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

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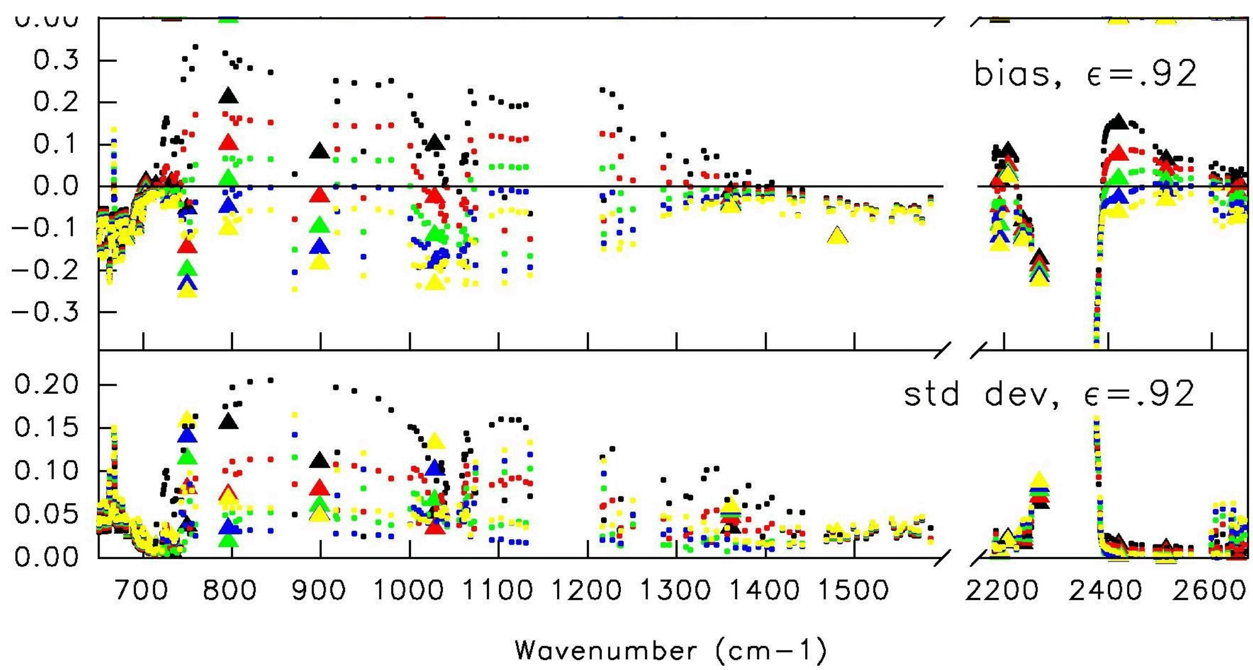
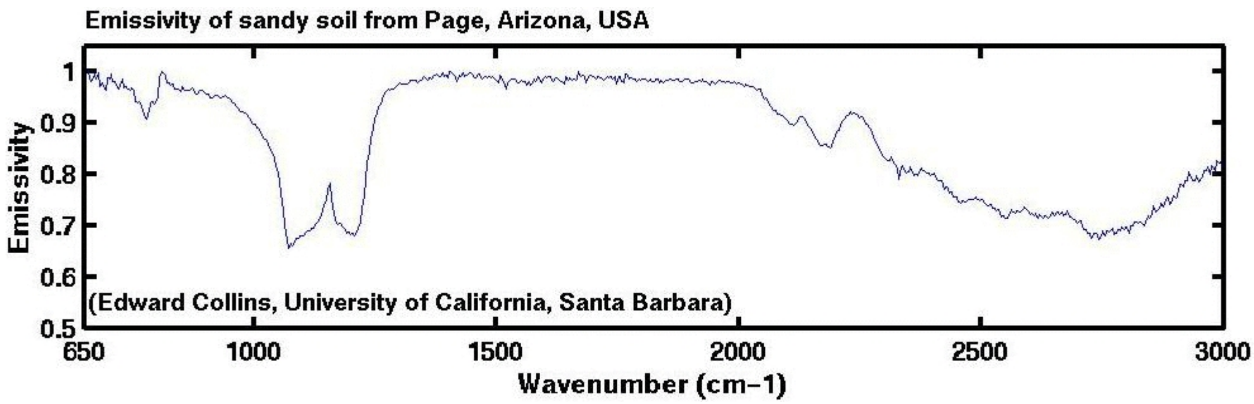
- ☞ at ITSC12 demonstrated the current algorithms for the attenuated reflected downward flux term did not work well for all the channels considered
- ☞ in general small biases existed only for high emissivities & low altitudes



