RESULTS FROM THE HIRS-AMSU INTERCOMPARISON OF RADIATIVE TRANSFER CODES

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1. INTRODUCTION

There have been several intercomparisons of radiative transfer codes in the past, mostly for broadband schemes designed for application to atmospheric models. More recently, an intercomparison was carried out under GVaP (GEWEX Global Water Vapor Project) to validate codes applied specifically to the 6.3 micron band as observed by the NOAA-12 satellite (Soden et al, 1999). The interest there was initiated by the climate community working on the quantification of means and trends in upper tropospheric humidity. The present effort is an extension of the GVaP study to 7 infrared and 4 microwave channels. It was initiated by the ITWG (International ATOVS Working Group) interested in the assimilation of radiances in numerical weather prediction (NWP). The basic goals of this study are:

a) the identification and quantification of weaknesses in fast radiative transfer models (RTM)

b) the evaluation of the level of agreement between line-by-line models (LBL) used as "truth" in the development of fast RTMs (and some more efficient narrow-band models as well).

c) the examination of individual gas transmittances as well as Jacobians with respect to temperature (T) or gaseous concentration (Q).

2.DEFINITION OF THE INTERCOMPARISON

A set of 42 atmospheric profiles was provided, defined on 43 fixed pressure levels. The participants were asked to compute brigthness temperatures (BT) for up to 11 channels: HIRS: 02, 05, 09, 10, 11, 12 and 15 onboard NOAA-14 and AMSU 6, 10, 14 and 18 from NOAA-15. The surface emissivity was defined as unity in HIRS channels and 0.6 for AMSU channels. Total upward transmittances from each level to the top of the atmosphere (0.1 mb) were requested as well as H_2O and O_3 transmittances (where appropriate). Similarly Jacobian profiles with respect to T, H_2O and O_3 were required for 5 of the profiles. Jacobians are defined by the change in BT (K units) to a local 1 K temperature increase or to a local 10% Q decrease. Jacobians represent a fundamental quantity in data assimilation as they control the shape of analyzed T and Q increments. Only a brief summary is presented here.

3. BT RESULTS

3.1 HIRS channels

The 42 profiles came from a larger dataset of 189 profiles commonly used at AES (Turner, 1999). The first 6 are AFGL standard profiles: mean tropical, midlatitude/subarctic summer/winter and US standard. Then, 12 bins representing T, H_2O and O_3 ranges were created for the remaining 36 profiles. Each profile is actually an average of 15 profiles. As a result of this averaging process, profiles are smoother than individual real profiles, and BT standard deviations against a reference model will tend to be underestimated (lower than in the GVaP exercise for HIRS-12, for example, see Table 1). Although the averaging procedure is not ideal, some profiles remain challenging for fast models and do expose their weaknesses.

Here, for reason of space, we examine only standard deviations, not biases. The models to be compared are a) three LBLs: AES-LBL, GENLN2 and LBLRTM (typically 0.005cm^{-1} resolution); b) four fast, equivalent monochromatic models: RTTOV5, OPTRAN, AES-FAST and MALKMUS; c) two narrow-band models: STREAMER (in fact quite broad: 20-40 cm^{-1}) and MODTRAN (1 cm^{-1}). Because results depend somewhat on the LBL used as reference, the other models are evaluated against each of the three LBLs. Table 1 summarizes the HIRS results. For HIRS-12, results of the GVaP exercise are also indicated (parentheses).

Table 1. BT standard deviations of various models against three LBLs. For HIRS-12, values between parentheses represent results obtained for the GVaP intercomparison based on 43 profiles (and a similar 6.7 micron channel on NOAA-12).

