evaluation of the gravimetric geoid, a number of associated problems were also tackled [terrain correction by digital computers, high degree spherical harmonics expansion of surface gravity, various 3-dimensional gravity modeling, etc.]. The first gravimetric geoid for Canada, and the refinements which became possible with the availability of more and more data will be shown and discussed briefly.

G43B-02 1330h POSTER

Values of a Correction to Helmert Orthometric Heights Resulting from Terrain Roughness

Robert Kingdon[1] ((506) 453-4671; w4etp@unb.ca)

Robert Tenzer[1] ((506) 453-4671; rtenzer@unb.ca)

Petr Vanicek[1] ((506) 453-5144; vanicek@unb.ca)

Marcelo Santos[1] ((506) 453-4671; msantos@unb.ca)

[1]Department of Geodesy and Geomatics Engineering University of New Brunswick, P.O. Box 4400, Fredericton, NB E3B 5A3, Canada

The poster will present results of the calculation of the effect of terrain roughness on orthometric height, and the resulting corrections to Helmert orthometric height. The computation is done using three approaches: the Mader approach, the Neithammer approach and the U.N.B. approach. The results of these computations indicate the the U.N.B. method is the most effective for computation of the correction to Helmert orthometric height. The poster gives some indication of the magnitude of the terrain roughness effect, showing that it has an effect on orthometric heights of up to 26 cm in a test area in the Rocky Mountains. It should be understood that a significant part of this correction is balanced out by the effect of the gravity disturbance generated by the geoid.

G43B-03 1330h POSTER

MEAN GRAVITY ALONG THE PLUMBLINE

Marcelo C. Santos[1] ((506)453-4671; msantos@unb.ca)

Robert Tenzer[1] ((506)453-4671; rtenzer@unb.ca)

Petr Vanicek[1] ((506)453-5144; vanicek@unb.ca)

[1]Department of Geodesy and Geomatics Engineering University of New Brunswick, P.O.Box 4400, Fredericton, NB E3B 5A3, Canada

The mean value of gravity along the plumbline between the earth surface and the geoid depends on the mass density distribution within the earth and the shape of the earth. Since the actual gravity along the plumbline cannot be measured, the mean value of gravity has to be computed from the gravity observed at the physical surface of the earth. This can be realized by reducing the observed gravity according to some accepted physical model. To evaluate the mean gravity, the actual gravity is decomposed into the normal gravity, geoid-generated gravity disturbance and the gravitational attraction of topographical and atmospheric masses. The mean normal gravity is defined according to Somigliana-Pizzeti's theory of the normal gravity field. The mean geoid-generated gravity disturbance is obtained by applying the Dirichlet's boundary value problem into the theorem of integral mean. The mean values of gravity generated by topographical and atmospheric masses are computed as the mean linear potential gradient

G43B-04 1330h POSTER

An Assessment of Global Digital Terrain Models Over Canada

Christian Malmquist[1] ((403) 220-4702; cmalmqui@ucalgary.ca)

Christopher Kotsakis[1] ((403) 220-4702; kotsakis@geomatics.ucalgary.ca)

Michael G. Sideris[1] ((403) 220-4985; sideris@ucalgary.ca)

[1]Department of Geomatics Engineering University of Calgary, 2500 University Drive, N.W., Calgary, AB T2N 1N4, Canada

