3.5.6 Global Geophysical Fluids Center (GGFC)

The Global Geophysical Fluids Center (GGFC), a product center of the International Earth Rotation and Reference Systems Service, serves the worldwide research community, by providing information on the geodetic effects of fluid motions within the Earth and on its surface. The products provided are estimates of the variations in the Earth's rotation, its shape, its gravitational field, and geocenter, (at various temporal and spatial scales) which are caused by the mass transport of geophysical fluids.

There are currently eight Special Bureaus (SB), which supply products in response to community requirements. These include: Atmospheres, Oceans, Hydrology, Tides, Mantle, Core, Loading, and Gravity/Geocenter (see attached reports). The various products generated by the SB's are based on global observations of surface fluid motion and/or state-of-the-art models, which estimate fluid motion within or on the surface of the Earth. The products are available through the individual SB web sites and can be accessed via the GGFC portal housed at the European Center for Geodynamics and Seismology (<http://www.ecgs.lu/ggfc/>).

In some SB's the yearly activity is high as new surface fluid models and data sets are constantly becoming available and are thus required by the geodetic research community. The annual activities of these SB's are included here in the annual report. In other SB's, the fluid models or data sets are well established and changes, if they occur, occur rarely and thus an annual report is not required. The annual report in this case, simply restates the model or data that are available from that particular SB. It is still valuable to have a single location where even established and validated fluid models and their predicted effects on geodetic observables can be found.

In 2005, the International Association of Geodesy established the Global Geodetic Observing System (<http://www.ggos.org/>). GGOS will provide observations of the three fundamental geodetic observables (the Earth's shape, the Earth's gravity field, and the Earth's rotational motion) and their variations. The official establishment of the GGOS potentially increases the importance of the GGFC, as now the GGFC represents a resource where anyone can obtain modeled estimates of geodetic effects due to the Earth's fluid motion to compare with the GGOS observations.

Members

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For other members see the lists of members of the individual Special Bureaus below.

Tonie van Dam

Special Bureau for the Atmosphere

In conjunction with the U.S. National Oceanic and Atmospheric Administration (NOAA) the SB Atmosphere has produced data from 4 different operational meteorological centres. We have also produced data from atmospheric reanalyses, spanning back to 1948. SB Atmosphere organized a system to operate in two modes. In the first, it supplies the data in near-real time through the services at NOAA, including analysis and forecast terms. In the second mode, it updates monthly archives of the data on the FTP server at Atmospheric and Environmental Research, Inc. (AER).

The principal data prepared relate to atmospheric excitations of the Earth rotation vector, as forced by changes in the winds and surface pressure of the atmosphere, known respectively as the motion and mass terms of the atmospheric angular momentum AAM. For the axial component, related to length-of-day, the stronger term is the motion one, and for the equatorial term, related to polar motion, the mass term generally dominates. An “inverted barometer” correction is produced to the mass terms, designed to model an equilibrium condition of the oceans in which the ocean depresses in response to a higher atmospheric pressure and rises in response to a lower one.

SB Atmosphere also computes the AAM terms locally, in a number of equal-area sectors distributed around the globe, as well as globally. In addition, SB Atmosphere computes the mean atmospheric surface pressure over the globe, and various spherical harmonics, which are related to the Stokes coefficients of the Earth gravity field, of particular interest to recent space-gravity missions. SB Atmosphere archives torques from the NCEP-NCAR reanalyses that relate to the angular momentum transfer from atmosphere to solid Earth, including topographic (mountain), friction, and gravity wave drag torques. Users log in to our ftp sites to obtain the desired information.

Dr. Yonghong Zhou became a member of the SBA. He has been processing the atmospheric data from his position at Shanghai Astronomical Observatory to help update the SBA archives. He processes both the NCEP-NCAR reanalyses using the revised codes that were developed while he was a visitor at Atmospheric and Environmental Research. The new procedure and related scientific results are detailed in Zhou et al. (2006). The revised procedure has improved on the treatment of the lower boundary and also updated a number of geophysical constants needed to calculate the atmospheric excitations.

