Recent radio occultation reprocessing at the Wegener Center: Profile and climatology data validation including uncertainty evaluation

Marc Schwärz[1,2], Gottfried Kirchengast[1,2], Josef Innerkofler[1], Florian Ladstädter[1], Armin Leuprecht[1]

[1]: Wegener Center for Climate and Global Change (WEGC), University of Graz, Austria
[2]: Institute of Physics, University of Graz, Austria

UCAR, Boulder, September 13, 2024

Thank's to supporting partners

Great support from

- EUMETSAT, Darmstadt
- ROMSAF/DMI, Copenhagen
- UCAR, Boulder
- ECMWF, Reading
- JPL, Pasadena
- AIUB, Berne
- NSSC Beijing
- others

Objective of presentation

Objectives

- motivation
- overview on processing at WEGC
- overview on rOPS
- validation and climatologies

Motivation

WEGC as part of ROM SAF

- rOPS data is/will be used as validation data for the GPAC data products
- rOPS is used as the R & D system of ROM SAF

General – not less important

- produce a dataset (utilizing the uncertainty of rOPS) which can show the power/consistency of the RO method
- produce a dataset which can be part of a various RO datasets for the next IPCC assessment report

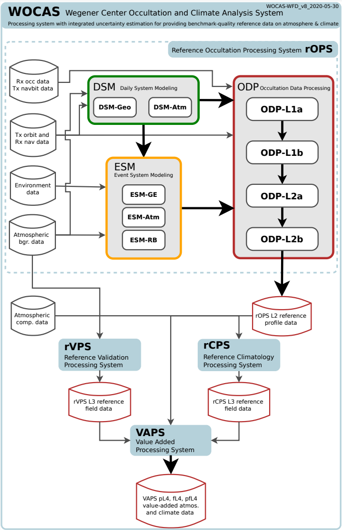
EUMETSAT ROM SAF
FFG
Wegener Center
UNI GRAZ

rOPS

Features of the new system

- processing of the data from raw measurement data (L0 data including orbit data processing) onward
- implementation using base band (minimize potential biases)
- provide an integrated uncertainty processing from:
  - raw orbit and measurement uncertainty input
  - and some assumptions for unknown raw uncertainties
- uncertainty propagation of these input uncertainties down to dry- and physical parameter
- get a new clean code base
- testing based on CI tools
- planned phase only QC had to be extended by an additional bending angle part

WOCAS overview



Overview of the Wegener Center Occultation and Climate Analysis System

rOPS intention

probably remember – time frame expectations

- 3 years (Gottfried) to 10 years (Uli)
- definitely much overestimated by Uli since we only needed 9 years

Processing setup

Satellites – base setup

- METOP-A/B/C and CHAMP
- output of:
  - excess phase data
  - bending angle data
  - dry parameter (refractivity, T_d, p_d, etc.)
  - physical parameter (T, p, q, etc.)
  - uncertainties for all these atmospheric species.

Test processing

- COSMIC-1, GRACE, COSMIC-2, SPIRE, FY3

Validation and comparison datasets

Validation dataset

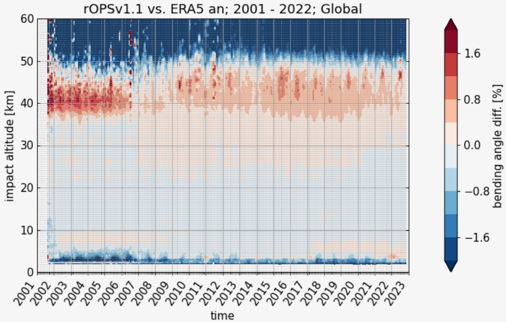
- ERA5 analysis (interpolated to RO locations)

Comparison datasets

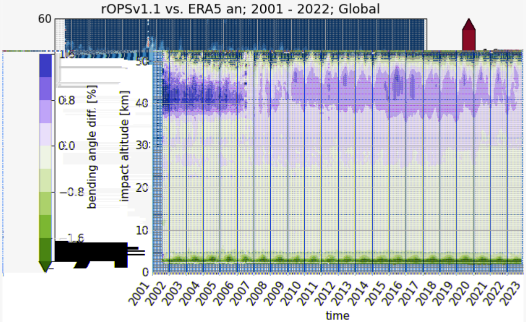
- GPAC CDR/ICDR data
- old CDAAC RO-Trends data