A variety of digital terrain models (DTMs) are nowadays available for use by the international scientific community. In terms of geodetic applications, such models are especially important for precise Stokesian geoid determinations, for geophysical and geodynamical studies related to the isostatic behaviour of the Earth's crust, and also for the development of realistic synthetic representations for the Earth's external gravitational field. However, the problem of which DTM should be chosen for such studies, as well as in other related applications of geo-sciences and engineering, is not a trivial question to answer. That is because most of the available global DTMs differ significantly in terms of their original data sources and their production technique, their accuracy and resolution levels and their actual spatial coverage. Furthermore, additional problems may arise from the fact that the accuracy characteristics within each DTM are not really homogeneous over the total coverage area, but they rather exhibit a spatially dependent behaviour which is often strongly correlated with the terrain morphology. Among the freely available DTMs covering Canada, the recently released SRTM30 model is of special interest for geodetic applications since it is based on the interferometric data gathered during NASA's Shuttle Radar Topography Mission (SRTM). The SRTM used space-borne radar interferometry sensors to produce a near global digital terrain model. The final SRTM30 model is thus primarily generated by a set of data which is consistent and of uniform quality over the entire coverage area. This is usually not the case for other global DTMs which are typically generated by merging existing topographic and/or cartographic data sources with varying (and often questionable) quality levels. This paper presents an initial assessment of the SRTM30 terrain model with respect to some other well known DTMs that are often used in practice, namely ETOPO2, GTOPO30 and the Canadian Digital Elevation Data (CDED) sets. The aforementioned models are evaluated and assessed through a statistical intercomparison over various test areas representing typical Canadian landforms (e.g., mountain ranges along the Rockies in western Canada, flatter regions in the eastern Canada). A type of absolute comparison for all these models is also performed using as reference the orthometric, ellipsoidal and geoid height values at a set of nearly 1930 geodetic leveling benchmarks distributed throughout Canada.

G43B-05 1330h POSTER

Modern GPS Positioning Tools for Geoscientists

Calvin Klatt[1] (613-943-0019; cklatt@nrcan.gc.ca)

Pierre Sauve[1] (613-995-8313; plsauve@nrcan.gc.ca)

[1]Geodetic Survey, Natural Resources Canada, 426, 615 Booth St., Ottawa, ON K1A 0E9, Canada

This presentation is intended to review the GPS positioning tools available to Geoscientists who may not be experts in Geodesy or for those who would like a review of the tools available. A growing list of tools for positioning has created opportunities for the geoscientist to obtain global position information in the field with unprecedented ease and accuracy. Rapid technological change, combined with the variety of different means of augmenting GPS has caused confusion for selecting the optimum methodology for obtaining a desired accuracy. This talk will review the positioning technologies and provide the necessary background to help the user identify which tool is most appropriate for their application. Beginning with the use of GPS for geometric positioning we will review the accuracy expected from basic broadcast GPS through to augmentation techniques, both real-time and post processing, using Canadian examples. The relationship between the NAD83, NAD83 (CSRS or NSRS), WGS84 and ITRF reference frames will be discussed. The determination of physical heights from GPS will follow. This determination relies on the use of mathematical models giving the sea-level (or similar) height. Two model types will be discussed; models intended to precisely represent the Geoid, and models that provide heights compatible with published height datums (incorporating any distortions that exist in these official datums). The presentation will be complemented by a Natural Resources Canada Geodesy booth, which will provide demonstrations of two GPS augmentation tools: CDGPS, a real-time GPS correction service and Precise Point Positioning (PPP), an Internet post-processing tool. Demonstrations of an online tool for physical height determination will also be provided.

URL: http://www.geod.nrcan.gc.ca/

G43C CC: 516 A Thursday 1330h

New Sensors of Our Planet: Modern Geodesy and New Insights in Earth Science II *(joint with OS, P, S, T, C, GC)*

Presiding: **N Sneeuw,** University of Calgary**; H Dragert,** Geological Survey of Canada

G43C-01 1330h INVITED

Terrestrial Gravimetry and the Development of Absolute Gravimeters

James E. Faller[1] (1-303-492-6807; fallerj@jila.colorado.edu)

Artyom L. Vitouchkine[1] (1-303-492-7763; vitushka@jila.colorado.edu)

[1]JILA, University of Colorado and National Institute of Standards and Technology, 440 UCB, Boulder, CO 80309-0440, United States

By extending the reach of our hands and quickening the response of our eyes, measurement methods and instrumental capabilities have driven and made possible much of scientific progress. By the middle of the nineteenth century, measurement capabilities for g had reached a precision of 1 in 10^6 and an accuracy of 1 in 10^5. Over the past 40 years, instruments have evolved to the point where measurements can be made at the parts in 10^9 level of precision and, in the case of absolute instruments, accuracy. In this talk, reasons will be given for this remarkable progress (4 orders of magnitude improvement in 40 years) in our ability to measure g. In the context of this session's title, "New Sensors of Our Planet," our recent—probably for one of us (JF) the last—development of a truly portable absolute gravimeter will be described. This small and portable absolute instrument drops a test mass 200 times a second while keeping the center of mass of the apparatus fixed—to avoid recoil effects—during the entire measurement cycle. The capabilities of this μgal-accuracy instrument will be demonstrated.

