A GPS-Based Study to Improve the Accuracy of Local Geodetic Ties at Co-located Sites that Exploits Small-Scale Atmospheric Structure

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Abstract The development of the next-generation of very long baseline interferometry (VLBI) systems, known as VLBI Global Observing System (VGOS), is well underway. Co-location of VGOS stations with instruments from the other space geodetic techniques (i.e., GPS, SLR, and DORIS) is essential for synergistic, robust global reference frame realization. The local ties between reference points of geodetic instruments at co-location sites effectively connect the various techniques together. Precise ties are required for a multi-technique reference frame that is suitable for high-accuracy geophysical applications such as global sea-level change. Unfortunately, the uncertainties of local tie vectors remain above 3 mm. We are investigating approaches that could improve the accuracy of relative positions estimates of the co-location sites. These approaches use external constraints based on local atmospheric structure at core geodetic sites where multi-techniques are co-located. The challenge is to add information to the geodetic solution based on our knowledge of atmospheric structure without biasing the estimates of the intersite vectors. Here, we present preliminary results from tests wherein atmospheric structure is used to enhance the strength of geodetic solutions and combinations. In this study, we use data from existing small-scale GPS networks as a proxy for co-location sites instrumented with next-generation geodetic systems.

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1 Introduction

Improving the accuracy and stability of the Terrestrial Reference Frame (TRF) is critical to determine precise locations on the dynamic earth that meets the scientific standard [1]. The benefit of the scientific observations would be significantly reduced without an accurate and stable TRF [2]. An ITRF is estimated using four major geodetic techniques: Very Long Baseline Interferometry (VLBI), Global Navigation Satellite System (GNSS), Satellite Laser Ranging (SLR), and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). To establish an accurate and stable TRF, the local geodetic ties can be one of the limiting sources of error, since determining the ties between two different techniques can be challenging due to limited accessibility of station reference points [3]. Thus, during the combination of the recent ITRF (e.g., ITRF 2014), the discrepant local ties were downweighted and space geodetic techniques were given more weight [3]. Space geodetic techniques deal with the timing of electromagnetic signals. The atmosphere slows down, bends the signal path, and causes atmospheric refraction, which was studied for single sites in many locations. Yet, ITRF-like solutions do not take into account the known atmospheric structure. Adding atmospheric constraints have the potential to improve the solution significantly. Improved agreement between space geodetic techniques at core geodetic sites (Figure 1) and local ties could help estimating a more robust and accurate future ITRF.

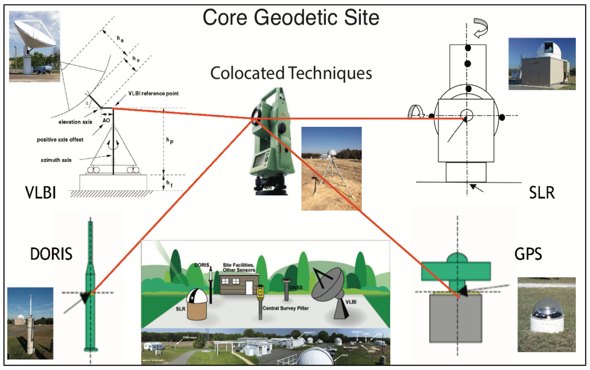

Fig. 1 An example of a core geodetic site with multiple geodetic techniques.

2 Objectives

This paper investigates approaches to improve the accuracy of site position estimates using external constraints (Figure 2). The constraints are generally based on the stochastic and systematic disturbance of the atmosphere at core geodetic sites. Here, we only focused on a GPS-based study because of the data availability and simplicity. We assumed the co-located GPS stations as a proxy for multiple co-located techniques. We will develop a software to read GAMIT [4] normal equations and impose atmospheric constraints incorporating other techniques in the future.

