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Absolute Gravity Measurements at Jang Bogo Station and Mario Zucchelli Station, Antarctica, in 2019

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Abstract: We present the results of absolute gravity measurements that were acquired at Jang Bogo Station (JBS) and Mario Zucchelli Station (MZS), Terra Nova Bay, Antarctica, during the 2019–2020 austral summer season. We employed a Micro-g LaCoste (MGL) FG5-210 absolute gravimeter for the measurements, with the MGL g9 software used for both the data acquisition and processing. The JBS measurements were acquired at an existing gravity reference point, JBSAG1, and a newly established gravity reference point, JBSAG2, with about 19,000 and 14,400 drops conducted, respectively. The MZS measurements were acquired at two existing gravity reference points, TNB AB and IAGS, where absolute gravity measurements have been repeatedly acquired, with about 12,800 and 12,300 drops conducted, respectively. The precision of the measurements is better than 0.4 μGal (1 μGal = 10^{-8} m·s^{-2}), yielding an estimated accuracy of better than 5 μGal at each of the occupied gravity reference points. The provided data sets consist of the binary format files from the g9 software to fully ensure the ability to reprocess these data in the future. The data are also provided in three different text formats, thereby allowing these data to be readily used for a range of potential applications. A summary of the obtained absolute gravity values is provided as an Excel file, particularly for any users that are interested in the details of the absolute gravity values.

1. Background & Summary

Absolute gravity measurements have been acquired across Antarctica since the early 1990s[1]. The primary purpose of these measurements is to determine the absolute values at gravity reference points, which can also be used as reference values for relative gravity surveys. Recent gravity monitoring motivations have targeted the gravity changes due to both Earth dynamics, such as glacial isostatic adjustment (GIA), and present-day ice-mass changes. However, the number of absolute gravity reference points in Antarctica is around 20, still quite small, and the number of points with repeated measurements is even more limited[1]. The establishment of new absolute gravity reference points and the acquisition of repeated measurements at existing gravity reference points have therefore become increasingly urgent priorities for Antarctic gravity studies[2].

Nowadays, two types of instruments, *i.e.*, FG5 and A10, are widely employed for absolute gravity measurements. The A10 gravimeter is a useful instrument for field surveys[3,4], however its accuracy is inferior to that of the FG5 gravimeter. While the accuracy of recent absolute gravity measurements via an FG5 instrument is considered to be within a few μGal[5], the expected gravity changes due to GIA effects and the present-day ice-mass changes are generally quite small, with changes of ~1 μGal/yr or less often observed. Furthermore, several necessary corrections must be applied to obtain the final absolute gravity values, which may easily yield errors that are notably larger than the actual gravity changes[5,6]. It is important to ensure that a consistent data processing approach is employed to minimize these errors, particularly when temporal gravity changes are investigated; standardization of both the absolute gravity measurement process and data processing approach is currently under discussion[5]. The raw data should therefore be archived to ensure future reprocessing when improved data analyses become available.

There is an established gravity reference point at Jang Bogo Station (JBS), a South Korean Antarctic research station in Terra Nova Bay, Victoria Land, that has been occupied using the MGL A10-036 absolute gravimeter[7]. Therefore, we acquired the absolute gravity measurements at JBS using the FG5-210 gravimeter. This instrument is expected to provide a more precise gravity reference value, thereby providing an invaluable contribution to the monitoring of long-term gravity changes.

There are two established gravity reference points at Mario Zucchelli Station (MZS), an Italian Antarctic research station in Terra Nova Bay, where repeated absolute gravity measurements have been acquired using the FG5 gravimeter[8,9]. We have acquired new measurements at these two reference points since the last measurements in 2015[9], thereby providing an update of any changes to the previous gravity values.

This paper reports the details of these recent absolute gravity measurements, including reference point descriptions, the measurement method, and data processing steps, which comprise the primary information contained in the database presented here.

2. Locations

The locations of JBS and MZS are shown in Fig. 1, and the absolute gravity reference points are shown in Figs. S1–S4.

