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RESEARCH FOR GRAND CHALLENGES

MULTI-GNSS ACTIVITIES FOR ATMOSPHERE SOUNDING AT GFZ

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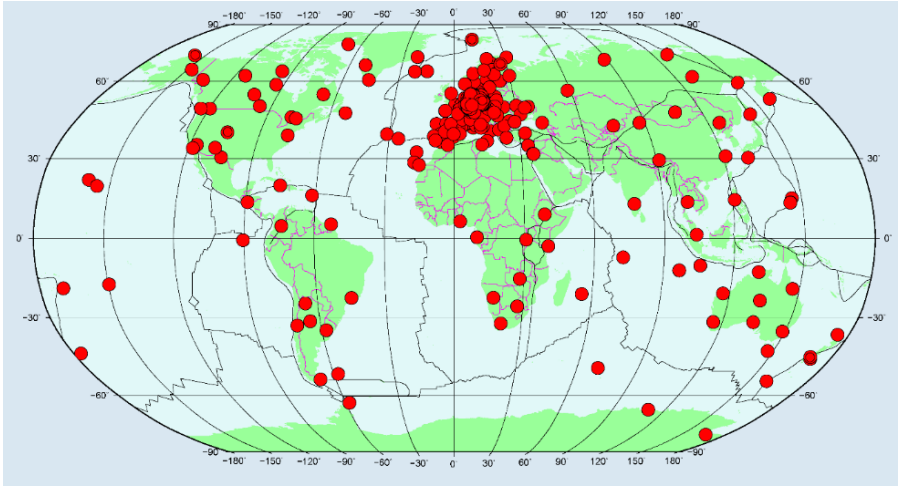
GFZ German Research Centre for Geosciences
Potsdam, Germany

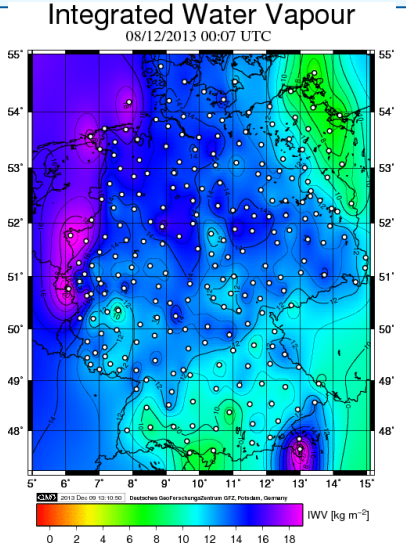
IGS Workshop, Oct 29 - Nov 2, 2018, Wuhan, China

Operational ATMO Monitoring at GFZ

- Automatic processing of **hourly GPS** data since 2000
- GFZ EPOS software, PPP mode, GFZ orbits and clocks
- ~600 stations in processing (German SAPOS + EUREF + IGS + GRUAN)
- Products: ZTD/IWV with 15 min. time resolution, STD with 2.5 min. time resolution, hourly gradients
- Time delay < 30 minutes after the end of each hour (**near real-time**)
- Accuracy: ~1-2 mm IWV



Zenith Total Delay
Precipitable Water
Slant Total Delay
Gradients

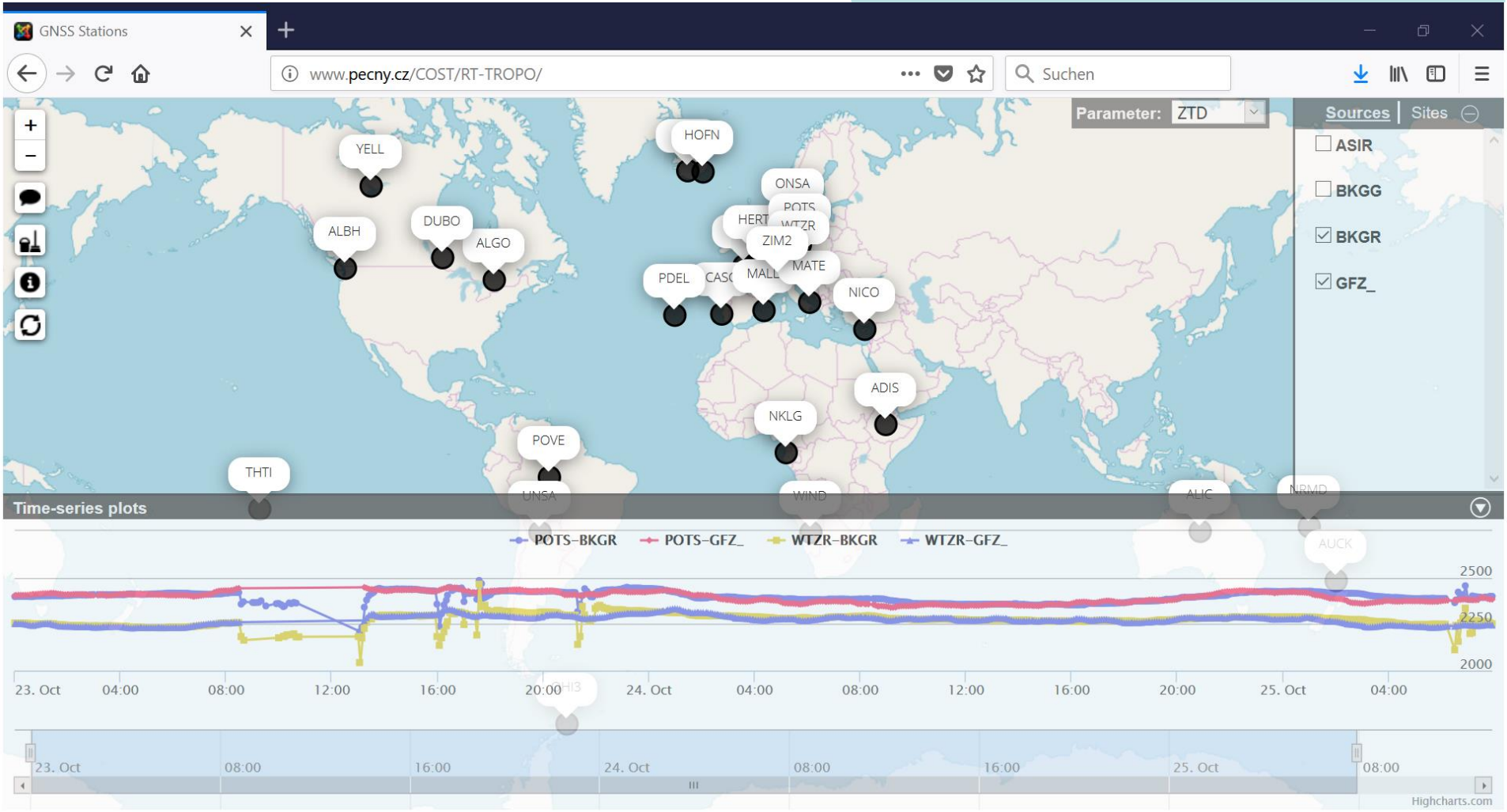


Orkan Xaver, Germany, December 2013

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

Real-Time ZTD Processing at GFZ (EPOS-RT)

Monitoring at: http://www.pecny.cz/COST/RT-TROPO



RT Demonstration Campaign of EU COST Action GNSS4SWEC
(Start 2015, monitoring at GOP)

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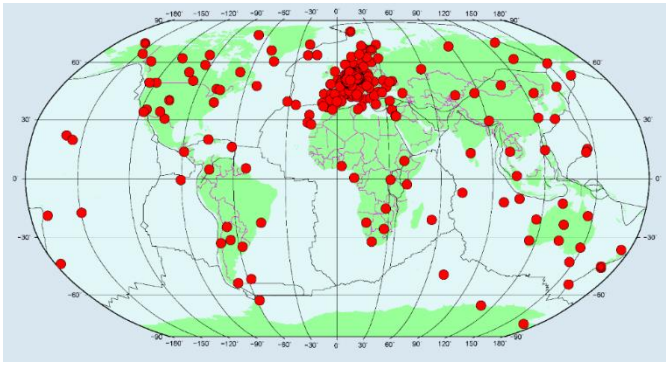
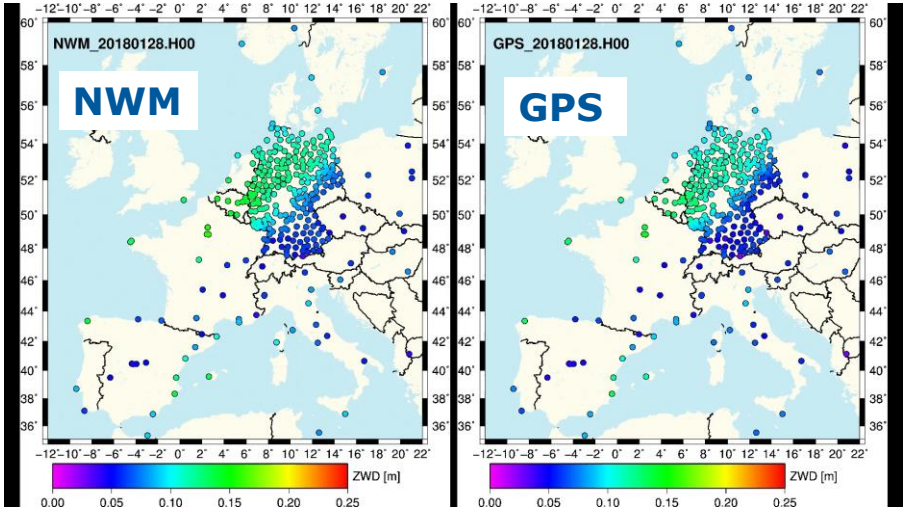
GFZ ATMO Activities/Projects

