On the estimation and usage of GNSS tropospheric gradients for meteorological applications

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Horizontal tropospheric gradients

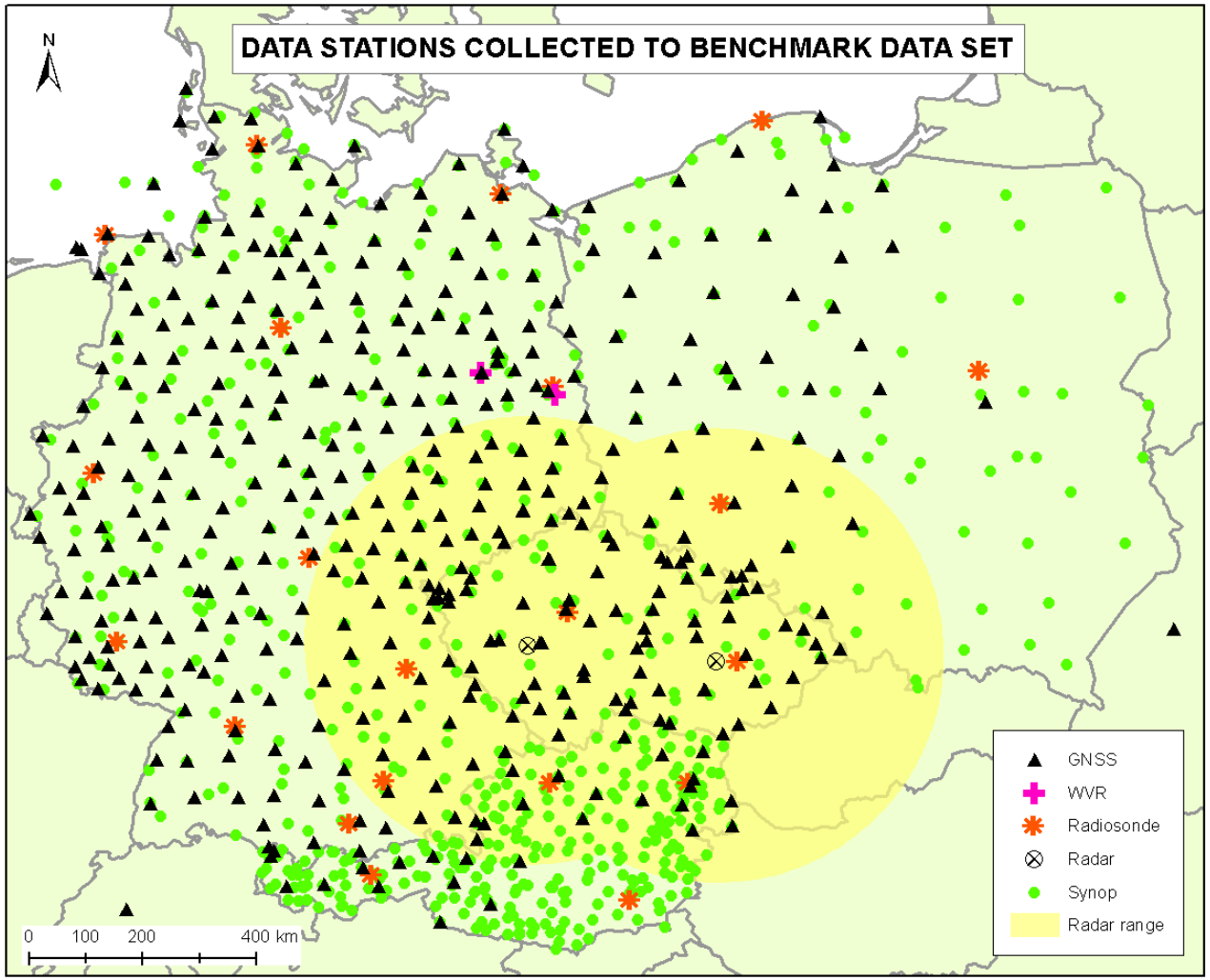
- In GNSS data processing, regarding troposphere, we usually estimate Zenith Total Delay (ZTD)

- and we (can) also get
  - *horizontal tropospheric gradient*
  - *representing the first order asymmetry of the signal delay in the azimuth direction*
  - *gradients estimation was proofed to improve receiver's position and ZTDs*

$$STD(a,e) = mfh(e) * ZHD + mfw(e) * ZWD + mfg(e) * (Gn * cos(a) + Ge * sin(a))$$

What data we used for our study?

