Simulating infrared limb radiances from MIPAS in the ECMWF system

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ASSET

Assimilation of Envisat Data

Outline

- Introduction: MIPAS
- RTMIPAS: Fast radiative transfer model for MIPAS
- 1DVAR simulations
- Outlook and outstanding issues

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MIPAS characteristics

MIPAS: Michelson Interferometer for Passive Atmospheric

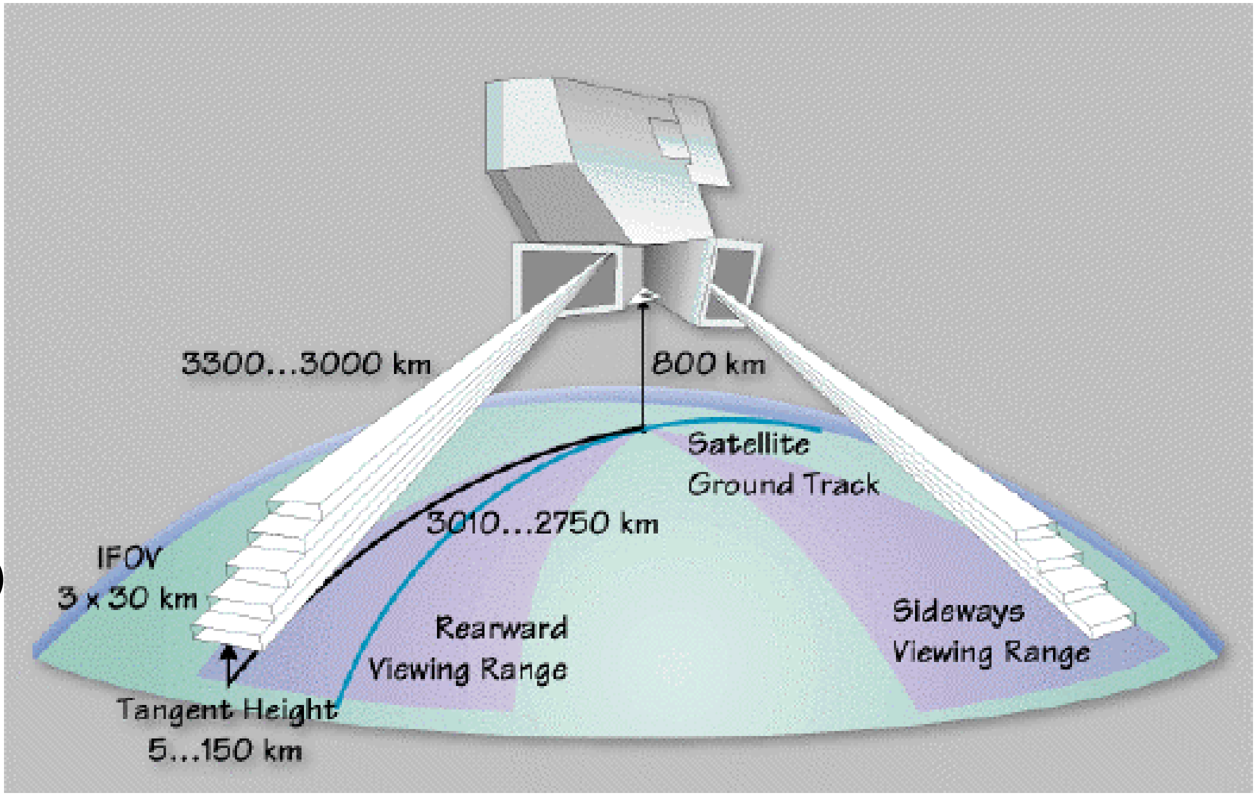
Research instrument
onboard Envisat

Spectral range:
685-2410 cm^{-1}
or 4.15-14.6 μm

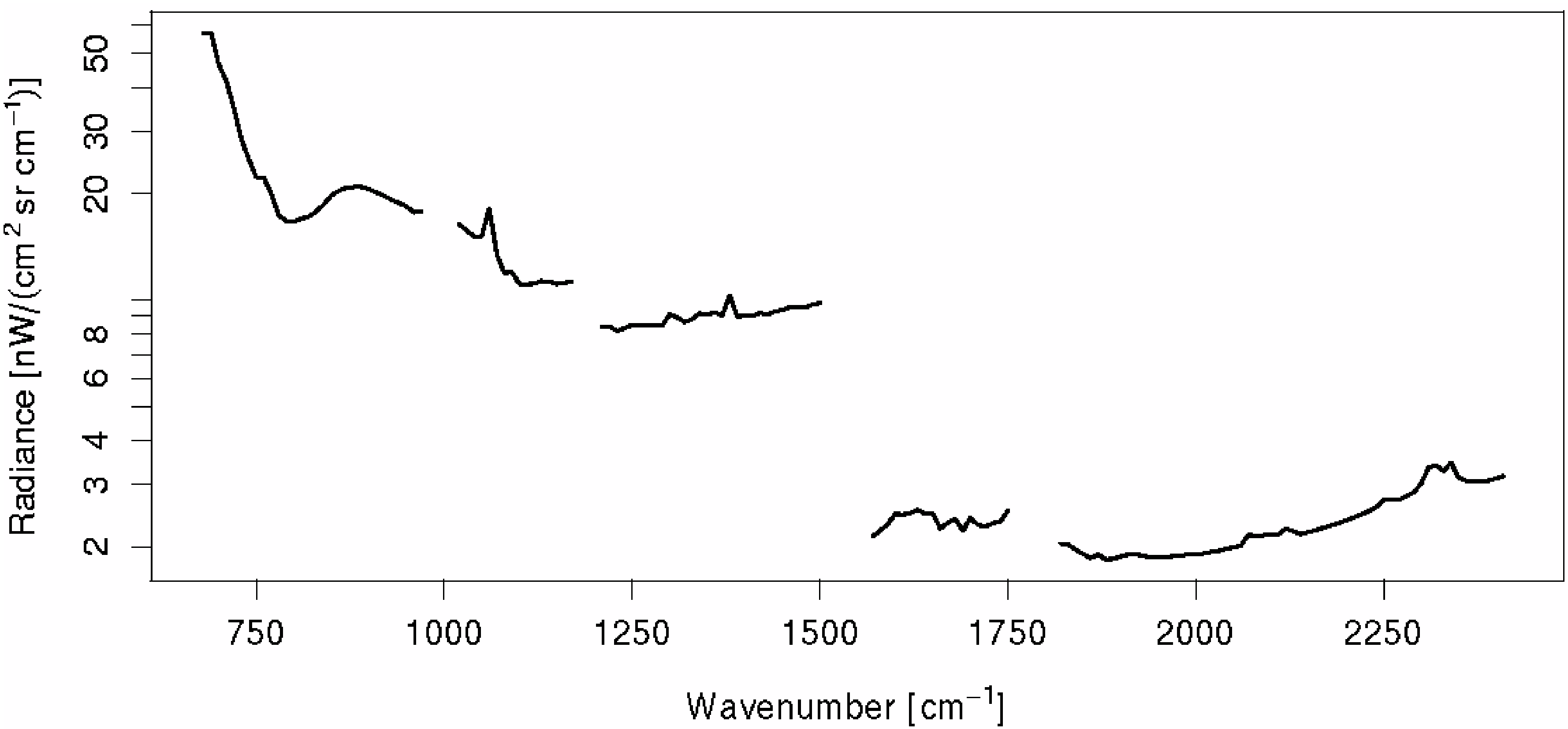
Spectral resolution:
0.025 cm^{-1}

Field of view:
3x30 km (at tangent point)

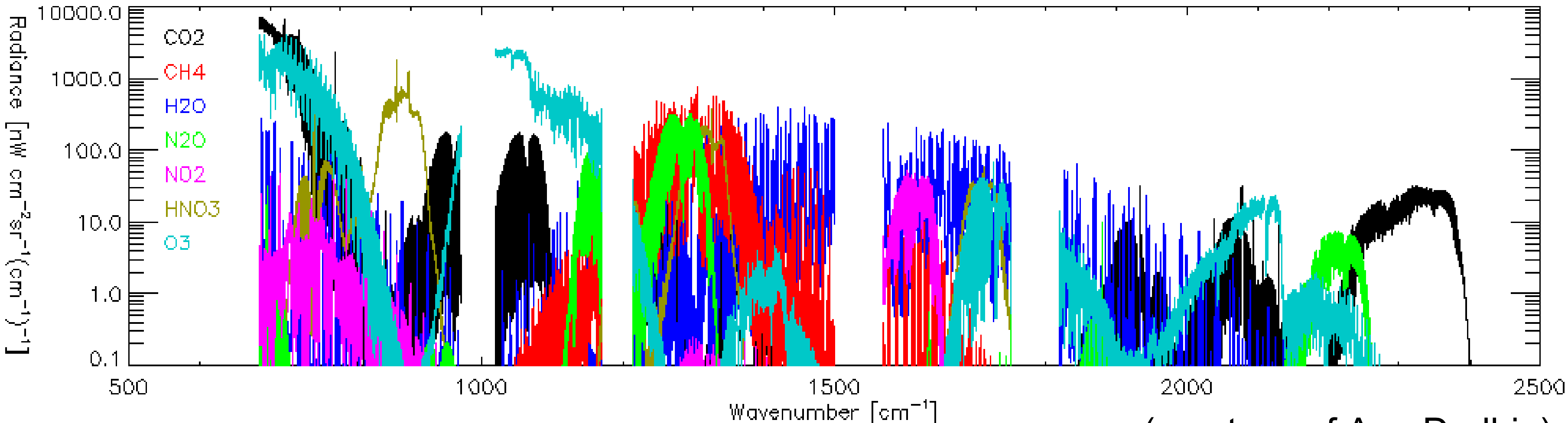
Normal tangent heights:
6-42 km at 3 km steps,
47, 52, 60, 68 km



