The Effect of SCIGN Domes on the Vertical Phase Centre Position in Routine Processing of GPS Data

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Abstract

The question of phase centre shifts for GPS antennas introduced by the addition of domes is receiving more attention as the number of continuous GPS sites multiply and the precision of solutions continue to improve. Our earliest experiences with clear acrylic domes used in the Western Canada Deformation Array (WCDA) had shown that changes in the vertical position of the phase centre exceeding 1.5 cm could be caused by the introduction of a dome. More recently, our deployments of SCIGN domes at WCDA sites showed no discernable shifts in the horizontal components but apparent shifts of over 2 cm in the estimates of height. Such large shifts have also been observed in practice by others but contradict calibration tests carried out by SCIGN and by NGS which indicate maximum vertical shifts of only a few millimetres due to the introduction of domes. Tests with the SCIGN short dome carried out at our GPS site at the Pacific Geoscience Centre (PGC5) demonstrate clearly that domes can introduce an elevation-dependent (1/cosZ) delay and consequently, the nominal mounting of SCIGN domes biases the tropospheric zenith delay resulting in an apparent shift in the L3 estimate of station height. Since estimates of the tropospheric delay are strongly dependent on the elevation cutoff used in the analysis as well as local site horizons, it is not possible to provide an "absolute" calibration correction for this effect. However, mounting the SCIGN dome so that its centre of curvature coincides with the mean position of the L1/L2 phase centres of the Dorne Margolin element significantly reduces this bias and effectively eliminates the large spurious change in height. This “dome effect” can be explained in terms of “lensing” of incident plane waves inside the dome.

Introduction

Continuous GPS stations of the Western Canada Deformation Array (WCDA) (Dragert et al., 1995) utilize standard concrete pillar geodetic monuments to mount Dorne-Margolin chokering antennas and over the past ten years, domes have been introduced at almost all WCDA sites. The purpose of the domes is to protect the antennas and minimize problems due to the accumulation of snow, ice, leaves, or other debris. As early as 1996, Dragert et al. (1996) reported unexplained vertical offsets exceeding 1 cm associated with changes in antenna mounting and the additions of acrylic domes. Using closely spaced (~ 14 m) concrete pillar monuments, recent systematic tests at the Pacific Geoscience Centre have shown that the introduction of SCIGN (Southern California Integrated Geodetic Network) domes can cause an apparent shift in the position of the vertical exceeding 2 cm in routine data analysis. It should be emphasized at the outset that such changes are analysis dependent - specifically, such shifts appear only when solving for tropospheric delay using the nominal 1/cosZ mapping function.

Experimental Design

The Pacific Geoscience Centre located in Sidney, British Columbia, has several concrete pillar monuments within a fenced antenna compound used for testing GPS systems. Two of these monuments (site ID’s PGC4 and PGC5) are shown in Figure 1. Each monument consists of a standard brass, forced-centre plate embedded in the top of a 2m high, 0.5m diameter concrete column anchored into the roof of a buried concrete water reservoir. PGC4, located about 14m from PGC5, is an active control station operated by the Base Mapping and Geomatics Services Section of the B.C. provincial government for the Victoria Capital Regional District. Tropospheric delay decorrelates quickly with station separation and the close proximity of the independent site PGC4 to PGC5 enabled the resolution of the apparent change in the tropospheric

Figure 1. Forced-centre concrete pillar monuments for continuous GPS sites PGC4 and PGC5. PGC4, operated by the Base Mapping and Geomatic Services Branch of British Columbia, uses a Trimble micro-strip antenna with an extended ground-plane. PGC5, operated by the Geological Survey of Canada, uses a Dorne-Margolin chokering antenna. Each antenna is mounted on a 10 cm stainless-steel collar that permits antenna rotation. The monuments are about 14 m apart.

Figure 2. PGC5 antenna with a SCIGN short dome. The dome is held in place using the base ring-mount attached to the outer edge of the antenna groundplane. View is looking north from the PGC4 monument.

