The least squares method for fitting the Doppler residuals does not fix this ratio, but allows J_2 and C_{22} to vary independently and determines the correlation between them. The *a priori* assumption is consistent with the hydrostatic equilibrium of a satellite, but it does not require hydrostaticity. Values of μ show that J_2 and C_{22} are independently determined only for Io; the ratio of J_2 and C_{22} is consistent with a hydrostatic Io. J_2 and C_{22} are not independently determined for Ganymede even though there are both equatorial and polar flybys of the satellite. A quadrupole field is insufficient to fit the Ganymede data to the noise level. The additional signal is interpreted in terms of mascon anomalies at the surface of Ganymede. The gravitational coefficients, together with the assumption that the degree 2 gravitational fields of the satellites derive from their hydrostatic distortions to rotation and the Jovian tidal force, are used to infer the moments of inertia of the satellites and their internal structures. The mass and closest approach distance for Amalthea can be determined from Doppler data from the Galileo encounter of 5 November 2002. The final results indicate a density that is significantly smaller than the approximate 1000 kg m^{-3} density of water ice. The quadrupole components of Amalthea's gravitational field are undetectable in the encounter Doppler data.

G42C-02 1615h

Lunar Rotation, Orientation and Tides

James G. Williams[1] (818 354-6466; James.G.Williams@jpl.nasa.gov)

J. Todd Ratcliff[1] (818 354-0204; J.Todd.Ratcliff@jpl.nasa.gov)

Dale H. Boggs[1] (818 354-1630; Dale.H.Boggs@jpl.nasa.gov)

Jean O. Dickey[1] (818 354-3235; Jean.O.Dickey@jpl.nasa.gov)

[1]Jet Propulsion Laboratory, California Institute of Technology, MS 238-332, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

Many satellites exhibit synchronous rotation. The Moon is the most familiar example. For the Moon there is a) Lunar Laser Ranging measurements of tides and three-dimensional rotation variations and b) supporting theoretical understanding of both effects. The lunar rotational variations are up to 1 km while tidal variations are about 0.1 m, so the former effect has been more useful. Analysis of the lunar variations in pole direction and rotation about the pole gives moments of inertia, gravity harmonics, tidal Love number k_2, tidal dissipation (Q), and evidence for a liquid core. The experience with the Moon is a starting point for exploring the tides, rotation and orientation of the other synchronous bodies of the solar system.

G42C-03 1630h INVITED

Mercury's Interior From Geodesy of Librations

Stanton J. Peale (805 893 2977; peale@io.physics.ucsb.edu)

UCSB, Dept. of Physics, Santa Barbara, CA 93106, United States

Mercury offers a unique opportunity to use the equilibrium rotation state and librations about this state to investigate properties of its interior. In equilibrium, Mercury rotates at a uniform rate $\dot{\psi} = 3n/2$ (n = orbital mean motion) in a Cassini state with the spin axis displaced slightly from the orbit normal (obliquity near 1.6 arcmin), which displacement is induced by the precession of the orbit on the Laplacian plane. The spin axis, orbit normal, and normal to the Laplacian plane remain coplanar while the former two precess about the latter with the period of the orbital precession. If displaced slightly from this state, Mercury's spin will exhibit a free precession about the state with period near 1300 years and a free libration in longitude with period near 12 years. Tidal dissipation will damp both free precession and libration on time scales << the solar system age, so we expect to find Mercury very close to its equilibrium Cassini state where it remains during slow orbital variations because of an adiabatic invariant. The gravitational torque on the axial asymmetry is the restoring torque for the free librations when averaged over the orbit. This same torque causes a small forced libration in longitude (amplitude 20 to 40 arcsec) with an 88 day period due to the torque's periodic reversal around the orbit . It is desirable to determine Mercury's obliquity θ and the amplitude of its forced libration in longitude ϕ to very high accuracy, because their determination along with accurate values of the gravitational harmonic coefficients C_{20} and C_{22} can reveal whether or not Mercury's core is molten by determining the ratio C_m/C. C_m and C are the maximum principal moments of inertia for the mantle and entire planet respectively, where both moments of inertia are determined independently. This assertion relies on the axial asymmetry being due to the mantle alone, where the 88 day forced libration in longitude will have twice the amplitude if the mantle is decoupled from the interior by a molten layer than it would have if the planet is a rigid body. The precise measurements necessitated by the small values of both the obliquity and the forced libration amplitude as well as similarly precise determination of C_{20} and C_{22} will be possible from either of two spacecraft, MESSENGER from the U.S. and BepiColombo from Europe, which will orbit Mercury during the next decade. More astounding, a radar technique called Radar Speckle Differential Interferometry (RSDI) (Holin, 1992) is capable of arcsec accuracy in determining both the obliquity and the forced libration amplitude from the ground, where feasibility has been demonstrated (Margot *et al.* 2002). The RSDI and spacecraft techniques will be described. Assumptions necessary for success of the experiment will be detailed, and recent numerical calculations of Mercury's spin evolution will be discussed. Some caveats will be pointed out, but as the assumptions are likely to be satisfied, there is a high probability that precise geodesy will yield the desired information about Mercury's interior.

