G41C-04 0830h POSTER

Satellite Formation Flying for Geodetic Applications: Analysis of J2-Disturbed Orbits

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Future geodetic satellite missions will most probably make use of the concepts of satellite formation flying. Most studies use Hill equations (HE) to describe the relative motion of the chief satellite and deputy satellite. Some underlying assumptions limit the applicability of HE: (1) the Earth is spherically symmetric; (2) the orbit of the Hill frame is rigorously a circle; (3) the relative distance between the satellites is small compared with the radius of the Earth. Under these assumptions, the homogeneous solutions of HE describe relative orbit motion very well. In reality, the situation is much more complicated. The second zonal spherical harmonic of the Earth,J2 ,produces the primary gravitational perturbations. This J2 force includes secular, long-periodic, and short-periodic components, which consequently will perturb the satellite orbits. Our objective in this presentation is to study the relative motion between arbitrary chief and deputy satellite configurations due to J2 disturbance for geodetic applications. Four different methods, (1) numerical integration of Newton equations; (2) numerical integration of Lagrange Planetary Equations (LPE) in Gauss form, (3) numerical integration of HE; and (4) nontrivial analytical solutions of HE, will be used to analyze the relative motions in the Hill rotating frame. Since this J2 perturbation has a two cycle per revolution (CPR) frequency component, we developed a complementary analytical solutions for the non-homogeneous HE, which combine the homogeneous, resonant and non-resonant solution. Our preliminary results show that numerical integration of Newton equations and LPE can capture all disturbance characteristics, while the numerical or analytical method of HE perform relatively well in the differential mode. Furthermore, one can get any designed shapes of the relative motion by setting specific initial positions and velocities, e.g. 2 by 1 elliptic motion in the orbital plane.

G41C-05 0830h POSTER

Analysis of Spatial and Temporal Stability of Airborne Laser Swath Mapping Data using Mutual Information

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Airborne laser swath mapping (ALSM) is capable of measuring ranges and intensities of thousands of laser returns per second. This capability allows ALSM to not only create accurate maps of large areas but also to remotely sense the area as it is surveying. Two classes of objects which appear frequently in ALSM data are buildings and trees. These classes are often difficult to separate because their elevations and local gradients can be quite similar. They are also often found in close proximity. In order to determine the remote sensing capability of ALSM, a more complete set of features is explored to determine the separability of these two classes across geographically and temporally diverse data sets. Mutual information provides a means to quantify the separability of the classes using the different features. This information provides new insight into the spatial and temporal stability of ALSM features. Mean intensities and standard deviation of intensities are found to be features which provide the ability to discriminate between the building and tree classes. The features appear to be quite stable over geographically diverse data sets. Although the ALSM data are not temporally invariant, it is still possible to discriminate between the two classes. Mutual information also quantifies the ability to discern between buildings and trees using only ALSM data. Using the features that have the highest ranking according to mutual information, a classification accuracy of better than 90% can be achieved across dissimilar geographical areas.

G41C-06 0830h POSTER

Absolute Gravity Measurements And GPS Observations Along A Profile Crossing The Rhine Graben From The Vosges To The Black Forest.

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The Alsatian plain is located in the Rhine graben limited by the Vosges Mountains (France) and the Black Forest (Germany). The present-day tectonic evolution of this system is not totally clear: is the graben subsiding, are the mountains uplifting, what is the relative behaviour of the 3 different geological components? In attempting to answer these questions, we compare for the first time in this region time series of absolute gravity (AG) measurements at different sites to the available GPS observations. We consider 3 AG sites: our reference station is the gravimetric Observatory Strasbourg J9, located in the Rhine plain where AG measurements are regularly performed since 1997 and where superconducting gravimeter (SG) observations are available almost continuously for 17 years; the satellite sites are the Welschbruch station in the Vosges, where 5 AG measurements have been conducted since 1997 and the Black Forest Observatory (BFO) where 2 AG measurements are available. GPS permanent receivers are collocated at the Strasbourg-J9 site (since 1999) and at the Welschbruch station (since 2000); GPS permanent receivers are located in the surroundings of the BFO. We will compare the long term content of these two types of geodetic measurements with special emphasis on the trend; we will discuss in particular the admittance value for the ratio gravity change/vertical displacement change and its link to different physical processes.