Figure 3. Raised dome for PGC5. The two panels show the details of mounting the SCIGN dome raised by 3.6cm

delay introduced by the dome changes at PGC5. Although PGC4 does not use a Dorne Margolin chokering antenna, the noise level on the PGC5-PGC4 differential Zenith Delay (ZD) was at the expected level of about 2 mm. The PGC5 Dorne-Margolin chokering antenna is mounted on a 10 cm aluminum base which permits orientation of the antenna. No metal RF screening was used at this site to shield the gap between the antenna ground-plane and the top of the pier and thus mitigate near-field multipath effects. In Figure 1, the PGC5 antenna is shown mounted without a dome; Figure 2 shows the PGC5 antenna mounted with the SCIGN short dome (SCIS).

For testing the effects of a "raised dome", the SCIGN short dome was raised 3.6 cm above the ground-plane of the chokering antenna using long machine screws (see Figure 3). This elevated mounting brought the centre of curvature of the dome into the approximate average L1/L2 relative phase centre location (PCL) as defined by IGS PCV tables. Note that this simple mounting using metal screws may introduce unaccounted for near-field effects, and that the adopted IGS PCL height is not the true height of the absolute phase centre.

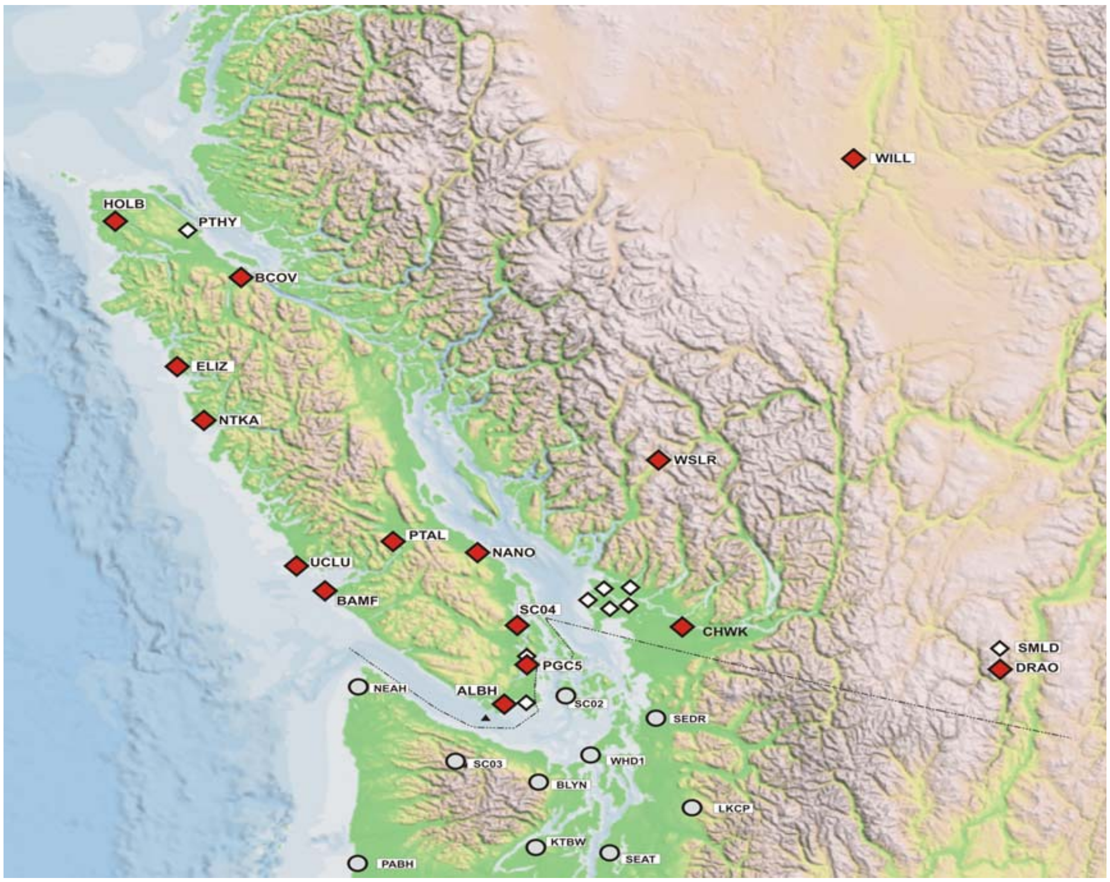


Figure 4. Location of continuous GPS stations included in routine daily data analysis. Shaded (red) diamonds, open diamonds, and open circles show sites from the WCDA, BCACS, and PANGA networks respectively. The GPS site at Penticton (DRAO) is used as a fixed reference site in the GPS analysis.

