



GNSS ACTIVITIES AT GFZ FOR E-GVAP

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E-GVAP Expert Teams Meeting

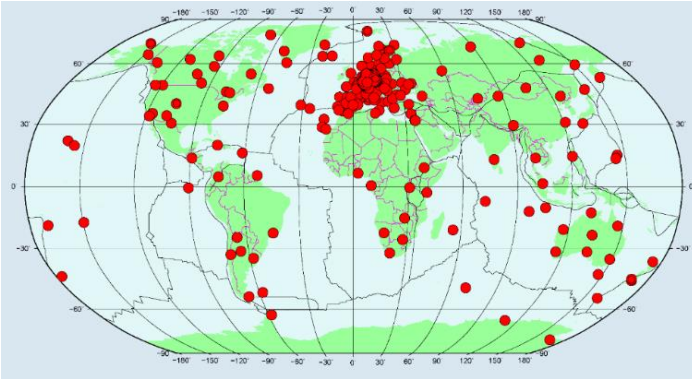
November 28-29, DWD, Offenbach, Germany

New Funding Period of GFZ ATMO research

- GNSS atmosphere sounding activities will be a core element of GFZ scientific work in the new Helmholtz Research Topic 1 **“The Atmosphere in Global Change” (2021-2027)**
- GFZ Director for Topic 1: Jens Wickert
- Contribution to subtopic 1.2 **“Climate Feedbacks”** and subtopic 1.3 **“Future Weather and Extremes”**
- Evaluation of the new programme will be Dec 2-5, 2019
- Extension of the current activities by GNSS reflectometry with focus on meteorological applications, geomagnetic field/ionosphere and magnetosphere research, VLBI-based atmosphere/ionosphere studies

GFZ GNSS Activities for ATMO

Global/Regional Networks



REPRO

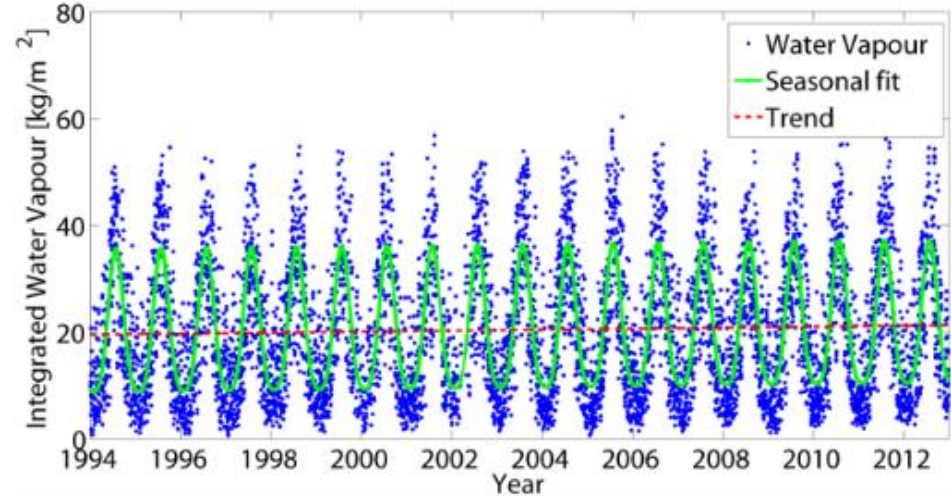


NRT/RT



GNSS Operational Meteorology: E-GVAP

Example: **Greenbelt** (+0.94 mm/decade)



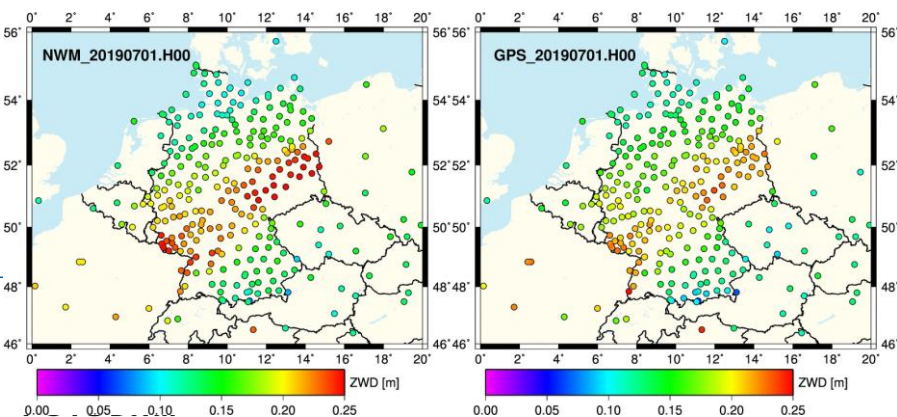
Climate Research:
long term IWV trend analysis



GRUAN:
The Climate Reference Network

Model GFS

GPS



Overview of GNSS Processing at GFZ

NRT processing with GFZ EPOS8 software, PPP mode:

- GF1R “rapid” product, about 480 stations, ready at hh:25
- GF1G “global” product, about 600 stations, ready at hh:55
- Operational at Meteo-France since October 2019
- German SAPOS + global IGS + EUREF + GRUAN, RINEX2 and 3
- ZTD/IWV/STD/Gradients products (are available at GFZ ftp)
- GRUAN processing (delay about 1h)

Processing with old EPOS6 version:

- old E-GVAP GFZ_ product (about 290 stations), RINEX2
- still running -> open issue replacement of GFZ_ with GF1R/GF1G in E-GVAP web => CLOSED! THANKS to Siebren!

RT processing (EPOS-RT):

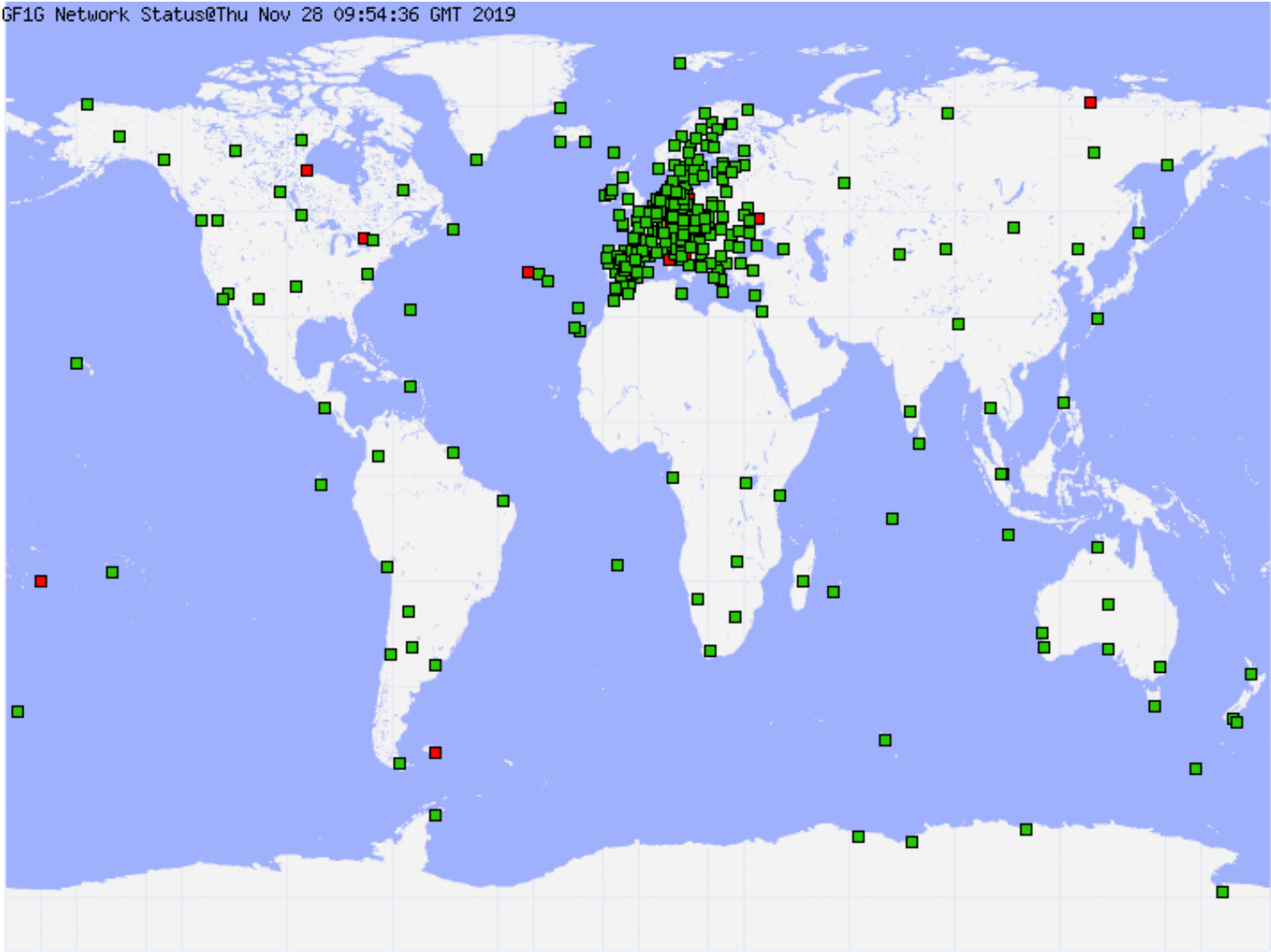
- GPS only, continue to run for RT DEMO Campaign of GNSS4SWEC

