In response to EUMETSAT Invitation Tender ITT 22/224312

Development of VIcarious Calibration tool for MWI and ICI using RadioSoundings (VICIRS)

Final Review Meeting, 4 March 2024

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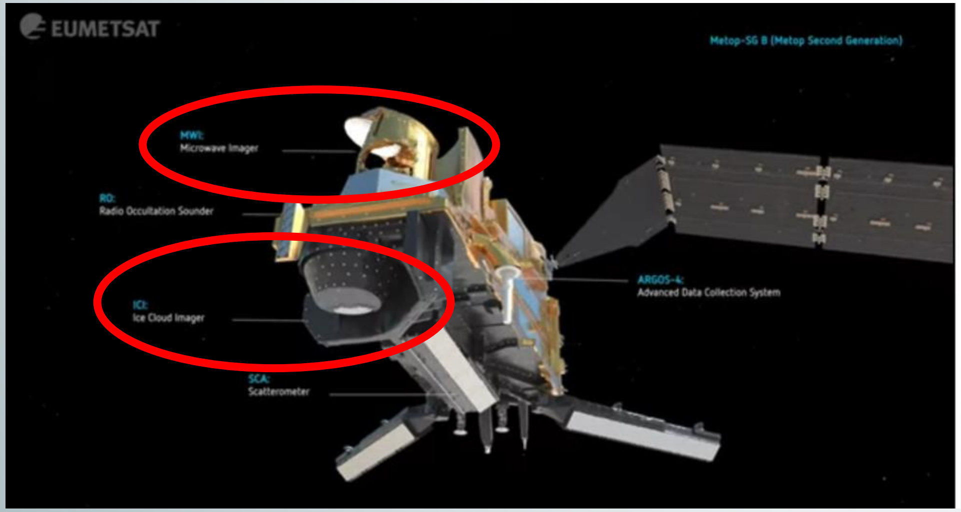
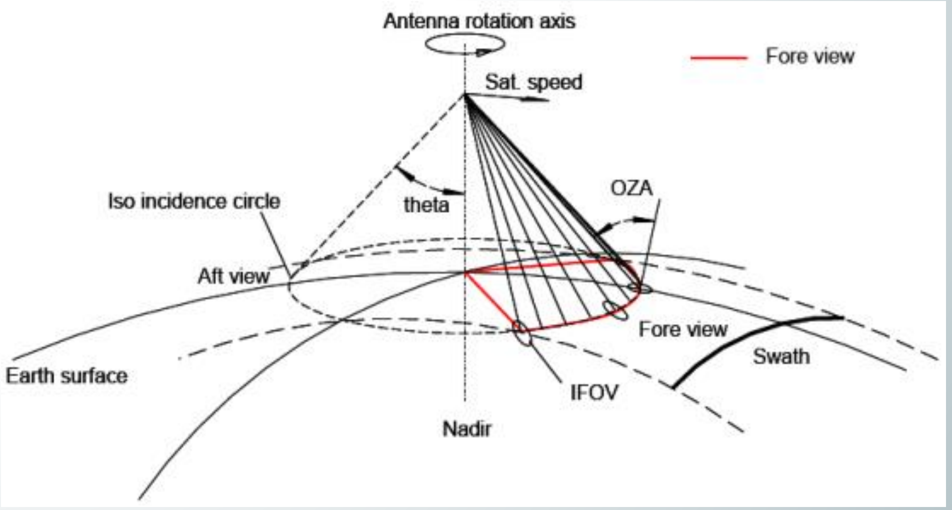
INTRODUCTION

Objective: develop a vicarious calibration and validation (Cal/Val) tool to compare MWI and ICI observations against radiosoundings.

Vicarious calibration: post-launch calibration based on targets imaged near-coincidently by the sensor to be calibrated and by one or more well-calibrated sensors (from satellites, aircraft, balloon or ground).

MicroWave Imager (MWI) and Ice Cloud Imager (ICI) are conical-scanning microwave radiometers that will fly from 2025 onward aboard the 2nd generation European Polar Satellites (METOP-SG-B).





VICIRS

INTRODUCTION

MWI

- 26 channels centred at 18 frequency bands (from 18 to 183 GHz)

Main applications:

- cloud/precipitation in support of NWP
- ocean surface (wind speed, sea ice)
- MW legacy in support of long-term climate records

Channel	Frequency (GHz)	Bandwidth(MHz)	NEDT (K)	Radiometric Bias (K)	Polarization	Footprint Size at 3dB (km)
MWI-1	18.7	200	0.8	1.0	V, H	50
MWI-2	23.8	400	0.7	1.0	V, H	50
MWI-3	31.4	200	0.9	1.0	V, H	30
MWI-4	50.3	180	1.1	1.0	V, H	30
MWI-5	52.7	180	1.1	1.0	V, H	30
MWI-6	53.24	400	1.1	1.0	V, H	30
MWI-7	53.750	400	1.1	1.0	V, H	30
MWI-8	89.0	4000	1.1	1.0	V, H	10
MWI-9	118.7503±3.20	2x500	1.3	1.0	V	10
MWI-10	118.7503±2.10	2x400	1.3	1.0	V	10
MWI-11	118.7503±1.40	2x400	1.3	1.0	V	10
MWI-12	118.7503±1.20	2x400	1.3	1.0	V	10
MWI-13	165.5±0.75	2x1350	1.2	1.0	V	10
MWI-14	183.31±7.0	2x2000	1.3	1.0	V	10
MWI-15	183.31±6.1	2x1500	1.2	1.0	V	10
MWI-16	183.31±4.9	2x1500	1.2	1.0	V	10
MWI-17	183.31±3.4	2x1500	1.2	1.0	V	10
MWI-18	183.31±2.0	2x1500	1.3	1.0	V	10

Incidence angles within 53°±2°
Observations acquired ± 65° in azimuth in the fore view (about 1700 km swath)
Footprints overlap ≥20%.
Spatial sampling: ~9 km along track ,~2.5 km across track.

VICIRS

INTRODUCTION

ICI

- 13 channels centred at 11 frequency bands (from 183 to 664 GHz)

Main applications:

- ice cloud products for climate monitoring
- information on non-precipitating ice

Channel	Frequency (GHz)	Bandwidth (MHz)	NEDT (K)	Radiometric Bias (K)	Polarization	Footprint Size at 3dB (km)
ICI-1	183.31±7.0	2x2000	0.8	1	V	16
ICI-2	183.31±3.4	2x1500	0.8	1	V	16
ICI-3	183.31±2.0	2x1500	0.8	1	V	16
ICI-4	243.2±2.5	2x3000	0.7	1.5	V, H	16
ICI-5	325.15±9.5	2x3000	1.2	1.5	V	16
ICI-6	325.15±3.5	2x2400	1.3	1.5	V	16
ICI-7	325.15±1.5	2x1600	1.5	1.5	V	16
ICI-8	448±7.2	2x3000	1.4	1.5	V	16
ICI-9	448±3.0	2x2000	1.6	1.5	V	16
ICI-10	448±1.4	2x1200	2.0	1.5	V	16
ICI-11	664±4.2	2x5000	1.6	1.5	V, H	16

Incidence angles within 53°±2°

Observations acquired ± 65° in azimuth in the fore view (about 1700 km swath)

Footprints overlap ≥40%.

Spatial sampling: ~9 km along track ,~2.5 km across track.

VICIRS

INTRODUCTION

Why vicarious calibration against radiosoundings?

Crucial for unprecedented channels
(ICI-4 : ICI-11), (MWI-9 : MWI-12)*

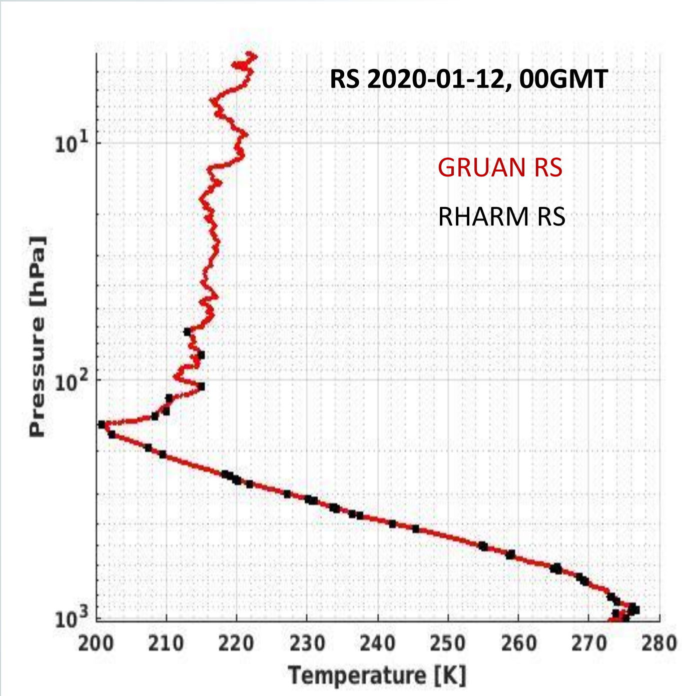
Processed with RTM to compute simulated observations (Brightness Temperature BT)

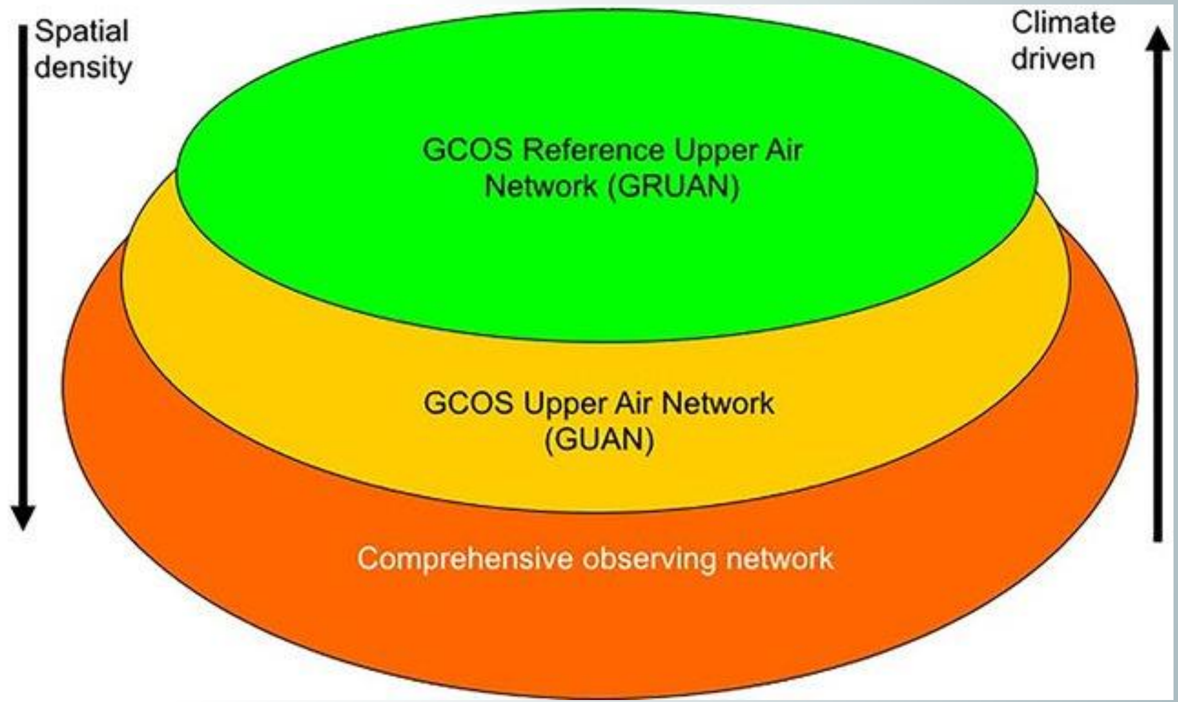
How to characterize the uncertainty of simulated BT?

* Except for TROPICS

INTRODUCTION

Propagating radiosounding uncertainties





What radiosonde archive?

GCOS tiered-network concept

Seidel et al., 2009

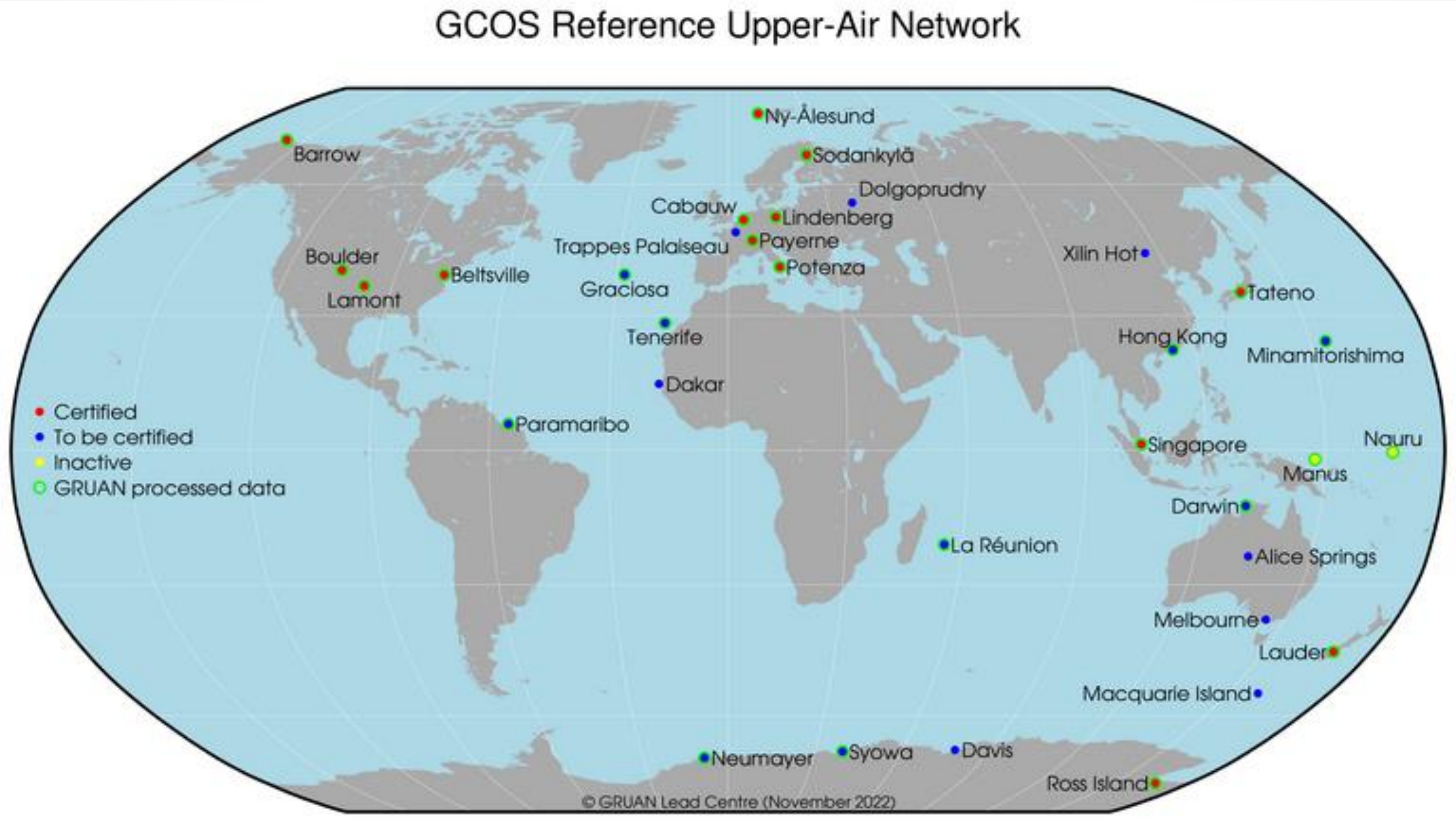
RADIOSONDE OBSERVATIONS

Global Climate Observing System (GCOS) Reference Upper-Air Network (GRUAN)

