Met Office

Radiative transfer modeling for MTG-IRS

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James Hocking[1], Pascal Brunel[2], Stephan Havemann[1], Marco Matricardi[3]

[1]Met Office [2]Météo-France [3]ECMWF

Contents

This presentation covers the following areas

“Classical” RTTOV

RTTOV overview

- RTTOV is a fast radiative transfer (RT) model widely used for assimilation of passive IR and MW radiances in NWP models.
- The core of RTTOV is a fast parameterisation of gas absorption.
- Layer optical depths are calculated from a linear regression on atmospheric “predictor” quantities which are derived from the input profile (view angle, temperature, gas abundances).
- The regression coefficients are obtained off-line by using a line-by-line RT model (currently LBLRTM v12.2 in the IR) for a set of diverse training profiles.
- An important aspect of the prediction scheme is that it deals with channel-integrated transmittances and (effective) layer optical depths.

Clear-sky RT equation

ν	frequency	t	transmittance from TOA*	t_s	transmittance from TOA* to surface
L	radiance	T	temperature	T_s	surface skin temperature
		B	Planck function	ε_s	surface emissivity

$$L(\nu) = \int_{t_s}^{1} B(\nu,T)\,dt + t_s(\nu)\varepsilon_s(\nu)B(\nu,T_s) + (1-\varepsilon_s(\nu))t_s^2(\nu)\int_{t_s}^{1}\frac{B(\nu,T)}{t^2}\,dt$$

upwelling atmospheric emission

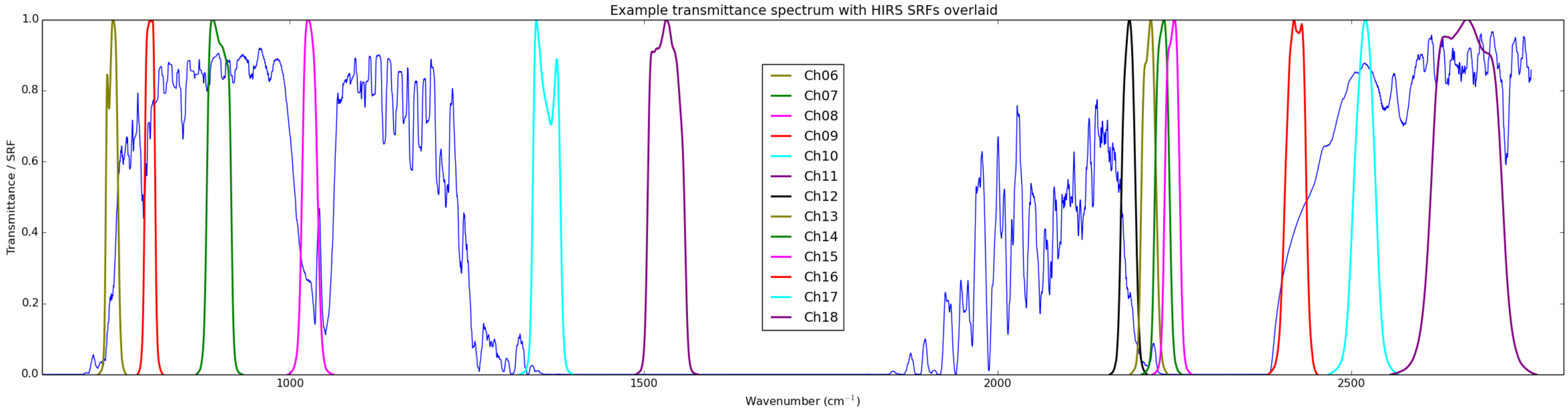
surface emission

downwelling atmospheric emission reflected by surface

*TOA = top of atmosphere

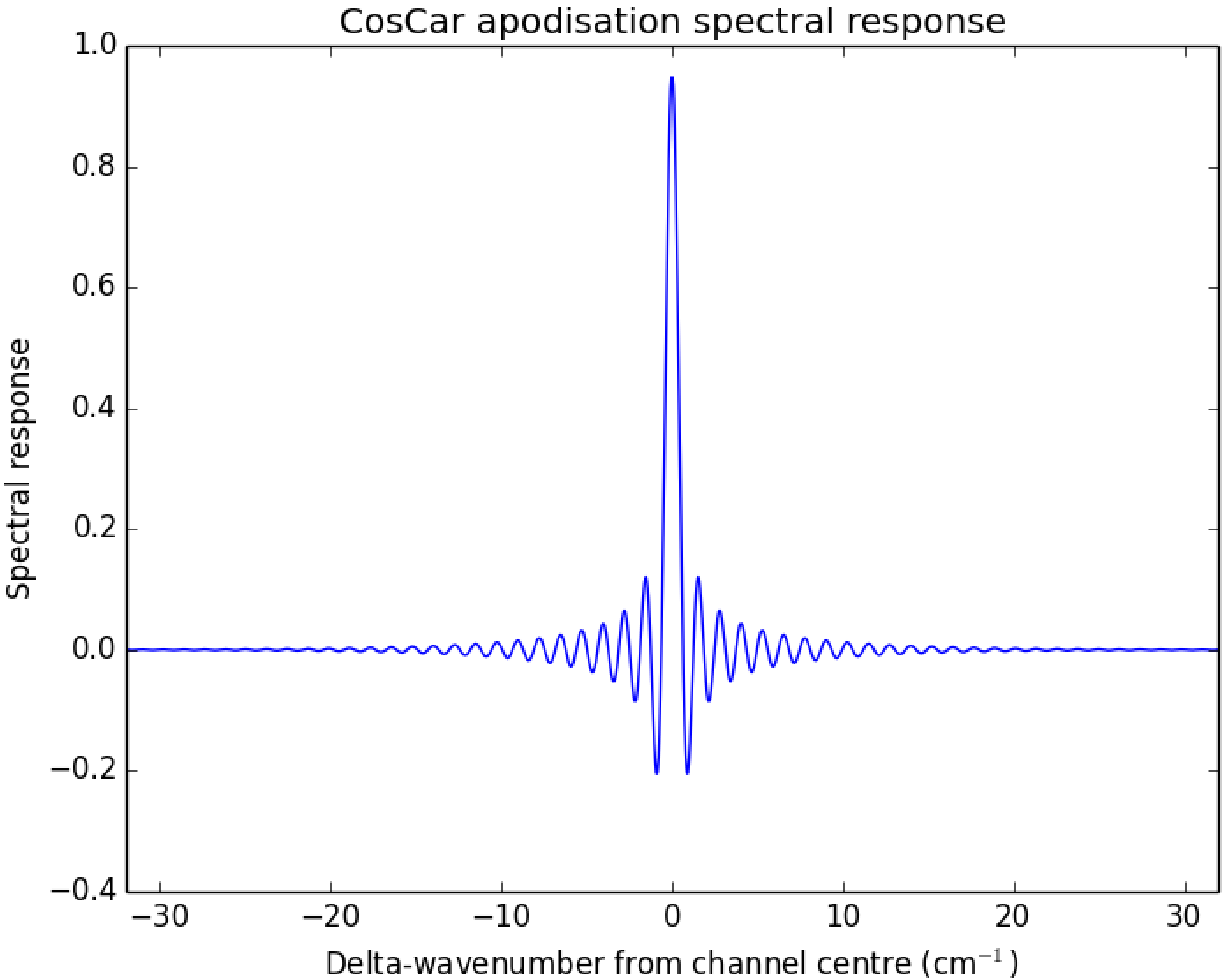
Polychromatic channels

Passive IR/MW sensor channels are not monochromatic.



Ideally we would solve the RT equation at many wavelengths and integrate the resulting radiances over the channel spectral response function (SRF).

In practice we integrate transmittances over the SRF and solve the RT equation once per channel.



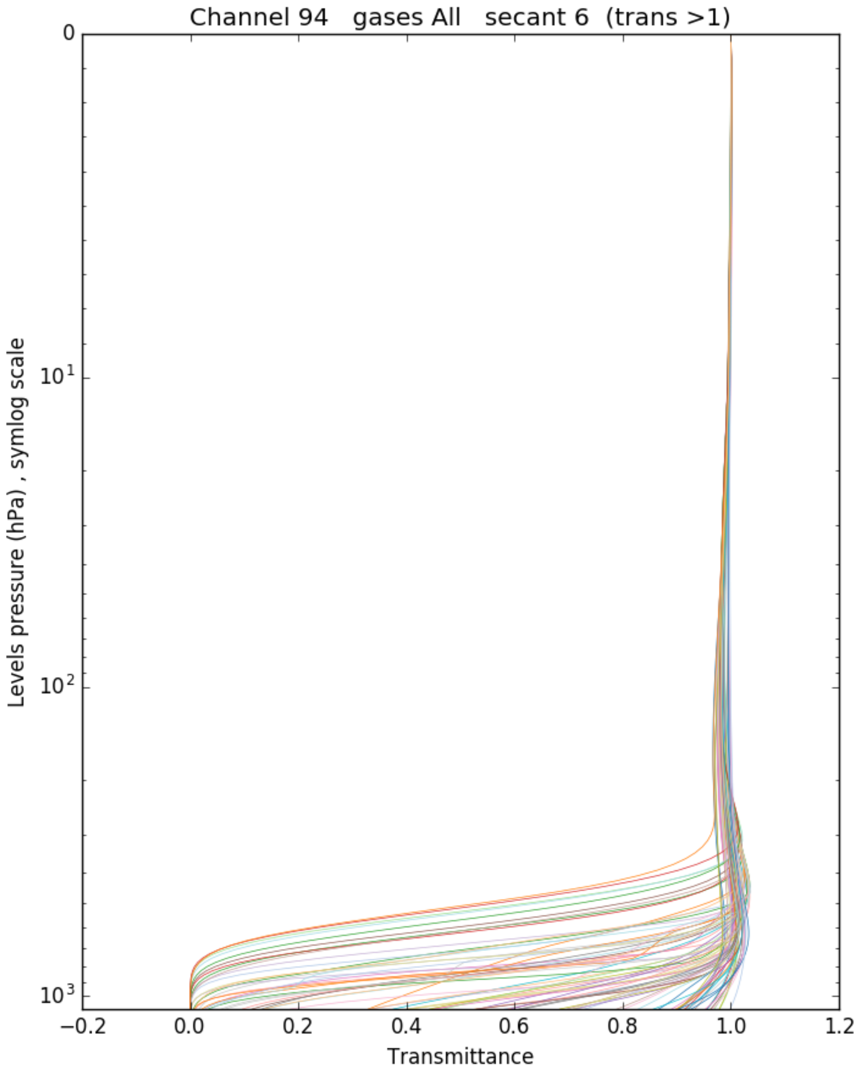
CosCar apodisation spectral response
Spectral response
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−30
−20
−10
0
10
20
30
Delta-wavenumber from channel centre (cm^{-1})

Problematic channels

MTG-IRS Channel 94
(758.125 cm-1 / 13.19 microns)