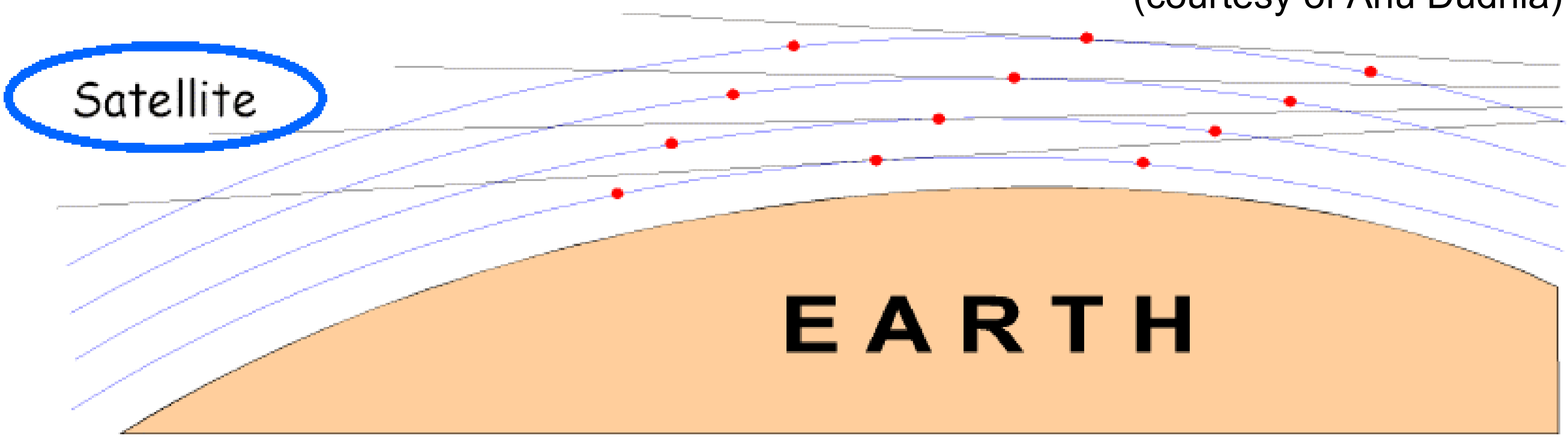
MIPAS noise characteristics



Simulated MIPAS spectrum at tangent height 21 km



(courtesy of Anu Dudhia)



MIPAS products

- Profiles routinely available from ESA's near-realtime processing:
  - Temperature
  - H_2O, O_3, HNO_3, CH_4, N_2O, NO_2
- Ozone profiles have been assimilated operationally at ECMWF from 7 October 2003 to 26 March 2004.
- Due to mechanical problems with the instrument, MIPAS (and the data processing) is currently being reconfigured and no near-realtime products are available.

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- **RTMIPAS: Fast radiative transfer model for MIPAS**
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RTTOV/RTMIPAS methodology

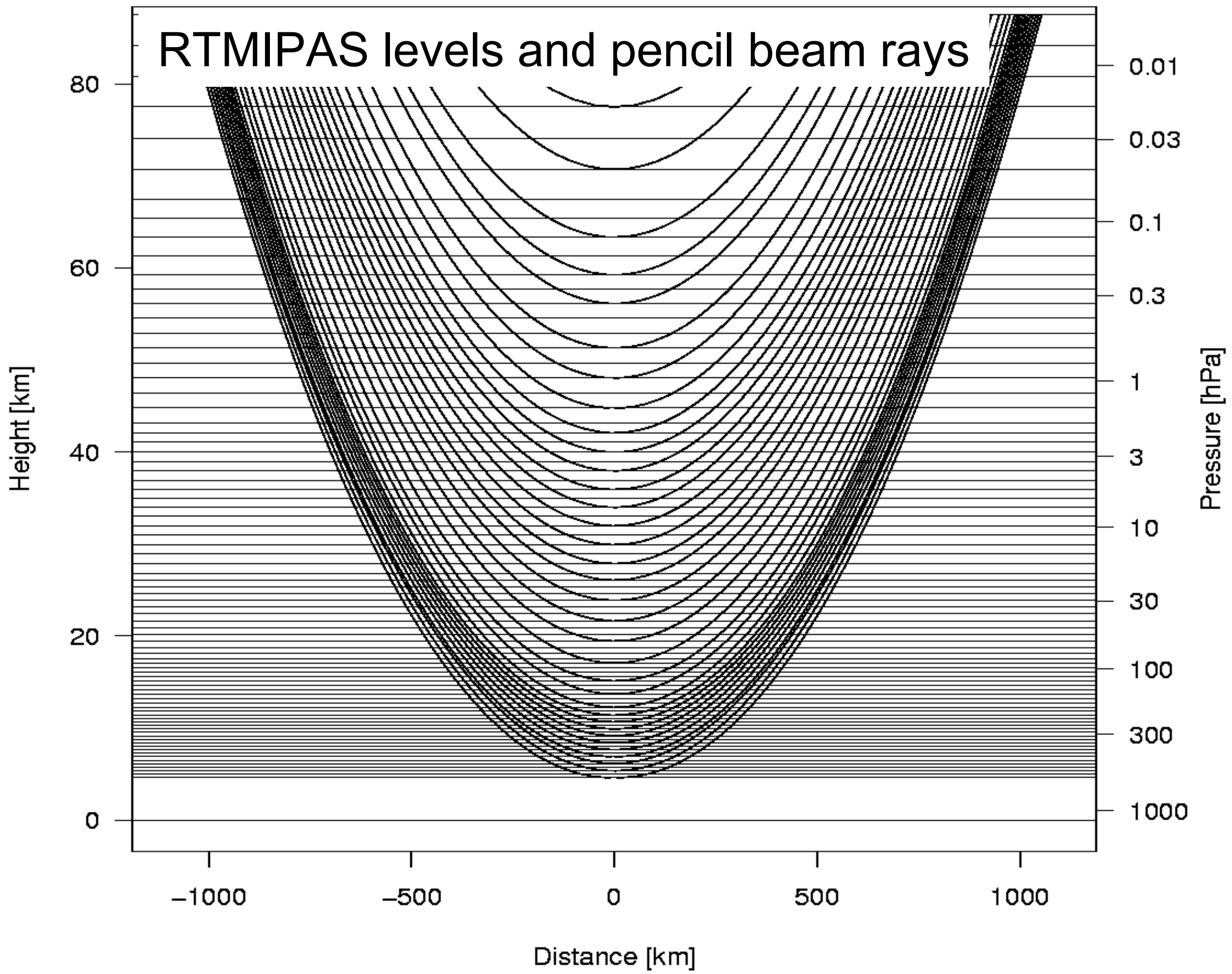
RTMIPAS is a new fast radiative transfer model for MIPAS data, following RTTOV methodology.

Main characteristics:

- Atmosphere on 81 fixed pressure levels.
- Parameterisation of convolved level-to-space transmittances through regression models for effective layer optical depths.
- Regressions derived from results of line-by-line computations for a suitable set of training profiles.
- Regressions for all MIPAS pseudo-channels below 2000 cm^{-1} (43,205 channels).
- Humidity and ozone variable, other gases fixed.

RTMIPAS methodology:
What are the main differences to RTTOV?

- Limb geometry:
  - Raytracing required.
  - Layers crossed (up to) twice -> twice as many regressions.
- Predictors:
  Revised set of predictors, based on scaling with layer path lengths instead of Sec(zenith angle).
- Field of View:
  Account for FOV in the vertical through cubic fit through 34 pencil beam radiances.



RTMIPAS methodology:
Predictors for fast layer optical depths

Based on predictor set for nadir models, but with some changes for limb view – more details on request!

Predictor number	Fixed gases	Water vapour (line)	Ozone	Water vapour (continuum)
1	$\Delta\tilde{s}$	$\Delta\tilde{s}\,\tilde{W}_r$	$\Delta\tilde{s}\,\tilde{O}_r$	$\Delta\tilde{s}\,\tilde{W}_r^{cc}/\tilde{T}_r^{cc}$
2	$\Delta\tilde{s}^2$	$\Delta\tilde{s}\,\tilde{W}_r\,\tilde{T}_r$	$\Delta\tilde{s}\,\tilde{O}_r\,\tilde{T}_r$	$\Delta\tilde{s}\,\tilde{W}_r^{cc}/(\tilde{T}_r^{cc})^2$
3	$\Delta\tilde{s}\,\tilde{T}_r$	$\Delta\tilde{s}\,\tilde{W}_r\,\tilde{T}_r^2$	$\Delta\tilde{s}\,\tilde{O}_r\,\tilde{T}_r^2$	$\Delta\tilde{s}\,(\tilde{W}_r^{cc})^2/\tilde{T}_r^{cc}$
4	$\Delta\tilde{s}\,\tilde{T}_r^2$	$\Delta\tilde{s}\,\tilde{W}_r/\sqrt{\tilde{W}_w}$	$\Delta\tilde{s}\,\tilde{O}_r/\sqrt{\tilde{O}_w}$	$\Delta\tilde{s}\,(\tilde{W}_r^{cc})^2/(\tilde{T}_r^{cc})^4$
5	$\Delta\tilde{s}\,\tilde{T}_r^3$	$\Delta\tilde{s}\,\tilde{W}_r\,\sqrt{\tilde{W}_w}$	$\Delta\tilde{s}\,\tilde{O}_r\,\sqrt{\tilde{O}_w}$	
6	$\Delta\tilde{s}\,\tilde{T}_r^4$	$\sqrt{\Delta\tilde{s}\,\tilde{W}_r}$	$\sqrt{\Delta\tilde{s}\,\tilde{O}_r}$	
7	$\Delta\tilde{s}^{\frac{3}{2}}\,\sqrt{\tilde{T}_r}$	$\sqrt{\Delta\tilde{s}\,\tilde{W}_r}\,\tilde{T}_r$	$\sqrt{\Delta\tilde{s}\,\tilde{O}_r}\,\tilde{T}_r$	
8	$\tilde{T}_r$	$\sqrt{\Delta\tilde{s}\,\tilde{W}_r}/\sqrt{\tilde{W}_w}$	$(\Delta\tilde{s}\,\tilde{O}_r)^{1.5}/\sqrt{\tilde{O}_w}$	
9	$\tilde{T}_r^2$	$\sqrt{\Delta\tilde{s}\,\tilde{W}_r}\,\sqrt{\tilde{W}_{tw}}$	$\sqrt{\tilde{O}_{tw}}$	
10	$\tilde{T}_w$	$(\Delta\tilde{s}\,\tilde{W}_r)^2$	$\tilde{O}_{tw}^2$	
11	$\tilde{T}_w^2$	$\sqrt{\tilde{W}_w}$	$\sqrt{\tilde{O}_w}$	
12		$\tilde{W}_w^2$	$\tilde{O}_w^2$	
13			$\Delta\tilde{s}\,\tilde{T}_r^3$	

RTMIPAS development

Transmittance data used for training:

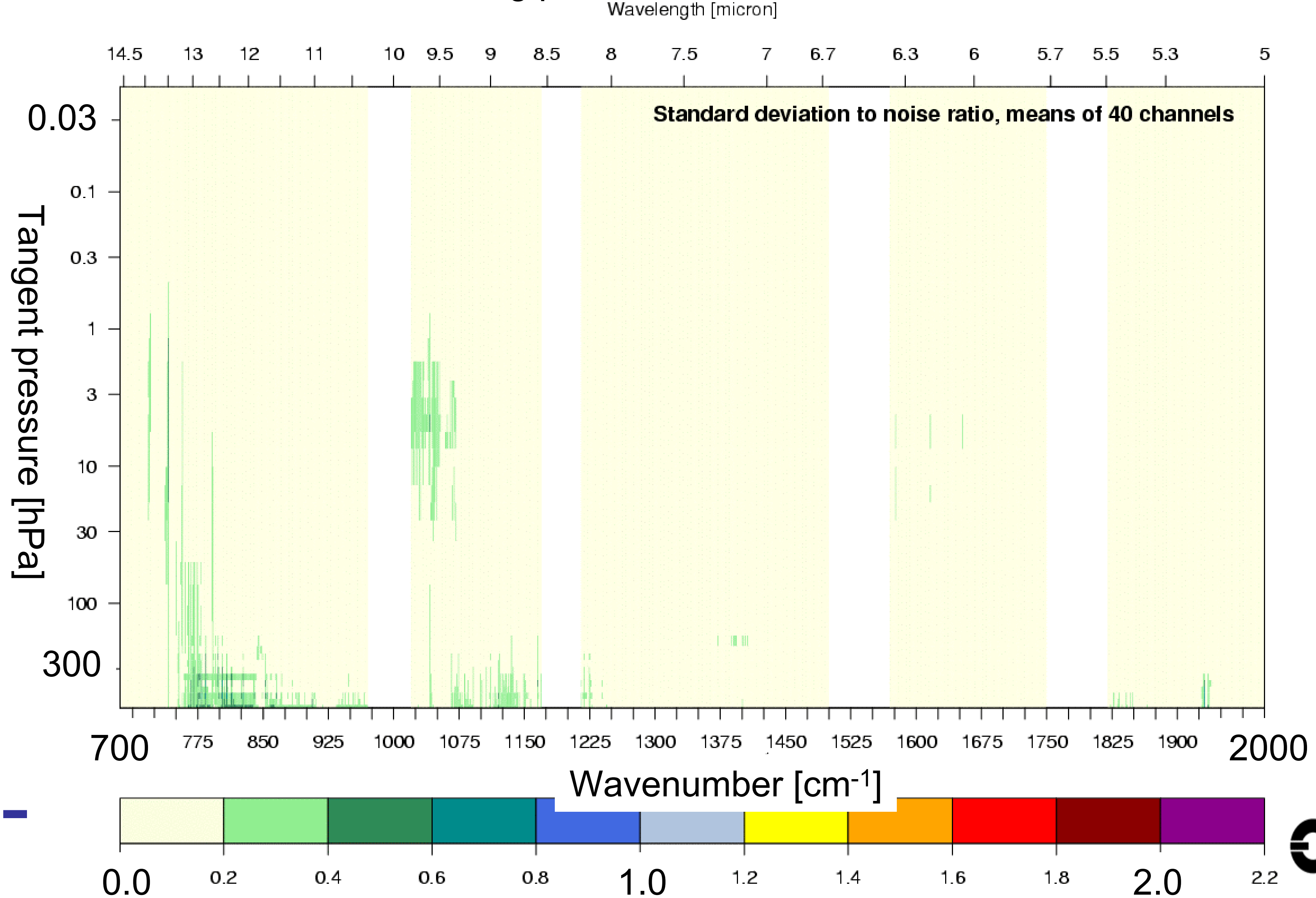
- Line-by-line model: Reference Forward Model (RFM, Uni. Oxford)
- Calculations for:
  - 46 diverse profiles, sampled from ERA-40 data, optimising the variability above 550 hPa (Chevallier et al. 2002).
  - 34 pencil beams with tangent points at selected pressure levels.
- Separate database for water vapour continuum model (using CKD2.4).

Validation based on comparison with RFM results for:

- 46 training profiles
- 53 independent profiles, also sampled from ERA-40 data.

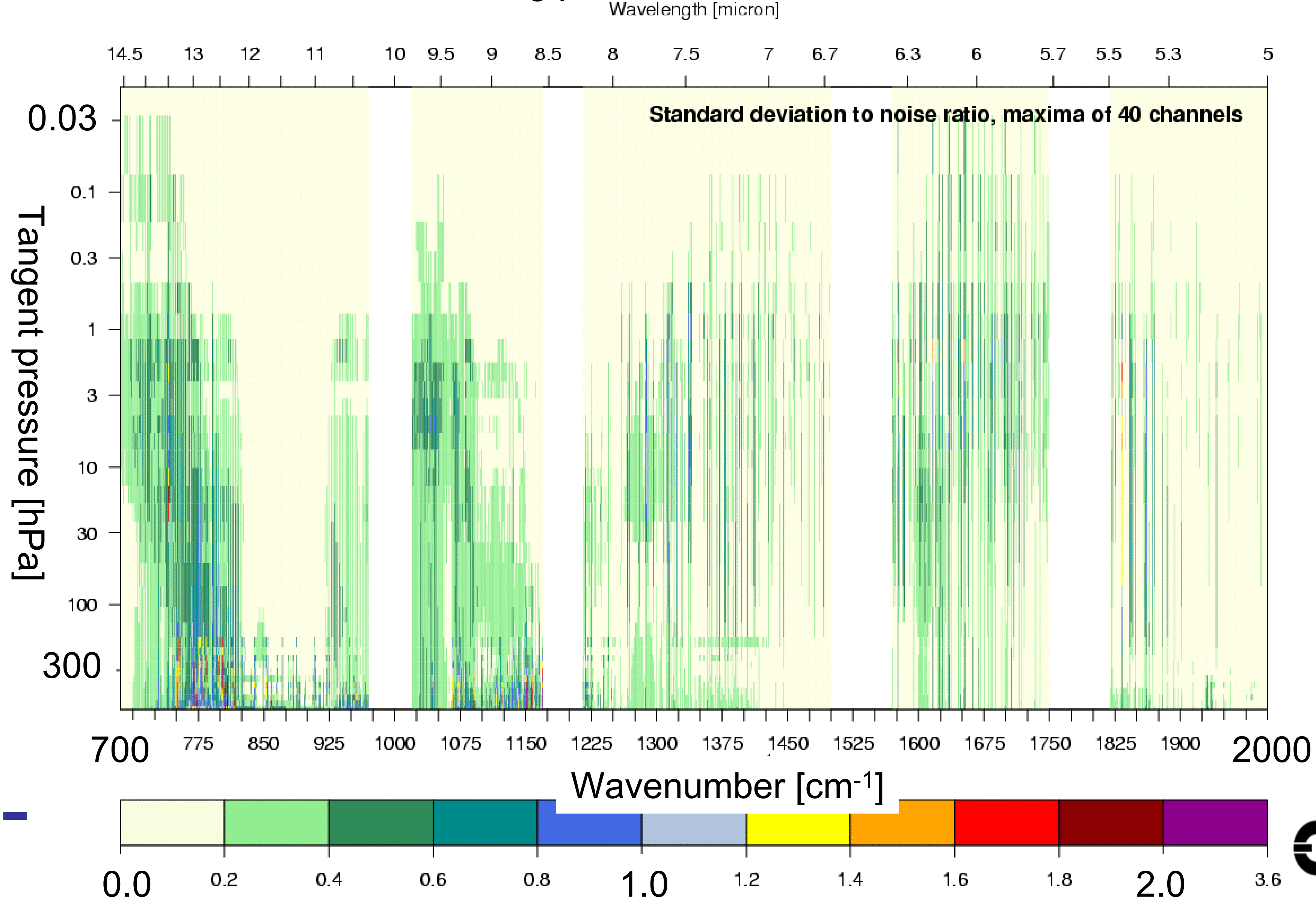
Validation: RTMIPAS-RFM radiances, standard deviation to noise ratio

Means of 40 channels, training profile set



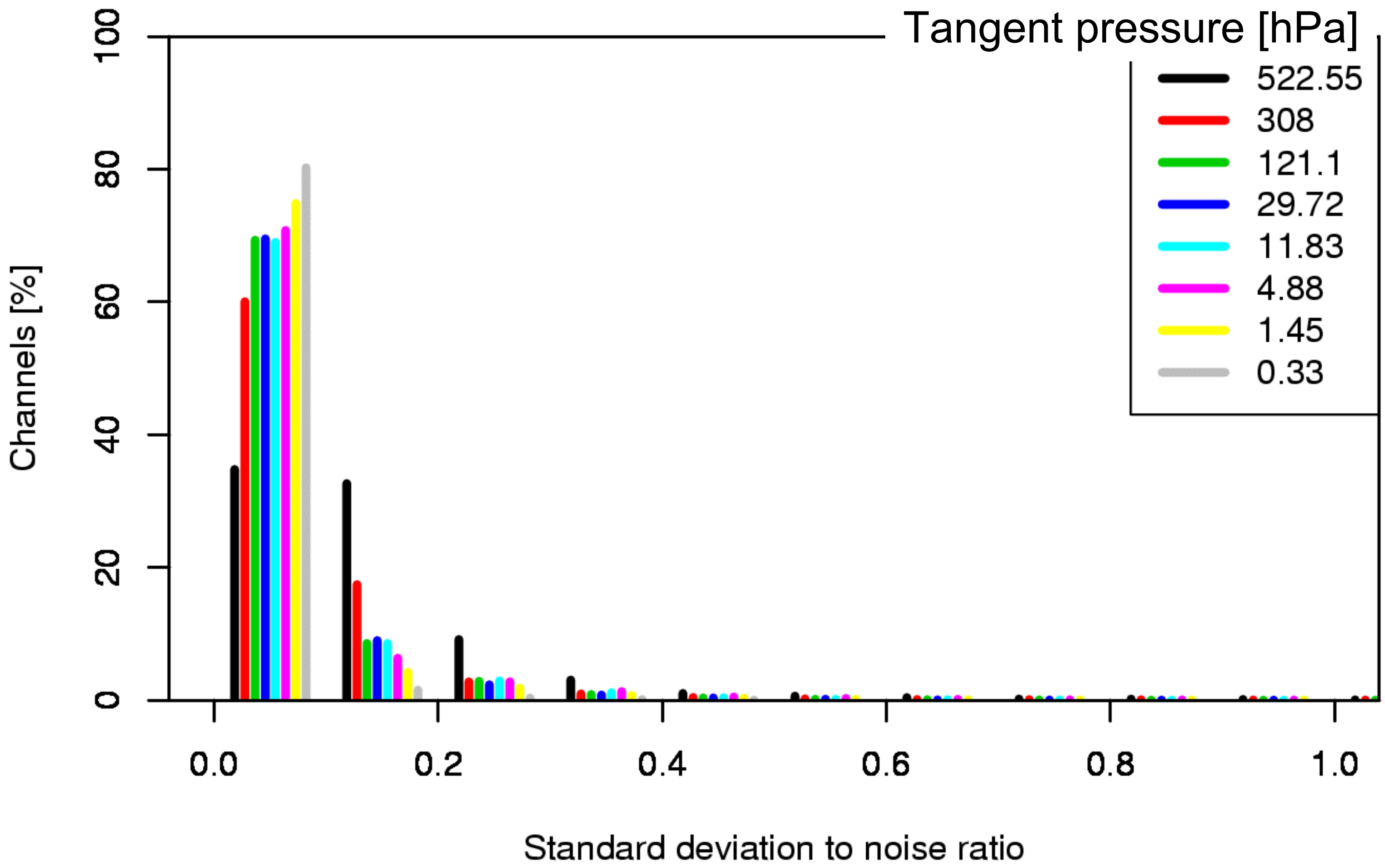
Validation: RTMIPAS-RFM radiances, standard deviation to noise ratio