• homogeneous and fully traceable - with quantified uncertainties

• 31 sites, 14 of which have been GRUAN certified

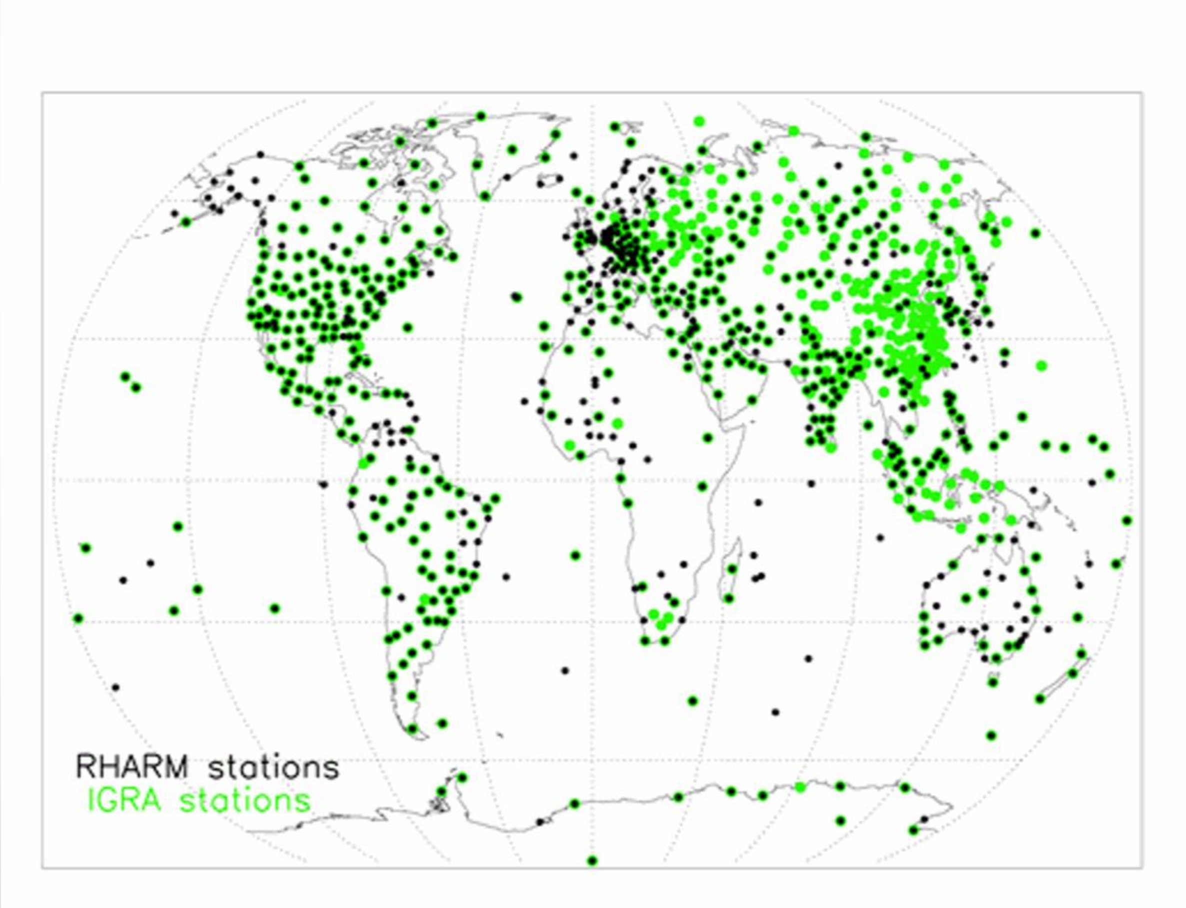
• 23 with active data streams (other under implementation)



RADIOSONDE OBSERVATIONS

Copernicus Climate Change Service (C3S), Radiosounding HARMonization (RHARM)

- bias-adjusted radiosounding observations from the Integrated Global Radiosonde Archive (IGRA)
- estimated uncertainties (building on GRUAN expertise and intercomparison data)
- 700 sites (+ ships)



(Madonna et al., 2022)

ROADMAP *TO VICIRS*

VIcarious **C**alibration and validation tool to compare MWI and **I**CI observations to **R**adio**S**oundings
VICIRS

Task 1
Critical review of literature methods

Task 2
Methodology analysis

Task 3
Development of VICIRS tool

Task 4
Testing of VICIRS tool on real and simulated obs

INTRODUCTION TO VICIRS TOOL: OVERVIEW

Uncertainty analysis

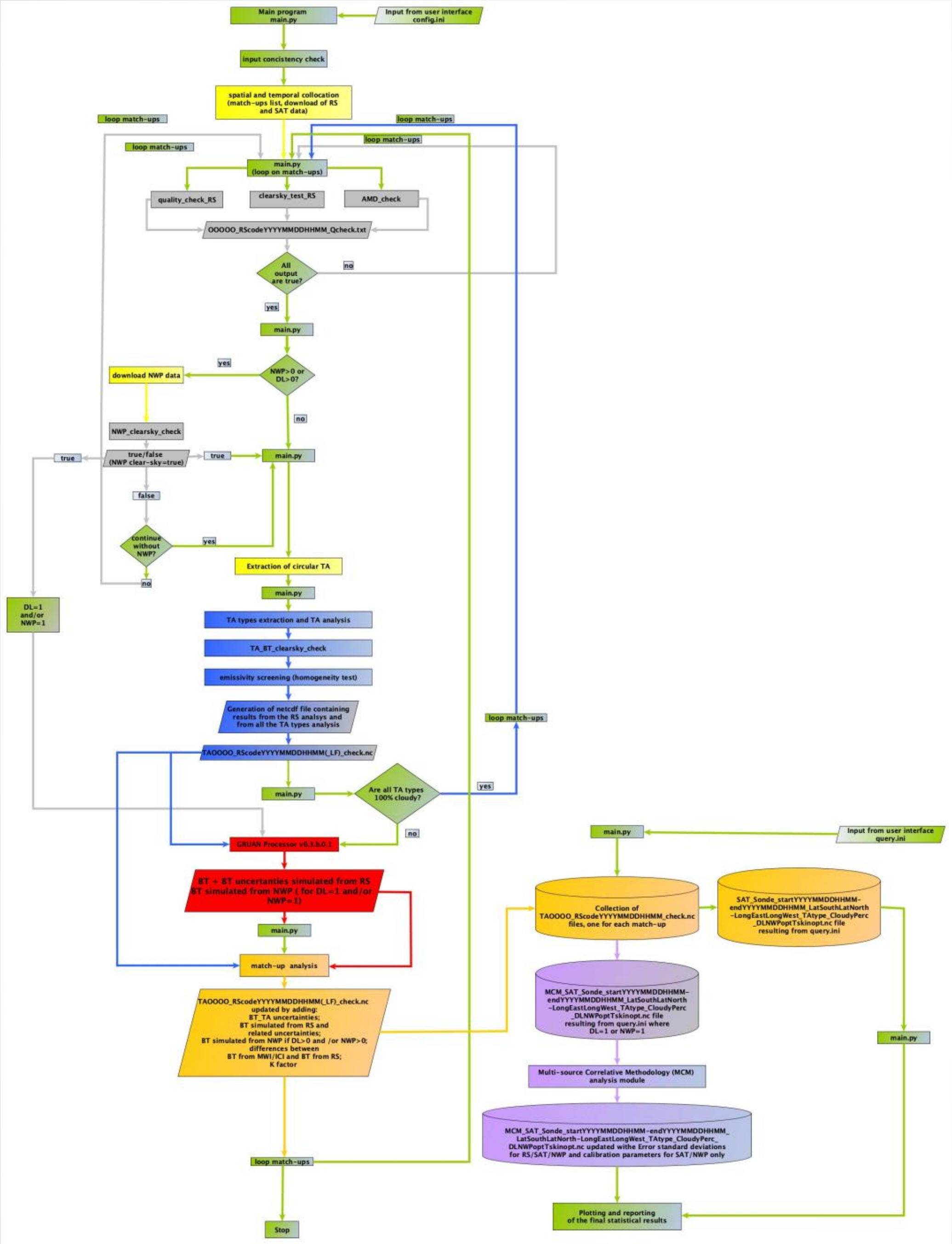
RS GRUAN
RS RHARM

NWP

VICIRS TOOL

- match-ups collection
- input analysis
- simulation of BT from RS (and NWP)
- reporting and plotting statistics

VICIRS TOOL FLOWCHART



Step *: Input/output management, decision loop and plotting/reporting management

STEP I: match-ups search; data download

STEP II: RS quality check; RS and NWP clear-sky check; RS AMD test

STEP III: TA types extraction, TA clear-sky check and emissivity screening

STEP IV: BT simulation

Step V: bias and uncertainties analysis

Step VI: Multisource Correlative Methodology analysis (MCM)

FIRST PHASE: DATA COLLECTION

Flexible input

- radiosonde archive: → GRUAN & RHARM
- temporal range: → aaaa-mm-dd hh:mm (start) to aaaa-mm-dd hh:mm (end)
  $-15' \leq \Delta t \leq 45'$
- temporal distance: → -1 hour $\leq \Delta t \leq 1$ hour
  -3 hours $\leq \Delta t \leq 3$ hours

- spatial range: → lat North/long West/lat South/long East
- land fraction (LF): → maximum value of MWI/ICI FOV (100)
- Multisource: → Dedicated RS & NWP

RS AND NWP CHECK

Is RS useful for calibration process?

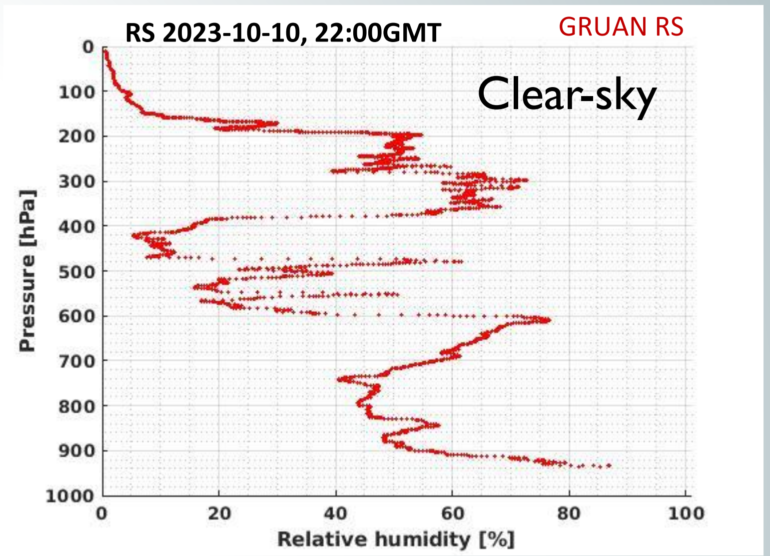
RS quality check

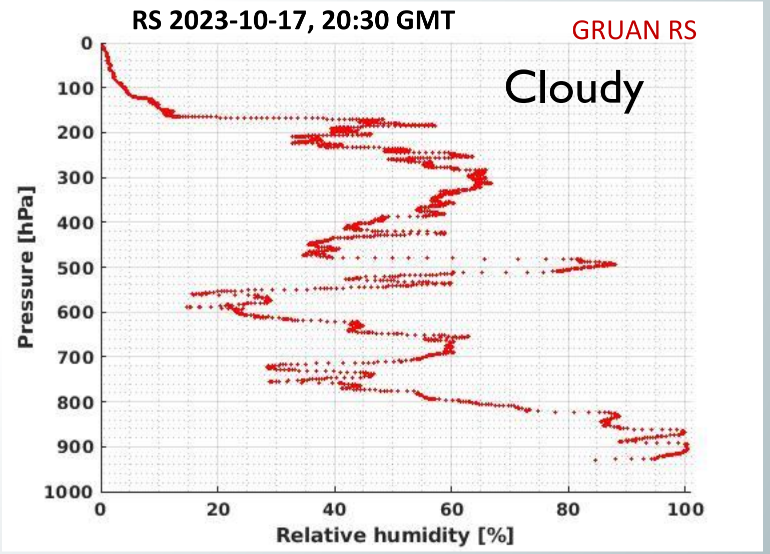
- number of pressure levels;
- pressure minimum value;
- air mass displacement (Buehler et al. 2004);
- clear-sky test (Zhang et al. 2010)

Is NWP useful for calibration process?

NWP quality check

- clear-sky test





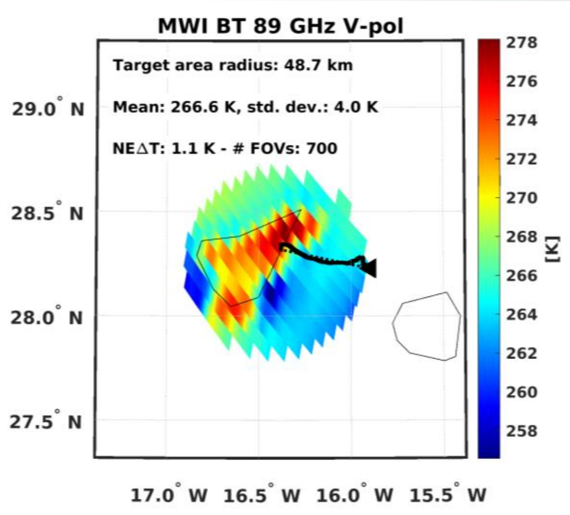
VICIRS TOOL: TA ANALYSIS

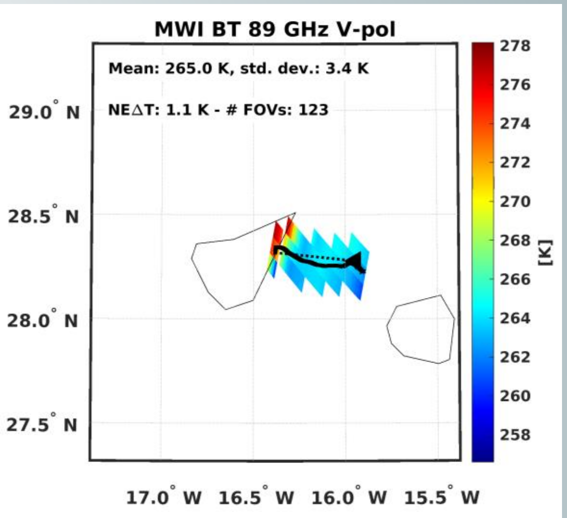
Target Area (TA) analysis

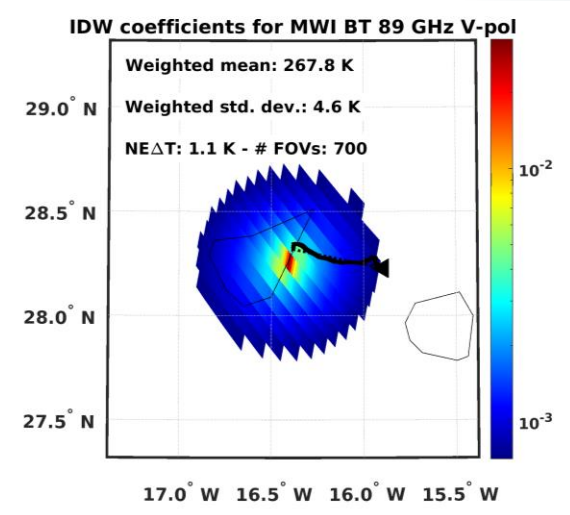
TA types	1: circular TA
	2: circular TA (inverse distance weight)
	3: circular TA (inverse squared-distance weight)
	4: RS-driven TA
	5: RS-driven TA (3x3)

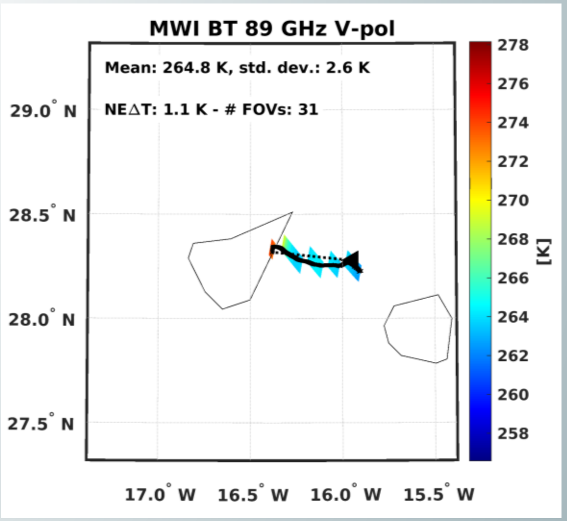
$$BT_{TA} = \sum_{i=1}^{N} BT_i \cdot \lambda_{i,j} \qquad \lambda_{i,j} = \frac{d_{0i}^{-j}}{\sum_{i=1}^{N} d_{0i}^{-j}}$$

- Homogeneity test $SD\_BT_{TA} < NE\Delta T$ (Buehler et al, 2004)
- Clear sky test