Validation vs. ERA5

Bending angle mean/median – time series

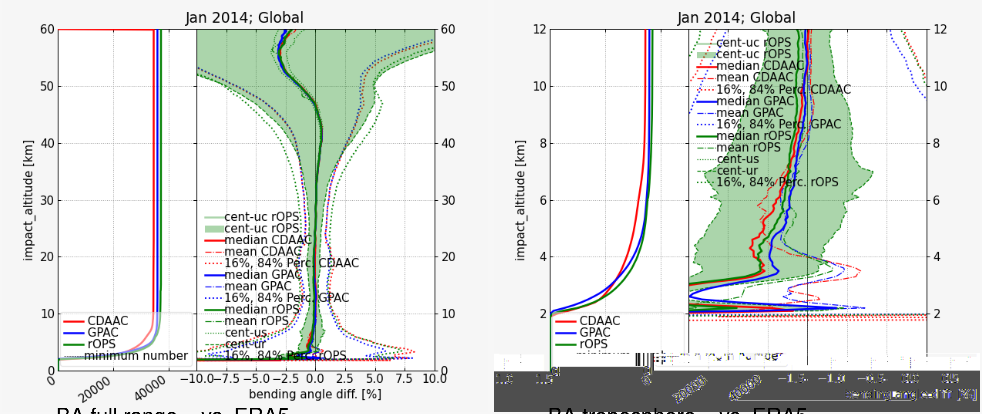


BA mean – vs. ERA5



BA median – vs. ERA5

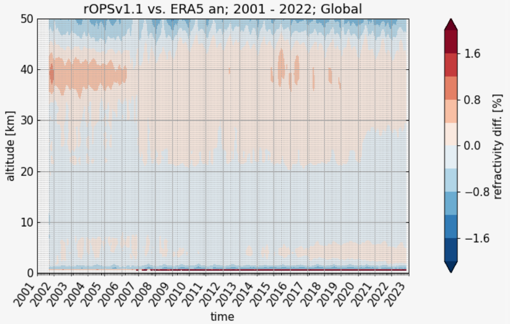
Bending angle – example month



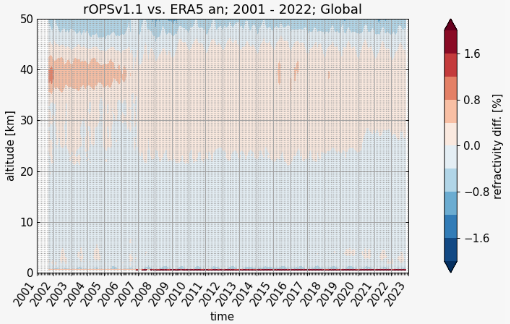
BA full range – vs. ERA5

BA troposphere – vs. ERA5

Refractivity mean/median – time series

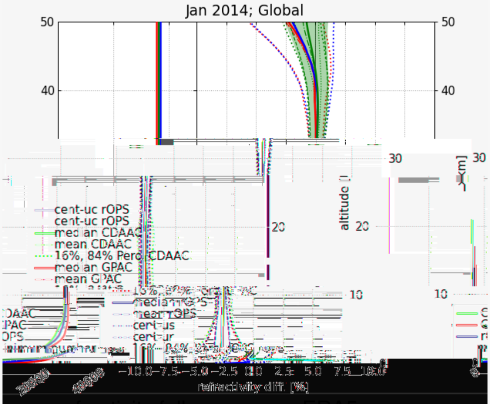


refractivity mean – vs. ERA5

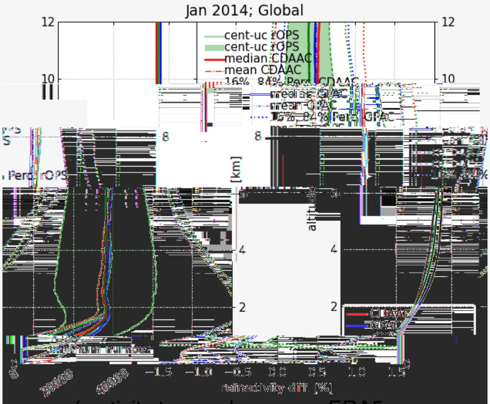


refractivity median – vs. ERA5

Refractivity – example month

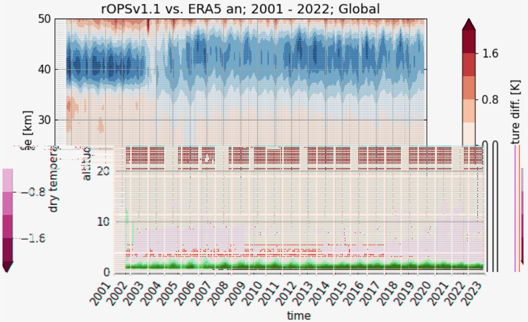


refractivity full range – vs. ERA5

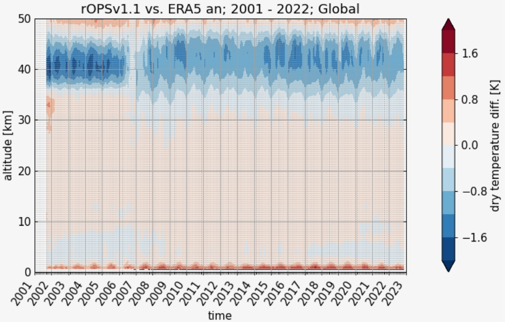