Reprocessing (e.g. for climate applications, on-going):

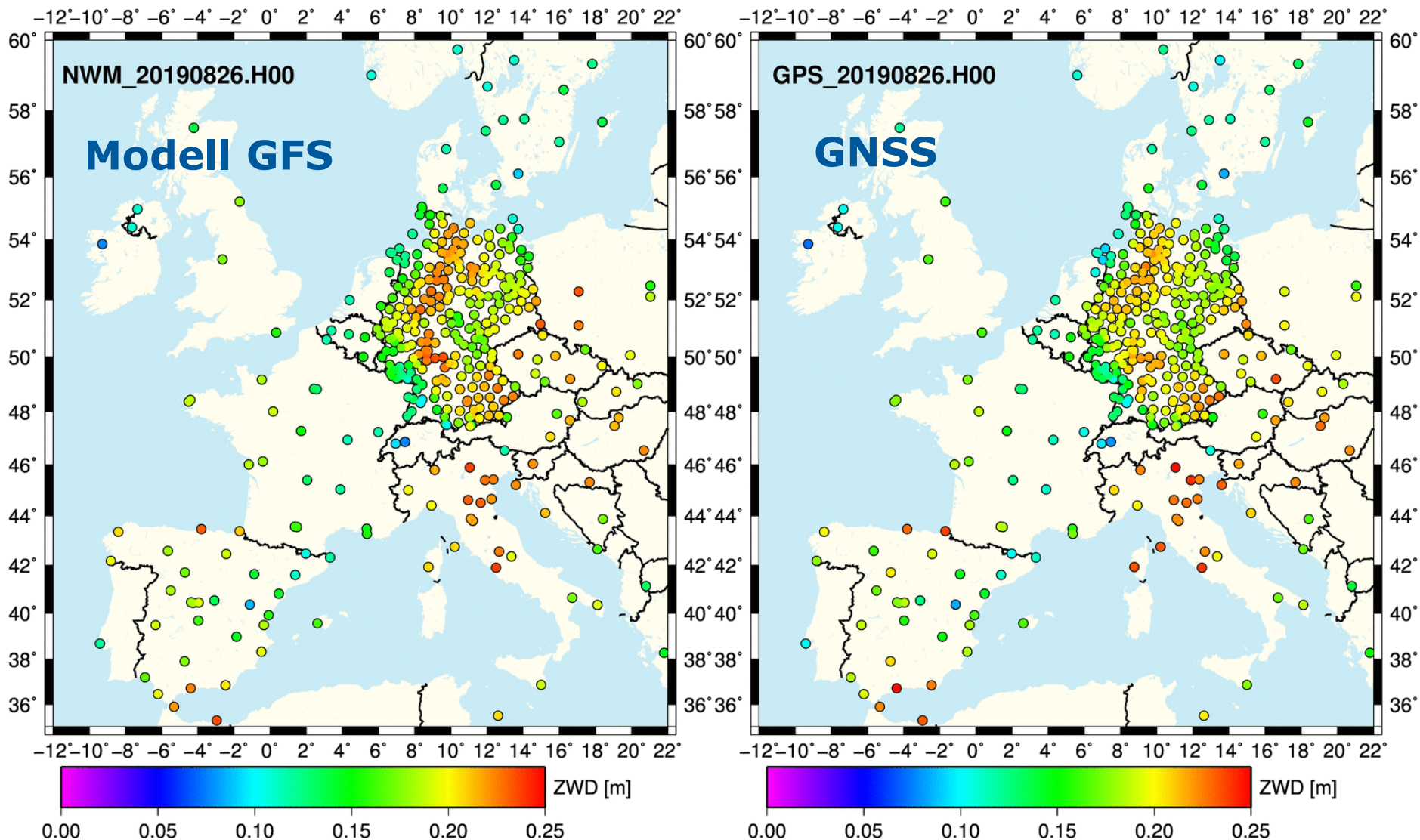
- about 700 stations in processing

Current Global Network in Processing

GF1G Network Status@Thu Nov 28 09:54:36 GMT 2019

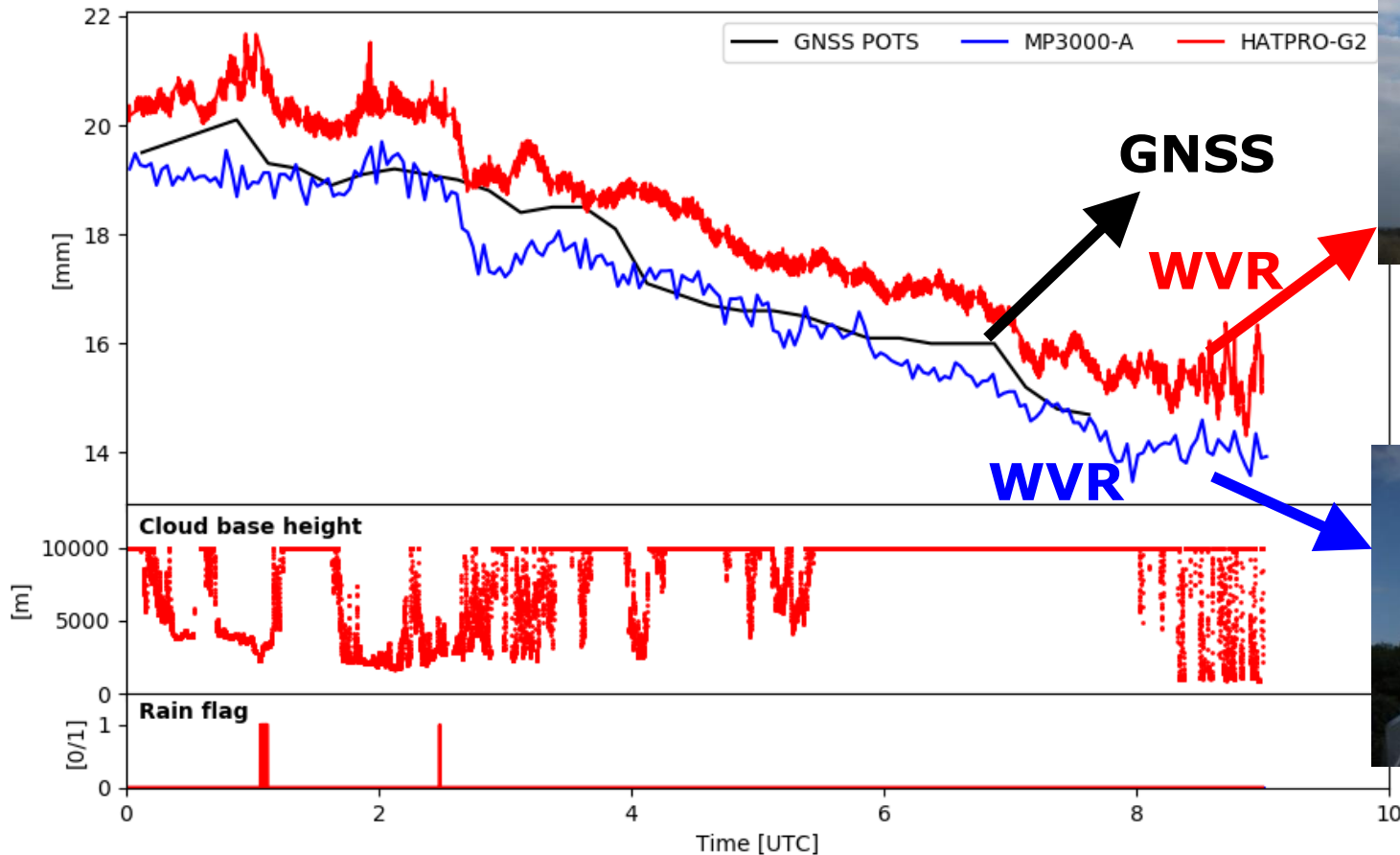


Operational Monitoring of GNSS-derived ZWD: Comparison with Weather Model GFS



