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RESEARCH FOR GRAND CHALLENGES

GNSS-PW DATA PRODUCT: TOWARDS CERTIFICATION

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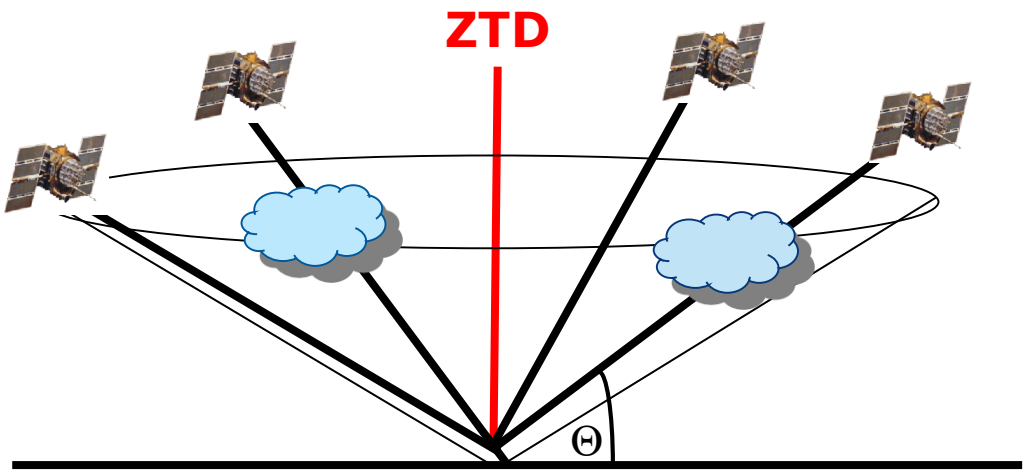
GNSS-derived Precipitable Water Vapor



Isotropic water vapor distribution & known mapping function (~1/sin Θ)

Additional: pressure and temperature at the station for conversion of ZTD to PW

Result of GNSS data analysis: Zenith Total Delay (ZTD) with mm-accuracy

dry, hydrostatic wet

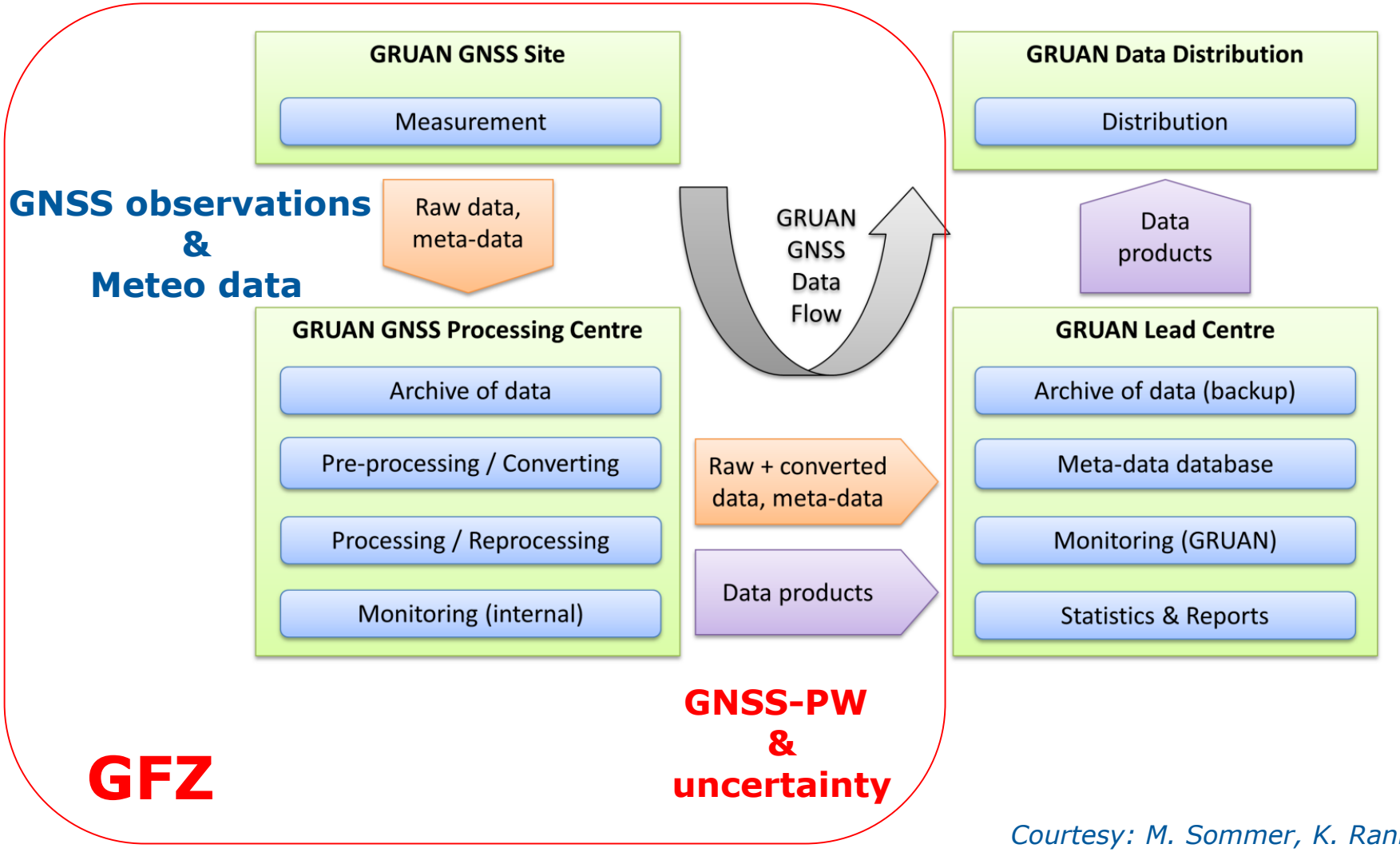
$$ZTD = ZHD + ZWD$$

$$ZHD = f(\text{pressure}) \; [\pm 1 \text{ mm accuracy}]$$

$$PW = \Pi(T_m) \bullet ZWD$$

Converted Precipitable Water Vapor (PW)