G

G43C-02 1350h

Development of an Interferometric Laser Ranging System for a Follow-On Gravity Mission to GRACE

R. S. Nerem[1] (303-492-6721; nerem@colorado.edu); P. Bender[2]; M. M. Watkins[3]; W. Folkner[3]; M. Stephens[4]; T. Delker[4]; J. Leitch[4]; R. Pierce[4]

[1]Colorado Center for Astrodynamics Research, University of Colorado, UCB431, Boulder, CO 80309-0431, United States

[2]JILA, University of Colorado, UCB440, Boulder, CO 80309-0440, United States

[3]Jet Propulsion Laboratory, 4800 Oak Grove Dr., Pasadena, CA 91109, United States

[4]Ball Aerospace and Technologies Corp., P. O. Box 1062, Boulder, CO 80301

The Gravity Recovery and Climate Experiment (GRACE) has ushered in a new era for satellite measurements of the Earth system. GRACE provides monthly estimates of the time-varying gravity field, which are largely due to the redistribution of water mass in the Earth system, with a spatial resolution of 500 km and an accuracy of 1 cm equivalent water. This is accomplished via a suite of instruments including a microwave ranging system, precision accelerometers for measuring non-gravitational forces, and a GPS navigation system. These measurements are providing a new observing tool for hydrologists, oceanographers, glaciologists, and many other disciplines. These tremendous advances made by GRACE have led to an interest in launching a follow-on mission with even better performance. The spatial resolution can be improved by improving the ranging performance, implementing a drag-free control system, and flying at a lower altitude. This presentation will focus on improving the ranging performance by developing an interferometric laser ranging system that we expect to perform near the 1 nm/sec level or better over 5 second intervals, which when coupled with other mission improvements, would improve the spatial resolution to 100 km for 1 cm water equivalent accuracy. We will present our design for the laser ranging system. We plan to build an engineering model of the instrument and demonstrate its accuracy in the laboratory over the next few years. The laser system will range directly to the proof masses of the drag-free system, eliminating many of the difficulties associated with post-processing the accelerometer data on GRACE. We will also present the results

of an error analysis for the ranging system, how these errors are expected to propagate into the gravity field estimates, and discuss the potential science benefits.

G43C-03 1405h INVITED

GPS as a Global Sensor of System Earth: Status and Future Prospects

Geoffrey Blewitt[1] (+1-775-784-6691 x171; gblewitt@unr.edu); Peter J. Clarke[2] (peter.clarke@ncl.ac.uk); David Lavallee[1] (lavallee@unr.edu); Richard Gross[3] (richard.gross.jpl.nasa.gov); Konstantin Nurutdinov[2] (konstantin.nurutdinov@ncl.ac.uk); Tonie van Dam[4] (tvd@ecgs.lu)

[1]Mackay School of Earth Sciences and Engineering, University of Nevada, 1664 North Virginia Street, Mail Stop 178, Reno, NV 89557, United States

[2]School of Civil Engineering and Geosciences, University of Newcastle, Newcastle upon Tyne NE1 7RU, United Kingdom

[3]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

[4]European Center for Geodynamics and Seismology, Rue Josy Welter, 19, Walferdange L-7256, Luxembourg

