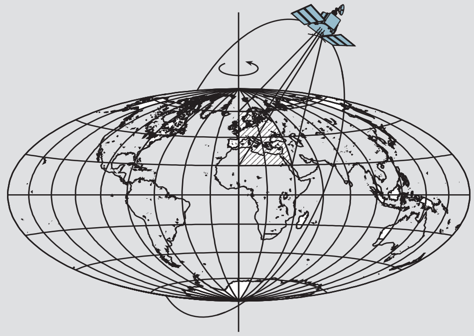


Proceedings of the

Weikko A. Heiskanen Symposium in Geodesy

1 - 4 October 2002

Organized by

Laboratory for Space Geodesy and Remote Sensing

Department of Civil and Environmental Engineering and Geodetic Science

The Ohio State University
Columbus, Ohio 43210-1275

edited by

Christopher Jekeli

February 2003

Table of Contents

Foreword

This electronic document is the *Proceedings of the Weikko A. Heiskanen Symposium in Geodesy*. The Symposium was held at Ohio State University, Columbus, Ohio, 1-4 October 2002 and attracted more than 180 attendees from all over the world, including many alumni from our Geodetic Science Program. Over 110 papers were presented either orally or as posters. In addition to the submitted abstracts, this document (through links to separate files) contains many of the actual presentations, as well as several papers that were prepared by the authors. These presentations and papers were converted to the pdf format wherever possible; but a small number of presentations remain in Microsoft PowerPoint format due to technical difficulties encountered in the conversion. Some presenters provided movie clips that also remain in their original format. The very interesting talks given at the Ice Breaker and the Symposium Banquet are also included.

A student paper competition was organized for the Symposium to attract student participation. The participants and winners were as follows:

First place: Shin-Chan Han, Ohio State University, CHAMP Gravity Solutions determined from Different Orbits.

Second Place: Hung Kyu Lee, University of New South Wales, Effects of Introducing Pseudolite Measurements into an Integrated GPS/INS System.

Third Place: Yudan Yi, Ohio State University, Performance Analysis of a Land-Based GPS/INS/Pseudolite Integrated System.

Other participants:

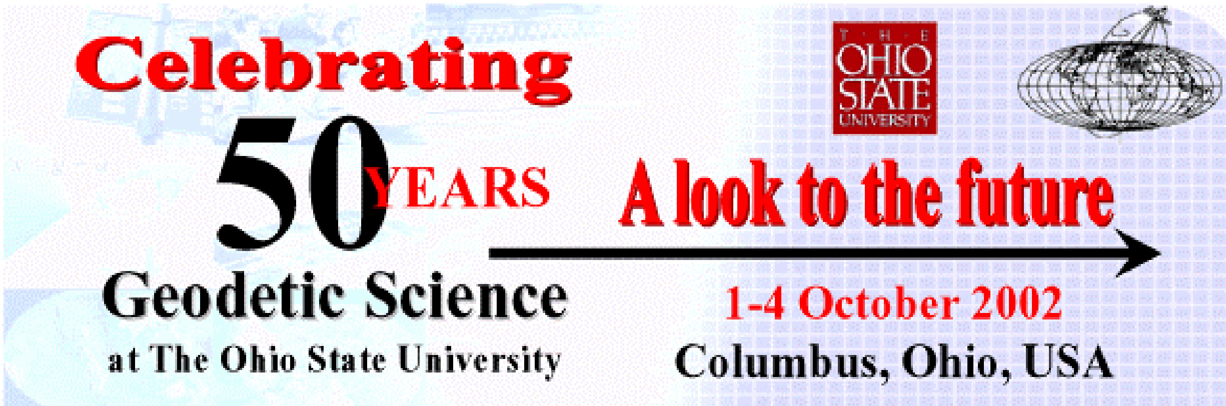
Mosa'b Hawarey, Purdue University;
Juan G. Serpas, Ohio State University;
G. Esteban Vazquez, Ohio State University;
Mike J. Willis, Ohio State University.

Prizes (including travel support) were generously sponsored by the Institute of Navigation and Woolpert LLP.

On behalf of the Organizing Committee, I would like to thank all participants for making this Symposium a truly memorable event. Our gratitude and appreciation go, of course, also to the Session Chairs, to the staff and students that helped with the organization and realization of the Symposium, and to the many sponsors who gave important financial support.

Christopher Jekeli
Chair, Scientific Committee
February 2003

The editor takes no responsibility for errors in submitted material. [back to Table of Contents]



http://geodesy.eng.ohio-state.edu/50_years [back to Table of Contents]

Weikko A. Heiskanen Symposium in Geodesy

Technical Program

Blackwell Conference Center
Fisher College
The Ohio State University

2110 Tuttle Park Place
Columbus, Ohio, U.S.A.

1 – 4 October, 2002

Organized by
Laboratory for Space Geodesy and Remote Sensing Research
Department of Civil and Environmental Engineering & Geodetic Science
The Ohio State University
Columbus, Ohio, U.S.A.

http://geodesy.eng.ohio-state.edu

Organization and Contacts [back to Table of Contents]

Scientific Committee

Chairman:	Christopher Jekeli
Members:	Dorota Grejner-Brzezinska
	Christopher Jekeli
	Rongxing Li
	Alan Saalfeld
	Burkhard Schaffrin
	C. K. Shum

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Chairman:	C. K. Shum
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	Peter H. Luk

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Dept. of Civil and Environmental Engineering and Geodetic Science
The Ohio State University
2070 Neil Ave.
Columbus, OH 43210-1275
U.S.A.

GENERAL INFORMATION [back to Table of Contents]

Information to Participants

Venue

The Symposium is held at *The Blackwell Conference Center* (http://theblackwell.com), 2110 Tuttle Park Place, Fisher College, The Ohio State University, Columbus, Ohio, U.S.A. (please see Map on p.6 or on http://www.osu.edu/map/index.html).

Oral presentations are given in the Pfahl Executive Conference Center, 140 Pfahl Hall, next to the Blackwell Inn. Poster presentations are located in Ballroom A of the Blackwell Inn.

Registration Desk

The registration and information desk is located in front of the Conference Room, 140 Pfahl Hall, and will operate during the Symposium as follows:

Monday, 30 September	13:30 – 18:00
Tuesday - Thursday, 1 – 3 October	7:30 – 14:00

Internet Access

Internet and e-mail access are provided to the participants (1) with desktop PCs in the Executive Board Room next to the Conference Room, (2) with wireless stations (IEEE 802.11 b compatible, 11 Mbps) near the Conference area and in the Poster Session area for participants equipped with portable computers with wireless PC cards or Macintosh airport cards, (3) with desktop PCs in the Fischer Business School Library, 120 Mason Hall, and (4) each seat in the Conference Room (140 Pfahl Hall) is equipped with active internet port**.** It is advised that users of portable computers also bring their own Ethernet cables.

Parking

Valet parking is available at $9.00 per day in front of the Blackwell Inn with unlimited in and out during the day. Garage parking is also available in Tuttle Parking Garage and Northwest Parking Garage (please see Map below and at http://www.osu.edu/map/index.html), a walking distance of about 5 minutes from the Blackwell. Maximum charge for one day is $6.50.

Information to Authors

Oral Sessions:

Time for oral presentation is generally set to 20 minutes. Speakers should check the Final Program to confirm the schedule for their talks. For the benefit of both the audience and the next speaker, all speakers are kindly requested to adhere strictly to the time limit that otherwise will be enforced by the Session Chairs.

An overhead projector, a data/video beamer (PC Projector) and a computer (PC) will be available in the Conference Room. Only Microsoft Office Power Point (*.ppt) and Acrobat Reader (*.pdf) presentations are supported. For computer presentations, speakers should provide a copy of their presentation in the form of CD-ROM or USB flash card drive, well in advance of the presentation time, to the Technician on duty. To avoid delays between presentations, no personal laptops will be allowed to connect to the PC projector.

Presenters can also upload electronic copies of their presentations (*.ppt or *.pdf formats only) through the web: http://geodesy.eng.ohio-state.edu/50_years click "Upload Presentations".

Authors wishing to give a computer presentation are advised to prepare and bring also overhead slides to be used in the unlikely event of a technical emergency.

Chairs and Authors:

Session chairs and presenting authors should meet in the Conference Room 10 minutes prior to the beginning of the Session.

Poster Sessions:

The dimensions of the posters should not exceed 4 feet by 4 feet in height and width, or 122 cm by 122 cm. The authors are expected to be present at their respective poster sessions during the breaks, before and after lunch, and after the oral sessions have concluded each day.

The posters from all sessions should be displayed in Ballroom A, starting at noon, Tuesday, October 1, and should be taken down, after noon, Friday, October 4. All posters will be displayed for the full 3 days (half day on Tuesday and Friday, full day on Wednesday and Thursday) of the Symposium. Posters not removed by 14:00 on the last day of the Symposium may be lost and the organizers are not responsible to return them to the authors.

Conference Publications

All submitted abstracts will be published in the Symposium Program. Extended Abstracts (manuscripts with **4**-page limit strictly enforced) submitted by October 15, 2002 (absolute deadline), will be published in the Symposium Proceeding (CD-ROM or paper publication). (Student papers are allowed a page limit of 6).

All authors should submit three (3) hard copies of their manuscript as well as a soft copy, in an appropriate medium (i.e., CD-ROM, floppy disk, etc.), in Adobe Acrobat Reader (*.pdf) format only (please do not number the pages in your manuscript). The name(s) of the author(s) and the title of the submitted paper should appear on the CD-ROM and on the hard copies. Preparation of the manuscripts must follow the guidelines described in "Typing Instructions for Heiskanen Symposium in Geodesy": http://geodesy.ceegs.ohio-state.edu/50_years/TypInstr.doc.

Manuscripts should be sent to:

The OSU Geodesy Symposium C/O Peter Luk
The Ohio State University
470 Hitchcock Hall, 2070 Neil Ave.
Columbus, OH 43210-1275
U.S.A.

The Scientific Committee will consider a further publication of peer-reviewed papers in the form of a book volume, special journal issue (e.g., Journal of Geodesy), or a monograph (e.g., AGU Monograph).

Restaurants for Lunch and Dinner

Restaurants for Lunch and Dinner

There will be a sign-up sheet at the Registration Table each day for a buffet lunch at the Blackwell Ballroom, for ~$10 (minimum 30 people). The Blackwell Inn also has its own restaurant with seating for 110. There are some restaurants located within walking distance (5-7 minutes) from the Conference Center, e.g. Cooker Restaurant, Holiday Inn Restaurant. There are plenty of restaurants located in downtown Columbus, in the Short-North area, German Village, Grandview, etc. Restaurant list and maps are available from the hotel concierge.

Evening Programs

Ice Breaker (Welcome Reception)

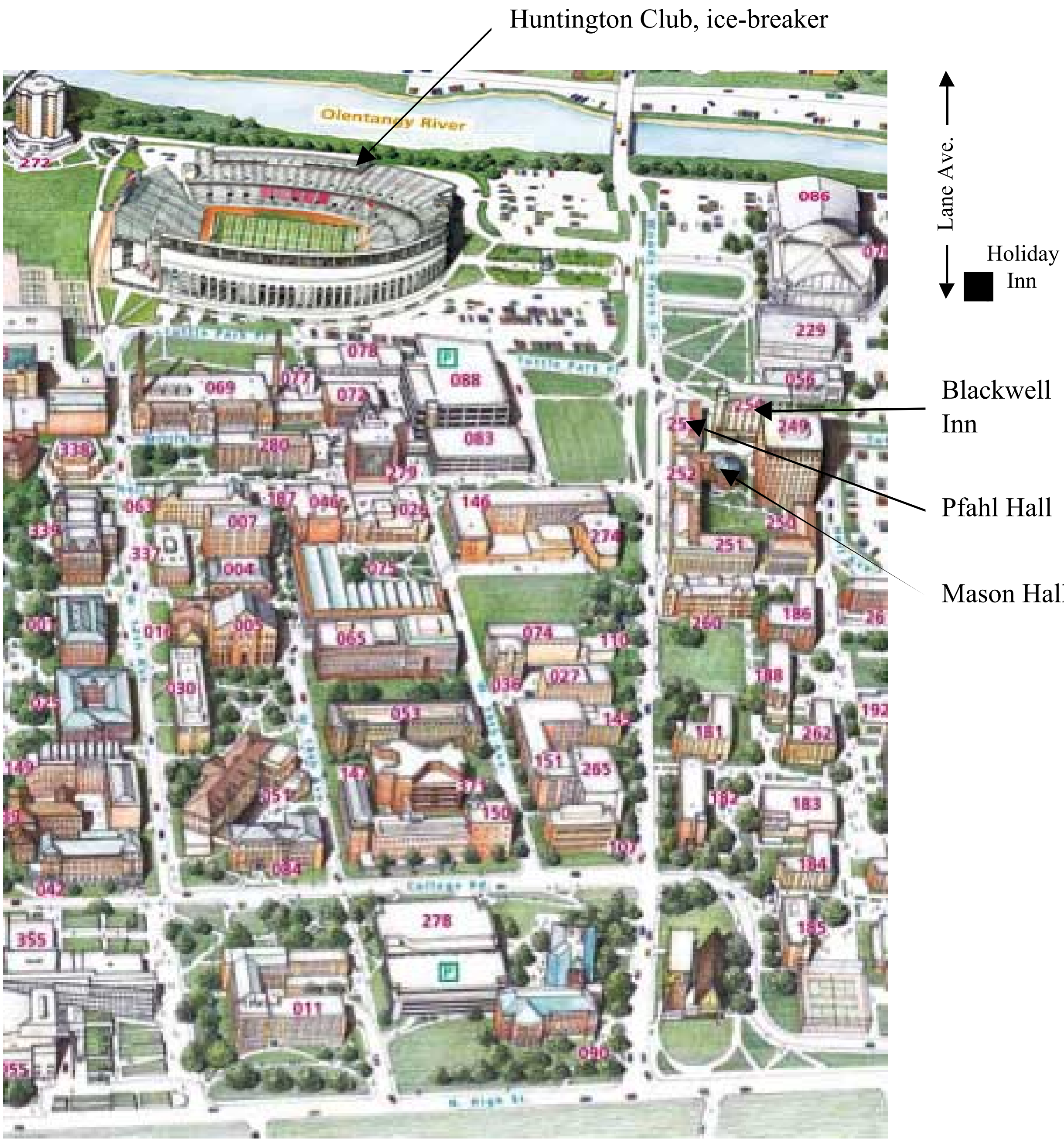
Tuesday, October 1, 2002 at 18:00 – 21:00 at the Ohio Stadium (see Map on p.6).

The Ice Breaker will be held on the second floor of the Huntington Club with cash bar, located between Gates 17 and 23 on the west side of the Ohio Stadium. This is within walking distance (5-7 min) from the Blackwell.

All registered participants and accompanying persons are welcome. The registration badges serve as admission tickets.

Banquet

The Symposium Banquet will be held on Thursday, October 3, at 19:00 – 22:00 at the Ballroom (B and C) of the Blackwell Inn. Banquet tickets (included with your registration) are required for admission. Limited additional tickets may be purchased on a first-come-first-served basis only in advance by e-mailing to:
50_years@geodesy.eng.ohio-state.edu or by contacting Peter Luk, 614-292-5196.



Ohio State University Campus

North

Weikko A. Heiskanen Symposium in Geodesy

Celebrating 50 Years of Geodetic Science at The Ohio State University, A Look to the Future

Dedicated to the Memory of William M. Kaula

Blackwell Inn Conference Center
2110 Tuttle Park Place

AGENDA

30 September 2002, Monday

13:30 – 18:00 Registration and hotel check in

Oral Sessions

1 October 2002, Tuesday AM, Opening Session	[back to Table of Contents]

7:30 – 14:00 Registration

8:30 – 9:00	Opening Remarks: Christopher Jekeli, Professor, Geodetic Science Welcome: Karen Holbrook, President, The Ohio State University Ohio State University's Academic Plan and Research Focus: Brad Moore, Vice President for Research, The Ohio State University
9:00 – 9:20	NASA's Role, Its Plan and Achievement in Global Climate Research Ghassem Asrar, Associate Administrator, NASA [movie clip 1, 2, 3]
9:20 – 9:40	National Geodetic Survey's Mission and Role in Shaping the Navigation and Mapping Needs of the United States: Charles Challstrom, Director, National Geodetic Survey
9:40 – 10:00	NIMA's Geodetic Mission and Academic Research Program: Steve Malys, Academic Research Program Director, National Imagery and Mapping Agency

10:00 – 10:20 BREAK

Session 1:	**1 October 2002, Tuesday AM, Interdisciplinary Science and Missions** **Chair: C. Jekeli** [back to Table of Contents]

10:20 – 10:40	1.1	The GRACE Mission, Its Status and Early Results: Byron Tapley
10:40 – 11:00	1.2	Antarctic Ice Sheet Mass Imbalance: A Geodetic Success Story: Duncan J. Wingham
11:00 – 11:20	1.3	The Shuttle Radar Topography Mission: Tom G. Farr and M. Kobrick
11:20 – 11:40	1.4	Altimetric Bathymetry from Surface Slopes (ABYSS): Seafloor Geophysics from Space for Ocean Climate: Walter H. F. Smith, R. Keith Raney, and the ABYSS team
11:40 – 12:00	1.5	Modeling and Interpretation of Mars' Gravity Field: David E. Smith
12:00 – 12:20	1.6	Constraints on Crustal Deformation from Imaging Geodesy: Mark Simons

12:20 – 13:30 LUNCH

Session 2:	**1 October 2002, Tuesday PM, Advances in Geodetic Adjustment and Representation** **Chair: B. Schaffrin** [back to Table of Contents]

13:30 – 14:00	2.1	The Power of the Gauss-Jacobi Combinatorial Algorithm to Detect Outliers and Solve Linear as well as Nonlinear Adjustment Problems: LPS-GPS Applications: Erik W. Grafarend and J. Awange
14:00 – 14:20	2.2	Multiple Gross Error Isolation Using L1-Norm Minimization: John Marshall
14:20 – 14:40	2.3	The Bayesian Approach in Two-Step Modeling of Deformations: Karl R. Koch, and Haim B. Papo
14:40 – 15:10	2.4	Self-Repeller: A Theory for Nonlinear Inverse Problems: Peiliang Xu

15:10 – 15:30 BREAK

Session 3:	1 October 2002, Tuesday PM, Global Sea Level and Ice Mass Balance Chair: D. Milbert [back to Table of Contents]

15:30 – 15:50	3.1	Space Geodetic Constraints on Glacial Isostatic Adjustment: Solving the Puzzle of Global Sea Level Rise: W. Richard Peltier
15:50 – 16:10	3.2	Determination of 20th Century Sea Level Rise: C. K. Shum, C. Kuo, Y. Yi, and A. Braun
16:10 – 16:30	3.3	A Global Inverse Approach to Ice Mass Variations and Earth Rheology: Xiaoping Wu, E. Ivins and J. Fastook
16:30 – 16:50	3.4	New Results on the Estimation of the Mass Balance of the Antarctic Ice Sheet from the Mass-Budget Method: Eric Rignot
16:50 – 17:10	3.5	Physical and Dynamical Properties of the Antarctic Ice Sheet from Radarsat-1: Kenneth C. Jezek
17:10 – 17:30	3.6	Investigations of Ice Dynamics at the Grounding Zone of an Antarctic Ice Shelf Utilizing SAR-Interferometry: Michael Baessler, and Reinhard Dietrich
17:30 – 17:50	3.7	Investigating the Long-Term Behavior of the Greenland Ice Sheet: Bea Csatho, Toni Schenk, and Kees van der Veen

18:30 – 21:00 ICE-BREAKER at The Ohio Stadium
"Professor Weikko A. Heiskanen, the Scientist" by Juhani Kakkuri

Session 4:	2 October 2002, Wednesday AM, Geodetic Instrumentation and Moving Platforms Chair: D. Grejner-Brzezinska [back to Table of Contents]

7:30 – 14:00 Registration

8:30 – 9:00	4.1	Gravimetic Instrumentation: New Instruments and Old: James E. Faller
9:00 – 9:20	4.2	Airborne Gravimetry - The Canadian Experience: Klaus-Peter Schwarz, and A. Bruton
9:20 – 9:40	4.3	Geoid Profiling Using Airborne GPS/INS Vector Gravimetry: Christopher Jekeli and Juan Serpas

9:40 – 10:00	4.4	The Contribution of Airborne Gravimetry to the Arctic Gravity Project and Future Earth Gravity Models: Steve Kenyon, R. Forsberg, J. Brozena, and N.K. Pavlis
10:00 – 10:30	4.5	Inertial Sensor Requirements for Georeferencing Data Collected on an Airborne Platform: Joe Hutton

10:30 – 10:50 BREAK

Session 4 (Continued): 2 October 2002, Wednesday AM, Geodetic Instrumentation and Moving Platforms
Chair: D. Chadwell [back to Table of Contents]

10:50 – 11:10	4.6	Moving Platform Gravity Gradiometry with Ultra-Cold Atoms: G. Biedermann, K. Bongs, J. Fixler, G. Foster, T. Kawakami, W. Li, J. Petricka, K. Takasi, B. Young, and Mark Kasevich
11:10 – 11:30	4.7	Cross-Venue Geodetic & Geophysical Applications of Future Inertial Force Sensors: David Gleason
11:30 – 11:50	4.8	The Delay-Doppler Altimeter: More Precision and a Smaller Footprint: R. Keith Raney, W. H. F. Smith
11:50 – 12:10	4.9	Spaceborne Laser Altimetry: Bob E. Schutz
12:10 – 12:30	4.10	Laser Scanning: Space-Geodesy to Micro-Geodesy: William E. Carter
12:30 – 12:50	4.11	A Practical Approach to LIDAR Sensor Calibration: Charles Toth, and Dorota Grejner-Brzezinska

12:50 – 14:00 LUNCH

Session 5:	**2 October 2002, Wednesday PM, State of the ITRF and Its Stability** **Chair: R. Snay** [back to Table of Contents]

14:00 – 14:20	5.1	The International Terrestrial Reference Frame: Kristine Larson, C. Boucher, Z. Altamimi, and P. Sillard
14:20 – 14:40	5.2	GPS Geodesy in Antarctica for The Realization of the ITRF and Geodynamic Studies: Reinhard Dietrich, and A. Rülke
14:40 – 15:00	5.3	The National and Cooperative CORS Program: Richard Snay, Gordon Adams, and Miranda Chin
15:00 – 15:20	5.4	National CORS Network Design: Station Spacing and Data Rates: Gerald L. Mader
15:20 – 15:40	5.5	Hydrographic Surveying in a Tidal Datum with Kinematic GPS Control: Dennis Milbert, and Jack Riley
15:40 – 16:00	5.6	Redefinition of the Indian Geodetic Datum: G.D. Gupta, and B. Nagarajan

16:00 – 16:20 BREAK

Session 6:	**2 October 2002, Wednesday PM, Geodynamics** **Chair: B. Archinal** [back to Table of Contents]

16:20 – 16:40	6.1	Regional Continuous GPS Networks for Crustal Deformation: Detection of Vertical and Dynamic Motions: Yehuda Bock, Rosanne Nikolaidis, H. Cecil, and M. Ida
16:40 – 17:00	6.2	Crustal Velocity Field of Western Europe from Permanent GPS Array Solutions, 1996-2001: J.-M. Nocquet, and Eric Calais
17:00 – 17:20	6.3	Secular, Transient and Periodic Crustal Deformation Observed in the Japanese Nationwide GPS Array: Kosuke Heki
17:20 – 17:40	6.4	Geodynamics of the Andes: New Insights from GPS Geodesy: Michael Bevis, Eric Kendrick, and Benjamin Brooks
17:40 – 18:00	6.5	Low Power Remote GPS Observatories in Southern Victoria Land, Antarctica: Larry D. Hothem, and Mike Willis

Session 7:	**3 October 2002, Thursday AM, Advances in Gravity Field Representation** **Chair: N. Pavlis** [back to Table of Contents]

7:30 – 14:00 Registration

8:30 – 8:50	7.1	Inertia of Quadratic Forms and General Bases in Geopotential Approximations: Petr Holota
8:50 – 9:10	7.2	Representation of Spatial Functions in Geodesy Using B-Spline Wavelets with Compact Support: Rainer Mautz, Burkhard Schaffrin, Michael Schmidt, and C. K. Shum
9:10 – 9:40	7.3	New Multiresolution Representations of the Earth's Gravity Field: Gregory Beylkin
9:40 – 10:00	7.4	Multi-Resolution Representation of the Gravity Field Using Spherical Wavelets: Michael Schmidt, and C. K. Shum

10:00 – 10:20 BREAK

Session 8:	**3 October 2002, Thursday AM, Advances in Gravity Field Modeling** **Chair: S. Kenyon** [back to Table of Contents]

10:20 – 10.40	8.1	Earth's Gravity Spectrum, Kaula's Law & Geoid Computation: Roger Hipkin
10:40 – 11:00	8.2	Estimating Geoid Grid Spacing: Robert C. Anderson, and James Davenport
11:0 – 11:20	8.3	Some Design Considerations for the Development of a New Earth Gravitational Model: Nikolaos K. Pavlis
11:20 – 11:40	8.4	Gravity Field Models beyond CHAMP, GRACE and GOCE: A Synergetic View of Global Gravity Field Computation: Thomas Gruber
11:40 – 12:00	8.5	LISA/Cartwheel Orbit Type for Future Gravity Field Satellite Missions: Nico Sneeuw

12:00 – 14:00 LUNCH

Session 9:	**3 October 2002, Thursday PM, Meteorology from Space Geodetic Observations** **Chair: Y. Bock** [back to Table of Contents]

