) , the transmittance will not vary with moisture variation at level z, $\frac{\partial \tau(z',\infty)}{\partial \ln q(z)}$ =0. Therefore, the radiance change can be written as

$$\delta I = - \left(\int_0^{z} \frac{\partial B}{\partial z'} \frac{\partial \tau(z',\infty)}{\partial \ln q(z)} dz'\right) \delta \ln q(z) \quad (4)$$

We define a response function $Wc(z)$,

$$Wc(z) = - \frac{1}{I} \int_0^{z} \frac{\partial B}{\partial z'} \frac{\partial \tau(z',\infty)}{\partial \ln q(z)} dz',$$

which measures the contribution of water vapor variation at level z to the relative change of outgoing radiance at the top of the atmosphere, $\delta I/I$. Three quantities, τ, W and Wc, are all relevant to the ability of a channel for atmospheric moisture remote sensing, but the transmittance τ and weighting function W can not show such ability, clearly.

Fig.1 shows the transmittances of three HIRS/2 water vapor channels and one GOES I/M channel for low atmospheric moisture remote sensing. Their corresponding weighting functions are given in Fig.2. From these two Figs., compared with 1345 cm^{-1} channel, the 1217 cm^{-1} channel is more transparent and its maximum contribution to the measured radiance comes from the lower part of the atmosphere. Therefore, it seems the most transparent 1217 cm^{-1} channel is more favorable to the moisture remote sensing in the low atmosphere, in fact, it is not necessarily the case.

The response function, *Wc*, can show the atmospheric moisture remote sensing ability of a channel more clearly. Fig.3 shows the response functions of these channels. Obviously, if $Wc(z)=0$, the water vapor variation at level z will not cause outgoing radiance change at the top of the atmosphere, and such channel can provide no information about water vapor at level z. The larger the $Wc(z)$ is, the more information about water vapor at level z can be provided by the channel. If the land surface is a black body, the response function for any channel is always equal to zero, $Wc(z=0)\equiv 0$, and no channel can provide useful information about the surface moisture. From Fig. 3, it can be seen that in the wet mid-latitude summer atmosphere, below about 2.5 km, the 1217cm^{-1} channel can provide some more water vapor information than 1345 cm^{-1} channel, but above about 2.5 km, the water vapor information content provided by 1217cm^{-1} channel is less than that provided by 1345 cm^{-1} channel. In dry mid-latitude winter atmosphere, at all levels in the lower part of the atmosphere, the 1345 cm^{-1} channel can provide more moisture information than 1217 cm^{-1} channel. Put two and two together, such characteristics might be relevant to that compared with HIRS/2 water vapor channels, with GOES I/M water vapor channels, better retrieval results might be obtained.

Through radiative transfer simulation, it is found that there are other channels, which can provide moisture information in the lower atmosphere more effectively than 1217 cm^{-1} channel, such as the channel centered at 1255 cm^{-1}. The transmittance, weighting function and response function of this channel in mid-latitude winter and summer atmospheres are shown in Figs. 1, 2 and 3, respectively. From the transmittance curves, it can be seen that the absorption of this channel is stronger than that of 1217 cm^{-1} channel, but less than that of 1345 cm^{-1} channel. The level of its maximum contribution to the outgoing radiance at the top of the atmosphere is also between the peaks of these two channels. From the curves of the response function shown in Fig.3, it can be seen clearly, in both wet and dry atmospheres, this channel can provide the moisture information in the lower atmospheres more effectively than 1217 cm^{-1} channel. Hence, it might be a more suitable channel for lower atmospheric moisture remote sensing. If such channel is used instead of 1217 cm^{-1} channel, then the ability of lower atmospheric water vapor remote sensing might be improved.