Level-to-space transmittance profiles for the 83 diverse training profiles

Effect of unphysical transmittances on TOA BT = 1.6K

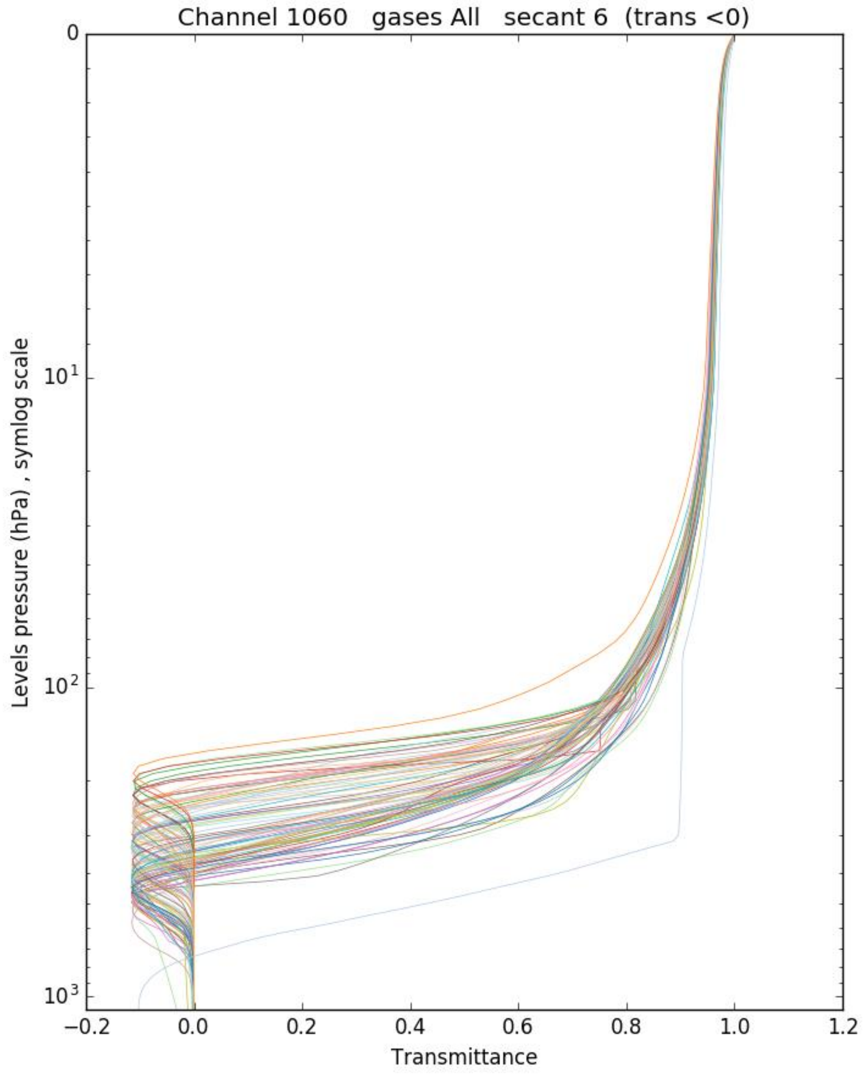


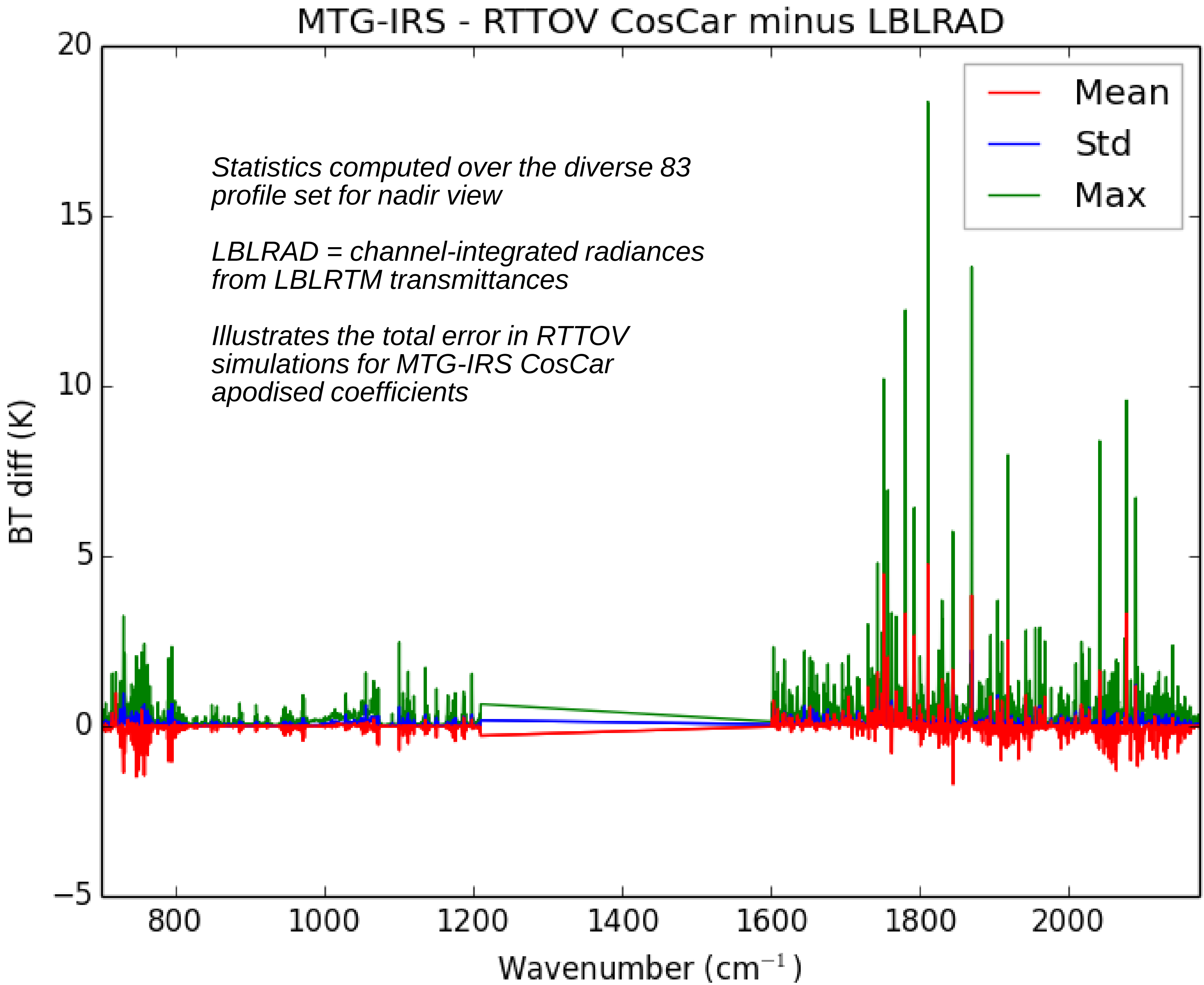
Problematic channels

MTG-IRS channel 1060
(1813.75 cm^{-1} / 5.51 microns)

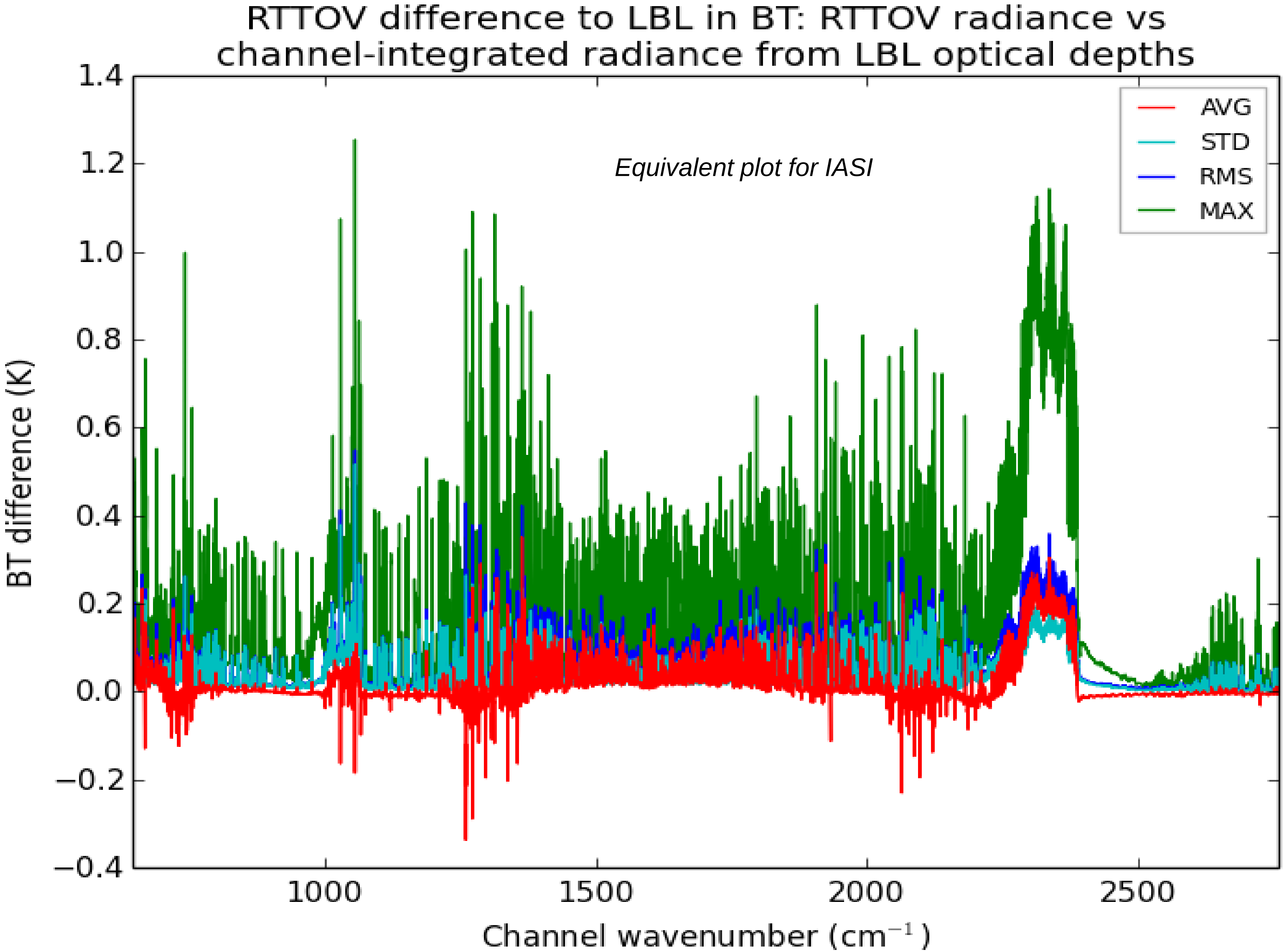
Level-to-space transmittance profiles for the 83 diverse training profiles

