An Alternate Algorithm to Evaluate the Reflected Downward Flux Term for a Fast Forward Model

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- at ITSC12 demonstrated the current algorithms for the attenuated reflected downward flux term did not work well for all the channels considered
- in general small biases existed only for high emissivities & low altitudes



▲ HIRS, ● AIRS



Item affects land retrievals where emissivities may be considerably less than .9 and p_s < 800hPa</p>

require a fast scheme that is acceptable for a wider range of emissivities and surface pressures Top of the atmosphere (TOA) radiance is the sum of 3 terms: attenuated surface emissions attenuated atmospheric upward emissions attenuated reflected downward flux

$$<\Re_{s}(\theta,p_{s})> = \langle \varepsilon B(T(p_{s})) \Re(\theta,p_{s}) \rangle + \langle \int_{o}^{p_{s}} B(T) d\Re(p,\theta) \rangle + \langle r \Re(\theta,p_{s}) F^{\downarrow}(p_{s}) \rangle$$

p - pressure	θ - satellite zenith angle
B - Planck function	\Im - p to TOA transmittat

S - p to TOA transmittance

ε - surface emissivity

 F^{\downarrow} - downward flux

r - surface reflectivity

subscript 's' denotes a topographical or cloud top surface

 \mathfrak{R} \mathfrak{R} , \mathfrak{F} , \mathfrak{B} , ε and r are functions of wavenumber

•
$$< f > = \int_{\Delta \tilde{v}} \phi(\tilde{v}) f(\tilde{v}) d\tilde{v} \qquad \phi$$
 - response function

variables of the form < f > are evaluated using MSC's Fast Line-By-Line (FLBL) radiative transfer model

Attenuated reflected downward flux (ARDF) term is approximated as

$$\left\langle r \,\mathfrak{S}(\theta, p_s) F^{\downarrow}(p_s) \right\rangle \approx r \left\langle \mathfrak{S}(\theta, p_s) F^{\downarrow}(p_s) \right\rangle \approx r \left\langle \mathfrak{S}(\theta, p_s) \right\rangle \left\langle F^{\downarrow}(p_s) \right\rangle$$

$$r < \mathfrak{R}_s^{\theta} > \left[\frac{1}{\pi} \left(\sum_{k=1}^s \frac{< \mathfrak{R}_{k-1}^{\varphi} > - < \mathfrak{R}_k^{\varphi} >}{< \mathfrak{R}_{k-1}^{\varphi} > < \mathfrak{R}_k^{\varphi} >} < \overline{B}_k > \right) < \mathfrak{R}_s^{\varphi} > \right]$$

assume ^{ISF} r is constant across φ

- isotropic reflection for this work, ie $r = (1-\epsilon)/\pi$
- approximate F^{\perp} by replacing the angular integration of \mathfrak{F}^{f} with $\mathfrak{F}(\varphi)$, sec φ is the diffusivity factor, usually set to 1.66
- $\square < a b >$ can be decomposed as < a > < b >

RTTOV
$$\Im$$
 \Im $(\phi) = \Im$ (θ)

(Saunders, 1999)

MSCFAST $\Re (\varphi) = \Im (1.66)$ (Garand, 1999) \Re requires 2nd pass of transmittance model

- past experience tells us that $\langle a | b \rangle$ can not be decomposed as $\langle a \rangle \langle b \rangle$ (Turner, 2001)
- test for reliability of the decomposition of the return transmittance and the downward flux using the FLBL, ie; how well does $\delta BT = 0$?