Maxima of 40 channels, training profile set



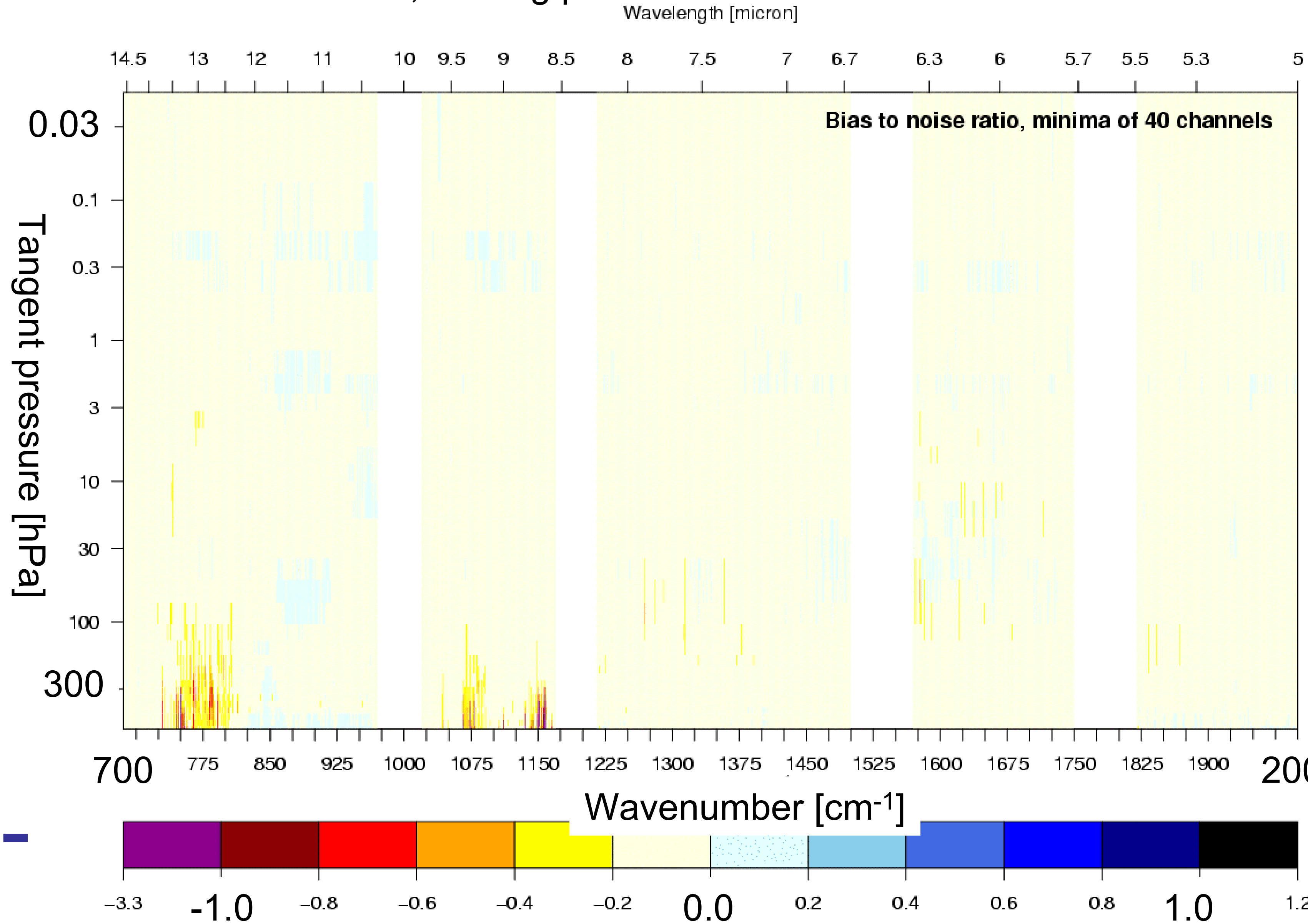
Validation: RTMIPAS-RFM radiances, histogram of standard deviation to noise ratio for selected pencil beams

(training profile set)



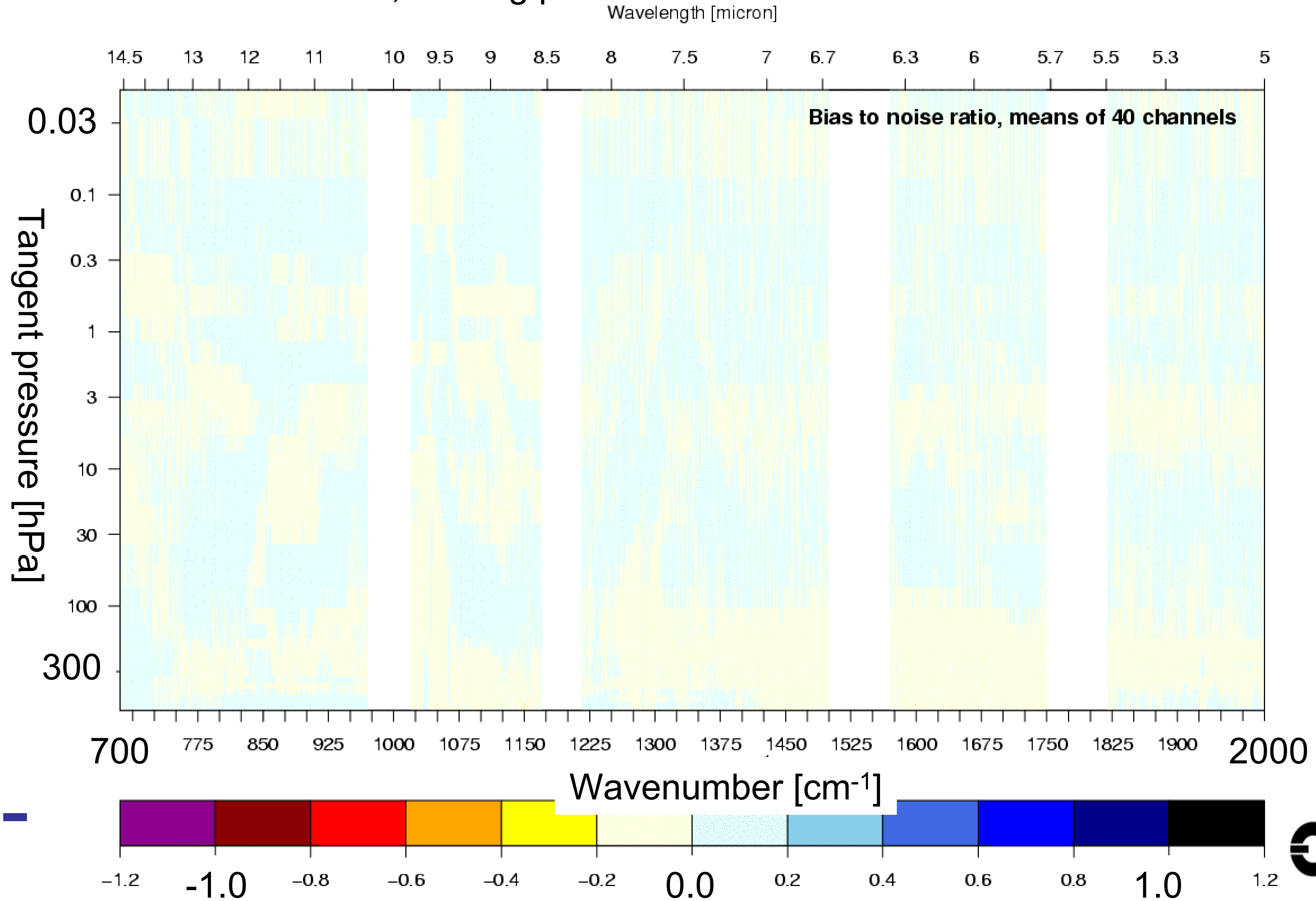
Validation: RTMIPAS-RFM radiances, bias to noise ratio