Effect of unphysical transmittances on TOA BT = 5K

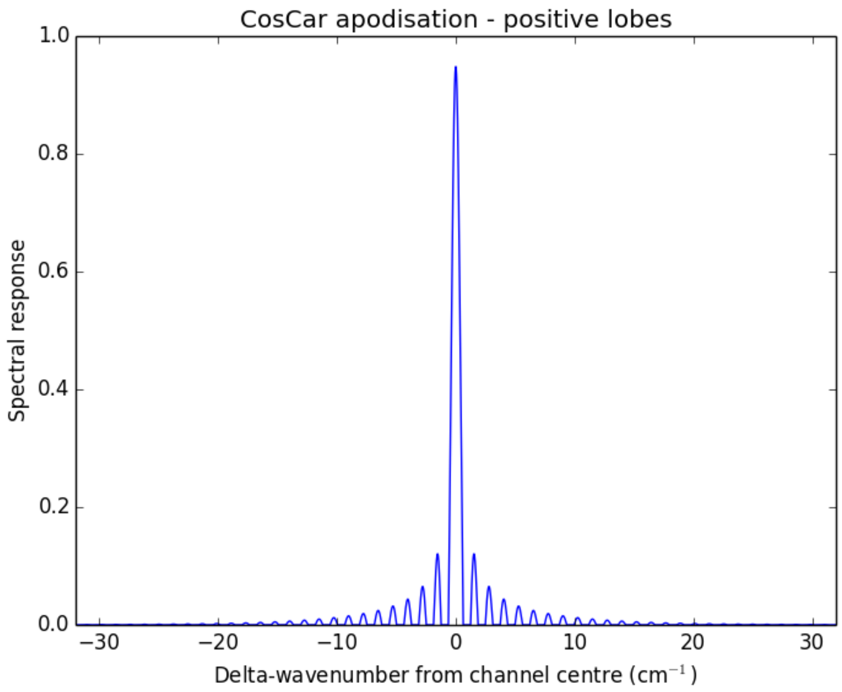


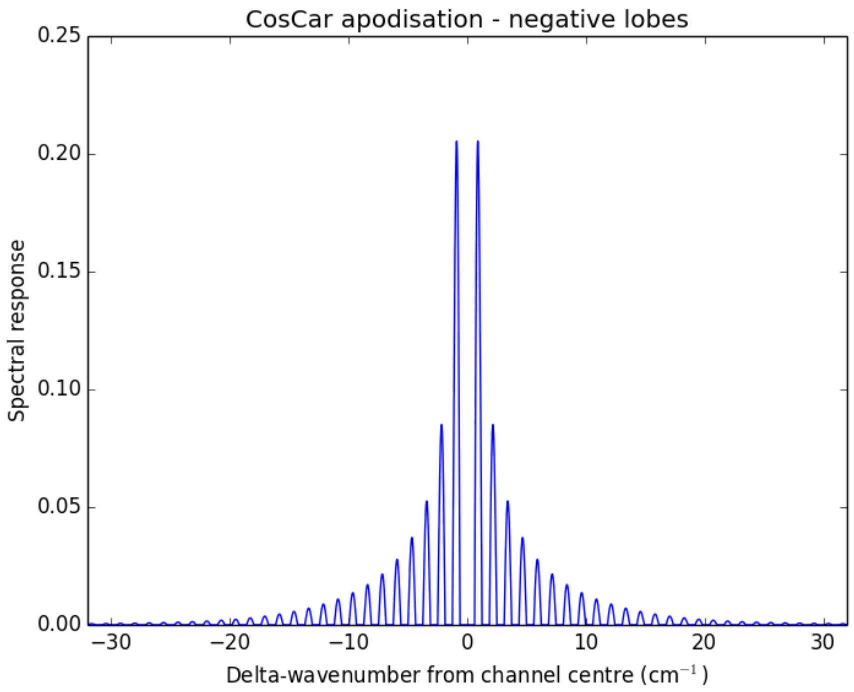


MTG-IRS - RTTOV CosCar minus LBLRAD
Mean
Std
Max
Statistics computed over the diverse 83 profile set for nadir view
LBLRAD = channel-integrated radiances from LBLRTM transmittances
Illustrates the total error in RTTOV simulations for MTG-IRS CosCar apodised coefficients
BT diff (K)
Wavenumber (cm^{-1})
20
15
10
5
0
−5
800
1000
1200
1400
1600
1800
2000


RTTOV difference to LBL in BT: RTTOV radiance vs
channel-integrated radiance from LBL optical depths
Equivalent plot for IASI
AVG
STD
RMS
MAX
BT difference (K)
Channel wavenumber (cm⁻¹)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
1000
1500
2000
2500

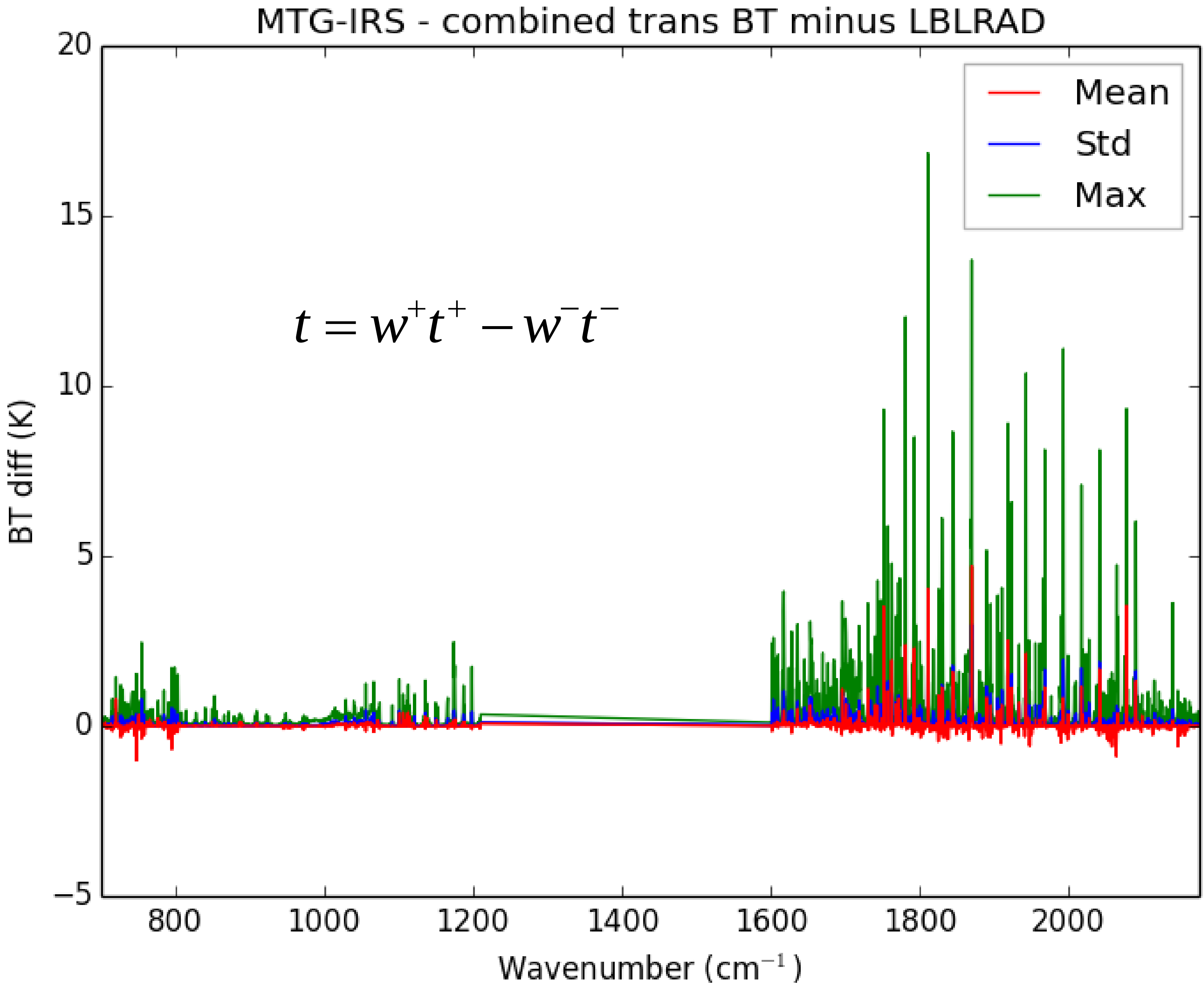
CosCar spectral response

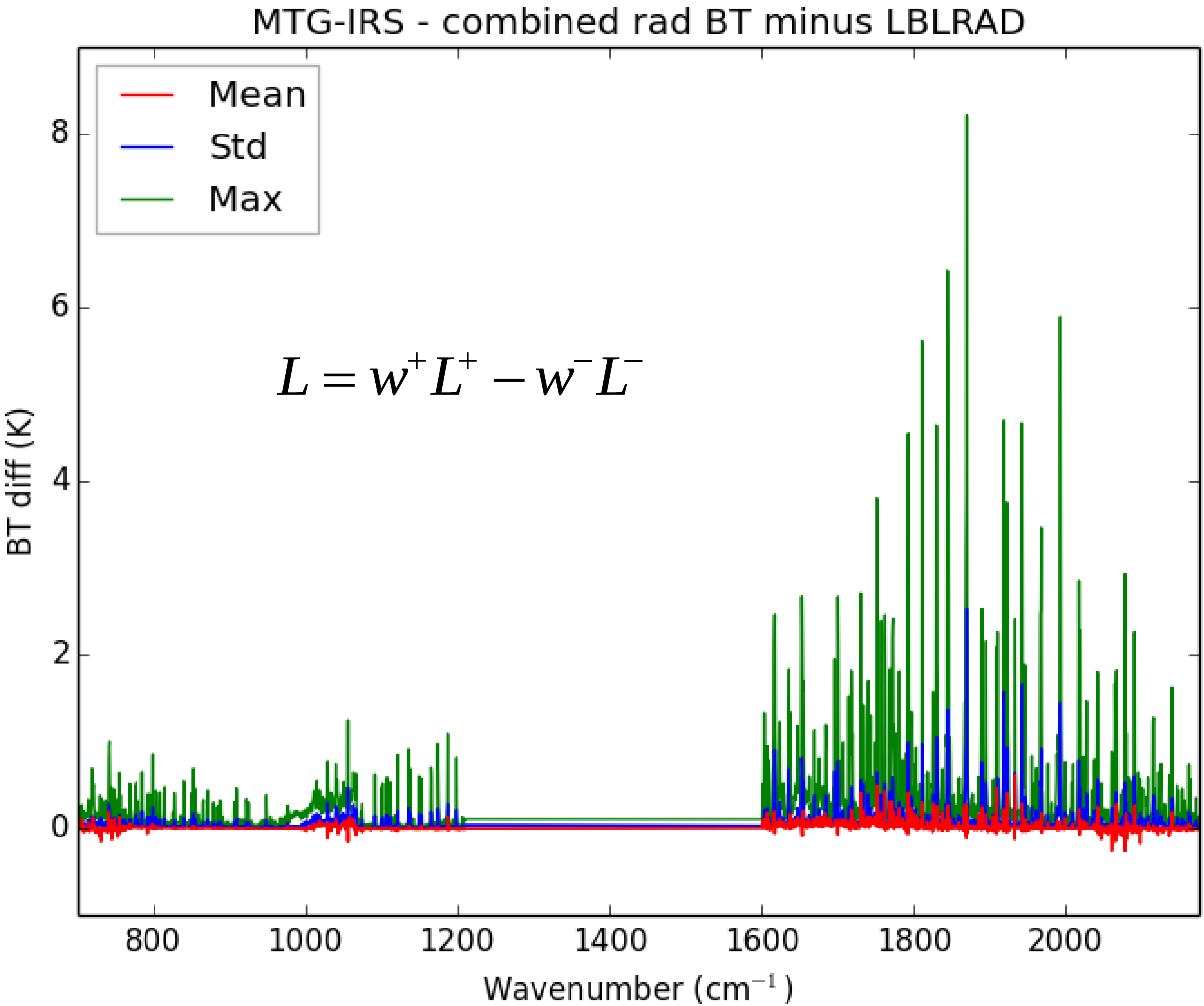




Integral: $w^+ = 1.6925$

Integral: $w^- = 0.6925$


MTG-IRS - combined trans BT minus LBLRAD
Mean
Std
Max
$t = w^{+}t^{+} - w^{-}t^{-}$
BT diff (K)
Wavenumber (cm^{-1})
20
15
10
5
0
−5
800
1000
1200
1400
1600
1800
2000


MTG-IRS - combined rad BT minus LBLRAD
Mean
Std
Max
$L = w^{+}L^{+} - w^{-}L^{-}$
BT diff (K)
Wavenumber (cm^{-1})
0
2
4
6
8
800
1000
1200
1400
1600
1800
2000

Alternative approach

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Problem:

- Channel-averaged level-to-space transmittances lie outside [0,1] which causes problems in the optical depth regression

During coefficient training:

- Shift transmittances to be >0 (or scale-and-shift transmittances to lie in [0,1])
- Carry out regression to obtain RTTOV coefficients

Within RTTOV:

- Undo the shift or scale-and-shift to recover the original (unphysical) transmittances

This needs to be done per channel. More investigation required.

