

Review of progress of data product: **GNSS PW**

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GFZ on Telegrafenberg in Potsdam

Date of foundation: 1st of January 1992

Employees (as of 30.09.2017)

The GFZ currently employs 1261 persons: 841 scientific, technical, and administrative staff as well as 147 student assistants and apprentices, and 273 guests (primarily scientists).

Annual Budget 2017

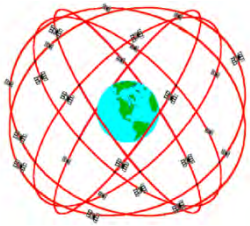
€ 73 million institutional funds provided by the Federal Government (90%) and the State of Brandenburg (10%)

€ 37 million from third-party funding

€ 110 million overall



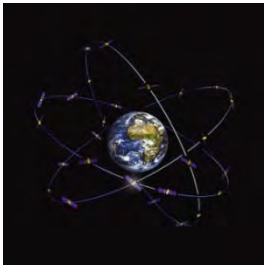
GNSS: Global Navigation Satellite Systems



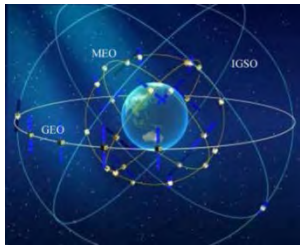
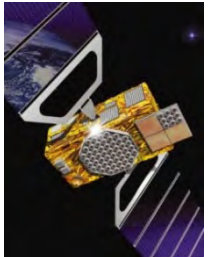
NAVSTAR-GPS (USA): 31 satellites



GLONASS (Russia): 24 satellites



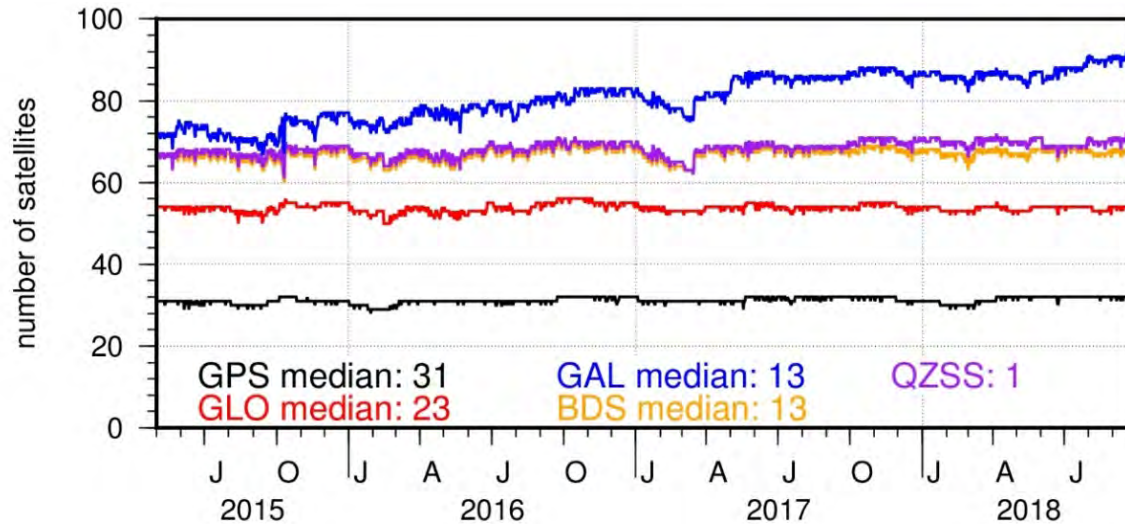
Galileo (EU): currently 26 from 30 satellites



BeiDou (China): currently 20 from 35 satellites

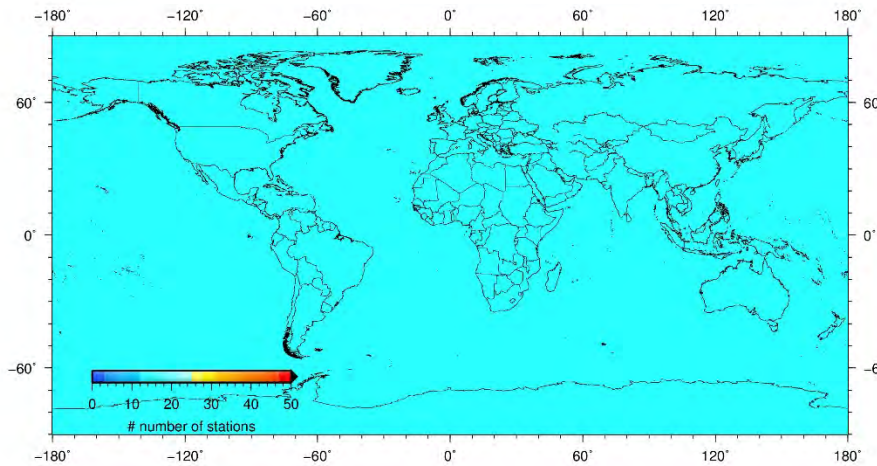


IGS Activities at GFZ

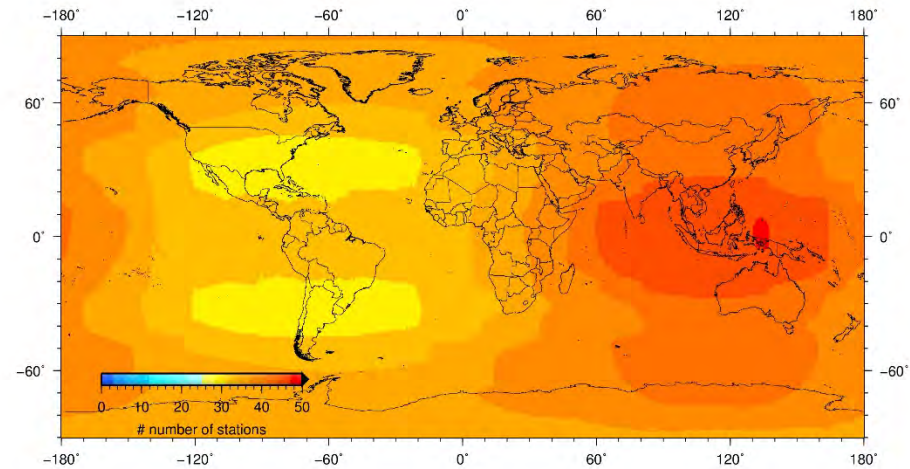


Since 2015 GFZ IGS AC provides ultra-rapid products for five satellite systems
GPS/GLO/GAL/BDS/QZSS

GPS only

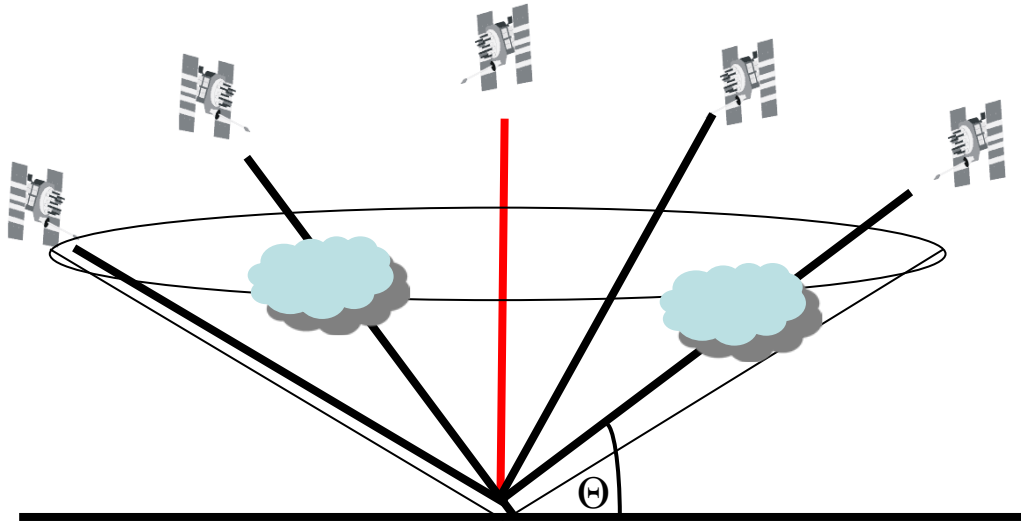


GPS/GLO/GAL/BDS/QZSS



Satellite coverage map for September 8, 2018

GNSS-derived Precipitable Water Vapor



Isotropic water vapor distribution & known mapping function ($\sim 1/\sin \Theta$)

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

$$\text{ZTD} = \text{dry, hydrostatic ZHD} + \text{wet ZWD}$$

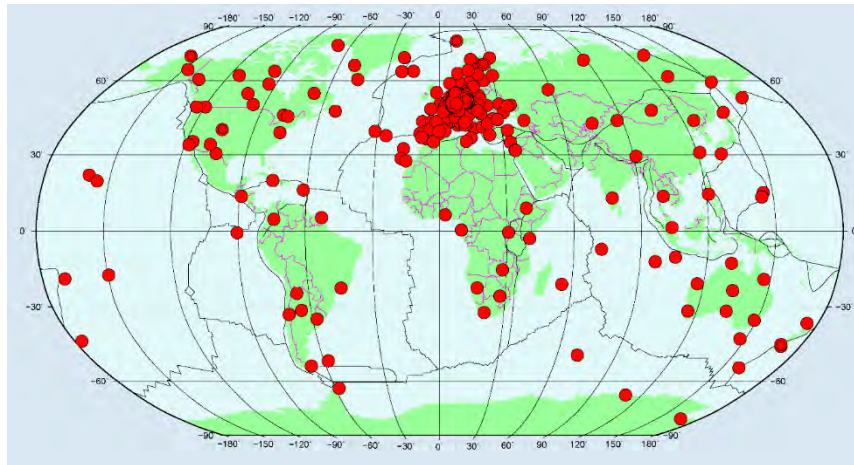
$$\text{ZHD} = f(\text{pressure}) [\pm 1 \text{ mm accuracy}]$$

$$\text{PW} = \Pi(T_m) \cdot \text{ZWD}$$

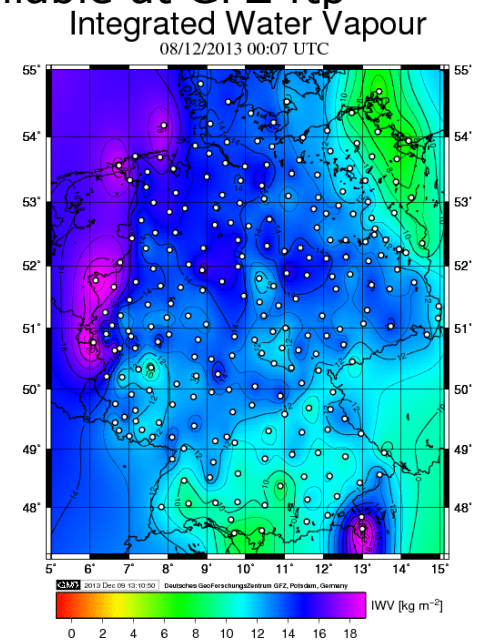
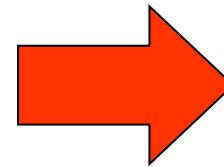
Converted Precipitable Water Vapor (PW) or Integrated Water Vapor (IWV)

