# GNSS-PW status update, Metrological closure between GNSS-PW and radiosonde (C11, C12)

15-19 November 2021

Virtual meeting

# GNSS TT (status update)

- No changes in GNSS TT membership.

- The GNSS TT has worked on topics listed on the GRUAN Master Action Item list as re-scheduled after ICM-12 – Tasks C11 (GDP data format), C12 (Metrological closure of RS, GNSS).

- The TT has worked on GRUAN GNSS data product certification and improving the GRUAN GNSS data flow (continuous process).

**GRUAN-presentations in 2021:**

GNSS-based Precipitable Water Vapor: Certification for the Global Climate Observing System

G. Dick[1], J. Jones[2], J. Wang[3], K. Rannat[4], J. Wickert[1], F. Zus[1], K. Balidakis[1], K. Wilgan[1]

1) GFZ German Research Centre for Geosciences, Potsdam, Germany
2) Met Office, Exeter, United Kingdom
3) University at Albany, USA
4) Tallinn University of Technology, Estonia

1st ICCC Workshop (online), March 29-31, 2021

**GNSS for the Global Climate Observing System: Precipitable Water Vapor Processing Centre at GFZ**

G. Dick[1], F. Zus[1], J. Wickert[1,2], B. Männel[1], M. Bradke[1], M. Ramatschi[1], K. Balidakis[1], K. Wilgan[1,2], H. Schuh[1,2]

1) GFZ German Research Centre for Geosciences, Potsdam, Germany
2) Technische Universität Berlin

Scientific Assembly of International Association of Geodesy
June 28 – July 2, 2021

GNSS-based Precipitable Water Vapor for the Global Climate Observing System

G. Dick[1], J. Jones[2], J. Wang[3], K. Rannat[4], J. Wickert[1,5], F. Zus[1], B. Männel[1], K. Balidakis[1], and K. Wilgan[1,5]

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5) Technische Universität Berlin, Germany

EMS Annual Meeting 2021 online, 3-10 September 2021

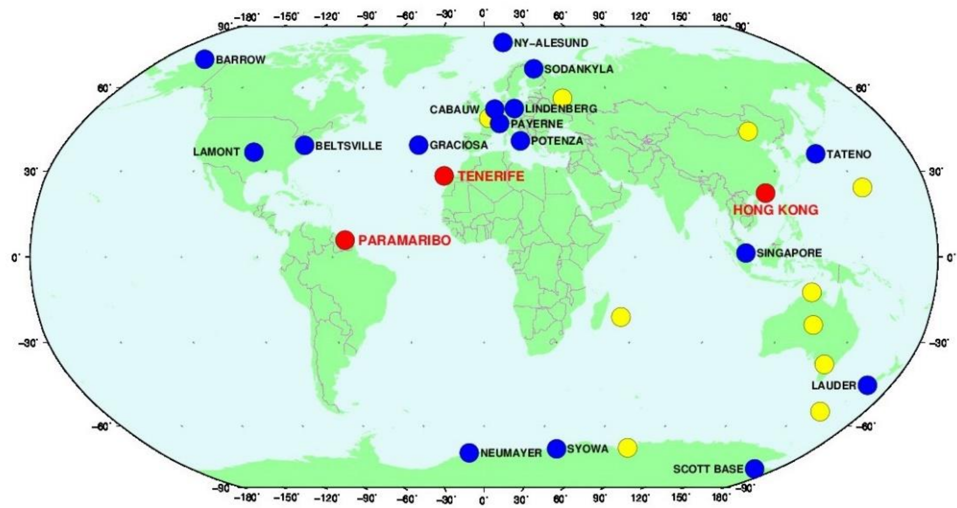
# GNSS-PWV – the sites, data processing and validation at GFZ

**GNSS network:**
- Currently **16** GNSS sites in PWV processing (blue dots)
- 3 planned sites (red dots)

**Operational Data Center:**
- GNSS data handling
- Data archiving
- Monitoring of all changes

**GNSS Processing Centre:**
- Operational PWV estimation
- Consistent re-processing
- Quality control
- Uncertainty estimation

**Product Validation:**
RS, WVR, VLBI, NWM, …




# Status of GNSS sites and data flow (updates since ICM-12)

**Current stations in PW processing (14th November 2021):**

**ENAO (Graciosa)**
**HUNC (Beltsville)**
**LDB2 (Lindenberg)**
**LDRZ (Lauder)**
**LIN0 (Lindenberg (renamed and re-located LDB0))**
**MSS1 (Singapore)**
**NYA2 (Ny-Alesund)**
**PAYE (Payerne)**
**POTM (Potsdam)**
**POTS (Potsdam)**
**SCTB (Scott Base)**
**SGPO (Lamont)**
**SODA (Sodankylä)**
**SODF (Sodankylä)**
**TITO (Potenza)**
**TSK2 (Tsukuba)**
**UTQI (Barrow)**

**Co-located non-GRUAN sites, used for validation purposes**

**New in processing TITO (Potenza) and HUBC (Beltsville).**

**Planned stations for 2022: Paramaribo (Suriname) and Tenerife.**

# TASKS LEFT AFTER ICM-12

**C11 GNSS GDP format**

TT GNSS-PW; Lead Centre (review)

DWD developing NetCDF format. Keeping in touch with DWD progress mainly via E-GVAP, but GFZ in direct contact with DWD. Ongoing (GFZ + DWD), last conversation October 2021.

**C12 Metrological closure of GNSS-IWV and radiosondes**

GNSS-IWV; TT- radiosonde

For GRUAN sites that perform both GNSS-IWV measurements and radiosoundings, analyze the comparison of the GRUAN data products (and their respective uncertainties) for these data streams to establish whether metrological closure is attained. Ongoing, further results will be published in a scientific paper.

Preliminary results (will be presented on a few next slides )

# Activities in frames of Task C12:

Using GRUAN-processed RS & GNSS data (Gruan Data Products - GDP)
Both GNSS and RS GDPs are compared against independent techniques (WVR and VLBI) and ERA5 reanalysis.