G42C-04 1645h INVITED

Constraints on Mars Interior from k2 Love number, Moment of Inertia and Crustal Thickness

Charles F Yoder[1] (310-589-2683; charles.f.yoder@jpl.nasa.gov)

Alex Konopliv[1] (Alex.konopliv@jpl.nasa.gov)

William M Folkner[1] (William.M.Folkner@jpl.nasa.gov)

[1]Jet Propulsion Lab, CalTech, 4800 Oak Grove Drive, Pasadena, CA 91109

The solar tide of Mars, measured by its potential Love number k2 (=0.153+-0.015) has been obtained from analysis of MGS radio tracking through June 2003. Atmospheric tides and inelasticity contribute to the observed signal, and we estimate that the elastic' component is k2=0.145+-0.0015. This parameter is sensitive to core size and mantle rigidity profile and indirectly on mantle composition and thermal profile. Similarly, the moment of inertia C (=0.3650+-0.0012) has been deduced from the secular precession of Mars pole of rotation, where Pathfinder and Viking tracking data are the primary data constraints. Moment of inertia is sensitive to thickness and density of the primary units: crust, mantle and core. Correlation of Mars nonspherical gravity field (primarily contrained by MGS tracking) and surface topography (fixed by MOLA data) promises to limit the thickness and density of the crustal unit overlying the mantle, with theoretical thickness estimates ranging from 50 to 100km , although any given model estimate typically limits thickness to +-10km. We shall discuss the reliability of the estimated parameters. The details related to constructing interior models (composition, density, thickness of units), from which theoretical estimates of moment and Love number are derived, also shall be discussed.

G42C-05 1700h INVITED

Estimation of Seasonally-varying CO_2 Ice Mass and Mean Atmospheric Pressure on Mars from Temporal Changes in the Gravitational Field

Maria T Zuber (617-253-6397; zuber@mit.edu)

Department of Earth, Atmospheric and Planetary Sciences, 54-518 Massachusetts Institute of Technology, Cambridge, MA 02139-4307, United States

The seasonal exchange of CO_2 between the atmosphere and cryosphere of Mars modifies the planetary mass distribution and results in small changes in the long-wavelength gravitational field. Over the course of the Martian year ∼18% of the total volatile mass will be exchanged between the atmosphere and the surface, resulting in a re-distribution of $\sim 1 \times 10^{-8}$ of the total mass of Mars. Changes in the Martian long-wavelength gravity field have been detected from orbiting spacecraft and the challenge is to relate these variations to the CO_2 cycle. In the current study we develop an analytical approach to relate gravity field changes to seasonal variations in CO_2 ice mass and to the global mean atmospheric surface pressure. We have also performed a direct recovery of temporally-varying cryospheric mass and demonstrate an equivalence to the recovery using low-degree gravity coefficients. In addition, we have estimated gravity anomalies over the poles, as yet another representation of the same phenomenon. We compare our estimates with Viking lander pressure measurements and with predictions from a General Circulation Model (GCM) simulation for a typical Mars year. This combined theoretical and observational approach provides a means of estimating the global-scale volatile mass exchange and global mean pressure on Mars on a routine basis from precise tracking of orbital spacecraft.

G42C-06 1715h

Simulation Of The Effect Of Higher Order Zonal Gravity Field Coefficients Of Mars On Jointly-Estimated Time-Varying J2, J3 And Rotation.

Julien Duron[1] (Julien.duron@oma.be)

Ozgur Karatekin[1] (Ozgur.karatekin@oma.be)

Pascal Rosenblatt[1] (Pascal.Rosenblatt@oma.be)

Veronique Dehant[1] (Veronique.dehant@oma.be)

Jean-Pierre Barriot[2] (Jean-Pierre.Barriot@cnes.fr)

[1]Royal Observatory of Belgium, 3, Avenue Circulaire, Brussels 1180, Belgium

[2]Midi-Pyrenees Observatory, 14 avenue Edouard Belin, Toulouse 31400, France

Largest seasonal variations in the gravity field of Mars occur for the J2 and J3 coefficients. These coefficients were estimated recently from MGS data. It is believed that these estimates contain also additional information from the higher order coefficients. In the present study, we investigate the effect of higher order zonal gravity field coefficients on the estimation of the time-varying J2 and J3. Numerical simulations with an orbit determination computer program (GINS, provided by GRGS/CNES) are performed. Seasonal variations in the gravity field coefficients are given as input with the help of the Global Circulation Model of LMD. We study the ability to recover these values from simulated tracking data between an orbiter and the Earth. Additional radio links between the orbiter and lander(s) on the surface are also used in order to accurately constrain rotation variations.