Operational GNSS PW Monitoring at GFZ

- Automatically processing of hourly GNSS data with GFZ EPOS.P8 Software
- ~600 stations in processing (German SAPOS + EUREF + IGS + GRUAN networks)
- Time delay < 30 minutes after the end of each hour (near real-time)
- ZTD/PW with 15 minutes time resolution
- ZTD/PW products both in COST and TRO-SINEX format, available at GFZ ftp
- Other products are also available: slants, gradients



Zenith Total Delay
Precipitable Water
Slant Total Delay
Gradients



Orkan Xaver 8.12.2013

Operational use of GFZ ZTD data by several European meteo services for weather forecast (Met Office, MeteoFrance)

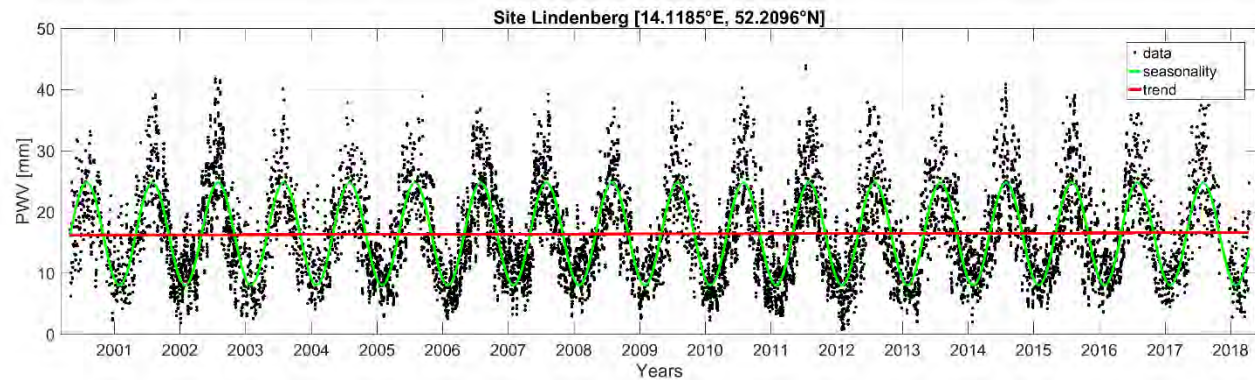
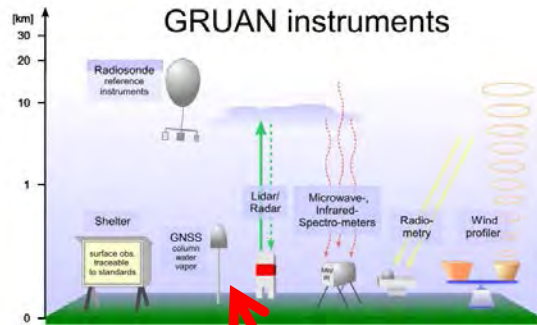
PW Trends for Climate Research

PW with mm accuracy



Long term PW trend analysis for climate research

GNSS is priority
number one
technique for
PW monitoring



Long-term time series of GPS-based PW at GRUAN station Lindenberg, Germany

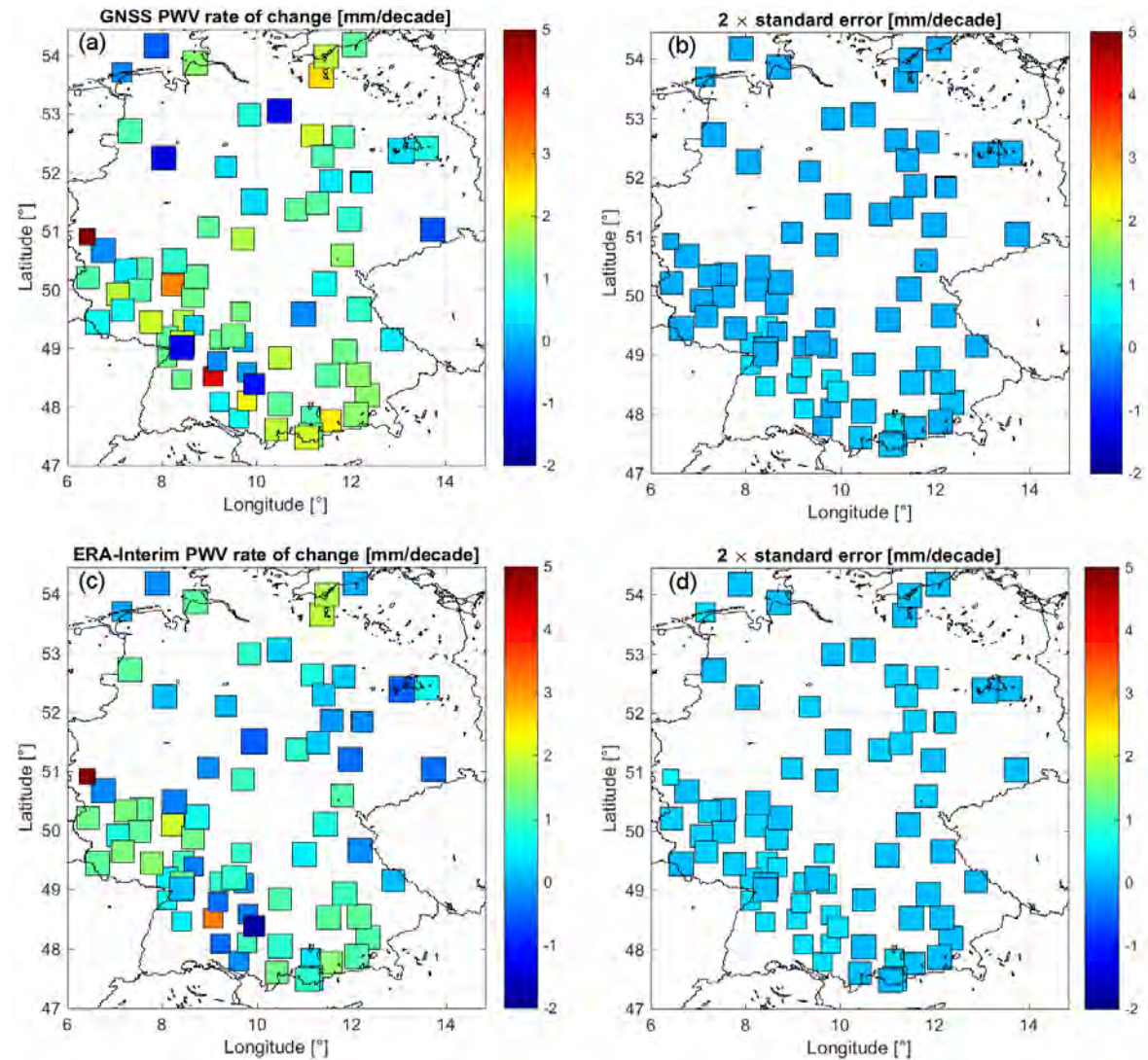
**Trend value is 0.31 mm/decade,
sigma (trend) is 0.075 mm/decade**