Although the results (RS versus GNSS) are presented only for Lindenberg, the analysis includes all GRUAN sites where the data is available for both techniques.

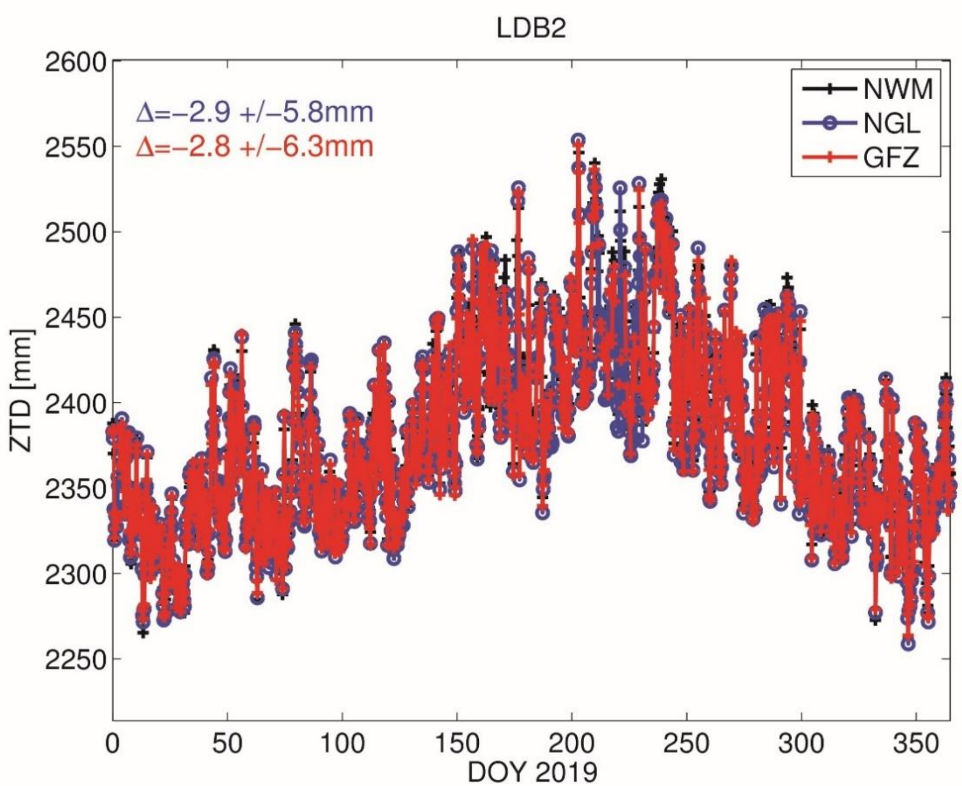
Some complementary analysis is made with non-GRUAN GNSS and RS datasets also.

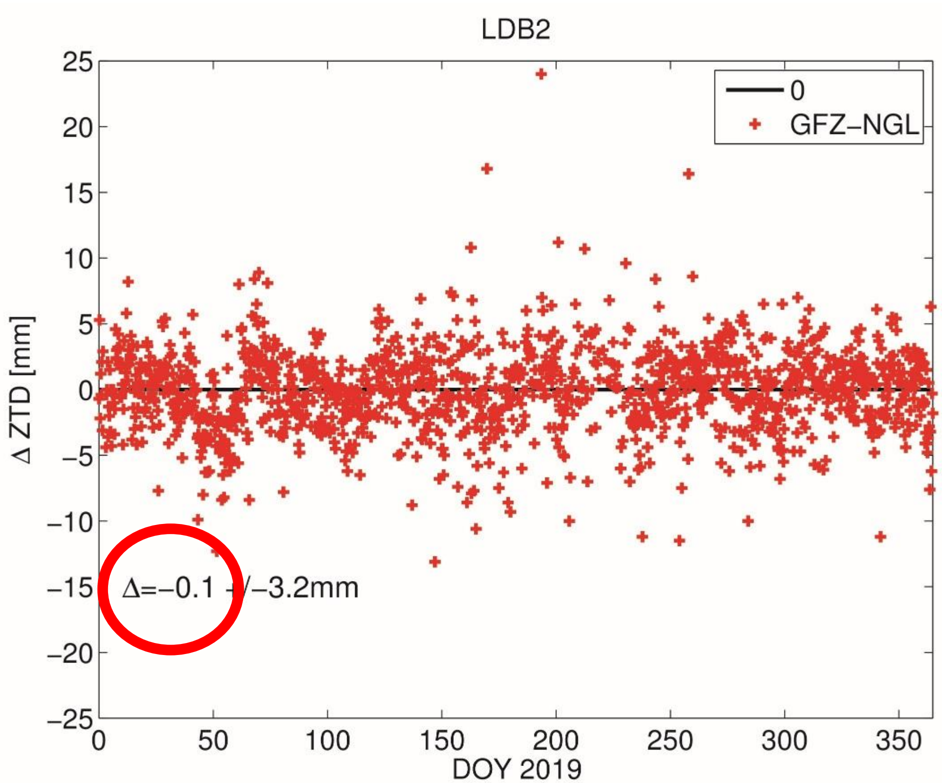
The task is not finished, the results will be published (hopefully before ICM-14)

The preliminary results will follow ...

