GNSS Data Processing at GFZ

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Global Navigation Satellite Systems (GNSS)

Position determination by range measurements to each satellite:
Global Navigation Satellite Systems

GPS (USA): 31 satellites, fully operational

GLONASS (Russia): 24 satellites, fully operational

Galileo (EU): currently 18 satellites, 13 operational satellites

BeiDou (China): currently 21 satellites (3 MEO satellites)

Soon more than 100 satellites in the sky -> higher accuracy
Result of GNSS data analysis: Zenith Total Delay (ZTD) with mm-accuracy

\[ \text{ZTD} = \text{ZHD} + \text{ZWD} \]

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

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

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

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

Atmosphere Sounding with ground-based GNSS

Converted Precipitable Water Vapor (PWV)
Why GNSS-derived PWV?

- locally high resolution in space and time
- all-weather capability
- high accuracy (1-2 mm PWV): comparable with meteorological instrumental measurements, like RS, WVR
- long-term stability, continuous time series (for climate research)
Operational Water Vapor Monitoring at GFZ

- Automatically processing of hourly GNSS with GFZ EPOS Software since 2000
- ~ 500 stations in NRT processing in (German SAPOS + EUREF + global IGS)
- ZTD/PWV with 15 min. time resolution
- STD with 2.5 min. time resolution

Operational use of GFZ ZTD data by several European meteo services for weather forecast (e.g. MeteoFrance, UKMet Office)
GFZ Participation in European Meteo Projects

EUMETNET GPS Water Vapor Programme
20 Analysis Centres in Europa
(10 operational)
More than 4000 GNSS stations

Statistics GFZ processing July 2016

97% reliability (90% required)
(from E-GVAP Web)
Operational “Slant Delays” Processing

EPOS software feature: automatic processing of ~100 000 “slants” per hour (in case of “global” solution with ~500 stations)

Delivering to DWD for the assimilation tests for NWP

“Slant delays”, derived from German SAPOS network
Positive Impact of Slants Assimilation on Rain Forecast

DWD results for 28 May 2014, 1:00 UTC, 0:00 UTC forecast, 1 mm/h threshold

Control experiment

Radar observations

'Slants' assimilation

Courtesy: M. Bender (DWD)
Monitoring network

E-GVAP (EUMETNET GPS Water Vapor)
EU-COST Action: GNSS4SWEC

GFZ TERENO: TERrestrial ENvironmental Observatories

Assimilation in the numerical weather models

GWV trends for climate research

Meteo Campaigns: DESERVE (atmospheric and climate research)

GRUAN: GCOS Upper Air Network (climate research)
GNSS Data Handling at GFZ


GFZRNX toolbox (Th. Nischan): metadata/data editing, splicing, splitting, converting
GFZ GNSS Global Network

[Map image showing global network of GNSS stations with markers at various locations around the world.]

2014 Oct 21 11:08:12
GFZ GNSS Operational Data Centre

GNSS sites operated by GFZ

- 21 stations @ IGS International GNSS Service, 6 core stations
- 20 stations @ MGEX Multi-GNSS EXperiment
- 15 stations @ GRAS GNSS Receiver for Atmospheric Sounding within MetOp
- 02 stations @ EPN EUREF Permanent Network
- 04 stations @ ESA European Space Agency: Galileo Experimental Sensor Stations
- 05 stations @ GRUAN GCOS Reference Upper Air Network
Global GNSS Network in NRT Processing for PWV

RTT_GLOBAL Station Network for DOY 2016–335

1. set of stations: (#476)
  2016_305_07_sta_select_prep

2. set of stations: (#468)
  2016_305_07_sta_select_data

3. set of stations: (#99)
  2016_305_07_sta_select_base
GFZ EPOS Software (PPP strategy):

Part 1 - Network orbit improvement:
- Adjustment of precise orbits & clocks
- Global network: ~80 IGS + German sites
- Input orbits: GFZ 3h Ultra Rapid (pred.)

Part 2 - PPP Analysis:
- Estimation of trop. parameters
- Large set of parameters possible: high sampling rate, ZTD/PWV/STD/Gradi

Processing time (LINUX PC):
<15 min for more than 500 sta

Product generation (conversion to PWV)
Product distribution
Overview of GNSS Processing at GFZ for PWV

**NRT processing:**
- GF1R “rapid” solution for E-GVAP (about 360 stations)
- GF1G “global” solution for E-GVAP (about 460 stations)
- GRUAN processing (delay > 1h)

**TIGA reprocessing project of IGS (finished):**
- about 800 globally distributed TIGA stations
- 19 years data span
- ZTD products are available at GFZ ftp

**Reprocessing for climate applications (on-going):**
- German SAPOS + global IGS + GRUAN network
- about 600 stations in processing
- more than 15 years data span
- ZTD/PWV products both in COST and TRO-SINEX format, available at GFZ ftp
- other products are also available: gradients, slants
Long term water vapor trends

- Recent consistent reprocessing
- ~800 stations
- 19 years of data (1994 - 2013)

Example:
Greenbelt (+0.94 mm/decade)

Quality of the entire data set currently evaluated
Homogenization of PWV Time Series

- Required for detecting climatic trends

- Inconsistencies in time series:
  - change processing setup → avoidable by reprocessing
  - change hardware or software of GNSS stations → not avoidable!
    → homogeneity check

- Uncertainty estimation → detect and correct inhomogeneity
GRUAN GNSS Site Lindenberg (Germany)

- GFZ site LDB0, installed 2007
- GNSS data available since 2007
- PWV NRT products available starting from 2007
- Reprocessing on-going
- Automatically hourly GNSS raw data flow and NRT analysis
- Co-located GNSS site LDB2 (operated by BKG)
GRUAN GNSS Site Ny-Alesund (Norway)

- GFZ site NYA2, installed 2011
- GNSS data available since end of 2011
- PWV products available starting from 2011
- Reprocessing on-going
- Automatically hourly GNSS raw data flow and NRT analysis
- IGS sites NYAL and NYA1 (close to NYA2)
GRUAN GNSS Site ‘Table Mountain‘ Boulder (USA)

- GFZ site TMS3, installed 2014
- GNSS data available since end of 2016
- ZTD NRT products available starting from Jan 2017
- Re-processing will be done
- Automatically hourly GNSS raw data flow and NRT analysis
• FMI/GFZ site SODF, installed Feb 2015, GFZ site software

• GNSS data available since 2015

• PWV NRT products available starting from 2017

• Reprocessing will be done

• Automatically hourly GNSS raw data flow and NRT analysis

• Another GNSS site SODA

Courtesy: Rigel Kivi (FMI)
Pittiovaara

SODA

97 m

20 km

SODF

Sodankyla

Courtesy: Rigel Kivi (FMI)
GRUAN GNSS Site Lauder (New Zealand)

- GNSS site LDRZ
- installed 2012
- GNSS data available since 2012
- PWV products available only in reprocessing mode
- Reprocessing on-going
- NO automatically hourly GNSS raw data flow and NRT analysis
Future Work

GNSS data processing:
- Reprocessing 2000-2016 (about 600 sites, including GRUAN)
- PWV time series homogenisation and trend analysis
- PWV uncertainty estimation

GRUAN sites:
- GNSS site in NSA-C1 site of Barrow: installation of GNSS test equipment (July 2017)
- Payerne (Switzerland), Cabauw (Netherlands) and Potenza (Italy): GNSS data flow and processing at GFZ (in progress)
- Dolgoprudny (Russia): negotiations on GNSS data flow and processing via GFZ
- Singapore (Singapore) and Tateno (Japan): GFZ contacted these sites
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Many thanks for your attention!