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PC-RTTOV

PC-RTTOV

- PC-RTTOV is a Principal Components-based RT model for hyperspectral sounders.
- PC-RTTOV is built in to RTTOV and is run using the same subroutines.
- Classical RTTOV radiances for a carefully selected set of sensor channels are used as the predictors in a linear regression to obtain the PC scores for the simulated spectrum.
- Optionally reconstructed radiances and brightness temperatures can be returned for an arbitrary set of channels.
- In principle PC-RTTOV coefficients can be created for MTG-IRS which use heavily (e.g. Hamming) apodised classical RTTOV radiances to predict the PC scores for lightly (CosCar) apodised spectra.
- It is planned to produce MTG-IRS PC-RTTOV coefficients by Q1 2018.

PC-RTTOV

- Currently PC-RTTOV coefficients are available for RTTOV v12.1 with the following capabilities:
  - clear-sky over land and sea surface types
  - optionally include non-LTE effects
- New coefficients have been created with additional capabilities:
  - allow variable trace gases supported by RTTOV (O_3, CO_2, CO, CH_4, N_2O)
  - aerosol-affected radiances
- In the past PC-RTTOV coefficients have been created which allow for cloud-affected radiances: this capability could be resurrected.

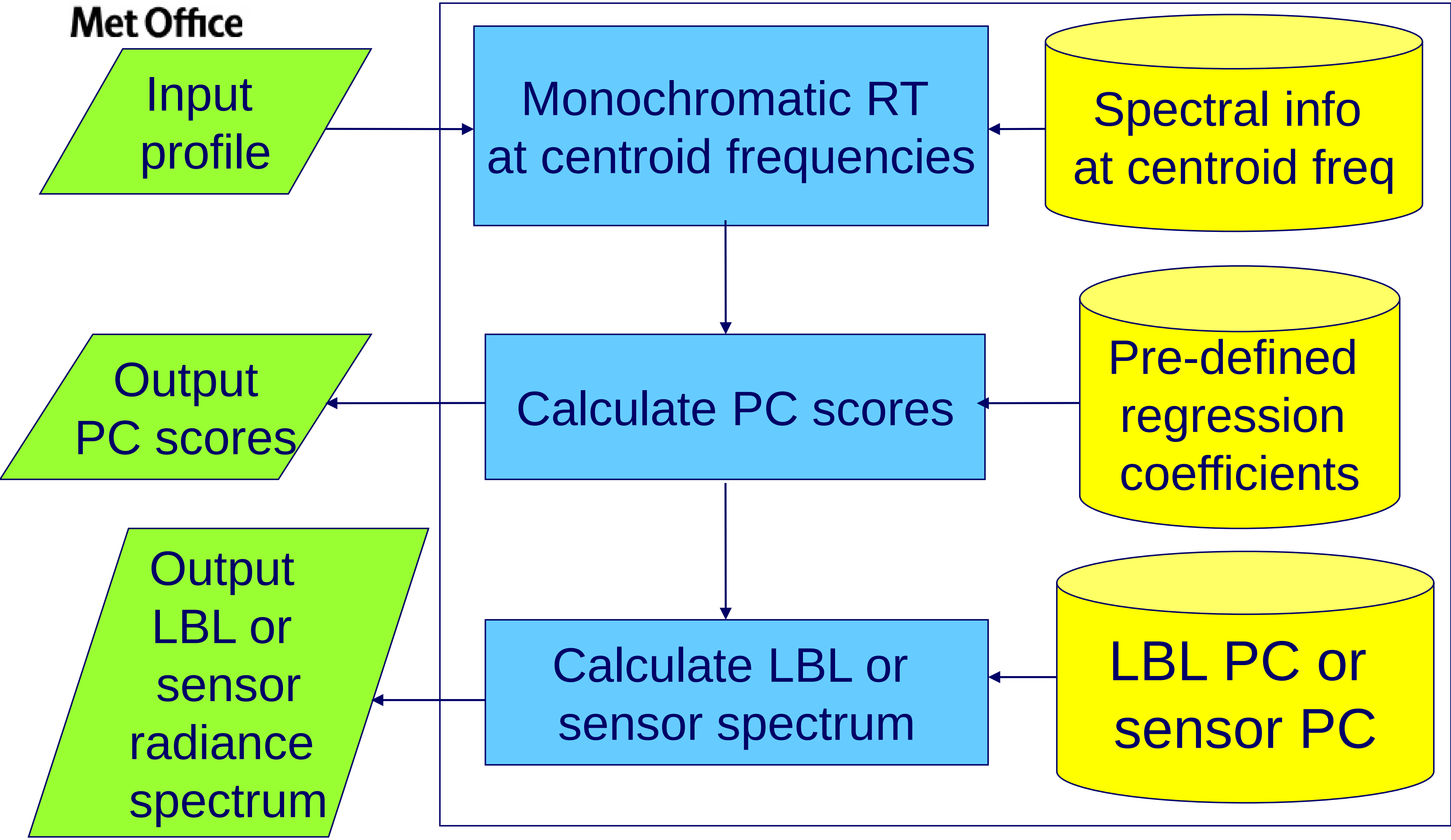
HT-FRTC

Havemann-Taylor Fast Radiative Transfer Code

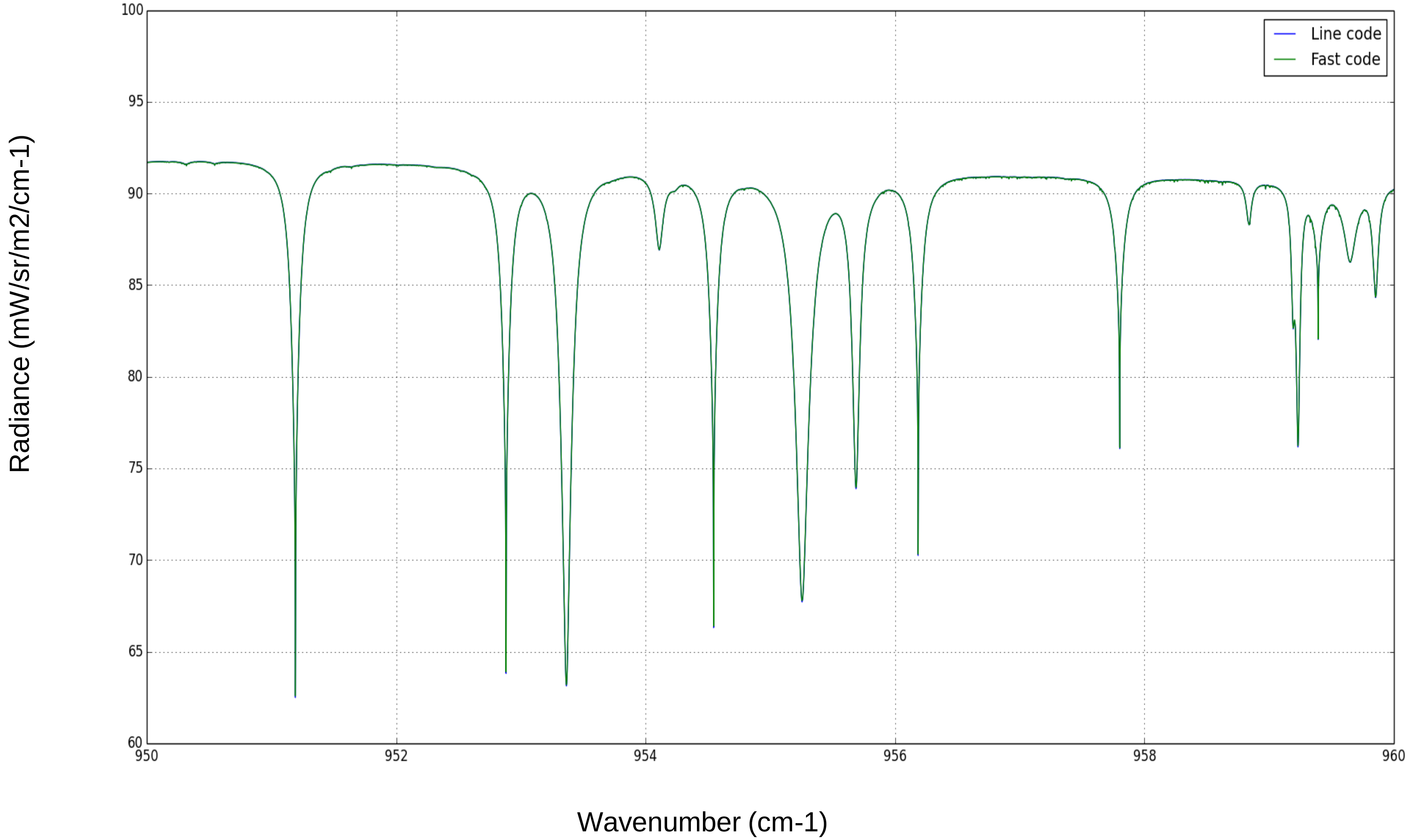
HT-FRTC overview

- HT-FRTC is based on monochromatic calculations.
- It has no equivalent to the RTTOV coefficients.
- Monochromatic absorption coefficients are interpolated in pressure, temperature and gas amount.
- No problems with negative side-lobes. Works for any and no apodization.
- The Principal Components are a full ultra-fine resolution (10^{-3} cm^{-1} or even finer at the internal LBLRTM resolution).
- No retraining is required for additional sensors.
- The different SRF of the individual detectors elements in the array can be modelled with the same code without retraining.
- Any drift in the SRF can be included “on the fly” in the forward model.