▲ secθ=1, ▲ secθ=1.25, ▲ secθ=1.5, ▲ secθ=1.75, ▲ secθ=2

▲ HIRS, • AIRS



- ☞affects land retrievals where emissivities may be considerably less than .9 and p_s < 800hPa

- ☞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

$$< \Re_s(\theta, p_s) > \; = \; \left\langle \varepsilon B(T(p_s)) \Im(\theta, p_s) \right\rangle + \left\langle \int_o^{p_s} B(T)\, d\Im(p, \theta) \right\rangle + \left\langle r\, \Im(\theta, p_s) F^{\downarrow}(p_s) \right\rangle$$

p - pressure | θ - satellite zenith angle

B - Planck function | $\Im$ - p to TOA transmittance

ε - surface emissivity | r - surface reflectivity

$F^{\downarrow}$ - downward flux

subscript 's' denotes a topographical or cloud top surface

- ☞ $\Re$, $\Im$, B, ε and r are functions of wavenumber
  - $$< f > \; = \; \int_{\Delta\tilde{\nu}} \phi(\tilde{\nu})\, f(\tilde{\nu})\, d\tilde{\nu}$$ ϕ - 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

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

$$r\;<\Im_s^{\theta}>\left[\frac{1}{\pi}\left(\sum_{k=1}^{s}\frac{<\Im_{k-1}^{\varphi}>-<\Im_k^{\varphi}>}{<\Im_{k-1}^{\varphi}><\Im_k^{\varphi}>}<\bar{B}_k>\right)<\Im_s^{\varphi}>\right]$$

assume ☞ r is constant across ϕ

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

RTTOV ☞ $\Im(\varphi) = \Im(\theta)$ (Saunders, 1999)

MSCFAST ☞ $\Im(\varphi) = \Im(1.66)$ (Garand, 1999)

☞ requires 2nd pass of transmittance model

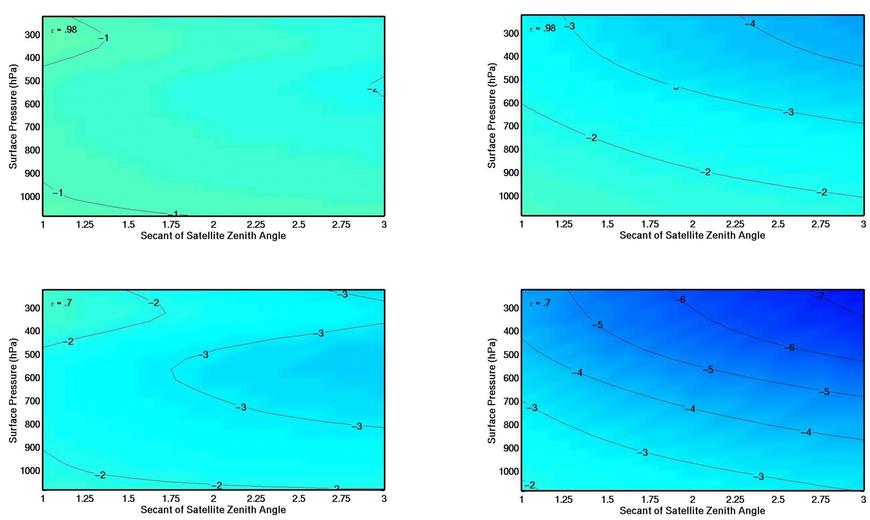
☞ past experience tells us that $<a\ b>$ can not be decomposed as $<a><b>$ (Turner, 2001)

☞ test for reliability of the decomposition of the return transmittance and the downward flux using the FLBL, ie; how well does δBT = 0 ?