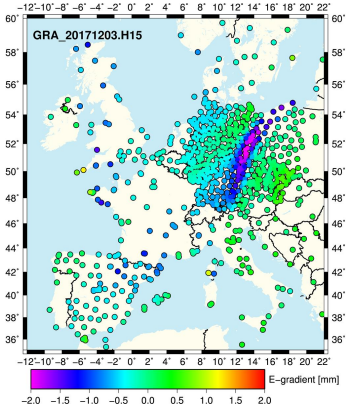
Monitoring Network



NRT/RT

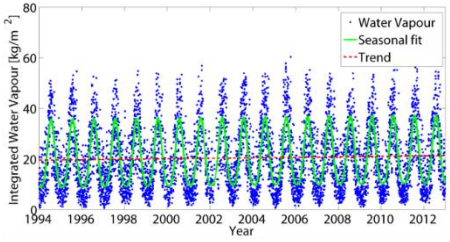


REPRO



Operational monitoring and investigations of **horizontal gradients** (talk by M. Kačmařík)

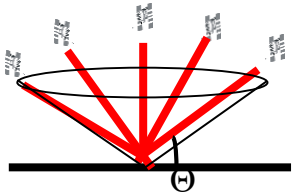
Climate Applications



IWV trends

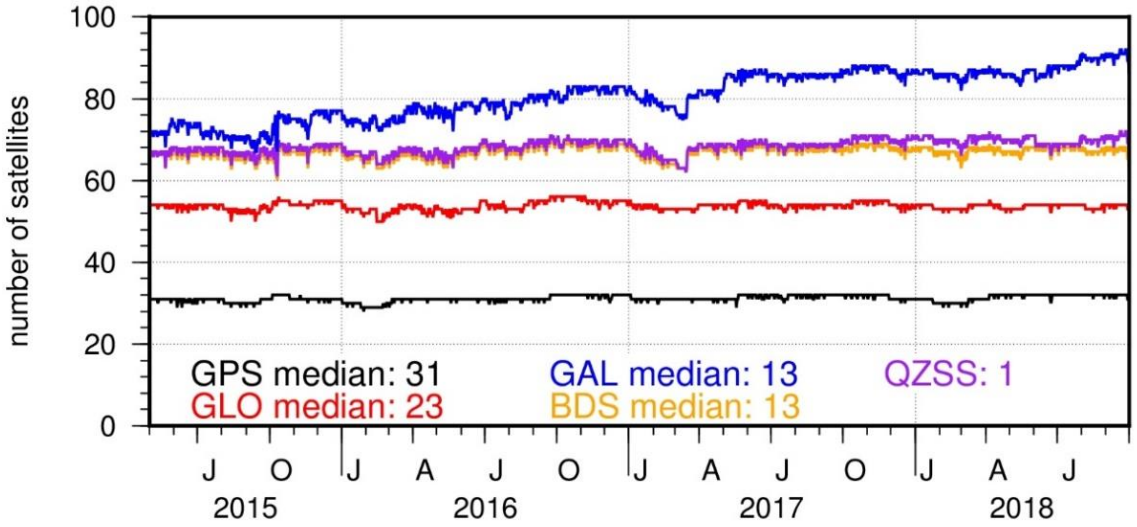
GRUAN

GCOS Reference Upper Air Network (talk by J. Wang)



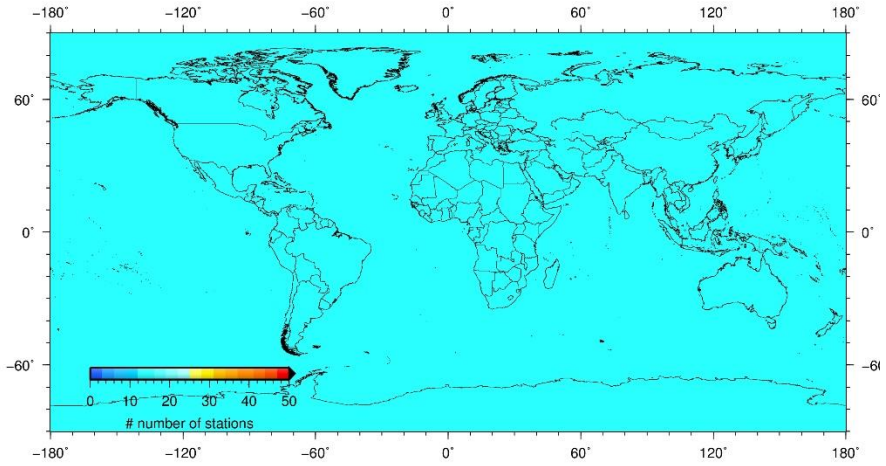
Operational processing of **Slant Total Delays**, assimilation studies with German Weather Service DWD

MGEX Activities at GFZ

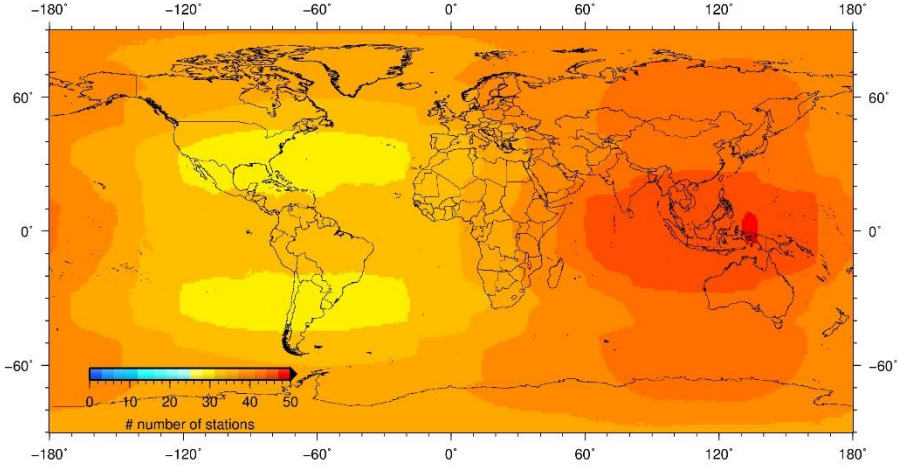


Since 2015 GFZ MGEX AC provides ultra-rapid products for five satellite systems GPS/GLO/GAL/BDS/QZSS

GPS only



GPS/GLO/GAL/BDS/QZSS



Satellite coverage map for September 8, 2018

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ftp://ftp.gfz-potsdam.de/GNSS/products/mgex/

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European Union COST Action GNSS4SWEC

„Advanced GNSS Tropospheric Products for Monitoring Severe Weather Events and Climate“

Chair: J. Jones (UK MetOffice); co-chair: G. Guerova (Uni Sofia, Bulgaria)

2013-2017

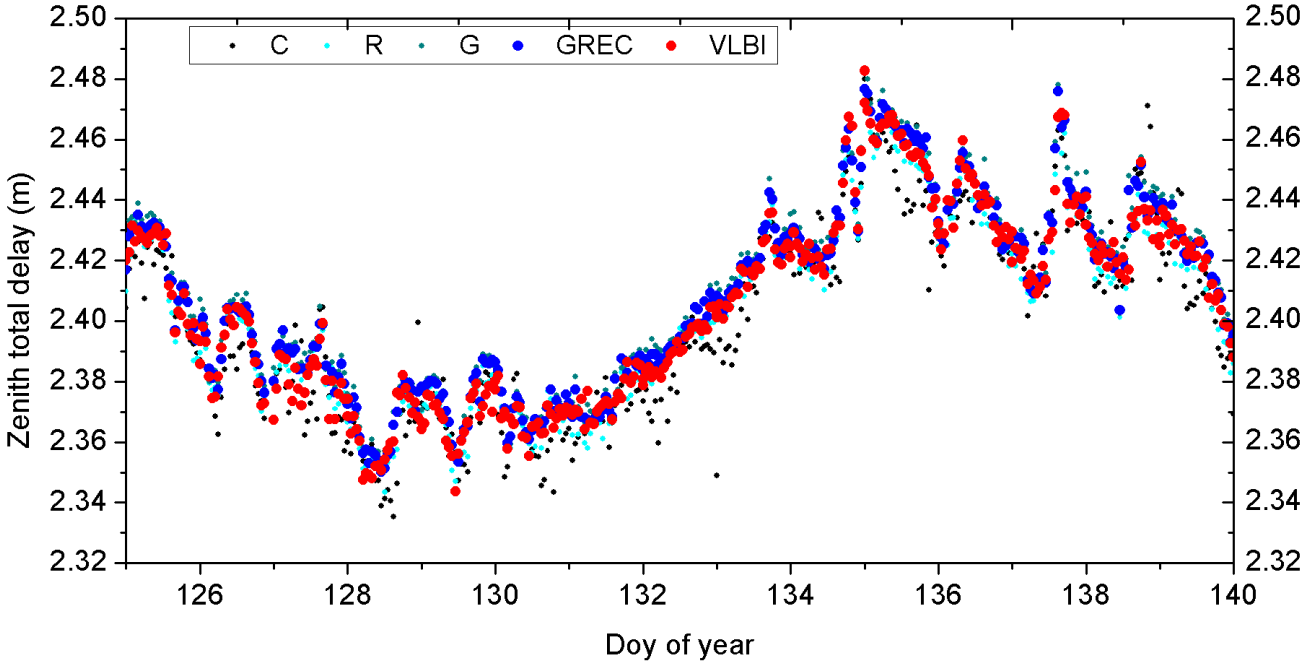
29 European countries / 5 non-EU partners / more than 160 participants