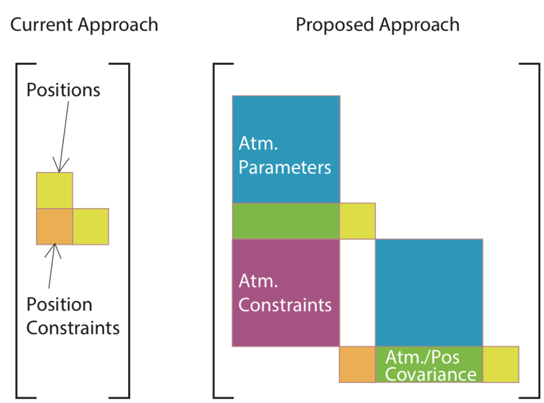

Fig. 2 Covariance Matrix of Geodetic Analysis. Left: Current approach – position parameters (yellow) at core sites are uncorrelated before local-tie constraints (orange) are applied. Right: Proposed approach – position parameters (yellow) are further constrained by atmosphere constraints (purple) applied to local atmosphere parameters (blue) via covariance with position parameters (green).

3 Data and Methods

To test our hypothesis, we selected two core geodetic sites, GGAO and Wettzell, with co-located GPS stations (Figure 3). The inter-station baselines at the core sites are 0 m to 140 m and the baseline between GGAO and WETT is 6500 km. We have used eight stations from both networks; GODE, GODN, GODS, and GODZ from the GGAO network, and WTZA, WTZR, WTZS, and WTZS from the WETT network. Among these stations, GODE and GODZ share the same GPS antenna and form a zero baseline, which provides an opportunity to test and validate our results.

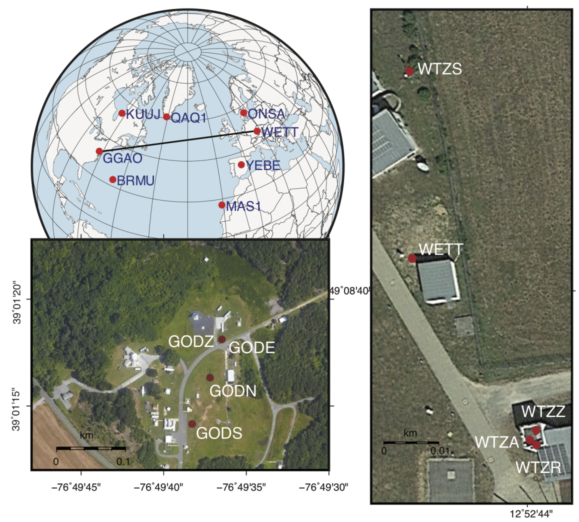

Fig. 3 GPS stations from GGAO (left) and WETT (right) used in this analysis.

We have processed these eight stations in the GAMIT GPS processing software [4]. Six other IGS stations (BRMU, MAS1, YEBE, ONSA, KUUJ, and QAQ1) were used as reference stations to stabilize the solution. The daily normal equations resulting from GAMIT were saved with both position and atmospheric parameters such as zenith delay and gradient as well as their fully populated covariance matrices. We have developed a software to read the normal equations and imposed simple atmospheric constraints on the local baseline using the constrained least squares method. The constraints are based on the local atmospheric structures (e.g., Kolgomorov-type turbulence and frontal systems). The result between