14:00 – 14:20	9.1	The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC): William Schreiner, D. Hunt, Y.-H. Kuo, C. Rocken, and S. Sokolovskiy
14:20 – 14:40	9.2	GPS Radio Occultation Data Applied to Antarctic Weather Analysis and Forecasting: David Bromwich, H. Wei, Y.-H. Kuo, T.-K. Wee, and C. K. Shum
14:40 – 15:00	9.3	Improving Precipitation Forecasts in the Mediterranean Region through the Use of GPS Derived Integrated Water Vapor Measurements: Jennifer Haase, Eric Calais, and Henrik Vedel
15:00 – 15:20	9.4	Water Vapor Monitoring Using GNSS: Experiments and Perspectives of Applications in Brazil: J. Francisco Galera Monico
15:20 – 15:40	9.5	Determination of Tropospheric Parameters by VLBI as a Contribution to Climatological Studies: Harald Schuh and H. Böhm

15:40 – 16:00 BREAK

Session 10:	**3 October 2002, Thursday PM, Innovative Applications of Space Geodetic Instruments** **Chair: A. Saalfeld** [back to Table of Contents]

16:00 – 16:20	10.1	A Global Framework for Interdisciplinary Science and Applications: The International GPS Service: Ruth E. Neilan, C. Reigber, and R. Weber
16:20 – 17:50	10.2	Global Navigation Satellite Systems: Emerging Capabilities and Research Opportunities: Gerard Lachapelle
16:50 – 17:10	10.3	Oceanography with GPS**:** Cinzia Zuffada
17:10 – 17:30	10.4	GPS Positioning of Platforms Floating on the Ocean Surface**:** C. David Chadwell

19:00 – 22:00 BANQUET, Blackwell Inn Ballroom
"William Kaula, Scientist and Individual", by Bernie Chovitz

Session 11:	4 October 2002, Friday AM, Planetary Geodesy and Geophysics Chair: R. Li [back to Table of Contents]

8:30 – 8:50	11.1 Numerical Simulations for Geodetic Parameter Estimation from Space VLBI Data: Madhav N. Kulkarni, and Syndor Frey
8:50 – 9:10	11.2 Satellite Gravity Exploration of the Terrestrial Planets and the Moon: Ralph von Frese, Hyung Rae Kim, Timothy Leftwich, and Laramie V. Potts
9:10 – 9:30	11.3 Geoid height and Stress in the Lithosphere of Venus and the Earth: David T. Sandwell
9:30 – 9:50	11.4 Planetary Geodesy: The Mapping of Mars at Global to Local Scales: Brent Archinal
9:50 – 10:10	11.5 Mars Landing Site Mapping and Rover Localisation: Rongxing Li, K. Di, F. Xu, L. H. Matthies, and C. F. Olson

10:10 – 10:30 BREAK

Session 12:	4 October 2002, Friday AM, Geophysical Fluids: Observations and Modeling Chair: C. Hwang [back to Table of Contents]

10:30 – 10:50	12.1 Tides And Modern Geodesy: Richard D. Ray
10:50 – 11:10	12.2 The Chandler Wobble: Richard S. Gross
11:10 – 11:30	12.3 Earth Rotation Variations: A Budget Assessment: Clark R. Wilson, Jianli Chen, and Ki-Weon Seo
11:30 – 11:50	12.4 Polar Motions Detected by Geodetic Means and Excited by the Atmosphere: Barbara Kolaczek, J. Nastula, and D. Salstein
11:50 – 12:10	12.5 Satellite Measurements of Time-Variable Gravity, and Their Possible Applications for Hydrology: John Wahr, Sean Swenson, and Isabella Velicogna
12:10 – 12:30	12.6 Analysis of Time-variable Gravity by Satellite-Laser-Ranging in the Last Quarter Century: Christopher Cox, B. F. Chao, and A. Au
12:30 – 12:50	12.7 Seasonal to Decadal Variations of Low-Degree Gravity Field induced by Oceanic Mass Redistribution: Results from GEOSAT, ERS and TOPEX/POSEIDON Satellite Altimetry: Cheinway Hwang, Y. C. Kao and C. K. Shum

12:50 – 13:00 CLOSING

Poster Sessions:

1 October 2002, Tuesday, 12:00 noon – 4 October 2002, Friday, 12:00 noon

General [back to Table of Contents]

P01	Crossing the Olentangy River: The Cold War and the Establishment and Triumph of the Geodetic and Allied Sciences at Ohio State University: John G. Cloud
P02	Geospatial Information and Analysis for Coastal Management and Decision Making: R. Li, K. W. Bedford, C. K. Shum, J. R. Ramirez, A. Zhang and K. Di

Satellite Altimetry and Sea Level [back to Table of Contents]

P03	The ENVISAT RA-2 Radar Altimeter System: J. Benveniste, M.P. Milagro-Perez, M. Roca, and G. Levrin
P04	Operational and Precise Orbit Determination for Geosat Follow-On Altimetry: John Lillibridge, Nikita Zelensky, Frank Lemoine, Brian Beckley, and Yuchan Yi
P05	Satellite Altimetry Applications: Operational Oceanography from Space: M. Srinivasan, R. Leben, Lee-Lueng Fu, Y. Menard, E. Dombrowsky, and F. Blanc
P06	Altimetric Bathymetry from Surface Slopes (ABYSS): Seafloor Geophysics from Space for Ocean Climate: Walter H. F. Smith, R. Keith Raney, and the ABYSS Team
P07	Tide Gauge Data Analysis in the North Sea for Altimetry Calibration: Alexander Braun, and Johannes Wuensch
P08	Radar Altimeter Absolute Calibration Using GPS Buoy and Tide Gauges: Kai-Chien Cheng, C.K. Shum, and Stephane Calmant
P09	Studying Seasonal Sea-Level Variations in the Baltic Sea Using Geodetic Measurements and Oceanographic Model: K. Novotny, G. Liebsch, R. Dietrich, A. Lehmann
P10	Great Lakes Monitoring Using Space Geodetic Technologies: Chung-yen Kuo, Yuchan Yi, Kai-Chien Cheng, and C.K. Shum
P11	Glacial Isostatic Adjustment Inferred by Tide Gauges and Satellite Altimetry: Chung-yen Kuo, and C.K. Shum

Crustal Dynamics and GPS Applications [back to Table of Contents**]**

P12	Meteorology Using GPS Limb-Sounding of Low-Earth Orbiters: Shengjie Ge, C. K. Shum
P13	Improving Precipitation Forecasts in the Mediterranean Region through the Use of GPS derived Integrated Water Vapor Measurements: Jennifer Haase, Eric Calais, and Henrik Vedel
P14	The Crustal Response to Changing Tidal Loads Imposed by a Pinned Ice Shelf: Mike Willis
P15	Post Glacial Rebound and Rift Tectonics of the Antarctic Interior: Mike Willis, and Terry Wilson

P16	Use of Global Positioning System on High Precision Geodetic Control of Nepal: Krishna Raj Adhikary
P17	GPS Detection of Izmit Earthquake and Shape Model of Already GPS-Detected Launch of Space Shuttle in 1993: Mosa'b Hawarey
P18	Evaluating Multipath Effects at Stations in the National CORS Network: Stephen Hilla and Michael Cline
P19	Preliminary Results of the GPS Studies for the January 2001 Gujarat Earthquake: Madhav N. Kulkarni
P20	Geodetic and Geophysical Studies for Monitoring Crustal Deformation in Kachchh Region of Gujarat, India: G.D. Gupta, and B. Nagarajan
P21	Effects of Introducing Pseudolite Measurements into an Integrated GPS/INS System: Hung Kyu Lee
P22	Precise Positioning Estimators Based on the Stochastic Analysis and Alternative Variance Covariance Matrix of GPS Observables: G. Esteban Vazquez B.
P23	Need for Integrated Approach in Monitoring of Earthquake Precursors: Bimal Chandra Roy
P24	Regional 3-Dimensional Deformation Observed by VLBI: Zhigen Yang, and C.K. Shum
P25	Performance Analysis of Land-Based GPS/INS/Pseudolite Integrated System: Yudan Yi
P26	A Memo on the Modeling of Baseline Length Repeatability: Jinling Li
P27	Great Lakes Continuous GPS (CGPS) Network For Geodynamics, Meteorology and Safe Navigation: Richard Snay, Miranda Chin, David Conner, Tom Soler, Chris Zervas, Jeff Oyler, Michael Craymer, Seth I. Gutman, C.K. Shum, Kai-Chien Cheng, and Chung-yen Kuo
P28	Near Real-time Kinematic Orbit Determination Using GPS: Dorota Grejner-Brzezinska, Tae-Suk Bae and Chang-Ki Hong

Gravity Field and Polar Motion,[back to Table of Contents]

SESSION 1

Interdisciplinary Science and Missions

October 1, 2002, Tuesday AM

1.1

The GRACE Mission, It's Status and Early Results

Byron Tapley

University of Texas at Austin, Center of Space Research

Abstract: [back to Session 1]

The Gravity Recovery and Climate Experiment (GRACE) is a dedicated satellite mission whose objective is to map the global gravity field with unprecedented accuracy over a spectral range from 500 km to 40,000 km. The measurement precision will support gravity field solutions in this frequency range that are between 10 and 1000 times better than our current knowledge. Highly accurate measurements, with both high spatial and temporal resolution, will allow studies of the gravitational signals associated with the mass exchange between the solid Earth and the hydrological, ocean and atmospheric components. The primary measurement provided by the High Accuracy Inter-satellite Ranging System (HAIRS) is the range change between two satellites orbiting one behind the other at an approximate distance of 200 km. The range change will be measured with a precision better than 10 microns. A highly accurate three-axis accelerometer, located at the satellite mass center, will be used to measure the surface force and attitude control induced accelerations. Satellite GPS receivers will position the satellites over the earth with centimeter level accuracy. With this set of measurements, GRACE will provide highly accurate measurements of the global gravity field once every thirty days. The two satellites were launched on March 17, 2002 and were designed to operate for a period of five years. The satellites will fly in coplanar nearly polar orbits, at an altitude between 500 and 300 km, separated by approximately 200 km along track. The mission, which is one of the first NASA Earth System Pathfinder Missions, is implemented through a collaborative arrangement by NASA and DLR. The presentation will summarize the mission structure, the early satellite and instrument performance, the data system and ancillary data requirements and will describe some of the early analysis results.

1.2

Antarctic Ice Sheet Mass Imbalance: A Geodetic Success Story

Duncan J. Wingham

Center for Polar Observation and Modeling, University College London.

Abstract: [back to Session 1]

As recently as 1992, it was possible for one author to conclude that, as far as we knew, the Antarctic ice sheet could be anything from a 600 Gt/yr source to 600 Gt/yr sink of ocean mass, a contribution of anything between adding or subtracting 2 mm each year to eustatic sea level. Underlying this uncertainty was the great difficulty of establishing through ground based observations the difference between the mass accumulated on the sheet through snow-fall and that lost through flow to the ocean at the ice sheet margins. In addition, the division of the mass loss between iceberg calving and ice shelf melting was more or less unknown, although the implications for the buoyancy forcing of the ocean of the two mass losses is quite different.

In the space of a decade, satellite radar altimetry, particularly the observations of the European ERS satellites, have transformed our understanding of a great proportion of the ice sheet. We now know that the interior of the East Antarctic ice sheet is in a state of mass balance. Taken as whole, the sheet appears to be in a state of balance to within ~ 150 Gt/yr, in keeping with geodetic and sea level evidence that indicates Antarctic mass balance over the past few thousand years. On the other hand, altimetry has revealed that the grounded ice streams and basins of the Amudsen and Bellinghausen Sea sectors of the West Antarctic ice sheet are thinning. In some cases, the thinning is large: in some cases the streams will be completely afloat in 500 years if the thinning continues unabated.

This paper will review the achievements of the past decade in observing the mass imbalance of the Antarctic ice sheet, detailing both the scientific and technical achievements. It will also outline the remaining problems, and comment on how the future US ICESAT and European CryoSat satellite missions will contribute to closing the uncertainty associated with this largest of the Earth's ice sheets.

1.3

The Shuttle Radar Topography Mission

Tom G. Farr, and M. Kobrick

Jet Propulsion Laboratory

Abstract: [back to Session 1]

The Shuttle Radar Topography Mission (SRTM), which flew successfully aboard Endeavour in February 2000, is a cooperative project between NASA, the National Imagery and Mapping Agency (NIMA), and the German and Italian Space Agencies. The mission was designed to use a single-pass radar interferometer to produce a digital elevation model of the Earth's land surface between about 60 degrees north and 56 degrees south latitude.

SRTM used a modification of the radar instrument that comprised the Spaceborne Radar Laboratory that flew twice on the Shuttle Endeavour in 1994. To collect the interferometric data, a 60 m mast, additional C-band antenna, and improved tracking and navigation devices were added. A second X-band antenna was also added by the German Space Agency, and produced higher resolution topographic measurements in strips nested within the full, C-band coverage.

First results indicate that the radars and ancillary instruments worked very well. Data played back to the ground during the flight were processed to DEMs and products released hours after acquisition. An continuing program for calibration and verification of the SRTM data has shown vertical accuracies as good

as 5 m. As of August 2002, production processing has been completed for North America, South America, and Australia. Full resolution data for the US have been released through the US Geological Survey's EROS Data Center. Other smaller areas have been processed for NASA science investigators. Public release of 90 m resolution data will occur in stages, with complete release likely by the end of 2003. NIMA will handle Department of Defense distribution.

1.4

Altimetric Bathymetry from Surface Slopes (ABYSS): Seafloor Geophysics from Space for Ocean Climate

Walter H. F. Smith (1), R. Keith Raney (2), and the ABYSS Team

(1) NOAA Satellite Altimetry Lab, (2) Johns Hopkins University Applied Physics Lab

Abstract: [presentation] [back to Session 1]

Forecasts of climate and sea level on inter-annual and longer time scales require accurate models of the advection and mixing of heat, salt and greenhouse gases in the oceans. These models are sensitive to global ocean bathymetry on fine spatial scales (10 to 30 km full-wavelength), and model uncertainty is now a focus of global change debate. Sea floor topography is isostatically uncompensated at these wavelengths, and so climatically useful bathymetry may be recovered by inversion of gravity field observations, if data of sufficient precision (1 to 2 mGal) in this wavelength band can be obtained over most of the global oceans. Space-based mapping is faster and cheaper than a systematic ship survey, but upward continuation to orbital altitudes eliminates the bathymetric signal; thus, space gravity missions (CHAMP, GRACE, GOCE) cannot detect the signal, and one must use radar altimetry of the ocean surface to recover gravity at bathymetric scales. Experience with GeoSat and ERS-1 proves the feasibility of the technique and shows how to optimize a new mission to fully achieve the required resolution. Short-wavelength resolution requires greater range precision and smaller along-track footprint than conventional altimetry has achieved. Azimuthally isotropic resolution requires that errors project nearly equally into north and east components of geoid slope, requiring an orbit of moderate inclination. A delay-Doppler radar altimeter operating for six years on the International Space Station or other suitable orbiter can achieve the required resolution, and at the same time can operate closer to shore than other altimeters and with better spatio-temporal sampling of tides, yield wind and wave data in near-real time, and explore the geology and resource potential of the continental margins. Our proposal to NASA ESSP for such a mission is called ABYSS, for Altimetric Bathymetry from Surface Slopes. Further information on delay-Doppler altimetry and ABYSS is in a paper by R. K. Raney at this meeting.

1.5

Modeling and Interpretation of Mars Gravity Field

David E. Smith

Laboratory for Terrestrial Physics, Goddard Space Flight Center

Abstract: [presentation] [back to Session 1]

Since September 1997 when the Mars Global Surveyor (MGS) spacecraft arrived at Mars there has been considerable improvement in our knowledge of the planet and much of that has been due to significant improvements in the geodesy of Mars. MGS carried 4 instruments, including a laser altimeter, and a radio science experiment that included gravity field mapping and modeling. Five years after arrival at Mars and 3 1/2 years after the beginning of the mapping phase of the mission we have high quality

global gravity and topographic models of the planet that have enabled us to derive a crustal thickness model for Mars and develop ideas for the early evolution of the planet and the formation of its large volcanoes. In addition, changes in some of the very low degree terms in the gravity field together with altimeter measurements of the seasonal changes in the heights of the icecaps have permitted the density of the seasonal icecap material to be estimated to have a density of about 2/3 of solid carbon dioxide suggesting CO2 snow or frost.

1.6

Constraints on Crustal Deformation from Imaging Geodesy

Mark Simons

Seismological Laboratory, Caltech

Abstract: [presentation] [back to Session 1]

Complimenting temporally continuous GPS measurements, satellite-based geodetic imaging methods can now provide spatially continuous glimpses of crustal deformation. These imaging methods include Interferometric Synthetic Aperture Radar (InSAR) and Pixel Coregistration (PC) techniques. InSAR relies on phase differences between repeat radar images and provides measurements of surface deformation in the satellite line-of-sight direction with sensitivities of a small fraction of the radar wavelength (sub-cm). InSAR is well suited to studying deformation associated with all phases of the seismic cycle, volcanic activity, and glacier flow. PC techniques track features in the amplitude of an image (radar or optical) by successive cross-correlation between small subsets of pairs of images that span a deformation event. For nadir-oriented images, PC techniques provide two horizontal components of the displacement field with sensitivities of a small fraction of the image pixel size, and are therefore most useful for studying large deformational processes such as major earthquakes and ice stream.

Using the existing imagery archive from the ERS-1, ERS-2, and JERS satellites, we discuss the use of InSAR and PC methods to constrain the fault slip parameters of several recent large earthquakes including 1992 Mw 7.3 Landers (CA), 1996 Mw 8.1 Antofagasta (Chile), 1999 Mw 7.1 Hector Mine (CA), and 2001 Mw 8.0 Kunlun (Tibet). The high spatial density of observations, at all distances from the surface rupture, allow us to constrain the depth distribution of slip with unprecedented resolution. Such models provide insight into the rheological behavior of the lithosphere. In particular, we begin to address the role of co-seismic inelastic strain occurring off the main fault as well as the depth of maximum slip, which we infer to correspond to the bottom of the region where the crust the behaves purely elastically between earthquakes.

We also discuss the relative ease with which we can know survey large regions of the Earth for surface deformation associated with volcanic activity. As a demonstration, we review the results of a recently completed survey of over 900 volcanoes in the volcanic arc in the central Andes (southern Peru, Bolivia, and northern Chile). This survey finds four previously undocumented sources of deformation indicating subsurface movement of fluids and/or magma. One of these sources, inferred to lie at about 7 km depth, is probably magmatic in nature, and is not associated with a volcanic edifice. We suggest that this source may be an incipient volcanic calderas.

Systematic use of geodetic imaging techniques is limited by the temporal and geographic sparseness of available image archives as well as the cost of buying data from foreign distributors. Future radar satellite missions should provide observations allowing a complete characterization of the surface deformation field associated with most shallow earthquakes, as well a comprehensive survey of the level of deformational activity associated with Earth's major volcanoes.

SESSION 2

Advances in Geodetic Adjustment and Representation

October 1, 2002, Tuesday PM

2.1

The power of the Gauss-Jacobi Combinatorial Algorithm to Detect Outliers and Solve Linear as well as Nonlinear Adjustment Problems: LPS-GPS applications

Erik W. Grafarend and J. Awange

Geodaetisches Institut, Universitaet Stuttgart

Abstract: [back to Session 2]

The algebraic techniques of Gröbner bases and Multipolynomial resultants are presented as efficient algebraic tools for solving the nonlinear geodetic problems. The capability of the Gröbner bases and the Multipolynomial resultants to solve explicitly nonlinear geodetic problems enables us to use them as the computational engine in the Gauss-Jacobi combinatorial algorithm to solve the nonlinear Gauss-Markov model, namely in identifying outliers. References are GPS Solutins 5 (2002) 20-23, 80-93 as well as J.L. Awange (Groebner Bases, Multipolynomial Resultants and the Gauss-Jacobi Combinatorial Algorithms - Adjustment of Nonlinear GPS/LPS Observations: Schriftenreihe de Institute des Studienganges Geodäsie und GeoInformatik, Report 2002.1, http://elib.uni-stuttgart.de/opus/volltexte/2002/986).

2.2

Multiple Gross Error Isolation Using L1-Norm Minimization

John Marshall

National Geodetic Survey

Abstract: [presentation] [back to Session 2]

L1 norm minimization is unique among the various estimation methods available today because it yields valuable pre-analysis information concerning multiple gross error detection. The pre-analysis information consists primarily of residual signs which are gleaned from feasible solutions to the linear programming solution to L1 norm minimization. Tabulating the residual signs illuminates those pairs, triplets, etc. of gross errors which L1 norm minimization is capable of tolerating while still supplying approximate parameter values for later use with least squares. The technique is general and applies to typical adjustment problems found in geodesy and photogrammetry.

2.3

The Bayesian Approach in Two-Step Modeling of Deformations

Karl R. Koch, and Haim B. Papo

Bonn and, Haifa

Abstract: [presentation] [back to Session 2]

Deformations are detected in a two-step procedure using Bayesian statistics. At the first step the coordinates of points in a network are determined with respect to a chosen datum from measurements of different kinds, that were made at a number of different epochs. Variance components of the measurements at each specific epoch are estimated together with the respective point coordinates. At the second step of the analysis the estimated variations of point coordinates are modeled by a new set of unknown parameters. One can experiment with a number of different parameter sets and respective step-two models. Analysis of the second step is based on three conceptually different approaches:

(a) Regularization approach, where the optionally singular normal matrix of unknown parameters is regularized. The posterior distribution of the regularization parameter is given.

(b) Extended free net approach, featuring isometric mapping of point coordinates.

(c) Prediction and filtering approach, introducing unknown system noise. Posterior distributions of the unknown parameters and of the system noise are given.

The choice of an appropriate approach would depend on the particular application. The above two steps can be combined into a single-step procedure, so that estimation of the deformation model parameters would follow directly. To obtain identical results with the respective two-step solution certain conditions have to be observed. A simple numerical example is simulated and analyzed in detail to serve as an illustration of the theory.

2.4

Self-Repeller: A Theory for Nonlinear Inverse Problems

Peiliang Xu

Disaster Prevention Research Institute, Kyoto University, Japan

Abstract: [presentation] [back to Session 2]

Inverse problems in science and engineering can ultimately be turned into an optimization (maximization or minimization) model. Practically, almost all real-life cost functions are nonlinear and nonconvex, and are represented by a number of parameters, depending on the problem under study. Finding correctly the optimal solution, in particular, the global optimal solution (or earth model) has been a painstaking endeavour, and can often fail. This is particularly true in the Earth Sciences. The reasons for this can be very obvious, since geoscientists have almost always used either well developed Gauss-Newton algorithms or simulated annealing, genetic algorithms and/or other evolutionary methods to search for a model that fits best to data in a certain sense. However, the first category of algorithms is of local nature. There exists no warranty that a local optimization algorithm can produce the global optimal solution(s), unless the cost function has some special features, convexity, for example. The second category of algorithms is of random nature. Unless the number of samplings tends to infinity, the algorithms of random nature provide no warranty to identify the global optimal earth model(s) either. In other words, the condition for the convergence of algorithms of random nature is practically unrealistic.

In principle, interval arithmetic based techniques can always result in the correct global optimal solution(s). However, for highly nonlinear and nonconvex cost functions, these methods can be quite slow, since the basic idea of such methods is the branch and bound. In this talk, we will develop a new global optimization method for nonlinear nonconvex inversion by combining local optimization methods with feasible point finders. Local optimization algorithms have been proved to be robust, reliable and quickly convergent to a local optimal solution in the neighborhood of a starting point. Feasible point finders serve as an engine, either for repelling or lifting the whole algorithm from trapping into a local optimal solution or for providing the warranty that the global optimal (earth model) solution has been found correctly. A number of examples of one- and multiple-dimensions will be used to demonstrate how the method works.

SESSION 3

Global Sea Level and Ice Mass Balance

October 1, 2002, Tuesday PM

3.1

Space Geodetic Constraints on Glacial Isostatic Adjustment: Solving the Puzzle of Global Sea Level Rise

W. Richard Peltier

Department of Physics, University of Toronto

Abstract: [back to Session 3]

Although estimates of the ongoing rate of sea level rise have most often been produced on the basis of analysis of tide-gauge recordings, such data are strongly contaminated by the influence of the global process of glacial isostatic adjustment (GIA; eg. Peltier, 2001). This contamination must be accurately removed in order that the gauge measurements may be usefully employed to estimate the influence of modern climate change upon the global signal. It has recently been suggested that such data are further contaminated simply by virtue of their coastal locations (Cabanes et al., 2001), this source of contamination serving to bias observed rates of secular sea level change upwards by as much as a factor of two. If this were true it would imply that the average rate of 20th century sea level rise of approximately 1.84 mm yr-1 determined on the basis of GIA decontaminated long tide gauge recordings should be reduced to approximately 0.92 mm yr-1 in order to estimate the global sea level impact of climate change over the last century. Given that the best estimate of the rate of global sea level rise based upon available estimates from the Topex/Poseidon satellite altimetry system is near 2.4 mm yr-1 (Nerem and Mitchum, 2001), this would imply that the rate has accelerated significantly over the most recent decade.