Minima of 40 channels, training profile set



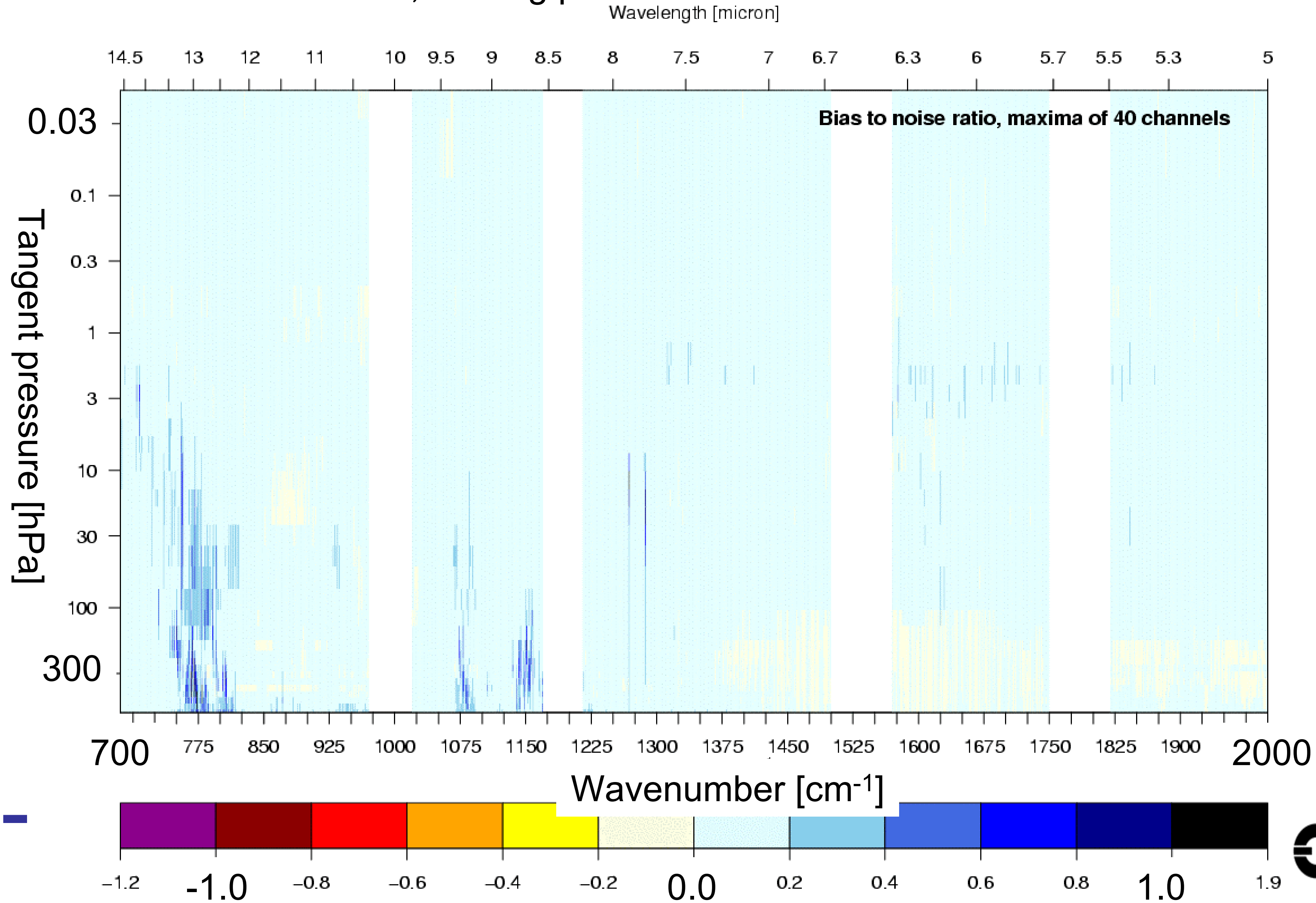
Validation: RTMIPAS-RFM radiances, bias to noise ratio

Means of 40 channels, training profile set



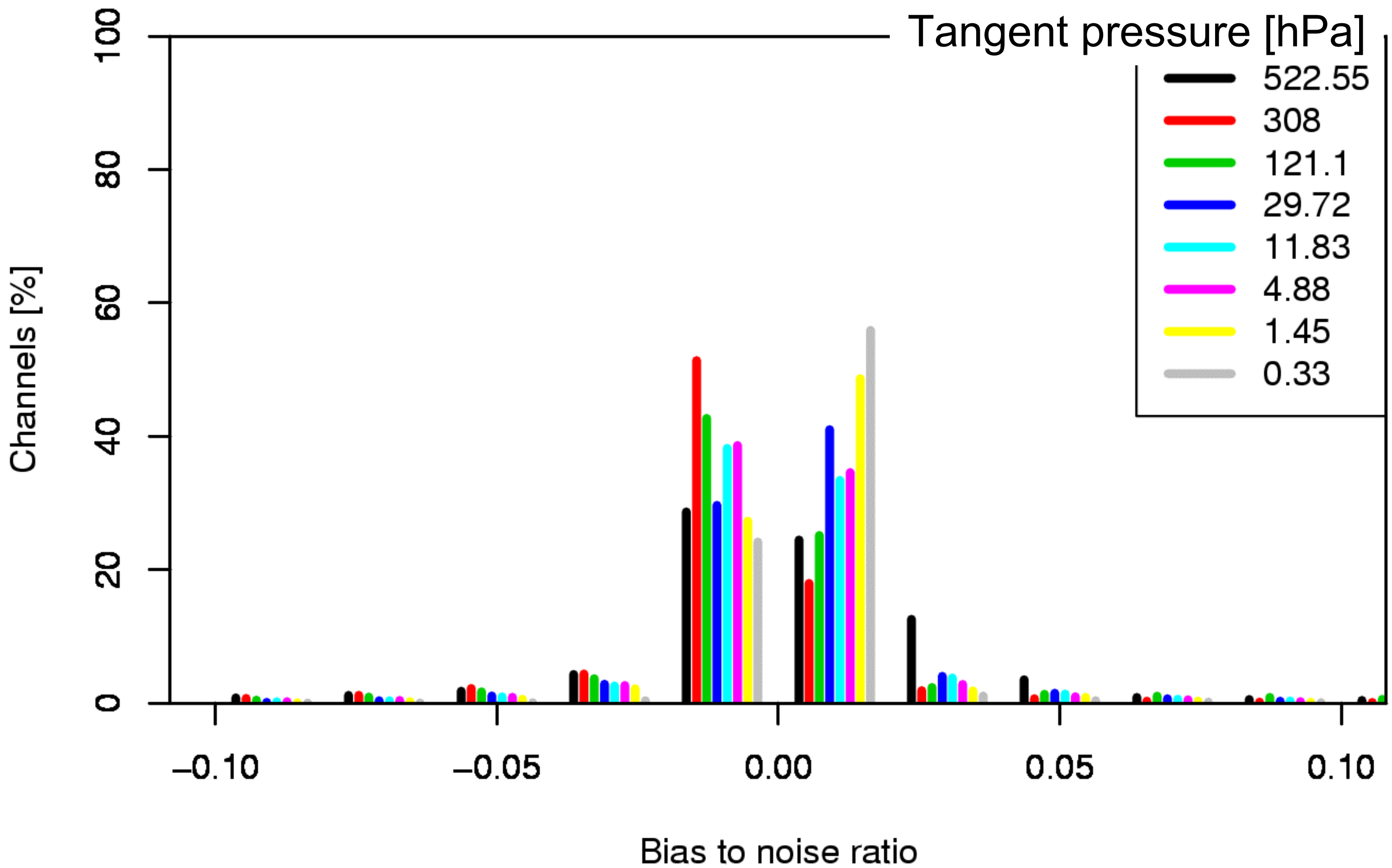
Validation: RTMIPAS-RFM radiances, bias to noise ratio

Maxima of 40 channels, training profile set



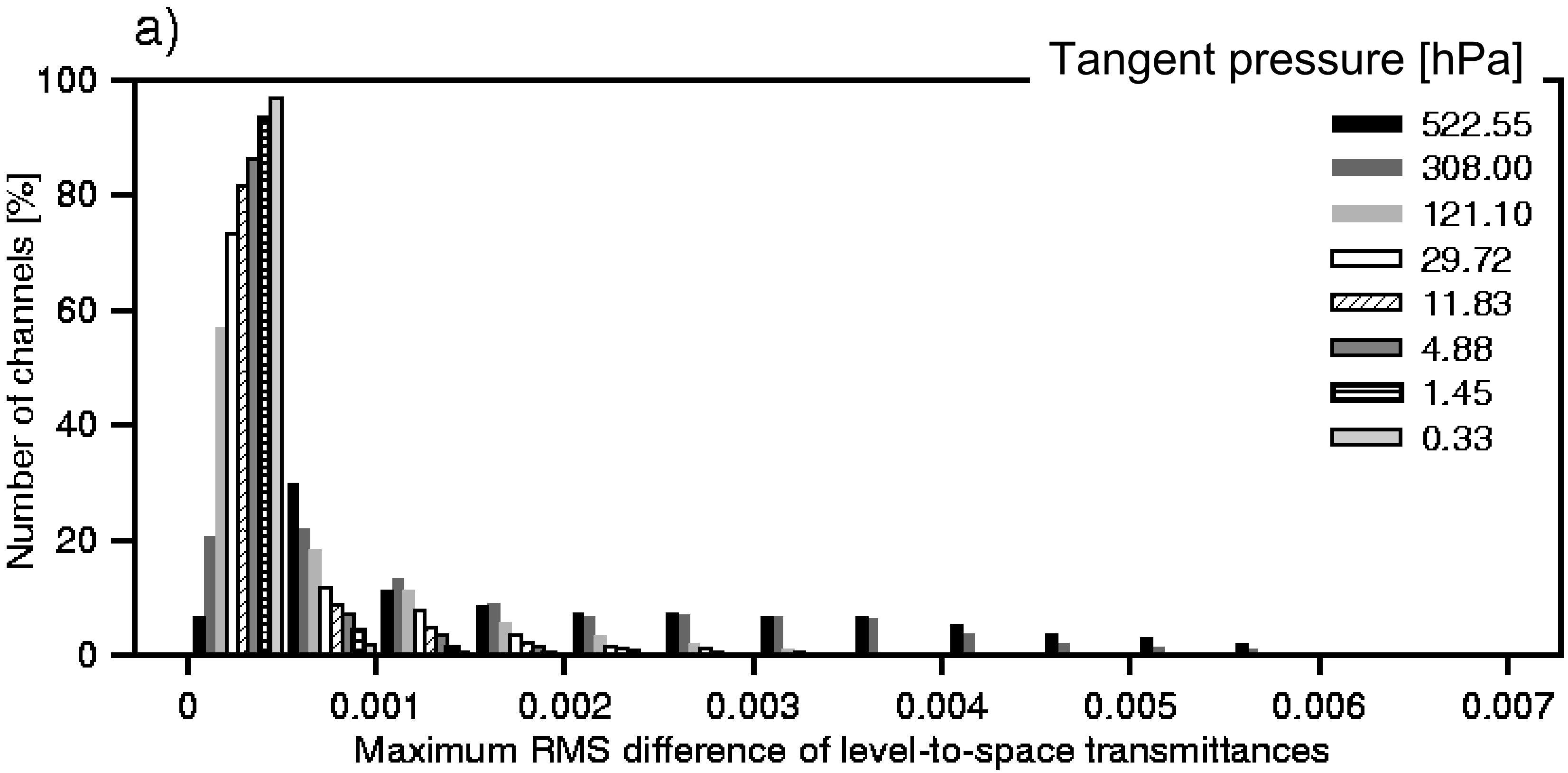
Validation: RTMIPAS-RFM radiances, histogram of bias to noise ratio for selected pencil beams

(training profile set)