Comparisons of **GNSS ZTD GFZ** solution with other GNSS solutions and **Very Long Baseline Interferometry**

# GRUAN Station Lindenberg (Germany)

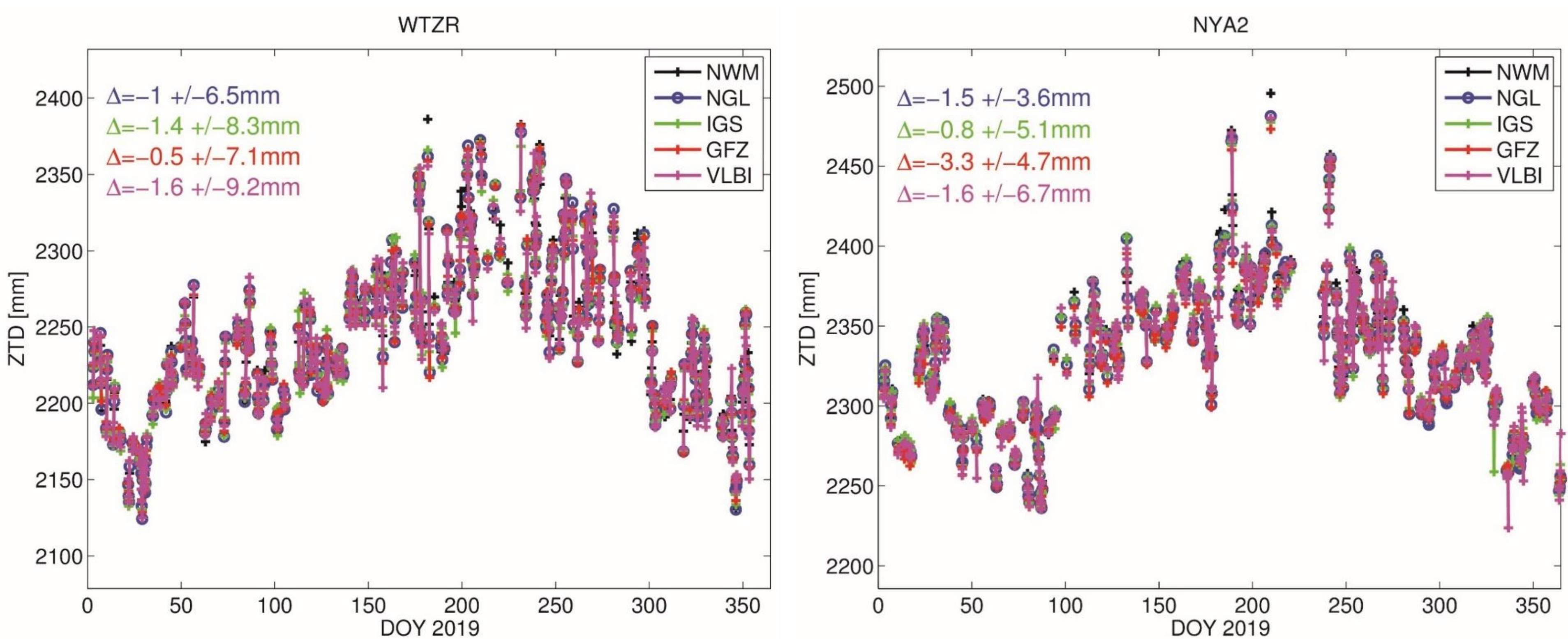



**Differences between GFZ and NGL**

**Black:** **ERA5 atmospheric reanalysis of ECMWF**
**Blue:** **GNSS solution of Nevada Geodetic Laboratory (NGL)**
**Red:** **GNSS solution of GFZ**

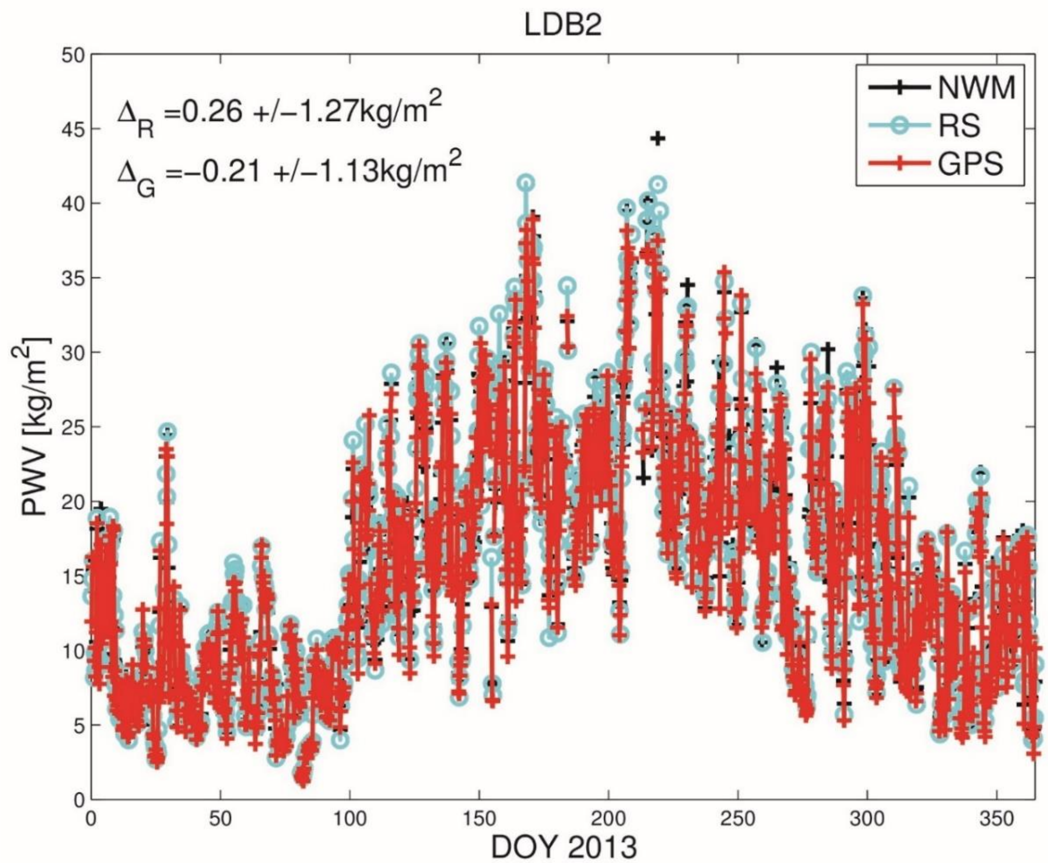
# VLBI vs GNSS for Ny Alesund (Norway) and Wettzell (Germany) for 2019