Observations → GRUAN GNSS-PW Data Product



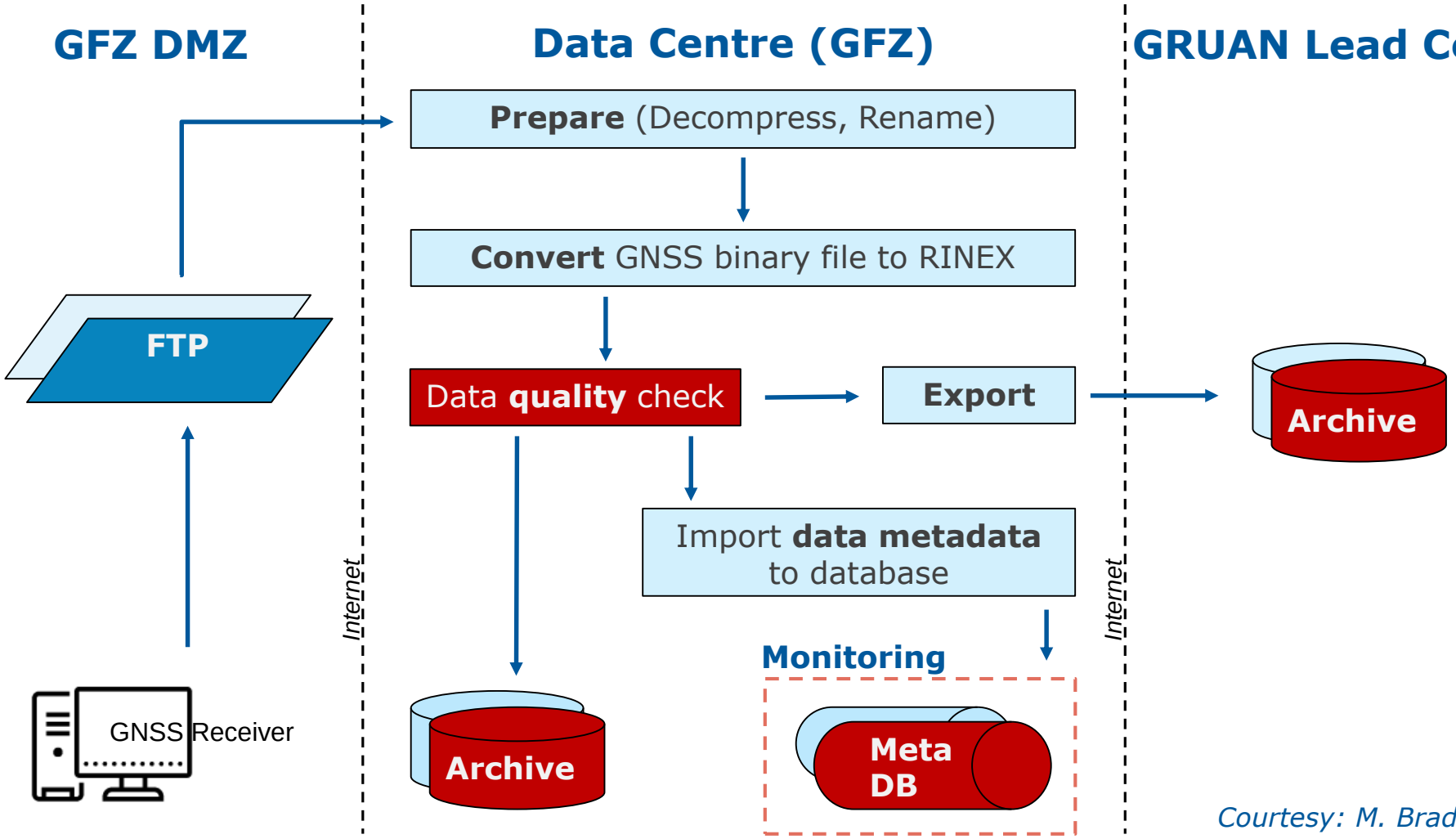
Courtesy: M. Sommer, K. Rannat

Operational Data Centre (ODC) at GFZ

- Operational since 2018
- Ability to process all GNSS related data
- Data passes quality check before GNSS data analysis
- Monitoring of station behavior
  - Instant feedback for station operators
- Short data processing latency (< 1 minute per station)

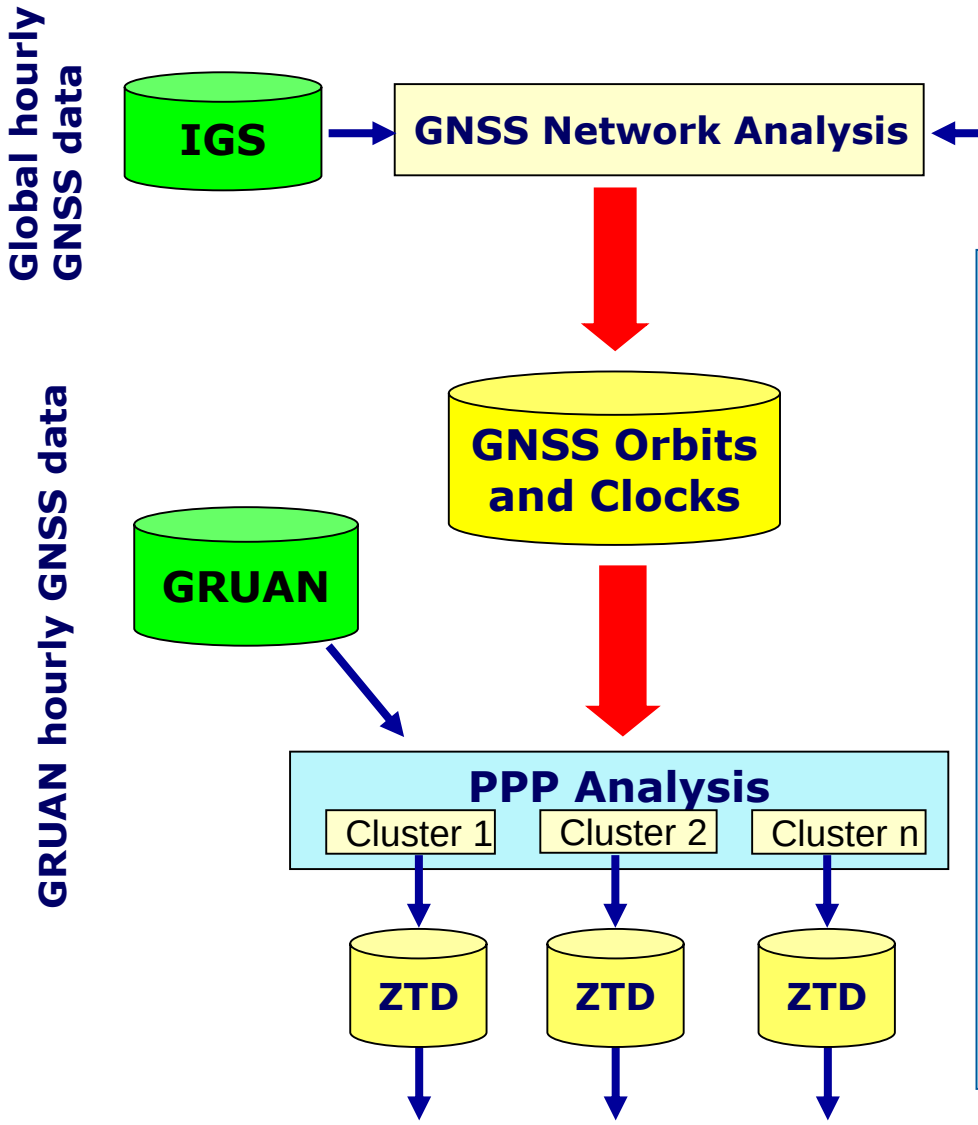
Courtesy: M.Bradke

Raw GNSS Data Flow



Courtesy: M. Bradke

GNSS Processing with GFZ EPOS.P8 Software



Part 1 - Orbit Improvement

- Adjustment of precise orbits & clocks using global GNSS network of IGS

Part 2 - PPP Analysis

- Estimation of ZTDs and other tropospheric parameters with high sampling rate (15 minutes for ZTD/PW)