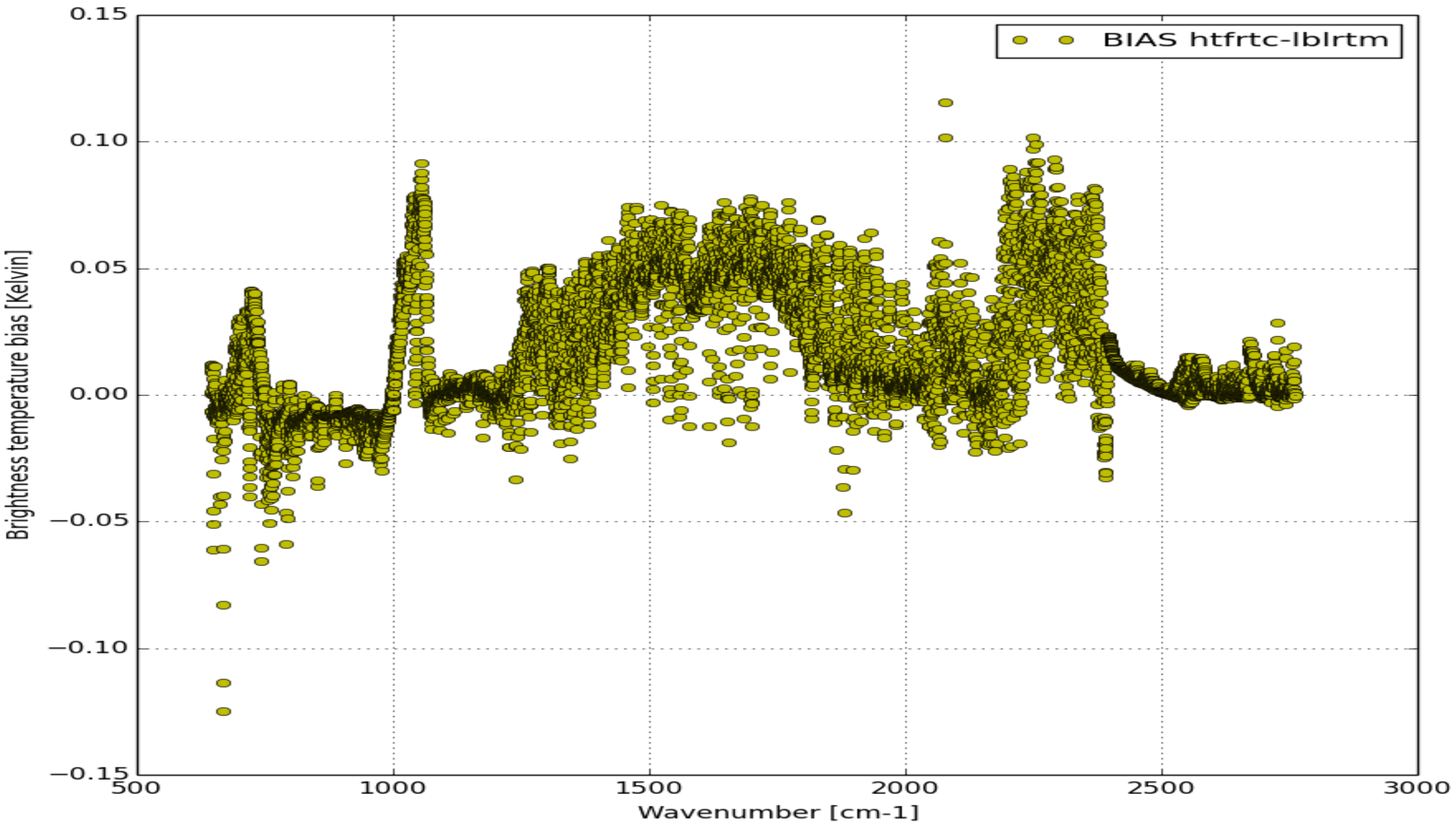
HT-FRTC FAST MODEL STEP



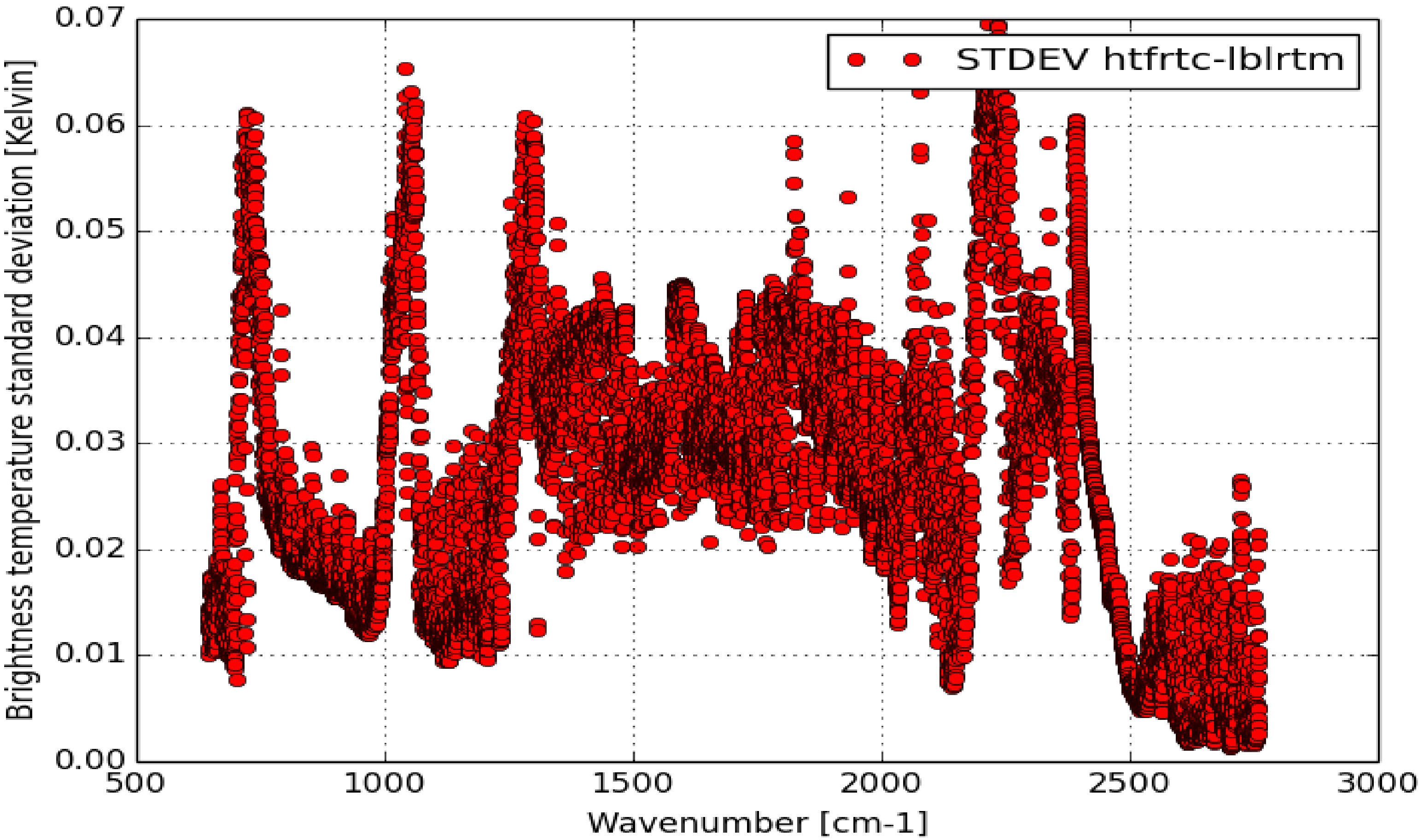
HT-FRTC at full spectral resolution and line code



HT-FRTC – LBLRTM : BIAS for IASI
(100 random independent profiles)

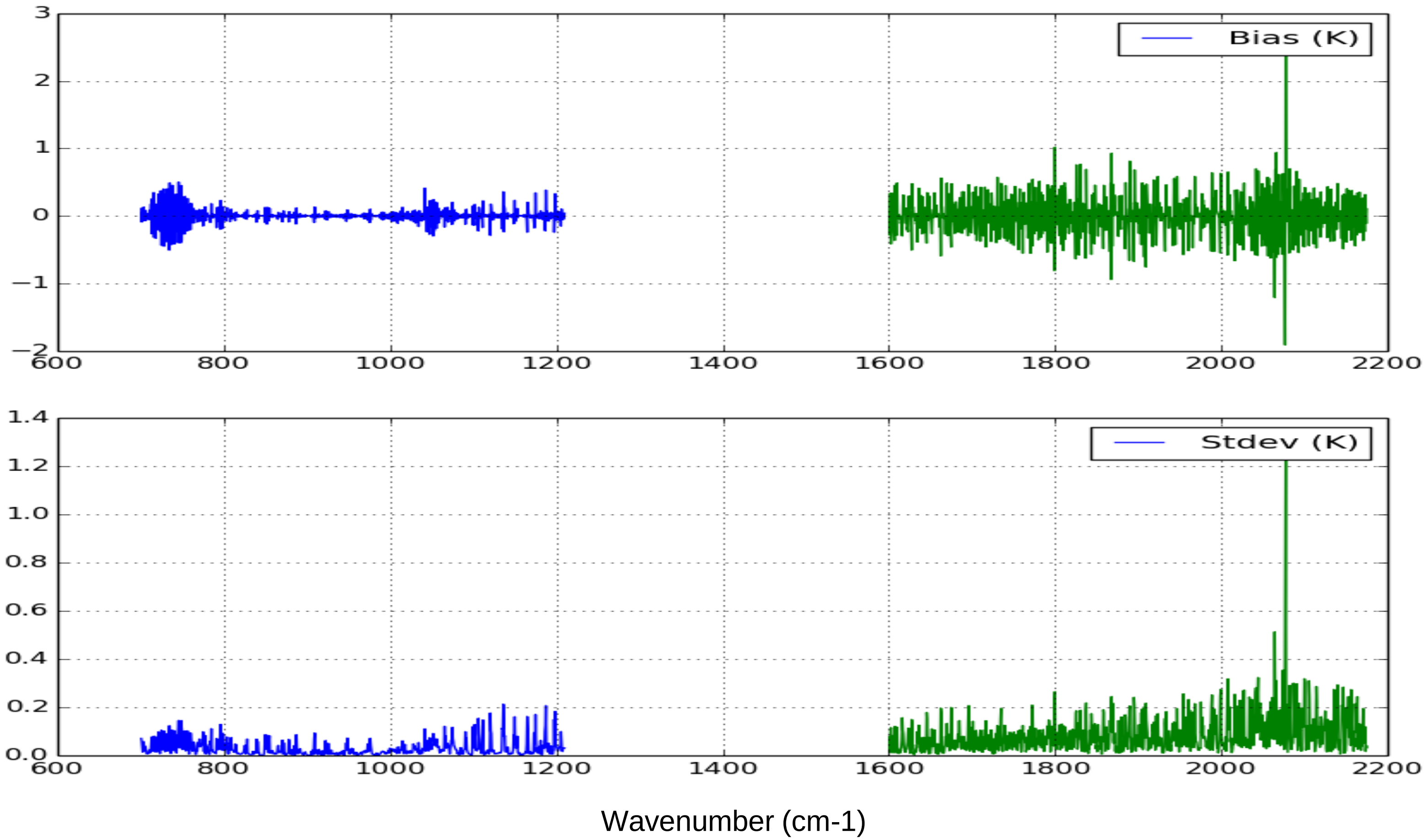


HT-FRTC – LBLRTM : STDEV for IASI
(100 random independent profiles)



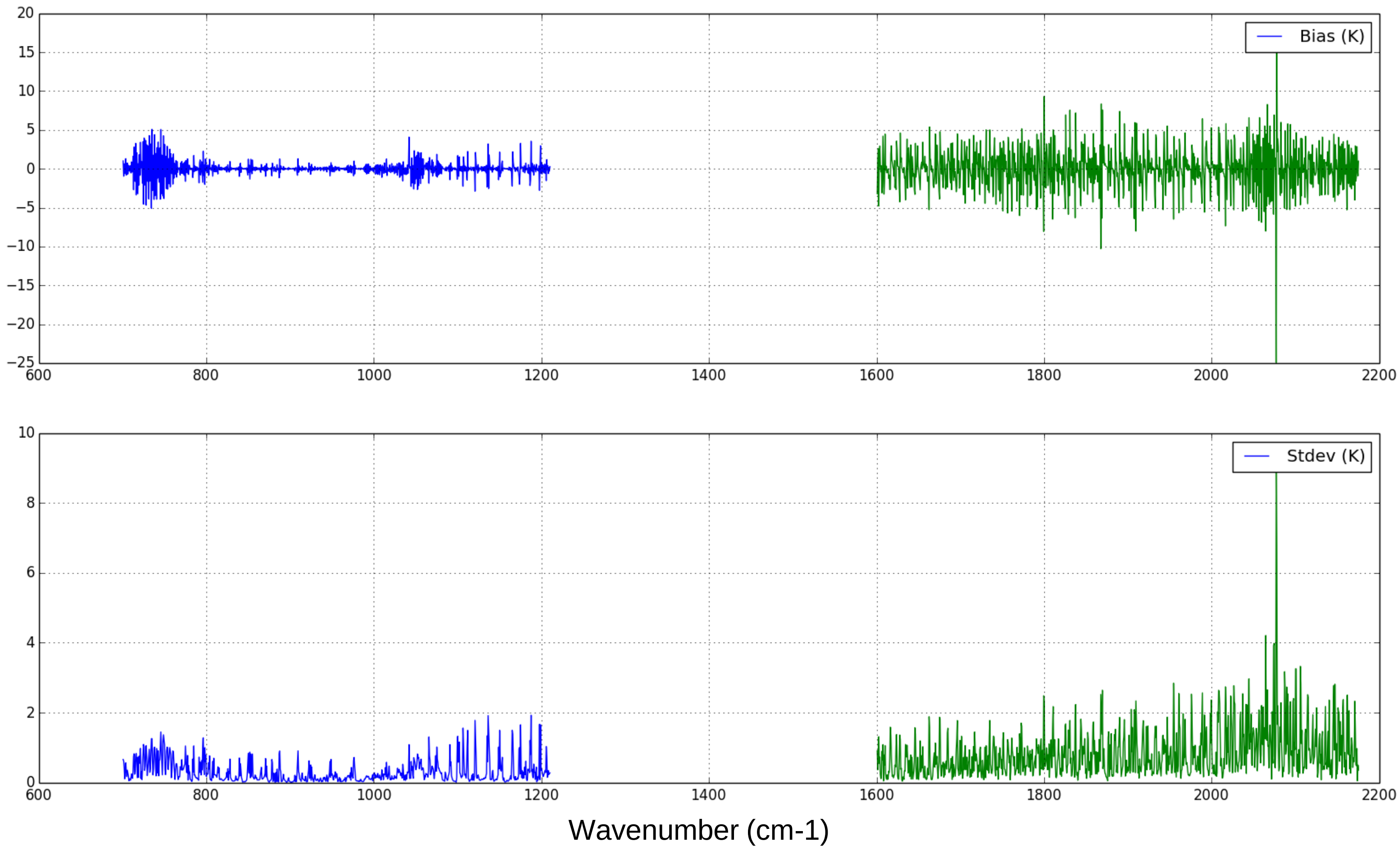
HT-FRTC MTG-IRS example results

1000 random profiles, unapodized, bias and stdev for a change in position and width to 0.625cm^{-1} x (1+10^{-5}). Results show similar structure to those found by S.M. Newman in simulations for IASI



