Met Office

RTTOV design

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Met Office

Acknowledgements
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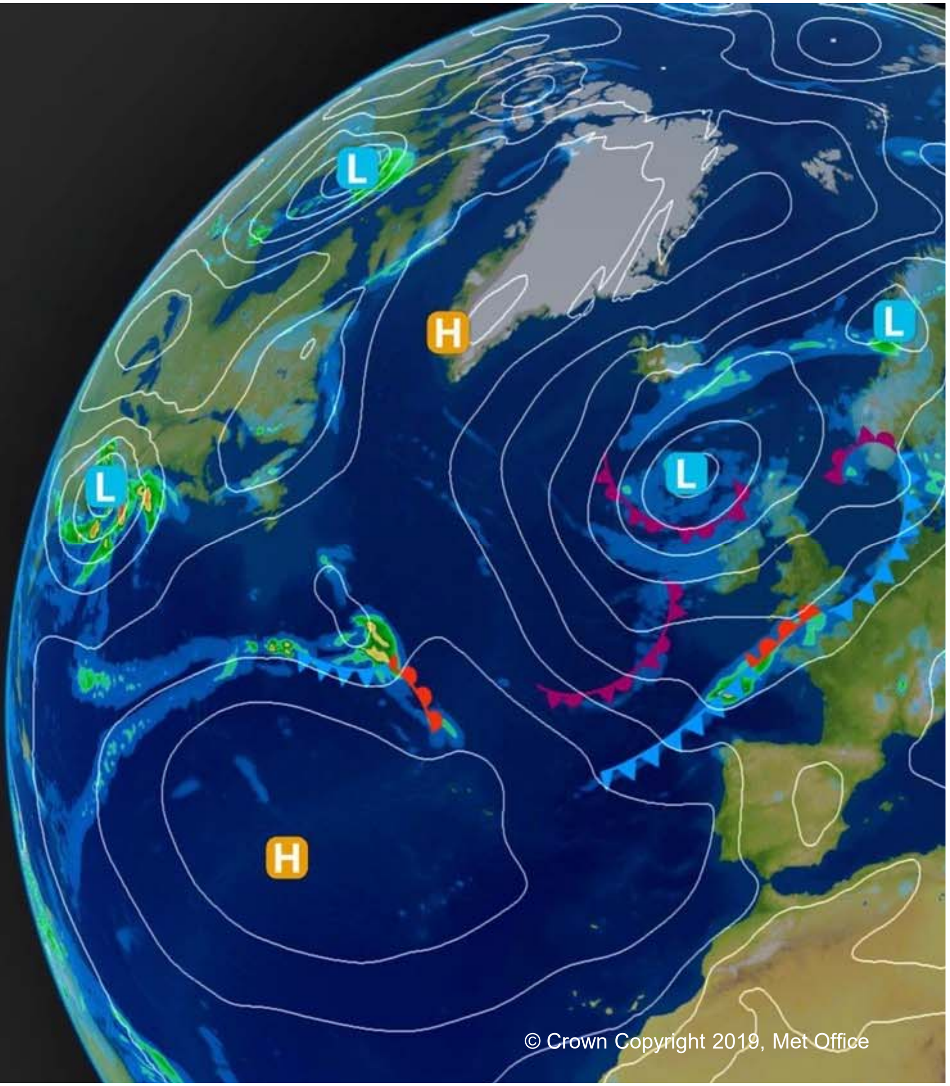
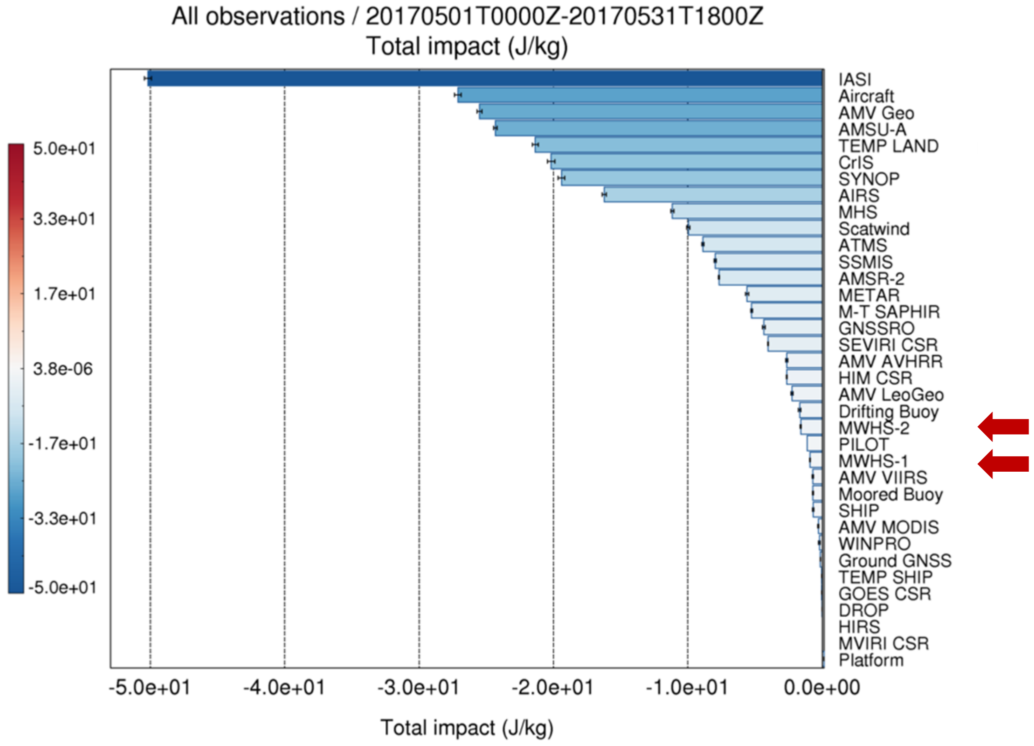
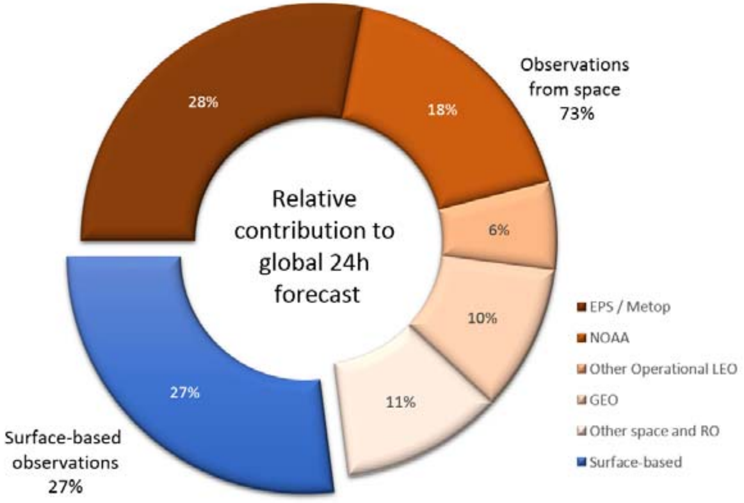
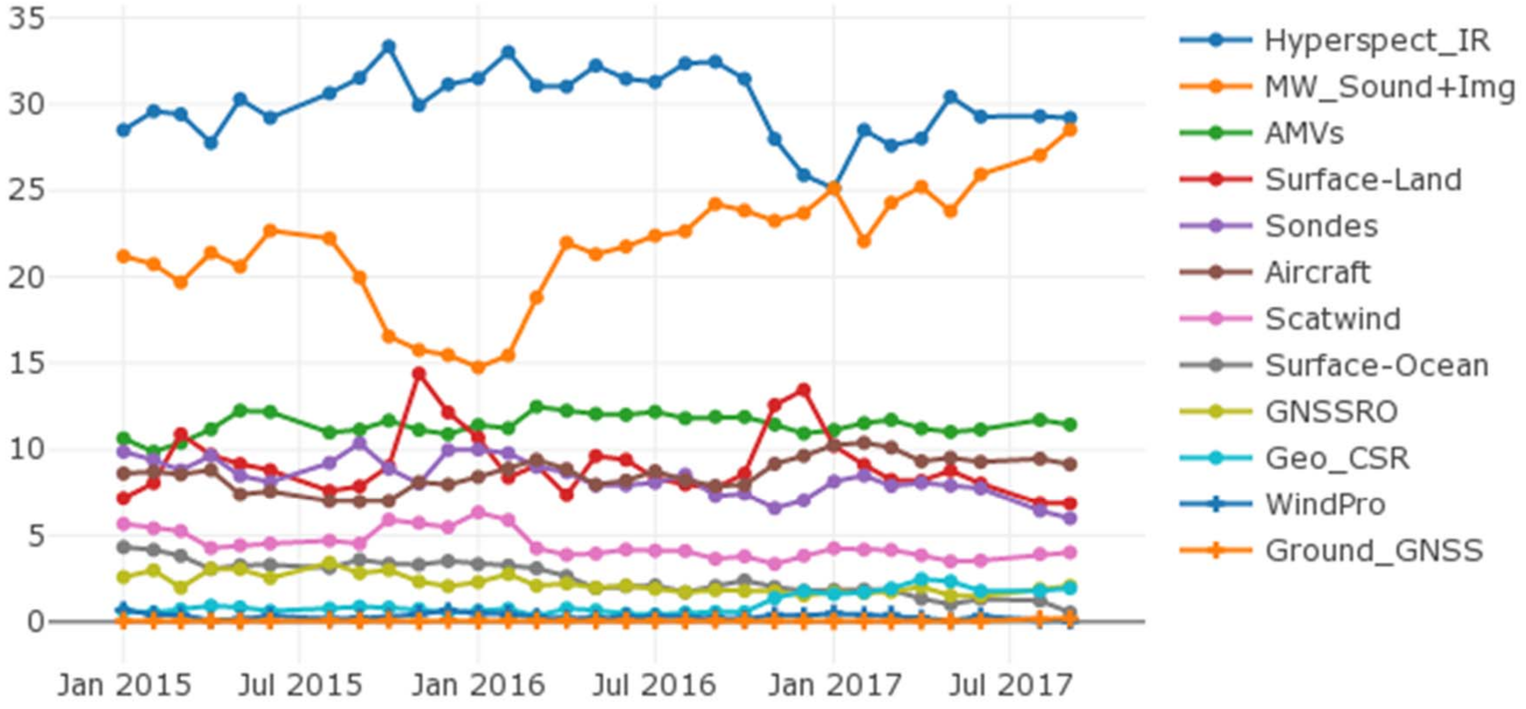


Impact of satellite data in global NWP

FSOI results showing impact of observations for 24hr forecasts in global model







Office Global FSOI: Total Percentage Impact on 24-hr Forecast Error Reduction

Outline of Talk

- Basic radiative transfer
- Profiles and Line by line reference models
- RTTOV implementation
- RTTOV performance
- Technical considerations
- User outreach

What is a fast RT model?

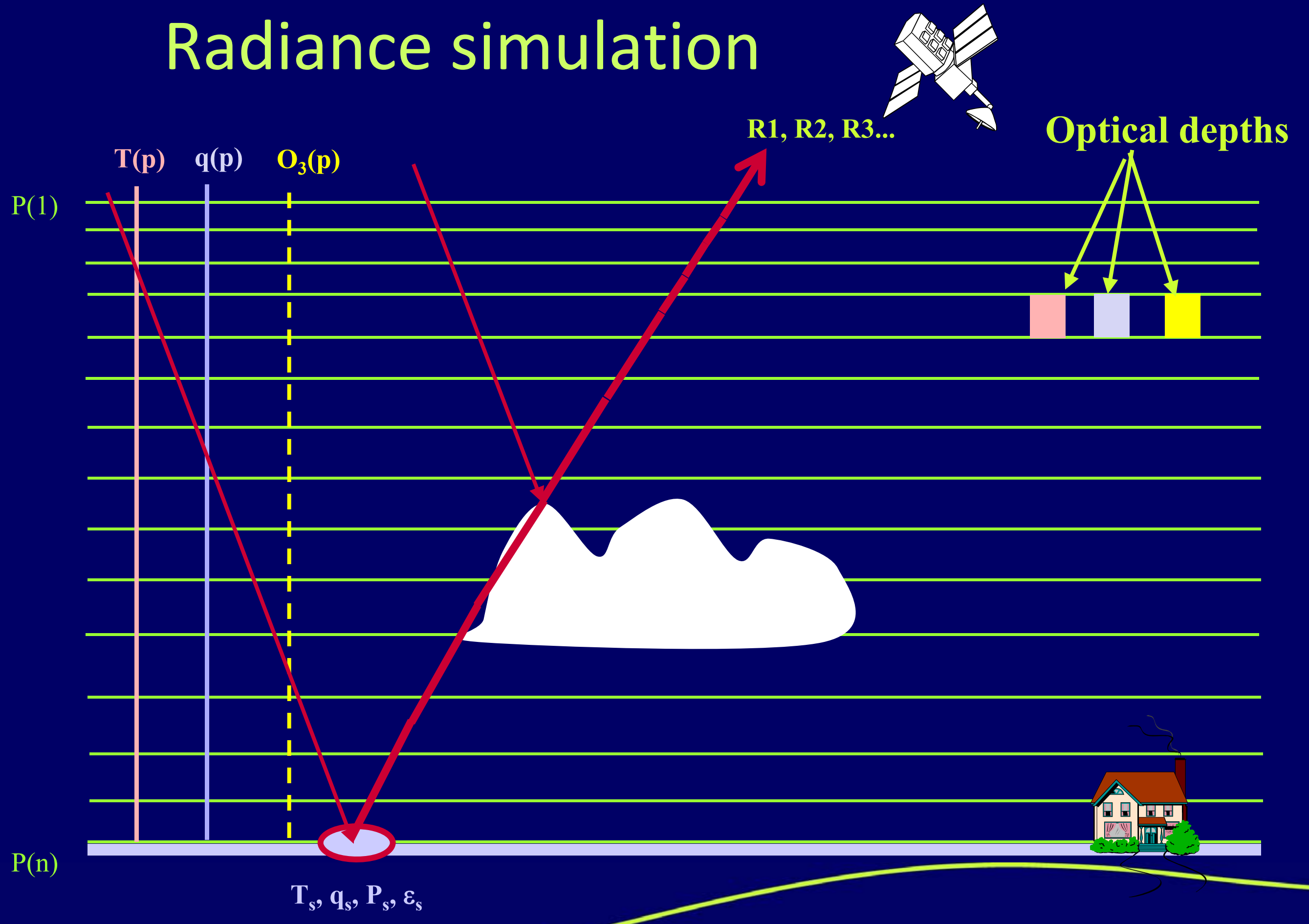
- **For simulating top-of-atmosphere radiances as would be measured by visible, infrared and microwave satellite sensors - within a few msecs.**
- **Also provides layer to space transmittances**
- **Optionally provides jacobians, TL, AD**
- ***Optionally computes IR spectrum as PCs (Marco)***
- ***Not*** **part of model radiation scheme which provides SW/LW fluxes & heating and cooling rates (e.g. Edwards & Slingo UM-5)**

How to set up a Fast Radiative Transfer Model?

- Divide atmosphere into discrete layers from surface to top of atmosphere which are assumed to be homogenous w.r.t. particle number density.
- Ideally would like to run line-by-line (LBL) model at high spectral resolution to obtain channel-integrated optical depth in each layer and plug into solution of RT equation. *Too slow for operational use.* ☹
- **Fast models:**
    - Developed in the mid-1970s by McMillin & Fleming in NOAA for TOVS
    - Parameterised* the Line by Line channel-integrated layer optical depths in terms of profile variables to allow a quick calculation of later optical depth.

* More strictly: perform a multivariate Taylor expansion of the formulation of the ratio between channel-integrated transmittances of 2 adjacent layers (effective transmittance)

Radiance simulation



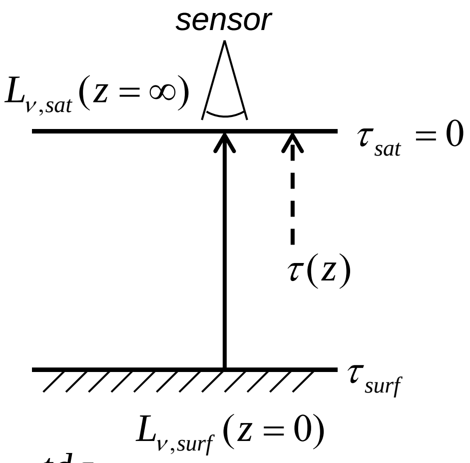
Clear-sky RT equation (IR, MW)

(no scattering)

$$\frac{d}{d\tau}(L_\nu e^{-\tau}) = -B_\nu(T)e^{-\tau}$$

Consider atmosphere between surface and sensor:

τ is the optical depth from the sensor.



Integrating from τ_{surf} to $\tau_{sat}=0$:

$$L_{\nu,sat} = L_{\nu,surf}e^{-\tau_{surf}} - \int_{\tau_{surf}}^{0} B_\nu(T)e^{-\tau}d\tau$$

Define *transmittance* $t = e^{-\tau}$ so that $0 \le t \le 1$ and $dt = -td\tau$

And note that $L_{\nu,surf} = \varepsilon_{\nu,surf}B_\nu(T_{surf})$

$$L_{\nu,sat} = \boxed{\varepsilon_{\nu,surf}B_\nu(T_{surf})t_{surf}} + \boxed{\int_{t_{surf}}^{1} B_\nu(T)dt} + \boxed{(1-\varepsilon_{\nu,surf})t_{surf}^{2}\int_{t_{surf}}^{1}\frac{B_\nu(T)}{t^2}dt}$$

Surface emission

Upwelling atmospheric emission

Downwelling surface-reflected atmospheric emission

Weighting functions

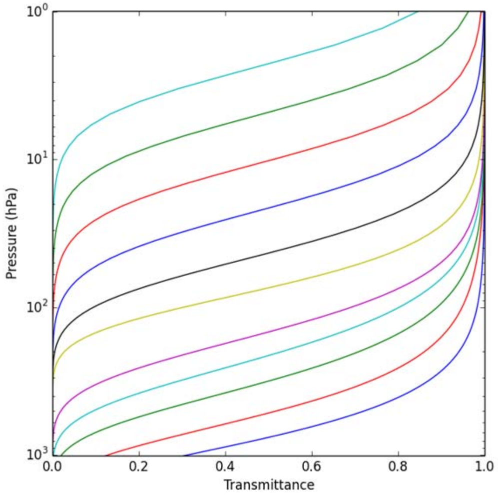
Transmittance *t* varies monotonically with height *z*

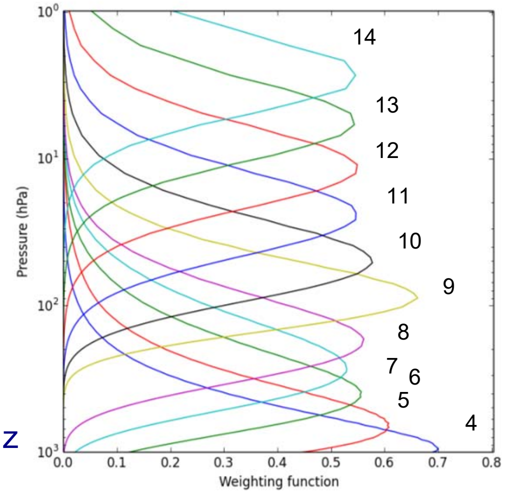
$$L_{\nu,sat} = \varepsilon_{\nu,surf} B_{\nu}(T_{surf}) t_{surf} + \int_0^{\infty} B_{\nu}(T) \frac{\partial t}{\partial z} dz$$

Weighting function: $w(z) = \frac{\partial t}{\partial z}$

The upwelling emission is an integral of the Planck function weighted by *w(z)*.