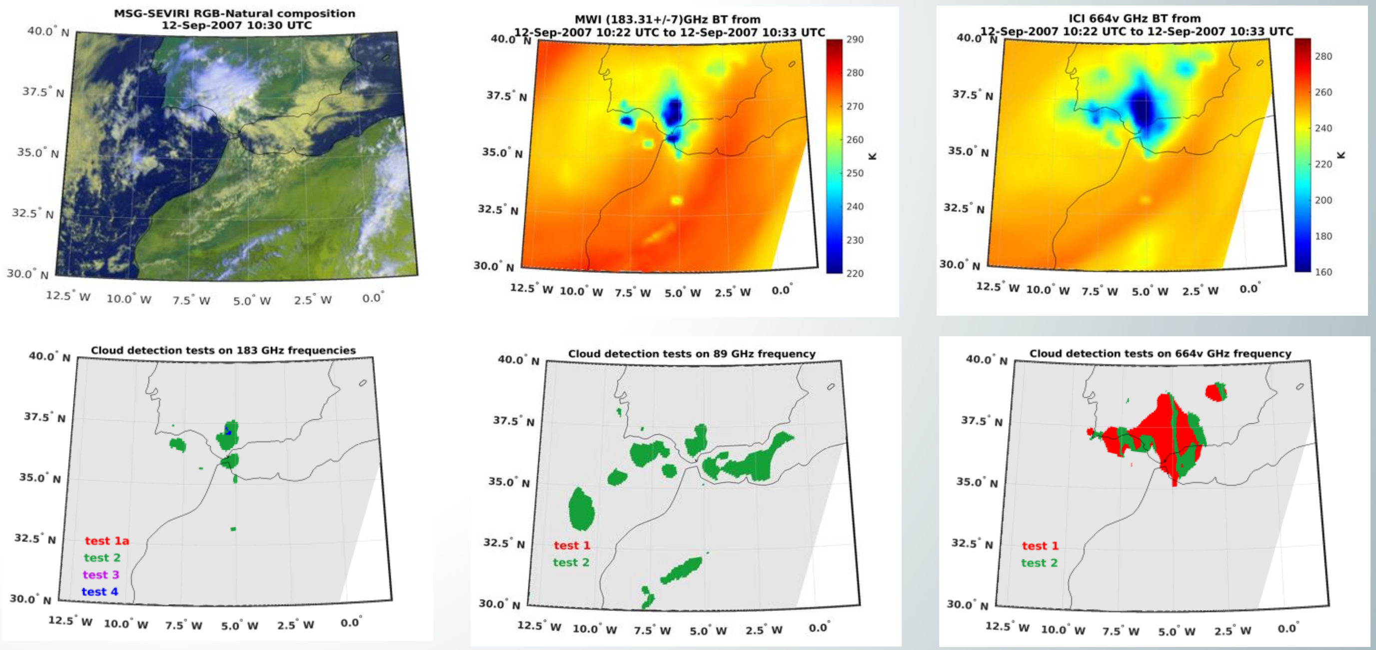


CLOUD SCREENING

	183 GHz	89 Ghz	165 Ghz	664v GHz
MWI	Buehler et al, 2007 Hong et al, 2005 Clain et al, 2005	over land: Yaping et al, 2008 over sea: Gong and Wu, 2017	Yaping et al, 2008	
ICI				Gong and Wu, 2017

MWI/ICI level 1B data orbit 4656 (20070912102225 to 20070912120114) simulated from 2007-09-12 10:00 UTC ERA-5 data

MSG-SEVIRI image acquired on 2007-09-12 10:15 UTC



GRUAN Processor v6.3.b.0.1

GRUAN Processor v6.3

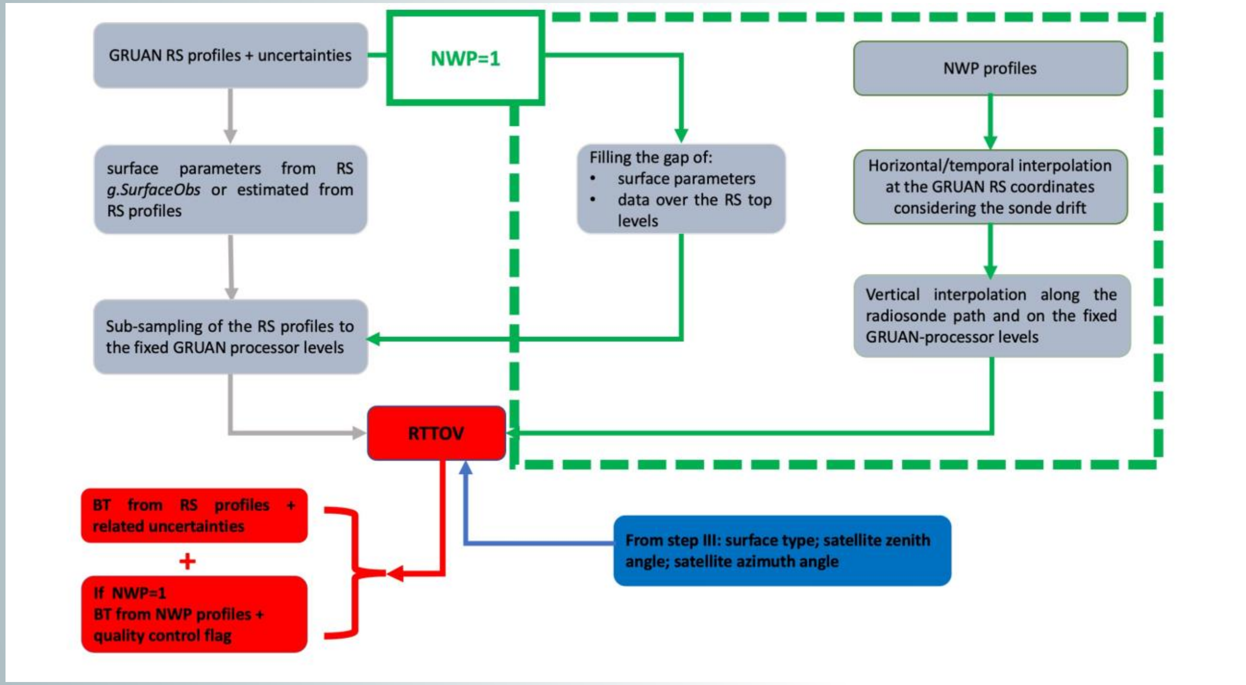
- developed by Carminati et al. (2019) to process GRUAN RS and propagate RS uncertainties
    - based on RTTOV and RadSim (from NWP-SAF)

GRUAN Processor v6.3.b.0.1

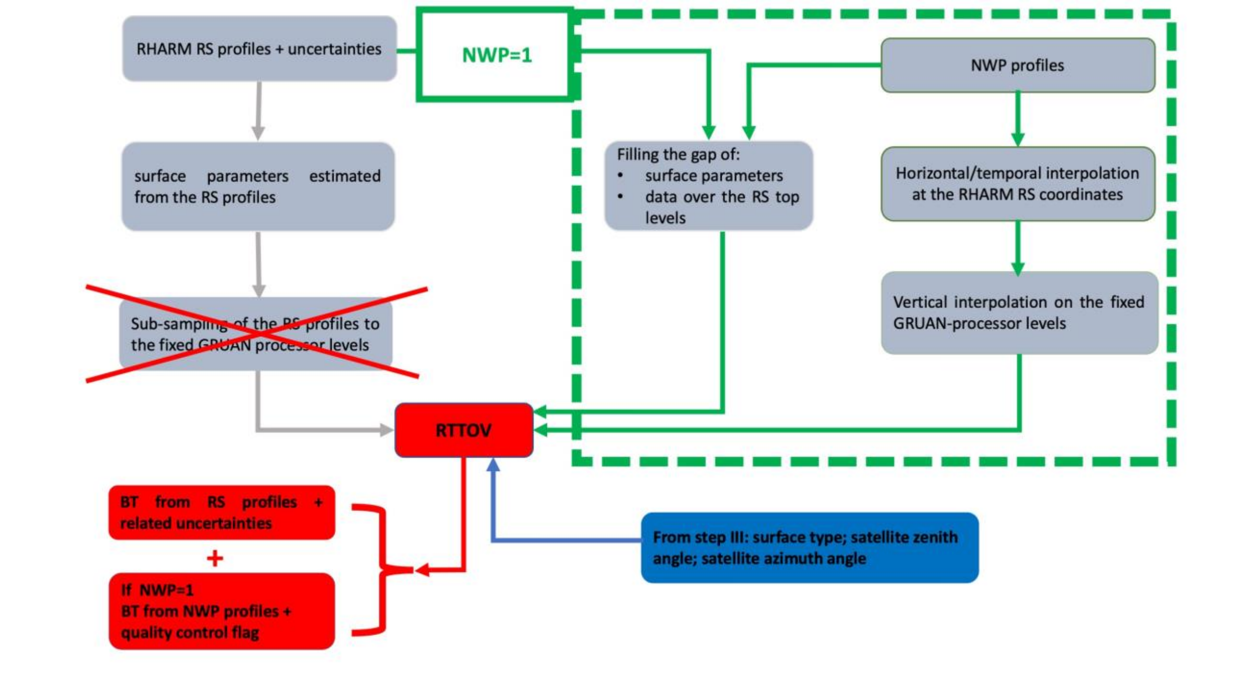
- upgraded to work with
    - latest RTTOV (v13.2)
    - latest GRUAN RS (RS41)
    - RHARM RS
    - latest emissivity model

BT SIMULATION

BT simulation from GRUAN RS



BT simulation from RHARM RS

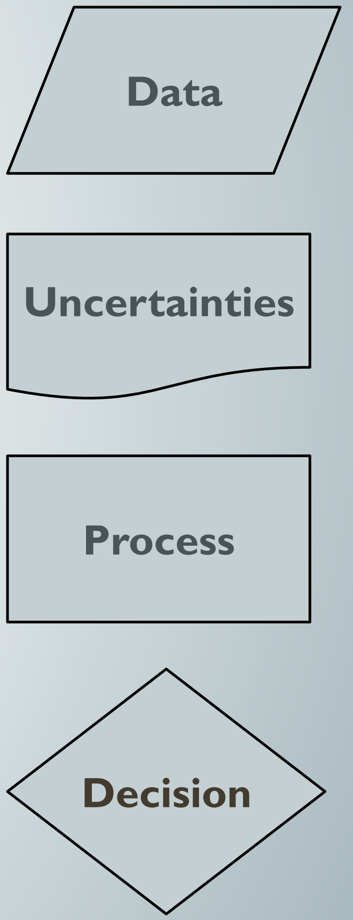


$$BT_{RS} = LF_{TA} \cdot BT_{RS\_}l + (1 - LF_{TA}) \cdot BT_{RS\_}s$$

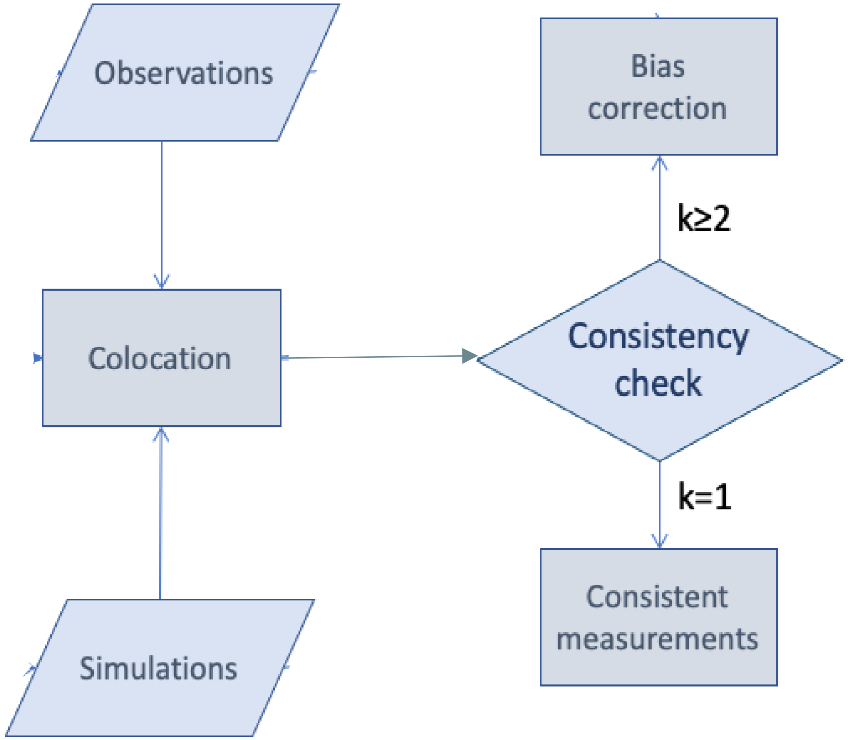
$$uBT_{RS} = \sqrt{LF_{TA}(i,j)^2 \cdot uBT_{RS\_}l(i)^2 + (1 - LF_{TA})^2 \cdot uBT_{RS\_}s^2)}$$

UNCERTAINTY ANALYSIS

- Uncertainty model diagram
- Review of uncertainty sources
- Knowledge gap analysis

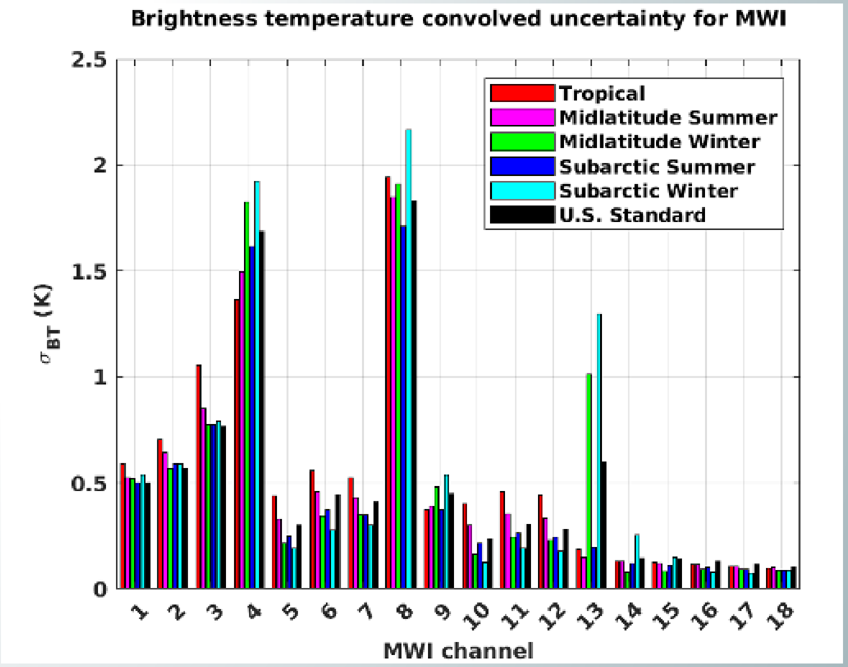


UNCERTAINTY MODEL DIAGRAM



REVIEW OF UNCERTAINTY SOURCES

- Instrument noise
  - Calibration
  - NEΔT
- Radiosonde uncertainty
  - GRUAN
  - RHARM
- Radiative transfer model (RTM) uncertainty
  - Absorption model



Gallucci et al, ACPD, egusphere-2023-3160

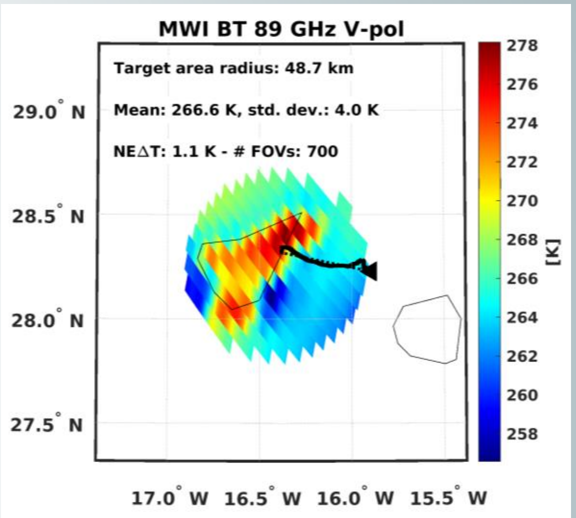
KNOWLEDGE GAP ANALYSIS

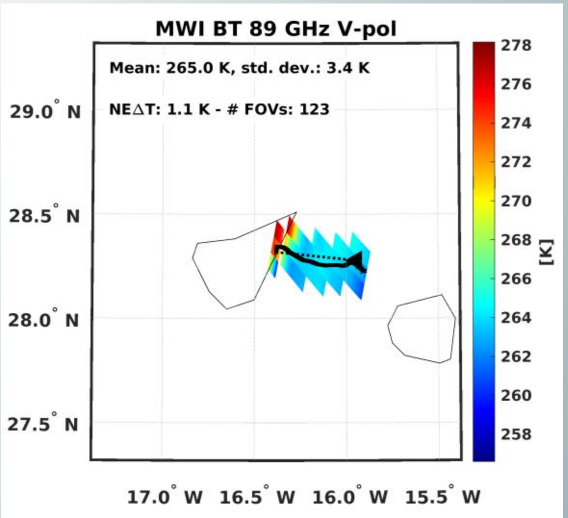
- Spatial colocation
- Geolocation
- RTM contribution of:
  - Surface emissivity model
  - Atmospheric model
    - Optimization
    - Discretization

KNOWLEDGE GAP ANALYSIS

Spatial colocation

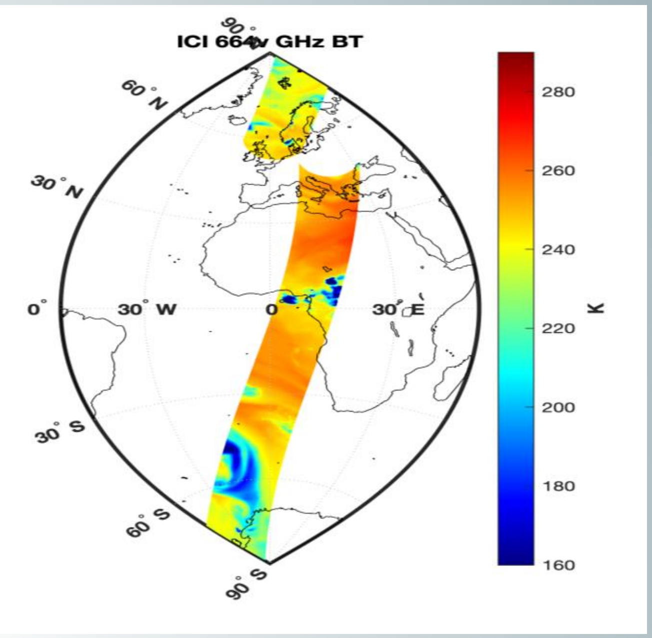
- Target area (TA) approach[1]
- $u_{BT} = STD(BT_{TA})$
- Circular, RS-driven





