A new model of tropospheric directional gradients in global positioning system and its application to investigate extreme weather events

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Introduction

The delay in GPS L-band frequency signals caused by the presence of atmospheric water vapor molecules has been used for monitoring temporal and spatial changes of the troposphere using permanent ground-based GPS stations. Some research has been dedicated to investigating the relationship between water vapor accumulation and precipitation systems (e.g. Champollion et al. , 2004). In a recent study by Labbouz et al. (2015), it was shown that precipitable water vapor (PWV) could potentially be used as a short-term indicator of heavy precipitation. Although such studies are still in early stages, and despite the unknown complications of weather systems, there still seems to be demand for further work on horizontal movements of the moisture and the link with formation of extreme precipitation events.

Troposphere is usually considered azimuthally symmetric in mapping functions used in GPS modelling. To compensate for this assumption, horizontal gradients are generally estimated together with other parameters. However, the gradient model currently in use by most analysts is a simple NS/EW planar model. While such a planar model is sufficient in most cases, there are specific cases where a plane is not truly representative of the troposphere.

We have developed and implemented a new directional model of gradients in which the gradients are estimated at different directions around the site with a piecewise function between the nodes. The new model has the capability to detect isolated rapid spatial changes in specific azimuth angles. Simulations are performed to validate this capability of the model and to evaluate the effect of the new model on other parameters.

A real case study of the 9 September 2002 extreme precipitation in Southern France is used as an example of how the directional gradients can provide information about the local variability of the troposphere around a GPS site, and how they might potentially be used for investigating specific extreme weather events.

Tropospheric modelling in GPS and the proposed directional gradient model

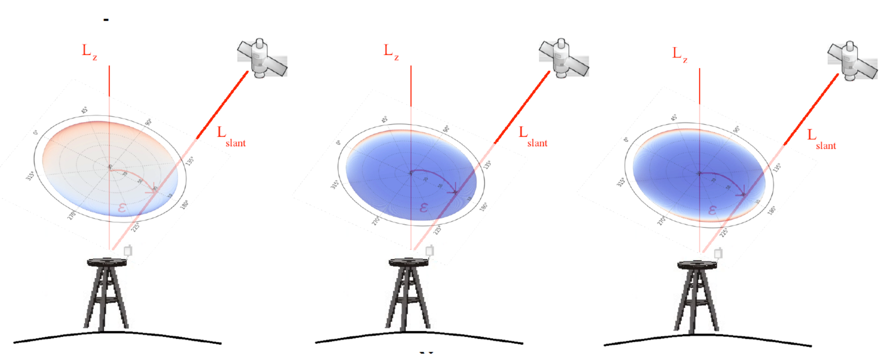
The azimuthally symmetric part of the tropospheric delay (Davis et al., 1985):

$$L_{sym}(\varepsilon) = L_h^z m_h(\varepsilon) + L_w^z m_w(\varepsilon)$$

The azimuth-dependent part of the tropospheric delay modelled as conventional North-South and East-West gradients (Chen and Herring, 1997):

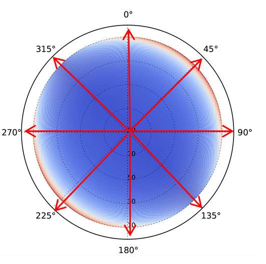
$$L_{az}(\varepsilon,\alpha) = L_{NS} m_{az}(\varepsilon)\cos(\alpha) + L_{EW} m_{az}(\varepsilon)\sin(\alpha)$$

