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RECENT IMPROVEMENTS TO THE FAST TRANSMITTANCE MODEL, OPTRAN, FOR NOAA DATA ASSIMILATION

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1. INTRODUCTION

The assimilation of satellite radiance observations into numerical weather and climate prediction models is a key research area for improving weather forecasts. Development of, and improvements to, radiative transmittance models are essential for data assimilation. Optical Path Transmittance (OPTRAN) (McMillin and Fleming, 1995) is one of several regression-based fast radiative transmittance models, and has used in the Global Data Assimilation System (GDAS) by the National Oceanic and Atmospheric Administration, National Weather Service, National Centers for Environmental Prediction, Environmental Modeling Center (NOAA/NWS/NCEP/EMC) (Kleespies et al., 2004).

In OPTRAN and many other fast transmittance models, the absorption of radiation by the gases in the atmosphere is usually treated as three components, i.e. water vapor, ozone and the remaining gases such as CO_2, N_2O, CO, CH_4, N_2, O_2 and other trace gases that we refer to collectively as dry gases as was done before. Note this is different from the general concept of dry gas in atmospheric science. Since the concentrations for these dry gases are generally held constant, they are often referred to as fixed gases in other literature. However, as the channel transmittances are not monochromatic, the product of the polychromatic transmittances of dry gases, water vapor and ozone is not strictly equal to the total transmittance. Therefore in the past, the effective transmittance concept has been used so that the product of the transmittances of these three components is equal to the total transmittance as follows:

$$\tau_{total} = \tau_d \left(\tau_{d+o} / \tau_d \right) \left(\tau_{total} / \tau_{d+o} \right) = \tau_d \tau_o^* \tau_w^* \quad (1)$$

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where τ_d is the transmittance of dry gases from the top of atmosphere to a layer, τ_{d+o} contains the effects of the dry gases and of ozone, and τ_{total} contains the effects of all gases. τ_w^* and τ_o^* are called effective water vapor and effective ozone transmittances respectively, and are defined as:

$$\tau_o^* = \tau_{d+o} / \tau_d$$
$$\tau_w^* = \tau_{total} / \tau_{d+o} \quad (2)$$

A set of regression equations is developed to parameterize the absorption coefficients for each of these three components. Since the absorption coefficient for each gas is a function of the absorber amount, the atmosphere is discretised in terms of integrated path absorber amounts (which simplified to a fixed pressure level times the secant of the local zenith angle discretisation for the fixed (dry) gases) in OPTRAN. By predicting the channel absorption coefficients for dry gases, effective water vapor and ozone, OPTRAN can be used to compute the transmittance and radiance under clear sky condition.

2. THE FORMULATION OF OPTRAN-V7 AND RECENT IMPROVEMENTS

2.1 The Formulation of OPTRAN-V7

One disadvantage of the above effective transmittance approach is that when the layer-to-space transmittance of dry (τ_d) or dry plus ozone (τ_{d+o}) is equal to zero, the values of τ_o^* and τ_w^* become indeterminate at that layer and all successive layers below. Different choices of the independent component and the sequences to define the effective transmittances lead to different results. Another disadvantage is the need to calculate the transmittance by LBL models for all or most of the combinations of the individual gases for the derivation of the effective transmittances. If we include more than three gases, or make the definition of effective transmittance wavelength (or channel) dependent, even more of the possible combinations of gases need to be calculated from line-by-line models. To avoid the numerical problems and to reduce the LBL computational burden, an alternative to the effective transmittance approach for the calculating polychromatic transmittance in rapid transmittance models was developed (Xiong and McMillin, 2004). In this approach, we have:

$$\tau_{total} = \tau_d \tau_{w\ln} \tau_{wco} \tau_o \tau_c \quad (3)$$

where τ_{wco} and $\tau_{w\ln}$ are the transmittances of water continuum absorption and water line absorption, τ_c is the correction term defined as follows:

$$\tau_c = \tau_{total} \Big/ \left(\tau_d \tau_{w\ln} \tau_{wco} \tau_o\right) \quad (4)$$

It was found that the use of the correction term solves some numerical problems that were associated with the use of effective transmittances, greatly reduces the line-by-line computational burden, and allows for the efficient inclusion of more gases (Xiong and McMillin, 2004). The overall accuracy of OPTRAN-V7 using the correction term is comparable to that using the effective transmittances when the same absorber spaces and candidate predictors are used.