G42C-07 1730h

Mars Polar motion excitation.

Veronique M. Dehant[1] (3223730266; v.dehant@oma.be)

Ozgur Karatekin[1] (3223736732; karatekin@oma.be)

Olivier de Viron[1] (3223730312; deviron@oma.be)

Tim van Hoolst[1] (32237302668; vanhoolst@oma.be)

[1]Royal Observatory of Belgium, 3 avenue Circulaire, Brussels B1180, Belgium

The planet Mars is ellipsoidal and has most probably a liquid outer core. The existence of a solid inner part in the core is questionable. We compute the atmospheric excitation of the Chandler Wobble and of the possible Inner Core Wobble. The atmosphere and ice caps of Mars excite these free modes. We examine whether they are excited to an observable level in future geodetic measurements of polar motion. We have developed a theoretical approach to compute polar motion in response to the excitation of atmosphere and polar caps calculated from the output of a global circulation model.

G51A MCC: 2010 Friday 0800h

Advancing the Cutting Edge of Geodesy I: Positioning

Presiding: **Y Bock,** Scripps Institution of Oceanography**; K Larson,** University of Colorado at Boulder

G51A-01 0805h INVITED

High-Rate GPS Applications for Seismology: What Next?

Kristine M. Larson (303 492-6583; kristine.larson@colorado.edu)

Department of Aerospace Engineering Sciences, UCB 429 University of Colorado, Boulder, CO 80309, United States

It has been demonstrated that high-rate GPS provides useful measurements of seismic waves in cases where seismic instrumentation clips. But many important questions remain to be answered. In the absense of clipping, are there any specific scientific questions that can be answered with high-rate GPS data but not with seismometers or strainmeters? At what rate should we operate GPS receivers ? What are the cost-benefit trade-offs ? Should we concentrate on real-time or post-processed high-rate GPS solutions? Examples from analysis of high-rate GPS data will be shown and discussed.

G51A-02 0825h

Measuring Seismic Surface Waves with 1-Hz GPS

Andria Bilich[1] (303-492-3489; andria.bilich@colorado.edu)

Kristine Larson[1] (303-492-6583; kristine.larson@colorado.edu)

Herb Dragert[2] (250-363-6447; dragert@pgc.nrcan.gc.ca)

Paul Bodin[3] (901-678-4845; bodin@ceri.memphis.edu)

Joan Gomberg[4] (901-678-4858; gomberg@usgs.gov)

[1]Department of Aerospace Engineering Sciences, University of Colorado at Boulder, UCB 429, Boulder, CO 80309-0429, United States

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

[3]Department of Earth Sciences, Center for Earthquake Research and Information, University of Memphis, Memphis, TN 38152, United States

[4]United States Geological Survey, 3876 Central Ave., Ste. 2, Memphis, TN 38152-3050, United States

Large earthquakes can cause seismological instrumentation to saturate or 'clip', even hundreds to thousands of kilometers away from the epicenter. In cases where seismological instruments fail to record ground motion, high-rate GPS data can serve as a replacement for these missing seismic data. We present an analysis of 1-Hz GPS data collected after the 2002 November 3 M7.9 Denali Fault earthquake. A significant number of seismic instruments clipped during this earthquake. An initial analysis demonstrated that surface waves could be observed on 1-Hz GPS instruments as far away as Colorado Springs, CO. In this study we add data from over 20 GPS receivers recording at 1-Hz in Canada and the western United States. Horizontal displacements exceeded 30 cm at some of these sites. We also investigate techniques for reducing GPS-specific errors. If available, 1-Hz GPS data collected in days before and after the earthquake are used to estimate and remove GPS errors, significantly improving 1-Hz GPS precision. Also, the impact of receiver mixing and ambiguity resolution performance is assessed.

G51A-03 0840h

Gps Real Time Monitoring of Active Volcanoes: Experience During the 2002-2003 Eruption of Stromboli (Aeolian Islands, Italy) and Data From Etna Network.