$$m_{az}(\varepsilon) = \frac{1}{\sin(\varepsilon)\tan(\varepsilon) + 0.003}$$

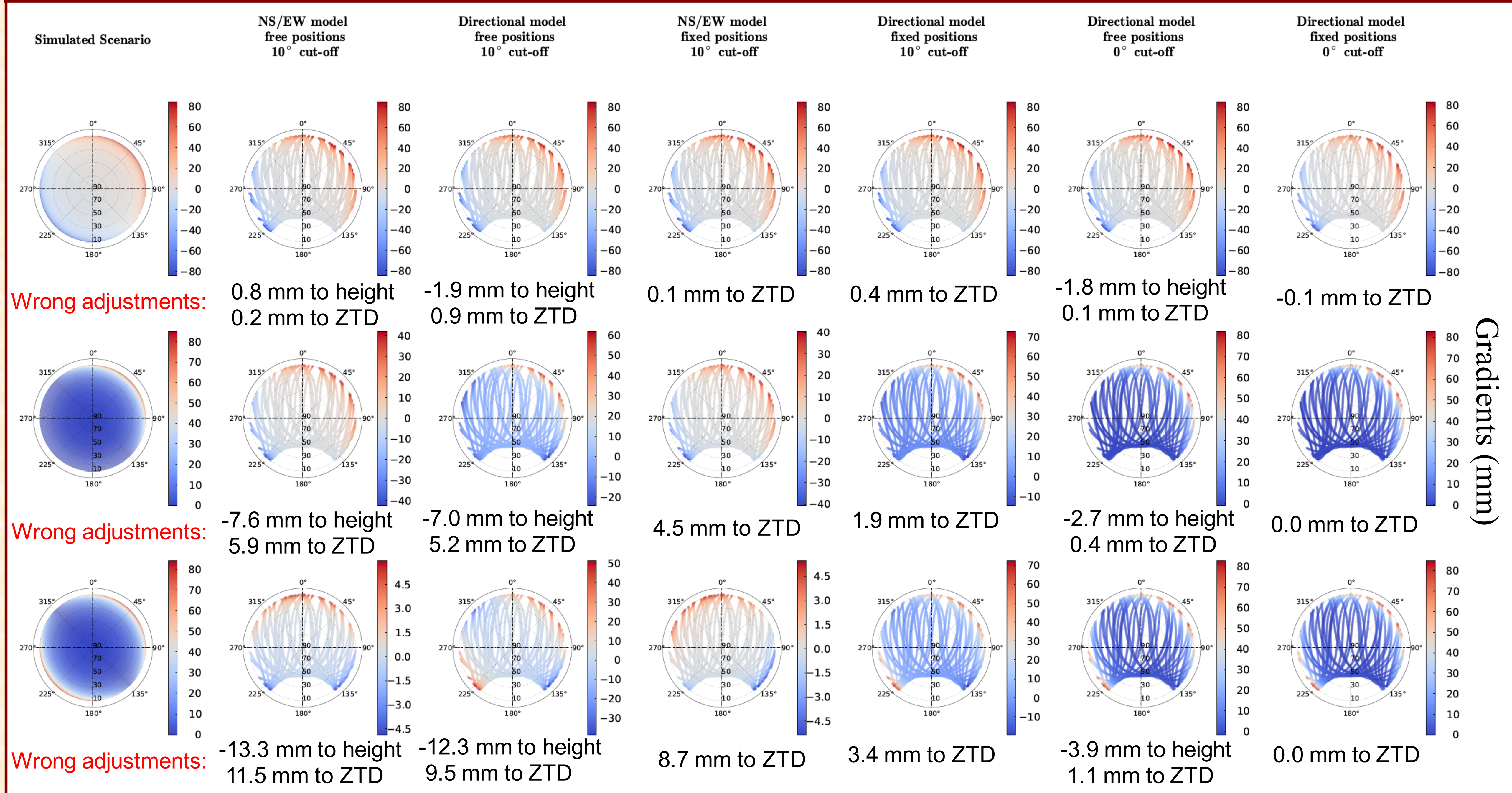


The new proposed model of gradients:

$$L_{az}(\varepsilon,\alpha) = \sum_{j=1}^{N} L_j m_{az}(\varepsilon) m_{PW}(\alpha)$$