Data Analysis

The routine analysis of continuous GPS data for northern Cascadia carried out at the Pacific Geoscience Centre includes stations from the Western Canada Deformation Array (WCDA), the British Columbia Active Control System (BCACS), and the Pacific Northwest Geodetic Array (PANGA) (Figure 4). For the tests of dome effects at PGC5, data from all of these networks were used to obtain daily network solutions which provided estimates of daily positions with respect to Penticton (DRAO) and hourly estimates of tropospheric delay for all sites. The GPS analysis strategy is summarized in Table 1.

TABLE 1: PGC ANALYSIS STRATEGY

PROCESSING PARAMETERS	**PROCESSING STRATEGY:**
Processing package	Bernese 4.2 (Hugentobler et al., 2001)
Processing strategy	double-difference baselines formed relative to DRAO (DRAO assumed fixed)
GPS observable	L3 (LC) phase
Ambiguities	fixed, resolved using QIF strategy
Adjustment	network, with all correlations modelled
Orbits and EOP	final IGS orbits & poles
Elevation cutoff angle	10 degrees
Elevation dep. weighting	yes, according to cosine of the zenith angle
Solution sampling rate	120 s
Zenith tropospheric delay	stochastic, piecewise constant (1hr estimates)
A Priori Troposphere Model	Saastamoinen
Troposphere Mapping	wet Niell
Troposphere gradients	yes (6hr estimates)
Solid Earth Tide	on
Ocean tidal loading	on (Pagiatakis, 1992)
Antenna phase centre variations	yes

The network analyses described above were used to determine the time series of changes in height at PGC5 relative to the reference station DRAO, about 300 km away. Least-mean-squares regression was used on the day-to-day changes in the vertical position of PGC5 to estimate simultaneously the linear trend, an annual component and the offsets at times coincident with changes to the dome configuration. The plots shown in Figure 5 have the linear trend and the annual signal removed in order to clearly show the steps that coincide with changes to the dome configuration. Panel A displays the entire time series for the test period, while Panel B has an expanded time scale to show steps 4 and 5 in greater detail. The steps identified by numbers 1 through 5 are summarized in Table 2. The tabulated height changes and the formal one-sigma estimates are those calculated from the regression. The "ZD-inferred" changes in height are discussed below.

