The GPS Tide Gauge Problem, Revisited

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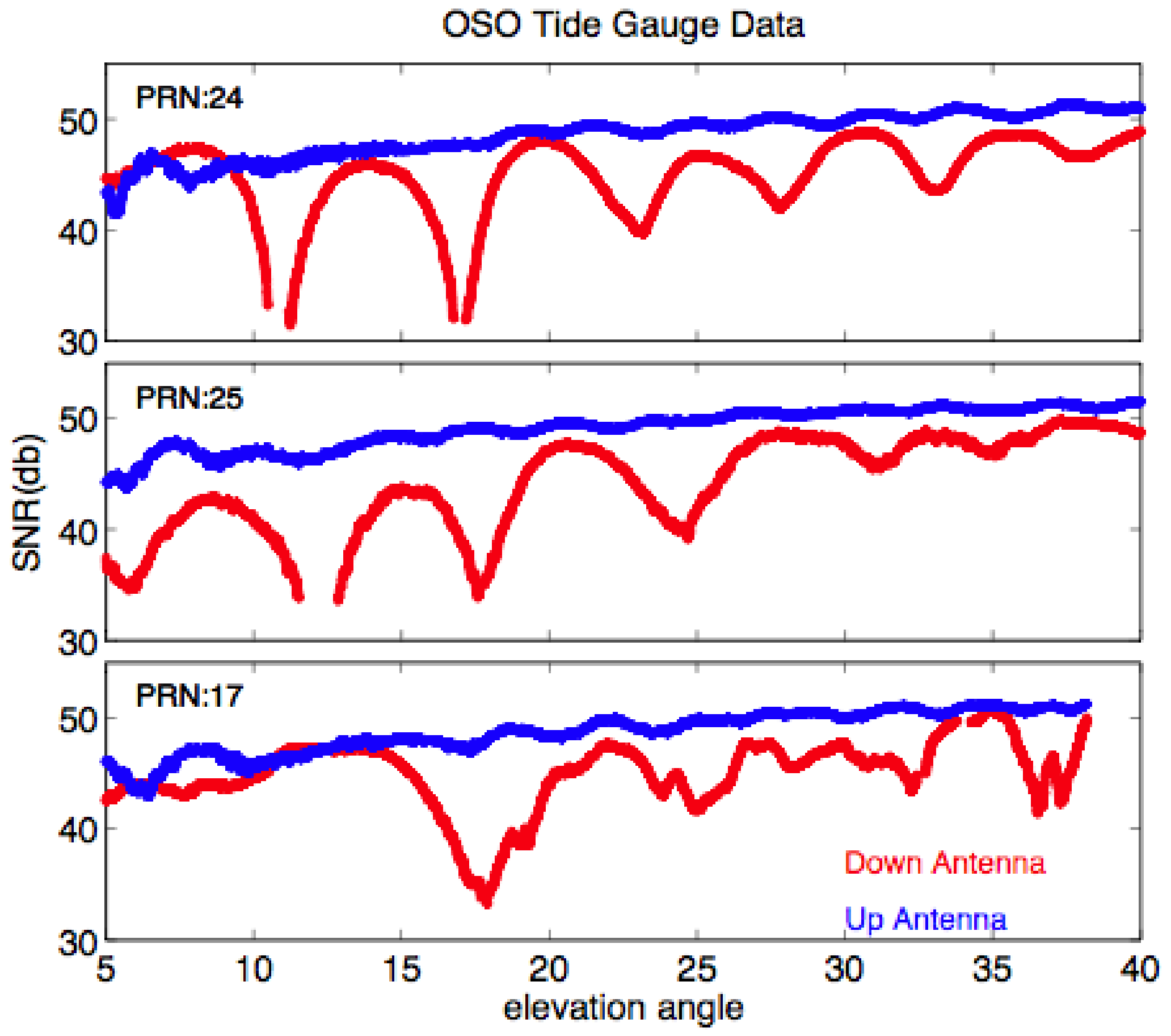
Introduction