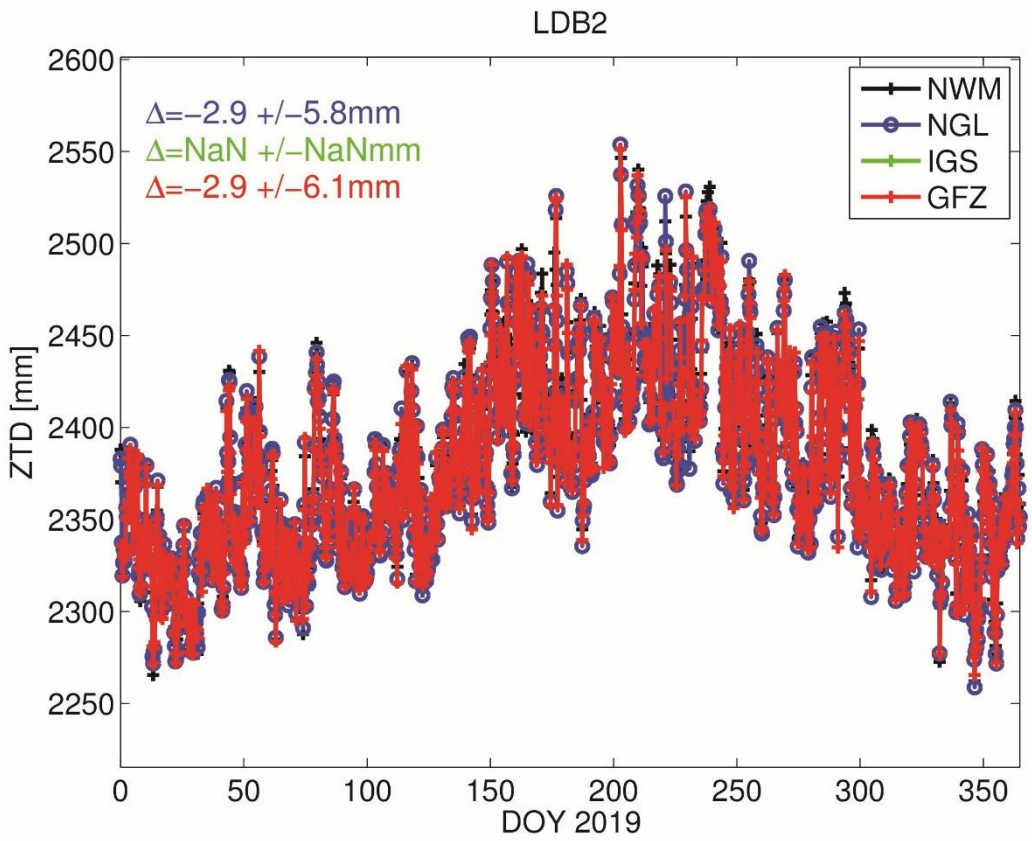
Part 3 - Product Generation

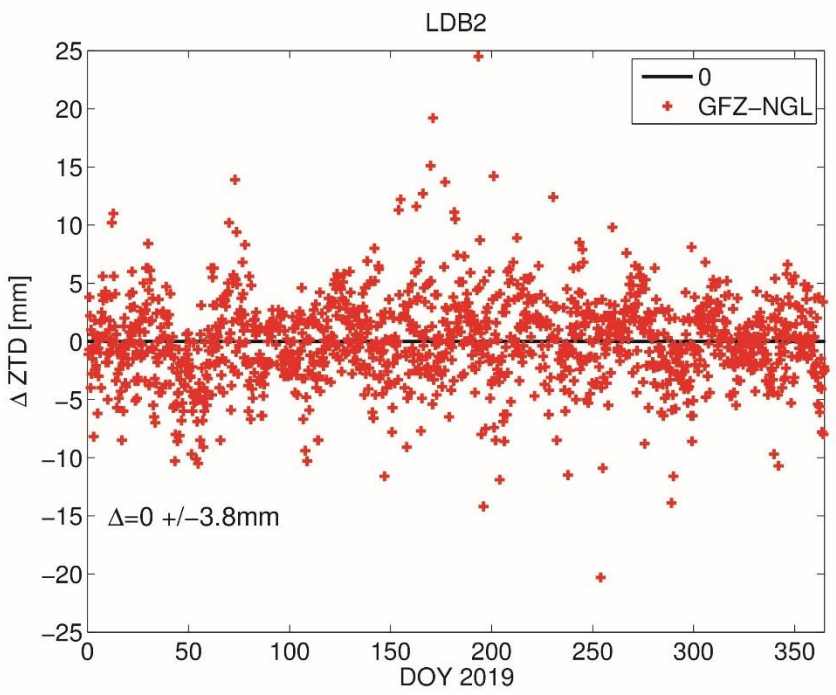
- Conversion ZTDs to PW
- Estimation of PW uncertainty

Product generation:
conversion to PW, uncertainty estimation
Product distribution to GRUAN LC

Comparison of GNSS ZTD solutions for selected stations for 2019

GRUAN Station Lindenberg (LDB2)

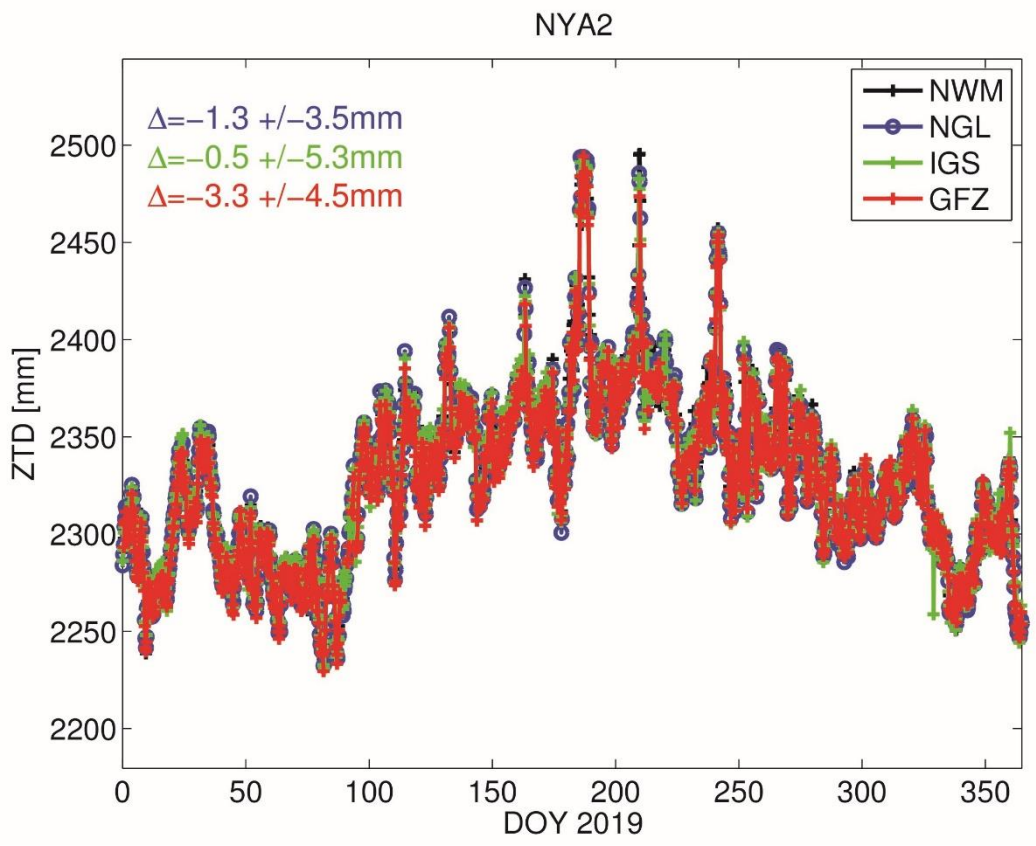


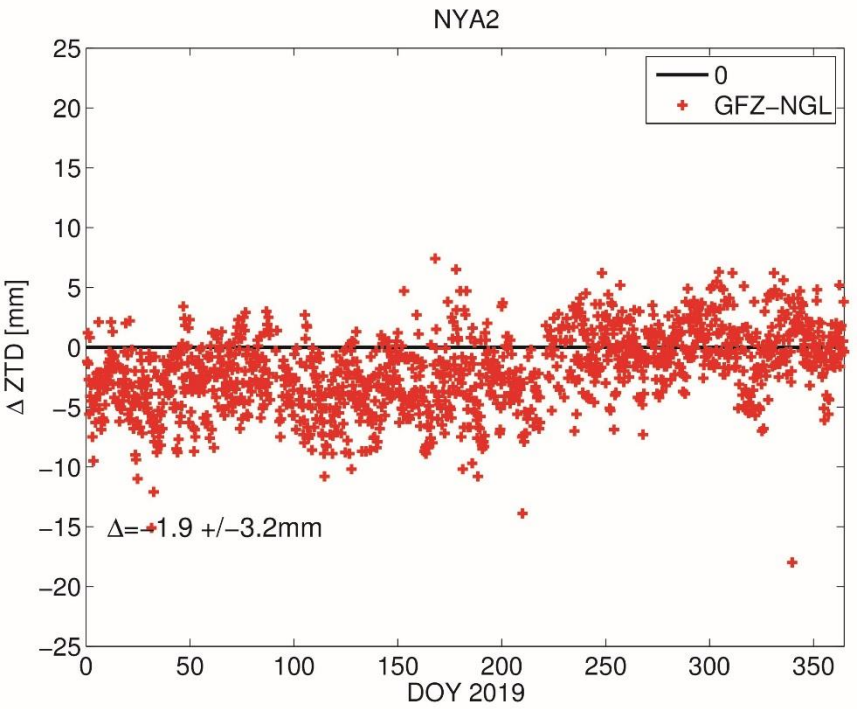


Differences between GFZ and NGL

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

GRUAN Station Ny Alesund (NYA2)