	HIRS-02			HIRS-05		
	AESLBL	GENLN2	LBLRTM	AESLBL	GENLN2	LBLRTM
RTTOV5	.19	.08	.12	.12	.22	.26
AESFAST	.41	.34	.36	.12	.21	.23
MALKMUS	1.00	.90	.93	.21	.29	.31
OPTRAN	.12	.09	.08	.18	.09	.08
MODTRAN	.11	.03	.05	.51	.62	.65
STREAMER	.92	.84	.87	2.17	2.24	2.29
AESLBL	.00	.10	.07	.00	.13	.16
GENLN2	.10	.00	.04	.13	.00	.04

Table 1. Continued

		HIRS-09			**HIRS-10**	
	AESLBL	GENLN2	LBLRTM	AESLBL	GENLN2	LBLRTM
RTTOV5	.20	.21	.19	.23	.23	.26
AESFAST	.27	.25	.28	.04	.05	.05
MALKMUS	.25	.25	.28	.32	.32	.30
OPTRAN	1.39	1,40	1.38	.07	.07	.07
MODTRAN	.32	.30	.31	.15	.15	.15
STREAMER	.85	.87	.85	.36	.36	.33
AESLBL	.00	.04	.02	.00	.01	.02
GENLN2	.04	.00	.05	.01	.00	.03

		HIRS-11			**HIRS-12**	
	AESLBL	GENLN2	LBLRTM	AESLBL	GENLN2	LBLRTM
RTTOV5	.46	.38	.37	.43	.42(.85)	.43
AESFAST	.08	.31	.27	.15	.06(.28)	.19
MALKMUS	.46	.11	.16	.23	.29(.33)	.26
OPTRAN	.27	.12	.10	.18	.31(.45)	.15
MODTRAN	.47	.29	.29	.20	.25(.20)	.20
STREAMER	.74	.48	.51	.14	.15(.43)	.16
AESLBL	.00	.35	.32	.00	.15(.19)	.18
GENLN2	.35	.00	.06	.15	.00(.00)	.18

Results for HIRS 15 are not presented in Table 1. All fast models were very good with STDs < .20 K in that channel. STREAMER is not really designed for channels 2, 5 and 15 because its spectral resolution (20 cm-1 at best) is too coarse. Among the four fast models, we note the following:

HIRS-02: OPTRAN and RTTOV5 are good, AES-FAST is marginal and MALKMUS is weak.

HIRS-05: OPTRAN is best, the other three are acceptable.

HIRS-09: RTTOV is best, OPTRAN is weak; the other two are acceptable.

HIRS-10: AES-FAST and OPTRAN are excellent, the other two are acceptable.

HIRS-11: RTTOV-5 is marginal; the other three are good with results depending on the LBL.

HIRS-12: AES-FAST is best, OPTRAN is second. MALKMUS is good and RTTOV5 is marginal.

Fig. 1 shows BT values for the 42 profiles in HIRS-05 for several models. The spread is significant, notably for warmest (15-18) and moistest (25-30) profiles.

3.2 **AMSU channels**

Table 2 shows BT standard deviations of fast models versus LBL models for AMSU channels. Results appear fully satisfying for AMSU-06 and AMSU-10. In AMSU-14, OPTRAN and OSS do very good against some LBLs, but not against others. This is because AESLBL differs from the others significantly (RTTOV5 is close to that model). OPTRAN seems less accurate than the other two fast models in AMSU-14. The same is true for RTTOV-5 in HIRS-18, with SDs near 0.3 K against all LBLs. Overall, OSS is the most accurate model.

Table 2. BT standard deviations between three fast models and four LBL models for the four AMSU channels.

	AMSU-06				**AMSU-10**			
	AESLBL	LBLRTM	OSSLBL	ATM	AESLBL	LBLRTM	OSSLBL	ATM
RTTOV5	.08	.11	.16	.20	.05	.18	.17	.14
OPTRAN	.10	.07	.05	.05	.15	.07	.04	.06
OSS	.08	.05	.01	.06	.12	.02	.01	.03
AESLBL	.00	.04	.08	.13	.00	.12	.12	.09
LBLRTM	.04	.00	.05	.10	.12	.00	.03	.04
OSSLBL	.08	.05	.00	.05	.12	.03	.00	.04

	AMSU-14				**AMSU-18**			
	AESLBL	LBLRTM	OSSLBL	ATM	AESLBL	LBLRTM	OSSLBL	ATM
RTTOV5	.07	.80	.86	.81	.31	.30	.32	.35
OPTRAN	1.00	.30	.24	.31	.14	.10	.24	.19
OSS	.77	.04	.05	.05	.15	.14	.10	.14
AESLBL	.00	.74	.80	.74	.00	.14	.24	.10
LBLRTM	.74	.00	.07	.05	.14	.00	.19	.19
OSSLBL	.80	.07	.00	.09	.24	.19	.00	.15

Fig. 2 shows the spread between five models for AMSU-14. As noted in Table 2, RTTOV5 follows closely AESLBL while OSS is close to LBLRTM and OSSLBL (the latter not shown). OPTRAN differs from the others.