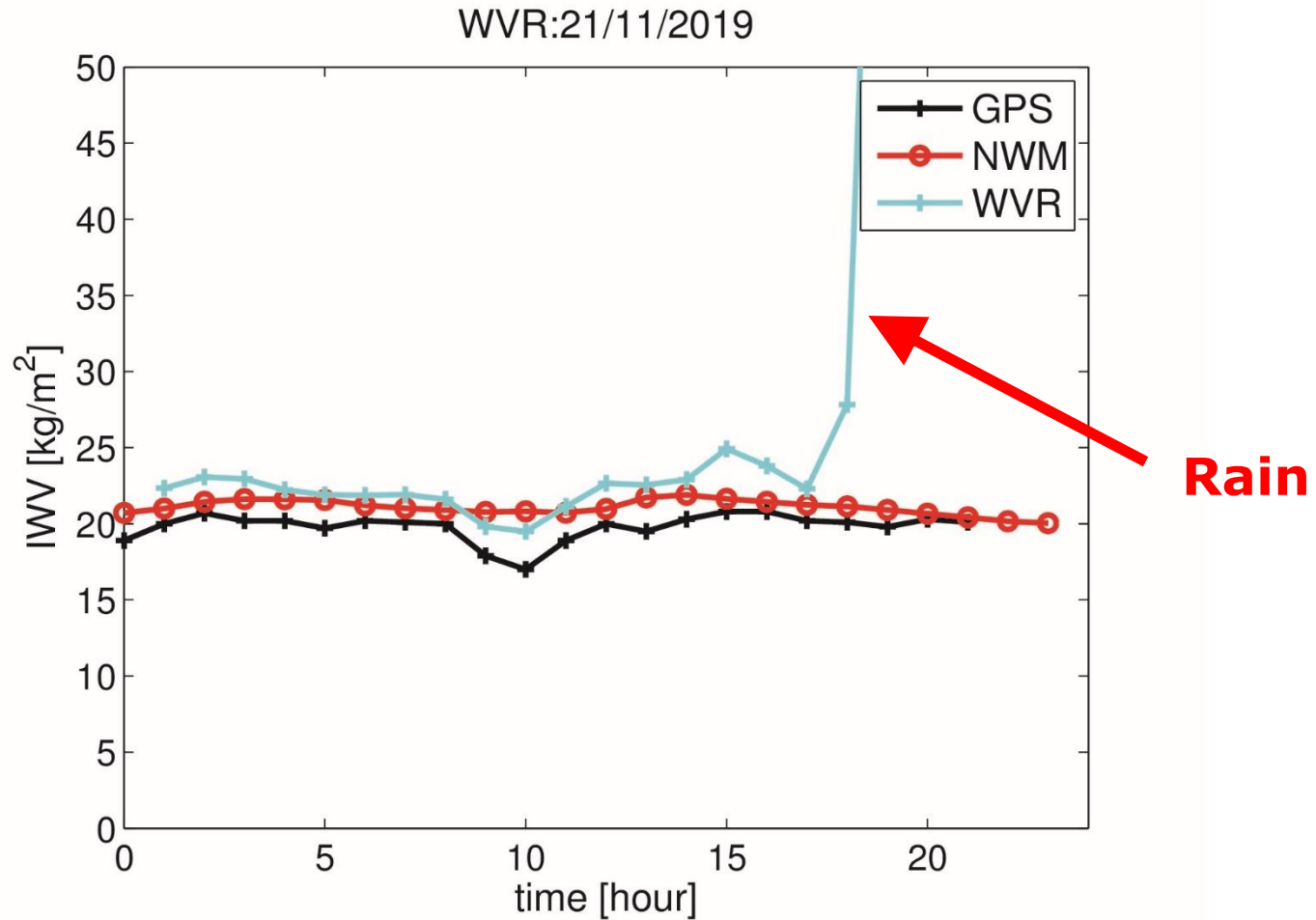
GNSS-IWV: validation with WVR

Integrated Water Vapor (14/08/19)



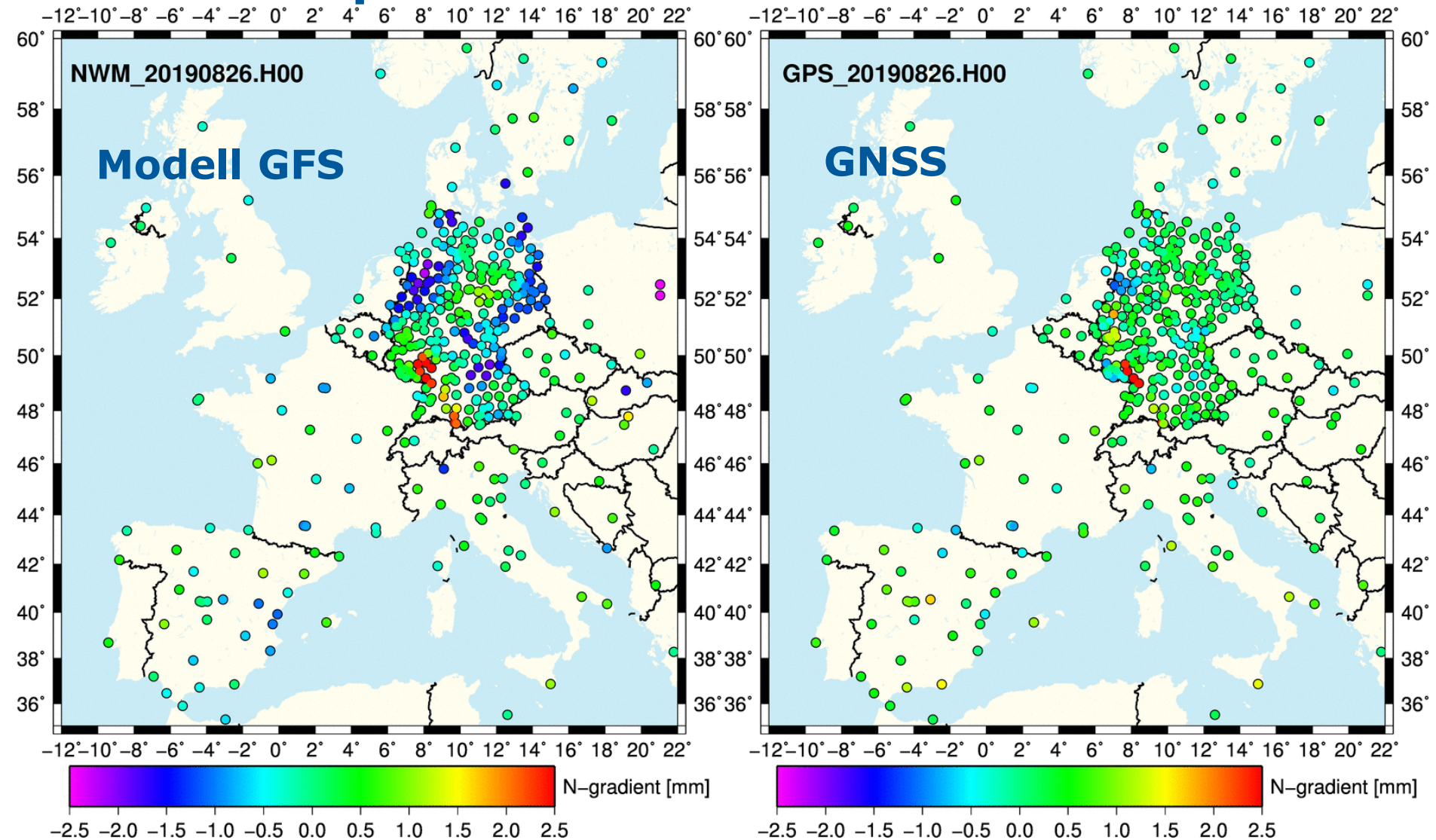
GNSS-derived IWV for station Potsdam: comparison with WVR instruments of GFZ: **HATPRO and **RADIOMETRICS** (example Aug 14, 2019)**

