Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 39 (2007) 1604–1611
ADVANCES IN SPACE RESEARCH (a COSPAR publication)
www.elsevier.com/locate/asr

CHAMP and GRACE resonances, and the gravity field of the Earth

R.H. Gooding [a,*], C.A. Wagner [b], J. Klokočník [c,d], J. Kostelecký [d,e,f], Ch. Gruber [c]

[a] Surrey Space Centre, University of Surrey, Guildford, England, UK
[b] National Oceanic and Atmospheric Administration, Laboratory for Satellite Altimetry, Silver Spring, MD, USA
[c] Astronomical Institute, Czech Academy of Sciences, Ondřejov Observatory, Czech Republic
[d] Center for Earth Dynamics Research, Prague-Ondřejov, Czech Republic
[e] Faculty of Civil Engineering, TU, Prague, Czech Republic
[f] Research Institute of Geodesy, Topography and Cartography, Zdiby, Czech Republic

Received 24 October 2006; received in revised form 29 January 2007; accepted 23 February 2007

Abstract

Using orbital data far more precise than existed a quarter of a century ago, we have derived values for lumped geopotential harmonic coefficients from the passage of the satellites CHAMP (Challenging Minisatellite Payload) and GRACE (Gravity Recovery And Climate Experiment) through particular resonances. Due to orbit decay, CHAMP first passed through the 46/3 resonance (orbit repeating after 46 revolutions over three days) and then, in due course, 77/5, 31/2 and 47/3; indeed it passed through 31/2 three times, following orbit raises to extend the satellite's useful lifetime.

The orbit data we used for CHAMP came from the retrospectively computed and highly accurate state vectors, but for GRACE (both satellites) only the routine (less accurate) TLEs (Two-Line mean Elements) have so far been available, being used for 61/4 analysis. Values for the lumped harmonics come from analysis of the large variation in the orbital inclination (and to a lesser degree the nodal right ascension) that they cause.

Our main success has been for the 31/2 resonance, including the implicit 62/4, but in all cases our lumped values agree well with values based on the complete CHAMP and GRACE high-degree global gravity models (Eigen-3p and Eigen-Grace02s, respectively), though essentially independent of them. This confirms both the validity of our method and the high quality of the new global models.

Keywords: Gravity field resonances; Lumped coefficients; CHAMP; GRACE

1. Introduction

The use of a satellite's passage through orbit resonance to evaluate lumped geopotential harmonics was pioneered by Gooding (1971). Resonant lumped harmonics are the linear combinations of the standard harmonics that, due to the particular resonance, amplify the long-term variation of the orbital elements, in particular of I (inclination), e (eccentricity), and Ω (right ascension of the node). Here, we worked mainly with I, the element most commonly used, taking advantage of the resonances experienced by CHAMP and GRACE (launched with the specific aim to derive global gravity models of unprecedented accuracy from single satellites), but we also used Ω. We identify a resonance by the ratio β/α, for an orbit having a ground-track repeat rate of β revolutions over α synodic days. These integers are co-prime and define the *fundamental* resonance, but *overtone* and *sideband* resonances (the latter usually less important) may also be relevant: the (γ-1)th overtone is specified as $\gamma\beta/\gamma\alpha$, with $\gamma\beta = m$, the order of that resonance (Gooding and King-Hele, 1989), whilst a sideband involves a final index, q, which modifies the effect of $\gamma\alpha$ (as we will see in Section 2.1). Thus we obtained results for 62/4 and 93/6 as well as 31/2, and for 94/6 as well as 47/3.

* Corresponding author.
E-mail addresses: family.gooding@virgin.net (R.H. Gooding), carl.wagner@noaa.gov (C.A. Wagner), jklokocn@asu.cas.cz (J. Klokočník), kost@fsv.cvut.cz (J. Kostelecký).

0273-1177/$30 © 2007 Published by Elsevier Ltd on behalf of COSPAR.
doi:10.1016/j.asr.2007.02.086

Before the widespread use of laser tracking, the evaluation of resonance-based lumped harmonics was often superior to that of harmonics based on scattered Doppler or high-precision camera observations from several non-resonant orbits, the rationale for this being the amplification of the perturbations over long-periods. Today, however, in view of continuous high-precision GPS satellite-to-satellite tracking for both CHAMP and GRACE, plus inter-satellite data between GRACE A and GRACE B, resonant analyses cannot always compete with the high-degree global models derived from such observations (see Section 4). But between 2000 and 2006 these very satellites spent long enough periods in near-repeat orbits (with $\beta/\alpha = 46/3$, 77/5, 31/2, and 47/3 for CHAMP, and 61/4 for GRACE) to make the resonance technique once more viable, if only as an independent check of the precision of fields derived directly from their tracking.

