linear temperature profiles, better agreeing with measurements from the field. Based on this data we can eliminate from consideration the closed model, at least in its present form in which surface recharge penetrates deep into the model.

G52A MCC: Hall C Friday 1330h

Advances in Geodetic Techniques Posters *(joint with S)*

Presiding: **Y Bock,** University of California, San Diego**; F Vernon,** University of California, San Diego

G52A-0955 1330h POSTER

Sea Level Variation in Seismic Normal Mode Band Observed With On-Ice GPS and On-Land SG at Syowa Station, Antarctica

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We analyze sea level variation data from a differential GPS and gravity data from a superconducting gravimeter (SG) at Syowa Station, East Antarctica (69.0^{o}S, 39.6^{o}E), in an eight month period of 1998. At frequencies between 0.2 and 2.5 mHz in seismic normal mode band we observe similar spectral peaks in both of the data. Power spectral densities of these peaks are about $5 \times 10^{-2} \mathrm{m}^2$/Hz in the GPS data and about $5 \times 10^{-17} (\mathrm{ms}^{-2})^2$/Hz in the SG data. We also observe high coherence and zero phase between the two data at frequencies of these peaks. Results of response analysis and simple mode calculation suggest that the observed peaks in the SG data are due to the effects of ocean water attraction and loading associated with the sea level variation, a possible cause of which is seiche in Lützow-Holm Bay around the station. Applying a transfer function method to both of the data, we can reduce the background noise due to the oceanic effects in the SG data.

G52A-0956 1330h INVITED POSTER

GPS Fault Slip Sensors in Earthquake Alert Systems

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The potential for issuing a warning of imminent strong shaking was initially proposed by J. D. Cooper in 1868. The idea has been further developed more recently (e.g., Heaton, T. H., *Science*, 1985), and early warning systems have now been developed and implemented (e.g., the UrEDAS system in Japan). Limitations in the robustness and trustworthiness of the systems, as well as costs, may explain why they are not more widespread. To our knowledge, before now, only seismic sensors have been considered in designing solutions to this problem. We describe, and expect to show test results from, the first deployment of a GPS-based augmentation to earthquake alert systems. GPS can be used to detect surface slip on a fault in real-time. Thus, adding GPS can improve response time and robustness of the system, and could decrease the chance that a small event (without surface rupture) is somehow interpreted by the seismic sensors as being a large event. Our system detects slip on a fault, in real-time, if slip exceeds a few centimeters. Where two So. Calif. Integrated GPS Network (SCIGN) stations straddle the San Andreas fault near Gorman, the fault is not known to creep, so a detected displacement would be a clear indication that a large event is in progress. This could occur within seconds after a large event has begun, conceivably well before the seismic array data alone can yet be relied upon to assess whether the event is large or small. With this and several other specific cases where we are deploying this instrumentation, we feel that GPS data acquired and processed in real-time can significantly add to earthquake alert systems. The potential for providing earthquake information rapidly after future earthquakes, from a variety of real-time GPS systems, is considerable. The GPS slip sensor concept relies upon high sampling-rate data, acquired and processed in real-time. Preferably, the data would be from a braced array that is located close to, and spanning, the main strands of an active fault. Such arrays are not likely to be included in projects that are intended to study longer wavelength deformation of the crust, so may require special deployments along hazardous active faults. Furthermore, such arrays could someday provide unique observations of near-field dynamic and static motions that would be useful for understanding earthquake source physics.

URL: http://pasadena.wr.usgs.gov/office/hudnut/slipsensor/

G52A-0957 1330h INVITED POSTER

Combining Real-time Seismic and Geodetic Data to Improve Rapid Earthquake Information

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The Berkeley Seismological Laboratory operates seismic and geodetic stations in the San Francisco Bay area and northern California for earthquake and deformation monitoring. The seismic systems, part of the Berkeley Digital Seismic Network (BDSN), include strong motion and broadband sensors, and 24-bit dataloggers. The data from 20 GPS stations, part of the Bay Area Regional Deformation (BARD) network of more than 70 stations in northern California, are acquired in real-time.

We have developed methods to acquire GPS data at 12 stations that are collocated with the seismic systems using the seismic dataloggers, which have large on-site data buffer and storage capabilities, merge it with the seismic data stream in MiniSeed format, and continuously stream both data types using reliable frame relay and/or radio modem telemetry. Currently, the seismic data are incorporated into the Rapid Earthquake Data Integration (REDI) project to provide notification of earthquake magnitude, location, moment tensor, and strong motion information for hazard mitigation and emergency response activities.

The geodetic measurements can provide complementary constraints on earthquake faulting, including the location and extent of the rupture plane, unambiguous resolution of the nodal plane, and distribution of slip on the fault plane, which can be used, for example, to refine strong motion shake maps. We are developing methods to rapidly process the geodetic data to monitor transient deformation, such as coseismic station displacements, and for combining this information with the seismic observations to improve finite-fault characterization of large earthquakes. The GPS data are currently processed at hourly intervals with 2-cm precision in horizontal position, and we are beginning a pilot project in the Bay Area in collaboration with the California Spatial Reference Center to do epoch-by-epoch processing with greater precision.

G52A-0958 1330h POSTER

Simultaneous Synthesis of Static and Dynamic Ground Motions Near a Finite Fault in a Layered Medium

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Recent development of geophysical observation instruments such as GPS have allowed us to obtain precise broadband data in wide dynamic and wide frequency ranges, including static displacements in a large area. Since theoretical studies analyze dynamic motions and static displacements individually, this study attempts to synthesize not only dynamic motions but also static displacements simultaneously and estimate effects of a surface layer on displacements in a frequency range of 0 - 1.5 Hz.