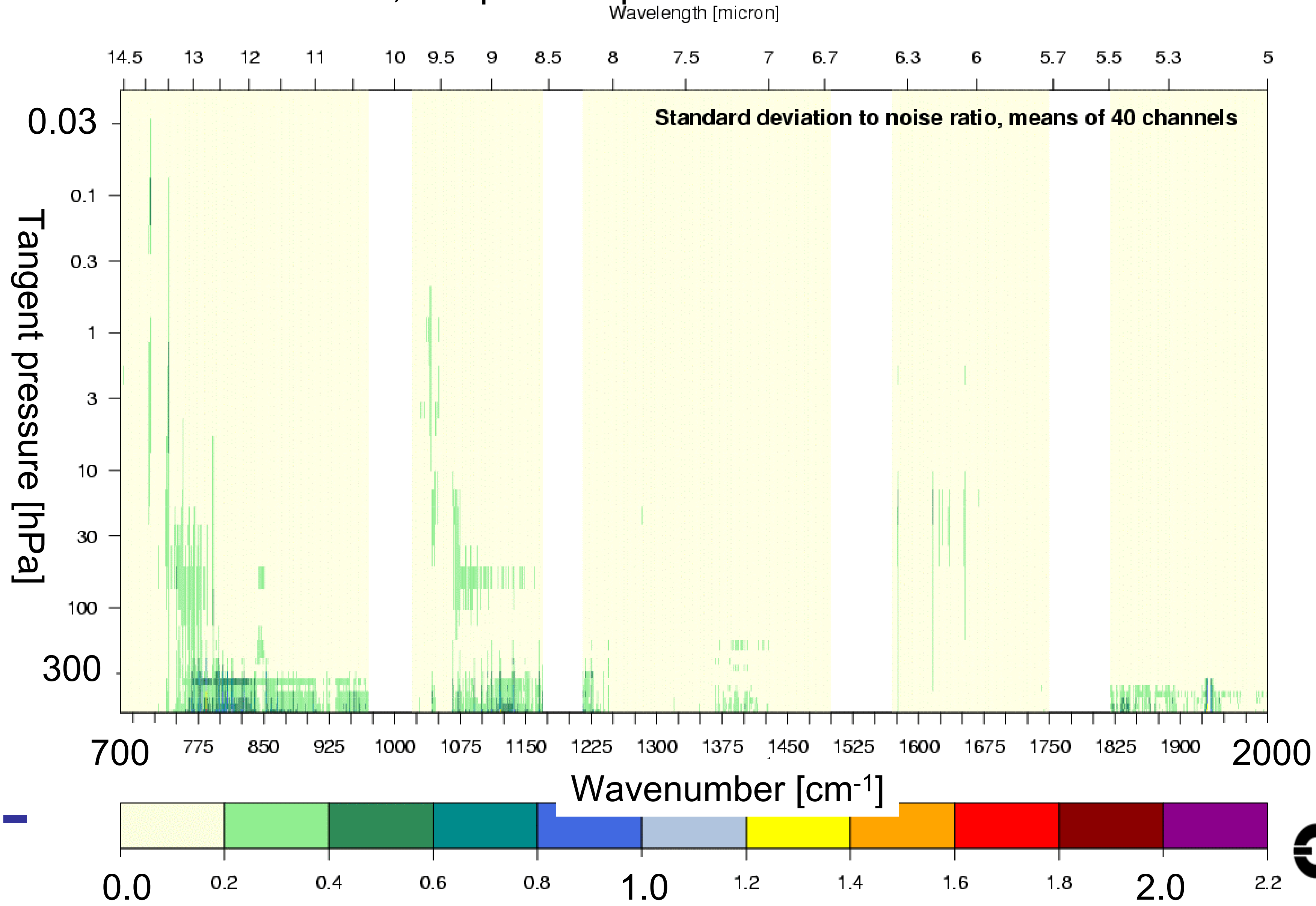
Validation: RTMIPAS-RFM transmittances, histogram of maximum RMS difference for selected pencil beams

(training profile set)



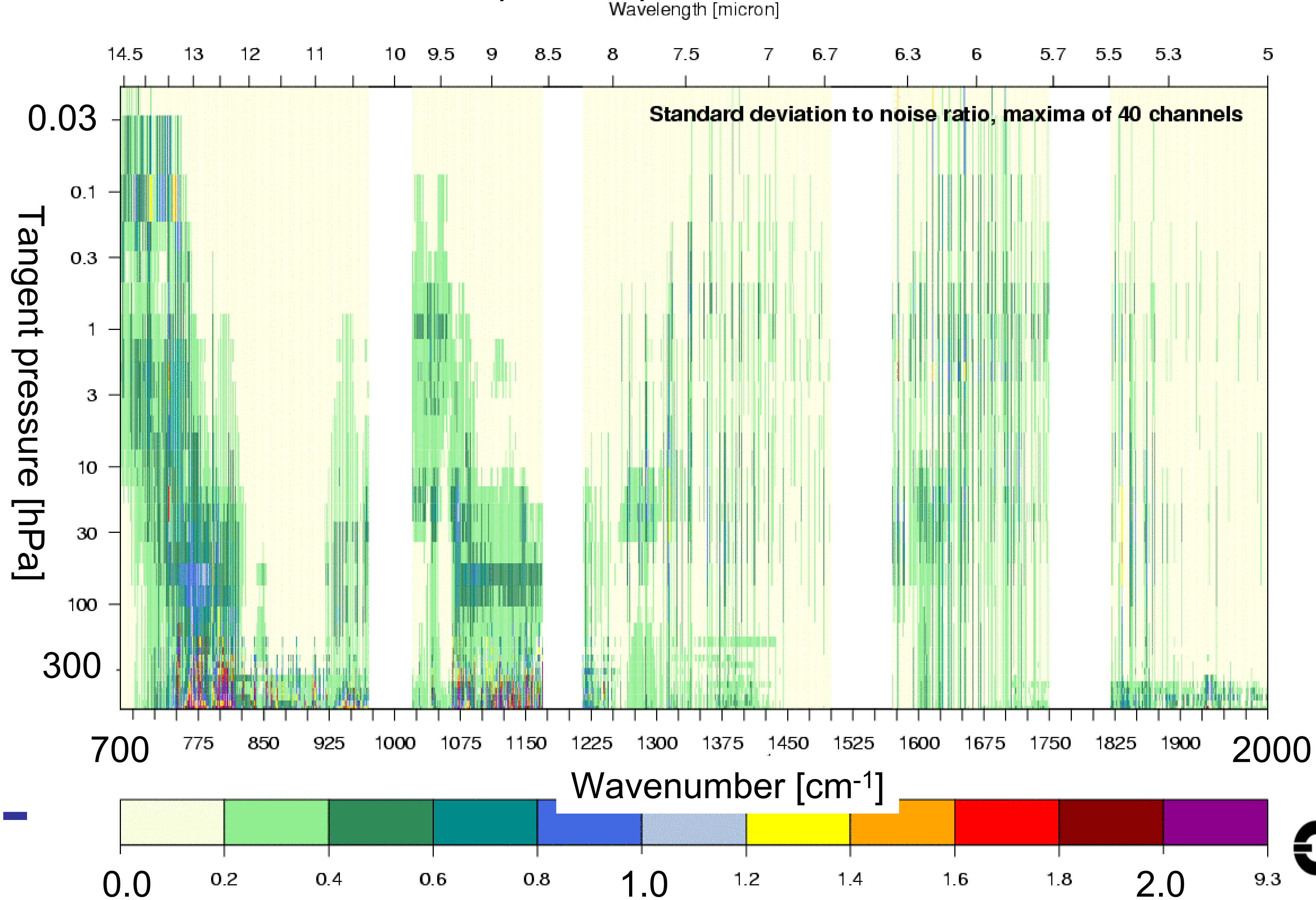
Validation: RTMIPAS-RFM radiances, standard deviation to noise ratio

Means of 40 channels, independent profile set



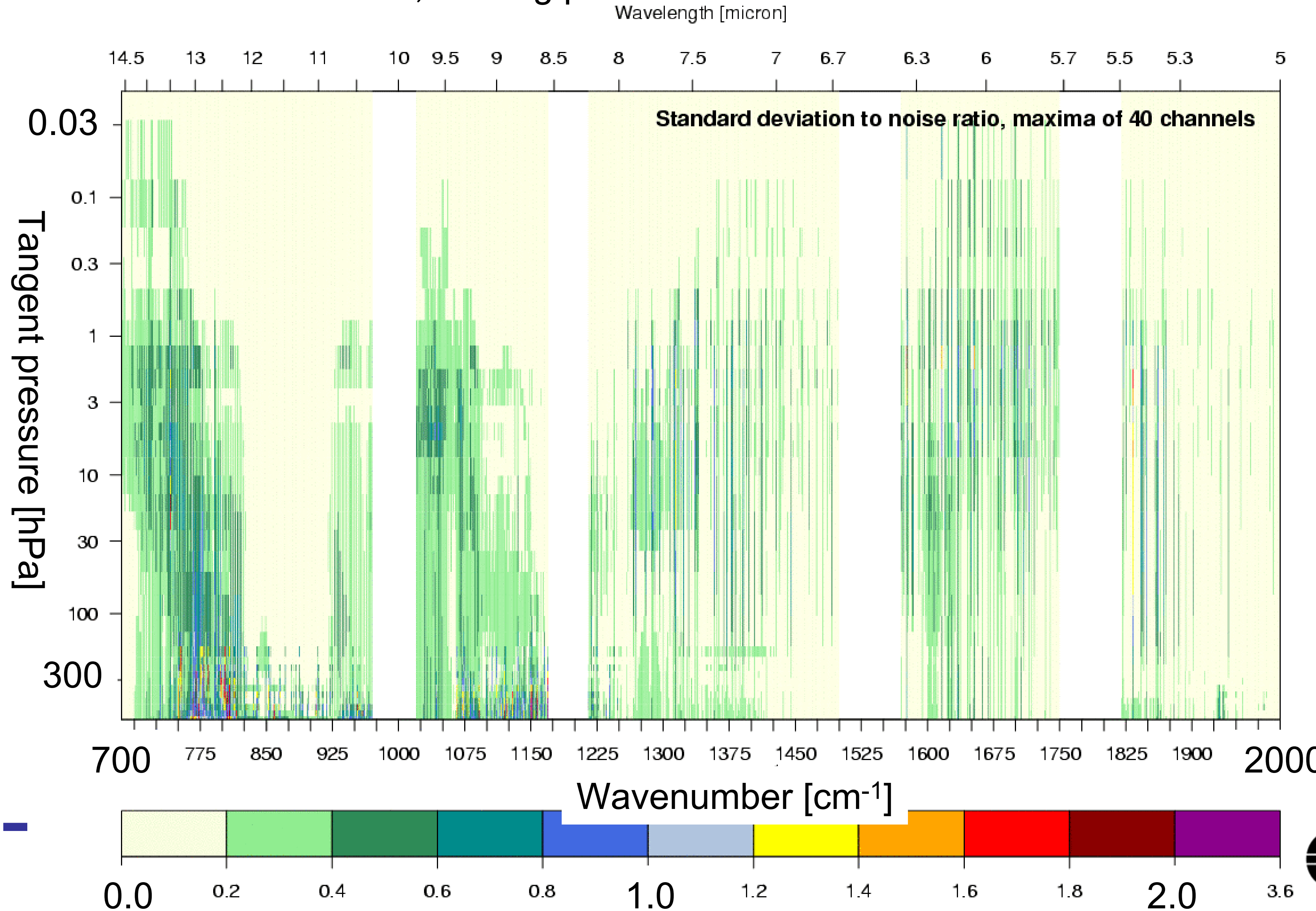
Validation: RTMIPAS-RFM radiances, standard deviation to noise ratio

Maxima of 40 channels, independent profile set



Validation: RTMIPAS-RFM radiances, standard deviation to noise ratio

Maxima of 40 channels, training profile set



RTMIPAS summary

- A regression-based approach to transmittance modelling has been successfully adapted to MIPAS limb radiances.
- Validation against RFM shows that RTMIPAS is capable of reproducing line-by-line radiances to an accuracy below the noise level of the MIPAS instrument for most channels and pencil beams.
- Validation for transmittances indicates an accuracy comparable to that of fast models for nadir geometry.
- There is a relatively small increase in the RTMIPAS-RFM differences when calculated for 53 independent profiles rather than the 46 profiles used for training.
- Tangent linear and adjoint routines have been developed for variational data assimilation.
- More details: Bormann, Matricardi, and Healy 2004, ECMWF Tech. Memo. 436 (available as pdf via ECMWF library pages).