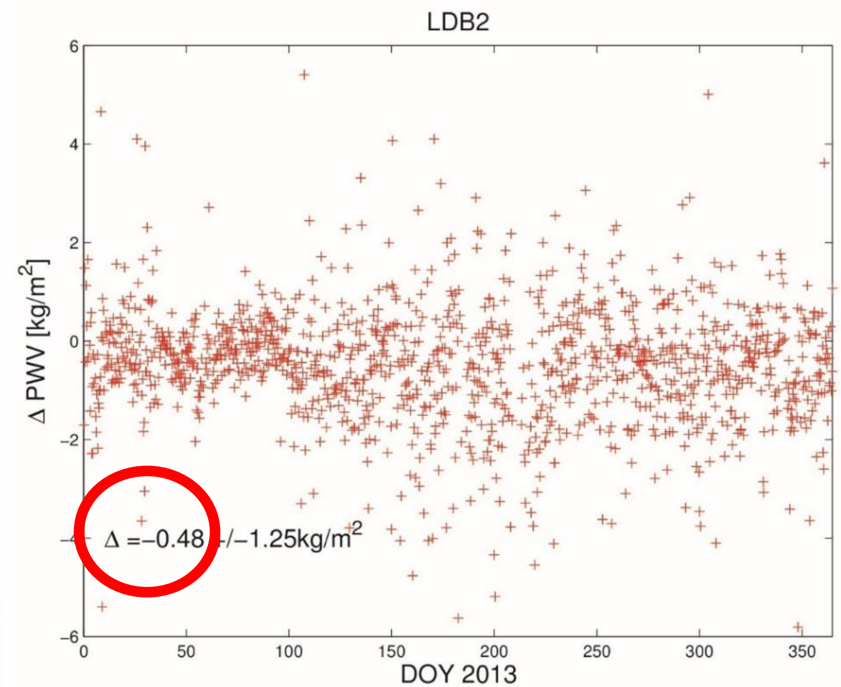



**Black:** ERA5 atmospheric reanalysis of ECMWF
**Blue:** GNSS solution of Nevada Geodetic Laboratory (NGL)
**Green:** GNSS solution of IGS
**Red:** GNSS solution of GFZ
**Purple:** VLBI solution of GFZ

