Description of the Level 2 and Level 3 IGETS data produced by EOST (version 2)

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Abstract

The document presents the processing of the superconducting gravimeter data performed at EOST (Ecole et Observatoire des Sciences de la Terre) in Strasbourg, France. Starting from the raw 1-minute gravity and pressure records (level-1 products), we eliminate major perturbations, such as instrumental offsets, gaps and spikes and produce the level-2 products, ready for tidal analysis.
Finally, from these level-2 data, we produce gravity residual time series after correction for solid and oceanic tides, polar motion and length-of-day, atmospheric loading and instrumental drift (level-3 products).

This new version describes changes in the Level-3 data processing; we corrected 2 bugs in the Polar-Motion and the Tidal models, and improved the atmospheric loading correction using ERA5 (Hersbach et al., 2020) instead of MERRA2 (Gelaro et al., 2017) atmospheric reanalyses (changes compared to the older documents are provided in red).

1. Introduction

The primary objective of the International Geodynamics and Earth Tide Service (IGETS) is to provide a Service to monitor temporal variations of the Earth gravity field through long-term records from ground gravimeters and other geodynamic sensors. IGETS continues the activities of the Global Geodynamic Project to provide support to geodetic and geophysical research activities using superconducting gravimeter data within the context of an international network. IGETS also continues the activities of the International Center for Earth Tides, in particular, in collecting, archiving and distributing Earth tide records from long series of gravimeters, and other geodynamic sensors.

The IGETS data base, hosted by GFZ, is the main data center of worldwide high precision SG records; the different products are, according to the terms of references (http://igets.u-strasbg.fr/Documents/IGETS_ToR.pdf) :

- Raw gravity and local pressure records sampled at 1 or 2 seconds, in addition to the same records decimated at 1-minute samples (Level 1 products).
- Gravity and pressure data corrected for instrumental perturbations, ready for tidal analysis. This product is derived from the previous datasets, and is computed by one or several Analysis Centers (Level 2 products).

- Gravity residuals after particular geophysical corrections (including solid Earth tides, polar motion, tidal and non-tidal loading effects). This product is also derived from the previous dataset and is computed by one or several Analysis Centers (Level 3 products)

We present the processing of the superconducting gravimeter data available at the IGETS database (Voigt et al., 2016), and describe quickly the file format and content. The two next sections are devoted first to the level-2 data processing and then for the level-3 data.

2. EOST Level 2 data

2.1 Methodology

Raw 1-minute gravity and pressure (Level 1 data) are calibrated using the available calibration files.
We first process the pressure data, removing interpolated hourly surface pressure from ERA5 (Hersbach et al., 2020) reanalysis model. We correct manually these residuals for eventual offsets, and fill any gaps with a linear interpolation. The de-gapped series is then corrected for the remaining perturbations (spikes) using a threshold on its derivative, following Crossley et al. (1993) procedure.
The full pressure is then restored by adding back the ERA5 pressure.

For gravity, the methodology is similar: calibrated gravity is corrected for a local tidal model, including polar motion, and local air pressure effects. Offsets are manually corrected, gaps are filled with a linear interpolation, and remaining perturbations (spikes, earthquakes) are corrected using a threshold on the derivative of the gravity residuals.
The full gravity is then restored by adding back the modeled tidal signal and air pressure effects.