[1]Buehler et al, 2004; Moradi et al, 2010

KNOWLEDGE GAP ANALYSIS

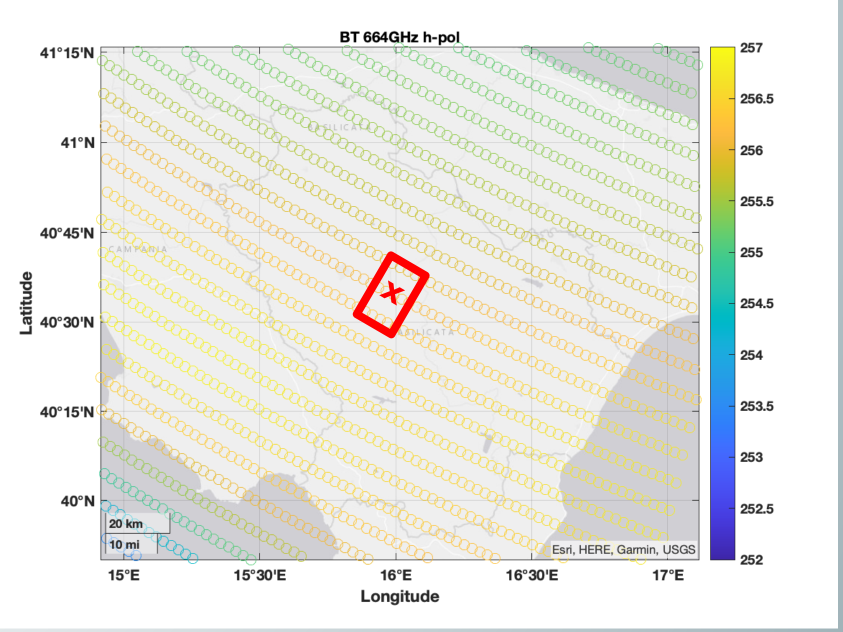


Geolocation

- Analysis based on 183-GHz channels[1]
  - Average geolocation error ~6 km
  - ~113 km^2

- Same order of magnitude of MWI/ICI IFOV distances
  - ~2x9 km (cross-track x along-track)

- $u_{GEOL} = STD(BT_{(3x5\text{-}IFOV)})$
  - ~144 km^2
  - Based on simulated MWI & ICI lev1b data



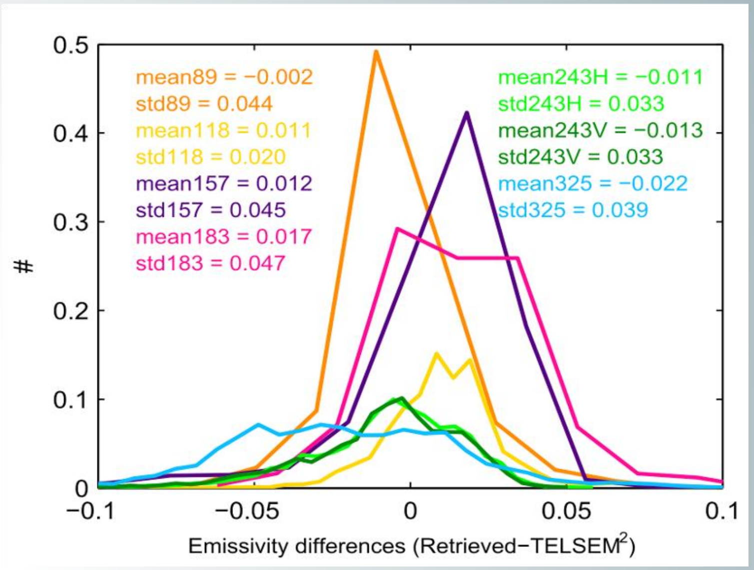
[1]Papa et al, 2021 doi: 10.1109/TGRS.2020.3024677

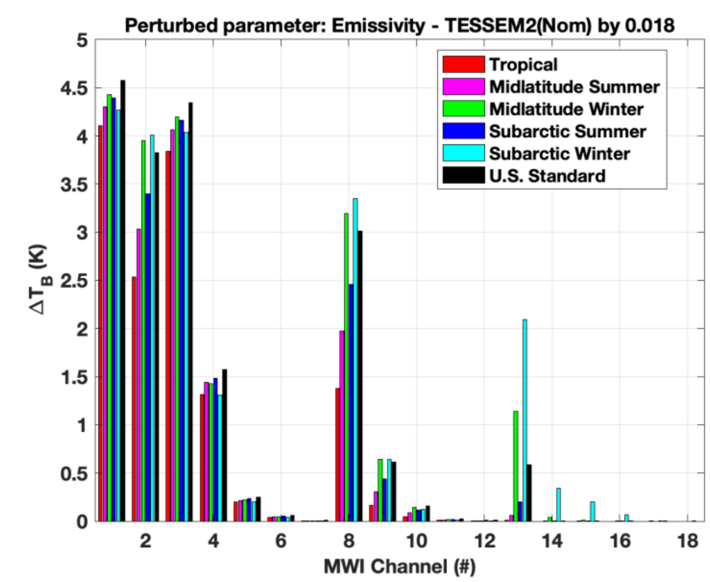
KNOWLEDGE GAP ANALYSIS

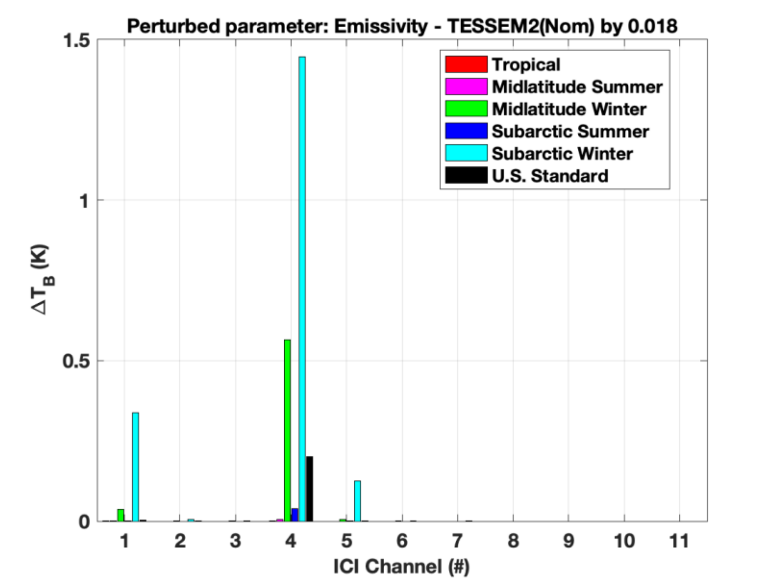
RTM contribution of surface emissivity

- RTM perturbation

- According to land/sea surface uncertainty estimate[1,2]
  - σ_e = 0.05 (over land)
  - σ_e = 0.018 (over ocean)







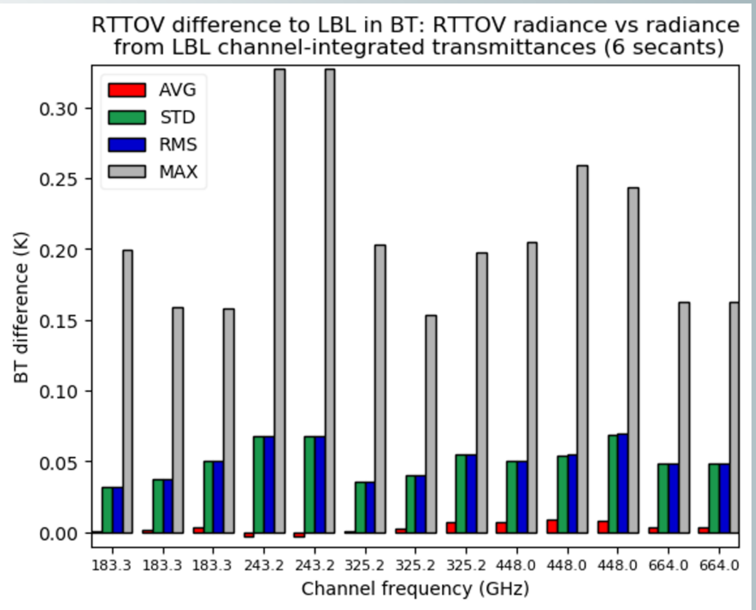
[1]Wang et al. 2017, doi: 10.1175/JTECH-D-16-0188.1
[2]Kilic et al. 2023, doi:

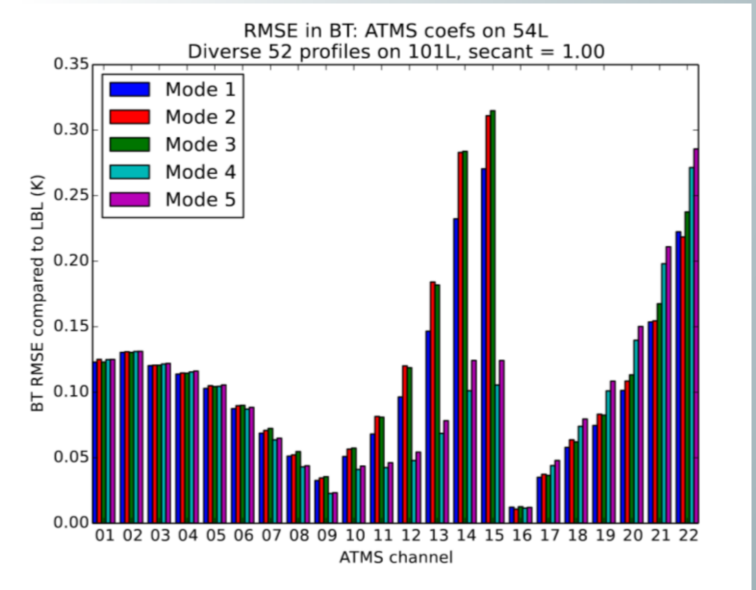
KNOWLEDGE GAP ANALYSIS

RTM contribution of atmospheric model

- RTM optimization
  - Fast parameterized (RTTOV) vs. accurate line-by-line (LBL)
  - RTTOV vs LBL BT[1]
    - diverse 83 profile set and six zenith angles

- Vertical interpolation[2]
  - Discrete levels vs. dense atmosphere
  - $N_{user\ lev} > N_{coef\ lev}$
  - Adapted to MWI/ICI from ATMS channels





[1]Hocking, NWPSAF, LBL vs RTTOV v13
[2]Hocking 2014, NWPSAF Techl Rep No: 590

TOTAL UNCERTAINTY

- Total uncertainty comes from all the contributions of estimated sources

$$u_{all} = \sqrt{\sum u_i^2} = \sqrt{u_{i_{OBS}}^2 + u_{i_{SIM}}^2 + u_{i_{COL}}^2}$$

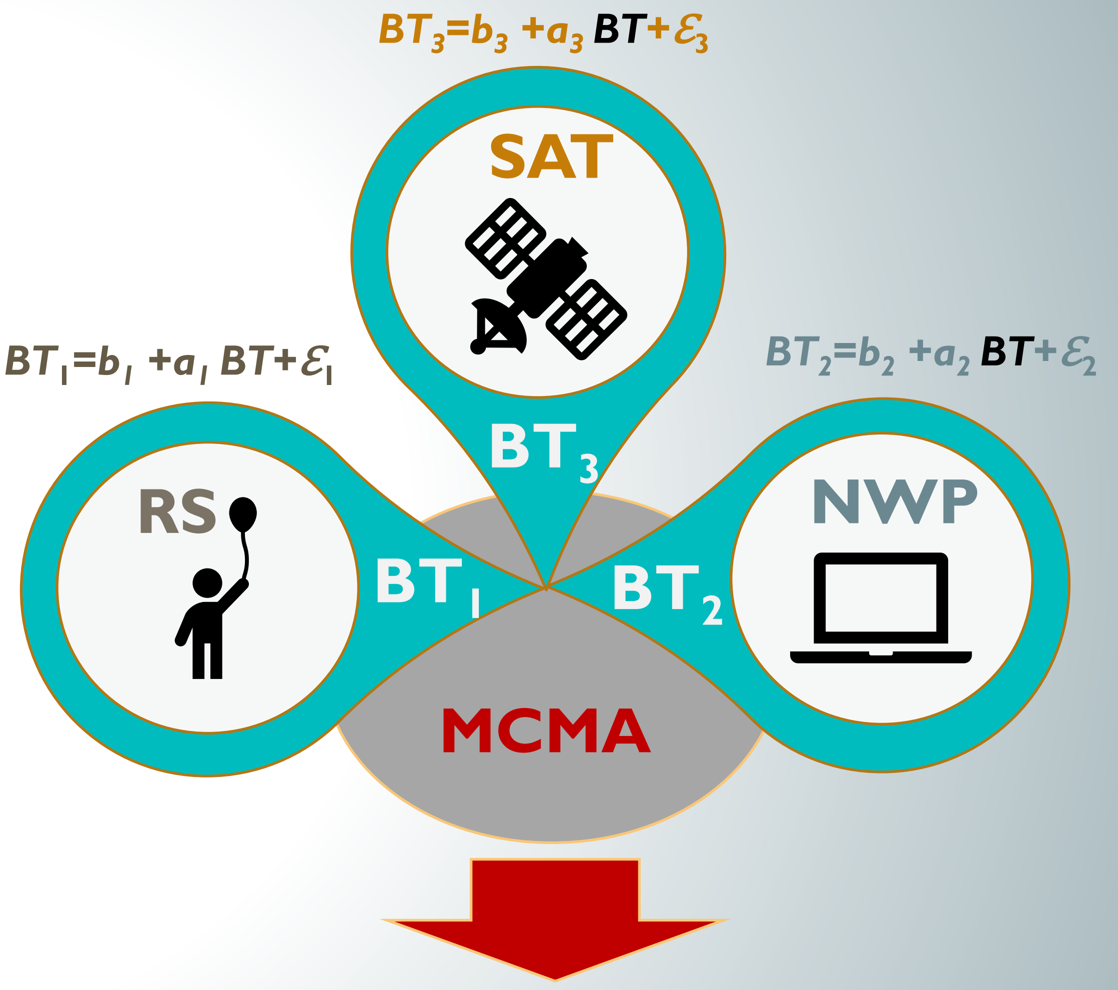
MULTISOURCE CORRELATIVE METHODOLOGY ANALYSIS

Introduction

- **GOAL of MCMA methodology**
  - Provide an error variance estimate ($\sigma^2_{\mathcal{E}i}$) of three sources of BT (e.g. RS, SAT, NWP)
  - Provide an estimate of calibration parameters (bias: b_i and scaling a_i) of two out of three sources (eg. sources 2 and 3)
- **Main requirements for MCMA**
  - Each source, BT_i , has a linear dependence with the unobserved truth BT
  - The tree sources of BT_i are space-time collocated (i.e. they are originated by the same quantity BT)
  - The *ERRORS* ($\mathcal{E}_i$) are independent to each other.

(IF NOT, some extra errors have to be considered in the final estimation of $\sigma^2_{\mathcal{E}i}$)

  - Plus, other requirements which are typically verified...



