THE DEPENDENCE OF RAPID TRANSMITTANCE MODELS ON THE LINE-BY- LINE INPUT MODELS

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1. INTRODUCTION

This paper presents the results of a test where one rapid transmittance algorithm using one set of predictors was tested using two independent Line-By-Line (LBL) sources as input. The comparison of one fast model using two of the commonly used LBL models as input is an important aspect of this study. At the same time, we used two fast models as well. We compared OPTRAN to a constant pressure approach. Ideally, one would like to compare results with just one factor differing between tests. Unfortunately this is not always possible because the LBL input data are associated with other differences. But the results presented here go as far in that direction as was possible at the time the study was run. The use of two inputs to a single fast model revealed that some of the differences that have been attributed to differences in fast models are actually due to differences in the training data. When the differences in the training sets are taken into account some of the conclusions from past studies change because differences in fast models can reflect the choice of input data rather than the inherent differences in the model accuracies. The approach used in this paper gives an evaluation of the line-by-line model that is easiest to fit with all other things being equal. Our assumption is that fast models that rely on a skilled selection of predictors have a potential to perform even better if given a better starting point.

2. BACKGROUND

It is necessary to carefully describe the test factors. We used two sources of line-by-line data for this paper. The calculations are similar in that the profiles used to compute the database of line-by-line transmittances are chosen to represent the range of variations in temperature and absorber amount found in the real atmosphere. Only a few atmospheric gases are allowed to vary, the others are held constant and will be referred to as "fixed" in the text but are labeled "dry" in the figures. Gases are considered as fixed if their spatial and temporal concentration variations do not contribute significantly to the observed radiance. In this paper only H2O and O3 are allowed to vary. The transmittances computed for the diverse profiles become the predictands for the fast model regression.

The differences between the two calculations are the number of profiles used and the LBL programs used for the calculations. One set is based on LBLRTM calculations (Clough & Iacono, 1995) using a set of 32 profiles, while the second set is based on GENLN2 calculations (Edwards,1992) using a set of 43 profiles for water vapor and temperature and 34 profiles for ozone. It should be mentioned that profile 23 out of the 34 in this data set has an usually large ozone concentration and was not used in this regression. In addition, the set of 32 profiles used for LBLRTM contain only 6 different profiles for ozone. One of the 6 is assigned to each of the 32 profiles based on climatology. Since ozone is strongly correlated with temperature, this is not a serious limitation for typical cases, but models based on this data set do not produce accurate transmittances for rare ozone patterns. In addition, the Jacobians are affected by this approach. Due to the limited number of ozone profiles, it is difficult to draw any conclusions about the performance of a rapid model for ozone that is trained on this data set. The coefficients tend to fit the training data well, primarily because the training set is so easy to fit. But this does not mean that the model will do well on an independent set of atmospheres that contains the full range of atmospheric conditions. Our expectation is that it will not perform as well on independent data. The next paragraph describes the details of the LBLRTM independent data set. The two paragraphs that follow it describe the details of the GENLN2 dependent data set.

The first data set is the set of 32 profiles used by NESDIS in its rapid transmittance calculations. These profiles are described in (McMillin and Fleming, 1976). The 6 ozone profiles are derived from the US Standard atmosphere (COESA, 1962) and are assigned by finding the profile in the US standard set that best matches the temperature and water vapor. The LBL calculations are performed using a version LBLRTM that has been modified to limit some of the approximations made in the code. In its normal setting, LBLRTM makes decisions about which lines to include in the calculations to improve the speed. The included lines can change with pressure. When they do, the change produces features that are difficult to fit. For example, near the top of the atmosphere where the transmittance is nearly 1.0, the transmittance can actually increase with depth. These features are too small to have noticeable effect on the radiance, but they can cause havoc with the regression coefficients that are derived for the fast models.