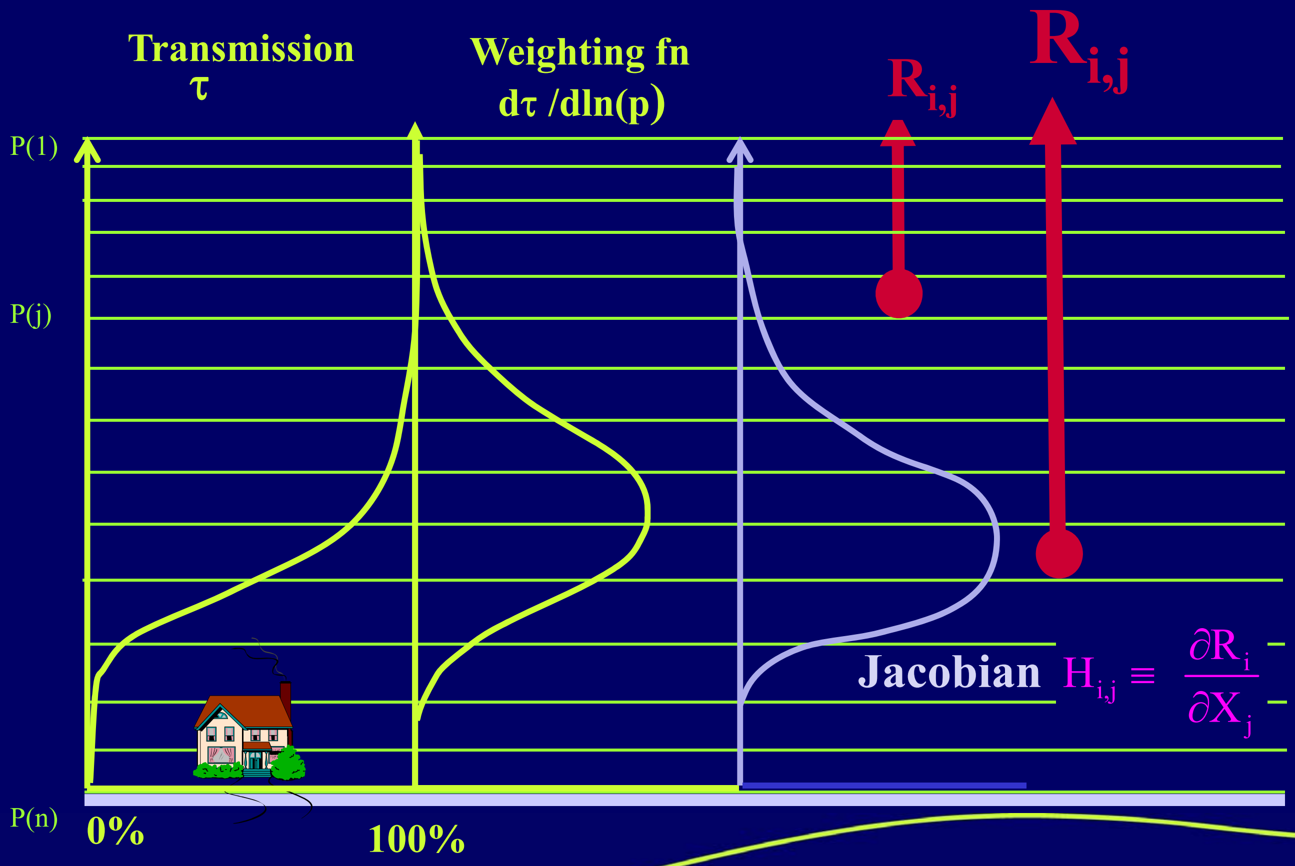
The largest contribution comes from the region where *w(z)* is largest *i.e.* where *t* changes most rapidly with height.





AMSU-A:
50-57 GHz
channels

Jacobian matrix



Transmission
τ

Weighting fn
$d\tau / d\ln(p)$

$R_{i,j}$

$R_{i,j}$

P(1)

P(j)

P(n)

0%

100%

Jacobian $H_{i,j} \equiv \dfrac{\partial R_i}{\partial X_j}$

Tangent linear, adjoint, Jacobian (K) models

$$J = \underbrace{(x - x_b)^T B^{-1} (x - x_b)}_{J_b} + \underbrace{(y - H(x))^T R^{-1} (y - H(x))}_{J_o}$$

The gradient of the cost function with respect to the control variables is required in the minimisation.

The gradient of J_o is given by :

$$\nabla_{\delta x} J_0 = \mathrm{H}^T R^{-1} d$$

$$d = y - H(x)$$

This can be done by:

- Computing H explicitly (using the 'K code') and doing the matrix multiplication ($\mathrm{H}^T \times R^{-1}d$) , or
- Using the AD code, taking $R^{-1}d = \nabla_{\delta y} J_0$ as input

Tangent linear, Adjoint, Jacobian (K) models

Model	**Function**	**Input**	**Output**
‘Direct’	Forward calculation: generate T_B from profile (x)	· Profile (x) · Channel specifications · Observation geometry	Radiances, usually as brightness temperatures (T_B) for all channels and layer transmittances.
K	Generate full Jacobian matrices (H)	[as for direct]	Arrays containing H (= dT_B/dx …) for all profile variables, and channels.
TL	Generate increments in radiance (δT_B) from increments in profile variables	[as for direct] + … increments in profile variables (δx)	Increments in radiances (δT_B)
AD	Generate gradients of cost wrt profile variables from gradients of cost wrt T_B.	[as for direct] + normalised departures: $R^{-1}.d$ $= R^{-1}(y-H(x))$ or $R^{-1}(y-H(x_b)-H\delta x)$	Gradients of cost wrt profile variables.

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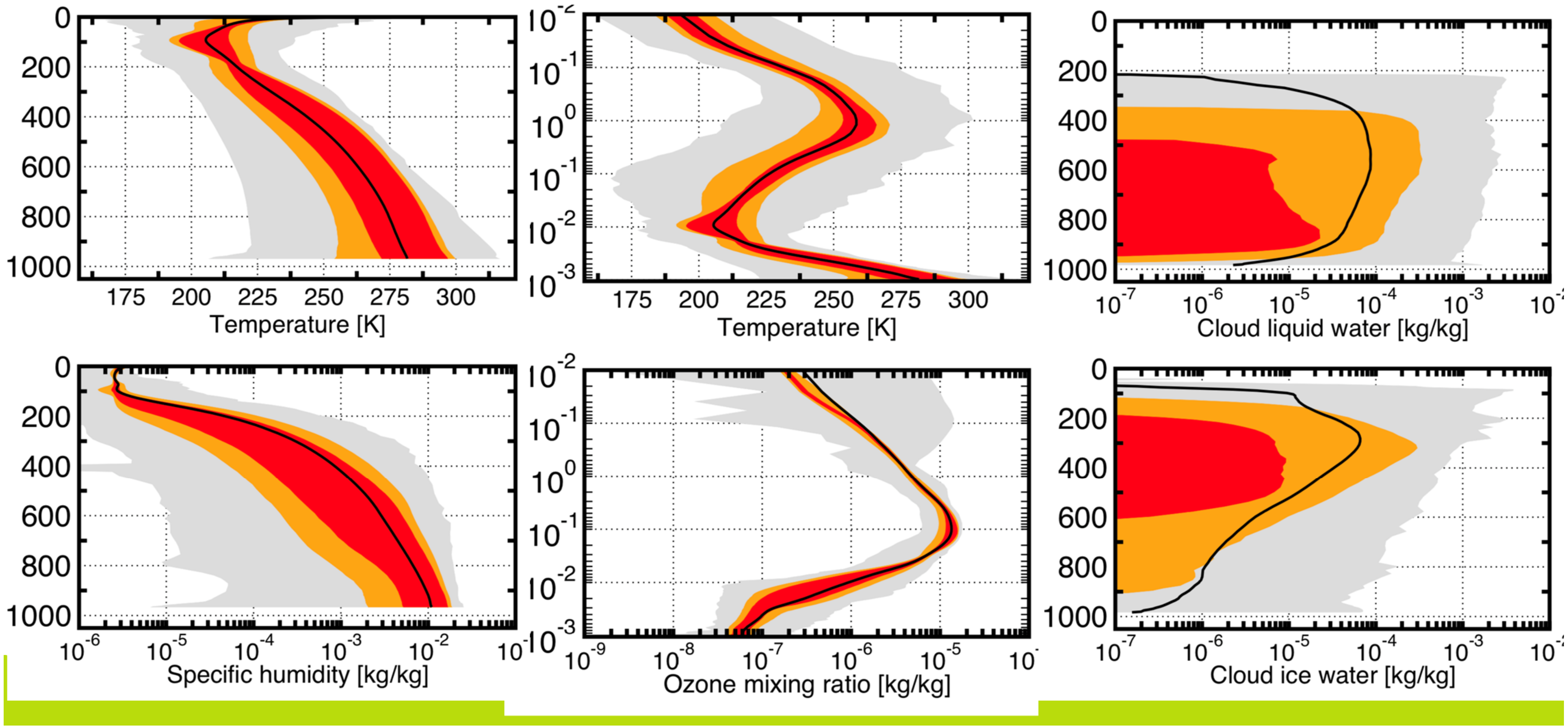
Diverse profiles from ECMWF model

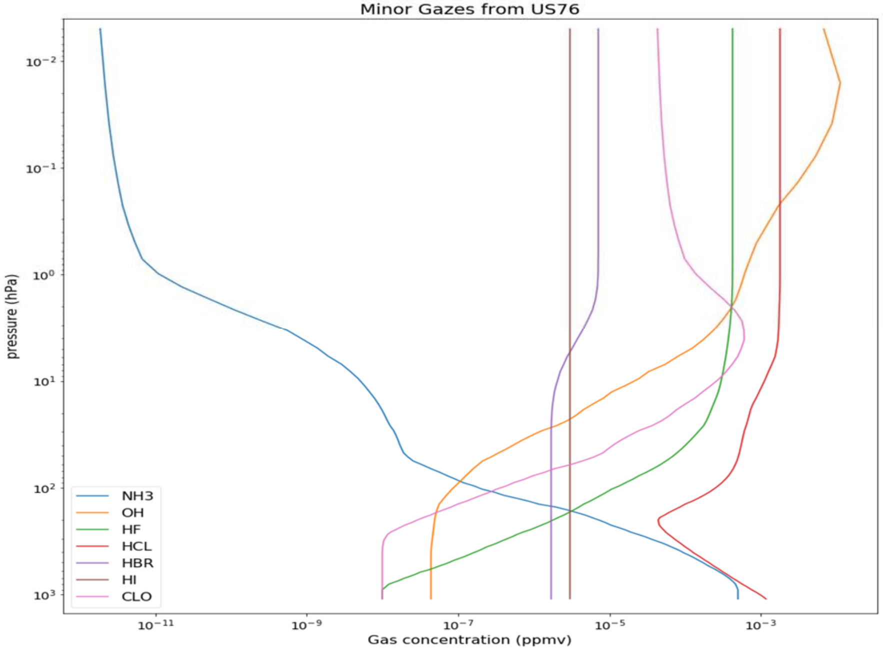


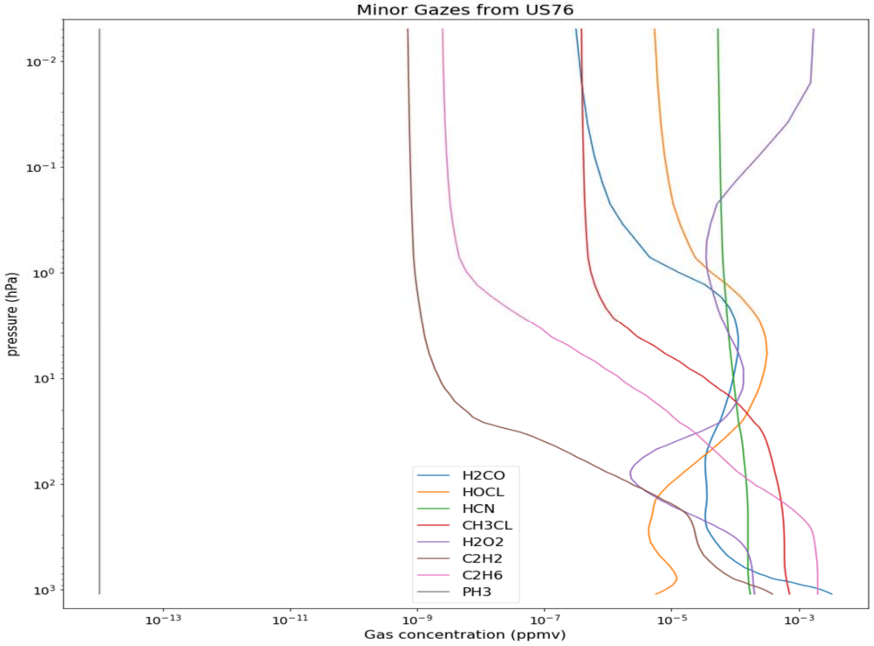
Trace Gas Profiles for fixed gas transmittances

- Infrared LBL updates: gas concentrations for 1970s and other eras

GAS concentrations US76 (AFGL):

'O2', 'NO', "NO2', 'NH3', 'HNO3', 'OH', 'HF', 'HCl', 'HBr', 'HI', 'ClO', 'OCS', 'H2CO', 'HOCl', 'N2', 'HCN', 'CH3Cl', 'H2O2', 'C2H2', 'C2H6', 'PH3', 'COF2', 'SF6', 'H2S', 'HCOOH', 'HO2', 'O', 'ClONO2', 'NO+',





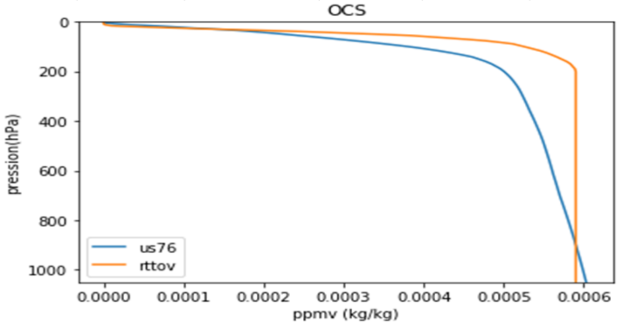
Profile datasets

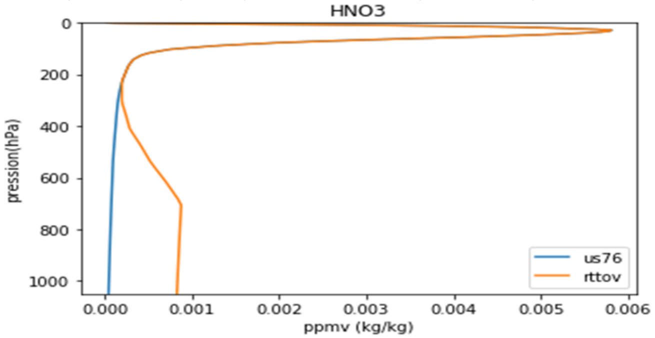
Infrared LBL updates: gas concentrations for 1970s and other eras

GAS concentrations US76 (AFGL):

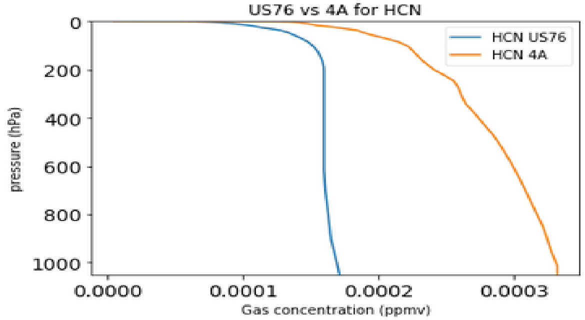
'O2', 'NO', "NO2', 'NH3', '**HNO3**', 'OH', 'HF', 'HCl', 'HBr', 'HI', 'ClO', '**OCS**', 'H2CO', 'HOCl', 'N2', **'HCN'**, 'CH3Cl', 'H2O2', 'C2H2', 'C2H6', 'PH3', 'COF2', 'SF6', 'H2S', 'HCOOH', 'HO2', 'O', 'ClONO2', 'NO+', 'HOBr', 'C2H4', 'CH3OH'

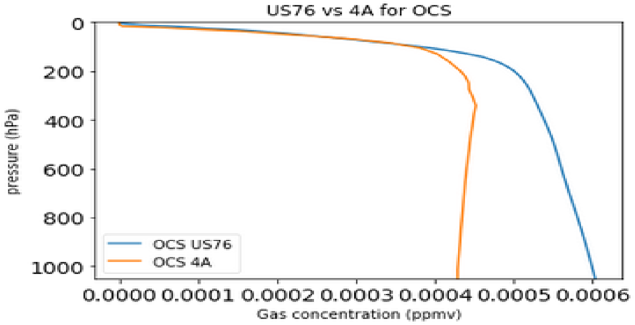
Main differences
RTTOV/US76

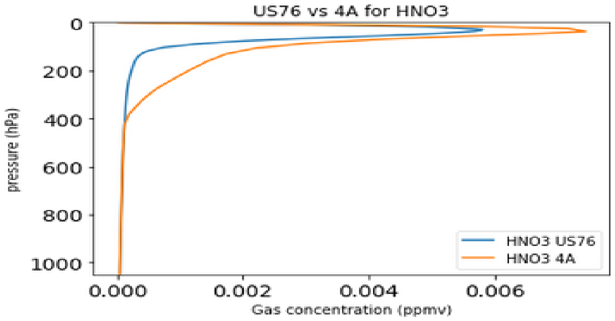




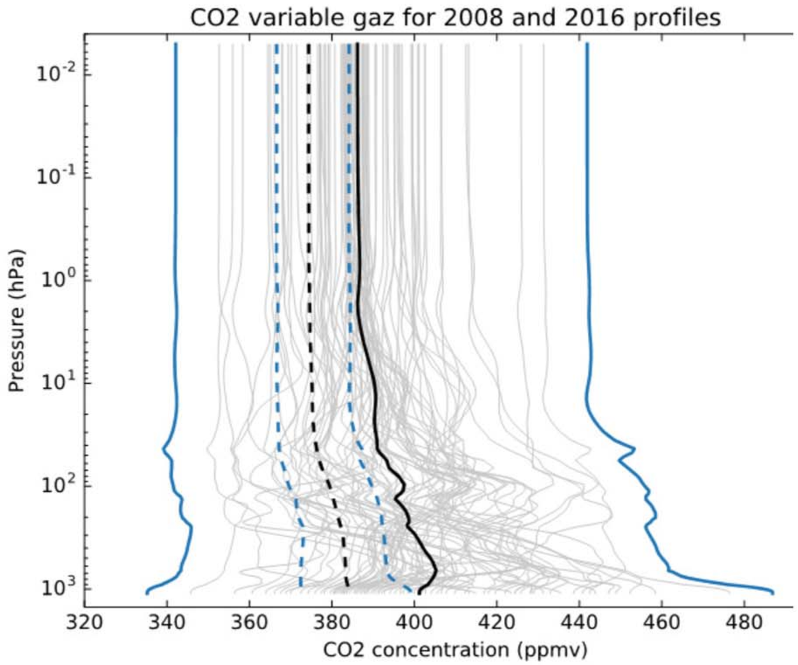
Main differences 4A/US76 :



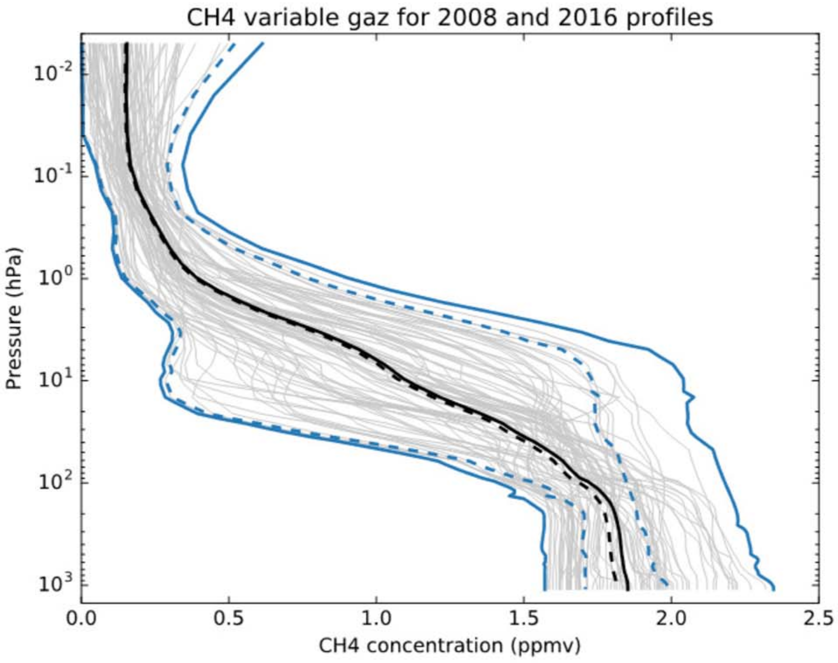




Gas concentrations can vary over time



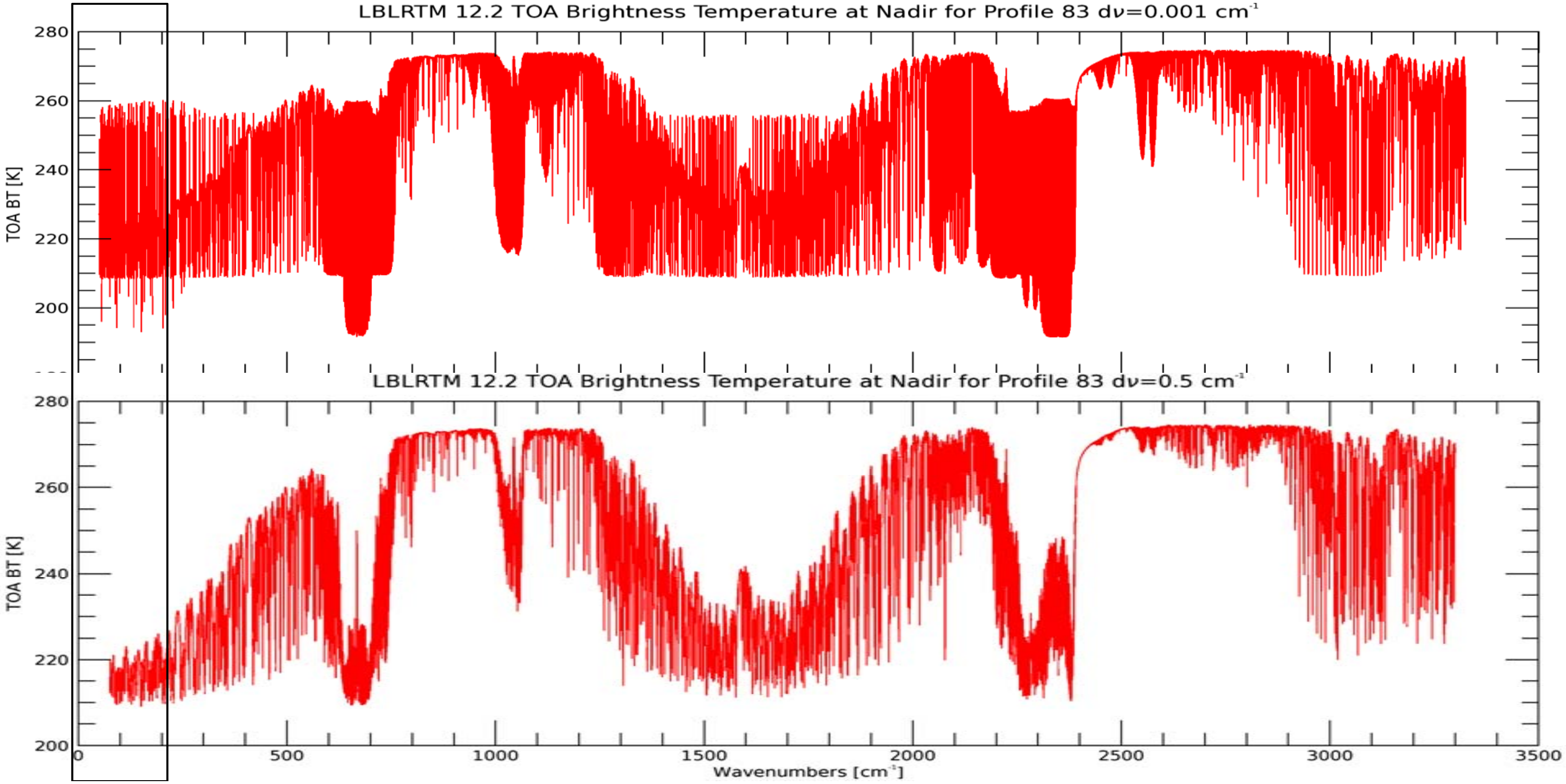
CO2 variable gaz for 2008 and 2016 profiles



