Recent progress towards a GRUAN MWR product

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National Research Council of Italy

istituto di metodologie per l'analisi ambientale

Why a GRUAN MWR?

Microwave Radiometer (MWR) provides:

- Low-resolution Temperature and Humidity profiles
- Total water vapor + liquid water column (TWVC, TLWC)
- ~1 min temporal resolution
- ~all weather

With respect to radiosondes

- Highly redundant (but much lower resolution)
- Independent (e.g. RS80 dry bias)
- Complement diurnal cycle
- Complement TLWC (no other GRUAN instrument)

GRUAN MWR Program Guide

STATUS:

- Following the GRUAN Guide (GCOS-171)
- First draft delivered (15 April 2016)

- **GRUAN MWR Program Guide TD-N.1.0**
    1. Introduction
    2. Instrumentation
    3. Reference Measurements
    4. Measurement Uncertainty
    5. Measurement Scheduling
    6. Data Management
    7. Post-processing Analysis and Feedback
    8. Quality Management
    9. Site Assessment and Certification
    - Appendix 1 - Acronyms
    - Appendix 2 - Examples of MWR lv1 and lv2 data files
    - References

GRUAN MWR Program Guide

- **V1.0 touches all sections**
  - but it’s only a first draft (by no means complete)
- **V1.0 is a living document**
  - continuous updates following TOPROF/GAIA-CLIM activities
- **Drafting stopped when**
  - MWR TD-N.1.0 ↔ MWR Product 1.0

Progress from 2016 until today

In the framework of:

- TOPROF (EU cooperation action, COST Action)
- GAIA-CLIM (EU research project, H2020)

Progress goes faster when funding are available…

GAIA-CLIM Gap Assessment

5 gaps for MWR products

Technology: NIST

1. Missing MW standards maintained by Metrological Institute

Knowledge: GAIA-CLIM

2. Missing the uncertainty associated with MW absorption models used in MWR retrievals

Cooperation: TOPROF

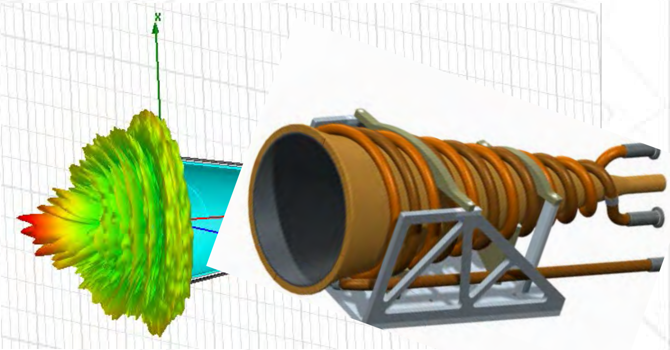
3. Lack of unified tools for automated MWR data quality control
4. Missing agreement on calibration best practices and instrument error characterization
5. Lack of a common effort in homogenization of retrieval methods

Technology gap (NIST)

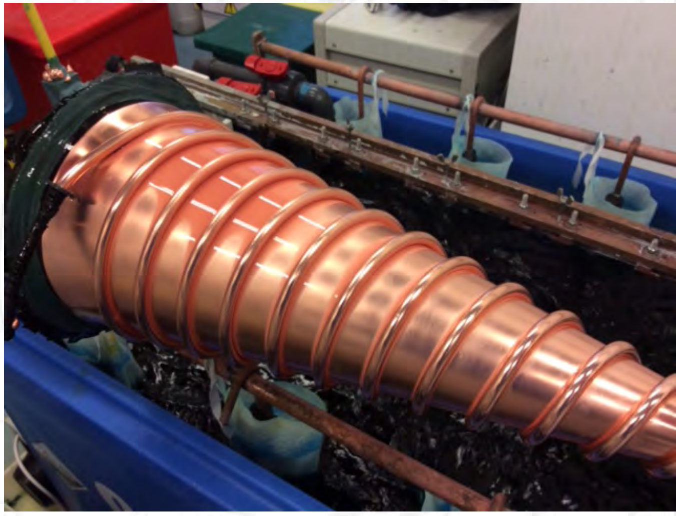
- **Missing MW standards maintained by NMI**

- **Remedy**: Development of MW Standard Target at NIST*

*Houtz et al., Microrad, 2018



- Designed for satellite MWR
- Careful characterization
  - Design (simulations)
  - Lab tests



- This development shall allow transfer standards for certifying commercial MWR calibration targets

Cooperation gaps (TOPROF)

3. Lack of unified tools for automated MWR data quality control
   - **Remedy**: Development of standardized centralized QC

4. Missing agreement on calibration best practices and instrument error characterization
   - **Remedy:**
     - Review best practices for MWR operations
     - Draft protocols for calibration and maintainance
     - Investigate calibration characterization
       - repeatability, stability, and uncertainty

5. Lack of a common effort in homogenization of retrieval methods
   - **Remedy:**
     - Development of two uniform “standard” retrieval method
       - Regression
       - 1DVAR

Unified tools + homogenization

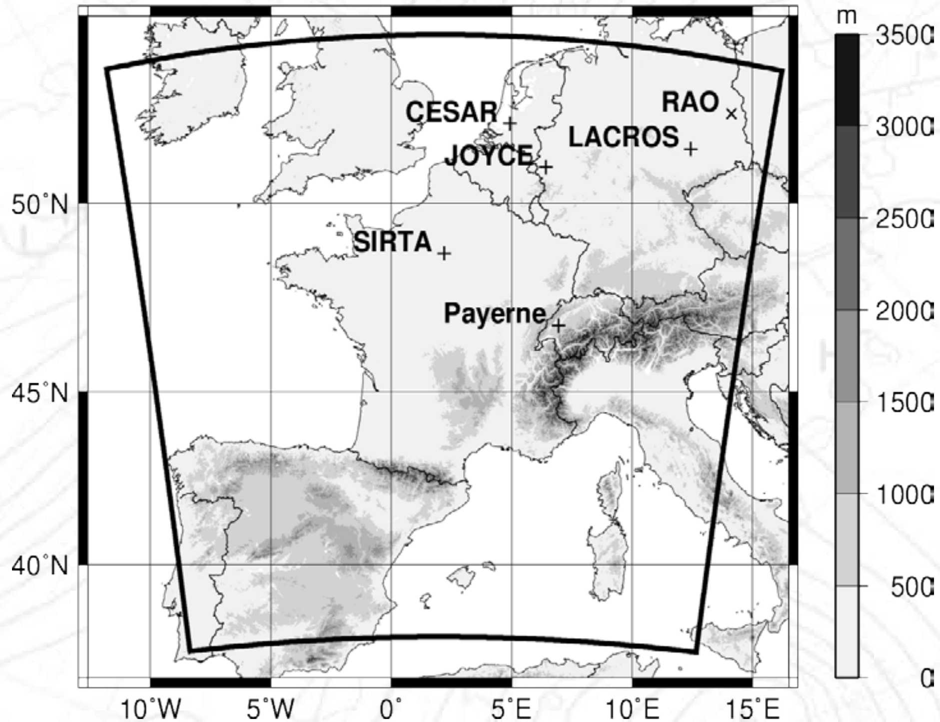
Forward model development

RTTOV-gb (De Angelis et al., Geosci. Model Develop., 2016)

- Ground-based fast forward model adapted from RTTOV
  - EUMETSAT NWP SAF RTTOV → RTTOV-gb
- RTTOV-gb is in experimental use at Meteo-France, DWD, U.Koeln
- RTTOV-gb was added to the GRUAN processor
- RTTOV-gb will be distributed by NWP SAF/MetOffice similarly to RTTOV

Unified tools + homogenization

- Prototype Network of 6 MWR mostly EU GRUAN sites
  - CESAR (NL)
  - JOYCE (DE)
  - LACROS (DE)
  - Payerne (CH)
  - RAO (DE)
  - SIRTA (FR)



- 1-year data set (2014)
- Homogenized processing …but **offline**!
- Observations minus Background (O-B)

