we find poorer constraints on the resulting best fit, suggesting the complicating influence of lateral inhomogeneity.

G51B CC: 516 A Friday 0830h

Heights and Geoid Modeling: North America II *(joint with OS, T, SEDI)*

Presiding: **D R Roman,** U.S. National Geodetic Survey**; M Veronneau,** Geodetic Survey Division, National Resources Canada

G51B-01 0830h

A Gravimetric Geoid Model for Vertical Datum in Canada

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The need to realize a new vertical datum for Canada dates back to 1976 when a study group at Geodetic Survey Division (GSD) investigated problems related to the existing vertical system (CGVD28) and recommended a redefinition of the vertical datum. The US National Geodetic Survey and GSD cooperated in the development of a new North American Vertical Datum (NAVD88). Although the USA adopted NAVD88 in 1993 as its datum, Canada declined to do so as a result of unexplained discrepancies of about 1.5 m from east to west coasts (likely due to systematic errors). The high cost of maintaining the vertical datum by the traditional spirit leveling technique coupled with budgetary constraints has forced GSD to modify its approach. A new attempt (project) to modernize the vertical datum is currently in process in Canada. The advance in space-based technologies (e.g. GPS, satellite radar altimetry, satellite gravimetry) and new developments in geoid modeling offer an alternative to spirit leveling. GSD is planning to implement, after stakeholder consultations, a geoid model as the new vertical datum for Canada, which will allow space-based technology users access to an accurate and uniform datum all across the Canadian landmass and surrounding oceans. CGVD28 is only accessible through a limited number of benchmarks, primarily located in southern Canada. The new vertical datum would be less sensitive to geodynamic activities (post-glacial rebound and earthquake), local uplift and subsidence, and deterioration of the benchmarks. The adoption of a geoid model as a vertical datum does not mean that GSD is neglecting the current benchmarks. New heights will be given to the benchmarks by a new adjustment of the leveling observations, which will be constrained to the geoid model at selected stations of the Active Control System (ACS) and Canadian Base Network (CBN). This adjustment will not correct vertical motion at benchmarks, which has occurred since the last leveling observations. The presentation provides an overview of the “Height Modernization” project, and discusses the accuracy of the existing geoid models in Canada.

G51B-02 0845h INVITED

Recent Progress Towards New Australian Geoid Models

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The members of the Western Australian Centre for Geodesy and our collaborators in Australia and around the world are active in the determination of future generations of the Australian geoid model and its relation to the Australian Height Datum (AHD). As part of ongoing Australian Research Council grant funding, we continue to improve our geoid determination theories, techniques and computer software for provision to the National Mapping Division of Geoscience Australia (formerly AUSLIG). We aim to release a new geoid model this year, called AUSGeoid2004. This paper summarises our work over the last few years on several key aspects to produce a new generation of geoid model for Australia that will better support the direct transformation of GPS-derived heights to the 1971 realisation of the AHD. These activities include:
· Experiments with global geopotential models derived from the new dedicated satellite gravity field missions, which seem to identify long-wavelength errors in the Australian land gravity data;
· Optimisation of the kernel modification so as to high-pass filter out these long-wavelength errors;
· Computation of new high-resolution grid of gravimetric terrain corrections from version 2 of the GEODATA 9-arc-second digital elevation model;
· Identification of erroneous ship-track gravity data using multi-mission satellite altimetry, and the selection of the best grid of altimeter-derived gravity anomalies around Australia;
· Trials of the University of New Brunswick’s approach to regional geoid determination, and its comparison with the classical remove-compute-restore technique and the approaches that were used for AUSGeoid98;
· Experiments on griding different types of terrestrial gravity anomalies prior to regional gravimetric geoid computation;
· Investigation of various methods to fit the gravimetric geoid model to the AHD with regional GPS data, to produce a geoid-type’ surface that will support the more direct transformation of GPS-derived heights to the AHD. Results of experiments on all these facets will be presented, together with some coarse estimates of the improved precision that can be expected from future releases of the Australian geoid models in relation to the AHD.

G51B-03 0905h INVITED

Using Energy Integrals for Airborne Geoid Profiling With GPS/INS

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Traditional geoid determination from airborne gravimetric data is based on the conventional space-wise approach that transforms the vertical gravitational acceleration to gravitational potential (and the geoid) in the form of a solution to a boundary-value problem in potential theory. The combination of 3-D airborne GPS and an inertial navigation system (INS) (consisting of accelerometers and gyros) has recently also been used to transform the horizontal gravitational acceleration into potential (and geoid) differences by simple line integration (essentially a time-wise approach), thus enabling geoid profiling without extensive areal survey coverage. In both cases, GPS positions must be numerically differentiated twice (or Doppler velocities once) to obtain the kinematic acceleration. We have developed a new profiling technique for geoid determination from airborne GPS/INS that utilizes velocities rather than accelerations to yield potential (and geoid) differences on the basis of conservation of energy. This eliminates an essentially redundant differentiation with subsequent integration of GPS velocities. Preliminary tests on airborne GPS/INS data show that this new technique, borrowed from recent satellite gravity mapping data processing methods, yields relative geoid accuracy that is better than 10 cm, and is comparable to the alternative profiling method.