Gravity reference points JBSAG1 and JBSAG2 are both located in the JBS heavy gear maintenance building, which was constructed on Quaternary glacial sedimentary deposits that overlie a basement consisting of early Paleozoic schists and gneisses. JBSAG1 is an existing absolute gravity reference point that has previously been occupied by an A10-036 gravimeter. The vertical gravity gradient is expected to be nonlinear owing to its position at the bottom of the maintenance bay (Fig. S2), which may introduce additional uncertainties when comparing the gravity data from different instrument types. We therefore established a new reference point, JBSAG2, on the flat floor of the same building, as shown in Fig. S2, to mitigate the nonlinearity of the vertical gravity gradient and provide a more reliable absolute gravity reference point for long-term monitoring.

We first determined the position of an entrance to the building using precise point positioning of global positioning system (GPS) measurements since both reference points are located inside the building. We then determined the positions of both the gravity points based on this GPS location and the relative distances between the entrance and reference points. Note that the heights were determined as the sum of the observed ellipsoidal heights and calculated geoid heights using Earth Gravitational Model EGM2008[10], which yields an elevation accuracy of ~1 meter. The locations of the points are summarized in Table 1, along with the relevant parameters and obtained gravity values. These values were also included in the Excel summary file (described in the Data Records section).

The absolute gravity measurements at MZS were conducted at two existing reference points, TNB AB and IAGS. We used the same locations and relevant parameters that were employed by Rogister *et al.*[8,9] to ensure the necessary consistency for temporal gravity change studies since repeated absolute gravity measurements have been acquired at these reference points. These details are summarized in Table 2 and included in the Excel summary file.

3. Methods

We followed the standard procedure described in the FG5 user's manual[11] during the absolute gravity measurements. The FG5-210 instrument was transported from Japan to New Zealand and then Antarctica via cargo flights. The transit took many days, resulting in degradation of the vacuum chamber. Therefore, the vacuum chamber was baked out and evacuated using a turbo vacuum pump prior to the JBS gravity measurements. The vacuum chamber was maintained via an ion-pump during the transit from JBS to MZS, mitigating the need for turbo-pumping at MZS.

We note that the room temperature of the JBS heavy gear maintenance building was ~0 °C or below because the building was not equipped with heating facilities. We therefore used a small tent with a volume of about 5 m^3 and an oil heater to keep the temperature around the gravimeter above 20 °C since this was a requirement for obtaining accurate absolute gravity measurements. The reference gravity points at MZS were equipped with heating facilities, such that the room temperature was kept above 20 °C during the measurements.

The g9 software package[12] was used for the data acquisition and processing. The g9 software manages a unit of measurements as a "project", and a project usually consists of multiple "sets," with each set consisting of successive measurements that are called "drops."

The JBS measurements were acquired during 17–28 November 2019. The measured drop data were used to determine the absolute gravity values and provide a calibration factor for the iGrav-021 superconducting gravimeter that is operated at JBS[2]. Although a longer measurement period was desirable for the calibration, too many drops might have caused unnecessary exhaustion to the instrument. We therefore varied the measurement patterns at JBSAG1 to balance the needs of the absolute gravity determination and calibration: 100 drops/set at a 30-min set interval for 24 h during the 18–19 November period; 50 drops/set at a 60-min set interval for 24 hours during the 19–22 November period; and 50 drops/set at a 30-min set interval for 24 h during the 23–24 November period, and in total 19,101 accepted drop values were obtained. The JBSAG2 measurements were made during the 25–28 November period, with 100 drops/set acquired at a 30-min set interval for 48 h, and 14,398 accepted drop values were obtained.

The vertical gravity gradient at the reference point is necessary to translate the gravity value at the actual measurement height to that at some arbitrary height. However, it should be measured by a relative gravimeter due to the strong influence of local mass distributions, such as the rock density below the measurement point and the surrounding building materials, on the gravity measurements. Relative gravity differences at different heights above the gravity reference points were therefore measured using the LaCoste & Romberg Model D-58 relative gravimeter[2].