In order to reduce the uncertainty that exists because of the large differences between the results obtained on the basis of these three distinct methods of inference, global coverage of the oceans such as is provided by T/P and the follow-on altimetric mission Jason is clearly required. The Gravity Recovery And Climate Experiment (GRACE) is expected to produce a much higher resolution and accuracy data set that will significantly improve the T/P based estimates of the modern signal. It should be clear, however, that both the T/P and GRACE measurements must also be decontaminated to remove the influence of the GIA process. As previously demonstrated (Peltier, 2001), this source of contamination of the signal is such that the spatially averaged rate of sea level rise measured with respect to the center of mass is biased downwards by approximately 0.3 mm yr-1. The GRACE data set promises much more than an improved measurement of the globally averaged rate, however, since its high spatial resolution may enable us to employ the observed pattern of variability of the signal over the oceans to begin to identify the geographical regions (eg. Antarctica, Greenland) from which meltwater may be reaching the ocean basins. I will discuss recent extensions of the theory of the GIA process and the space geodetic observables that the theory predicts, focussing especially upon those which promise to be of assistance in aiding us to better understand the climate change induced process of global sea level rise.

3.2

Determination of 20th Century Sea Level Rise

C. K. Shum (1), C. Kuo (1), Y. Yi (1), and A. Braun (2)

(1) Laboratory for Space Geodesy and Remote Sensing Research, Department of Civil and Environmental Engineering and Geodetic Science, The Ohio State University
(2) Byrd Polar Research Center, The Ohio State University

Abstract: [presentation] [back to Session 3]

Sea level rise has been widely recognized as a measurable signal as one of the consequences of human-induced global climate change. The small rate of sea level rise signal, at 1-2 mm/yr during the last century [*IPCC*, Church et al., 2001], could only be partially explained by a number of competing geophysical processes, each of which is a complex process within the Earth-atmosphere-ocean-cryosphere-hydrosphere system. They include geological change of the ocean basin; redistribution of atmosphere masses and water from ice sheet and glacier melt; visco-isostatic rebound of the lithosphere and mantle from Pleistocene deglaciation; resulting gravity changes; thermal expansion and halosteric contraction of the ocean; the extraction of ground water and storage of water in man-made reservoirs; astronomical and atmospheric tides; and changes in coastal sedimentation and erosion. The dominant effects are the melting of the continental ice sheets and glaciers, and the steric (thermosteric and halosteric) effects of the ocean [Pattulo et al., 1955], especially if the warming trend continues. The recently published 20th century sea level rise rate of 1.84±0.35 mm/yr [Douglas, 2001; Peltier, 2001] is not fully explained by 0.2-1.2 mm/yr of the signal. Recent studies [Cabanes et al., 2001; Gille, 2001; Shum et al., 2001] using the Levitus data indicate significantly more upper-ocean (above 500 m) warming in the Southern Ocean, and implies significant geographical variations in both the thermal [Shum et al., 2001] and the "self-gravitational" sea level signal as result of present-day ice melt [Mitrovica et al., 2001] which limits tide gauge determination of the 20th century sea level rise. In this paper, we provide an updated quantification and characterization of the 20th century sea level rise using data from multiple satellite altimetry missions spanning over 16 years and long-term tide gauges, for the sea level signal components of thermal expansion, oceanic mass variation, self-gravitation and vertical motion corrections at long-term tide gauge locations.

3.3

A Global Inverse Approach to Ice Mass Variations and Earth Rheology

Xiaoping Wu (1), E. Ivins (1) and J. Fastook (2)

(1) Jet Propulsion Laboratory, California Institute of Technology,
(2) Department of Computer Science, University of Maine

Abstract: [presentation] [back to Session 3]

We study present-day surface mass trends, global ice history, and the earth rheology profile using a global and simultaneous inverse approach. A nonlinear global inverse algorithm is being developed at JPL for parallel operations on massively clustered supercomputers. The simultaneous inversion for all relevant parameters will not only yield optimal estimates, but also enable a statistical evaluation of the resolution and uncertainties. Our covariance and simulation analyses indicate that GRACE gravity and altimeter/GPS elevation rate measurements can distinguish between signatures of present-day surface mass change and viscoelastic rebound. For example, the mean Antarctic present-day ice mass balance can be determined to about 4 mm/yr, corresponding to an error of 0.1 mm/yr in the Antarctic contribution to sea-level change. However, the geodetically determined rebound signatures cannot be used alone to distinguish

between the Earth rheology and ice load history. A further combination of secular gravity/elevation data and historical relative sea-level (RSL) records should be used to facilitate an improved parameter separation and to enhance spatio-temporal resolving power. By comparing and combining the inversion results with the University of Maine dynamic ice evolution model, we also seek to validate both the inversion and the model, to bridge data gaps in time and space, and to understand the mechanisms of cryogenic change and its relationship with climate. The significance of the new satellite data and the global simultaneous solution, the enormous challenges of inverse modeling the high volume/precision multiple data sets, and research/development progress will be discussed in this presentation.

3.4

New Results on the Estimation of the Mass Balance of the Antarctic Ice Sheet from the Mass-Budget Method

Eric Rignot

Radar Science and Engineering Section, Jet Propulsion Laboratory

Abstract: [presentation] [back to Session 3]

As summarized by the most recent IPCC report, we do not know whether the Antarctic ice sheet is gaining or losing mass to the ocean at present, hence leaving a major uncertainty in the current sea-level rise budget. Radar altimetry results published in 1998 suggested a modest imbalance of the Antarctic ice sheet, however based on a survey of 63 percent of the grounded ice, that excluded a 200-km wide band along the coast where radar altimetry measurements are challenging due to steep slopes. From the mass budget method, most researchers have embraced the study of Bentley and Giovinetto published in 1991 which concluded on a positive mass budget, however with considerable uncertainty. Their estimate was including largely positive budgets for Pine Island Glacier and Lambert glaciers. Even today, most researchers interested in post glacial rebound use those results as a plausible representation for present-day mass balance. New studies reveal that those sectors suspected to be gaining mass are in fact loosing mass or being close to balance. These new studies employ interferometric SAR to measure ice velocity and grounding line position around the periphery of Antarctica, combined with a radar altimetry map of surface elevation to estimate ice thickness from hydrostatic equilibrium. While the results are still affected by uncertainties associated with the lack of quality direct measurements of ice thickness, they are clearly outlining major differences in behavior in different regions. Areas believed to be in a state of positive balance (Pine Island, Lambert) are in fact losing mass or in equilibrium; while sectors presumed to be losing mass (Ross ice streams) are in fact gaining mass. Overall, the West Antarctic Ice Sheet exhibits a bimodal behavior, thickening in the west and thinning in the north but overall thinning predominates. In East Antarctica, glacier survey is currently incomplete (only 56% of the ice sheet is covered), but the results suggest an ice sheet close to a state of mass balance. In summary, most significant change seem to be taking place in West Antarctica, especially the Amundsen sea sector where ice thinning is rapid and widespread, whereas most of East Antarctica should be considered as pretty close to balance.

This work was performed at the California Institute of Technology's Jet Propulsion Laboratory under a contract with the Cryospheric Science Program of the National Aeronautics and Space Administration.

3.5

Physical and Dynamical Properties of the Antarctic Ice Sheet from Radarsat-1

Kenneth C. Jezek

Byrd Polar Research Center, The Ohio State University

Abstract: [presentation] [movie clip] [back to Session 3]

Radarsat-1 has now been used in two successful campaigns to image Antarctica. The initial campaign occurred during the fall of 1997. The campaign was highlighted by the first, high-resolution radar mapping of the entire continent and by the acquisition of significant amounts of 24-day exact repeat observations for interferometric studies. A complete, high-resolution mosaic was created and is now available for use by the science community. The second campaign occurred during the fall of 2000. The satellite acquired data over 3, 24-day cycles, capturing ascending and descending images from 81^{o} S latitude to the sea ice covered coastal waters. The extraordinary amount of data collected in 2000 is being used to measure the surface velocity field of the ice sheet.

Together, the two parts of the Radarsat Antarctic Mapping Project provide extraordinary opportunities for studying the detailed physical properties of the ice sheet (ranging from kilometer scale crevasse field and snow dunes to 100's of km scale ice streams and to 1000's of km scale mountain chains and ice divides), for estimating the surface velocity of the ice sheet (using combinations of feature retracking techniques, differential phase interferometry, and speckle retracking), and for gauging changes in surface properties and flow dynamics. This paper describes recent results derived from the combined data sets. In particular, several coastal sectors of the ice sheet are examined to determine where changes in ice sheet extent have occurred or where ice sheet extent has remained stable (Queen Maud Land, Antarctic Peninsula, and Ruppert Coast). The dynamical properties of the ice sheet in each sector are examined, compared, and used to assess the significance of coastal changes on the behavior of the interior ice sheet.

3.6

Investigations of Ice Dynamics at the Grounding Zone of an Antarctic Ice Shelf Utilizing SAR-Interferometry

Michael Baessler and R. Dietrich

Technische Universitat Dresden, Germany

Abstract: [presentation] [paper] [back to Session 3]

The grounding zone – the transition between the grounded and the floating portion of an ice sheet – is an important glaciological feature. Its position is sensitive to sea level variations including ocean tides, sea bed topography and ice thickness. The mass flux across the grounding line is of special interest for ice mass balance studies since the floating ice is already included in the worlds ocean volume and will therefore not contribute to a further raise of the sea level.

It is not an easy task to locate the grounding zone for a larger area in the field, however, Synthetic Aperture Radar Interferometry - a more recent satellite remote sensing technique – has the potential to precisely map this crucial transition across entire ice shelves.

This study will focus on the ice dynamics of the Nivlisen ice shelf in Dronning Maud land, Antarctica. Besides the estimation of the grounding zone position and its vertical motion induced by ocean tides, a contemplation of interferometrically derived surface velocities will reflect on the ice shelves dynamics in this area.

3.7

Investigating the Long-Term Behavior of the Greenland Ice Sheet

Bea Csatho (1), Toni Schenk (2), and Kees van der Veen (1)

(1) Byrd Polar Research Center, The Ohio State University
(2) Department of Civil and Environmental Engineering & Geodetic Science, The Ohio State University

Abstract: [back to Session 3]

It is well known that the mass balance of polar ice sheets directly influence the global sea level. However, it is still not known whether the Greenland and Antarctic ice sheets are increasing or decreasing in size. An improved understanding of the past and present behavior of the large ice sheets is necessary for predicting future changes and the response of ice sheets to the global temperature increase predicted by climate models. Mass balance can be inferred from precise repeat measurements of surface elevations. Starting in 1993 NASA has conducted aircraft laser-altimetry surveys over the Greenland ice sheet. Future missions that will map changes in ice sheet volume and mass distribution include NASA's Geoscience Laser Altimeter System (GLAS), to be launched on IceSAT in 2002 and the Gravity Recovery And Climate Experiment (GRACE) mission. The repeat aircraft laser-altimetry surveys over Greenland have shown that the central part of the ice sheet is in balance but thinning predominates at lower elevations. Results have revealed rapid changes on many outlet glaciers, including widespread large thinning rates, short-term, major velocity increase on some fast glaciers, and grounding line retreat on some northern glaciers. It is difficult to interpret elevation and ice margin changes observed over a comparatively short time period. Short-term changes in snow surface elevation reflect interannual fluctuations in snowfall and ablation. These fluctuations may result in apparent thickening and thinning trends, sustained over several years similar to the path resulting from a random-walk process. To evaluate whether observed elevation changes are climatically significant, changes must be determined over longer time frames. We use satellite imagery, aerial photographs and laser altimetry data to construct long-term time series of ice extent and surface elevation. Ice extent and elevation measured from aerial photographs and satellite imagery provides a time series for the last 50-60 years. Photogeologic interpretation of stereo aerial photographs and spectral information obtained by multispectral satellite imagery is used to map glacial-geological features (moraines, trimlines), which in turn are used to infer past conditions of the ice sheet. These data are used to establish a benchmark, against which future observations can be compared to assess the state of balance of the Greenland ice sheet. They also provide important constraints for the interpretation of the viscoellastic response of the Earth to the changing ice load during the last few thousand years. The long-term record of selected outlet glaciers may also be used for testing ice sheet models.

A time series of surface elevations, glacier extent and ice velocities of the Kangerdlugssuaq glacier in east Greenland will be used to illustrate our approach. A discussion of the available data sources, data processing techniques and accuracy requirements will also be included.

SESSION 4

Geodetic Instrumentation and Moving Platforms

October 2, 2002, Wednesday AM

4.1

Gravimetic Instrumentation: New Instruments and Old

James E. Faller

JILA, University of Colorado and National Institute of Standards and Technology

Abstract: [paper] [back to Session 4]

Instrumental capabilities have evolved over the past 40 years to the point where, today, both relative and absolute measurements can be made at the parts in 10^9 level of precision. 'Large' but still portable absolute gravimeters have also reached the parts in 10^9 level of accuracy. The development of smaller absolute gravimeters would be of considerable value for field applications. One approach to a 'small' field-usable absolute instrument might involve measuring g by dropping atoms. This development would use not just new physics but would also have associated with it a (somewhat) different set of measurement-limiting errors. In the meantime (and I suspect there may be a significant meantime), several smaller 'old fashioned' instruments are being developed to further the field use of gravity. In this talk, I will describe some of the reasons for the remarkable progress in our ability to measure gravity, and also discuss the future prospects for 'old' gravity continuing to assist us in learning about the Earth on which we live.

4.2

Airborne Gravimetry - The Canadian Experience

Klaus-Peter Schwarz (1) and A. Bruton (2)

(1) Department of Geomatics Engineering, The University of Calgary
(2) APPLANIX Corporation, Toronto, Canada

Abstract: [back to Session 4]

In 1999, a project on Airborne Gravity for Exploration and Mapping (AGEM) was started within the Canadian GEOIDE Centre of Excellence Network. It brought together researchers from university, government and industry, as well as users and developers of airborne gravimeters. The major objective of the project was the development of methodologies and products to fully exploit the potential of airborne gravity for geoid mapping and resource exploration.

The project was concluded in 2001. In this paper, an overview is given of the progress in airborne gravimetry made through this project. Topics discussed include:

- The establishment and documentation of airborne gravity test areas intended for use by the international community.
- A comparison of three different gravimetry systems on common flights in different test areas. Results of these campaigns for geoid determination and for exploration will be summarized.
- The refinement and optimization of differential GPS and inertial system models for airborne gravimetry.
- The use of airborne gravity data as the primary source of information for the determination of regional geoids.

A brief discussion of further research needed in this area concludes the discussion.

4.3

Geoid Profiling Using Airborne GPS/INS Vector Gravimetry

Christopher Jekeli, and Juan Serpas

Laboratory for Space Geodesy and Remote Sensing Research
Department of Civil/Environmental Engineering & Geodetic Science,
The Ohio State University

Abstract: [presentation] [back to Session 4]

High-accuracy GPS/INS systems on aircraft have been proven to be suitable for vector gravimetry by a number of analyses and tests with actual data. We have shown that under ideal conditions, the total gravity vector can be determined with a precision of 3-6 mgal and a resolution of about 10 km. This translates into a geoid profiling capability with precision of better than 10 cm. Analyses of three separate test data sets show convincingly that our techniques work. This paper reviews our results so far and identifies essential components of a successful profile, as well as key elements that require further improvement.

4.4

The Contribution of Airborne Gravimetry to the Arctic Gravity Project and Future Earth Gravity Models

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Abstract: [presentation] [back to Session 4]

The technique of airborne gravimetry has advanced tremendously over the last decade. Beginning with Greenland and extending to other regions of the world lacking in terrestrial gravity observations, airborne gravity surveys have proven to be accurate and cost effective. Airborne gravimetry has made a significant contribution to the Arctic Gravity Project, an initiative under the International Gravity and Geoid Commission, where the gravity anomaly field of the entire Arctic region north of 64°N has been compiled

on a 5'x5' grid. Likewise, airborne gravimetry has contributed to the development of EGM96 and will play a significant role in future Earth Gravity Models being planned by NIMA. In this paper we outline the data coverage, techniques, and accuracy of past airborne gravimetric surveys and the planned uses of the data. Airborne gravimetry is ideal for remote and inhospitable regions of the Earth, with the Amazon, Antarctica, and other major gravity data voids around the world awaiting future missions.

4.5

Inertial Sensor Requirements for Georeferencing Data Collected on an Airborne Platform

Joseph Hutton

APPLANIX Corporation

Abstract:[back to Session 4]

The use of integrated GPS/Inertial navigation systems to directly georeference sensor data collected in the air has grown tremendously over the last decade. Much of this growth has been due to the advent of new sensor technologies being used for remote sensing applications. Line based scanners, LIDAR, and SAR simply cannot be georeferenced to the Earth in a practical fashion without first removing the effects of the aircraft motion. However even in the case of frame cameras where georeferencing can still be done through aerial triangulation (AT), data from GPS/Inertial systems is being used successfully with softcopy photogrammetry to reduce or by-pass AT all together.

In each of these applications, the requirements on the GPS/Inertial system are slightly different. This means that the inertial sensors used in one application may not be suitable for use with another. This paper looks at the different requirements for direct georeferencing, and discusses which inertial sensor technology is most effective in meeting them.

4.6

Moving Platform Gravity Gradiometry with Ultra-Cold Atoms

Grant Biedermann (1), Kai Bongs (1), Jeff Fixler (1), Greg Foster (1), Todd Kawakami (1), Wei Li (1), Jessie Petricka (1), Ken Takasi (1), Brent Young (1), and Mark Kasevich (2)

(1) Yale University
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Abstract: [presentation] [back to Session 4]

Atom de Broglie wave interference has been exploited in recent years to develop a new generation of high accuracy inertial force sensors, including accelerometers, gravimeters and gyroscopes. The physical attributes of these sensors will be reviewed, with a particular focus on their application to gravity gradient measurements. We have recently demonstrated a laboratory prototype gravity gradiometer based on these sensors, and will discuss our current effort to develop a field-ready mobile system for helicopter and truck platforms. This system is expected to have sufficient sensitivity to detect near field gravity anomalies from underground voids. Finally, we will discuss possible applications to next-generation gravity-compensated high-accuracy inertial navigation systems.

4.7

Cross-Venue Geodetic & Geophysical Applications of Future Inertial Force Sensors

David Gleason

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Abstract: [presentation] [back to Session 4]

A bold prediction of a recent panel looking at emerging navigation technologies is the arrival of a drift-free inertial measurement unit (IMU) by the year 2025. Whether the total set of physics laws permits this feat remains to be seen. Yet an instrumentally perfect IMU, by itself, will not totally solve the many geodetic and geophysical cross-venue problems linked to it. By extension, if one can build a drift-free IMU, a drift-free gravity gradiometer follows. A combined IMU/gravity gradiometer system addresses more aspects of the relevant problems. A presentation will be given on applying futuristic IMU/gravity gradiometer systems (drift-free or not) to the following cross-venue concerns: (1) the detection and characterization of geophysically important subsurface features, (2) the development of gravity-aided inertial navigation systems, (3) the enhancement of global gravity models from GRACE-like satellite missions using ultra-stable laser satellite-to-satellite range-rate change (total line-of-sight acceleration) measurements and absolute accelerometer (non-g) measurements of comparable accuracies, and (4) the improvement of GPS satellite solar radiation pressure models from a single satellite accelerometer mission at GPS satellite altitude. Performance specs for each application will be addressed. Atom optics inertial sensor technology is a candidate for such future systems and will be overviewed.

4.8

The Delay-Doppler Altimeter: More Precision and a Smaller Footprint

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(2) NOAA Laboratory for Satellite Altimetry

Abstract: [back to Session 4]

The sea surface slope measurements provided by the Geosat radar altimeter (together with selected ERS-1 data) are the state-of-the-art for geodetic observations from space. However, those results fall significantly short of the potential resolution and sensitivity set by physical limits. Spaceborne radar data can approach these limits only if the instrument is substantially improved, and if the orbit is optimized. (Further information on the scientific goals, requirements, and benefits of improved data may be found in a companion paper by W. H. F. Smith at this meeting.)

A delay-Doppler radar altimeter can deliver the required height precision and spatial resolution. This innovative satellite altimeter uses signal processing strategies borrowed from synthetic aperture radar to improve height measurement precision by a factor of two, and to reduce along-track footprint size by a factor of five or more in marked contrast to a conventional radar altimeter. The signal processing can be performed on-board in real-time, resulting in a modest data downlink rate. The delay-Doppler altimeter has been built and flight-tested on NRL and NASA P-3 aircraft. The airborne instrument-the D2P altimeter-also included cross-track angle measurement using a pair of interferometric receive antennas. Results verify the predicted along-track resolution and delay-Doppler signal properties. In addition, it was demonstrated that angular offsets in the along-track (pitch) plane are measured uniquely in the Doppler domain, and that angular offsets in the cross-track (roll) plane are measured by the interferometer.

If a dedicated free-flying implementation were available, the orbit should be non-repeating, and have an inclination relatively near 55 degrees. From such an orbit, the required measurements would be completed in less than five years by a solo delay-Doppler radar altimeter satellite, or less than twenty months by a constellation of three co-planar satellites.

As an alternative, the International Space Station (ISS) is also a candidate. The ISS has a non-repeating orbit at an inclination of 51.6 degrees. Although its orbit is nearly optimal, the angular motions of the ISS could disqualify it as a host platform. On the ISS, a D2P-style altimeter could be mounted on a mechanical gimbal. Angle measurements from the altimeter could be used to servo-steer the gimbal to maintain nadir pointing, regardless of the attitude of the ISS. The ISS was the nominal satellite of choice in the ABYSS ESSP project recently proposed to NASA. Further details are at http://fermi.jhuapl.edu/abyss and http://fermi.jhuapl.edu/d2p.

4.9

Spaceborne Laser Altimetry

Bob E. Schutz

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Abstract: [presentation] [back to Session 4]

The Geoscience Laser Altimeter System (GLAS) is planned for launch on ICESat in 2002, into a 600 km altitude, near polar orbit from Vandenberg, California. The system is designed to operate up to five years in orbit. GLAS is under development by NASA Goddard and it will be delivered to the spacecraft contractor, Ball Aerospace, for mating and testing with the spacecraft bus. The GLAS instrument will transmit both near infrared (1064 nm) and green (532 nm) pulses using a diode-pumped, Q-switched Nd:YAG laser. The 1064 wavelength will be used for surface altimetry, including dense clouds, and the 532 wavelength will be used for atmospheric backscatter measurements. The altitude measurement will provide a new tool for geodesy and geophysics. For example, the altimeter will produce elevation time series of the Greenland and Antarctic ice sheets, which will enable determination of present-day elevation change and mass balance. Other applications of the altimetry channel include precise measurements of land topography and vegetation canopy heights, sea ice roughness and thickness, and ocean surface elevations. The laser pulse energy at 1064 nm is about 75 mJ with a width of about 5 ns and the pulse has a divergence of about 0.11 mrad, which illuminates a spot on the surface with a 66 m diameter. The pulse echo is captured with a 1 m telescope mounted on the rigid GLAS optical bench. A Si analog detector receives the return pulse and an A/D converter digitizes the pulse with a 1 GHz sampling rate. Two detectors and two digitizers are available for redundancy. Unlike wide pulse radar altimeters, accurate knowledge of the laser beam direction is required for the laser altimeter. The pointing will be determined with the assistance of an innovative system of CCD cameras that will measure the direction of each laser pulse with respect to the instrument optical bench and the spatial orientation of the bench will be determined using a system of star cameras and gyros. The combination of the laser pulse round trip time of flight and the pointing determination system provides an altitude vector. The magnitude of this vector has a single shot precision of better than 10 cm and the directional information has an accuracy of about 1.5 arcsec (4.5 m on surface). In addition to the instrumentation required to produce the altitude vector, the position of GLAS with respect to the center of mass of the Earth is required. This position vector will be determined to an accuracy better than 5 cm using data collected by a geodetic quality GPS receiver carried on ICESat, which will be validated using data from the SLR network. The mission will use an orbit with characteristics that produce a 183-day ground track repeat, although an 8-day repeat will be used in the post-launch months to provide repeated overflights of calibration/validation sites. To achieve close orbit repeats in spite of orbital perturbations, especially atmospheric drag, both orbit control and off-nadir pointing control will be used.

4.10

Laser Scanning: Space-Geodesy to Micro-Geodesy

William E. Carter

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Abstract: [presentation] [back to Session 4]

In the preface of the first edition of his book Geodesy, published in 1952, B. G. Bomford stated that the "first object [of geodesy] is to provide an accurate framework for the control of topographical surveys". By the 1960ís the space age had begun and W.M. Kaulaís book Theory of Satellite Geodesy presented loftier goals, centering on the use of space technology to determine the size and shape of the earth and its gravitational field. In the decades that followed Doppler satellite positioning, lunar laser ranging, satellite laser ranging, very long baseline interferometry, absolute and cryogenic gravimetry, and the Global Positioning System comprised the leading edge of geodetic technology, and applications focused on global-scale issues: modeling the gravity field, verifying plate motion, creating an international terrestrial reference frame, and monitoring changes in earth orientation.

During the past decade airborne laser scanning has brought topographic mapping back to the forefront of geodesy. Space missions will soon extend laser scanning to global coverage, and ground based laser scanning instruments are already rapidly extending the opposite end of the spectrum into the realm of micro-geodesy. The performance of laser scanning systems, characterized by the laser spot size and spacing, horizontal and vertical accuracies of the surface coordinates, area coverage per unit time, and the maximum practical extent of the coverage, span at least six orders of magnitude. Nested laser scanning data sets now make it possible, for the first time, to study natural geo-surficial processes on spatial scales extending from sub-millimeter single grain erosion in geologically old and passive regions, to large volume rock and land slides in geologically young and active regions, to regional crustal motions along plate boundaries, all in a consistent geodetic frame of reference. Laser scanning can also be used to assess the impacts of engineering projects on these natural processes and provide the information needed to restore and manage ecologically sensitive areas.