Operated under the auspices of the International GPS Service (IGS), the global GPS network became operational in 1994, and so is now becoming capable of measuring decadal-scale variation in many aspects of system Earth. Today the global IGS network has grown to 200+ geodetic quality stations that are being used to monitor time variation in the shape and orientation of the Earth with millimeter-level precision. This global sensor is also sensitive to motion of the solid Earth center with respect to the center of mass of the entire Earth system ("geocenter motion") at the few millimeter level. Furthermore, assuming that seasonal to decadal variations in Earth's shape are dominated by surface loading, the IGS network is effectively a precise sensor of the low-degree harmonics of the Earth's gravity field, without the problem (faced by in-situ gravimetry) of being very sensitive to local mass movements. At the one second time scale, the IGS network is being used to constrain the red spectrum errors of seismological instruments to study strong motion from earthquakes in action. This network of stations not only provides precise geometrical and gravitational information, but can monitor vertically integrated water vapor in the atmosphere and total electron content in the ionosphere. Just as sub-systems within the Earth are interconnected, so are the models used to explain and improve our understanding of the data from the global GPS network. Observations of Earth's shape can now be used to explain an essential component of Earth rotation. Using models, we can also assess the self-consistency of Earth's geometrical shape with satellite gravimetry, satellite altimetry, and in-situ measurements of sea level and ocean bottom pressure. This therefore raises the prospect of a more complete integration of these various data types in the near future. Ionospheric research using GPS may also lead to operational calibration of the GPS carrier phase data for higher order ionospheric effects, which may represent a significant component of systematic error in GPS geodesy for global-scale research. Toward improving global GPS research, other factors to consider include the spatial distribution and density of high-quality stations, the stability of monumentation and equipment configuration, the availability, accuracy and completeness of station metadata, and the stability and accuracy of data analysis by the IGS Analysis Centers. Finally, even when presented with a relatively error-free data set, the problem of inversion strategy and uniqueness is actually a difficult and significant problem, not dissimilar to long-standing problems in geoid inversions and downward continuation of the gravity field.

G43C-04 1425h

Progress in Centralized Monitoring of the International GPS Service Network

Angelyn W Moore[1] (1-818-354-5434; Angelyn.W.Moore@jpl.nasa.gov)

Peter N Jeziorek[1]

Eric W Richardson[1]

Ruth E Neilan[1]

[1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr. MS 238-540, Pasadena, CA 91109, United States

The International GPS Service (IGS) network today consists of 364 permanent, continuously operating, geodetic-quality GNSS stations managed by about 100 different agencies worldwide. The abundance of IGS data has driven advances in automated station monitoring, to increase the efficiency of the IGS network coordination activity. We will review the methods implemented to date, which include visual inspection of time series, comparison of parameters and their variances with those from other IGS sites to determine whether the site is "out of family," and change point analysis to mathematically flag potential behavioral changes for closer human inspection. These have proven useful for both site operators and analysts to quickly determine a site's recent performance. The principles are applicable to time series of any type and may be useful in screening other geodetic datasets and monitoring other types of equipment arrays.

G43C-05 1440h INVITED

High-Rate Real-Time GPS and its Role in Positioning and Seismology

Yehuda Bock (8585345292; ybock@ucsd.edu)

Scripps Institution of Oceanography, IGPP 0225 9500 Gilman Drive, La Jolla, CA 92093-0225, United States

Modern GPS receivers sample at rates of 1-10 Hz and higher, while third generation wireless technology allows for efficient real-time transmission of these data. Coupled with modern GPS analysis techniques such as instantaneous positioning and improved PDA-based processing power, GPS networks are now capable of providing precise high-rate real-time (less than 1 sec latency) positions for a variety of monitoring applications, and serving data to platforms (static and dynamic) instrumented with GPS sensors that can be positioned precisely with respect to the network in real time. I describe the use of new GPS real-time systems in California, upgraded from the existing CGPS infrastructure (SCIGN/BARD), for the detection of strong ground motions from the 2002 Denali fault and 2003 San Simeon earthquakes, and ongoing work to integrate seismic and high-rate GPS data as components of an improved displacement meter. Also, I describe the use of real-time high-rate network data for applications such as rapid field GPS surveys for coseismic and postseismic studies, volcano deformation, tsunami warning systems, and structural monitoring.

G43C-06 1530h

Contributions to Earthquake Hazard Characterization in Canada from Precision GPS Data

Herb Dragert[1] (250-363-6447; dragert@pgc.nrcan.gc.ca)

Roy D Hyndman[1] (rhyndman@NRCan.gc.ca)

Stephane Mazzotti[1] (smazzotti@NRCan.gc.ca)

Kelin Wang[1] (kwang@NRCan.gc.ca)

[1]Geological Survey of Canada, Pacific Geoscience Centre, 9860 West Saanich Road, Sidney, BC V8L 4B2, Canada

