**Introduction**

AMUSE is a recent research project, funded by the DFG (German Research Council) and performed in close cooperation of TUB, GFZ and DWD during 2019-2022. AMUSE is aiming at developments of advanced ultra-rapid multi-GNSS products with a goal of improving the weather forecasts (especially severe events) in Germany in cooperation with the German Weather Service DWD.

The main innovations are: 1) developments to provide multi-GNSS instead of GPS-only data, including GLONASS, Galileo and BeiDou; 2) developments to provide high quality slant observations, containing water vapor information along the line-of-sight from the respective ground stations; 3) developments to shorten the delay between measurements and the provision of the products to the meteorological services.

The project consists of three working packages (WP). In WP1, the multi-GNSS ultra rapid tropospheric products will be calculated using an in-house developed software EPOS. The GNSS-derived tropospheric products, such as Zenith Total Delays (ZTDs) and Integrated Water Vapor (IWV), will be delivered with a delay shorter than 15 minutes after each hour (ultra-rapid processing). Additionally, GFZ will provide Slant Total Delays (STDS) with a time resolution of 2.5 minutes. In WP2, for monitoring purposes, the GNSS estimates will be compared against external reference data in three categories: space-based techniques (e.g. VLBI/InSAR), conventional meteorological sensors (e.g. water vapor radiometer (WVR), radiometer) and numerical weather models (NWM). The project work at TUB and GFZ will be complemented in WP3 by a contribution of DWD to investigate in detail and to quantify the forecast improvement, which can be reached by using the new generation GNSS meteorology data.

**WP1: Ultra-rapid multi-GNSS products**

Currently, over 100 satellites are in orbit and transmitting data contributing to the multi-GNSS constellation. Courtesy: B. Männel (GFZ).

German SAPOS network consists currently of around 270 stations. Almost all of the stations are at least two-systems capable and half of them are four-systems capable as of March 2020. Courtesy: M. Bräcke (GFZ).

**WP2: Multi-technique validation**

Comparison of GPS and NWM STDS for one summer month (June 2019) and one winter month (December 2018). The NWM STDS are ray-traced through the atmospheric reanalysis model ERA5. Top: the differences between the observations and the model. The black line indicates the mean bias and the red line indicates the standard deviation. The differences are much larger for higher elevation angles. Bottom: the relative differences. The differences are always below 0.5%. There is no longer a dependence between the elevation angles and the differences.

**WP3: Data assimilation into NWM**

The results of precipitation forecast in Germany on 28 May 2014 (strong precipitation event) with high-resolution COSMO-DE model. Green: hits, red: false alarms, black: misses. The validation with the radar data proves that the assimilation of GNSS data improves the hit rate by 18% compared to the reference experiment.

Assimilation experiment in May/June 2016 using COSMO-DE model. The GNSS assimilation improves the forecasts by 1-4%. Adding the STDS to ZTDs improves the forecasts by 1-2%.

**References**

Kahlbäck et al. (2017). Inter-technique validation of tropospheric delay from GPS and SAPOS. JGR Atmospheres 122: 4267-4287.

Le et al. (2019). Real-time retrieval of precipitable water vapor from GPS and SAPOS observations. JGR Atmospheres. 124: 4267-4287.


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**AMUSE**

**AMUSE working package flowchart**

**Severe Weather Monitoring and Forecasting**

**Overview**

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