In addition to the use of the correction term in OPTRAN-V7, we have included (1) the change of the ozone absorber space for regression, (2) the use of some new predictors for each gas, and (3) the treatment of water continuum as a single gas separated from the water line absorption. With these improvements the accuracy of OPTRAN has been increased with the most significant improvement in the ozone channels. For this study, a 48 profile set at 101 grid levels is used as the training profile set, and the LBL transmittances were generated by using the Line-By-Line Radiative Transfer Model (LBLRTM) (Clough et al., 1992).

2.2 Recent Improvements in OPTRAN-V7

In OPTRAN it is necessary to define a standard set of absorber amounts at which the regression is done, and the absorber amount in each layer is defined as an exponentially increasing sequence[2], i.e. $\Delta A_{i+1} = \Delta A_i \, exp\,(\alpha)$, $i = 1, 2, \ldots, 300$, where ΔA_i is the absorber amount in layer i and α is a constant. The atmospheric state and the absorption coefficients at the pressure levels need to be interpolated to the levels in the absorber space for the regression step. This definition of the absorber space with the layer absorber amount increasing exponentially is appropriate for dry gases and water vapor because both the pressure and the amount of water vapor increase almost exponentially from the top of atmosphere to the ground. However, the maximum of a typical ozone profile is in the stratosphere, and the integrated ozone amount increases slowly in the lower atmosphere. So the absorber space for ozone is discretised as ΔA_i increasing linearly in the first 160 layers (The ozone amount A_{160} corresponds to the slant-path total amount of ozone for most profiles with viewing angle less than 45^o), and as a constant from layer 161 to 300 in OPTRAN-V7. This change of ozone space reduced the fitting error in High-resolution Infrared Radiation Sounders (HIRS) channel 9 by about 20%. Five predictors are used for each gas, but the 15 candidate predictors in OPTRAN-V6 have been increased to 18. These new ones are $P^{1/2}$ and T/P for the dry gases, $P^{1/4}$ and $P^{*1/4}$ for the ozone, $P^{1/2}$, $Q^{1/2}$ and q/T^2 for the water vapor line absorption, and q, q*P/T and q/T^2 for the water continuum absorption. For simplification one correction is made using the water vapor absorber space in the regression step. The absorber space for the water continuum is set the same as the water line absorption although it is easier to use the pressure space.

Figure 1 shows the effect of change the ozone absorber space and the use of new predictors on the fitting to HIRS. For most HIRS channels, the errors have been reduced by more than 10%. The errors in water vapor channels have been reduced by 15-20%. The most significant decrease is in the ozone channel. The separation of water continuum absorption from other gases has a significant impact in the atmospheric window regions. This is shown in Figure 2 where the rms errors of Atmospheric Infrared Sounder (AIRS) on Aqua in window regions have been reduced by about 50% based on the independent tests using ECMWF 52 profiles.

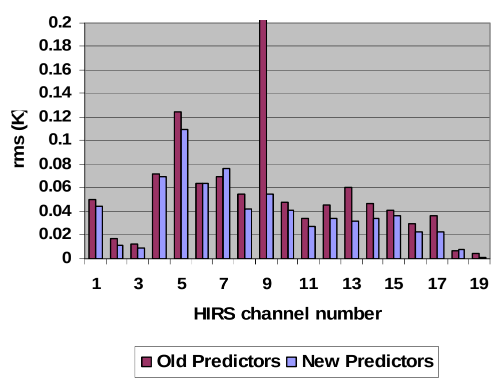

Figure 1 A comparison of the fitting errors for HIRS on NOAA-14 after using some new predictors in OPTRAN-V7 using 48 profiles in five viewing angles.

An overall comparison of the fitting errors of OPTRAN-V7 with OPTRAN-V6 (Kleepsies et al.,

2004) based on the 32 profile set can be shown in Figure 3. Note that the OPTRAN-V6 was based on 46 levels while OPTRAN-V7 is on 101 levels, and the LBL transmittance data used to train OPTRAN-V6 is also different from that used to train OPTRAN-V7 which is computed using the latest version of LBLRTM. So the significant improvement in OPTRAN-V7 in Figure 3 can be attributed partially to the increase of layer grid and recent improvement in the spectroscopy in the LBLRTM.

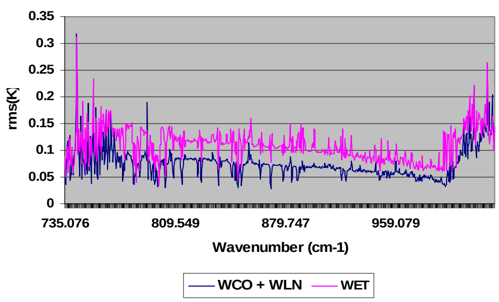

Figure 2 Comparison of rms errors before and after treating the water continuum as a single gas s for some AIRS channels in window region using ECMWF 52 profiles in five viewing angles.