Atmospheric thermal tides are known to cause diurnal variations in wind, which transfer here to variations in polar motion excitation. The diurnal signal, moreover, is seasonally modulated. Two functions (1 and 2) for polar motion were analysed for all twelve months in 2002; the axial (3) term was also processed, though it is relatively much smaller. The polar motion terms have strong variations with magnitude of ~ 10 mas. They have a distinct 'winter mode' (January to February, October to December) and 'summer mode' (March to September). The axial length of day term has very small daily variation with magnitude of ~ 0.009 ms. We established the similarity of these two terms from the NCEP and the JMA analyses.

During 2005 we investigated the possibility of using atmospheric models for more rapid subdiurnal scales. Fields from one of the NASA models can be extracted hourly, in between the six-hour analyses that are routinely used. We have been investigating the feasibility of calculations of the atmospheric excitation terms for the Earth orientation parameters. A test period was October 2002, during the special CONT02 campaign in which measurements from Very Long Baseline Interferometry developed high temporal resolution data.

Also during the year, Dr. Jolanta Nastula of the Space Research Centre of the Polish Academy of Sciences, Warsaw, visited AER for the purpose of calculating regional fields of the Earth orientation parameters to help understand better the atmospheric excitations of polar motion.

Acknowledgments

Dr. Zhou's visit to AER was sponsored by the Descartes-Nutation Program, chaired by V. Dehant, and we are grateful for this support. The U.S. National Science Foundation has supported activities, at AER of the SBA, and the visit of Dr. Nastula, under Grant ATM-0429975.

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David Salstein

Special Bureau for the Oceans

Introduction

The oceans have a major impact on global geophysical processes of the Earth. Nontidal changes in oceanic currents and ocean-bottom pressure have been shown to be a major source of polar motion excitation and also measurably change the length of the day. The changing mass distribution of the oceans causes the Earth's gravitational field to change and causes the center-of-mass of the oceans to change which in turn causes the center-of-mass of the solid Earth to change. The changing mass distribution of the oceans also changes the load on the oceanic crust, thereby affecting both the vertical and horizontal position of observing stations located near the oceans. As part of the IERS Global Geophysical Fluids Center, the Special Bureau for the Oceans (SBO) is responsible for collecting, calculating, analyzing, archiving, and distributing data relating to nontidal changes in oceanic processes affecting the Earth's rotation, deformation, gravitational field, and geocenter. The oceanic products available through the IERS SBO web site at <http://euler.jpl.nasa.gov/sbo> are produced primarily by general circulation models of the oceans that are operated by participating modeling groups and include oceanic angular momentum, center-of-mass, and bottom pressure.

Data Products

Five different oceanic angular momentum series are currently available from the IERS Special Bureau for the Oceans:

(1) ponte98.oam, a series computed by Ponte *et al.* (1998) and Ponte and Stammer (1999, 2000) from the products of a simulation run of the MIT ocean general circulation model which spans January 1985 to April 1996 at 5-day intervals;
(2) johnson01.oam, a series computed by Johnson *et al.* (1999) from the products of version 4B of the Parallel Ocean Climate Model (POCM) which spans January 1988 to December 1997 at 3-day intervals;
(3) c20010701.oam, a series computed by Gross *et al.* (2003, 2004) from the products of a simulation of the oceans' general circulation run by the Estimating the Circulation and Climate of the Ocean (ECCO) group at JPL which spans January 1980 to March 2002 at daily intervals;
(4) ECCO_50yr.oam, a series computed by Gross *et al.* (2005) from the products of a simulation of the oceans' general circulation run by the ECCO group at JPL which spans January 1949 to December 2002 at 10-day intervals; and
(5) ECCO_kf049f.oam, a series computed by Gross *et al.* (2005) from the products of a data assimilating model of the oceans' general circulation run by the ECCO group at JPL which spans January 1993 through March 2006 at daily intervals.

