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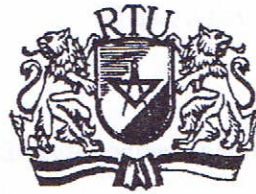
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GOCE Mission and Data Processing

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Abstract. Since 2010 at the Institute of Geodesy and Geoinformation, University of Latvia, the work on project “EUPOS contribution to GOCE (Gravity Field and Steady-State Ocean Circulation Explorer) mission” (Id: 4307) which was approved by European Space Agency in 2008 is progressing. One of the ESA’s Earth Observation Programmes is: The Living Planet. The paper gives an overview of the GOCE mission, its status on March 2011; as well as describes the GOCE’s three main instruments, the GOCE data access and the processing which has been carried out at the Institute of Geodesy and Geoinformation.

Keywords: ESA’s Living Planet Programme, GOCE, data access, data processing, precise orbit determination.

I. INTRODUCTION

European Space Agency (ESA) has been dedicated to observing Earth from space ever since the launch of its first meteorological satellite, Meteosat, in 1977.

One of the ESA’s Earth Observation Programmes is: The Living Planet.

In Toulouse in 1995, the ESA Ministerial Council set the course for the Agency’s Earth Observation Strategy and issued a ‘Proposal for a European Policy for Earth Observation from Space’, put forward jointly by ESA, the European Commission (EC) and the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat). In January 1998, the European Parliament voiced its very strong support for action.

Three fundamental objectives were set in Toulouse:

- developing our knowledge of the Earth,
- preserving the Earth and its environment,
- managing life on Earth in a more efficient way,

and the principle of two types of Earth Observation missions was adopted: *Earth Explorers* for research, including the demonstration of associated new observing techniques, and *Earth Watches*, prototype operational missions serving the operational applications oriented needs of market.

In response, ESA set up a Strategy Task Force and an Ad Hoc industrial Working Group, which helped to establish the ‘Living Planet’ Programme.

The family of *Earth Explorer* missions is a result of this strategy. Currently there are six missions in this category; among them: the Gravity Field and Steady-State Ocean Circulation Explorer (GOCE) and a further three undergoing feasibility study [1].

GOCE was launched on 17th of March 2009 from Plesetsk Cosmodrome in Russia. GOCE is the first core mission of ESA’s Living Planet Programme.

GOCE is controlled from the European Space Operations Centre (ESA/ESOC) in Darmstadt, Germany. The science data is processed and archived by the Payload Data Ground Segment (PDGS) located in ESA/ESRIN close to Rome, Italy.

Further data processing is then done by the High-level Processing Facility (HPF), operated under ESA contract by a consortium of European institutes, the European GOCE Gravity Consortium [2].

The aim of GOCE is to measure the Earth’s gravity field and to provide a model of the geoid with unprecedented accuracy, determining gravity field anomalies with an accuracy of 1 mGal (or 10^{-5} ms⁻²), and the geoid to an accuracy of 1 to 2 cm at a spatial resolution better than 100 km.

To obtain a sufficiently strong gravity field signal, GOCE orbits the Earth in a sun-synchronous orbit.

The altitude of GOCE’s satellite orbit is about 260 km, where the density of the Earth’s atmosphere is significant. Therefore the spacecraft is specifically designed for minimizing air drag forces and torques, and possesses the capability to counteract the air drag in order to maintain the orbit and cancel out non-gravitational forces. The actual orbit altitude is chosen according to the current solar activity level.



Fig. 1. GOCE in orbit. [3]

Accurate knowledge of the Earth’s gravity field has a wide range of applications.

Concerning the use of GOCE data products, five different themes have been distinguished:

- Oceanography;
- Solid-Earth;
- Geodesy;
- Glaciology;
- Sea level change studies.

In project the “EUPOS contribution to GOCE mission”, the emphasis generally is put on the use of data in geodesy. Further plans involve the use of GOCE’s data for comparison with a ground based observation data, for example GNSS (*Global Navigation Satellite Systems*)/leveling data. The high precision geoid model can serve for the studies of Earth crust

movements and for unification of height systems between *EUPOS* countries, using *EUPOS* - European Position Determination System. The aim is to approach to the solution attempts of GNSS determined height tasks [4] [5].

II. GOCE MISSION STATUS MARCH 2011

The nominal *GOCE* mission's lifetime was predicted for 12 months. Since early March 2011, the *GOCE*'s mission has completed its second year of continuous operations.