However, we have previously noted that we do not expect the vertical gravity gradient at JBSAG1 to be linear owing to its location at the bottom of the maintenance bay. We therefore made measurements at three different levels: 0 (*D*), 51.7 (*M*), and 112.5 cm (*U*) above the reference point. We calculated gradient values of −2.249, −2.452, and −2.012 μGal/cm for *U*−*D*, *U*–*M*, and *M*−*D*, respectively. In addition, the gradient can be represented by a linear function of height (h cm) as -0.07806 h - 0.18098 μGal/cm, if a quadratic function is assumed for fitting by the measured values. While the gradients varied from 0.2 to 0.3 μGal/cm for the various heights, for the simplicity, we used the *U*−*D* gradient value to calculate the absolute gravity value at the floor since the actual measurement height of the FG-5 instrument is ~128 cm, which is close to the height of *U* (112.5 cm).

We made measurements at two height levels at JBSAG2: 0 (*D*) and 82.2 cm (*U*). We obtained a gradient value of −2.997 μGal/cm, which was then employed for the data processing.

We used the parameters that are generally employed for absolute gravity measurement corrections and followed a standard data processing approach via the g9 software[11,12]. We applied

International Earth Rotation and Reference Systems Service Earth orientation data for the polar motion, Tamura's potential for the Earth tides, and the Schwiderski model for the ocean tides. The actual parameters that were employed for the data processing have been recorded in the corresponding "project.txt" (project summary) files (described in the Data Records section).

We moved to MZS after completing the JBS measurements, and acquired gravity measurements at the two MZS absolute gravity reference points from 29 November to 5 December 2019. The TNB AB measurements were conducted during the 29 November–2 December period, with 100 drops/set acquired at a 30-min interval. A total of 129 sets of measurements were made, with 12,812 accepted drop values obtained. The IAGS measurements were then conducted during the 3–5 December period, and the same sampling sequence was applied, with 12,304 accepted drop values obtained from 124 sets of measurements. We used the same coordinates, vertical gravity gradient, and other parameters that were employed by Rogister *et al.*[8,9] in the g9 software since both reference points have previously been occupied by FG5 gravimeters. All of the employed parameters have been recorded in the corresponding project summary files.

The absolute gravity value for each project is summarized in the Excel summary file, along with the reference point locations. The final absolute gravity values in the Excel summary file, which are shown in Tables 1 and 2, were calculated as the weighted mean values, with the number of accepted drop values used as the weights. The values at 0 cm can be used for a variety of applications, such as relative gravity surveys, where a reference absolute gravity value is needed.

4. Data Records

The g9 software manages a unit of measurements as a project, and maintains a binary project file that is labeled with the project name as the prefix and a ".fg5" extension. The project files contain all of the necessary information pertaining to the measurements: station information, system parameters, control parameters, such as the number of sets and drops to be acquired, gravity correction parameters, and a list of all of the binary gravity set filenames. A binary gravity set file, which has a ".gsf" extension, stores the raw observation data (drop data), including the time of the drop, fringe times, and auxiliary sensor data, for each set.

We adopted the following convention for naming the project files. The file name begins with an abbreviation for the gravity reference point, followed by the measurement start day in "yyyymmdd" format, and finally an alphabetic character (in ascending order) to distinguish between projects that began on the same day. For example, the file name for the first project, which began on 20191117 at JBS1, is "JBS120191117a.fg5". The software automatically names the gravity set files as follows once a project name is given: JBS120191117axxx.gsf, where xxx is the corresponding set number. The software also saves all of the files related to the same project in the directory with the same prefix name, with JBS12019117a being the directory name in this case.

The data sets provided here include all of the raw data files (the .gsf files and .fg5 file) to fully ensure any need for data reprocessing in the future. The g9 software or another compatible software is required for file management since the raw data are stored in binary format. The g9 software has a function to export the “gsf” and “fg5” binary data in ASCII format[12]. However, we think there is almost no benefit to include these exported ASCII format files, because the g9 software should be used for the raw data processing. Instead, we have included three additional g9-generated text files for each project, “drop.txt” (drop-value), “set.txt” (set summary), and “project.txt” (project summary), to avoid any inconveniences. These files are also included in the same project directory.