HT-FRTC MTG-IRS example results

1000 random profiles, unapodized, bias and stdev for a detector corner element versus a centre element SRF relative shift (about 10^{-4}) and width taken from talk by Coppens et al. IASI conference, Antibes, 2016



Standalone HT-FRTC capabilities

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The HT-FRTC uses sensor-independent principal components at “line-by-line” resolution (for MTG-IRS: Different SRF do not require retraining, any and no apodisation).

Works from the microwave through the infrared and the short-wave.

Can treat all HITRAN gases as variable gases.

Does contain different aerosols, liquid and frozen precipitation.

Clouds are treated as grey clouds, with Chou scaling (like RTTOV) or slower but more accurate full scattering (with a monochromatic version of Edwards-Slingo and DISORT)

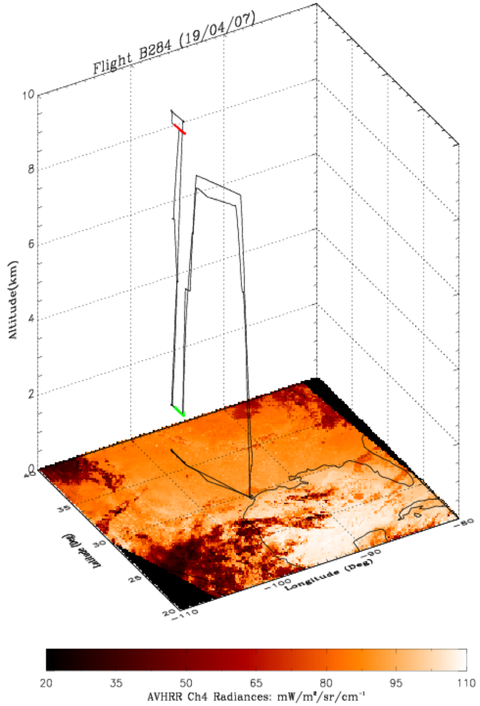
Does treat any spectrally resolved surface emissivity / reflectance.

Works for any sensor-height, for up and down-looking instruments (air / space borne or ground-based)

Computes radiances, fluxes and transmittances.

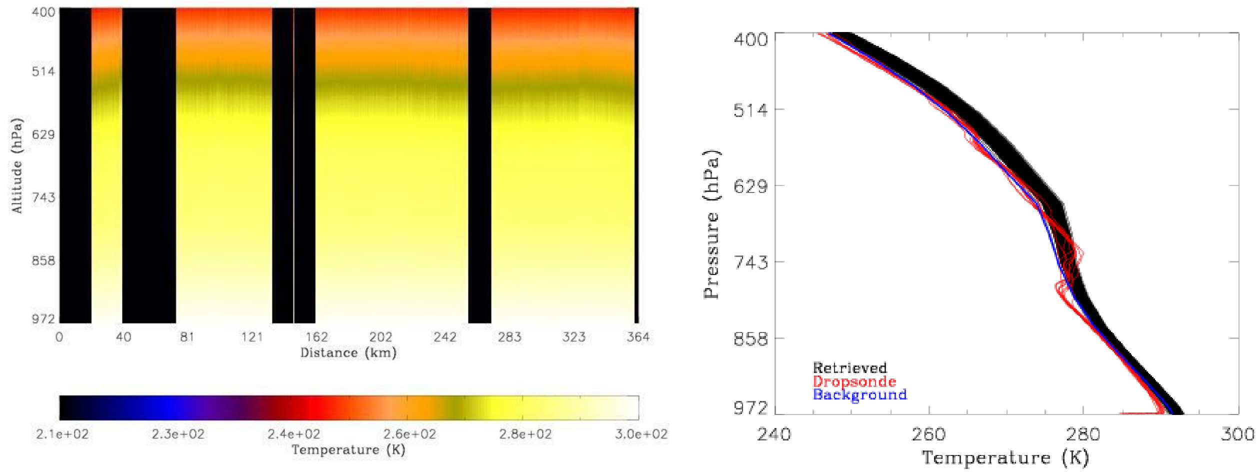
Has been used operationally in Met Office Defence TDAs (NEON) since 2008.

Clear-Sky Longwave Retrievals from ARIES

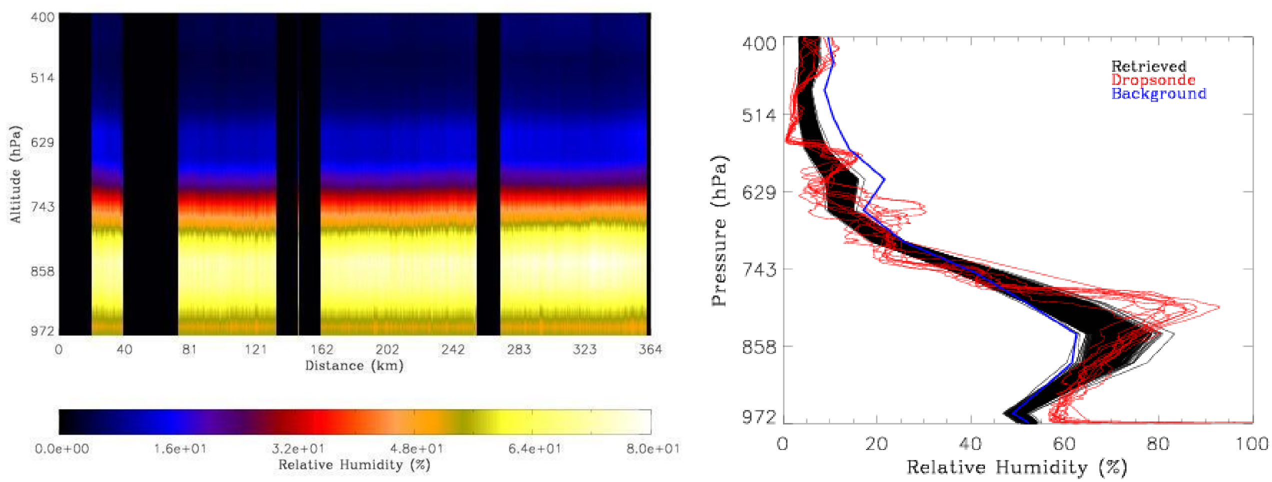


Night-Time flight B284 of JAIVEx Campaign

Measurements taken over the Oklahoma ARM Site



Temperature Retrievals from 1700 radiance measurements



Humidity Retrievals from 1700 radiance measurements

Clear-Sky Longwave Retrievals from ARIES

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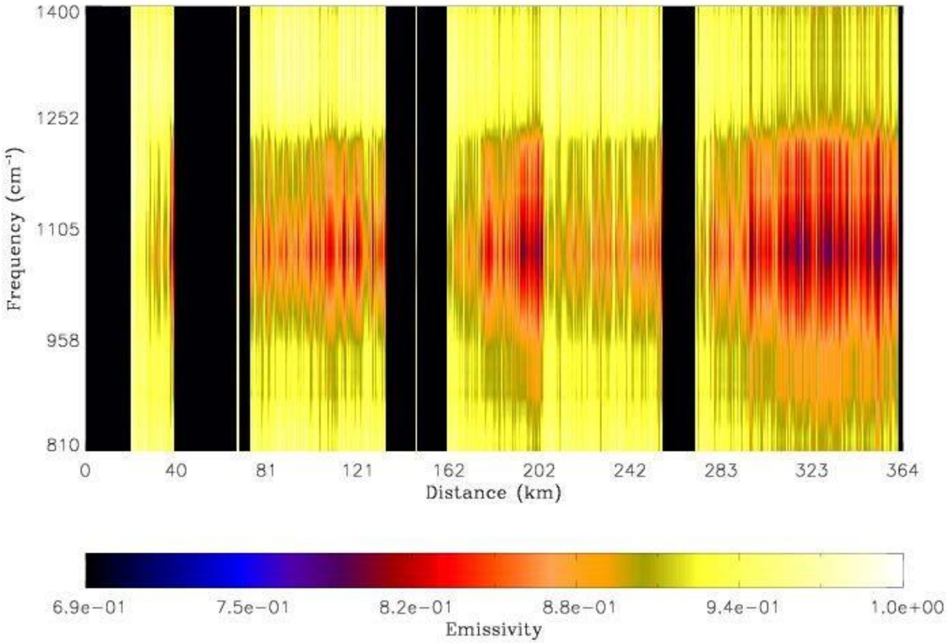
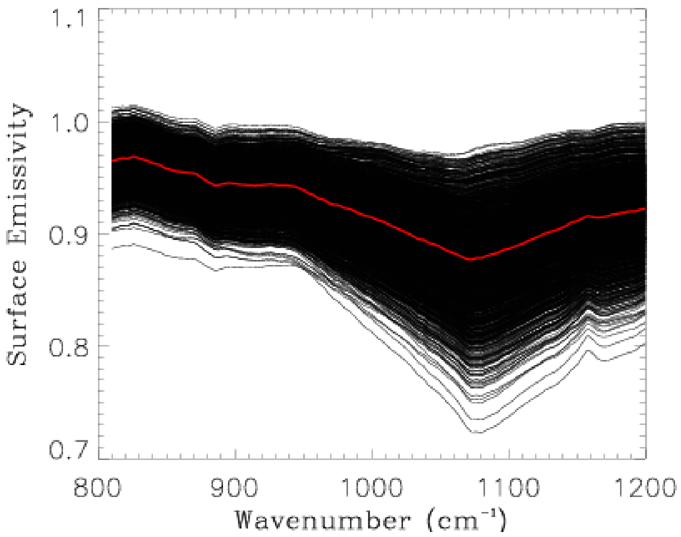
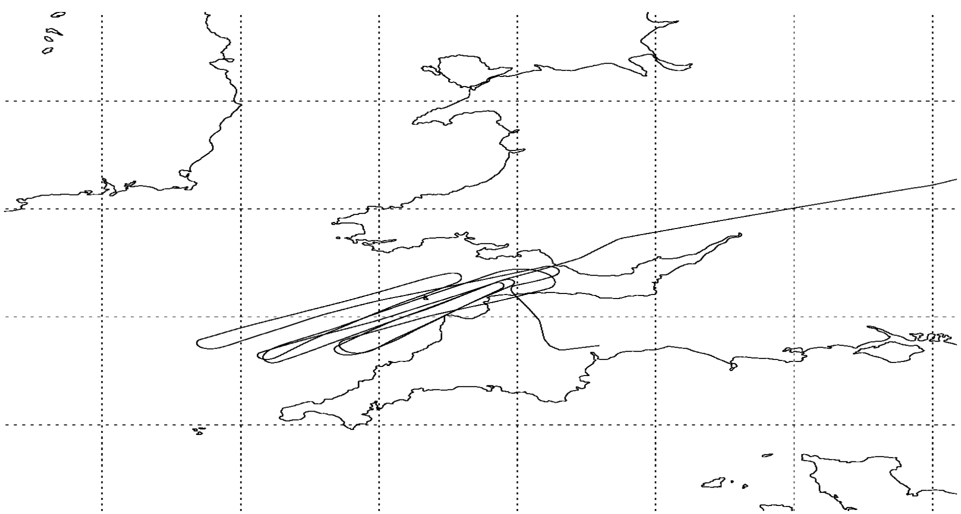
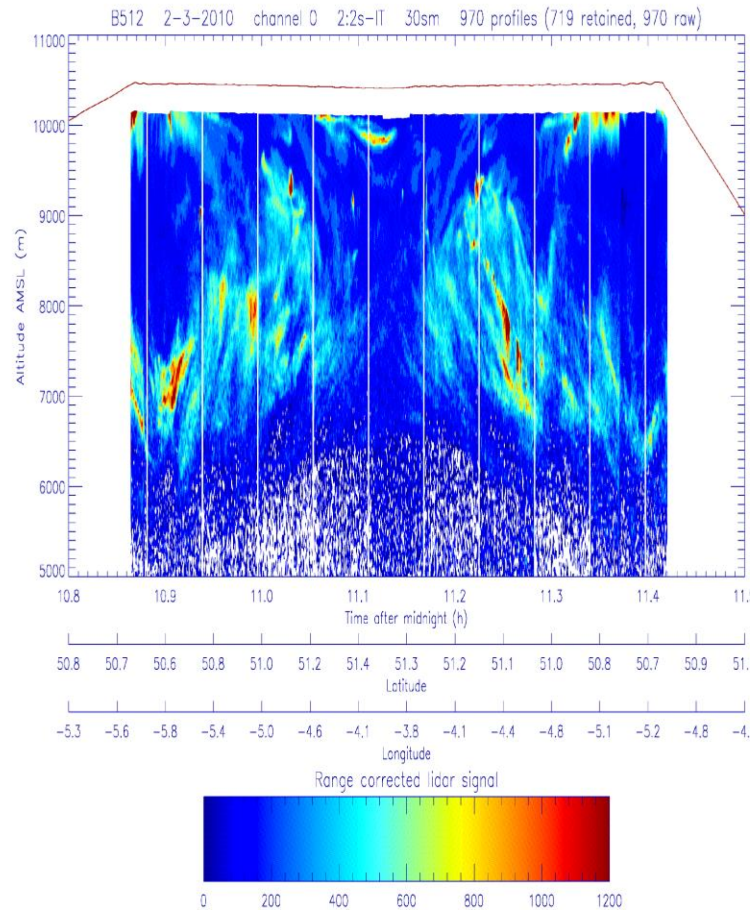