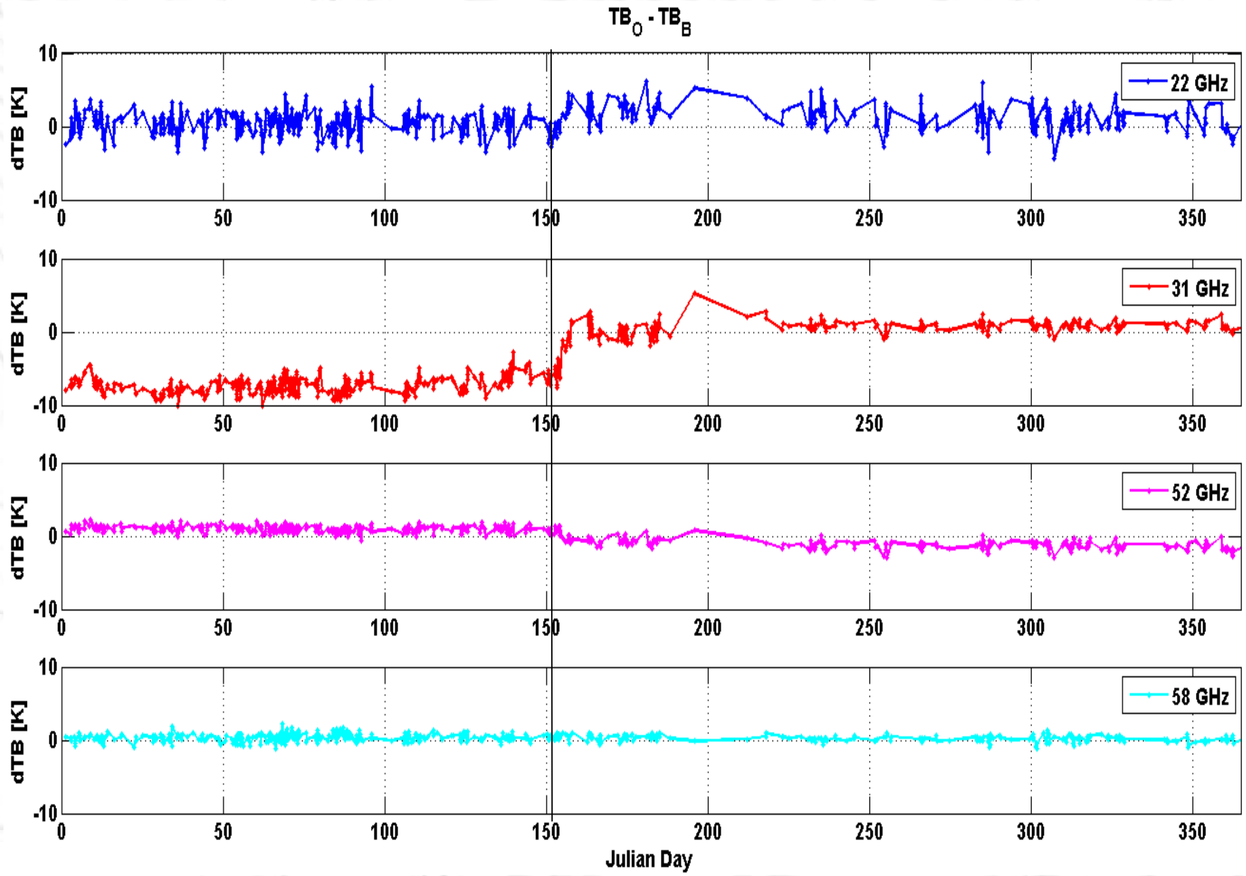
Obs: MWR T_B
Bkg: Simulated T_B

* De Angelis et al., Atm. Meas. Tech., 2017

Unified tools + homogenization

- O-B Temporal analysis (clear-sky)
- Automated QC
  - + Instrument native software

1-year O-B T_B (for JOYCE)



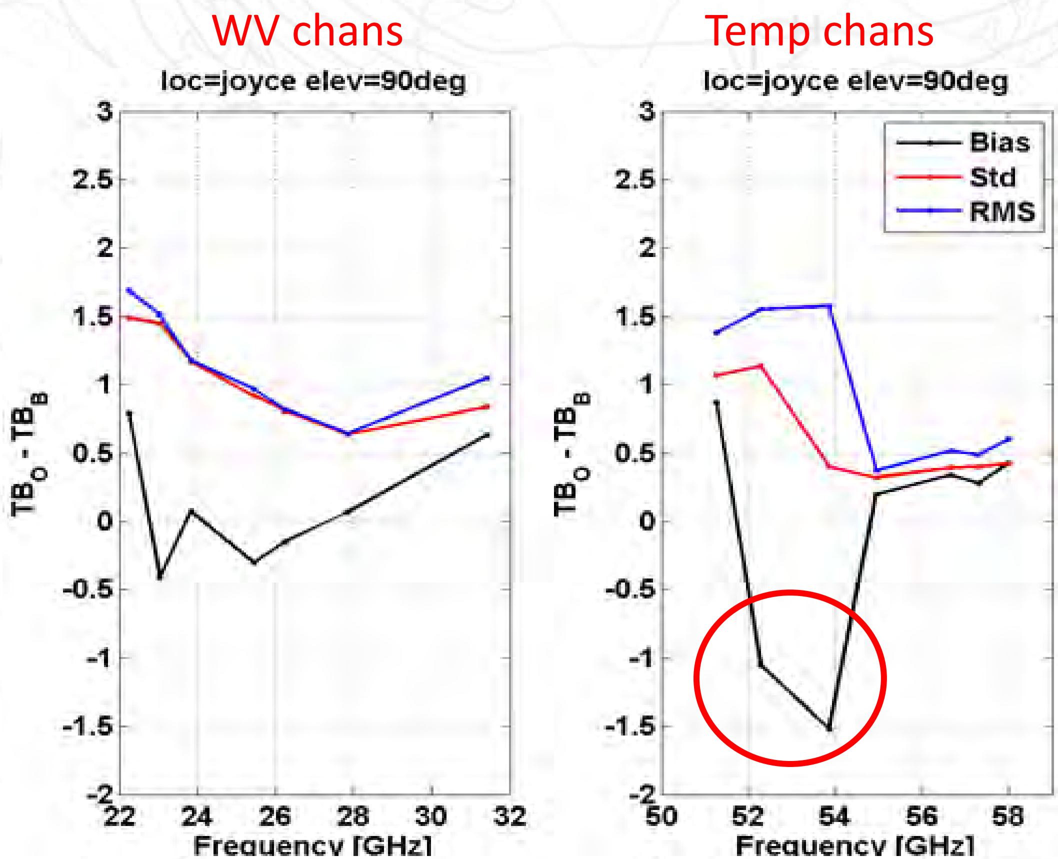
The black solid line represents the time of a new calibration (June 3rd, 2014).

De Angelis et al., AMT, 2017

Unified tools + homogenization

- O-B Spectral analysis

JOYCE, 90° only



Consistent stats throughout the network

clear sky screening
$T_{IR} < -30°C$ &
$\sigma_{Tb31GHz} < 0.5K$

Knowledge gap (GAIA-CLIM)

2. Missing MW absorption model uncertainty

- **Remedy**: Quantification of MW absorption uncertainty
  - Review literature (considering latest changes)
  - Propagate spectroscopic parameter uncertainty through radiative transfer
  - Quantify the impact on retrievals

2. Missing MW absorption model uncertainty

Note that reported uncertainties are NOT necessarily SI-traceable

Water Vapor Continuum

Parameter [units]	Meaning	Value	Uncertainty	Reference
Cf [km^{-1} mb^{-2} GHz^{-2}]	Foreign-broadened water vapor continuum coefficient	$5.43e^{-10}$	$5.56e^{-11}$	Rosenkranz 1998; Turner et al., 2009
Cs [km^{-1} mb^{-2} GHz^{-2}]	Self-broadened water vapor continuum coefficient	$1.8e^{-8}$	$3.245e^{-9}$	Rosenkranz 1998; Turner et al., 2009
Xf [unitless]	Foreign-broadened temperature dependence coefficient	3.0	0.6	Tretyakov, 2016
Xs [unitless]	Self-broadened temperature dependence coefficient	7.5	0.6	Tretyakov, 2016

Lines

Parameter [units]	Meaning	Value @22GHz	Uncertainty @22GHz	Value @183GHz	Uncertainty @183GHz	Reference
ν_0 [kHz]	Line frequency	22235079.85	0.05	183310087	1	Tretyakov, 2016
γ_a [MHz/mb]	Air-broadening parameter	2.7227	0.1050	2.9447	0.0150	Tretyakov, 2016
γ_w [MHz/mb]	Water-broadening parameter	13.2011	0.3750	14.7762	0.3750	Tretyakov, 2016
n_a [unitless]	Temperature-exponent of air-broadening	0.70	0.05	0.74	0.03	Tretyakov, 2016
n_w [unitless]	Temperature-exponent of water-broadening	1.20	0.05	0.78	0.08	Tretyakov, 2016
S [Hz/cm^2]	Line strength	$1.3161e^{-14}$	$1.2891e^{-16}$	$2.3222e^{-12}$	$2.3084e^{-14}$	Tretyakov, 2016
SR [unitless]	Shift to width ratio	$2.7548e^{-4}$	0.0275	-0.0245	0.0026	Tretyakov, 2016