A drop-value file includes detailed information about the measured gravity values, as well as the measurement date and time in a project. It also includes all of the values of the gravity corrections and ambient environmental data for each drop. The drop-value files do not include the raw observation data, such as the fringe times; however, it is generally unnecessary to reprocess the raw observation data. It is generally sufficient to apply different gravity corrections and/or to calculate a mean gravity value by editing the bad data; the measured drop gravity values and other information in the drop-value file can be employed for these purposes. Figure S5 shows an example of the “drop.txt” file. It can be easily read and managed by most spreadsheet programs because it is a tab-delimited text file.

The set summary file contains set-by-set information, which primarily consists of the mean time, mean gravity value, and other information associated with the drop data in a given set. Figure S6 shows an example of the set summary file. The file is also tab-delimited, and can easily be imported into most spreadsheet programs.

The project summary file is a simple text file and is designed as a primary report of the project. It includes all of the information necessary for the data processing and corrections, as well as the processing results. The binary raw data can therefore be validated by checking whether the g9 software reproduces the same results with the same parameters in the project summary file. Figure 2 shows an example of the project summary file, which provides a clear and understandable summary of the selected project.

An Excel file of the summarized project results is also provided for researchers who are interested in the details of the absolute gravity values. This file includes the weighted mean values of the projects at each gravity point, along with their uncertainties and other associated information, such as measurement date and time, reference point coordinates, and vertical gravity gradient. This file should provide the necessary information for providing the reference gravity value at the reference point for relative gravity surveys, and would be applicable for studies of temporal gravity changes as well.

All of the related files are stored at https://ads.nipr.ac.jp/dataset/A20210810-001. The structure of the directories is shown in Fig. 3; all of the files in the root directory (./2019-FG5-210-JBS-MZS) and some files in the “JBS120191117a” directory are shown to illustrate the structure of the files included in a project related directory. The “tree.txt” file in the root directory includes all of the directory and file names.

5. Technical Validation

Absolute ballistic gravimeters, such as the FG5 instrument, are currently regarded as one of the most accurate instruments. It is impossible to calibrate the FG5 instrument because no other instrument can attain a better measurement precision. Therefore, the only way to ensure the accuracy of absolute gravimeters and provide reliable absolute gravity values is via a comparison of the measurement results at reference points. A comparison strategy has been discussed[13] and comparisons of the measurement results of various absolute gravimeters have been conducted[14] to determine the accuracy and measurement precision of these instruments.

The FG5-210 instrument has regularly been employed in domestic absolute gravimeter comparisons that have been held at Ishioka Geodetic Observing Station, which is maintained by the Geospatial Information Authority of Japan (GSI). A comparison of the FG5-210 gravity observations in 2019 and 2020, both before and after the Antarctic measurements, indicates that the measured FG5-210 values are largely within 5 µGal of the values that have been obtained by other FG-5 instruments (GSI, personal communication). Furthermore, FG5-210 measurements were obtained at Avalon Base, New Zealand, which is maintained by GNS Science, in April 2018 and December 2019, both before and just after the Antarctic measurements, and the measured absolute gravity values were within 2 µGal of each other[15]. These measurements suggest that there was no evidence of instrumental problems during the Antarctic gravity measurement campaign, such that the accuracy of the observed absolute gravity values is considered to be within 5 µGal.

We note that the strategy/convention of the gravity data processing approach may change in the future, which may cause changes in the presented absolute gravity values. However, all of the raw data are included in the database to ensure both the ability to reproduce the presented absolute gravity values and reprocess the data as gravity processing approaches evolve, and to ensure the validity of the data sets.

6. Usage Notes

Not particularly.

7. Competing interests

No potential conflict of interest was reported by the authors.