Differences between GFZ and NGL

Black: ERA5 atmospheric reanalysis of ECMWF
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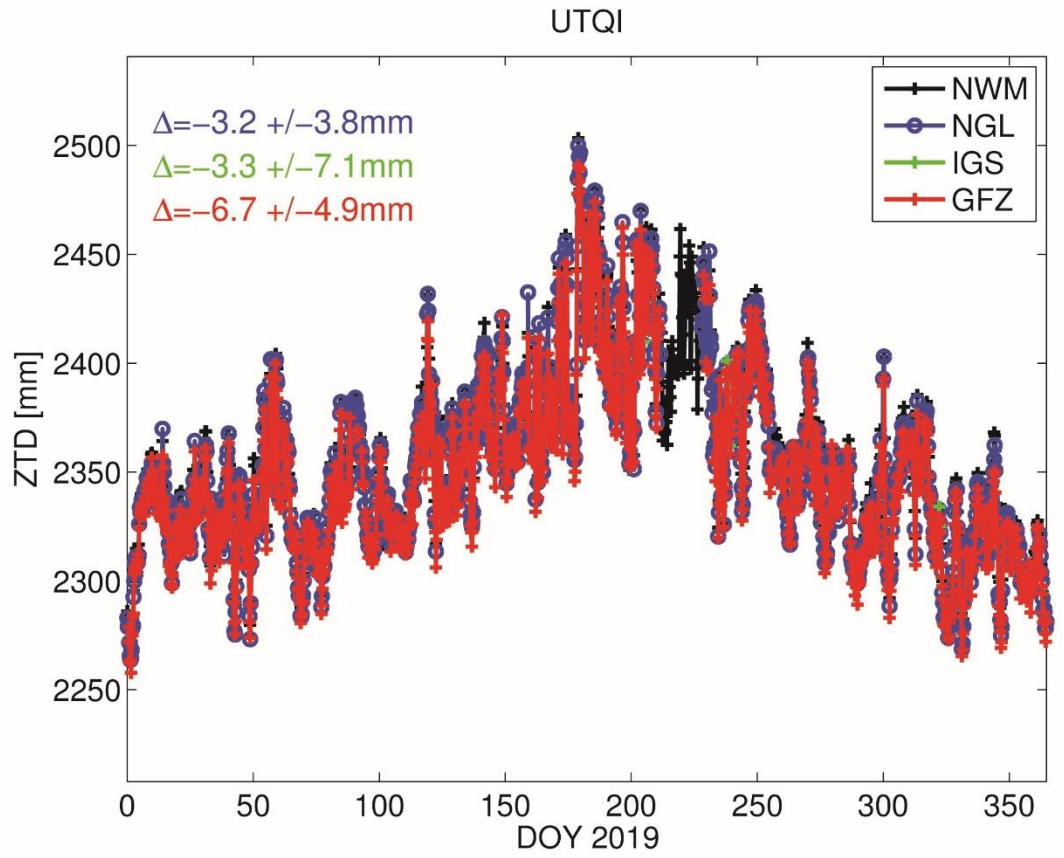
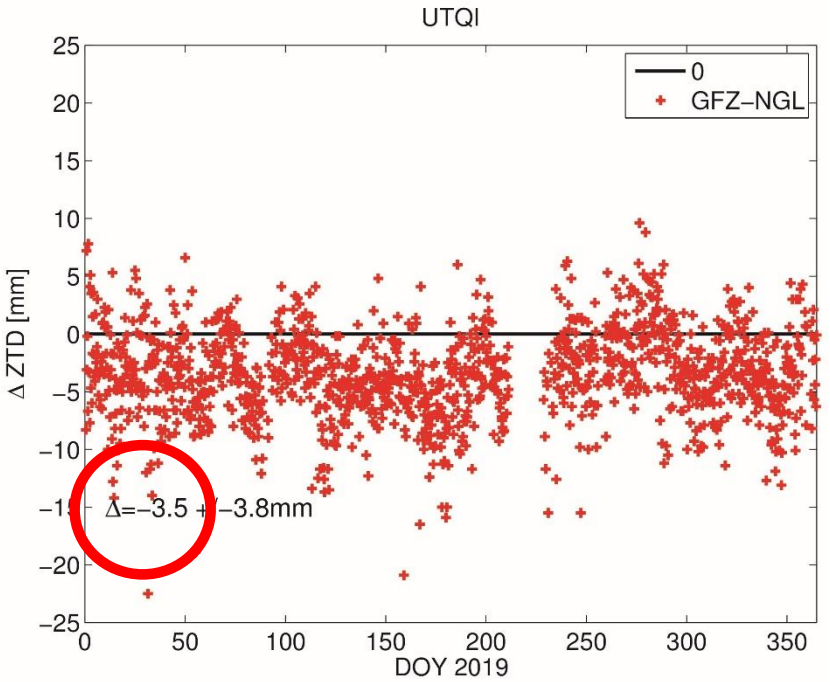
Red: GNSS solution of GFZ

GRUAN Station Barrow (UTQI)





Differences between GFZ and NGL

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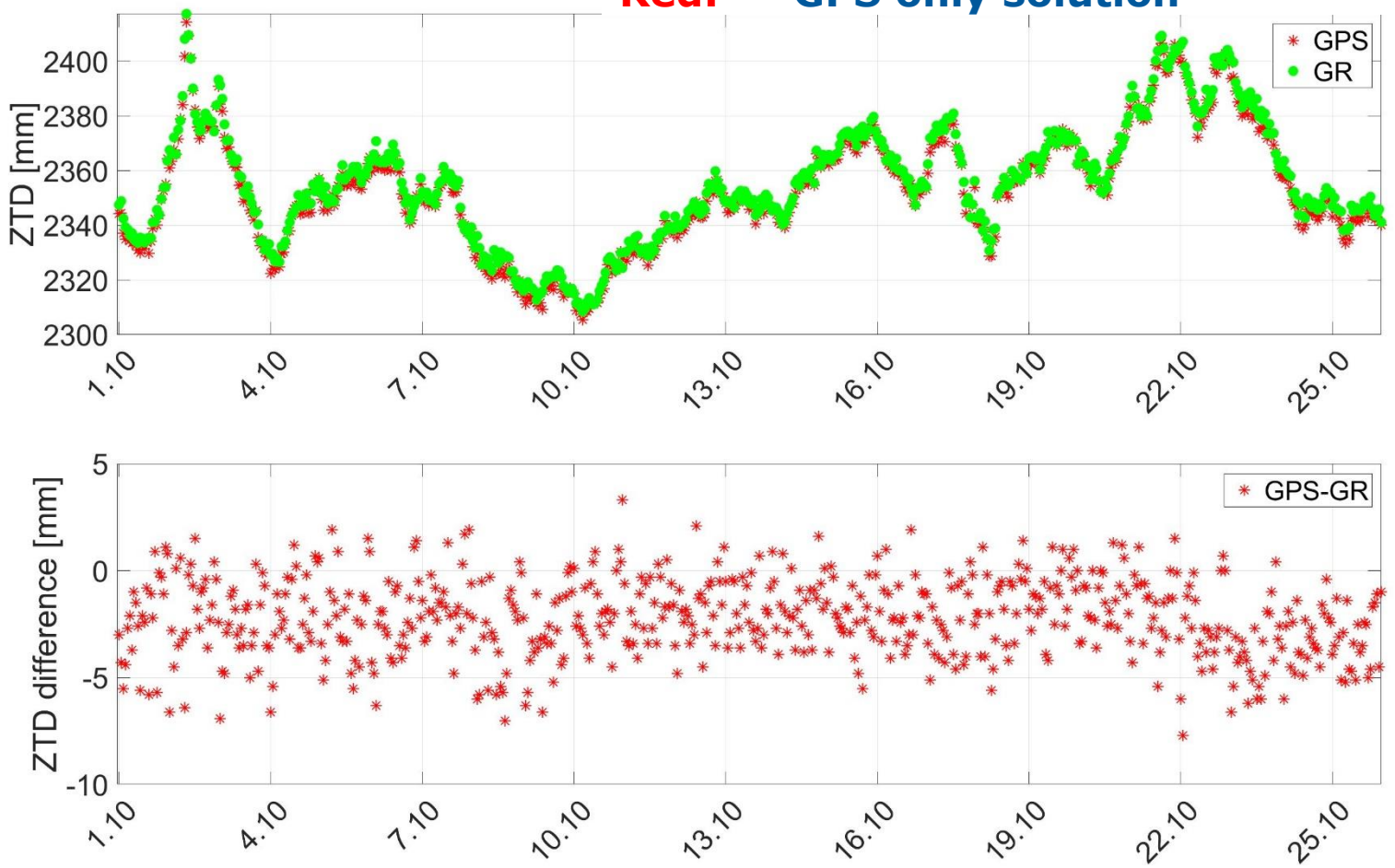
GPS+GLONASS Solution for UTQI (Oct 2020)