CH4 variable gaz for 2008 and 2016 profiles

Line-by-line models

- **Infrared LBL updates**: extension to FIR (75-200 cm^{-1}), example for profile 83

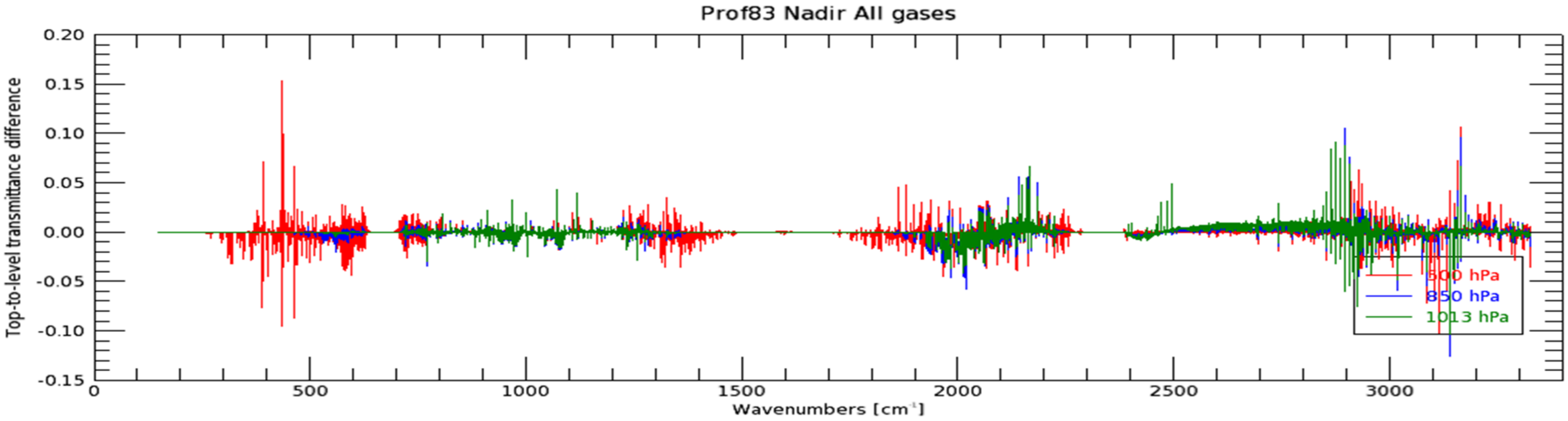


Line-by-line models

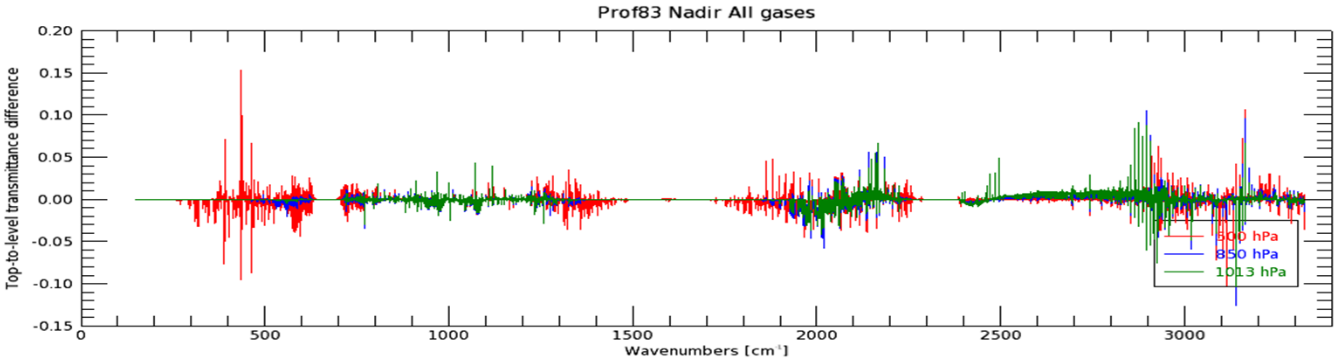
- Infrared LBL updates:

LBLRTM v12.8 compared to 12.2:

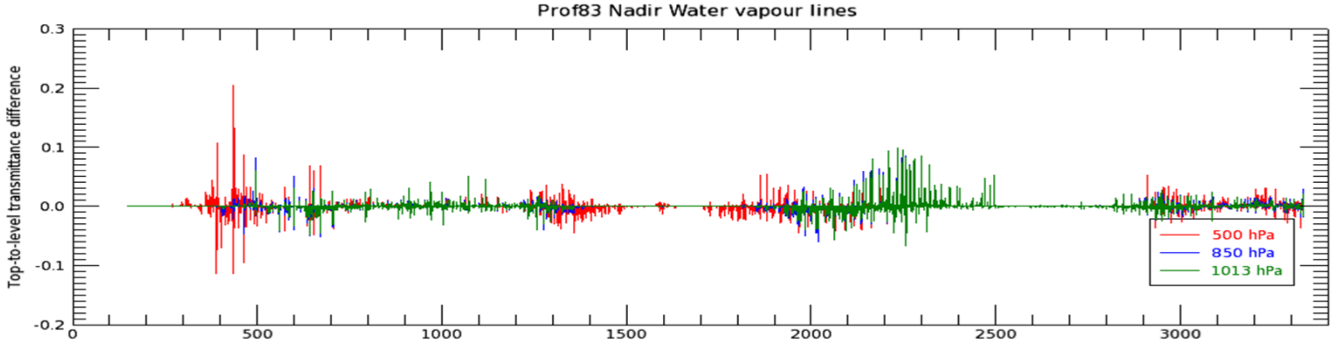
- Improved spectroscopic database: HITRAN 2012 (improved H_2O lines, same O_3)
- Improved water vapour continuum: MT-CKD 3.2 (instead of 2.5.2)



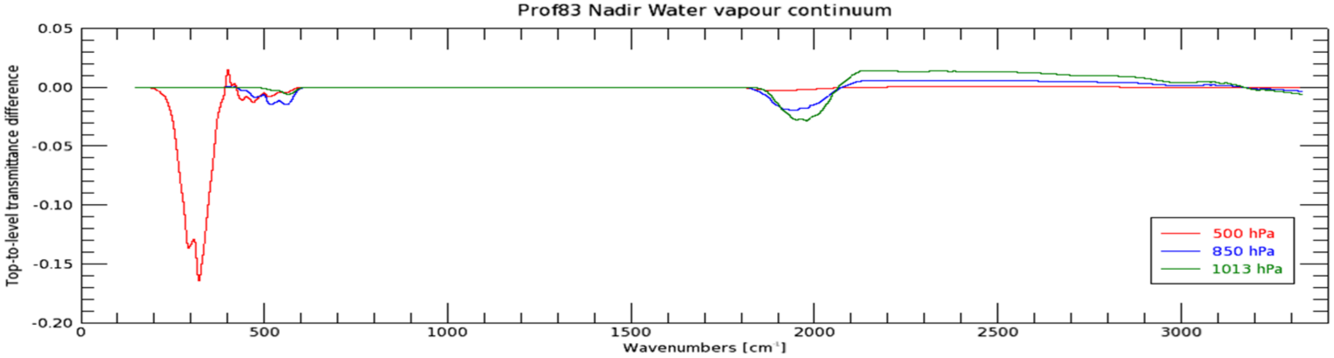
Line-by-line models



Water vapour lines difference



Water vapour continuum difference



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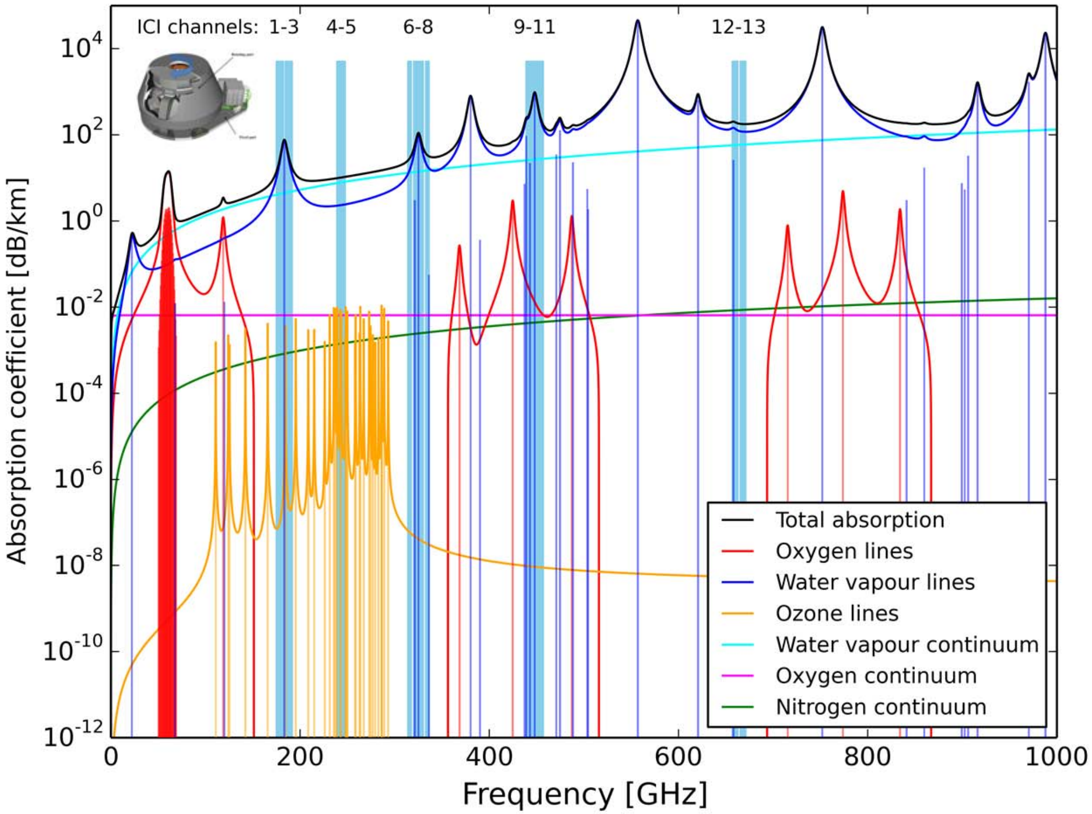
For MW RTTOV uses AMSUTRAN

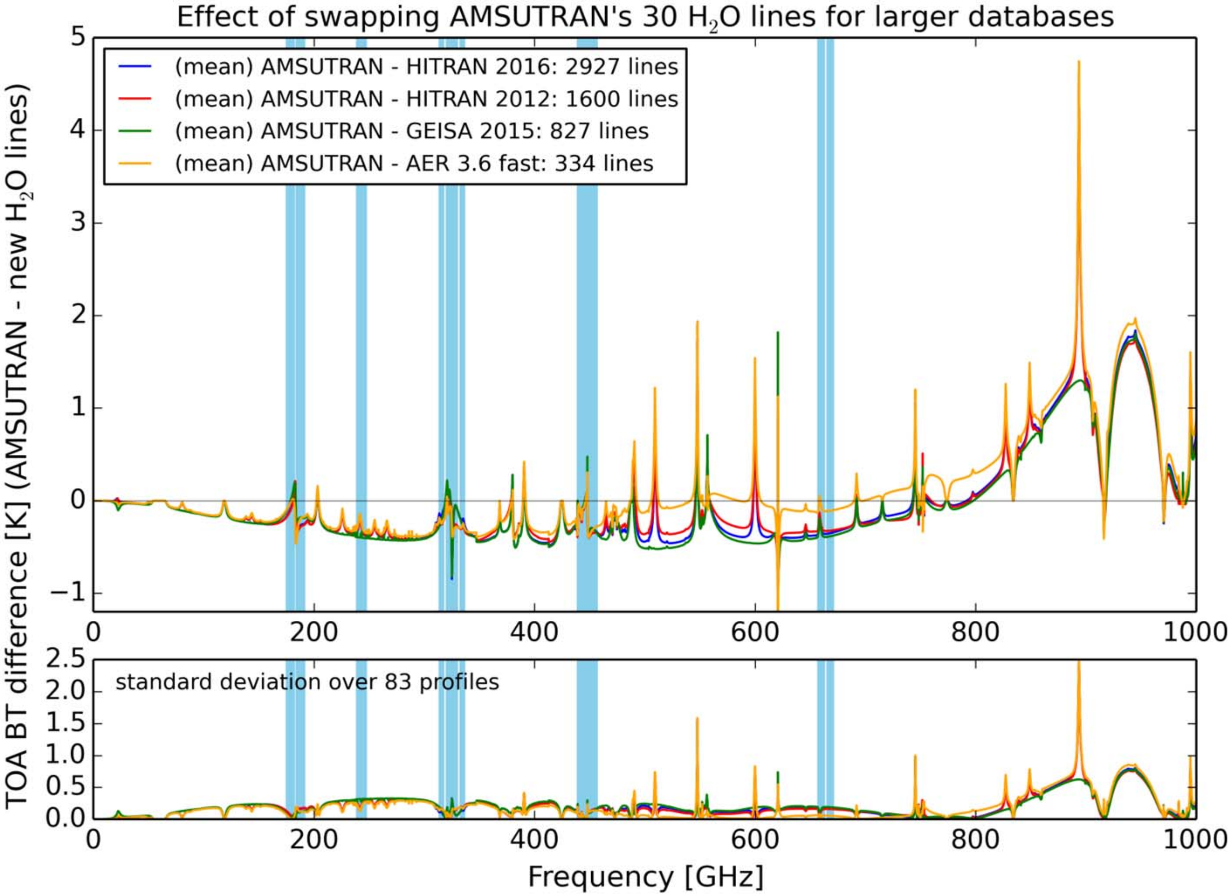
Current limitations:

- Ozone lines
  - Must include > 300 GHz
  - Make variable gas
- Water vapour
  - 30 lines possibly not enough
  - Current continuum measured in the lab at 137 GHz in 1989
    - … and is only valid for 30 lines



Water vapour lines

- Spike at 893 GHz due to absent line in MPM models (and GEISA)
- Brightness temperatures can be up to 2 ±1.5 K higher at line centre locations (547 GHz)
  - We have never simulated these higher frequencies before
- Below 200 GHz differences are up to 0.3 ±0.2 K lower in the windows



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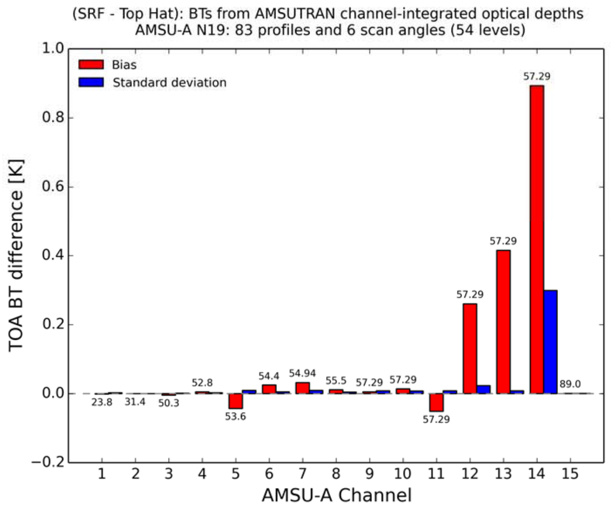
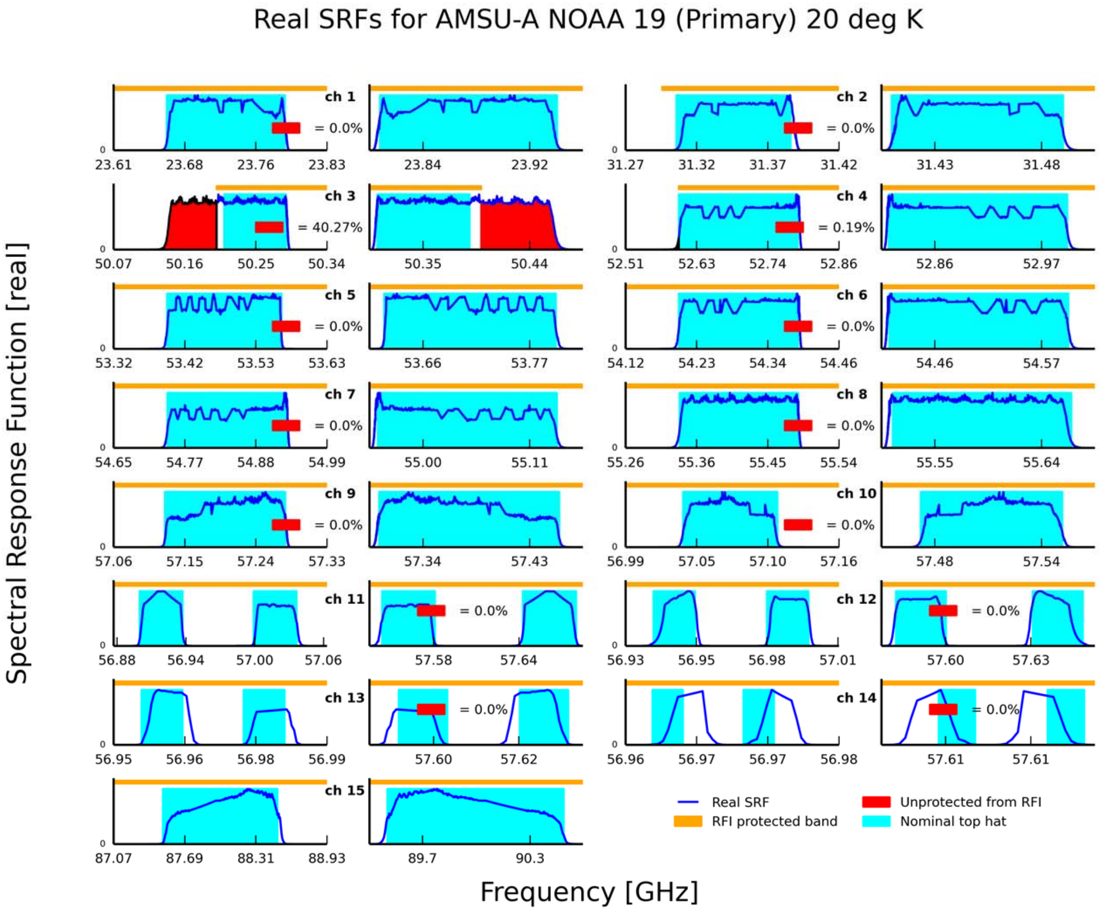
AMSU-A on NOAA-19