Validation of GNSS-IWV with WVR



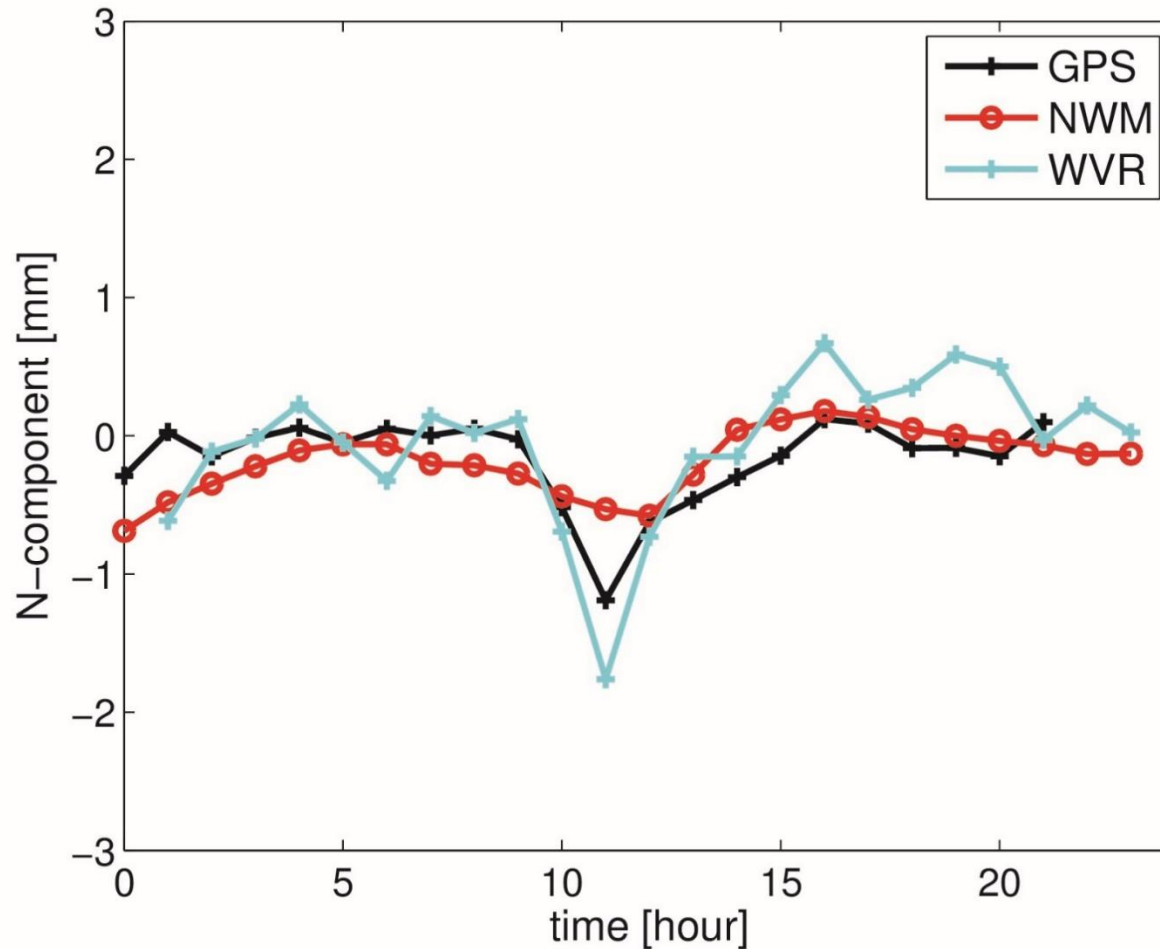
GNSS-IWV for station Potsdam: comparison with WVR HATPRO and with NWM GFS (example Nov 21, 2019)

Operational Monitoring of Gradients: Comparison with Weather Model GFS



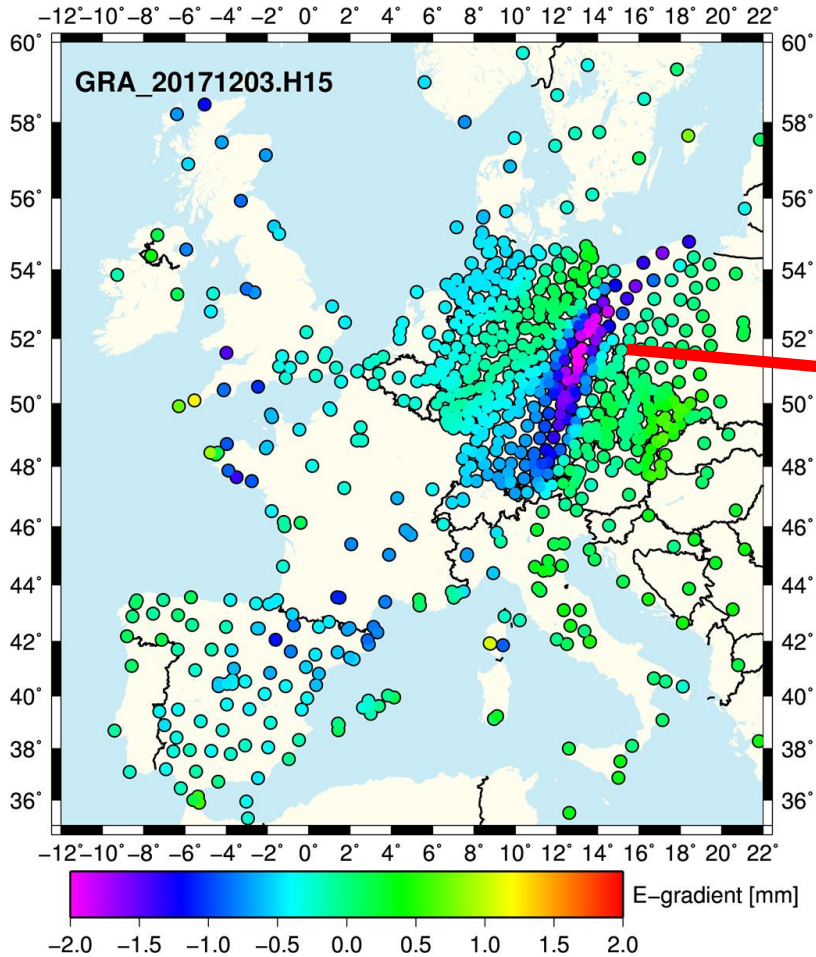
Validation of Gradients with WVR

WVR:21/11/2019

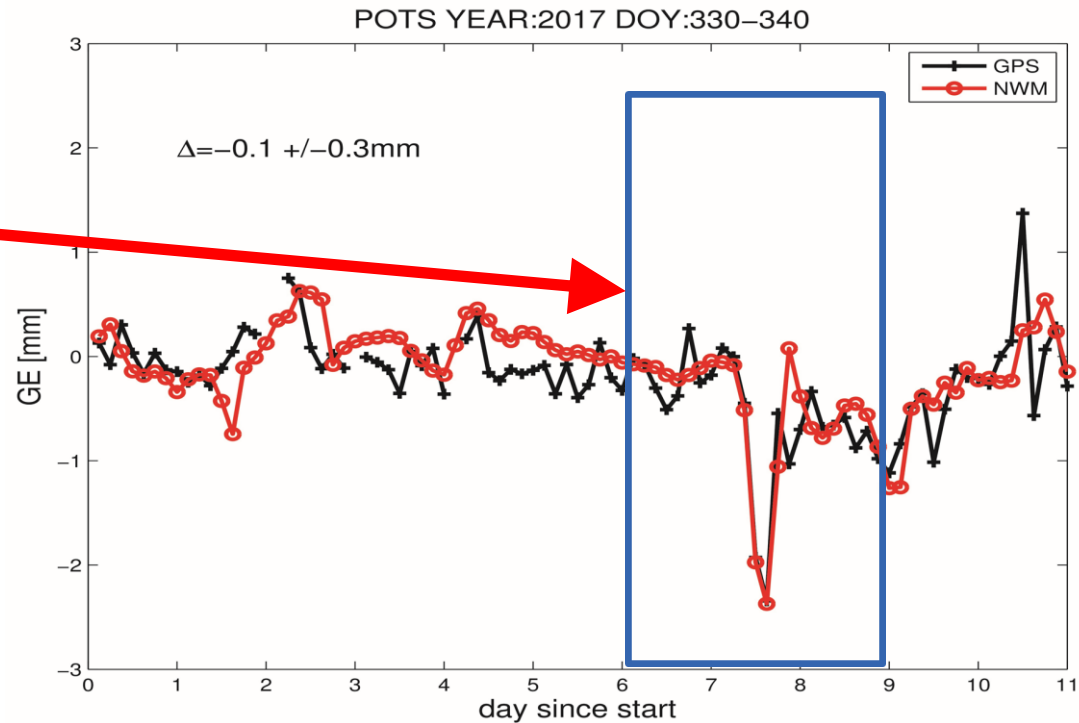


Horizontal tropospheric N-gradient for station Potsdam: comparison with WVR HATPRO and NWM GFS(example Nov 21, 2019)

Operational Monitoring of Gradients



**Example of strong tropospheric
East-gradients caused by weather
front in Germany on December 3, 2017**



**Excellent agreement of East-gradients
from GPS with GFS NWM for station
Potsdam, Germany**

GFZ Contribution to Climate Research

What is GRUAN?