Variances of $\mathcal{E}_1, \mathcal{E}_2, \mathcal{E}_3$

two out of three set of calibration parameters:
$b_2, a_2; b_3, a_3;$

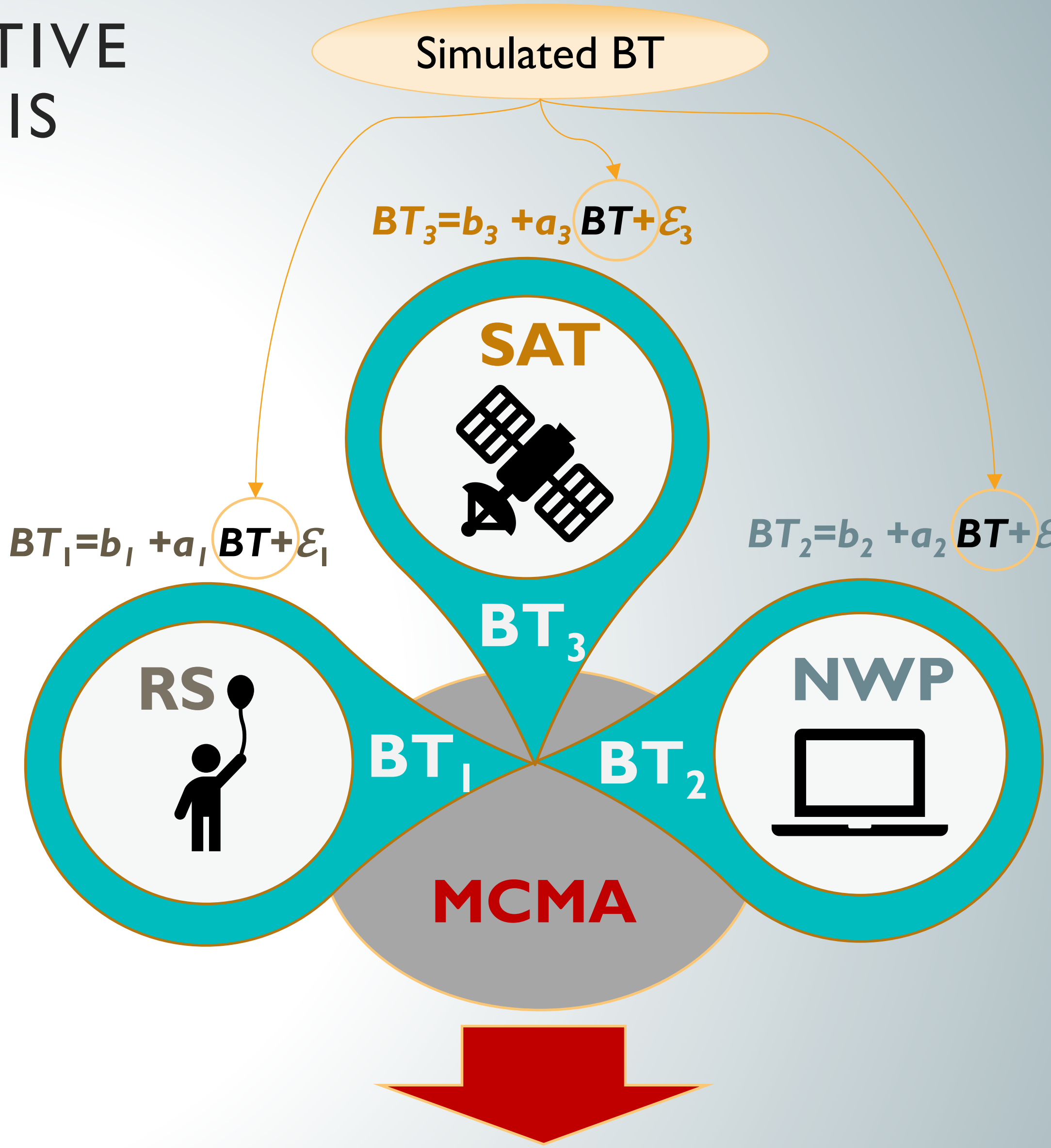
MULTISOURCE **C**ORRELATIVE **M**ETHODOLOGY **A**NALYSIS EXPERIMENT SET UP

Error variances $\sigma^2_{\varepsilon_i}$ (K²)					
	0.1^2	0.5^2	1.0^2	1.5^2	2^2

- 5×5×5 =125 different combinations of the error triplets $\varepsilon_1, \varepsilon_2, \varepsilon_3$
- For each error triplet configuration, a variable N_s samples of BT are considered

Calibration parameters used to generate input triplets								
Cases	label	a_1	a_2	a_3	b_1	b_2	b_3	ρ_{12}
Ideal case	(ID)	1	1	1	0	0	0	0
Inter. case	(IN)	1	1.25	0.75	0	1	1	0
Worst case 1	(W1)	0.75 – 1.25	1.25	0.75	0	1	1	0
Worst case 2	(W2)	0.75 – 1.25	1.25	0.75	0	1	1	0.1
Worst case 3	(W3)	0.75 – 1.25	1.25	0.75	0	1	1	0.3

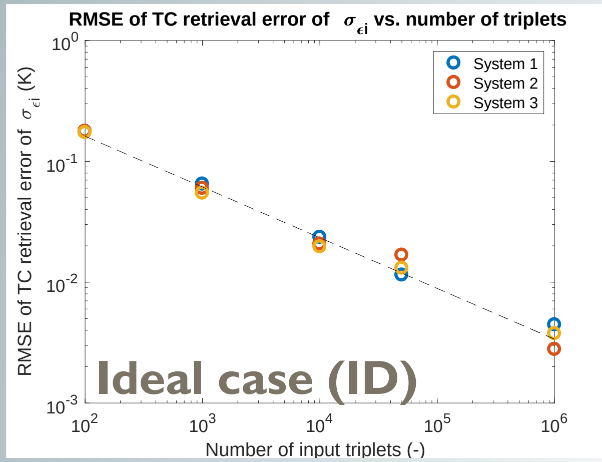
- Five cases (ID,IN,W1,W2,W3) are considered
- Last column indicate the degree of error correlation between system 1 and 2 to check the error tolerance to such condition

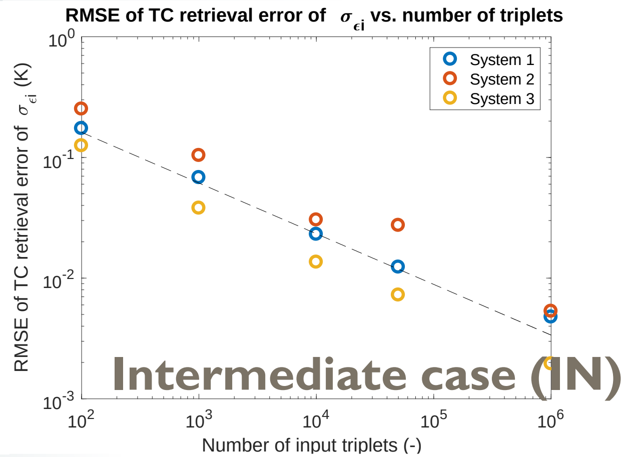


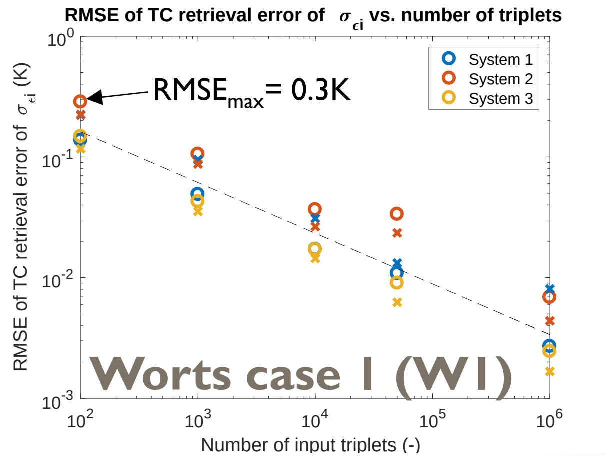
Variances of $\mathcal{E}_1, \mathcal{E}_2, \mathcal{E}_3$

two out of three set of calibration parameters:
$b_2, a_2; b_3, a_3;$

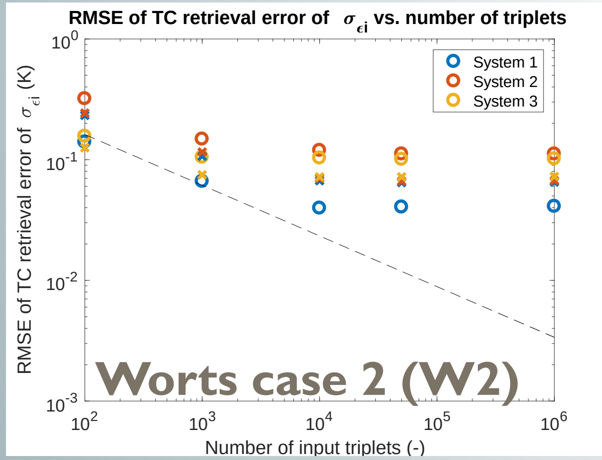
MULTISOURCE CORRELATIVE METHODOLOGY ANALYSIS RESULTS: $\hat{\sigma}_{\varepsilon_i}$ RETRIEVAL

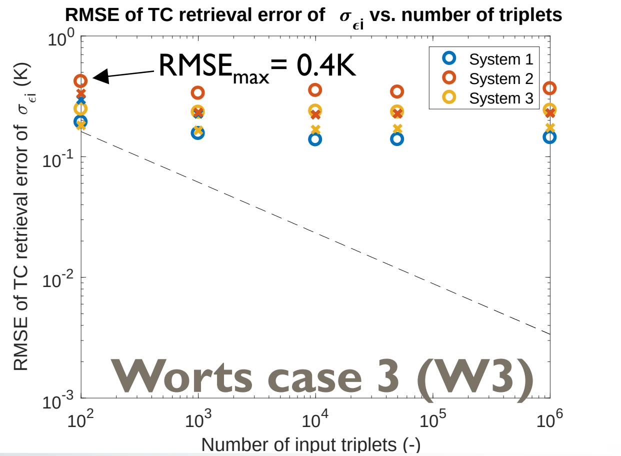






calibration parameters used to generate input triplets								
Cases	label	a_1	a_2	a_3	b_1	b_2	b_3	ρ_{12}
Ideal case	(ID)	1	1	1	0	0	0	0
Inter. case	(IN)	1	1.25	0.75	0	1	1	0
Worst case 1	(W1)	0.75 – 1.25	1.25	0.75	0	1	1	0
Worst case 2	(W2)	0.75 – 1.25	1.25	0.75	0	1	1	0.1
Worst case 3	(W3)	0.75 – 1.25	1.25	0.75	0	1	1	0.3

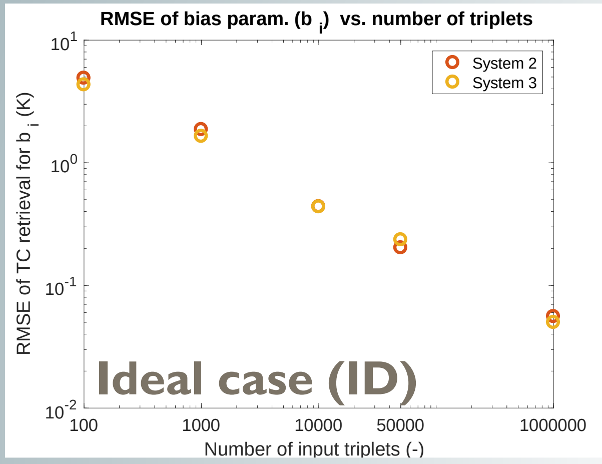


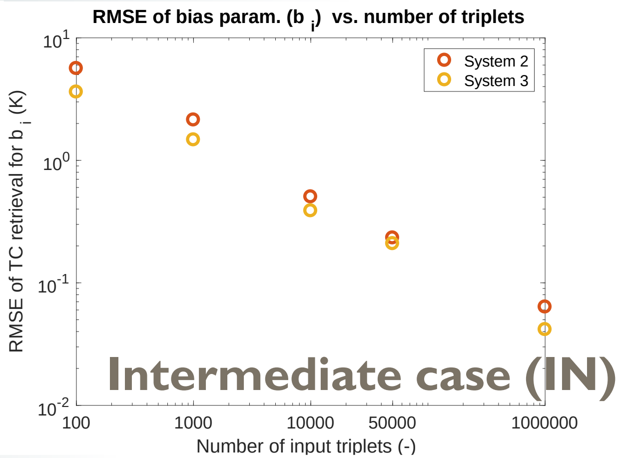


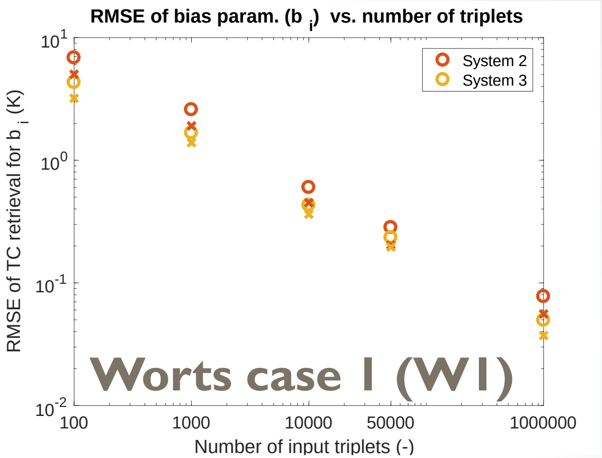
- As long as the system errors 1 & 2 are not correlated ($\langle \varepsilon_1\ \varepsilon_2 \rangle = 0$) there is an inverse dependence of estimated $\hat{\sigma}_{\varepsilon_i}$ from the number of samples (*Ns*) considered (cases in the upper panel rows).
- When considering $\langle \varepsilon_1\ \varepsilon_2 \rangle \neq 0$, errors generally increases and the dependence from *Ns* tends to vanish (lower panels).
- At worst (W3), if $\hat{\sigma}_{\varepsilon_i}$ is estimated with a minimum of *Ns* =100 samples, the estimation uncertainty of MCMA is of $0.4\ K$ RMSE.

VICIRS

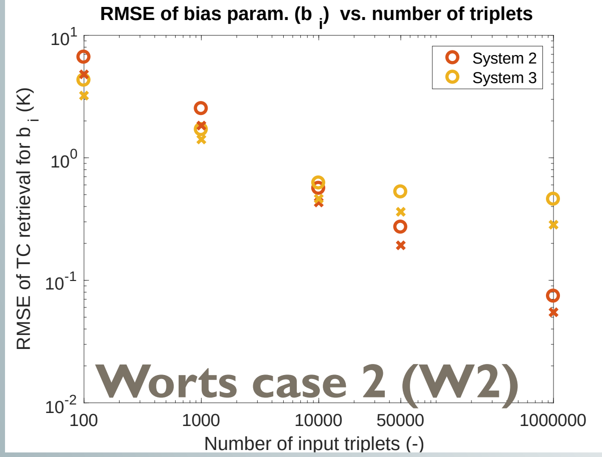
MULTISOURCE CORRELATIVE METHODOLOGY ANALYSIS RESULTS: b_i RETRIEVAL

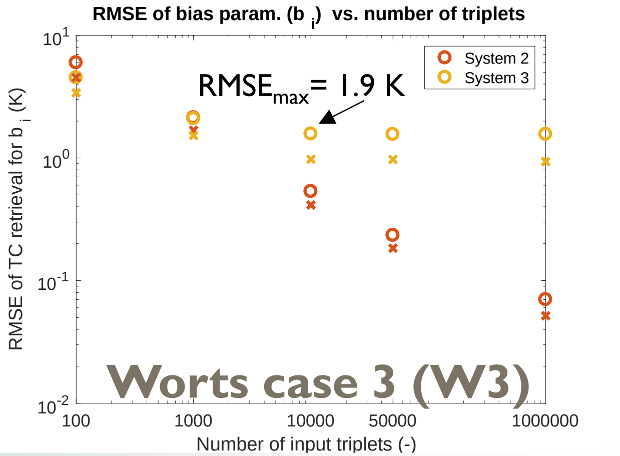






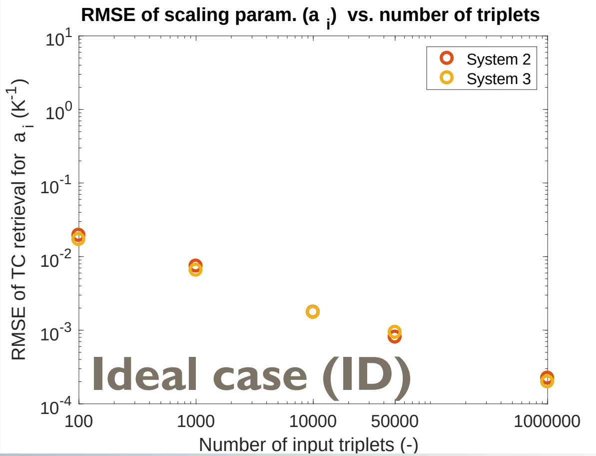
calibration parameters used to generate input triplets								
Cases	label	a_1	a_2	a_3	b_1	b_2	b_3	ρ_{12}
Ideal case	(ID)	1	1	1	0	0	0	0
Inter. case	(IN)	1	1.25	0.75	0	1	1	0
Worst case 1	(W1)	0.75 – 1.25	1.25	0.75	0	1	1	0
Worst case 2	(W2)	0.75 – 1.25	1.25	0.75	0	1	1	0.1
Worst case 3	(W3)	0.75 – 1.25	1.25	0.75	0	1	1	0.3

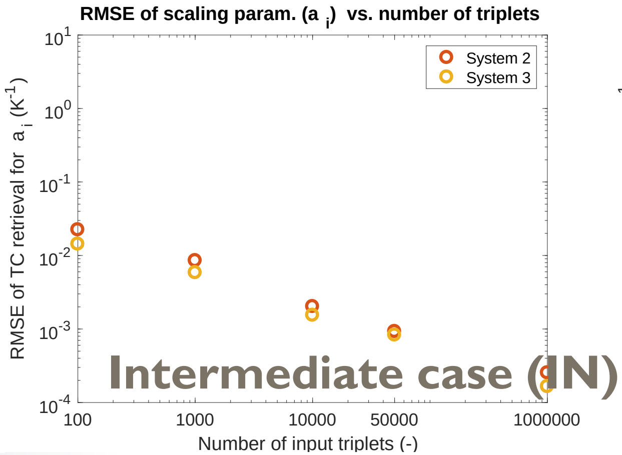


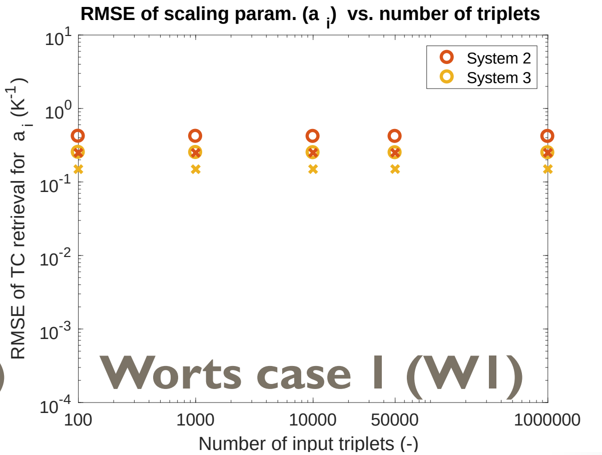


- The bias b_i has a very strong dependence from the number, N_s , of triplets considered and, in general, a high number of them can guarantees acceptable estimation accuracy.
- E.g. $N_s > 10^3$ triplets are needed to achieve an accuracy less than 2K for $\hat{b}_i$ of system 3 in the worst W3 experiment.