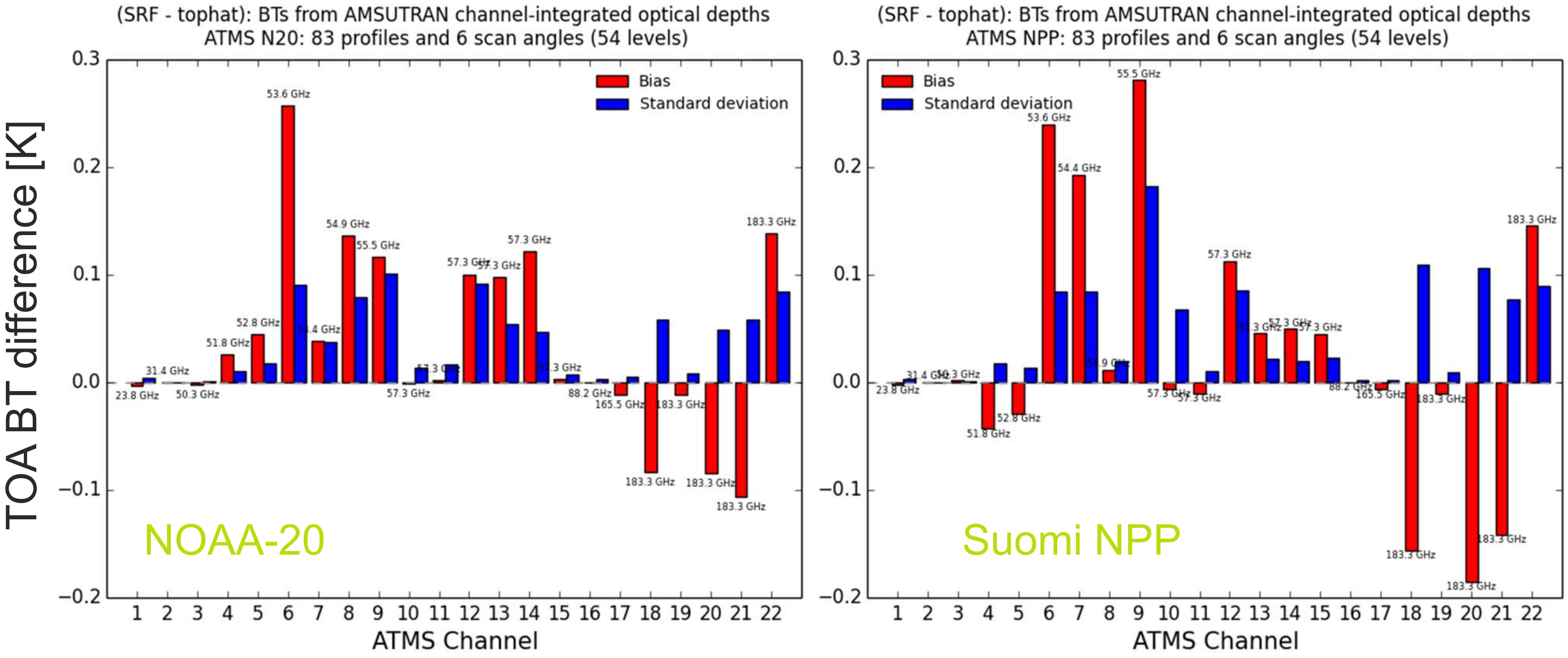
- Impact of up to 0.9 ±0.3 K in channel 14


(SRF - Top Hat): BTs from AMSUTRAN channel-integrated optical depths
AMSU-A N19: 83 profiles and 6 scan angles (54 levels)


Real SRFs for AMSU-A NOAA 19 (Primary) 20 deg K

Impacts (relative to tophat): ATMS

- SNPP has larger impacts
  - up to 0.29 K in channel 9
  - Up to -0.19 K in channel 20

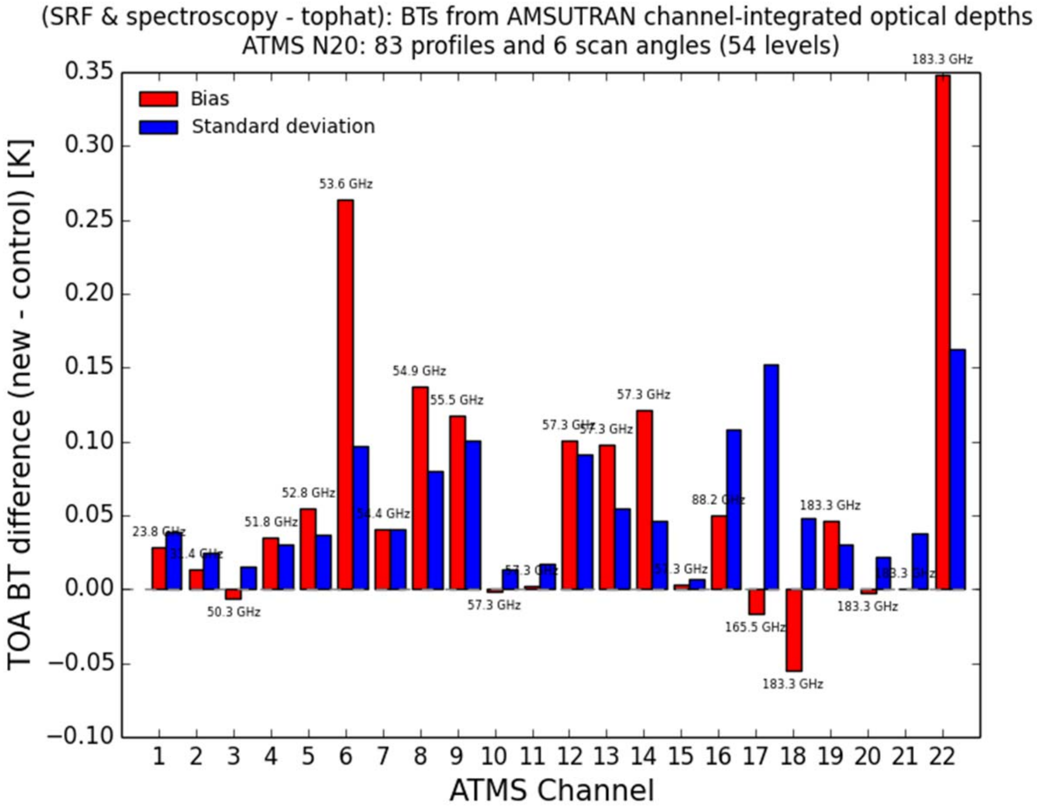


(SRF - tophat): BTs from AMSUTRAN channel-integrated optical depths
ATMS N20: 83 profiles and 6 scan angles (54 levels)

(SRF - tophat): BTs from AMSUTRAN channel-integrated optical depths
ATMS NPP: 83 profiles and 6 scan angles (54 levels)

MW Impacts: WV

- The effect of changing the water vapour spectroscopy in microwave instruments is small
- ATMS: BTs increased by up to 0.2 ±0.1 K (ch. 22, 183 GHz)
- Comparable or smaller than effect of adding SRFs
- SRF and spectroscopy combined has a max impact of 0.35 ±0.15 K (ch.22, 183 GHz)



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RTTOV coefficient training

83 diverse atmospheric profiles each at 6 zenith angles => *498 training profiles.*

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Divide atmosphere into 53* layers defined by 54 fixed pressure levels.

**For hi-res sounders we also produce coefficients for 100 layers/101 levels.*

RTTOV coefficient training

83 diverse atmospheric profiles each at 6 zenith angles => *498 training profiles.*

Divide atmosphere into 53* layers defined by 54 fixed pressure levels.

Calculate database of LBL optical depths for each layer at high spectral resolution for each training profile.

**For hi-res sounders we also produce coefficients for 100 layers/101 levels.*

RTTOV coefficient training

Define a set of atmospheric “predictors” derived from input profile variables
=> *there are separate sets of predictors for the optical depth due to mixed gases, water vapour and each additional trace gas.*

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Integrate the LBL optical depths in each layer over each instrument channel SRF for every training profile.

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=> *there are separate sets of predictors for the optical depth due to mixed gases, water vapour and each additional trace gas.*

Integrate the LBL optical depths in each layer over each instrument channel SRF for every training profile.

Regress layer optical depths onto predictors (p_i) for each channel
=> *coefficients* (c_i) *which are stored in a file for each instrument*

RTTOV optical depth calculation

Given input profile, compute predictors for each layer for each gas.

For each channel, for each layer, use the regression coefficients to compute the layer optical depth.

Optical depth due to mixed gases*

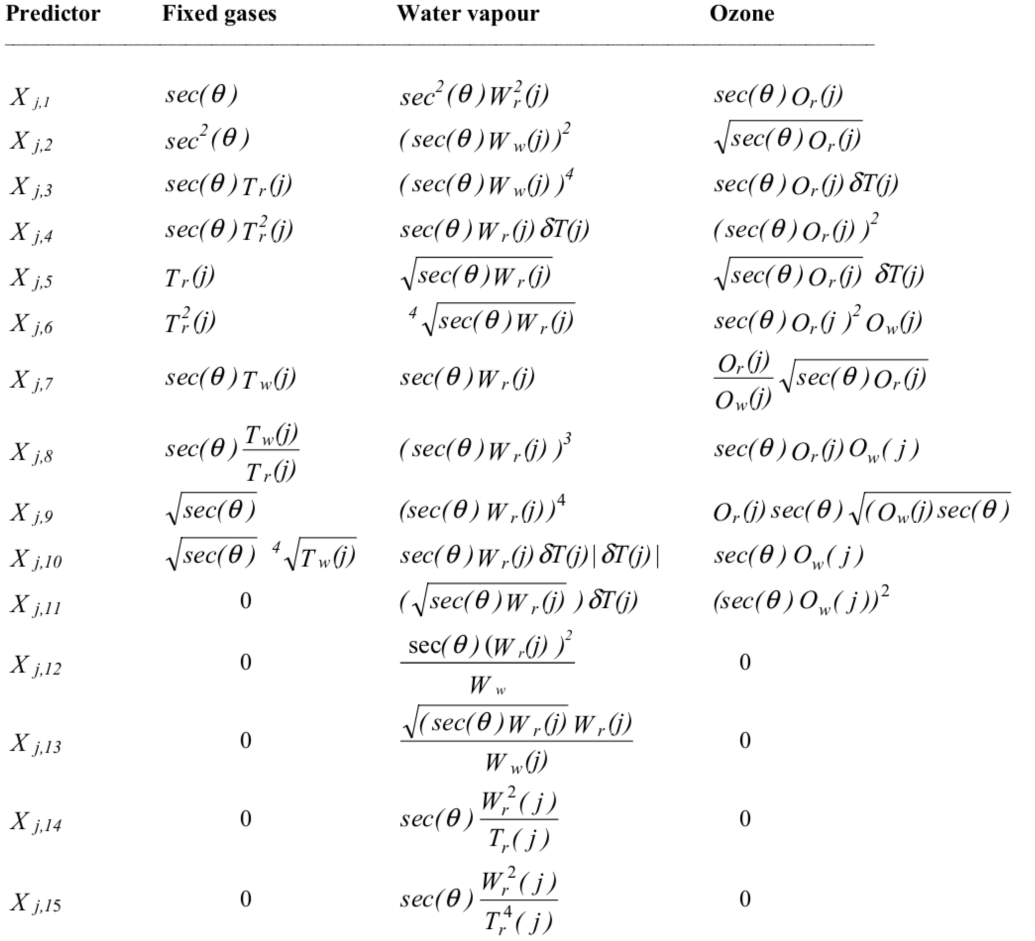
Optical depth due to water vapour*

Optical depth due to ozone*

$$\text{Total layer optical depth} = \sum_{i=1}^{n^{mg}} c_i^{mg} p_i^{mg} + \sum_{i=1}^{n^{wv}} c_i^{wv} p_i^{wv} + \sum_{i=1}^{n^{o3}} c_i^{o3} p_i^{o3}$$

** strictly speaking these are “pseudo” optical depths (RTTOV science and validation reports give more details)*

RTTOV Predictors used operationally



Predictor	Fixed gases	Water vapour	Ozone
$X_{j,1}$	$\sec(\theta)$	$\sec^2(\theta)W_r^2(j)$	$\sec(\theta)O_r(j)$
$X_{j,2}$	$\sec^2(\theta)$	$(\sec(\theta)W_w(j))^2$	$\sqrt{\sec(\theta)O_r(j)}$
$X_{j,3}$	$\sec(\theta)T_r(j)$	$(\sec(\theta)W_w(j))^4$	$\sec(\theta)O_r(j)\,\delta T(j)$
$X_{j,4}$	$\sec(\theta)T_r^2(j)$	$\sec(\theta)W_r(j)\,\delta T(j)$	$(\sec(\theta)O_r(j))^2$
$X_{j,5}$	$T_r(j)$	$\sqrt{\sec(\theta)W_r(j)}$	$\sqrt{\sec(\theta)O_r(j)}\;\delta T(j)$
$X_{j,6}$	$T_r^2(j)$	$\sqrt[4]{\sec(\theta)W_r(j)}$	$\sec(\theta)O_r(j)^2\,O_w(j)$
$X_{j,7}$	$\sec(\theta)T_w(j)$	$\sec(\theta)W_r(j)$	$\frac{O_r(j)}{O_w(j)}\sqrt{\sec(\theta)O_r(j)}$
$X_{j,8}$	$\sec(\theta)\frac{T_w(j)}{T_r(j)}$	$(\sec(\theta)W_r(j))^3$	$\sec(\theta)O_r(j)\,O_w(j)$
$X_{j,9}$	$\sqrt{\sec(\theta)}$	$(\sec(\theta)W_r(j))^4$	$O_r(j)\sec(\theta)\sqrt{(O_w(j)\sec(\theta)}$
$X_{j,10}$	$\sqrt{\sec(\theta)}\;\sqrt[4]{T_w(j)}$	$\sec(\theta)W_r(j)\,\delta T(j)\,\lvert\delta T(j)\rvert$	$\sec(\theta)O_w(j)$
$X_{j,11}$	0	$(\sqrt{\sec(\theta)W_r(j)})\,\delta T(j)$	$(\sec(\theta)O_w(j))^2$
$X_{j,12}$	0	$\frac{\sec(\theta)(W_r(j))^2}{W_w}$	0
$X_{j,13}$	0	$\frac{\sqrt{(\sec(\theta)W_r(j)}\,W_r(j)}{W_w(j)}$	0
$X_{j,14}$	0	$\sec(\theta)\frac{W_r^2(j)}{T_r(j)}$	0
$X_{j,15}$	0	$\sec(\theta)\frac{W_r^2(j)}{T_r^4(j)}$	0

Table 1: RTTOV-7 predictors for mixed gases, water vapour and ozone used in equ.2. The profile variables are defined in Table 2. j is the jth layer which is the layer above level j where the level number starts at 0 for the top of atmosphere.

RTTOV v13 – new optical depth parameterisation

Current parameterisation:

$$\tau_{total} = \left(\frac{\tau_{mixed+wv+o3}}{\tau_{mixed+wv}}\right)\left(\frac{\tau_{mixed+wv}}{\tau_{mixed}}\right)\tau_{mixed}$$

$$\tau_{total} = \widehat{\tau_{o3}}\widehat{\tau_{wv}}\tau_{mixed}$$

Xiong and McMillin (2005):

$$\tau_{total} = \tau_{mixed}\tau_{wv}\tau_{o3}\tau_{c}$$

where τ_c is a correction term to account for the error due to multiplying the polychromatic gas transmittances.

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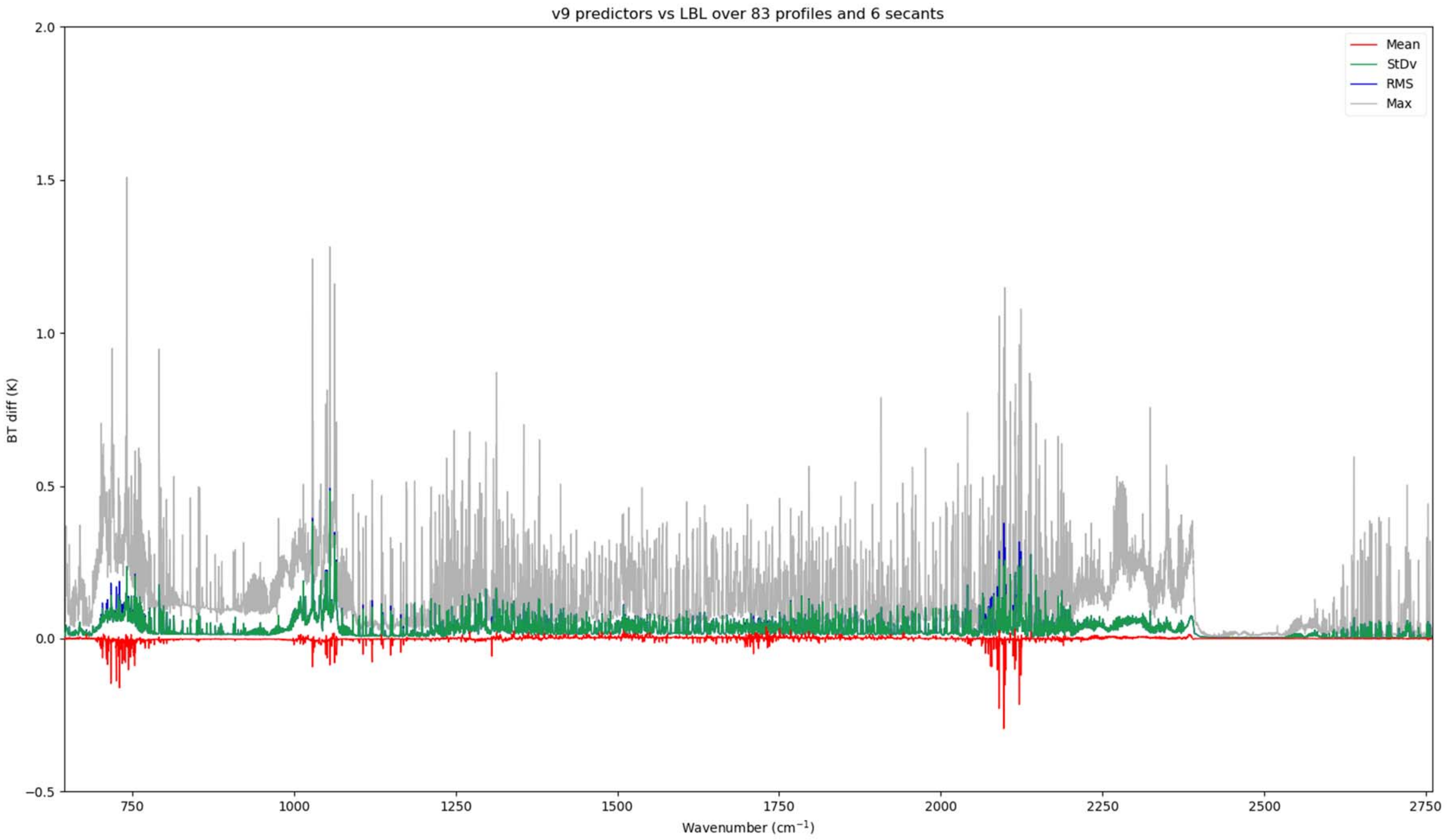
RTTOV v13 – new optical depth parameterisation

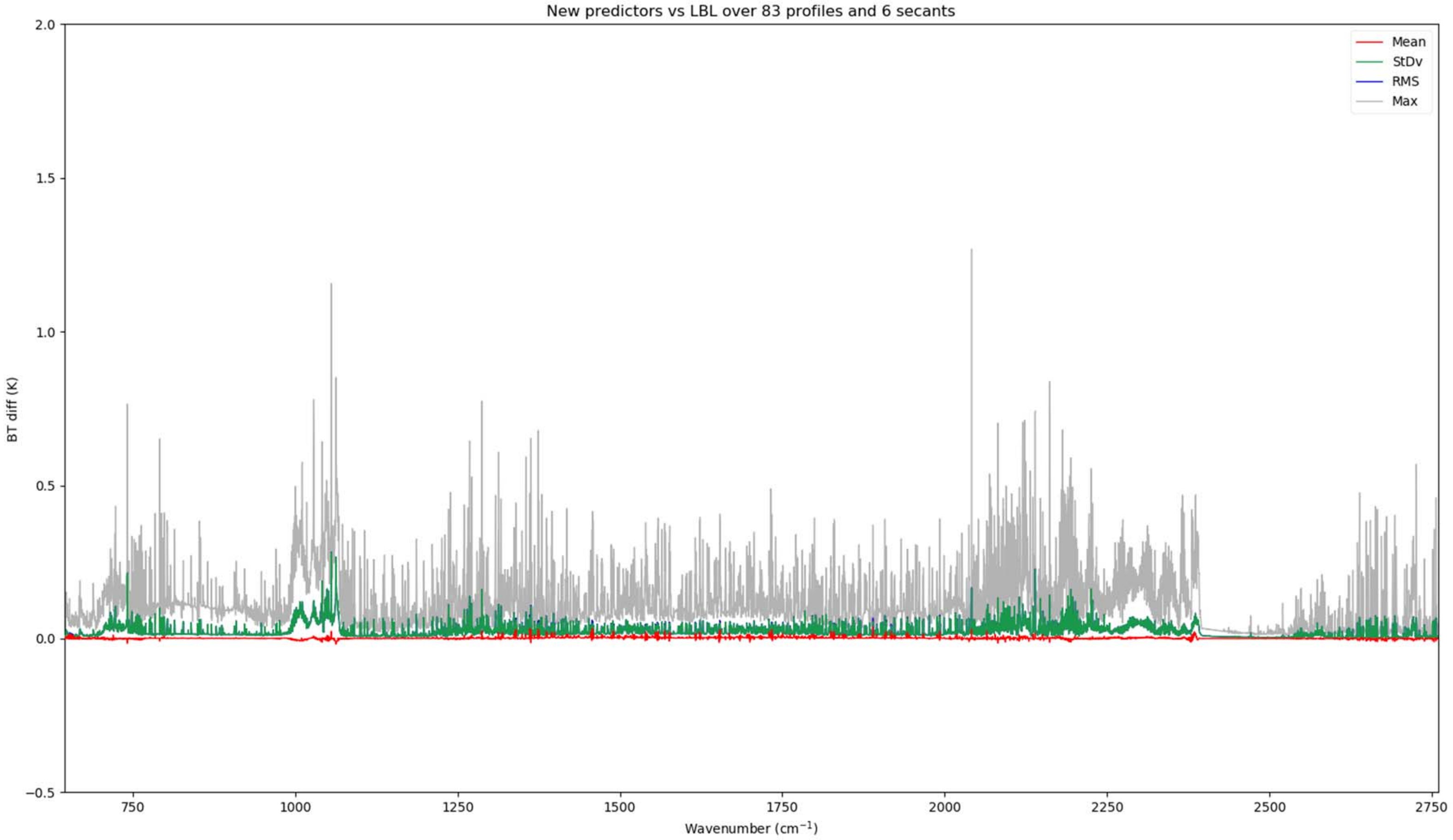
Initial implementation:

- based on the v9 predictors with some small modifications
- regression for gas optical depths is configured the same as for current coefficient generation
- wv continuum is always separated
- correction term predictors comprise temperature predictors and then some additional predictors for each gas which has significant* absorption
- correction term to be predicted is computed by dividing the LBL total transmittance by the product of predicted gas transmittances
- *correction term gas predictors are omitted if all gas layer optical depths are below a threshold (0.2 for wv, 0.1 for other gases) – this mitigates problems in the Jacobians

Current Scheme IASI all gas (no SO2) v9 predictor 6 secants



IASI all gas (no SO2) new predictor 6 secants



Visible/IR scattering solvers

Visible and/or IR – Discrete Ordinates Method *(full multiple scattering, slow)*

Essentially the idea is to do explicit calculations of radiance for a specific set of angles (ordinates), and then to interpolate these to obtain the radiance at an arbitrary angle.