Global **C**limate **O**bserving **S**ystem (GCOS) **R**eference **U**pper-**A**ir **N**etwork



Network for ground-based **reference** observations of the atmosphere for **climate** in the frame of GCOS (WMO)



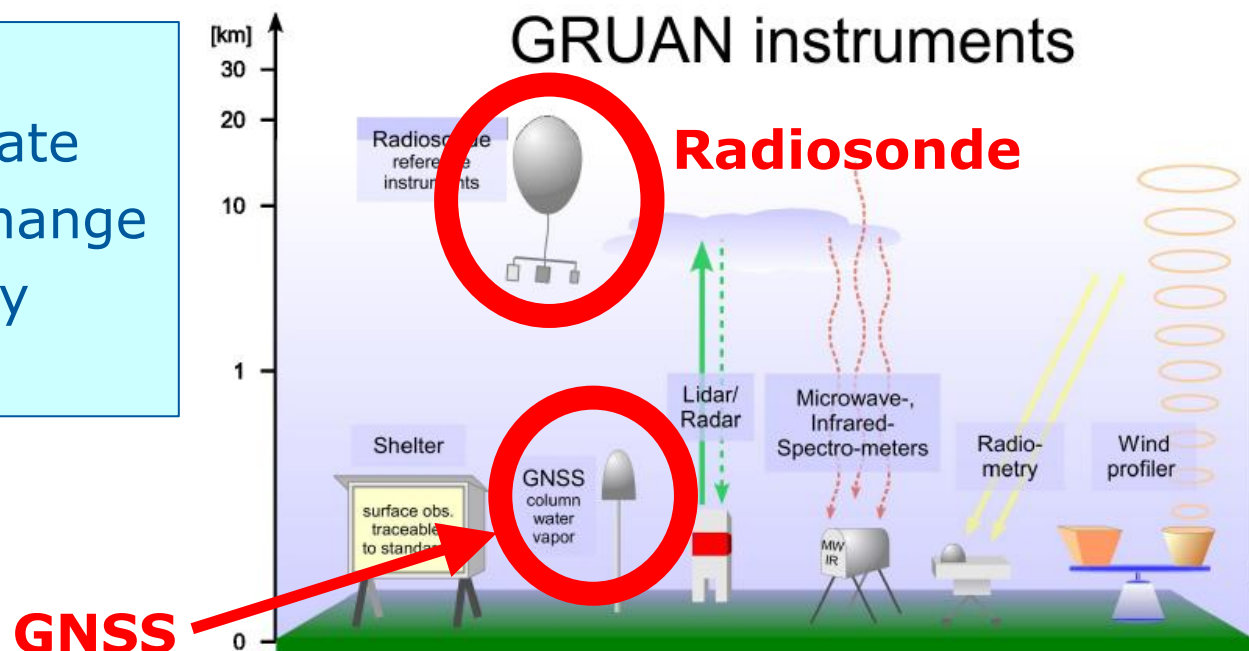
- **Start of implementation:** 2008
- **Lead Centre:** Meteorological Observatory Lindenberg of German Weather Service DWD
- **GNSS-PWV Processing Centre:** GFZ (since 2014)
- **Status:** currently 26 stations with a goal to be a network of up to 30-40 globally distributed sites

GRUAN Measurements

Priority 1: Temperature, pressure, water vapor

Priority 2: Ozone, methane, ...

- Traceability
- Uncertainty estimate
- Management of change
- Long-term stability
- Redundancy



GNSS is priority number one technique for PWV monitoring

GFZ Contribution to GRUAN

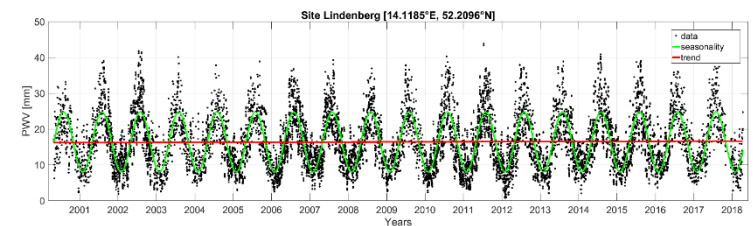
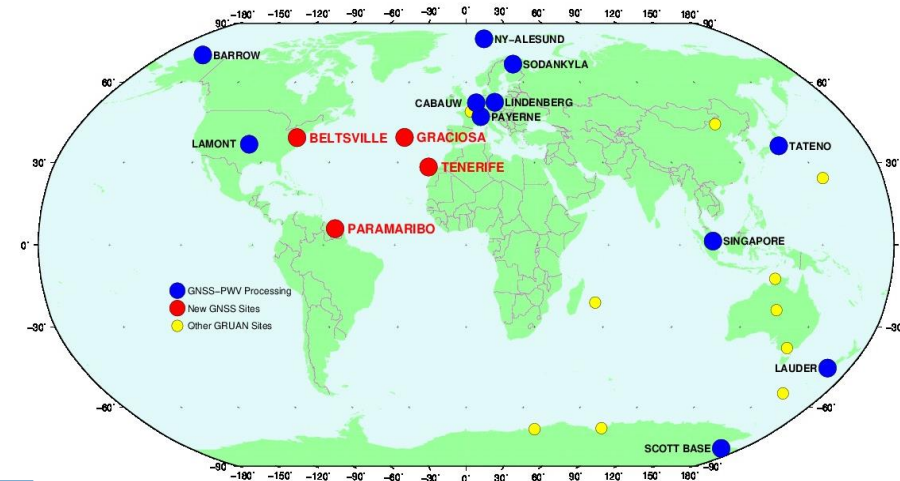
GNSS-PWV Task Team

GNSS network

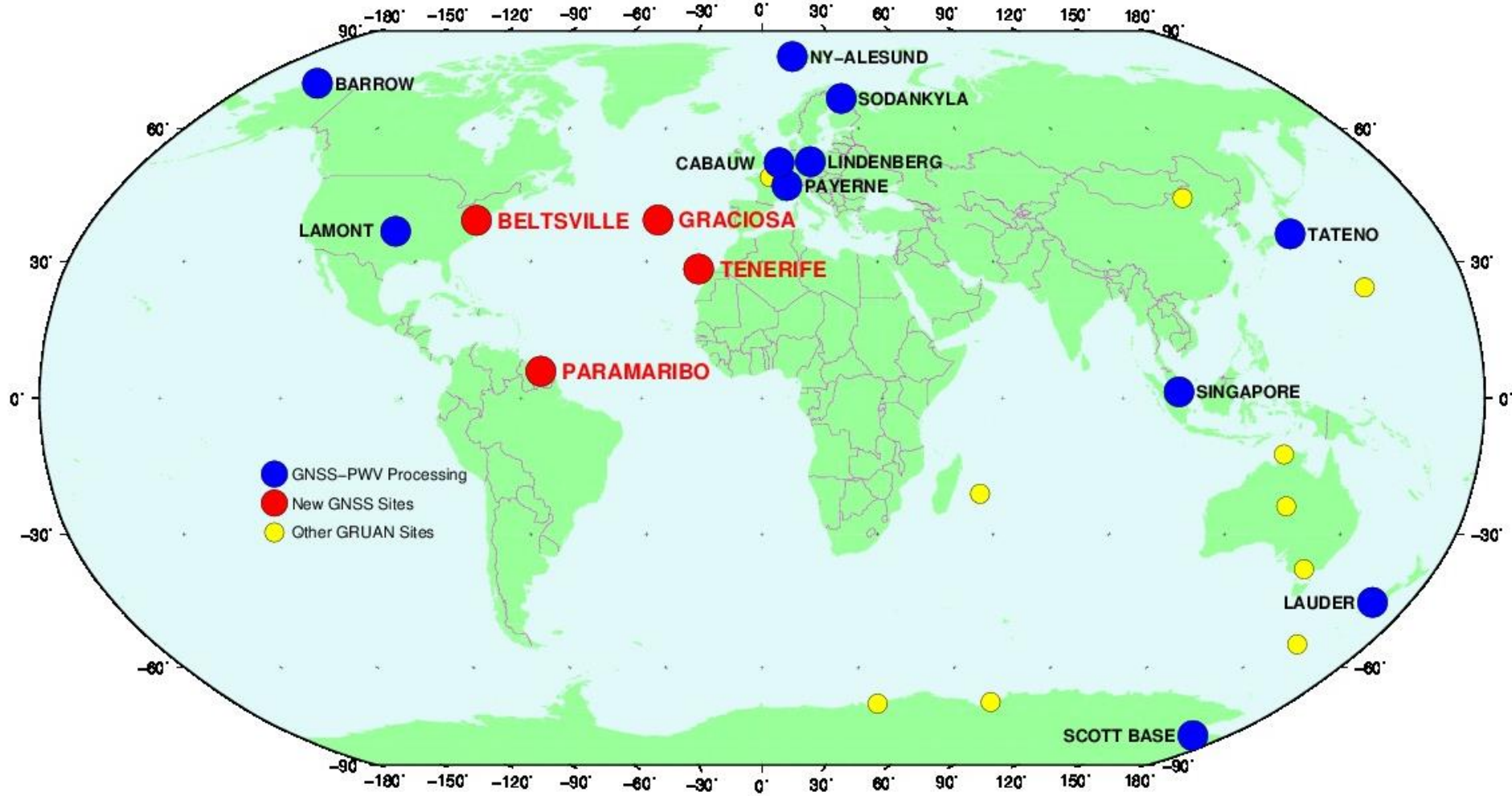
GNSS-PWV Processing Centre

Validations with RS, WVR,
NWM, VLBI, ...