When we represent seismic waves by the discrete wavenumber method, we face a difficulty in the choice of two factors to obtain accurate seismograms including static displacement: (1) the truncation number of wavenumber integration and (2) the representation of a potential in zero horizontal wavenumber. To find a suitable value of the truncation number of wavenumbers, we utilize a spatial domain solution using the analytic formulation for a homogeneous half space of Okada(1985) and estimate a wavenumber region in which the majority of energy is concentrated. For a finite rectangular fault buried in a half space, we find that a suitable value of the truncation number of wavenumber is 4 km^{-1} by comparing the the analytical solution of Okada for static deformation. Secondly we find a new kind of singularities for a finite rectangular fault when both horizontal wavenumbers, k_x and k_y, go to zero, or in a case corresponding to VTSE (vertically traveling plane S-wave element). In order to deal with VTSE from a finite fault, a new S wave potential is introduced to obtain a displacement whose polarization is restricted on a horizontal plane. In order to remedy these singularities, we take an asymptotic solution for $k_x = k_y = 0$. These devices make it possible to simulate accurate seismograms, including dynamic and static components, for any fault configurations and station locations by our method. Moreover, we can apply our procedure to layered media to estimate the effect of a soft surface layer on static displacement. In the case of vertical strike slip fault, if a soft surface layer exists above a fault, static displacement at the surface is amplified by twice of in the half space case.

G52A-0959 1330h POSTER

Evaluation of Accuracy in Kinematic GPS Analyses Using a Precision Roving Antenna Platform

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Most tectonic plate boundaries and seismogenic zones of interplate earthquakes exist beneath the ocean and our knowledge on interplate coupling and on generation processes of those earthquakes remain limited. Seafloor geodesy will consequently play a very important role in improving our understanding of the physical process near plate boundaries. Seafloor positioning using a GPS/Acoustic technique is the one potential method to detect the displacement occurring at the ocean bottom. The accuracy of the technique depends on two parts: acoustic ranging in seawater, and kinematic GPS (KGPS) analysis. Accuracy of KGPS have evaluated with following way:

1) Static test: First, we carried out an experiment to confirm the capability of the KGPS analysis using GIPSY/OASIS-II for a long baseline of about 310 km. We used two GPS stations on land, one as a reference station in Sendai, and the other in Tokyo as a rover one, whose coordinate can vary from epoch to epoch. This baseline length is required for our project because the farthest seafloor transponder array is 280 km east of the nearest coastal GPS station. The 1 cm stability of the KGPS solution was achieved in the horizontal components of the 310-km baseline over the course of one day. The vertical component showed fluctuation probably due to parameters unmodeled in the analysis such as multipath and/or tropospheric delay.

2) Sea surface experiment: During cruise KT01-11 of the R/V Tansei-maru, Ocean Research Institute (ORI), University of Tokyo, around the Japan Trench in late July 2001, we deployed three precision acoustic transponders on both the Pacific plate (280 km from the coast, depth around 5450 m) and the landward slope (110 km from the coast, depth around 1600 m). We used a surface buoy with 3 GPS antennas, a motion sensor, a hydrophone, and a computer for data acquisition and control to make combined GPS/Acoustic observations. The buoy was towed about 80 m away from the R/V to reduce the impact of ship noise on the acoustic measurements. The position of each antenna on the buoy was estimated independently with respect to the reference station in Sendai. Time variations of inter-antenna baseline lengths demonstrate that the short-term repeatability of kinematic GPS analysis on a drifting buoy were stable to less than 10 mm of RMS. We also compared the coordinates of a GPS antenna on

the buoy obtained from two baselines with two different land stations. The RMS residual in the difference is about 2 cm for the horizontal component. This error may possibly be an underestimation because common mode noises are removed by differencing. It is therefore necessary to compare KGPS results directory with known roving antenna coordinates.

3) Experiment using a precision roving antenna platform: A GPS antenna was mounted on the perimeter of the 34 m VLBI antenna at Kashima Space Research Center, Communications Research Laboratory. Both the VLBI antenna elevation angle and azimuth are well controlled at the level of a few millimeters. We compared the coordinates of the GPS antenna obtained from KGPS analyses with those determined from the elevation and azimuth log of the VLBI antenna. The preliminary result demonstrates that the residuals from the predicted horizontal position of the GPS antenna are 2 cm RMS.

In conclusion, we expect that the combined GPS/Acoustic technique will be capable of resolving centimeter-level seafloor displacements over the course of a few months.

G52A-0960 1330h POSTER

Joint IRIS/UNAVCO/NASA Remote Seismic/GPS/VSAT Installations

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The UNAVCO Boulder Facility on behalf of NASA is collaborating with The Incorporated Research Institutions for Seismology (IRIS) on remote broadband seismic and GPS installations in support of the Global GPS Network (GGN) and the Global Seismographic Network (GSN). Seismic and GPS instruments share VSAT communications, power, facilities, maintenance, and site security. Collaborative sites include Mbarara Uganda, Franceville Gabon, Galapagos Islands, and Easter Island. High quality seismic and GPS data are now flowing to the GGN and GSN data collection centers. Future opportunities for collaboration include 16 collocated seismic and GPS installations as part of the NSN/GSN component of EarthScope. This poster will highlight past collaborative efforts, technology achievements, and identify new opportunities.