4. JACOBIAN RESULTS

A measure of goodness of fit, M, is defined as follows:

$$M = 100\ [\mathrm{SUM}(X_i - X_{ref})^2 / \mathrm{SUM}(X_{ref})^2]^{1/2}$$

where X_i and X_{ref} are model and reference Jacobians, and the sum is over the 43 vertical levels. M here is evaluated for single profiles . This measure can be interpreted as an overall percentage of error. The measure has the same meaning for all channels (as opposed to straight standard deviation and bias measures). Values of M can be associated with the following evaluation:

M= 0-5: excellent fit, typical among LBL models

M=5-10: very good fit, achievable by fast models in some, but not all channels

M=10-20: fair fit, likely acceptable for NWP applications, some concerns above 18.

M=20-30: weak fit: improvements strongly suggested for use in NWP.

M > 30: bad fit, non acceptable.

4.1 HIRS Jacobians

Values of M were computed for 5 profiles and the 7 channels using both LBLRTM and GENLN2 as truth. This means 70 entries in total. Table 3 shows the M distributions for the four fast models and for AESLBL. An overall score is attributed as explained in the caption. AESFAST and OPTRAN get a similar performance. RTTOV5 has some problems, with 13 cases with M > 20.

Table 3. Number of occurrences of M ranges (out of a total of 70 cases, 10 for each of 7 HIRS channels) for temperature Jacobians for four fast models and an independent LBL (AESLBL) model. Score evaluated based on 2, 1.5, 1, 0, -2 points allowed to the 5 categories, respectively. GENLN2 was evaluated against LBLRTM only (35 cases with occurrences doubled).

M	0-5	5-10	10-20	20-30	>30	score
RTTOV5	14	27	16	8	5	74.5
AESFAST	5	39	24	2	0	92.5
MALKMUS	5	16	32	16	1	48.0
OPTRAN	14	32	18	4	2	90.0
AESLBL	28	23	18	1	0	108.5
GENLN2	22	34	14	0	0	109.0

Table 4 shows a similar analysis for humidity Jacobians in HIRS-10, 11 and 12. The level of agreement between GENLN2 and LBLRTM is very high. AESFAST gets a similar score to AESLBL from which it was tuned. Bad Jacobians for RTTOV5 are linked to profile # 31 (lowest ozone profile) for HIRS-11 and 12. Bad Jacobians for OPTRAN are associated to the same profile in HIRS-09. Models using a physical formulation of transmittances, AESFAST and MALKMUS, perform better from the viewpoint of water vapor Jacobians, than models using a regression formulation (OPTRAN and RTTOV5).

Table 4. Same as Table 3, but for H_2O Jacobians for HIRS-10, 11 and 12 only (30 cases).

M	0-5	5-10	10-20	20-30	>30	score
RTTOV5	0	4	21	1	4	19.0
AESFAST	9	14	7	0	0	46.0
MALKMUS	9	9	11	1	0	42.5
OPTRAN	2	8	11	7	2	21.0
AESLBL	12	9	9	0	0	46.5
GENLN2	30	0	0	0	0	60.0

Fig. 3 shows an example of temperature Jacobian for HIRS-09. STREAMER (M=35.6, 29.9 vs LBLRTM, GENLN2) and OPTRAN (M=45.5, 38.9) differ significantly from the other models. An incorrect kink is also noted at ~100 mb in the RTTOV5 (M= 33.6, 21.4) profile. The value of M for GENLN2 vs LBLRTM is 19.2. Values of M between these two LBLs in the range 15-20 only occur in HIRS-09 and HIRS-10. Values of M between AESLBL and GENLN2 are below 15 for all 35 profiles.

4.2 **AMSU Jacobians**

An evaluation of temperature Jacobians for AMSU is shown in Table 5 based on profile # 30. OPTRAN differs from the others in AMSU-6; the same applies to OSS in AMSU-18. All models are similar in AMSU-10. Results in AMSU-14 depend largely on which LBL is used as a reference.