CHAMP's orbit manoeuvres, in 2002 and 2006, increased a (semi-major axis), providing opportunities to analyze the same resonance (31/2 in 2002 and 2003, 47/3 in 2005–2006) more than once. These resonances are depicted chronologically, with the relevant changes in inclination as modelled by Eigen-3p (Reigber et al., 2005a), in Fig. 1.

The first CHAMP results, from Klokočník et al. (2003), had been for the earlier 46/3 resonance and their quality was limited through being based on the TLEs. The first results for orders 31 and 62 (also from the TLEs) were then presented by Gooding et al. (2005). Here, starting from 30-s state vectors kindly provided by GFZ Potsdam (GeoForschungsZentrum, www.gfz-potsdam.de, the CHAMP ISDC user directory), we reanalyze (for I) and also analyze for Ω. Thus, after converting the state vectors to mean elements (Section 2.2), which are significantly more accurate than the TLEs, we present new results for 31/2 and initial results from CHAMP's first passage through 47/3. We also present first results from the passage of GRACE (both A and B) through 61/4 resonance, but based only on the TLEs, state vectors for GRACE not having been available.

2. Overview of the method

2.1. General

More detail of the resonance technique may be found in King-Hele (1992), and of its revival in Gooding et al. (2005). In summary, we use (linear) least squares to fit the appropriate lumped harmonics to our observational data (the mean element selected for analysis, as it varies over time periods of many months). Prior to the fit we remove known non-resonant perturbations (see Section 2.3). Along with the resonant analysis of the reduced observations we also fit empirical terms: a constant, the effects (for I) of a super-rotating atmosphere, and tidal phases at periods revealed by the residuals from successive trial fits.

The resonance technique was originally used with any fortuitously suitable orbit, to obtain values for a handful of lumped harmonics not well determined by existing global models. Now, though CHAMP and GRACE have both been used for global models, our technique continues to focus on the amplified effects of very long periods that are only weakly represented by global models whose tracking data arcs span only one or two days. Thus, despite

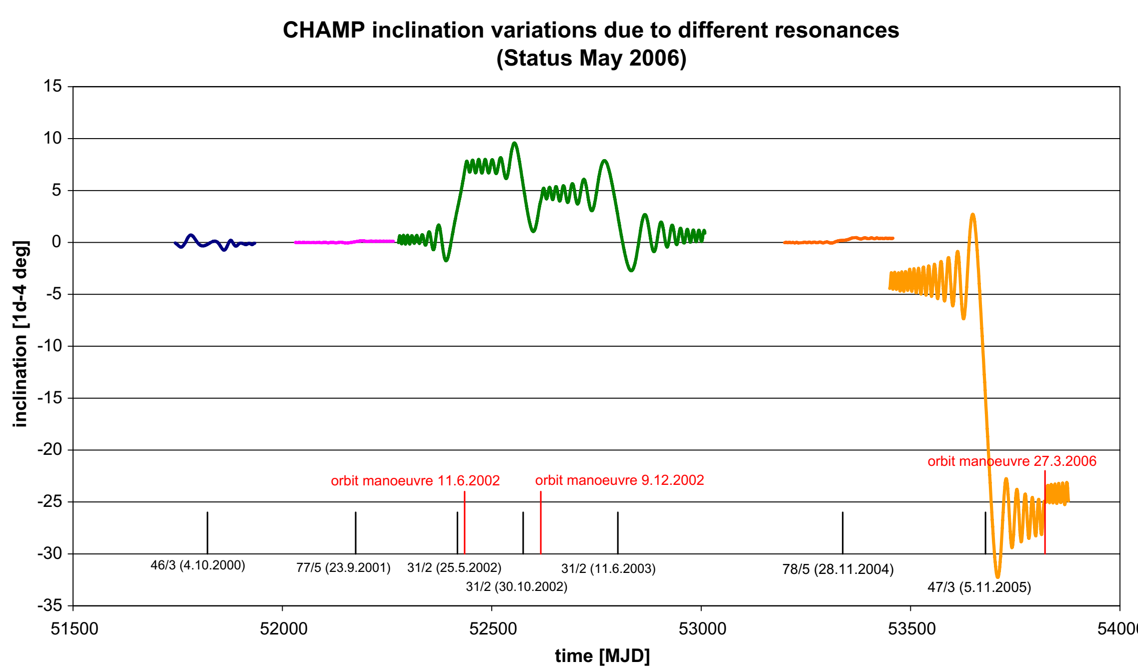

Fig. 1. CHAMP's inclination variation through the 46/3, 77/5, 31/2, 78/5, and 47/3 resonances, the maximum changes being equivalent to about 50 m for 31/2 and 150 m for 47/3.