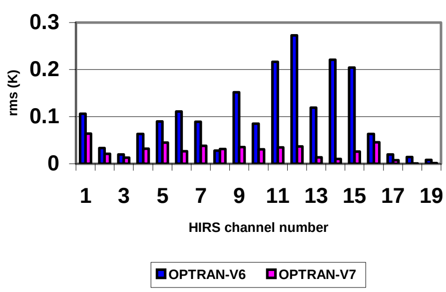

Fig. 3. Comparison of the fitting errors in OPTRAN-V7 versus OPTRAN-V6 for a dependent set of the 32 profiles and five viewing angles.

3. VALIDATION OF FORWARD COMPUTATION BY OPTRAN-V7

To validate the computation of radiance or brightness temperature at the top of atmosphere, a dependent test based on 48 profiles and five viewing angles and an independent test based on ECMWF profiles and five viewing angles have been made. As examples we show the results for HIRS on NOAA-17 and AIRS in Figure 4 and 5, and results for microwave sensors AMSUA/B on NOAA-17 and SSMIS in Figures 6 and 7. The average rms errors for 19 HIRS channels are 0.034 K and 0.047 K from dependent and independent tests respectively, and 0.034 K and 0.059 K for the 2378 AIRS channels. For microwave sensors, the errors are much smaller, and the average errors from dependent and independent tests are 0.020 K and 0.030 K for AMSUA/B, and 0.021 K and 0.034 K for SSMIS respectively. Note the errors in SSMIS channels 19 – 21 are relatively larger than other SSMIS channels, the reason is that the Zeeman effects are not included in the LBL calculation, and the SSMIS channels 19-24, used for mesosphere temperature sounding, are influenced significantly by Zeeman effects. For most infrared and microwave channels the errors are less than 0.1 K except in some peak channels of AIRS where the rms errors can be as high as 0.2-0.3K.

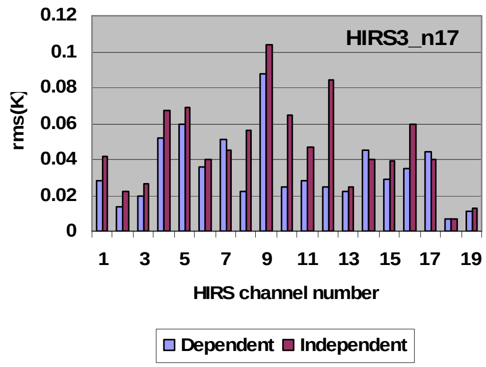

Figure 4 rms of the difference between OPTRAN-V7 and LBLRTM computed brightness temperature for dependent and independent profile sets for NOAA-17 HIRS3.

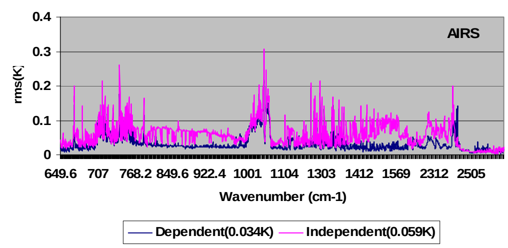

Figure 5 Same as Figure 4 but for AIRS.

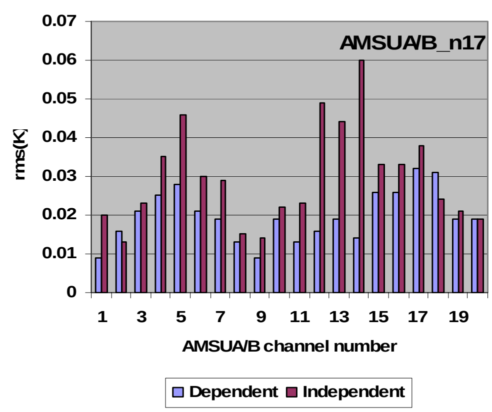

Figure 6 Same as Figure 4 but for AMSUA/B.

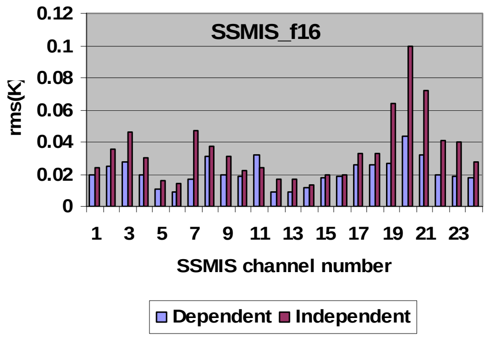

Figure 7 Same as Figure 4 but for SSMIS.