The speaker will review the performance specifications of currently available laser scanning instrumentation, and present early results from research projects involving nested airborne and ground based laser scanning data sets. Potential near term technological improvements, including single photon signal level laser scanning, will also be presented.

4.11

A Practical Approach to LIDAR Sensor Calibration

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Abstract: [presentation] [paper] [back to Session 4]

Deployment of LIDAR systems has recently experienced enormous growth. Improved performance as well as affordability have made LIDAR a primary tool for collecting a variety of high quality surface data in much shorter periods of time than previously was possible. In addition, some features unique to LIDAR, such as the capability to separate vegetation from the ground, have opened up new application areas. To achieve the highest accuracy, however, LIDAR systems have to be rigorously calibrated and the calibration parameters must be frequently checked. LIDAR systems are complex multi-sensor systems composed of high-precision navigation and various imaging sensors. Therefore, the calibration process includes the calibration of the individual sensors and then the calibration of the integrated multi-sensory systems. High-performance integrated GPS/INS navigation systems provide the platform orientation for LIDAR systems and consequently, the geo-referencing accuracy achieved by the navigation component determines the ultimate performance limit of the whole data acquisition system. Despite to the widespread use of GPS and the growing use of INS, maintaining a precise solution under various conditions is still a formidable task. The connection between the navigation system and the LIDAR scanner is described by the mounting bias or boresight. To determine and maintain the model parameters of this sensor relationship, well-planned experiments should be performed. Because of the nature of the LIDAR data, there is no direct solution for determining the boresight parameters. In this paper, we propose a method to determine the boresight parameters. Using raw LIDAR data from overlapping flight lines, including navigation and range components a boresight parameter adjustment is carried out.

SESSION 5

State of the ITRF and Its Stability

October 2, 2002, Wednesday PM

5.1

The International Terrestrial Reference Frame

Kristine M. Larson (1), Claude Boucher (2), Zuheir Altamimi (2), Patrick Sillard (2)

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Abstract: [back to Session 5]

The definition of the terrestrial reference frame is of utmost importance for scientific studies of the solid Earth, the atmosphere, and the ocean. The International Earth Rotation Service (IERS) has had the responsibility for its definition (International Terrestrial Reference System, ITRS) since its establishment in 1988. A series of International Terrestrial Reference Frames (ITRF) have been determined and published for the geodetic community, most recently ITRF2000. In this presentation, we review the decisions we made for ITRF2000 and discuss the relative contributions of the geodetic systems that were used in it. We close with a discussion of new challenges and future improvements we see for the ITRF.

5.2

GPS Geodesy in Antarctica for the Realization of the ITRF and Geodynamic Studies

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Abstract: [back to Session 5]

The GPS Campaigns of the Scientific Committee on Antarctic Research (SCAR) since 1995 have been used to contribute to the International Terrestrial Reference Frame 9ITRF). The data have been analyzed with the Bernese Software, Version 4.2 in order to provide SINEX files. These files have been incorporated into the official ITRF2000 solution as a regional densification network. The obtained plate kinematic motions will be discussed.

Furthermore, repeated GPS observations at bedrock sites in Dronning Maud Land have been carried out. The main goal is the detection of relative vertical motions to study the dynamics of the solid Earth as a result of historical and present-day ice mass changes. The observation technology, obtained results and their error budget as well as a first interpretation will be presented.

5.3

The National and Cooperative CORS Program

Richard Snay, Gordon Adams, Miranda Chin, Stephen Frakes, Tomas Soler, and Neil Weston

National Geodetic Survey, National Ocean Service, NOAA

Abstract: [presentation] [paper] [back to Session 5]

The tremendous diversity of GPS applications has motivated numerous organizations to establish several (essentially independent) networks comprised of ground-based, dual-frequency GPS base stations that operate on a continuous basis. The National Geodetic Survey (NGS), an agency of the National Oceanic and Atmospheric Administration (NOAA), is collaborating with most of these organizations to make data from hundreds of such GPS base stations located in the United States freely available to the public via the Internet. The term, CORS (Continuously Operating Reference Stations), is used to identify those stations participating in this integrated network. Regardless of the primary purpose of a CORS' existence, its data may find use in positioning, navigation, geophysics, and/or meteorology.

Currently (April 2002), the CORS network contains more than 600 stations in the United States and its territories, and this network continues to grow by several new stations each month. As of February 2002, each point in 49 States, plus much of Alaska, is located within 400 km of at least one CORS, and more than half the land area of these 49 States is located within 100 km of at least one CORS.

This presentation will describe the current status of the CORS program and some anticipated enhancements. The presentation will focus on (1) upgrading the web-based CORS information server, (2) upgrading the web-based utility--called OPUS--for automatically computing accurate positions with CORS data, (3) discussing the expected accuracy of positions derived with CORS data, and (4) describing specialized applications of CORS data to airborne mapping and crustal motion monitoring.

5.4

National CORS Network Design: Station Spacing and Data Rates

Gerald L. Mader

National Geodetic Survey, NOS, NOAA

Abstract: [presentation] [back to Session 5]

The National Continuously Operating Reference Station (CORS) Network is a composite of GPS tracking networks established by a wide variety of agencies and institutions, and which provides a reliable flow of GPS data from precisely known positions that can be used to easily access the National Spatial Reference System. The increasing number of GPS tracking stations and networks will allow CORS to select stations with a greater emphasis on station quality as opposed to geographic coverage. The option to select from an abundance of stations requires the National CORS to have well defined objectives and a rationale to meet those objectives and guide the station selection. This paper will discuss two of the most

important design criteria for a national network: the station spacing and the data collection rate.

Network station spacing is fundamentally driven by the correlation lengths of those phenomena affecting the GPS solutions. For distances of several hundreds of kilometers, the maximum distances likely to be encountered in the National CORS network, orbital accuracy is not a factor. The International GPS Service (IGS) is producing both precise (for post-processing) and predicted (for real-time) orbits whose error contributions to such baselines is practically negligible. Propagation effects due to the troposphere and the ionosphere are the primary determinants for network station spacing. An efficient network will maintain a manageable number of stations by using the largest station spacing that is still able to accurately model propagation within the interstation spacing. NGS is conducting post-processing and real-time tests demonstrating ambiguity resolution within several data epochs using propagation corrections interpolated from a local network spacing of about 200 km.

Kinematic GPS techniques are used routinely to calculate the trajectories of moving platforms that require data rates of 1 Hz or greater and matching data from a reference station located at a known position. It is difficult to contemplate permanent and continuously operating GPS networks providing these high-rate data in the future on a routine basis. Such a large volume of data can pose severe bandwidth problems communicating these data to the user, in addition to the need to possibly archive these data as well. A solution to these problems is to produce high-rate phase and range data (e.g. at a 1 second rate) at the reference stations by interpolating (for post-processing) or extrapolating (for real-time) lower-rate data (e.g. 5, 10, 15, Ö sec rate). Our initial results show RMS differences of 1 mm horizontally and 3 mm vertically for solutions using interpolated 5 sec data. These differences grow to only 5 mm horizontally and 13 mm vertically when interpolating 30 sec data. These results and their implication for National CORS network design will be discussed.

5.5

Hydrographic Surveying in a Tidal Datum with Kinematic GPS Control

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(2) Jack Riley, Coast Survey, NOS, NOAA

Abstract: [presentation] [back to Session 5]

For two days in June 2001, a test was performed in Delaware Bay on the capability of kinematic GPS control to substitute for the traditional method of reduction of hydrographic sounding data to the tidal datum. An array of 5 GPS stations were deployed on the perimeter of the bay, and were positioned relative to 3 CORS stations to 2 cm (95%) in ellipsoid height. Three GPS receivers with choke ring antennas were mounted on the bow, stern, and midpoint of the survey vessel and measured relative to the hydrographic sensor. Data were processed with an algorithm that restricts the ambiguity search based on admissible differential ionosphere values. It was possible to recover ship attitude to a fraction of a degree, and establish the coordinates of the sensor to 2 to 5 cm (RMS). Motions faster than the 1 Hz GPS data rate were obtained by spectral combination with an onboard inertial heave sensor. A vertical datum transformation software package for Delaware Bay (VDatum) was built using the combination of known 3-D frame relationships, the GEOID99 geoid height model, a fit of the NAVD 88 vertical datum bias, and gridded relationships of the Mean Lower Low Water (MLLW) tidal datum relative to Local Mean Sea Level. End-to-end system comparisons of MLLW soundings agree at the 10-15 cm level. This signal can be largely ascribed to the approximations in conventional tide zoning. An instance of over 40 cm of Kalman filter divergence (conventional process) was detected while the vessel was maneuvering. The test demonstrated the accuracy and robustness of GPS control of hydrographic surveying in areas where the tidal datums have been modeled.

5.6

Redefinition of the Indian Geodetic Datum

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(2) Director, Geodetic & Research Branch, Survey of India

Abstract: [presentation] [back to Session 5]

The Indian Geodetic Datum based on Everest ellipsoid was established in 1880 through an adjustment of geodetic data using the computational means, mathematical models and adjustment techniques available at that time. Few of the inadequacies of 1880 horizontal control network adjustment of India are as follows:

- Sufficient number of Laplace Azimuths were not available.
- Computational and adjustment methods were crude and approximate.
- Measurement of base lines in Indian foot gave distortions up to 3ppm in linear measurements.
- The horizontal angles were not corrected for deflection of vertical, skew normal, geodesic correction etc.

The serious short comings and several limitations in the defined 1880 Indian Geodetic Datum has rendered it unsuitable for many of the geodetic, geodynamic and geophysical applications demanding very high precision / accuracy.

With the availability of large amount of geodetic data including space geodetic observations, precise base line measurements, high precision leveling, gravity observations etc that have been added since 1880, an integrated adjustment in order to redefine the Indian Horizontal Geodetic Datum has been taken up by the Geodetic and Research Branch of Survey of India.

Readjustment of the Indian Geodetic Datum has been planned to be taken up in two Phases. In the first Phase the available geodetic data will be adjusted using the 'Big adjust' program supplied by National Geodetic Survey, USA on the locally best fitting ellipsoid i.e. Everest ellipsoid. For this the Indian geodetic network has been divided into five parts -four quadrilaterals and one southern trigon, As on today the data extraction of the entire geodetic network from the available volumes and the independent adjustment of three of the quadrilaterals have been completed. The remaining part of phase I is expected to be completed by December 2002. The second phase includes transformation of the co-ordinates from locally best fitting ellipsoid i.e. Everest to geocentric ellipsoid for e.g. ITRF. This job will be taken up after reviewing of Phase I.

This paper discusses the need and importance of such a project, the methodology adopted for its implementation, the present status and future plans and other details of the project.

SESSION 6

Geodynamics

October 2, 2002, Wednesday PM

6.1

Regional Continuous GPS Networks for Crustal Deformation: Detection of Vertical and Dynamic Motions

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Abstract: [back to Session 6]

The last decade has seen a proliferation of regional continuous GPS networks for monitoring crustal deformation at tectonic plate boundaries. In southern California, daily positions are being estimated for over 250 sites, of which a subset of sites have been operating for more than 10 years and have been displaced by three major earthquakes. We present a time series analysis of these position data that yields inter-, co-, and post-seismic deformation, non-tectonic seasonal effects, as well as their noise characteristics. Currently, the precision of a daily position is about 0.5 mm in the horizontal components and 2-3 mm in the vertical component for the most stable sites. At this level, we can estimate minute deformation signals due to tectonic motion in both horizontal and vertical directions. In this paper, we focus on subtle changes in vertical deformation rates before and after the Mw=7.1 1999 Hector Mine Earthquake. We also focus on the ongoing shift of regional networks to real-time, high-rate data collection and analysis to be able to detect dynamic as well as static displacements associated with large earthquakes such as the Hector Mine earthquake. After this earthquake, we were able to detect, using new instantaneous (epoch-by-epoch) positioning methods, the seismic wave as it propagated through southern California including the Los Angeles basin more than 200 km from the earthquake's epicenter. We present an overview of ongoing efforts to upgrade the Southern California Integrated GPS Network (SCIGN) sites in Orange County and western Riverside County to real-time, high-rate (1 Hz) operation and efforts to integrate these subnetworks with existing seismic arrays. Finally, we describe how these upgraded GPS subnetworks will also be used to support other dynamic applications such as RTK surveying, dam and bridge deformation, intelligent highways, and airborne navigation.

6.2

Crustal Velocity Field of Western Europe from Permanent GPS Array Solutions, 1996-2001

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Abstract: [presentation] [back to Session 6]

In the past decade, space geodetic measurements have become widely used to monitor crustal motions, from tectonic plates to local surveys of active faults, with precision levels on the order of 2-3 mm/yr (horizontally) routinely achieved. In the last few years, the increasing accuracy and density of space geodetic measurements has also permitted to test plate rigidity at a 2 mm/yr level (Argus and Gordon, 1996; Dixon et al., 1996; DeMets and Dixon, 1999; Kogan et al., 2000; Nocquet et al., 2001). However, 1-2 mm/yr of motion within several hundreds of kilometers can still lead to significant deformation over recent geological times. In particular, it may result in sufficient elastic strain accumulation to cause moderate to large earthquakes on faults with long recurrence intervals (1000 years and more). In addition, 1-2 mm/yr of internal deformation within a block or plate chosen as a "stable" reference frame for the purpose of a geophysical interpretation may introduce a significant bias in the velocity field, in particular in areas deforming at very slow rates. The determination of a dense and consistent velocity field at a continental scale, accurate at a sub-millimeter per year level still remains a challenge. Such a velocity field is however essential to investigate the processes that drive continental intraplate deformation and control the associated seismicity.

Our work is based on the 2000 realization of the International Terrestrial Reference Frame (ITRF2000), a global multi-technique geodetic solution that provides accurate position and velocities at about 500 globally distributed control sites (Boucher et al., 1997; Sillard et al., 1998). We use the ITRF2000 as a framework for combining geodetic solutions derived from three permanent GPS networks and derive a unique velocity field, consistent at a continental scale for Western Europe. We describe the combination methodology, show that the resulting combined solution provides velocities at 64 sites in western Europe with a 1 mm/yr accuracy, and provide a preliminary interpretation of the velocity field.

6.3

Secular, Transient and Periodic Crustal Deformation Observed in the Japanese Nationwide GPS Array

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Abstract: [presentation] [paper] [back to Session 6]

Dense GPS array observations in Japan over the last eight years have revealed various types of crustal deformation: secular (interseismic) movement, fast (coseismic) and slow (postseismic) transient deformation, and periodic (seasonal) signals. Secular deformation patterns showed that Japan is split into two tectonic plates; the North American and the Amurian Plates collide at the central Japan. Rigid plate movements are overprinted by interseismic deformation caused by the elastic loading of the Pacific and the Philippine Sea Plate slabs. Observations of coseismic crustal deformation provided information on fault plane geometries and slip distributions, and detections of slow transient signals lead to the discovery of totally silent earthquakes, and afterslips as large as main ruptures. Slow fault slip stared in 2001 March in the Tokai region, central Japan, but whether it is just another

silent earthquake or a precursor of the soon-to-occur Tokai earthquake is currently in dispute. Seasonal crustal deformation signals, which are highly systematic in space and time, were found to be due mainly to snow loads along the backbone range. Their causal relationship with the earthquake occurrence seasonality still remains uncertain.

6.4

Geodynamics of the Andes: New Insights from GPS Geodesy

Michael Bevis (1), Eric Kendrick (1), Benjamin Brooks (1), and Robert Smalley (2)

(1) University of Hawaii
(2) University of Memphis

Abstract: [back to Session 6]

We will review the program of GPS measurements we have pursued in the Central and Southern Andes since 1993, and the impact of our crustal velocity fields on our understanding of various geodynamical phenomenon in the region, including the earthquake deformation cycle, the mountain building process, and postglacial rebound.

6.5

Low Power Remote GPS Observatories in Southern Victoria Land, Antarctica

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Abstract: [presentation] [back to Session 6]

In the 2000-2001 austral summer, a low-power Global Positioning System (GPS) observatory was installed at the Cape Roberts peninsula of Southern Victoria Land, Transantarctic Mountains. Station ROB1, funded and established in cooperation with Land Information New Zealand (LINZ), is tied to the nearby tide gauge operated by LINZ, and collocated with a broadband seismic station of the Transantarctic Mountains Seismic Experiment (TAMSEIS). The mark for ROB1 was set in bedrock in 1996 and is included in the network of about 30 stations established in support of the Transantarctic Mountains Deformation Monitoring Network (TAMDEF). In this region of Antarctica is located the International GPS Station (IGS) MCM4 at McMurdo and TNB1 located at Terra Nova Bay. Powered with a large battery system charged by solar panels while sunlight was available before the darkness of the harsh winter environment, high quality L1/L2 data were successfully acquired at 30-second sampling rate for over 200 days. Data were not acquired during the days when the voltage level for the batteries was below acceptable limits. During the 2001-2002 field season, two additional remote operating GPS observatories using new receiver technology were installed at TAMDEF stations located at Mount Fleming (FLM2) and Fishtail Point (FTP1). The receiver at ROB1 was also upgraded with new technology that uses significantly lower power and a more robust data storage device. The upgraded dual-frequency 20-channel receiver (up to 20 SVs can be tracked and data logged) uses less than 2.2 watts of power (peak) and data are logged to a 0.5

Gb compact flash memory card. The antenna is a Dorne Margolin type. Stations FLM2, FTP1 and ROB1 are the first in a series of continuously operating GPS observatories planned for remote sites in the Victoria Land and Ross Island region of the Transantarctic Mountains. In addition to supporting objectives for the TAMDEF project, continuous GPS observations at selected and distributed sites will be used to evaluate atmospheric effects on GPS measurements in this part of Antarctica, quality of data and results for the core IGS station MCM4, data collected at collocated geodetic and geophysical observatories (e.g. tide gauge, seismic, and absolute gravity instruments), and the utility and practical aspects of operating late model low power dual-frequency GPS receiver/antenna systems through the winter darkness at remote sights in Antarctica. Furthermore, establishing remote GPS continuously operating observatories at optimally spaced sites meets primary goals of the Scientific Committee on Antarctic Research programs for Antarctic Neotectonics (ANTEC) and on the Geodetic Infrastructure of Antarctica (GIANT). The field team for this project consisted of members of the US Geological Survey, Land Information New Zealand and the Ohio State University.

SESSION 7

Advances in Gravity Field Representation

October 3, 2002, Thursday AM

7.1

Inertia of Quadratic Forms and General Bases in Geopotential Approximations

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Abstract: [presentation] [paper] [back to Session 7]

When using general function bases that not necessarily are endowed with an orthogonality property the respective mathematical operations face some non-standard problems that require an independent discussion. In applications problems of this kind may be encountered in connection with the use of systems of point masses, multipoles, non-band-limited radial basis functions etc. In the computation of functional norms associated with error estimates the need for manipulations with quadratic forms then appears as a natural part of the technique used. In the paper steps are considered that rely on the inertia of quadratic forms, their characteristic numbers, normal modes and the so-called frequency equation. These notions and concepts are then used in the investigation of error estimates and iteration procedures associated with topography effects in the solution of geodetic boundary value problems.

7.2

Representation of Spatial Functions in Geodesy Using B-Spline Wavelets with Compact Support

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(3) German Geodetic Research Institute (DGFI), Munich, Germany

Abstract: [presentation] [paper] [back to Session 7]

For the representation of a spatial function such as the topography or the geoid, scalar-valued spline wavelets may be used that are defined on a two-dimensional, but not necessarily planar domain. A certain type of spline wavelets is generated by B-splines, which can be implemented at different degrees: Degree 0 represents the Haar wavelet, degree 1 the linear B-spline wavelet or degree 3 the cubic B-spline wavelet. A non-periodic version of these wavelets allows us to handle data on a bounded domain without any edge effects. Using the piecewise linear version of B-spline wavelets, one may model the gravity field of the Earth by a patch-wise approach along a certain number of belts.

Such a wavelet expansion represents data given on a grid exactly, if the number of wavelet coefficients is equal to the number of grid points. But data compression is advised and can be carried out quite easily by eliminating the wavelet coefficients with small magnitudes. There may be very small deviations between the decompressed and the original data set.

A hierarchical decomposition not only allows an inexpensive calculation, but also a representation of different detail levels. Each level corresponds to a certain spatial frequency band, leading to a useful interpretation with regard to the frequency domain.
To achieve an optimal physical interpretation of the wavelet magnitudes we replace the standard wavelet transform by a search of single best fitting wavelets, defined on a continuous time and frequency domain. Since there are no restrictions as in the discrete transform, these best fitting wavelets will be found, allowing us an investigation into their physical background.

7.3

New Multiresolution Representations of the Earth's Gravity Field

Gregory Beylkin

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Abstract: [presentation] [paper] [back to Session 7]

Current models of the Earth's gravity field use the spherical harmonic expansion. Although it is a proper choice for coarse resolution, the spherical harmonic expansion is cumbersome and computationally intensive as higher and higher accuracy and resolution are required. The spherical harmonics are global, oscillatory functions which depend on cancellation to achieve local approximation. Thus, changing even a single coefficient in the model has a global effect. It is difficult, if not impossible, to adjust the spatial frequency contents locally. Increasing the number of terms in the spherical harmonic expansion leads to large ill-conditioned systems of equations with dense (full) matrices.

Improving accuracy of the geopotential model presents a challenging problem since the spatial frequency bandwidth changes both as a function of the

distance from the Earth and geographic location around the Earth. We will describe our approach to this problem using multiresolution techniques. We have investigated several representations using splines, multiwavelets and, more recently, functions associated with the prelate spheroidal wave functions (PSWFs) and will describe our results.

One of the benefits of multiresolution representations is that we have alternatives to the standard least-square estimation techniques. We will present the multiresolution QR factorization as an example of such alternatives.

7.4

Multi-Resolution Representation of the Gravity Field Using Spherical Wavelets

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(2) Department of Civil and Environmental Engineering and Geodetic Science, The Ohio State University

Abstract: [paper] [back to Session 7]

Usually the gravity field of the Earth is modeled by means of a series expansion in terms of spherical harmonics. An important disadvantage of this representation is the fact that the determination of the series coefficients requires preferably homogeneous distributed global data sets. Furthermore, regional or local changes of the gravity field affect all series coefficients. Thus, an appropriate model of the gravity field may consist of an expansion in terms of spherical harmonics for the global low-frequency part and a spherical wavelet expansion for the regional medium-frequency and the local high-frequency part of the geoid. Applying the spherical wavelet transform, a given data set is decomposed into a certain number of detail signals, which replace the spherical harmonics of the classical approach. The sum of the detail signals yields a representation of the data set. This spherical wavelet procedure means a multi-resolution representation, because each detail signal is related to a certain frequency band and resolution step. The computation of the detail signals may be carried out by applying the fast wavelet transform. Due to the structure of the gravity field the number of detail signals may vary in dependence on the spatial position. Hence, data compression methods can reduce the number of wavelet coefficients drastically. The presented method is applied to both simulated and real CHAMP data sets. Different operators, e.g. for downward and upward continuation, are introduced to demonstrate that the spherical wavelet transform is a powerful tool for the calculation of the gravity field using data from modern satellite missions.

SESSION 8

Advances in Gravity Field Modeling

October 3, 2002, Thursday AM

8.1

Earth's Gravity Spectrum, Kaula's Law & Geoid Computation

Roger Hipkin

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Abstract: [back to Session 8]

Once an error in the definition of the power spectrum for spherical coordinates is corrected, the EGM96 gravity field is very well represented by 4 statistically independent white noise components, plus a small element of surface noise. The new model is compared with Kaula's Law. It is robust, statistically well-defined
(^{2} = 379.5 with 350 degrees of freedom) and the observed quantiles of the residuals fit the gaussian distribution with a regression coefficient of 99.8%. The model suggests that there could be some small remaining errors in partitioning the information contained in order 13 resonances between different spherical harmonic degrees. The model gravity field gives quantitative answers to questions like "How big should the spherical cap be for Stokes' integration?" and "What is the error caused by approximating Stokes' function with a planar Fourier transform?". Being able to answer them independently allows the resulting geoid to be tested against external observations without circular logic. The model demonstrates that integration over a local region of gravity data is corrupted unless gravity-field components with wavelengths greater than about 600 km are removed first. The three stages needed – EGM96 / tailored global model / Fourier transformation of residuals – are illustrated for the European-shelf geoid EDIN2000.

8.2

Estimating Geoid Grid Spacing

Robert C. Anderson, and James Davenport

National Imagery & Mapping Agency

Abstract: [presentation] [paper] [back to Session 8]

With the advent of very dense and accurate (say, 1-3cm) ellipsoid heights from GPS, it is desirable to have corresponding geoid height data accurate to the few centimeter level. Current global models (EGM96) support a standard grid size with accuracies that vary with the area specific gravity field. Some applications

are adequately supported by very large geoid grids, while others require more accurate local geoid grids. Even within the same application, different grid spacing may be required as the geoid changes more rapidly in high variance elevation and gravity regions. We propose and test a mathematical model that when given the geoid height accuracy requirement for the region, with the specified underlying orthometric grid accuracy produces the required geoid grid spacing. The model is based on the total error variance equation of least squares collocation and uses a Gaussian covariance function valid over a local area. The statistical parameters of the geoid field are derived from the numerical integration of NIMA's world-wide two arcmin Deflection of the Vertical (DOV) data base. With the proposed model and a geoid accuracy requirement, one can answer how small and where a local geoid is needed.