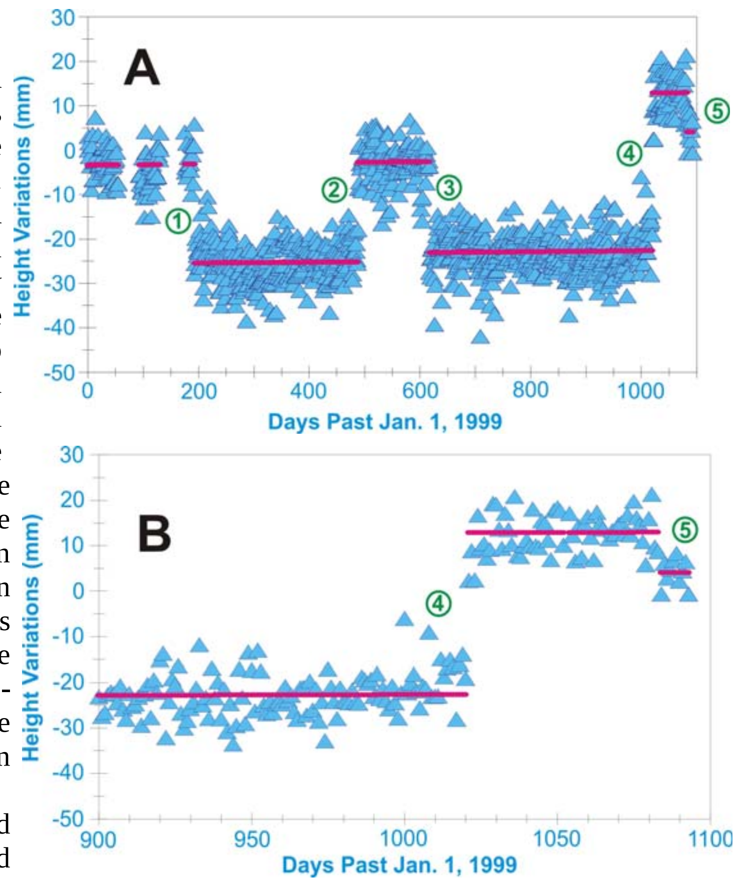


Figure 5. Apparent changes in height at PGC5 wrt DRAO at times of dome changes. Numbers refer to dome changes listed in Table 2. Panel B shows the last two changes (4 and 5) in greater detail. Generally, the presence of a dome delays GPS signals and thereby reduces height estimates since orbits are held fixed.

The zenith delay (ZD) is estimated hourly for the baselines PGC5-DRAO and PGC4-DRAO. Since the antenna setup for PGC4 was unchanged during the testing period, its ZD estimates were used as reference for PGC5 to resolve changes in ZD due to the dome changes at PGC5. From