G52A-0961 1330h POSTER

Development of a Real-Time GPS/Seismic Displacement Meter: GPS Component

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We report on the status of the Orange County Real-Time GPS Network (OCRTN), an upgrade of the SCIGN sites in Orange County and Catalina Island to low latency (1 sec), high-rate (1 Hz) data streaming, analysis, and dissemination. The project is a collaborative effort of the California Spatial Reference Center (CSRC) and the Orange County Dept. of Geomatics, with partners from the geophysical community (SCIGN), local and state government, and the private sector. As part of Phase 1 of the project, nine sites are streaming data by dedicated, point-to-point radio modems to a central data server located in Santa Ana. Instantaneous positions are computed for each site. Data are converted from 1 Hz Ashtech binary MBEN format to (1) 1 Hz RTCM format, and (2) decimated (15 sec) RINEX format. A second computer outside a firewall and located in another building at the Orange County's Computer Center is a TCP-based client of RTCM data (messages 18, 19, 3, and 22) from the data server, as well as a TCP-based server of RTCM data to the outside world. An external computer can access the RTCM data from all active sites through an IP socket connection. Data latency, in the best case, is less than 1 sec from real-time. Once a day, the decimated RINEX data are transferred by ftp from the data server to the SOPAC-CSRC archive at Scripps. Data recovery is typically 99-100%. As part of the second phase of the project, the RTCM server provides data to field receivers to perform RTK surveying. On connection to the RTCM server the user gets a list of active stations, and can then choose from which site to retrieve RTCM data. This site then plays the role of the RTK base station and a CDPD-based wireless Internet device plays the role of the normal RTK radio link. If an Internet connection is available, we will demonstrate how the system operates. This system will serve as a prototype for the GPS component of the GPS/seismic displacement meter.

G52A-0962 1330h POSTER

Development of a Real-Time GPS/Seismic Displacement Meter: Seismic Component and Communications

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In two abstracts, we report on an ongoing effort to develop an Integrated Real-Time GPS/Seismic System for Orange and Western Riverside Counties, California, spanning three major strike-slip faults in southern California (San Andreas, San Jacinto, and Elsinore) and significant populations and civilian infrastructure. The system relying on existing GPS and seismic networks will collect and analyze GPS and seismic data for the purpose of estimating and disseminating real-time positions and total ground displacements (dynamic, as well as static) covering all phases of the seismic cycle, from fractions of seconds to years. Besides its intrinsic scientific use as a real-time displacement meter (transducer), the GPS/Seismic System will be a powerful tool for local and state decision makers for risk mitigation, disaster management, and structural monitoring (dams, bridges, and buildings). Furthermore, the GPS/Seismic System will become an integral part of California's spatial referencing and positioning infrastructure, which is complicated by tectonic motion, seismic displacements, and land subsidence. This development is taking place under the umbrella of the California Spatial Reference Center, in partnership with local (The Counties, Riverside County Flood and Water Conservation District, Southern California Metropolitan Water District), state (Caltrans), and Federal agencies (NGS, NASA, USGS), the geophysics community (SCEC2/SCIGN), and the private sector (RBF Consulting). The project is leveraging considerable funding, resources, and research and development from SCIGN, CSRC and two NSF-funded IT projects at UCSD and SDSU: RoadNet (Real-Time Observatories, Applications and Data Management Network) and the High Performance Wireless Research and Education Network (HPWREN). These two projects are funded to develop both the wireless networks and the integrated, seamless, and transparent information management system that will deliver seismic, geodetic, oceanographic, hydrological, ecological, and physical data to a variety of end users in real-time. In this abstract we report on the seismic component, as well as the communications infrastructure. In the second abstract, we we describe the first implementation of the GPS component in Orange County.

G52A-0963 1330h POSTER

Joint IRIS/PASSCAL UNAVCO Seismic & GPS Installations, Testing, and Development

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Future large-scale deformation initiatives such as EarthScope (http://www.earthscope.org/) will provide an opportunity for collocation and integration of GPS receivers and broadband and short period seismic instruments. Example integration targets include PBO backbone and cluster sites with USArray Transportable (Bigfoot) and Permanent Array. A GPS seismic integration and testing facility at the IRIS/PASSCAL Instrument Center in Socorro, NM is currently performing side-by-side testing of different seismometers, GPS receivers, communications hardware, power systems and data streaming software. One configuration tested uses an integrated VSAT data communications system and a broadband seismometer collocated with a geodetic quality GPS system. Data are routed through a VSAT hub and distributed to the UNAVCO Data Archive in Boulder and the IRIS Data Management Center in Seattle. Preliminary results indicate data availability approaching 100% with a maximum latency of 5 sec.

G52A-0964 1330h POSTER

Confronting Very Long Period Vertical and Horizontal Seismometric Data With Tidal Predictions

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It is known that it is possible to retrieve reasonably good tidal signals (diurnal and semi-diurnal) from digital records of the output of modern long-period seismometers. This is specially true when the instruments are properly installed, on stable material, far from human activity and isolated from environmental perturbations. This is the case for several of the IRIS/IDA, Geoscope and other permanent broad-band world-wide seismological stations. The vertical component is usually less noisy than the horizontal ones and the vertical tidal signals predicted by the theory of an elastic Earth model with an oceanic load contribution are in very good agreement with the corresponding observations. On the contrary, the horizontal terms exhibit much larger discrepancies with respect to theoretical predictions. The well-known explanation for this disagreement lies in the local effects such as topography, geology and mainly the cavity effect when the sensor is installed inside a vault. Those effects are present on any seismometer of any station, they are different from place to place within very short distances (meters) and they are far of being negligible.