8.3

Some Design Considerations for the Development of a New Earth Gravitational Model

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Abstract: [back to Session 8]

The development of a new Earth Gravitational Model (EGM) aiming to support future realizations of NIMAís World Geodetic System is currently underway. Current plans call for the development of a gravitational model complete to degree and order 720 by 2005 or 2006. The new EGM will be based on the combination of satellite-derived gravitational information with corresponding information from surface gravity and satellite altimetry data. Within the design of the new EGM, special emphasis is placed on the gravitational information that is already becoming available from CHAMP and moreover the gravitational information anticipated from GRACE and later on GOCE. The sensitivity to the gravitational signal that is anticipated for the data from these missions (especially from GRACE and GOCE) is expected to provide a spectral "overlap" with the information contained within surface gravity and satellite altimetry data, much wider than that provided by "traditional" satellite tracking data types. This will enable (but also require) the appropriate modeling of non-gravitational effects that are contained within surface gravity (e.g., regional systematic errors) and satellite altimetry (e.g., Dynamic Ocean Topography) data. Models representing these effects could be estimated simultaneously with the gravitational potential coefficients in a combination solution environment. This presentation will review the main aspects of the design of such combination solutions, discuss some refinements and improvements made since the development of EGM96, and identify some open questions that are still under investigation.

8.4

Gravity Field Models beyond CHAMP, GRACE and GOCE: A Synergetic View of Global Gravity Field Computation

Thomas Gruber

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Abstract: [presentation] [paper] [back to Session 8]

With the successful launches of the German gravity and magnetic field mission CHAMP in July 2000 and of the US/German twin satellite gravity field mission GRACE in March 2002, a new era of gravity field mapping from space has been started. As the next step in 2006 the European Space Agency's gradiometric mission GOCE is scheduled for launch and will further enhance the gravity field in terms of accuracy and resolution. All three missions provide valuable information in different spectral domains and will

contribute to the overall goal to determine the global gravity field from space with highest accuracy and best resolution as possible. It has to be noted that only by a synergetic processing of data from all three missions this goal can be reached. Synergies between the missions can be identified mainly in the area of time dependent gravity field variations with frequencies from a few hours to months and longer, but also in the measurement bandwidth of the missions themselves. Further synergies can be identified with other missions, either in orbit or planned, such as Envisat, Jason-1, Cryosat, Icesat, SMOS and others. All of them can contribute significantly to the goals of the gravity field missions by providing useful ancillary observations.

A further enhancement of the satellite derived gravity field models can be reached by the inclusion of available surface and altimeter data as it was done in the past by a few groups, who computed combined and high resolution gravity field models. With the gravity field missions the role of the surface gravity and altimeter data has to be re-assessed. It has to be identified, if the currently available data are sufficient in accuracy and resolution and what are the requirements for the surface data when they are combined with the new missions gravity field solutions. New airborne gravity data like that from the Arctic Gravity Project, could significantly improve the quality and coverage of the surface observations and could be valuable for various purposes in combination with the gravity missions observations.

The first part of the paper focuses on the identification of synergies between the CHAMP, GRACE and GOCE missions with special emphasis on the time variable effects. It also investigates what other Earth observation missions observations can contribute to the data analysis in order to further improve the gravity field model. The second part the paper focuses on the future role of surface/airborne and altimeter data in combination with the satellite derived gravity field models. Finally some ideas on possible scenarios for gravity field modeling in the post GOCE time are developed and presented.

8.5

LISA/Cartwheel Orbit Type for Future Gravity Field Satellite Missions

Nico Sneeuw

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Abstract: [presentation] [paper] [back to Session 8]

The gravity field satellite missions CHAMP, GRACE and GOCE will dramatically contribute to our knowledge of the Earth's gravity field. Despite their major improvements over existing satellite gravity information, they are limited in terms of space and time resolution and accuracy nevertheless. New mission concepts beyond CHAMP, GRACE and GOCE are being discussed already.

Some of these future gravity missions make use of LISA-type orbits. Applied to the Earth environment---as opposed to a solar environment for LISA---this orbit type is also known as the Cartwheel concept, in particular in SAR interferometry. In this presentation this seemingly complicated orbit type will be explained in simple orbit mechanical terms. The so-called Hill equations are sufficient for a first order description. Concepts of future gravity missions based on this orbit type are investigated.

SESSION 9

Meteorology from Space Geodetic Observations

October 3, 2002, Thursday PM

9.1

The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC)

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Abstract: [presentation] [paper] [back to Session 9]

The Constellation Observing System for Meteorology, Ionosphere and Climate (COSMIC) is a joint U.S.-Taiwan six spacecraft mission that is funded and due to launch near the end of 2005. Each spacecraft will carry three payloads: 1) a GPS Radio Occultation (RO) receiver designed by JPL 2) a Tiny Ionospheric Photometer (TIP) developed by NRL and 3) a Tri-Band Beacon (TBB) developed by NRL. The spacecraft will be injected into a low Earth orbit (LEO) by a Minotaur launch vehicle and then, over the next ~12 months, will be separated in ascending node via differential precession to create a constellation that will provide globally distributed observations. The payload data will be transmitted after each 100 minute orbit in near real time (via two northern Earth stations) to the COSMIC Data Analysis and Archival Center (CDAAC) at UCAR. Data analysis at the CDAAC will consist of: data quality checking and reformatting of incoming data, LEO precise orbit determination (POD) and isolation of excess atmospheric phase delay for each RO, and the inversion of phase delay into profiles of atmospheric refractivity with Abel inversion software. The CDAAC will make all data products available to operational weather centers in near real time, and to universities and research institutions upon request. We present an overview of the COSMIC and CDAAC systems and discuss potential applications of CDAAC data products to meteorology, space weather, climate and geodesy. Current research conducted at UCAR related to POD and radio occultation profiling with the CHAMP and SAC-C datasets will also be presented.

9.2

GPS Radio Occultation Data Applied to Antarctic Weather Analysis and Forecasting

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Abstract: [presentation] [back to Session 9]

From many years of effort, the Polar Meteorology Group of the Byrd Polar Research Center has developed a version of the widely used Penn. State/National Center for Atmospheric Research (NCAR) Fifth generation mesoscale model (MM5) that is optimized for use over and around polar ice sheets (called Polar MM5). Generally high predictive skill by Polar MM5 has been found for Antarctica. This model is the basis of the Antarctic Mesoscale Prediction System (AMPS) that provides operational numerical weather prediction for the aircraft operations of the U.S. Antarctic Program. AMPS is a collaborative effort between the Polar Meteorology Group and the NCAR MMM Division, who perform the twice-daily model runs.

Initial work with Polar MM5 in the Antarctic revealed that the sea level pressure prediction over the coastal areas and adjacent ocean had some major shortcomings. Using GPS/Met. soundings for the period 13-16 October 1995 and assuming they have the same accuracy as radiosondes, led to the discovery that the upper tropospheric temperatures simulated by Polar MM5 were much too warm. This large warm bias is due to the incorrect treatment at the top of the model of vertically propagating gravity waves generated by the steep coastal slopes of the Antarctic continent. A new top boundary condition suitable for the Antarctic environment has been developed for Polar MM5. This eliminates the large warm biases aloft as well as the large biases in predicted near-surface pressure.

Several case studies have been performed to evaluate the performance of AMPS. The model success (perhaps not surprisingly) depends strongly on the initial conditions that are typically provided by global scale analyses (from ECMWF or NCEP). These coarse resolution analyses do not resolve mesoscale features that can be of decisive importance for Antarctic coastal weather. It is imperative that all available observations from the surface and space (e.g., GPS radio occultation soundings) be assimilated into the model initial conditions to provide the most accurate and high-resolution description of the atmospheric circulation.

An observing system simulation experiment (OSSE), also for the 13-16 October 1995 period, has been performed to identify the potential impact of the GPS radio occultation soundings from the COSMIC satellite constellation (scheduled for launch in 2005) on the predictive skill of MM5 in capturing this major synoptic-scale event. NCAR has developed a new four-dimensional variational data assimilation procedure that filters out most of the gravity waves causing problems at the model top, described previously. Repeated cycling in 6-hour windows to assimilate the GPS soundings led to a substantial improvement in the predicted placement and intensity of the synoptic-scale cyclone after 24 hours in comparison to a similar simulation without such GPS data. This test demonstrates the great potential of GPS radio occultation soundings for substantially enhancing the analysis and prediction of atmospheric behavior over the data sparse Southern Ocean and Antarctica.

9.3

Improving Precipitation Forecasts in the Mediterranean Region through the Use of GPS derived Integrated Water Vapor Measurements

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Abstract: [presentation] [back to Session 9]

Since Bevis (1992) originally proposed that the atmospheric refractive delay of GPS radio signals could provide integrated water vapor measurements, several initiatives have been begun in Europe to exploit this data source. We will present the results of the European Commission sponsored research project MAGIC? Meteorological Applications of GPS Integrated Column Water Vapor Measurements in the Western Mediterranean. In the MAGIC project, we designed and implemented an automatic processing system to derive the GPS zenith tropospheric delay (ZTD) and integrated water vapor (IWV). This system runs in post-processed and near-real-time (NRT) mode (latency 1h45min) ([Ge et al., 2000]) using data from a 50 station permanent international GPS receiver network. We showed the agreement of the GPS IWV with radiosondes to be at the level of 10 mm of zenith delay (better than 2 kg/m2 of IWV), and showed that it was more accurate than current water vapor fields available from numerical weather prediction models. Additional inter-comparisons of GPS with radiosondes, VLBI, sun photometers, and water vapor radiometers indicate that the data is more accurate than the radiosondes ([Pacione et al., 2001; Pugnaghi et al., 2001]). We showed that ground-based GPS zenith tropospheric delay data in some cases improved the prediction of precipitation in high rainfall storm events. Using the 3Dvar implementation of the High Resolution Limited Area Model (HIRLAM) that is run operationally at the Danish Meteorological Institute, we accumulated 2 weeks of forecast statistics and looked in detail at one event where the operational model underpredicted the amount of convective precipitation. Comparisons with observations showed that the GPS ZTD correctly increased localized precipitation estimates, in particular over Catalonia and the Alps ([Haase et al., 2001; Vedel et al., 2001]). In this talk we will also discuss planned future work in Europe and the Mediterranean in a proposed follow-up to the MAGIC project. Cyclogenesis in the Mediterranean is the focus of the project because it often leads to concentrated precipitation in localized regions and flash floods, and is of high importance for public safety and reducing economic losses. Typically, most of the accumulated precipitation falls in a few storm events each year, with rain rates up to 500 mm in 12 hours. Prediction of such rapidly developing storm systems has the most potential to benefit from the high temporal resolution GPS data.

9.4

Water Vapor Monitoring Using GNSS: Experiments and Perspectives of Applications in Brazil

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Abstract: [presentation] [paper] [back to Session 9]

Information about the quantity of water vapor in the atmosphere is very important for improving the quality of the numerical weather model (NWM) results. Due to the high costs of the conventional techniques for the quantification of IWV (Integrated Water Vapor), such as radiosondes launches and radiometers, the water vapor monitoring process is very deficient. This can be reduced by the utilization of GNSS (Global Navigation Satellite System) continuous networks of receivers, which may provide the best cost-benefits relation, compared to the conventional process. Besides being used in meteorology, such kind of network can be used as an active geodetic network, which has been its main purpose so far. In this paper it is presented the results of the firsts experiments carried out in Brazil using GNSS, more specifically GPS. A 10 days GPS campaign was performed in a site where radiosondes where launched twice a day. GPS processing was carried out using GIPSY Oasis Software. The results are in agreement with those described in the international GPS Meteorology literature. Comparisons between IWV computed from GPS data and radiosondes measurements provided agreement of the order of 1.8 kg/m2. A discussion about the perspectives of IWV monitoring using the Brazilian continuous GPS network and its assimilation by the local NWM is presented.

9.5

Determination of Tropospheric Parameters by VLBI as a Contribution to Climatological Studies

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Abstract: [presentation] [paper] [back to Session 9]

In geodetic VLBI (Very Long Baseline Interferometry) the observations of extragalactic radio sources are performed at two frequencies (2.3 and 8.4 GHz) by a global network of radio telescopes. The most important observable for geodesy is the time delay between the arrival times of a plane wavefront at two radio telescopes. From a sufficient number of these observables various parameters can be estimated with highest accuracy, e.g. the Earth orientation parameters or baseline lengths and differences of the station coordinates. The variable tropospheric refraction is a major error source for the estimation of these geodetic parameters by VLBI. The influence of the tropospheric refraction is taken into account by appropriate models which usually contain a hydrostatic and a wet part. By special mapping functions the tropospheric zenith delay is mapped to the elevation of the observation. In the last years it has become evident that the tropospheric parameters determined by VLBI can also be used for meteorological and climatological studies. In particular the wet component of the tropospheric zenith delay is of high interest. VLBI observations have been carried out at some stations since the beginning of the eighties, what allows the determination of the above-mentioned tropospheric parameters for more than 20 years. Time series of the wet component of tropospheric zenith delays can be compared with other data series of integral numbers of the wet part of the troposphere, e.g. provided by the ECMWF (European Centre for Medium-Range Weather Forecasts).

SESSION 10

Innovative Applications of Space Geodetic Instruments

October 3, 2002, Thursday PM

10.1

A Global Framework for Interdisciplinary Science and Applications: The International GPS Service

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Abstract: [back to session 10]

The Global Positioning System (GPS) provides unprecedented potential for precise ground and space based positioning and timing anywhere in the world. The use of this system continues to increase exponentially and extremely precise uses and applications of the GPS, particularly for Earth Sciences, stem largely from activities of the International GPS Service (IGS). The IGS is a highly successful international scientific federation and a model for international cooperation. More than 200 organizations in 75 countries contribute daily to the IGS, which is dependent upon a cooperative global network of over 300 GPS stations. Data is collected continuously and archived at distributed Data Centers. Analysis Centers retrieve the data and produce the most accurate GPS data products available anywhere. IGS data and data products are made accessible to users reflecting the organizations' open data policy. A similar suite of data and products is available for the Russian satellite system, GLONASS, demonstrating the ability of the IGS to incorporate observations from other Global Navigation Satellite Systems (GNSS) as a portent to the IGS incorporating the GALILEO system.

This presentation will describe the IGS as a framework for many global cooperative scientific activities, the current quality and availability of IGS data, products and applications, and descriptions of the innovative projects and working groups of the IGS. The authors will also highlight the critical role and involvement of Ohio State in the development of the IGS as a geodetic service.

10.2

Global Navigation Satellite Systems: Emerging Capabilities and Research Opportunities

Gerard Lachapelle

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Abstract: [presentation] [back to session 10]

The potential capabilities of two emerging multiple-frequency GNSS, namely GPS II/III and GALILEO are reviewed, with emphasis on the following positioning and navigation performance characteristics: availability, accuracy and reliability. System and user equipment enhancements and the need to continuously improve the above performance characteristics for both outdoor and indoor applications, are resulting in exciting research opportunities in positioning and navigation methodologies and algorithms, ranging from carrier phase ambiguity resolution to reliability enhancements, signal measurement under masking conditions (e.g. heavy foliage, urban canyons, indoor), code and carrier multipath reduction, and fusion with various classes of self-contained sensors. The anticipated performance of the new systems will result in novel and broad-based applications such as personal navigation, asset and people tracking, atmospheric parameter estimation, etc.

10.3

Oceanography with GPS

Cinzia Zuffada

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Abstract: [presentation] [back to session 10]

Recent efforts are under way to use GPS signals scattered off the ocean and sensed by an air- or space-borne receiver in a bistatic radar geometry, as a means of doing altimetry and scatterometry. The advantage of GPS is twofold: the transmitted signal is always globally present and the receiver technology is inexpensive, compared to alternative remote sensing systems. Upon impinging on the ocean surface, the GPS signal is reflected primarily in the specular (forward) direction, in an amount dependent on surface roughness and angle of incidence. An airborne or space-borne receiver, connected to a down-looking antenna, can collect such scattered signals. One such receiver, and the 24 transmitters, form a multistatic radar system, capable of intercepting reflections from several areas of the ocean simultaneously. By analogy to traditional altimetry, the bistatic GPS reflected signal are analyzed to derive the important descriptors of the ocean surface; i.e. ocean height and surface wind vector. Because of the nature of the GPS observations, they can improve our current capability of global sea surface measurements in two important ways: improved spatio - temporal resolution and coverage.

The communication will open with a review of the state-of-the-art in technology development and science demonstrations. Additionally, the most recent findings on sea-surface height from airplane altitude will be presented and the resolution and accuracy will be discussed. In particular, it is shown that the precision is suitable for eddy monitoring, on a temporal scale much shorter than that allowed by TOPEX/Poseidon and JASON. Coastal altimetry performed at the Harvest platform will complement the suite of altimetry experiments illustrated, pointing out the measurement ability for coastal monitoring. Next, the roadmap to future developments will be outlined, describing the basic features that future systems must have for space based oceanography and the advantages over existing technology.

10.4

GPS Positioning of Platforms Floating on the Ocean Surface

C. David Chadwell

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Abstract: [presentation] [back to session 10]

Approximately 70% of the earth's surface is ocean with atmosphere above and tectonically active seafloor crust below. GPS positioning of ships and buoys floating on the ocean surface provides a platform for measuring: (1) seafloor crustal deformation - by resolving acoustic ranges to seafloor transponders, (2) ocean wave and tidal signals - by measuring the platform dynamics and (3) atmospheric precipitable water (PW) - by resolving the zenith wet-path delay of the GPS signal.

Techniques and results from operations offshore the West Coast of the US will be presented.

SESSION 11

Planetary Geodesy and Geophysics

October 4, 2002, Friday AM

11.1

Numerical Simulations for Geodetic Parameter Estimation from Space VLBI Data

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Abstract: [back to Session 11]

Space Very Long Baseline Interferometry (SVLBI) is primarily a radio astronomical technique, which extends conventional VLBI baselines into the space. Its potential applications in Global Geodesy include interconnection of celestial and terrestrial reference frames, and orbit determination using the delay and delay rate observables. In the past two decades, there have been significant theoretical developments in this field. With the first SVLBI satellite of the VLBI Space Observatory Programme (VSOP), this technique has now been realized. The Geodesy Demonstration Experiment (GEDEX) is designed to explore the feasibility of the geodetic applications of SVLBI. In this paper, some results of the numerical simulations for geodetic parameter estimation from VSOP data are presented.

Based upon the mathematical model developed for geodetic parameter estimation from SVLBI observables, data simulation was carried out to estimate the optimum observing parameters and the precision achievable under these optimum conditions, by Kulkarni in 1992. With the availability of real data from VSOP, it is necessary to repeat such analysis to re-estimate the precision under realistic conditions. Numerical simulations for this purpose have been initiated, and the first results are presented in this paper. Conclusions drawn, based upon the results obtained, and implications for possible dedicated geodetic SVLBI missions in the future are discussed.

11.2

Satellite Gravity Exploration of the Terrestrial Planets and the Moon

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Abstract: [back to Session 11]

Terrestrial planetary bodies tend to be compositionally differentiated, and hence stratified in density that increases towards the center-of-mass. Mass flow related to the tectonic evolution of the bodies can result in undulations in the boundaries of the density layers that, in turn, constitute density contrasts which contribute to the gravity field observed at satellite altitudes. For example, the Moho and related crustal thickness variations can be readily mapped from the spectral correlations of the terrain gravity effects and free-air anomalies at satellite altitudes. Once stripped of the strong regional gravity effects of the terrain, the residual free-air anomalies reveal patterns that may be evaluated for mass flow patterns all the way into the core. These results provide important new constraints for subcrustal seismic, magnetic, electromagnetic, and heat flow modeling efforts. Several examples from the Earth, Moon, Mars and Venus demonstrate these applications.

11.3

Geoid Height and Stress in the Lithosphere of Venus and the Earth

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Abstract: [presentation] [back to Session 11]

Bill Kaula pioneered all aspects of satellite geodesy but his primary motivation was to develop these tools so they could be used to understand the geodynamics of the terrestrial planets. Nowadays we have high-resolution geoid and topography models for the Earth, Venus, and Mars and these data sets provide important constraints on the tectonics of these planets. My talk will focus on the use of geoid, topography, surface age and surface faulting to construct global stress and strain models for Venus and the Earth. For wavelengths greater than the compensation depth, the swell-push force is equal to the geoid height scaled by $-g^2/2\ G$ **Venus** has a very high correlation between gravity and topography at all wavelengths so the swell-push force dominates. Assuming Venus consists of a uniform thickness elastic shell over an inviscid sphere, we calculate the present-day global strain field using equations given in *Banerdt* [1986]; areas of positive geoid height are in a state of extension while areas of negative geoid height are in a state of compression. This model strain pattern is highly correlated with the global strain patterns inferred from Magellan-derived maps of wrinkle ridges and rift zones. Much of the observed deformation matches the present-day model strain orientations suggesting that most of the rifts on Venus and many of the wrinkle ridges formed in a stress field similar to the present one. In contrast to Venus, the correlation between geoid height and topography on the **Earth** is poor for spherical harmonic degrees less than 9. Moreover, stress in the Earth's lithosphere is the sum of three forces, slab pull, swell push and asthenospheric drag. These complications make it difficult to establish the global stress field for the lithosphere of the Earth. In the spirit of Bill Kaula, we forge ahead to establish bounds on the state of stress. The Earth's geoid is decomposed into a "lithosphere" contribution and a "deep mantle" contribution by making plausible assumptions about the compensation mechanisms of the continents and the seafloor spreading ridges. Results show good agreement with the style of faulting in mountainous areas of the continents but poor agreement with inferred stress patterns in the ocean basins suggesting slab pull is the dominant mechanism in the oceans.

11.4

Planetary Geodesy: The Mapping of Mars at Global to Local Scales

Brent A. Archinal

Astrogeology Team, U. S. Geological

Abstract: [presentation] [back to Session 11]

The USGS Astrogeology Team is continuing efforts, described here, to map Mars at global, regional, and local scales. These efforts rely heavily on planetary geodesy techniques for establishing control, developed in the 1960's through the late 1990's by Merton Davies and colleagues at the Rand Corporation and in the 1980's to the present at USGS. These photogrammetric, radargrammetric, and other techniques have been used to establish coordinate systems on and to map 22 planetary bodies.

A global photogrammetric control network for Mars was originally established using Mariner 9 images and then re-done in the early 1980's using Viking Orbiter images. This network served the dual purpose of defining a reference coordinate system for Mars and allowing for the creation of global image mosaics, such as the Mars DIM. This network has now been superseded by a MOLA derived coordinate system as an absolute reference for Mars coordinates, but it is still needed to control image mosaics which serve to supplement and "densify" MOLA DIMs, and for other purposes such as improving camera pointing information and providing "navigation" control points. I will describe our current efforts (Archinal, et al 2002, Lunar Planet. Sci. 33) to improve this network, and its connection to the MOLA coordinate system.

We are also continuing to establish control and cartographic products on Mars at regional and local scales, in support of various scientific investigations, geologic mapping, and landing site characterization. In particular we have recently developed techniques (Kirk, et al, 2002, IAPRS, 34, part 4) for high-resolution (~few meters) stereo mapping of portions of proposed landing sites using Mars Orbiter Camera (MOC) narrow angle (NA) line-scanner images. This work has been complicated by – sometimes severe – spacecraft motion during image collection that we are attempting to model. Examples of our mapping results will be presented.

We are at a point in the history of Mars exploration where a flood of new imaging data is about to arrive, which must be controlled and connected into new mosaics. The 2001 Mars Odyssey THEMIS camera is currently collecting global 18-m multi-color and 100-m multipspectral infrared (day and night) imagery of the entire planet. Mars Express will reach Mars in early 2004 and provide 20-m stereo coverage of large regional and local areas. Mars Reconnaissance Orbiter will arrive in 2006 and provide 0.25 m coverage of local areas. Several 2003 and 2007 missions will be relying on high-resolution control and landing site mapping. Our plans to handle the ingestion and integration of these varied sources of data will be described.

Mars Landing Site Mapping and Rover Localisation

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(3) University of Washington, Bothell, Computing and Software Systems

Abstract: [presentation] [back to Session 11]

The Mapping and GIS Laboratory has been involved in the past four years in a research project to provide highly precise localization for Mars rovers using images from both the descent and rover vehicles. This methodology has been developed using lander and rover image data from the Mars Pathfinder mission and data acquired at Silver Lake, CA, and will be further refined for the 2003 Mars Exploration Rover. Highly precise topographic information is needed from all available data sources in order to accomplish the critical positioning of Mars landers and rovers. Precise navigation and localization of the lander and rover are critical for safe navigation, and also for accomplishing the many geological and engineering objectives needed to successfully accomplish each Mars mission. In order to support future long-range rover missions (with traverses up to 1km and beyond), highly precise landing site mapping and rover localization are desirable. In addition, automation of mapping and rover localization is desired in order to achieve autonomous operation.

Supported by the NASA/JPL project "Mars Rover Localization Using Descent and Rover Imagery", we have developed algorithms and software for integrated bundle adjustment of descent, lander, and rover images. As the first step in this procedure, a three-dimensional image network is built by linking all the descent and ground-based images together with the aid of a vast amount of tie points that can be identified and selected either automatically or manually. Distinctive features that can be observed from the orbital images, such as mountain peaks and craters, serve as relative controls for the bundle adjustment. To enhance the adjustment, multiple correlations between orientation parameters are incorporated as constraints. One example of this constraint is the fixed distance between the stereo cameras. A least squares adjustment can then be used to derive the camera position and attitude of any image in the image network (descent, lander, or rover) as well as the 3D ground positions of all tie points. An incremental bundle adjustment model has also been developed that adjusts descent and rover images in a step by step method, resulting in greater computational efficiency.

