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Reactivation of the Venezuelan vertical deflection data set from classical astrogeodetic observations

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ABSTRACT

Astrogeodetic vertical deflections (VDs) are gravity field functionals which are independent from any other field observation such as gravity accelerations from gravimetry or geoid undulations from GPS and geometric levelling. They may be useful for the validation of global geopotential models or height transfer via GPS and astronomical levelling. VDs are sensitive to the local mass-distribution, so can be used in geophysical studies, too. Over Southern Hemisphere continents in general and South America in particular, VDs are exceptionally rare. This paper describes the reactivation of a unique VD data set that extends over parts of the Andes Mountains in Venezuela. The VD data was acquired 1983 and 1985 with classical astrogeodetic instrumentation at 24 field stations along a ~80 km traverse crossing the Cordillera de Mérida with observation site elevations as high as ~4500 m. To be compatible with modern geocentric gravity field products, the geodetic coordinates of the VD sites were transformed from the historic (non-geocentric) Venezuelan reference system to the geocentric ITRF2014, with residuals smaller than ~1 m. In the ITRF, the measured VDs have RMS signal strengths of ~20 arc-seconds (North-South) and ~14 arc-seconds (East-West), with magnitudes exceeding 60 arc-seconds at one benchmark. The observed VDs were compared against VDs from GRACE, GOCE and EGM2008 data and from the ultra-high resolution GGMplus gravity maps. The GGMplus model was found to capture ~85 to 90% (in terms of root-mean-square signals) of the measured VD signals. Both VD components are in ~2 arc-sec agreement with GGMplus. Overall, the agreement between observed VDs and modelled VDs is considered satisfactory, given the VDs were measured in a topographically rugged region, where residual signals may be large and global models are not well supported through regional terrestrial gravity data. The VDs may be useful, e.g., for the assessment of high-frequency constituents of present and future high-degree gravitational models (e.g., EGM2020) and calibration of model commission errors. The Venezuelan VD data is freely available.

1. Introduction

Vertical deflections (VDs) are angular differences between the direction of the plumb line and some geometric reference direction. With the ellipsoidal normal as reference direction at the Earth's surface, VDs in Helmert definition are obtained (Jekeli, 1999). Global Navigation Satellite Systems (GNSS), such as the Global Positioning System GPS (e.g., Seeber, 2003) deliver geodetic coordinates that define the ellipsoidal normal. The direction of the plumb line can be determined with astrogeodetic instrumentation for star observation and precise timing equipment (e.g., Torge and Müller, 2012, p162ff).

Before the advent of satellite surveying techniques, regional best-fitting ellipsoids were often used as reference for the geodetic coordinates. In that case, VDs are defined in a regional reference frame. Opposed to this, VDs are globally consistent when a global geocentric ellipsoid aligned to the axes of the International Terrestrial Reference System (ITRS) is used. When referred to a regional ellipsoid, VDs are sometimes denoted as *relative* VDs, and, conversely, in case of a global geocentric ellipsoid as *absolute* VDs (e.g., Featherstone and Rüeger, 2000, Featherstone and Olliver, 2013).

The primary value of astrogeodetic VDs is their independence from any other gravity field observable (e.g., gravity accelerations from gravimetry, gravity gradients from gradiometry, or geoid undulations from GPS heights and geometric levelling), making them suitable for validation of gravity field models (e.g., Jekeli, 1999). As another benefit, astrogeodetic VDs can be used for economic transfer of height differences by combining the classical technique of astronomical levelling with GPS heighting (Hirt, 2004). They are also suitable for