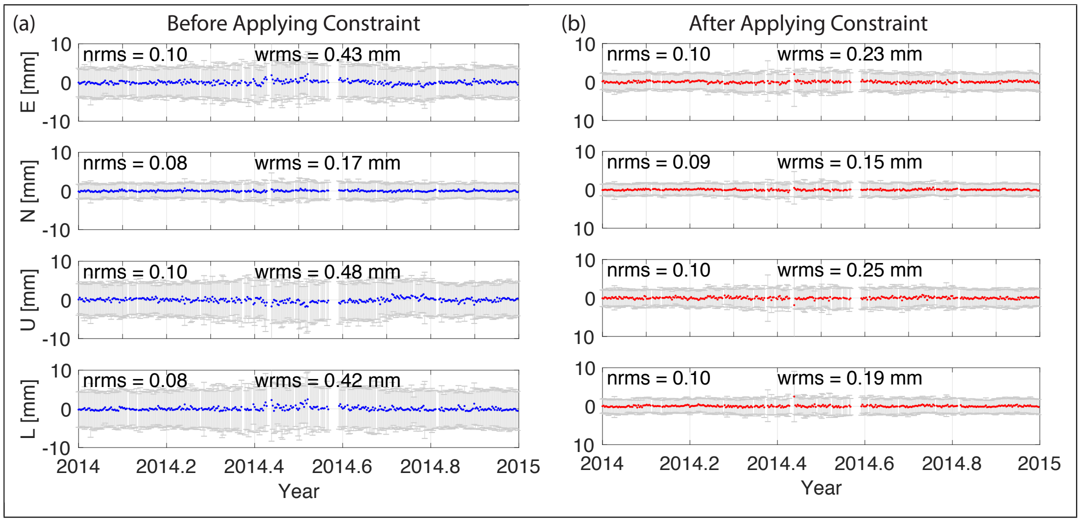

Fig. 4 GODE–GODZ (zero baseline) baseline scatter plot. a) Baseline scatter before applying atmospheric constraints, and b) Baseline scatter after applying atmospheric constraints.

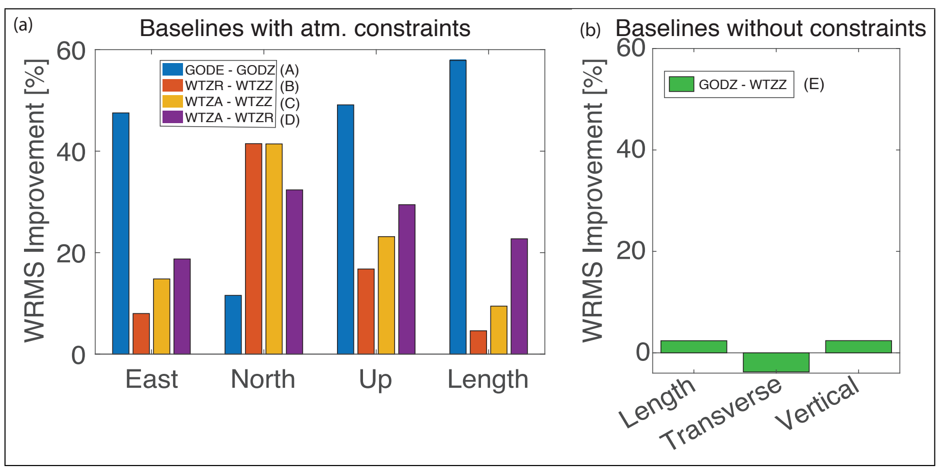

Fig. 5 a) Baselines with atmospheric constraints. b) Baseline without atmospheric constraints.

the constrained and non-constrained solutions were assessed whether it has any impact on baselines and their components.

4 Effect of Atmospheric Constraints on Geodetic Solutions

Here, we constrained the zenith total delay and multiple zenith delay differences between GODE and GODZ to be zero (Figure 4). This represents a ground-truth test because the two stations share the same GPS antenna; hence, it is a zero-baseline length. Similar constraints were applied to WTZA, WTZR, and WTZZ, because being only 1–3 m apart in practice they share the same atmosphere (Figure not shown here; summary is in Figure 5). We have compared the scatter of baseline component estimates before and after applying atmospheric constraints, and calculated in topocentric (i.e., east, north, and up) and baseline-centric (length, transverse, and vertical) coordinates for short and long baselines, respectively. Figure 4 shows that the baseline scatter of east, north, and up, and the length component between GODE and GODZ reduced by 50% after applying constraining the zenith total delay difference to be zero.

5 Conclusion and Future Steps

Our initial test suggests that adding atmospheric constraints into the combination reduced the scatter of topocentric baseline component and length estimates. In the future, we plan to analyze the multi-year solutions, incorporating data from the other geodetic techniques, and adding atmosphere constraints from meteorology and atmospheric dynamics.

Acknowledgements

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