GNSS-PWV trend analysis



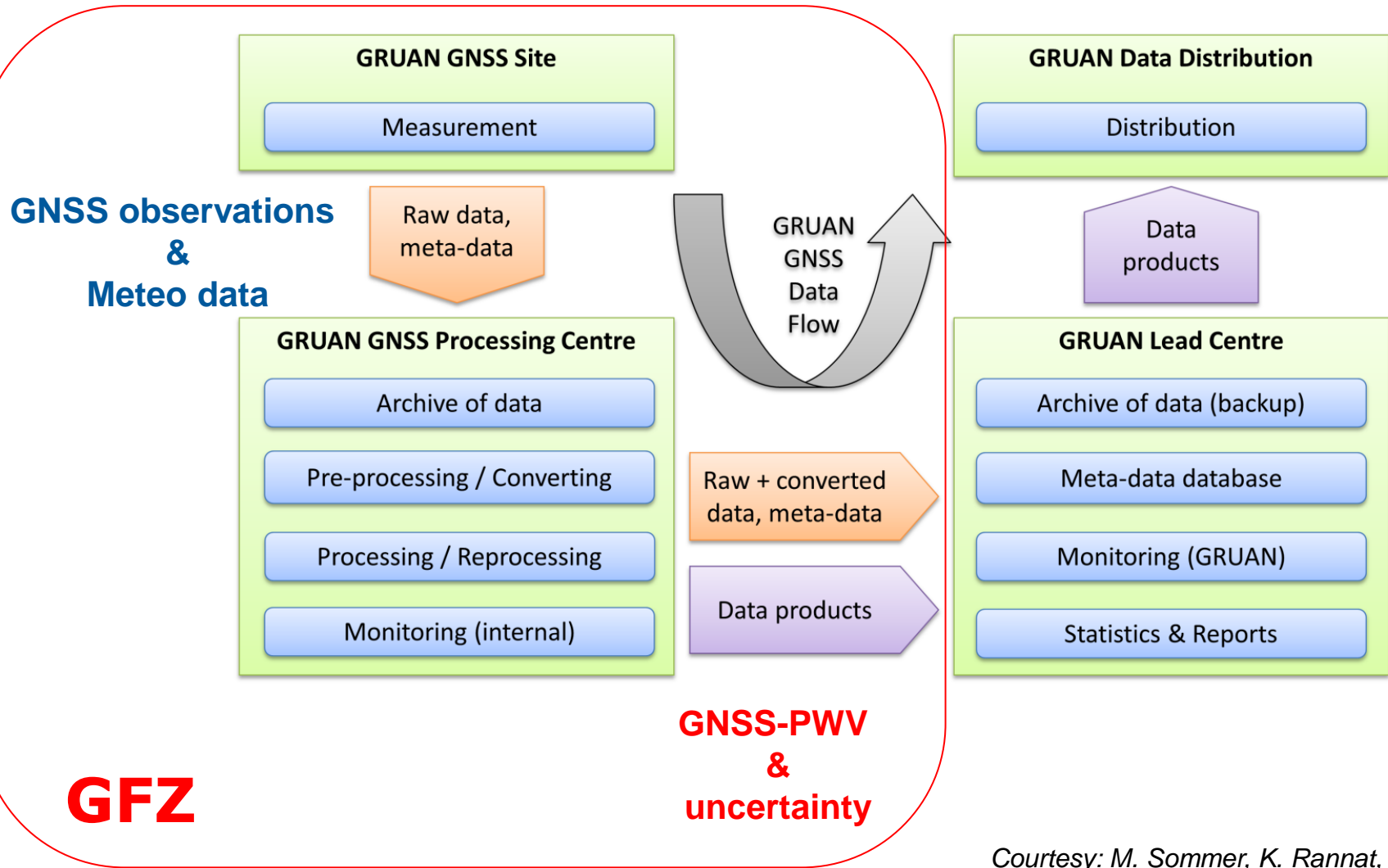
GRUAN GNSS Network



11 GNSS sites in GRUAN processing

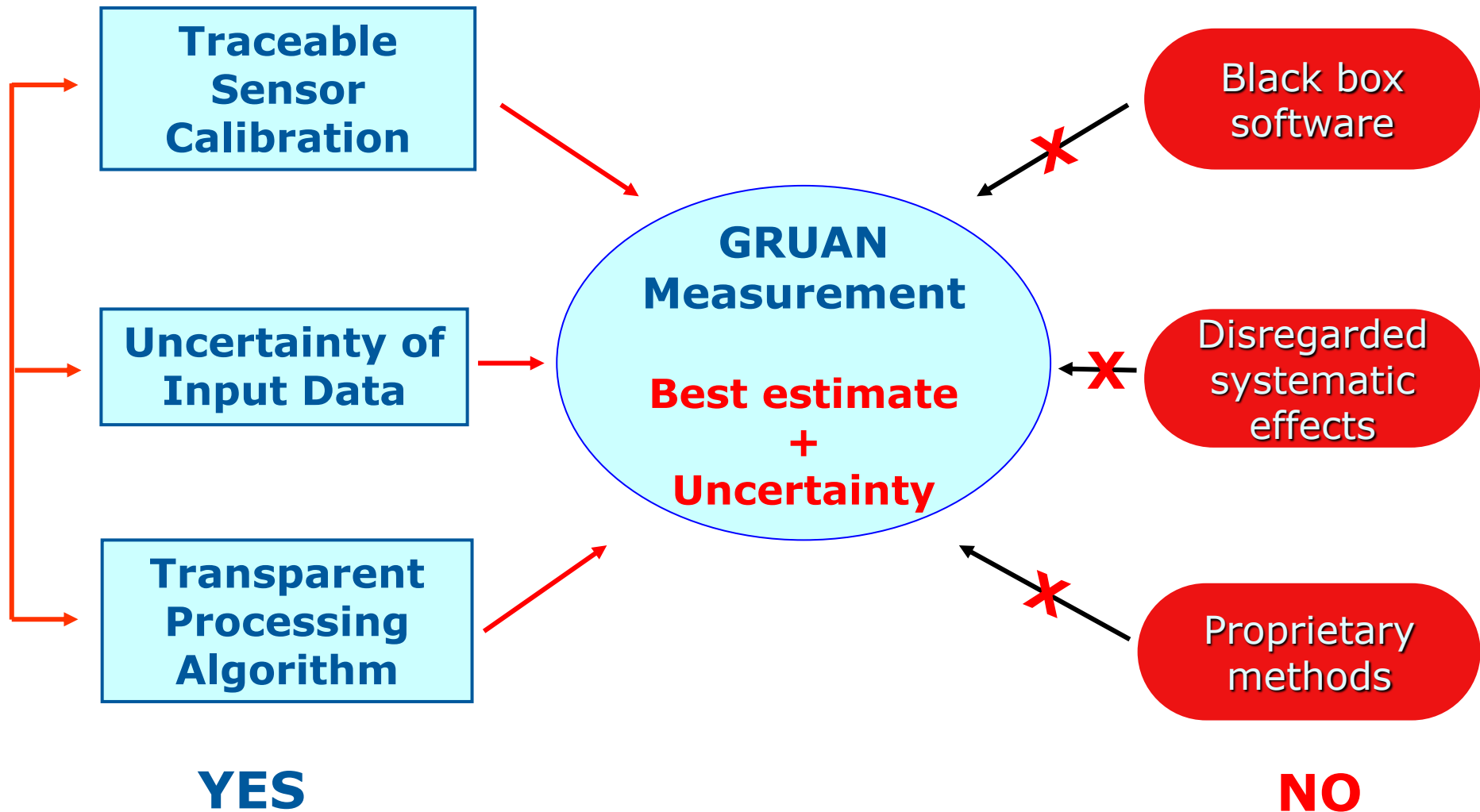
Red: 4 new GNSS sites (2019/2020)