2. Missing MW absorption model uncertainty

Oxygen

Note that reported uncertainties are NOT necessarily SI-traceable

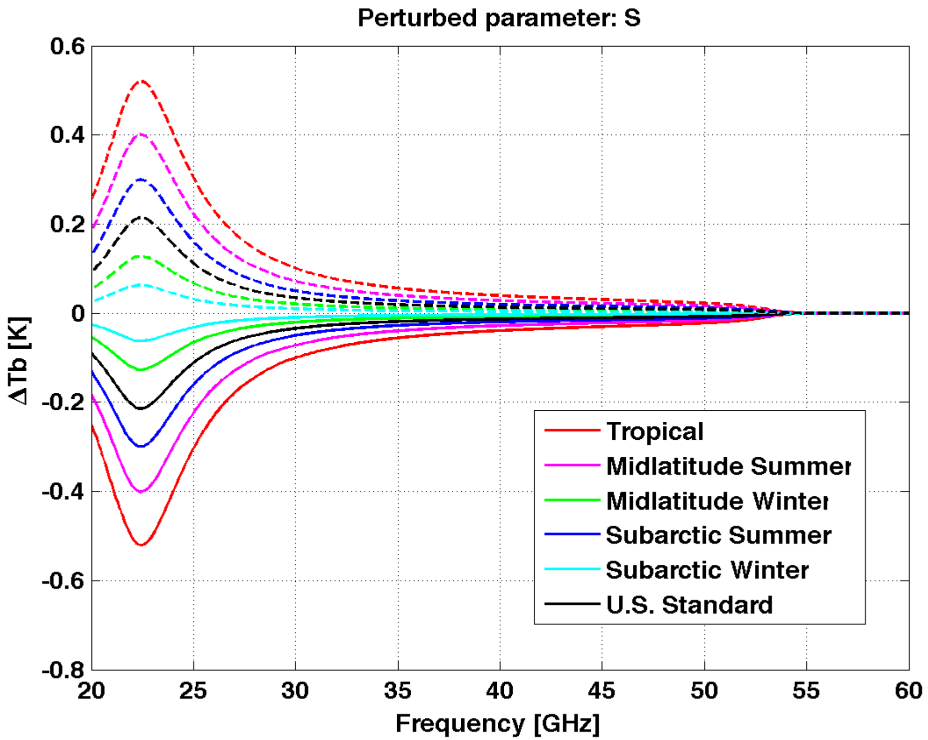
Par [units]	Meaning	Value	Uncertainty	Reference
APU [unitless]	Absorption Percentage Uncertainty (APU) due to line mixing parameters	1.00	0.02	Makarov et al. 2011
X [unitless]	Temperature dependence of broadening coefficient for O_2 lines	0.80*	0.05*	Tretyakov et al., 2005
w2a [unitless]	Water-to-air broadening ratio	1.20	0.05	Koshelev et al. 2015
ν_0 [kHz]	Line frequency	Table 1	Table 1	Tretyakov et al., 2005
S [Hz/cm^2]	Line strength	HITRAN, 2012	1%	Tretyakov, Pers. Comm. 2016
B_e [unitless]	Temperature-exponent for strength	HITRAN, 2012	<1%	Tretyakov, Pers. Comm. 2016
γ_i [MHz/mb]	Pressure-broadening parameter	Table 5	Table 1 + calculations	Tretyakov et al., 2005 Rosenkranz, 2017 Pers. Comm.
γ_0 [MHz/mb]	Non-resonant pressure broadening width	Table 5	15%	Rosenkranz, 2017 Pers. Comm.
Y [1/bar]	Mixing coefficients	Table	Table	Rosenkranz, 2017 Pers. Comm.
V [1/bar]	Mixing coefficients temperature dependence	Table 5 (last column)	20%	Rosenkranz, 2017 Pers. Comm.

2. Missing MW absorption model uncertainty

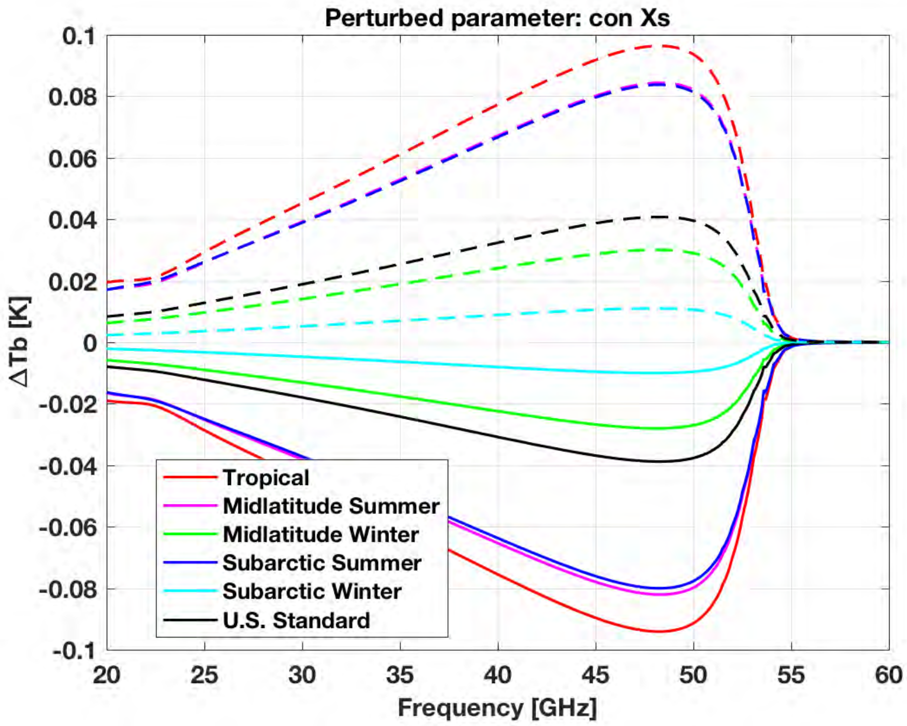
- Sensitivity to spectroscopic parameter uncertainty