Five different oceanic center-of-mass series are also currently available from the IERS Special Bureau for the Oceans:

(1) dong97_mom.cm, a series computed by Dong *et al*. (1997) from the results of a version of the Modular Ocean Model (MOM) run at JPL which spans February 1992 to December 1994 at 3-day intervals;
(2) dong97_micom.cm, a series also computed by Dong *et al*. (1997) from the results of running the Miami Isopycnic Coordinate Ocean Model (MICOM) at JPL which also spans February 1992 to December 1994 at 3-day intervals;
(3) c20010701.cm, a series computed by Gross (personal communication, 2003) from the results of a simulation run of the ECCO ocean model done at JPL which spans January 1980 to

March 2002 at daily intervals;

(4) ECCO_50yr.cm, a series computed by Gross (personal communication, 2004) from the products of a simulation of the oceans' general circulation run by the ECCO group at JPL which spans January 1949 to December 2002 at 10-day intervals; and

(5) ECCO_kf049f.cm, a series computed by Gross (personal communication, 2004) from the products of a data assimilating model of the oceans' general circulation run by the ECCO group at JPL which spans January 1993 through March 2006 at daily intervals.

Time series of the ocean-bottom pressure are currently available from the IERS SBO through a link to the JPL ECCO web site at <http://ecco.jpl.nasa.gov/external> from which two dimensional ocean-bottom pressure fields can be obtained that have been produced from purely surface flux-forced ocean models as well as ocean models that additionally assimilate satellite and in situ data. A link is also provided to the GLObal Undersea Pressure (GLOUP) data bank of ocean-bottom pressure measurements at <http://www.pol.ac.uk/psmslh/gloup/gloup.html>.

In addition to these data sets, a subroutine to compute oceanic angular momentum, center-of-mass, and bottom pressure from the output of general circulation models can be downloaded from the IERS SBO web site along with a bibliography of related articles.

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Special Bureau for Tides

The IERS Special Bureau for Tides collects datasets related to the effects of tides on Earth rotation and geocenter motions. The Special Bureau for Tides generates most of its own product data sets by analyzing the results of numerical computer models of the relevant geophysical fluids, in this case both ocean tides and atmospheric tides. The Bureau is therefore dependent upon the work of modelers to release their solutions to the EOP community; in the case of tides, this means solutions for both tidal elevations and tidal current or wind velocities on a global (or nearly global) grid. The data archive that the Bureau maintains has slowly grown as individual tidal investigators contribute to their modeling results. The data collected by the Special Bureau are publicly available via the internet at <http://bowie.gsfc.nasa.gov/tides>.

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Special Bureau for Hydrology

The Special Bureau for Hydrology provides internet access to data sets of water storage load variations for major land areas of the world. The web site contains results from four numerical models, the NCEP (National Center for Environmental Prediction) reanalysis, the ECMWF (European Center for Medium Range Weather Forecasting) reanalysis, the CPC (Climate Prediction Center) Land Data Assimilation System (LDAS), and NASA's Global Land Data Assimilation System (GLDAS). Global terrestrial water storage changes estimated from GRACE (Gravity Recovery and Climate Experiment) time variable gravity observations during the period April 2002 and November 2005 are also provided in our online data archive (at <http://www.csr.utexas.edu/research/ggfc/>). The NASA GLDAS and CPC LDAS data products are updated on a regular basis.

As a new addition to our online data archive, GLDAS is an advanced land surface modeling system jointly developed by scientists at the NASA Goddard Space Flight Center (GSFC) and the NOAA NCEP. GLDAS parameterizes, forces, and constrains sophisticated land surface models with ground and satellite products with the goal of estimating land surface states (e.g., soil moisture and temperature) and fluxes (e.g., evapotranspiration). In this particular simulation, GLDAS drove the Noah land surface model version 2.7.1, with observed precipitation and solar radiation included as inputs. GLDAS estimates are the sum of soil moisture (2 m column depth) and snow water equivalent. Greenland and Antarctica are excluded because the Noah model does not include ice sheet physics. The GLDAS data are provided on 1° x 1° grids and at 3-hourly intervals. Daily average terrestrial water storage is computed from the 3-hourly model estimates. Antarctica is not included in the model and estimates over Greenland are not recommended to use, because of the lack of ice dynamics in the model.