# Comparisons of **GNSS-PW** with instrumental measurements (RS, WVR) and NWM ERA5

# Validation of GNSS-PW with RS for Lindenberg

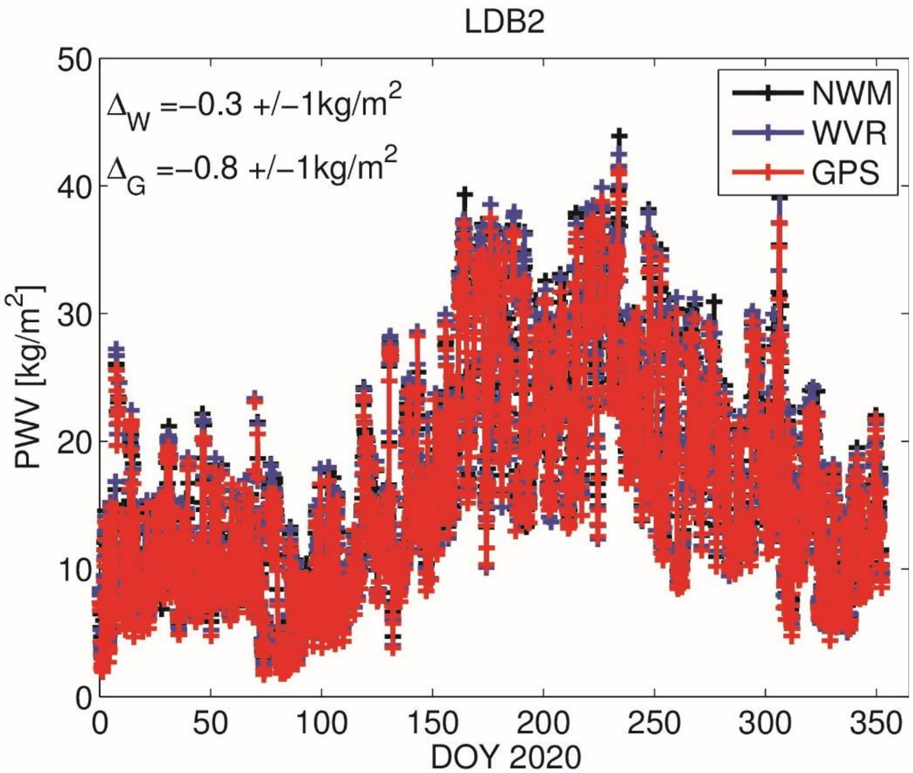


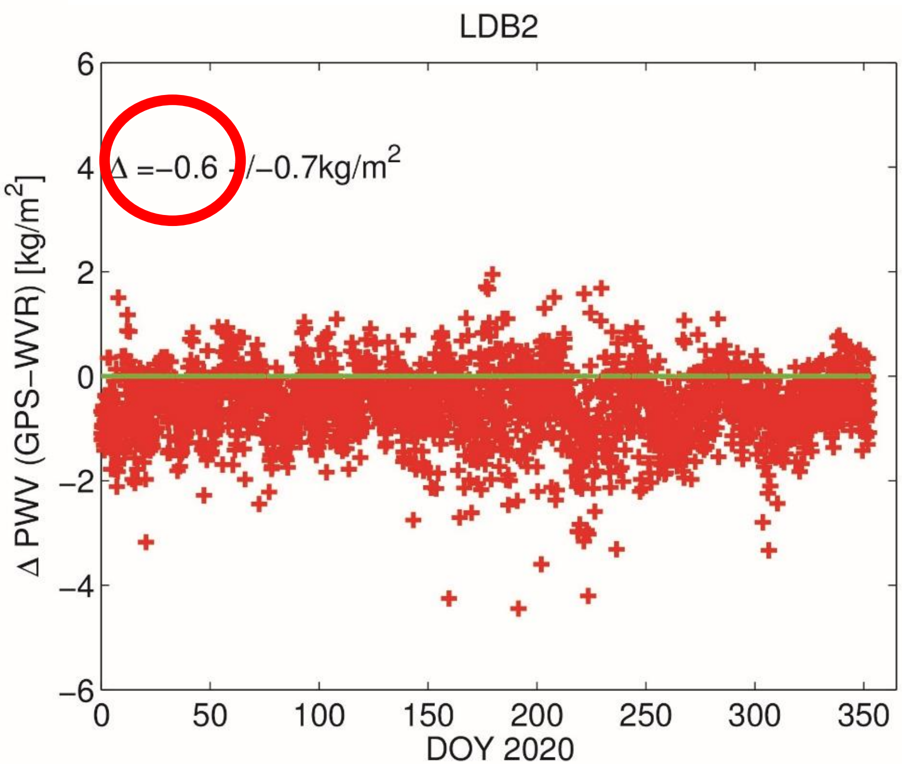




**Differences between GNSS-PW and RS92-PW for 2013**

**Black:** ERA5 atmospheric reanalysis of ECMWF
**Blue:** GRUAN Radiosonde product (RS92 GDP)
**Red:** GNSS solution of GFZ

# Validation of GNSS-PW with WVR for Lindenberg




**Differences between GNSS-PW and WVR-PW for 2020**

**Black:** **ERA5 atmospheric reanalysis of ECMWF**
**Blue:** **Water Vapor Radiometer (WVR)**
**Red:** **GNSS solution of GFZ**

# Summary (based on GRUAN GNSS, RS products)

- Very **good agreement** between GNSS and VLBI solutions
- **Small dry bias** of about -0.6 kg/m$^2$ PWV between GNSS-PW and instrumental measurements of RS and WVR
- In general, **the bias value is very small** for all GRUAN sites, indicating a very high accuracy of GNSS-PW data product
- **Certification: GRUAN GNSS GDP certified January 2021**

The results from comparing GFZ GRUAN GNSS re-analysis and GRUAN-processed RS data show good agreement between radiosonde and GNSS. However, for good agreement it is necessary to notice the importance of observational conditions, instrumental calibration and the data processing technology.

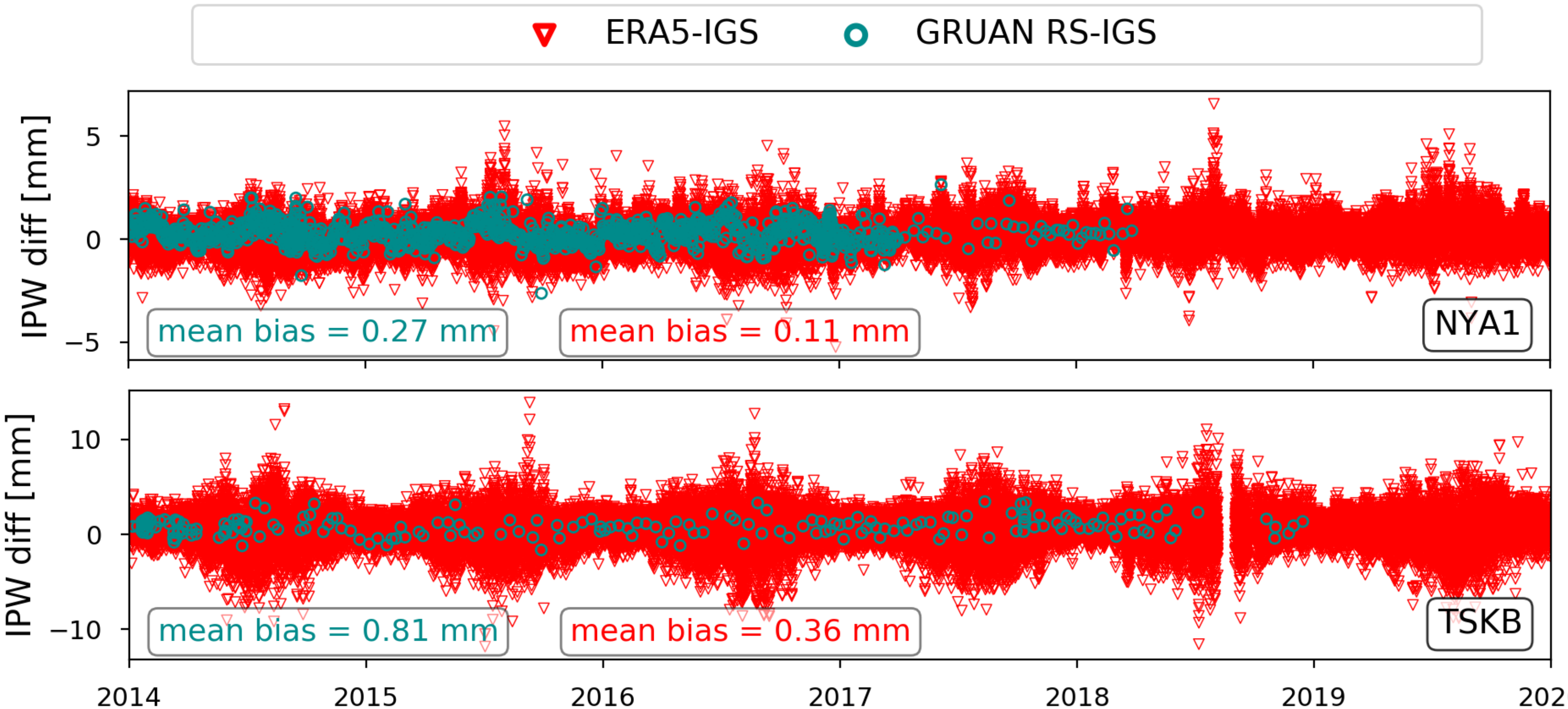
# Comparing the results with data from non-GRUAN sites and without GRUAN data processing methodology