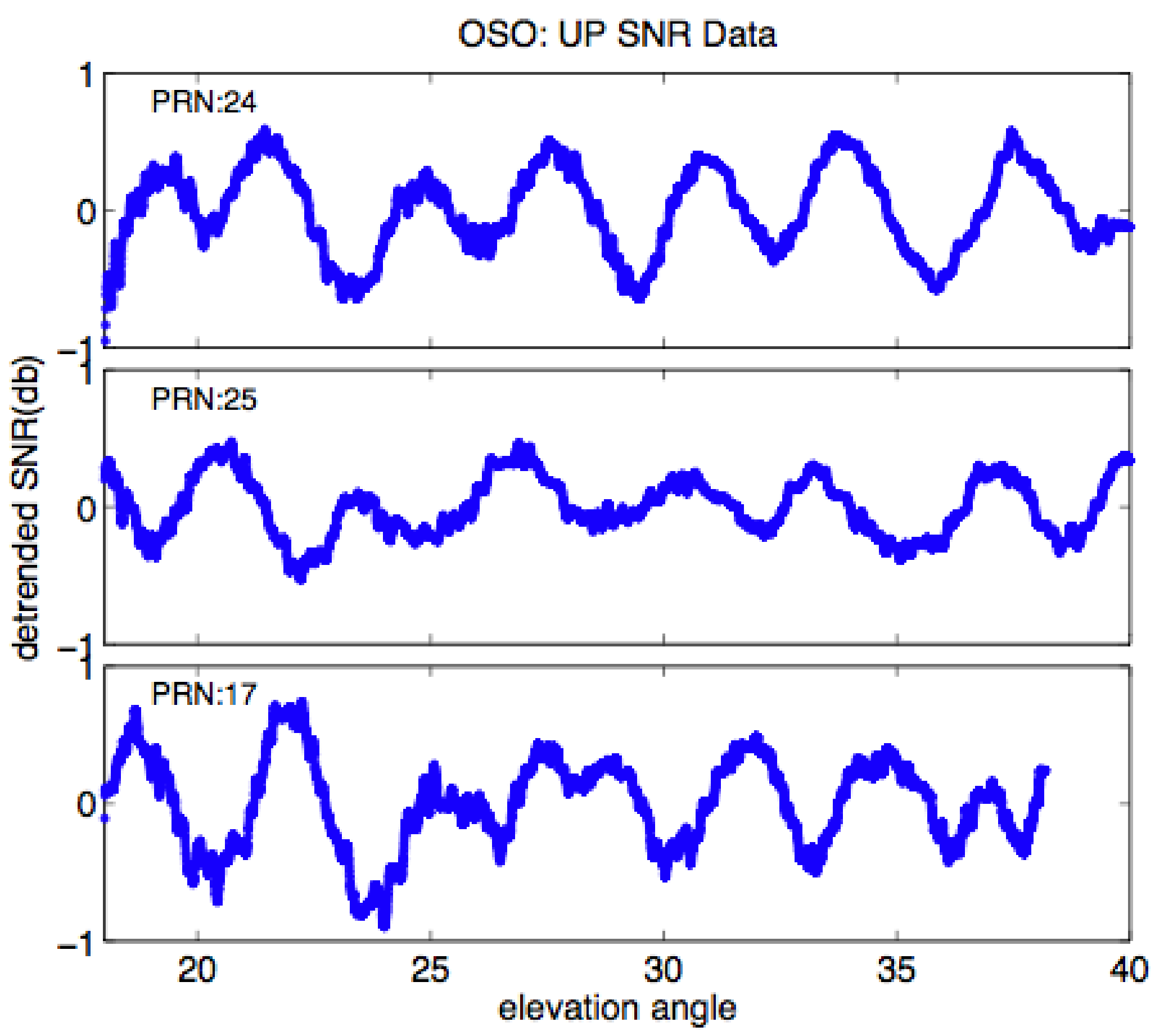
Martin-Neira [1993] first proposed that reflected GPS signals could be observed from space. He originally suggested that these reflections could be used for altimetry. Subsequent work demonstrated that reflections could also be observed using ground-based receivers, e.g. *Treuhaft et al.* [2001], *Soulat et al.*, [2005], *Belmonte-Rivas and Martin-Neira* [2006]. In these experiments, specially designed receivers/antennae were used in order to optimize retrieval of the reflected signal. The University of Colorado has led an effort to use GPS reflections from "geodetic-quality" GPS receivers. Instead of the carrier phase data, Signal-To-Noise Ratio (SNR) data stored in the RINEX files are used to determine the distance between the phase center of the antenna and the reflecting surface. This method has been successfully used to estimate reflections from snow and soil [*Larson et al.*, 2009; *Larson et al.*, 2010]. In this study, the same approach is used, but reflections from local sea surfaces are measured. The advantages of this method are: SNR data are straightforward to analyze, sea level can be measured in windy conditions, easily available GPS instrumentation can be used, and existing GPS instruments installed near the ocean can be used without modification to measure sea level.