An innovative approach has been investigated for automatic feature extraction and tie point selection from rover images taken in a traverse. The procedure of this approach includes: interesting point extraction using the Förstner operator, interesting point matching using normalized cross-correlation coefficients, verification based on the consistency of parallaxes, and final selection by gridding. Experiments have shown that this approach works well for stereo images taken at individual camera stations. The approach was further enhanced in order to find tie points for panorama images taken by the lander and/or rover stereo cameras. Tie points between adjacent stereo images were extracted and selected with the help of a coarse DEM generated from individual stereo pairs using the approximate orientation parameters.

Techniques for generating hierarchical DEM using descent and rover images were also developed for Mars landing site mapping and rover localization. Based on these improved image orientation parameters and DEM, orthophoto images and mosaics can be produced.

A systematic study of geometric image traverse design was carried out. We simulated several traverses of sideways looking and forward-backward looking rover image networks. Factors that affect the accuracy of rover localization were examined, including traverse leg length, convergence angles, tie point distribution, and effectiveness of cross-station tie points. Based on the results of the simulation, conclusions and suggestions have been developed for optimal rover traverse design.

In order to verify our algorithm and software, field tests were conducted in April 1999 and May 2000 at Silver Lake, California. Based on the data gathered, various rover localization experiments were carried out. Accuracy of rover localization of about 1m for a traverse length of 1km from the landing center was

achieved when both descent and rover images were used and bundle adjustment (either integrated or incremental) was performed. The root mean square (RMS) errors of the ground coordinates of checkpoints were 0.195m, 0.211m, and 0.429m in the X, Y, and Z directions, respectively. Experiment results also demonstrated that even if no descent images are available, as will be the case in the Mars 2003 MER (Mars Exploration Rover) mission, it is still feasible to localize the rover using only rover images and yet achieve the similar accuracy. This can be achieved by increasing efforts in optimal traverse design and image network generation. At Silver Lake test site, a hierarchical DEM was generated using the descent and rover images with their adjusted orientation parameters. This DEM has five layers with the resolutions ranging from one centimeter (in the immediate area of the landing center) to one meter (in the boundary region about 1km away from the center).

Besides the simulated data set, we conducted bundle adjustment experiments using lander and rover images acquired during the Mars Pathfinder (MPF) mission. Experiments with ten stereo pairs of lander images and two pairs of rover images showed that the adjustment reduced the image coordinate differences of features in adjacent stereo lander images from 2 ~ 15 pixels to a sub pixel level. Estimated rover localization accuracy was found to be about 2% of the distance from the lander.

We are currently processing the full panorama of MPF lander images. After bundle adjustment of the panorama, a landing site DEM and seamless orthoimage mosaic will be automatically produced.

Our techniques and software will be further improved in support of the Mars 2003 Mars Exploration Rover (MER) mission and other future missions.

SESSION 12

Geophysical Fluids: Observations and Modeling

October 4, 2002, Friday PM

12.1

Tides and Modern Geodesy

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Abstract: [back to Session 12]

In modern high-precision geodesy, and especially in modern space geodesy, every measurement that one makes contains tidal signals. Generally these signals are considered noise and must somehow be eliminated. The stringent requirements of the latest space geodetic missions place severe demands on tidal models. On the other hand, these missions provide the strongest data for improving tidal models. In particular, TOPEX/POSEIDON altimetry and LAGEOS laser ranging have improved models to such an extent that new geophysical information about the ocean and the solid Earth are coming to light. Presumably GRACE intersatellite ranging data will also add to this information. This paper discusses several of these new geophysical results, with special emphasis given to the dissipation of tidal energy. Strong constraints have recently been placed on the partitioning of energy dissipation among the ocean, atmosphere, and solid earth and between the deep and shallow ocean. The dissipation in deep water is associated with internal tides and has potentially important implications for understanding the ocean's thermohaline circulation.

12.2

The Chandler Wobble

Richard S. Gross

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Abstract: [back to Session 12]

The Earth rotates about its axis once a day, but does not do so uniformly. Instead, the rate of rotation fluctuates by up to a millisecond per day, and the Earth wobbles as it rotates. Much like the wobble of an unbalanced automobile tire, the Earth wobbles because the mass of the Earth is not balanced about its rotation axis. The wobbling motion of the Earth was first detected by Seth Carlo Chandler, Jr. in 1891 and has been under observation ever since. Analyses of these observations reveal that the Earth has, in fact, two dominant wobbling motions: (1) an annual wobble with a period of 12 months and an amplitude of about 3 meters, and (2) the Chandler wobble with a period of 14 months and an amplitude that varies between about 3 to 6 meters. The annual wobble is a forced motion of the Earth that is caused largely by the annual appearance of a high atmospheric pressure system over Siberia every winter. The Chandler wobble on the other hand is not a forced motion of the Earth, but is rather a resonant motion that was first predicted by the Swiss mathematician Leonhard Euler in 1765. Euler studied the general translational and rotational motion of rigid bodies and, by applying his theory to the Earth, predicted that if the Earth's mass were not balanced about its rotation axis then the Earth should wobble as it rotates. Frictional forces associated with the wobble-induced deformation of the solid Earth would cause the Chandler wobble to freely decay with an exponential time constant of about 68 years if no mechanism or mechanisms were acting to excite it. Observations of the Chandler wobble taken during the past century show that there are times when its amplitude has actually increased. Thus, some mechanism or mechanisms must clearly be acting to excite the Chandler wobble. But despite the numerous studies that have been conducted since it was first detected, the primary mechanism responsible for exciting the Chandler wobble has only recently been discovered. The recent availability of numerical general circulation models of the global oceans has allowed the impact of oceanic processes on the Earth's rotation to be studied. In particular, such models have been used to show that the change in the load on the oceanic crust due to changes in the weight of the overlying column of water associated with changes in the distribution of the oceanic mass is about twice as effective in exciting the Chandler wobble as is the changing atmospheric pressure over land. In fact, the sum of the changing atmospheric pressure over land and the changing ocean-bottom pressure can fully explain the excitation of the Chandler wobble.

12.3

Earth Rotation Variations: A Budget Assessment

Clark R. Wilson, Jianli Chen and Ki-Weon Seo

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Abstract: [presentation] [paper] [back to Session 12]

Comparisons of air and water excitations with observed earth rotation variations began almost a century ago, with the best early example being the 1916 study of Harold Jeffreys. By the late 20th century it was firmly established that nearly all earth rotation variations at time scales up to a few years or more are excited by air and water motion. At the beginning of the 21st century it is routine to estimate excitation budgets for both polar motion and length of day with global numerical data-assimilating models of the atmosphere and hydrosphere. We give an assessment of current understanding and open questions. Improved understanding will follow further developments, especially in data-assimilating models

of the oceans and terrestrial hydrology. Because time variable gravity, geocenter, and load deformation studies require similar information, the connections between numerical climate modeling and geodesy will continue to grow stronger in the future.

12.4

Polar Motions Detected by Geodetic Means and Excited by the Atmosphere

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Abstract: [presentation] [PowerPoint Slide Show] [paper] [back to Session 12]

Accurate knowledge of the motions of the pole is important for maintenance of reference frames and understanding of planetary physics. Such motions are routinely detected by space-geodetic techniques. At the highest frequencies, spectra of such signals based on GPS observations reveal maxima at 8 and 12 hours. Variations at such periods are noted as well in atmospheric excitations of polar motion based on analyses of global and regional surface pressure. At much longer scales also, the atmosphere has been observed to force polar motion, and it is accompanied by oceanic excitation as well. Such forcing of these two geophysical fluids has powerful annual and semiannual components. That of the atmosphere is related to known climate patterns and is particularly strong over regions in Eurasia and North America.

12.5

Satellite Measurements of Time-Variable Gravity, and Their Possible Applications for Hydrology

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Abstract: [back to Session 12]

Satellite laser ranging (SLR) measurements have provided information about changes in the longest-wavelength components of the earth's gravity field. These changes are caused by a combination of post-glacial-rebound, fluctuations in atmospheric mass, and the redistribution of water, snow, and ice on land and in the ocean. The spatial resolution of the SLR data is not sufficient to unambiguously separate the effects of these different processes.

The availability of GRACE data, with their much higher resolution and accuracy, should change this situation dramatically. Time-variable gravity measurements from GRACE will be useful for addressing a variety of problems, in a number of disciplines, that involve the redistribution of mass within the earth and at its surface. Especially promising is the likelihood that GRACE will deliver estimates of monthly changes in water/snow/ice storage on land, averaged over several hundred km and larger, to accuracies of better than a cm of water thickness. This will be useful for assessing and improving climate models, for better understanding large-scale hydrological processes, and for monitoring the distribution of land-based water for agricultural and water resource applications.

In this talk we describe methods of extracting the water storage signal from the gravity solutions, and estimate the probable accuracy of the results. For our analysis we construct a simulated hydrological gravity signal using a land surface model based on monthly

global precipitation records. Depending on the public availability of the GRACE data at the time of this talk, we will present estimates based on those data.

12.6

Analysis of Time-variable Gravity by Satellite-Laser-Ranging in the Last Quarter Century

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Abstract: [back to Session 12]

Temporal variations in the long-wavelength geopotential have been observed for the past two decades, principally using the satellite-laser-ranging technique. Estimates for the time rate of change in J2 have consistently shown a slight but significant decrease, which has been been attributed primarily to post glacial rebound. However, sometime around 1998, J2 began increasing. At present it is not possible to tell whether this aberration represents a change in the long-term rate of change in J2, or whether it is short term in nature. In addition to changes in the mean J2, the amplitude of the annual variation has been changing. This change signifies a large change in global mass distribution whose J2 effect clearly overshadows that of the post-glacial rebound. Some tantalizing evidences are investigated in an effort to identify the geophysical source(s) of this change. Some of the recent signal may result from changes in the cryosphere, however recent analysis suggests that a significant cause of the change lies within the oceans. We will present results of our analysis of the changes in the low-degree spherical harmonics, as well as our investigations into the causes.

12.7

Seasonal to Decadal Variations of Low-Degree Gravity Field induced by Oceanic Mass Redistribution: Results from GEOSAT, ERS and TOPEX/POSEIDON Satellite Altimetry

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Abstract: [paper] [back to Session 12]

Sea level anomalies (SLA) are determined from Geosat, ERS-1, ERS-2 and TOPEX/POSEIDON satellite altimeter data. The thermal (steric) effect is removed from SLA to compute low-degree gravity harmonic coefficients from 1985 to 2002, forming time series of low-frequency oceanic mass-induced gravity change that span 18 years. Such a time span allows analysis of gravity change at seasonal to decadal time scales. The thermal effect cannot be accurately determined owing to uncertainties of temperature data in both space and time. Wavelet analyses are used to decompose the time series of harmonic coefficients into wavelet spectra in time and frequency. These time series are found to consist of components of varying amplitudes and frequencies over time. Possible mechanisms of the oceanic mass-induced gravity change is discussed and comparison is made in this paper.

POSTER SESSIONS

1 OCTOBER NOON 2002, TUESDAY – 4 OCTOBER NOON 2002, FRIDAY

General

P01

Crossing the Olentangy River: The Cold War and the Establishment and Triumph of the Geodetic and Allied Sciences at Ohio State University

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Abstract: [back to Poster Session]

The progress in the geodetic and allied sciences at Ohio State University and the homage due Dr. Weikko Heiskanen are predicated on the foundation of the unique postwar research enterprise that brought Dr. Heiskanen to Ohio in the first place. This poster paper will describe the origins and early history of that enterprise, and its complex and enormously productive relationships to Cold War military and intelligence institutions, and their programs and funding. In 1947, the Mapping and Charting Research Laboratory was

founded, under the directorship of Dr. George Harding, as a uniquely modern research organization. The Laboratory was outside the normal university departmental organization, linked to a myriad of military and intelligence agencies based on the wartime contacts of the Laboratory's personnel, and funded almost exclusively through classified and unclassified research contracts with the US Air Force. Within a decade of its formation, the Laboratory had become the most important nexus of geodetic sciences research on the planet. In order to train the next generation of students appropriately, the Laboratory crossed the Olentangy River to the campus proper and established the Institute of Geodesy, Cartography and Photogrammetry. Eventually the Laboratory was ended, and the Institute was absorbed into the Department of Geodetic Sciences, which in turn evolved as a part of larger academic units. The significance of the research and teaching enterprise is far larger than its academic component, however, and it includes several generations of deeply secret programs that effectively precluded nuclear exchanges and kept the peace during the Cold War.

P02

Geospatial Information and Analysis for Coastal Management and Decision Making

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Abstract: [back to Poster Session]

This paper presents the status and outcomes of the first year of an NSF-funded Digital Government project. The goal of the three-year project is to investigate and develop technologies to enhance the operational capabilities of federal, state, and local agencies responsible for coastal management and decision making. The research team will develop a spatio-temporal data model for inter-governmental agency operations that will enable agencies to account for the dynamic nature of coastal zones in policy formulation and implementation. Multiple high-resolution spaceborne and in situ remote-sensing measurements will be combined with spatio-temporal databases, coastal hydrological modeling, and geospatial information analysis to provide detailed information for highly efficient modeling and forecasting capabilities along with a high degree of coordination between coastal management and policy making.

When successfully implemented, this project will a) significantly enhance the capability for handling spatio-temporal coastal databases, b) build a fundamental basis of coastal geospatial information for inter-governmental agency operations, and c) provide innovative tools for all levels of governmental agencies to increase efficiency and reduce operating costs.

Satellite Altimetry and Sea Level

P03

The ENVISAT RA-2 Radar Altimeter System

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Abstract: [back to Poster Session]

Following the success of ERS-1 and 2 satellites, which have contributed to better understand the role that ocean and ice play in determining the global climate, the European Space Agency has successfully launched ENVISAT, its largest remote sensing satellite, on 1 March 2002 by Ariane 5. The main objective of the Envisat programme is to endow Europe with an enhanced capability for the remote sensing of the Earth from space The payload include an advanced instrument complement designed to guarantee the continuity of observations started by its predecessors, to meet on a longer time scale the global Earth's monitoring requirement. In particular the Altimetry mission will benefit from the improved performance of a dual frequency new generation radar altimeter (RA-2) working in synergism with the microwave radiometer (MWR) and Doppler Orbitography and Radio positioning Integrated by Satellite (DORIS) instruments. The near real time ground processing products will be as comprehensive as the off-line products, being based on the same algorithms, differing only for the availability and quality of the auxiliary data. The new capabilities of the instrument and the remarkably improved data products are described. With almost two decades of altimetric measurements acquired by ESA, long term evolution of glaciologic and oceanographic parameters playing a key role in climate change can be addressed.

P04

Operational and Precise Orbit Determination for Geosat Follow-On Altimetry

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Abstract: [poster] [back to Poster Session]

The U.S. Navy's GEOSAT Follow-On spacecraft (GFO-1), launched in early 1998, began continuous radar altimeter coverage of the oceans in 2000. After an extensive series of calibration campaigns in 1999 and 2000, the satellite was accepted by the Navy on November 29, 2000. GFO supplements the altimetry data from TOPEX/POSEIDON and ERS-2 (and their successors JASON-1 and ENVISAT), by providing a different synoptic sampling of the oceans with its 17-day repeat cycle. Altimeter crossover analysis suggests that GFO is capable of "cm-class" altimetry, with orbit errors remaining the largest contributor to the sea surface height error budget. Satellite laser ranging (SLR), especially in combination with altimeter crossover data, offers the only means of high- quality precise orbit determination, due to the failure of the GPS tracking system on board GFO. SLR tracking is augmented by the operational Opnet/Tranet Doppler tracking system. These data have been used to tune the gravity field model and satellite macro-model (a 3-D representation of the spacecraft geometry and surface properties) used in the orbit determination software. Near real-time medium precision orbits (MOEs) are generated at GSFC within 72 hours and (in the absence of maneuvers) have radial orbit errors of 10 cm (1 σ) or less. These preliminary orbits are suitable for mesoscale studies where short-arc orbit error removal does not severely impact the sea surface height signals. Beginning in August, 2001 GSFC began releasing Precision Orbit Ephemeris (POE) data for use on the science-quality NOAA GDR and NASA Pathfinder Project. The POE orbits are more accurate than the MOEs, with orbit errors of 5 cm (1 σ) or less. Geophysical validation of the sea surface heights is performed by comparisons with in situ tide gauge data as well as height fields from contemporaneous altimetry missions. In this paper, recent developments will be discussed, including GFO GDR production for the year 2000 (Cycles 37-54, augmenting the existing data for Cycles 55-80), results of an improved “direct” sea state bias estimation, evaluation of a new GSFC gravity field model for orbit determination, and aspects of the ongoing GFO validation effort.

P05

Satellite Altimetry Applications: Operational Oceanography from Space

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Abstract: [back to Poster Session]

The successful December 2001 launch of the NASA/CNES Jason-1 satellite, follow-on to the highly successful TOPEX/Poseidon mission, provides oceanographers and marine operators across the globe with the unique opportunity of a continuous stream of sea surface height data beginning in late 1992, and extending through the expected mission life in 2006. This unprecedented resource of valuable ocean data

can be used to map sea surface height, geostrophic velocity, significant wave height, and wind speed over the global oceans. Altimeter data products are currently used by hundreds of researchers and operational users over the globe to monitor ocean circulation and improve our understanding of the role of the oceans in climate and weather. Altimeter data has also proved invaluable for a suite of practical applications including;

- Ocean forecasting systems,
- Ship routing,
- Precision marine operations such as cable-laying and oil production,
- Ocean acoustics for Navy operations,
- Fisheries management,
- Marine mammal habitat monitoring,
- Hurricane forecasting and tracking,
- Debris tracking

The data has been cited in over 1,000 research and popular articles since the launch of TOPEX/Poseidon in 1992, and almost 200 scientific users receive the global coverage altimeter data on a monthly basis. In addition to the scientific and operational uses of the data, the educational community has seized the unique concepts highlighted by these altimeter missions as a resource for teaching ocean science to students from grade school through college.

P06

Altimetric Bathymetry from Surface Slopes (ABYSS): Seafloor Geophysics from Space for Ocean Climate

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Abstract: [back to Poster Session]

Forecasts of climate and sea level on inter-annual and longer time scales require accurate models of the advection and mixing of heat, salt and greenhouse gases in the oceans. These models are sensitive to global ocean bathymetry on fine spatial scales (10 to 30 km full-wavelength), and model uncertainty is now a focus of global change debate. Sea floor topography is isostatically uncompensated at these wavelengths, and so climatically useful bathymetry may be recovered by inversion of gravity field observations, if data of sufficient precision (1 to 2 mGal) in this wavelength band can be obtained over most of the global oceans. Space-based mapping is faster and cheaper than a systematic ship survey, but upward continuation to orbital altitudes eliminates the bathymetric signal; thus, space gravity missions (CHAMP, GRACE, GOCE) cannot detect the signal, and one must use radar altimetry of the ocean surface to recover gravity at bathymetric scales. Experience with GeoSat and ERS-1 proves the feasibility of the technique and shows how to optimize a new mission to fully achieve the required resolution. Short-wavelength resolution requires greater range precision and smaller along-track footprint than conventional altimetry has achieved. Azimuthally isotropic resolution requires that errors project nearly equally into north and east components of geoid slope, requiring an orbit of moderate inclination. A delay-Doppler radar altimeter operating for six years on the International Space Station or other suitable orbiter can achieve the required resolution, and at the same time can operate closer to shore than other altimeters and with better spatio-temporal sampling of tides, yield wind and wave data in near-real time, and explore the geology and resource potential of the continental margins. Our proposal to NASA ESSP for such a mission is called ABYSS, for Altimetric Bathymetry from Surface Slopes.

P07

Tide Gauge Data Analysis in the North Sea for Altimetry Calibration

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Abstract: [back to Poster Session]

Data from 18 tide gauge stations in the North Sea have been analyzed to identify the instantaneous sea level in order to calibrate altimeter satellite measurements. Tide gauge data was available with mostly non-equidistant temporal spacing, e.g. extreme values. Harmonic analyses of non-equidistant data was performed to obtain the main tidal constituents at the particular station. For reference, hourly data has been analyzed to validate the results, if available.

Sea level trends have been estimated from the data for each individual station, although the time series of all stations already show a remarkably good agreement. An iterative approach was used to estimate the trends. Firstly, the original data sets were analyzed to obtain the main tidal constituents, secondly, the latter were used to predict time series and residuals. The residuals were analyzed in the same way to extract trends and signals not originating from known tidal constituents. The resulting trends and comparisons with altimetry data of the ongoing missions will be discussed.

P08

Radar Altimeter Absolute Calibration Using GPS Buoy and Tide Gauges

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Abstract: [back to Poster Session]

The knowledge of instrumental biases of radar altimeter systems (TOPEX/POSEIDON, GFO, ERS-2, Jason, and ENVISAT) and their potential drifts is an inherent and stringent requirement to use altimeters for measuring accurate global sea level changes. It requires knowing the relative biases between each of the systems at the 1-cm (1 sigma) level, and the drifts at <1 mm/yr (1 sigma) level. Operational and dedicated calibration sites exists (i.e., Harvest Platform, Burnie, English Channel, etc) for the absolute calibration of TOPEX/POSEIDON (T/P), and additional sites in the Mediterranean, including Corsica, Barcelona, in the North Sea, and near Vanuata, New Caledonia in the South Pacific, are planned or have been operational for dedicated calibrations of ENVISAT and Jason. In this study, we present early and updated results of dedicated altimeter calibration sites (1) at Lake Erie to use the existing NOAA water level gauge at Marblehead, Ohio, Lake Erie and GPS-buoy, and (2) at the Vanuatu calibration site in New Caledonia to calibrate multiple radar altimeters. The Marblehead gauge was selected due to the data availability and the proximity to the multiple altimetric ground tracks. It provides continuous water level measurements every six minutes continuously with respect to a regional vertical datum, namely IGLD 1985. A Continuous GPS (CGPS) station is being built to collocate with the water level gauge. Before the planned establishment of an automated GPS-buoy on US Coast Guard buoy, a wave-rider GPS buoy was deployed in a campaign in October 2001 next to the water level gauge in order to

convert the gauge measurements to a geocentric terrestrial reference system, to which the altimeter height measurements are referenced. The buoy was then deployed underneath and along the altimetric ground tracks to measure Lake surface gradients. Consequently, the gauge measurements are translocated to the altimetric footprint and to be compared with or calibrate the altimeter lake surface height measurements without the presence of a continuous running GPS-Buoy underneath the satellite groundtrack. The GPS buoy was deployed underneath a T/P ground track in a campaign in October 2001. This paper presents results of the October 2001 calibration campaign on T/P and early results on Jason and ENVISAT. The ORSOM Vanuatu calibration site consists of two bottom pressure gauges (BPG) moored in open sea at Wusi (under a T/P and Jason track) and at Sabine Bank (at an ERS-2 and ENVISAT crossover), collocated with CGPS stations. Preliminary analysis using data collected from 2000 to mid-2002 for calibration of T/P, ERS-2, Jason and ENVISAT will be presented.

P09

Studying Seasonal Sea-Level Variations in the Baltic Sea Using Geodetic Measurements and Oceanographic Model

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Abstract: [paper] [back to Poster Session]

Sea-level variations in the Baltic Sea can be divided into externally and internally forced variations. While the externally forced contribution of the sea-level variance is mostly explained by water exchange with the North Sea, the internally forced variations of the sea level are mostly due to conditions within the Baltic Sea area.

The Baltic Sea sea level can be studied using different sources of information. A dense network of tide gauge stations along the coast lines as well as satellite altimetry provide precise information about the sea level and its variations. In addition, sea level heights can also be obtained from a precise, high resolution oceanographic model of the Baltic Sea.

The presentation will focus on the analysis of the seasonal variation of the sea-level in the Baltic Sea from satellite altimetric observations. Looking at the spatial distribution of the variations and comparing these results with tie gauge observations and with the oceanographic model, the contribution of externally and internally forced sea-level variations to the total variance can be estimate.

P10

Great Lakes Monitoring Using Space Geodetic Technologies

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Abstract: [back to Poster Session]

Space geodetic measurements are accurate, abundant, all-weather system, and they are ideally suited to be used as a cost-effective data source for a number of environmental research and operational studies in the Great Lakes. Current observations used for environmental monitoring and coastal forecasting systems are tide gauges and GOES and AVHRR imageries, which are not all-weather measurement systems. There is also a winter data outage problem. This paper describes research ongoing using space

geodetic measurements as a complementary data set to the existing data used for environmental monitoring and Lake Circulation and weather forecasting. The primary objectives of the investigation is to demonstrate the use of space geodetic measurements (radar altimeters and GPS-buoys) for improving temporal and spatial resolutions of measurements for absolute lake elevation, wave height, wind speed, water vapor and lake ice boundary. The composite data are to be used to study the potential improvement of the accuracy in the current operational Great Lakes forecast systems. Continuous GPS (CGPS) stations are being established around the Great Lakes, including a proposed location on the Cooke Castle at the F.T. Stone Laboratory, Lake Erie, for studies including GPS meteorology, crustal motion, and safe navigation. The development of GPS-buoy water level instrument for absolute calibration of altimeters in Lake Erie will benefit global sea level and climate change studies.