DISORT is a well-known implementation of this algorithm. RTTOV includes a DOM solver which can be selected independently for solar and thermal radiation.

Visible/IR scattering solvers

The visible/IR solvers are built into the standard RTTOV model.

The main difference when running scattering simulations is the requirement to provide additional inputs:

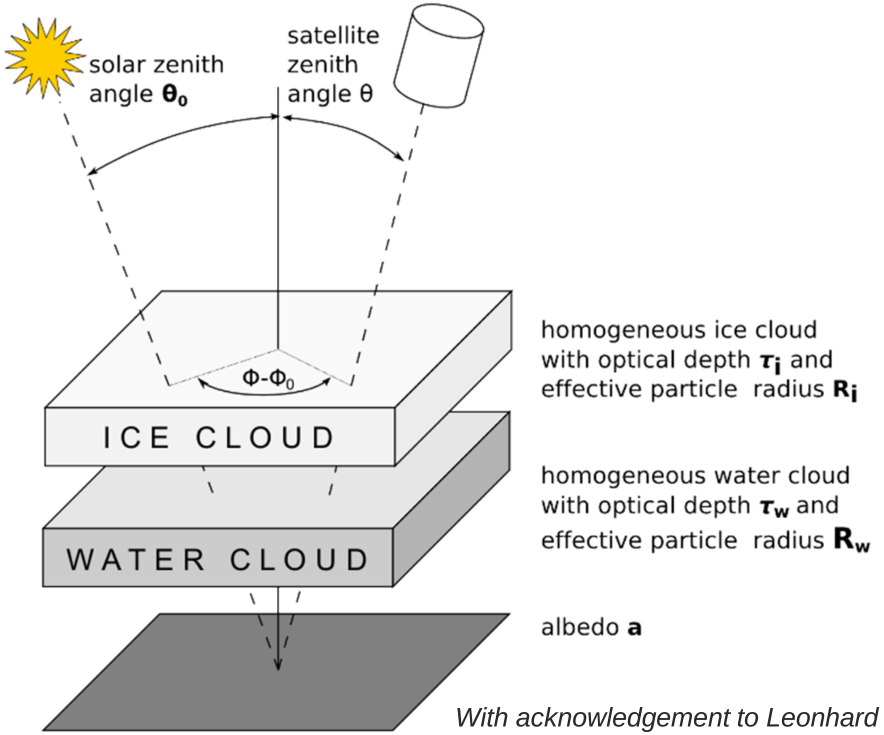
- vertical profiles of layer aerosol and/or cloud concentrations
- for cloud simulations profile of layer cloud fractions
- optical properties for the scattering particles

RTTOV provides a selection of aerosol and cloud properties, or you can use your own.

For cloud simulations, *maximum-random overlap* uses the input cloud concentration and fraction profiles to generate a number of columns each with a unique distribution of cloud. The RT equation is solved for each column and the TOA radiances are linearly combined.

Visible/IR scattering solvers

Visible (less than 1µm) – MFASIS *(fast parameterisation for cloud simulations)*



With acknowledgement to Leonhard Scheck

Look-up-table-based approach, parameterises DOM simulations of simplified cloud fields.

TOA reflectances are parameterised in terms of 8 variables: satellite and solar zenith angles, scattering angle, surface albedo, τ_w, R_w, τ_i, R_i

At least 1-2 orders of magnitude faster than DISORT.

See talk by Scheck

Met Office

IR scattering solver

IR – "Chou-scaling" *(fast approximation)*

Assumes diffuse radiation field is isotropic *(not true: e.g. in troposphere there is less downwelling radiation than upwelling radiation as lower atmosphere is warmer).*

Compute the mean fraction of radiation scattered into the backward hemisphere:

$$b = \frac{1}{2}\int_0^1 d\mu \int_{-1}^0 \bar{P}(\mu,\mu')d\mu' \qquad b \in [0,1]$$

Define the *apparent* extinction optical depth of a layer as:

$$d\bar{\tau} = d\tau_{abs} + b.d\tau_{sca}$$

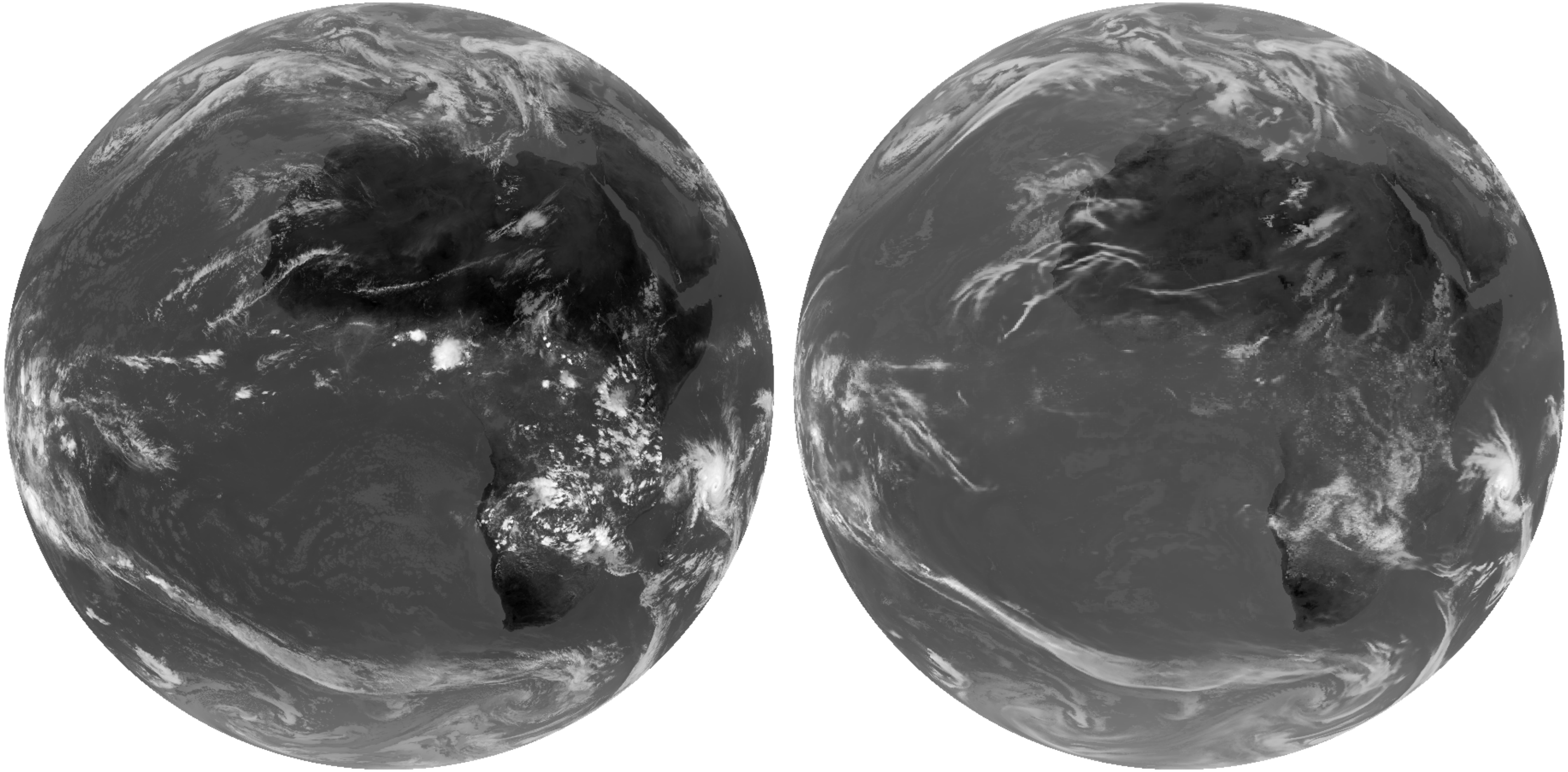
Then we solve the RT equation in the same way as for the clear-sky case => fast!

Errors due to scaling approximation are <1K for aerosols, and can be up to several Kelvin for clouds: given uncertainties in optical properties and profiles, this is useful.

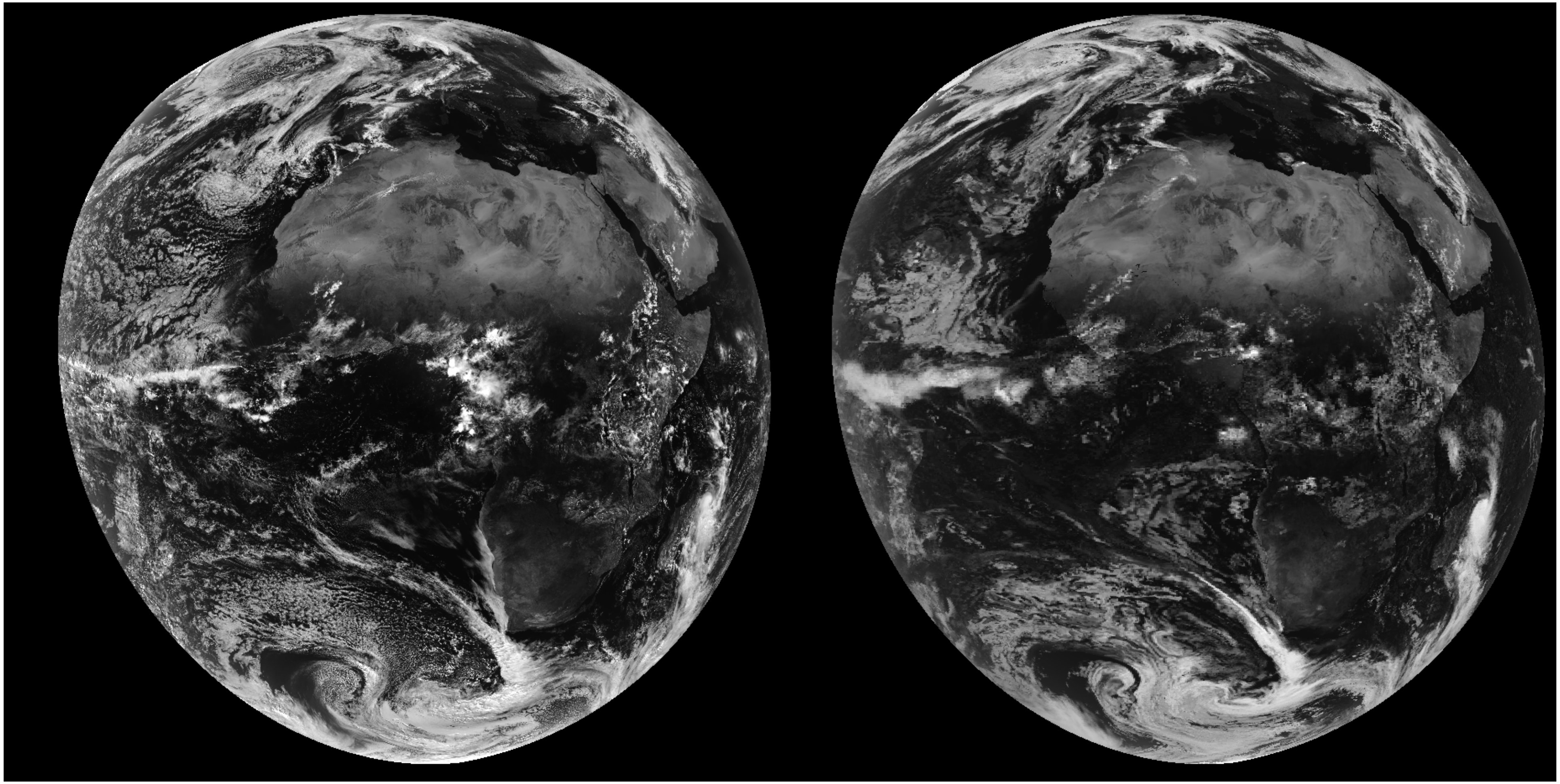
Options in RTTOV for simulating the effects of cloud, precipitation and aerosols.

Option in RTTOV	Microwave	Infrared	Visible
Simple cloud (no scattering)			
Grey optically thick cloud	No	Yes	Yes
Liquid water absorption	Yes (through normal RTTOV interface)	No	No
Scattering solutions			
Delta-Eddington	Yes (through RTTOV-SCATT interface)	No	No
Chou Scaling	No	Yes	No
Discrete Ordinates	No	Yes	Yes
MFASIS	No	No	Yes

SEVIRI 10UTC 10.8µm: *left* obs, *right* Chou-scaling (~2 minutes)

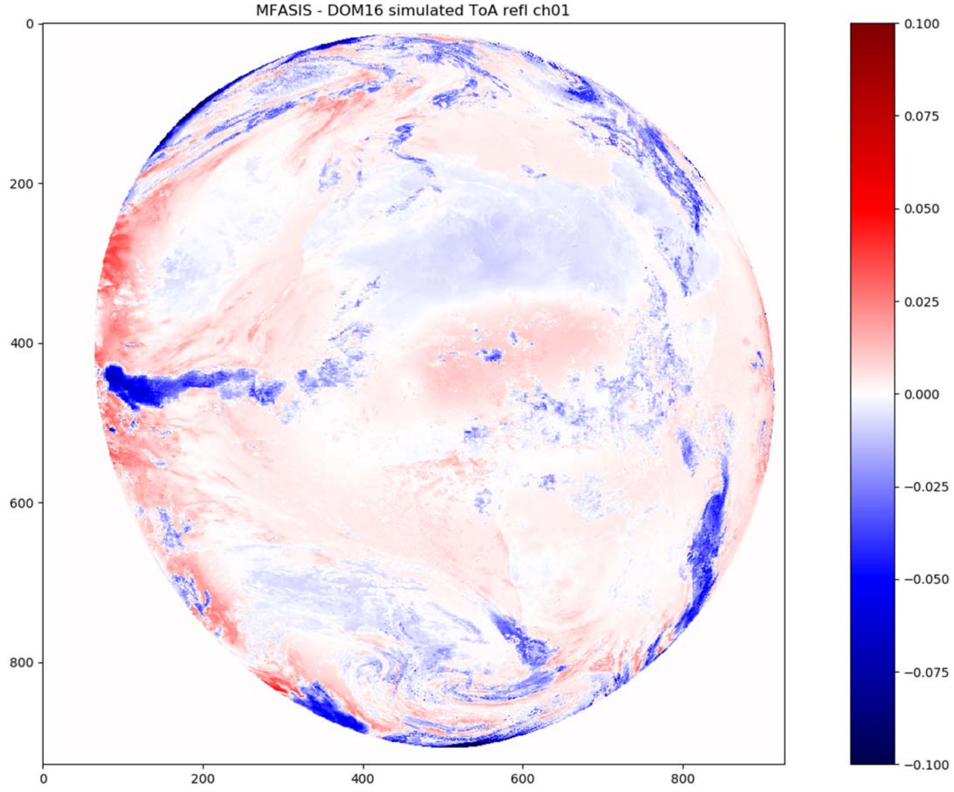


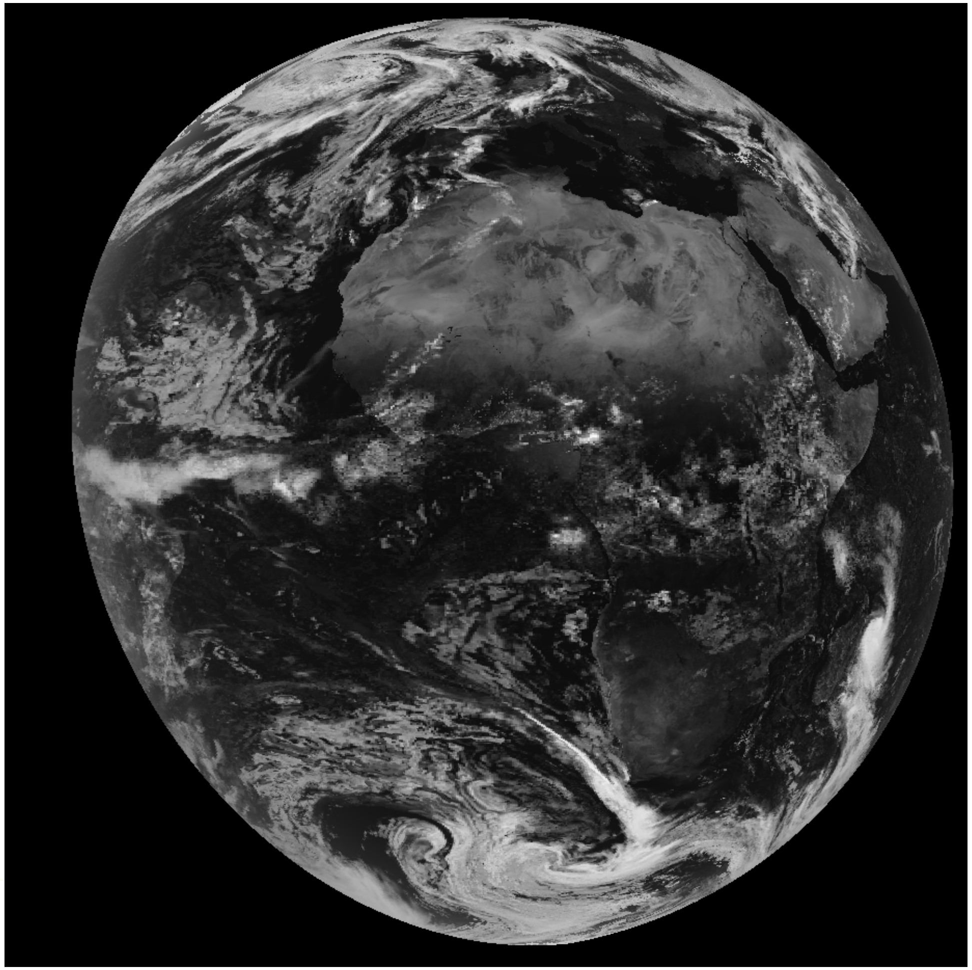
SEVIRI 10UTC 0.6µm: *left* obs, *right* DOM 16 streams (~10 hours)



Met Office

SEVIRI 10UTC 0.6µm: *left* MFASIS-DOM difference, *right* MFASIS (~10 minutes)





RTTOV-SCATT

RTTOV-SCATT carries out scattering simulations at MW frequencies: this is a separate model which calls RTTOV to calculate the gas absorption optical depths.

Uses the delta-Eddington approximation.

Four hydrometeors are considered (liquid cloud, ice cloud, rain and snow). Optical properties calculated from Mie theory, except for snow which assumes non-spherical particles.

Effective cloud fraction *C* computed as average of layer cloud fractions weighted by layer total hydrometeor amounts.

Top of atmosphere BT calculated as:

$$BT_{allsky} = (1 - C).BT_{clear} + C.BT_{cloudy}$$

Errors due to the approximation are ~0.5K (compared to a reference multiple-scattering solver). This is used operationally for all-sky radiance assimilation.