We present here a very simple and stable procedure to take into account the instrumental response in order to recover gravity from seismometric recordings at long periods ($T > 10$ min). We treat long series (~ 1 month) of data from several permanent broad band seismological stations. Vertical records are shown to accurately reproduce either the measurements of nearby gravimeters in the tidal and subtidal frequency bands ($T < 24$ h) or the theoretical predictions, especially when pressure data are available and included in the analysis. We also treat records from horizontal channels in order to examine the contribution of the different geophysical observables: tilts, horizontal and vertical displacements, strains, gravity. Special attention is devoted to the problem of finding a minimal set of observables necessary to predict the seismological records, to the inverse problem of recovering the observables from a set of records and to the stability in the long term (years) of the result of such analysis.

G52A-0965 1330h POSTER

Role of density and of lateral variation of rheology on the Earth tides : a numerical approch

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Earth strain and gravity responses to phenomenon such as tides or atmospheric loads, are generally calculated assuming earth models radially stratified, and at hydrostatic equilibrium.

However, some local observations show unexplained perturbations on the tidal gravity signal. A possible cause for those perturbations is the neglect of rheology and density lateral variations.

We investigated a non radially symmetrical earth numerical model with the intent to study the earth response to low frequency forcings. This model uses a finite element method (spectral element) developed on

the "cubed sphere" mesh (Ronchi et al., 1996), and resolves gravito- elasticity equations. It is an extension of an elastodynamical model originally made for the calculation of synthetical sismogram (Chaljub, 2000). We needed therefore to add Poisson equation and gravity perturbation on the original one. Finally, the non hydrostaticity of the Earth is taken into consideration by a first order perturbation theory.

As a first application, we investigate the possible influence of a mega- plume on gravity tide. We present here, the theoretical principle of our approch and our first results.

G52A-0966 1330h POSTER

Trials for better precision of seafloor geodetic observation system

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Institute of Industrial Science, University of Tokyo, and Hydrographic Department, Japan, have been developing seafloor geodetic observation system and conducting observations using the system. Precise acoustic ranging and kinematic GPS positioning techniques are combined into the system. Seafloor reference station which consists of four mirror type transponders is deployed on the seafloor and measures its position in reference to GPS stations on land and ship. Fourteen seafloor geodetic reference stations have been distributed on the forearc areas of Japan island arc. Subsea crustal deformation due to subducting two oceanic plates of the Pacific and the Philippine sea can be monitored by using the seafloor reference stations.

Although we obtained satisfactory results with the already existing system, we come up with possible improvements of the system as we accumulate the experience of the observations using the system. Trials to improve the system are always done. In this poster, we will present two of such trials.

1. To improve the stability of the rigid pole connecting the GPS antenna and the ship-board transducer. The bending of the GPS pole was found by examining the offsets in the acoustic ranging residuals. Acoustic ranging is made with condition that the ship drifts over sea surface. Drag force generated between surface current and the pole makes the pole itself bend. The pole was replaced by new, more rigid pole to overcome the problem. Also, we monitor amount of bending of the pole, that is, the offset between the GPS antenna and the transducer, using tiltmeter through the observation.

2. To reduce the acoustic ranging error due to shape of the transducer. Coded sinusoidal acoustic wave with 15cm wave length is used as the ranging signal. This wave length is comparable to the dimension of the cylindrical transducers employed both on the shipboard system and on the seafloor transponder. Transducer can not be regarded as a point considering the wave length of the ranging signal. This implies possible ranging error is caused depending on the incident angle of the acoustic signal to the transducer, that is, to which part of the transducer (ex, top, edge, or side) does the first front of signal get. We have started water tank experiment to confirm the cause of the ranging error. Analyses are now going on and we will show the result. If the size and shape of the transducer are actually causing the problem, we may solve it both in software and hardware. For example, it will be possible to develop a new correction method on the ranging. Also, adopting spherical omni-directional transducer may improve the ranging error.

G52A-0967 1330h POSTER

Modeling and forecast of the polar motion excitation functions for short-term polar motion prediction

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The dynamics of polar motion (in the range of daily to sub-decadal frequencies) is dominated by the Chandler wobble, a resonant oscillator excited by variations of atmospheric, oceanic, and ground water origins. Understanding the origin of the excitation of the polar motion including the Chandler wobble remains incomplete. A simple stochastic model of the excitation function, such as a random walk, is generally sufficient for operational earth orientation analyses due to availability of various measurements for updates. More accurate models are still desirable for short-term prediction, especially during the observation voids between measurement epochs. Moreover, spacecraft navigation typically requires estimates of the earth orientation parameters up to 7 days of lead time.

The goal of this study is in improvement of the short-term prediction of the polar motion in the context of state-space modeling suitable for the Kalman filter operations, such as the Kalman Earth Orientation Filter (KEOF) at Jet Propulsion Laboratory. Empirical periodicities are determined from an analyzed polar motion excitation function time series, and these periodicities are to be extrapolated in time. Fourier series expansion is a standard technique for spectral analysis; however, the sinusoidal Fourier basis functions lack the time-local specificity that is characteristics of the polar motion time series. In particular, the magnitude, frequency, and phase need to be allowed to vary slowly in time for an effective sinusoidal representation for polar motion. While a variety of techniques are reported in the literature for direct prediction of polar motion time series, this report focuses on modeling and prediction of the excitation function.

G52A-0968 1330h POSTER

Estimation of Uncertainty in 3D Gravity Inversion Using Simulated Annealing

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Inversion of gravity data can result in several non-unique solutions. Therefore it becomes important to assign uncertainties in the resulting model parameters along with their covariances. Uncertainties arise due to several reasons, namely, noise in the data, approximation in mathematical formulation of forward problem, inappropriate inverse technique etc. Though one cannot remove these factors completely, uncertainty can be reduced considerably by using sufficient a priori information, which helps to restrict the inverted models to be within realistic geological setup. We have used simulated annealing (SA) based inversion technique to invert the gravity data in two and three dimensions. In our implementation of SA, we generated several thousand models with same control parameters but different starting models, selected from a prior distribution of model. Using a Bayesian framework, we use all these sampled models to construct marginal posterior probability density function (PPD), and several orders of moments. The correlation matrix shows the dependence of one parameter with other. Several correlation plots are used to study the effect of a-priori information in reducing the uncertainty in the solutions. We applied the technique to a few synthetic data and 3D field data over lake Vostok, East Antarctica. A priori constraints were developed from available seismic and radar profiles. The inversion results produced a map of the structure of the basin along with their associated uncertainties.