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1DVAR with RTMIPAS:
Some preliminary, idealised Monte-Carlo experiments with simulated data…

- Control variable:

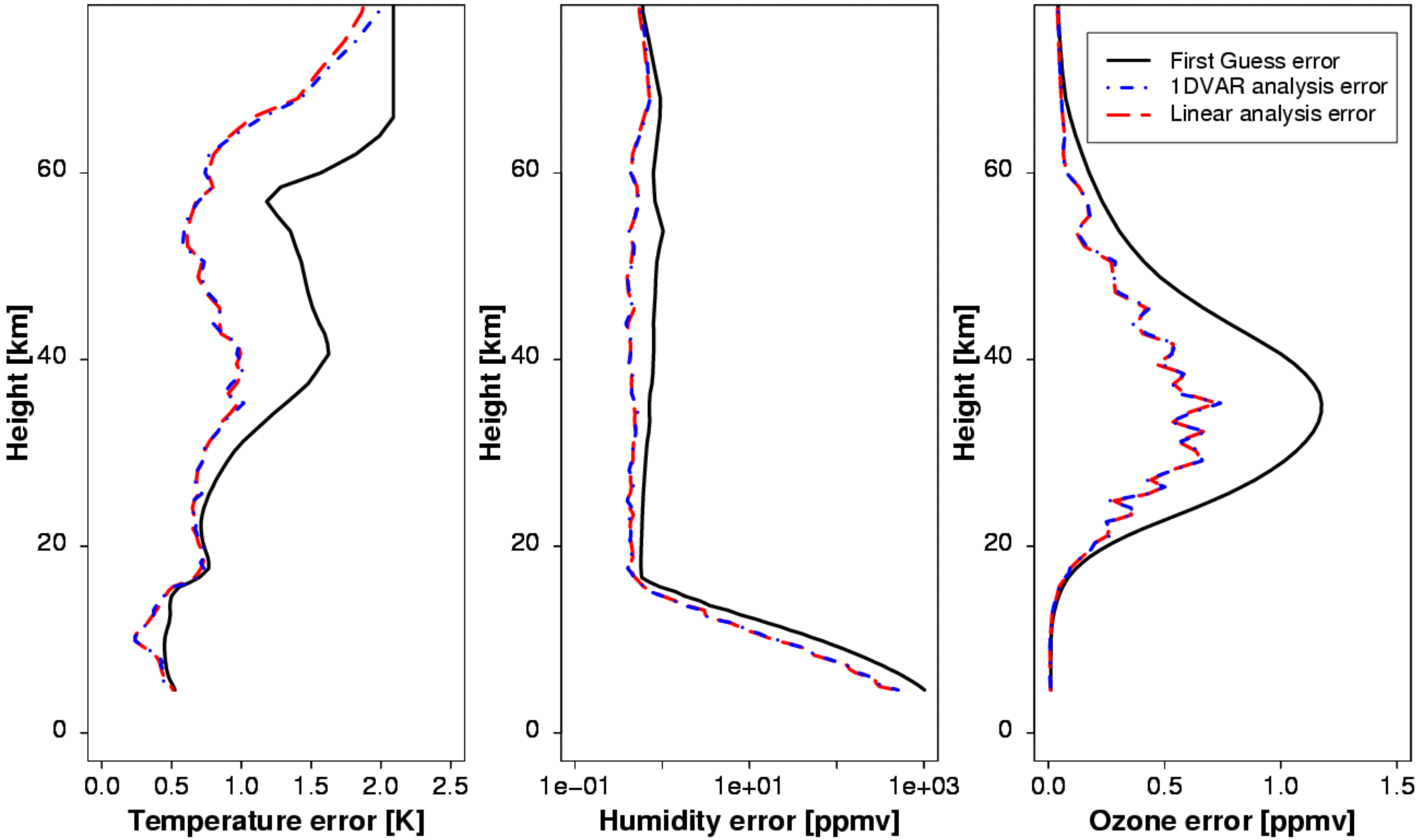
  Temperature, humidity, and ozone on 81 RTMIPAS pressure levels
- Observations:

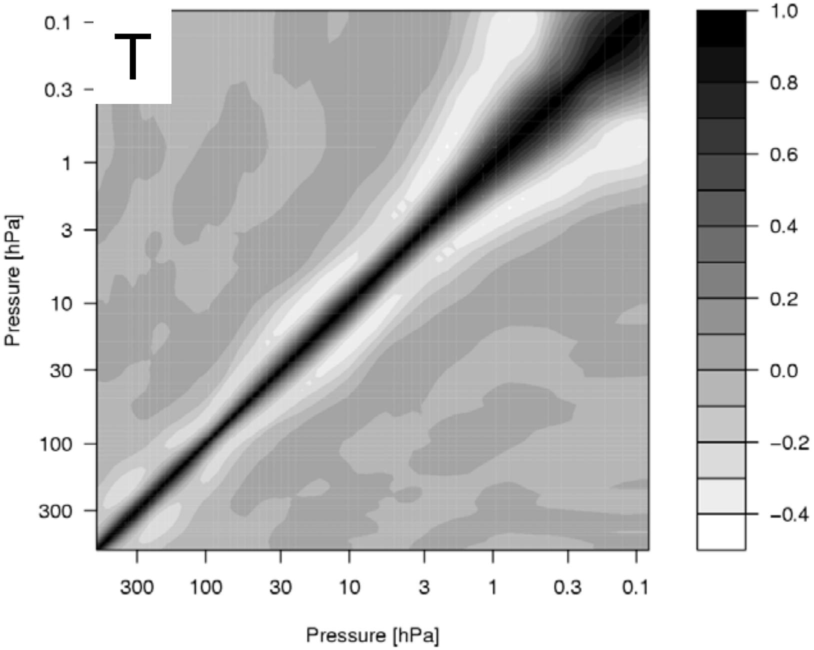
  MIPAS radiances from 129 channels at (up to) 17 nominal tangent heights in normal scanning mode (1348 observations)
- Background error from ECMWF system (with adjustments for humidity and ozone in the stratosphere).
- Observation error from in-flight MIPAS noise measurements.

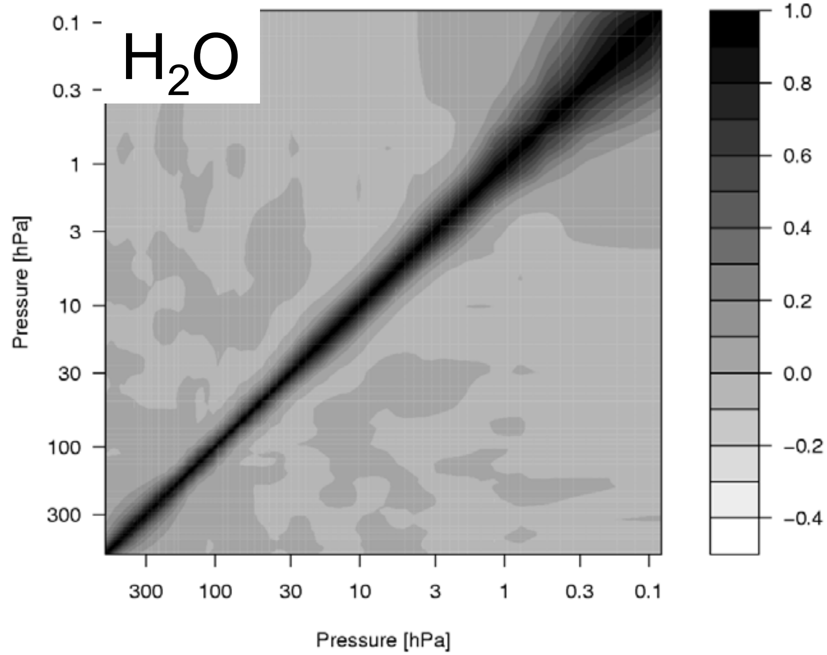
- True atmosphere: Mid-latitude daytime
- True observations: Simulated from true atmosphere

- Background data and simulated observations obtained by adding Gaussian noise according to error covariances.
- Perform 500 realisations.

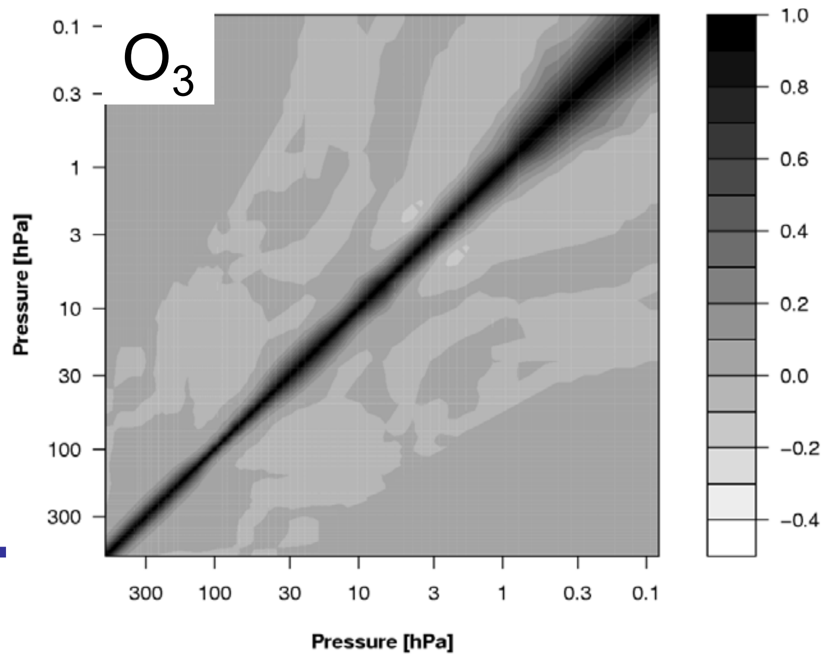
1DVAR with RTMIPAS: Some preliminary, idealised Monte-Carlo experiments with simulated data…







Background error correlation matrices



1DVAR with RTMIPAS:
Some preliminary, idealised Monte-Carlo experiments with simulated data…

• The simulations give an idea of the information in the selected observations on top of the ECMWF background under very idealised conditions:

- The observation + forward model error is equal to the instrument error.
- Background errors are as specified.
- All observations are clear-sky.
- Pointing information from the satellite is perfectly known.
- Height of the lowest level is perfectly known.