As stated in the *GOCE* newsletter for March 2011 the *GOCE* satellite and its payload are in excellent conditions and operating nominally. The configuration of both payloads and all satellite subsystem has remained unchanged, as well as the orbital altitude of 254.9 km and the respective 61 days repeat cycle have remained constant since launch.

The persistent low solar activity throughout 2010, the good health of the power subsystem and the excellent thermo-elastic stability of satellite and gradiometer have allowed to continue science measurements during eclipse phases. Operating all year round significantly increases the overall data return compared to pre-launch planning, which foresaw hibernating the satellite during eclipses.

Currently, measurement cycle #7 is being executed. The individual measurement cycles are shifted with respect to each other along the equator in order to decrease the distance between ascending node crossings. An average distance of ascending node crossings of 10 km has been achieved. The advantage of this strategy, compared to longer repeat cycles which would yield a denser ground coverage pattern, lies in a reduced sensitivity to measurement interruptions due to satellite anomalies [6].

III. GOCE INSTRUMENTS

GOCE satellite consists of three main instruments:

1. Electrostatic Gravity Gradiometer with three pairs of accelerometers (EGG),
2. Satellite-to-Satellite Tracking Instrument (SSTI)
3. Laser Retroreflector,

described and represented below.

GOCE is the first spacecraft employing the concept of gradiometry, i.e. the measurement of acceleration differences over short baselines between proof masses of a set of accelerometers of *GOCE*'s Electrostatic Gravity Gradiometer (see Fig. 2).

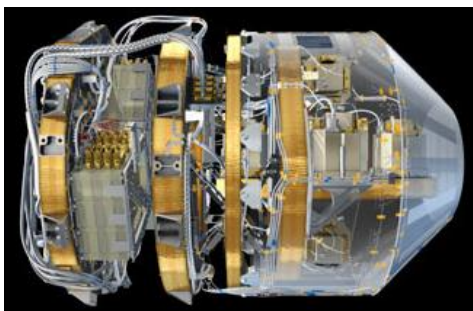


Fig. 2. EGG – Electrostatic Gravity Gradiometer with three pairs of accelerometers. [7]

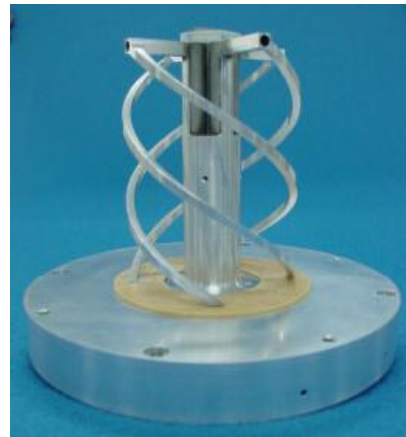


Fig. 3. Satellite-to-Satellite Tracking Instrument. (SSTI) [8]

The EGG is used to measure high-resolution features of the gravity field, while large-scale phenomena in the gravity field are obtained through analysis of *GOCE*'s orbit as measured with a scientific GNSS receiver on-board the spacecraft, the Satellite-to-Satellite Tracking Instrument (see Fig. 3).



Fig. 4. Laser Retroreflector. [8]

One of the other main instruments of *GOCE* is a Laser Retroreflector (see Fig. 4), which provides accurate positioning for orbit determination and data products.

IV. GOCE DATA ACCESS

Due to the exceptionally low solar activity level in the first half of 2009 as well as later most of the commissioning phase period from March till September was spent lowering the satellite orbit through natural decay to an altitude where the average air drag would meet the envelope of the ion propulsion based drag-free control system. The gradual decay was halted at 254.9 km mean altitude in mid-September 2009 [9].

As a result of these manipulations, the first *GOCE* data set covers the period from 01-11-2009 until 30-11-2009. It and later *GOCE* data sets (until 30-11-2010) are available through *GOCE*'s Virtual on-line Archive (VOA) or through *ESA*'s Multi-Mission archive, EOLI-SA.

EOLi (Earth Observation Link) is the European Space Agency's client for Earth Observation Catalogue and Ordering Services.

Data on EOLI-SA are organized in collections. A screenshot is shown in Fig. 5.