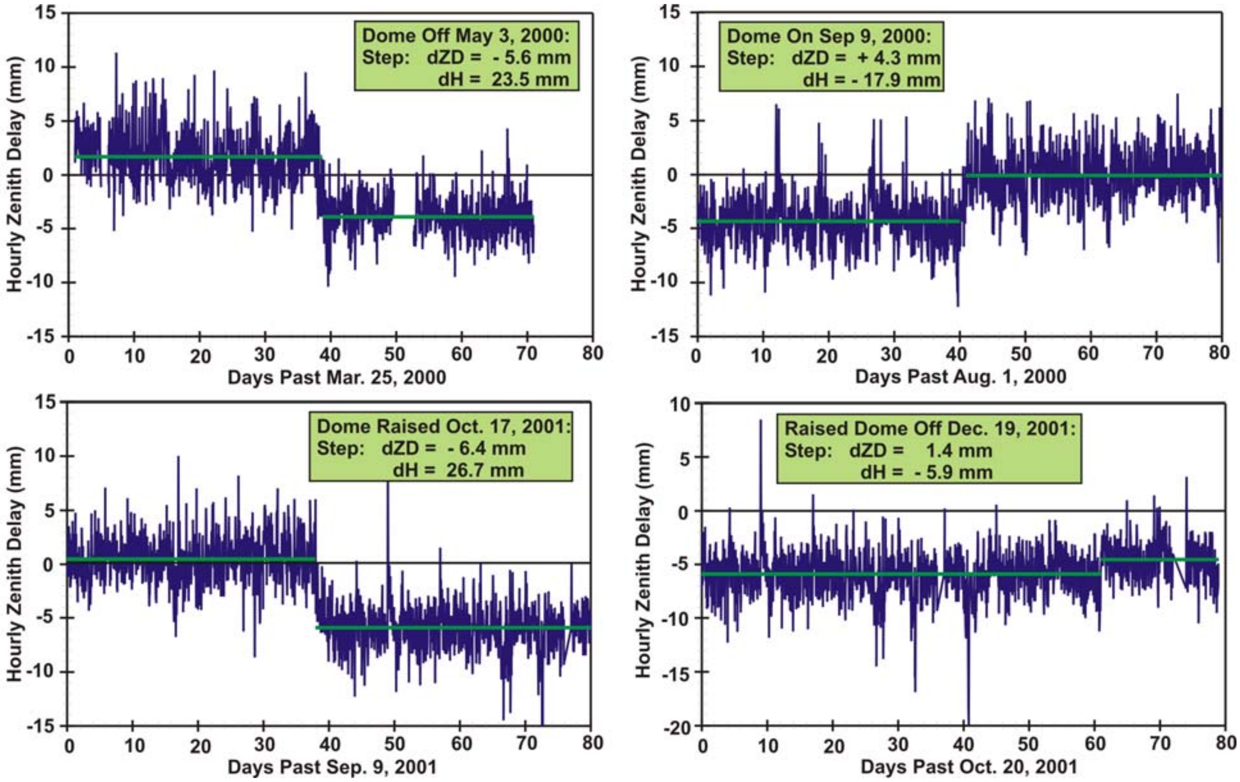


Figure 6. Differential (PGC5-PGC4) Zenith Delay (ZD) estimates. Changes in the hourly ZD estimates at PGC4 are subtracted from those at PGC5. Offsets are estimated by differencing 20 to 40 point averages before and after dome changes. The four panels correspond to actions 2 through 5 listed in Table 2.

Figure 6 which shows the differential ZD (PGC5-PGC4), it is clear that the presence of a dome biases the tropospheric delay estimates. From this we conclude that the dome introduces delay with a 1/cosZ functionality, where Z is the Zenith angle of a satellite. Changes in tropospheric delay directly impact height estimates with a scaling factor that is dependent on elevation cut-off angles and site latitude (Santerre, 1991). For PGC5 (~48^{O}N), the scaling factor is ~4.2. The last column of Table 2 summarizes the expected changes in height based on the observed changes in ZD which were computed from 20 to 40-day averages before and after dome changes. It is significant that raising the dome has an effect analogous to removing the dome, thus mitigating the effect of the dome. The fact that raising the dome 3.6 cm in a sense "over- compensated" dome removal may be a secondary effect related to the introduction of near-field effects due to the screws used to raise the dome, the possible absorption of a "mean-dome-delay" effect into the clock solution, or possibly related to differential L1/L2 effects.

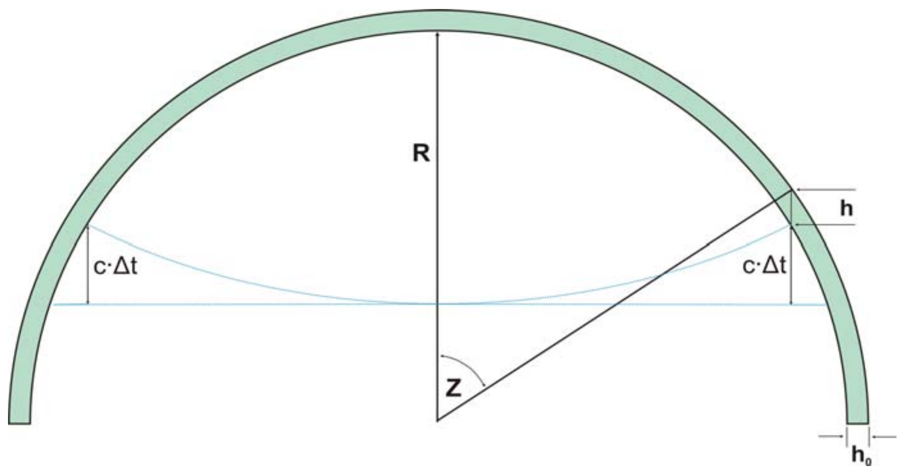
TABLE 2: SUMMARY OF STEPS CAUSED BY DOME CHANGES

STEP#	DATE:	ACTION:	APPARENT HEIGHT CHANGE: Observed	*ZD-Inferred
1.	Jul.13, 1999	Dome On	- 22.3 ±1.4 mm	N/A
2.	May 3, 2000	Dome Off	+22.4 ±1.4 mm	+23.5 ±12.4 mm
3.	Sep. 9, 2000	Dome On	- 20.5 ±1.5 mm	- 17.9 ±13.0 mm
4.	Oct.17, 2001	Dome Raised	+35.5 ±1.7 mm	+26.7 ±12.2 mm
5.	Dec.19, 2001	Raised Dome Off	- 8.9 ±3.1 mm	- 5.9 ±11.3 mm

* ZD-Inferred height changes are calculated from the observed changes in the zenith delay scaled by Santerre's (1991) nominal 1/cosZ factor for mid-latitudes (~4.2).