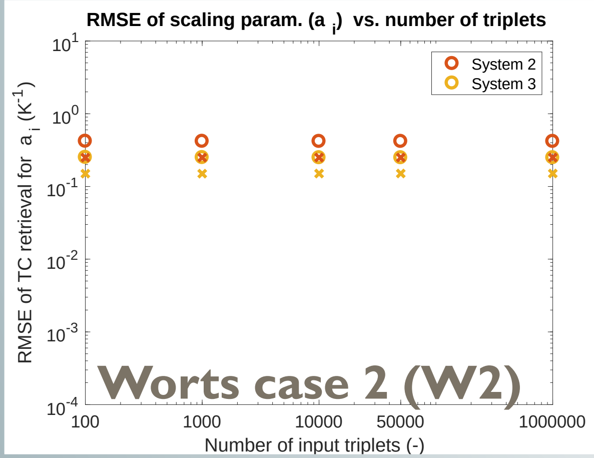
MULTISOURCE CORRELATIVE METHODOLOGY ANALYSIS: RESULTS: a_i RETRIEVAL

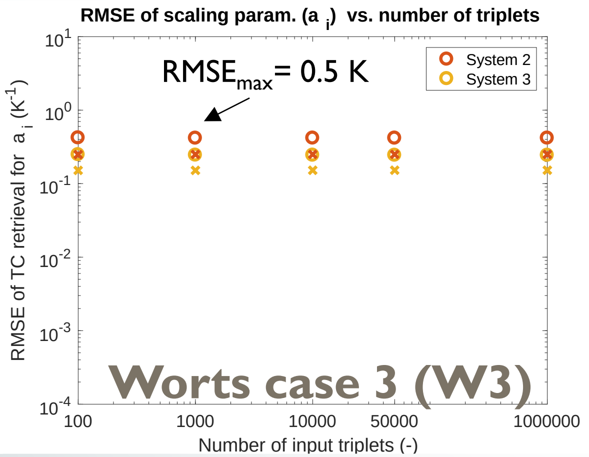






calibration parameters used to generate input triplets								
Cases	label	a_1	a_2	a_3	b_1	b_2	b_3	ρ_{12}
Ideal case	(ID)	1	1	1	0	0	0	0
Inter. case	(IN)	1	1.25	0.75	0	1	1	0
Worst case 1	(W1)	0.75 – 1.25	1.25	0.75	0	1	1	0
Worst case 2	(W2)	0.75 – 1.25	1.25	0.75	0	1	1	0.1
Worst case 3	(W3)	0.75 – 1.25	1.25	0.75	0	1	1	0.3





- RMSE of $\hat{a}_i$ are not much sensible to the number of input triplets in the presence of miscalibrations (i.e. when worst cases are considered, bottom panels).
- In the W3 case, the RMSE is always lower than 0.5 K^{-1} (i.e. $\pm 13°$ with respect to the 1:1 line in the scatterplot of the measurement x_i vs. the truth t.

MULTISOURCE CORRELATIVE METHODOLOGY ANALYSIS
CONCLUSIONS

- The number of input triplets play a role in the uncertainty of the final result. Less than 100 triplets risk to provide unrealistic results due to statistical fluctuations.

- The scaling parameter is estimated with an accuracy lower than $\pm$0.5 K^{-1} (worst case)

- The estimation of the bias parameter seems to be affected by large errors (<2 K, Ns>=10^3) when considering the worst case.

Final Remarks

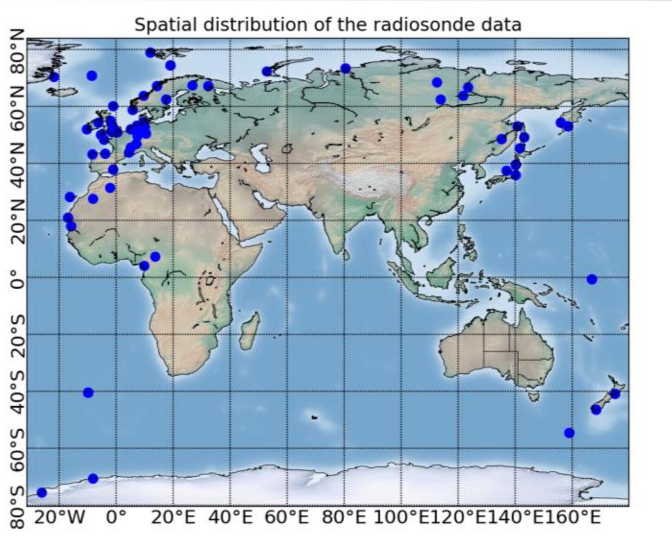
- Caution when using MCMA .
- Better to use MCMA as confirmatory tool together with more customary approaches.

DEMONSTRATION OF VICIRS TOOL

Testing of VICIRS tool on two datasets:

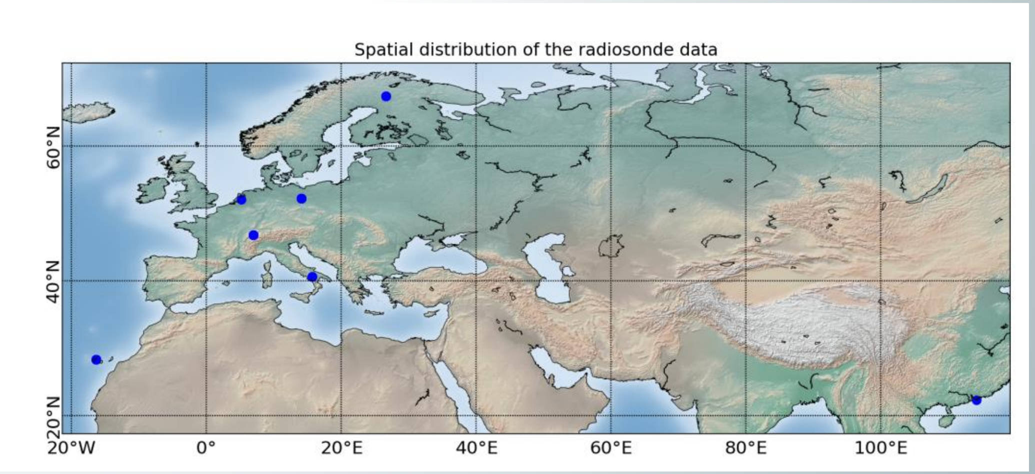
- **MWI and ICI L1B** simulated dataset and spatially and temporally collocated RSs from **RHARM** archive
    - ➢ 2007-09-12 08:00 to 2007-09-12 12:00
    - ➢ 2008-02-23 08:30 to 2008-02-23 10:30

    112 match-ups



- **NASA Global Precipitation Measurement (GPM) Microwave Imager (GMI)** observations, and spatially and temporally collocated RSs from **GRUAN** Archive
    - ➢ 2023-01-01 00:00 to 2023-04-30 23:59
    - ➢ 2023-09-01 00:00 to 2023-11-30 23:59

    65 match-ups



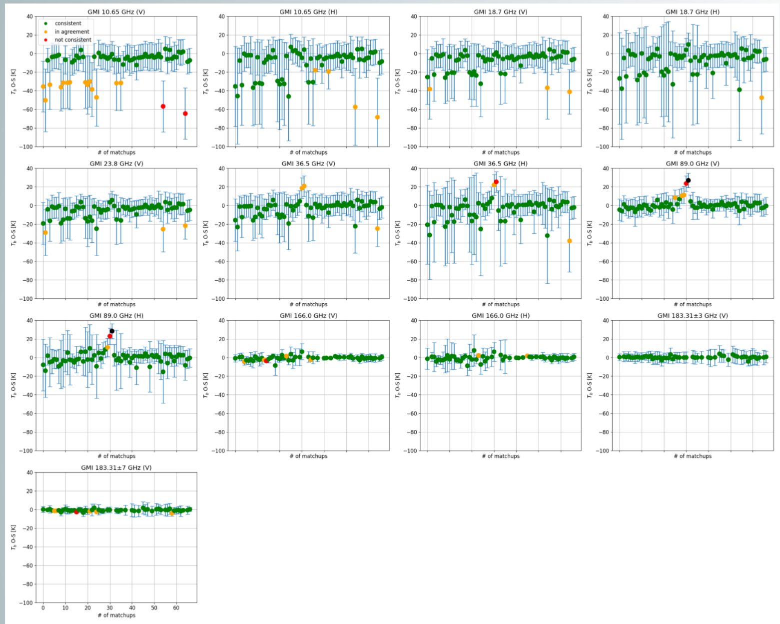
DEMONSTRATION OF VICIRS TOOL

SECOND PHASE: DATA QUERY

• radiometer	MWI, ICI, GMI
• radiosonde archive	GRUAN, RHARM
• temporal range	aaaa-mm-dd hh:mm (start) to aaaa-mm-dd hh:mm (end)
• temporal distance	○ -15’≤ ΔT ≤45’ ○ -1 hour ≤ ΔT ≤1 hour ○ -3 hours ≤ ΔT ≤3 hours
• spatial range	spatial range;
• target area	1, 2, 3, 4, 5
• land fraction range	[LFmin: LFmax]
• target area cloudy percentage	maximum value for cloudy percentage
• dedicated launches;	0,1
• NWP (and option for skin temperature)	0,1 (1,2)
• homogeneity flag	0 all TAs, 1 only homogeneous TA
• MCM analysis	0=no, 1=yes

QUERY ON MATCH-UPS: OUTPUT

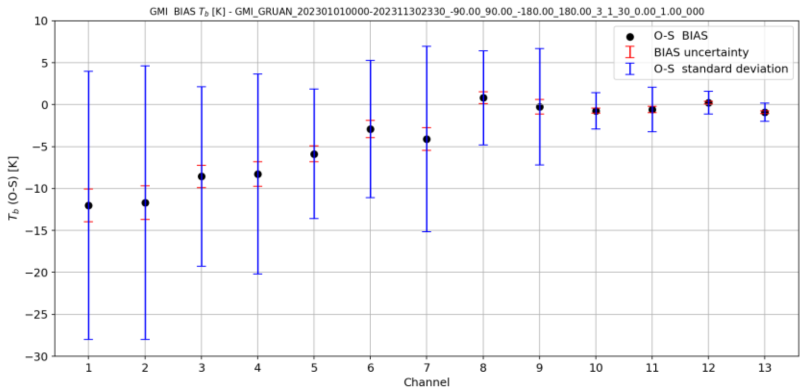
$$BT_{TA} - BT_{RS} \leq k \cdot u\_all$$



- **k=1 (data are *consistent*);**
- **k=2 (data are *in statistical agreement*);**
- **k=3 (data are *significantly different*);.**
- **results do not agree within k=3**

for all the match-ups and for all the frequencies

$$BIAS$$



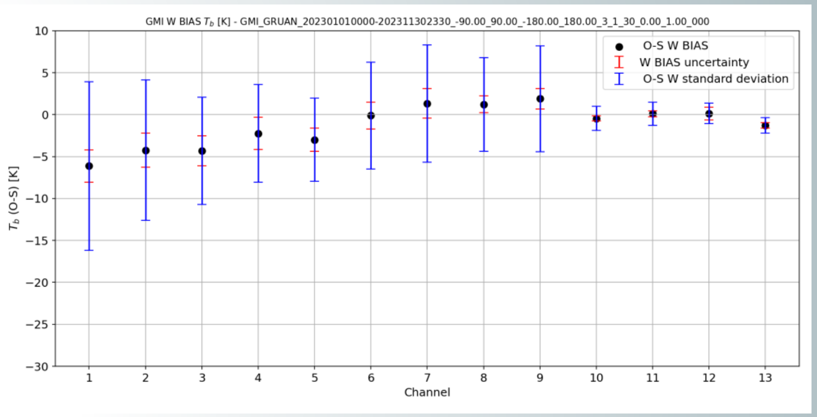
$$BIAS = \frac{\sum_{i=1}^{nsample} TA\_RS(i,j)}{nsample}$$

$$SD\_TA\_RS = \sqrt{\frac{\sum_{i=1}^{nsample} (BIAS(j) - TA\_RS(i,j))^2}{nsample}}$$

$$u\_BIAS = \frac{SD\_TA\_RS}{\sqrt{nsample}}$$

for all the frequencies

$$weighted\ BIAS$$



$$wBIAS = \frac{\sum_{i=1}^{nsample} w_{i,j} \cdot TA\_RS(i,j)}{\sum_{i=1}^{nsample} w_{i,j}}, \quad w_{i,j} = 1/(u\_all(i,j))^2$$

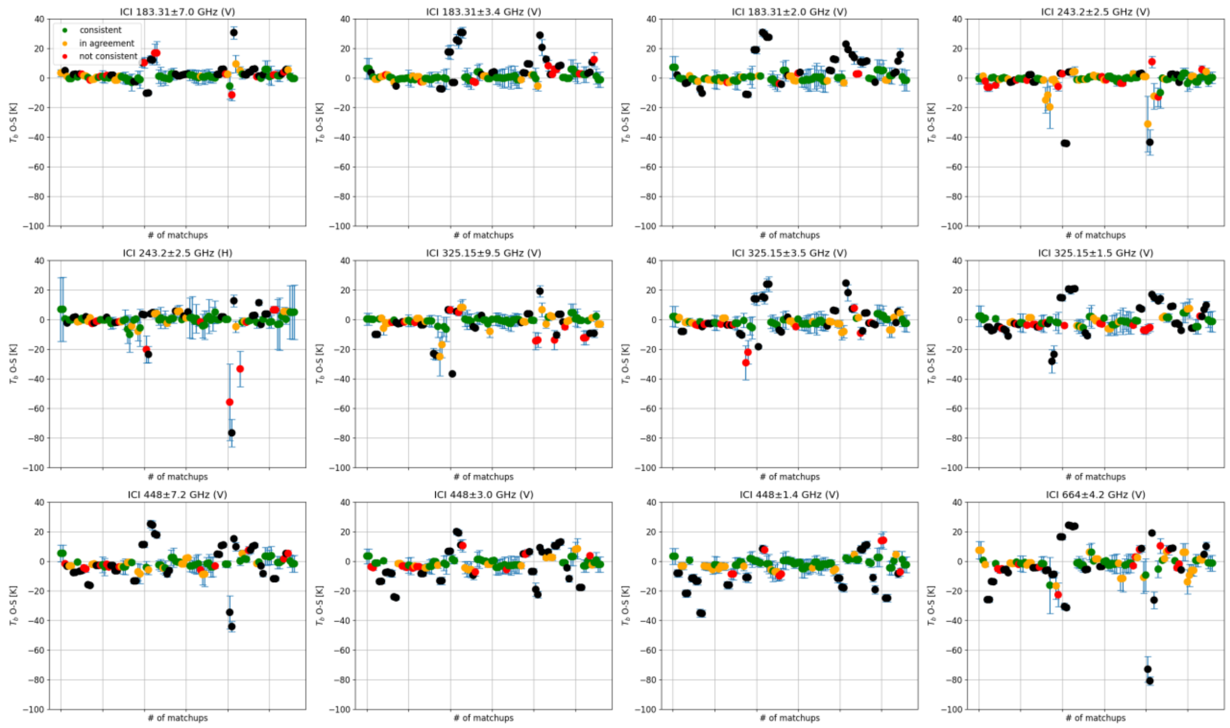
$$SDw\_TA\_RS = \sqrt{\frac{\sum_{i=1}^{nsample} w_{i,j} \cdot (wBIAS(j) - TA\_RS(i,j))^2}{\sum_{i=1}^{nsample} w_{i,j} - (\sum_{i=1}^{nsample} w_{i,j}^2 / \sum_{i=1}^{nsample} w_{i,j})}}$$

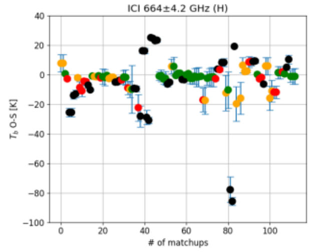
$$u\_wBIAS = \sqrt{\frac{1}{\sum_{i=1}^{nsample} w_{i,j}}}$$