2.2 File format

We provide monthly files, with the code “32”, of the corrected and filled gravity and pressure (columns 1 and 2), only valid gravity and pressure (columns 3 and 4), gaps and offsets being marked as “ 99999.999”, and the gravity and pressure cumulative offsets (columns 5 and 6).
All data are provided in physical units, i.e. nm s^{-2} and hPa for gravity and pressure respectively.
In the header, we also provide the gravity and pressure calibrations used to convert the level-1 data into physical units. An example is given on Figure 1.

```
Filename             : IGETS-SG-CORMIN-me020-19970132.ggp
Calibration          : -1107.000 &   -13.290 from 19940815 to 19970905
Calibration          : -1107.000 &    13.290 from 19970905 to 19980812
Calibration          : -1107.000 &     6.683 from 19980812 to 20010101
Calibration          : -1107.000 &     1.000 from 20010101 to 20030625
Product              : Level 2 from EOST
Author               : jeanpaul.boy@unistra.fr
Corrections          : offsets, gaps and spikes
Gravity              : filled with local tides
Pressure             : filled with hourly MERRA2
yyyymmdd hhmmss     g_fil     p_fil   g_nofil   p_nofil  g_offset  p_offset
C*********************************************************************
77777777
19970101      0  1014.994   -12.136 99999.999   -12.136 99999.999    -4.247
19970101    100  1014.543   -12.166 99999.999   -12.166 99999.999    -4.247
19970101    200  1014.084   -12.191 99999.999   -12.191 99999.999    -4.247
19970101    300  1013.621   -12.213 99999.999   -12.213 99999.999    -4.247
19970101    400  1013.159   -12.233 99999.999   -12.233 99999.999    -4.247
19970101    500  1012.683   -12.246 99999.999   -12.246 99999.999    -4.247
19970101    600  1012.143   -12.237 99999.999   -12.237 99999.999    -4.247
19970101    700  1011.646   -12.239 99999.999   -12.239 99999.999    -4.247
19970101    800  1011.130   -12.234 99999.999   -12.234 99999.999    -4.247
19970101    900  1010.528   -12.197 99999.999   -12.197 99999.999    -4.247
19970101   1000  1010.001   -12.183 99999.999   -12.183 99999.999    -4.247
19970101   1100  1009.511   -12.180 99999.999   -12.180 99999.999    -4.247
19970101   1200  1009.093   -12.199 99999.999   -12.199 99999.999    -4.247
19970101   1300  1008.730   -12.234 99999.999   -12.234 99999.999    -4.247
19970101   1400  1008.238   -12.223 99999.999   -12.223 99999.999    -4.247
19970101   1500  1007.728   -12.205 99999.999   -12.205 99999.999    -4.247
19970101   1600  1007.333   -12.222 99999.999   -12.222 99999.999    -4.247
19970101   1700  1006.888   -12.221 99999.999   -12.221 99999.999    -4.247
19970101   1800  1006.402   -12.204 99999.999   -12.204 99999.999    -4.247
19970101   1900  1006.006   -12.215 99999.999   -12.215 99999.999    -4.247
19970101   2000  1005.634   -12.231 99999.999   -12.231 99999.999    -4.247
19970101   2100  1005.285   -12.253 99999.999   -12.253 99999.999    -4.247
19970101   2200  1004.975   -12.285 99999.999   -12.285 99999.999    -4.247
```

Figure 1: Example of the first lines of the EOST Level-2 products (code 32) for the GWR T020 instrument installed in Metsahovi (Finland) for the month of January 1997. The “g_fil” and “p_fil” columns provide corrected gravity and pressure data; “g_nofil” and “p_nofil” provide only the valid gravity and pressure data (no correct gravity data here). The cumulative offsets are given in the two last columns “g_offset” and “p_offset”.

3. EOST Level 3 data

3.1 Geophysical Models

1-min. gravity residuals are computed after subtracting to the level 2 data:

- solid Earth tides and ocean tidal loading,
- atmospheric loading,
- polar motion and length-of-day induced gravity changes,
- an instrumental drift.

Tidal gravity variations are computed differently for the long-period tides and for the diurnal and sub-diurnal bands:

- At high frequency, a local tidal model, adjusted by least-squares, is used.
- At low frequency, we model the tidal signal using the DDW99 gravimetric factor (Dehant et al., 1999) and HW95 tidal potential (Hartmann and Wenzel, 1995) for the

Solid Earth tides, and FES2014c (Lyard et al., 2021; Carrère et al., 2016) for the ocean tidal loading.
FES2014c includes 7 different constituents: Sa, Ssa, Mm, Msf, Mf, Mtm and Msqm.

We choose the latest version of the FES model, but we also compare it to other tidal model. Figure 2 shows the differences with NAO99b (Matsumoto et al., 2000) for the Strasbourg station; in most cases, the differences are always below 0.1 nm s^{-2}.