Discussion

The observations that both the apparent height and the tropospheric delay estimates are affected by the presence and the vertical position of the SCIGN dome can be reconciled by considering the effect of a hemispherical dome on an incident plane wave. With reference to the schematic shown below, consider a plane wave incident from Z = 0 (overhead). This plane wave will develop a “curved” wavefront inside the dome, since the delay will be a function of the refraction index, r_m , and the obliquity of the tangent to the dome with the incident plane wave.



The length of travel through dome material is given by:

$$h = h_0 / \cos Z \qquad (1)$$

where h_0 = thickness of dome and Z = Zenith angle. The delay introduced by the dome material compared to travel through free air:

$$\Delta t = h/c_m - h/c = h(c - c_m) / cc_m$$

Substituting $c_m = c / r_m$ gives:

$$\Delta t = h(r_m - 1) / c \qquad (2)$$

Substituting for h from (1) gives the expression:

$$c{\cdot}\Delta t = h_0 (r_m - 1) / \cos Z \qquad (3)$$

Expression (3) gives the added distance delay along the wavefront as one moves away from the axis of symmetry. This distance delay has a 1/cosZ dependence. If the phase centre of the antenna is *not* coincident with the centre of curvature of the dome, then the delay due to the dome is mapped into tropospheric delay.

For the SCIGN dome, h_0 = 3.175 mm and $r_m \sim 3$, thus giving the relation:

$$c{\cdot}\Delta t \sim 6.35 / \cos Z \text{ mm} \qquad (4)$$

Expression (4) has the form $\Delta H = \Delta\rho / \cos Z_{max}$ which, to a first order, gives a station’s height bias, ΔH, as a function of relative tropospheric zenith delay error, $\Delta\rho$, and the maximum zenith angle of observation, Z_{max}. (Hugentobler, 2001). Using Santerre’s value of 4.2 for Z_{max} of 80^{O} used in our analyses for PGC 5 (i.e. a mid-latitude site), the bias in computed height predicted by (4) is approximately 2.5 cm, in agreement with observed values listed in Table 1.

Although this derivation is neither rigorous nor exact, it is clear that the vertical position of the dome can be adjusted to minimize the effect of utilizing domes - specifically by bringing the centre of curvature of the dome into closer coincidence with the mean L1/L2 phase centre , as pointed out by Braun et al. (1997) in their report on UNAVCO domes. We suggest that this effect be further investigated, since a simple ~3.6 cm extension of the cylindrical base of the dome may prove effective in minimizing spurious vertical shifts of estimated positions when a dome is introduced. A possible corroborative test would be to introduce a 1/cosZ parameter in the processing of existing calibration data with and without a SCIGN dome to examine shifts in the vertical due to such a parameterization.

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References:

Braun, J., B. Stephens, O. Ruud and C. Meertens, The effect of antenna covers on GPS baseline solutions, Technical Report, University NAVSTAR Consortium, Boulder, CO, http://www.unavco.org/facility/science_tech/dev_test/publications/dome_report/domeX5Freport-1.html, 1997.

Dragert, H., X. Chen, and J. Kouba, GPS monitoring of crustal strain in southwest British Columbia with the Western Canada Deformation Array, Geomatica, Vol. 49, 301-313, 1995.

Dragert, H., J. Henton, M. Schmidt, and X. Chen, The resolution of tectonic and non-tectonic signals with the Western Canada Deformation Array, Fall AGU Meeting, San Francisco, Dec. 15-19, 1996.

Hugentobler, U., S. Schaer, and P. Fridez (edit.), Bernese GPS Software Version 4.2, University of Berne, 515 pp, 2001.

Pagiatakis, S.D., Program LOADSDP for the calculation of ocean load effects, Manuscripta Geodetica, 17, 315-320, 1992.

Santerre, R., Impact of GPS satellite sky distribution, Manuscripta Geodetica, 16, 28-53, 1991.