refractivity troposphere – vs. ERA5

Dry temperature mean/median – time series

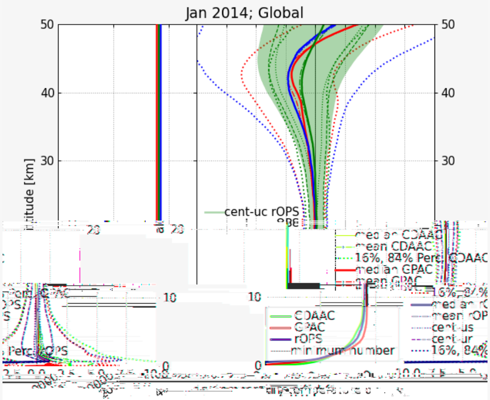


dry temperature mean – vs. ERA5

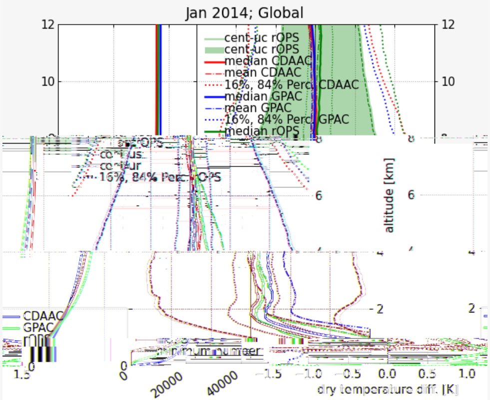


dry temperature median – vs. ERA5

Dry temperature – example month

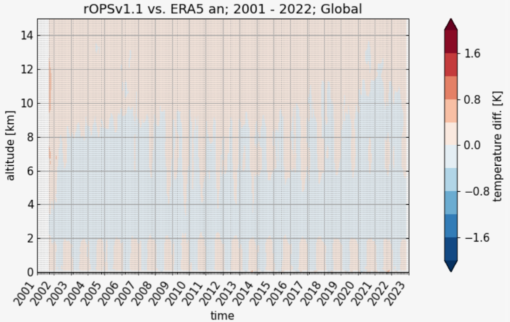


dry temperature full range – vs. ERA5

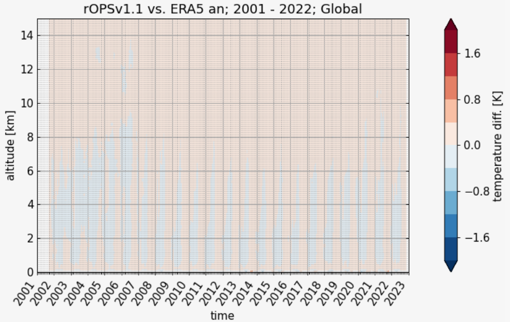


dry temperature troposphere – vs. ERA5

Temperature mean/median – time series



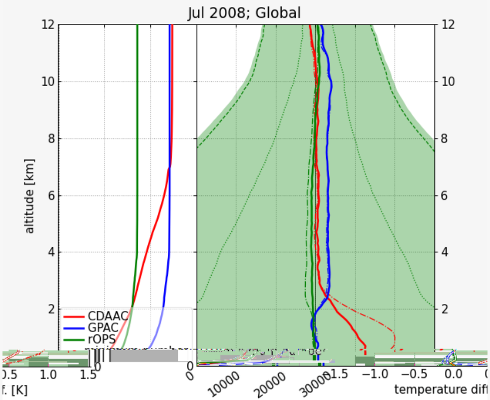
temperature mean – vs. ERA5



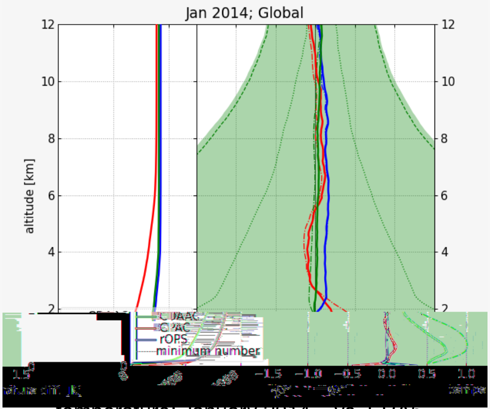
temperature median – vs. ERA5