G41C-07 0830h POSTER

Investigation of the Deep Earth's Interior with Superconducting Gravimeters: Study of the Gravest Seismic and Subseismic Modes

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Superconducting gravimeters (SGs) show extremely low drift (a few $\mu gal\ yr^{-1}$) and very high sensitivity in the long period seismic band. Below 1 mHz many SGs can achieve lower noise levels than the best long period seismometers (and spring gravimeters) and are thus well suited for the study of the gravest seismic modes. We demonstrate this by analysing SG series observed after the 2001 Mw = 8.4 Peru event in the normal mode band. The high resolution, seen for example in the splitting of ${}_0S_2$, contributes significant information to long-period normal mode seismology. The low noise level of SGs has led to the first detection of the degree one seismic mode ${}_2S_1$ (first elastic overtone of the Slichter translation of the solid inner core). The study of these long period seismic normal modes is of major interest as it leads to valuable constraints for the density structure in the mantle and core. The improvement of Earth's models needs observations of the splitting of the gravest modes, a task that is uniquely suited to SGs. Besides, SG data are most appropriate for the study of subseismic modes including the Slichter triplet of the inner core. The detection of that translational motion is primordial to provide some information on the density jump and probably on the viscosity at the inner core boundary, as well as on the stratification of the liquid outer core. We consider a possible seismic excitation of the Slichter triplet by looking for the optimal source parameters necessary to produce a sufficient surface gravity effect to be observed with a superconducting gravimeter.

G43A CC: 220 C-E Thursday 1330h

Computations in Geodesy and Geosciences II Posters *(joint with OS, GC)*

Presiding: **R Blais,** University of Calgary**; M Soofi,** University of Calgary

G43A-01 1330h POSTER

Quality Control Of Geodetic Networks Through Robustness Analysis

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After geodetic networks (e.g., horizontal control, leveling, GPS etc.) are monumented, relevant measurements are made and point coordinates for the control points are estimated by the method of least-squares, and the goodness' of the network is measured by a precision analysis making use of the covariance matrix of the estimated parameters. When such a network is designed, traditionally this again uses measures derived from the covariance matrix of the estimated parameters. This traditional approach is based upon propagation of random errors. Reliability of geodetic control networks (the detection of outliers/gross errors/blunders among the observations) has been measured using a technique pioneered by the geodesist Baarda. In Baarda's method a statistical test (data-snooping) is used to detect outliers. What happens if one or more observations are burdened with an outlier? It is clear that these outliers will affect the observations and produce incorrect estimates of the parameters. If the outliers are detected by a statistical test then those contaminated observations are removed, the network is re-adjusted, and we obtain the final results. In the approach described here, traditional reliability analysis (Baarda's approach) has been augmented with geometrical strength analysis using strain in a technique called robustness analysis. In statistical literature robustness is insensitivity to outliers in the data. Robustness analysis is a natural merger of reliability and strain and is defined as the ability to resist deformations induced by the largest undetectable outliers as determined from internal reliability analysis. This paper addresses the consequences of outliers not being detected by Baarda's test. This failure may happen for two reasons (i) the observation is not sufficiently checked by other independent observations or (ii) the test does not recognize the gross error (type II error). By how much can these undetected errors influence the network? If the influence of the undetected errors is small the network is called robust; if it is not it is called a weak network. In this study, the computational process to determine threshold values for robustness primitives is discussed and some results are presented.

G43A-02 1330h POSTER

A Critique on the Logic of the Least-Squares Principle for the Estimation of Geodetic Parameters

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Within the standard formalism of least-squares estimation there are several paradoxical and curious questions which are seldom explicitly formulated. The study of such questions is valuable not only from a theoretical point of view, but also from a practical perspective since it can contribute to a stronger comprehension of the potential drawbacks associated with the use of least-squares techniques in data analysis problems. Along these lines, the aim of this paper is to present an alternative viewpoint of the optimal statistical principles that are traditionally linked to least-squares estimation. Specifically, it is shown that the well known property of unbiasedness for the least-squares estimators can be replaced with a different, yet equivalent, constraint which implies that the numerical range of the unknown parameters is boundless. The consequences that arise from this strange dualism in the context of geodetic parameter estimation are discussed, and a short critique on the statistical foundations of the least-squares method is also made. In order to facilitate the above investigation, the shortcomings of the least-squares estimators are further exposed from

a deterministic-only perspective. In particular, it is explained how the process of minimizing the Euclidean norm of the adjusted residuals may generate a necessary and unavoidable increase of the Euclidean error norm for the computed parameters. For the purpose of preventing any possible misunderstanding, it should be noted that this paper does not represent a disagreement with the practice of applying the least-squares methodology for geodetic data processing. What is merely claimed here is that the optimality aspects that are typically associated with least-squares estimation techniques receive a more objective and careful treatment than is usually given to them.

