# Measuring geocenter location with GPS tracking: a simulation analysis on observability

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## Abstract

We describe a series of simulations aimed at the potential to improve the determination of geocenter location by augmenting GPS ground tracking with a low-Earth orbiter (LEO) carrying a GPS receiver. Various orbital configurations for the LEO are considered, and the performance of those tracking configurations is compared to that of satellite laser ranging (SLR) tracking. We identify the distance between a satellite and a ground tracking-site as the primary measurement for determining geocenter location. Compared to SLR, which yields an absolute and unambiguous measure of this distance, terrestrial GPS observations provide a weaker (relative) measurement for geocenter determination. The estimation of GPS transmitter and receiver clock errors, which is equivalent to double differencing four simultaneous range measurements, removes much of this absolute distance information. Estimation of carrier-phase ambiguity biases and tropospheric delay parameters for the GPS signals further weakens the data in an absolute sense. Despite these weaknesses we show that ground GPS tracking alone is still usable for geocenter location determination. We also show that when ground GPS tracking data is augmented with tracking data from a GPS receiver onboard a LEO, the observability of geocenter location increases significantly, and become competitive to that of SLR tracking. We compare a variety of LEO orbital configuration, including the proposed orbit for the Geodetic Reference Antenna in Space (GRASP) mission concept. The results suggest several favorable geometric conditions for geocenter location determination.

## Definition of geocenter location

The current conventional definition of geocenter location can be stated as the location of the center of mass of the Earth system in a terrestrial reference frame.

- Earth satellites orbit around the center of mass of the Earth system, governed by the equation of motion.
- Ground stations that define the terrestrial reference frame are tied to the surface of the solid Earth.

## Measuring geocenter location

$$\rho_i = | r - R_i |; \quad R_i = PNUXY(R_{fi} + R_g);$$

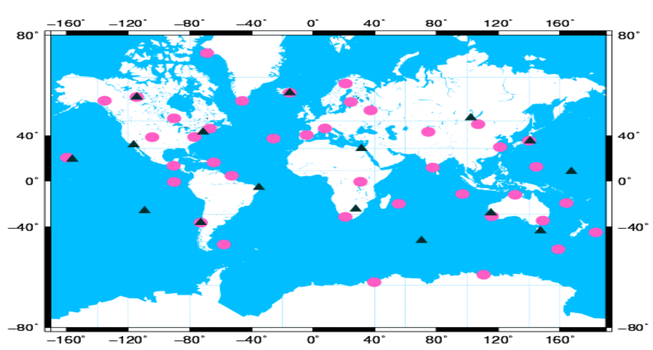
The distance between a satellite and a ground station, $\rho_i$, is the primary measurement for determining geocenter location. The position of satellite, $r$, and the position of ground station, $R_i$, are in Earth centered inertial system. The ground station position in the terrestrial reference frame is $R_{fi}$, and $R_g$ is the geocenter location in the reference frame. The coordinate transformation $P$, $N$, $U$, $X$, and $Y$ are for precession, nutation, Earth rotation and polar motion, respectively.

- "Fiducial method" fixes all $R_{fi}$ to estimate $R_g$.
- "Network shift method" zeroes out $R_g$ to estimate all $R_{fi}$, then derives $R_g$ through a Helmert transformation between the adjusted network and its corresponding polygonal figure in the reference frame.
- It is based on the assumption that the Earth's rotation axis goes through the center of mass that the estimated $R_g$ here represents the location of the center of mass.

## Simulation method

We use 40-station real GPS ground tracking scenario to simulate GPS orbit determination with geocenter location estimation. We use the same ground network for SLR tracking simulation for comparision.

- Use "Fiducial method" to estimate $R_g$, with and w/o LEO.
- Use formal error of estimated $R_g$ as a measure of its observability.
- Compare the observability for various tracking configurations.

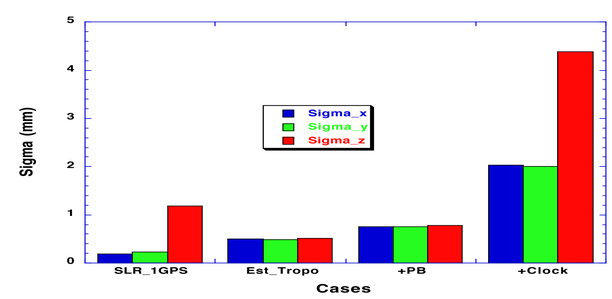


| Data Type | Noise Level (cm) | Elevation Cutoff (deg) |
|---|---|---|
| Ground PC | 50 | 7.5 |
| Ground LC | 0.65 | 7.5 |
| LEO PC | 50 | 0 |
| LEO LC | 0.65 | 0 |
| Ground SLR (2-way) | 1.3 | 20 |

## Ground-only GPS tracking

We use the ground SLR tracking to one GPS satellite as the control case for comparison. We use 1.3cm 2-way SLR measurement noise, equivalent to 0.65cm 1-way noise of GPS LC data, so that the formal errors from the SLR solution can be directly compared with GPS constellation solution.