Working Group 1: Advanced GNSS processing techniques

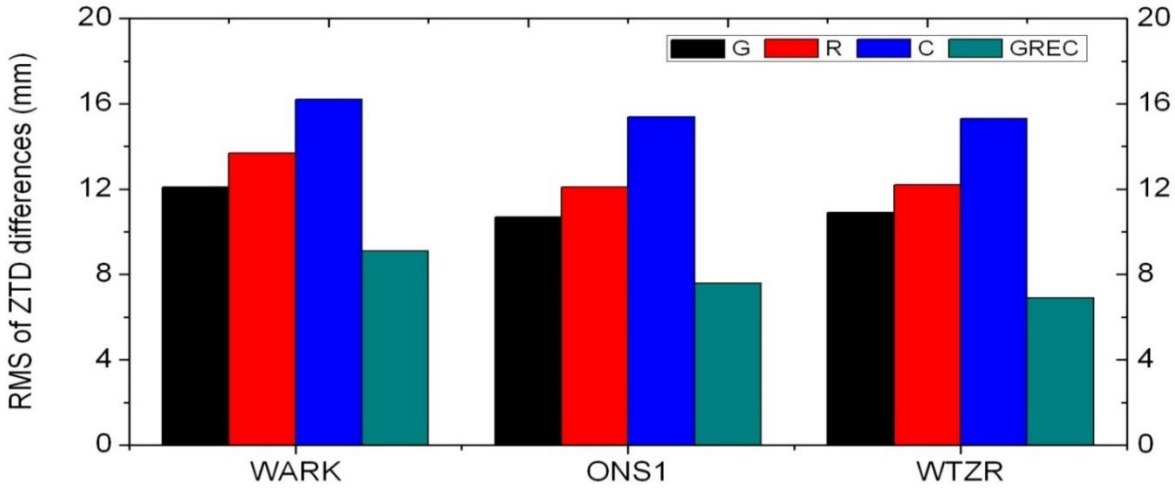
Advanced Tropospheric Products:

- ‘slant total delays’ (STDs) and gradients
- ‘ultra-fast’ and real-time tropospheric products
- Multi-GNSS: GPS / GLO / GAL / BDS

Multi-GNSS ZTD: Validation with VLBI



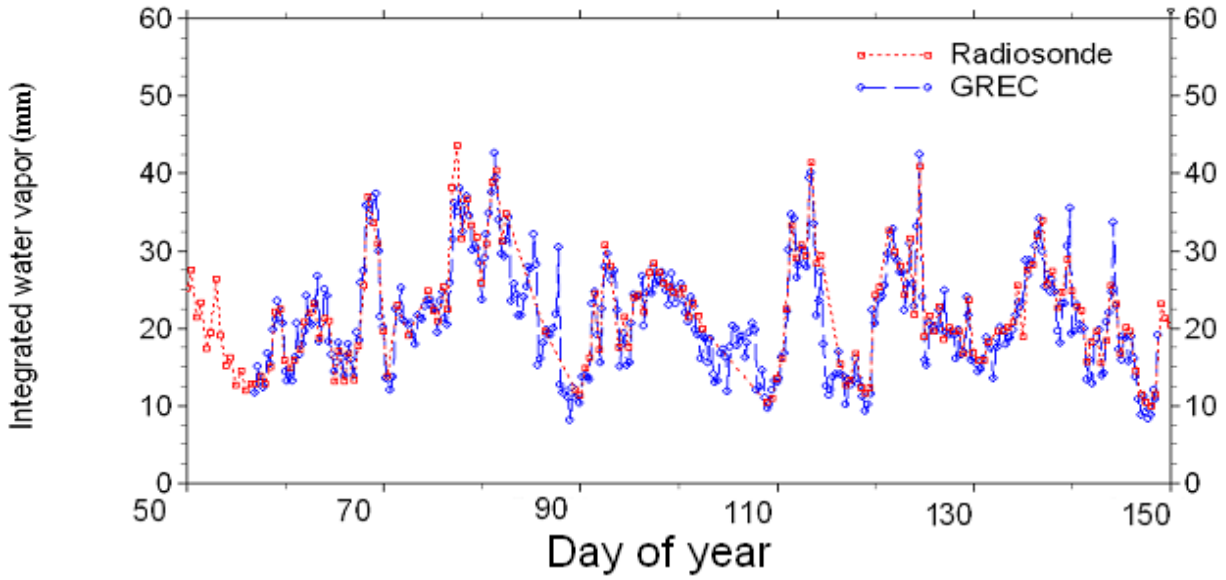
Station Onsala, Sweden



Li et al., JGRA, 2015

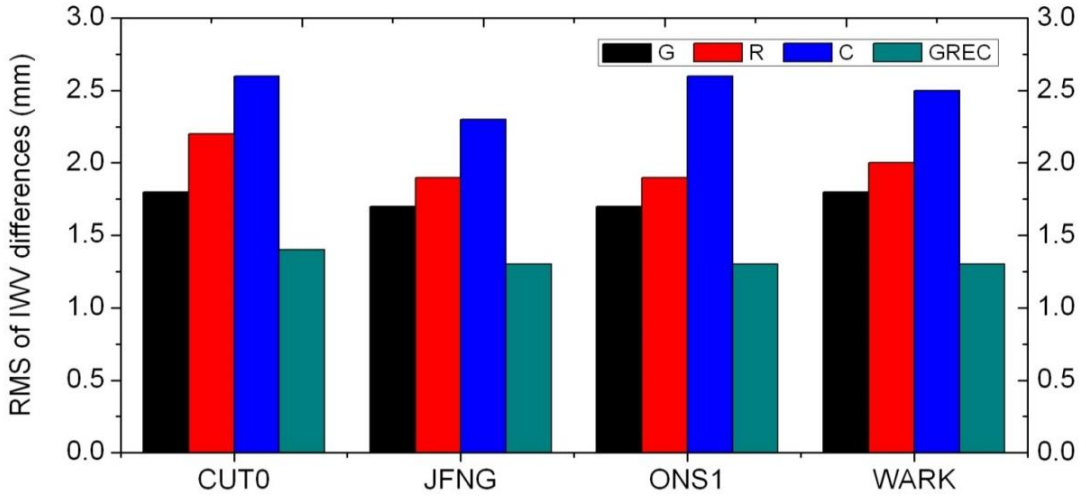
Multi-GNSS ZTD from simulated RT data: validation with VLBI for stations WARK, ONS1, WTZR (May 2014, CONT14 VLBI campaign)

Multi-GNSS IWV: Validation with Radiosondes



Station Curtin (CUT0), Australia

2014



Li et al., JGRA, 2015

Multi-GNSS IWV from simulated RT data: validation with RS for stations CUT0, JFNG, ONS1, WARK (Jan-June 2014)

