3.5.6 Global Geophysical Fluids Center (GGFC)

The International Earth Rotation and Reference Systems Service (IERS)'s Global Geophysical Fluids Center (GGFC) provides the geodetic community with models of geodetic effects (earth rotation, gravity, and deformation) driven by the temporal redistribution of the Earth geophysical fluids. These include fluid motions within the Earth system such as the core and mantle, as well as the motions of surface fluids (e.g. oceans, atmospheres, and continental water).

The GGFC is composed of four operational entities: the Special Bureau for the Atmosphere (SBA, Chair, D. Salstein), the Special Bureau for the Oceans (SBO, Chair, R. Gross), the Special Bureau for Hydrology (SBH, Chair, J.-L. Chen), and the Special Bureau for the Combination Products (SBCP, Chair, T. van Dam). The Atmosphere, Hydrology and Oceans SBs have been firmly established since the creation of the GGFC in 1998. The operational SB, Combination Products, was established in 2009 to house the new data sets that model the mass movement of combined environmental fluids such as oceans+atmosphere. There is a GGFC non-operational component, the GGFC Science and Support Products. This component serves as a repository for models and data used regularly in data processing but that do not change often. The GGFC is still actively searching for a Chair for this component.

Up to the latest realization of the International Terrestrial Reference System (ITRS), namely ITRF2008 (Altamimi et al., 2011), technique contributions were requested not to include non-tidal loading models in the geodetic data processing. Attempts have been made to consider non-tidal loading corrections as a posteriori corrections to construct a multi-technique combined reference frame (Collileux et al., 2010). However, the improvement, while conclusive at some stations, has not been systematically observed. In the meantime, more and more scientific studies have included NT-ATML a priori corrections as a standard, as currently done by the International VLBI Service (IVS) for their operational products. Thus, the question is raised whether the application of NT-ATML corrections alone could improve the determination of the Terrestrial Reference Frame (TRF). Indeed, while some published studies quantifying the effects of NT-ATML corrections on positions and velocities can be found for most of the techniques, NT-ATML corrections have never been applied over the same period of time for the four techniques using the same model. While results have been supplied recently for a combination of GPS and SLR data (Sośnica et al., 2013), the impact on a combined coordinate dataset including all technique measurements has never been studied.

In addition, software and technique specific induced effects were never fully investigated regarding this specific issue. Following a recommendation of the Unified Analysis Workshop 2011 that took place in Zurich, the IERS decided to launch a campaign to assess the effect of NT-ATML corrections on the TRF. Space geodetic solutions, i.e. sets of station coordinates, EOPs, additional parameters and their covariances were requested over a period of five years. The GGFC and the various analysis centers contributed data with NT-ATML applied and not applied to the ITRF to evaluate the impact of NT-ATML corrections on estimated station positions, velocities and EOPs as a result of a combination of multi-technique solutions. The issue of applying mean daily/weekly NT-ATML corrections to solutions versus using the loading model at the observation level in the data processing was also revisited for the four space geodetic techniques. This method of correcting co-ordinates after the observation adjustment has the advantage of not requiring a full data reprocessing. Such a comparison has already conducted for VLBI and GPS only.

Special Bureau for the Oceans

The oceans have a major impact on global geophysical processes of the Earth. Nontidal changes in oceanic currents and ocean-bottom pressure are 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 SBO website 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. Through the SBO website, oceanic data can be downloaded and a bibliography of publications pertaining to the effect of the oceans on the solid Earth can be obtained. Additional information about the SBO can be found in an unpublished manuscript available through the SBO Publications website at <http://euler.jpl.nasa.gov/sbo/sbo_publications.html> and in the SBO chapter of IERS Technical Note 30, Proceedings of the IERS Workshop on Combination Research and Global Geophysical Fluids (http://www.iers.org/TN30).