Simulations



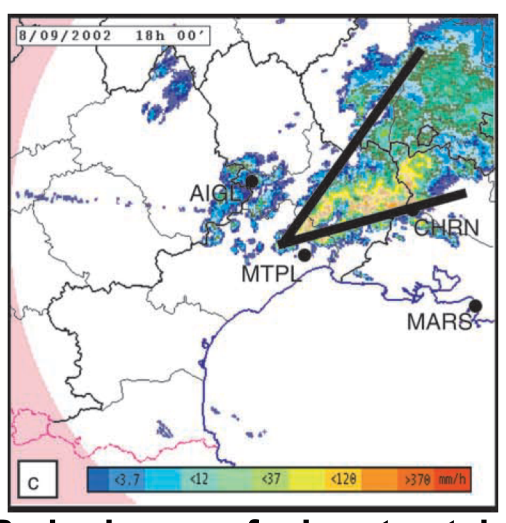
Correlations of the simulated planar scenario

NS/EW Model	Lat.		Lon.		Height		ZTD		L_{NS}	
Cut-off angle	10°	0°	10°	0°	10°	0°	10°	0°	10°	0°
Lon.	-0.08	-0.07								
Height	**0.34**	**0.38**	-0.06	0.02						
ZTD	0.05	-0.03	-0.02	-0.08	**-0.55**	**-0.38**				
L_{NS}	**0.22**	0.06	0.00	-0.02	-0.03	-0.01	0.02	0.00		
L_{EW}	-0.01	-0.01	**0.23**	0.05	0.00	0.04	-0.04	-0.01	-0.01	0.00