DEMONSTRATION OF VICIRS TOOL: ICI L1B – RHARM, $LF \in [0:100]$

ALL DATA (UNFILTERED)

ICI-RHARM 112 match-ups, $Rharm\ Pmin \in [10:400]hPa, nlev \geq 15$

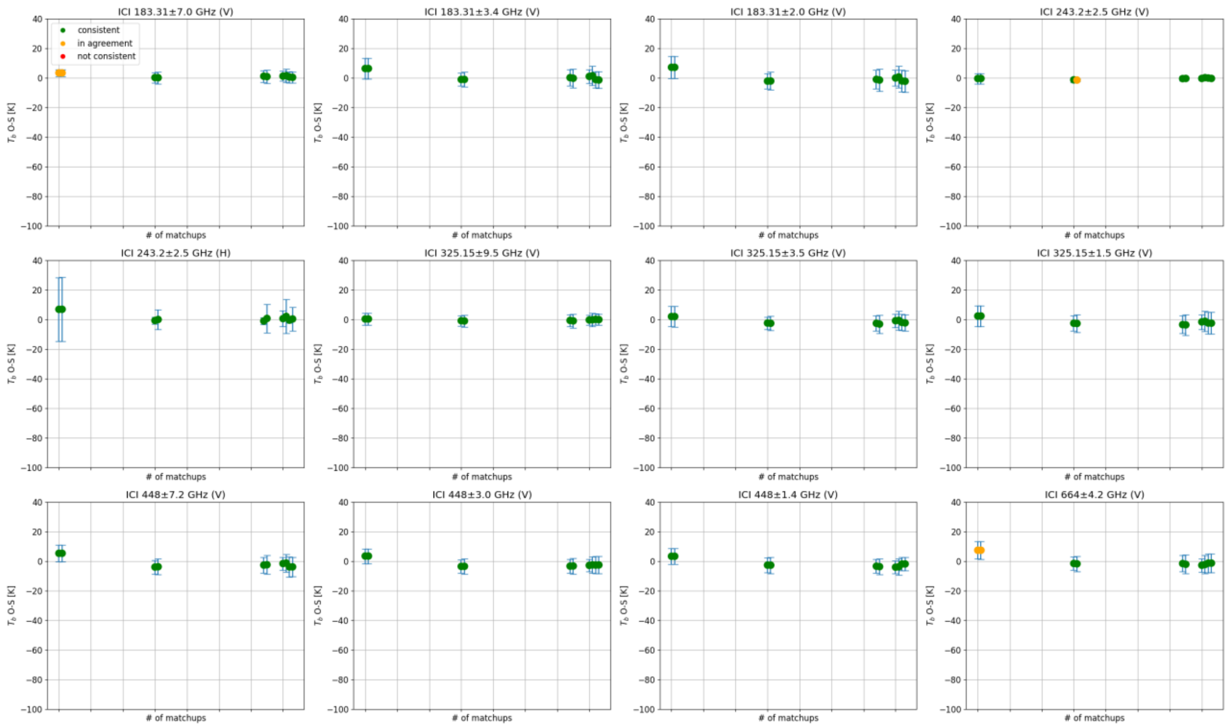


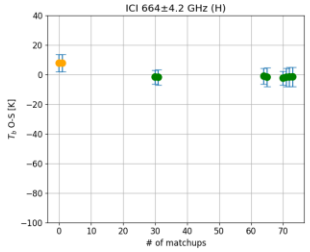


$$BT_{TA} - BT_{RS} \leq k \cdot u\_all$$

FILTERED (n_{lev}, P_{min})

ICI-RHARM 10 match-ups, $Rharm\ Pmin \in [10:100]hPa, nlev \geq 40$





- k=1 (data are *consistent*);
- k=2 (data are *in statistical agreement*);
- k=3 (data are *significantly different*);.
- results do not agree within k=3

DEMONSTRATION OF VICIRS TOOL: ICI L1B – RHARM, $LF \in [0:100]$

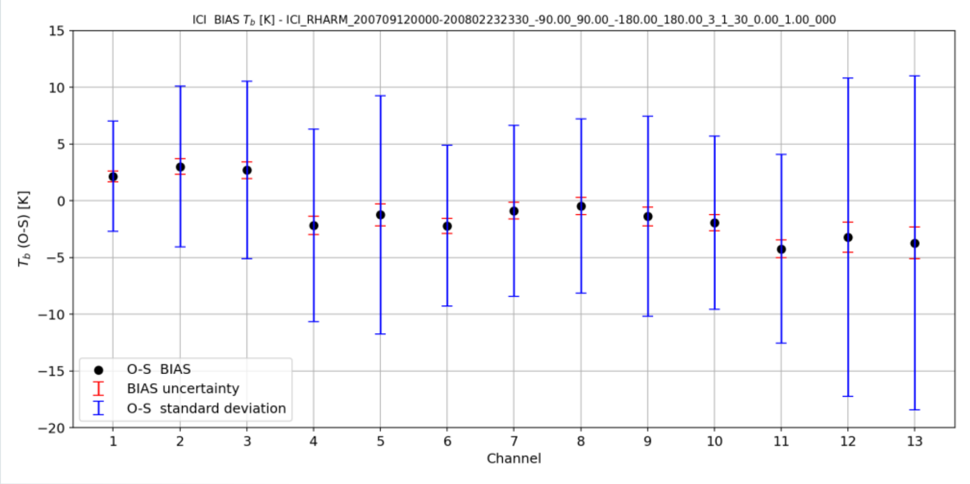
ALL DATA (UNFILTERED)

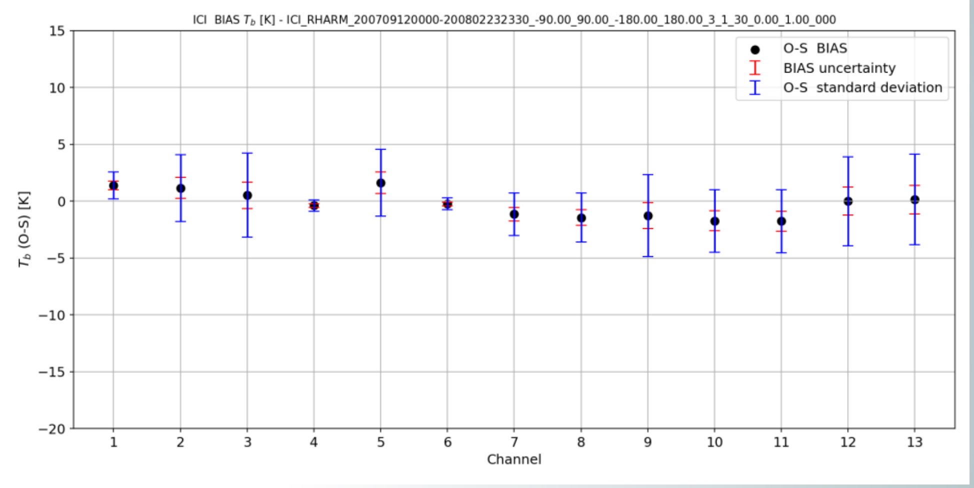
112 match-ups, $Rharm\ Pmin \in [10:400]hPa, nlev \geq 15$

FILTERED (n_{lev}, P_{min})

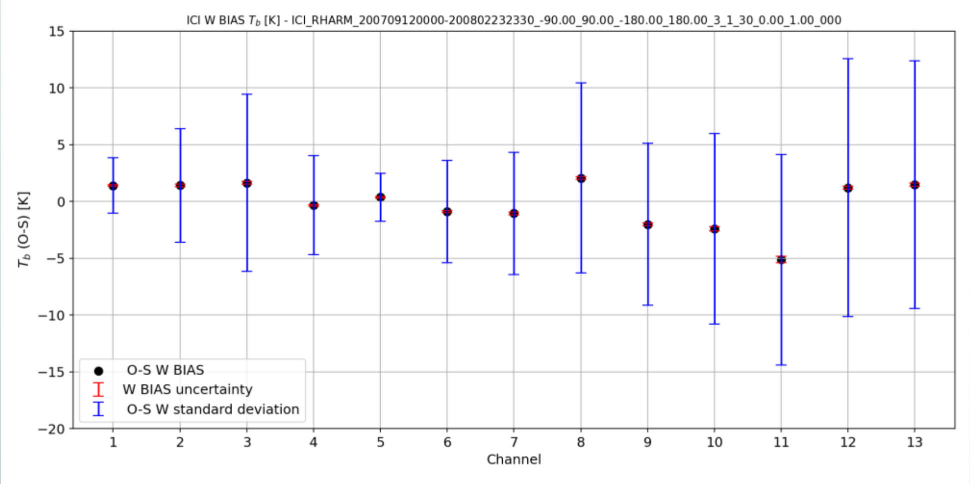
10 match-ups, $Rharm\ Pmin \in [10:100]hPa, nlev \geq 40$

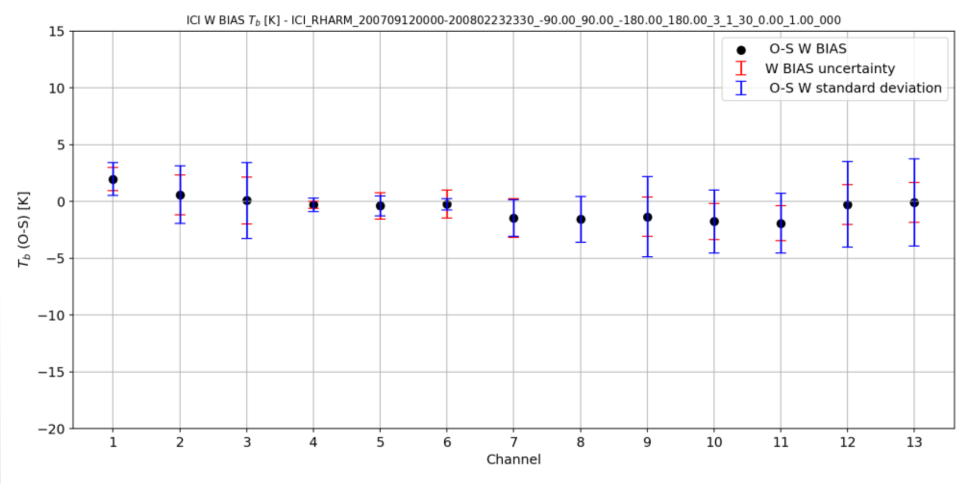
BIAS





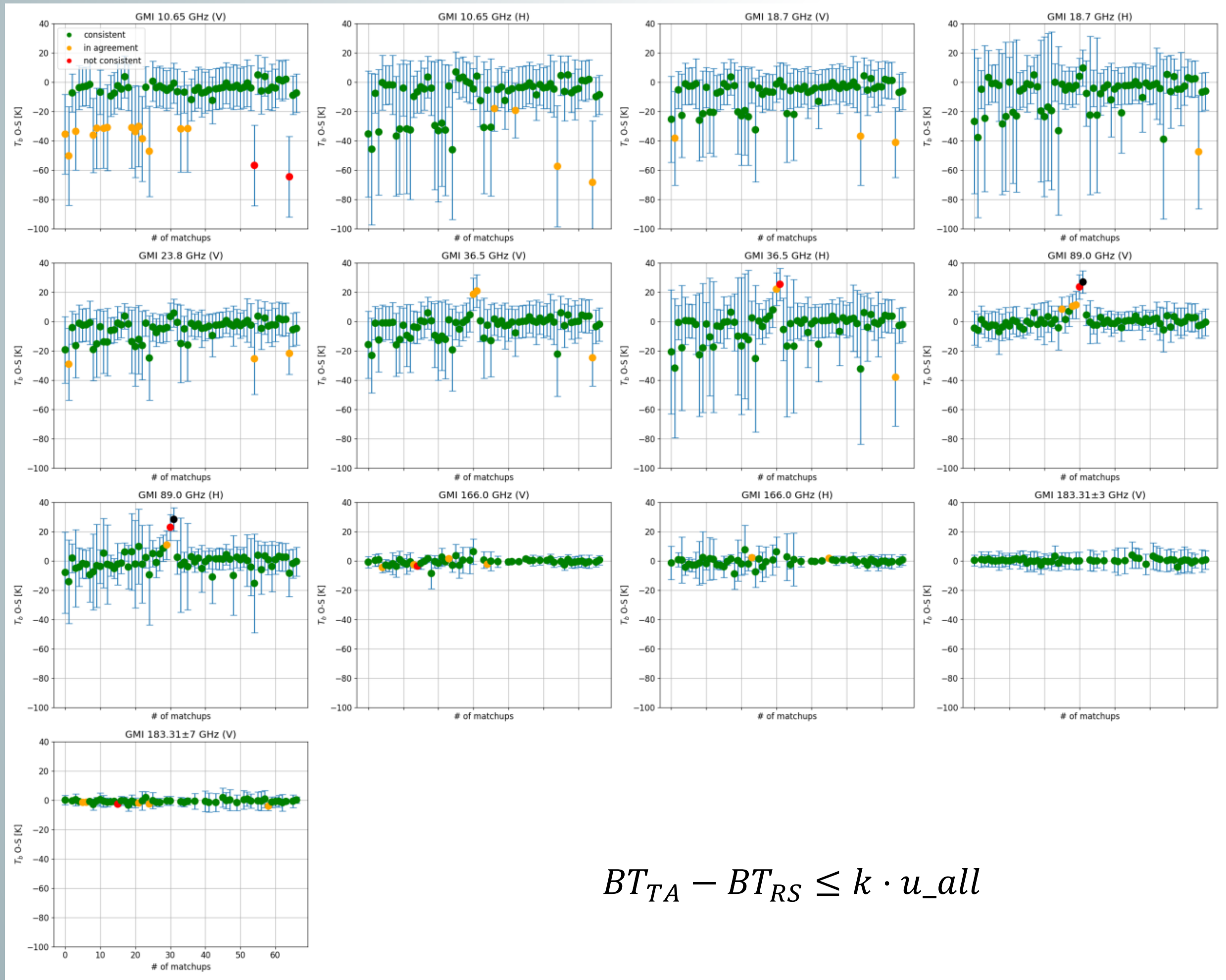
weighted BIAS





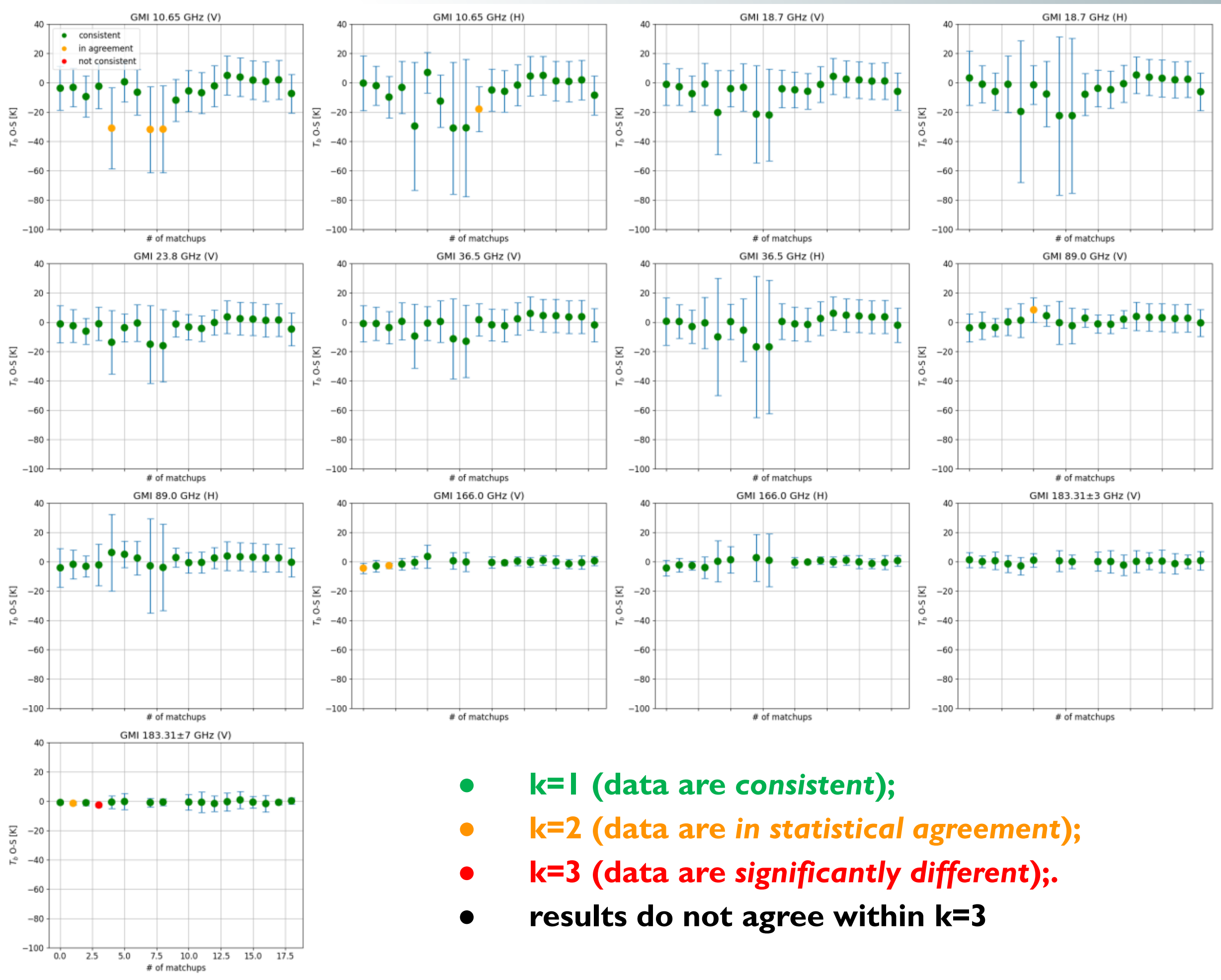
VERIFICATION AND VALIDATION OF VICIRS TOOL: GMI – GRUAN, $LF \in [0:100]$