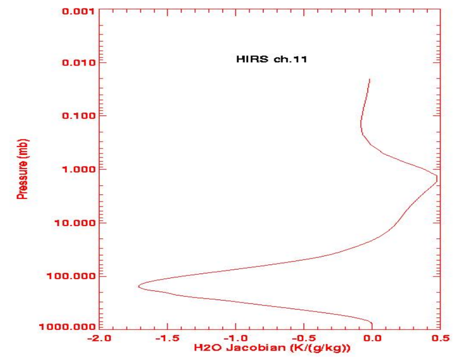

Figure 9 Same as Figure 8 but for the water vapor Jacobian of HIRS channel 12.

4. COMPUTATION OF JACOBIAN BY OPTRAN-V7

The codes for the analytical computation of Jacobian in OPTRAN-V7 have been completed recently, and their results agree well with those calculated from a finite difference, but the speed is much faster. As examples, Figures 8-10 show the computed temperature Jacobian in HIRS channel 5, water vapor Jocobian in HIRS channel 11, and ozone Jacobian in HIRS channel 9 for U.S. standard tropical profile. A comparison of the Jacobian from OPTRAN-V7 with the LBL computation will be made in the future.

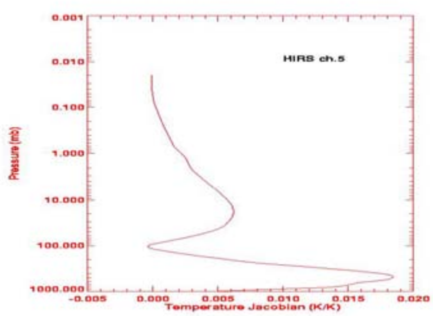

Figure 8 Temperature Jacobian in HIRS channel 5 for the U.S. standard tropical profile at nadir viewing angle.

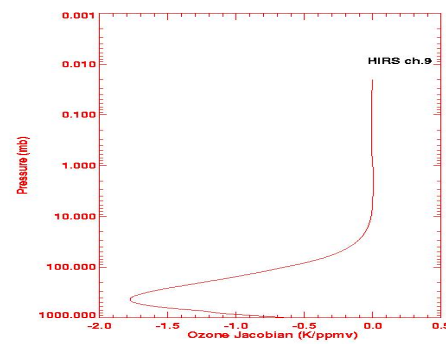

Figure 10 Same as Figure 8 but for the ozone Jacobian of HIRS channel 9.

5. SUMMARY AND CONCLUSIONS

An improved version of the fast and accurate transmittance calculation procedure, Optical Path TRANsmittance (OPTRAN), has been developed by (1) replacing the effective transmittance concept with a correction term, (2) adding new predictors for each gas, (3) utilizing a new absorber space for the fitting of ozone, and (4) treating the water continuum absorption as a single gas separated from other gases.

Compared to OPTRAN-V6, OPTRAN-V7 is more accurate and stable. The use of the new absorber space of ozone reduced the errors by 20% in the ozone channel. Using the new predictors the errors in most channels were reduced by more than 10% with the most significant reduction of error in the ozone channel. Handling the water continuum absorption from other gases has a significant impact in the atmospheric window region.

Use of the correction term solves some numerical problems that were associated with the use of effective transmittances, greatly reduces the line-by-line computational burden, and allows for the efficient inclusion of more trace gases. The correction method can easily be applied to other fast models.

ACKNOWLEDGEMENTS: This research was partially supported by funding from the Joint Center for Satellite Data Assimilation program, NOAA. The contents of this paper are solely the opinions of the author(s) and do not constitute a statement of policy, decision, or position on behalf of NOAA or the U. S. Government.

REFERENCES

Clough, S. A., M. J. Iacono, and J. L. Moncet, 1992: Line-by-line calculations of atmospheric fluxes and cooling rates: Application to water vapor, J. Geophys. Res., **97,** 15761-15785.

Kleespies, T. J., P. V. Delst, L. M. McMillin, and J. Derber, 2004: Atmospheric Transmittance of an Absorbing Gas. 6. OPTRAN Status Report and Introduction to the NESDIS/NCEP Community Radiative Transfer Model, *Applied Optics*, **43**, 3103-3109.

McMillin, L.M., L. J. Crone, and T. J. Kleespies, 1995: Atmospheric transmittance of an absorbing gas. 5. Improvements to the OPTRAN approach, Appl. Opt. **34**, 8396 - 8399.

Xiaozhen Xiong and L.M. McMillin, 2004, An Alternative to the Effective Transmittance Approach for Calculating Polychromatic Transmittances in Rapid Transmittance Models, *Applied Optics* (submitted)