G51B-04 0925h INVITED

The role of spaceborne gravimetry in height definition and unification

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The basic height equation, $h = H + N$, connects physical and geometric heights through the geoid. The equation is violated for several reasons: choice of height datum definition, height systems used, synoptic character of leveling and gravity data sets, extent and geography of leveling network, and others. Moreover, evaluation of the height equation occurs on discrete benchmarks, whereas the geoid and the gravity field are inherently field quantities with certain spectral characteristics. On top of these problems, we are now entering an era in which height systems must be regarded fundamentally as time-variable. This presentation attempts to identify and quantify the error sources that cause discrepancies in the height equation. It will then discuss how spaceborne gravimetry can contribute to the definition and establishment of a continental or even global height system. The discussion will include classical satellite-only models and the gravity satellite missions CHAMP, GRACE and GOCE.

G51B-05 0945h

Dynamic geoid modelling - A general overview

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Since the deloading of the ice at the end of the last ice age the Earth exerts continuous viscous rebound driven by the disequilibrium due to the mass imbalance in the initially ice covered areas. The process of the glacial isostatic adjustment (GIA) is identified by the geological and geophysical observations. In addition, a variety of geodetic measurements, such as time variations of gravity and geopotential, vertical and horizontal displacement rates, sea level variations measured by altimetry, etc., provide increasingly important constraints for GIA modelling. Vertical displacement rates over Laurentia predicted by the contemporary rebound models point to the necessity for the realization of a time-dependent reference surface for orthometric heights. An indispensable part of this is the determination of a time-dependent geoid, which raises the questions: (i) what kinds of data can be used and (ii) how they can be combined in an optimal way. In view of this problem, a cursory qualitative and quantitative analysis of the data available in Canada has been performed. The application of the classical geodetic techniques, such as Stokes integration and least squares collocation in time-varying gravity field modelling has been examined. Special attention has been paid to least squares collocation as a traditional technique for combining heterogeneous data. This paper presents an overview of the required analysis and recommends further studies that will contribute to the definition and realization of a dynamic geoid model for Canada.

G51B-06 1030h

Arctic Ocean Geoids from GRACE and Surface Gravity Data: Comparisons with Altimetric sea Surface Topography

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Altimetric observations of much of the Arctic Ocean’s sea-surface and sea-ice topography continue flowing from the ICESat and ENVISAT satellites. In addition, altimetric observations from CryoSat - scheduled for launch this November - should greatly enhance matters by extending coverage of the Arctic poleward to 88N. All these observations need to be referred to a highly accurate geoid in order to properly estimate the dynamic ocean heights as well as the ’freeboard’ heights of sea ice. Thus we are developing suitable high-accuracy, high resolution gravimetric geoids of the Arctic Ocean. We have completed a preliminary ”hybrid” geoid by combining data from the GRACE mission with detailed gravity from the international Arctic Gravity Project (ArcGP). This hybrid geoid will be compared with altimetric mean sea surfaces (ERS, ICESat etc) and evidence of dynamic topography (amplitudes on order of decimeters) will be presented. Such geoids will enable satellite altimeters to help monitor and comprehensively map thickness plus mass flux of Arctic sea ice. Moreover, these geoids will allow the application of satellite altimetry to mapping of the Arctic Ocean circulation and surface geostrophic currents. In addition, they will provide a reference against which absolute measurements of time-varying oceanographic features, such as dynamic topography and sea ice cover, can be repeatedly calculated through comparison with altimetric height measurements.

G51B-07 1045h

Estimation of Systematic Errors in the Canadian Terrestrial Gravity Data From GRACE Gravity Results

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Systematic errors in terrestrial gravity data arise from datum errors at the control stations and from elevation and instrumental errors at spot measurements. It is extremely difficult, if at all possible, to estimate and correct these errors through the analysis of the historical records of the gravity projects. The GRACE gravity mission is currently mapping the Earth's gravity field with a homogeneous accuracy better than 1 mGal in gravity, corresponding to a few centimeters in geoid height, for wavelength greater than 300 km. It provides an accurate reference for determining the long-wavelength systematic errors in the terrestrial gravity data. However, the challenge is to remove the short-wavelength components from the terrestrial data in order to eliminate the aliasing errors when estimating systematic errors. In other words, we need an effective low-pass averaging/filtering technique. Several former discussions contribute important insights on characteristics of commonly used methods: Pellinen 1966; Rapp 1977; Gaposchkin 1980; Colombo 1981; Jekeli 1981. In this study, we investigate methods of determining systematic errors in terrestrial gravity through a synthetic gravity field, and apply them to the actual terrestrial gravity data in Canada. EGM96, up to degree and order 360, is used for the synthetic gravity field. First, we test four methods (blockwise, Pellinen's, Gaussian and ideal averaging) to perform low-pass filtering of the EGM96 high frequency gravity field. Second, we derive harmonic gravity models to degree and order 70 from the filtered synthetic field. Third, the new harmonic models are compared to EGM96 (degree and order 70). The best filtering method is expected to give residuals converging towards zero. For the actual gravity field, a harmonic gravity model (degree and order 70) is derived from the filtered Canadian terrestrial gravity data, which are expanded to the entire Earth surface by a GRACE gravity model. This harmonic model is compared to the GRACE gravity model (for the same degree and order) to estimate the systematic errors. Finally, the estimated biases are applied to the terrestrial gravity data for determining a geoid model for Canada, which is validated against GPS/leveling data.