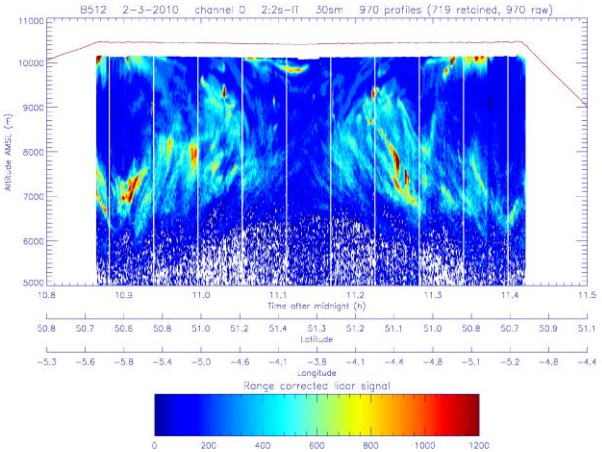
1700 surface emissivity profiles obtained from the high altitude radiance measurements.

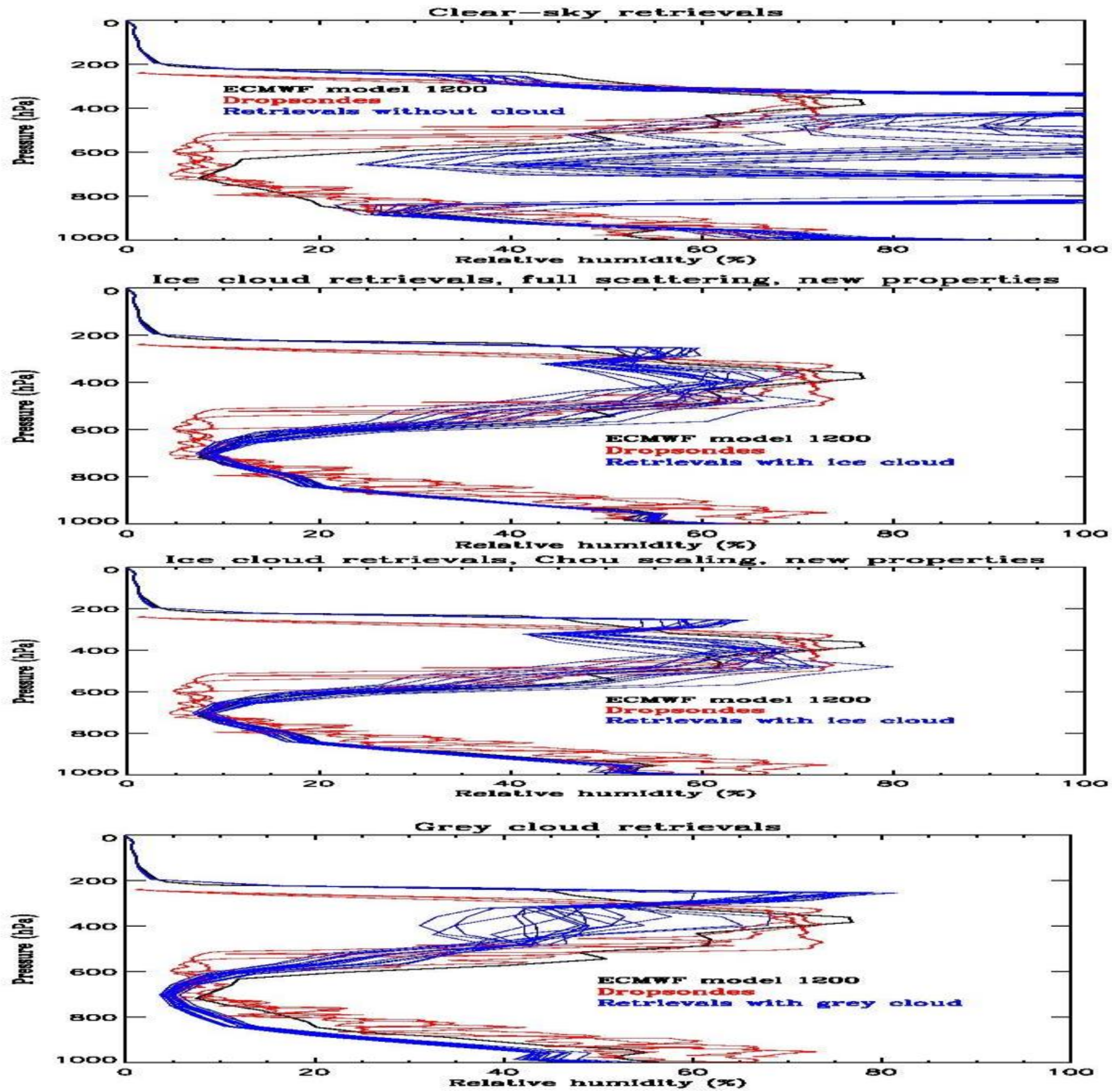
LW Cloudy Retrievals from IASI





LW Cloudy Retrievals from IASI

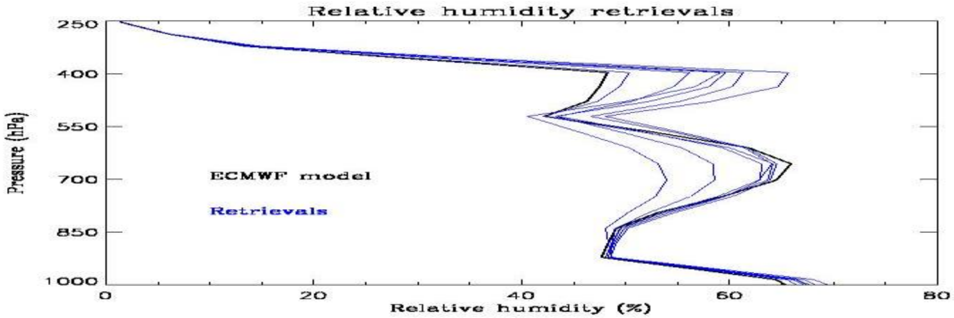


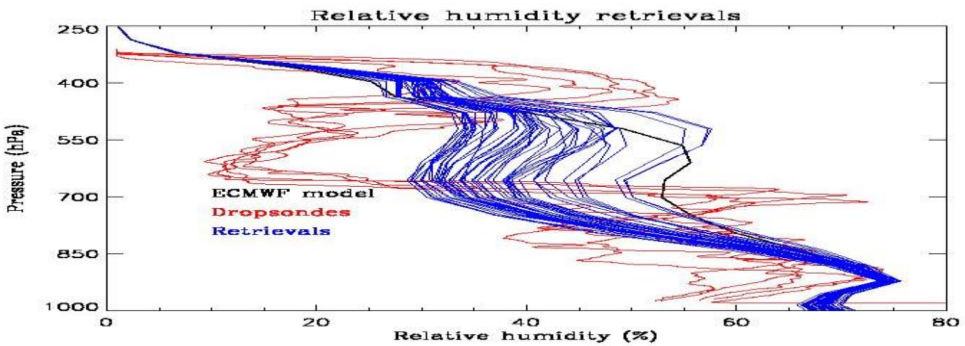


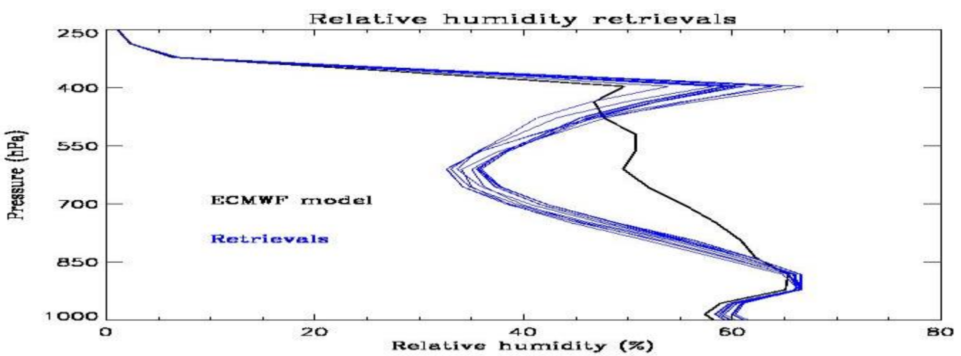
Relative humidity retrievals:

clear-sky
ice cloud: full scattering
ice cloud: Chou scaling
grey cloud

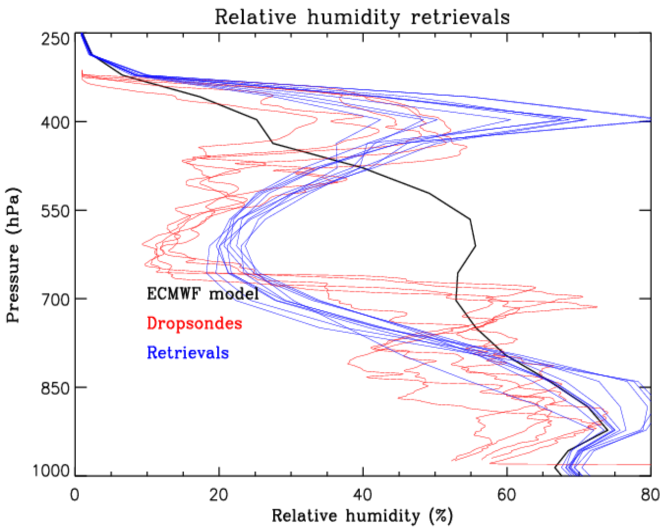
Longwave Cloudy Retrievals (different case): Relative humidity from ARIES and IASI







There is information about the humidity profile below a cirrus layer.



