SLR MEASUREMENTS OF VERTICAL MOTION

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Abstract

The twenty year record of vertical position at SLR stations tracking the LAGEOS satellite contains signals with periods between hours and years, as well as the long-term effects of crustal movements and post-glacial rebound. This analysis focuses on the trends observed in vertical position at the strongest SLR stations with the longest data spans. On-going advances in overall system accuracy, in conjunction with improved satellite, Earth, orbit perturbation and relativity modeling now allow us to use the Global Laser Tracking Network to connect regional and local positioning networks monitoring sea level change in a geocentric reference frame.

Introduction

The Global SLR network provides precision orbit determination, Earth orientation and station motion resolution, tracking a variety of satellites with a variety of stations. In this study, we present the results of an analysis to determine long-term vertical motion at those predominantly European stations which have tracked LAGEOS-1 over a time span of a decade or more. The precision to which vertical positions are being measured with space geodetic systems is now approaching that of horizontal measures. This allows the study of all aspects of plate boundary deformation and permits the study of major intra-plate deformation associated with unloading of post glacial rebound (PGR).

Independent measures of PGR from space geodetic instruments will further the knowledge of coastline dynamics allowing more precise measures of present-day sea level changes. Continuing measurements of plate boundary deformation provides observational constraints necessary to address fundamental questions about the vertical and horizontal structure of the lithosphere, to understand plate driving forces, and to clarify the behavior of the viscosity and dynamics of the upper mantle as it contributes to lithospheric deformation.

Science Background

The process of post-glacial rebound modeling described by Peltier et al. [1994] is under-going constant re-appraisal. The Earth's response to deglaciation from the last glacial maximum described by the ICE-4G model [Peltier, 1995] was presented as an improvement over a previous ICE-3G model [Tushingham and Peltier, 1991]. The existing European VLBI stations have been used to quantify the PGR signal in Fenno-Scandia [Argus, 1996]. The strong SLR systems lie in the region of forebulge collapse, within which subsidence is expected, and can thus help to define the background reference field against which post-glacial rebound is measured. Horizontal motion associated with post-glacial rebound is an order of magnitude less than in the vertical, although it is actually more sensitive to possible vertical variations in mantle viscosity [Peltier et al., 1989]. That accuracy requirement at the SLR stations considered here is yet to be achieved for horizontal measurements.

Data Background

The development of the Global Laser Tracking Network has been marked by steady improvement in both measurement precision and in the evolution of observing systems. Typical measurement accuracies approach a few mm/year in both horizontal and vertical components [Dunn et al., 1995]. Additionally, the development of lightweight, portable and relatively inexpensive space geodetic systems based on the Global Positioning System have made possible frequent measurements from many more sites [Heflin et al., 1994]. The promising future of space geodetic studies of the Earth lies not only in the improving instrumentation but also in reconsidering measurements already made with enhanced measurement models.

The Crustal Dynamics Data Information System (CDDIS) provided the tracking data for analysis, which was conducted using the GEODYN orbit determination and geodynamic parameter estimation program. This system is capable of processing a variety of space geodetic data, and has a comprehensive representation of conservative and non-conservative forces perturbing satellite motion. A companion matrix manipulation and inversion program, SOLVE, was used to combine sets of normal equations produced by the data reduction program.

Analysis Background

Our analysis approach was to model known system errors, but to estimate satellite model errors which might influence vertical station position determination. The approach is based on dynamic methods, which require an accurate theory for the satellite's orbital behavior. All perturbing forces on the spacecraft must be accurately modeled as well as the position of the orbit plane with respect to the rotating station network. The orbit improvement process, which is the basis of the dynamic approach, can also help identify causes of significant perturbing effects on the satellite motion. Earth orientation parameters are referenced to a system based on the LAGEOS orbit plane, and depend on the adopted dynamical equator and equinox.

In our adopted dynamic analysis, LAGEOS tracking data are partitioned into time spans of approximately 30 days (occasionally 35), thus forming a basic orbital arc which is separately processed, evaluated, and qualified. Data anomalies are either edited or rectified prior to processing the individual arcs. The parameters of importance in our global solution include the center-of-mass tracking station locations, the polar motion and UT1 variations of the earth, and station tidal variations. The gravity field and the earth and ocean tidal models also affect the solution, as well as arc dependent radiation pressure coefficients and along-track acceleration parameters which are used to empirically model a drag-like effect on the satellite. The station positions and velocities are estimated for each station in the network over the full data time span. The reference frame is set by fixing some station components at GGAO and Hawaii [Smith et al., 1990], but no vertical constraints are applied, and the rates in that component are independent of the chosen reference frame. The height velocities are however directly dependent on the instrument characteristics, and we have attempted to correct for all known biases that may appear in the data residing in the CDDIS, as they are documented in the ILRS web site.