The water vapor and fixed gas fast transmittance coefficients for the second data set were derived using a training set of 42 profiles (Matricardi and Saunders, 1999) selected from the 1761 profile TOVS Initial Guess Retrieval (TIGR) data set (for more details see Chedin et al.,1985). To generate the ozone fast transmittance coefficients, 33 ozone profiles (selected from a set of 383 profiles from NESDIS supplemented by a few extreme Antarctic profiles) were used (R. Rizzi, University of Bologna, personal communication). Note that within the regression scheme the global mean of either the 1761 TIGR profiles for temperature and water vapor or the 383 ozone profiles for ozone is included to serve as a reference profile. These profiles were found adequate to cover most of the range of observed temperature, water vapor and ozone behavior. The number of selected profiles is a compromise between the computational time needed to build up the database and the need to cover the range of profile behavior in the regression.

Each profile has temperature and absorber amounts at each of the pressure values used in the radiative transfer computations. However, the quality of the radiosonde stratospheric humidity measurements in the TIGR data set is a matter of concern. When generating coefficients for a regression-based fast RT model, a realistic variability for the stratospheric water vapor is required. To provide such variability a compilation has been made of 32 diverse HALOE water vapor profiles (D. Evans, Imperial College, personal communication) as a subset of the data set produced by Harries et al. (1996), for the stratosphere. The effective vertical resolution of HALOE varies between 3 and 4 km. Six latitude bands are covered. For each of the 42 TIGR water vapor profiles, the specific humidity was extrapolated as pressure cubed over the pressure range from 300 hPa to 100 hPa.. The 100 hPa value is that obtained by averaging the values from the HALOE profiles whose latitude band matches the TIGR profile latitude. The averaged HALOE water vapor values for the latitude band have then been used for the region from 100 hPa to 0.005 hPa to add some realistic variability to the stratospheric humidity. The TIGR profile temperatures were unchanged and each profile was checked for supersaturation and the water vapor was adjusted if necessary. The same extrapolation and supersaturation check was applied to the water vapor amounts that come with the ozone profiles.

3. TEST PROCEDURE

Rapid transmittance programs can appear to be similar while differing in some important aspects. To understand the results, it is important to know all the differences between the models being compared. Two of the most important involve the procedures used to interpolate the transmittances to intermediate levels. These can have implications on the evaluations. For example, many programs use a smoothly varying pressure spacing and interpolate between levels, often using spline interpolations. The smoothly varying pressures are essential for the successful use of the spline procedure because the transmittance for a layer depends on the thickness of the layer. In these models, the atmospheric state vectors are interpolated to the smoothly varying pressure grid, then the transmittances and radiances are calculated on this grid. The transmittances are then interpolated back to the original pressures for the integration of the radiative transfer equation. It has been found that interpolation on the optical depths is more accurate than interpolation on transmittances, and interpolation on absorption coefficients removes the interaction between pressure spacing and the interpolation. Interpolation of the absorption coefficients also provides the opportunity to interpolate the regression coefficients to the profile pressure spacing, thus saving one interpolation. This approach is used in the forecast model at NOAA's Environmental Modeling Center. Another approach is to use a fixed pressure grid that is never changed. In this case the transmittances are calculated directly on the grid spacing, avoiding interpolation entirely. A potential problem with this approach is that interpolation to a different pressure spacing is frequently required in use and the interpolation error is unknown. It becomes especially difficult to compare this approach with one requiring interpolation on the pressure grid it uses, because a this compares an approach with an interpolation to one without.

With all these variation, we need to clearly stat the differences between the various models. The approach used by Hannon et al. 1996) is a constant pressure approach given the name Pressure Layer Optical Depth (PLOD) approach (Hannon et al. 1996). More recently it has been given the newer name of Pfast. It calculates transmittances at 100 levels that vary smoothly in the vertical. Optcial depths are predicted.

RTTOVs differs in that the pressures are the model pressures and are not required to vary smoothly in the vertical. Optical depths are predicted. The derivatives of the transmittances with respect to pressure have a component that is due to the non uniform pressure spacing.

For the constant pressure approach used in this study, regression coefficients for the absorption coefficients are generated at uniformly spaced intervals in pressure. We will call this the test approach. It is essentially the OPTRAN approach with the pressure substituted for the absorber amount as the space on which the predictors are defined, and the secant of the viewing angle substituted for the pressure as one of the predictors. Absorption coefficients are predicted.