3. CONCLUSION

From above analysis, it seems that the 1217 cm^{-1} channel is not an optimal moisture remote sensing channel for lower atmospheric moisture remote sensing, although it has been used for long time. There are other channels that can provide the moisture information in the lower atmospheres more effectively than the 1217 cm^{-1} channel aboard the NOAA satellites. The vertical resolution is closely related to the spectral resolution of remote sensing channels as pointed by Huang et al. (1992), but for same number of channels with similar spectral resolution that is also related to channel selection. With similar spectral resolution, increasing the number of remote sensing channels will be helpful to improving the vertical resolution and retrieval accuracy (Zhao, 1980). For the new generation of satellite infrared sounder of high spectral resolution and large quantity of channels with the optimal remote sensing channels included, such as the Advanced Infrared Sounder (AIRS, Aumann and Pagano, 1994) and the High-Resolution Interferometer Sounder (HIS, Smith et al., 1983), the vertical resolution will be improved, significantly, and much more useful atmospheric moisture information can be provided, therefore, it can be expected that much better water vapor retrieval results could be obtained.

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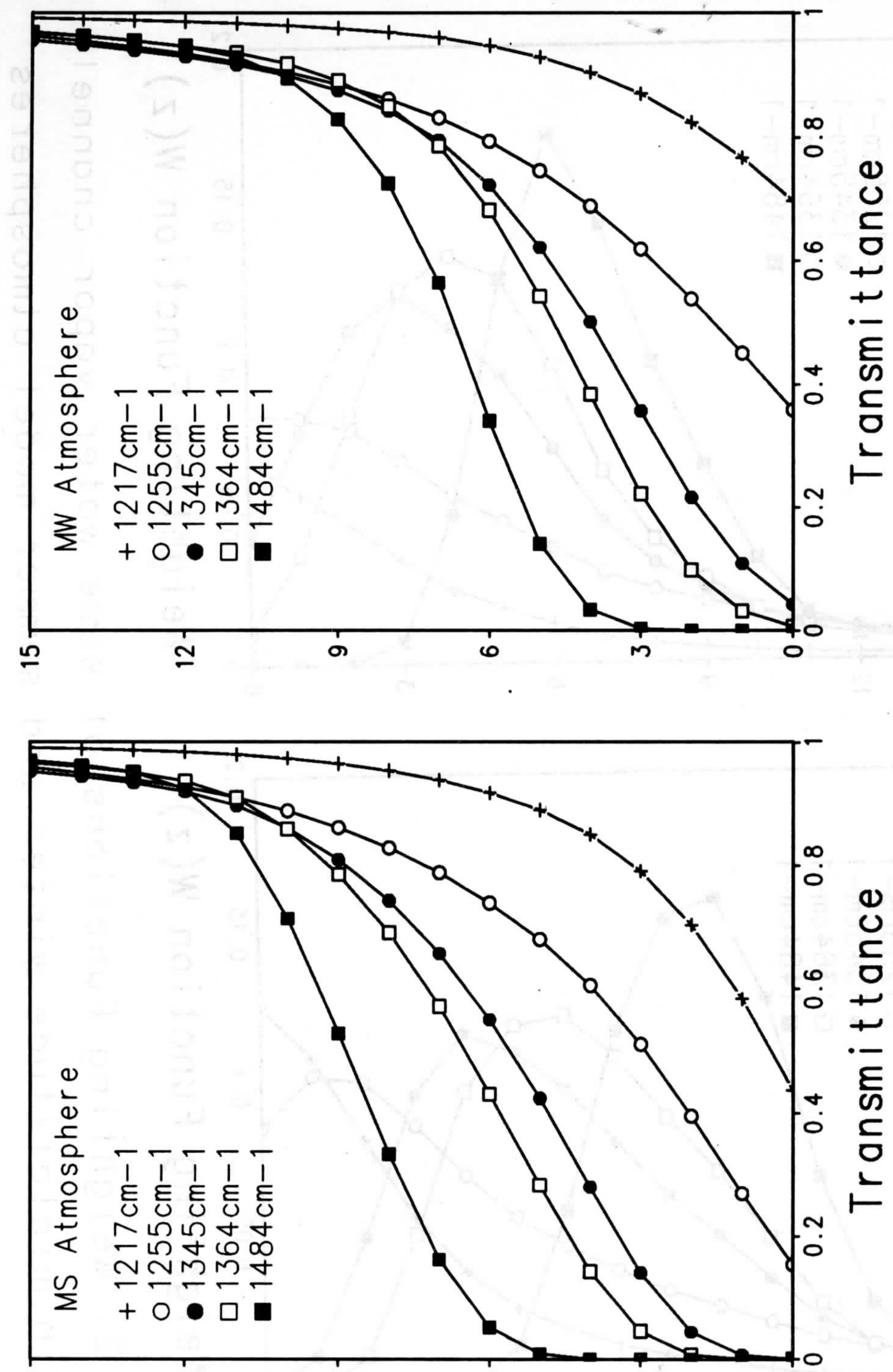