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

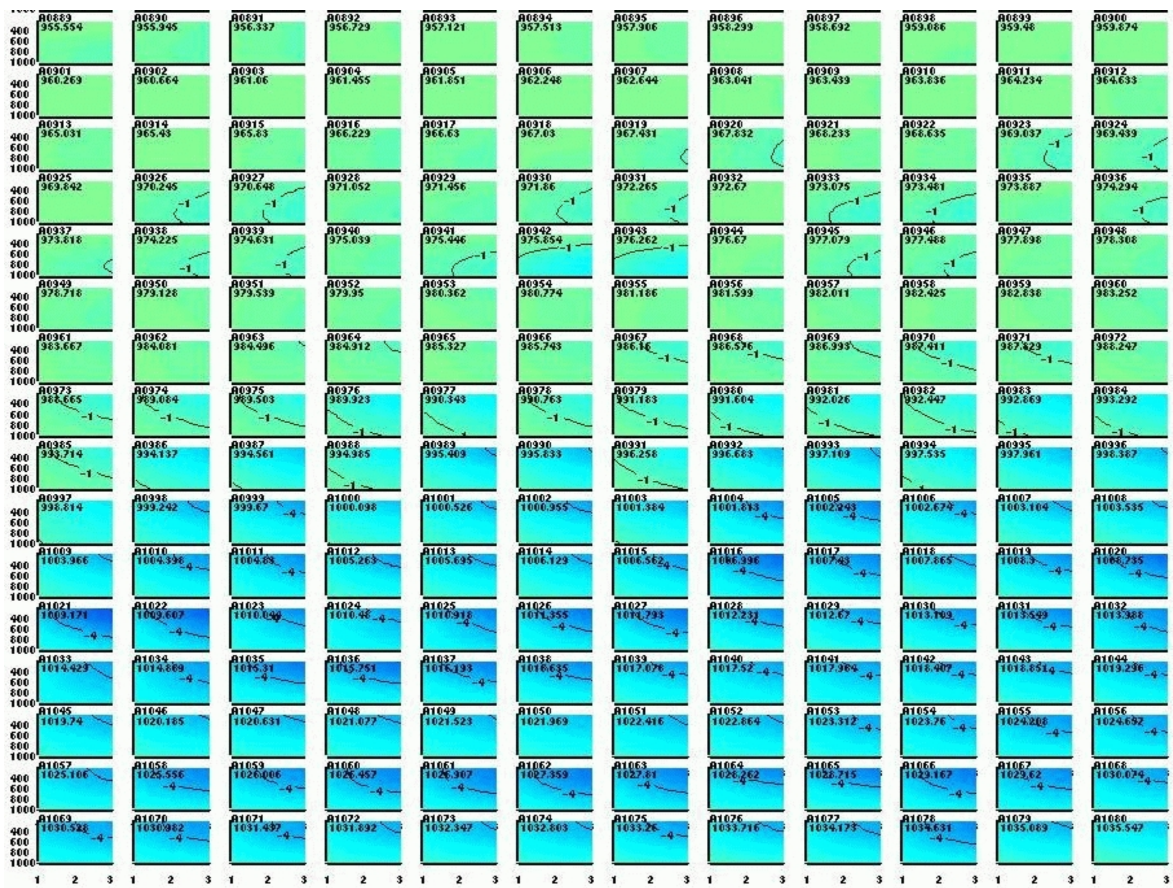
☞ decomposition fares poorly

- plot the bias of δBT across 52 ECMWF profiles for ε=.98 & ε=.7
- many channels exhibit large errors that increase with θ, ε & p_s



AIRS352, 752.07 (cm^{-1}) AIRS1018, 1007.87 (cm^{-1})

☞ if decomposition of $\Im\,F^{\downarrow}$ is unreliable, then further decomposition of $F^{\downarrow}$ into [] is probably not reliable, thus new scheme must account for errors due to these decompositions



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

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

Alternate Algorithm

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

$$r < \Im_s(\theta) > \left[\frac{1}{\pi} \left(\sum_{k=1}^{s} \frac{< \Im_{k-1}^{\theta} >^{\kappa(p_s,\theta)} - < \Im_{k}^{\theta} >^{\kappa(p_s,\theta)}}{< \Im_{k-1}^{\theta} >^{\kappa(p_s,\theta)} < \Im_{k}^{\theta} >^{\kappa(p_s,\theta)}} < \bar{B}_k > \right) < \Im_s^{\theta} >^{\kappa(p_s,\theta)} \right]$$

☞ $\kappa(\theta, p_s)$ 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

☞ develop the basic fast transmittance model (ie ε=1)