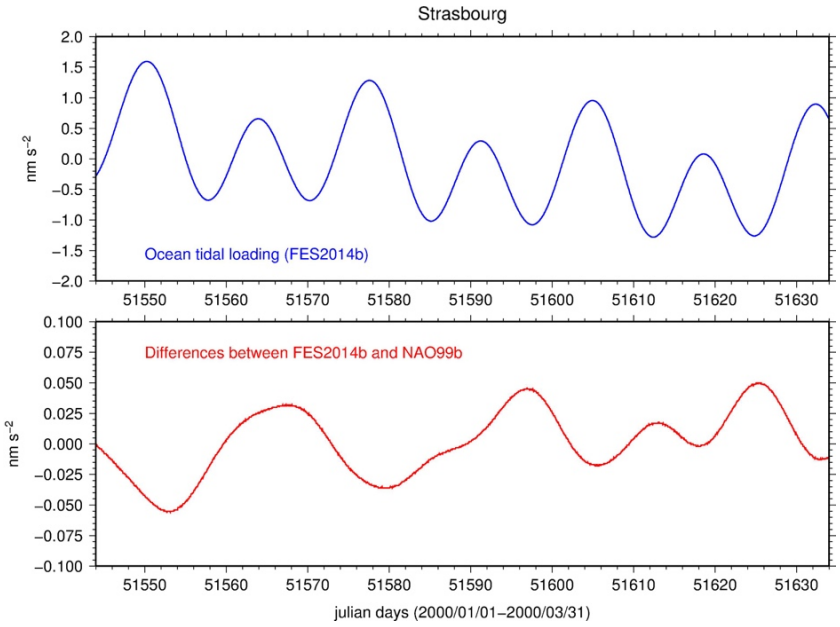

Figure 2: Long-period ocean tidal loading in Strasbourg modeled using FES2014c (Lyard et al., 2021; Carrère et al., 2016) (7 waves: Sa, Ssa, Mm, Msf, Mf, Mtm and Msqm) (top, in blue) and differences with NAO99b (Matsumoto et al., 2000) (7 waves: Sa, Ssa, Msm, Mm, Msf, Mf and Mtm) (bottom, in red).

This hybrid methodology allows us to remove most of the short-period tides, and to keep all other long-period variations, including, for example, the seasonal hydrological contributions (Boy and Hinderer, 2006).

Atmospheric loading is computed according to Boy et al. (2002), using ERA5 (Hersbach et al., 2020) hourly surface pressure, and assuming an inverted barometer ocean response to pressure. ERA5 pressure is replaced by the 1-minute local pressure record for angular distance less than 0.10° to the station.

The polar motion and length-of-day induced gravity variations are modeled using the IERS EOPC04 daily series (http://hpiers.obspm.fr/iers/eop/eopc04/) (Wahr, 1985), and assuming a δ_2 factor of 1.16. We also model ocean pole tide as a self-consistent equilibrium response (Agnew and Farrell, 1978; Chen et al., 2008).

Depending on the sensor, the instrumental drift is generally modeled as a polynomial or an exponential function (Van Camp and Francis, 2007). When available (currently only for

Strasbourg instruments, see Figure 3), we use time series from absolute gravimeters for the adjustment.

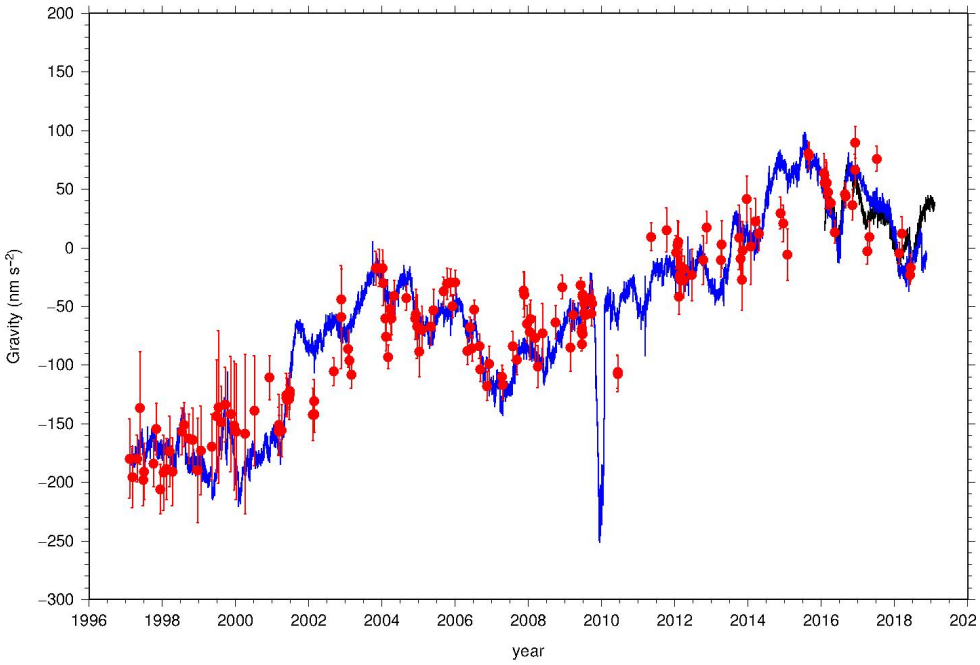

Figure 3: Gravity residuals (level 3) in Strasbourg for the CO26 (blue) and iOSG #23 (black) instruments, after correcting for geophysical models and instrumental drift, compared to FG5 #206 absolute gravity observations (red).