PW Trends Estimation for Germany

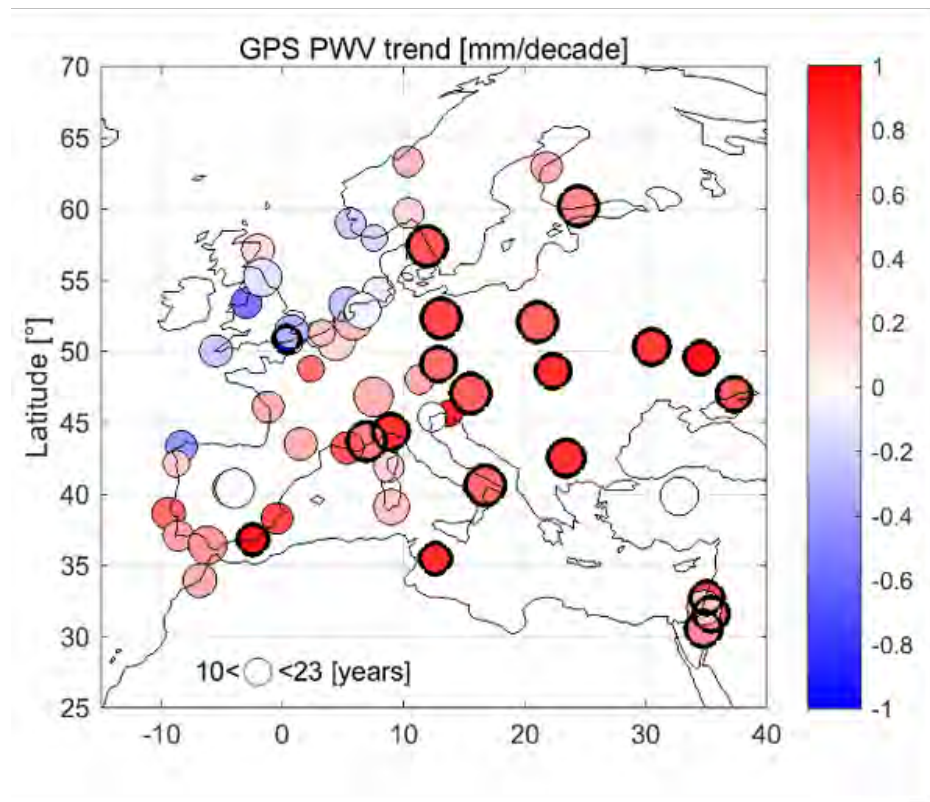
GPS

Length of time
series:
10-19 years
119 stations

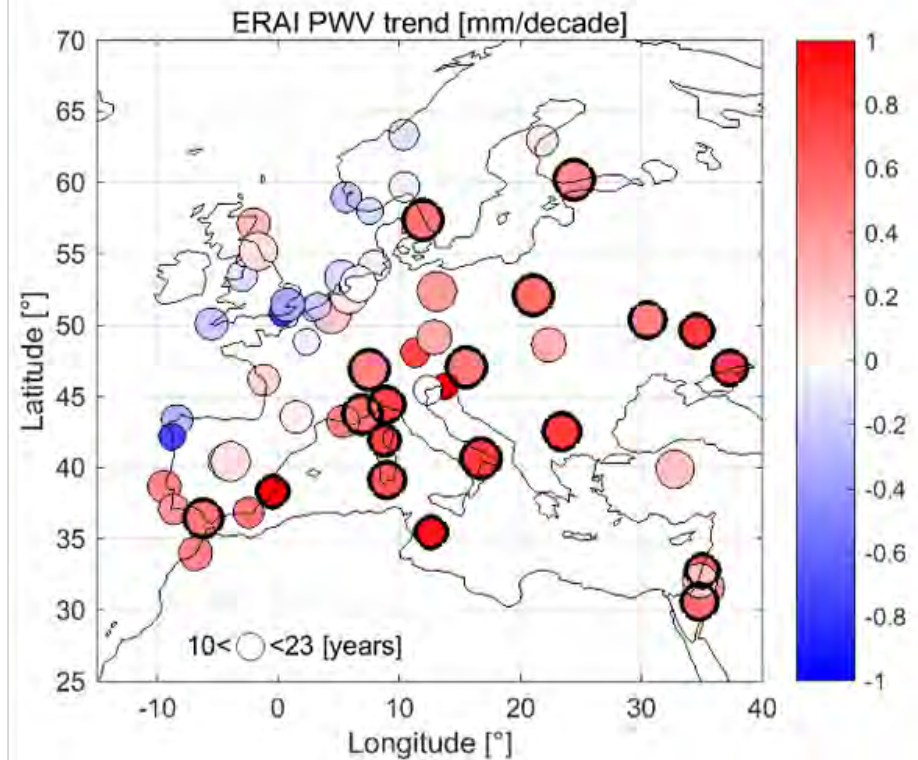
**Model
ERA-
Interim
(ECMWF)**



PW Trends Estimation for Europe



GPS

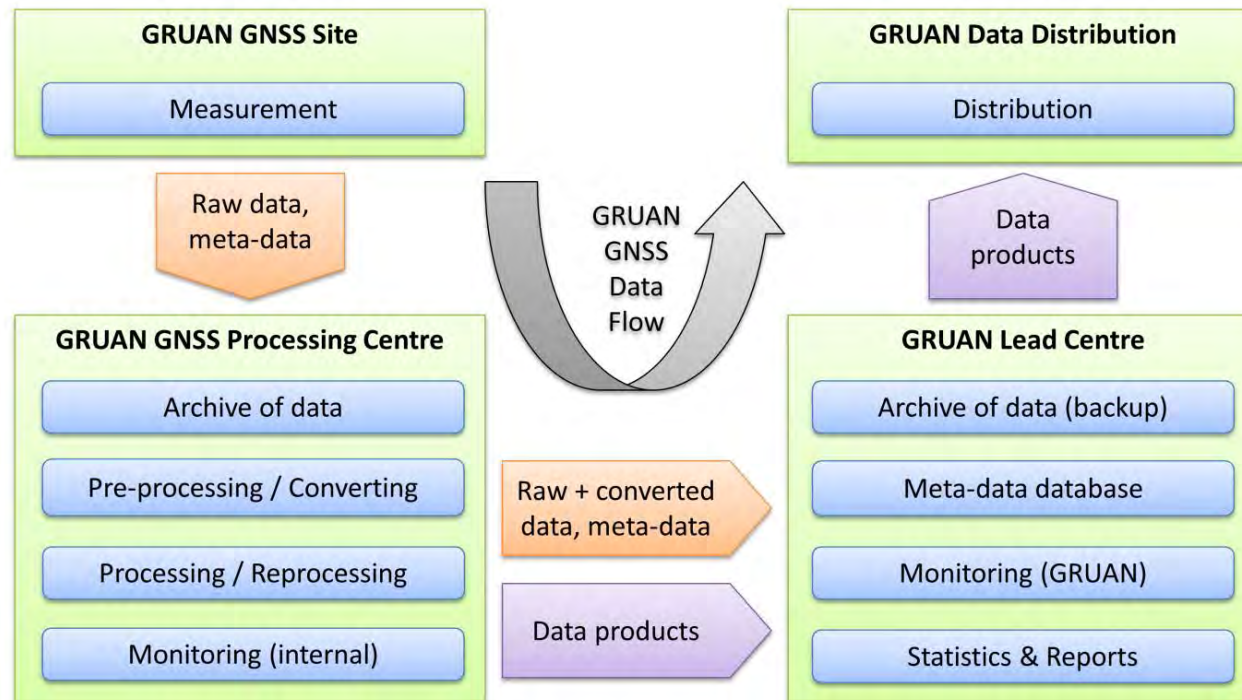


**Model
ERA-Interim**

Length of time series 10-23 years

Observations → GRUAN GNSS Data Product

**GNSS obs.
&
site meteo.**



**GNSS PW
&
uncertainty**

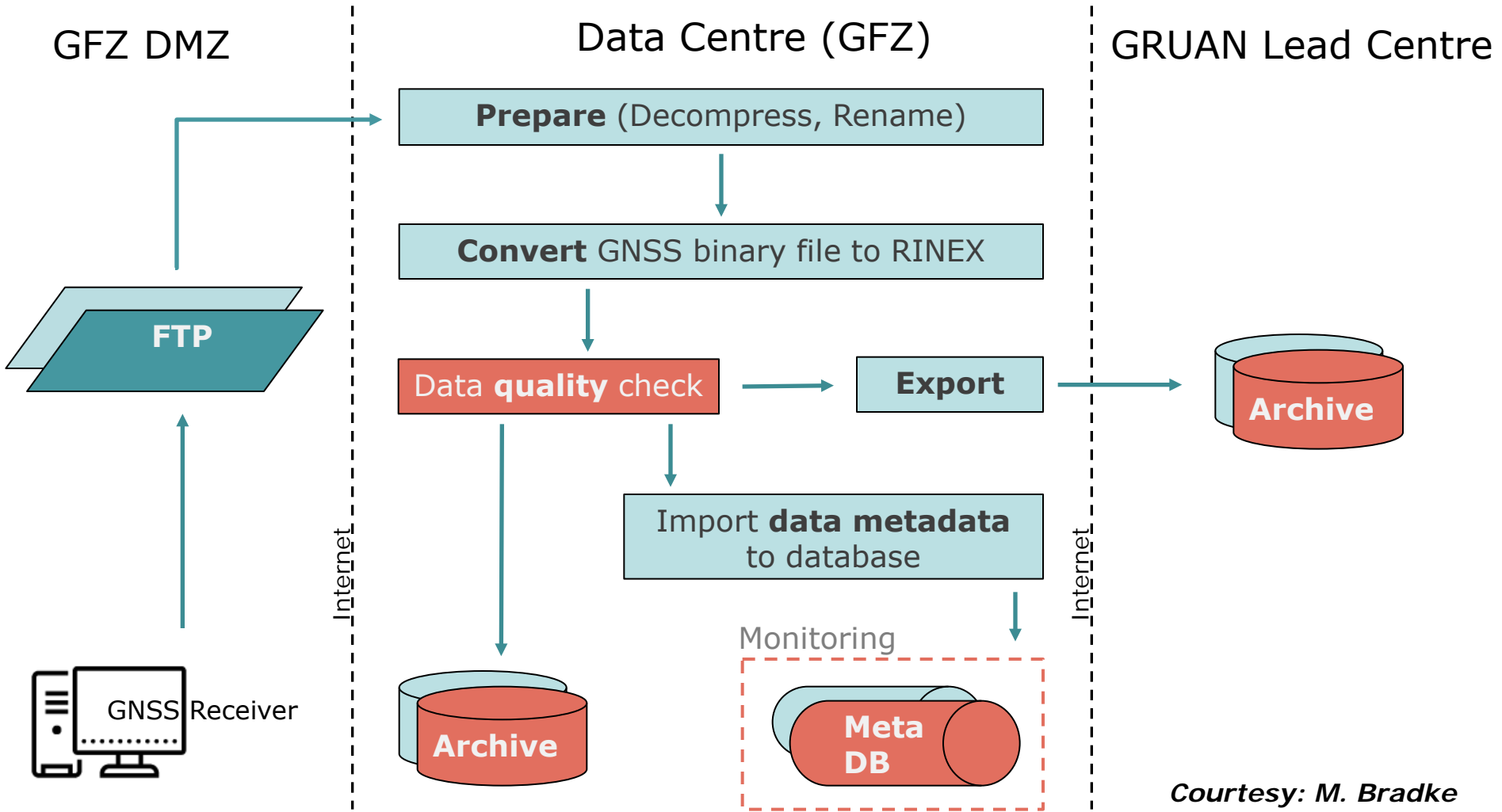
**GNSS PW
&
uncertainty**

Courtesy: M. Sommer, K. Rannat

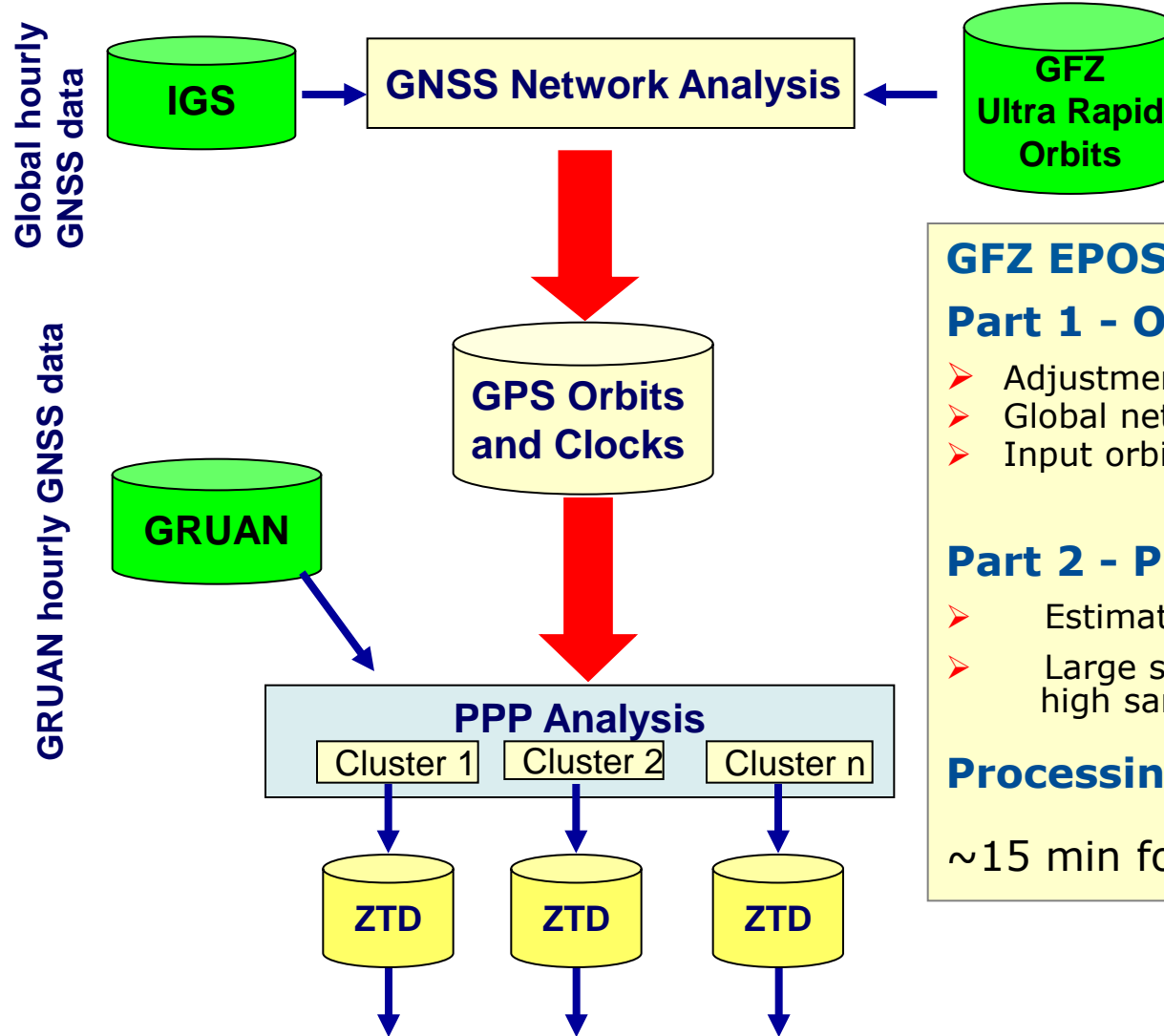
Operational Data Centre (ODC) at GFZ

- Operational since July 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
 - Presentation in a WebGUI
- Short data processing latency (< 10 seconds per station)

Raw GNSS Data Flow



GNSS Processing with GFZ EPOS.P8 Software



GFZ EPOS.P8 Software (PPP):

Part 1 - Orbit improvement:

- Adjustment of precise orbits & clocks
- Global network: ~100 IGS + German sites
- Input orbits: GFZ 3h Ultra Rapid (pred.)