P11

Glacial Isostatic Adjustment Inferred by Tide Gauges and Satellite Altimetry

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Abstract: [back to Poster Session]

Glacial isostatic adjustment (GIA) of the solid Earth due to recent deglaciation and deglaciation since the last Ice Age (Pleistocene) is characterized by its viscous-elastic rebound as a result of relaxation of the shear stresses inside the Earth. GIA uplift (in the form of 3-D crustal motion and the ensuing geoid change due to redistribution of mass in the solid Earth) has been recently measured with long-term GPS (e.g., the BIFROST project). In this paper, we used long term (1800-2000) tide gauges located around the Great Lakes and other regions near the source of the postglacial rebound such as Fennoscandia, and satellite altimetry measurements (TOPEX/ POSEIDON and Geosat, 9-15 year data span) to measure the vertical (crustal) land motion of the area near the vicinity of the tide gauges. Preliminary results indicate that Lake Superior, Lake Michigan, Lake Huron, Lake Erie, and Lake Ontario, are uplifting at a rate of 1.8, 0.9, 1.4, -0.5, and 1.0 mm/yr, respectively, and with an estimated uncertainty of ±0.1-0.4 mm/yr. The uncertainty of the measurement is primarily due to the error in satellite altimetry due to its relatively short data span. The results in the Great Lakes region are compared with available GIA models, including ICE-4G, and BIFROST model by Mitrovica-Milne [2001] models, as well as relative vertical motion measured using water level gauges [Manville et al., 2001]. The Fennoscandia observed motion is compared with the BIFROSAT GPS vertical motion (crust and geoid change). Analysis also includes the examination of GIA models using different estimates of mantle thickness and upper and lower mantle viscosity.

Crustal Dynamics and GPS Applications

P12

GPS Meteorology Using GPS Limb-Sounding with Low-Earth Orbiters

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Abstract: [back to Poster Session]

Radio occultation limb-sounding, first used to remote sensing planetary atmosphere, can also be applied to Earth's atmosphere by using Low-Earth-Orbiting (LEO) satellites equipped with GPS occultation receivers. First successfully demonstrated by GPS/MET experiment in 1995, GPS occultation technique represents a new independent data source and shows great prospective to provide accurate pressure, temperature and water vapor profiles in the Earth's neutral atmosphere. GPS occultation measurements (excessive phase delays which can be converted to bending angles or refractivity) with enhanced temporal and spatial resolution, provide a valuable data source in addition to the traditional measurements (e.g., radiosonde, nadir-viewing satellite based radiometers) and ground-based GPS networks (antenna zenith delays) for precipitable water vapor (PWV) measurements. The new generation Blackjack GPS receivers onboard the currently operating LEOs (SAC-C, CHAMP, GRACE), the future COSMIC mission and European proposed multi-satellite occultation constellations--ACE+ and METOP based on GRAS GPS receivers would contribute an unprecedented global coverage and continuous GPS atmospheric limb-sounding data for research in climate, meteorology and space weather. For data "poor" or polar regions, the near-real time use of these data could potentially improve regional weather forecasting. These data also could be used to improve global surface pressure fields to quantify atmospheric mass redistribution on Earth, allowing other climate-sensitive mass variation signals such as hydrological, oceanic and cryospheric to be separated from atmospheric loading. One of the limitations of atmospheric occultation which impedes extracting accurate soundings is that weak and noisy signal in the lowest several kilometers of troposphere could not be well tracked by the current relatively low gain GPS occultation antennas and phase lock-tracking algorithm. This paper discusses atmospheric occultation data retrieval algorithmic and technical problems, including mitigation of multipath propagation, lower tropospheric inhomogeneities, etc.; rapid LEO orbit determination techniques, choice of upper boundary conditions for retrieval. Preliminary results based on CHAMP and SAC-C datasets, and their validations using European Center for Medium-range Weather Forecasts (ECMWF) and National Center for Environmental Prediction (NCEP) data are also presented in this paper.

P13

Improving Precipitation Forecasts in the Mediterranean Region through the Use of GPS derived Integrated Water Vapor Measurements

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Abstract: [back to Poster Session]

Since Bevis (1992) originally proposed that the atmospheric refractive delay of GPS radio signals could provide integrated water vapor measurements, several initiatives have been begun in Europe to exploit this data source. We will present the results of the European Commission sponsored research project MAGIC? Meteorological Applications of GPS Integrated Column Water Vapor Measurements in the Western Mediterranean. In the MAGIC project, we designed and implemented an automatic processing system to derive the GPS zenith tropospheric delay (ZTD) and integrated water vapor (IWV). This system runs in post-processed and near-real-time (NRT) mode (latency 1h45min) ([Ge et al., 2000]) using data from a 50 station permanent international GPS receiver network. We showed the agreement of the GPS IWV with radiosondes to be at the level of 10 mm of zenith delay (better than 2 kg/m2 of IWV), and showed that it was more accurate than current water vapor fields available from numerical weather prediction models. Additional inter-comparisons of GPS with radiosondes, VLBI, sun photometers, and water vapor radiometers indicate that the data is more accurate than the radiosondes ([Pacione et al., 2001; Pugnaghi et al., 2001]). We showed that ground-based GPS zenith tropospheric delay data in some cases improved the prediction of precipitation in high rainfall storm events. Using the 3Dvar implementation of the High Resolution Limited Area Model (HIRLAM) that is run operationally at the Danish Meteorological Institute, we accumulated 2 weeks of forecast statistics and looked in detail at one event where the operational model underpredicted the amount of convective precipitation. Comparisons with observations showed that the GPS ZTD correctly increased localized precipitation estimates, in particular over Catalonia and the Alps ([Haase et al., 2001; Vedel et al., 2001]). In this talk we will also discuss planned future work in Europe and the Mediterranean in a proposed follow-up to the MAGIC project. Cyclogenesis in the Mediterranean is the focus of the project because it often leads to concentrated precipitation in localized regions and flash floods, and is of high importance for public safety and reducing economic losses. Typically, most of the accumulated precipitation falls in a few storm events each year, with rain rates up to 500 mm in 12 hours. Prediction of such rapidly developing storm systems has the most potential to benefit from the high temporal resolution GPS data.

P14

The Crustal Response to Changing Tidal Loads Imposed by a Pinned Ice Shelf

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Abstract: [paper] [back to Poster Session]

The Transantarctic Mountains DEFormation (TAMDEF) project is a long term monitoring network of GPS stations in southern Victoria Land, Antarctica. The network was installed with the specific goal of determining rates of motion due to post-glacial rebound and rifting in the area. Several sites within the network display daily fluctuations in position on the order of 5-15mm between consecutive days. In addition to tectonic and rebound signals, motions at these sites may be affected by ocean and atmospheric loading. In particular, the floating Ross Ice Shelf, which is pinned to bedrock immediately adjacent to

the GPS sites, may deform the crust as it undergoes tidal flexure. These load changes may be contaminating the secular motion of the sites. If these tidally-induced changes can be modeled then they can be corrected for. The effects of varying ocean loading models will be investigated.

P15

Post Glacial Rebound and Rift Tectonics of the Antarctic Interior

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Abstract: [back to Poster Session]

The TransAntarctic Mountain DEformation project (TAMDEF) is an investigation of modern rates of crustal motion in southern Victoria Land, Antarctica. This region is characterized by extreme relief, with 4.5km high mountains adjacent to an offshore rift basin that is at least 10 km in depth. The area is thought to be tectonically active (Wilson, 1999) and is a focus of Cenozoic volcanism. The grounded margins of the Antarctic Ice sheets have fluctuated throughout the region in the past 100,000 years. The visco-elastic crustal response to these fluctuations has been examined spatially using measurements from a dense GPS network. Between 1996 and 2002 GPS data were collected at 28 first-order rock-pin monuments in southern Victoria Land. These daily campaign data have been reduced using the PAGES-V and the GAMIT processing packages to produce independent daily positions for each of the GPS points. The results have been stacked and long-term motions estimated. Vertical motions indicate the bedrock in the area is rising at about 4mm/yr over the area. This rate is similar to that predicted for post-glacial rebound by James and Ivins, 1998. We are investigating the partitioning of vertical motion into the instantaneous elastic component driven by modern ice thickness change and the component driven by glacio-isostatic rebound since the last glacial maximum. Horizontal motions are examined against the East Antarctic cratonic motion. This allows investigation of rift activity over the offshore Terror Rift and the onshore Transantarctic Mountains Front Zone. Sites east of the Terror Rift have a northeasterly motion of 4mm/yr away from the inland East Antarctic sites. Coastal sites have a similar sense but smaller magnitude of motion (about 2mm/yr) with respect to cratonic sites. The differential motions measured in this study are small and are comparable in magnitude to those measured over the East African Rift valley, an analogous tectonic setting.

Wilson, T., J. 1999 Cenozoic structural segmentation of the Transantarctic Mountain rift flank in Southern Victoria Land. Global and Planetary Change, 23. p105-127.

P16

Use of Global Positioning System on High Precision Geodetic Control of Nepal

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Abstract: [back to Poster Session]

This paper describes the observation procedure and the adjustment results of the existing higher order control network of Nepal established in different time using different types of equipment and techniques. Attempt has been made to give some idea on the use of Global positioning System on high precision geodetic control of Nepal for the production of topographic map of the country and GPS control network extension for the preparation of large scale maps including cadastral maps of the country.

P17

GPS Detection of Izmit Earthquake and Shape Model of Already GPS-Detected Launch of Space Shuttle in 1993

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Abstract: [paper] [back to Poster Session]

In this paper, the GPS data collected at Mediterranean GPS Network's station called TUBI during 17 August 1999's Izmit Earthquake is processed. This station is located in Izmit province itself. By passing the Total Electron Content through a high-pass filter, the energy released by the earthquake is thought to be detected. Also, a past study where a space shuttle launch that took place on October 18, 1993 from Kennedy Space Center (Cape Canaveral, Florida) for the STS-58 mission was detected through similar processing of GPS data collected in Bermuda island is presented. The results of this detection are re-generated and used to develop a shape model that may prove beneficial for similar detections in the future.

P18

Evaluating Multipath Effects at Stations in the National CORS Network

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Abstract: [poster] [back to Poster Session]

The National Continuously Operating Reference Station (CORS) Network is a cooperative effort involving several agencies, universities, and private companies who seek to make available to the general public GPS data from dual frequency, geodetic-quality receivers located throughout the United States and its territories. Originally, the primary concern for the CORS Network was insuring that there were sufficient stations to guarantee a reasonable station spacing. Since this concern is now being met in most areas, it becomes possible to place a greater emphasis on station quality. Such quality considerations might include the multipath characteristics of a site, its monument stability, and its data reliability. The first of these factors, multipath, becomes especially important to those using short periods of data (one to ten minutes) and to those performing kinematic positioning. It is anticipated that the number of kinematic users will increase in the future due to advances in receiver and wireless technology and due to real-time initiatives undertaken by individual states using their own regional networks. Multipath effects may also become important to researchers testing the kinematic capabilities of the High Accuracy National Differential Global Positioning System (HANDGPS), a demonstration project recently announced by the U.S. Coast Guard and Federal Highway Administration.

This paper discusses the current status of the 280+ stations in the National CORS network with regards to the level of pseudorange and carrier phase multipath experienced at each station. It is expected that in the future, equipment at some CORS may be upgraded to reduce multipath; this study will assist in identifying those stations with the highest levels of multipath. For certain high accuracy applications such as those involving integer ambiguity fixing, it may also prove useful to know how much one reference station might be preferred over another. Various approaches for identifying and eliminating the effects of pseudorange multipath will be compared. Several emerging techniques for the in-situ calibration of carrier phase multipath will also be discussed.

P19

Preliminary Results of the GPS Studies for the January 2001 Gujarat Earthquake

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Abstract: [back to Poster Session]

Global Positioning System (GPS) provides a valuable tool for monitoring the crustal deformations for understanding the complex earthquake mechanism After the tragic earthquake that struck the Gujarat region of western India on 26 Jan. 2001, immediate GPS observations were carried out in the area by the GPS team of Indian Institute of Technology Bombay (IITB), for estimating the post-earthquake deformations. Repeat observations of the GPS network established were completed in February, 2002. The preliminary results of these GPS studies are presented here.

An extensive GPS network is being established in India under the 'National GPS for Geodynamics Programme' by Govt. of India, a brief overview of which is provided. A collaborative field work, involving GPS observations at existing geodetic triangulation stations in the earthquake-affected area of Gujarat near Bhuj has been taken up since February 2001. The aim is not only to understand the post-earthquake crustal deformation pattern, but also to establish precise GPS control for monitoring crustal dynamics in this earthquake-affected region in the future. During the field work carried out in Feb. 2001, GPS observations at 17 geodetic stations , covering the entire region around the epicentre, have been carried out, including 5 old GT stations, which were found intact, 12 new stations established close to GT stations found destroyed/disturbed, and one base station. Repeat observations at these stations have been carried out in February, 2002, to study the deformation pattern. The data has been processed and analyzed using Bernese, GAMIT and DYNAP software. The preliminary results from the analysis of the data from these two epochs, and future plan of work, are presented here.

P20

Geodetic and Geophysical Studies for Monitoring Crustal Deformation in Kachchh Region of Gujarat, India

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Abstract: [back to Poster Session]

Bhuj earthquake, one of the most devastating earthquakes in the last 50 years which destroyed vast area of Gujarat state in India has attracted worldwide attention and necessitated retrospection by Indian geodetic and geophysical community. The earthquake has re-confirmed the high vulnerability of this region to earthquakes of higher magnitude causing massive surface deformations and geophysical changes. The earthquake, which is supposed to have been caused due to intra-plate activities, have highlighted the need of continuously monitoring the seismic activities in the region using various geodetic and geophysical techniques available today.

The Geodetic and Research Branch (G&RB) of Survey of India has been entrusted the responsibility of carrying out geodetic and geophysical observations in the region to study the surface deformations

associated with Bhuj earthquake. GPS, gravity, geomagnetic and leveling observations were carried out during February-April 2001 to assess the magnitude of surface and subsurface deformations in post earthquake scenario. GPS observations were carried out at 28 old existing stations covering the entire area of interest. All the data collected during the fieldwork was processed using IGS ephemerides with Bernese scientific post-processing software. GPS derived co-ordinates for all stations were compared against the existing values. The differences in their horizontal and vertical positions were taken into consideration for forming conclusions about the magnitude of surface deformations arising out of the earthquake. The visible anti clockwise rotation of this plate provided an interesting insight to the anticipated movements.

Repeat gravity and geomagnetic measurements along with high precision leveling lines were also carried out and the results analyzed. The results provided a broad indication of surface and geophysical changes caused by the earthquake. Repeat geodetic observations at suitable interval has been planned to derive definite conclusion about the surface and sub surface movements in post earthquake scenario. This paper discusses the results obtained from various geodetic and geophysical monitoring techniques and provides the first iteration conclusions about the surface movements.

P21

Effects of Introducing Pseudolite Measurements into an Integrated GPS/INS System

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Abstract: [paper] [back to Poster Session]

This paper discusses the issue of the integration of pseudolites into a GPS/INS system with a view to improving signal availability, solution integrity, and positioning/attitude accuracy in a localized area. Even though an integrated GPS/INS system can overcome inherent shortcomings of each of the navigation technologies (line-of-sight requirement for GPS, and INS errors that grow with time), performance can nevertheless still be degraded under certain adverse operational conditions. Some typical examples are when the duration of satellite signal blockage exceeds an INS bridging level, resulting in a large accumulated INS error (that is not able to be calibrated by GPS). Such a scenario is unfortunately a common occurrence for many kinematic applications. To address such shortcomings, a GPS/pseudolite/INS integration scheme is proposed. In such an integration, the pseudolites can play different roles depending on the operational circumstances, such as the number and geometry of the visible satellites. In order to gain the maximum benefit from additional pseudolite measurements it is necessary to investigate how pseudolites can best complement an existing GPS/INS integration system. Through a series of simulations and experiments the impact on accuracy of integrating pseudolite(s) has been assessed for a variety of operational conditions and different system configurations. The results indicate that the overall performance of the system can indeed be significantly improved using additional pseudolite measurements.

P22

Precise Positioning Estimators Based on the Stochastic Analysis and Alternative Variance Covariance Matrix of GPS Observables

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Abstract: [paper] [back to Poster Session]

Traditionally, in GPS data processing the variance-covariance (v-c) matrix (as a part of the stochastic model) usually comprises only the variances of the individual carrier phase and pseudo-range observations and generally disregards any possible correlation among them, except for mathematical correlation, which results of applying differential techniques. However, for high precision (i.e. optimal GPS positioning estimators) it might be important to account for the possible correlation among the GPS observables. Two fundamental considerations are within the scope of this research. The primary one is related to the stochastic analysis of the different types of GPS observables in order to estimate and interpret the level of the measurement noise (based on single-difference residuals). For this purpose, a static survey on zero baseline was performed with six pairs of geodetic-grade GPS receivers of different type and make. Based on these data, the normalized autocorrelation, covariance and cross-covariance, power spectral density functions and histograms were thoroughly examined. The secondary consideration is related to the construction of an alternative v-c matrix, which implements the major outcomes of the stochastic analysis (covariance and cross-covariance functions), in order to test its impact in the positioning estimators (~2.2 km baseline solution) using precise static GPS positioning. The results indicate that the different types of geodetic-grade GPS receivers analyzed here, possess distinct noise characteristics (receiver specific). Furthermore, correlation exists among the different types of GPS observables and it varies between the receivers. In terms of positioning estimators, the results obtained with the alternative v-c matrix (which accounts for correlation among the observables) compare better to “true” values, as opposed to those obtained using the traditional approach (diagonal matrix). It should be point out here, that the results obtained in this case study does not necessarily apply to any survey data, and more research is needed to formulate a more generic model.

P23

Need for Integrated Approach in Monitoring of Earthquake Precursors

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Abstract: [presentation] [paper] [back to Poster Session]

Earthquake is a natural disaster, which causes irreparable loss of lives and properties and disrupts the normal functioning of civil life for a considerable period of time wherever it occurs. Although with the availability of more advanced technologies and instruments, earth scientists of various disciplines have gained considerable amount of knowledge and understandings about the earthquake mechanism but these are not yet enough to model the earthquake occurrence.

Generally, barring a few advanced countries, not enough attention is paid by the respective Governments to encourage scientific monitoring of various earthquake precursors in a systematic way. The response from Government is normally sporadic. Whenever a devastating earthquake occurs,

Government wakes up and makes some bold announcements in the direction of monitoring of precursors and mitigations of sufferings of affected people. For few subsequent months workshops/seminars/meetings on the subject continues and various promises are made but soon it becomes things of past and very little effort is made thereafter to strengthen/restructure the existing systems or to establish new organization to monitor various earthquake precursors.

Further, the information required for monitoring of these precursors are firstly, not available in one organization. Secondly, no single organization is nationally responsible and therefore has no national mandate to gather information from various organizations for the purpose of evolving a prediction model by integration of various precursors. Thirdly, various organizations normally do not want to share with the data collected by them. The result is that, even if some earth scientists, of their own interest, try to obtain data from other departments, they are generally unsuccessful.

What we need to do is to evolve a national/international system with the responsibility and mandate of obtaining the required information for modeling of earthquake occurrences by integrating various precursors. Through this paper, an effort has been made to analyze the importance of various precursors and to evolve a national strategy for monitoring them on short term and long-term basis.

P24

Regional 3-Dimensional Deformation Observed by VLBI

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Abstract: [paper] [back to Poster Session]

Accurate determination of station position and velocity vectors for the realization and maintenance of the international terrestrial reference frame (ITRF) are among one of the contributions by global VLBI stations. The baseline rate between two continental VLBI stations on the surface of Earth is caused primarily by the relative motion between two different plates, the regional deformations around the stations, the possible apparent deformations of antenna offsets, and other possible signals, such as the potential changes of the Earth's geometric figure. ITRF solutions such as ITRF96, ITRF97, ITRF2000, which are combination solutions using different space geodetic techniques could have potential "inconsistencies". At present, the estimated uncertainty for VLBI determined baseline change is approximately ±2.0 mm/yr. This study discusses results of the determination of local/regional vertical deformation rate (VDR) and horizontal deformation rate (HDR) for most of the International VLBI Service (IVS) and other VLBI stations in the world. The technique uses the baseline rates as input and determines improved deformations at a regional or local spatial scale mitigating the "inconsistency" in the global solutions. This paper will also quantify local relative deformation between two nearby VLBI stations a few hundred meters apart and will discuss preliminary results on possible geometric change of the Earth as observed by global VLBI stations.

P25

Performance Analysis of Land-Based GPS/INS/Pseudolite Integrated System

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Abstract: [paper] [back to Poster Session]

Normally, GPS/INS integrated systems can take advantage of both the high accuracy in short time and high sampling rate for INS and stable high accuracy for GPS, and then are regarded as the principal sensors to support direct platform orientation (DPO) in airborne and land-based mapping applications. However, the accuracy and reliability of such systems, especially for landed-based integrated system will be constrained by the frequent losses of GPS lock while they are operated in urban regions. In order to overcome the above limitation, ground-based satellites called pseudolite (PL for short) were introduced in this paper to strengthen the geometry of satellites in urban regions with few available GPS satellites to maintain the stable, reliable accuracy for such systems. The accuracy of GPS/INS/PL integrated systems will also be expected to be improved, especially in height component because of the low elevation angle of PLs. The concept and the model for land-based GPS/INS/PL integrated systems are addressed here, and results and performance analysis based on experimental data conducted on May 4, 2001 and simulated data are presented in this paper.

P26

A Memo on the Modeling of Baseline Length Repeatability

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Abstract: [paper] [back to Poster Session]

It is believed that the baseline length repeatability is an intrinsic measure of the quality of astrometric and geodetic VLBI global solutions since the baseline is the fundamental observable of this technique. In this memo we discuss the quadratic modeling of the baseline length repeatability and the strategy for applying the weights in solving for the model parameters. Our tests show that the weighted quadratic modeling of the baseline length repeatability is more stable and reliable than the even weights modeling.

P27

Great Lakes Continuous GPS (CGPS) Network For Geodynamics, Meteorology and Safe Navigation

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Abstract: [back to Poster Session]

A status report of the Great Lakes Continuous GPS (CGPS) Network is presented in this paper. The Network is a partnership between many national and international research and operational agencies and Universities. The Network supports research and applications such as static and kinematic GPS positioning in aerial and land-based surveys, vertical datum, Great Lakes environmental monitoring for forecasting, ground-based GPS limb-sounding and retrieval of atmospheric profiles to support meteorology research, crustal motion, intelligent transportation, safe navigation in the Great Lakes, fudicial stations for moving platforms (GPS sea-level and aircraft positioning), and radar altimeter calibration. To the extent possible, the CGPS stations are collocated with water level stations operated by agencies in U.S. (COOPS) and Canada (MEDS). The partnership agencies include National Oceanic Service's National Geodetic Survey (NGS), NGS' National CORS Program, NOAA's Center for Operational Oceanographic Products and Services, Forecasting Systems Lab., Great Lakes Environmental Research Lab., Natural Resources Canada, Marine Environmental Data Service, Canada, NSF Suominet, International GPS Service (IGS) and IGS Pilot Projects TIGA and LEO Analysis Centers, Ohio State University's Stone Laboratory and Laboratory for Space Geodesy and Remote Sensing Research.

P28

Near Real-time Kinematic Orbit Determination Using GPS

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Abstract: [back to Poster Session]

The rich observing geometry provided by GPS has been used in the past few years for determination of the trajectories of low earth orbiters (LEO) using either reduced dynamic or kinematic approaches. The rationale for kinematic approach to LEO orbit determination is the method's simplicity and short processing time, as well as the underlying fact that, particularly at lower altitudes, the actual trajectory

may be closer to the precise GPS position estimates rather than the trajectory determined by the dynamics. However, the method has also some drawbacks related to its sensitivity to weak GPS/LEO/tracking stations geometry. Namely, for the weak geometry, the orbit quality degrades and cannot be bridged by the model, as used in the reduced dynamic approach. The implementation of the dynamic method allows for using either force models with additional parameters, or replacing the non-conservative forces with the accelerometer data sensed by the onboard accelerometer, supplemented by sensor error estimates in the state vector.

In this paper we will present a geometric approach to LEO POD (precision orbit determination) based exclusively on triple differenced carrier phase observable. CHAMP (altitude ~ 450 km) mission data will be used to present the accuracy, speed and efficiency of the processing algorithms, to discuss the methods of data screening as well as to discuss the optimal station/satellite configuration and the final achievable accuracy, including the limitations and benefits of both methods. CHAMP navigation data quality will also be discussed. The triple difference approach, entirely eliminating the ambiguity resolution (which is a complicated task by itself for space applications), renders the algorithms very efficient, enabling near real-time orbit determination. This method has already demonstrated 15-20 cm RMS of fit to the dynamic CHAMP orbit.

Gravity Field and Polar Motion

[back to Table of Contents]

P29

System Dynamics of Polar Motion and Length of Day Variation

Erik W. Grafarend

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Abstract: [back to Poster Session]

The Liouville perturbation theory of the Euler angular momentum equation of the Earth considered as a deformable body leads to a first order inhomogeneous system of integro- differential equations which is classified in terms of system theory. With respect to a viscoelastic Earth model of homogeneous spherical shells the spectrum of the Liouville operator is analyzed. Following a proposal of M. Schneider (BKG Proc. 5, pp. 28-33, Frankfurt 1999) the first order system is differentiated to a second order system and alternatively classified as a second order inhomogeneous system of integro- differentiated equations. It leads to the interpretation that the characteristic equations of polar motion represent an excited, coupled, damped approximatively elliptic oscillator, while the characteristic equation of length-of-day variation documents an excited, damped non-periodic motion. Solutions are presented both in the Laplace as well as in the Fourier domain. Open problems are solution analysis in the dynamical wavelet domain and the fractal domain.