During 2014, the SBO website was maintained and products from the ECCO/JPL ocean model were updated. Daily values of oceanic angular momentum, oceanic excitation functions, and oceanic center-of-mass from the kf079 (simulation) and kf080 (data assimilating) runs of the ECCO/JPL ocean model are now available from 01 January 1993 through 31 December 2014. These values can be extended back to 01 January 1949 using the corresponding values from a 50-year-long simulation run of the ECCO/JPL ocean model whose results are also available through the SBO website.

In addition, a link is provided to the ECCO/JPL website at <http://ecco.jpl.nasa.gov> from which grids of modeled ocean-bottom pressure can be obtained, a link is provided to the GGFC website at <http://geophy.uni.lu/ggfc-oceans/ECMWF-loading.html> from which grids of ocean loading determined from the ECCO/JPL modeled ocean-bottom pressure can be obtained, and a link is provided to the GLObal Undersea Pressure (GLOUP) data bank of ocean-bottom pressure observations at <http://www.ntslf.org/files/acclaimdata/gloup/gloup.html>. Finally, a link is provided to the GFZ Helmholtz Centre Potsdam's Effective Angular Momentum Functions (EAM) website at < http://www.gfz-potsdam.de/en/section/earthsystemmodelling/services/data-products/> from which consistent estimates of atmospheric, oceanic, and hydrologic angular momentum can be obtained.

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 SBO website along with a bibliography of related articles.

Acknowledgments. The work described in this Section was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

Special Bureau for the Atmosphere

The Special Bureau for the Atmosphere (SBA) is concerned with the atmospheric information that is needed for a number of geodetic issues. The SBA was an outgrowth of the earlier Sub-bureau for Atmospheric Angular Momentum prior to the creation of the GGFC, and can be accessed at <https://www.aer.com/science-research/earth/earth-mass-and-rotation/special-bureau-atmosphere>.

Calculations of atmospheric angular momentum (AAM) are made from a number of global meteorological operational analyses and reanalyses, and are archived at the SBA. Long-term archives are at Atmospheric and Environmental Research in the file <http://ftp.aer.com/pub/anon_collaborations/sba/>. AAM from analyses and forecasts are updated daily at NOAA on <http://ftp.cpc.ncep.noaa.gov/long/aam/>. On-line readme files on these two sites are useful in documenting the data sets.

Operational atmospheric analyses are fields determined from observations during the epoch they are valid from the resident atmospheric analysis system in use at that time. Thus the systems, the main components of which are atmospheric forecast models and data assimilation systems, have changed over the years. In contrast, atmospheric reanalysis systems use a constant analysis system to reprocess the historical atmospheric observational data. Thus the earlier periods are analyzed with a more advanced system than existed during their era, and the whole record of reanalysis is more suitable for long-term studies. The reanalyses were developed for consistent climate studies, and we use them here for long-term geodetic studies.

The AAM and related data are from the following large meteorological centers: US National Centers for Environmental Prediction, NCEP (formerly known as the National Meteorological Center); the Japan Meteorological Agency, JMA; the United Kingdom Meteorological Office, UKMO; and the European Center for Medium-Range Weather Forecasts (ECMWF). The ECMWF AAM is not updated daily in the on-line service but rather by links by our contributors, as noted below.

The SBA has on-line links from a number of contributors listed on the website; these include a number of atmospheric data related to surface loading, path delays, and gravity. The specialized ECMWF fields are accessed this way. Cooperating institutions are: the Geoforschungszentrum, Potsdam, Germany; Vienna University of Technology, Austria; University of Luxembourg, Goddard Space Flight Center, University of Strasbourg, France, and the University of New Brunswick, Canada.

During 2014, the SBA updated all fields from AAM; the updates were performed by Dr. Y. Zhou of the Shanghai Astronomical Observatory, China.

We participated in the recent GGFC workshop presenting analysis of the archived analyses, and possible addition of other analyses to the datasets, including the U.S. Navy's NAVGEM analysis and forecasts.