G43A-03 1330h POSTER

Linear versus Non-Linear Least Squares Adjustment with Emphasis on the 3-D Coordinates Transformation Problem

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Different optimization procedures are employed to study one of the main geodetic problems, the three-dimensional coordinates transformation. Results are given for Egypt, where the old geodetic networks are related to the old Egyptian geodetic datum EGD of Helmert 1906, which is a non-geocentric regional datum. The paper's main objective is the transformation of geodetic control from the old EGD to the new WGS84 datum using different methods of non-linear least squares adjustment. 16 common stations are used in the computations of the seven transformation parameters. This is followed by the transformation of 23 stations using the transformation parameters determined from the nonlinear least squares algorithms. Five optimization methods have been tested for the solution of this problem. These methods are: Steepest Descent, Trust region, Gauss-Newton, Levenberg-Marquardt method, and traditional combined least squares adjustment with weighted observations. Conclusions and recommendations are given with respect to the suitability, accuracy and efficiency of each method.

G43A-04 1330h POSTER

STUDY OF EASTERN CANADIAN COASTAL SITE DISPLACEMENT DUE TO OCEAN TIDE LOADING USING A GPS NETWORK IN ATLANTIC CANADA

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The continuously operating GPS stations of The Princess of Acadia project, especially the Coast Guard station in Saint John, New Brunswick and the station Digby in Halifax, Nova Scotia, both of which lie in the proximity of highly turbulent waters of Bay of Fundy, are subjected to perpetual movements due to temporally oceanic water mass surface loading of the lithosphere by the ocean tides. If the affects of ocean tide loading are not taken into consideration they can affect high- accuracy positioning especially in the final solutions for height. It is proposed under this project that ocean tidal loading studies be carried out in the area using atleast 1 year of GPS data with varying data processing sessions. Time series would then be extracted from discrete 24-hour solutions for ocean tide loading studies. Data collection in this regard is already in progress and 3 hr and 24 hr solutions are being extracted, cleaned and processed using DIPOP 3.1 software. The role of the tropospheric delay and its effect on height estimates when ocean tide loading effects, whether modeled or ignored, would also be investigated.

G43A-05 1330h POSTER

REGIONAL COMPUTATION OF TEC USING A NEURAL NETWORK MODEL

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One of the main sources of errors of GPS measurements is the ionosphere refraction. As a dispersive medium, the ionosphere allow its influence to be computed by using dual frequency receivers. In the case of single frequency receivers it is necessary to use models that tell us how big the ionospheric refraction is. The GPS broadcast message carries parameters of this model, namely Klobuchar model. Dual frequency receivers allow to estimate the influence of ionosphere in the GPS signal by the computation of TEC (Total Electron Content) values, that have a direct relationship with the magnitude of the delay caused by the ionosphere. One alternative is to create a regional model based on a network of dual frequency receivers. In this case, the regional behaviour of ionosphere is modelled in a way that it is possible to estimate the TEC values into or near this region. This regional model can be based on polynomials, for example. In this work we will present a Neural Network-based model to the regional computation of TEC. The advantage of using a Neural Network is that it is not necessary to have a great knowledge on the behaviour of the modelled surface due to the adaptation capability of neural networks training process, that is an iterative adjust of the synaptic weights in function of residuals, using the training parameters. Therefore, the previous knowledge of the modelled phenomena is important to define what kind of and how many parameters are needed to train the neural network so that reasonable results are obtained from the estimations. We have used data from the GPS tracking network in Brazil, and we have tested the accuracy of the new model to all locations where there is a station, accessing the efficiency of the model everywhere. TEC values were computed for each station of the network. After that the training parameters data set for the test station was formed, with the TEC values of all others (all stations, except the test one). The Neural Network was trained with this parameters, and tested by computing the TEC for the test station. This assessment was carried out several times, one for each station of the network. Maps of the results of the estimations for the whole network will be shown.