Temperature – example months

Introduction
Motivation
System
Val and Clim
S & O

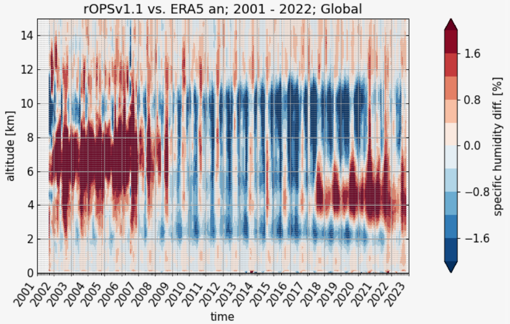


temperature; July 2008 – vs. ERA5

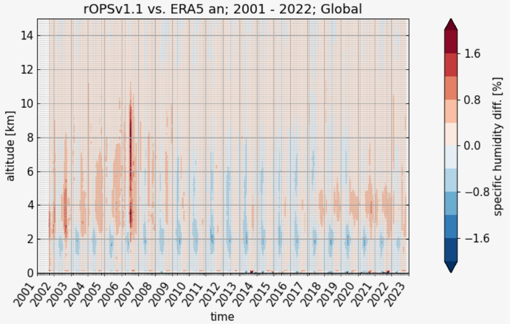


temperature; January 2014 – vs. ERA5

Specific humidity mean/median – time series

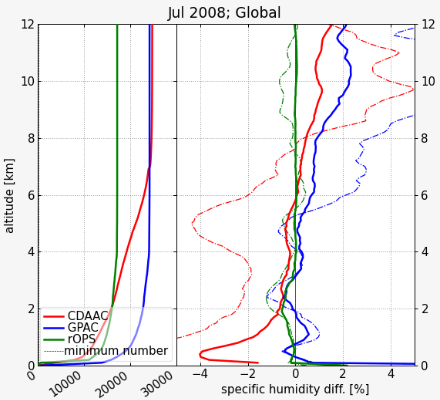


specific humidity mean – vs. ERA5

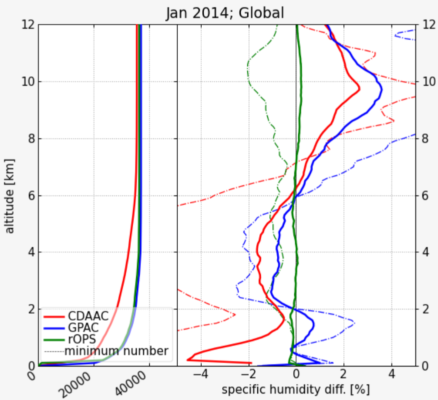


specific humidity median – vs. ERA5

Specific humidity – example months



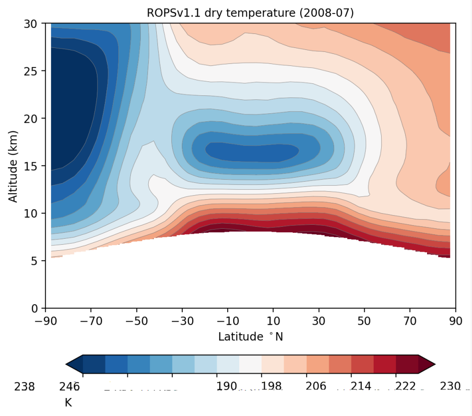
specific humidity; July 2008 – vs. ERA5



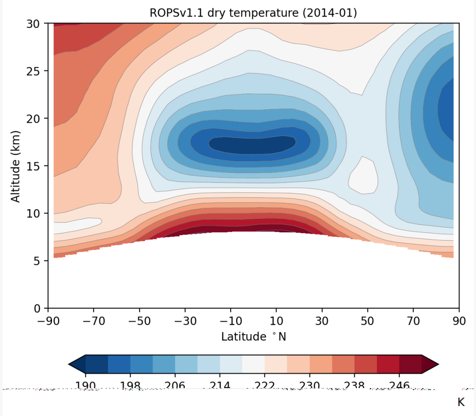
specific humidity; January 2014 – vs. ERA5