8. Figures

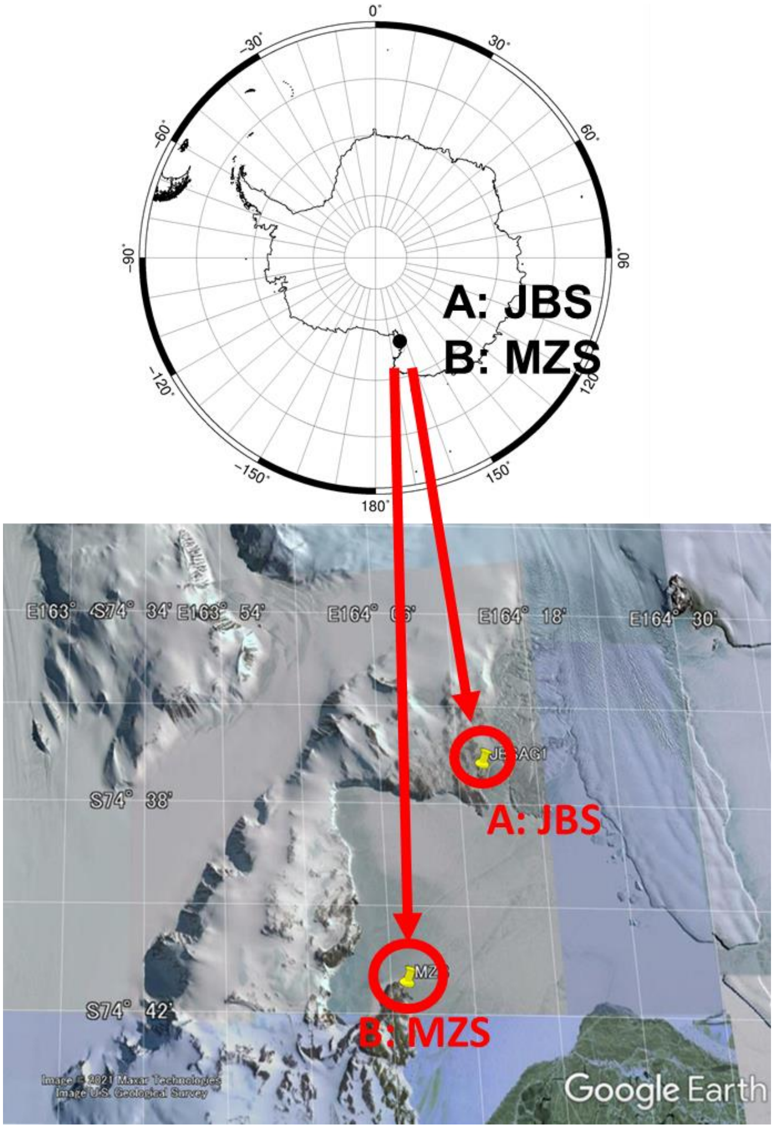
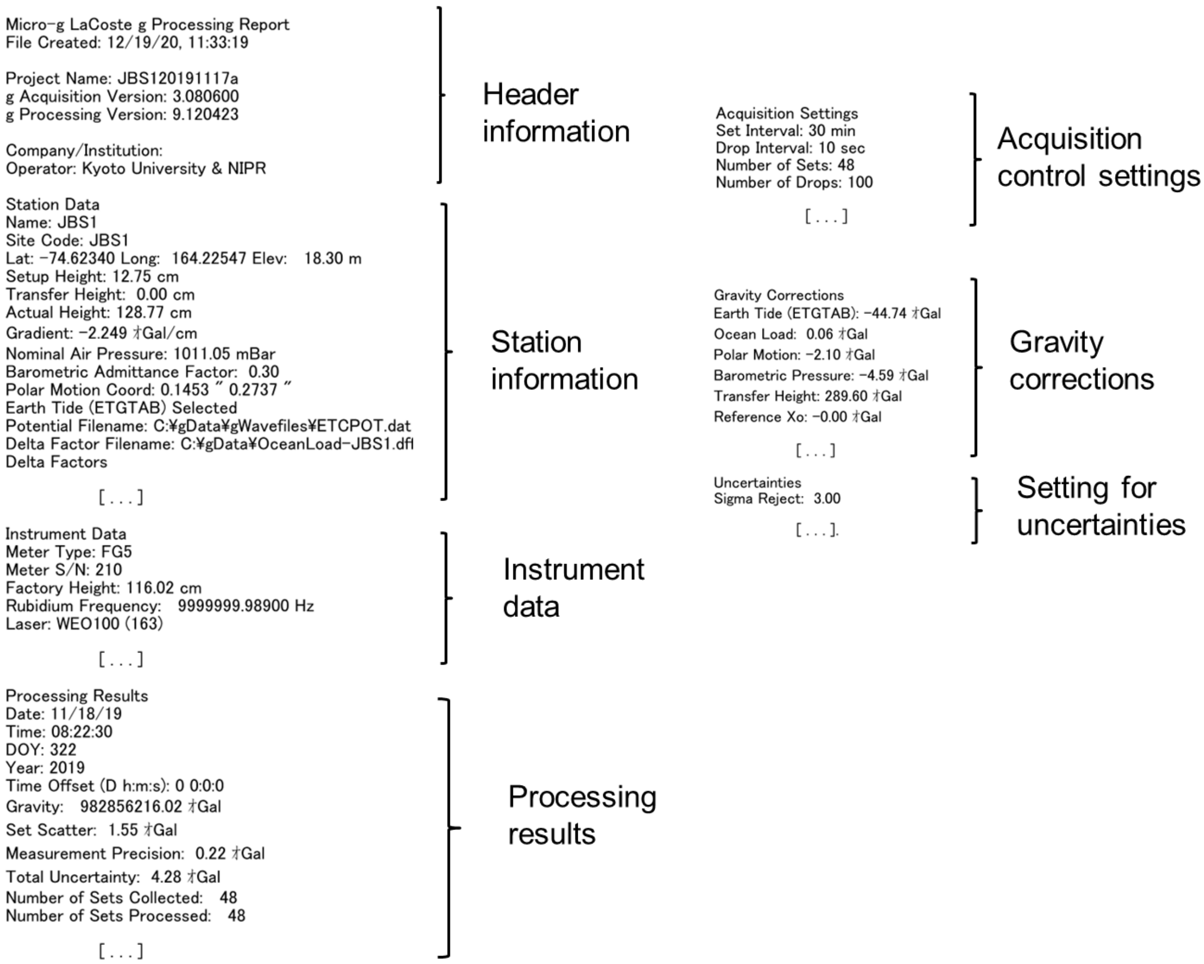