Part 2 - PPP Analysis:

- Estimation of trop. parameters
- Large set of parameters possible with high sampling rate: ZTD/PW/STD/Gradi

Processing time (LINUX PC):

~15 min for more than 500 stations

GNSS PW Uncertainty Estimate

$$\begin{aligned} \text{ZWD} &= \text{ZTD} - \text{ZHD} \\ \text{ZHD} &= f(P_s) \\ \text{PW} &= \Pi * \text{ZWD} \quad \Pi = f(T_m) \end{aligned}$$

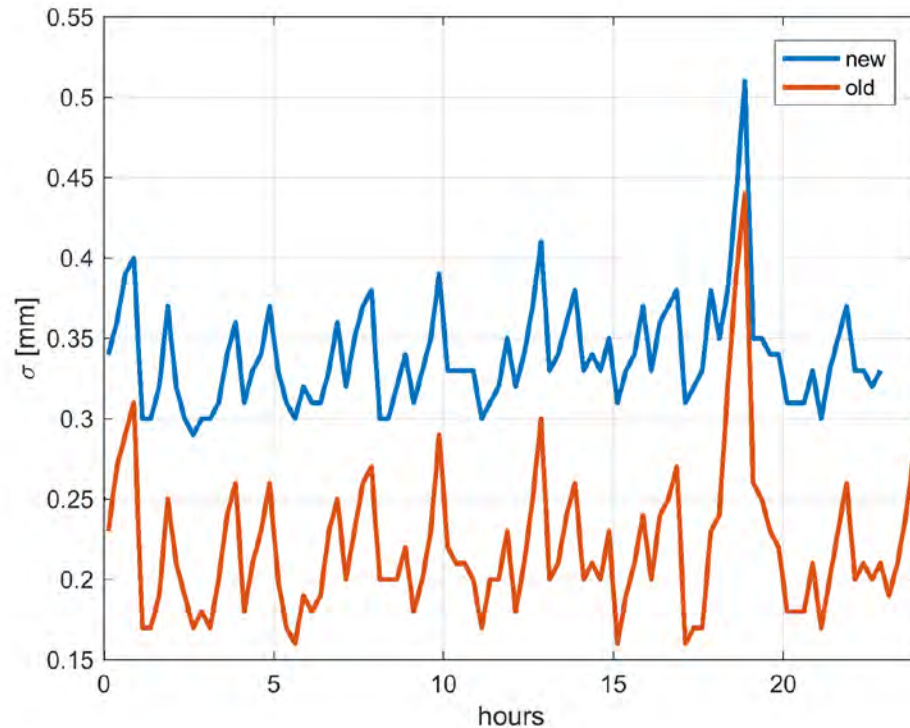
Ning, T., Wang, J., Elgered, G., Dick, G., Wickert, J., Bradke, M., Sommer, M., Querel, R., and Smale, D.: The uncertainty of the atmospheric integrated water vapour estimated from GNSS observations, Atmos. Meas. Tech., 9, 79-92, doi:10.5194/amt-9-79-2016

$$\delta q = \sqrt{\left(\frac{\partial q}{\partial x} \delta x\right)^2 + \dots + \left(\frac{\partial q}{\partial z} \delta z\right)^2}$$

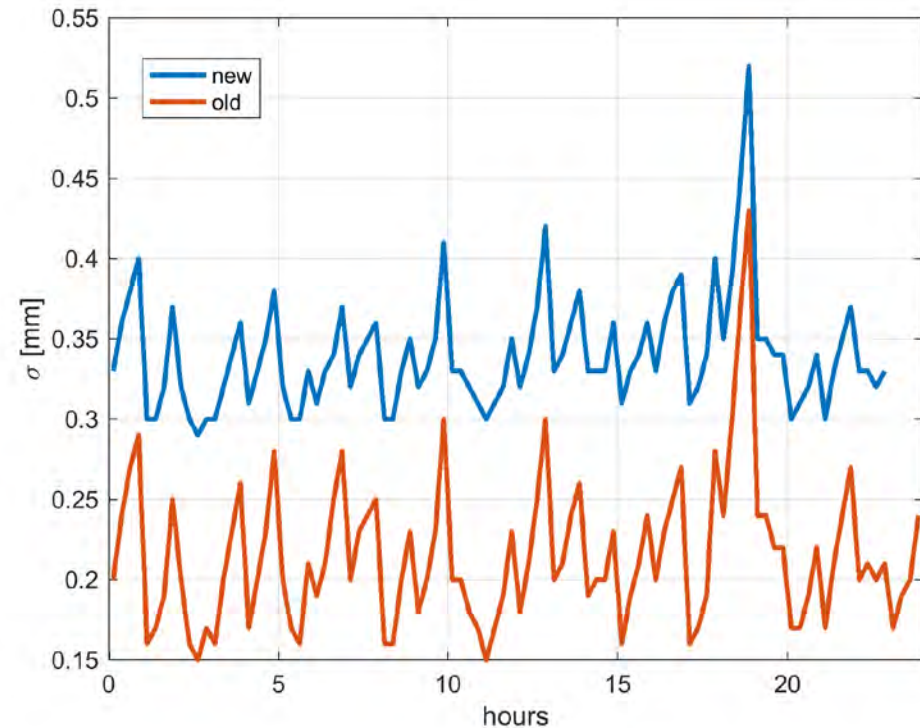
$$\sigma_{PW} = \sqrt{\left(\frac{\sigma_{ZTD}}{\Pi}\right)^2 + \left(\frac{2.2767 \sigma_{P_0}}{f(\lambda, H) \Pi}\right)^2 + \left(\frac{P_0 \sigma_c}{f(\lambda, H) \Pi}\right)^2 + \left(PW \frac{\sigma_{\Pi}}{\Pi}\right)^2}$$

$$\sigma_{ZTD} (>75\%); \sigma_c (10-20\%); \sigma_{T_m} (2-4\%)$$

GNSS-PW Uncertainty Estimate (old vs new)



Potsdam

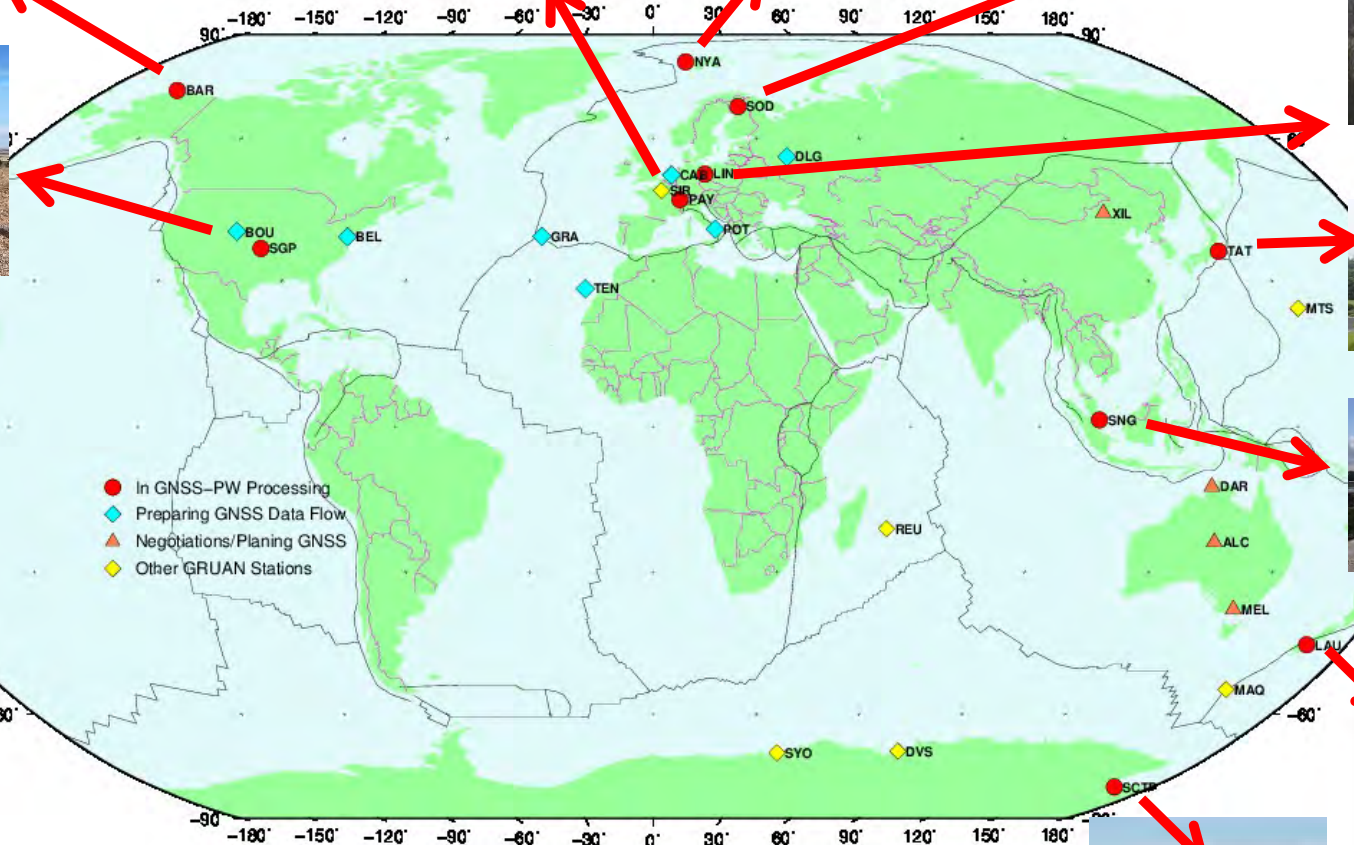
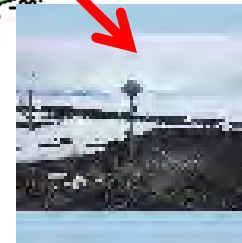
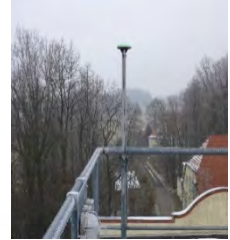


Lindenberg

GNSS PW uncertainties as estimated according to Tong Ning algorithm (blue) and according to 'old' estimation procedure (red, ZTD only).
Examples for stations Potsdam and Lindenberg, 8th of April, 2019

Status of GNSS GRUAN sites

GRUAN GNSS Network 2019



In PW processing
2018: 10 GNSS sites
2019: 6 GNSS sites

GNSS Stations in PW Processing

GNSS stations in automated PW processing

Lindenberg (LDB0, LDB2)
Ny-Alesund (NYA2, NYAL, NYA1)
Sodankyla (SODF, SODA), no meteo data
Lauder (LDRZ)
Barrow (UTQI)