Mario Mattia[1] (0039957165805; mattia@ct.ingv.it)

Massimo Rossi[1] (00397165840; rossi@ct.ingv.it)

[1]Istituto Nazionale di Geofisica e Vulcanologia, Piazza Roma 2, catania 95123, Italy

In this work we present the data from the real time GPS network "SciaraDat", installed after a tsunami wave-creating flank collapse on the western slope of Stromboli volcano. The utility of this monitoring tool is demonstrated with emphasis on the clear relationship between GPS data and volcanological phenomena. Moreover, data from the 2001 Etna eruption, post-processed with the epoch-by-epoch algorithm, demonstrate the importance of the instantaneous positioning approach for both scientific and civil defence communities related to the potential danger of a volcanic eruptions.

G51A-04 0855h

Real-Time High-Rate Upgrades of SCIGN Sites

Yehuda Bock (8585345292; ybock@ucsd.edu)

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

We are in the process of upgrading sites of the Southern California Integrated GPS Network (SCIGN) to real-time (1 sec latency), high-rate (1 Hz) operations, and have completed the upgrades for more than 25 sites. The normal operation for most of the network includes 30-second sampling with data downloads every 24 hours. The purpose of the upgrades is twofold: (1) to provide data rates useful for measuring strong ground motions to complement traditional seismic instruments in the event of a medium to large earthquake and data latencies useful for seismic response, risk mitigation, and rapid earthquake model determinations based on coseismic displacements; (2) to provide real-time access to high-rate data to surveyors, GIS professionals, structural engineers, transportation engineers and others requiring access to precise positioning and navigation information, under the umbrella of the California Spatial Reference Center (CSRC). We report on the status of upgrades in three sub-networks, each with a distinct focus: (1) the Orange County Real Time Network in collaboration with the County of Orange Public Facilities and Resources Division, (2) the Parkfield region in collaboration with the USGS and UC Berkeley's NCEDC and (3) the Riverside County Real Time Network in collaboration with the Riverside County's Department of Transportation and Flood Control and Water Conservation District. In the latter sub-network, we are developing a real-time displacement meter that will integrate broadband seismic and GPS measurements. We highlight achievements and lessons learned from these upgrades and assess whether it is feasible and desirable for the Earthscope project to pursue a similar approach.

G51A-05 0910h

Streaming GNSS Data over the Internet: The EUREF-IP Ntrip Broadcaster

Denise Dettmering[1] (+49-696333253; denise.dettmering@bkg.bund.de)

Georg Weber[1] (+49-696333391; georg.weber@bkg.bund.de)

[1]Federal Agency for Cartography and Geodesy, Richard-Strauss-Allee 11, Frankfurt 60598, Germany

The global Internet can be used for the real-time collection and exchange of GNSS data, as well as for broadcasting derived differential products. The EUREF community decided in June 2002 to set up and maintain a real-time GNSS infrastructure on the Internet using stations of its European GPS/GLONASS Permanent Network EPN. A pilot project was established called EUREF-IP (IP for Internet Protocol). This real-time GNSS data service uses a new dissemination technique called "Networked Transport of RTCM via Internet Protocol" (Ntrip). Ntrip stands for an HTTP application-level protocol streaming GNSS data over the Internet. Currently about 110 data streams are available through EUREF-IP Ntrip Internet Broadcaster. This paper introduces the EUREF-IP Ntrip Broadcaster with its available real-time data streams from different networks. It focuses on positioning accuracy as well as on data latency, monitoring aspects and standardization.

G51A-06 0925h

GFZ HR/LL GPS Ground station networks and their use

Christoph Reigber[1] (+49 331 288 1100; reigber@gfz-potsdam.de)

Roman Galas[1] (galas@gfz-potsdam.de)

Wolfgang Koehler[1] (wolfk@gfz-potsdam.de)

Matthias Forberg[1] (forberg@gfz-potsdam.de)

Markus Ramatschi[1] (maram@gfz-potsdam.de)

[1]GeoForschungsZentrum Potsdam (GFZ), Department 1 "Geodesy & Remote Sensing", Telegrafenberg A17, Potsdam 14473, Germany

The contribution presents GFZ's global and local High-Rate and Low-Latency GPS networks. The global HR/LL network was established, in collaboration with JPL, to support the CHAMP and GRACE POD activities and the radio occultation experiment on both missions. The GFZ sub-network is composed of 13 continuously tracking stations, generating 15-min 1 Hz GPS data files and transmitting them to GFZ every 15 minutes. Eight stations contribute to the Galileo mission preparations. Since early 2003 eight HR sites are streaming GPS data in real time. Three of them take part in the IGS Real-Time Prototype Network. GPS HR/LL network for deformation monitoring is an example of local HR/LL GPS array. This 1 Hz network was installed on Popocapetel volcano end of 1999. For the calibration of satellite altimetry, an autonomous 10 Hz GPS-Buoy was developed by GFZ and is operating in the North Sea. The presentation describes shortly the three systems and discusses issues such as: data performance, real-time data aspects and quality monitoring. Application results from ultra-rapid CHAMP/GRACE orbit processing, radio-occultation routine processing, buoy monitoring and volcano monitoring in geodesy, geophysics and meteorology will be presented.