$$\Delta T_B = T_B(P_i) \pm T_B(P_i \pm \sigma_{Pi})$$

WV line strength @ 22.2 GHz

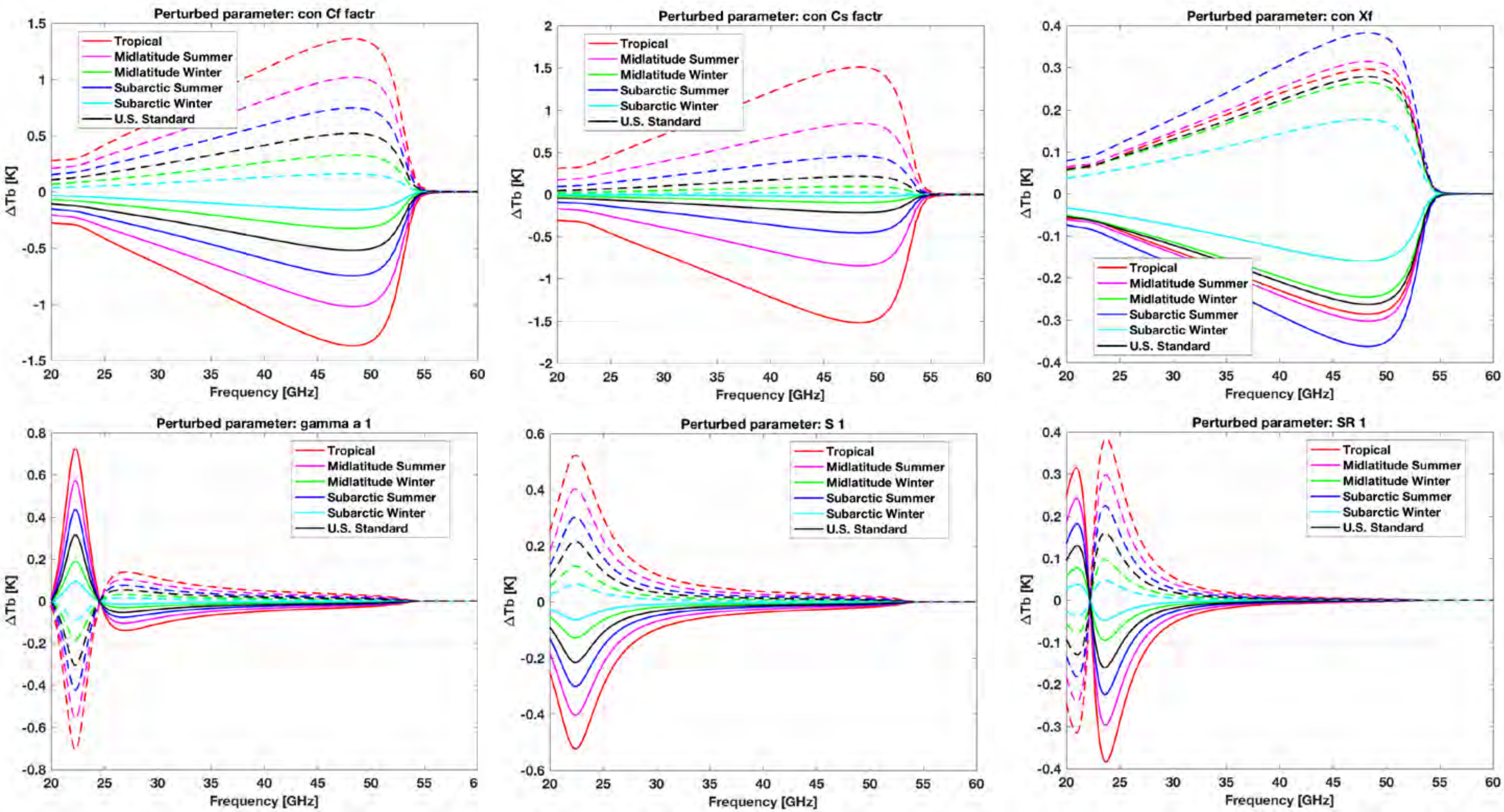


WV self-continuum T exponent



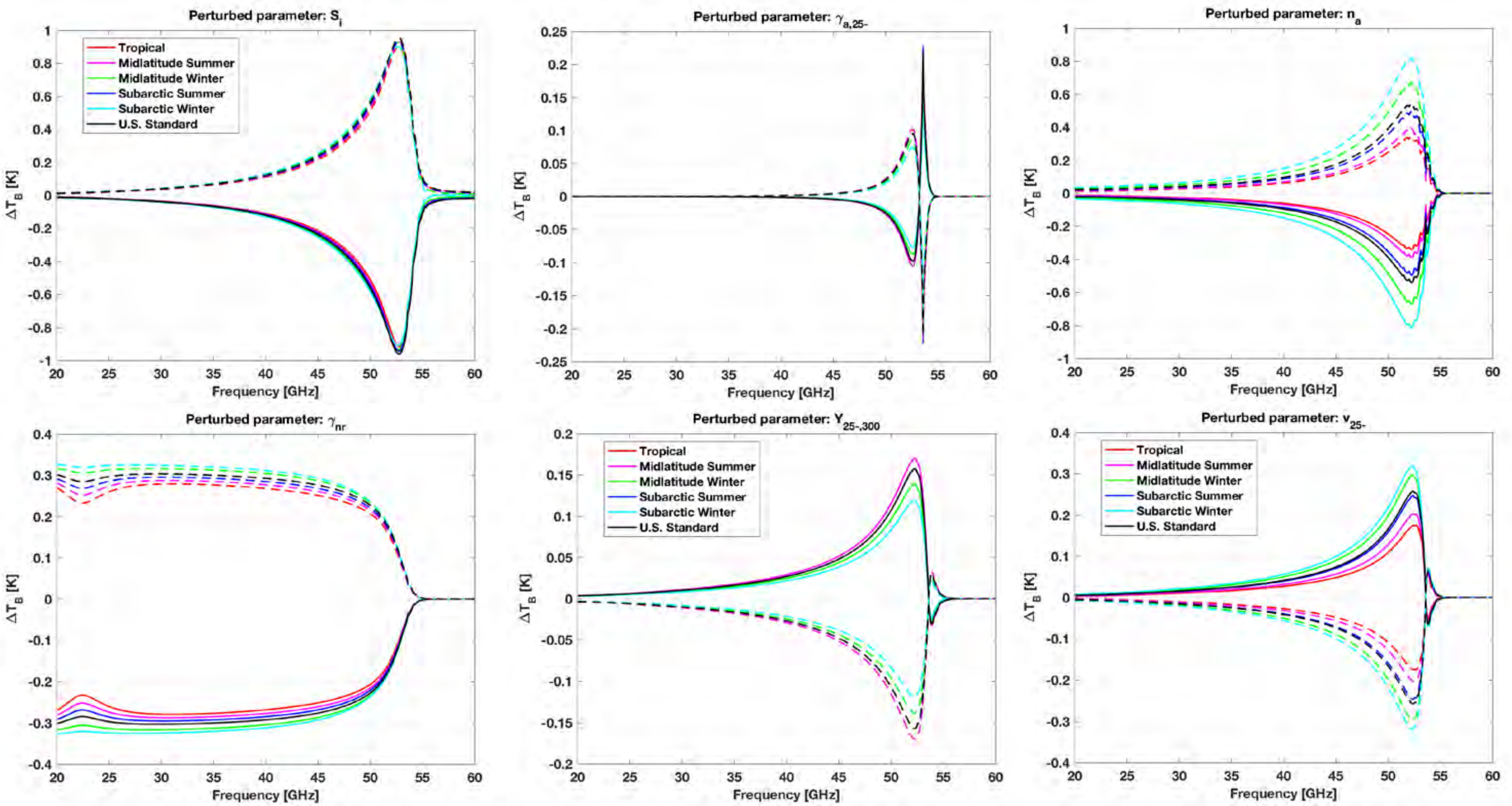
2. Missing MW absorption model uncertainty

- H_2O: Among 21 parameters, 6 are found to be dominating



2. Missing MW absorption model uncertainty

- O_2: Among 298 parameters, 105 are found to be dominating



2. Missing MW absorption model uncertainty

- Once the dominant terms are determined, uncertainty shall be propagated

$$\boldsymbol{S}_{y_p} = \boldsymbol{K}_p * \boldsymbol{S}_p * \boldsymbol{K}_p{}^T$$

$\boldsymbol{S}_p$ Uncertainty covariance matrix of spectroscopic parameters p

$\boldsymbol{K}_p$ Jacobian of the measurement with respect to spectroscopic parameters