OPTRAN (McMillin et al. 1995b) uses coefficients at fixed amounts of absorber in the viewing path to predict absorption coefficients at the fixed absorber amounts. The absorption coefficients are then interpolated to the required pressure levels. In this paper, the test approach was used was compared to the OPTRAN approach. Absorption coefficients were generated at fixed pressures rather than fixed absorber amounts. An advantage of this approach over other constant pressure approaches is that it can be used on different pressure spacings with no change in error since interpolation is always used. The interpolation error was checked by using the true transmittances and found to be negligible. However, since the levels are common, the interpolation errors in the "true" transmittances match the interpolation errors in the predicted transmittances and, to some extent, the interpolation errors cancel.

There has been one other attempt of which we are aware to test OPTRAN versus the fixed pressure approach (Hanon et al. 1996). In fact, those results were one of the motivations for this study. They reported that, for the fixed gases and for ozone, methods based on fixed pressures worked as well or better than OPTRAN. But they also optimized the predictors for each of the two approaches. We found little dependence of the accuracy on the choice of predictors. To some extent, the results they reported are a reflection of the predictor selection. In addition, the version of OPTRAN used in that paper predicted the optical depths and not the absorption coefficients. In the development of OPTRAN (McMillin et al. 1995), the change from optical depth to the absorption coefficient was a significant improvement. We suspect that differences between the results reported in that paper and the results we obtained are explained by these differences between the approaches they compared in their paper and the two approaches we compare here. They also noted that, for high resolution instruments, it is important to maintain adequate vertical resolution at the top of the atmosphere at the line centers. They note that the 300 levels used for OPTRAN do not maintain good spacing for the intense lines. We find evidence that this is true. We find a tendency for the error in OPTRAN to start to increase for the higher peaking channels such as HIRS channel 1 and find a larger trend for the higher peaking channels found in higher resolution instruments.

As mentioned, in the development of OPTRAN, the absorption coefficient was predicted rather than transmittance or optical depth, because the absorption coefficient produced the smallest interpolation errors. The perfect test would be to evaluate the methods on line-by-line transmittances generated at different pressure levels than those used to generate the transmittances used to train the models. This could not be done for this test because the required line-by-line calculations are not available. So the reader should be aware that when the results of this paper are compared to other tests, the version of the constant pressure approach used in this paper includes an interpolation and makes a more unbiased comparison.

4. RESULTS

Figure. 1 shows the comparison for the fixed gases. The most striking feature in this figure is the large error for the LBLRTM models at channel 11. This does not cause a large error in the calculated radiance because the water vapor transmittances dominate the calculations for this channel, but the feature does suggest a problem in the LBLRTM model. Although the options for selecting lines have been turned off in this model, a possible explanation for these results is that LBLRTM may still make some selection of the lines to be used for the fixed gases based on the amount of water vapor present and the strength of the water vapor lines in a particular profile. That would explain the result that we observe. For our use, the cause is not important. We prefer to use models that don't show this pattern to generate the coefficients for our rapid models. LBLRTM also shows significantly larger errors than GENLN2 for channels 12 through 15 as well. Another feature shown in this figure is that, for the fixed gases, there is no significant difference between OPTRAN and the constant pressure approach. The other feature that we note is that GENLN2 shows larger errors for channels 1 and 15. These are the highest peaking channels. In addition, if the channels are ranked in order of increasing height, the errors increase as these channels are approached. We