The large negative anomaly in late 2009 and early 2010 for the CO26 instrument is due to a malfunction of the tilt compensation system.

In addition to the residuals, each correction is provided in the monthly Level-3 data, in addition to the original gravity and pressure. Except for the solid Earth tides and ocean tidal loading, all geophysical models used to produce IGETS level 3 data are also available at the EOST loading service (http://loading.u-strasbg.fr)

3.2 File format

1-minute gravity residuals are provided as monthly files with the code “r2”. In the header, we provide a reminder of the localization of the station, the different calibrations applied in our processing and the different geophysical corrections applied. The characteristics of the modeled instrumental drift (polynomial, exponential or derived using AG measurement) are also written in the header. An example of a file is given on Figure 4.

```
Filename             : IGETS-SG-RESMIN-dj060-201512r2.ggp
Station              : Djougou, Benin
Instrument           : GWR o060
N Latitude (deg)     :   9.7424 0.0001    measured
E Longitude (deg)    :   1.6056 0.0001    measured
Elevation MSL (m)    : 483.0000 1.0000    estimated
Calibration          :  -709.800 &     1.000 from 20100101 to 20190131
Processing           : IGETS Central Bureau
Author               : jeanpaul.boy@unistra.fr
LP tides             : DDW99 + HW95 / FES2014c
SP tides             : local model
Rotation             : PM + LOD (del=1.16) / Self consistent ocean
Atmos. load          : ERA5/IB + local pressure
Drift                : degree-1 polynomial
yyyymmdd hhmmss   res_fil res_nofil     tides  rotation  atm_load     drift     g_fil     p_fil
C*************************************************************************************************
dj060              1.0000    1.0000     0.000         1
77777777
20151201      0    22.142    22.142   -43.693     1.040    -3.695   849.230   825.024     3.165
20151201    100    22.153    22.153   -49.496     1.040    -3.668   849.230   819.259     3.154
20151201    200    22.096    22.096   -55.302     1.040    -3.644   849.231   813.420     3.145
20151201    300    22.143    22.143   -61.111     1.040    -3.616   849.231   807.687     3.134
20151201    400    22.313    22.313   -66.923     1.040    -3.590   849.231   802.072     3.124
20151201    500    22.365    22.365   -72.736     1.040    -3.574   849.232   796.327     3.119
20151201    600    22.284    22.284   -78.552     1.040    -3.560   849.232   790.444     3.115
20151201    700    22.201    22.201   -84.369     1.040    -3.546   849.233   784.558     3.111
20151201    800    22.110    22.110   -90.187     1.039    -3.541   849.233   778.655     3.111
20151201    900    22.071    22.071   -96.005     1.039    -3.537   849.233   772.801     3.112
20151201   1000    22.134    22.134  -101.825     1.039    -3.527   849.234   767.055     3.110
20151201   1100    22.214    22.214  -107.643     1.039    -3.510   849.234   761.335     3.105
20151201   1200    22.320    22.320  -113.461     1.039    -3.490   849.235   755.643     3.099
20151201   1300    22.389    22.389  -119.279     1.039    -3.461   849.235   749.923     3.089
```

Figure 4: Example of the first lines of the EOST Level-3 products (code r2) for the GWR OSG #060 instrument installed in Djougou (Benin) for the month of December 2015. The “res_fil” and “res_nofil” columns provide the gravity residuals from the Level-2 “g_fil” and “g_nofil” products (see Figure 1). The “tides”, “rotation” and “atm_load” provide the geophysical corrections applied (respectively solid and ocean tides, Polar Motion and Length-of-Day including a self-consistent ocean and global atmospheric loading using ERA5 and assuming an IB ocean). The modeled instrumental drift is given in the “drift” column. The original “g_fil” and “p_fil” columns are finally given.

For any use of the IGETS products, please cite Boy et al. (2020) reference, as well as the doi corresponding to the different SG stations (https://isdc.gfz-potsdam.de/igets-data-base/).

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