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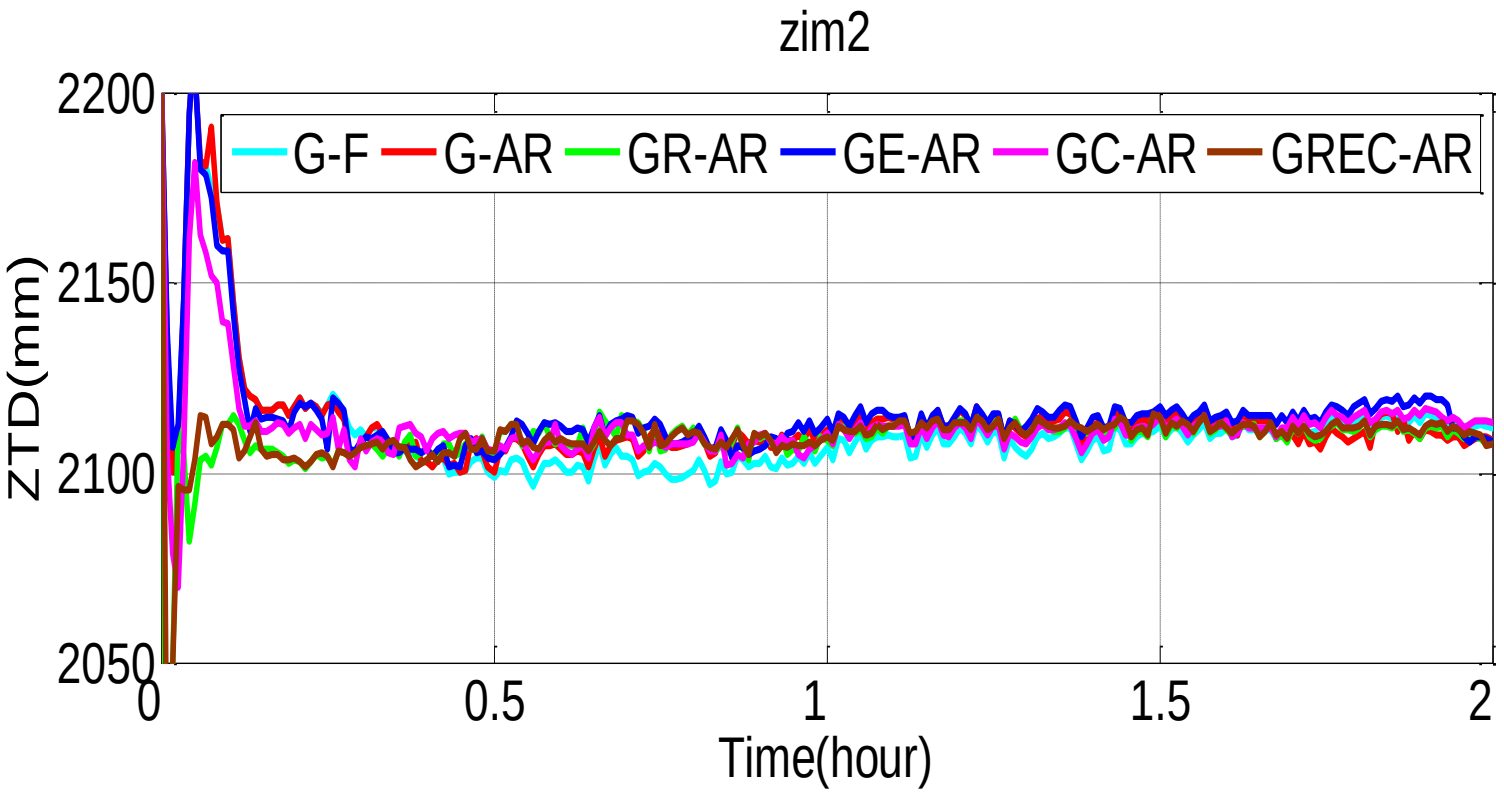
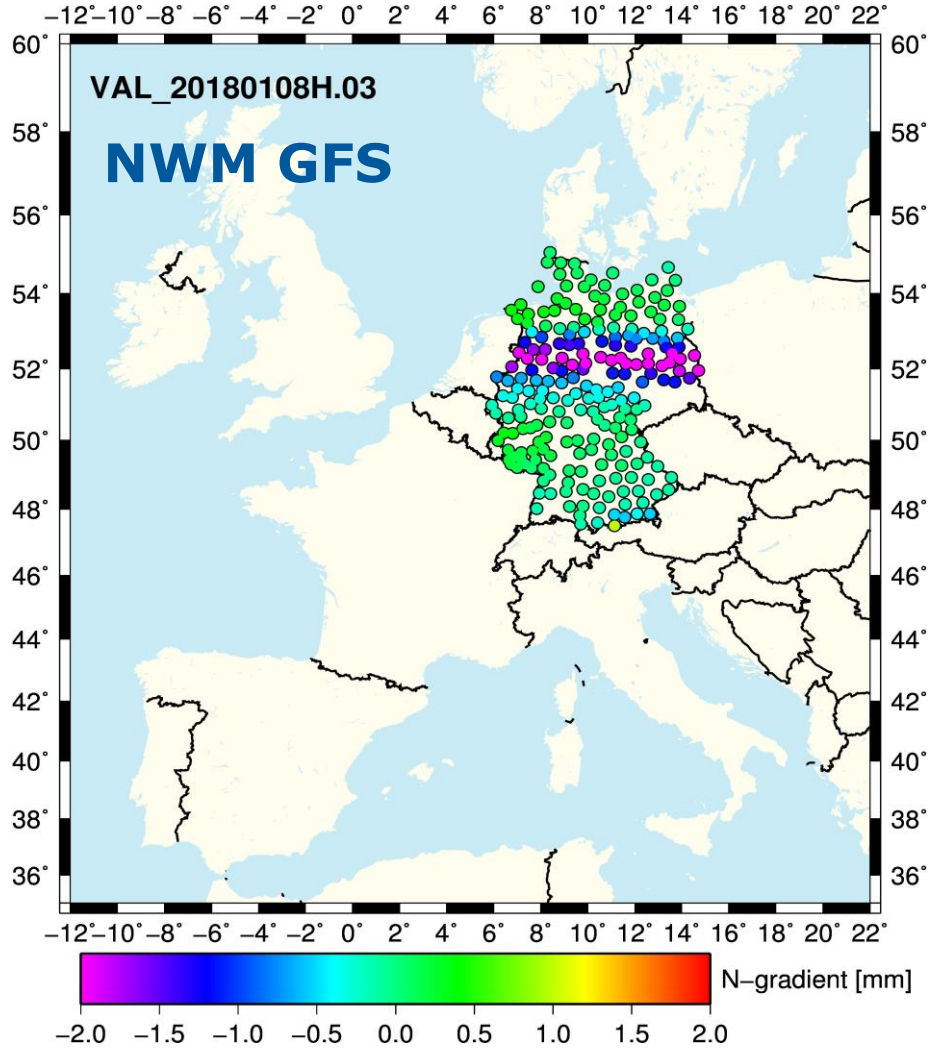
Multi-GNSS RT ZTDs: Convergence Time

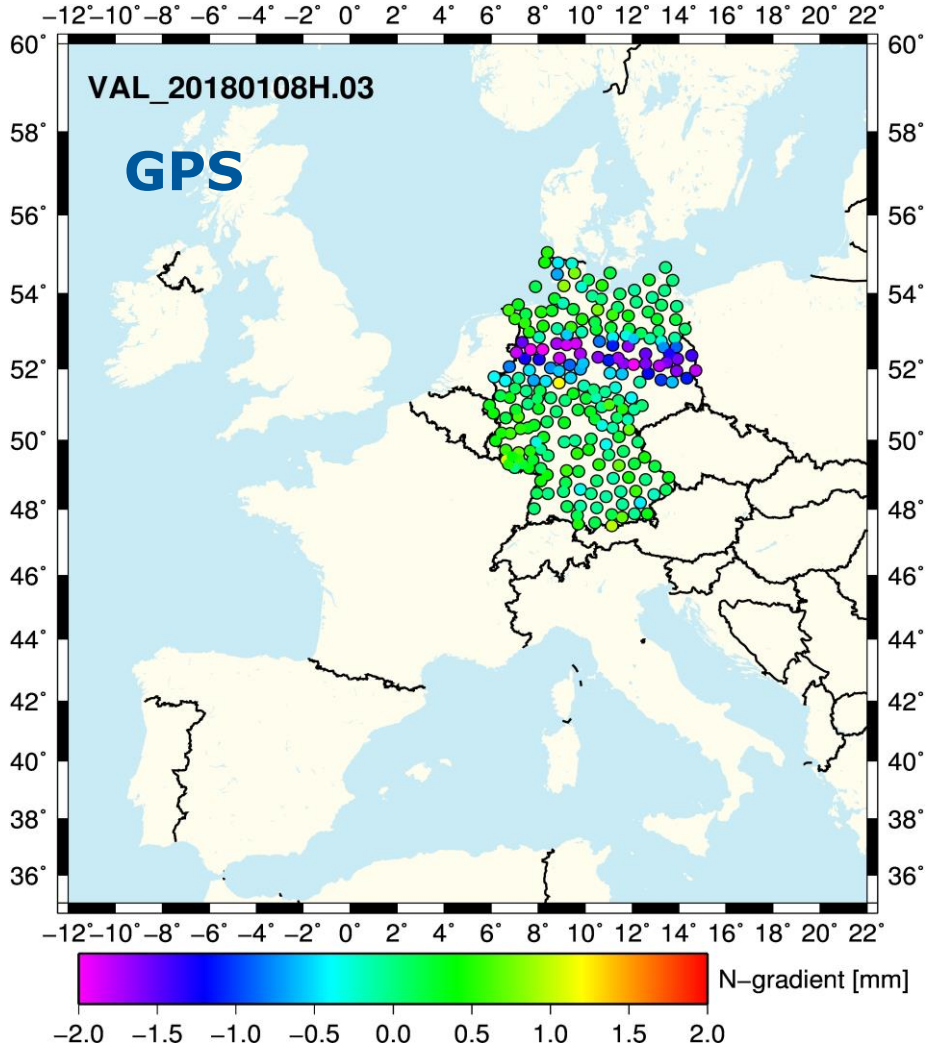


Real-time ZTDs of station ZIM2 (Jan 3, 2017)

Improvement of convergence time of RT ZTDs by multi-GNSS processing compared to GPS-only