Some results from:

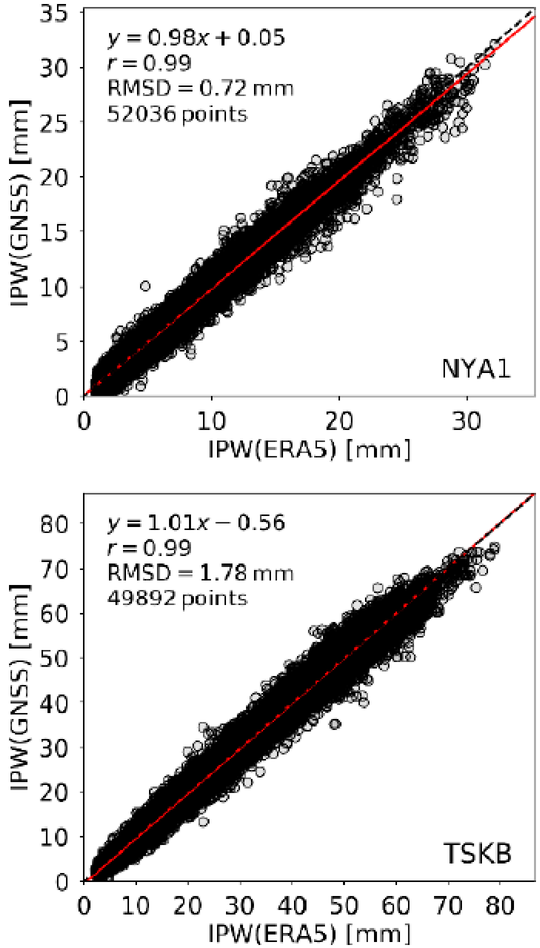
C3S_311a_Lot3_CNR – SC1
Access to observations from baseline and reference networks

# 17 Radiosonde stations chosen for comparing IPW from ERA5, and IPW retrieved from IGS tropospheric product (non-GRUAN product)

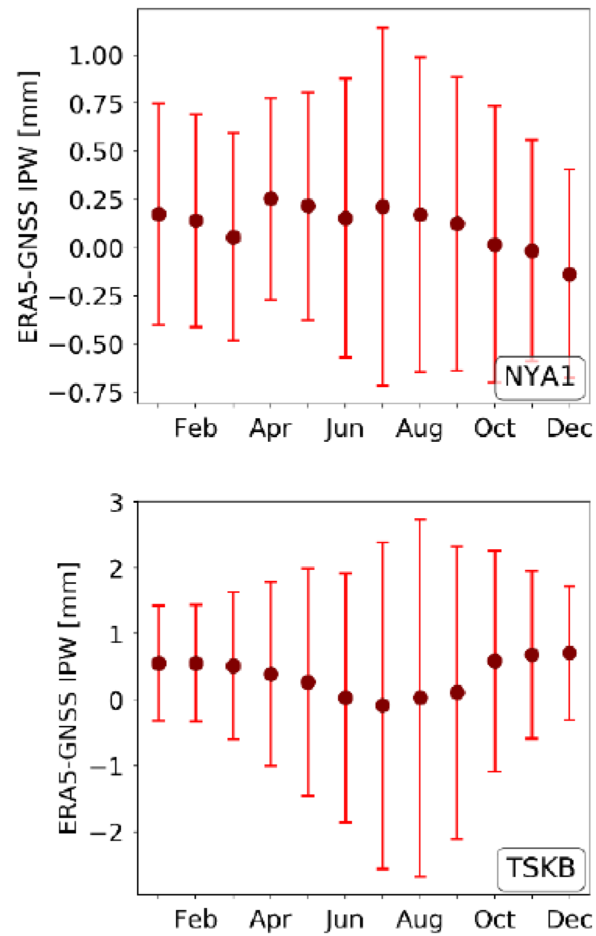
| IGRA or GRUAN station | WMO ID | Name | Lat | Lon | Elev (m asl) | Co-located GNSS station | Elev of co-located GNSS station (m asl) | Distance from GNSS station (km) |
|---|---|---|---|---|---|---|---|---|
| IGRA | ASM00094326 | Alice Springs Airport | -23.80 | 133.89 | 545.3 | ALIC | 588.3 | 13.9 |
| IGRA | TUM00017130 | Ankara | 39.95 | 32.88 | 891.0 | ANKR | 937.6 | 12.7 |
| IGRA | CAM00071926 | Baker Lake, UA | 64.32 | -96.00 | 50.8 | BAKE | 46.3 | 0.2 |
| IGRA | BDM00078016 | L F Wade International Airport | 32.37 | -64.68 | 4.0 | BRMU | 20.8 | 1.8 |
| IGRA | AYM00089611 | Casey | -66.28 | 110.52 | 40.0 | CAS1 | 39.5 | 0.2 |
| IGRA | CKM00096996 | Cocos Island Aeroport | -12.19 | 96.83 | 3.0 | COCO | 3.4 | 0.1 |
| IGRA | UKM00003882 | Herstmonceux | 50.90 | 0.32 | 52.0 | HERS | 31.4 | 3.8 |
| IGRA | ASM00094998 | Macquarie Island | -54.50 | 158.94 | 6.0 | MAC1 | 12.3 | 0.1 |
| GRUAN | SVM00001004 | Ny-Ålesund | 78.92 | 11.92 | 15.5 | NYA1 | 48.1 | 1.4 |
| IGRA | CIM00085934 | Punta Arenas | -53.00 | -70.84 | 38.0 | PARC | 12.2 | 15.0 |
| IGRA | CAM00071845 | Pickle Lake, UA | 51.45 | -90.20 | 386.2 | PICL | 353.0 | 4.2 |
| IGRA | BRM00082824 | Porto Velho | -8.77 | -63.92 | 102.0 | POVE | 107.6 | 6.8 |
| IGRA | GLM00004339 | Ittoqqortoormiit | 70.48 | -21.95 | 70.0 | SCOR | 71.5 | 0.1 |
| IGRA | SHM00061901 | St. Helena Is. | -15.94 | -5.67 | 435.0 | STHL | 436.6 | 0.1 |
| GRUAN | JAM00047646 | Tateno | 36.06 | 140.13 | 25.2 | TSKB | 27.4 | 6.3 |
| IGRA | SWM00002591 | Visby | 57.65 | 18.35 | 45.0 | VIS0 | 54.7 | 1.1 |
| IGRA | RSM00024959 | Jakutsk | 62.02 | 129.72 | 98.3 | YAKT | 108.8 | 2.5 |