Green: GPS plus GLONASS ZTD solution
Red: GPS only solution



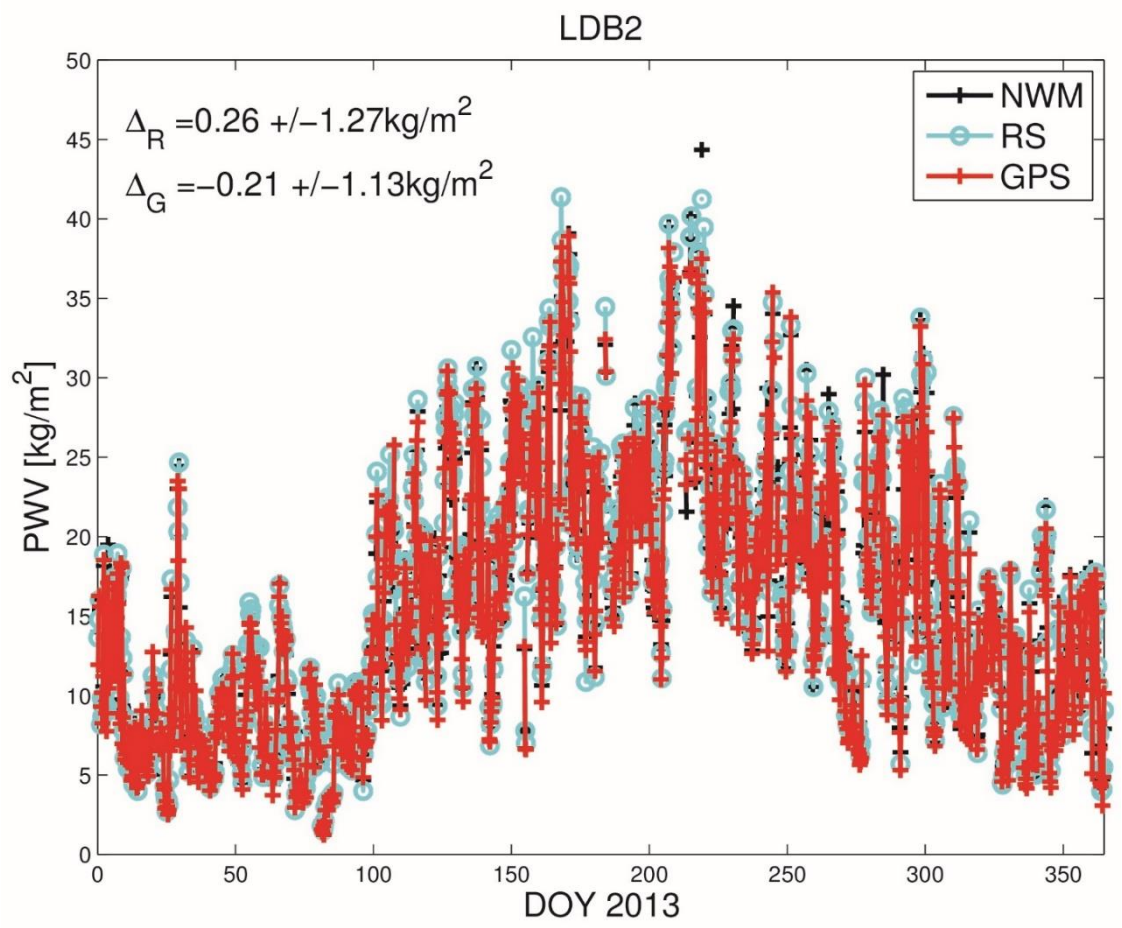
Adding of GLONASS satellites gives better results for ZTDs in case of UTQI: bias between GNSS and other solutions becomes smaller

Courtesy: K.Wilgan

Summary of ZTD Comparisons

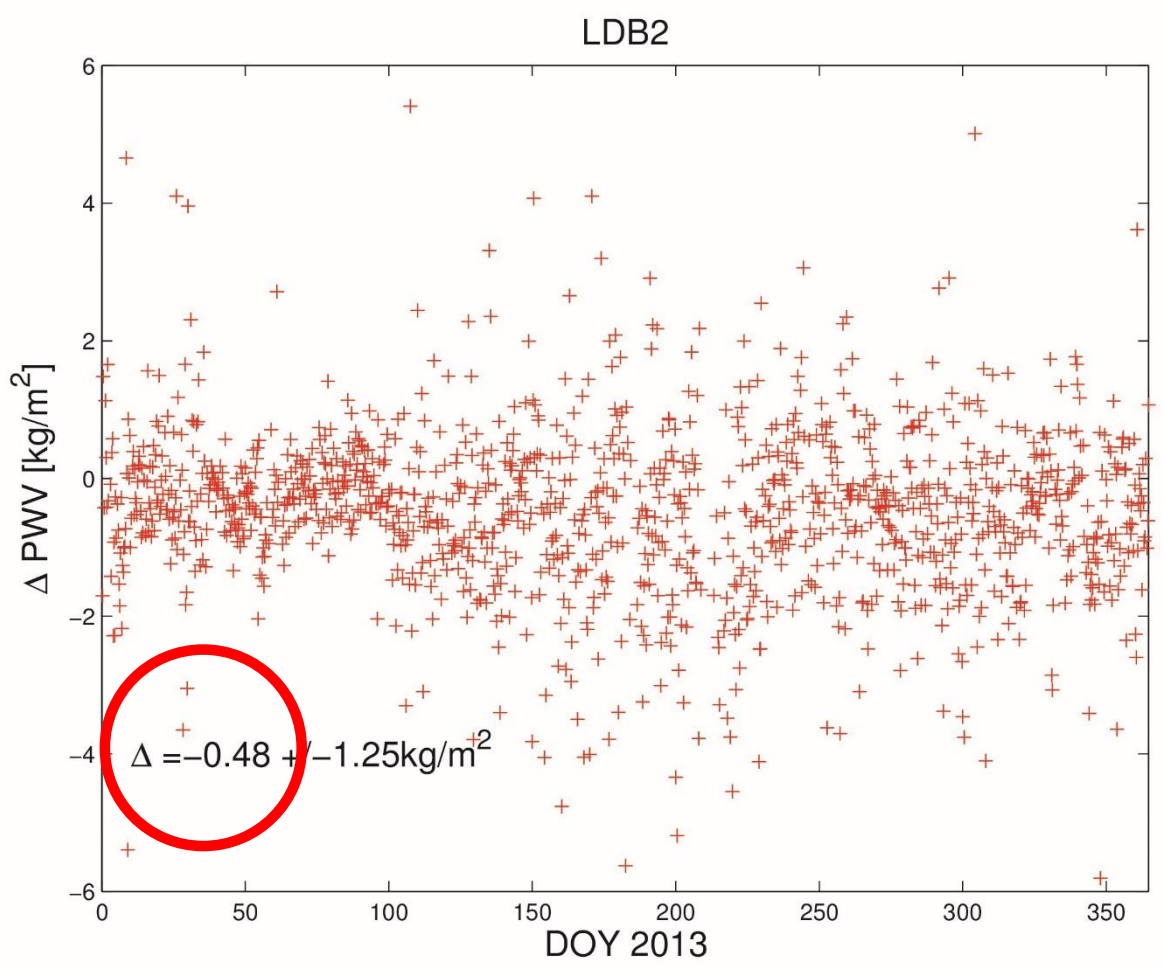
- Small mean deviations between the GNSS solutions
- However, the mean deviation reaches -3.5 mm at station UTQI between GFZ and NGL solutions. This corresponds to about -0.5 kg/m^2 PW
- The mean deviations w.r.t. to ERA5 are negative (up to a few mm), i.e., the GNSS solution appears drier than the NWM solution
- The mean deviation reaches -6.7 mm at station UTQI (GFZ – ERA5) and this corresponds to about -1.0 kg/m^2 PW
- Adding more satellites (e.g. GLONASS) does not influence ZTD solutions significantly, except of the sites located close to the poles, like UTQI