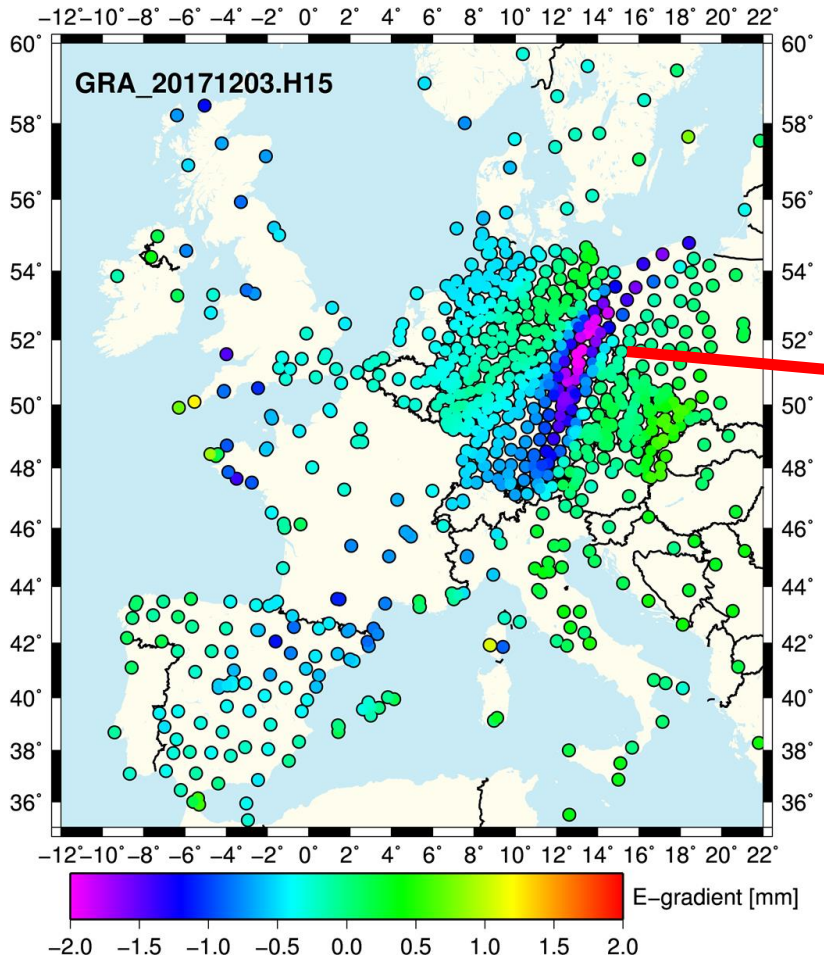
Comparison of horizontal gradients from GPS with Numerical Weather Model GFS



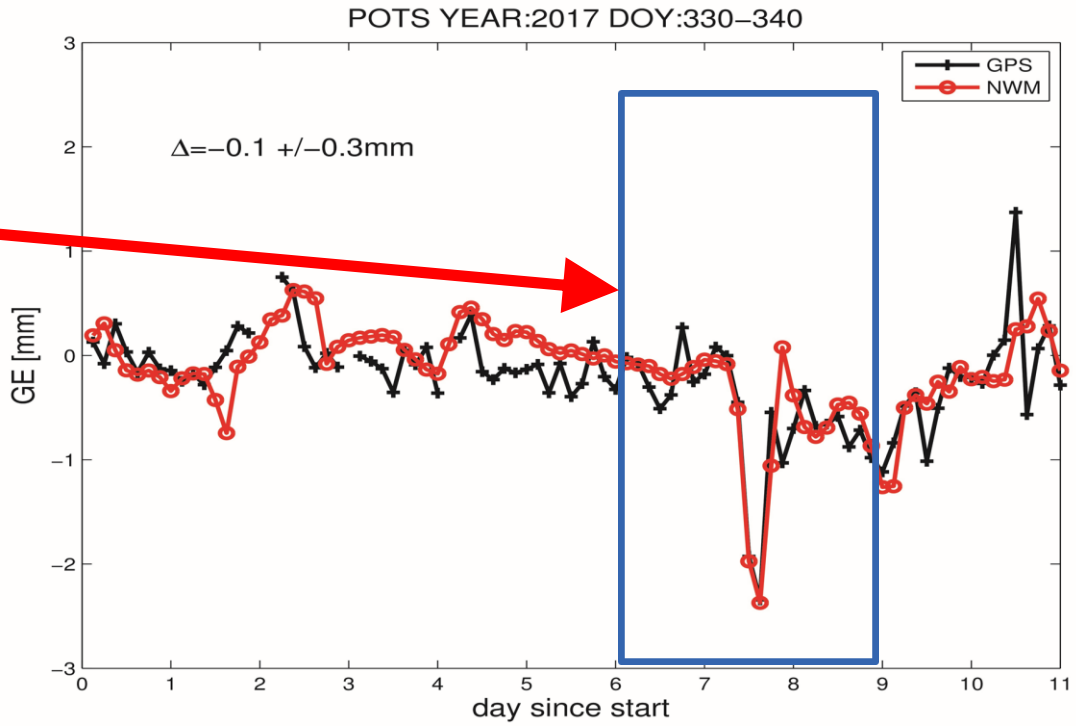


NWM & GPS horizontal gradients show a good agreement

Operational Monitoring of Gradients

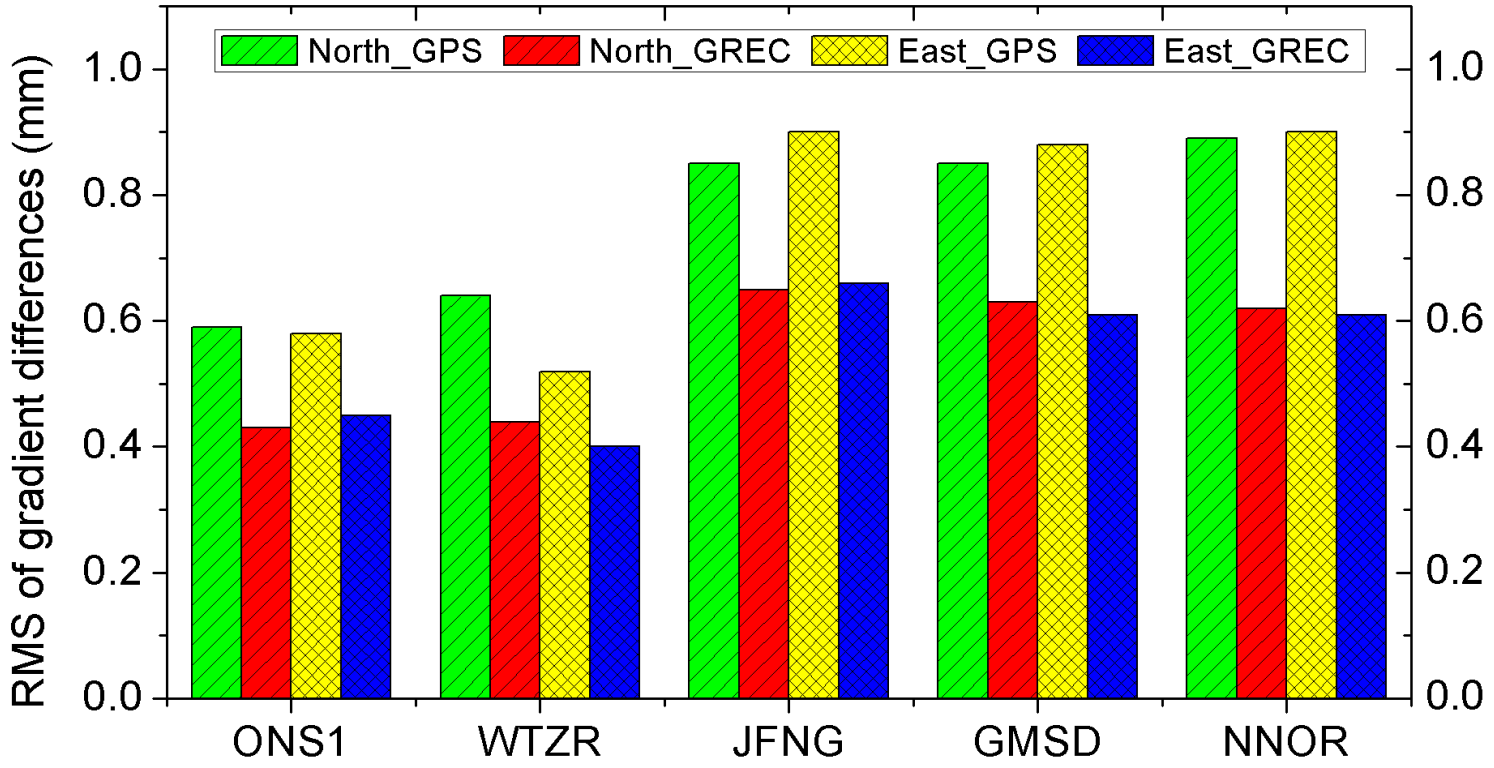


Example of strong tropospheric East-gradients caused by weather front in Germany on December 3, 2017