Fig 1. Transmittances of some water vapor channels in midlatitude winter and summer model atmospheres

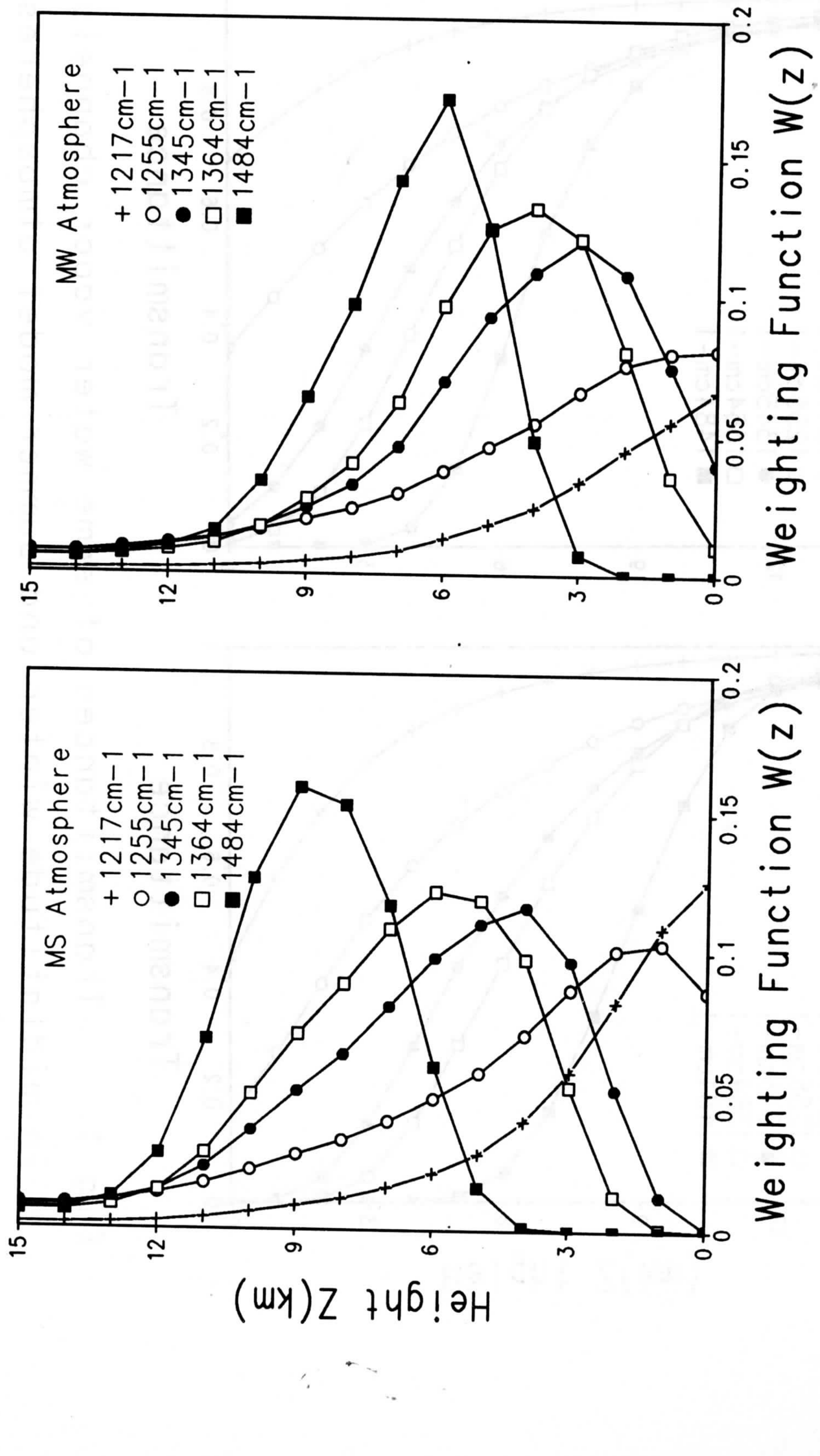

Fig 2. Weighting Functions of some water vapor channels in midlatitude winter and summer model atmospheres