The NCEP reanalysis model is a fixed data-assimilating global numerical model, designed mainly for atmospheric studies. It has been run for a period starting in 1948, up to the present. NCEP results are valuable for their global coverage and long duration. The hydrologic part of this model is mainly employed as a lower boundary condition in the model, and reflects a combination of an imposed (non data-assimilating) hydrologic cycle, and interaction with the atmosphere. The NCEP reanalysis variations are probably representative of the real Earth, but not accurate in detail. They lack the level of inter-annual variability expected in the real hydrologic cycle, and observed in some more sophisticated data-assimilating land surface model results. In addition, there are evident flaws over Antarctica and Greenland, which probably result from locating highly variable sea ice at land grid points. Therefore Antarctica and Greenland are excluded from geodetic calculations. The web site includes daily NCEP water storage in Gaussian grid (T62) form for Jan. 1979 – Dec. 2004, and polar motion and length of day excitation time series for Jan. 1948 – Dec. 2004, as well.

The ECMWF data-assimilating reanalysis model, similar to NCEP, also with a surface hydrologic cycle. We find that it appears more realistic than NCEP, showing greater interannual variability. In addition, its seasonal cycle resembles long-term average results based on local budget (Precipitation-Evaporation-Runoff) calculations. The web site includes 2.5-degree gridded values at daily intervals for the period 1979–1993.

CPC LDAS is forced by observed precipitation, derived from CPC daily and hourly precipitation analyses, downward solar and longwave radiation, surface pressure, humidity, 2-m temperature and horizontal wind speed from NCEP reanalysis. The output consists of soil temperature and soil moisture in four layers below the ground. At the surface, it includes all components affecting energy and water mass balance, including snow cover, depth, and albedo. Monthly averaged soil water storage changes are provided on a 1 x 1 degree grid. These data are averaged from the original 0.5 x 0.5 degree grid and converted into NetCDF and standard ASCII format. The data cover the period Jan. 1980 through Dec. 2005. No estimate is provided over Antarctica. A README file and a few Matlab scripts used for doing the conversion are provided as a reference to the data format.

The README file with the NCEP and ECMWF data also includes details on the way in which actual loads are calculated from the soil moisture model field. Data are available in both ascii and NetCDF (.nc) formats. In addition, there are helpful sample Matlab commands lists and m-files for reading the data in NetCDF format with Matlab, and for interpolating from the original model grid to a uniform (for example 1 x 1 degree) grid.

We provide estimates of equivalent surface water storage using GRACE time variable gravity observations provided by the GRACE team at the Center for Space Research (CSR), University of Texas at Austin. 22 monthly, unconstrained GRACE solutions (RL01) covering the period April 2002 and July 2004 are used to estimate global surface mass change on a 1 x 1 degree grid. Results with 3 different spatial Gaussian smoothing scales, 600 km, 800 km, and 1000 km are provided. The GRACE spherical harmonics are truncated at degree and order 60, and the C20 term is not included. A newly added similar product is the equivalent surface water storage change derived from 3.5 years of GRACE RL01 constrained solutions provided by CSR. This new product is from 40 GRACE monthly solutions covering the period April 2002 and November 2005.

The Special Bureau for Hydrology is currently planning to provide the community a few new data products, which should be available online in late 2005. The new data products include combined surface mass load changes from the atmosphere, ocean, and land water. The purpose is to provide a product similar to the GRACE atmospheric and oceanic dealiasing (AOD) dataset, but to also include the hydrology part and apply a full baroclinic ocean general circulation model. The plan is to combined NCEP reanalysis 6-hourly atmospheric pressure change, 12-hourly ocean bottom pressure change from the ECCO (Estimating the Circulation and Climate of the Ocean) data assimilating ocean general circulation model, and the GLDAS 3-hourly terrestrial water storage change to generate a 6-hourly AOW (atmosphere, ocean, and water) surface mass load product. A number of issues need to be addressed, including mass conservation of a dynamically coherent system, data representation (spherical harmonics and surface grids), data format, and etc.