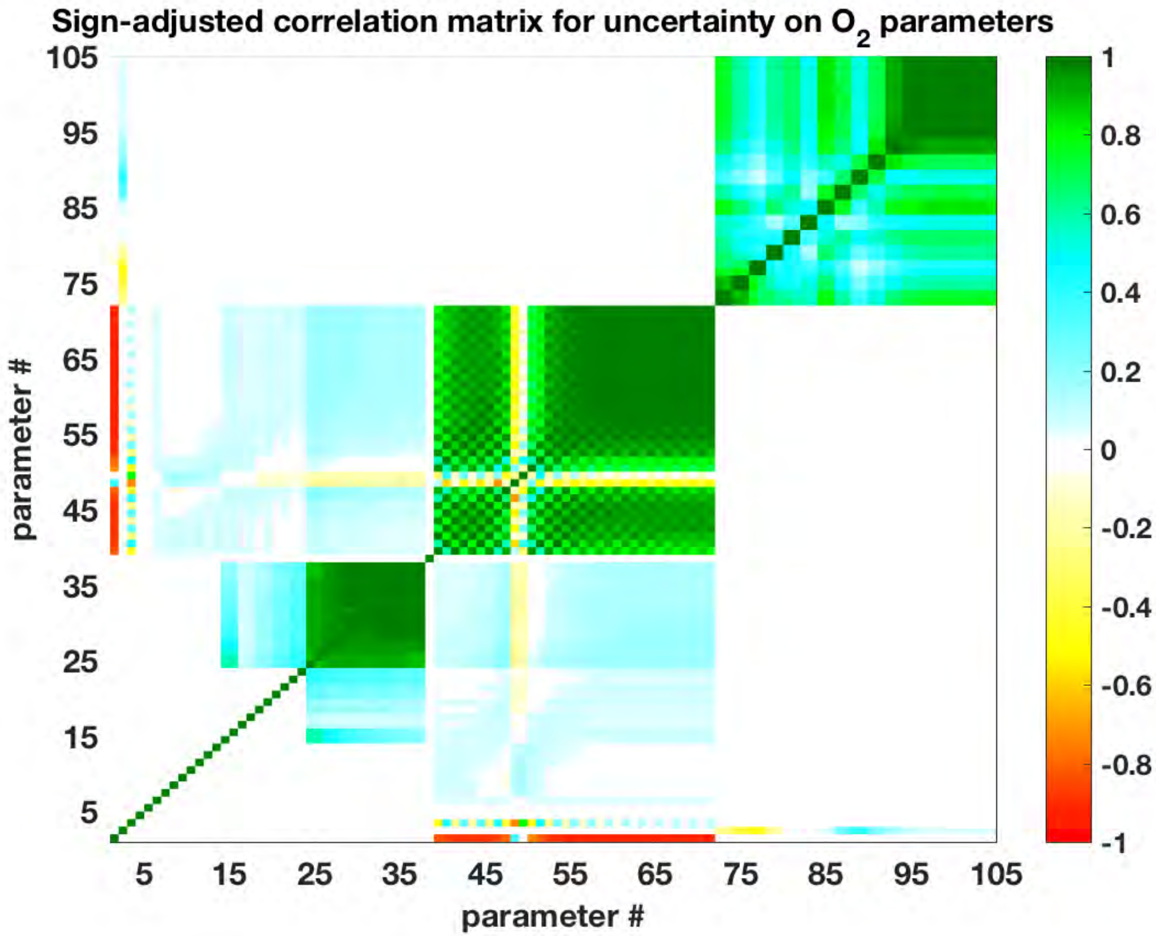
$\boldsymbol{S}_{y_p}$ Simulated measurement uncertainty covariance matrix due to p

- Off-diagonal terms of $\boldsymbol{S}_p$ are also important!

2. Missing MW absorption model uncertainty

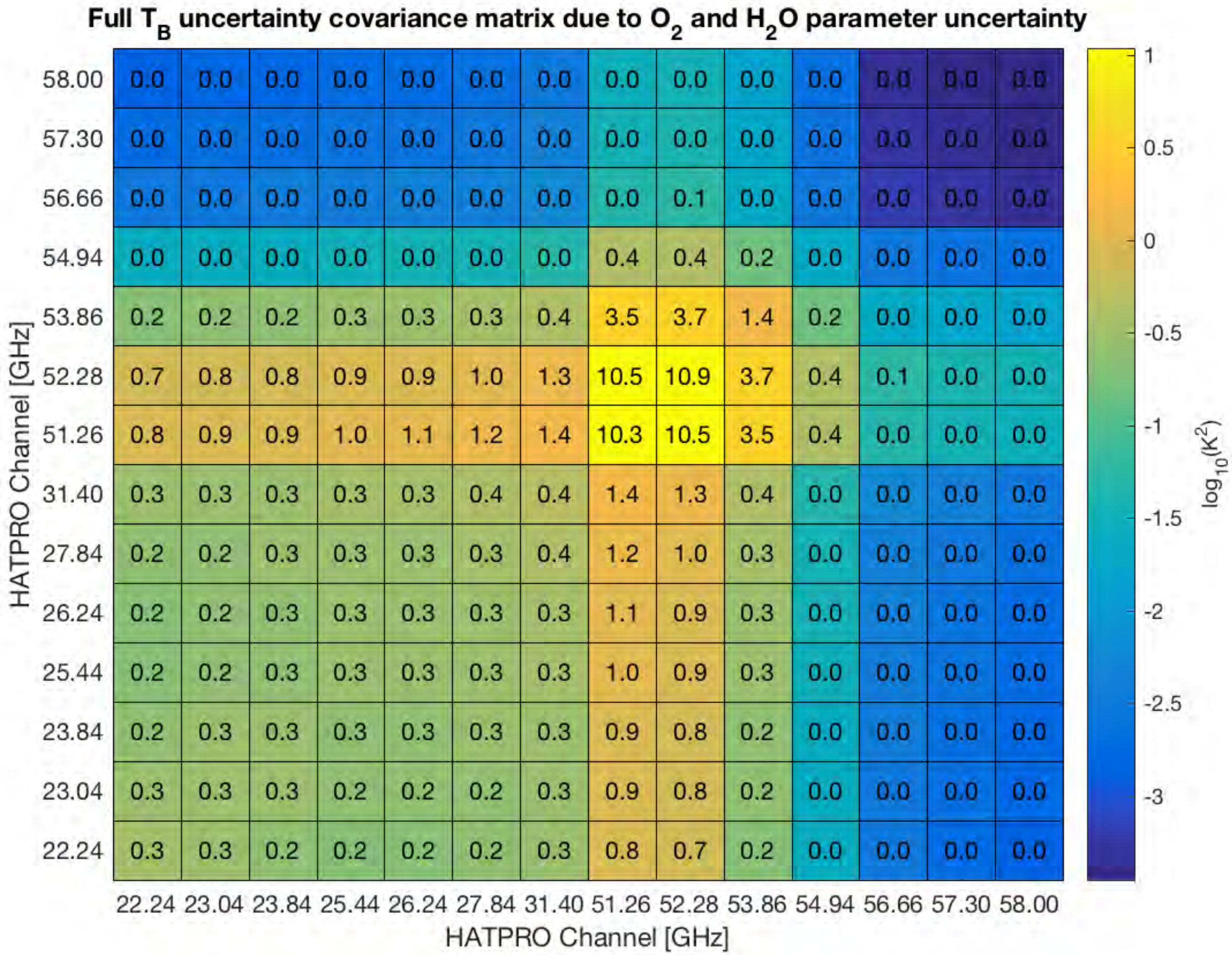
Parameter uncertainty covariance

- Contribution from: Phil Rosenkranz (MIT, USA), Misha Tretyakov, Maksim Koshelev (IAP, RAS, RU)



2. Missing MW absorption model uncertainty

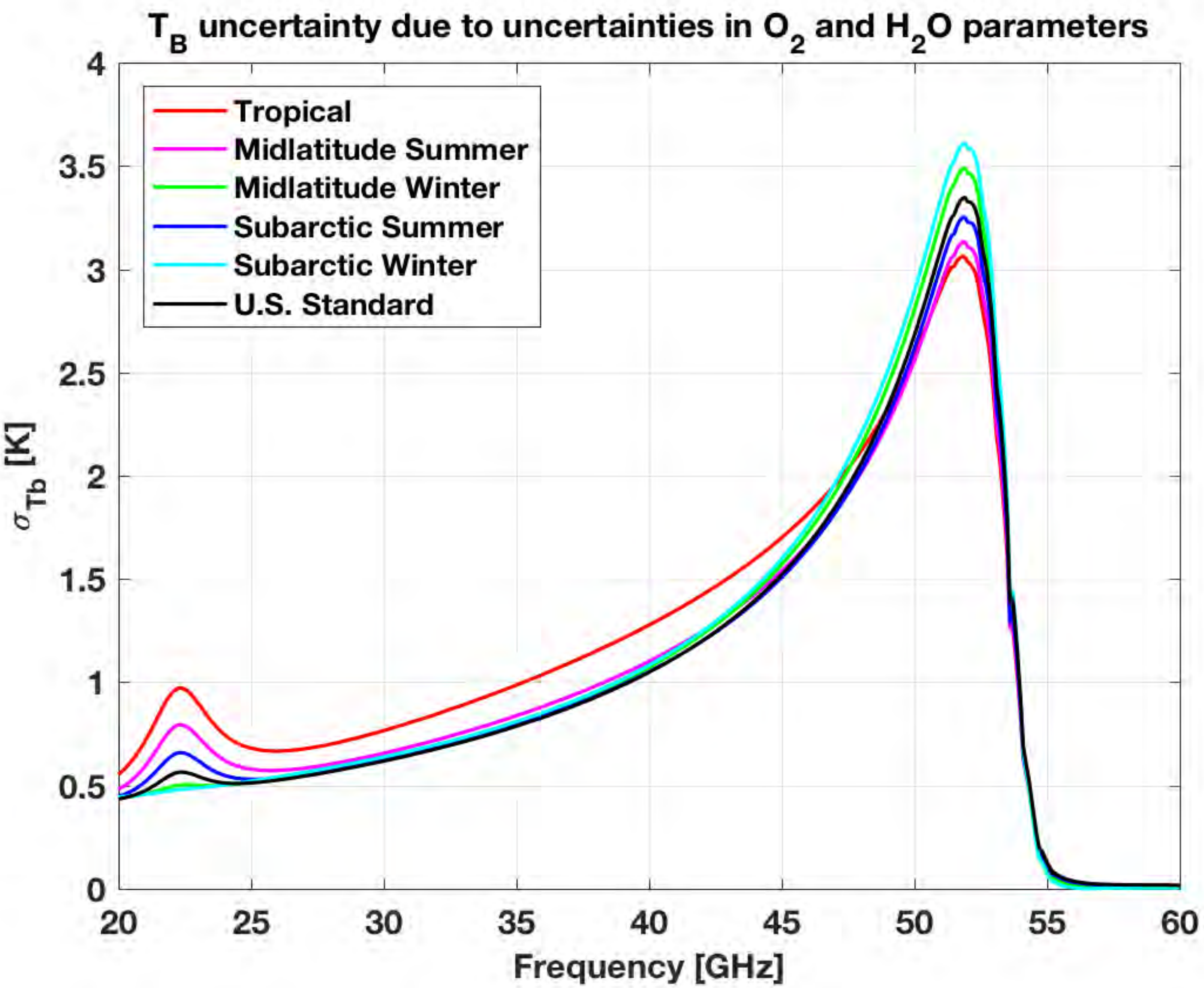
- Total T_B uncertainty (full matrix)