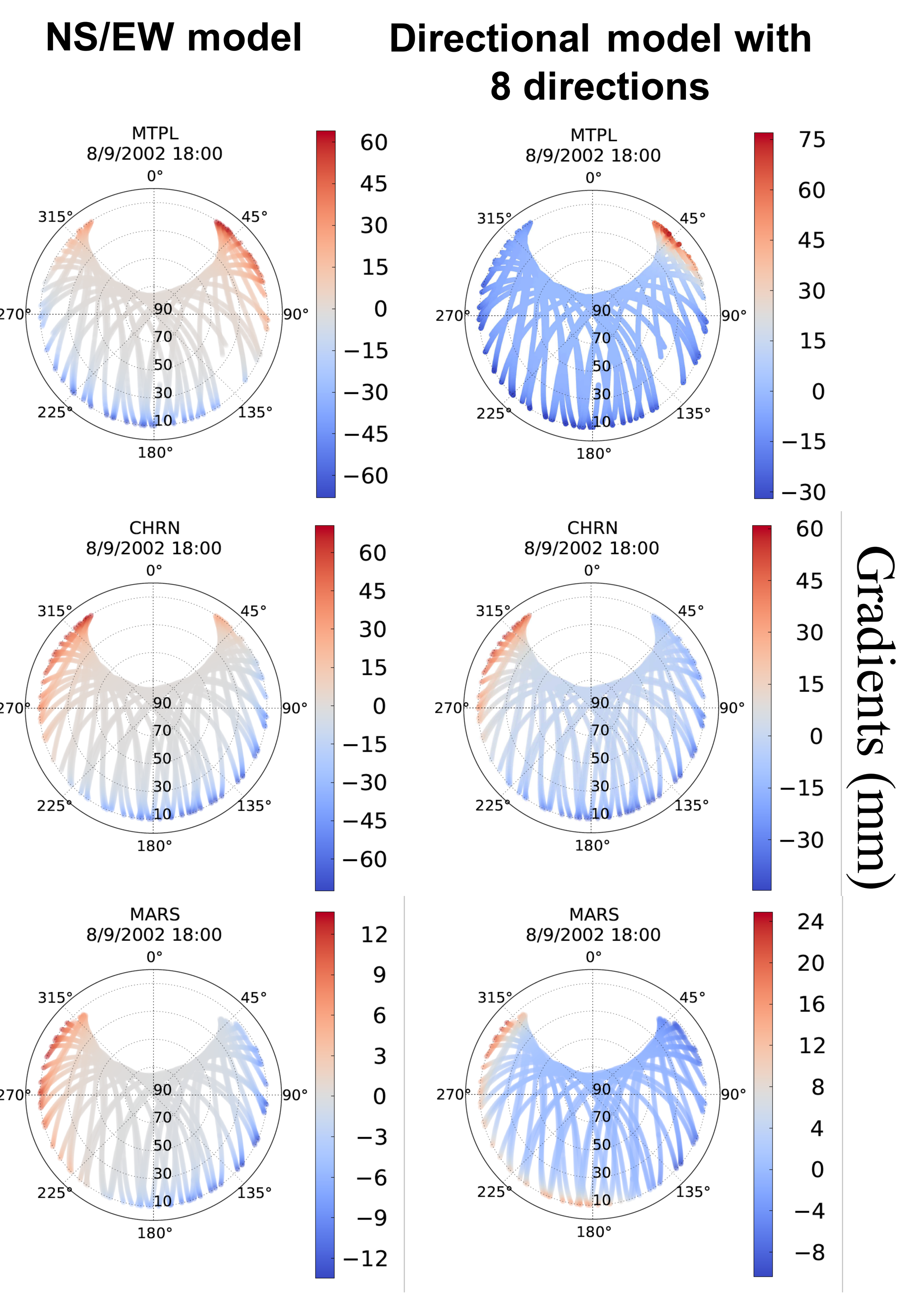
Directional Model	Lat.		Lon.		Height		ZTD		L_N		L_{NE}	
Cut-off angle	10°	0°	10°	0°	10°	0°	10°	0°	10°	0°	10°	0°
Lon.	-0.17	-0.10										
Height	**0.40**	**0.38**	-0.13	-0.02								
ZTD	0.12	0.02	-0.02	-0.01	**-0.57**	**-0.39**						
L_N	0.05	-0.01	-0.01	0.00	**0.43**	0.11	-0.02	0.00				
L_{NE}	0.01	-0.02	0.07	0.01	**0.40**	0.12	0.00	0.00	**0.51**	0.14		
L_E	-0.07	-0.02	0.09	0.01	**0.37**	0.12	0.00	0.01	**0.56**	0.14	**0.55**	0.15

- Looking at the correlations between the estimated parameters can give us a clue why the directional model is still unable to fully recover the gradients while position components are also estimated. The new gradient parameters are highly correlated with heights and with each other. These correlations are significantly reduced when including low-elevation observations, which results in more accurate estimates.

Real case study of Southern France September 2002



Radar image of rain rates taken from Champollion et al. (2004)



Processing strategies

Software	GAMIT
Orbit	IGS final orbits
Weighting	Elevation-dependent
ZTD estimation	Every 30 mins
Gradient estimation	Every 1 hour
ZTD a priori	VMF1 For hydrostatic / GPT2 for wet (ZWD estimated)
ZTD mapping func.	VMF1
Ocean loading	FES2004
Earth tide	IERS03
Atmospheric loading	Tidal and non-tidal at observation level
Antenna phase variations	IGS08 + ESM (Moore et al., 2014)
A priori coordinates	ITRF2008
Position constraints	Fixed at best estimates from monthly run and ITRF2008 absolute plate rotation poles

Conclusion

- The proposed directional model of gradients has the capability to isolate rapid spatial changes of the tropospheric delay/water vapor in specific azimuthal directions around a GPS site
- This capability may be used for deriving valuable information about the local atmosphere around a GPS site, in particular for extreme weather events
- While the directional gradient model parameters are highly correlated with height, these correlations are largely broken when the positions are fixed, leading to more realistic estimates of gradients.
- This new model will lead to improved tropospheric slant delays for weather model assimilation purposes.

References

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