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\delta BT = BT(\left\langle \mathfrak{S}(\theta, p_s) F^{\downarrow}(p_s) \right\rangle) - BT(\left\langle \mathfrak{S}(\theta, p_s) \right\rangle \left\langle F^{\downarrow}(p_s) \right\rangle)
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- decomposition fares poorly
 - plot the bias of δBT across 52 ECMWF profiles for ϵ =.98 & ϵ =.7
 - many channels exhibit large errors that increase with $\theta, \epsilon \mbox{ \& } p_s$



AIRS352, 752.07 (cm⁻¹) AIRS1018, 1007.87 (cm⁻¹)

if decomposition of S F¹ is unreliable, then further decomposition of F¹ into [] is probably not reliable, thus new scheme must account for errors due to these decompositions

400 600 800	A0889 955.554	A0890 955.945	A0891 956.337	A0892 956.729	A0893 957.121	A0894 957.513	A0895 957.906	A0896 958.299	A0897 958.692	A0898 959.086	A0899 959.48	A0900 959.874
400 600 800	A0901 960.269	A0902 960.664	A0903 961.06	A0904 961.455	A0905 961.851	A0906 962.248	A0907 962.644	A0908 963.041	A0909 963.439	A0910 963.836	A0911 964.234	A0912 964.633
400 600 800	A0913 965.031	A0914 965.43	A0915 965.83	A0916 966.229	A0917 966.63	A0918 967.03	A0919 967.431	A0920 967.832	A0921 968.233	A0922 968.635	A0923 969.037 -1	A0924 969.439 -1
1000 400 600 800	A0925 969.842	A0926 970.245	A0927 970.648	A0928 971.052	A0929 971.456	A0930 971.86	A0931 972.265 -1	A0932 972.67	A0933 973.075	A0934 973.481	A0935 973.887	A0936 974.294 -1
1000 400 600 800	A0937 973.818	A0938 974.225	A0939 974.631	A0940 975.039	A0941 975.446 -1-	A0942 975.854	A0943 976.262 -1-	A0944 976.67	A0945 977.079	A0946 977.488 -1	A0947 977.898	A0948 978.308
1000 400 600 800	A0949 978.718	A0950 979.128	A0951 979.539	A0952 979.95	A0953 980.362	A0954 980,774	A0955 981.186	A0956 981.599	A0957 982.011	A0958 982,425	A0959 982.838	A0960 983.252
1000 400 600 800	A0961 983.667	A0962 984.081	A0963 984.496 ~	A0964 984912 🥿	A0965 985.327	A0966 985.743	A0967 986.16	A0968 986.576	A0969 986.993	A0970 982,411	A0971 987.829 _1	A0972 988.247
1000 400 600 800	A0973 988,665 -1 _	A0974 969.084 -1	A0975 969.503 -1	A0976 989.923	A0977 990.343	A0978 990.763 -1	A0979 1911.183 -1	A0980 991.604	A0981 992.026	A0982 992,447	A0983 992.869	A0984 993.292
1000 400 600 800	A0385 998,714 -1 ~	A0986 994137	A0987 999.561	A0988 994.985	A0989 995.409	A0990 995.833	A0991 996.258	A0992 996.683	A0993 997.109	A0994 997.535	A0995 997.961	A0396 998.387
1000 400 600 800	A0997 998.814	A0998 999.242	A0393 393.67 _4 ~	A1000 1000.098	A1001 1000.526 ~~	A1002 1000.955	A1003 1001.384	A1004 1001.8¥3 -4	A1005 1002:243 -4	91006 1002.674_4~	A1007 1003.104	A1008 1003.535 ~~
1000 400 600 800	A1009 1003.966	A1010 1004.398_4	A1011 1004.88	A1012 1005.263	A1013 1005.695	A1014 1006.129	A1015 1006.5624	A1016 1086.396 -4	A1017 100743 -4	A1018 1007.865	A1019 1008.34	A1020 1088,735 -4~
1000 400 600 800	A1021 1009.171 -4	A1022 1009.607 -4	A1023	A1024 1010.48_4 ~_	A1025 1010-918 -4	A1026 1011,355 -4	A1027 1019,793 -4 -	A1028 1012/231	A1023 1012.67_4	A1030 1013.709 -4 -	A1031 10135549 -4	A1032 1013.388 -4~_
1000 400 600 800	A1033 1014.429	A1034 1014.889 -4 ~.	A1035 1015.31 -4	A1036 1015.751 -4	A1037 1016 193 _4-	A1038 1016.635	A1039 1017.076_4 ~	A1040 1017.52 _4 ~	A1041 1017.984 -4-	91042 1018.407_4 ~	A1043 1018.8514	A1044 1019.296_4~
400 600 800	A1045 1019.74	A1046 1020.185	A1047 1020.631	A1048 1021.077	A1049 1021.523	A1050 1021.969	A1051 1022.416	A1052 1022.864	A1053 1023.312 _4 .	A1054 1023.76 _4 -	A1055 1024208 -4	A1056 1024692 -4 -
400 600 800	A1057 1025.106	A1058 1025.556 -4	A1059 1026006 -4-	A1050 1026.457 -4	A1061 1026,907 -4	A1062 1087.359 -4	A1063 1027.81 -4	A1064 1028.262	A1065 1028.715 -4	A1066 1029.167 -4 -	A1067 1029,62 -4	A1068 1030.0744
400 600 800 1000	A1069 1030.528 _4 -	91070 1030/982 -4	A1071 1031.4 97 -4	A1072 1031.892	A1073 1032.347	A1074 1032.803	91075 1033.26 -4	A1076 1033.716	91077 1034173	A1078 1034,631 -4	A1079 1035.089	A1080 1035.547