GPS Tide Gauge at the Onsala Space Observatory

The Onsala Space Observatory (OSO) GPS tide gauge is an example of a two antenna-two receiver GPS tide gauge [Löfgren et al., 2011]. Both antennas are connected to dual-frequency geodetic-quality GPS receivers (Leica GRX1200 model). The UP antenna is a geodetic choke-ring model that is optimized to receive Right-Handed Circularly Polarized energy from above the horizon. The DOWN antenna was a specially designed choke-ring antenna modified to emphasize Left-Handed Circularly Polarized energy from below the horizon. Both the UP and DOWN receivers were tracking at 1-Hz. Rather than a geodetic installation, where the antenna is pounded into bedrock, these antennae have been deliberately set above the local sea surface. There was no *in situ* tide gauge at OSO during the period of this experiment, September-December 2010. However, tide gauges at Ringhals (18 km) and Göteborg (33 km) are available for comparison.



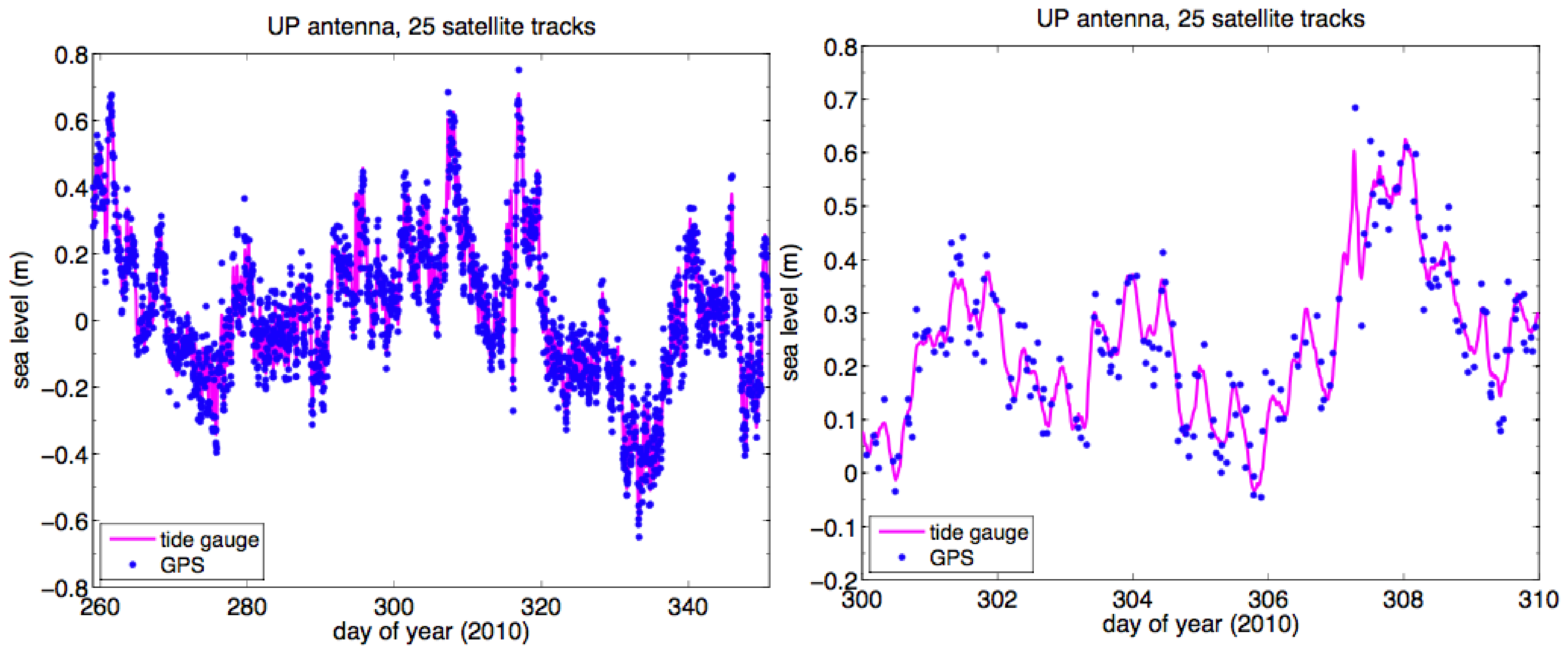
The SNR data for the UP and DOWN antenna are significantly different. The UP antenna primarily shows the effect of the direct signal, with strong signal strength consistent with code-tracking. The DOWN antenna shows deep fades associated with the reflections. The distance between the fades provides the information about the height of local sea level. The DOWN SNR data are consistent with previous studies of Hannah [2001].