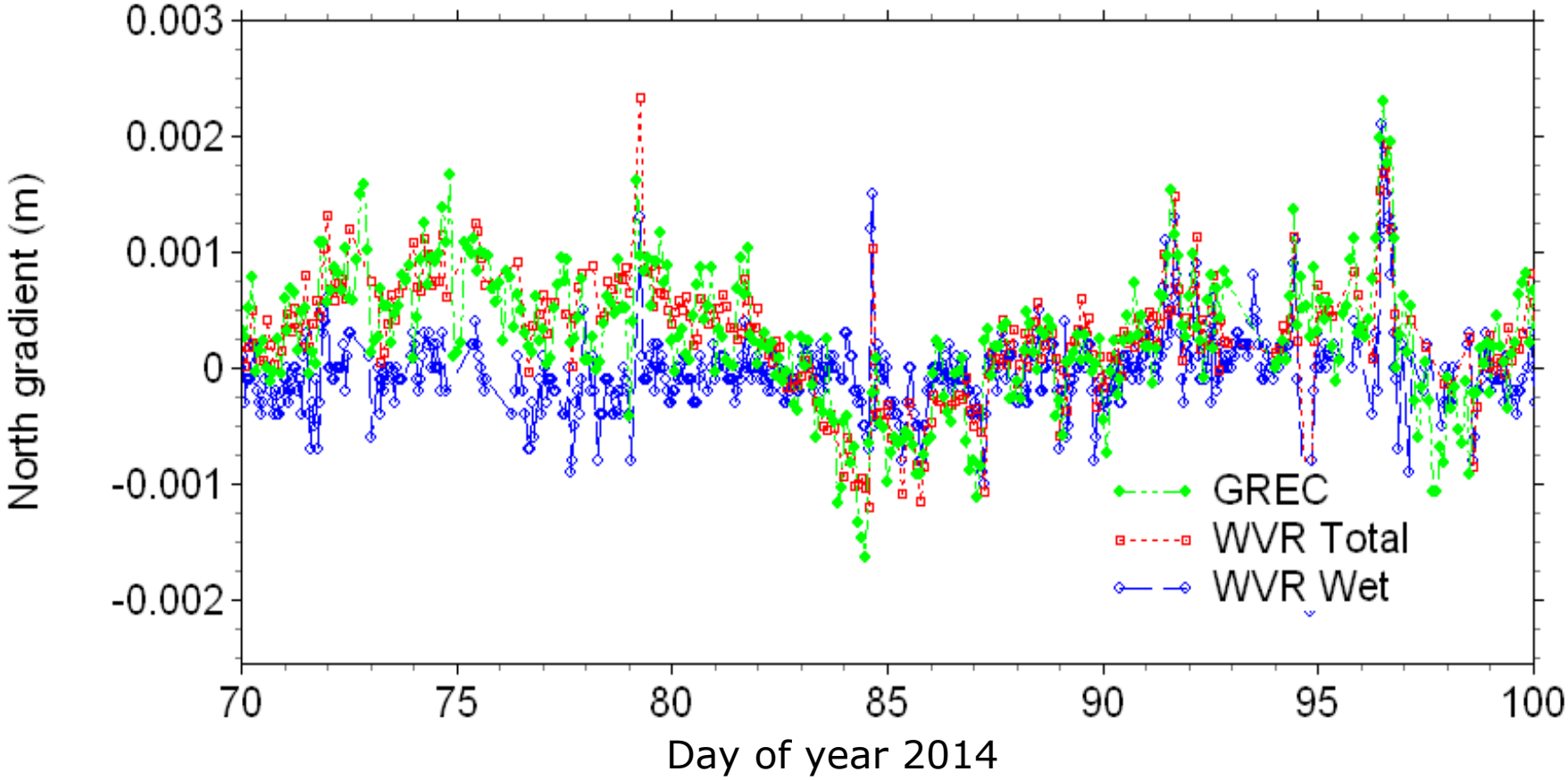
Excellent agreement of East-gradients from GPS with GFS NWM for station Potsdam, Germany

Multi-GNSS High-resolution Tropospheric Gradients



Validation with tropospheric gradients from the NWM of the ECMWF (European Centre of Medium range Weather Forecast) January-June 2014

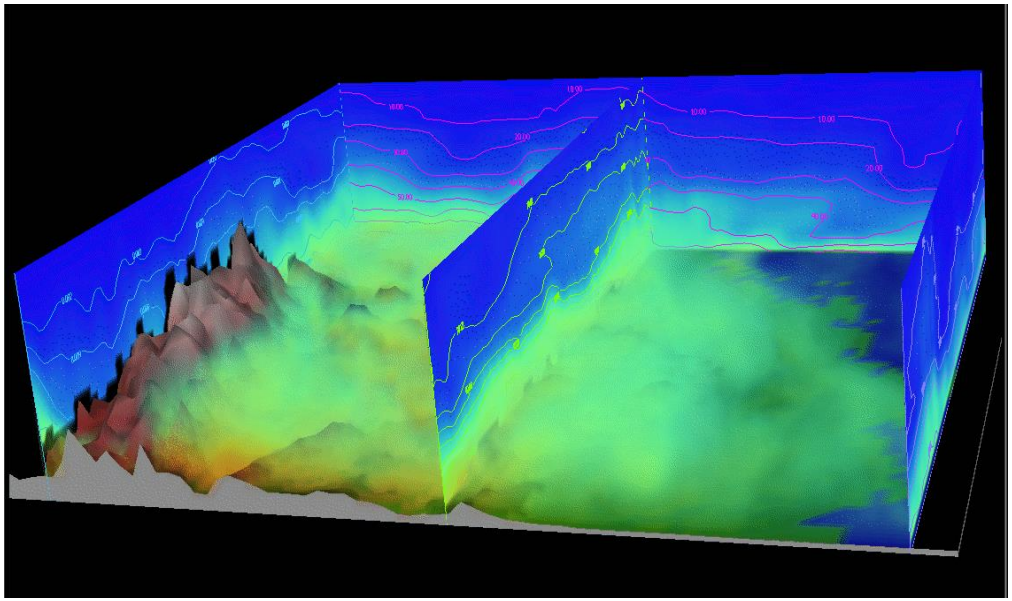
Multi-GNSS High-resolution Tropospheric Gradients



Validation with instrumental measurements of Water Vapour Radiometer for station Onsala, Sweden

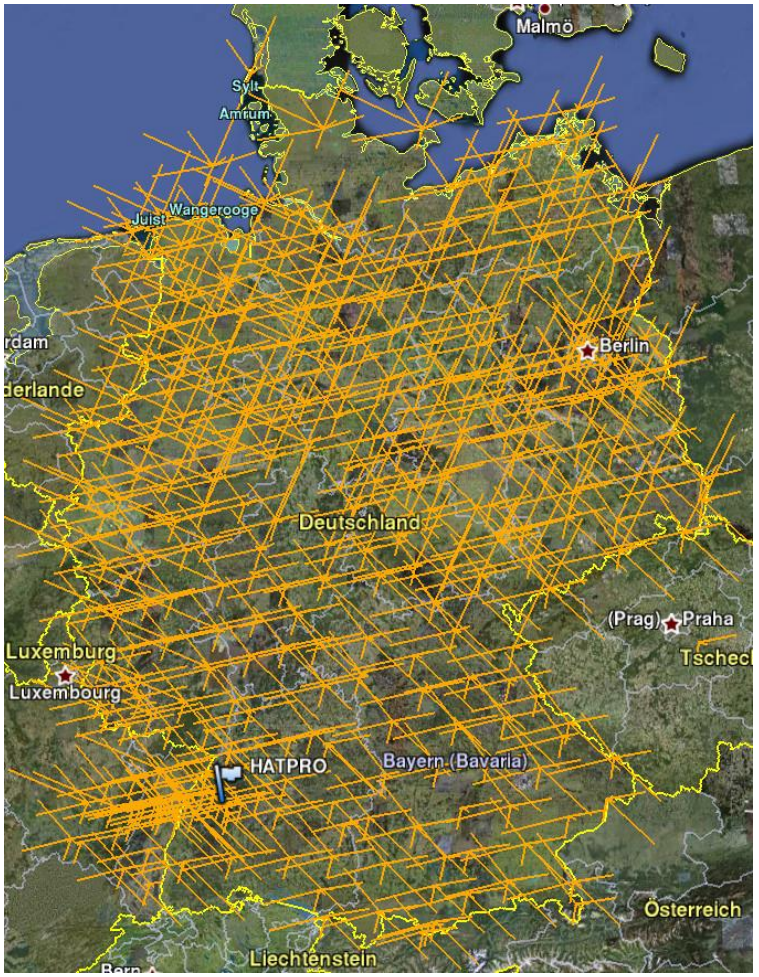
(RMS: ~20% improvement)

Operational “Slant Delays” Processing



3D Water Vapour Tomography over Germany

- Automatic processing of ~100000 “slants” per hour in case of global network with ~600 stations
- Delivering to German Weather Service DWD for pre-operational assimilation