URL: http://www.ig.utexas.edu

G52A-0969 1330h POSTER

Error estimation of Doppler measurements in SELENE project

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The study on orbital motion and the interior structure of the Moon and planets is one of the methods to approach for the revolution as a dynamical system and the origin of the solar system. It is a powerful method to measure the gravity fields obtained by the orbital motion of a spacecraft in order to estimate the inner layer and the density structure of the Moon and the planets. Doppler measurement is one of the major methods of positioning of spacecrafts in space. In order to study the lunar gravity field precisely, Spacecrafts in SELENE project will be tracked by 2-way and 4-way Doppler measurements with the accuracies of 0.2mm/s and 1mm/s in range rate, respectively. Error sources of Doppler measurements that affect the accuracies are summarized. Especially, conditions of phase noise in tracking station are shown in detail.

URL: http://www.miz.nao.ac.jp/staffs/kono/

G52A-0970 1330h POSTER

On the stability of horizontal positions of acoustic transponders for seafloor geodesy deployed on thick sediment

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The Japan Trench east of northeastern Japan is an appropriate site for the study of seismic coupling in subduction zones. The Pacific plate is subducted there at an average convergence rate of 85 mm/year, and large earthquakes occur there at relatively short intervals. For example, earthquakes off Miyagi Prefecture in northeastern Japan occur at intervals of 26 to 42 years with an average of 37 years between events. The seismic coupling, however, has been estimated to be less than 40 percent (Kawasaki et al., 2001). Leveling data support the hypothesis that post-seismic deformation is an important contributor to the low seismic coupling (Uyeda, 2002).

Planning to make in situ observations of seismic coupling and motion of the Pacific Plate near the Japan Trench (about 200 km from the coast), we deployed three precision acoustic transponders (PXPs) in 2001 on both the Pacific plate (70 km from the trench axis at a depth of 5450 m) and the landward slope (70 km from the axis at a depth of 2800 m). The PXP system was developed for the full ocean depth in collaboration with a group at the Scripps Institution of Oceanography (Fujimoto et al., 2001). We have also demonstrated an accuracy of 2-3 cm for the sea-surface kinematic GPS positioning at a baseline length of 350 km (Miura et al., 2002). One of the remaining questions is how well the acoustic transponders are anchored to the old oceanic crust underlying thick sediment. The acoustic transducer is mounted one meter above the seafloor. If the transponder frame tilts by 1 degree due to differential settling, the horizontal position of the transducer shifts by 1.7 cm. Horizontal motion of the transponder independent of real crustal motion is undesirable.

We have confirmed the anchor stability through visual inspection of PXPs deployed on the Pacific Plate seaward of the Japan Trench. We recently replaced the original PXPs with new ones due to a hardware problem in the old design. Three new PXPs were deployed from the sea surface and one of the original design was recovered with the JAMSTEC ROV Kaiko in July 2002. During the dive, we could visually inspect how the old and new PXPs were deployed on the thick sediment. The original PXPs were each installed on a flat frame of 1m x 1m, and the new PXPs on a frame of 1m x 2m. The frames were confirmed to be level and buried within the sediment. We confirmed that the thick sediment was stable enough to hold each anchor for centimeter-precision geodesy. We carried a new PXP to a new location about 4 m to the south of an old PXP and measured the relative positions between the two PXPs with a resolution of about 10 cm. This resolution can be improved in a subsequent operation because both PXP frames remain on the seafloor. This demonstrates the feasibility of continuing a precise seafloor geodetic study beyond the lifetime of the original PXPs.

G52A-0971 1330h POSTER

An Evaluation of Positioning Error Estimated by the Mesoscale Non-Hydrostatic Model

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We are now evaluating atmospheric parameters (equivalent zenith wet delayand linear horizontal delay gradients) derived from VLBI, GPS, and WVR by comparing with slant path delays obtained by ray-tracing through the non-hydrostatic numerical weather prediction model (NHM) with 5 km horizontal resolution. Our ultimate purpose is to establish a new method for reducing atmospheric effects on geodetic positioning. We first seek to establish the level of positioning error due to intense mesoscale phenomena such as the passing of cold fronts, heavy rainfall events, and severe storms. The NMH provides temperature, humidity and pressure values at the surface and at 38 height levels (which vary between several tens meters and about 35 km), for each node in a 5 km by 5 km grid that covers all of central Japan and surrounding ocean. We are performing ray tracing experiments for the entire grid at 16 epochs corresponding to successive operational runs of the NHM between 1200 UT 10/19/2000 and 1200 UT 10/20/2000. At each station-epoch we trace about 100 rays to each station with roughly uniform density (count per unit solid angle) on the upperhemisphere, so as to approximate a sampling geometry similar to both GPS and VLBI. We will present the horizontal and vertical displacement of the site position estimated by the delay residuals between the ray traced slant delays and the anisotropic mapping function.