L1 SNR data from the UP antenna

The effects of reflected signals can be seen in the UP antenna if the effects of the direct signal are removed. In the figure to the left, a low-order polynomial was fit to the original SNR data and then removed. The oscillations are caused by reflections from the sea surface. The frequencies of these oscillations contains the information about the local sea level height. If one assumes the sea level does not change during a satellite pass, *the oscillation frequency is constant as a function of sine of the elevation angle*.

In order to estimate local sea level from the SNR data, a Lomb Scargle periodogram was used. Each day the peak frequency for each satellite arc that rose or set over the sea was estimated. These frequencies are converted to reflector height by scaling by λ/2, where λ is the GPS carrier wavelength.



Each blue point represents sea level estimated for a single rising/setting GPS data arc. The magenta line is a linear combination of the Ringhals and Göteborg tidegauge data. RMS agreement between the tidegauge data and the GPS reflections is 4.5 cm.

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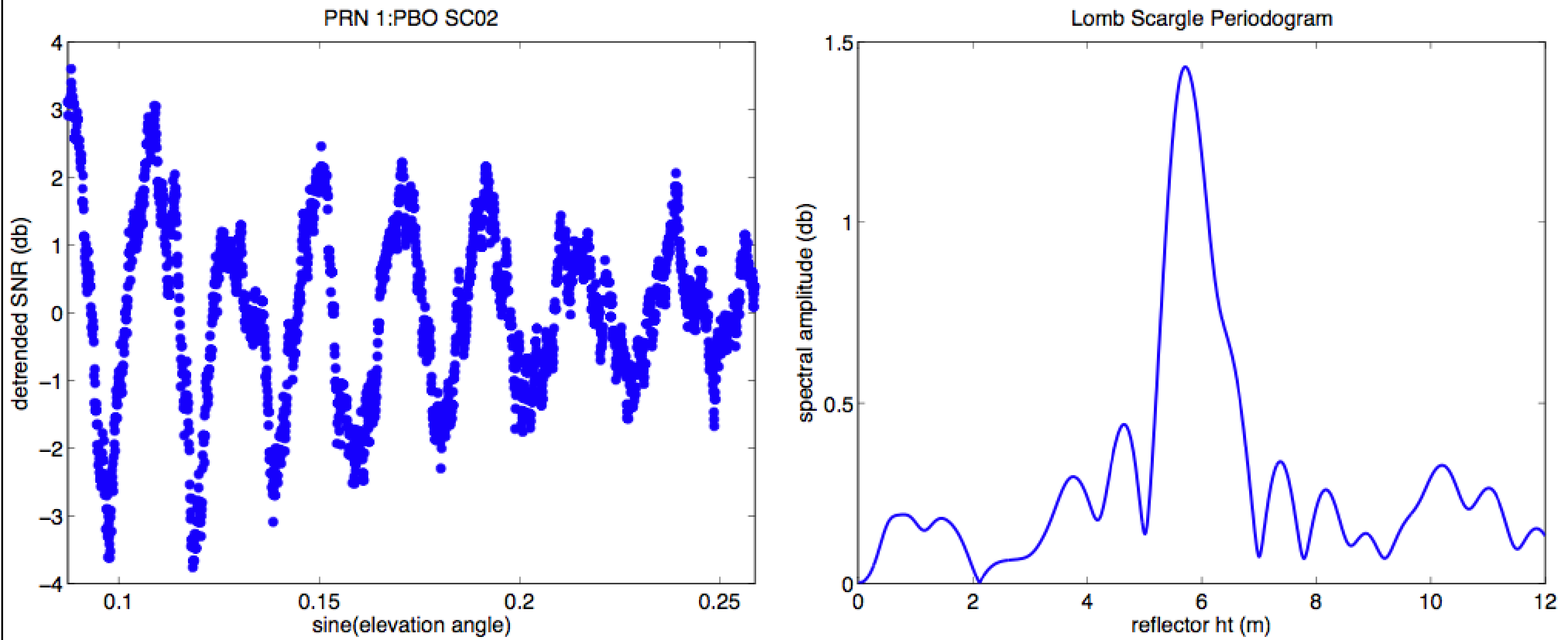