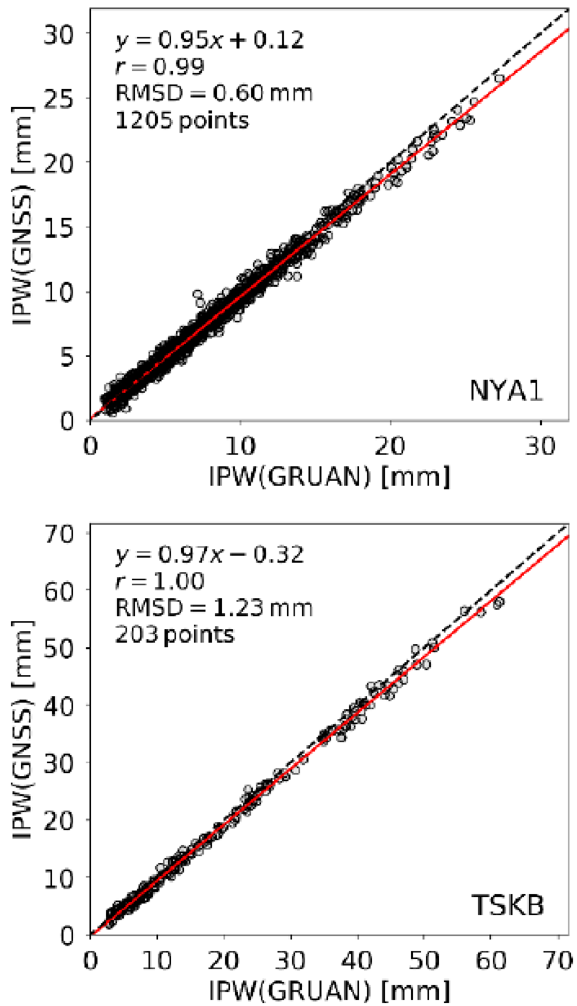
ERA5-IGS
GRUAN RS-IGS
IPW diff [mm]
5
0
−5
mean bias = 0.27 mm
mean bias = 0.11 mm
NYA1
IPW diff [mm]
10
0
−10
mean bias = 0.81 mm
mean bias = 0.36 mm
TSKB
2014
2015
2016
2017
2018
2019
2020

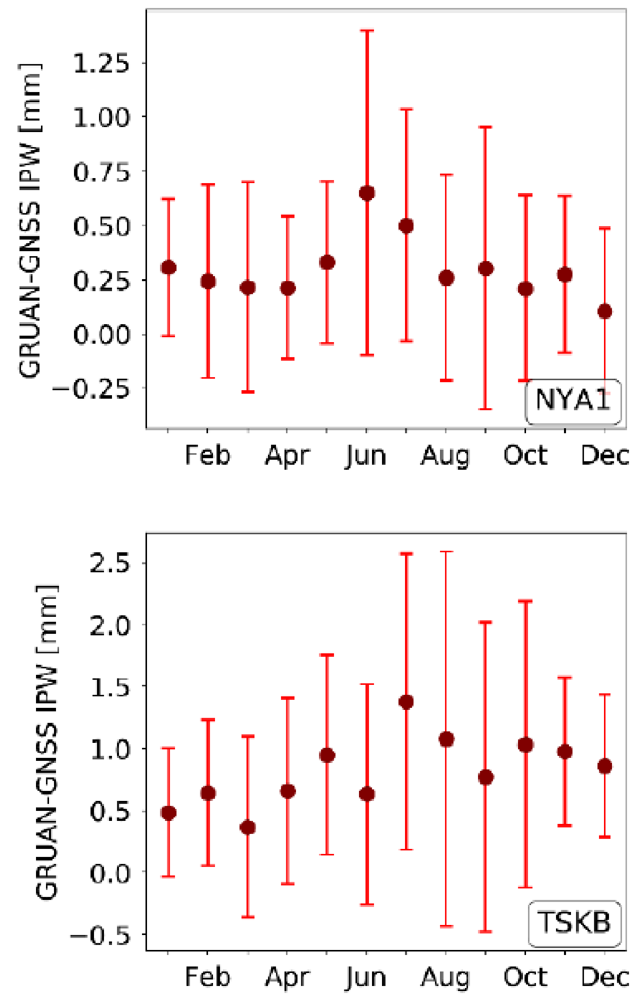



Comparison of IPW between **ERA5 and GNSS** stations during 2014–2019.