HATPRO Channel [GHz]	22.24	23.04	23.84	25.44	26.24	27.84	31.40	51.26	52.28	53.86	54.94	56.66	57.30	58.00
58.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
57.30	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
56.66	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0
54.94	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.4	0.2	0.0	0.0	0.0	0.0
53.86	0.2	0.2	0.2	0.3	0.3	0.3	0.4	3.5	3.7	1.4	0.2	0.0	0.0	0.0
52.28	0.7	0.8	0.8	0.9	0.9	1.0	1.3	10.5	10.9	3.7	0.4	0.1	0.0	0.0
51.26	0.8	0.9	0.9	1.0	1.1	1.2	1.4	10.3	10.5	3.5	0.4	0.0	0.0	0.0
31.40	0.3	0.3	0.3	0.3	0.3	0.4	0.4	1.4	1.3	0.4	0.0	0.0	0.0	0.0
27.84	0.2	0.2	0.3	0.3	0.3	0.3	0.4	1.2	1.0	0.3	0.0	0.0	0.0	0.0
26.24	0.2	0.2	0.3	0.3	0.3	0.3	0.3	1.1	0.9	0.3	0.0	0.0	0.0	0.0
25.44	0.2	0.2	0.3	0.3	0.3	0.3	0.3	1.0	0.9	0.3	0.0	0.0	0.0	0.0
23.84	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.9	0.8	0.2	0.0	0.0	0.0	0.0
23.04	0.3	0.3	0.3	0.2	0.2	0.2	0.3	0.9	0.8	0.2	0.0	0.0	0.0	0.0
22.24	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.8	0.7	0.2	0.0	0.0	0.0	0.0

2. Missing MW absorption model uncertainty

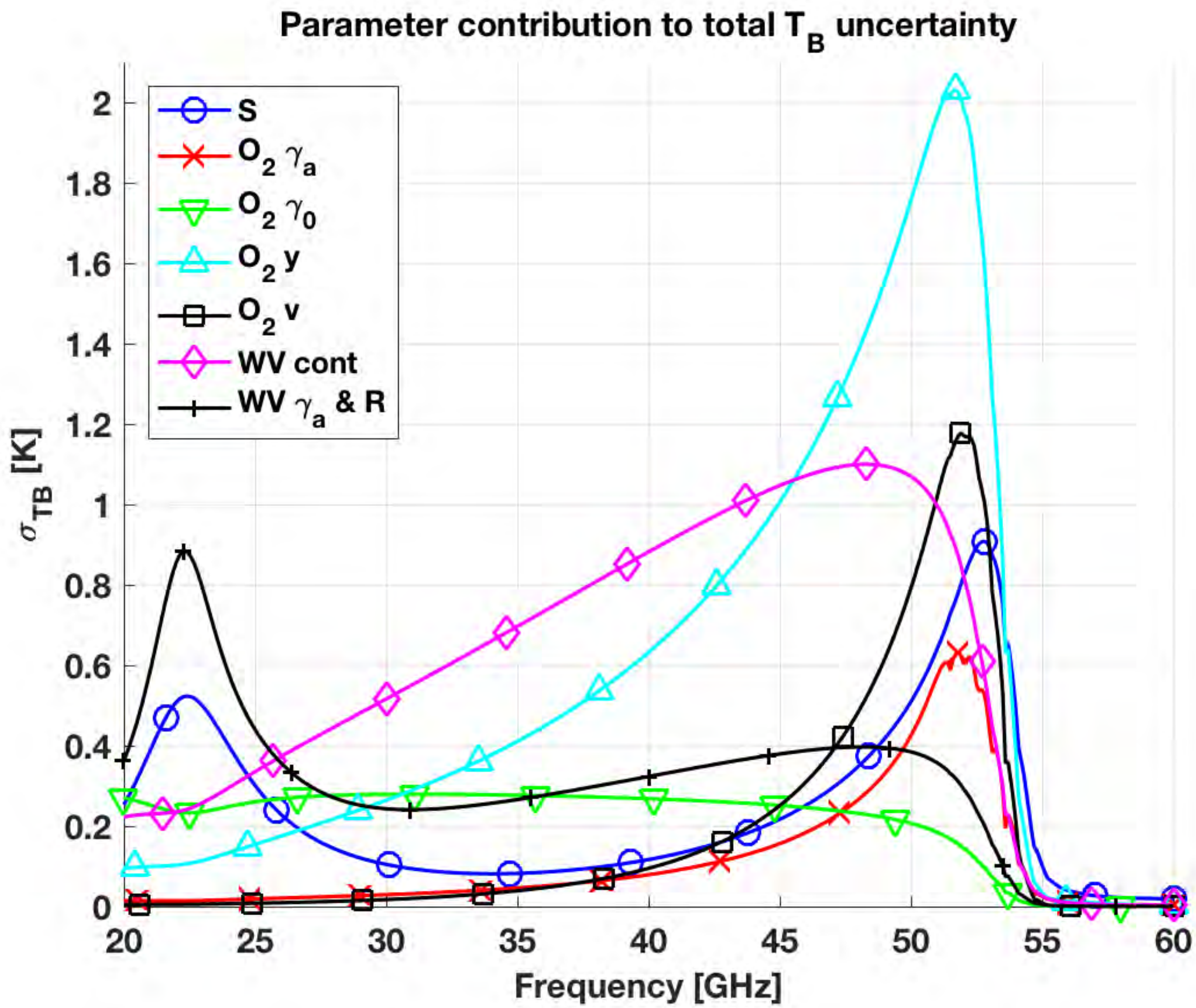
- Total T_B uncertainty (diagonal terms)