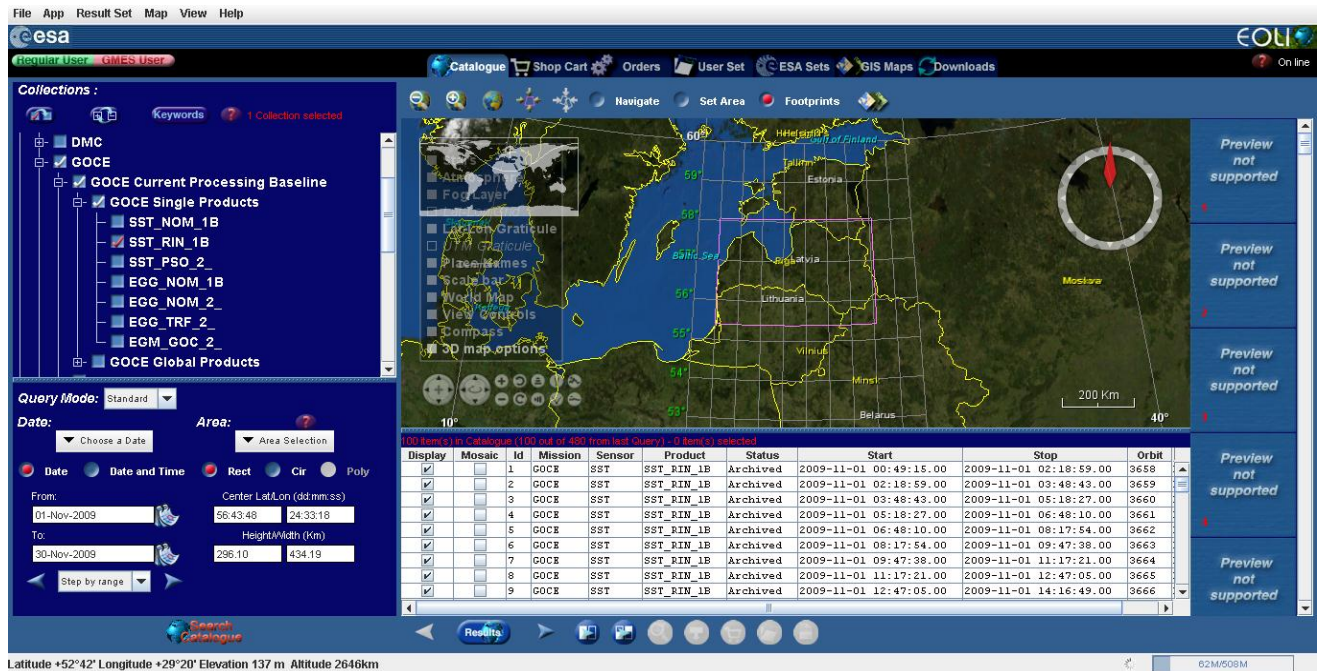


Fig. 5. GOCE SST_RIN_1b product selection in EOLI-SA user interface. [by authors]

Users can search the *GOCE* catalogue and submit orders free of charge. Once a Category-1 project is accepted and/or user registration is completed, and also the Terms and Conditions have been signed, the *ESA*'s Help and Order Desk will provide users with an EOLI-SA account with ordering privileges [9].

Personal username and password for the *GOCE*'s Virtual on-line Archive are the same as for EOLI-SA.

EOLI users receive, for each order, a link for downloading the data via ftp, while Virtual Archive users can directly download data through http, without the need of submitting orders. EOLI interface offers, however, more flexibility and tools for data selection in comparison with *GOCE* Virtual Archive [6].

GOCE data set contains data from the three principal sensors on *GOCE*: Star Tracker (STR), Electrostatic Gravity Gradiometer (EGG) and Satellite to Satellite Tracking Instrument (SSTI). The product types that contain this information are:

- 1) SST_NOM_1b (nominal SSTI L1b product);
- 2) SST_RIN_1b (SSTI RINEX L1b product);
- 3) EGG_NOM_1b (nominal EGG product).

There is no dedicated Star Tracker product, as the "optimal" attitude information is not based on star trackers only but on sensor-fusion of the star tracker and gradiometer data. This derives from the fact that the gradiometer is in fact also an excellent attitude sensor (gyro).

The *GOCE* attitude information is therefore contained inside the EGG_NOM_1b product.

All *GOCE* L1b products have a validity period of one orbit, from ascending node crossing to the next [9].

V. GOCE DATA PROCESSING

According to the project "EUPOS contribution to *GOCE* mission", the work on *GOCE* data processing at the Institute of Geodesy and Geoinformation at the University of Latvia has been commenced.