Longwave Cloudy Retrievals from ARIES and IASI: Cirrus properties

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	Background values	Run 7	Run 8	Run 9	IASI
Cirrus IWC	10 mgm-3	26±8 mgm-3	23±14 mgm-3	24±6 mgm-3	20±7 mgm-3
Cirrus cloud top pressure	Flight level	302±1 hPa	315±6 hPa	323±7 hPa	313±15 hPa
Cirrus cloud thickness	10 hPa (200 m)	14±3 hPa (280±60 m)	13±6 hPa (260±120 m)	18±4 hPa (360±80 m)	11±5 hPa (220±100 m)
Cirrus cloud fraction	1.00	1.06±0.03	0.98±0.04	1.01±0.03	0.96±0.05

HT-FRTC-in-RTTOV

- RTTOV v12.1 provides a basic interface to HT-FRTC allowing IASI simulations.
- This allows HT-FRTC to be called through the standard RTTOV interface with only minimal changes required in user code.
- There are a number of limitations and performance issues in this initial implementation.
- RTTOV v12.2 will offer much faster HT-FRTC performance and will improve the capabilities for clear-sky simulations.
- More sensors will be supported, including lightly (CosCar) apodised MTG-IRS

HT-FRTC-in-RTTOV

Looking further ahead, more options could be added:

- support for RTTOV variable trace gases
- cloud-affected radiances
- aerosol-affected radiances
- solar radiation

Summary and future plans

Summary

RTTOV is a fast RT model for passive visible, IR and MW sensors:

- The current gas optical depth prediction method does not work well for lightly apodised radiances, but heavily apodised (e.g. Hamming) radiances are supported.

PC-RTTOV is a PC-based fast RT model for hyperspectral IR sounders which is run through the RTTOV interface:

- This will be able to simulate lightly apodised MTG-IRS spectra.

HT-FRTC is another fast RT model:

- RTTOV v12 has an interface to HT-FRTC which will provide an alternative method of simulating lightly apodised MTG-IRS spectra.

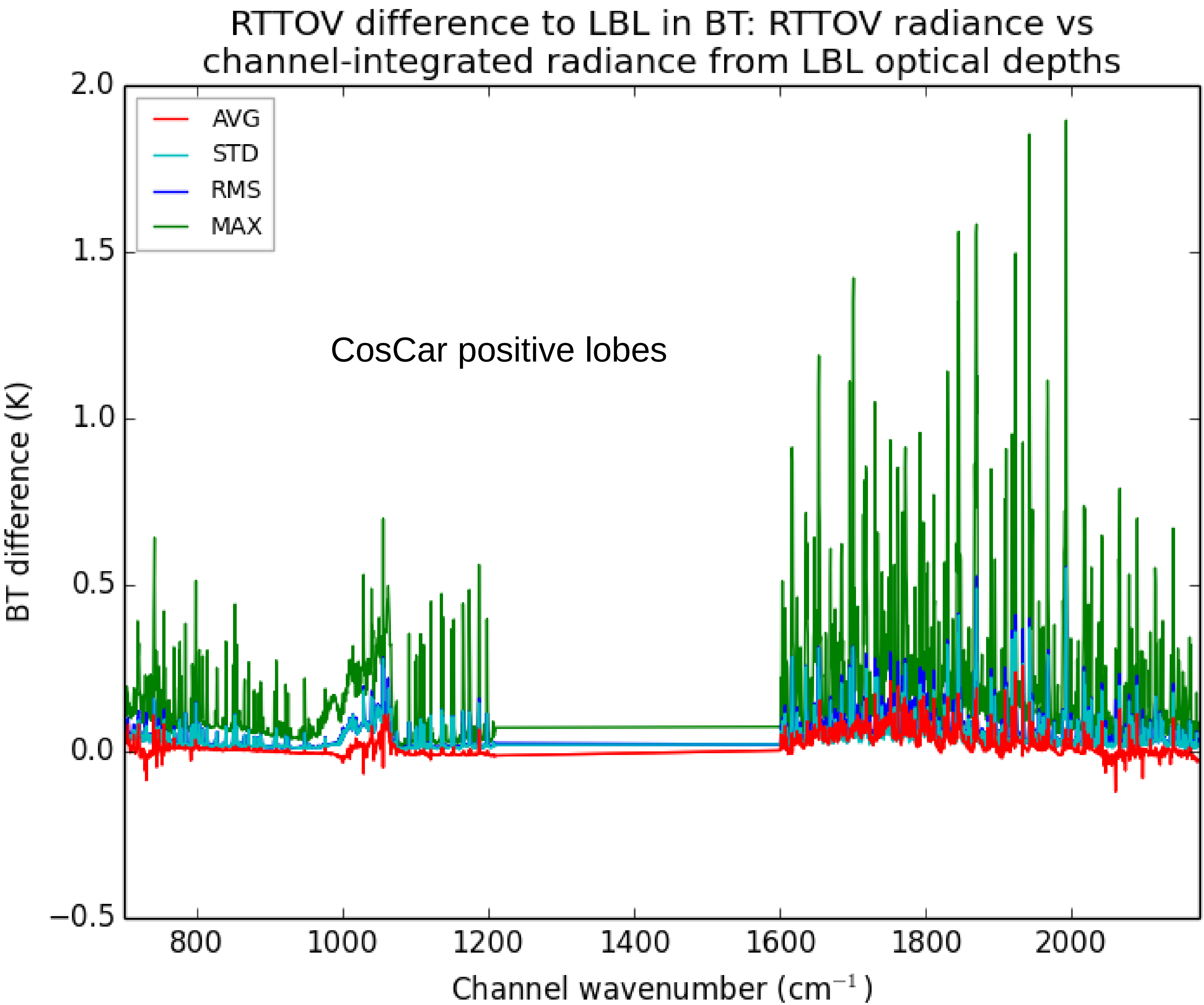
Future plans

- RTTOV v12.2 is due for release in Q1 2018.

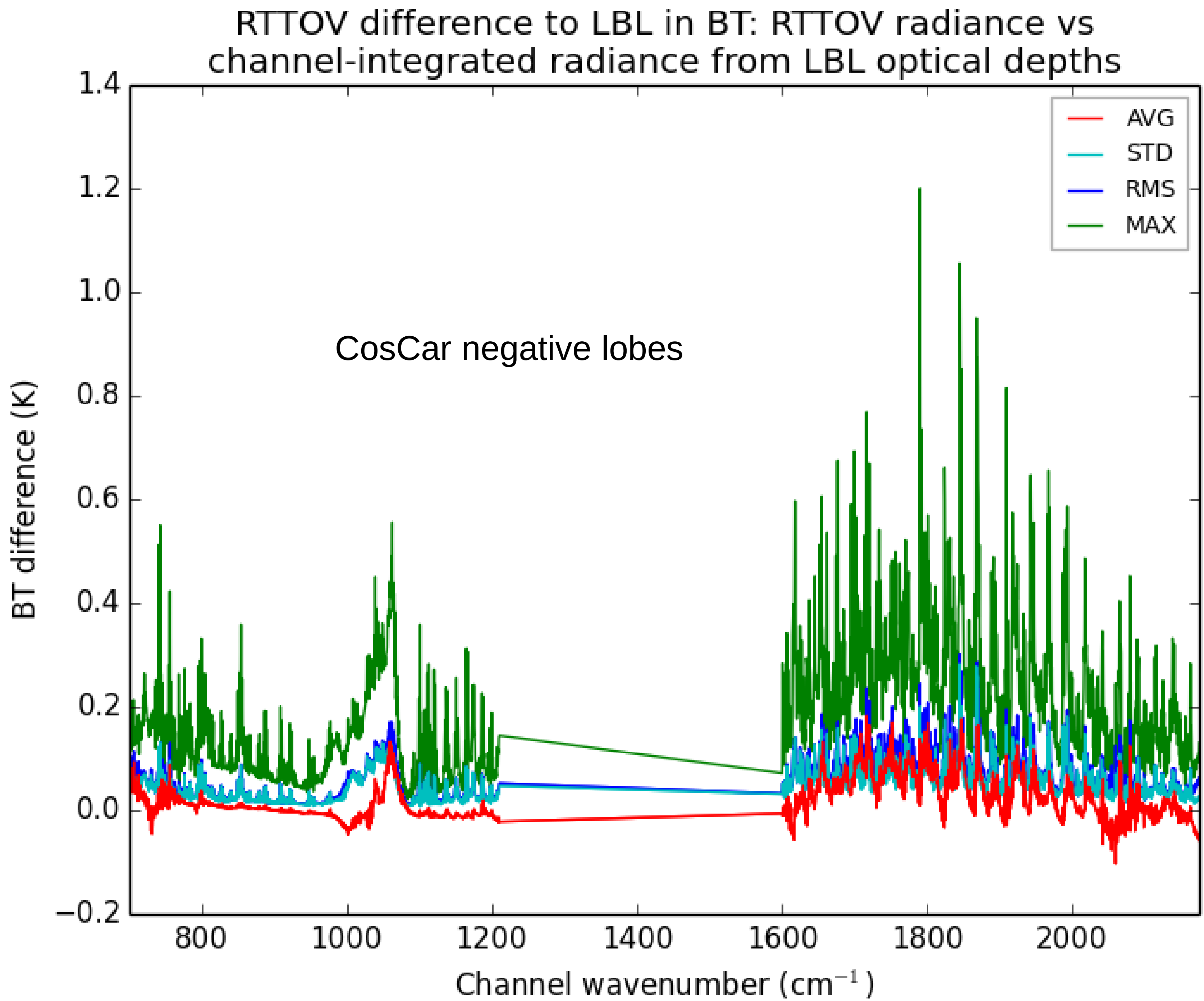
- In v12.2 both PC-RTTOV and HT-FRTC-in-RTTOV will provide (at least) clear-sky lightly-apodised (CosCar) MTG-IRS simulations.

- Investigations are on-going into lightly-apodised MTG-IRS simulations in classical RTTOV.

Thanks for your attention



RTTOV difference to LBL in BT: RTTOV radiance vs
channel-integrated radiance from LBL optical depths
AVG
STD
RMS
MAX
CosCar positive lobes
BT difference (K)
2.0
1.5
1.0
0.5
0.0
−0.5
800
1000
1200
1400
1600
1800
2000
Channel wavenumber (cm^{-1})



RTTOV difference to LBL in BT: RTTOV radiance vs
channel-integrated radiance from LBL optical depths
CosCar negative lobes
AVG
STD
RMS
MAX
BT difference (K)
Channel wavenumber (cm⁻¹)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
800
1000
1200
1400
1600
1800
2000