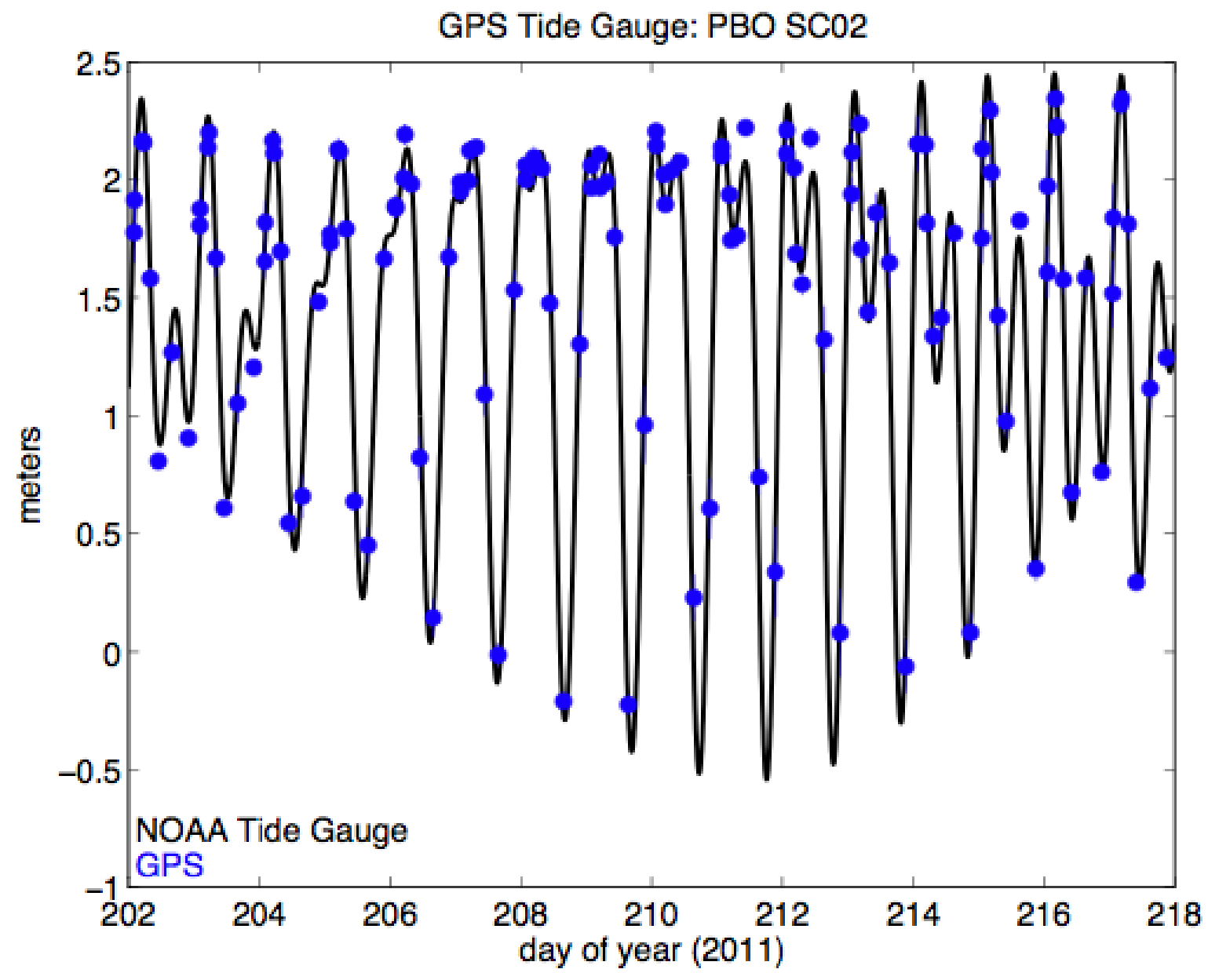
GPS Tide Gauge: Plate Boundary Observatory

The EarthScope Plate Boundary Observatory (PBO) GPS tide gauge at SC02 (Friday Harbor, WA) is an example of a single antenna-receiver GPS tide gauge. The antenna is a geodetic choke-ring model that is optimized to receive RHCP energy from above the horizon. The receiver is a Trimble NetRS, and the default PBO sample interval is 15 sec. Unlike the OSO GPS tide gauge, the PBO site has been installed in bedrock.



Left: L2C SNR data for PRN 1 between elevation angles of 5 and 15 degrees; right: Lomb Scargle periodogram for these data, showing a strong reflector ~6 meters below the antenna phase center.

NOAA operates a tide gauge at Friday Harbor, ~300 meters from the GPS site. The comparison to the right shows these tide gauge data and GPS sea level retrievals for all L2C transmitting satellites that rise or set over the harbor. The formal error for each retrieval is ~3cm, but the true error will be larger if sea level is changing quickly during the satellite track. Future work will include estimation of the sea level rate as well as a sea level bias.



Acknowledgements

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