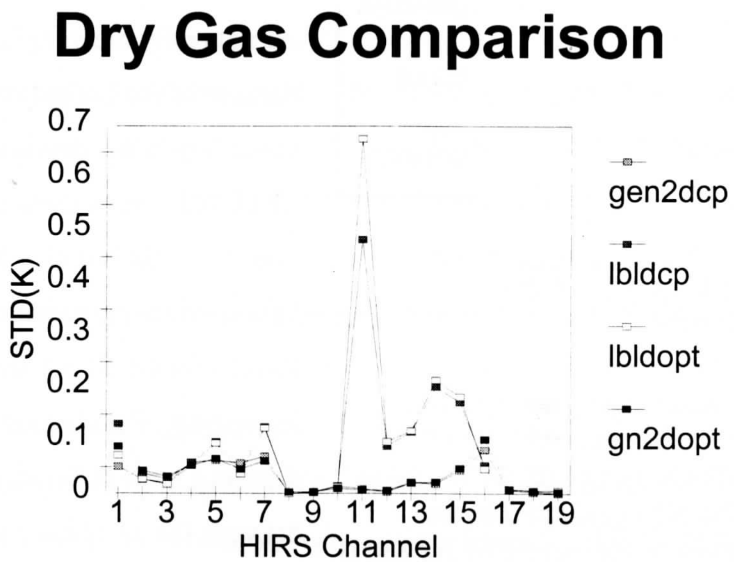

Figure 1 Standard errors for the dry gas radiances as a function of the channel number. The lines are for the test approach using GENLN2 - gen2dcp, the test approach using LBLRTM - lbldcp, OPTRAN using LBLRTM - lbldopt, and OPTRAN using GENLN2 - gn2dopt.

attribute this effect to the spacing of levels used to calculate the LBL transmittances used to generate the coefficients. We suspect that the vertical resolution in both the LBL results and the rapid models needs to be increased to reduce this increase in error with channel height.

Figure 2 shows the results for water vapor. It is clear that the OPTRAN approach has a definite advantage for water vapor. The results for LBLRTM and GENLN2 are roughly equal. GENLN2 shows larger errors for channels 1-4, but this is not important for the total transmittance because the dry gas absorption dominates for these channels.

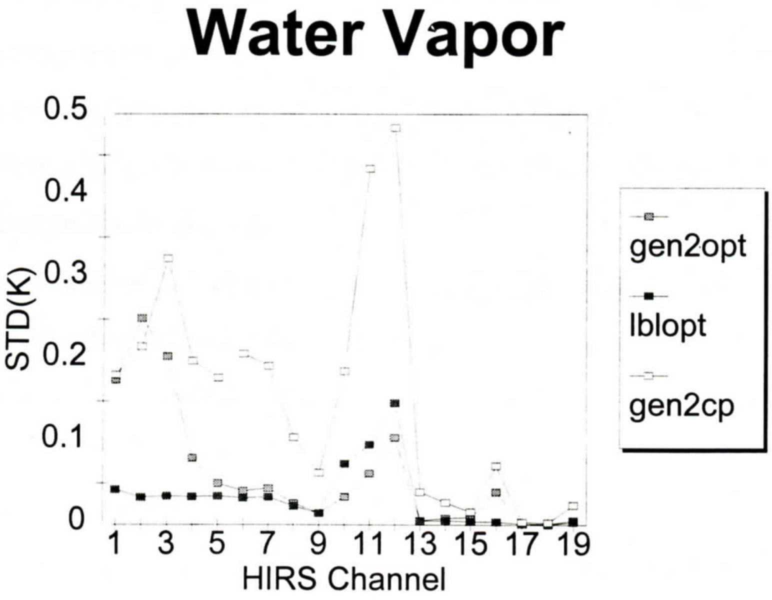

Figure 2 Standard error for the water vapor radiances as a function of the channel number. The lines are for OPTRAN using GENLN2 - gen2opt, OPTRAN using LBLRTM - lblopt, and the test approach using GENLN2 - gen2cp. The test approach using LBLRTM is similar to the one GENLN2 and is not shown.