- Benchmark data set collected within the GNSS4SWEC COST Action (2013-2017)
- central Europe
- May+June, 2013
- >430 GNSS stations



GNSS data processing

- G-Nut/Tefnut software developed at GO Pecný (Jan Douša et al.)
- PPP processing
- Kalman filter (FLT) + optional backward smoothing (SMT)
- **in total 8 variants of solution were provided for benchmark campaign to study impact of various settings on horizontal tropospheric gradients**

Solution name	Elevation cut-off	Constellation	Gradient mapping function	Products	Mode
GxCH3	3	GPS	Chen and Herring	ESA final	FLT+SMT
GRCH3	3	GPS+GLONASS	Chen and Herring	ESA final	FLT+SMT
GRBS3	3	GPS+GLONASS	Bar-Sever	ESA final	FLT+SMT
GxCH7	7	GPS	Chen and Herring	ESA final	FLT+SMT
GRCH7	7	GPS+GLONASS	Chen and Herring	ESA final	FLT+SMT
RT1GxCH3	3	GPS	Chen and Herring	IGS01 RT	FLT
RT3GxCH3	3	GPS	Chen and Herring	IGS03 RT	FLT
RTEGxCH3	3	GPS	Chen and Herring	ESA final	FLT

NWM data processing

- tropospheric parameters (ZTD, gradients, …) derived from NWM fields
- GFZ ray-tracing technique (Florian Zus)
- two NWMs
  - ERA5 – global reanalysis, provided by ECMWF, ~31 km horizontal resolution, output every 1 hour
  - WRF – local simulation of 24-hour free forecast, run at GFZ with initial and boundary conditions taken from global NCEP GFS model, 10 km horizontal resolution, output every 1 hour