Observations → GRUAN GNSS-PWV Data Product



Courtesy: M. Sommer, K. Rannat, G. Dick

Establishing Reference Quality



GNSS-PWV Uncertainty Estimate

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

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

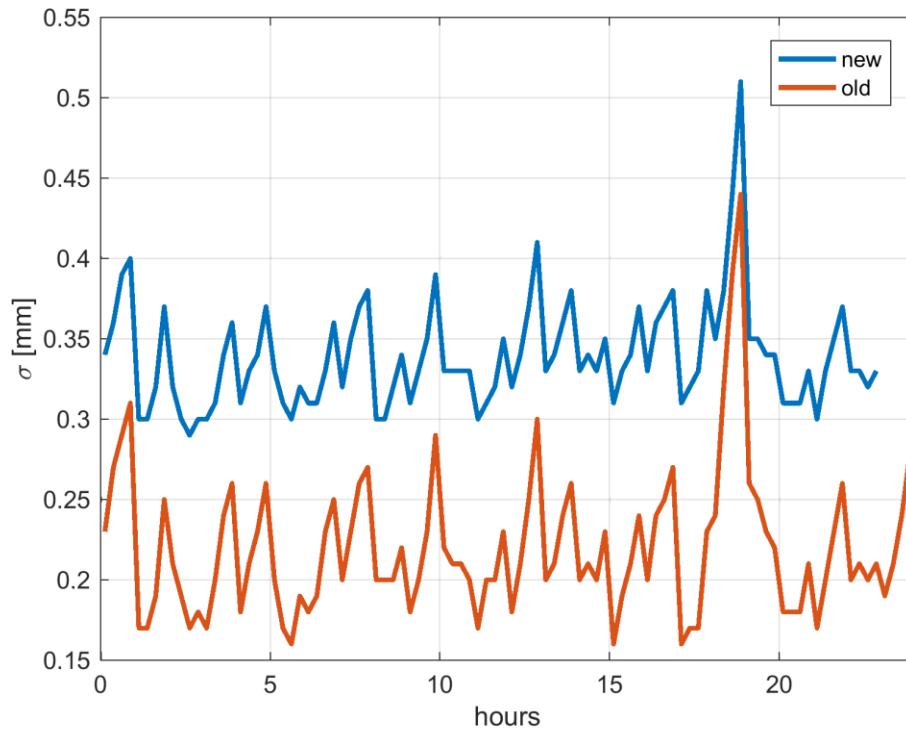
$$\text{PWV} = \Pi(T_m) \bullet \text{ZWD}$$

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

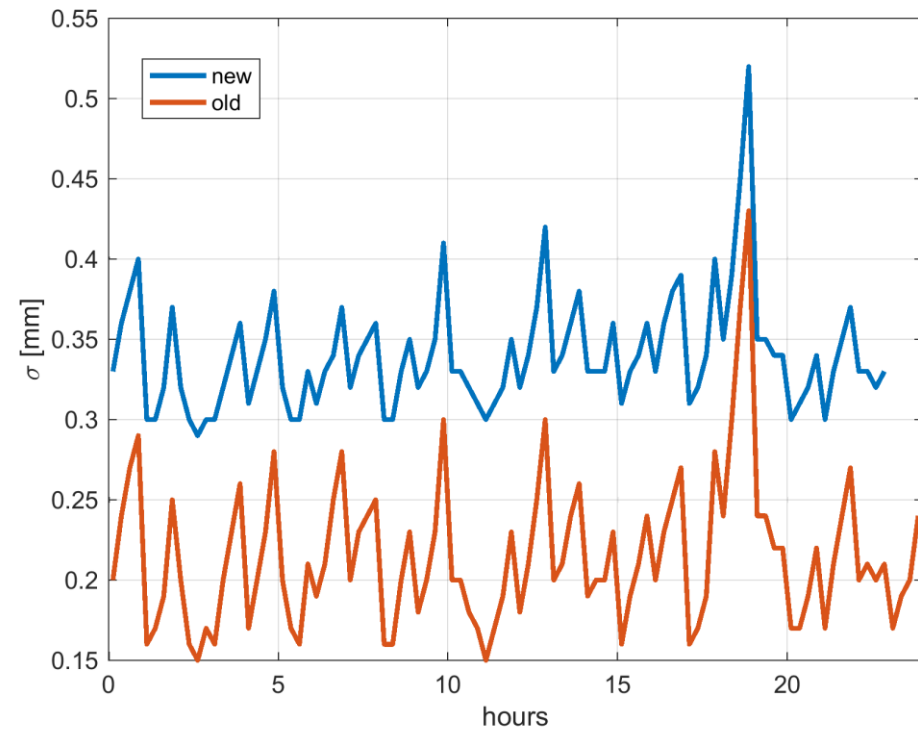
Ning et al., 2016: The uncertainty of the atmospheric integrated water vapour estimated from GNSS observations, AMT

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

GNSS-PWV Uncertainty Estimate



Potsdam

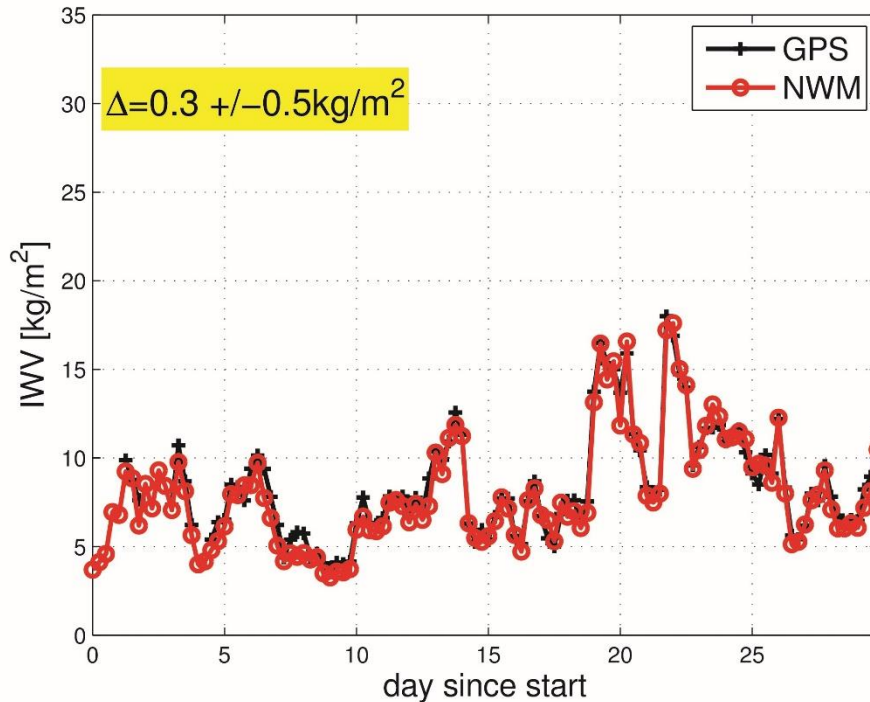


Lindenberg

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

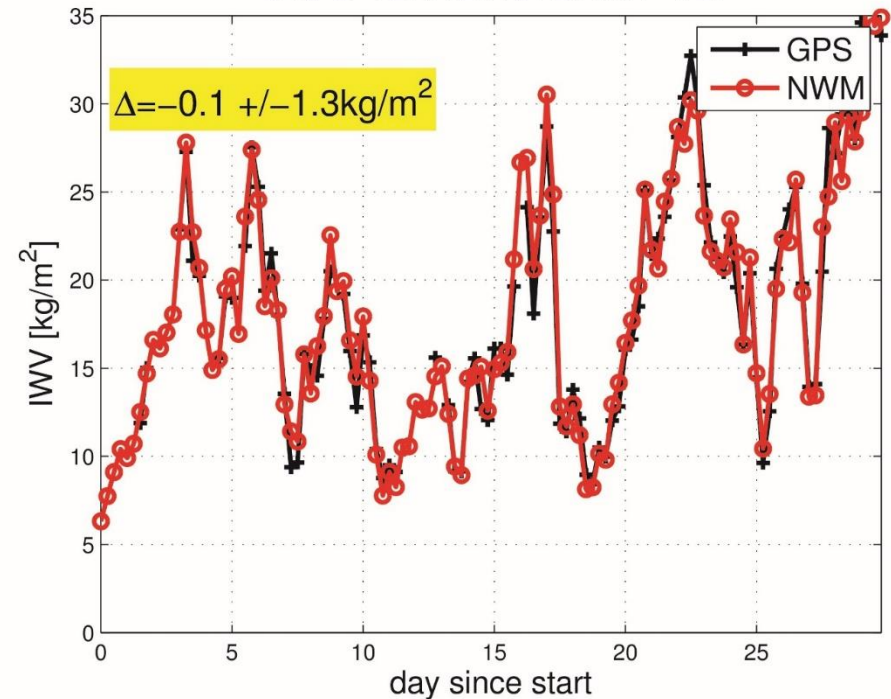
GNSS-IWV Validation with NWM

SODF YEAR:2019 DOY:91-120



Sodankylä (SODF)