P30

A Wavelet Filterbank for High Resolution Signal Decomposition – Extraction of the Chandler Wobble

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Abstract: [back to Poster Session]

Polar motion consists of two main signal components: the Chandler wobble and the annual oscillation. In particular the Chandler wobble is characterized by a time-varying energy behavior, i.e. the amplitude and the frequency are time-dependent functions. Since wavelet analysis is an appropriate tool for the detection of signal components with time-varying amplitudes and/or frequencies, wavelet synthesis tools may be used for the extraction or filtering of a desired signal component. Furthermore, due to the fact that the Chandler period is relatively close to one year, high resolution wavelet analysis with respect to the frequency domain is required. Thus, the quasi-compactly supported complex-valued Morlet wavelet function is qualified, since it is characterized by the possibly smallest time-frequency window. Due to the fact that the Morlet wavelet is nonorthogonal, the filterbank techniques for orthogonal wavelets fail. This gave reason to create a filterbank based on the Morlet wavelet to provide both, high resolution and very effective numerical implementation. It is obvious that the wavelet transform of the filtered signal shall recover the manipulated wavelet coefficients as close as possible. Thus, the filtered signal may be determined by means of a least squares adjustment. Using the described method, signal components can be extracted from a given data set. For example, this procedure enables a Morlet wavelet based representation of the Chandler wobble derived from polar motion time series.

P31

Approaches of Estimating the Lunar Topography Models and the Correlations with the Gravity Anomalies

Jinsong Ping (1,2), K. Heki (2), K. Matsumoto (2), Y. Tamura (2), H. Araki (2), T. Sugano(2)

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Abstract: [paper] [back to Poster Session]

Different methods, where the least square fitting and others are included, have been applied and compared to estimate the lunar topographic spherical harmonic models, from the lunar topographic 0.25x0.25 (degree x degree) grid data, which had been carried out by filtering the laser altimetry measurements of the Clementine mission (http://pds-geophys.wustl.edu/pds/clementine/). The models of 150 orders and degrees are compared with the GLTM-2 model and the original grid data. The global correlation analysis is carried out between the lunar topography and the gravity, based on the obtained topography models and the lunar gravity models detected from Lunar Prospector mission. Some characteristics appear in the analyzing results. The data analysis methods developed or used in the research will benefit the research of the near future lunar mission, i.e. SELENE (SELenological and ENgineering Explorer) project.

P32

CHAMP Gravity Solutions Determined from Different Orbits

Shin-Chan Han

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Abstract: [paper] [back to Poster Session]

It has been demonstrated that the energy conservation principle can be used to determine the global gravity field in an efficient manner. It relates the kinetic energy of the satellite (from orbit data) and the dissipating energy (from accelerometer data) to the Earth's gravitational potential. The CHAMP satellite, which carries geodetic quality GPS receivers and high precision accelerometers, can be used to verify this principle and recover a new series of Earth's gravity field models. However, it is found that the gravity solution determined from the particular orbit product (for example, the dynamic orbit from GFZ) is significantly correlated with the prior gravity model (GRIM5C1, pre-CHAMP gravity model from GFZ) used to compute the orbit [Han et al., 2002]. It is necessary to determine how much CHAMP GPS satellite-to-satellite tracking data (involved in the dynamic orbit computation) and STAR accelerometer data can improve the prior gravity model. In addition, it is not known yet how much gravity solutions differ when reduced-dynamic and kinematic orbits are used. In this paper, a series of gravity solutions based on different orbit products (including dynamic, reduced-dynamic, and kinematic), which are available from the CHAMP orbit campaign, are calculated through the energy conservation principle. They will be compared with other recent gravity models and assessed with external data sets like GPS-leveling data and Arctic gravity anomaly data. Finally, the sensitivity of the gravity solutions to the types of orbit will be discussed.

P33

Defining the Vertical Datum By $W_o \equiv U_o$, Not Mean Sea Level (2^{nd} Choice)

Roger Hipkin

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Abstract: [back to Poster Session]

The mean sea surface is not level – the amplitude of sea surface topography is in the order of 2 m – and, in a century, global warming will displace it vertically by about 200 mm. Sea level rise caused solely by the thermal expansion of water would leave external equipotentials more or less unchanged. Thus 'Mean Sea Level' is in principle no longer an adequate way to define a vertical datum, or to connect datums between regions separated by the sea. I propose that the geoid be defined by $W_o \equiv U_o$. If we *adopt* a value for *a* (*a* is not an inherent property of the Earth), well-determined observed values for *GM*, and J_2 (or adopted versions of them) can be inserted into the Somigliani formula to define a value for U_o. The greatest merit of making $W_o \equiv U_o$ is that the vertical datum is now defined to be *fixed* and *exact*, making it simpler to investigate for example sea level rise. This proposal leads to many theoretical simplifications and has a long pedigree but underlines that the geoid is a conventional entity dependent on the arbitrary choice of *a*. The paper discusses how to marry this definition with practical surveying.

P34

The Geoid Edin2000 and Mean Sea Surface Topography around the British Isles

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Abstract: [back to Poster Session]

This paper describes a new rationale for computing a gravimetric geoid and reports that the resulting geoid model, EDIN2000, is now good enough to resolve previously contradictory estimates for mean sea surface topography (MSST) around Britain. For at least 30 years, it has been known that MSST derived from tide-gauges, leveling and oceanography were mutually inconsistent and differed by an order of magnitude. When combined with an altimetric mean sea surface, EDIN2000 is also able to map realistic MSST over the north-west European shelf, and identify and quantify mean currents flowing in the deep ocean parallel to the shelf edge. When compared with 11 GPS referenced tide-gauges on the British mainland our estimate of MSST has a standard deviation of only 0.03 m and its variation with latitude is not significantly different from zero. For these sites, long distance leveling errors are larger than geoid errors. We identify a systematic jump (by 0.24 ± 0.05 m) in the leveled transfer of Ordnance Datum Newlyn, affecting all sites in Great Britain to the north of latitude 53°N. Even after this correction, the variability of leveling remains larger than that of the geoid and GPS. Away from coasts we find that the best way to validate marine gravity data is their ability to predict MSST with low local variability when combined with altimetric mean sea level. There is a large reduction in MSST variability when marine gravity data are subjected to an anti-aliased adjustment of the mismatch where ship tracks cross. We also report two MSST model comparisons from a shelf seas and a deep ocean model, both of high resolution. There is quantitative and qualitative agreement between our geoid-derived MSST and the model predictions, indicating significant improvements compared with earlier geoid models. We also show that with the improved accuracy of geoid-based MSST, it will become necessary to validate models and observations at matching epochs.

P35

Absolute Gravity Epoch Measurements in the McMurdo Sound and Terra Nova Bay Region of Antarctica

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Abstract: [back to Poster Session]

In 1995, the USGS, supported by the National Science Foundation, Office of Polar Programs, and in cooperation with the Geosciences Division, National Geodetic Survey, National Oceanic and Atmospheric Administration, initiated the first in series of epoch absolute gravity measurements in the McMurdo Sound region of Antarctica using a transportable Micro-G Solutions model FG5/102 meter. A primary objective for these epoch measurements is to detect µGal level gravity changes (vertical changes of order of 6 mm). Data were successfully collected at two stations: McMurdo Station (S77E50'49", E166E40'05") and, in cooperation with the Italian Antarctica Science Program, at Terra Nova Bay (S74E41'36",

E164E05'59"). The gravity station at McMurdo is co-located with the International GPS Service station MCM4. The gravity station at Terra Nova Bay is also co-located with a permanent GPS observatory (IGS station TNB1) and tide gage. In 1997, the second in series of observations with the FG5/102 meter were conducted that included repeat occupation of the stations at McMurdo and Terra Nova Bay, and the establishment of two new stations in the South Victoria Land region of the Transantarctic Mountains. One of the new stations is located at Cape Roberts (S77E02'07", E163E10'45") and is collocated with a continually running tide gage (established in 1991), a continuously operating GPS observatory deployed on a station of the Transantarctic Mountains Deformation Monitoring Network (TAMDEF), and a broadband seismic station of the Transantarctic Mountains Seismic Experiment (TAMSEIS). This paper summarizes the analysis of the 1995 and 1997 data sets, the consistency of the results, comparisons with relative gravity values transferred to McMurdo as part of the International Gravity Standardization Net (IGSN71), and comparison with absolute gravity values obtained with an earlier model meter at Terra Nova Bay in 1992. The estimated accuracies for the FG5 absolute gravity measurements are of order "2 μGal. Planning is underway to continue the series of epoch measurements using the new portable low power absolute gravimeter, model A-10, built by Micro-g Solutions, on an expanded network of stations in McMurdo Sound and Victoria Land region.

P36

Helmert Condensation Method and the Geoid

Juan Gilberto Serpas

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Abstract: [paper] [back to Poster Session]

The solution of the geodetic boundary value problem for geoid determination requires gravity anomalies referred to the geoid. Actual measurements are carried out at terrain level and a reduction scheme has to be adopted to comply with this condition. The most popular technique is the use of the Helmert condensation method, which consists of the mathematical removal of the masses above the geoid and the restoration as a thin surface layer. Two different ways to apply this reduction are studied. The classical approach (Wang and Rapp, 1990, Heiskanen and Moritz, 1987), and the one by Vaniĉek and Kleusberg (1987), extended by Martinec et al (1993).

The classical approach (Wang and Rapp, 1990, Heiskenen and Moritz, 1987) argues that the effect of the condensed layer has to be evaluated at geoid level and not at the terrain level as stated by Vaniĉek and Kleusberg, 1987. Martinec et al., 1993 stated that there is no way to decide which of the above described solutions is correct "since for different reasons both approaches are only approximate". According to Heck (1993), the Vaniĉek and Martinec approach is more correct from the theoretical point of view, but other authors think it is less useful in practical applications (Forsberg, 1994). Martinec et al (1993) included the downward continuation of gravity anomalies to the geoid, and argue that the Wang and Rapp approach was the Vaniĉek and Kleusberg approach plus downward continuation under the assumption of linear relationship between the gravity anomalies and the topography. Jekeli and Serpas (2002) showed that both methods are correct from the theoretical point of view, and the difference is in the order of the remove, restore and downward continuation procedure and that the Wang and Rapp approach does not rely on a linear relationship between gravity anomalies and topography. Martinec and Vaniĉek (1994), Nadvandchi (2001), Jekeli and Serpas (2002) have developed different solutions where spherical approximations are included.

The computation of the geoid is analyzed under the two mentioned approaches and the results are compared to geoid undulations coming from GPS and orthometric heights in the USA Rocky Mountains. Numerical assessment of the different approaches shows that both yield similar results in relatively flat areas, and that the classical approach provides better results in mountainous areas with rough topography.

P37

Great Lakes Gravity Field Improvement Using Satellite Altimetry

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Abstract: [back to Poster Session]

The Great Lakes represent an invaluable resource for fresh water supply, fishery, navigation and recreational purposes. The determination and maintenance of the vertical datum in the Great Lakes, which are associated with the gravity field, are of significant practical importance. One existing model of the global gravity field, EGM96, and a detailed geoid model, NGS Geoid99 model, have known differences of meter level and tilts (in Lake Superior). In this paper, we discuss results of the determination of gravity field (gravity anomalies) in the Great Lakes using satellite altimeter data including TOPEX/POSEIDON and GEOSAT Geodetic Mission (GM). Although the Lake surface is not the geoid surface, it mimics one of the level surfaces of the geopotential if the Lake variability could be accounted for. In our technique, the seasonal change of lake level is assumed observable in TOPEX/POSEIDON satellite altimeter data. To remove this change from GEOSAT Geodetic Mission (GM) altimeter data on non-repeating tracks, along-track slope of lake surface height was used in the determination of gravity anomalies. The along-track distance and the lake surface height of GEOSAT GM data were used to calculate the along-track slope of lake surface height and azimuth of ground tracks. Procedures for computing gravity anomalies from altimeter-derived along-track sea surface slopes and azimuth along with mean lake surface height data using a least-squares collocation procedure are described. These results are compared to other models and in situ data available in the Great Lakes.

P38

Ross Sea Ocean Tide Modeling Using Radar Altimeter and SAR Interfeormetry

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Abstract: [back to Poster Session]

Ocean tides play a significant role in the complex interactions between the atmospheres; ocean, sea ice and floating glacial ice shelves. Tidal currents create turbulent mixing at the bottom of the ice shelf contributing to the creation of rifts for the possible detachment of part of the ice bergs and can influence heat transport between the ice shelf and sea water [Robertson et al., 1998]. Tides near and under floating ice shelves and sea ice, and depending on surface and basal slopes, grounding line migrates with time within a grounding zone [Rignot, 1998; Metzig et al., 2000]. Improved knowledge of the grounding line is inherently necessary to study ice mass balance and its contribution to the global sea level change. Predictability of barotropic ocean tides is significantly less accurate in the coastal regions, littoral and shallow seas, and oceans not covered by TOPEX/POSEIDON, than in the deep ocean (>1000 m depth) and within $\pm 66^0$ latitude. Even with the availability of most recent suite of global tide models based primarily on TOPEX/POSEIDON data, e.g., GOT00, NAO99, Delft, FES00, extreme southern ocean tides (-60^0 latitude South pole-ward) are limited both in accuracy and resolutions, especially in regions near Antarctica, seasonally or permanently sea-ice-covered oceans. In our initial study with the objectives to improve tides in Antarctica oceans for accurate prediction of ground-line locations to enhance ice mass balance studies, we

provide an assessment of accuracy of tide models in the region. In addition to global models, regional models such as the Padman model (includes Weddell Sea and Ross Sea) are currently available. A test model (-50^0 latitude South pole-ward) using available over-ocean and over sea ice and ice-shelf data from T/P, ERS-1/2, and GFO, will be presented. InSAR tidal deformation analysis using ERS-1/-2 tandem missions over Ross Sea and in a test region over the Sulzberger Ice Shelf, Ross Sea (-77.5^0 latitude, 150^0 East Longitude) will be presented.

P39

Crustal Analysis of the Moon, Mars and Venus from Satellite Free-Air Gravity and Terrain Data

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Abstract: [back to Poster Session]

We quantitatively modeled the crustal attributes of the Moon, Mars, and Venus from available gravity and topography observations. The correlation spectrum between gravity effects of the terrain and free-air gravity anomalies was used to separate at satellite altitude the terrain-correlated and terrain-decorrelated components of the free-air gravity anomalies. Subtracting the terrain-correlated free-air gravity anomalies from the terrain gravity effects yielded compensated terrain effects that were interpreted for Moho undulations and crustal thickness variations. The terrain-decorrelated anomalies were differentiated further into crustal and subcrustal components on the basis of their correlation spectrum with the free-air anomalies. Terrain-decorrelated crustal maxima over central basins predicted fill thicknesses ranging from several hundred meters to a few kilometers. Terrain-correlated free-air anomaly components were also investigated for uncompensated mass variations of the crust.

The crustal attributes of lunar multi-ring basins show a strength dichotomy. The far side crust appears to be significantly more rigid than the nearside crust reflecting a higher thermal gradient due to enhanced abundances of radioactive elements in the nearside mantle and crust. Transient cavity diameters of Martian multi-ring basins exhibit growth with crustal ages and an inverse association with crustal thickness suggesting increase viscosity due to crustal cooling. For Venus, contrasting models for the evolution of the annuli of coronae, lowlands, and highlands include crustal subduction, extension, and other tectonic sources of uncompensated lithospheric mass.

P40

Fitting Variogram Models by Total Least-Squares

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Abstract: [back to Poster Session]

Total Least-Squares (TLS) is a method to estimate parameters in Linear Models that include random errors in all their variables. This method is here used to fit nonlinear mathematical semi-variogram models to their empirical values. Although a few other methods have been widely applied, the TLS method seems particularly suited in this case since it treats the lag distance and the empirical semi-variogram values symmetrically under the assumption of random errors in both variables. Proper measures for the estimation accuracy are developed, with special emphasis on the crucial behavior near the origin. Based on this technique, the semi-variogram of aeromagnetic data is computed, and a comparative analysis with respect to accuracy and computational efficiency is provided.

[back to Table of Contents]

OTHER SUBMITTED ABSTRACTS

Slepian and Other Bases for Harmonics Functions in Spherical Domains

Alberta Albertella, and Fernando Sanso

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Abstract:

Base functions in L^2 on the sphere can be used to solve Boundary Value Problems for spherical domains. When such functions have an easy harmonic continuation in the outer domain then they are particularly useful for the above purpose, because of Cimmino's theorems. This happens in particular for spherical harmonics which are well known to be an ortho-normal complete set in L^2. The classical proof of this fact relies on the spectral theory of bounded L^2-operators, however a different proof, based only on Gauss theorem combined with finite dimensional considerations, is given in the appendix. The transition from harmonic functions to other different bases, more useful when specific problems are treated, can be conveniently accomplished, when finite dimensional algorithms can be applied. As such we mention purely Fourier bases, Slepian functions and wavelets.

Testing RTK GPS System in Urban Areas

E. Ata, and A. Pirti

Yildiz Technical University, Department of Geodesy and Photogrammetry, Be¸ikta¸, Istanbul, Turkey

Abstract:

RTK GPS is provided with cm accuracy and real time surveying system. For providing this conditions, the reference is necessary for high accuracy position. Because this station is transmitted the corrections to the other receivers. At the some time this system is required common satellites on the receiver to compute integer ambiguity solution. In addition to the conditions, the data transmission device’s range is very important.

Although RTK GPS technique has a lot of advantages, many problems meet in practice. One of the most important problem in RTK system, which is very useful and reliable in the rural areas, uses in the urban areas.

We search this article, how influence RTK GPS applications on satellite numbers, multipath, data transmission device’s range capability and etc. in the urban areas.

Testing the Accuracy of the Reference Points

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Abstract:

We will study large scale GPS network in order to use RTK GPS reference points. Firstly we will process our GPS network with Ashtech - Winprism software package. Then we will analyze reliability of our solution with academical software package Bernesse 4.2 V. We will investigate the results of solutions for the discrepancies.

We will address the cause of discrepancies for several aspects. We will take a look at atmospheric affects on our measurements and processing scheme.

Applications of Stereo and Interferometric SAR Techniques

John C. Curlander

President and CEO, Vexcel Corporation

Abstract:

Mapping with synthetic aperture radar has advanced significantly in recent years with the development of interferometric SAR techniques. For spaceborne systems, repeat-pass interferometry is required since the operational systems only have a single antenna. As a result, application of this technique is limited to areas with low vegetation due to surface changes (such as vegetation growth) between passes. In addition, differences in atmospheric water vapor between passes will cause errors in the elevation models. This paper will discuss the value of adding stereo to interferometry to improve the overall estimate of surface elevation. In addition it will present another important applications of spaceborne interferometry in surface change detection. Results will be shown from Radarsat and ERS sensor. The importance of the two antenna spaceborne mapping system SRTM will also be discussed as it applies to current and future map products.

20th Century Global Sea Level Rise

Bruce C. Douglas

International Hurricane Center, Florida International University

Abstract:

Although the *long-term* average global sea level rise (GSL) for the last few millennia has been stable at a level near zero, there is reliable evidence from coastal land records, lake and river ice cover, and water level measurements that GSL abruptly began to rise at the modern rate near the middle of the 19th century, but without evidence of acceleration during the 20th century. Actual numerical values of 20th century GSL rise published in the last dozen years range from 1 – 2.4 mm per year, despite all investigators having employed essentially the same data base of tide gauge measurements maintained by the Permanent Service for Mean Sea Level in the UK. This lack of consensus is much discussed in the Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC), and the document is careful not to present a "best estimate" of 20th century GSL rise. The IPCC report, by design, presents a snapshot of published analyses over the previous decade or so, and interprets this broad range of estimates as suggesting the uncertainty of our knowledge of GSL rise. I shall argue in this presentation that values much below 2 mm per year are inconsistent with regional observations of sea level rise and the continuing physical response of the earth to the most recent episode of deglaciation. This is not a trivial issue for climate science; if the correct value of GSL rise is really near 1 mm per year, thermal expansion of the oceans and melting of small ice sheets and mountain glaciers due to the 0.6 deg C increase in global surface temperature during the last 100 years provide an appealingly simple explanation. This explanation would further imply that melting of the great Greenland and Antarctic ice sheets is not contributing now to sea level rise. But if the true rate of contemporary GSL rise is nearer 2 mm per year, the situation is more complex, and current climate model analyses will need refinement. The rate of GSL rise provides an important constraint on models of the global hydrologic cycle, and there is a significant possibility that the projections of 21st century GSL rise provided in the IPCC TAR are too low.

Using RTK GPS and Total Station System in Polygon Line

A. Pirti, and E. Ata

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Abstract:

Until firstly GPS is one of the new useful methods RTK GPS is enlarged the GPS techniques. RTK GPS is provided with cm accuracy and real ñ time surveying system. The reference station coordinates are necessary for very robust and suitable for topographic condition.

Testing RTK GPS system survey polygon points. The classical surveying methods will perform the definite range and takes a long time. RTK GPS System is very fast and gains subcentimeter accuracy. Testing accuracy which get in the surveying polygon points by RTK GPS System. The coordinates in RTK GPS System compare with coordinates of the classical system.

Staking Out (The ITRF System) By Using RTK GPS

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Abstract:

In the field of RTK GPS we have seen great technological advances for the past few years and it is now used in wide ranges of engineering applications for precise positioning such as survey applications.

I will stake out (ITRF System) 25 points in the project area by two reference stations. I will test the staking out, particularly position (X, Y) and orthometric heights (H) by considering sea level factor using two reference stations (repetitively). For the applications we benefit from the guidelines on standards and specifications for GPS surveys and ground surveys of Wisconsin Department of Transportation (USA).

The results of survey are evaluated and tested. Whether the advantages of the ITRF staking out is available or not.

Height Accuracy of RTK GPS System and Proposals

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Abstract:

Even GPS system in long term observations has problems in height surveying. The factors having influence on the work of this system and obtaining height data is present (Number of satellites, Multipath, etc.).

We researched in this study, height having the influence on changing the satellite numbers, whether this effects are modeled or not. For this study, we select the project area, and then GPS network is established, the reference stations are performed level surveying, and then determine the distinct height. All points are surveyed the reference stations by using RTK GPS System. The results obtaining all surveys are evaluated and tested.

Testing the RTK System in High Voltage Line

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Abstract:

RTK GPS is an accurate and efficient method of conducting surveys topographic data collection for establishing control, however RTK has some apparent disadvantages over the definite areas. One of these areas is high voltage line.

The aim of this paper will demonstrate how the high voltage line has influence on RTK Survey Technick. (I will perform this points static GPS surveying). The results indicate that high voltage line how influence on RTK system accuracies and the other components.

How Steep is the Gravity Wall?

Reiner Rummel, Thomas Gruber

Institute for Astronomical and Physical Geodesy, Technical University Munich

Abstract:

In 1969, under the leadership of William M. Kaula, the Williamstown-Report pointed out the need in Earth sciences and oceanography of a much more detailed knowledge of the Earth's gravity field. Satellite-to-satellite tracking and satellite gradiometry were recommended as technical solutions. Naturally, it is by definition a great challenge to derive a detailed gravity field from measurements at altitude. In the three decades that followed various concepts were studied in a variety of modifications, both by NASA and ESA, the scientific rationale became more and more refined, the mission baselines more and more realistic. With CHAMP, GRACE and GOCE much more accurate, detailed and homogeneous measurements will finally become available. Thus it is the right time to address the question of weather these three missions will meet all our needs and, if not, of weather how further improvement would be possible.

Semi-Automatic Extraction Buildings with Analyze MNE

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Abstract:

The first photogrammetric plotters was analogic plotters, that request much time for execution of photogrammetric tasks, been have as problem the high cost, the error introduction accuse by tasks repeat of operators and by optic and mechanic components, and a fall of automatics process. With the advent and popularization of computers, born the Digital Photogrammetric Systems, that return possible automation of many tasks, as the interior and relative orientation, generation of DTM (Model Terrain Digital) and generation of digital ortophoto, however the stage that need more time of operators and that, is

more cost, isn't automatize. Feature extraction is the more time consuming photogrammetric task, and it is not fully automatic. Semi-automatic feature extraction has been considered as a tool that could increase the efficiency of photogrammetric restitution. Buildings are features that represent 50% of total of features that should be extracted in cadastral projects. There are several stages that can be performed for feature extraction. An example of such process is: smoothing; edge detection; thresholding; thinning; linking; adjustment of straight lines; and polygon closing. The process of feature extraction is a complex task, due to different types of structures and shapes of buildings, effect of shadows, relief displacement and others factors. The aim of this work is to implement a tool that reduces the effort of photogrammetric operators in feature extraction. An ideal solution should be collect just one seed point (by the operator), and to use an automatic pipeline of building extraction, using the DEM (Digital Elevation Model) as a additional level to remove lines in the process. The obtained results show that the number of selected points is reduced, mainly in isolated buildings, but there is a need to improved the process with better building modeling.

On the Application of the Variational Principle to Geodetic Boundary Value Problems

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Abstract:

The variational principle is applied to a generalized geodetic boundary value (GBV) problem. The gravity field is represented by a solution that has continuous first order derivatives and piecewise continuous second order derivatives. This solution has the following advantages:

Different data types, such as surface gravity data, satellite altimeter data and airborne gravity data, can be used in a high-resolution solution.

The disturbing potential and its derivatives (e.g., gravity anomalies, and deflections of vertical) in the near space on and above the Earth's surface can be computed from the solution. The associated accuracy can also be obtained from the accuracy estimate of the solution by using the law of error propagation.

After simplification, the solution is easy for numerical realization. The solution can be computed locally, hence the computational effort is minimal.

The drawback of this method is that there is no global spectral analysis. This drawback can be mended by computing the gravity anomaly in a regular grid and performing the spectral analysis in a separate step.

Author List [back to Table of Contents]