Results of the Analysis

The vertical motion at SLR stations for which we have enough data to determine height rates to an accuracy better than two millimeters per year are shown in Table 1. The sites capable of PGR model assessment all lie in the region of fore-bulge collapse. ICE–4G [Peltier, 1996] predicts subsidence at Herstmonceux and Potsdam of about one mm/year. On the other hand (and on the other ice-sheet), the model predicts a larger subsidence of more than two mm/year at GGAO, which is a strong signal for results that reach an accuracy of better than ½ mm/year for these observations. Most of the other stations in the European SLR Network would all be expected to exhibit vertical motion less than ½ mm/year.

Table 1: HEIGHT RATES FOR SLR STATIONS

ICE-4G	SLR	+/-	SPAN	STATION
RATE IN MM/YR				
-0.81	0.28	3.8	85-91	POTSDAM1
	-0.96	1.3	92-99	POTSDAM2
-0.23	-1.30	1.6	85-91	WETTZELL1
	0.26	4.2	92-99	WETTZELL2
-0.81	0.55	1.9	92-99	BOROWIEC
-0.08	0.02	1.0	92-99	GRASSE
+0.14	0.80	1.4	85-95	ZIMWALD1
-0.70	-0.99	0.6	85-99	RGO
-0.09	-0.07	0.6	85-99	GRAZ
-0.12	-0.48	0.8	85-99	MATERA
-2.53	-1.81	0.5	85-99	GGAO

Conclusions

The long-term vertical motion at Matera, Grasse and Graz amount to less than ½ mm/yr, which is the level of resolution of the most capable stations. The stations at Zimmerwald and Borowiec were found to need time to accumulate a long enough record to reach this level of accuracy. The Potsdam station was found to exhibit a hint of subsidence, which is consistent with prevailing models of post-glacial rebound. The station at Herstmonceux demonstrates significant subsidence in good agreement with the model, which places it in the area of fore-bulge collapse at the edge of the original ice sheets.

These vertical motions observed on the edge of the Fenno-Scandia rebound area can be directly compared to model predictions for the present-day uplift based on shoreline data, as well as with developing PGR model predictions, and to constrain the lateral homogeneity of the upper mantle. The change in the uplift across the rebound area can also be compared with the observed in the Laurentide in Canada, enabling us to test models for the uplift, and also to assess the lateral homogeneity of the whole upper mantle, on whose viscosity the rate of rebound depends.

References

Argus, D., Postglacial Rebound from VLBI Geodesy: on establishing a vertical reference, Geophys. Res. Let., 23, 9, pp 973-976, May, 1996.

Dunn, P. J., M. H. Torrence, D. E. Smith, R. Kolenkiewicz, Vertical Crustal Motion at SLR Stations, spec. suppl. of Eos Trans. p S86, April 25, 1995

Heflin, M., D. Jefferson, Y. Vigue, M. Watkins, F. Webb, J. Zumberge, and G. Blewitt, GPS Times Series: January 22, 1991 - April1, 1994, JPL Interoffice Memo, November 23, 1994.

Peltier, W. R. ICE-4G model predictions for the IERS sites, found at http://maia.usno.navy.mil/conventions/chapter7/pgr.model, 1996.

Peltier, W. R., VLBI baseline variations from the ICE-4G model of postglacial rebound, Geophys. Res. Let, 22, 4655-468, 1995.

Peltier, W. R., Ice Age Paleotopography, Science, 265, 195-201, 1994.

Peltier, W.R., G.T. Jarvis, A.M. Gorte, and L.P. Solheim, The radial structure of the mantle general circulation, Mantle Convection, Plate Tectonics, and Global Dynamics, pp. 765 -818, Gordon Beach Science Publishers, New York, 1989.

Peltier, W.R., R.A. Drummond, and A.M. Tushingham, Post-glacial rebound and transient lower mantle rheology, Geophys, J.R. Astron, Soc., 87, 79-116, 1986.

Tushingham, A. M. and Peltier, W. R., Ice-3G: a New Global Model of Late Pleistocene Deglaciation Based Upon Geophysical Predictions of Post-Glacial Relative Sea Level Change, J. Geophys. Res., 97, 3285-3304, 1991.