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# The information content of GPS Slant Total Delays

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**Abstract:** Radio signals which are transmitted by GPS satellites and received by a ground-based station allow the estimation of the Zenith Total Delay (ZTD). The ZTD is of limited value in weather forecasting because it does not contain information about horizontal (and vertical) refractivity gradients. Here we show that the estimated Slant Total Delays (STDs), i.e. the atmospheric induced signal travel time delays between the station and the GPS satellites in view, contain the desired additional information.

**Method:** At first we determine Numerical Weather Model (NWM) STDs by point-to-point raytracing and retrieve NWM refractivity gradients through a non-linear least square analysis. The NWM data are 6h forecasts from the Global Forecast System. Then, we repeat this calculation but use GPS STDs instead to retrieve GPS refractivity gradients. This procedure is done station-by-station for ~200 stations in Germany and maps of NWM and GPS horizontal refractivity gradients are generated. The similarity bewteen the maps is a rough measure of the information content of GPS STDs.

**Data:** We have two techniques to estimate the STD for a station-satellite link:

(1) GPS phase data: The precise point positioning [1] estimates the **GPS STDs**.

(2) NWM field data: The direct numerical simulation [2] computes **NWM STDs**.

Gradients from both techniques are retrieved as follows: given a bunch of STDs for a single station, we estimate the refractivity profile $\eta=(\eta_1,\ldots,\eta_k)$ and the North-South $N$ and East-West $E$ gradient:

$$STD(e_1,a_1)=S_1[\eta_1,\ldots,\eta_k]+C(e_1,a_1)\cdot N+B(e_1,a_1)\cdot E$$
$$STD(e_2,a_2)=S_2[\eta_1,\ldots,\eta_k]+C(e_2,a_2)\cdot N+B(e_2,a_2)\cdot E$$
$$STD(e_3,a_3)=S_3[\eta_1,\ldots,\eta_k]+C(e_3,a_3)\cdot N+B(e_3,a_3)\cdot E$$
$$STD(e_4,a_4)=S_4[\eta_1,\ldots,\eta_k]+C(e_4,a_4)\cdot N+B(e_4,a_4)\cdot E$$
$$\ldots$$

Here $S$ denotes the point-to-point raytrace operator assuming a spherically layered atmosphere, and $C$ and $B$ depend on the elevation angle $e$ and the azimuth angle $a$ [3].