In the active seismic regions of Canada, the hazard posed by the recurrence of potentially devastating (M >7) earthquakes is not well defined due to the brevity of the instrumental and historical records, the lack of clear paleoseismic evidence for past large events, and the inexact nature of extrapolating the rate of occurrence of frequent small events to the occurrence of rare large events. This serious shortcoming of probabilistic seismic hazard estimation can be addressed through high-precision GPS measurements which can monitor crustal motions and regional crustal strain associated with the build-up of stress before a large earthquake. In southwestern British Columbia, over a decade of observations of motions of GPS sites of the Western Canada Deformation Array (WCDA) and GPS campaign sites have led to improved models of the locked plate interface on the Cascadia Subduction Zone and better estimates of the landward extent for the next megathrust (M∼9) rupture. Regional strain rates based on continuous GPS data from the WCDA and PANGA (Pacific Northwest Geodetic Array) show that the recurrence interval for M7 crustal earthquakes is of the order of 400 years, not several decades as once estimated. Continuous GPS data from these arrays have also led to the discovery of "silent slip" or "slow earthquakes" on the deeper plate interface which do not generate impulsive seismic waves but relieve stress over periods of one to two weeks. For southern Vancouver Island and northwestern Washington State, these slip events appear to occur regularly at 14 month intervals and have now been found to be associated with distinct, non-earthquake tremors, coining the name "Episodic Tremor and Slip" (ETS) for this newly discovered phenomenon. The repeated relief of small amounts of stress in the ETS zone provides an additional definition of the down-dip limit of megathrust rupture, and the onset of ETS activity could mark times of higher probability for the occurrence of thrust rupture in the Cascadia subduction zone. It is expected that the occurrence of large earthquakes in other active seismic regions in Canada (lower St. Lawrence & Ottawa Valley, Queen Charlotte Islands, the Yukon) could be similarly characterized through long-term precise GPS monitoring.

G43C-07 1545h

Eigenpattern analysis of eastern Canadian GPS data

Kristy Tiampo[1] (519-854-1311; ktiampo@uwo.ca)

Stephane Mazzotti[2]

John B Rundle[3]

[1]University of Western Ontario, Dept. of Earth Sciences Biological & Geological Sciences, London, ON N6A 5B7, Canada

[2]Geological Survey of Canada, Pacific Geoscience Center, Sidney, BC V8L 4B2, Canada

[3]Center for Computational Science and Engineering, University of California, Davis, CA, United States

Geodetic data, the spatial and temporal surface expression of complex geophysical processes in the earth, is being acquired today at unprecedented rates and accuracies. Previous research has demonstrated that an eigenpattern decomposition technique known as Karhunen-Loeve expansion (KLE) analysis can be used to identify a unique, finite set of deformation patterns for a given regional network of GPS stations. Similar in nature to the empirical orthogonal functions historically employed in the analysis of atmospheric and oceanographic phenomena, the method derives the eigenvalues and eigenstates from the diagonalization of the correlation or covariance matrix. After decomposing large data sets into their orthonormal eigenvectors and associated time series, based upon the spatiotemporal relationships that exist in the data, it can be used to study those modes most responsible for these correlations and their sources, to remove those uninteresting modes in the system, or project their trajectories forward in time. Here we demonstrate its application to continuous GPS data acquired between 2001 and 2004 in eastern Canada and examine some of the potential sources for the vertical and horizontal deformation modes, including the detection of teleseismic earthquake signals.

G43C-08 1600h

The Plate Boundary Observatory: Operational Status and Data Plans

Greg Anderson[1] (anderson@unavco.org)

Karl Feaux[1] (feaux@unavco.org)

Mike Jackson[1] (jackson@unavco.org)

Will Prescott[1] (prescott@unavco.org)