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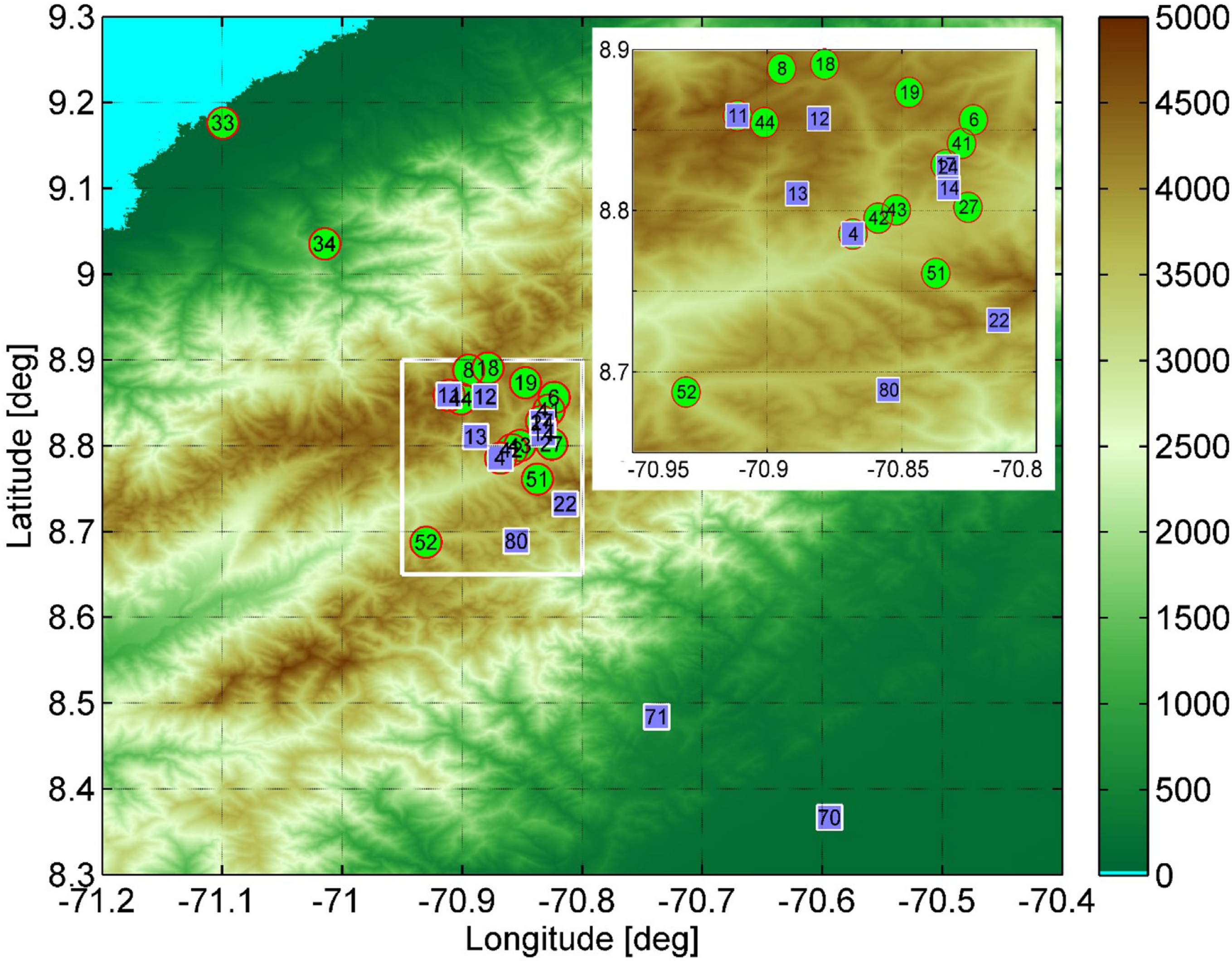

Fig. 1. Topographic map of the North-Eastern extension of the Andes, known as *Cordillera de Mérida* (Merida Mountains), and location of the 16 zenith camera measurements (green circles, BM 4 and BM 11 observed with zenith camera, too) and 11 astrolabe measurements at 10 sites (blue squares). Topography from the MERIT DEM. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

geophysical study of the local mass-density distribution (e.g., Tugluoglo, 1971; Wildermann, 1988; Bürki, 1989; Somieski, 2008).

Historically, classical instrumentation such as theodolites or astrolabes were used for VD measurements. In the ~1970s, photographic zenith cameras were developed to accelerate the field observation (e.g., Wissel, 1982; Wildermann, 1988; Bürki, 1989). Since the beginning of the 21st century, astrogeodetic observations are mostly carried out with efficient and automated digital instruments such as digital zenith cameras (e.g., Kudrys, 2009; Hirt et al., 2010a; Abele et al., 2012; Halicioglu et al., 2012; Hanada et al., 2012; Wang et al., 2014; Guillaume, 2015) or imaging theodolites (Guillaume et al., 2012; Tóth and Völgyesi, 2016; Hauk et al., 2017; Schack et al., 2018).

Today, available VD data sets concentrate on North America (Pavlis et al., 2012; Smith et al., 2013; Van Westrum, 2016; Wang et al., 2017) and Europe (e.g., Bürki, 1989; Kühtreiber, 2003; Hirt, 2004; Müller et al., 2004; Bürki et al., 2007; Somieski et al., 2007; Somieski, 2008; Hirt et al., 2010b; Voigt, 2013; Bucha et al., 2016), and also cover parts of Australia (Claessens et al., 2009; Schack et al., 2018). However, most countries of Asia, Africa and South America are still devoid of VD observations. An exception is Venezuela, where dedicated VD measurement campaigns have been carried out in 1983 and 1985 along a geotraverse crossing the Merida Mountains (Wildermann, 1988). The VD data has been collected with a photographic zenith camera and astrolabe at 24 field stations and utilized in a case study of the rugged gravity field of the Andes (Wildermann, 1988).

The goal of the present paper is to reactivate the Venezuelan VD data set for modern gravity field studies. We start by giving a brief review of the VD campaigns and instrumentation deployed in the Merida Mountains (Section 2). Then, the transformation of the original geodetic station coordinates from the local network to the ITRS is described. This is crucially important to make the VDs compatible with modern gravity field data that implicitly relies on global geocentric reference frames (Section 3). The transformed VDs are then compared with VDs derived from two global gravity field models of different spatial resolution, showing relatively good agreement between both data sets (Section 4). Error sources affecting the quality of the VDs are discussed in Section 5 before an outlook is given in Section 6.

The VD data set discussed in this paper can be rated as exceptionally rare. To the knowledge of the authors, the Venezuelan VD data is one of the few – if not the only VD traverse data set – that is available over the Andes in particular and South America in general. The data set covers one of the topographically most rugged regions in the world, and extends over an elevation range of ~4500 m. Opposed to other parts of the world, terrestrial gravity data sets are not very dense over Venezuela. Consequently, global gravity field models are not very well supported by ground observations at short spatial scales, and VD data