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Special Bureau for Mantle

The Special Bureau for Mantle was established to provide services for information and data exchange to facilitate research in the geodynamic effects due to motions in the mantle. Accounting for 68% of the mass and 89% of the moment of inertia of the entire Earth, the solid, but non-rigid, mantle is perpetually in motion. There are motions caused by external forces, including tidal deformation, atmospheric and oceanic loading, and occasional meteorite impacts. For internal processes, volcanic eruptions and pre-seismic, coseismic and post-seismic dislocations associated with an earthquake act on short timescales. On longer timescales, present-day post-glacial rebound, surface processes of soil erosion and deposition, and tectonic activity such as plate motion, orogeny, and internal mantle convection, all transport large masses over long distances. Finally, the entire solid Earth undergoes an equilibrium adjustment in response to the secular slowing down of the Earth's spin due to tidal friction.

As with any geophysical processes that involve mass transports, these large-scale motions produce variations in Earth's rotation, gravity field, and geocenter. Among them, however, currently only two topics have been extensively investigated: co-seismic excitation of Earth rotational and gravitational changes and glacial isostatic adjustment.

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Special Bureau for the Core

Introduction

Flow in the fluid outer core, and also motion of the inner core with respect to the outer core, can result in various geodetic phenomena observable from the Earth's surface or space. These phenomena include variations in the Earth's rotation and orientation, surface gravity changes, geocenter variations, and surface deformations. Although small, these variations can or could be observed by very precise space geodetic techniques. Observation of these effects yields unique insight into the core, which cannot be observed directly, and the resulting better understanding of the core will lead to improved models and predictions for the geodetic quantities.

Activities

The Special Bureau for the Core is responsible for collecting, archiving, and distributing data related to the core and plays a role in promoting and coordinating research on this topic. In particular, the SBC focuses on theoretical modelling and observations related to core structure and dynamics (including the geodynamo), and on inner core – outer core – mantle interactions. The SBC has about twenty members from the fields of geomagnetism, Earth rotation, geodynamo modelling (numerical and experimental), and gravimetry. The SBC has set up a web site (<http://www.astro.oma.be/SBC/main.html>) as the central mechanism for providing services to the geophysical community. Since one of the goals of the SBC is to distribute general information on the core, to make the geophysical community aware of the various geodetic effects that could be linked with the core, and to stimulate, support and facilitate core research, we present on our website concise explanations on topics as core convection, core flow, geomagnetism, core-mantle boundary torques, inner core differential rotation, Earth's rotation changes due to the core, and core composition. Additionally, we have built and continuously update a bibliography of articles relevant to the core that at present contains more than a thousand references.

Data products

The web site presently contains model data on core flow and core angular momentum. Most data are based on the observed surface geomagnetism field, and various hypotheses and physical assumptions are used to determine the flow and the angular momentum of the core. Moreover, a high-resolution time series is given that is determined by subtracting computed atmospheric angular momentum series from a time series for length of day variations. In addition to the data, a description is given of the relevant theories and of the dynamical assumptions used for constructing the flows.

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Special Bureau for Gravity/Geocenter

The Special Bureau for Gravity/Geocenter continued its focus on building a gateway to the GRACE and CHAMP primary gravity and ancillary analysis data permanently archived at the Physical Oceanography Distributed Archive (PO.DAAC) at JPL and the ISDC in Potsdam, as well as various SLR and GPS solutions. The Head of the SBGG also worked with a NASA-funded team to develop a user-focused gateway for GRACE products (<http://grace.jpl.nasa.gov>). This site provides useful interactive post-processing products of the primary gravity products archived at PO.DAAC and ISDC, and may be more useful for many SBGG customers.

The US/European joint science team for GRACE provided a major release of new gravity field solutions in November of 2005. These solutions include the mean gravity field, the monthly variations, and the 6-hr dealiasing products based on a barotopic and baroclinic ocean models (driven by ECMWF pressure and winds over the ocean) and ECMWF pressure over the land. Links are available to these solutions from the SBGG website.

Associates of the Special Bureau continue to play major roles in seeking additional dealiasing and data correction (loading) models through discussion with associates of other special bureaus.