Table 5. Values of M (T Jacobians) in AMSU channels for profile # 30. Two values are given: M with respect to AESLBL and LBLRTM, respectively.

	AMSU-6	AMSU-10	AMSU-14	AMSU-18
RTTOV5	1.5, 1.1	1.4, 5.2	2.1, 30.9	3.8, 1.8
OPTRAN	20.0, 20.6	6.8, 6.8	46.4, 16.7	8.2, 6.3
OSS	2.7, 2.7	7.4, 6.1	34.2, 9.8	17.4, 15.8
LBLRTM	1.1, 0.0	4.7, 0.0	30.3, 0.0	3.6, 0.0
AESLBL	0.0, 1.1	0.0, 4.8	0.0, 29.2	0.0, 3.6

Fig. 4 shows the temperature Jacobian for AMSU-14 for the same models shown in Fig. 2. The same conclusions can be drawn: closeness between the pairs RTTOV-5-AESLBL and OSS-LBLRTM, and OPTRAN somewhat different than the others.

5. SUMMARY

The HIRS-AMSU intercomparison of radiative transfer codes is an important exercise which should help to answer many of the questions raised on the quality of these codes and eventually on the level of precision required for NWP. Right now, it appears reasonable to suggest that a level of precision of 0.2 K for BT and values of M < 20 is satisfying from the viewpoint of NWP applications. Among fast models suitable for NWP, the good news is that these criteria are already met or close to be met in all channels, - but no single model meets the criteria in all channels. Non acceptable errors still occur for individual cases. The level of disagreement between LBL models is most evident in HIRS-11 and AMSU-14 from examination of BTs only. The more detailed examination of Jacobians indicate that LBLs can differ significantly in HIRS-09 and HIRS-10. It will likely not be easy for LBL modelers to identify the causes for these differences. Perhaps an examination of transmittances for individual gases available from this intercomparison will help. Jacobian profiles provide evidence of fast model weaknesses which could not be detected easily before. Hopefully, results from this exercise will be useful not only for current applications of ATOVS data, but also for the modeling of narrower infrared channels which will eventually replace HIRS. A complete report will be available in the near future.

REFERENCES

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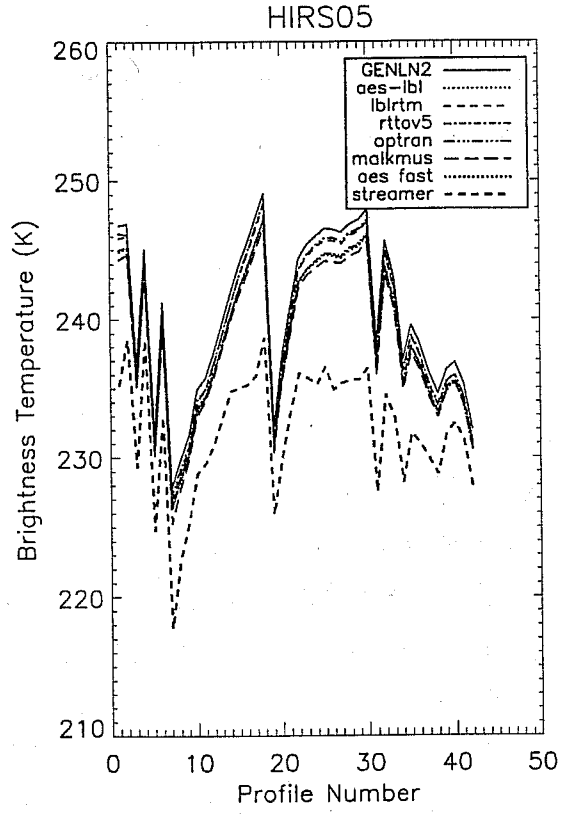

Fig. 1. HIRS-05 BTs for various models.