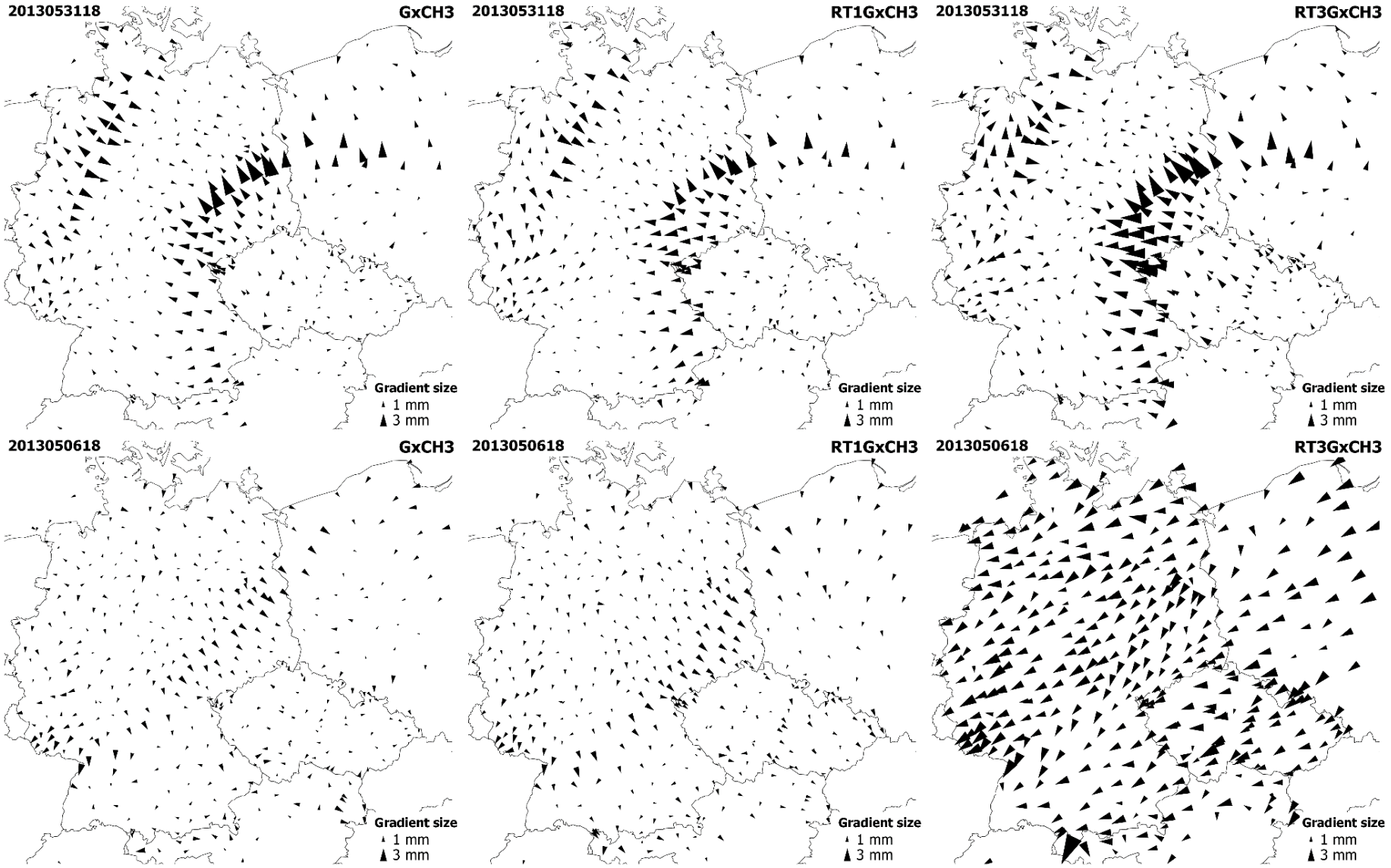
Geodetic point of view

Impact of processing settings on GNSS horizontal tropospheric gradients

- positive impact from using lower cut-off elevation angle (change from 7 to 3 degrees)
- very small positive impact from using GPS+GLONASS constellation instead using GPS only (in post-processing mode!)
- gradients from real-time processing experience a quality penalty which is dominated by the quality of used IGS RTS products

detailed results in *Kačmařík et al.: Sensitivity of GNSS tropospheric gradients to processing options, Annales Geophysicae, 2018, in review*

Horizontal tropospheric gradients from real-time processing



POST-PROCESSING **RT IGS01 RTS** **RT IGS03 RTS**

Gradient mapping function *mfg* impact

- on average, Bar-Sever *mfg* provided 17 % smaller gradients than Chen and Herring *mfg*
  - **systematic difference occur in magnitude** of gradients, but **not in** their **direction**

- reason = Bar-Sever provides higher mapping factors (values of the *mfg* itself)

$$STD(a,e) = mfh(e) * ZHD + mfw(e) * ZWD + mfg(e) * (Gn * cos(a) + Ge * sin(a))$$

- **it is necessary to agree on the *mfg* whenever tropospheric gradients from various sources are to be compared!**

Meteorological point of view

Our objective

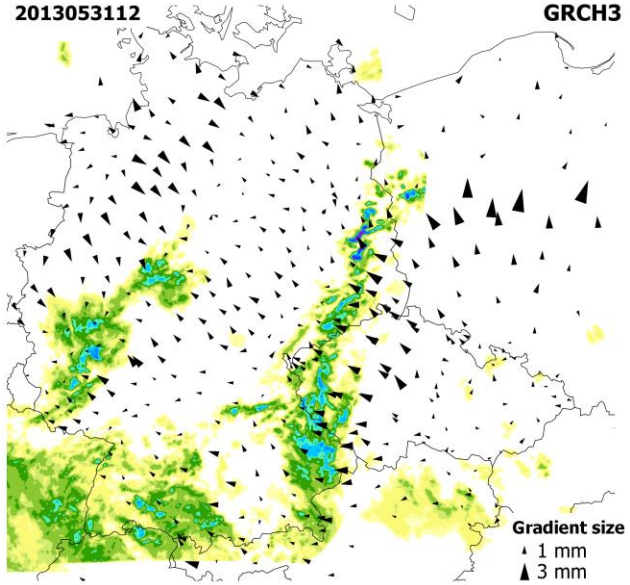
1. Show that GNSS horizontal tropospheric gradients contain real tropospheric information

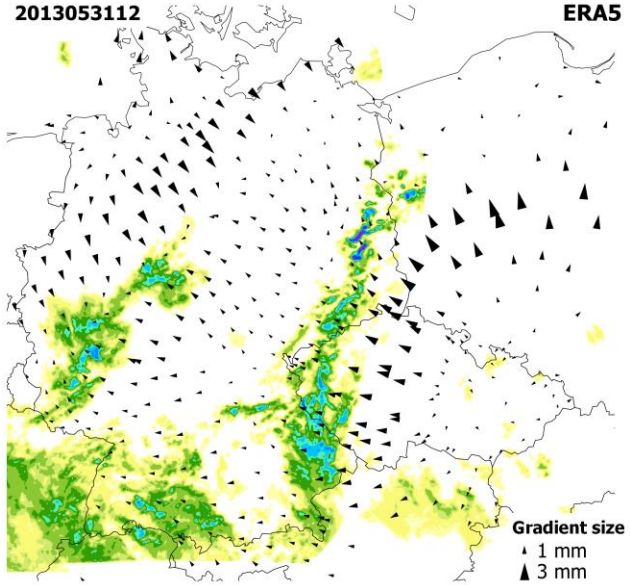
   show how well GNSS horizontal tropospheric gradients agree with standard meteorological techniques