Initially work started with the processing of LatPos and EUPOS-Riga base station data. The processing is being performed with the Bernese v5.0 software package.

The Bernese GPS Software allows computing precise orbits for Low Earth Orbiters (*LEOs*) equipped with GPS receivers. The software allows to process data from many kinematic GNSS applications, including the kinematic and reduced-dynamic precise orbit determination (*POD*) for *GOCE*. *LEO*'s may be considered either as satellites, like GNSS but at lower attitude, or as receiver, like ground stations but in orbit [10].

In order to process *GOCE* data, the guidelines for *LEOs* data processing described in Bernese v5.0 software manual were used.

The used data inputs and resulting outputs for *GOCE* precise orbit determination with Bernese GPS Software are listed below:

Inputs:

- a) CODE high rate final clocks, 30-second values: CODwwwd.CLK;
- b) CODE final orbits: CODwwwd.EPH;
- c) Earth Orientation parameters – CODE final ERPs belonging to the final orbits: CODwww7.ERP;
- d) differential (P1-C1) code bases for satellites and receivers: PIC1yymm.DCB;
- e) GPS satellite problem file: SAT_yyyy.CRX;
- f) *GOCE* satellite RINEX observation data files (SST_RIN_1b – SSTI RINEX L1b product);

- g) *GOCE* satellite attitude data (is necessary, but hasn't been used);
- h) station information file: EXAPLE.STA;
- i) the coordinate file, which needs to contain an entry for the satellite, where coordinates may be zero;
- j) satellite information file: SATELLIT.I05;
- k) phase center file: PHAS_COD.I05;
- l) receiver information file: RECEIVER.

Outputs:

- a) inertial (J2000) positions of center of mass of *GOCE* satellite in Bernese STD format;
- b) Earth-Centered-Earth-Fixed (*ECEF*) positions of center of mass of *GOCE* satellite in SP3c format.

Currently, at the Institute of Geodesy and Geoinformation the ionosphere-free observations in a zero-difference reduced-dynamic filtering approach for *GOCE* precise orbit determination are used.

The zero-difference approach requires estimation of zero-difference ambiguities and epoch-wise clocks for the *LEO* and the availability of high-rate (synchronous with *LEO* epochs) GPS satellite clock offsets. Fortunately, the pre-elimination of *LEO* clocks and ambiguities from the normal equation (NEQ) system allows for efficient zero-difference processing [11].

The processing steps for *GOCE* precise orbit determination with Bernese GPS Software are the following:

1. The import of a *GOCE* RINEX file is done with program RXOBV3.
2. An initial orbit may be generated on the basis of code observations using program CODSPP in kinematic mode. Within this CODSPP run the receiver clock is synchronized to GPS system time. CODSPP writes estimated kinematic coordinates.
3. The resulting kinematic coordinate file has to be converted to a precise orbit file with program KINPRE.
4. From the precise file a standard orbit is computed using program ORBGEN. The orbit integration has to be based on a recent gravity field model EIGEN2. The output consists of a STD orbit file and radiation pressure file (RPR).
5. The screening of the phase data by using program MAUPRP in zero-difference mode has to be completed. This program performs cycle slip detection and correction for the zero-difference *LEO* ionosphere-free observations. If an attitude file is

available for the satellite, it should be selected in the field "LEO attitude".

6. The screened phase observation files are used in GPSEST to improve *LEO* orbit parameters. The radiation pressure file together with the corresponding standard orbit (obtained in step 4) has to be introduced.
7. The improved *GOCE* orbital elements are introduced in the input field "Update standard orbit" of the top panel of ORBGEN. The result is an improved standard orbit for the *GOCE*.
8. The screening procedure should be performed iteratively repeating the processing steps from (5) to (7). Usually, after the second iteration the screening is finalized.
9. The reduced-dynamic orbit resulting from the last update from ORBGEN is already of good quality [10].
10. STDPRE program creates a precise *LEO* SP3c orbit file from the updated STD orbit file.

The reduced-dynamic orbit may be selected as a priori information and the screened phase observation files may also be used for the determination of the kinematic trajectory [10].

VI. RESULTS

Unfortunately, it is not possible to process the *GOCE* GNSS data using Bernese Version 5.0. The observation epochs of *GOCE* are not at the full seconds but Version 5.0 is not capable to handle correctly the seconds with fractions. According the information from Bernese authors it will be solved in programme Version 5.2.