**Results:**

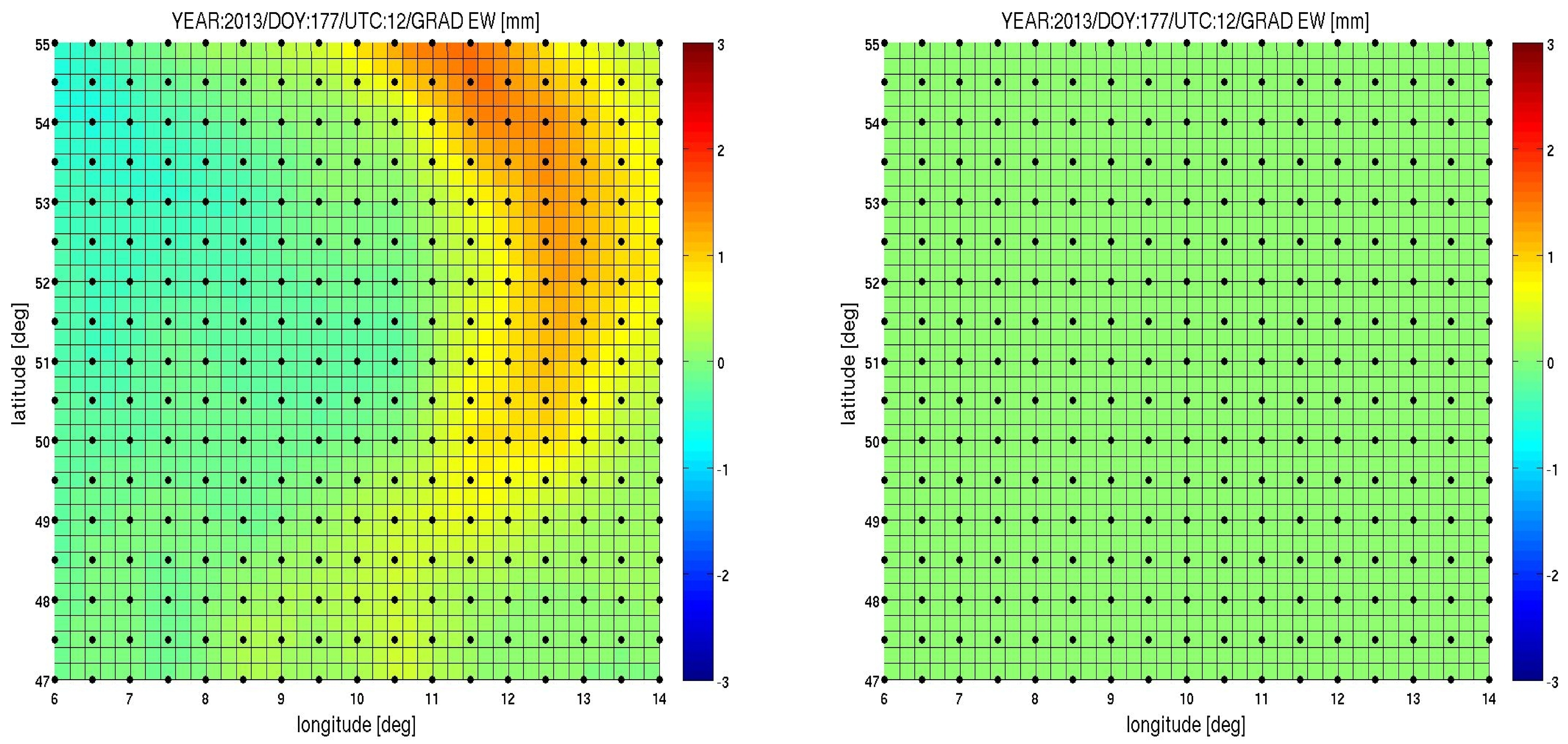


***Figure 1:*** *We use artificial stations and artificial station-satellite links. The locations of the stations are indicated by black dots. The station-satellite links correspond to a perfect observation geometry, i.e., azimuth scans for various elevation angles. For a single station we collect STDs and estimate the refractivity gradients. The E-gradients [mm] are assembled and produce a map. The left panel shows the E-gradient map utilizing NWM STDs. The right panel shows the E-gradient map if we use NWM STDs derived under the assumption of a spherically layered atmosphere.*

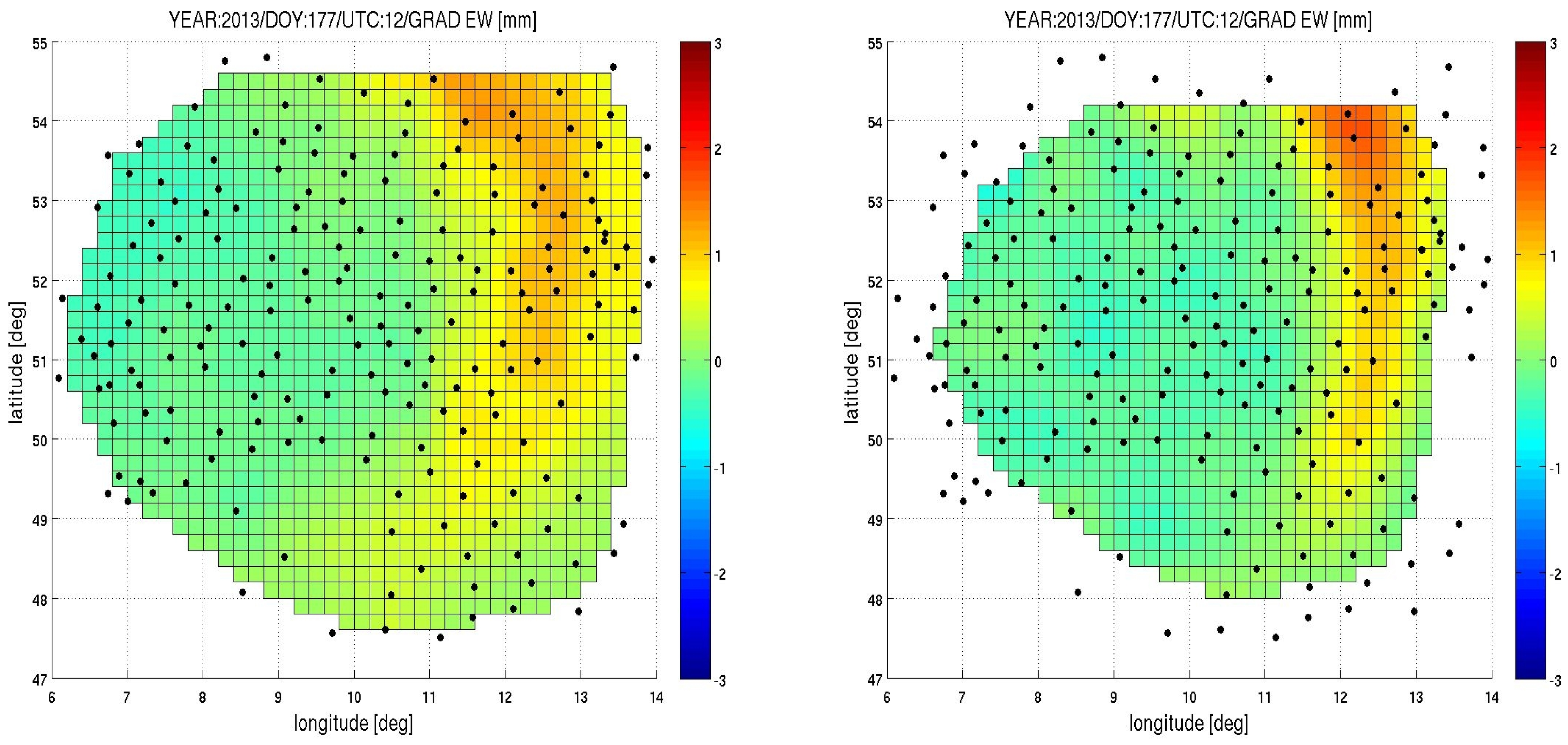


***Figure 2:*** *We use real stations and real station-satellite links ±10 minutes around the analysis time. The locations of the stations are indicated by black dots. The station-satellite links correspond to the GPS satellite constellation. For a single station we collect STDs and estimate refractivity gradients. The E-gradients [mm] are assembled and produce a map. The left panel shows the E-gradient map utilizing NWM STDs. The right panel shows the E-gradient map utilizing GPS STDs.*

**Conclusion & Outlook:** We generate NWM and GPS gradient maps. The remarkable close agreement between the maps leads to the conclusion that GPS STDs carry the signature of the atmospheric asymmetry. Since GPS STDs are available in near-real time they are considered a valuable data source for weather forecasting. Conversely, NWM data potentially improve the GPS solution.

**References:**
[1] Zumberge et al. 1997, J. Geophys. Res.
[2] Zus et al. 2014, Radio Sci.
[3] Chen and Herring 1997, J. Geophys. Res.

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