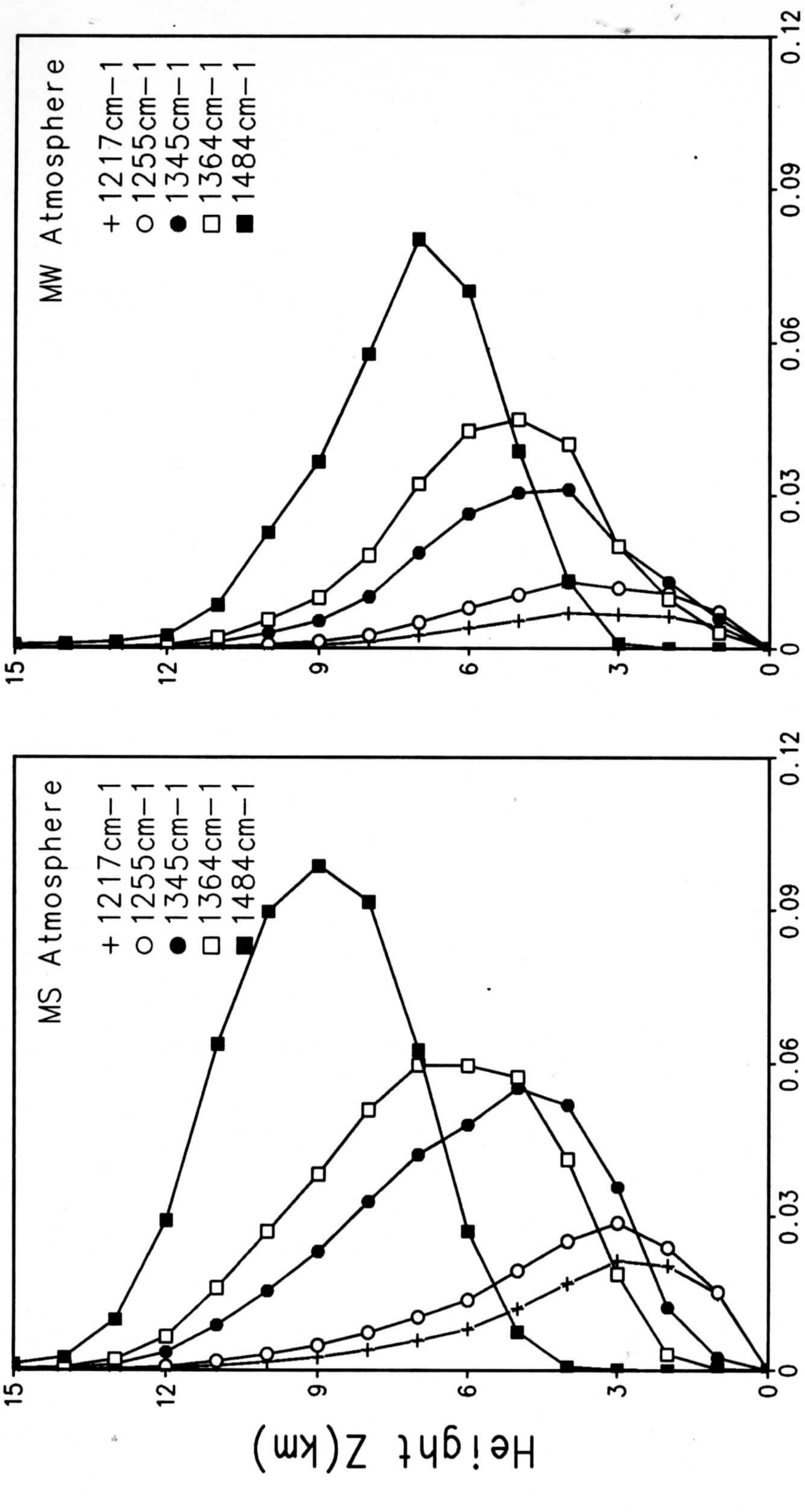

Fig 3. Response Functions of some water vapor channels in midlatitude winter and summer model atmospheres

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