GMI-GRUAN 67 match-ups, $temporal\ distance = 3$



$$BT_{TA} - BT_{RS} \le k \cdot u\_all$$

GMI-GRUAN 19 match-ups, $temporal\ distance = 1$



- k=1 (data are *consistent*);
- k=2 (data are *in statistical agreement*);
- k=3 (data are *significantly different*);.
- results do not agree within k=3

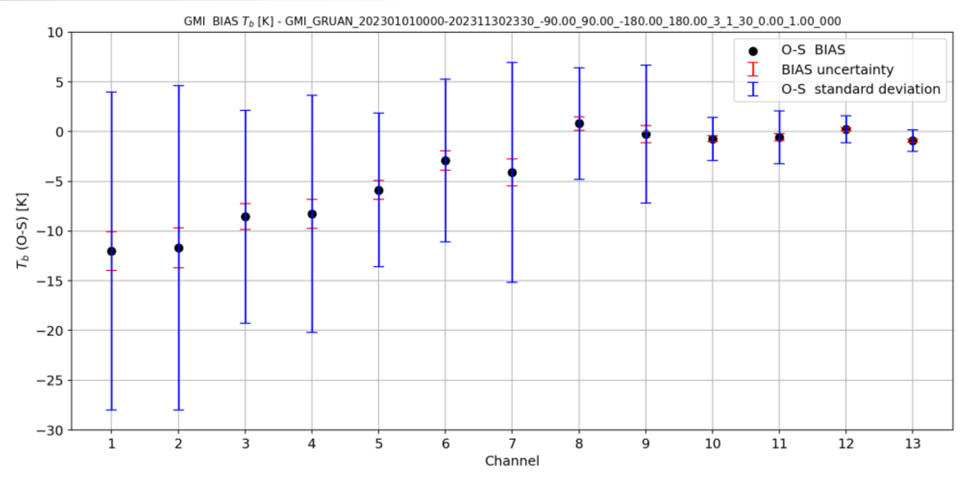
VERIFICATION AND VALIDATION OF VICIRS TOOL: GMI – GRUAN

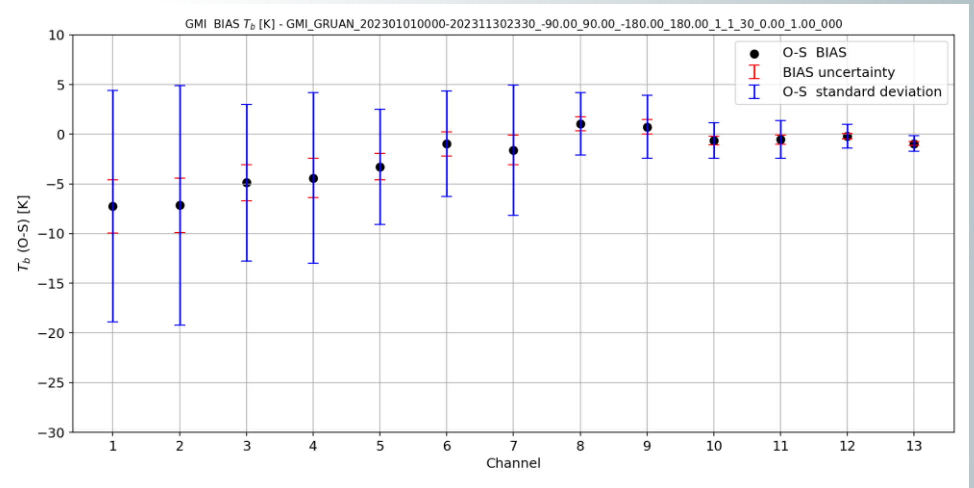
TA $\%cloudy = 0,$
$LF \in [0{:}100]$

GMI-GRUAN 67 match-ups, $temporal\ distance = 3$

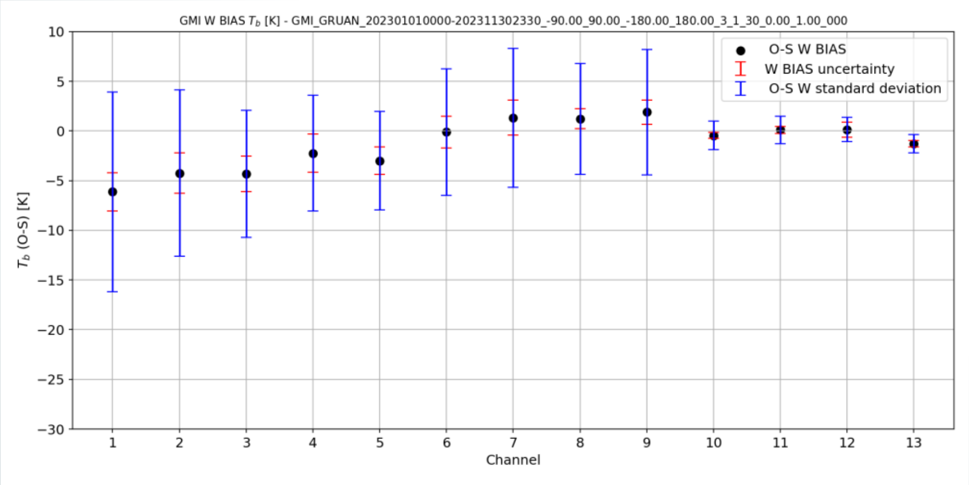
GMI-GRUAN 19 match-ups, $temporal\ distance = 1$

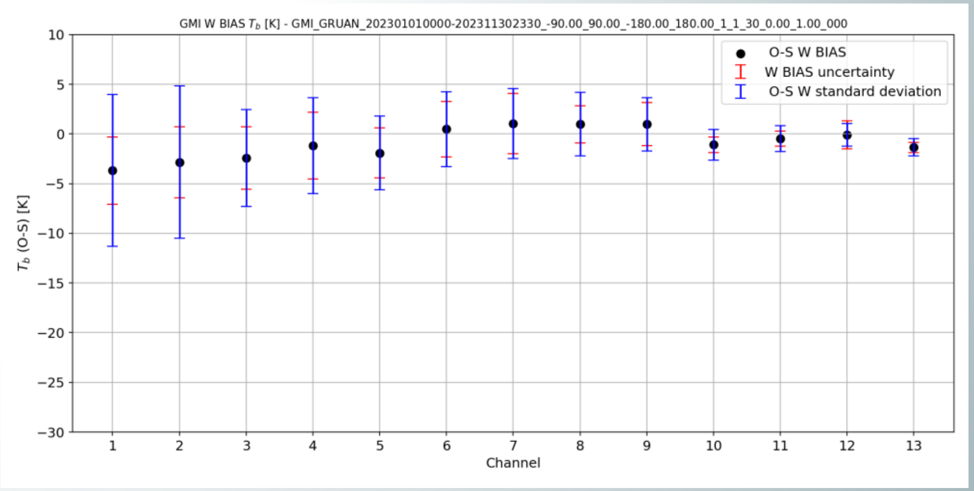
$BIAS$





$weighted\ BIAS$





VICIRS

SUMMARY & CONCLUSIONS

VICIRS tool for the vicarious calibration of MWI/ICI observations against radiosonde observations

- flexible
- user friendly
- GRUAN and RHARM RS
- uncertainty characterization & multisource analysis
- tested with simulated and real observations
    - MWI/ICI & GMI

SUMMARY & CONCLUSIONS

Current limitations

- RHARM v1 archive (n_{lev} & P_{min})
- land fraction for GMI (not available)
- will be surpassed with RHARM v2 & MWI/ICI land fraction

Future work

- further uncertainty characterization
  - e.g., temporal collocation, NWP,…
- assess overall quality of estimated bias and accuracy vs. RS quantity and quality
- use VICIRS tool within the MWI/ICI Cal/Val activities

VICIRS

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- **MetOffice**: Fabien Carminati
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Consiglio Nazionale delle Ricerche

imaa Istituto di Metodologie per l'Analisi Ambientale

ISAC

HIPPOCRATICA CIVITAS STUDIUM SALERNI

BACK-UP SLIDES

VICIRS tool: Step II *RS and NWP check*

RS is in clear sky. The presence of cloudy layers is verified by comparing the RH values with the reference values for clear sky as determined by Zhang et al. (2010). It outputs the number of levels contaminated by low, middle and high clouds.

GRUAN site	POD (%)	FAR (%)	Bias	Accuracy
LAU	94	8.62	1.03	0.87
GVN	99	10.4	1.10	0.89
LIN	95	7.98	1.03	0.88
PAY	88	2.16	0.89	0.87
SNG	100	0.00	1.00	1.00

RH test (Zhang et al. 2010) vs RS-GRUAN SynopClouds
Dichotomous statistical scores between cloud detection methods

MULTISOURCE CORRELATIVE METHODOLOGY ANALYSIS: EQUATIONS (1/2)

- **Measurement x** from i-th source (MWR, NWP, RAOB ….) at n-th space-time location

$$x_i = b_i + a_i\, t + \varepsilon_i$$

a_i: ***calibration scaling*** of measuring system $i-th$

b_i: ***calibration bias*** of measuring system $i-th$

t: ***unobserved truth*** which is common to all the measuring systems

ε_i: ***unknown random error*** of system $i-th$

Assumptions

Assumption1 (A1). Linearity: eq. (1) holds.

Assumption2 (A2): ε_i is zero average random error.

Assumption3 (A3): Error orthogonality, i.e. $\langle \varepsilon_i\, t \rangle = 0$.

Assumption4 (A4): Error independence i.e.: $e_{ij} = \langle \varepsilon_i\, \varepsilon_j \rangle = 0$ with $i \neq j$

Assumption5 (A5): Stationarity of both t and x_i

Assumption6 (A6): the three measuring systems, x_i, $i = 1, 2, 3$ must observe the same quantity t.

Outcomes

Error variances

$$\hat{\sigma}^2_{\varepsilon_1} = \sigma^2_{x_1} - \frac{C_{13}}{C_{23}}(C_{12} - e_{12})$$

$$\hat{\sigma}^2_{\varepsilon_2} = \sigma^2_{x_2} - \frac{C_{23}}{C_{13}}(C_{12} - e_{12})$$

$$\hat{\sigma}^2_{\varepsilon_3} = \sigma^2_{x_3} - C_{13}\, C_{23}\left(\frac{1}{C_{12} - e_{12}}\right)$$

Correlation coefficients

$$\hat{\rho}_{t,x1} = \frac{1}{\hat{\sigma}_{x1}}\sqrt{\frac{(C_{12} - e_{12})\, C_{13}}{C_{23}}}$$

$$\hat{\rho}_{t,x2} = \frac{1}{\hat{\sigma}_{x2}}\sqrt{\frac{(C_{12} - e_{12})\, C_{23}}{C_{13}}}$$

$$\hat{\rho}_{t,x3} = \frac{1}{\hat{\sigma}_{x3}}\sqrt{\frac{C_{23} C_{13}}{(C_{12} - e_{12})}}$$

Covariance definition:

$$C_{ij} = \frac{1}{N_s - 1}\sum_{n=1}^{N_s}\left[\left(x_i(n) - \mu_{x_i}\right)\left(x_j(n) - \mu_j\right)\right] = \left\langle \left(x_i - \mu_{x_i}\right)\left(x_j - \mu_j\right)\right\rangle$$

Mean definition:

$$\mu_{x_i} = \frac{1}{N_s}\sum_{n=1}^{N_s} x_i(n) = \langle x_i \rangle$$

MULTISOURCE CORRELATIVE METHODOLOGY ANALYSIS: EQUATIONS (2/2)

- **Measurement** x from *i*-th source (MWR, NWP, RAOB ….)

$$x_i = b_i + a_i\, t + \varepsilon_i$$

a_i: ***calibration scaling*** of measuring system $i-th$

b_i: ***calibration bias*** of measuring system $i-th$

t: ***unobserved truth*** which is common to all the measuring systems

ε_i: ***random error*** of system $i-th$

Assumptions

Assumption1 (A1). Linearity: eq. (1) holds.

Assumption2 (A2): ε_i is zero average random error.

Assumption3 (A3): Error orthogonality, i.e. $\langle \varepsilon_i\, t \rangle = 0$.

Assumption4 (A4): Error independence i.e.: $e_{ij} = \langle \varepsilon_i\, \varepsilon_j \rangle = 0$ with $i \neq j$

Assumption5 (A5): Stationarity of both t and x_i

Assumption6 (A6): the three measuring systems, x_i, $i = 1, 2, 3$ must observe the same quantity t.

Outcomes

Error variances

$$\hat{\sigma}_{\varepsilon_1}^2 = \sigma_{x_1}^2 - \frac{C_{13}}{C_{23}}(C_{12} - e_{12})$$

$$\hat{\sigma}_{\varepsilon_2}^2 = \sigma_{x_2}^2 - \frac{C_{23}}{C_{13}}(C_{12} - e_{12})$$

$$\hat{\sigma}_{\varepsilon_3}^2 = \sigma_{x_3}^2 - C_{13}\, C_{23}\left(\frac{1}{C_{12} - e_{12}}\right)$$

If calibration parameters of system 1, a_1, b_1, are known

Calibration parameters

$$\hat{a}_2 = \frac{C_{23}}{C_{13}} a_1 \quad ; \quad \hat{a}_3 = \frac{C_{23}}{(C_{12} - e_{12})} a_1$$

$$\hat{b}_2 = \langle x_2 \rangle - \frac{C_{23}}{C_{13}} \langle x_1 \rangle + \frac{C_{23}}{C_{13}} b_1;$$

$$\hat{b}_3 = \langle x_3 \rangle - \frac{C_{23}}{(C_{12} - e_{12})} \langle x_1 \rangle + \frac{C_{23}}{(C_{12} - e_{12})}$$

b

MULTISOURCE CORRELATIVE METHODOLOGY ANALYSIS: ERROR CORRELATION TERMS

Error variances

$$\hat{\sigma}^2_{\varepsilon_1} = \sigma^2_{x_1} - \frac{C_{13}}{C_{23}}(C_{12} - e_{12})$$

$$\hat{\sigma}^2_{\varepsilon_2} = \sigma^2_{x_2} - \frac{C_{23}}{C_{13}}(C_{12} - e_{12})$$

$$\hat{\sigma}^2_{\varepsilon_3} = \sigma^2_{x_3} - C_{13}\, C_{23}\left(\frac{1}{C_{12} - e_{12}}\right)$$

Error covariance e_{12}

$$e_{12} = \langle \varepsilon_1\, \varepsilon_2 \rangle = \rho_{12}\, \sigma_{\varepsilon_1}\, \sigma_{\varepsilon_2}$$

ρ_{12}: **correlation term**

- The term e_{12} describe the degree of error correlation between system 1 and 2 (RS and NWP for example)
- e_{12} is generally unknow. Any indication of its value allow to completely characterize the terms $\hat{\sigma}^2_{\varepsilon_i}$

- In the special case of RS and NWP, they share the same RTE to produce the BT. Consequently, we can assume their errors perfectly correlated (i.e. ρ_{12}=1) and of the same magnitude ($\mathrm{i.e.}\ \sigma_{\varepsilon_1} = \sigma_{\varepsilon_2} = \sigma_{\varepsilon_{RTE}}$).
- Thus, e_{12} reduces to $\sigma^2_{\varepsilon_{RTE}}$. The if we know the the error variance introduced by RTE we can estimate , e_{12} and refer to MCMA performance cases with no error correlations (upper panels)

MULTI-SOURCE CORRELATIVE METHODOLOGY ANALYSIS

MCM analysis input:

From Step-V output (Qt=2)

BT_RS (for each frequency and for each match-up);
BT_NWP(for each frequency and for each match-up);
BT_SAT(for each frequency and for each match-up);

MCMconfig.ini

scaling calibration parameter for RS reference system	bias calibration parameter for RS reference system	error covariance between RS and NWP
a1=1 (default) gain is assumed to be normalized to 1 by GRUAN compensation processing **s_a1=0** (default) (error SD of a1, TBD)	**b1=0** (default) bias calibration parameter. It is assumed to be compensated by GRUAN processing **s_b1=0** (default) (error SD of b1 TBD)	**e12=0** (default)

MCM analysis output:

- error standard deviations for RS/SAT/NWP
- calibration parameters for SAT/NWP only