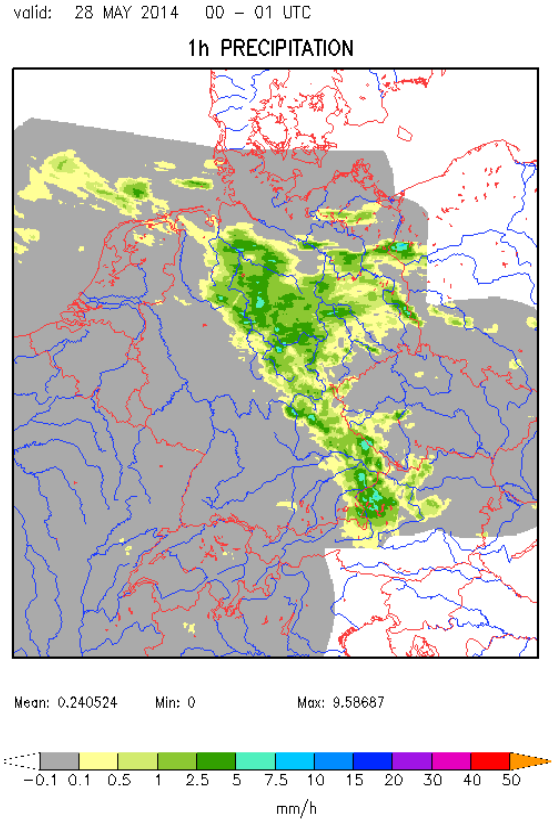


“Slant delays”, derived from German SAPOS network

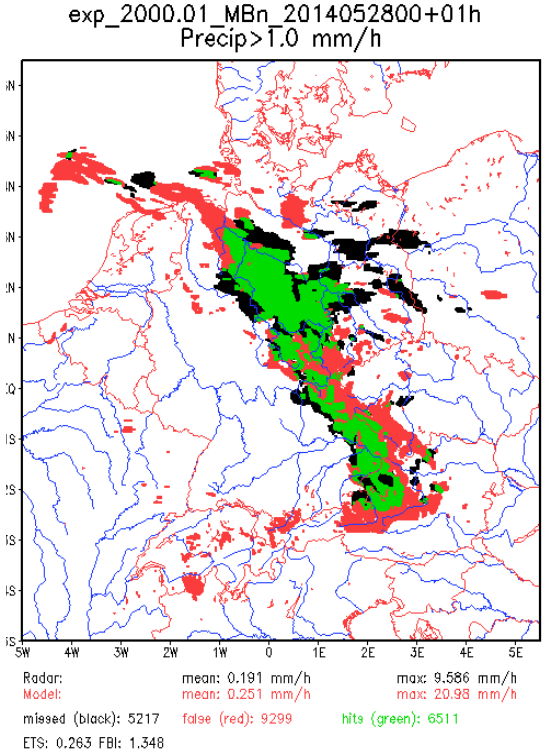
Precipitation Forecast (DWD results)

28.5.2014, 1:00 UTC, 0:00 UTC forecast

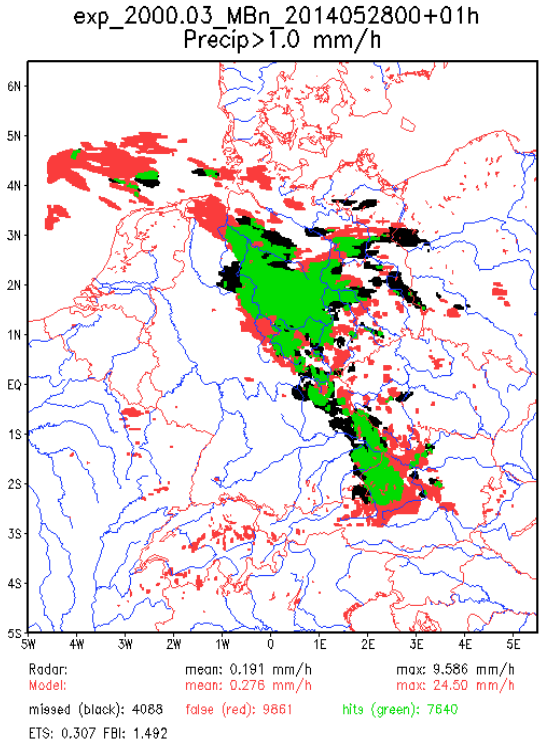
Radar observations



control experiment



STD assimilation



~20% improvement of precipitation forecast

by assimilation of GPS slant data

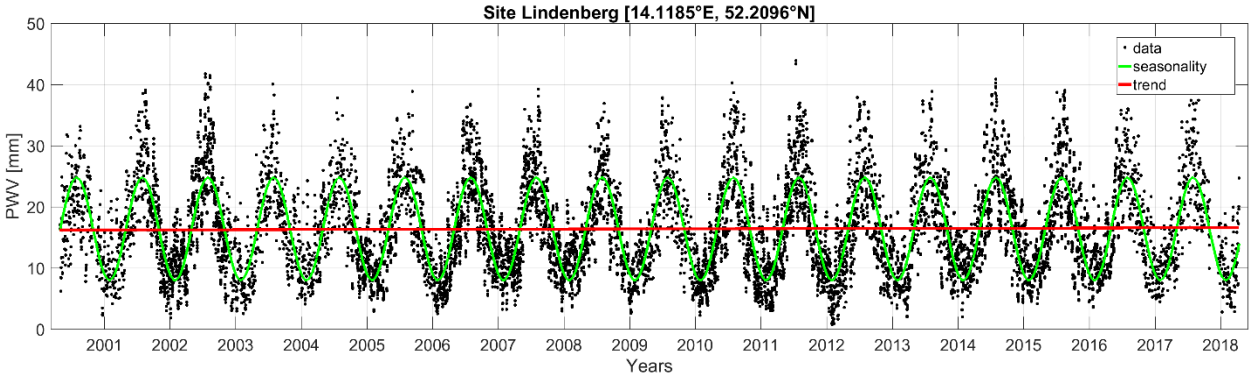
Thanks to C. Schraff/M. Bender (DWD)

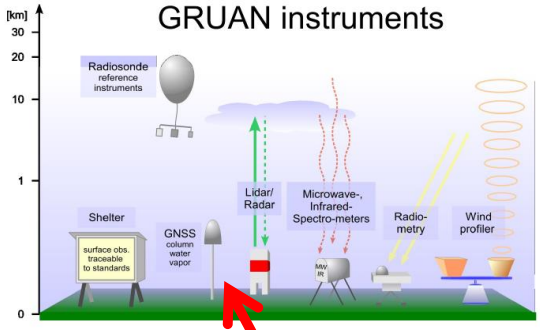
IWV Trends for Climate Research

IWV with mm accuracy

Long term IWV trend analysis for climate research

GNSS is priority number one technique for IWV monitoring





GNSS

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

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

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Alshawaf et al., JGR, 2018

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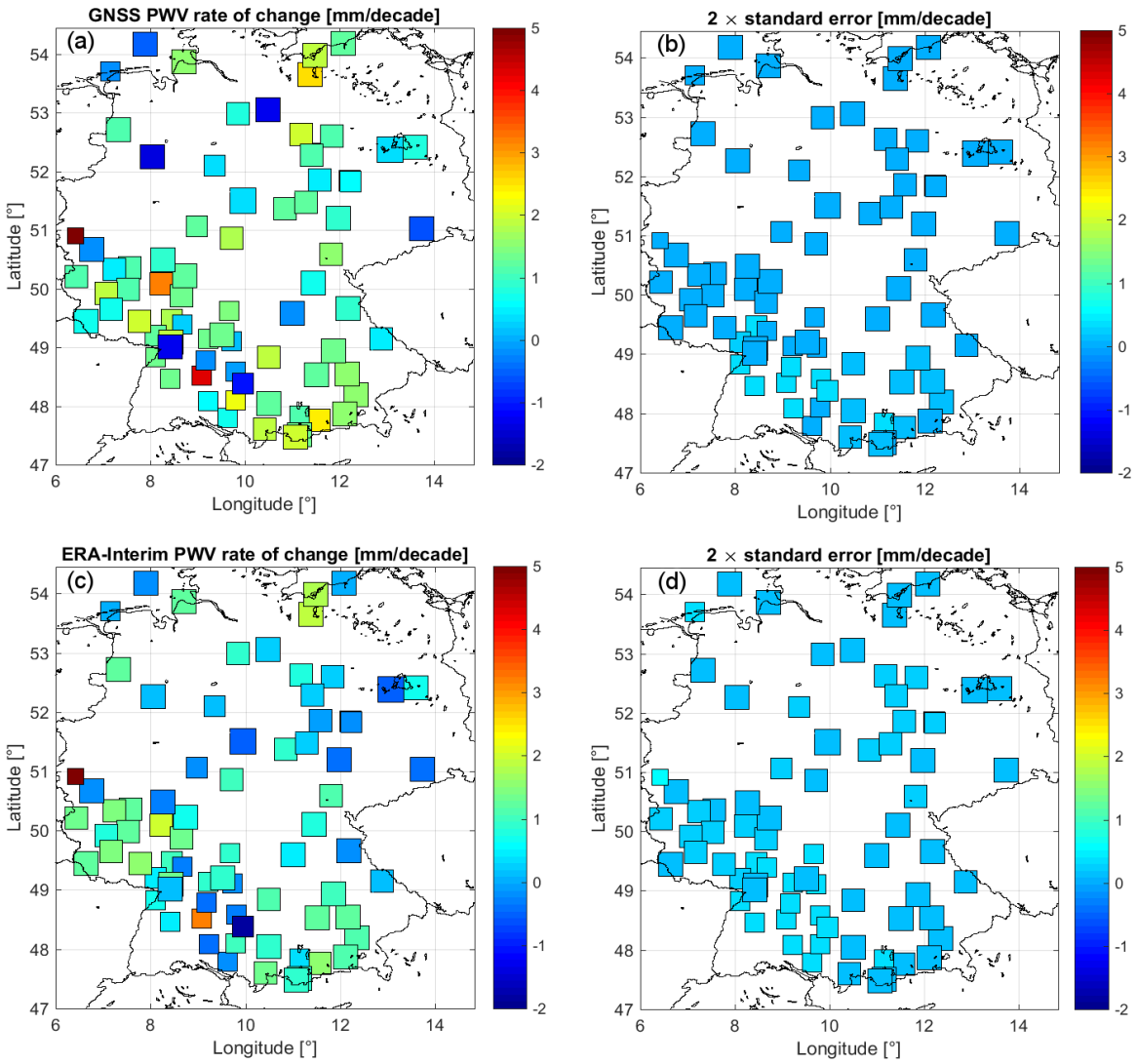
IWV Trends Estimation for Germany