G52A-0972 1330h POSTER

Parameter Bias When Processing GPS Data Containing Unmodelled Vertical Signals: Sensitivity Analysis

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We have identified biases in sub-daily estimates of position obtained from GPS data using batch least squares due to the presence of unmodelled vertical signals in the GPS data. The estimation of sub-daily position is commonly used for ocean loading and ice movement studies, for example. The biases are most evident in the horizontal components of the coordinates and in the case of the unmodelled vertical signal being periodic (i.e., tidal), the biases are also periodic with magnitudes of about 40-50% of the amplitude of the vertical periodic signal. The shape of the periodic horizontal signals is a function of the first derivative and the square of the unmodeled vertical signal. The artifacts are predominantly evident in the east-west component and can be removed by fixing the carrier phase ambiguities to integer values.

These findings have important consequences for GPS investigations into the horizontal components of ocean tide loading, for example, or for historic campaign-style measurements where ocean loading was not modelled and ambiguities were not fixed to integer values.

We present an investigation into this problem by way of a sensitivity analysis. The sensitivity analysis is compatible with the results obtained using field data. In particular, we discuss the latitudinal variation of the artifacts, the effect of different ambiguity resolution success rates and the averaging effect as session lengths are increased. Finally, we investigate the influence of unmodeled vertical linear and periodic signals in 24 hour batch least squares solutions.

G52A-0973 1330h POSTER

A new assimilation technique for estimating global tidal currents, application to tidal energy dissipation.

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For this study we used a set of measured tidal constants at 1 second intervals on the ground track of TOPEX/POSEIDON. This database contains very dense information on the deep oceanic and coastal tides. We assimilate these data in a dynamic global spectral tide model. In the model we aim to solve for tidal elevations and depth integrated currents discretized on a 1/2 degree grid. During assimilation we minimize a cost function that balances the residuals between observations and the dynamics, the weight to assign to dissipation parameters in the model and the weight to assign to boundary conditions. The method itself relies upon a preconditioned conjugate gradient solver modified to efficiently solve large sparse linear systems that follow from the minimization of the cost function. With this technique we avoid explicit storage of the normal matrix which greatly relaxes the problem of storing large matrices. The solved for elevations and currents are then compared to a verification dataset consisting of a network of tide gauges and the solved for tidal currents and elevations are used in a tidal energetics equation in order to obtain dissipation rates for M_2 at any part of the model domain. In the presentation we will emphasize the computational hurdles to obtain the local dissipation rate; ie. it is necessary to compute the gravitational work put into the tidal system, in addition we need the divergence of energy flux. Both terms require careful evaluation of convolution operators that operate on tidal elevations. Computational aspects and comparisons of our results to other known-solutions will be shown. Our findings confirm oceanic dissipation rates for the M_2 constituent and confirm the picture of energy conversion whereby tidal energy is dissipated by internal waves and mixing.

G52A-0974 1330h POSTER

Airborne Laser Swath Mapping: First and Second Epoch Surveys of Landslide Areas in South Dakota

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Landslide areas at the Oahe Dam, near Pierre, South Dakota, were surveyed using airborne laser swath mapping (ALSM), in August 2000 and again in June 2002. The two surveys were conducted using the same basic flight plan, including flying height (nominally 600 m agl), scan angle (20 degree half angle), scan rate (28 Hz) and a 50 percent overlap of adjacent swaths. However, the ALSM system used for the two surveys was upgraded from 10,000 pps to 33,000 pps between the two surveys, resulting in more than a three-fold reduction in the nominal point-to-point spacing of the surface points. Digital color photographs were collected simultaneously with the ALSM observations during the 2000 survey and a small landslide area was also mapped with a ground based laser scanner during the 2002 survey. The topographic relief across a single swath was as much as fifty meters, with hillside slopes as steep as 70 degrees.

Both the 2000 and 2002 surveys clearly delineate the landslide features, including the head scarps and the toes. However, when Digital Elevation Models are derived from the two surveys, using all of the observations, differences in the elevations are strongly correlated with breaks in the slope of the terrain. When the 2002 data set is thinned, keeping only those points closest and horizontally within 30 centimeters of the 2000 survey points, the differences between the two surveys are reduced. The RMS difference in heights is approximately 6 cm. Still, the largest differences are correlated with the terrain break lines. It appears that differences between the horizontal positioning of the surface points, both real and observational errors, limit the achievable accuracy of the height results in steep terrain to a few decimeters, making it difficult to accurately compute the volume of material involved in subtle landslides.

G52A-0975 1330h POSTER

High accuracy applications of Galileo: A test case for the Galileo System Test Bed

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Many geodetic and practical positioning applications such as surveying, process management, monitoring of infrastructure (e.g. oil platforms, large bridges and reservoirs), scientific studies in fields such as geodynamics, earthquake research and global change, and determination of accurate reference frames, require near-real time accuracy below 10 centimetres, post-processing accuracy of the order of 1 cm and long-term stability of the order of 1 mm/year. The future Galileo system, if build according to the specifications for the Galileo System Test Bed (GSTB), would not meet these accuracy requirements without additional augmentation system such as IGS and EUREF. In this respect, Galileo would replicate a disadvantage of the existing systems, particularly GPS. The relatively low accuracy inherent in GPS necessitates a globally coordinated activity in order to make the system available for high-accuracy applications.

The "Geodetic Galileo" Stand-Alone Test Case (SATC) has the objective to specify system requirements for a Galileo system which would inherently provide geodetic accuracy. Limiting factors for the accuracy of the system are the satellite orbits and clocks and the ability to correct for User Equivalent Range Errors (UERE). Therefore, the "Geodetic Galileo" SATC focuses on (1) orbit and clock determination and prediction, with the main objective to determine the number of tracking stations and uplink sites required to provide highly accurate broadcast orbits and clocks; and (2) UERE contributions and mitigation, with the main objective to characterise the different factors contributing to UERE (i.e. orbit and clock errors, ionosphere and troposphere, local environment including multipath and interference) and to determine algortithms for mitigation. The first part is based on data from the global IGS network augmented by regional stations, while the second part is primarily based on data from the dense CGPS network in Scandinavia augmented by other ionospheric and tropospheric observations.