Validation of GNSS-PW with RS for Lindenberg (LDB2) for 2013



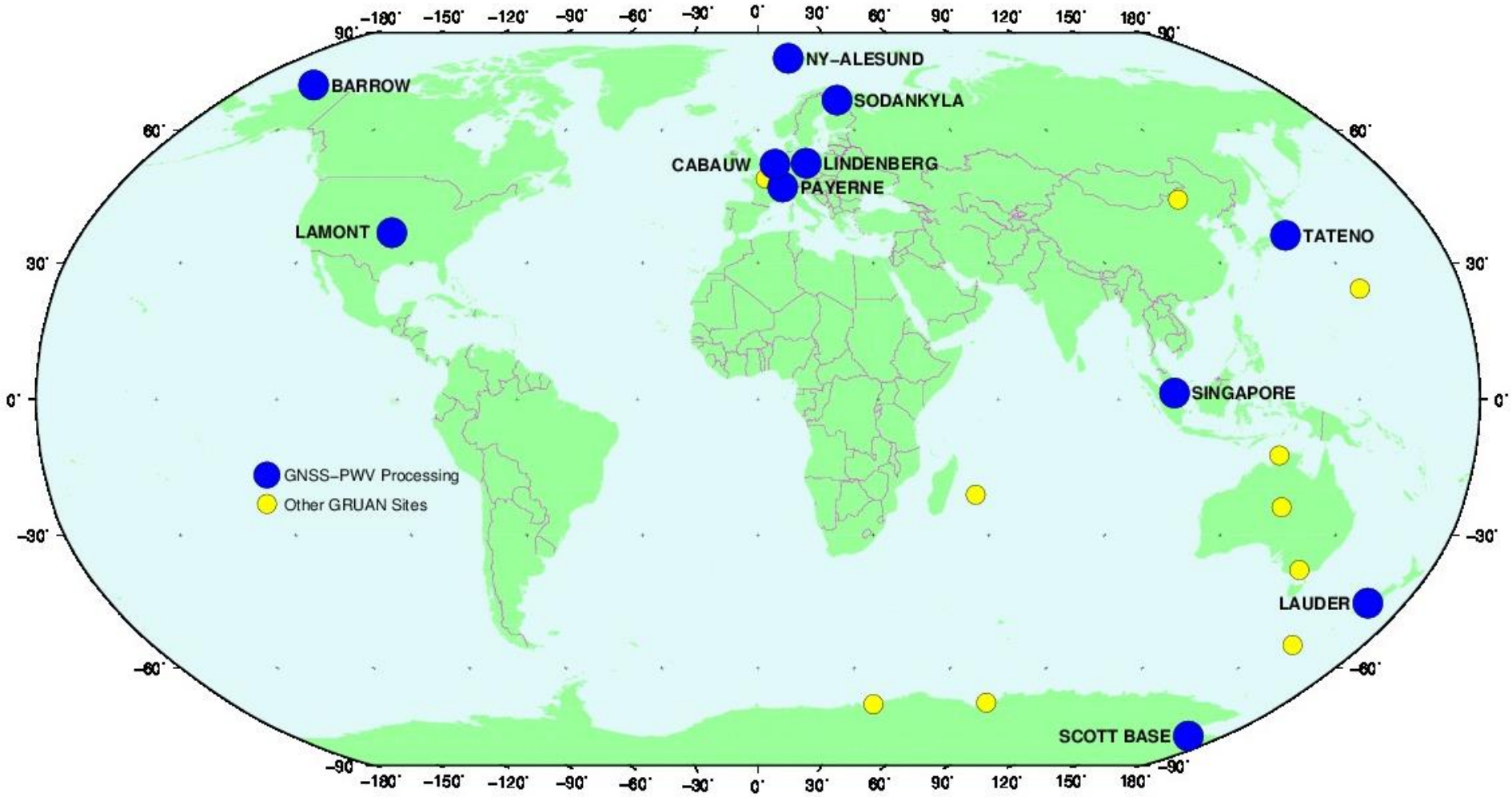
Black: ERA5 atmospheric reanalysis of ECMWF
Blue: GRUAN RS product (RS92 GDP)
Red: GNSS solution of GFZ

Validation of GNSS-PW with RS for Lindenberg (LDB2) for 2013



Differences between GNSS-PW and RS

GRUAN GNSS Network

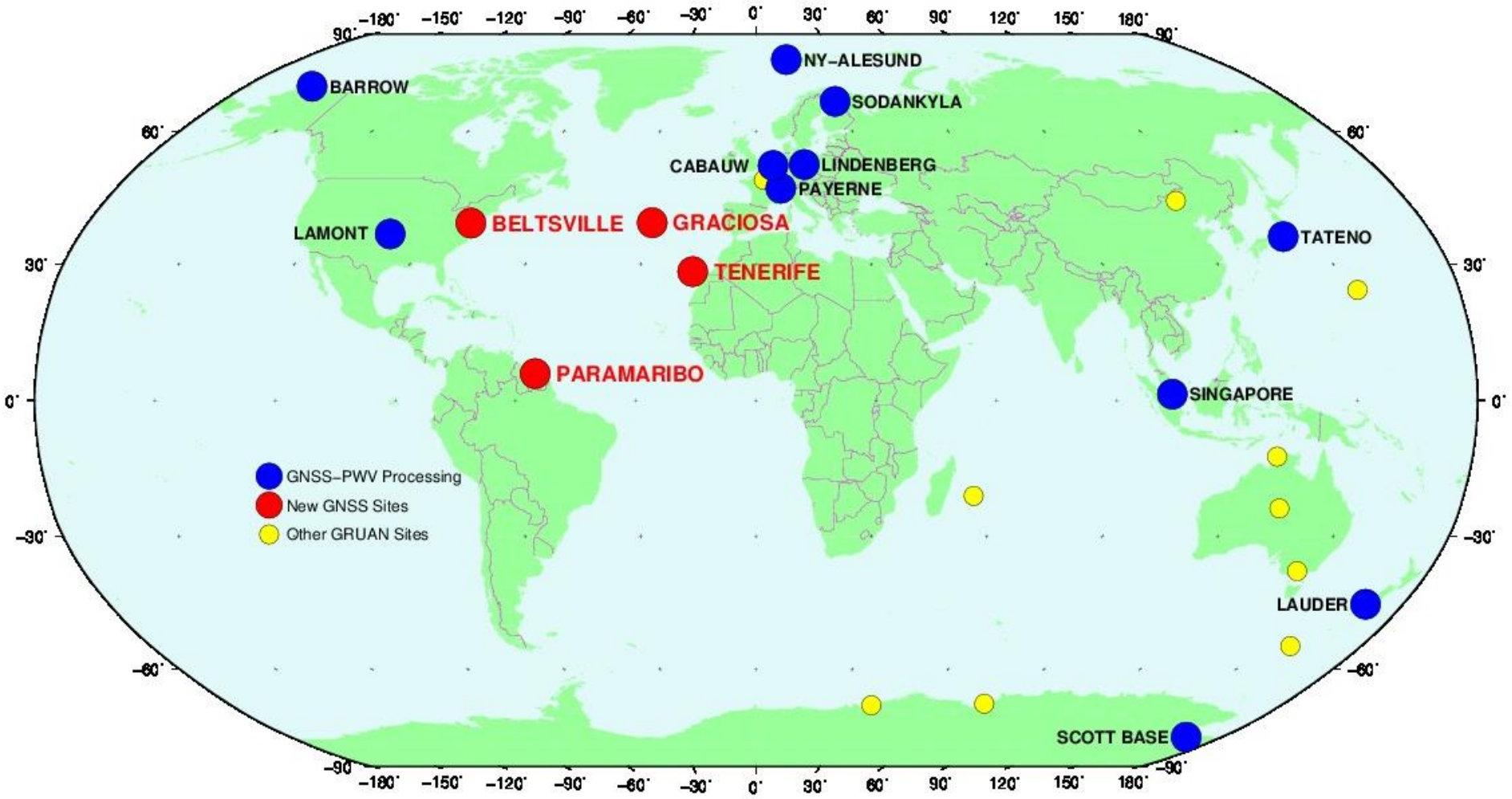


11 sites in GNSS-PW processing 2019

11 GNSS Stations in PW Processing

- Lindenberg (LDB0, LDB2, LIN0)
- Ny-Alesund (NYA2, NYAL)
- Sodankyla (SODF, SODA), no meteo data, work in progress
- Lauder (LDRZ)
- Barrow (UTQI)
- Payerne (PAYE), no meteo data, work in progress
- Lamont (SGPO)
- Singapore (MSS1)
- Tateno (TATN), no meteo data, work in progress
- Ross Island (SCTB)
- Cabauw (CBW1), no meteo data, work in progress

GRUAN GNSS Network



Planned for 2019/2020: 4 new GNSS sites

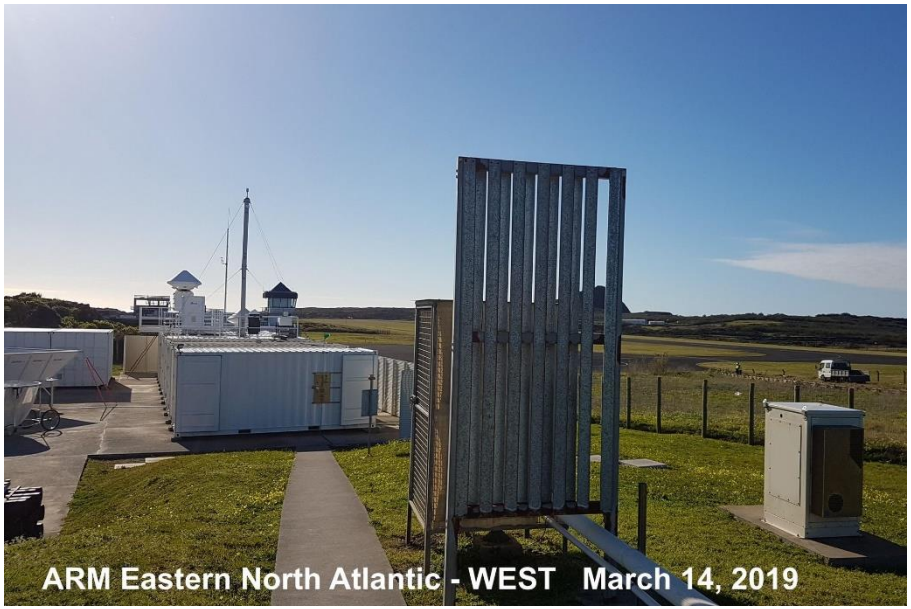
Status of 4 Planned GNSS Stations

Planned to be installed after ICM-11:

- **Graciosa (Portugal): operational since August 2019**
- **Beltsville (USA):** hardware will be shipped soon
- **Tenerife (Spain):** intend to install own GNSS receiver
- **Paramaribo (Suriname):** cancellation of visit due to COVID-19

Graciosa Island, Azores (Portugal)

- GNSS station name ENAO
- ARM Eastern North Atlantic site (ENA)
- Installed by GFZ in August 2019
- Automatic hourly GNSS data analysis
- PW products are available since August 2019



Additional New GNSS Sites

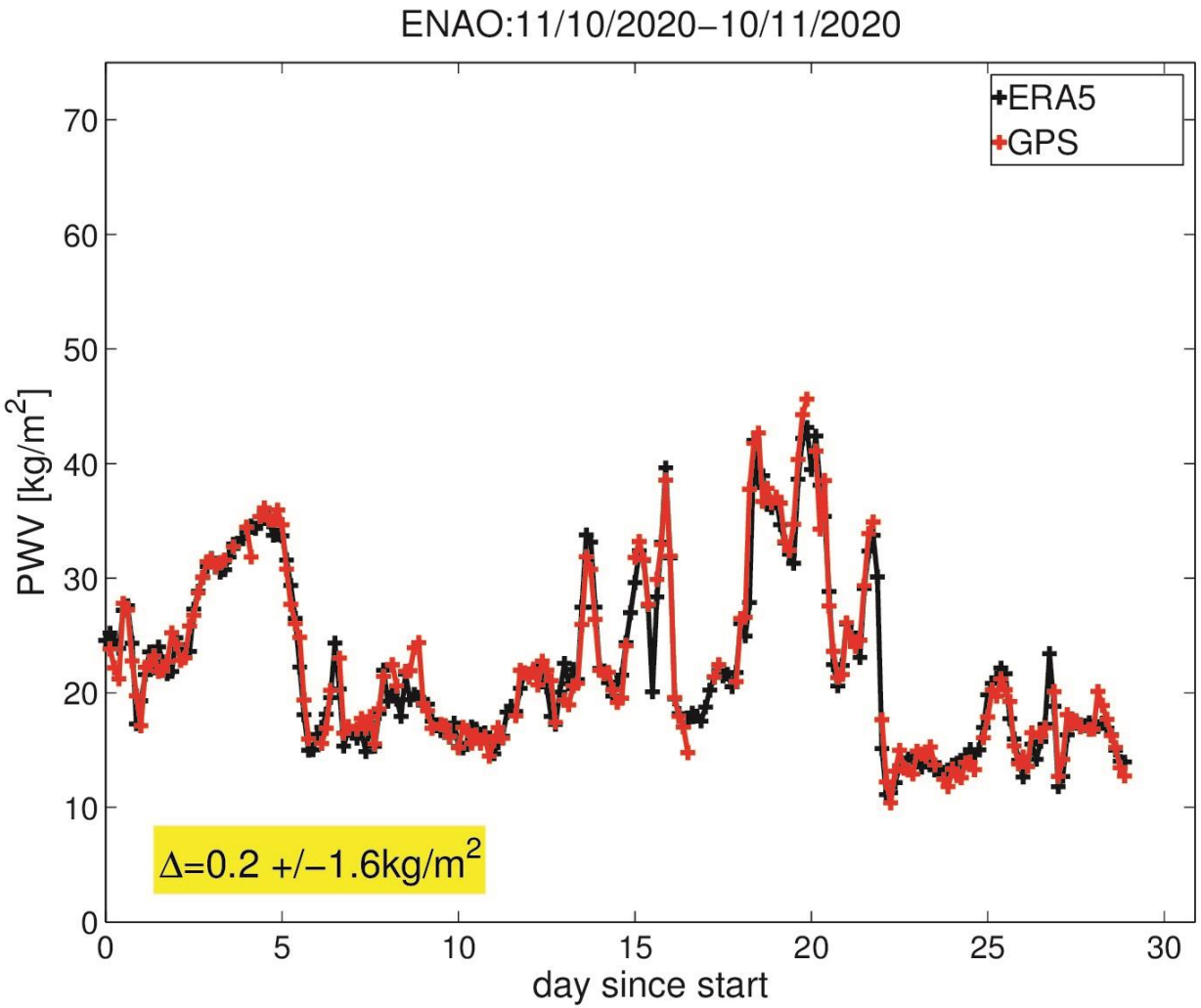
Since ICM-11:

- **Tsukuba (TSK2):**
  - site close to Tateno
  - included to operational hourly processing
- **Potenza (TITO):**
  - included to operational hourly processing
  - some technical issues have to be solved
- **Neumayer (NMSH):**
  - new GRUAN site in Antarctica, operated by AWI/GFZ
  - will be included to operational processing
- **Lindenberg (LIN0):**
  - replacement of GFZ site LDB0

PW Validation with Numerical Weather Model ERA5 of ECMWF

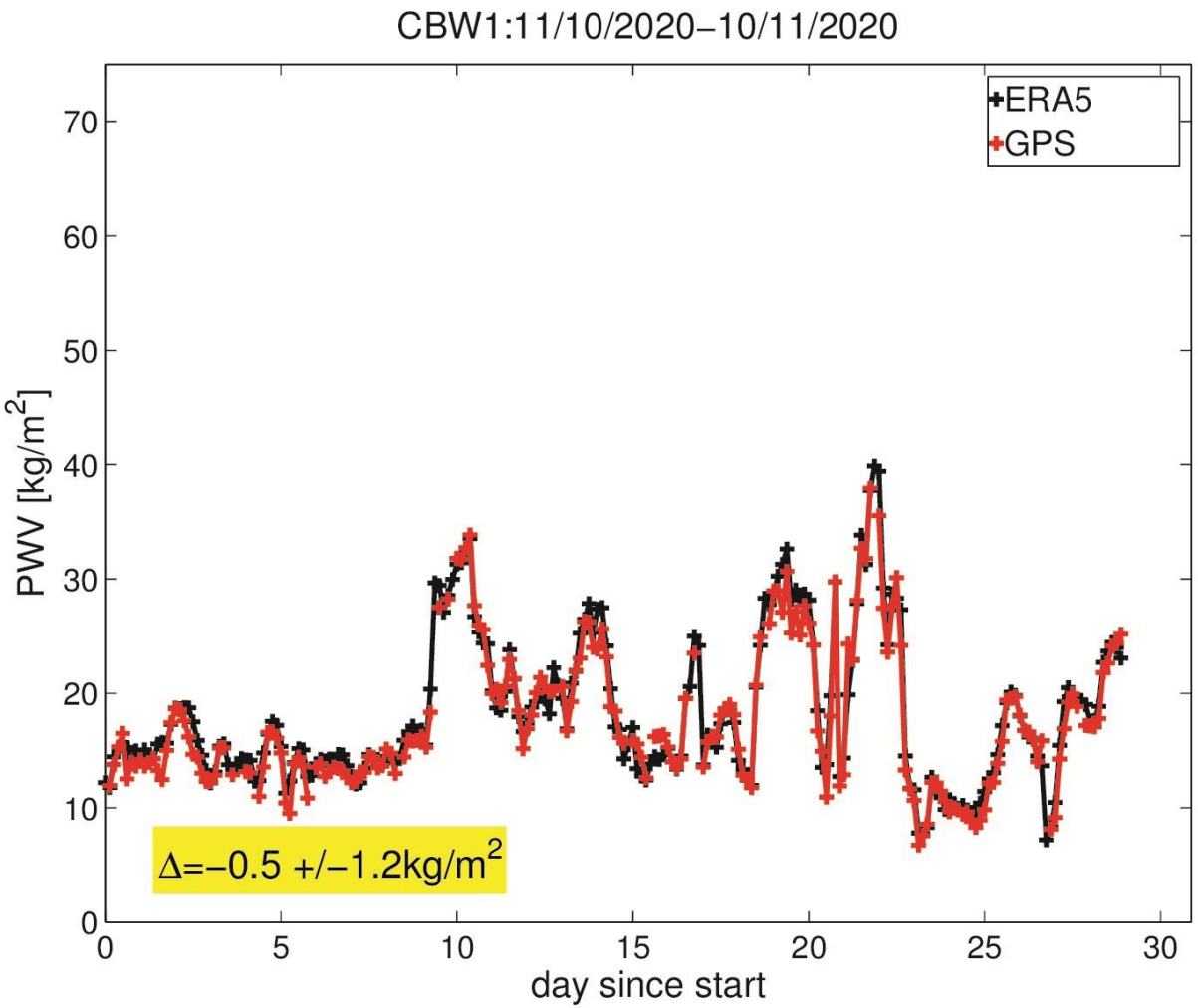
Daily updated validation plots are available at
ftp://ftp.gfz-potsdam.de/GNSS/products/nrttrop/MONITORING_IFS/