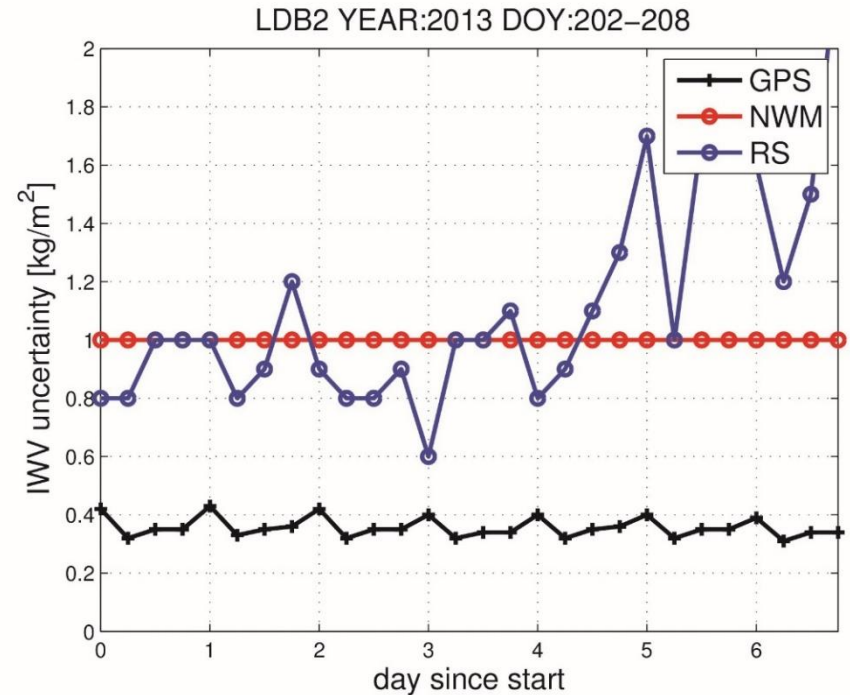
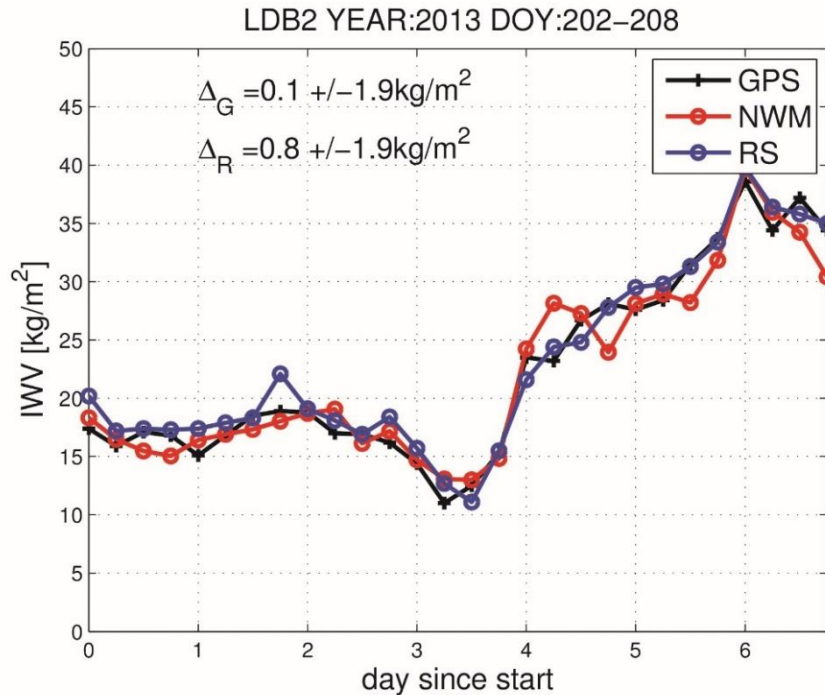
SGPO YEAR:2019 DOY:91-120



Lamont (SGPO)

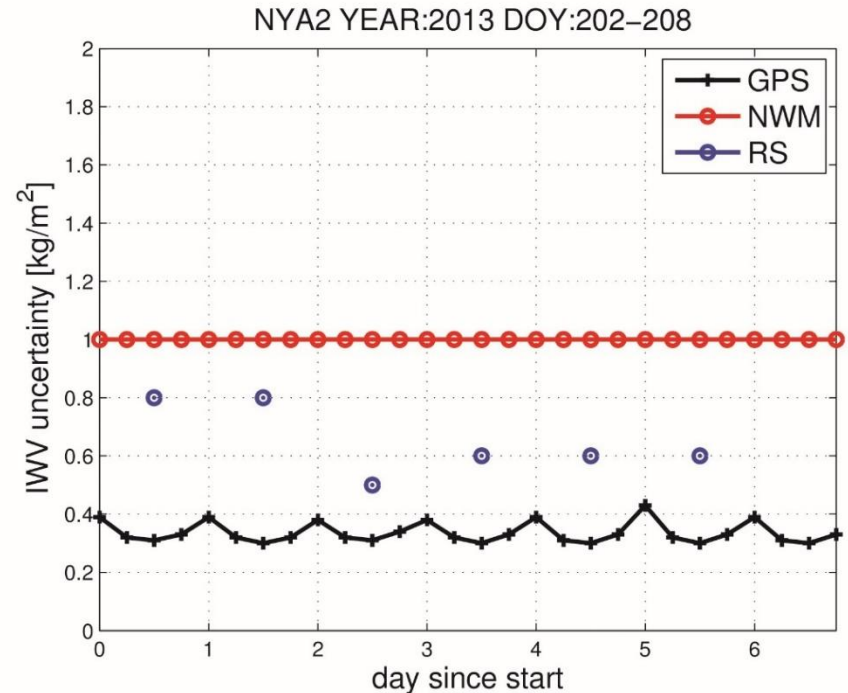
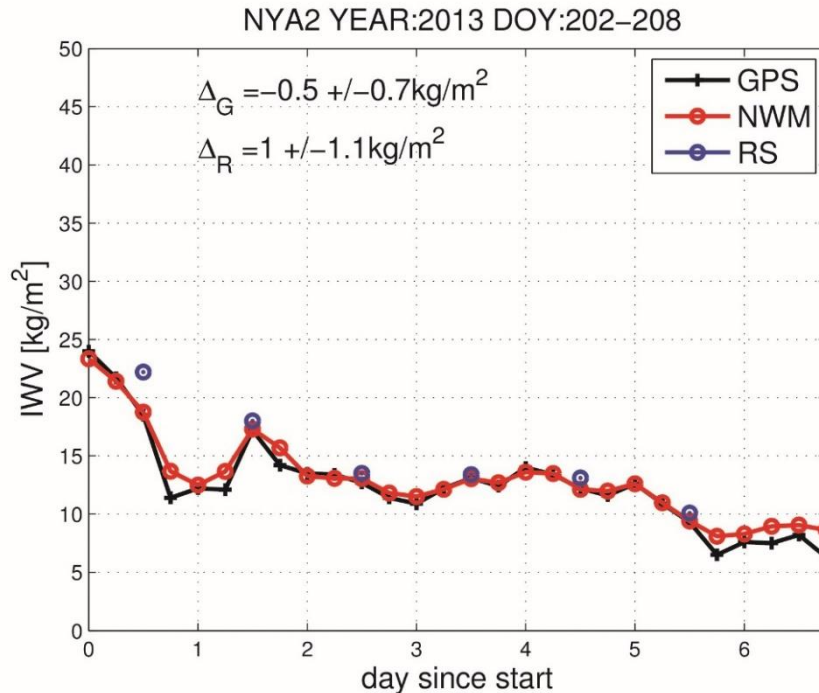
Examples of validation with operational analysis of European Centre for Medium-Range Weather Forecasts (ECMWF, red) for GRUAN sites Sodankylä (Finland) and Lamont (USA), April 2019

Validation results for Lindenberg



Validation of GNSS-IWV and uncertainties (black curves) with radiosondes (blue) and ECMWF model ERA5 (red) for GRUAN site Lindenberg (Germany), July 2013

Validation results for NyAlesund



Validation of GNSS-IWV and uncertainties (black curves) with radiosondes (blue) and ECMWF model ERA5 (red) for GRUAN site NyAlesund (Norway), July 2013

Expedition „MOSAiC”: Multidisciplinary drifting Observatory for the Study of Arctic Climate

- The largest-scale Arctic research expedition of all time
- 20th of September 2019 the German research icebreaker Polarstern departed from Tromsø, Norway
- Will spend the next year drifting through the Arctic Ocean, trapped in the ice.
- Total of 600 people from 19 countries participate, headed by the Alfred Wegener Institute for Polar and Marine Research (AWI), Germany
- GFZ GNSS equipment on board of Polarstern for IWV measurements



Outlook

➤ **GNSS Meteorology/E-GVAP**

Project **AMUSE** (PI J. Wickert): “Advanced MULTI-GNSS Array for Monitoring Severe Weather Events”, funded by the DFG for 3 years (start 2020):

- AMUSE is aiming at improving the forecast of strong precipitation events in Germany in cooperation with DWD
- sub-hourly (15 minutes) and RT GNSS data processing

➤ **Climate research**

- Expedition „**MOSAIC**“
- **GRUAN**: equipment of GRUAN sites with GNSS
- Re-processing (on-going)

➤ **Format issues:** Implementation of NetCDF

Thank you very much!