G51A-07 0940h

Utilizing Site-Specific Antenna Phase Center Calibration Maps for Reducing the Noise in the GPS Vertical

Daniel M Morken[1] (303-492-1142; Morken@Colorado.EDU)

Bruce J Haines[2] (818-354-0686; BJH@Cobra.JPL.NASA.GOV)

R Steven Nerem[1] (303-492-6721; Nerem@Colorado.EDU)

[1]Colorado Center for Astrodynamics Research, University of Colorado at Boulder, Campus Box 431, Boulder, CO 80309, United States

[2]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

The Global Positioning System has emerged as a leading tool in the field of geodesy. GPS observations have been shown to be a useful geodetic tool for such applications as monitoring post-glacial rebound and calibrating satellite altimeters to study sea level change. We have been analyzing data from 40 GPS sites near tide gauges for the purpose of developing vertical crustal motion estimates, which are subsequently used in the calibration of satellite altimeter measurements. However, site-specific errors such as multipath have limited the positioning accuracy, especially in the vertical. To combat these site-specific errors, antenna phase center calibration maps were developed by averaging the residuals over the time series of each point-positioned GPS site into bins 2 x 5 degrees in elevation and azimuth. No elevation cut-off was used for the purpose of exploring the effects of the maps on observations made at very low elevation angles. This was done separately for pseudorange and carrier phase. In addition, each antenna used at a given site had a unique map. This technique was iterated upon several times, using every day in the time series, until the variations were sufficiently captured. It will be shown that the antenna phase center calibration maps dramatically reduced the elevation dependence of the point-positioned solutions, especially between 0 degree and 10 degree elevation cut-offs. For example, at MacQuarie Island (MAC1), the difference in estimated trends over the 0 - 10 degree elevation cut-offs varied by as much as 3.5 mm/yr without using the calibration maps, whereas the maximum difference with the maps was 0.5 mm/yr over the same range. Also, there was a significant reduction in the vertical repeatibility of 1 - 2 mm in most cases. A list of new estimated trends at approximately 40 sites, as well as a thorough analysis of the associated errors will be shown.

G51B MCC: Level 1 Friday 0830h

Advanced Tropospheric Sensing Methods and Accuracy of Tropospheric Information Determined by Space Geodetic Techniques II Posters *(joint with A)*

Presiding: **Y Bar-Sever,** Jet Propulsion Laboratory, California Institute of Technology**; H Schuh,** Vienna University of Technology

G51B-0025 0830h POSTER

The Tropospheric Products of the International GPS Service

Yoaz Bar-Sever[1] (818-354-2665; Yoaz.Bar-Sever@jpl.nasa.gov)

Sung Byun[1] (Sung.Byun@jpl.nasa.gov)

Gerd Gendt[2] (gendt@gfz-potsdam.de)

[1]JPL, Mail Stop 238-600, Pasadena, CA 91109, United States

[2]GeoForschungsZentrum, Telegrafenberg A17, Potsdam 14473, Germany

The International GPS Service (IGS) produces several tropospheric products that are based on combined contributions from several IGS Analysis Centers. These products contain time series of total zenith delay from a large subset of the IGS network of ground-based GPS receivers. The IGS has recently adapted a new method for the derivation of the combined tropospheric products. In this paper we describe this method and assess its benefits. Each product consists of time series of total zenith troposphere delay at 5 minute intervals from a set of IGS ground sites. Total zenith delay values are estimated with the precise point positioning approach, using the IGS combined GPS orbit and clock solutions, and Rinex files generated by each site. Presently there are two types of IGS tropospheric products: "Final", and "near real time (nrt)". The Final product is based on the IGS "Final", and most precise combined GPS orbit and clock products, and on daily Rinex files, and has a latency of approximately 10 days after the data is collected. The NRT product is based on the IGS ultra-rapid GPS orbit and clock products, and on hourly Rinex files. The latency is up to three hours after data has been collected. We compare this new approach for generating the IGS combined tropospheric products