It is expected that the results of the "Geodetic Galileo" SATC will have an effect on the design and future performance of the Galileo system.

G52A-0976 1330h POSTER

Advances in SLR Orbit Determination

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Since the LAGEOS II satellite was launched from the space shuttle in October 1992, the Global Laser Tracking Network has provided an extensive set of Satellite Laser Ranging (SLR) data. These data have been used to supplement the 26 years of SLR data obtained from LAGEOS I satellite. The contrasting behavior of small, unmodeled along-track accelerations in the orbits of each satellite can be used to help explain the sources of these perturbations. LAGEOS II's inclination provides gravity and tidal sensitivity to improve on the advances from LAGEOS I in a shorter time, as LAGEOS II's nodal precession period is about one half that of LAGEOS I's three year period. The geometry added by LAGEOS II has been found to improve station positioning accuracy to better than one centimeter in latitude, longitude and height. This is an asset for the determination of the regional deformation in the vicinity of the SLR sites. The improved SLR global reference frame can now be used to accurately define orbit and station positions for scientific applications and the support of altimeter missions.

G52A-0977 1330h POSTER

Using a Numerical Weather Model to Improve Geodesy

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The delay of the radio waves by the neutral atmosphere continues to be a significant source of error for geodetic measurements by VLBI and GPS. A numerical weather model (NWM) provides the best global information on the state of the atmosphere along the entire path traversed by the signal from the satellite or extragalactic radio source. Mapping functions for the hydrostatic and wet components of the atmosphere based on a NWM have demonstrated a substantial improvement in repeatability of baseline lengths, corresponding to a reduction in the atmosphere contribution to vertical error of about 4 mm, for a two-week high quality VLBI data set. The mapping functions, designated IMF, have now been implemented in the SOLVE VLBI estimation package using the NCEP numerical weather analysis results. Initial tests on the full VLBI data set (1979-2002 August) and on selected subsets confirm that use of the NWM improves the results of both. Further evaluation, including the impact on seasonal and diurnal signals, will be reported.

G52A-0978 1330h POSTER

An Integrated Bathymetric and Topographic Digital Terrain Model of the Canadian Arctic Archipelago

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Currently, the International Bathymetric Chart of the Arctic Ocean (IBCAO) [Jakobsson et al. 2000], contains the most up-to-date digital bathymetric model of the entire Canadian Arctic Archipelago. IBCAO is a seamless bathymetric/topographic Digital Terrain Model (DTM) that incorporates three primary data sets: all available bathymetric data at the time of compilation; the US Geological Survey GTOPO30 topographic data; and the World Vector Shoreline for coastline representation. The horizontal grid cell size is 2.5 x 2.5 km on a Polar Stereographic projection, which is adequate for regional visualization and analysis, but which may not be sufficient for certain geoscientific and oceanographic applications. However, the database that was constructed during the IBCAO project holds bathymetric data of a high quality throughout most of the Canadian Arctic Archipelago, justifying a compilation resolution that is better than 2.5 x 2.5 km. This data is primarily from historical hydrographic surveys that were carried out by the Canadian Hydrographic Survey (CHS).

The construction of a higher resolution bathymetry/topography DTM of the Canadian Arctic Archipelago (complete with an error estimation of interpolated grid cells) requires a consideration of historical metadata which contains detailed descriptions of horizontal and vertical datums, positioning systems, and the depth sounding systems that were deployed during individual surveys. A significant portion of this metadata does not exist in digital form; it was not available during the IBCAO compilation, although due to the relatively low resolution of the original DTM (2.5 x 2.5 km), its absence was considered a lesser problem.

We have performed "data detective" work and have extracted some of the more crucial metadata from CHS archives and are thus able to present a preliminary version of a seamless Digital Terrain Model of the Canadian Arctic Archipelago. This represents a significant improvement over the original IBCAO DTM in this area. The use of a merged seamless bathymetry/topography model substantially facilitates the overlay and incorporation of other spatially referenced geological and geophysical datasets. For example, one intended use of the model is to merge the results from the mapping of regional glacial morphology features, in order to further address the glacial history of the region.

Jakobsson, M., Cherkis, N., Woodward, J., Coakley, B., and Macnab, R., 2000, A new grid of Arctic bathymetry: A significant resource for scientists and mapmakers, EOS Transactions, American Geophysical Union, v. 81, no. 9, p. 89, 93, 96.

G61A MCC: Hall C Saturday 0830h

Slow Earthquakes in Subduction Zones Posters *(joint with S, T)*

Presiding: **T Melbourne,** Central Washington University**; M M Miller,** Central Washington University

G61A-0963 0830h POSTER

Aseismic Deformation, Plate Subduction and Stress Localization in Kanto-Tokai (Central Japan) Revealed by GPS