Nevertheless, the work has been performed with Bernese GPS Software v5.0 and data of *GOCE* initial and zero-difference reduced-dynamic orbits has been obtained for the period, where the observation epochs of *GOCE* are at the full seconds (19-12-2009 – 20-12-2009). This data is obtained as a space-based solution; it means that *GOCE* orbit determination has been performed without ground station observations.

Coordinates of the *GOCE* initial orbit have been imported to the MicroStation V8i for orbit better representation (see the Fig. 6).

The result data of zero-difference reduced-dynamic orbit for *GOCE* has been obtained without attitude characteristics, because Bernese GPS Software Version 5.0 does not support at the moment the *GOCE* attitude data format. That is why obtained data can contain some inaccuracy. This will be solved in the nearest future.

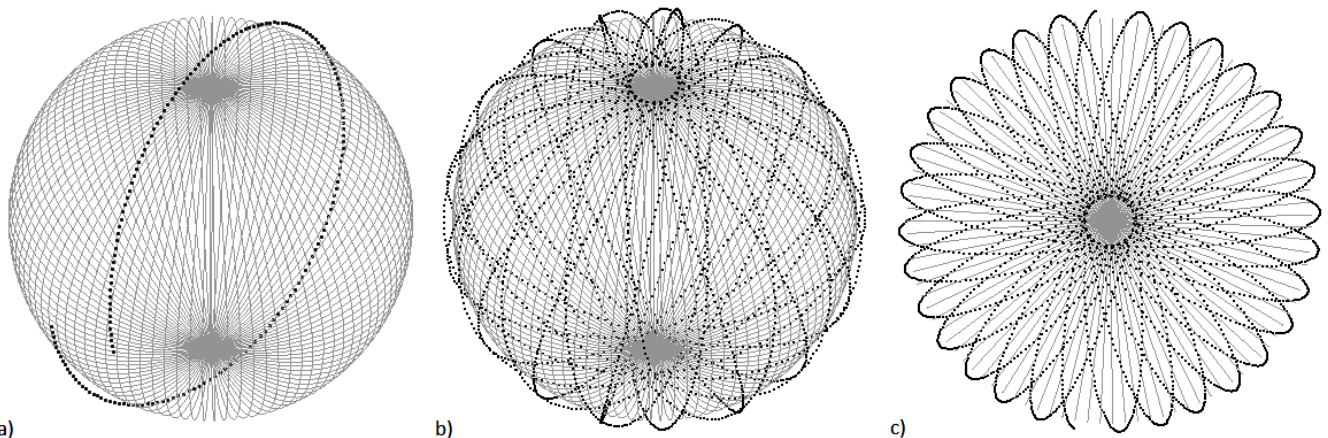


Fig. 6. GOCE initial orbit visualization (data with 30 sec interval):

- a) 1 h 30 min time span;
- b) 23 h 10 min time span;
- c) 23 h 10 min time span, view from the top. [by authors]

VII. CONCLUSIONS

Preparation for *GOCE* data processing has been started in October 2010. The problem, which stopped workflow for a few months, was incomplete compilation of the Bernese GPS software. Then it was successfully solved.

Unfortunately, it turned out that it is not possible to process the *GOCE* GNSS data with Bernese Version 5.0, because the observation epochs of *GOCE* are not at the full seconds. Nevertheless, the work has been performed with v5.0 and data of *GOCE* initial and zero-difference reduced-dynamic orbits has been obtained for the period, where the observation epochs of *GOCE* are at the full seconds.

The result data has been obtained without *GOCE* attitude characteristics, because Bernese GPS Software Version 5.0 does not support at the moment the *GOCE* attitude data format. This will be solved in the nearest future.

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Madara Normand, Diāna Haritonova. GOCE misija un datu apstrāde