**Monthly ERA5-GNSS IPW differences** at IGS stations. Error bars represent the standard deviation of ERA5-GNSS IPW difference during one month




Comparing **GNSS** with **GRUAN RS**

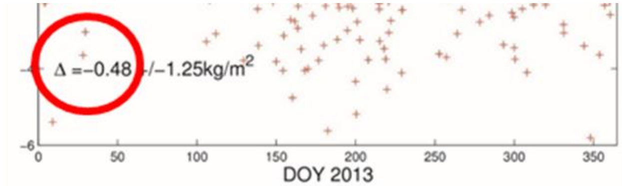
Monthly **GRUAN RS– IGS GNSS** IPW difference

Seasonal average IPW difference and its standard deviation for GRUAN GDP.2 (RS92) and **GNSS (IGS)** at NYA1 and TSKB for 2014-2019, in mm.

| | | Winter | Spring | Summer | Autumn | Average |
|---|---|---|---|---|---|---|
| NYA1 | GRUAN RS–GNSS IPW diff | 0.22 | 0.25 | 0.47 | 0.28 | 0.31 |
| | GRUAN RS–GNSS IPW diff STD | 0.39 | 0.39 | 0.59 | 0.42 | 0.45 |
| | GNSS $\sigma_{IPW}$, (using $\sigma_{ZTD}$ = 4 mm) | 0.65 | 0.65 | 0.68 | 0.67 | 0.66 |
| | GNSS $\sigma_{IPW}$, (from CDDIS) | 0.43 | 0.43 | 0.45 | 0.43 | 0.43 |
| | GRUAN RS $\sigma_{IPW}$ | 0.21 | 0.22 | 0.50 | 0.33 | 0.31 |
| TSKB | GRUAN RS–GNSS IPW diff | 0.74 | 0.66 | 1.03 | 0.95 | 0.84 |
| | GRUAN RS–GNSS IPW diff STD | 0.55 | 0.76 | 1.15 | 1.15 | 0.90 |
| | GNSS $\sigma_{IPW}$, (using $\sigma_{ZTD}$ = 4 mm) | 0.68 | 0.71 | 0.77 | 0.73 | 0.72 |
| | GNSS $\sigma_{IPW}$, (from CDDIS) | 0.43 | 0.48 | 0.53 | 0.50 | 0.49 |
| | GRUAN RS $\sigma_{IPW}$ | 0.46 | 0.82 | 1.89 | 1.12 | 1.07 |

Here: RS – GNSS > 0
(GNSS is «dryer»)

Lindenberg LDB2
(**GRUAN GNSS & RS92_GDP.2**)



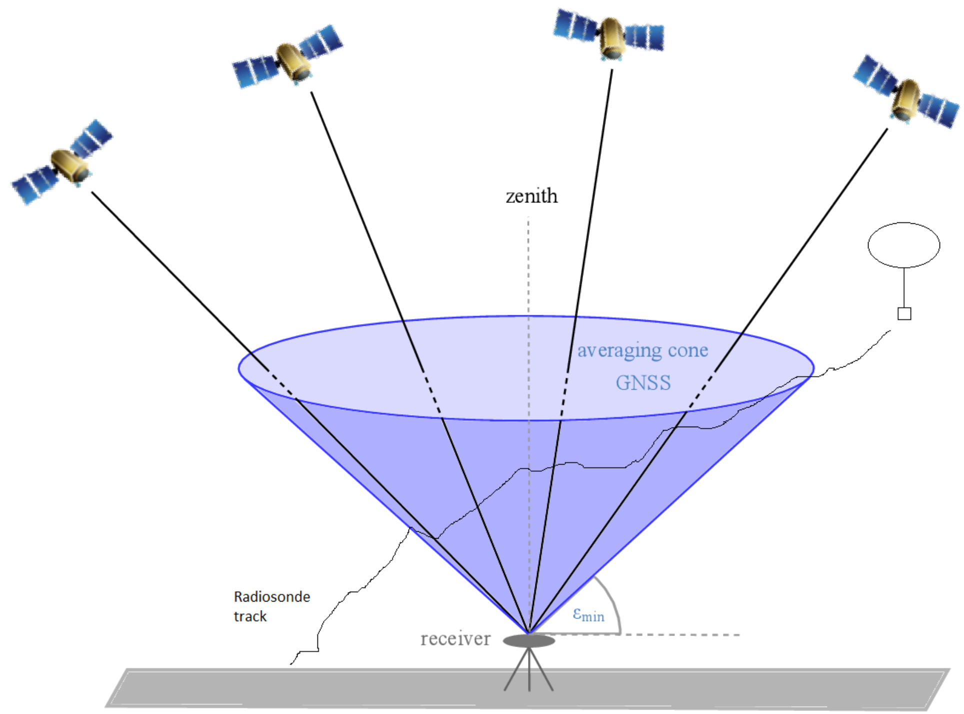

**Differences between GNSS-PW and RS92-PW for 2013**

Regarding IPW comparison between ERA5 and all 18 GNSS sites, the average difference (ERA5-GNSS) ranges from −0.9 mm (at CAS1) to 0.93 mm (at ONSA).

The corresponding numbers when comparing IGRA/GRUAN RS with GNSS are −0.9 mm (also CAS1) to 1.81 mm (at POVE). In most cases, the GNSS is “dryer”, as also seen from GRUAN sites with GRUAN GDP.

# GNSS observations versus Radiosonde observations – metrological closure

**What do we expect from the results?**
**What should we expect?**
**Could the results be the same?**




GNSS and RS observations are very different things. RS PWV is an accumulation of spot measurements @ 2sec intervals, whereas GNSS is an amalgamation of all the satellites in view ("cone of atmosphere") over a period of time (e.g. 15mins or 1 hour RINEX).

**To some degree it is (and always will be) comparing apples with oranges, you will never get 100% agreement and we should live with that knowledge.**

# Summary

## Differences in comparisons

## GRUAN GNSS – GRUAN RS

## IGS – GRUAN RS

## IGS - IGRA RS

Comparing the data from IGRA radiosondes and IGS – the preliminary results are similar, but not «as good» as for GRUAN RS versus GNSS from IGS.

Better results from GRUAN intercomparison reflect the benefit gained from applying GRUAN centralized data processing and –methodology.

The GNSS IPW shows a small dry bias compared to the radiosonde (similar results gained from both GRUAN and non-GRUAN tropospheric products.

The results from comparing GFZ GRUAN GNSS re-analysis and GRUAN-processed RS data show good agreement between radiosonde and GNSS. However, good observational conditions, instrumental calibration and the data processing technology are the key for good agreement between RS and GNSS.

# Thank you for your attention!