Special Bureau for Hydrology

The Special Bureau for Hydrology (http://www.csr.utexas.edu/research/ggfc/) provides internet access to data sets of terrestrial water storage (TWS) variations from major climate and land surface models and GRACE (Gravity Recovery and Climate Experiment) satellite gravity measurements. The web site contains TWS estimates from five 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), the NASA's Global Land Data Assimilation System

(GLDAS), and the NOAA LadWorld land dynamics model. Global gridded TWS changes estimated from GRACE time-variable gravity observations are also provided in our online data archive (at <http://www.csr.utexas.edu/research/ggfc/dataresources.html>). The NASA GLDAS and GRACE data products are updated on a regular basis.

SBH also provides fully normalized gravity spherical harmonic coefficients (in the same definition as the GRACE products) up to degree and order 100, computed from the GLDAS-estimated TWS changes. This product offers the convenience for hydrologists who want to compare GRACE estimates and model predictions in a more consistent way by applying similar truncation and spatial filterings to both GRACE and model estimates. This data set is highly welcomed by the hydrological community.

In addition, TWS change estimates from historical GRACE release-01 and release-04 products are also provided in our online data archive (at <http://www.csr.utexas.edu/research/ggfc/dataresources.html>). Some other data sets available in the SBH online data archive include daily hydrological excitations of polar motion and length-of-day computed from the NCEP/NCAR Reanalysis and the list of global major artificial reservoirs and their compacities.

During 2014, we have updated the monthly GLDAS TWS estimates to extend the coverage from January 1979 to December 2014. GLDAS gravity spherical harmonic coefficients have also been updated to cover the period January 2002 to December 2014. GRACE release-05 monthly TWS estimates with decorrelation and 300 km and 500 km Gaussian smoothing applied have been updated to extend the coverage to August 2014.

Combinational Products

Here we provide updated information on the AOD Products used to estimate loading.

- GRACE non-tidal high-frequency atmospheric and oceanic mass variation models are routinely generated at GFZ as so-called Atmosphere and Ocean De-aliasing Level-1B (AOD1B) products to be added to the background static gravity model during GRACE monthly gravity field determination. AOD1B products are 6-hourly series of spherical harmonic coefficients up to degree and order 100, which are routinely provided to the GRACE Science Data System and the user community with only a few days time delay.
- The GRACE AOD1B products were accepted by the International Earth Rotation and Reference Systems Service (IERS) Global Geophysical Fluid Center (GGFC) as Provisionary Products in 2009 and have been given the status of GGFC Operational Products in May 2012.

- The most recent AOD1B product version for the period 2000 till today is release 05 (RL05) which is based on ECMWF operational data.
- In March 2015 GFZ has also generated and delivered AOD1B RL05 products for 1979–2000 based on ERA-interim data.
- Details can be found at <http://www.gfz-potsdam.de/aod1B>.

GGFC Operational Products	**Principal Investigator**	**Proposed GGFC Operational Center**
• UNB Vienna Mapping Function Service • <http://unb-vmf1.gge.unb.ca/Products.html>	M. Santos	University of New Brunswick
• AAM analysis (and forecast*) series from: ○ NCEP Reanalysis (1948–) ○ NCEP operational (1976–)*, also known as NMC ○ JMA operational (1993–)* ○ UKMO operational (1986–2006; and also to present)* ○ ECMWF operational (1988–01.2000) ○ ECMWF ERA-40 reanalysis (1959–2002)	D. Salstein	Atmospheric and Environmental Research
• Vienna Mapping Function Service • AAM series from 6-hourly ERA-40 and operational analysis data starting in 1980 • AAM series from 10-day forecast data • Cartesian coordinates of the center of mass of the atmosphere and total mass of the atmosphere at 6-hourly intervals • Atmospheric loading ECMWF • Atmospheric gravity coefficients: thin layer approach and vertical integration approach	J. Boehm and M. Schindelegger	Technical University of Vienna
• Global Mass Change Fields From GRACE (RL 05 & 04, 1x1 deg) • GLDAS Monthly Water Storage (1x1 deg) • Gravity Spherical Harmonics from GLDAS Monthly Water Storage Change • NOAA LadWorld Monthly Water Storage (1x1 deg) • CPC Monthly Water Storage (1x1 deg) • Daily hydrological excitations of polar motion and LOD from NCEP/NCAR Reanalysis • List of Major Artificial Reservoirs with Water Capacity Exceeding 10 km^3 • http://geophy.uni.lu/ggfc-hydrology.html	J.L. Chen	University of Texas at Austin GGFC Special Bureau for Hydrology
• Atmospheric loading: NCEP (2.5 deg; 6-hr) • <http://gemini.gsfc.nasa.gov/aplo/> • Continental water loading: GLDAS • <http://lacerta.gsfc.nasa.gov/hydlo/>	D. MacMillan	Goddard Space Flight Center