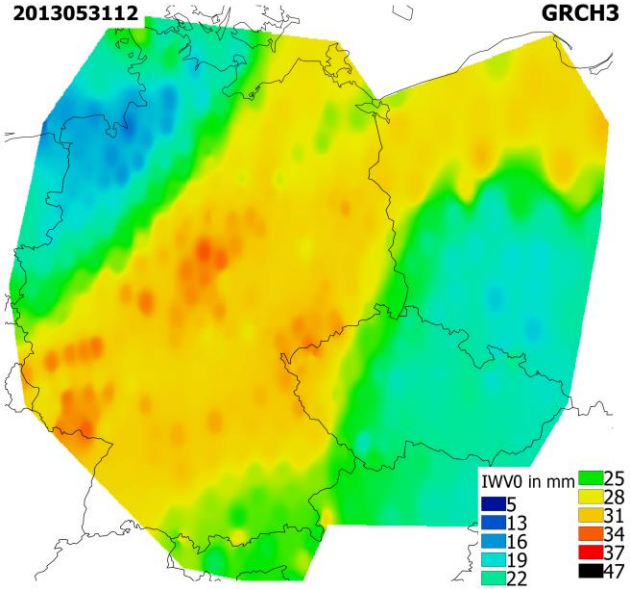
2. Stimulate following research potentially leading to usage of GNSS horizontal tropospheric gradients in meteorological applications