2. Missing MW absorption model uncertainty

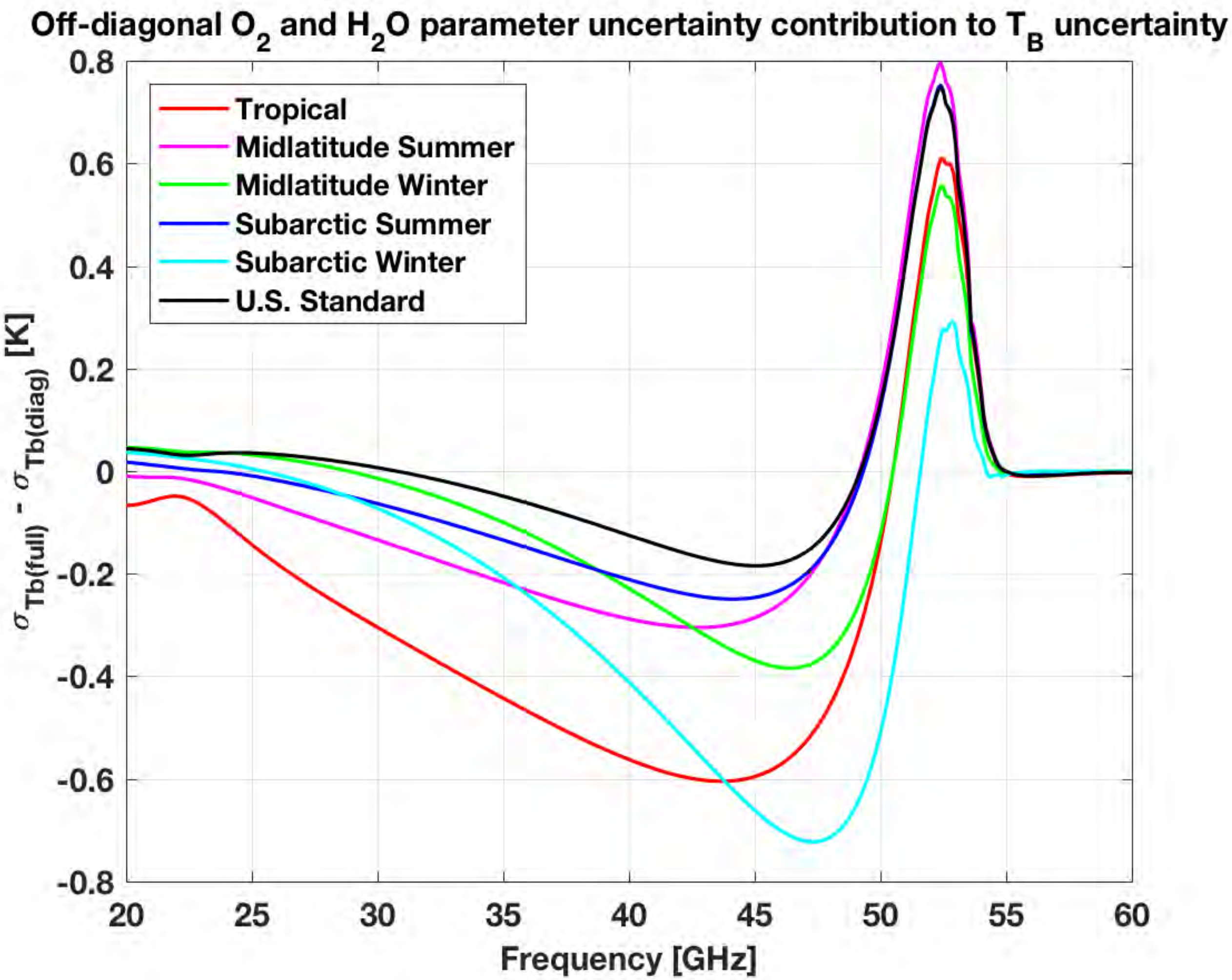
- Contributions T_B uncertainty

Tropical atmosphere



2. Missing MW absorption model uncertainty

- Off-diagonal terms contributions to T_B uncertainty



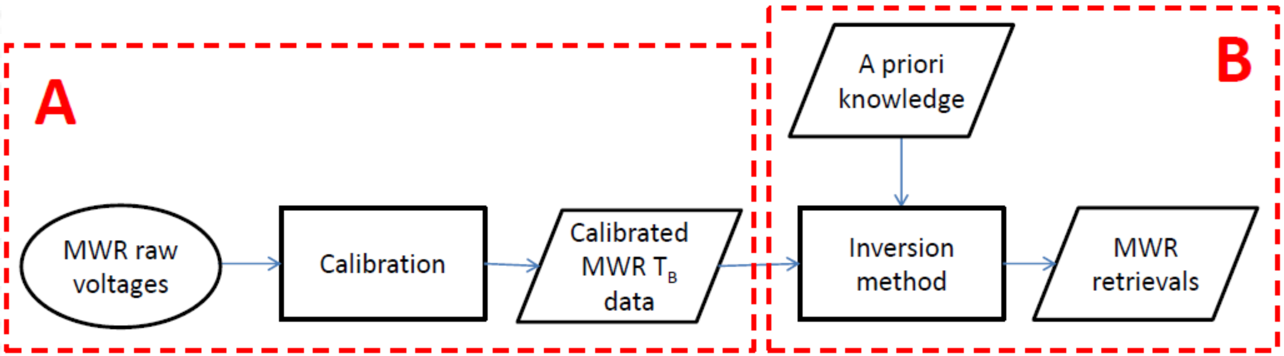
Cimini et al., Uncertainty of atmospheric absorption model in the 20-60 GHz range: impact on ground-based MWR simulations and retrievals, to be submitted to ACP.

MWR measurement model diagram (GAIA-CLIM)

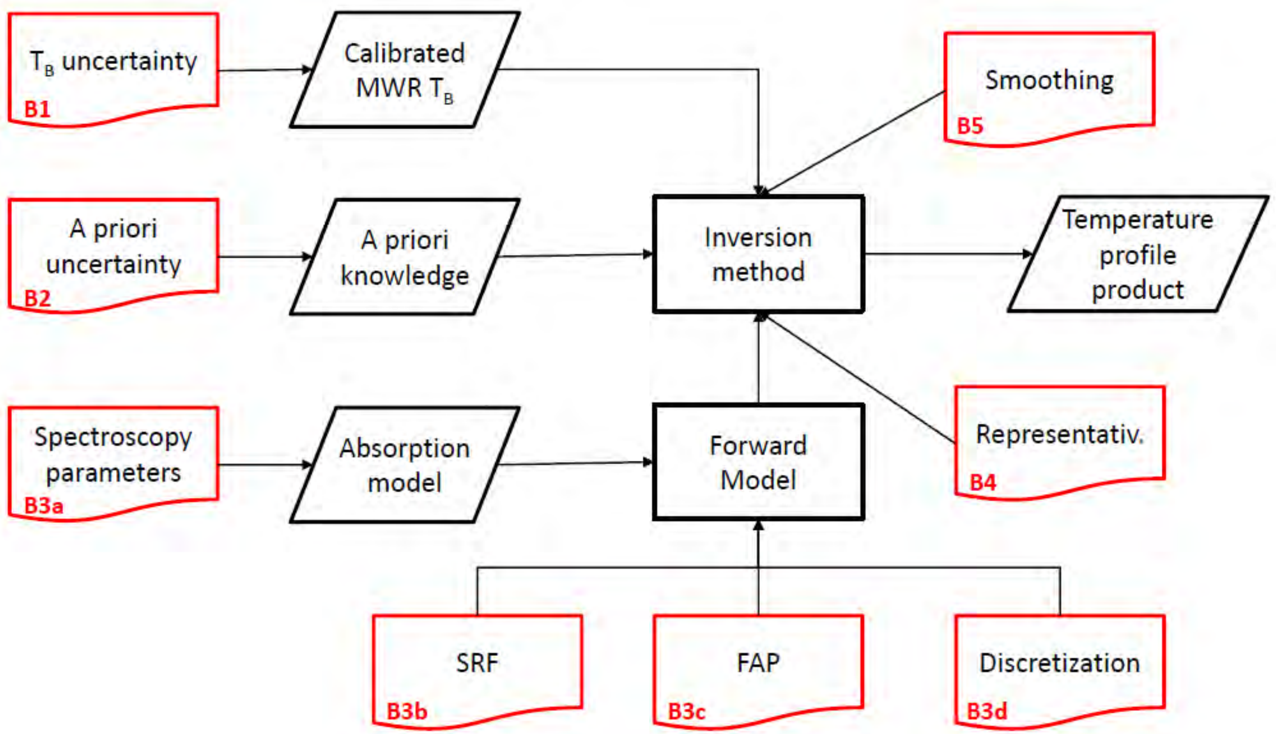
A visual sketch of the processing steps leading to a product and its traceability chain