PW for Graciosa Island



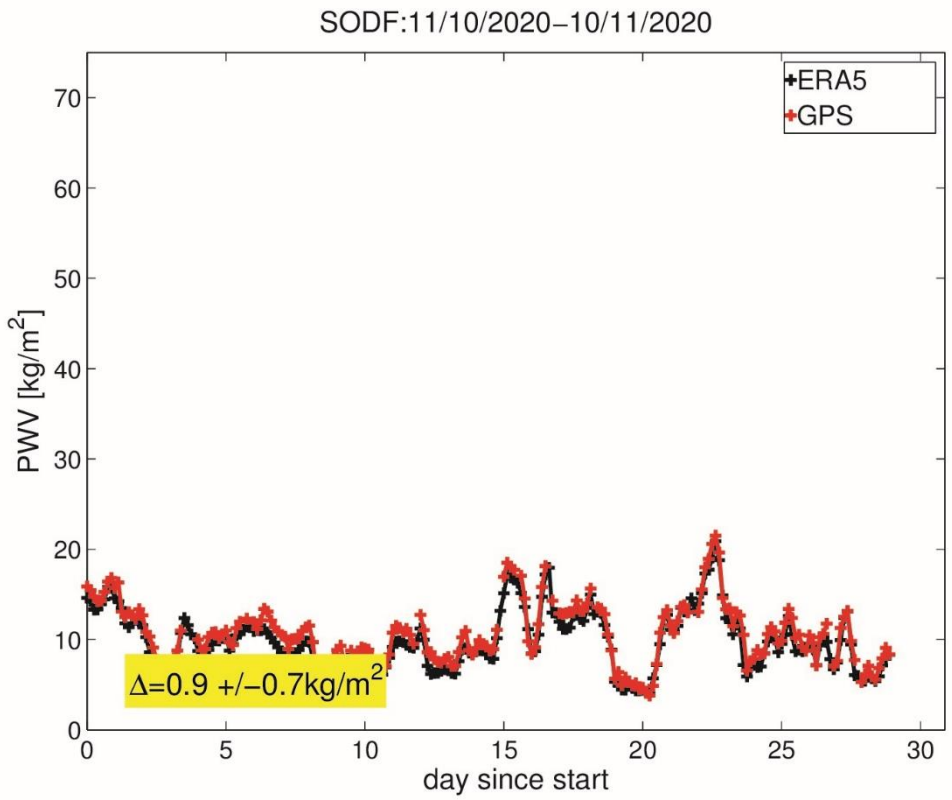
Validation with NWM ERA5 for Graciosa Island (ENAO), Nov 2020

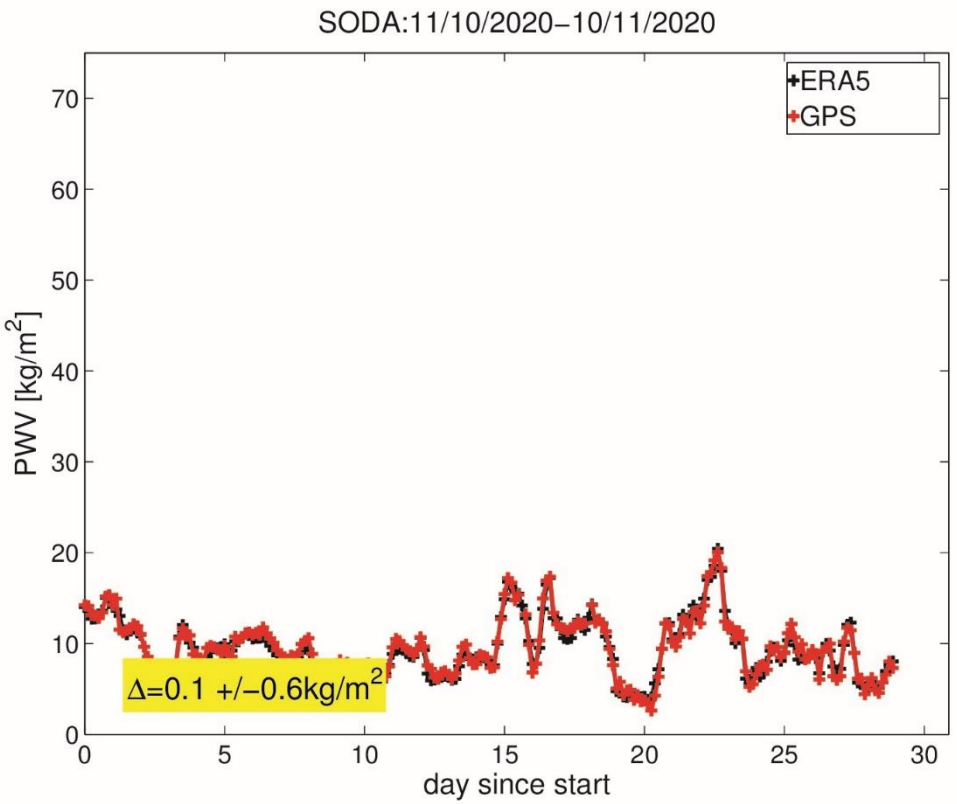
PW for Cabauw



Validation with NWM ERA5 for Cabauw (CBW1), Nov 2020

PW for Sodankyla





SODF **SODA**

Examples of validation with NWM ERA5 for SODF and SODA, Nov 2020

Future GNSS GRUAN Sites

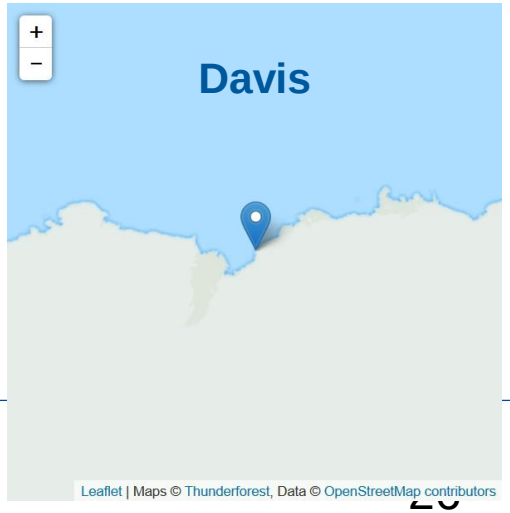
- **Syowa and Minamitorishima (Japan):** work in progress
- **Boulder (USA):** Loan Agreement signed, work in progress
- **Dolgoprudny (Russia):** pending
- Other GRUAN sites will be contacted by GFZ and PW TT: Paris, La Reunion, Xilinhot, Hong Kong, Dakar

- GFZ offer to install and operate GNSS receivers on GRUAN sites

- **Requirements:**
  - power supply
  - internet connection
  - adequate antenna installation site

Australia: pending

Negotiations with Geoscience Australia



GNSS-PW Data Product

Summary:

- Automatic hourly GNSS raw data flow and PW analysis established at GFZ (24/7)
- Data flow to LC
- GNSS-PW uncertainties estimation after Tong Ning added to automated processing chain in April 2019
- New GNSS sites added to GNSS-PW data products
- Continuous validation with RS, WVR and NWM
- Monitoring of product quality

Future Work

- Reprocessing with new PW uncertainty estimation for the whole time period 2011-2020 will be continued
- Including other satellite systems (GLONASS, Galileo) to automated processing, reprocessing with multi-GNSS for period 2011-2020
- Validation with RS, WVR and NWM will be continued
- Implementation of NetCDF
- Including of new GNSS sites to GDP

Acknowledgements

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Many thanks for your attention!