GNSS gradients NWM gradients GNSS IWV

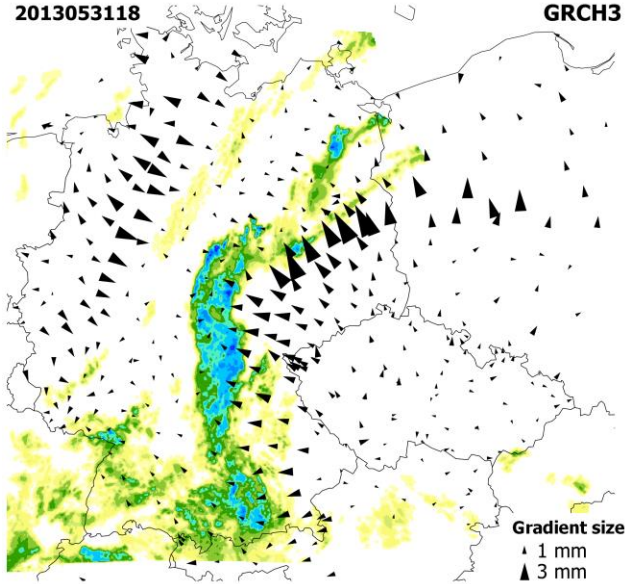
May 31, 2013, 12 UTC

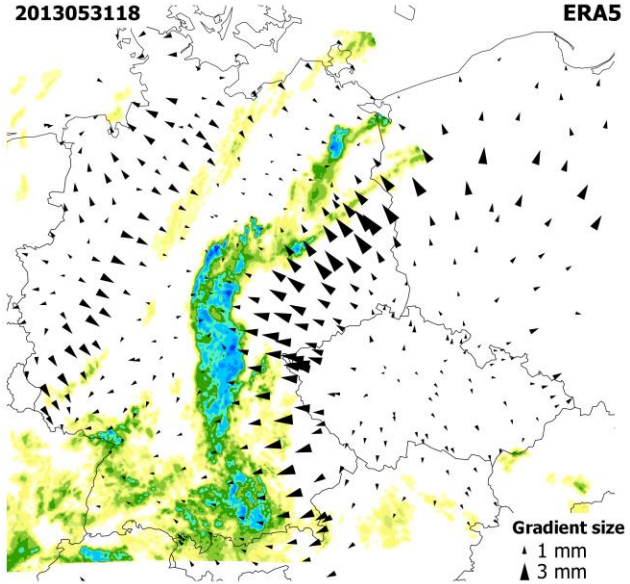


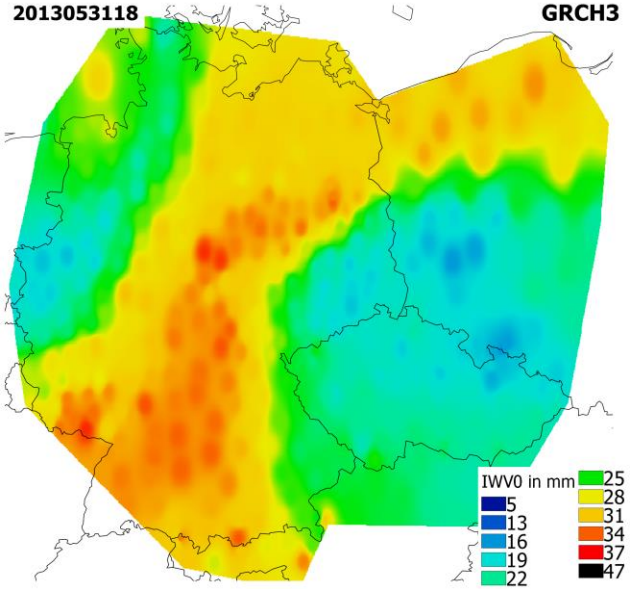




18 UTC

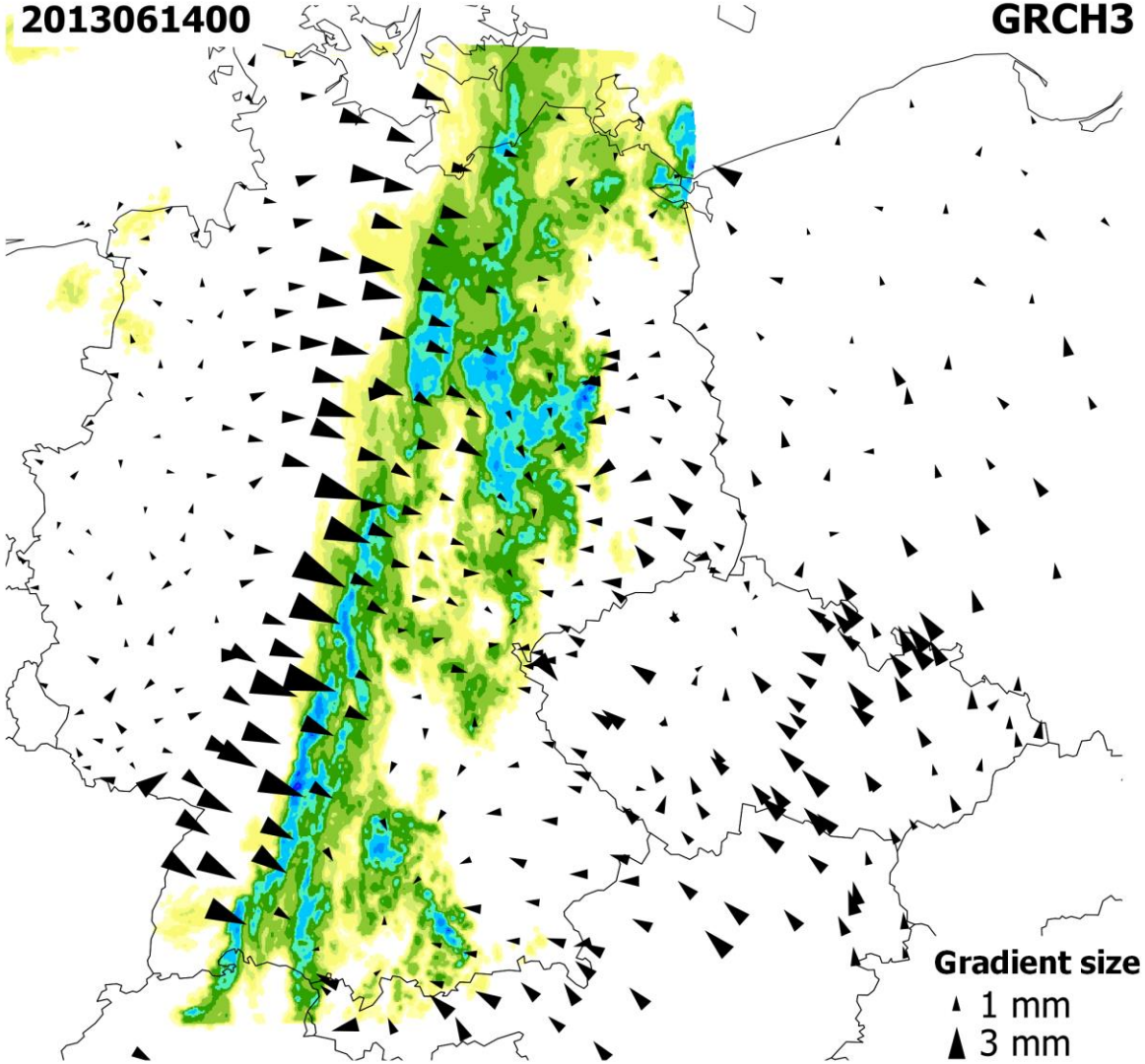


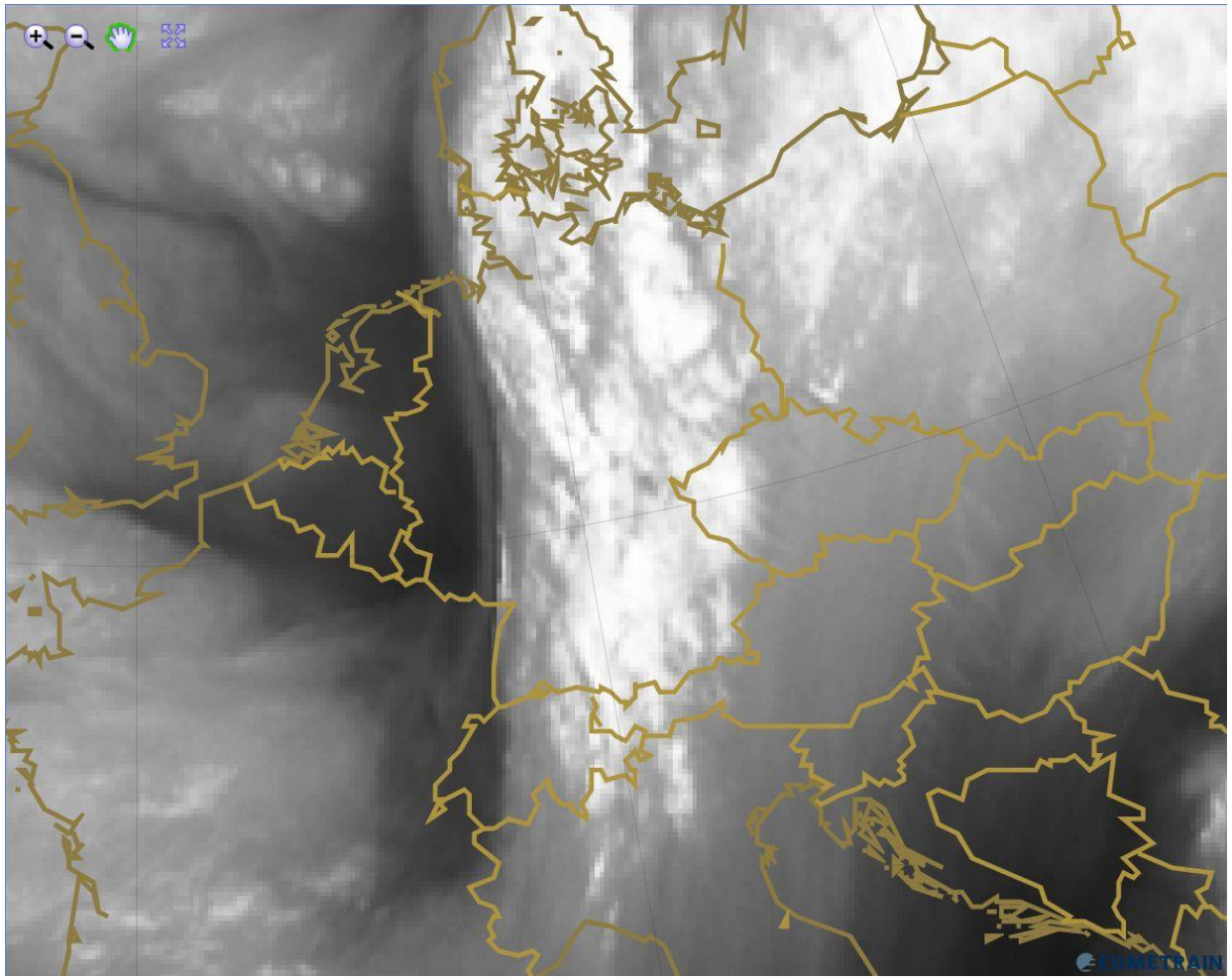




GNSS tropospheric gradients versus meteorological radar and satellite imagery

June 14, 2013, 00:00 UTC

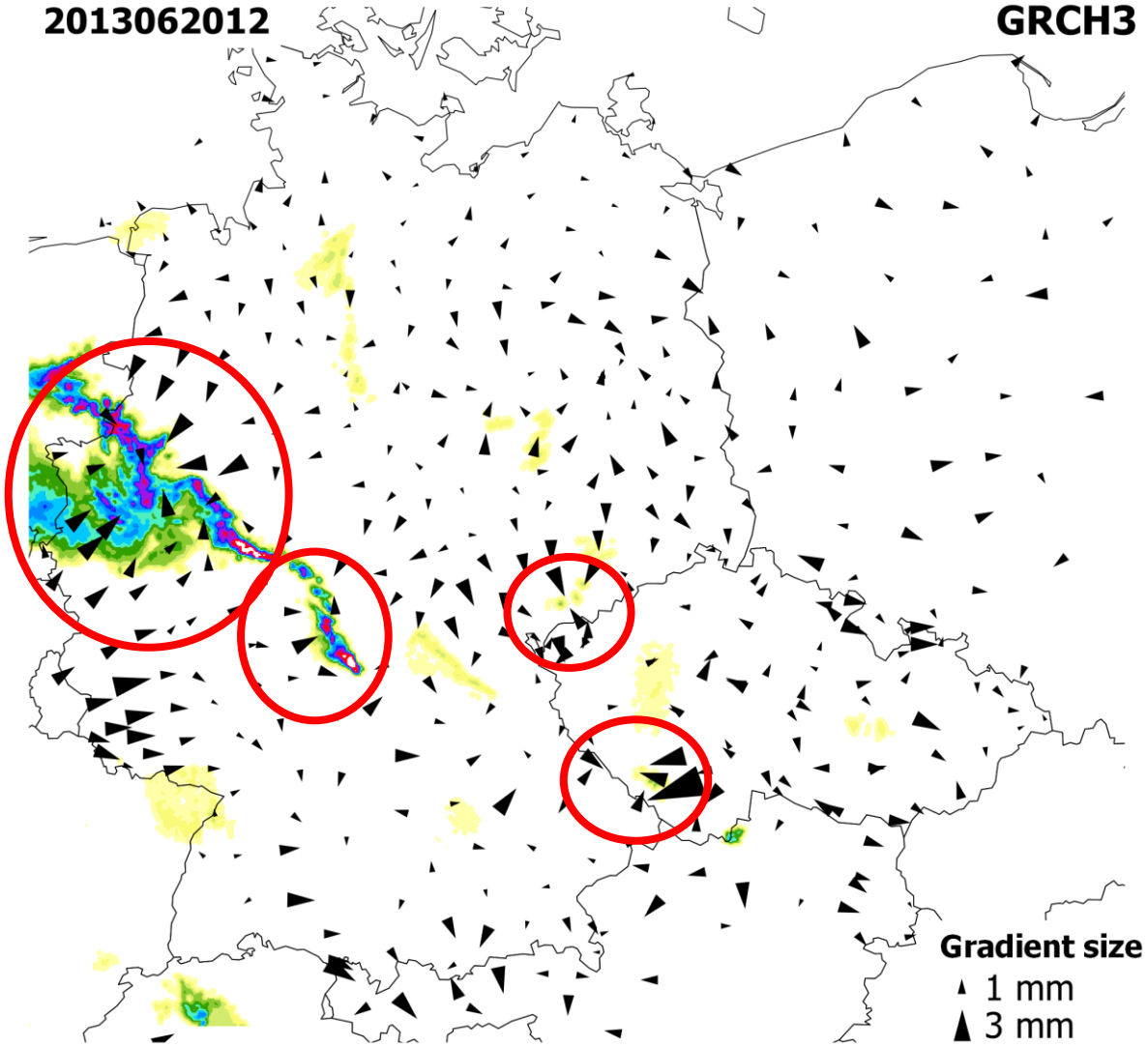


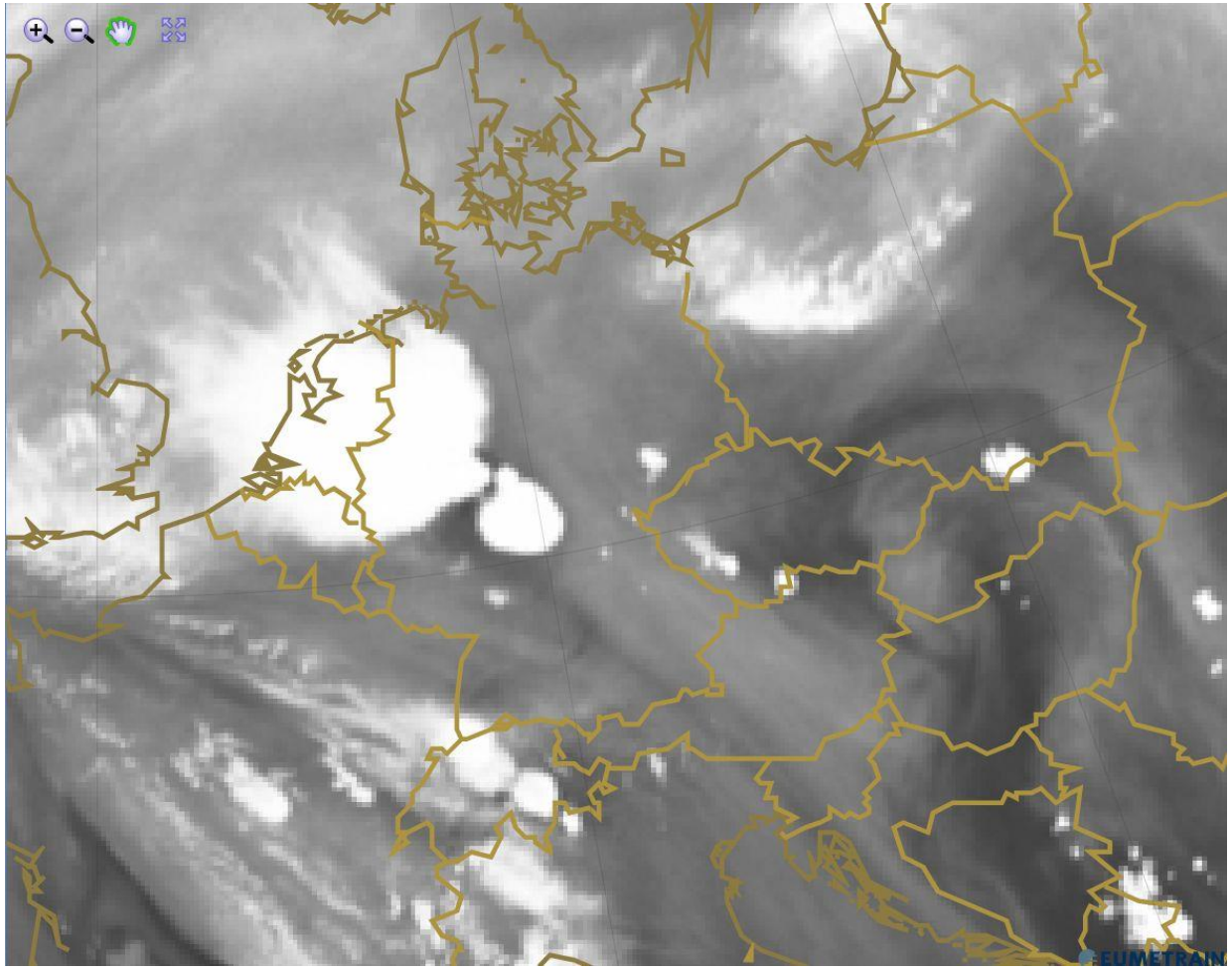


Meteosat MSG image, water vapor channel 6.2μm