It helps understanding all the uncertainty contributions to be considered

MWR measurement: Main Chain

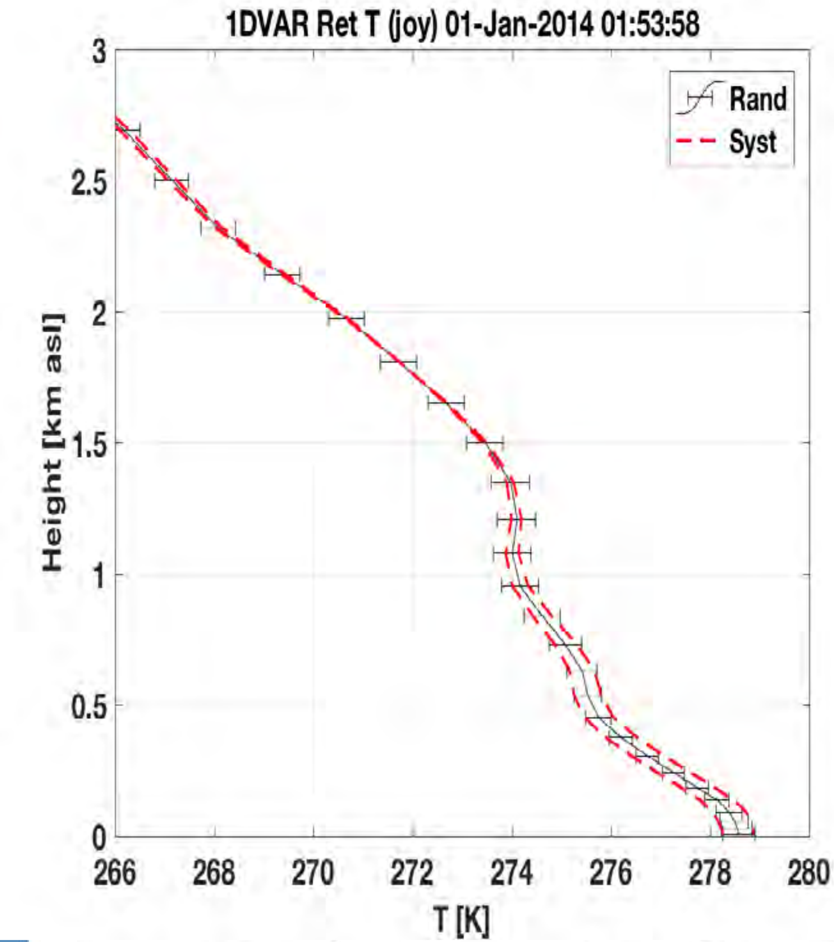


MWR temperature profile product

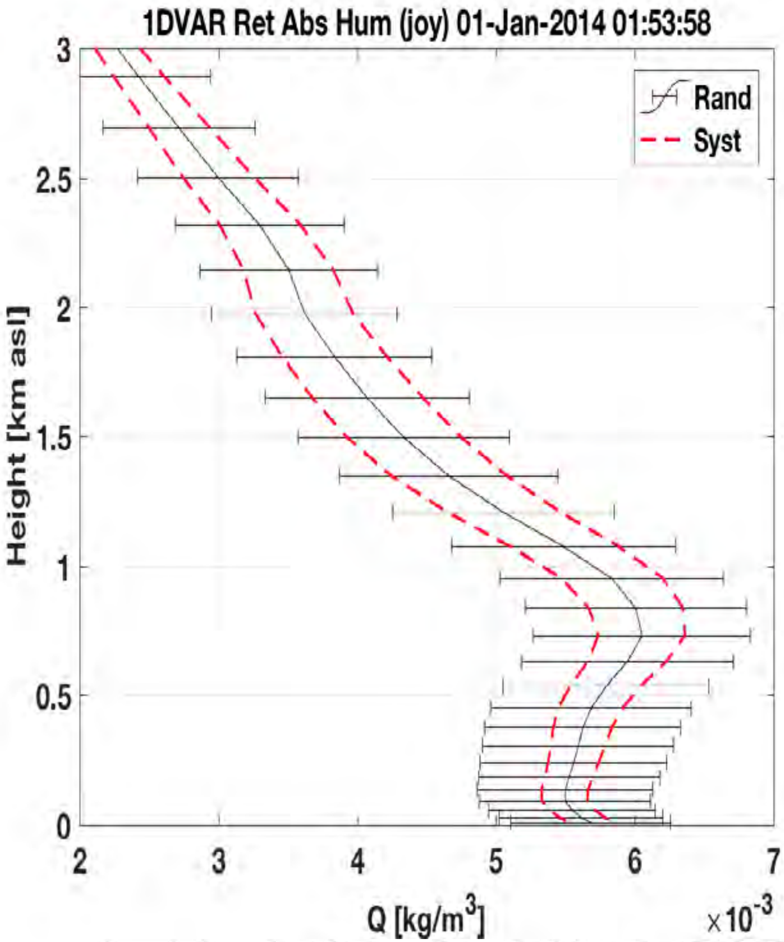


Examples of MWR products with uncertainty

Temperature

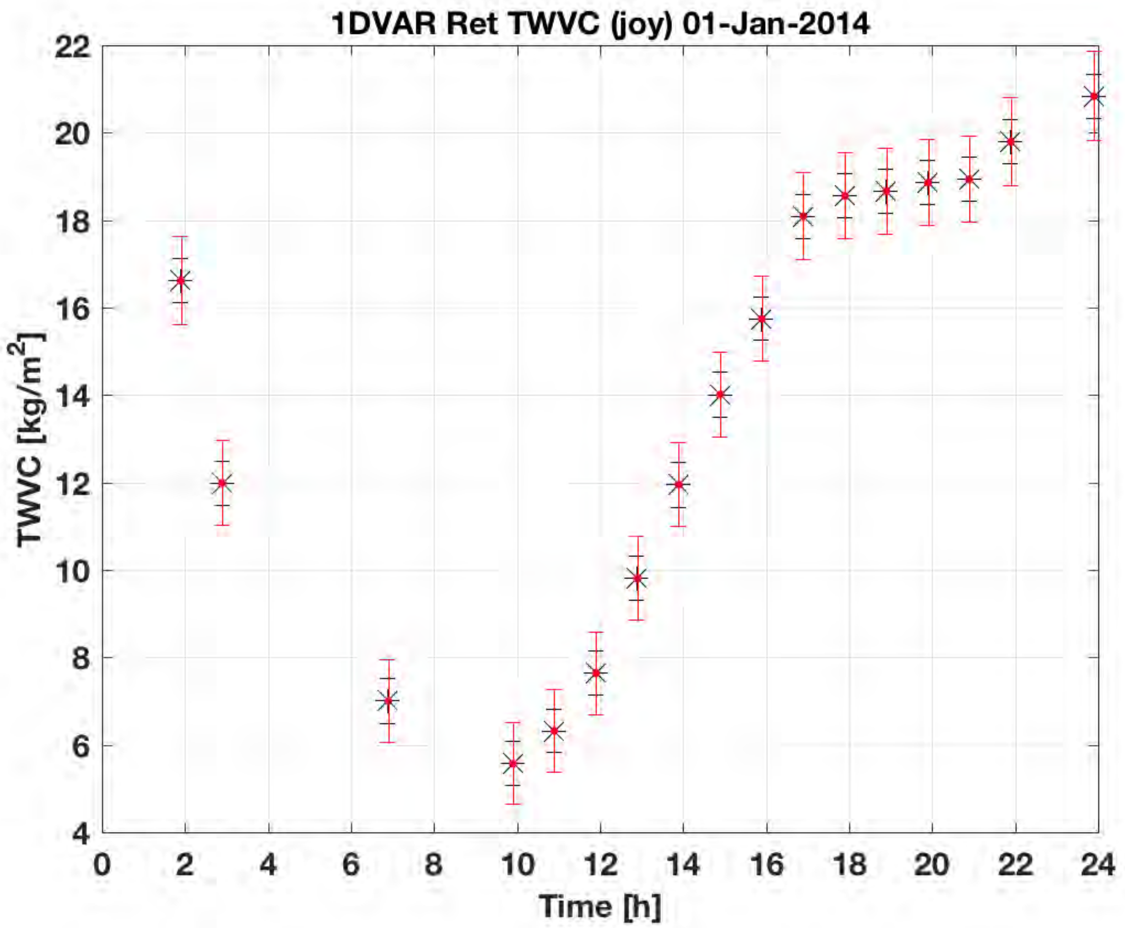


Specific Humidity



Examples of MWR products with uncertainty

Total Water Vapor Column



What’s missing for a GRUAN MWR product?

- Implementation of automatic MWR data product
  - Who shall/could develop this?
  - Centralized data processing facility?

- Current observation accuracy corresponds to >10-year old technology
  - much better characterization of new generation instruments
  - not currently available at GRUAN sites

What's missing for full SI-traceability?

1. MW transfer standard calibration targets
   - NIST is working on this development
2. Certified internal temperature sensors
   - Manufacturers should provide certifications
3. Uncertainties on *a priori* model background and radiative transfer model are not SI-traceable

Summary and conclusions

- First draft of MWR Program Guide is on hold
  - GRUAN MWR Program Guide TD-N.1.0
- Prototype uniform procedure is available
- MWR SI-treaceability needs a breakthrough
  - Partially being addressed at NIST

Thank you very much for your attention!