Sampling of biases across the 52 ECMWF profiles for ϵ =.98 (AIRS 889-1080)

$$\delta \mathrm{BT} = \mathrm{BT}(\left\langle \mathfrak{F}(\theta, p_s) F^{\downarrow}(p_s) \right\rangle) - \mathrm{BT}(\left\langle \mathfrak{F}(\theta, p_s) \right\rangle \left\langle F^{\downarrow}(p_s) \right\rangle)$$

Alternate Algorithm

assume that for a given (θ, p_s) there exists a value κ such that replacing $\mathfrak{F}(\theta)$ with $\mathfrak{F}^{\kappa}(\theta)$ provides a good estimate of the ARDF term

$$r < \mathfrak{F}_{s}(\theta) > \left[\frac{1}{\pi} \left(\sum_{k=1}^{s} \frac{<\mathfrak{F}_{k-1}^{\theta} >^{\kappa(p_{s},\theta)} - <\mathfrak{F}_{k}^{\theta} >^{\kappa(p_{s},\theta)}}{<\mathfrak{F}_{k-1}^{\theta} >^{\kappa(p_{s},\theta)} < \mathfrak{F}_{k}^{\theta} >^{\kappa(p_{s},\theta)}} < \overline{B}_{k} > \right) < \mathfrak{F}_{s}^{\theta} >^{\kappa(p_{s},\theta)} \right]$$

 ${}^{\tiny \hbox{\tiny ISS}}$ $\kappa(\,\theta,p_{_{s}}\,)$ is interpolated from a pre-determined look-up table

- advantages replaces the 2nd pass of the fast transmittance model with a lookup table followed by an exponentiation should be faster
 - accounts for decomposition of $< \Im F^{\downarrow} >$
 - preserves current program structures hence, easier to implement

κ - Lookup Table Determination

Image we develop the basic fast transmittance model (ie ε=1)
 Image we develop the basic model, minimize

$$\left\langle \mathfrak{S}(\theta, p_s) F^{\perp}(p_s) \right\rangle - \{\mathfrak{S}_s^{\theta}\} \left(\sum_{k=1}^s \frac{\{\mathfrak{S}_{k-1}^{\theta}\}^{\varkappa(p_s,\theta)} - \{\mathfrak{S}_k^{\theta}\}^{\varkappa(p_s,\theta)}}{\{\mathfrak{S}_{k-1}^{\theta}\}^{\varkappa(p_s,\theta)} \{\mathfrak{S}_k^{\theta}\}^{\varkappa(p_s,\theta)}} \{\overline{B}_k^{\theta}\} \right) \{\mathfrak{S}_s^{\theta}\}^{\varkappa(p_s,\theta)} \left| \leq \delta$$