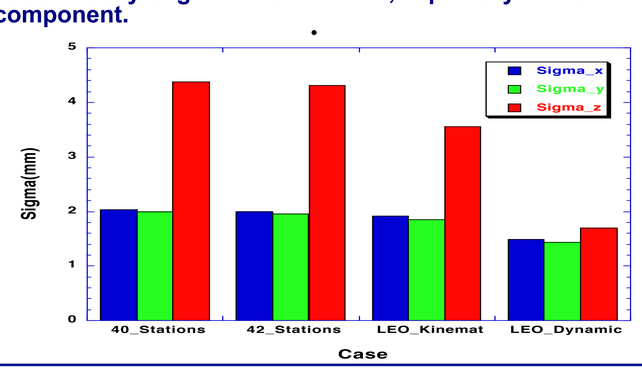
- Estimating tropospheric delay for all GPS stations makes the formal error for $R_g$ bigger than 1-sat SLR solution.
- Estimating phase biases for all GPS carrier phase data passes increases the formal error further.
- Estimating all clock biases as white noise degrades the observability most. However, the geocenter location is not "unobservable" with ground GPS tracking.




## LEO-augmented GPS tracking

We add a GPS receiver onboard LEO satellite to augment the ground GPS tracking, solving for both GPS and LEO orbits, as well as geocenter location.

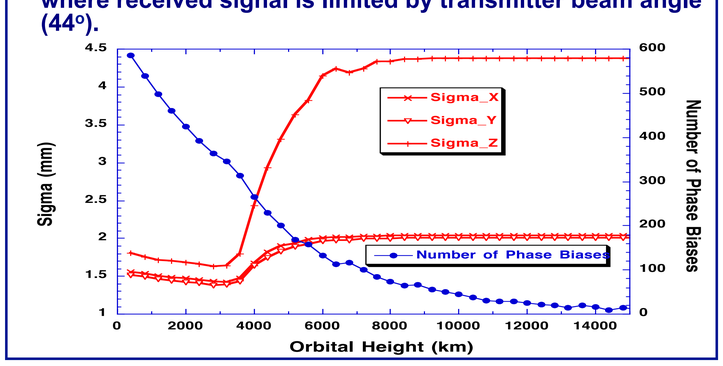
- Adding ground stations has little effect in improving observability of geocenter location.
- Adding LEO-GPS tracking significantly improves the observability of geocenter location, especially the Z component.




## Effect of LEO height

We compare various orbital height for a LEO with inclination angle of 100°:

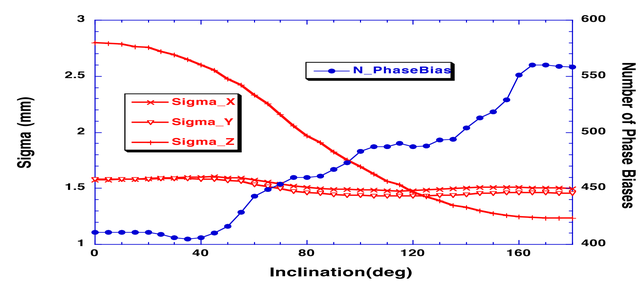
- Observability improves as LEO height increases;
- The formal errors reach minimum at height of 3500km, where received signal is limited by transmitter beam angle (44°).

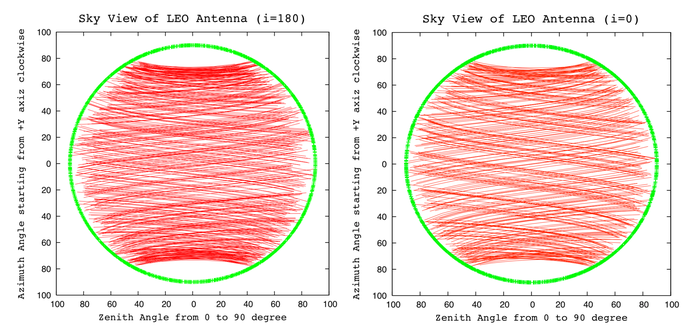



## Effect of LEO inclination

We compare various orbital inclination for a LEO with height of 1400km:

- Observability of Z component improves dramatically as the inclination angle increases;
- Possible reason may be the faster relative motion between LEO and GPS satellites for a retrograde LEO.

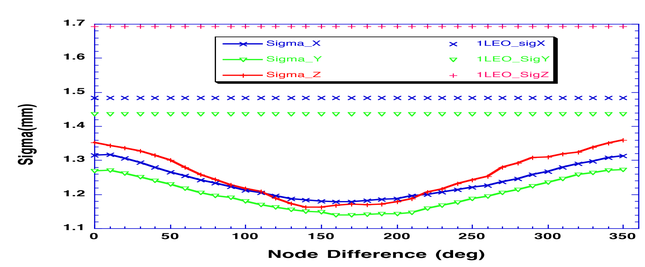


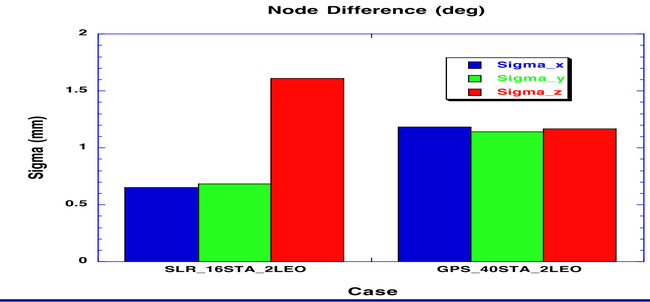




## Effect of LEO plane nodes

We compare various orbital plane node separations for two LEOs with height of 1400km and inclination angle of 100°:

- The formal errors reach minimum at plane separation of 180°;
- Geocenter location observability comparable to that of 16-station SLR tracking to two LEOs.




## Summary

- Ground only GPS tracking is weak for geocenter location determination, but still useable.
- Adding LEO-GPS tracking improves the observability significantly, retrograde LEO is more appealing;
- With two LEOs the GPS tracking is comparable to SLR.

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