Example climatologies – dry temperature

Introduction
Motivation
System
Val and Clim
S & O



dry temperature climatology; July 2008



dry temperature climatology; January 2014

Usage of climatologies

Talk of Andrea on Tuesday

Processing Summary

rOPS

- base reprocessing using METOP and CHAMP looks mature
- bending angle data: very consistent to GPAC and CDAAC data – well within the rOPS uncertainty bounds
- refractivity: very consistent up to about 42 km – above within uncertainty bounds
- dry temperature: very consistent up to about 30 km – above within uncertainty bounds
- temparature: almost no bias with respect to ERA5 in median statistics, very small bias ($<$0.1 K) in mean statistics
- specific humidity: almost no bias with respect to ERA5 in median statistics down to about 3 km, below $<$0.5 %; mean statistics: bias $<$2 %

Outlook

Todo

- include other missions (COSMIC-1, GRACE, COSMIC-2, Spire, etc.)
- perform detailed validation including external non-RO datasets and different analysis and forecast fields
- use in a range of RO & Climate scientific studies (within ROM SAF context, IPCC AR7, etc.)

Literature

G. Kirchengast, M. Schwärz, B. Angerer, J. Schwarz, J. Innerkofler, V. Proschek, J. Ramsauer, J. Fritzer, B. Scherllin-Pirscher, and T. Rieckh
Reference OPS—DAD, Doc-ID: WEGC-rOPS—2018—TR01, Issue 2.0, 2018

Gorbunov, M. E. and G. Kirchengast
Wave-optics uncertainty propagation and regression-based bias model in GNSS radio occultation bending angle retrievals *Atmos. Meas. Tech.*, 11, 111—125, 2018; doi: 10.5194/amt-11-111-2018

Innerkofler, J., G. Kirchengast, M. Schwärz, C. Pock, A. Jäggi, Y. Andres, and C. Marquardt
Precise Orbit Determination for Climate Applications of GNSS Radio Occultation including Uncertainty Estimation *Remote Sens.*, 12, 1180, 2020; doi: 10.3390/rs12071180

Innerkofler, J., G. Kirchengast, M. Schwärz, C. Marquardt, and Y. Andres
GNSS radio occultation excess phase processing for climate applications including uncertainty estimation *Atmos. Meas. Tech.*, 16.21, 2023, pp. doi: 10.5194/amt-16-5217-2023

Literature

- **Li, Y., G. Kirchengast, B. Scherllin-Pirscher, R. Norman, Y. B. Yuan, J. Fritzer, M. Schwärz and K. Zhang**
  Dynamic statistical optimization of GNSS radio occultation bending angles: advanced algorithm and performance analysis *Atmos. Meas. Tech.*, 8, 3447—3465, 2015; doi: 10.5194/amt-8-3447-2015
- **Schwarz, J., G. Kirchengast, and M. Schwärz**
  Integrating uncertainty propagation in GNSS radio occultation retrieval: From bending angle to dry-air atmospheric profiles, *Earth Space Sci.*, 4, 200—228, 2017; doi: 10.1002/2016EA000234
- **Schwarz, J., G. Kirchengast, and M. Schwärz**
  Integrating uncertainty propagation in GNSS radio occultation retrieval: from excess phase to atmospheric bending angle profiles *Atmos. Meas. Tech.*, 11, 2601—2631, 2018; doi: 10.5194/amt-11-2601-2018
- **Li, Y., G. Kirchengast, B. Scherllin-Pirscher, M. Schwärz, J. K. Nielsen, S-P. Ho, Y-B. Yuan**
  A New Algorithm for the Retrieval of Atmospheric Profiles from GNSS Radio Occultation Data in Moist Air and Comparison to 1DVar Retrievals *Remote Sens.*, 11.23, 2019; doi: 10.3390/rs11232729

EUMETSAT ROM SAF
FFG
Wegener Center
UNI GRAZ

That's it!