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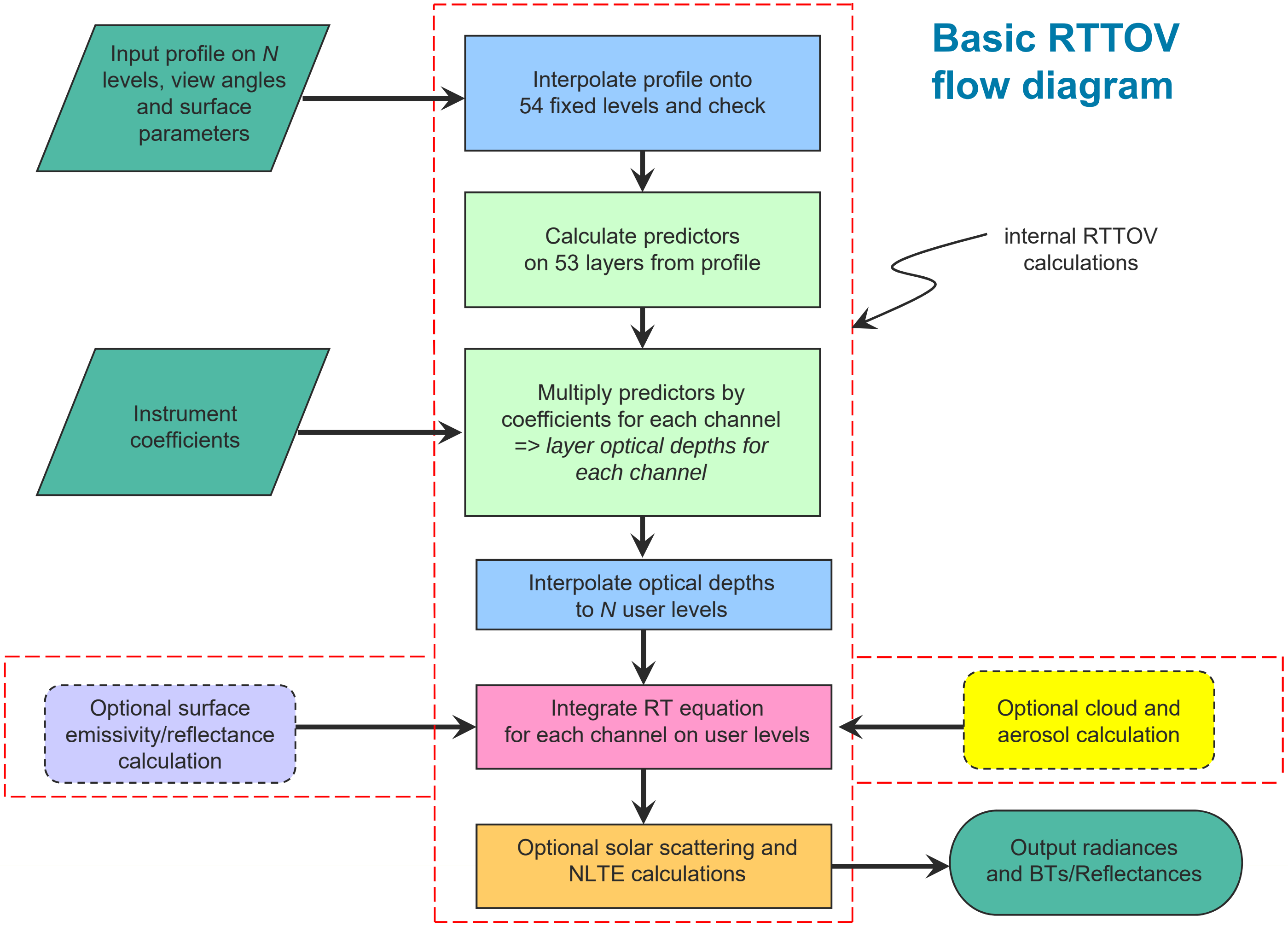
Basic RTTOV flow diagram



Input profile on *N* levels, view angles and surface parameters

Interpolate profile onto 54 fixed levels and check

Calculate predictors on 53 layers from profile

internal RTTOV calculations

Instrument coefficients

Multiply predictors by coefficients for each channel *=> layer optical depths for each channel*

Interpolate optical depths to *N* user levels

Optional surface emissivity/reflectance calculation

Integrate RT equation for each channel on user levels

Optional cloud and aerosol calculation

Optional solar scattering and NLTE calculations

Output radiances and BTs/Reflectances

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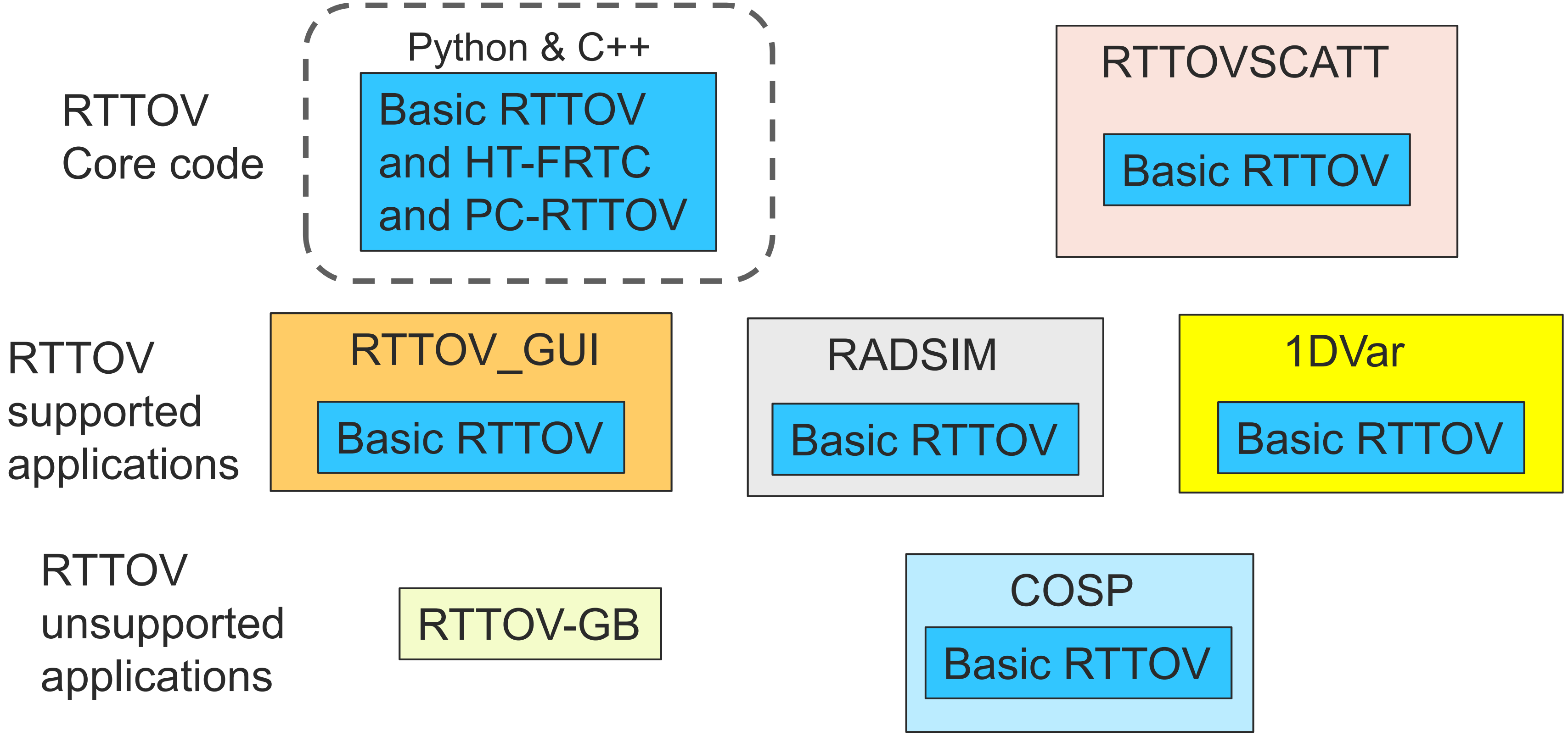
RTTOV Applications



RTTOV Core code

Python & C++

Basic RTTOV and HT-FRTC and PC-RTTOV

RTTOVSCATT

Basic RTTOV

RTTOV supported applications

RTTOV_GUI

Basic RTTOV

RADSIM

Basic RTTOV

1DVar

Basic RTTOV

RTTOV unsupported applications

RTTOV-GB

COSP

Basic RTTOV

Outline of Talk

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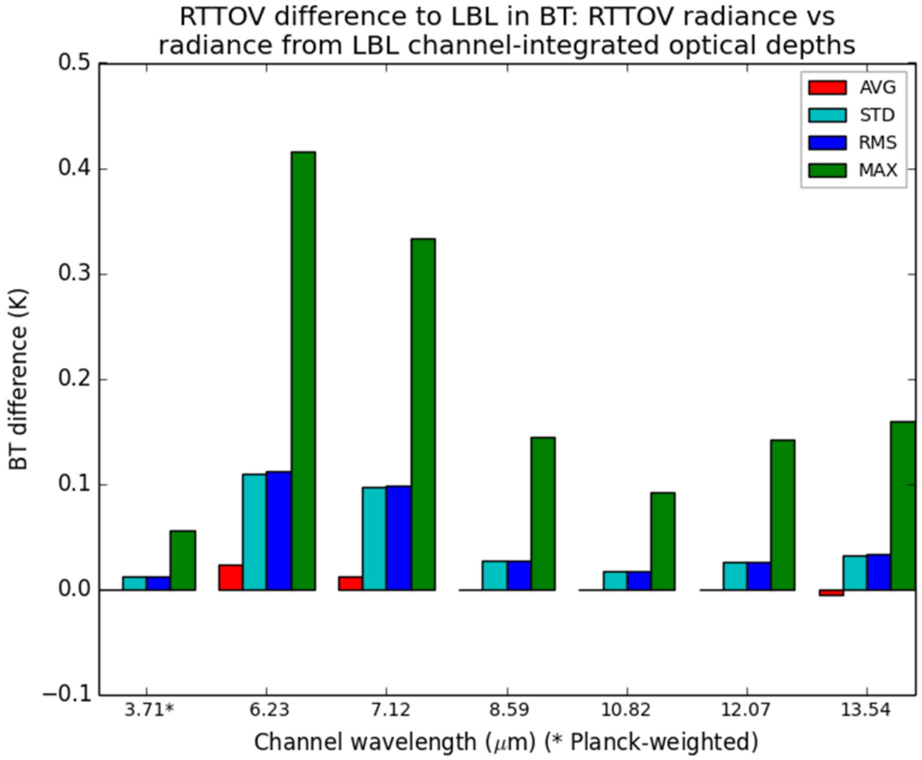
- User outreach

Sources of RTTOV errors

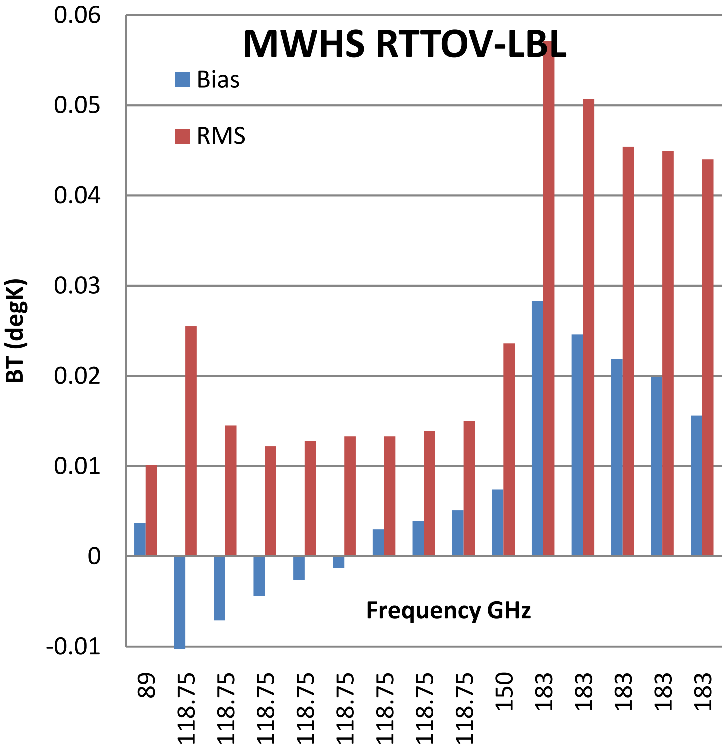
- Errors in underlying spectroscopy used in training
- Regression model used for fast model (usually small)
- Polychromatic assumption (only for broad channels)
- Surface properties (can be big)
- Exclusion of other factors (e.g. variable trace gases, NLTE, Zeeman, ..)
- Discretisation of atmosphere into homogenous layers and associated interpolation
- Input profiles values (including zenith angle) lying beyond the limits of the training set

RTTOV for Chinese instruments

FY-4A AGRI IR channels (all angles)



FY-3C MWHS-2 (nadir)



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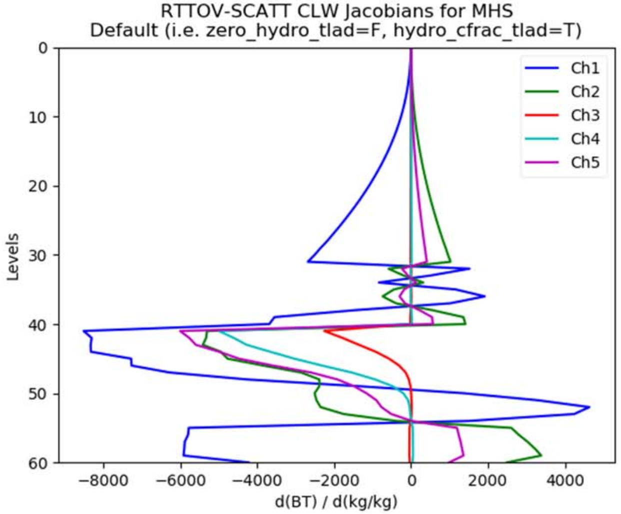
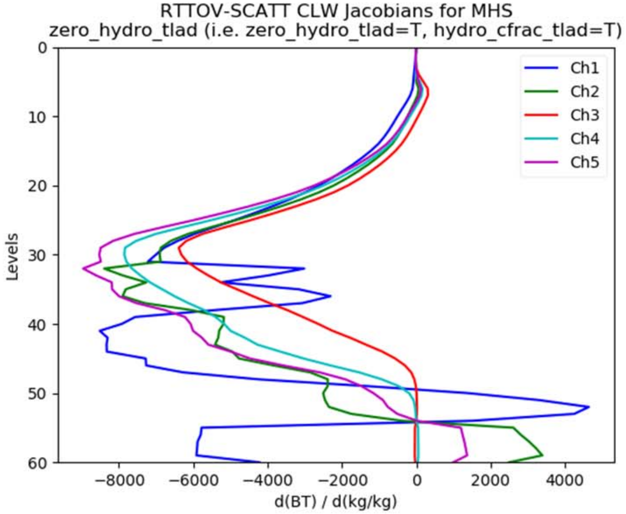
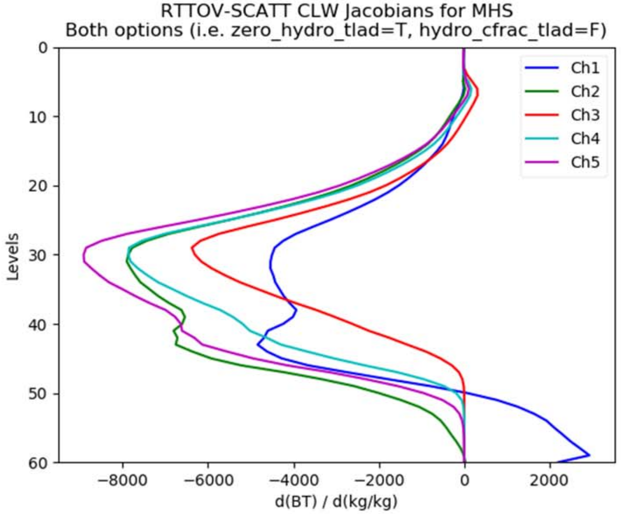
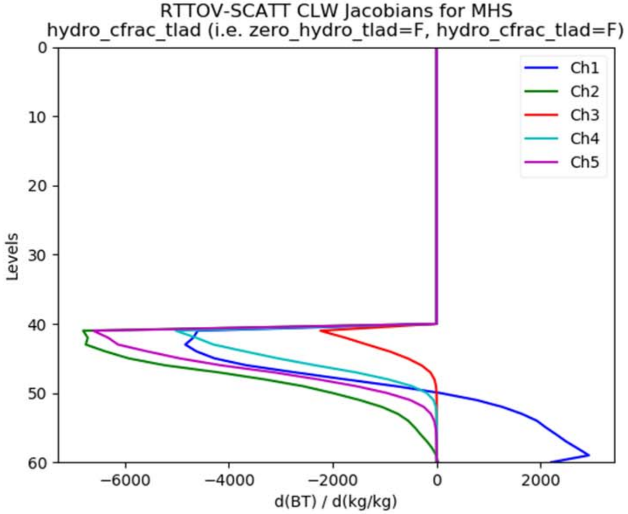
Problems with Jacobians. Example here is for RTTOVSCATT

When developing forward model don’t forget the Jacobian performance!


RTTOV-SCATT CLW Jacobians for MHS
Default (i.e. zero_hydro_tlad=F, hydro_cfrac_tlad=T)


RTTOV-SCATT CLW Jacobians for MHS
zero_hydro_tlad (i.e. zero_hydro_tlad=T, hydro_cfrac_tlad=T)

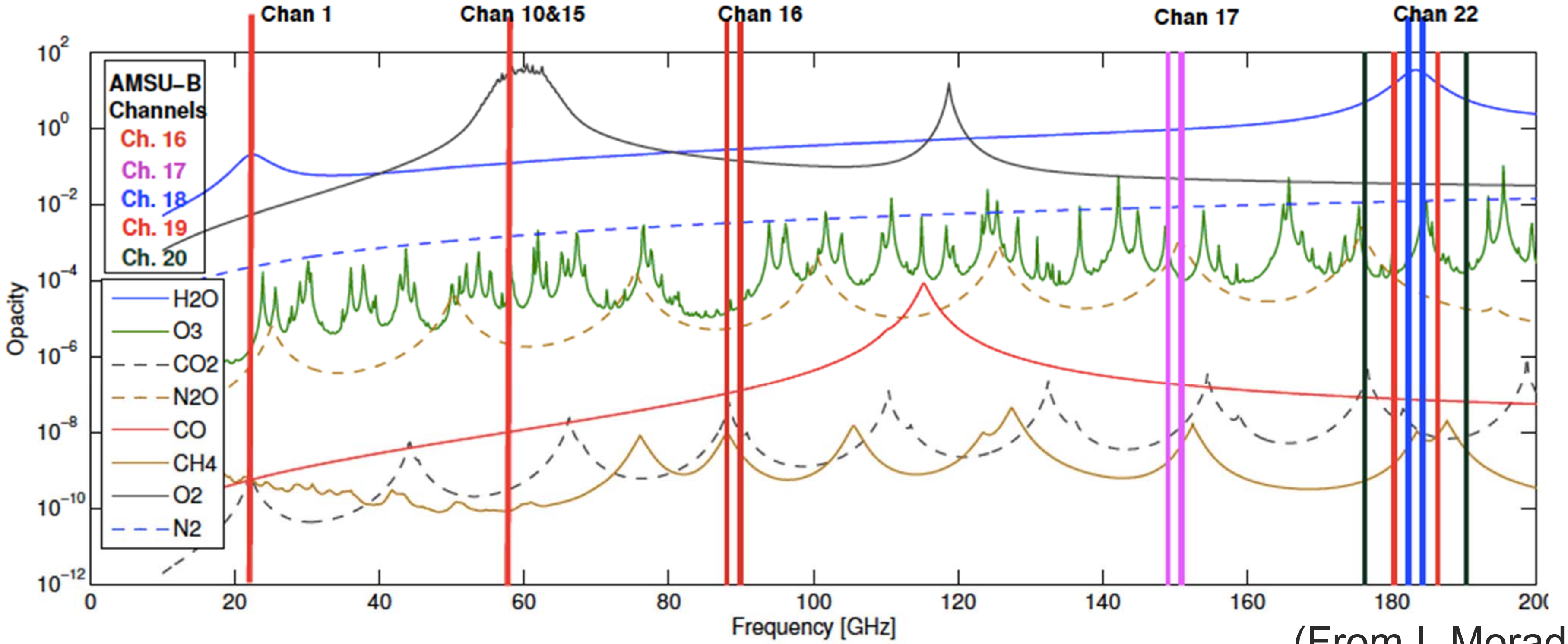

RTTOV-SCATT CLW Jacobians for MHS
Both options (i.e. zero_hydro_tlad=T, hydro_cfrac_tlad=F)


RTTOV-SCATT CLW Jacobians for MHS
hydro_cfrac_tlad (i.e. zero_hydro_tlad=F, hydro_cfrac_tlad=F)