☞ using the same atmospheres to develop the basic model, minimize

$$\left| \left\langle \Im(\theta, p_s) F^{\downarrow}(p_s) \right\rangle - \{\Im_s^{\theta}\} \left(\sum_{k=1}^{s} \frac{\{\Im_{k-1}^{\theta}\}^{\varkappa(p_s,\theta)} - \{\Im_k^{\theta}\}^{\varkappa(p_s,\theta)}}{\{\Im_{k-1}^{\theta}\}^{\varkappa(p_s,\theta)} \{\Im_k^{\theta}\}^{\varkappa(p_s,\theta)}} \{\bar{B}_k\} \right) \{\Im_s^{\theta}\}^{\varkappa(p_s,\theta)} \right| \leq \delta$$

for a set of $\kappa(\theta, p_s)$ for each atmosphere

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

NOTE: < *f* > - 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)

☞ M1, $\varphi = \theta$, $\varkappa = 1$ single pass thru' fast transmittance model

☞ M2, $\varphi = \theta$, $\varkappa = 1$ two passes thru' fast transmittance model

☞ M3, $\varphi = \theta$, $\varkappa = \kappa(\theta, p_s)$ single pass thru' fast transmittance model followed by exponentiation of $\Im(\theta)$
- $\kappa(\theta, p_s)$ determined for 24 p_s (223 to 1085hPa) and 6 secants (1, 1.25, 1.5, 1.75, 2 & 2.25)

☞ evaluate BT all 3 models & FLBL for
- 24 surface pressures (223 to 1085hPa0
- 21 emissivities (0 to 1), r = 1/π to 0
- 52 ECMWF atmospheres
- 2378 AIRS channels

☞ compare bias and standard deviation (stdv) across 53 profiles of the difference,

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

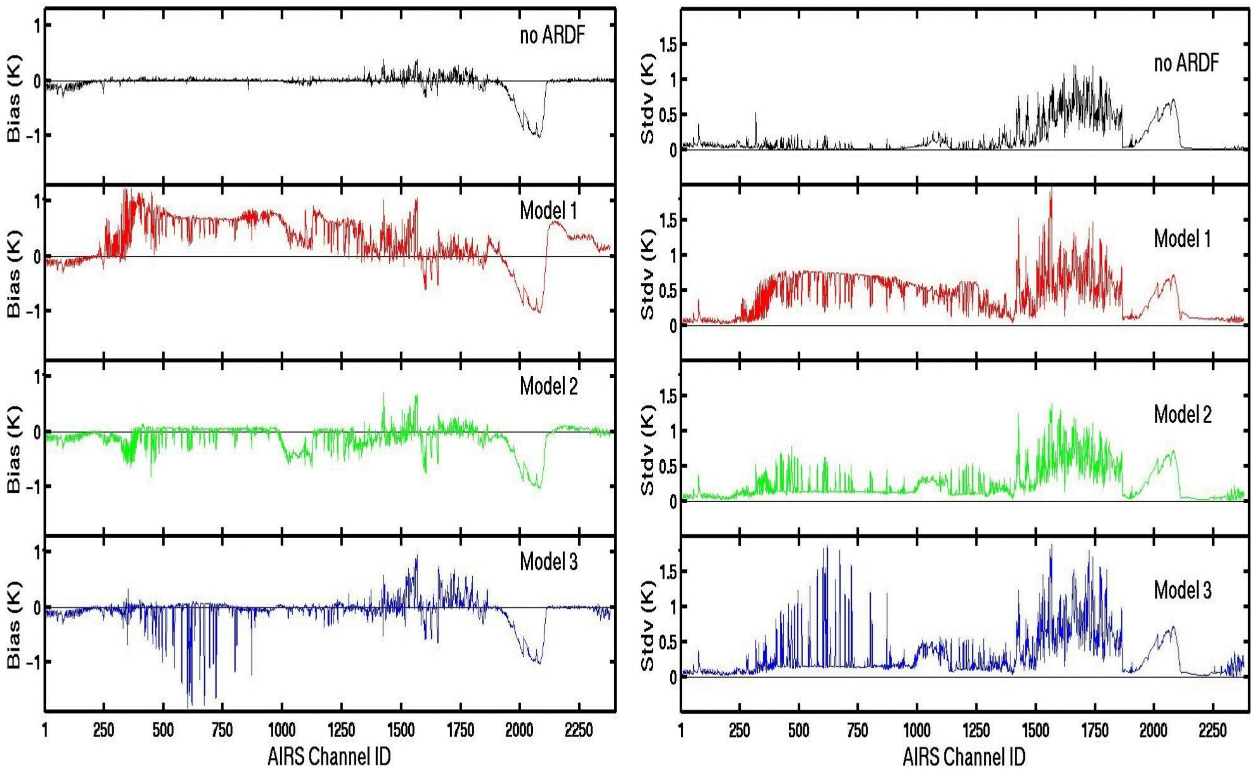
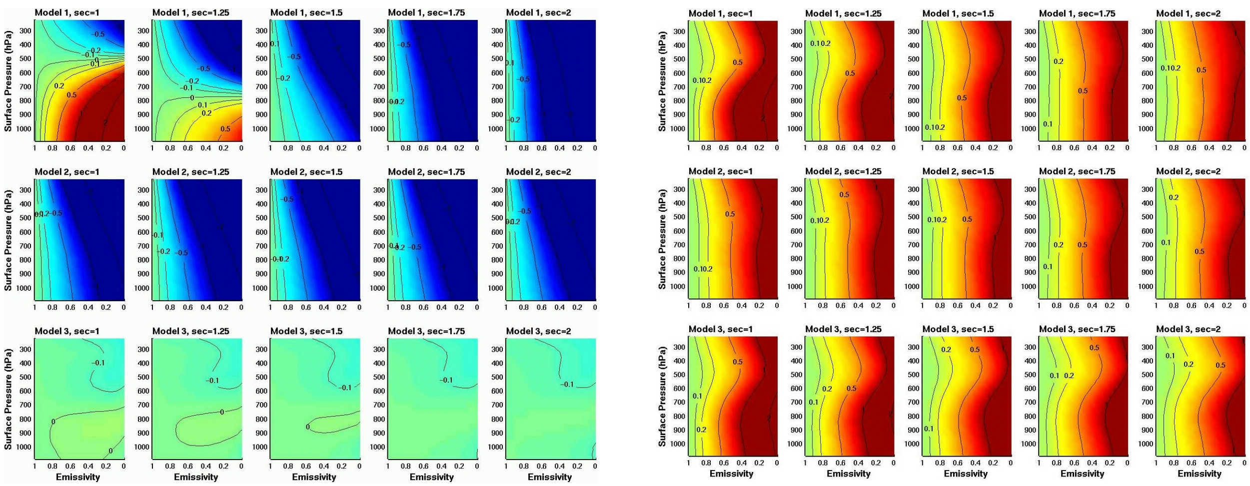