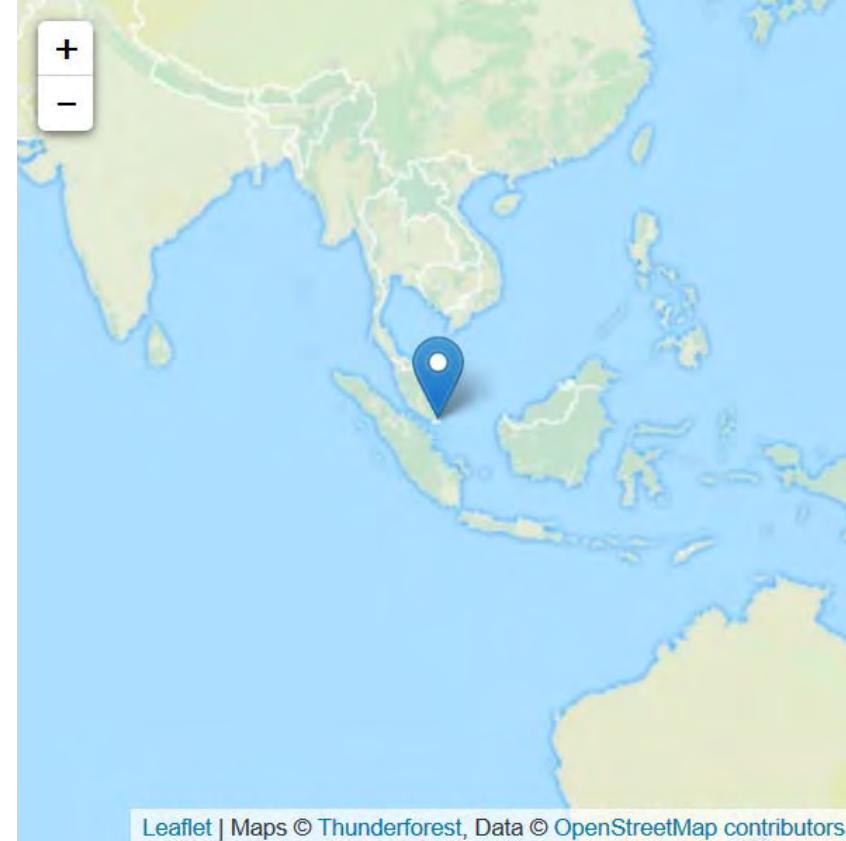
Boulder TMS3 closed in October 2018

New since ICM10:

Payerne (PAYE), no meteo data
Lamont (SGPO)
Singapore (MSS1)
Tateno (TATN), no meteo data
Scott Base (SCTB) in Antarctica, close to Arrival Heights

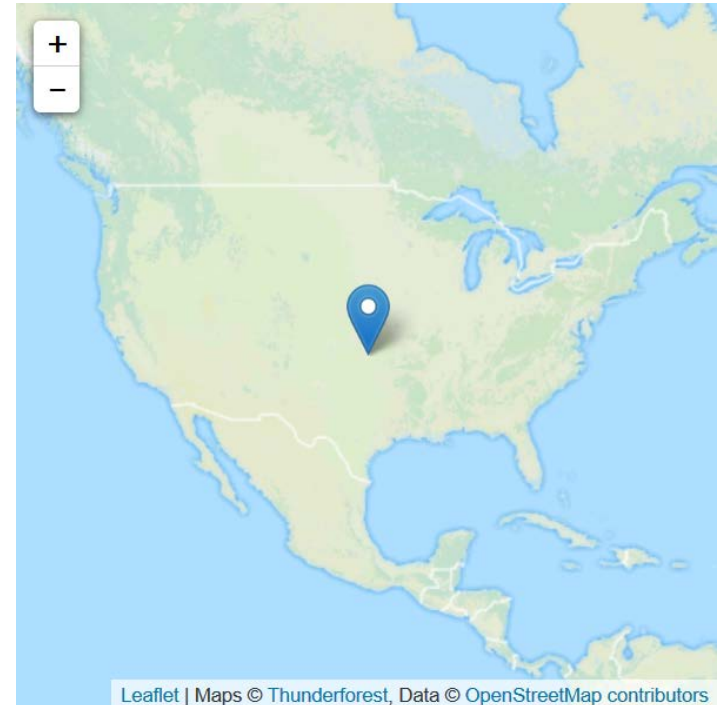
Singapore

- GNSS station name MSS1
- Automatic hourly GNSS data analysis
- PW products are available operationally since April 2019



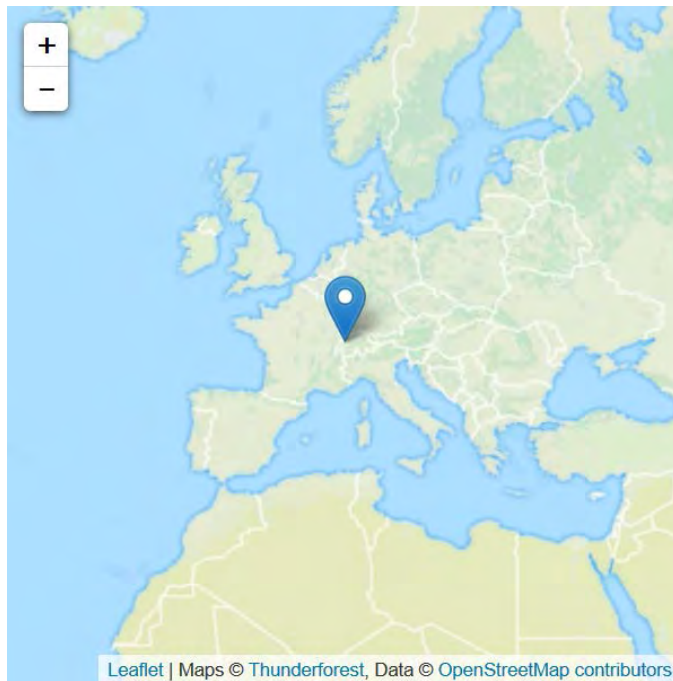
SGP Lamont, Oklahoma (USA)

- GNSS station name SGPO
- Installed by GFZ in Feb 2019
- Automatic hourly GNSS data analysis
- PW products are available operationally since Feb 2019



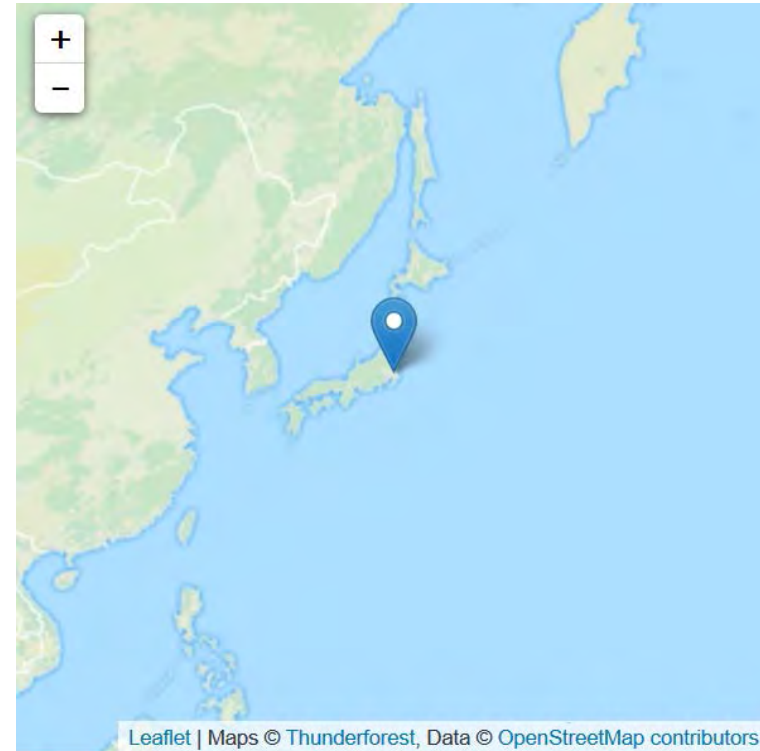
Payerne (Switzerland)

- GNSS station name PAYE
- Automatic hourly GNSS data analysis, PW products are available operationally since 2019, **no meteo**



Tateno (Japan)

- GNSS station name TATN
- Monthly data uploads
- PW products will be available after reprocessing (this year)
- **no meteo**



Scott Base (Ross Island, Antarctica)

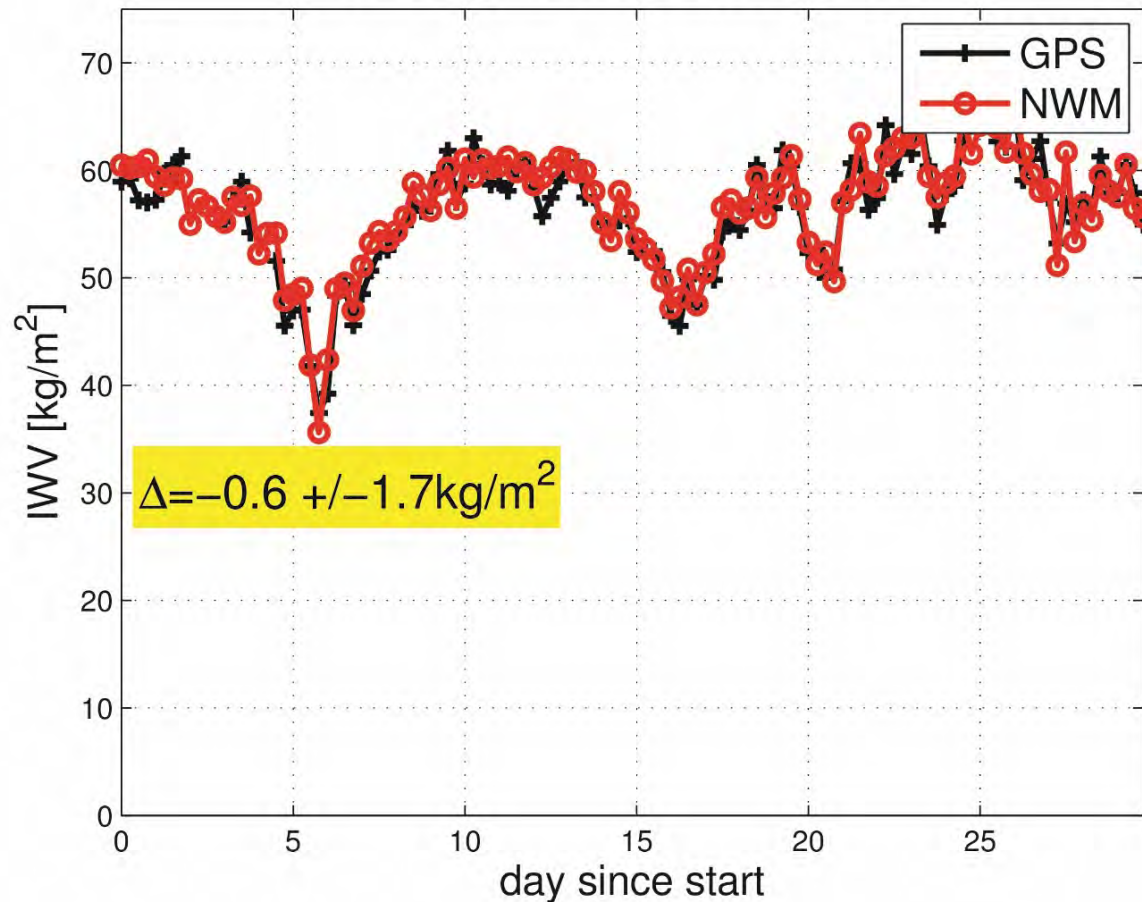
- Three IGS GNSS stations:
ARHT (JPL)
MCM4 (JPL)
SCTB (Land Information, NZ)
- SCTB: automatic hourly GNSS data analysis, PW products are available operationally since March 2019, **no meteo**