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Aseismic deformation detected by GPS (Global Positioning System) at subduction zones reveals that a large proportion of strain energy associated with plate subduction during an interseismic period is released through aseismic slip. The aseismic slip to some extent controls the pattern of stress at a subduction zone, as evidenced by the transient deformation and stress change associated with episodic slip or slow earthquakes. Previous analysis of GPS observations mainly focused on the pattern of deformation or strain, and did not attempt to assess stress change associated with plate subduction. While the studies revealed the first-order features of plate coupling, they do not fully include the effect of the major plate driving forces acting at a subduction zone such as the slab pull, ridge push and drag force. Since stress concentration/localization is indicative of where earthquakes could occur, a quantitative assessment of stress change is crucial for a better understanding of the stress accumulation process at a subduction zone. In this study, using the surface deformation determined by the Japan permanent GPS array and the depth distribution of earthquakes in the Kanto-Tokai region as quantitative constraints, we construct a three-dimensional model to simulate the subduction of the Philippine Sea plate at the Suruga and Sagami troughs and the Pacific plate at the Japan trench. The model incorporating the effect of major plate driving forces (ridge push, slab pull and drag force) provides an overall fit to the horizontal deformation observed by GPS during 2001 in the Kanto-Tokai region. After extracting the regional deformation associated with subduction of the Philippine Sea and the Pacific plates from the GPS observations through an inversion analysis, a distinct boundary is revealed between two types of motion trend in the region, which provides a strong support for the presence of the North American plate in central Japan. Further, a large band of stress concentration (0.6 bar/yr at a depth of 15 km) is found around the Suruga trough with the largest stress change at the joint of the Suruga and Sagami troughs, which corresponds well with the locations of the most recent interplate earthquakes. Our results indicate that the pattern of stress localization is mainly controlled by the characteristics of subducted slabs (geometry and slip distribution) and the persistent stress concentration is responsible for repeated large interplate earthquakes in the region.

G61A-0964 0830h INVITED POSTER

Partitioning between seismogenic and aseismic slip as highlighted from slow slip events in Japan

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1. Introduction

It has been recognized that fault slip in a subduction zone takes place with a source duration varying from seconds (ordinary earthquakes) to even years (slow fault slip). Such a slow fault slip must readjust the stress distribution in the seismogenic zone to control the occurrence of a future large earthquake. In this study, we present a numerical method to analyze the GPS data, and examine slow fault-slips in Hyuga-nada and Sanriku-oki, Japan.

2. Data

The time interval analyzed is from 1996 June to 1998 December for Hyuga-nada region where the Philippine Sea plate subducts northwest beneath the Eurasian Plate, and from 1994 December to 1995 March for Sanriku-oki region where the Pacific plate subductes west beneath the northeastern Japan island arc. The GPS data of Hirosaki University is also used for Sanriku-oki region.

3. Method

We take a fault model region on the plate boundary considering the fault plane of previous earthquakes and seismicity, and divide it into many sub-faults. The slip-rate function at each sub-fault is modeled by a series of isosceles. Neglecting the source duration of ordinary earthquakes, the coseismic fault slip is described by Heaviside step function. To get better resolution for co-seismic and aseismic slip distribution, we imposed a weak constraint of a priori information due to coseismic slip determined by seismic wave analysis.

4. Results

In Hyuga-nada, after two large earthquakes in 1996, a slow fault-slip expanded from the source area to the north and then triggered another slow event with characteristic source duration of about one year. The aseismic slip has increasingly highlighted a particular site where little slow fault-slip takes place but where the subducting plate drags the overriding plate. It is noteworthy that the highlighted area is just the site of a past large earthquake: the 1968 Hyuga-nada earthquake (Mw7.5). We propose that this area is a possible site for a future large earthquake.

In Sanriku-oki, the co-seismic and post-seismic slip of 1994 Sanriku-haruka-oki earthquake do not overlap, but share a plate boundary region. The post-seismic slip was triggered in an area surrounding the fault plane of the main shock. It rapidly developed a shear stress concentration at an edge of its slip area, and triggered the largest aftershocks.

URL: http://iisee.kenken.go.jp/staff/yagi/

G61A-0965 0830h POSTER

Chilean Analog for 17th-Century Uplift Along the Southern Kuril Trench

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What caused a meter or so of widespread uplift in eastern Hokkaido in the last decades of the 17th century A.D.? Coasts along the Kamchatka, Kuril, and Japan Trenches lack documented modern analogs for uplift this large and geologically fast. But a meter of uplift, in 1960-1990, raised shorelines inland from the seismic rupture plane of the 1960 Chile earthquake. By this Chilean analogy, Hokkaido's 17th-century uplift may have occurred aseismically-during minutes of precursory slip and also during decades of postseismic creep, all downdip from the seismic rupture surface.

Hokkaido's area of 17th-century uplift extends at least 50 km along the southern Kuril Trench. It includes the estuaries Akkeshi-ko and Hichirippu, on the Pacific coast, and Furen-ko and Onneto, on the Okhotsk Sea. At each estuary, intertidal and subtidal flats rose with respect to tide level; wetland plants colonized the emerging land; and peaty wetland deposits thereby covered mud and sand of the former flats. Such evidence for uplift was first reported by Sawai and coworkers, who identified at least three uplift events from the past 2500 years at Akkeshi-ko [Quat. Res. 56, 231-241, 2001]. The youngest of the uplift events probably began in the 1660s or 1670s, as dated by tephra layers. The uplift probably exceeded 1/2 m (inferred from paleoecology) without far exceeding 1 m (estimated by comparing early descriptions of Akkeshi-ko).

Though this evidence permits the Hokkaido uplift to have been coseismic or aseismic or both, depths to the subducting Pacific plate probably preclude seismic rupture of the plate boundary directly beneath the uplifted area. These depths exceed 50 km and also exceed depths of seismic coupling inferred from continuous GPS [Mazzotti et al., JGR 105, 13159-13177, 2000; Ito et al., EPSL 176, 117-130, 2000]. When Hokkaido's plate boundary ruptured in earthquakes of Mw 8.1 (in 1952) and 7.8 (1973), the ruptures occurred offshore at depths less than 50 km, and the adjoining coast either subsided several centimeters or failed to change level.