Figure 3 shows the results for ozone. As discussed earlier, the results for the LBLRTM are not really meaningful because of the limited ozone variability in the data set. The LBLRTM results show that it is easy to match such a limited data set with any method. Results for GENLN2 are more interesting. For channel 9, there is a large difference between the accuracies for the constant pressure and

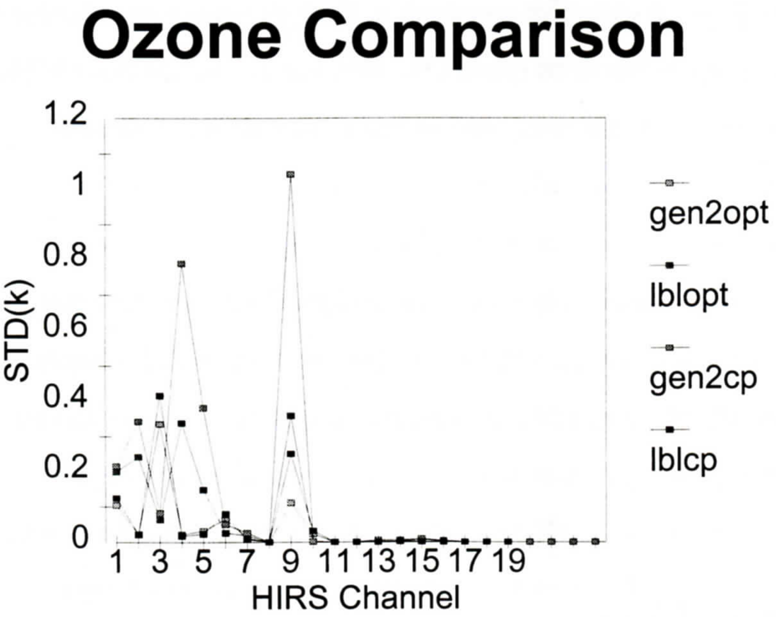

Figure 3 Standard errors for the ozone radiances as a function of the channel number. The lines are for OPTRAN using GENLN2 - gen2opt, OPTRAN using LBLRTM - lblopt, the test approach using GENLN2 - gen2cp, and the test approach using LBLRTM - lblcp.

OPTRAN approaches. We think this is due to the interpolation in the constant pressure approach. We performed a test in which we replaced the predicted absorption coefficients with the actual values, but still performed the OPTRAN interpolations. The interpolation errors were generally small, but did increase for channels peaking higher in the atmosphere. For channel 9, the absorption occurs in the high levels. This explains the difference between our results in this paper and other results which show the channel 9 ozone temperatures to be more accurate.

5. SUMMARY AND CONCLUSIONS

These tests indicate that OPTRAN provides results that are similar to those produced by a constant pressure approach for the dry gases, and better than the constant pressure approach for water vapor and for ozone when interpolation is considered. For use in a numerical prediction model or other application that uses pressure levels that change (for example with the surface pressure) these conclusions are valid. If a fast model always uses fixed pressures, then coefficients based on the fixed pressures do not show the interpolation error.

A comparison done by Hannon et al. (1996) reported that a constant pressure approach provided more accurate results. That study differed from this approach in that optical depths rather than absorption coefficients were predicted. It has been found (McMillin et al. 1995b) that OPTRAN works best when the absorption coefficients are predicted and suspect that that difference is responsible for the difference in results. We are also aware that another model (Saunders 1999) provides excellent accuracy. That model generates coefficients for the pressure grid on which it is to be applied and the evaluations were performed on the same grid. This procedure bypasses the interpolation, so the accuracy of this approach when interpolation is required is unknown. When these factors are taken into account, the apparent disagreement between these tests and the reports reported here vanishes. The differences do, however, suggest some additional tests that need to be done. For a valid comparison, the constant pressure approaches need to be compared to OPTRAN after interpolation and OPTRAN has to implemented in its final absorption coefficient form. We also suspect that the accuracy of OPTRAN could be improved by adding predictors and adding more upper atmospheric levels.

In some of these tests, we find we were limited by the speed of the LBL models. In other words, we never were able to get all the cases we would have liked to study for our development of our rapid models. For example, the test at the interpolated levels requires additional LBL runs. Although increases in computer speed may someday solve this problem, there are intermediate models that are faster than LBL approaches, but not fast enough for direct use in a numerical model. One of these models is needed for a thorough test of the rapid approaches. We strongly support their development and use.

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