GPS

Length of time series:
10-19 years
119 stations

Model ERA-Interim (ECMWF)



Marker size is proportional to the length of time series

Alshawaf et al., AMT, 2017

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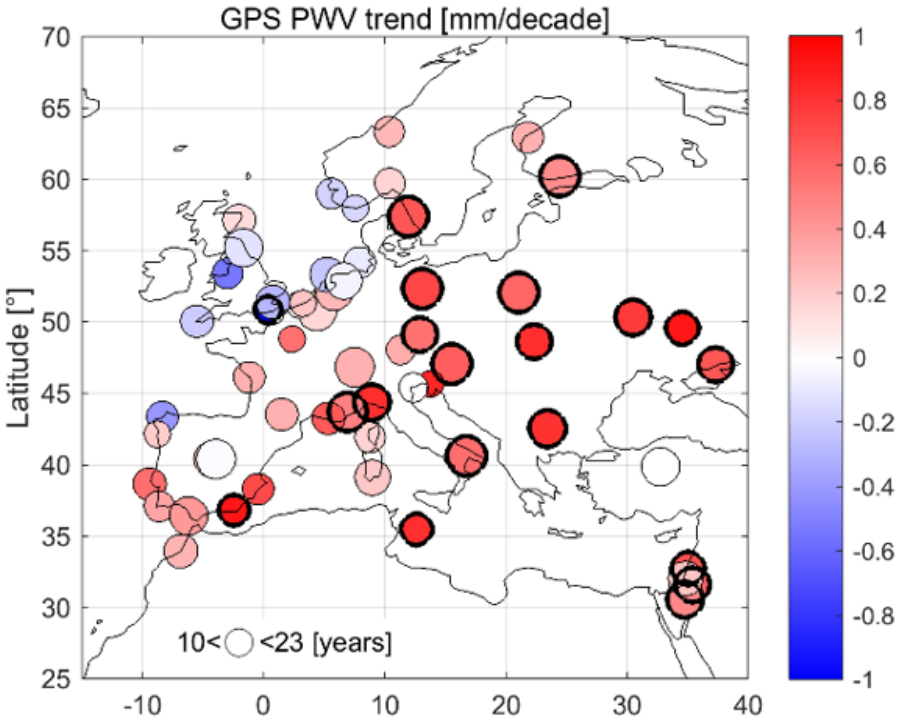
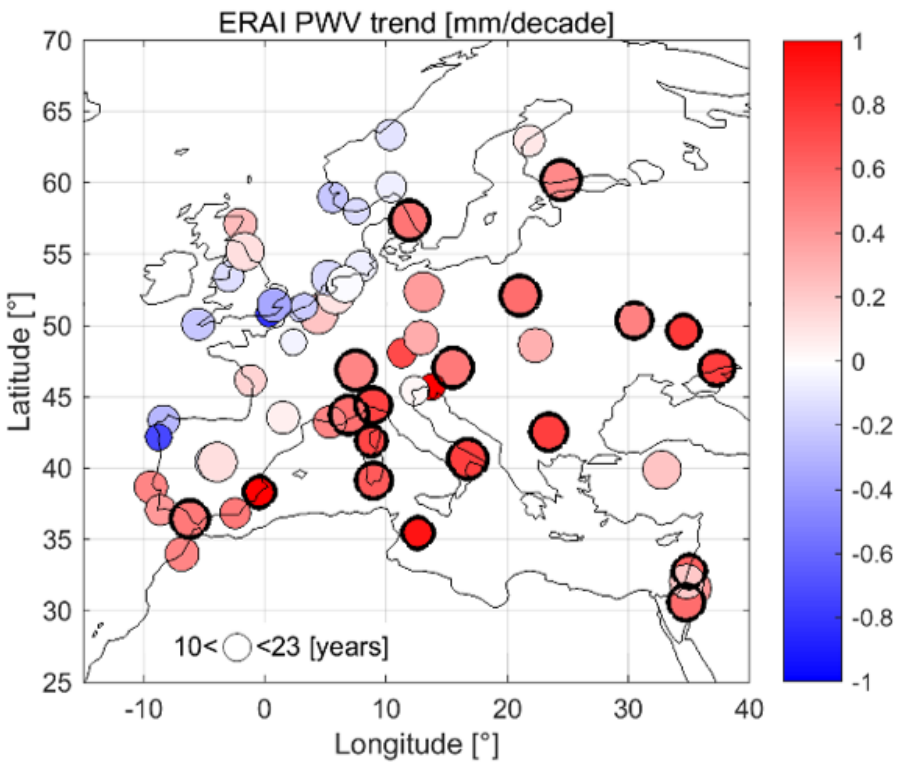
IWV Trends Estimation for Europe





GPS

Model
ERA-Interim

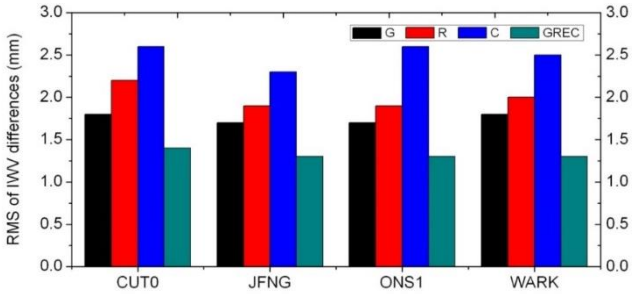
Length of time series 10-23 years

Alshawaf et al., JGR, 2018

Summary

Multi-GNSS for atmospheric research

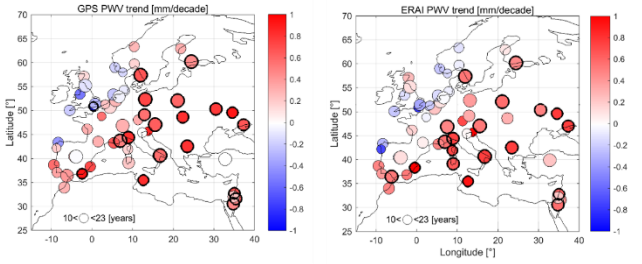
- Higher accuracy of multi-GNSS ZTD/IWV, gradients and slants, especially in RT
- Improvement of convergence time of RT ZTDs



Li et al.: Retrieving high-resolution tropospheric gradients from multiconstellation GNSS observations, Geophys Res Lett (2015)
Lu et al.: Real-time retrieval of precipitable water vapor from GPS and BeiDou observations, J Geodesy (2015)
Li et al.:. Retrieving of atmospheric parameters from multi-GNSS in real time: Validation with water vapor radiometer and numerical weather model, JGR Atm (2015)
Li et al.: Multi-GNSS meteorology: Real-time retrieving of atmospheric water vapor from BeiDou, Galileo, GLONASS and GPS observations. IEEE Transactions (2015)
Lu et al.: Estimation and evaluation of real-time precipitable water vapor from GLONASS and GPS, GPS Solutions (2016)
Lu et al.: Real-time tropospheric delay retrieval from multi-GNSS PPP ambiguity resolution: Validation with final troposphere products and numerical weather model, Remote Sens (2018)

Multi-GNSS for climate research

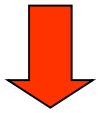
- Impact due to higher accuracy of multi-GNSS



Alshawaf et al.: Estimating trends in atmospheric water vapor and temperature time series over Germany, Atmos Meas Tech (2017)
Alshawaf et al.:On the statistical significance of climatic trends estimated from GPS tropospheric time series. Journal of Geophysical Research: Atmospheres (2018)

Outlook and Conclusions

- Multi-GNSS will provide many benefits for atmosphere sounding
- Performance of multi-GNSS processing will be further improved:
  - launch of more satellites
  - further improvement of satellite systems (e.g. BDS-3)
  - setup of more multi-GNSS stations



Goal: move IGS to full multi-GNSS service

- Continue to update IGS sites to multi-GNSS
- Provide combined multi-GNSS products

Many thanks for your attention!