G51B-08 1100h

A Precise Gulf of Mexico Geoid for Oceanographic and Hydrographic Applications

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The Naval Research Laboratory and the Naval Oceanographic Office have been developing a precise gravimetric geoid for the Gulf of Mexico. The geoid provides a unified MSL datum for altimetry (airborne and satellite), tide gages, moored pressure gauge/inverted echo sounders and other water-level measurement systems. Source gravity data for the geoid include GRACE, historical terrestrial and marine gravity data, and new airborne gravity profiles collected on dense grids in the northern Gulf and along TOPEX, ERS-1/2 and GFO sub-satellite tracks. Additionally, several thousand airborne expendable bathythermograph (AXBT) profiles were obtained along the altimetry tracks to calculate dynamic heights of the sea-surface. These dynamic heights were differenced with the total sea-surface heights from concurrent satellite and airborne altimetry, resulting in point relative geoid estimates by steric leveling. The "steric geoid" heights provide an independent standard of comparison for the gravimetric geoid, and clearly delineate where lack of gravity data in the southern Gulf and Caribbean impact the accuracy of the gravimetric geoid. Over the northern half of the Gulf (north of 26 degrees) we estimate the rms accuracy of the gravimetric geoid at approximately 10 cm. The steric leveling data can also be used to develop a low-order correction surface to the distorted southern Gulf geoid, extending the area of validity. By subtracting the corrected geoid from the GSFC00 altimetric mean sea-surface model we obtain an estimate of the mean dynamic topography (and by geostrophic balance the mean currents) that are built into the mean altimetry model.

G51B-09 1115h

Effect of High Resolution Altimetric Gravity Anomalies on the North America Geoid Computations

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Geoid computation is a global integration of the surface gravity data. On the North America continent, more than 3 million surface gravity data were used. Outside the continent, altimetric gravity anomalies are used to fill in the ocean areas. More than two decades of altimetry provide abundant data for marine geoid and gravity anomaly recovery, a number of models are available. Even if the gravity anomaly differences between the models are about ±3 mgals, the impact of the differences on the geoid is noticeable. A preliminary test made between the KMS98 and GSFC00.1 gravity models revealed a RMS value of the differences of 5 cm, accompanying an east-west slope of 0.03 ppm over the United States. The impact is profound in the shoreline areas. The geoid change reaches 10 cm in Florida. A clear improvement was shown in comparison with the GPS/leveling data in the Florida area, where the RMS value of the differences decreased from 26 cm to 18 cm. The effect of altimetric gravity is important for the cm-geoid. Various models will be tested and optimal ways to deal the ocean gravity data will be explored. As a quality indicator of the geoid, the sea surface topography will be computed and compared with other oceanic models.

G51B-10 1130h

Atmospheric effect in three-space scenario for the Stokes-Helmert method of geoid determination

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Abstract: According to the Stokes-Helmert method for the geoid determination by Vanîèek and Martinec (1994) and Vanîèek et al. (1999), the Helmert gravity anomalies are computed at the earth surface. To formulate the fundamental formula of physical geodesy, Helmert's gravity anomalies are then downward continued from the earth surface onto the geoid. This procedure, i.e., the inverse Dirichlet's boundary value problem, is realized by solving the Poisson integral equation. The above mentioned "classical" approach can be modified so that the inverse Dirichlet's boundary value problem is solved in the No Topography (NT) space (Vanîèek et al., 2004) instead of in the Helmert (H) space. This technique has been introduced by Vanîèek et al. (2003) and was used by Tenzer and Vanîèek (2003) for the determination of the geoid in the region of the Canadian Rocky Mountains. According to this new approach, the gravity anomalies referred to the earth surface are first transformed into the NT-space. This transformation is realized by subtracting the gravitational attraction of topographical and atmospheric masses from the gravity anomalies at the earth surface. Since the NT-anomalies are harmonic above the geoid, the Dirichlet boundary value problem is solved in the NT-space instead of the Helmert space according to the standard formulation. After being obtained on the geoid, the NT-anomalies are transformed into the H-space to minimize the indirect effect on the geoidal heights. This step, i.e., transformation from NT-space to H-space is realized by adding the gravitational attraction of condensed topographical and condensed atmospheric masses to the NT-anomalies at the geoid. The effects of atmosphere in the standard Stokes-Helmert method was intensively investigated by Sjöberg (1998 and 1999), and Novák (2000). In this presentation, the effect of the atmosphere in the three-space scenario for the Stokes-Helmert method is discussed and the numerical results over Canada are shown. Key words: Atmosphere - Geoid - Gravity

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