[1]UNAVCO, Inc., 6350 Nautilus Drive, Boulder, CO 80301-5554, United States

The Plate Boundary Observatory (PBO), part of the larger NSF-funded EarthScope project, is designed to study the three-dimensional strain field resulting from deformation across the active boundary zone between the Pacific and North American plates in the western United States. The science goals of PBO require that plate boundary deformation be adequately characterized over the wide range of spatial and temporal scales common to active continental tectonic processes. PBO will meet these needs using 875 continuous GPS sites, 175 borehole strainmeter stations, and five laser strainmeters, all installed over the next five years. In addition, 255 existing continuous GPS sites will be incorporated into PBO, and there will be a pool of 100 portable GPS receivers available for survey-mode observations. These stations will provide raw observations from which PBO Analysis Centers will create a wide range of derived data products, including time series of strain and GPS station position, GPS velocity vectors, and regional strain maps. All PBO data and data products will be made available to the community as rapidly and freely as possible through the EarthScope Data Portal. PBO began operations in September 2003 and the first five new PBO continuous GPS stations were installed in January 2004, with the first PBO borehole strainmeter installations anticipated by September 2004. The initial data from the first PBO sites are now available through the PBO archives at the UNAVCO Facility in Boulder and the Scripps Orbit and Permanent Array Center in San Diego. We will present an update on the current status of, and future plans for, PBO operations, data collection and analysis, and distribution of PBO data products.

G43C-09 1615h

Spaceborne Laser Altimetry

BOB E SCHUTZ (512-471-4267; schutz@csr.utexas.edu)

Center for Space Research, University of Texas at Austin, Austin, TX 78759, United States

A new spaceborne geodetic tool was launched on ICESat in January 2003 into a 600 km altitude, near polar orbit. ICESat carries a laser altimeter, the Geoscience Laser Altimeter System, designed to generate high accuracy profiles of the polar ice sheets that enable detection of surface change. A variety of other applications have been demonstrated, which include land topography, vegetation canopy height, atmospheric and ocean. The laser altimetry uses a 1064 nm wavelength with a beam divergence that produces an illuminated surface spot of approximate 70 meters in diameter. With a pulse repetition rate of 40 Hz and the orbital motion, successive spots on the Earth's surface are separated by 170 m. This new geodetic tool has a precision of a few centimeters on flat surfaces and horizontal knowledge of the illuminated spot location has been shown to approach the requirement of 4.5 meters. A variety of calibration/validation techniques have been applied since laser operations began in February 2003 and numerous examples of high accuracy surface profiles have been collected. This paper will summarize the current operational status and illustrate the variety of applications to Earth science.

G43C-10 1630h

Photon Counting Airborne Laser Swath Mapping

W. E. Carter[1] (352-392-5003; bcarter@ce.ufl.edu)

R. L. Shrestha[1] (352-392-4999; rshre@ce.ufl.edu)

K. C. Slatton[1] (352-392-0634; slatton@ece.ufl.edu)

[1]University of Florida, Department of Civil and Coastal Engineering, Gainesville, FL 32611, United States

During the past decade airborne laser swath mapping (ALSM) has brought topographic mapping to the forefront of geodesy. ALSM has made it possible, for the first time, to study natural geo-surficial processes on spatial scales extending from meters to hundreds of kilometers, all in a consistent geodetic frame of reference. The conventional approach to ALSM has been to use lasers with enough energy per pulse, and optics with large enough collecting areas, to obtain returns of thousands of photons per shot. This approach minimizes the impact of spurious range values caused by noise, such as background solar radiation and sensor thermal noise, but also constrains the minimum size, weight and power consumption of the hardware. Current systems typically operate at rates approaching 100,000 pulses per second, and another order of magnitude increase would be needed to provide contiguous coverage with a spatial resolution of 30 cm or better. This high signal-to-noise ratio approach affords little scalability for significantly downsizing the hardware, or reducing the costs. University of Florida (UF) researchers are developing an ALSM unit based on a different paradigm, which we refer to as photon counting ALSM, or simply PC-ALSM. The approach is to transmit relatively low energy laser pulses, and to illuminate a surface patch' about an order of magnitude larger than the typical footprint of a conventional ALSM system. The returning signal will have far fewer photons per unit area of the receive optics, making it more difficult to discriminate between return signal and noise. If a single channel detector were used, the spatial resolution would also be degraded. However, by using a multi-channel photomultiplier tube to detect the returns, the surface patch can be divided into an array of groundals, and by using a multi-stop timing system false ranges can be filtered out of the data during post flight processing. Researchers at NASA GSFC have already tested a first generation system based on this new paradigm, operated from a high altitude aircraft, to develop a satellite based instrument. Details of the preliminary UF design for a second generation system that will operate from a light aircraft flying less than 1000 meters above local ground level and providing contiguous coverage of the terrain with 30 cm spatial resolution will be presented.