MW Spectrum and ATMS Channels

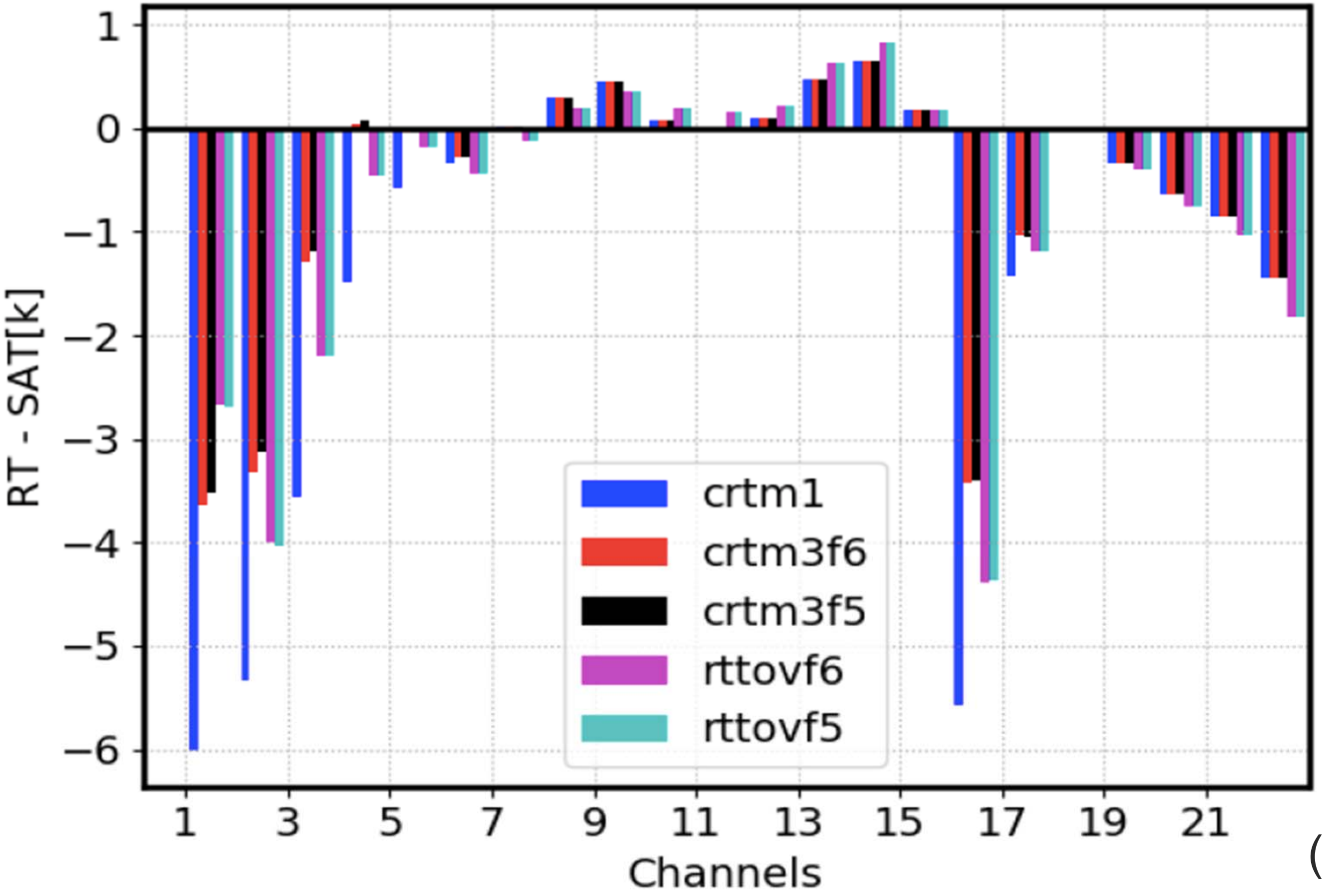
Chan 1: 23.8 GHz, Chan 10: 55.5, Chan 15: 57.290344±0.3222±0.0045

Chan 22: 183.31±1



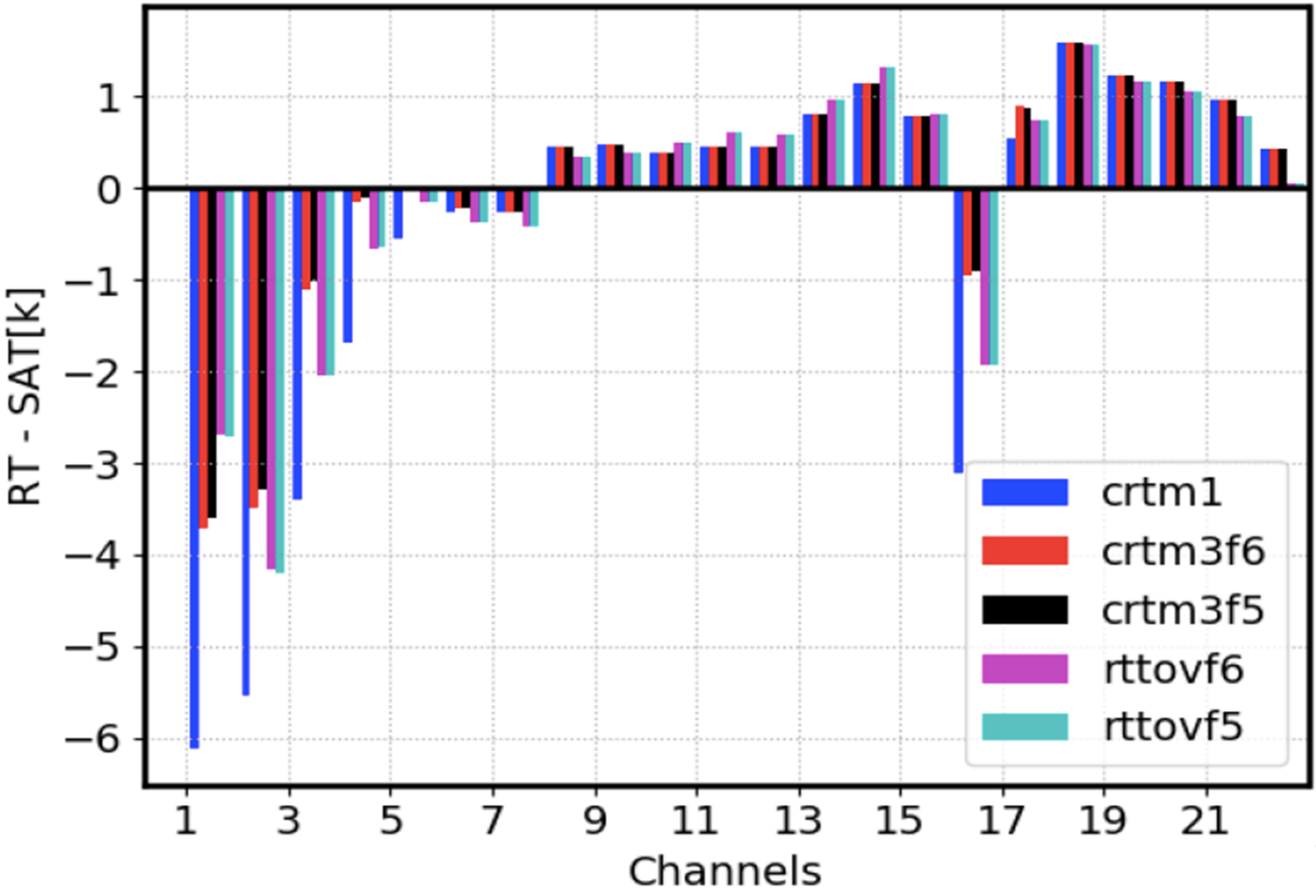
(From I. Moradi)

ATMS-N20 Biases vs. different RTMs



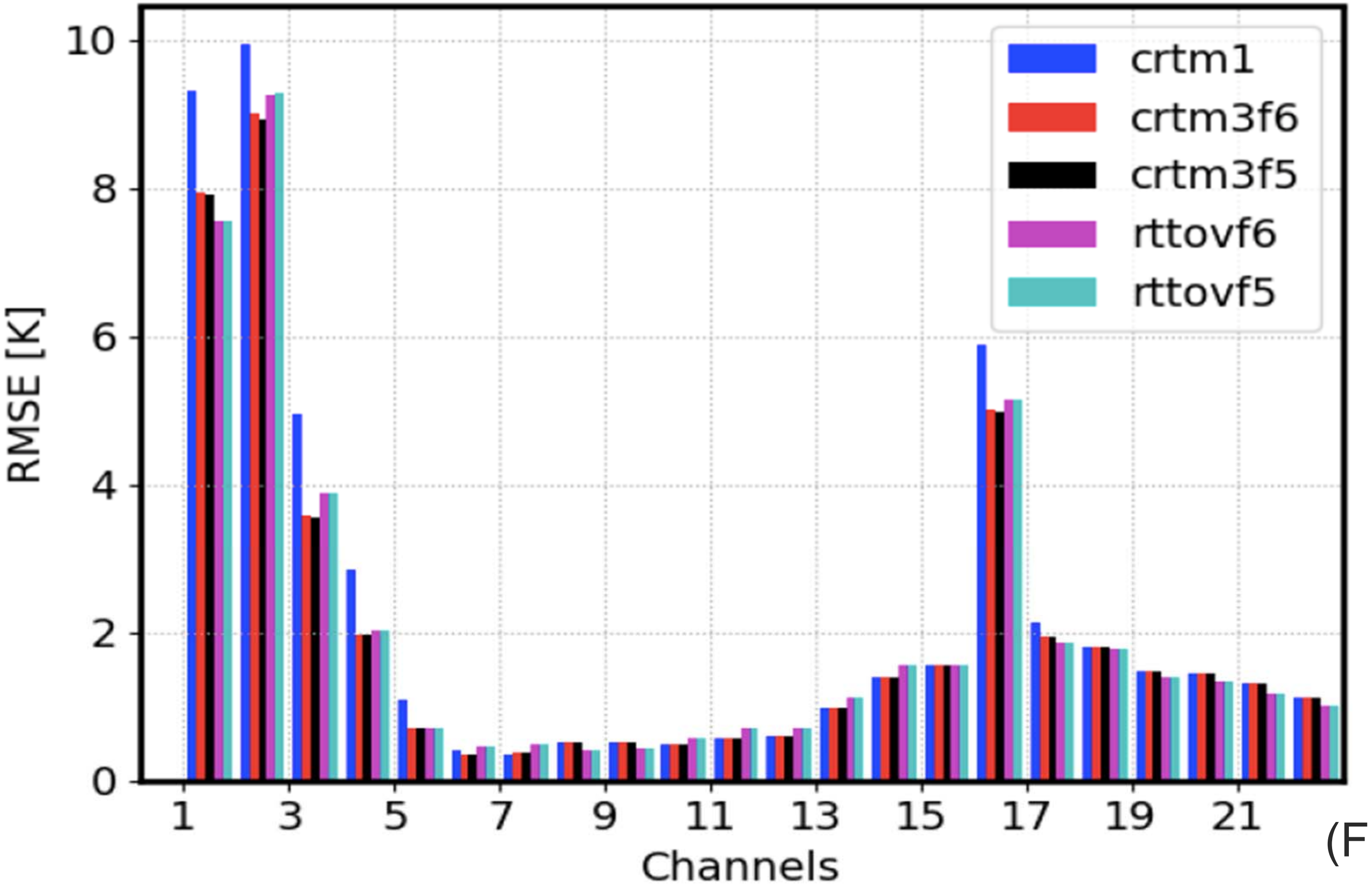
(From I. Moradi)

ATMS-NPP Biases vs. different RTMs



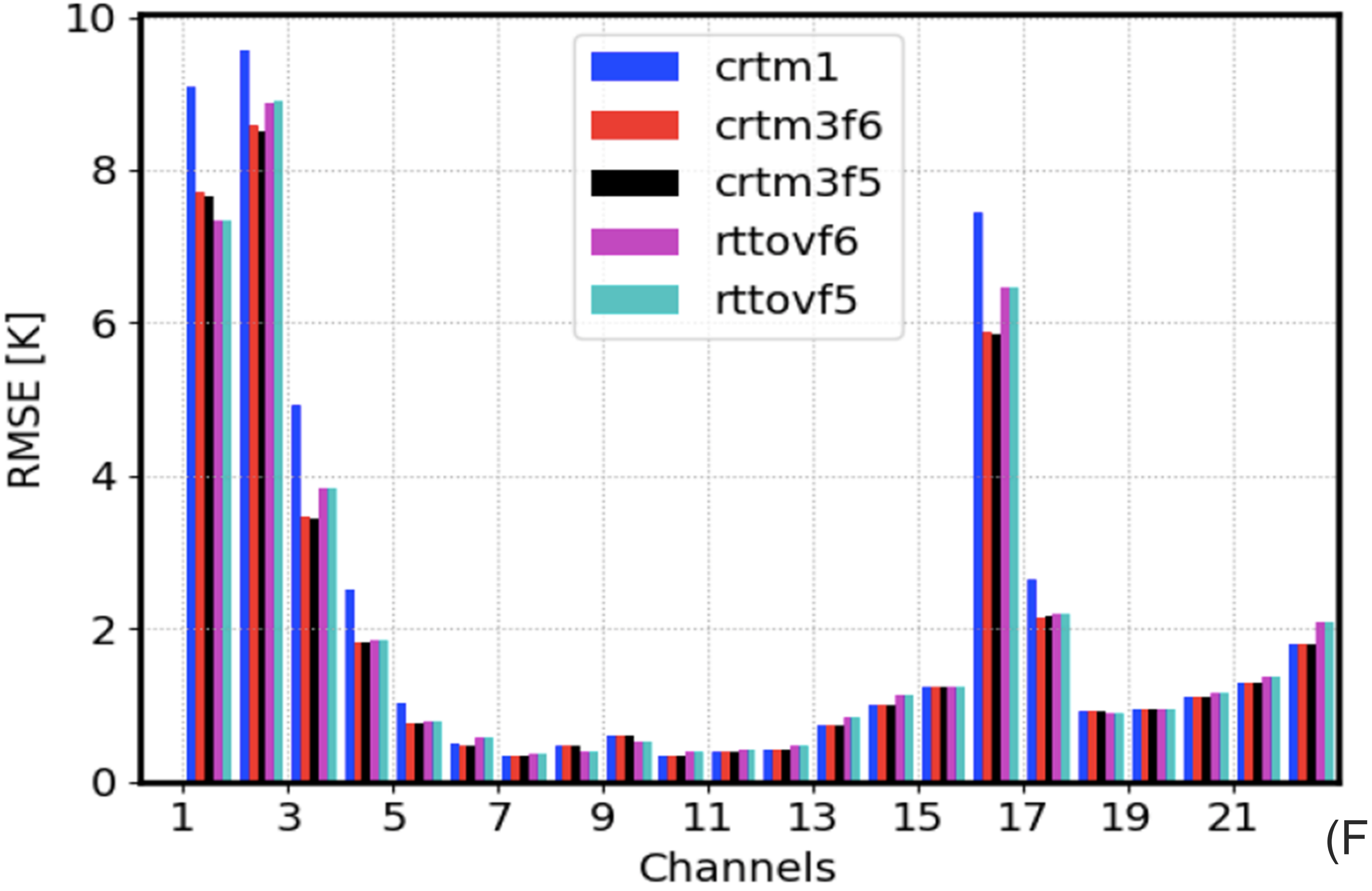
(From I. Moradi)

ATMS-NPP RMSE vs. different RTMs



(From I. Moradi)

ATMS-N20 RMSE vs. different RTMs



(From I. Moradi)

Outline of Talk

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Speed (secs)

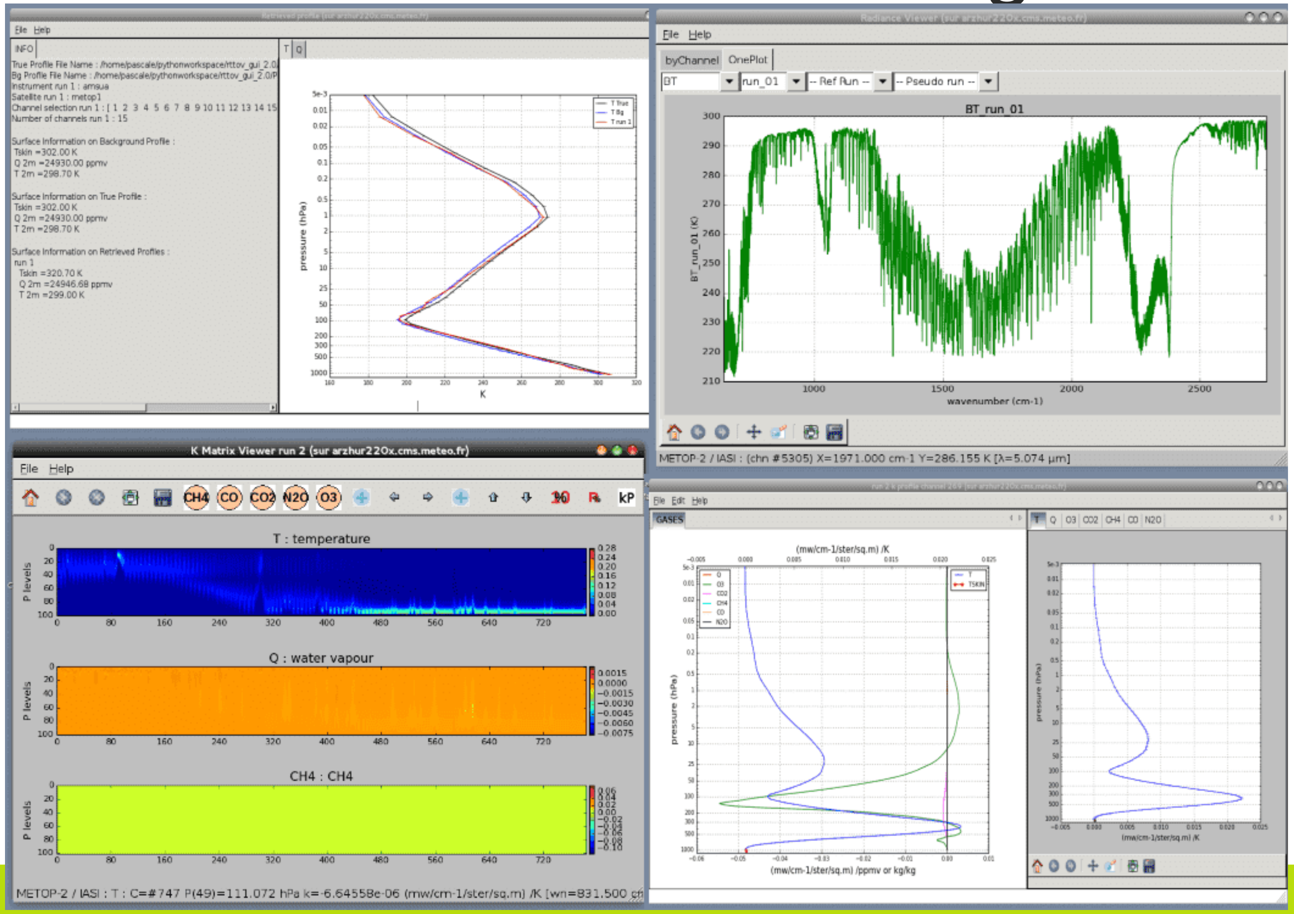
Compute Resources

Test case	Model	Intel gfortran v12.1	Intel gfortran v12.2	Intel gfortran v12.2:v12.1	Intel ifort v12.1	Intel ifort v12.2	Intel ifort v12.2:v12.1
	Direct	0.441	0.436	0.99	0.293	0.283	0.97
1	TL	0.755	0.753	1.00	0.541	0.538	1.00
MW, no interp	AD	0.903	0.913	1.01	0.661	0.657	0.99
	K	1.223	1.22	1.00	0.938	0.925	0.99
	Direct	0.727	0.725	1.00	0.479	0.457	0.95
2	TL	1.217	1.216	1.00	0.84	0.827	0.98
MW, interp	AD	1.493	1.505	1.01	1.007	0.995	0.99
	K	2.063	2.079	1.01	1.389	1.362	0.98
	Direct	0.35	0.351	1.00	0.241	0.241	1.00
3	TL	0.613	0.612	1.00	0.421	0.423	1.00
IR v7 clear	AD	0.738	0.75	1.02	0.503	0.516	1.02
	K	1.008	1.015	1.01	0.707	0.7	0.99
	Direct	0.393	0.368	0.94	0.247	0.259	1.05
4	TL	0.712	0.64	0.90	0.465	0.45	0.97
IR v8 clear	AD	0.899	0.823	0.92	0.558	0.55	0.99
	K	1.557	1.135	0.73	0.864	0.786	0.91
	Direct	0.536	0.537	1.00	0.536	0.38	0.71
5	TL	0.89	0.888	1.00	0.867	0.698	0.81
Visible clear	AD	1.057	1.044	0.99	0.922	0.761	0.83
	K	1.308	1.327	1.01	1.11	0.924	0.83
	Direct	6.884	6.824	0.99	4.328	4.554	1.05
6	TL	11.624	11.506	0.99	7.902	7.726	0.98
All gas clear	AD	13.216	13.31	1.01	9.482	9.348	0.99
	K	40.37	40.47	1.00	30	29.88	1.00
	Direct	0.331	0.331	1.00	0.248	0.244	0.98
7	TL	0.581	0.6	1.03	0.447	0.464	1.04
IR aerosol	AD	0.686	0.712	1.04	0.514	0.531	1.03
Chou-scaling	K	1.041	1.056	1.01	0.8	0.8	1.00
	Direct	0.39	0.386	0.99	0.446	0.41	0.92
8	TL	0.659	0.654	0.99	0.842	0.831	0.99
IR cloud	AD	0.8	0.84	1.05	1.017	0.992	0.98
Chou-scaling	K	1.153	1.141	0.99	1.215	1.081	0.89