GNSS tropospheric gradients versus meteorological radar and satellite imagery

July 20, 2013, 12:00 UTC



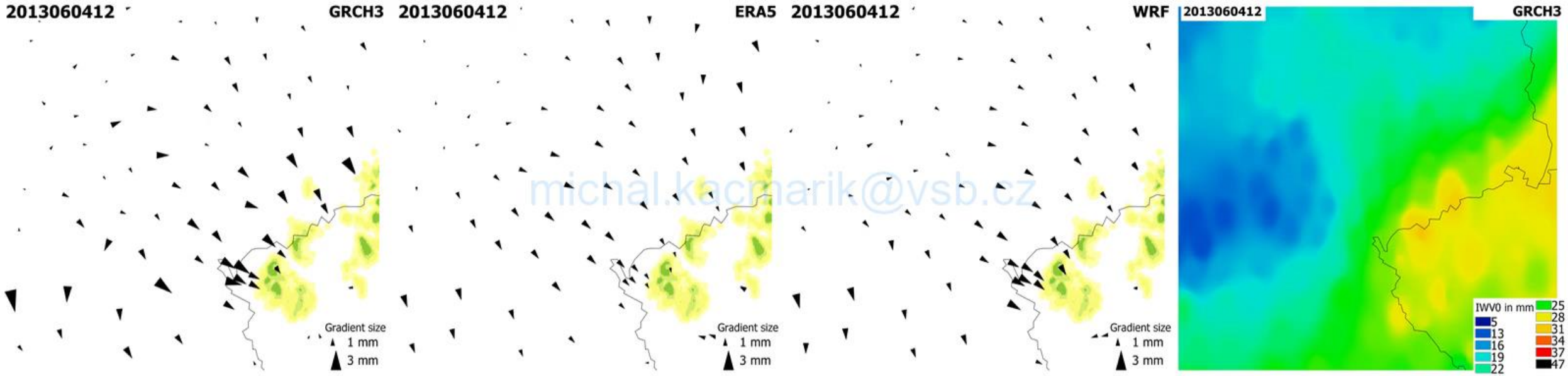


Meteosat MSG image, water vapor channel 6.2μm

Go to

http://geoinformatika-1.vsb.cz/gnss_gradients/

for animated movies



- with maps of GNSS horizontal tropospheric gradients we can **detect and track** water vapor tropospheric structures related to:
  - large scale frontal systems
  - **mesoscale convective systems (local storms)**

- a potential complementary tool for meteorological nowcasting (of severe weather events)

Assimilation of GNSS horizontal tropospheric gradients into NWM

- question – would it be worthy to assimilate ZTDs plus gradients?

- in our tests an assimilation of gradients in addition to the ZTDs:
  - significantly **improved** the refractivity fields around 800 hPa while assimilating data **from a single station**
  - resulted in a **small positive impact** while assimilating data from a dense **network of stations**

detailed results in *Zus et al.: Estimating the impact of GNSS horizontal delay gradients in variational data assimilation, Remote Sensing, 2018, in review*

Say it in one sentence

“GNSS meteorology can provide

not just 1 number (ZTD),

but 3 numbers (ZTD+Gn+Ge)!“

Message for IGS

- do not stick to ZTD only, try to exploit gradients more
- check the quality of gradients in official IGS final troposphere product
- if the quality of real-time satellite orbit and clock products is improved, the quality of horizontal tropospheric gradients would improve as well

Thank you for your attention

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