G43A-06 1330h POSTER

Parallel 2D and 3D Prestack Depth Migration Using Recursive Kirchhoff Wavefield Extrapolation

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Recursive Kirchhoff wavefield extrapolation in the space-frequency domain can be thought of as a simple convolutional filter that calculates a single output point at depth z+dz using a weighted summation of all input points within the extrapolator aperture at depth z. The desired velocity values for the extrapolator are the ones that provide the best approximation of the true phase (propagation time) of the seismic wavefield between the input points and the output point. Recursive Kirchhoff extrapolators can be designed to handle lateral variations in velocity in a number of ways: a PSPI-type (phase shift plus interpolation) extrapolator uses only the velocity at the output point, a NSPS-type (nonstationary phase shift) extrapolator uses the velocities at the input points; a SNPS-type (symmetric nonstationary phase shift) extrapolator incorporates two extrapolation steps of dz/2 where the first step uses the velocities at the input points (NSPS-type) and the second step uses the velocity at the output point (PSPI-type); while the Weyl-type extrapolator uses an average of the velocities between each input point and the output point. Here, we introduce the PAVG-type (slowness averaged) extrapolator, which uses velocity values calculated by an average of slowness along straight raypaths between each input point and the output point. Parallel 2D and 3D prestack depth migration algorithms have been coded in both MATLAB and C and tested on a small Linux cluster. A simple synthetic with a lateral step in velocity shows that the PAVG Kirchhoff extrapolator is very close to the exact desired response. Tests using the 2D Marmousi synthetic data set suggest that the extrapolator behaviour is only one of many considerations that must be addressed for accurate depth imaging. Other important considerations include preprocessing, aperture size, taper width, extrapolator stability, and imaging condition.

G43A-07 1330h POSTER

Earth Science Data Grid System

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The Earth Science Data Grid System (ESDGS) is a software system in support of earth science data storage and access. It is built upon the Storage Resource Broker (SRB) data grid technology. We have developed a complete data grid system consistent of SRB server providing users uniform access to diverse storage resources in a heterogeneous computing environment and metadata catalog server (MCAT) managing the metadata associated with data set, users, and resources. We also develop the earth science application metadata; geospatial, temporal, and content-based indexing; and some other tools. In this paper, we will describe software architecture and components of the data grid system, and use a practical example in support of storage and access of rainfall data from the Tropical Rainfall Measuring Mission (TRMM) to illustrate its functionality and features.

G43A-08 1330h POSTER

On Detecting Shallow Mass Anomalies With Ground and Airborne Gradiometry by Filtering Techniques

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Shallow mass anomalies, such as voids and other significant density contrasts, generate distinct gravitational gradient signals within the background gradient field of the Earth. These signals attenuate rapidly with survey altitude of an airborne gradiometer whose resolving capability is further affected by flight velocity and measurement noise. The prospects of new highly sensitive gradiometers enhance the possibility of detecting such anomalous sources if careful data filtering techniques are carried out. We have developed a matched filter whose weighting coefficients basically enhance the signal-to-noise ratio (SNR) for detection of small gradient signals contained in geological background noise. Results from simulations are compared to similar detection procedures using the Wiener filter. An airborne survey is simulated based on the power spectral density (PSD) model for gravitational gradients, derived from EGM96, 1'x1' mean gravity anomaly data, and 30"x30" elevation data over an area of moderately rough gravitational signal strength. Instrument noise characteristics are based on a range of sensitivities of current and future gradiometers. The study evaluates the filtering options and trade-offs in measuring different gradient tensor components in order to assess the capability to detect subsurface density contrasts by ground and airborne surveys.

G43B CC: 220 C-E Thursday 1330h

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

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

G43B-01 1330h POSTER

Gravity and Geoid in Canada

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The presentation, based upon my involvement over more than four decades with the application of gravity data to some problems of geodesy, consists of two parts: 1. It will show the progress of gravity surveys in Canada based upon the mission mandated by the Dominion Observatory. The surveys started in 1902 with the pendulum measurements, later adding some local Eötvös torsion balance determination and continued from 1945 with the much faster gravity measurements. During the presentation the point distributions, prepared for each decade, and also the relevant data set for the various gravimetric geoid for Canada [1972, 1988, 1995] will be shown. 2. In the 1960s, with the increasing availability of gravity data, the computation of gravimetric deflections and/or geoid determination became a top priority of the Gravity Division of the Observatory. The first computer implementation for gravimetric deflections of the vertical computations were carried out in the early 60s, complemented with terrain corrections computations based on digital elevation data. Parallel to the development of the practical