PW Validation with Numerical Weather Model ERA (ECMWF)

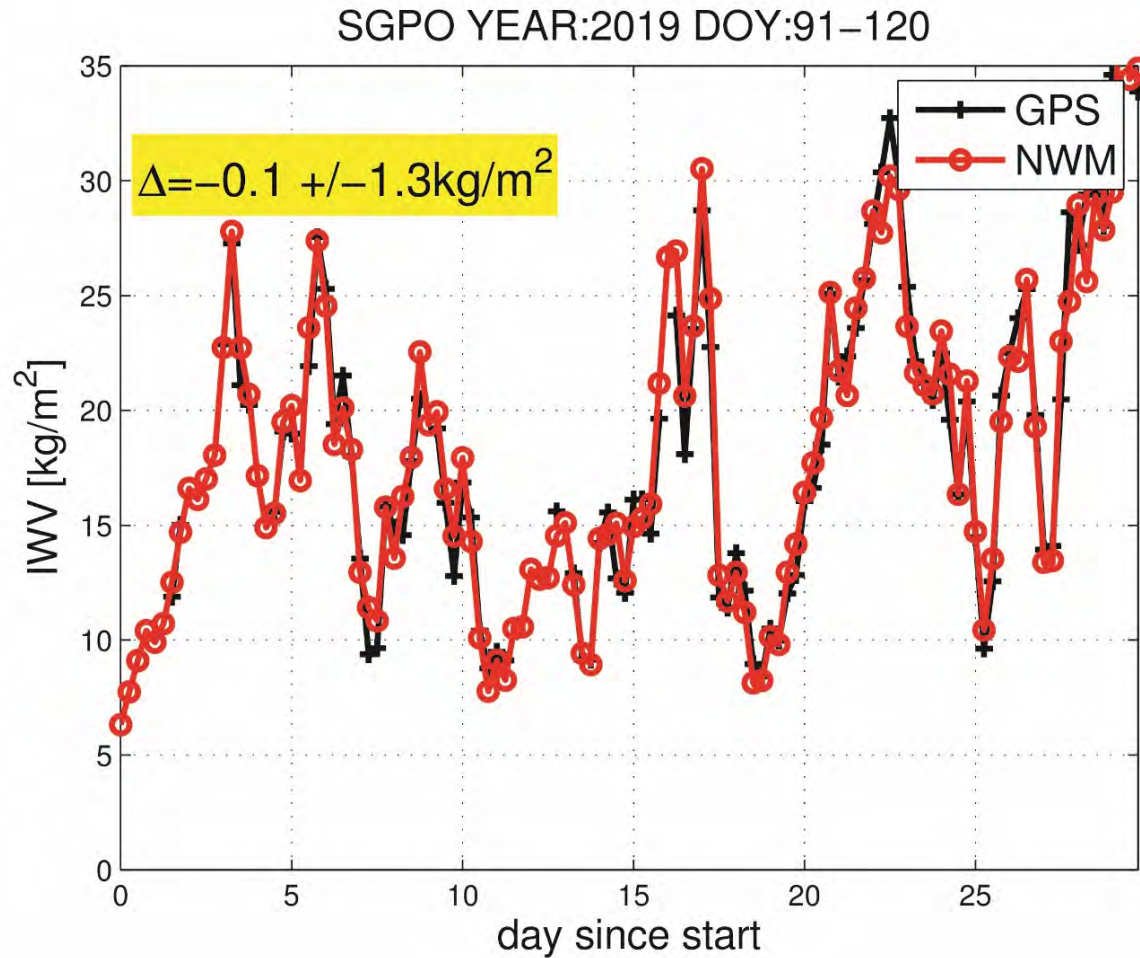
PW for Singapore

MSS1 YEAR:2019 DOY:91–120



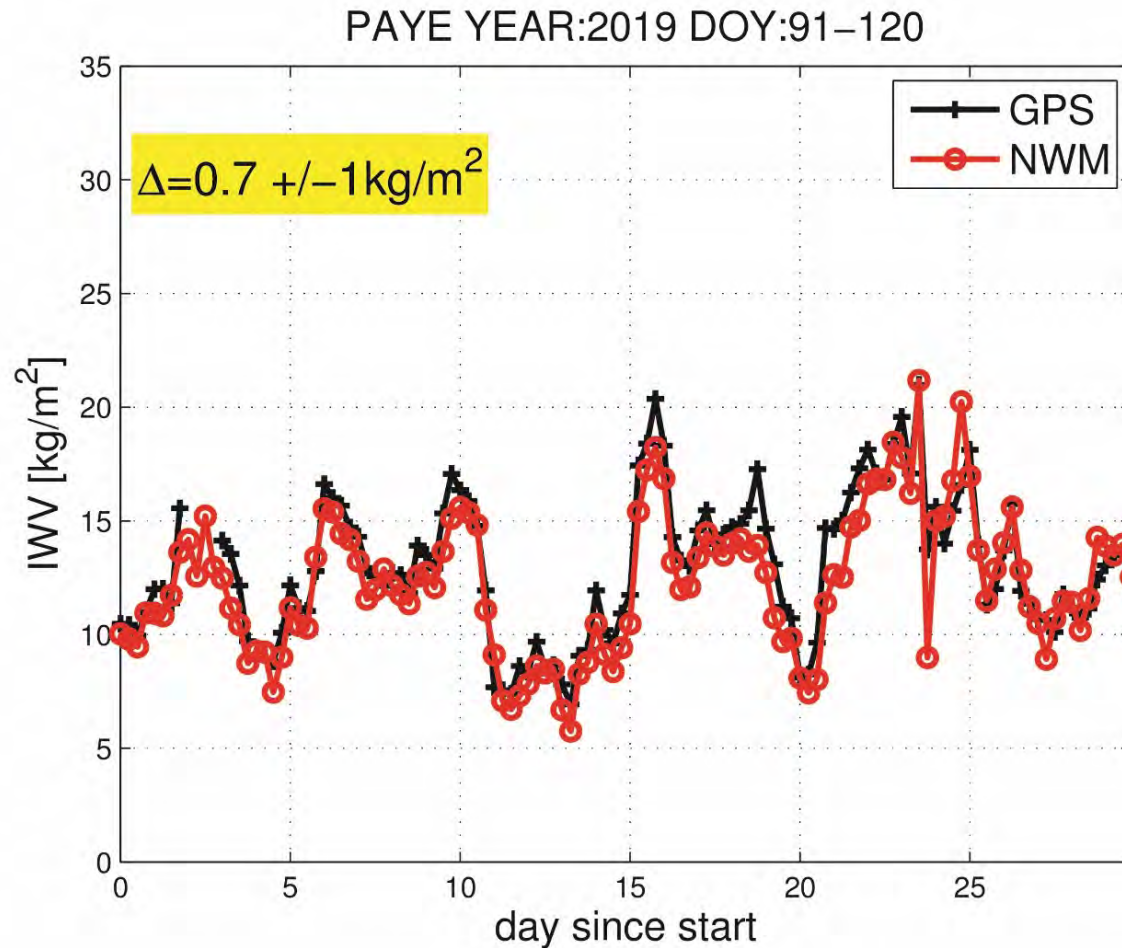
Example of validation with NWM ERA for MSS1, April 2019

PW for Lamont



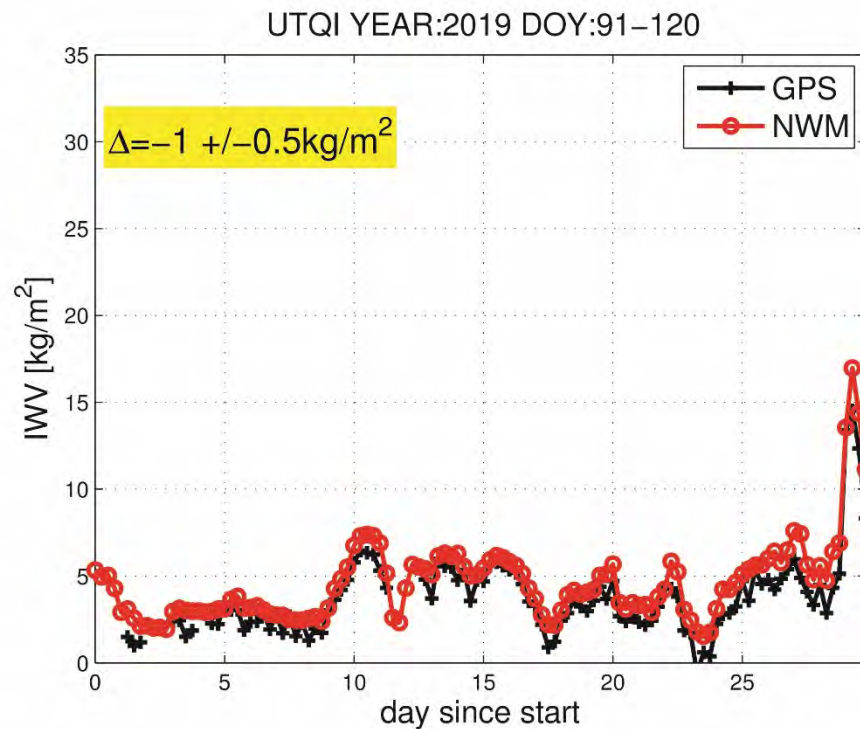
Example of validation with NWM ERA for SGPO, April 2019