G43C-11 1645h

Multi-mission mean sea surface and geoid models for ocean monitoring within the GOCINA project

Ole B Andersen[1] (301 614 6777; oa@bowie.gsfc.nasa.gov)

Per Knudsen[2] (+45 3587 55318; pk@kms.dk)

Vest L Anne[2] (+45 3587 5050; alv@kms.dk)

[1]National Survey, Denmark,, presently NASA/GSFC code 926, Greenbelt, MD 20771, United States

[2]National Survey and Cadastre, Denmark, Rentemestervej 8, Copenhagen DK-2400, Denmark

A major goal of the EU project GOCINA (Geoid and Ocean Circulation In the North Atlantic) is to develop tools for ocean monitoring using satellite altimetry combined with satellite gravimetry. Furthermore, the project will determine an accurate geoid in the region between Greenland and the UK and, hereby, create a platform for validation of future GOCE Level 2 data and higher order scientific products. The central quantity bridging the geoid and the ocean circulation is the mean dynamic topography, which is the difference between the mean sea surface and the geoid. The mean dynamic topography provides the absolute reference surface for the ocean circulation. The improved determination of the mean circulation will advance the understanding of the role of the ocean mass and heat transport in climate change. To calculate the best possible synthetic mean dynamic topographies a new mean sea surface (KMS03) has been derived from nine years of altimetric data (1993-2001). The regional geoid has furthermore being updated using GRACE and gravimetric data from a recent airborne survey. New synthetic mean dynamic topography models have been computed from the best available geoid models (EGM96, GRACE, GOCINA) and the present mean sea surface models (i.e. CLS01, GSFC00, KMS03). These models will be compared with state of the art hydrodynamic mean dynamic topography models in the North Atlantic GOCINA area. An extended comparison in the Artic Ocean will also be presented to demonstrate the impact of improved geoid and mean sea surface modeling. Particularly using the GRACE derived geoid models, and the KMS03 mean sea surface.

URL: http://www.gocina.dk

G51A CC: 516 D Friday 0830h

Pleistocene Ice-Mass Change, Displacement and Gravity Change, and Their Interpretation With 3-D Earth Models II *(joint with H, OS, S, T, C, GC, PP, SEDI)*

Presiding: **V Klemann,** GeoForschungsZentrum Potsdam**; A Lambert,** Geological Survey of Canada**; P Wu,** University of Calgary

G51A-01 0830h INVITED

Laurentide Deglaciation

Arthur S. Dyke (1-613-992-0643; adyke@nrcan.gc.ca)

Geological Survey of Canada, 601 Booth St, Ottawa, ON K0A 2X0, Canada

An updated sequence of maps illustrating the deglaciation of North America was recently released as Geological Survey of Canada Open File 1574. These represent extensive revisions of the Dyke and Prest (1987; Géographie physique et Quaternaire, 41: 237-263) ice margin reconstructions. Age control on ice margins and glacial lake shorelines is provided by a chronological data set of about 4000 radiocarbon dates as well as key varve and tephra dates. Dates on problematic materials, such as marl, freshwater shells, lake sediment with low organic carbon content, marine sediment, bulk samples yielding probable blended ages, and most deposit-feeding marine molluscs from calcareous substrates were excluded. These culled samples, many of which had been used in previous reconstructions, yield ages that are too old. Retained marine shell dates were adjusted for regionally variable marine reservoir effects, based on a new set of radiocarbon measurements on pre-bomb molluscs from Pacific, Arctic, and Atlantic shores. These corrections range from 800 years in the Pacific Ocean and the Champlain Sea to 450 years in the SW Gulf of St. Lawrence, and hence are larger than the previous "conventional" correction, a uniform 400 years. The net effect is that deglaciation ages are diminished in most places by 1000-2000 years in comparison to Dyke and Prest (1987). However, the spatial pattern remains similar to previous reconstructions, being guided by the continental scale glacial geology. The revised deglaciation chronology places most of the major mid-deglaciation moraines into the Younger Dryas interval and brings the deglaciation of Hudson Bay into correlation with the 8200 cal yr BP event (Barber et al., 1999; Nature 400: 344-348).