Kopš 2010. gada Latvijas Universitātes Ģeodēzijas un ģeoinformātikas institūtā notiek darbs pie projekta "EUPOS contribution to GOCE mission" (Id: 4307), kuru 2008. gadā apstiprināja Eiropas Kosmosa aģentūra (EKA). Projektā "EUPOS contribution to GOCE mission" galvenais uzsvārs tiek likts uz datu pielietošanu ģeodēzijā. Tālākie plāni ietver GOCE datu salīdzināšanu ar Zemes staciju novērojumu datiem, piemēram, GNSS (*Globālās navigācijas satelītu sistēma*) vai nivelēšanas datiem. Augstas precizitātes ģeoida modelis var kalpot Zemes garozas kustības pētījumiem un augstuma sistēmu saistīšanai starp EUPOS valstīm, izmantojot Eiropas Pozīcijas noteikšanas sistēmu (EUPOS - *European Position Determination System*). Šī projekta īstenošanai tika izpētītas GOCE datu iegūšanas iespējas, tajā skaitā datu lejupielāde no GOCE Virtuālā arhīva (VOA) un datu pasūtīšana, izmantojot EOLI-SA interfeisu. Tika izanalizētas Bernese GPS Software Version 5.0 opcijas GOCE datu apstrādē, kā arī iegūtas GOCE aptuvenās sākuma un dinamiskās orbītas. GOCE datu apstrādes gaitā tika konstatēts, ka Bernese programmatūras versija 5.0 nav pielāgota GOCE datu apzīšanai; galvenā problēma ir tāda, ka GOCE RINEX novērojumu failos epohas satur nevis veselas sekundes, kā tas parasti ir bāzes staciju novērojumu failos, bet sekunžu daļas, kuras Bernese programmatūra nespēj korektu identificēt. Šī problēma ir atrisināma ar Bernese programmatūras versiju 5.2, kura pēc aktuālās informācijas tiks izdota 2011. gada beigās. Neskatoties uz to, darbs netika pārtraukts, un GOCE orbītas datu aprēķinam tika atrasts un izvēlēts laika posms, kurā GOCE novērojumu epohas ir ar veselām sekundēm. GOCE orbītas tika noteiktas bez satelīta pozīcijas datiem, kuri satur informāciju par satelīta asu izvietojumu inerciālajā telpā, kas samazina precīzās orbītas noteiktību. Šo problēmu ir iespējams un ir plānots atrisināt, pielāgojot Bernese programmatūru tā, lai tā atbalstītu GOCE pozīcijas datu formātu. Iegūtās GOCE orbītas koordinātas balstās uz tā saukto kosmisko risinājumu, kurā netiek izmantoti Zemes staciju novērojumi. Turpmākais mērķis ir vērsts uz LatPos bāzes staciju un GOCE satelīta novērojumu datu integrēšanu.

Мадара Норманд, Диана Харитоновна. Миссия и обработка данных спутника GOCE

С 2010 года в Институте геодезии и геоинформатики Латвийского университета ведётся работа над проектом "EUPOS contribution to GOCE mission" (Id: 4307), который был утверждён Европейским космическим агентством (EKA) в 2008 году. В проекте "EUPOS contribution to GOCE mission" главный акцент направлен на применение данных в геодезии. Дальнейшие планы включают в себя сравнение данных спутника GOCE с данными наблюдений наземных станций, например, с данными GNSS (*Глобальная Навигационная Спутниковая Система*) или нивелирования. Высокоточная модель геоида может служить для исследований движения земной коры и для соединения систем высот между странами EUPOS, используя Европейскую систему нахождения позиции (EUPOS - *European Position Determination System*). Для осуществления этого проекта были изучены возможности доступа данных, в том числе загрузка данных с Виртуального архива GOCE (VOA) и запрос данных используя интерфейс EOLI-SA. Были проанализированы опции Bernese GPS Software Version 5.0 для обработки данных GOCE и получены начальные приблизительные и динамические орбиты GOCE. В процессе обработки данных спутника GOCE было констатировано, что версия 5.0 программного обеспечения Bernese не распознаёт данные GOCE; главная проблема заключается в том, что эпохи в файлах наблюдений GOCE формата RINEX содержат не целые секунды, как это обычно принято в файлах наблюдений станций, а дробные секунды, которые не могут быть правильно идентифицированы программным обеспечением. Эта проблема разрешима в версии 5.2, которая по актуальной информации будет выпущена в конце 2011 года. Несмотря на это, работа не была прервана, и для поиска данных орбит GOCE был найден и выбран период времени, в котором эпохи наблюдений GOCE – с целыми секундами. Орбиты GOCE были получены не используя данные о позиции спутника, которые содержат информацию о расположении осей спутника в инерциальном пространстве, что увеличивает погрешность точной орбиты. Эту проблему возможно, а также планируется разрешить приспособив программное обеспечение Bernese так, чтобы оно поддерживало формат данных GOCE о позиции. Полученные координаты орбиты GOCE базируются на, так называемом, космическом решении, в котором не используются наблюдения наземных станций. Дальнейшая цель направлена на интеграцию данных наблюдения базовых станций системы LatPos и спутника GOCE.