PW for Payerne

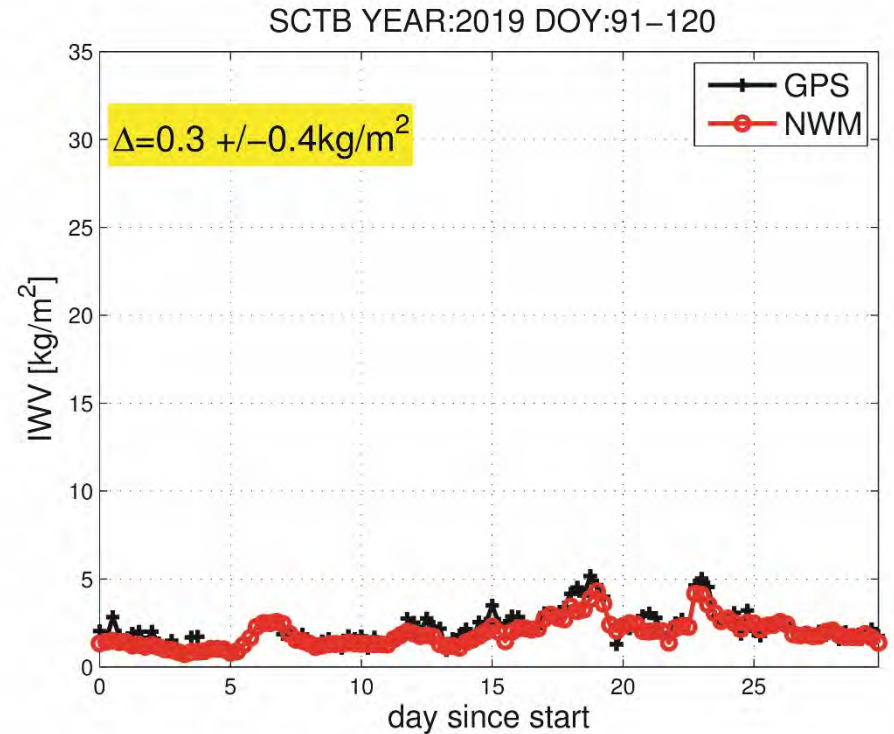


Example of validation with NWM ERA for PAYE, April 2019

PW for Barrow and Scott Base



UTQI

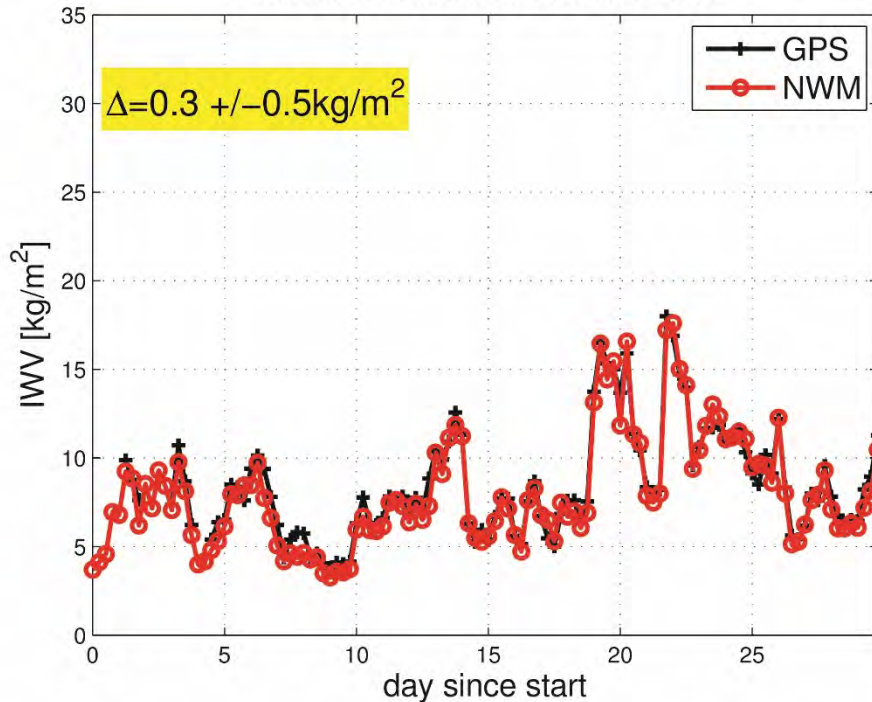


SCTB

Examples of validation with NWM ERA for UTQI and SCTB, April 2019

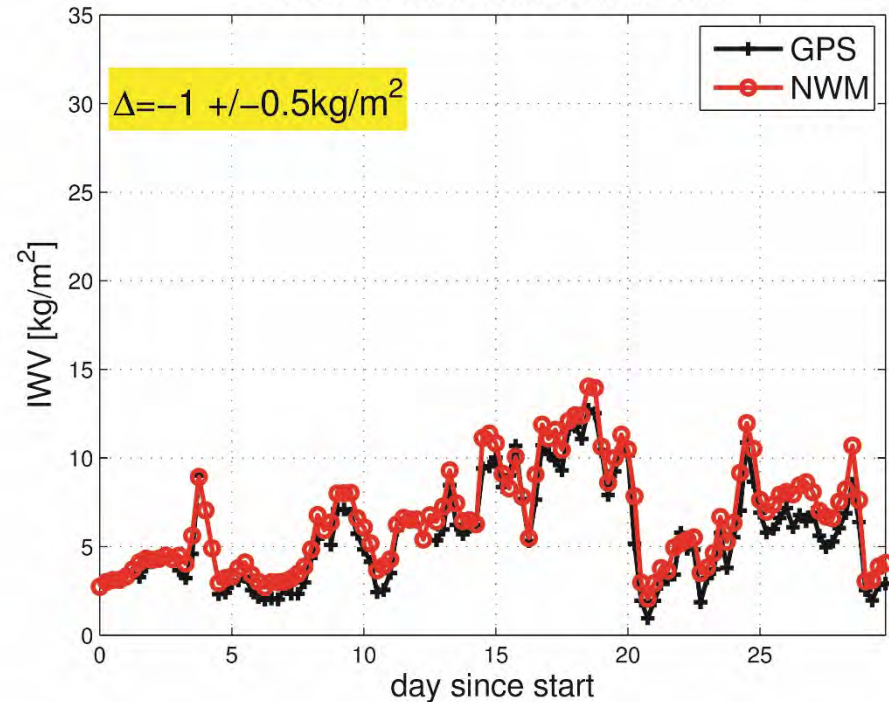
PW for Sodankylä and Ny-Ålesund

SODF YEAR:2019 DOY:91–120



SODF

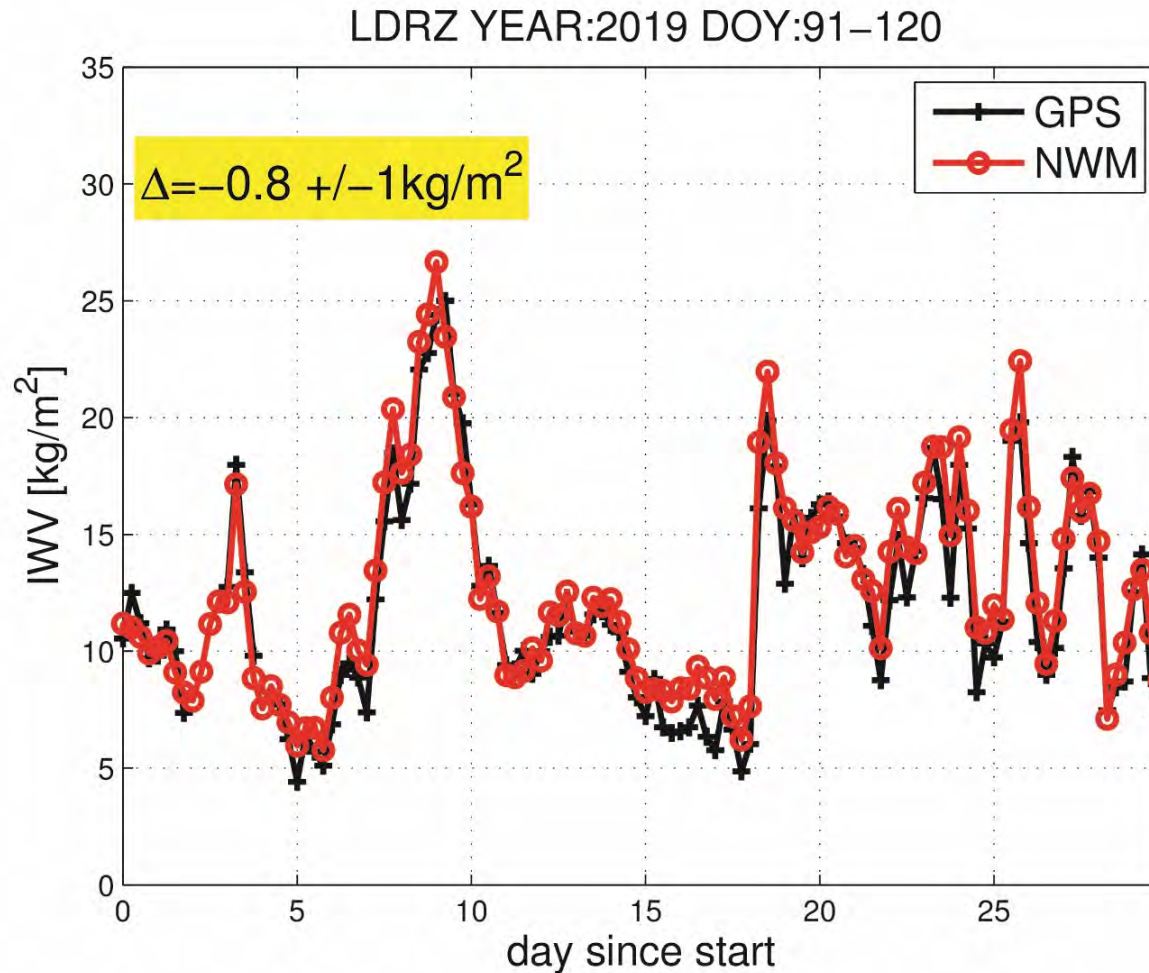
NYA2 YEAR:2019 DOY:91–120



NYA2

Examples of validation with NWM ERA for SODF and NYA2, April 2019

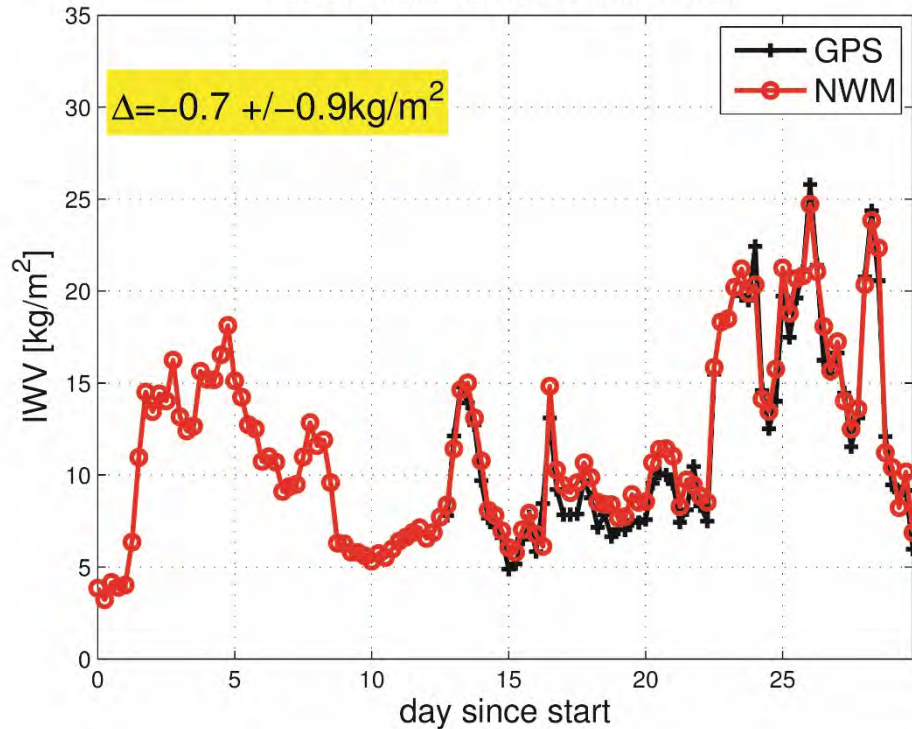
PW for Lauder



Example of validation with NWM ERA for LDRZ, April 2019

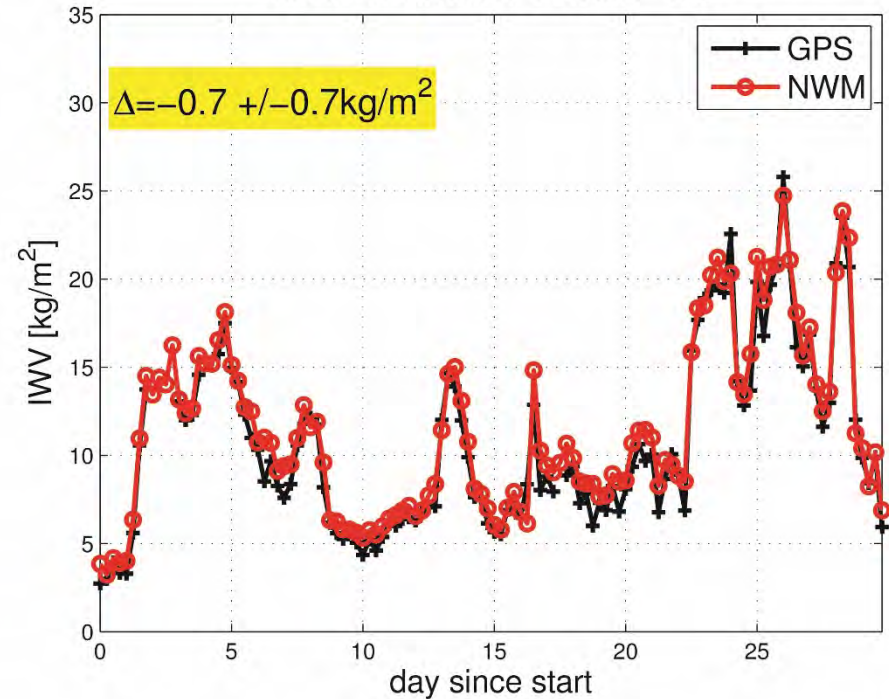
PW for Lindenberg

LDB0 YEAR:2019 DOY:91-120



LDB0

LDB2 YEAR:2019 DOY:91-120



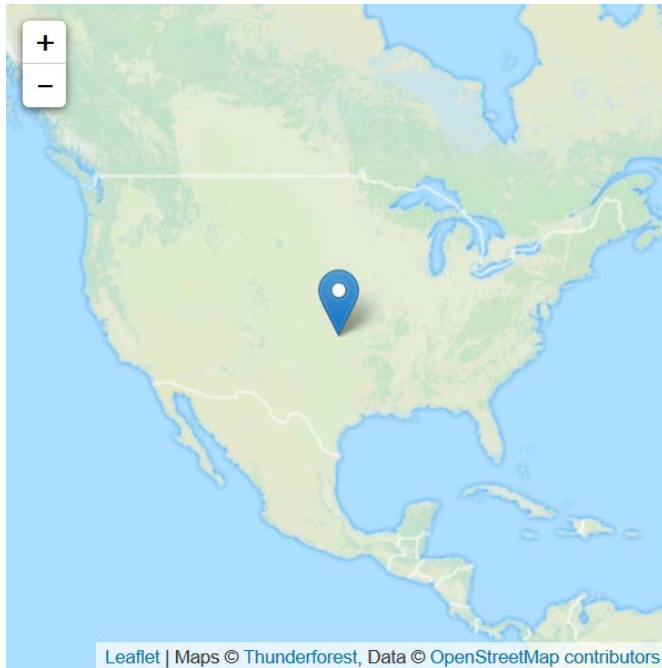
LDB2

Examples of validation with NWM ERA for LDB0 and LDB2, April 2019

Next GNSS GRUAN sites

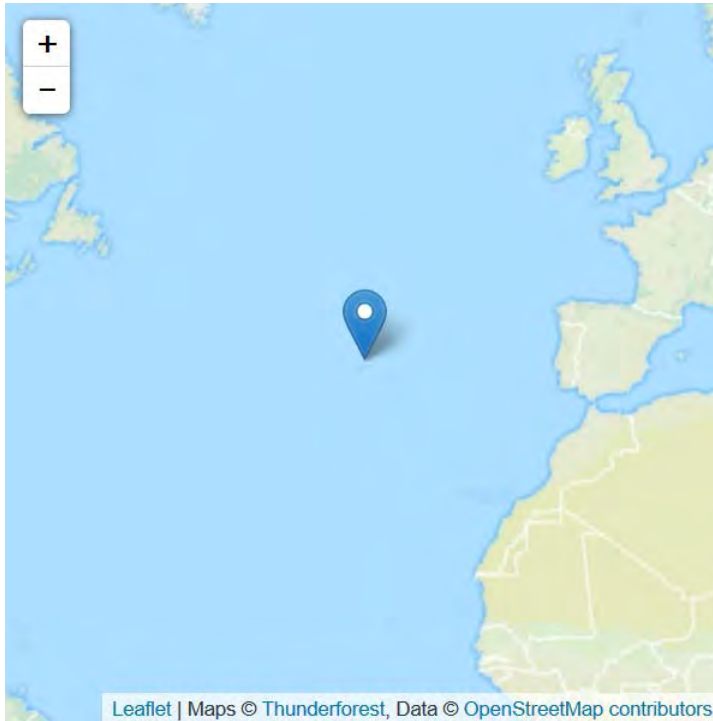
Marshall, Boulder (USA)

- TMS3 (close to Boulder) closed in October 2018
- New GNSS site will be installed on GRUAN site BOU (Marshall Field Test Site)
- MoU between NCAR and GFZ signed
- GNSS hardware will be installed by GFZ this summer



Graciosa Island, Azores (Portugal)

- ARM Eastern North Atlantic site (ENA)
- GRUAN site GRA
- MoU between ARM and GFZ signed
- GNSS hardware will be installed by GFZ this summer



Paramaribo (Suriname)

- Meteorological Service of Suriname (MDS) agreed to host and to support GNSS site (thanks to Ankie Pitters, KNMI)
- Hardware will be installed by GFZ



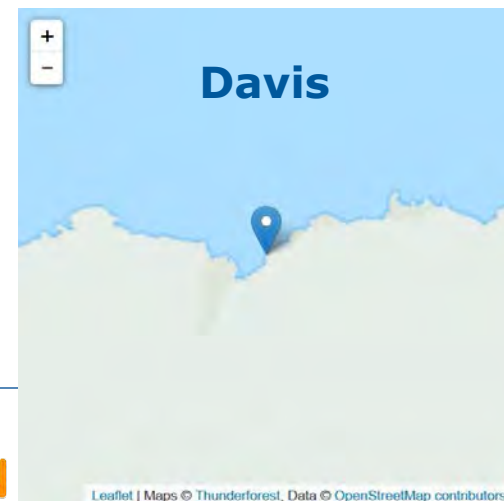
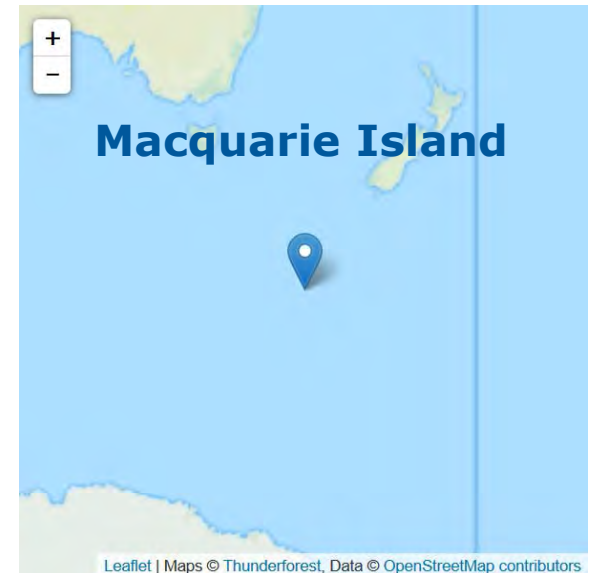
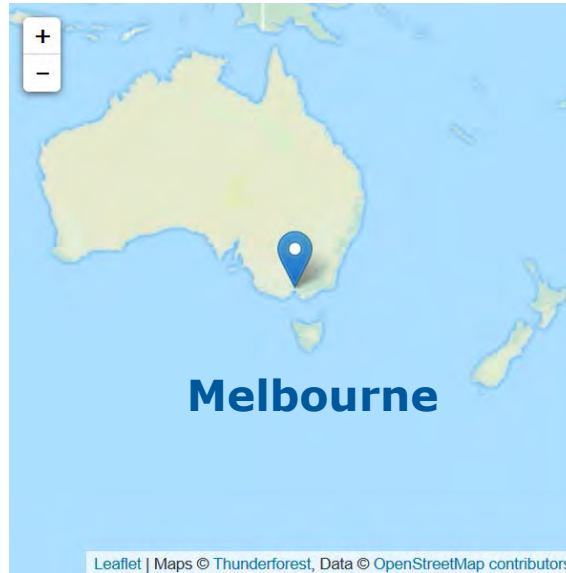
GRUAN Sites with GNSS

- **Cabauw (Netherlands):**
 - GNSS hardware updated
 - data flow to GFZ since May 18th
 - new log file in preparation
 - PW processing will be started soon
- **Potenza (Italy):** work in progress on GNSS data flow to GFZ
