GEOPHYSICS, VOL. 66, NO. 6 (NOVEMBER-DECEMBER 2001); P. 1660–1668, 4 FIGS., 3 TABLES.

# Tutorial

# Ellipsoid, geoid, gravity, geodesy, and geophysics

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**ABSTRACT**

Geophysics uses gravity to learn about the density variations of the Earth's interior, whereas classical geodesy uses gravity to define the geoid. This difference in purpose has led to some confusion among geophysicists, and this tutorial attempts to clarify two points of the confusion. First, it is well known now that gravity anomalies after the "free-air" correction are still located at their original positions. However, the "free-air" reduction was thought historically to relocate gravity from its observation position to the geoid (mean sea level). Such an understanding is a geodetic fiction, invalid and unacceptable in geophysics. Second, in gravity corrections and gravity anomalies, the elevation has been used routinely. The main reason is that, before the emergence and widespread use of the Global Positioning System (GPS), height above the geoid was the only height measurement we could make accurately (i.e., by leveling). The GPS delivers a measurement of height above the ellipsoid. In principle, in the geophysical use of gravity, the ellipsoid height rather than the elevation should be used throughout because a combination of the latitude correction estimated by the International Gravity Formula and the height correction is designed to remove the gravity effects due to an ellipsoid of revolution. In practice, for minerals and petroleum exploration, use of the elevation rather than the ellipsoid height hardly introduces significant errors across the region of investigation because the geoid is very smooth. Furthermore, the gravity effects due to an ellipsoid actually can be calculated by a closed-form expression. However, its approximation, by the International Gravity Formula and the height correction including the second-order terms, is typically accurate enough worldwide.

## INTRODUCTION

Geophysics has traditionally borrowed concepts of gravity corrections and gravity anomalies from geodesy. Their uncritical use has sometimes had unfortunate results. For example, the "free-air" reduction was historically interpreted by geodesists as reducing gravity from topographic surface to the geoid (mean sea level). This interpretation is a useful fiction for geodetic purposes, but is completely inappropriate for geophysics. In geophysics, gravity is used to learn about the density variations of the Earth's interior. In geodesy, gravity helps define the figure of the Earth, the geoid. This difference in purpose determines a difference in the way to correct observed data and to understand resulting anomalies.

Until a global geodetic datum is fully and formally accepted, used, and implemented worldwide, global geodetic applications require three different surfaces to be clearly defined. They are (Figure 1): the highly irregular topographic surface (the landmass topography as well as the ocean bathymetry), a geometric or mathematical reference surface called the ellipsoid, and the geoid, the equipotential surface that mean sea level follows.

Gravity is closely associated with these three surfaces. Gravity corrections and gravity anomalies have been traditionally defined with respect to the elevation. Before the emergence of satellite technologies and, in particular, the widespread use of the Global Positioning System (GPS), height above the geoid (i.e., the elevation) was the only height measurement we could make accurately, namely by leveling. The GPS delivers a measurement of height above the ellipsoid. Confusion seems to have arisen over which height to use in geophysics.

Published on Geophysics Online May 31, 2001. Manuscript received by the Editor August 9, 2000; Revised manuscript received February 26, 2001.
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