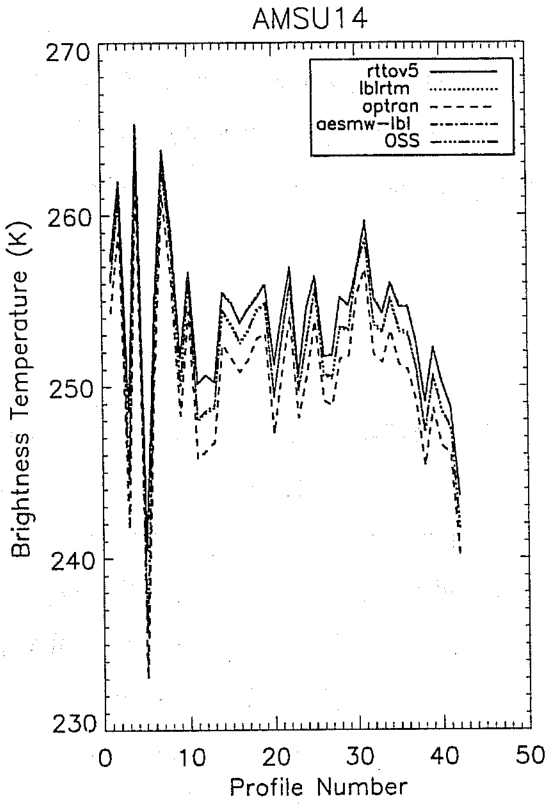

Fig. 2. AMSU-14 BTs for various models.

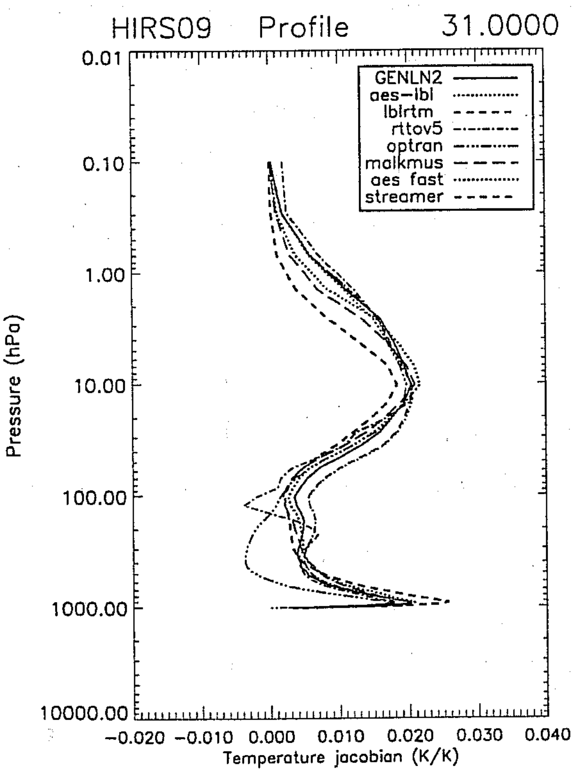

Fig. 3. HIRS-09 T Jacobians for profile 31.

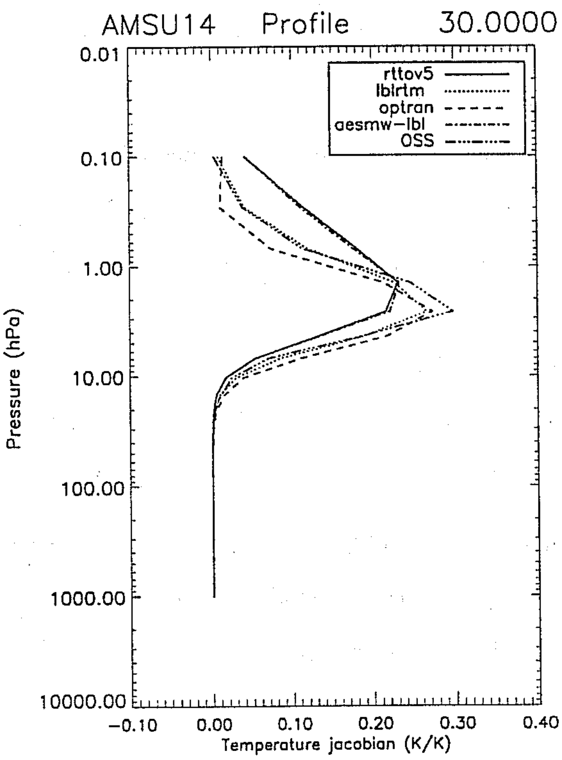

Fig.4. AMSU-14 T Jacobians for profile 30.