for a set of $\kappa(\theta,\,p_{_{S}}\,)$ for each atmosphere

table entry is the average $\kappa(\theta, p_s)$ across the atmospheres

NOTE: $\langle f \rangle$ - FLBL model, $\{f\}$ - fast model

Comparisons

- [™] compare 3 modified forms of RTATOV (Saunders, 1999)
 - add extra levels at .005, .014, .037, 1048.51 & 1085 hPa
 - fast transmittance model coefficients determined from FLBL calculations using ECMWF 52 diverse profile set (AIRS inter-comparison)
 - 6 secants (1, 1.25, 1.5, 1.75, 2 & 2.25)
- IS M1, $\phi = \theta$, $\varkappa = 1$ single pass thru' fast transmittance model
- Solution M2, $\varphi = \theta$, $\varkappa = 1$ two passes thru' fast transmittance model
- M3, φ = θ, $κ = κ(θ, p_s)$ single pass thru' fast transmittance model followed by exponentiation of ℜ (θ)
 - $\kappa(\theta, p_s)$ determined for 24 p_s (223 to 1085hPa) and 6 secants (1, 1.25, 1.5, 1.75, 2 & 2.25)
- realuate BT all 3 models & FLBL for
 - 24 surface pressures (223 to 1085hPa0
 - 21 emissivities (0 to 1), $r = 1/\pi$ to 0
 - 52 ECMWF atmospheres
 - 2378 AIRS channels
- compare bias and standard deviation (stdv) across 53 profiles of the difference,

$$BT(\langle R^{surf} + R^{\dagger} + r \Im(\theta, p_s) F^{\downarrow}(p_s) \rangle) - BT(\langle R_{surf} \rangle + \langle R^{\dagger} \rangle + r \langle \Im(\theta, p_s) \rangle \langle F^{\downarrow}(p_s) \rangle)$$



Fig: M1, M2 & M3 bias & stdv as a function of channel for sec θ = 1, ϵ = .7 and p_s = 1013hPa

- IS M2 & M3 fare much better than M1
- not clear which performs better M2 or M3 wrt bias or stdv
- IST on average M3 is ~1.25 slower than M1 and M2 is ~1.6 slower than M1
- ^{IS™} M3 faster than M2



Bias (left) & stdv (right) for channel 1018 (1007.86(cm⁻¹)) as a function of θ , ϵ & p_s

- strong θ dependency in M1, weaker in M2 & M3
- small region of low bias & stdv in M1 & M2
- IP M3 applicable over a wider range of $\varepsilon \& p_s$
- M3 models the ARDF term very well in terms of bias
- stdv doesn't improve using M3, but not any worse



- Fig: Bias (left) & stdv (right) for channel 610 (851.8(cm⁻¹)) as a function of θ , ϵ & p_s
- strong θ dependency in M1, weaker in M2 & M3
- small region of low bias & stdv in M1
- ${}^{\hbox{\tiny I\!S\!T}}$ M2 applicable over a wider range of ϵ & $p_{_s}$
- Reference example of when M2 better than M3
- some improvement in stdv over M1



Fig: More examples of the bias & stdv comparisons

Summary

- algorithm effects bias more than stdv
- IS both M2 & M3 are an improvement over M1
- ^{IS™} M3 is faster than M2
- M2's &/or M3's stdv are generally no worse than M1's
- useful range of ε and p_s increased (ie manageable biases)
- $\sim 65\%$ of the channels perform as well or better than M2 with M3

Problems

the bias vs channel curve contains many spikesfrequently M2 is better than M3 at these spikes



Fig: Upper box illustrates the bias curves for $\theta=0$, $\epsilon=.6$ and $p_s=1013hPa$ (M1,M2, M3). The middle box is an enlargement of the upper box superimposed on a TOA total transmittance curve. The M1, M2, M3 values of { \Im } are marked by circles. The lower box is a further enlargement of the middle box with some AIRS spectral response functions superimposed.

IS problem channels are collocated with the core/near wing of H_2O spectral lines, these regions are very non-linear

M3 needs more consideration prior to implementing M3

Conclusions

- the 2 pass transmittance model is preferable over the simple "reflection" model some tuning of the diffusivity factor may be required
- new algorithm is faster than current algorithms, but does not work for 100% of the channels ideally would like to use M3 exclusively, but need to "fix the spikes" first
- note that M3 does not depend on the relationship between r & ε, they can be independent of each other only require that they are constant over the response function

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