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Special Bureau for Loading

Introduction

All mass movements on the Earth’s surface load and deform the solid Earth and impact the gravity field and rotation on a level significant for the geodetic reference frame and the interpretation of geodetic time series. Mass transport in the atmosphere, oceans, continental hydrosphere, and cryosphere takes place on a wide range of temporal and spatial scales, thus introducing load-induced signals in all geodetic observations from sub-hourly (in the case of tsunamis, Plag et al., 2006) to millennium time scales (in the case of postglacial rebound, PGR) and from local to global spatial scales. In the vertical component, loading signals significantly exceed and are at the 10 mm level at diurnal and seasonal time scales, respectively, while secular signals associated with PGR are on the level of 10 mm/yr. On global scale, surface displacements induced by seasonal exchanges between ocean and terrestrial hydrosphere are of the order of 10 mm (Blewitt & Clarke, 2003), affecting the geodetic reference frame at the same order of magnitude.

SBL goals and contributions

As part of the IERS Global Geophysical Fluid Center, the Special Bureau for Loading (SBL) has the long-term goal to provide predictions of surface-load induced changes in the Earth's geometry, gravity field and, eventually, rotation. When established in 2002, the short-term goal of the SBL was the provision of predictions of changes in Earth's geometry induced by atmospheric loading, preferably in near-real time. In 2003, time series of atmospheric load induced station displacements for the main global and regional geodetic networks were made available, and in 2004, the semi-operational near-real time provision of station displacement as well as global grids was started. While the former (denoted as Research Products) were provided for different atmospheric pressure data sets, Earth models, and computational approaches (see Van Dam et al., 2003, for more details), the latter (denoted as Operational Products) were made available for air pressure provided by the *European Center for Medium Range Weather Forecast* (ECMWF), only (see <http://www.sbl.statkart.no/products> for more information on these products).

Atmospheric loading

In 2005, one focus was on the intercomparison of the research products. The maximum differences found for predictions given in the same reference frame are of the order of 4 mm and 1 mm for the vertical and horizontal components, respectively, though strongly depending on location. Results from other web pages providing access to loading predictions were included in the comparison (which also identified errors in some of these predictions). Main sources for the discrepancies are seen in the different air pressure data sets and the implementation of the inverted barometer response of the ocean, while differences in Earth models and computational approaches appear not to be important (see also Van Dam et al., 2003). The comparisons so far show that the detailed error budget of the loading computations is not well understood.

For the computation of the atmospheric loading signal, the air pressure anomaly is required at the Earth's surface, where the surface needs to be given with sufficient spatial resolution. In the meteorological models, the Earth's surface is represented by a model orography, typically given with a resolution of one or more degrees. The ECWMF does not routinely give access to the model surface pressure as computed on the model orography. In 2004, the SBL was advice to compute the pressure at topographic height from the air pressure and temperature at mean sea level. However, it was later discovered that the pressure at sea level is derived by a coarse approximation from the model surface pressure (see Section 2.4.3 in White, 2003), which leads to large, time-dependent errors particularly under the large ice sheets and high mountain areas. Thus, this parameter is found to be inadequate for the computation of air pressure anomalies at topographic height. As a result of using the ECMWF pressure at mean sea level for the near-real time loading calculations, these products are biased at seasonal time scale particularly over Antarctica, Greenland, and Central Asia.

Postglacial rebound

On global and regional scales, one of the main secular signal in geodetic quantities results from PGR. For many studies utilizing geodetic time series, this signal has to be removed (e.g. Velicogna & Wahr, 2006; Sato et al., 2006), while for others, it provides a means to validate the geodetic observations (e.g. Plag & Kreemer, 2006). In order to make available predictions of the present-day PGR signal in geodetic quantities, the SBL issued a Call for Submission of predictions early in 2005, which was widely distributed to the PGR research community. The predictions submitted so far (3 groups), which include also the ice history and the Earth models, are made available through <http://www.sbl.statkart.no/projects/sbl>. The intercomparison of the predictions as well as the comparison to geodetic observations is in progress.

Perspective

The near-real time provision of atmospheric loading predictions has to be based on model surface pressure and temperature, from which the pressure at topographic height can be computed. However, the spatial resolution of the surface topography is a parameter affecting the overall error budget of the predictions. The SBL in 2006 focuses on establishing the detailed error budget of the loading calculations at the sub-millimeter level. The determination of the required spatial resolution of the Earth topography in order to keep the error contribution due to topography on the 0.1 mm level is one of the goals in studying the full error budget.

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