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Outstanding issues: Channel/tangent height selection

Need to select suitable subset of channels/tangent heights that maximise some measure of Information Content (⟶ Anu Dudhia's talk on Tuesday).

Microwindow concept: "rectangle" in wavenumber/tangent height domain.

Two concepts possible:

- Use 200 (or so) "best" single-channel microwindows.

  Theoretically optimal in terms of Information Content.

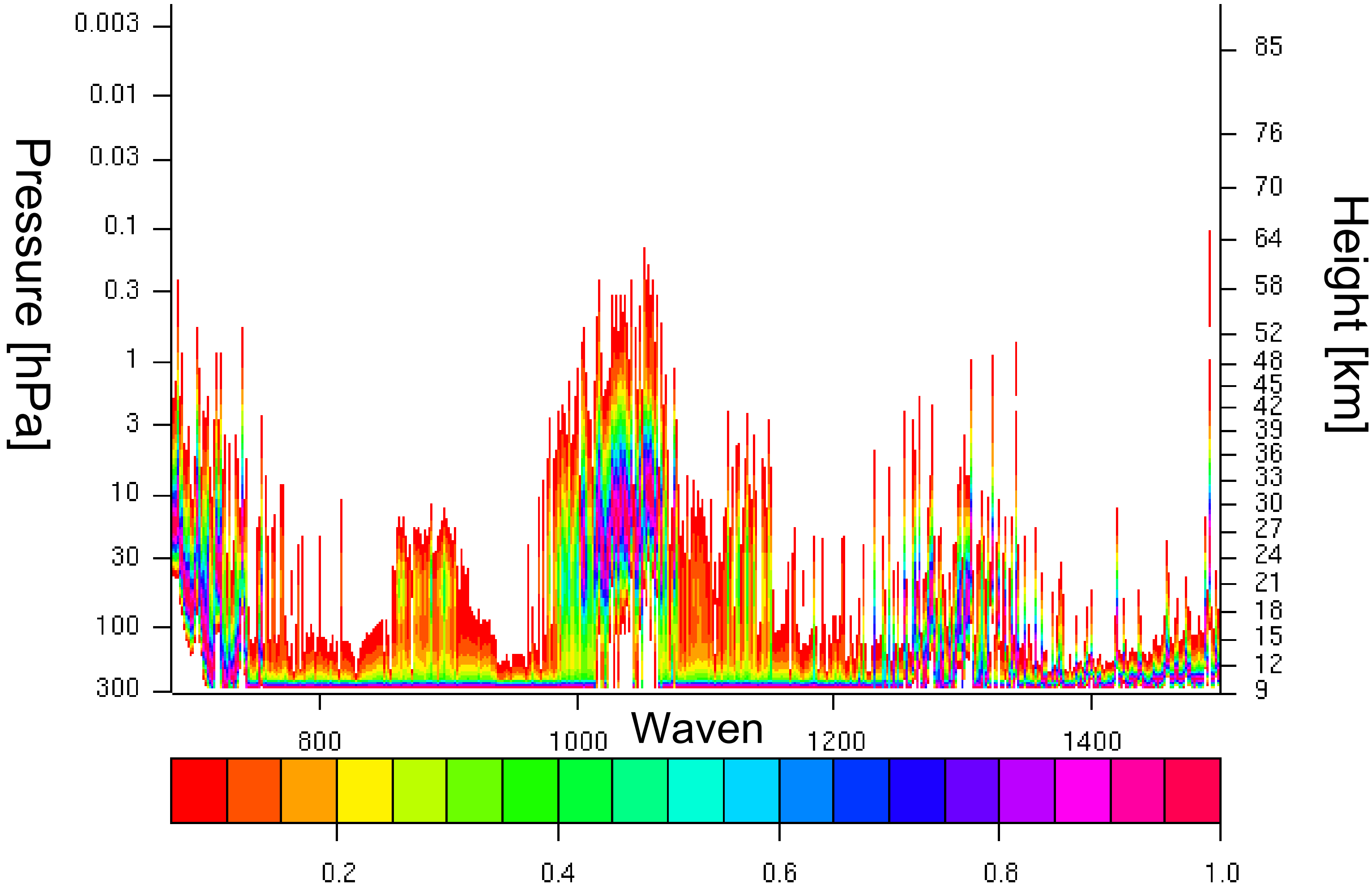
Or

- 10 (or so) "best" 1-3 cm^{-1} microwindows.

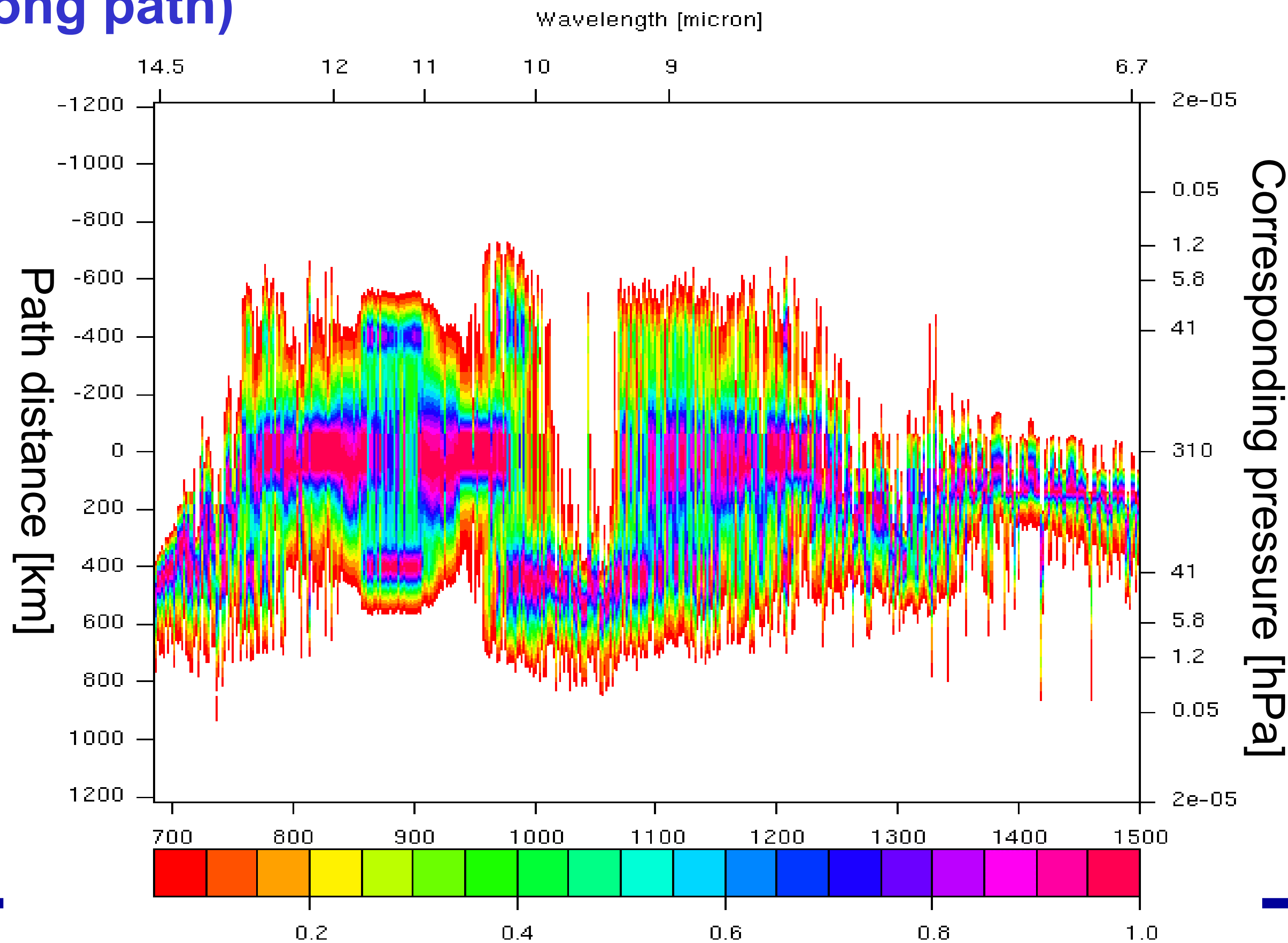
  May be beneficial for spotting systematic errors, correcting continuum-like biases.

  Correlated observation errors.

Normalised weighting functions for 9 km tangent (vertical)



Normalised weighting functions for 9 km tangent (along path)



Outstanding issues:
Interface analysis ↔ 2d-observation operator

- Interface is technically challenging in multiprocessor environment: probably based on passing a series of profiles to the obs operator.
- Tomographic retrievals (based on an entire orbit of MIPAS data) show benefits in terms of retrieval error and horizontal resolution compared to single scan/single profile retrieval.
- Developments in combination with work on assimilating GPS radio-occultation bending angle measurements.

- Benefits for other candidates of limb data that could be assimilated in the future:
  - HIRDLS, MLS (Aura)
  - GPS radio-occultation (CHAMP, METOP, COSMIC, …)

Outstanding issues: Miscellaneous

Pointing information for assimilation:

Satellite pointing information considered not accurate enough.

Possible solutions:

- Use tangent pressure from level 2 products.
- Perform tangent pressure retrieval in pre-assimilation step.
- Perform tangent pressure retrieval in main assimilation.

Background errors/biases in stratosphere:

- New humidity control variable (normalised relative humidity).
- Revised J_B for ozone?
- Combination AIRS stratospheric channels + MIPAS may allow better characterisation of model biases in the stratosphere.