• Site displacements due to atmospheric pressure loading • Low degree harmonic time series from LAGEOS[1] • <ftp://gfzop.gfz-potsdam.de/nt-atml/>	J.-C. Raimondo R. Koenig	Helmholtz Centre Potsdam – GFZ German Research Centre for Geosciences
• High resolution atmospheric loading (3-hr; 0.5 deg): ECMWF (Operational)+IB and ECMWF+MOG2D • ERA Interim+IB 6 hours • Continental water loading: GLDAS/NOAH (3hr), ERA interim (6 hours) • Effects on gravity and tilt • <http://loading.u-strasbg.fr>	J.-P. Boy	Ecole et Observatoire des Sciences de la Terre; University of Strasbourg
• Atmospheric loading (NCEP 2.5 x 2.5; 6 hourly) • <http://geophy.uni.lu/ggfc_atmosphere/NCEP-loading.html> • GLDAS continental water storage loading (2.5 x 2.5; monthly) • <http://geophy.uni.lu/ggfc-hydrology.html> • ECCO bottom pressure (2.5 x 2.5; 12 hourly) • <http://geophy.uni.lu/ggfc-oceans.html> • GRACE AOD ATM + OBP mass data (1.8 x 1.8 deg; 6 hourly) see Section on Combination Products • GRACE AOD ATM + OBP loading effects (2.5 x 2.5 deg; 6 hourly) • <http://geophy.uni.lu/ggfc-combination/about-2.html> • S1/S2 tidal loading calculator • <http://geophy.uni.lu/ggfc-atmosphere/tide-loading-calculator.html>	T. van Dam	University of Luxembourg
• Hydrological Loading from LSDM water (0.5 x 0.5; 24 hr) • <http://www.gfz-potsdam.de/en/section/earthsystemmodelling/services/hydl/>	R. Dill	GFZ
• AAM, HAM, OAM (ECMWF operational, ECMWF forecasts, ERA-Interim, ERA40) • <http://www.gfz-potsdam.de/en/section/earthsystemmodelling/services/data-products/>	M. Thomas	GFZ
• GRACE AOD dealiasing products (6 hourly) • <http://www.gfz-potsdam.de/en/section/earthsystemmodelling/services/aod1b-product/>	F. Flechner	GFZ

[1] The system is not operational yet as we decided to augment our data basis to the ensemble of geodetic satellites (AJISAI, STARLETTE, STELLA, and LARES in addition to the LAGEOS satellites). We expect to become operational by June/July. Also in this case we'll provide the products via site.

Many of the centers above also provide products that will soon become provisional products in the GGFC archive, e.g. GSFC (MacMillan) provides Atmospheric gravity (deg/order 72/72, 20/20), loading from ECCO bottom pressure (1 deg, 12-hr) and raytraced VLBI troposphere delays. These products have not yet been tested and compared with existing products.

For information on submitting proposals for GGFC operational products, please go to <http://geophy.uni.lu/ggfc-about/to-submit-new-proposals-for-products.html> or contact T. van Dam (tonie.vandam@uni.lu).

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