GPS APPLICATIONS FOR GEODYNAMICS AND EARTHQUAKE STUDIES

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ABSTRACT
Geodetic measurements obtained with the Global Positioning System (GPS) are increasingly more widely applied in geophysical studies. In this paper, we review the changes to the technology of GPS geodesy over the last five years that are responsible for this increased applicability. We survey geophysical investigations employing GPS to measure coseismic, postseismic, and interseismic deformation; plate motion and crustal deformation at plate boundaries; volcano deformation; and the deformation associated with glacial isostatic adjustment and its application to sea-level studies. We emphasize the use of GPS determinations for the modeling of this wide variety of geophysical phenomena. We also discuss the recent advent of permanent GPS networks for regional geophysical studies, as well as the possible future of GPS surveying in light of the recent advances.

INTRODUCTION
The Global Positioning System (GPS), designed by the US Department of Defense for military and civilian navigation and positioning, has become the geodetic method of choice for studying a wide range of geophysical phenomena. GPS measurements are now in use to determine the motion of the Earth’s tectonic plates, to study deformation around active faults and volcanos, and to measure the adjustment of the Earth’s surface due to past and present changes in...
signal multipath (see below), and offer improved ambiguity resolution and estimation of atmospheric delays. So-called rapid-static (e.g. Merminod & Rizos 1994) or kinematic (e.g. Lu & Lachapelle 1992) methods have achieved centimeter-level horizontal precision on short to intermediate baselines.

In the remainder of this section, we focus on four areas that have evolved significantly in the last several years. These areas are (a) the GPS constellation, including the impact of broadcast signal degradation and encryption; (b) GPS receivers and antennas, with a discussion of errors caused by antenna phase-center variations, multipath, and electromagnetic coupling; (c) available global infrastructure for GPS geodesy; and (d) atmospheric propagation delay, one of the most important sources of error in the analysis of GPS data. Of course, this is far from an exhaustive list of all issues relevant to the technology of GPS surveying. Blewitt (1993), for example, discusses ambiguity resolution, treatment of clock errors, and surveying methods, and because of the important changes to GPS in the last several years, all these topics could be revisited here. Instead, our treatment is limited to several important topics, and the discussion of the detailed implications for GPS surveying methods and technology can be found in the cited works.

The GPS Constellation

The 24-satellite GPS network was first realized in July 1992. It is difficult to overestimate the impact that the increased satellite coverage has had, not only on logistical planning for a measurement campaign, but also on the accuracy achievable in parameter estimates (e.g. Santerre 1991) and, ultimately, on the kinds of science to which it is possible to apply GPS. For example, continuous satellite coverage enables subdaily, continuous estimation of position (Genrich & Bock 1992; Elósegui et al 1996) and atmospheric water vapor and temperature (e.g. Yuan et al 1993; Rocken et al 1995). The improved geometric coverage globally has also enabled the development of “fiducial-free” network solutions (e.g. Heflin et al 1992).

The related issues of selective availability (SA) and anti-spoofing (AS) continue to be concerns in geodetic applications. Both SA and AS were implemented for US national security reasons, and both limit the accuracy of the GPS technique for certain applications. SA degrades the quality of the broadcast satellite position information and clock corrections, as well as the effective satellite oscillator frequency. This “dithering” introduces noise to the measured carrier beat phases, with changes in the transmitted L1 frequency, for example, of up to 1 Hz (Feigl et al 1991). Several schemes have been developed for dealing with this aspect of SA (e.g. Feigl et al 1991; Rocken & Meertens 1991). For geodetic applications in which double-differencing (or its equivalent) can be applied to synchronized observations (e.g. Hofmann-Wellenhof et al 1994),

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