- **Dolgoprudny (Russia):** negotiations on GNSS data flow (in progress)

Future GNSS GRUAN sites

Australia

- Negotiations with Bureau of Meteorology, Australia



Other future GNSS GRUAN sites

- Beltsville (USA): MoU in progress
- Tenerife (Spain): intend to install own GNSS receiver
- Syowa and Minamitorishima (Japan): GFZ offer to install GNSS receivers
- Other GRUAN sites will be contacted by GFZ and PW
TT: Paris, La Reunion, Xilinhote

Future GRUAN sites

- Neumayer (Antarctica): GNSS is operating by GFZ/AWI
 - Barbados: first contacts, GFZ offer to install GNSS receivers
-
- GFZ offer to install and operate GNSS receivers on GRUAN sites
 - Requirements:
 - power supply
 - internet connection

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
- Validation with RS, WVR and NWM

Future work:

- Reprocessing with new PW uncertainty estimation will be done for the whole time period 2011-2019
- Validation with RS, WVR and NWM will be continued

GFZ Products on FTP

ftp <ftp.gfz-potsdam.de>

user: anonymous

GRUAN NRT:

```
cd GNSS/products/nrttrop/sinex_trop_GRUAN_EPOS8/w****
```

```
cd GNSS/products/nrttrop/product_GRUAN_COST_EPOS8/y****/m**
```

REPRO:

```
cd GNSS/products/nrttrop/REPRO/sinex_trop_EPOS8/w****
```

```
cd GNSS/products/nrttrop/REPRO/product_COST_EPOS8/y****/m**
```

GFZ Contacts

Operational Data Centre:

| | | |
|---------------|--|------------------|
| Markus Bradke | bradke@gfz-potsdam.de | +49 331 288 1182 |
|---------------|--|------------------|

GNSS Network & Hardware:

| | | |
|------------------|--|------------------|
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|------------------|--|------------------|

GRUAN Analysis Centre:

| | | |
|-------------|--|------------------|
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|-------------|--|------------------|

Many thanks for your attention!