Fig: M1, M2 & M3 bias & stdv as a function of channel for sec θ = 1, ε = .7 and p_s = 1013hPa

- ☞ M2 & M3 fare much better than M1
- ☞ not clear which performs better M2 or M3 wrt bias or stdv
- ☞ on average M3 is ~1.25 slower than M1 and M2 is ~1.6 slower than M1
- ☞ 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
- ☞ M3 applicable over a wider range of **ε** & p_s
- ☞ M3 models the ARDF term very well in terms of bias
- ☞ stdv doesn’t improve using M3, but not any worse

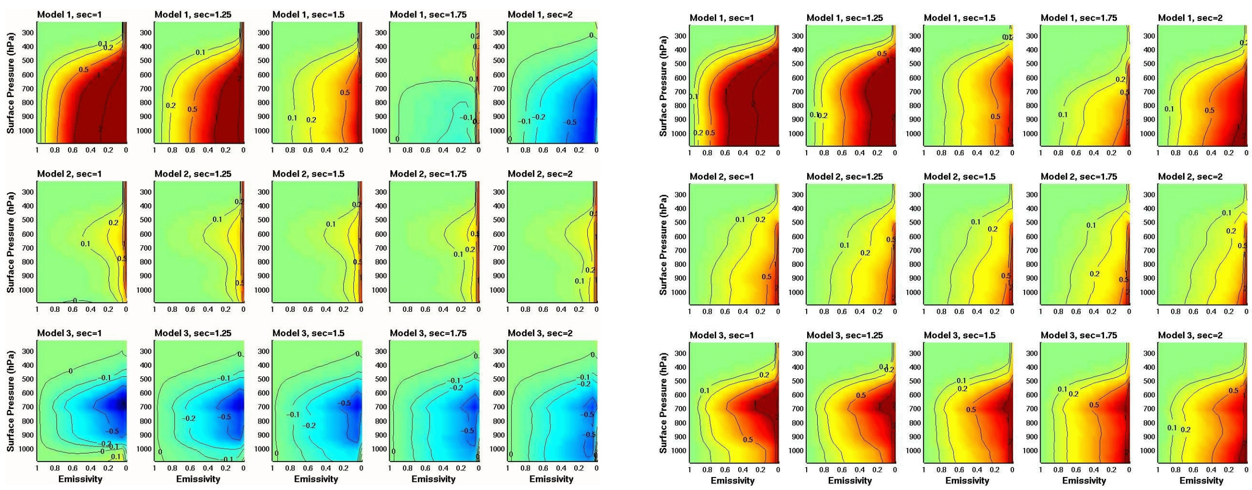


Fig: Bias (left) & stdv (right) for channel 610 (851.8(cm^{-1}))
as a function of θ, ε & p_s

- ☞ strong θ dependency in M1, weaker in M2 & M3
- ☞ small region of low bias & stdv in M1
- ☞ M2 applicable over a wider range of ε & p_s
- ☞ example of when M2 better than M3
- ☞ some improvement in stdv over M1