G51A-02 0850h INVITED

The Time Rate of Change of Gravity in Canada: New Results and Insights.

Spiros D Pagiatakis (416-736-2100; spiros@yorku.ca)

Dept. of Earth and Space Science and Engineering, York University, 4700 Keele Street, Toronto, ON M3J 1P3, Canada

Gravimetry in Canada plays a significant role in many different areas of scientific interest including geophysical prospecting, structural interpretation and imaging of the vast Canadian landmass. Although the first gravity measurements in Canada date back in the early 1900 using pendulum and torsion balance devices, it was in the mid 1940 when the first gravimeters (Worden and LaCoste-Romberg) were used to form what it became later the Canadian Gravity Standardization Network (CGSN). The re-observation of CGSN continued ever since, following stringent standards both in methodology and instrument calibration. Over the last few decades absolute and superconducting instruments have enhanced the accuracy of gravity measurements and when combined with high precision geodetic observations, including those from the recent satellite gravity missions, can provide important information and constraints on geodynamic phenomena such as plate tectonics and glacial isostatic adjustment. The long history of CGSN along with repeated high precision absolute gravity measurements have recently been considered carefully in anticipation to estimate the time rate of change of gravity (g-dot) in Canada that is probably dominated by the glacial isostatic adjustment. Results of these analyses have been presented in the past and most recently in JGR Solid Earth (S. Pagiatakis and P. Salib, 2003). Research in this area continues as more observations are acquired. The long series from the Canadian Superconducting Gravimeter Installation (CSGI) combined with absolute measurements as well as with atmospheric and hydrological records enhance our knowledge on g-dot at the Canadian Absolute Gravity Site (CAGS) and offer new constraints and insight in the analysis of CGSN. In this contribution we will present new results on g-dot and will make comparisons with other geophysical studies in an effort to stimulate discussion and multidisciplinary research that will enhance our knowledge on the glacial isostatic adjustment and climate change.

G51A-03 0910h

Global Glacial Ice Volume: The Eustatic Sea Level Constraint

William Richard Peltier (416-978-2938; peltier@atmosp.physics.utoronto.ca)

W.R. Peltier, Department of Physics, University of Toronto, Toronto, ON M5S-1A7, Canada

Although the classical oxygen isotope derived inference of the rise of eustatic sea level across the glacial-interglacial transition of 120m has been confirmed by direct observations of the LGM depression of relative sea level at several locations, the validity of this inference has been questioned recently by several authors. The basis for the suggestion that the ice-equivalent eustatic depression of RSL at LGM must be greater than the Del-18O dervided estimate has been provided by an implementation of the theory of post glacial relative sea level change. In this paper I will employ the refined model of planetary deglaciation denoted ICE-5G(VM2) together with an extremely detailed analysis of the impact of changing coastline upon the theoretical predictions of RSL history, to show that these suggestions of the existence of a significant error in the oxygen isotope derived estimate of LGM land ice volume (eustatic sea level depression) are unfounded. These analyses demonstrate that the LGM depression of eustatic sea level was very near the classical estimate of 120m. This result provides strong support for the newly developed ICE-5G model of planetary deglaciation.

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A glaciologically consistent model of northern hemisphere ice loading since the LGM

Philippe Huybrechts[1,2] (+49-471-4831-1194; phuybrechts@awi-bremerhaven.de)

Chris Zweck[1] (+49-471-4831-1736; czweck@awi-bremerhaven.de)

[1]Alfred-Wegener-Institut fur Polar- und Meeresforschung, Postfach 120161, Bremerhaven D-27515, Germany

[2]Departement Geografie, Vrije Universiteit Brussel, Pleinlaan 2, Brussel B-1050, Belgium

The chronology of northern hemisphere ice-sheet extent during the last deglaciation is now fairly well known from glacial-geological observations. The thickness and volume of the ice sheets is however much harder to reconstruct from the geomorphological evidence and generally needs to be inferred from indirect evidence and modelling. One approach consists of glacio-isostatic modelling of relative sea-level changes in regions far away and in the vicinity of the former ice sheets to both determine the time-dependent change in global ice volume and the source contributions from individual ice sheets from some inverse modeling scheme.