Memory usage

Test case	Model	v12.1 peak memory (MB)	v12.2 peak memory (MB)	v12.2:v12.1
	Direct	1.745	1.934	1.11
1	TL	1.745	1.934	1.11
MW, no interp	AD	1.745	1.934	1.11
	K	2.437	2.568	1.05
	Direct	1.745	1.934	1.11
2	TL	1.984	2.121	1.07
MW, interp	AD	2.002	2.139	1.07
	K	2.95	3.107	1.05
	Direct	1.168	1.358	1.16
3	TL	1.461	1.599	1.09
IR v7 clear	AD	1.468	1.605	1.09
	K	1.832	1.973	1.08
	Direct	1.224	1.396	1.14
4	TL	1.518	1.66	1.09
IR v8 clear	AD	1.524	1.667	1.09
	K	1.934	2.097	1.08
	Direct	1.322	1.521	1.15
5	TL	1.61	1.792	1.11
Visible clear	AD	1.613	1.795	1.11
	K	1.893	2.076	1.10
	Direct	707.6	707.8	1.00
6	TL	707.6	707.8	1.00
All gas clear	AD	707.6	707.8	1.00
	K	707.6	707.8	1.00
	Direct	1.505	1.64	1.09
7	TL	1.727	1.858	1.08
IR aerosol	AD	1.731	1.862	1.08
Chou-scaling	K	2.143	2.257	1.05
	Direct	1.935	2.045	1.06
8	TL	2.459	2.582	1.05
IR cloud	AD	2.458	2.581	1.05
Chou-scaling	K	4.018	4.147	1.03

RTTOV GUI for Training



```
True Profile File Name : /home/pascale/pythonworkspace/rttov_gui_2.0/
Bg Profile File Name : /home/pascale/pythonworkspace/rttov_gui_2.0/P
Instrument run 1 : amsua
Satellite run 1 : metop1
Channel selection run 1 : [ 1  2  3  4  5  6  7  8  9 10 11 12 13 14 15
Number of channels run 1 : 15

Surface Information on Background Profile :
 Tskin =302.00 K
 Q 2m =24930.00 ppmv
 T 2m =298.70 K

Surface Information on True Profile :
 Tskin =302.00 K
 Q 2m =24930.00 ppmv
 T 2m =298.70 K

Surface Information on Retrieved Profiles :
 run 1
  Tskin =320.70 K
  Q 2m =24946.68 ppmv
  T 2m =299.00 K
```

```
METOP-2 / IASI : (chn #5305) X=1971.000 cm-1 Y=286.155 K [λ=5.074 μm]
```

```
METOP-2 / IASI : T : C=#747 P(49)=111.072 hPa k=-6.64558e-06 (mw/cm-1/ster/sq.m) /K [wn=831.500 cn
```

Outline of Talk

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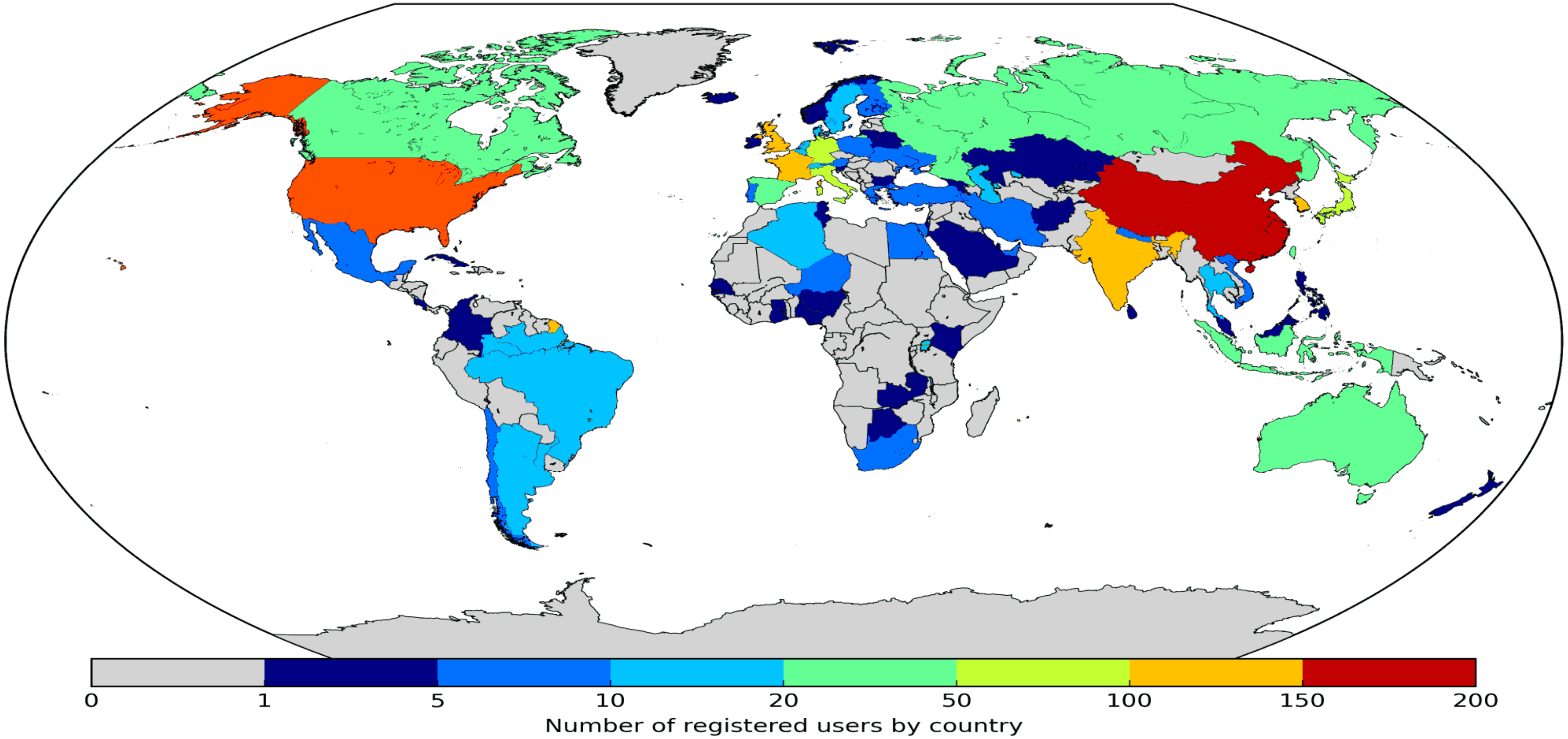
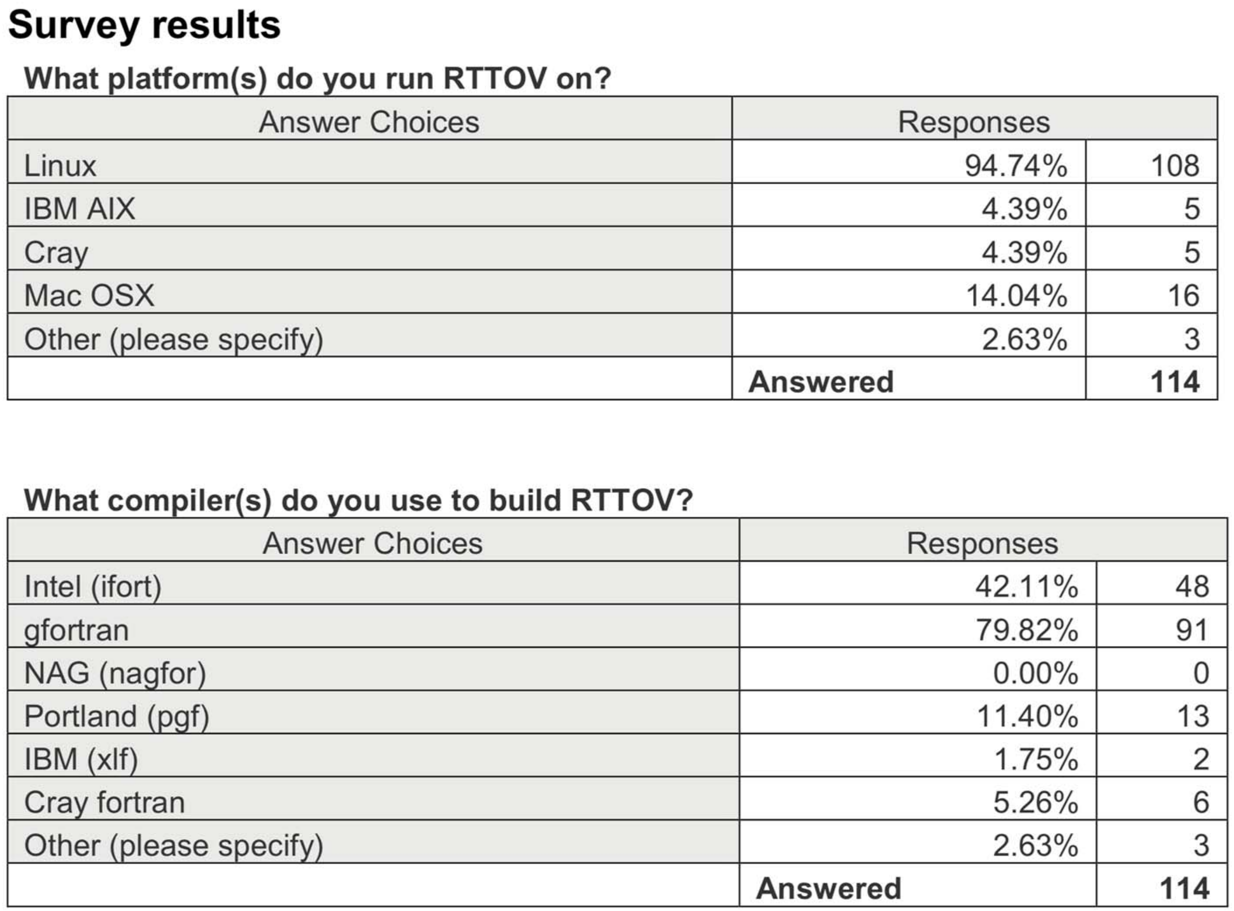
918 RTTOV-12 users



RTTOV user survey



Survey results

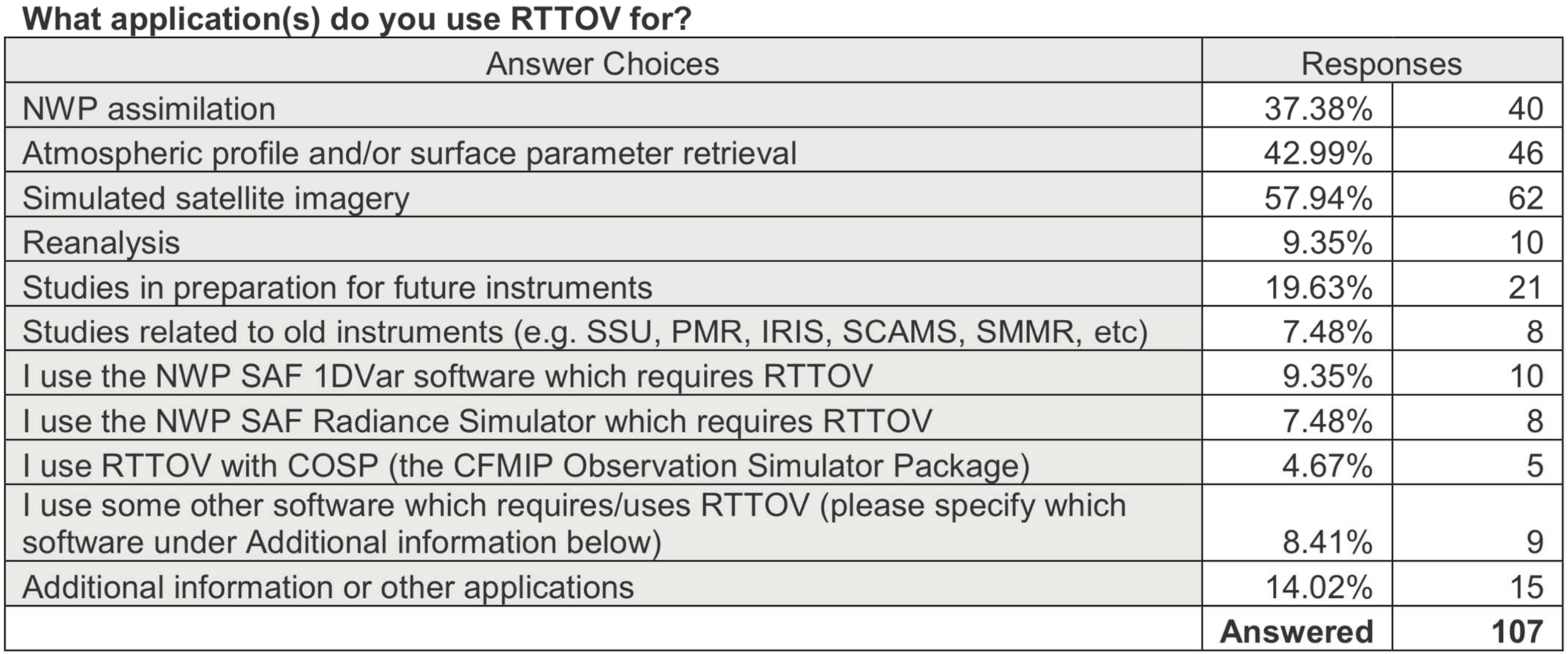
What platform(s) do you run RTTOV on?

Answer Choices	Responses	
Linux	94.74%	108
IBM AIX	4.39%	5
Cray	4.39%	5
Mac OSX	14.04%	16
Other (please specify)	2.63%	3
	Answered	**114**

What compiler(s) do you use to build RTTOV?

Answer Choices	Responses	
Intel (ifort)	42.11%	48
gfortran	79.82%	91
NAG (nagfor)	0.00%	0
Portland (pgf)	11.40%	13
IBM (xlf)	1.75%	2
Cray fortran	5.26%	6
Other (please specify)	2.63%	3
	Answered	**114**

User survey



What application(s) do you use RTTOV for?

Answer Choices	Responses	
NWP assimilation	37.38%	40
Atmospheric profile and/or surface parameter retrieval	42.99%	46
Simulated satellite imagery	57.94%	62
Reanalysis	9.35%	10
Studies in preparation for future instruments	19.63%	21
Studies related to old instruments (e.g. SSU, PMR, IRIS, SCAMS, SMMR, etc)	7.48%	8
I use the NWP SAF 1DVar software which requires RTTOV	9.35%	10
I use the NWP SAF Radiance Simulator which requires RTTOV	7.48%	8
I use RTTOV with COSP (the CFMIP Observation Simulator Package)	4.67%	5
I use some other software which requires/uses RTTOV (please specify which software under Additional information below)	8.41%	9
Additional information or other applications	14.02%	15
	Answered	**107**

RTTOV design considerations

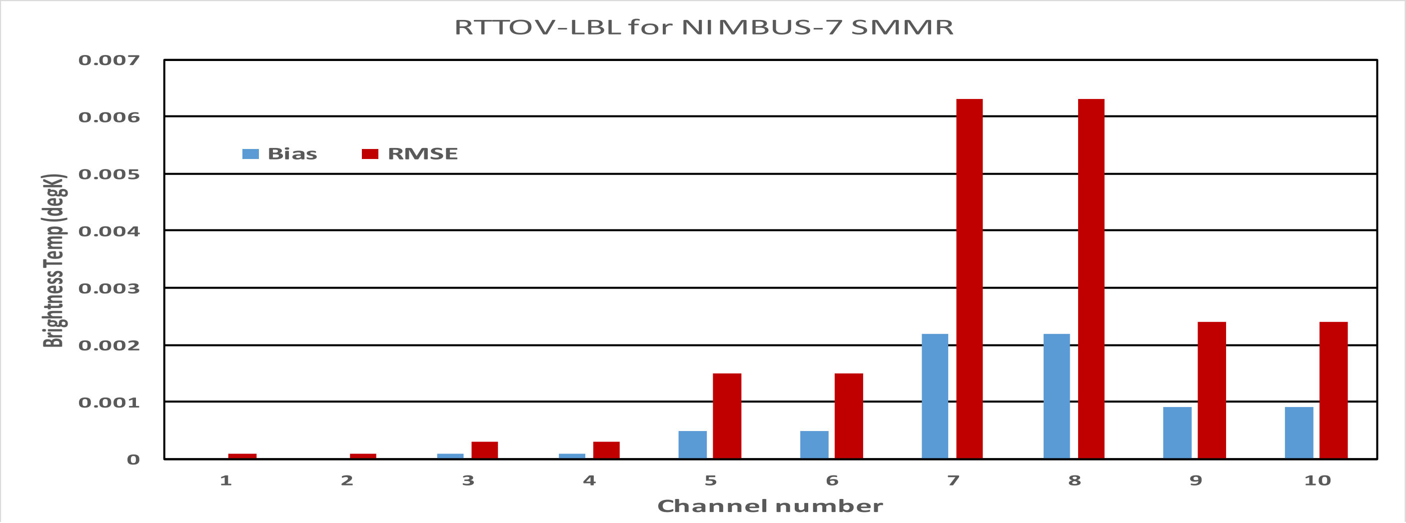
- Modular code in FORTRAN with python and C++ wrappers
- Direct, tangent linear, adjoint and K codes all provided
- Interfaces to user software only changes for major version changes
- New versions always backward compatible for one version so operational users can use new code but reproduce results with old code
- Software and main data files downloaded from gzipped tar file from web site. Large data files downloaded separately
- Associated documentation: User guide, Science & Validation Report, Software design, Performance report
- Help desk, user forum
- User survey every 5 years

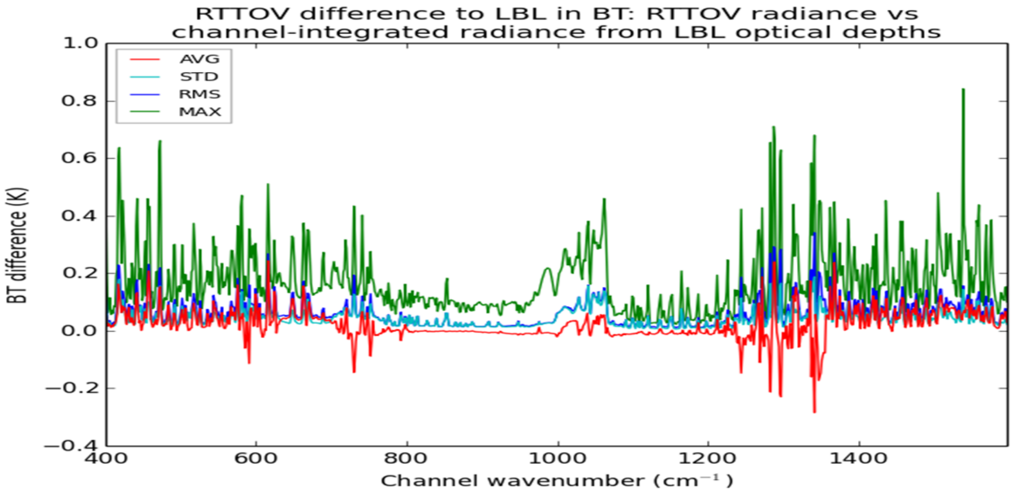
谢谢

C3S Data Rescue Project, RTTOV Coefficients

Name	Platform	IR channels	V7 pred.	V8 pred.	Comment
HIRS-1	Nimbus-6	16	Yes	Yes	
HIRS-2	NOAA-6 to 12 NOAA-14	19	Yes	Yes	2 versions: nominal and shifted
HIRS-3	NOAA-15 to 17	19	Yes	Yes	2 versions: nominal and shifted
HIRS-4	NOAA-18 & 19 METOP-A & B	19	Yes	Yes	2 versions: nominal and shifted
MVIRI	Meteosat-1 to 7	2	Yes	Yes	
IRIS-D	Nimbus-4	400-1600 cm^{-1}	No	Yes	2 versions: nominal and shifted at 101 levels
VTPR	NOAA-1 to 4	32 (8 chan.*4)	Yes	Yes	
MRIR	Nimbus-3	4	Yes	Yes	
THIR	Nimbus-4 to 7	2	Yes	Yes	
SSU	TIROS-N to NOAA-14	3	No	Yes	2 versions at 51 levels: nominal and changes in SRF due to outgassing
PMR	NIMBUS-6	9	No	Yes	The 9 channels correspond to different viewing angles of the same channel. 84 levels.
		MW Channels			
SMMR	NIMBUS-7	10	Yes	No	5 frequencies all dual polarisations
SSM/T2	DMSP F11-F15	5	Yes	No	
MSU	TIROS-N-NOAA-14	4	Yes	No	
SSM/I	DMSP F8,F10-15	7	Yes	No	4 frequencies some dual polarisations
SSMI(S)	DMSP F16-F19	24	Yes	No	Zeeman coefficients also available

Simulations of SMMR and IRIS-D using RTTOV v7/v8 predictors





IRIS-D