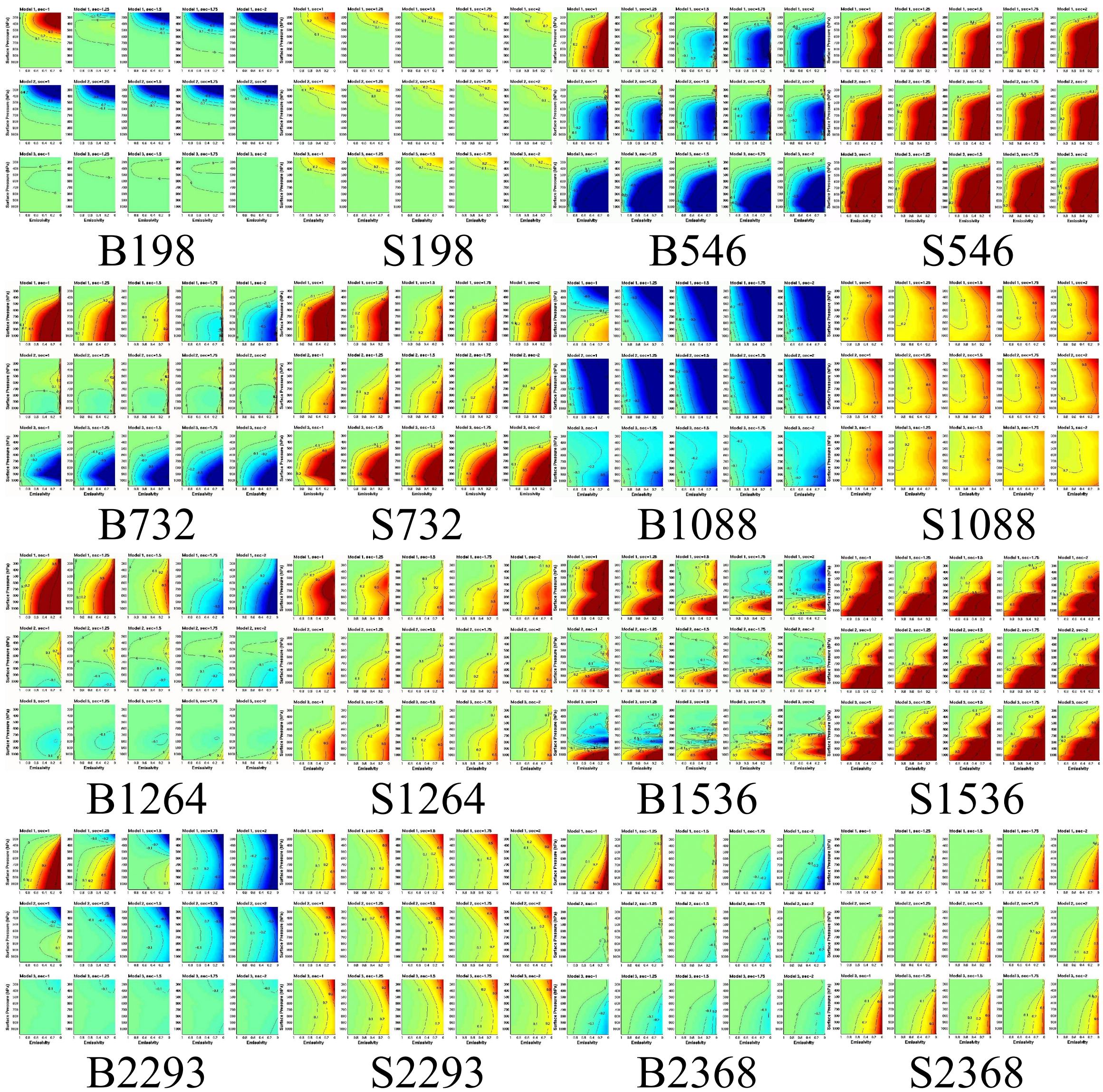


Fig: More examples of the bias & stdv comparisons

Summary

☞ algorithm effects bias more than stdv

☞ both M2 & M3 are an improvement over M1

☞ 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)

☞ ~65% of the channels perform as well or better than M2 with M3

Problems

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

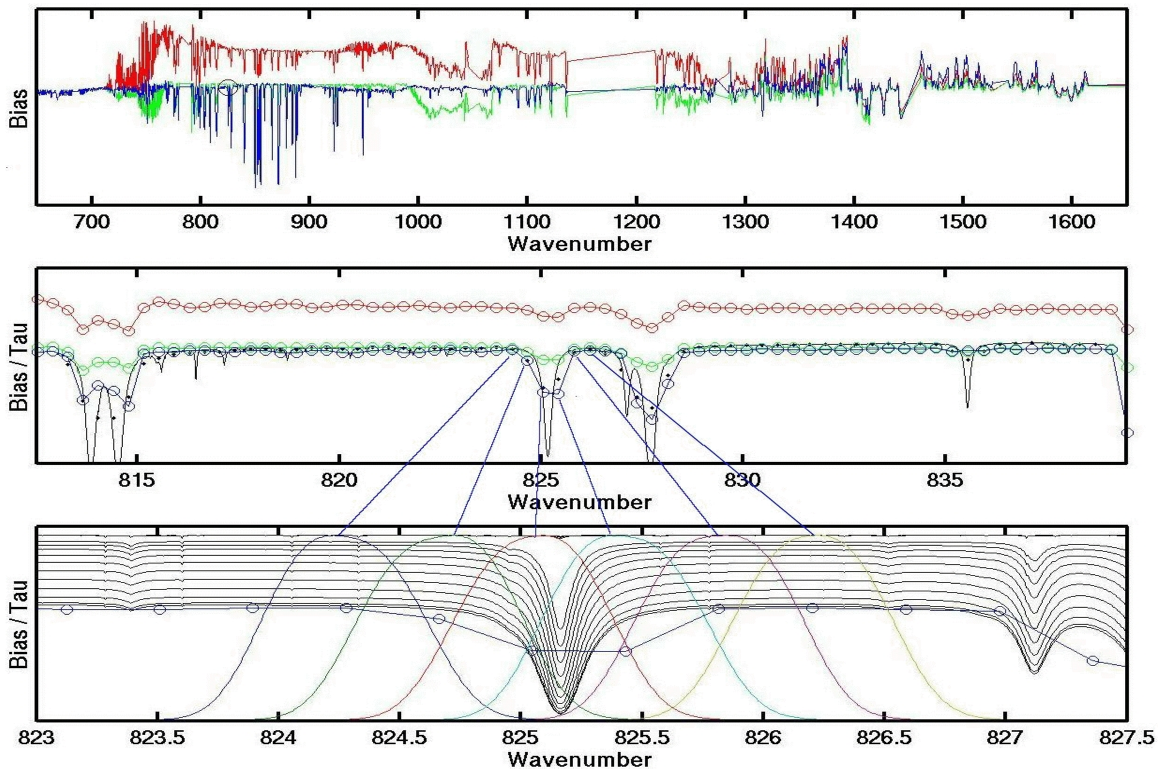


Fig: Upper box illustrates the bias curves for θ=0, ε=.6 and p_s=1013hPa (M1 ,M2, M3). The middle box is an enlargement of the upper box superimposed on a TOA total transmittance curve. The M1, M2, M3 values of {ℑ} are marked by circles. The lower box is a further enlargement of the middle box with some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

☞ 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