Fig. 1. Locations of A:Jang Bogo Station (JBS) and B:Mario Zucchelli Station (MZS), Terra Nova Bay, Victoria Land, Antarctica. The circle on the regional map (upper) marks the location of the local map (lower).


Micro-g LaCoste g Processing Report
File Created: 12/19/20, 11:33:19

Project Name: JBS120191117a
g Acquisition Version: 3.080600
g Processing Version: 9.120423

Company/Institution:
Operator: Kyoto University & NIPR

Station Data
Name: JBS1
Site Code: JBS1
Lat: -74.62340 Long: 164.22547 Elev: 18.30 m
Setup Height: 12.75 cm
Transfer Height: 0.00 cm
Actual Height: 128.77 cm
Gradient: -2.249 μGal/cm
Nominal Air Pressure: 1011.05 mBar
Barometric Admittance Factor: 0.30
Polar Motion Coord: 0.1453 " 0.2737 "
Earth Tide (ETGTAB) Selected
Potential Filename: C:¥gData¥gWavefiles¥ETCPOT.dat
Delta Factor Filename: C:¥gData¥OceanLoad-JBS1.dfl
Delta Factors

[. . .]

Instrument Data
Meter Type: FG5
Meter S/N: 210
Factory Height: 116.02 cm
Rubidium Frequency: 9999999.98900 Hz
Laser: WEO100 (163)

[. . .]

Processing Results
Date: 11/18/19
Time: 08:22:30
DOY: 322
Year: 2019
Time Offset (D h:m:s): 0 0:0:0
Gravity: 982856216.02 μGal
Set Scatter: 1.55 μGal
Measurement Precision: 0.22 μGal
Total Uncertainty: 4.28 μGal
Number of Sets Collected: 48
Number of Sets Processed: 48

[. . .]

Acquisition Settings
Set Interval: 30 min
Drop Interval: 10 sec
Number of Sets: 48
Number of Drops: 100

[. . .]

Gravity Corrections
Earth Tide (ETGTAB): -44.74 μGal
Ocean Load: 0.06 μGal
Polar Motion: -2.10 μGal
Barometric Pressure: -4.59 μGal
Transfer Height: 289.60 μGal
Reference Xo: -0.00 μGal

[. . .]

Uncertainties
Sigma Reject: 3.00

[. . .].

Fig. 2. Contents of an example project summary (project.txt) file.

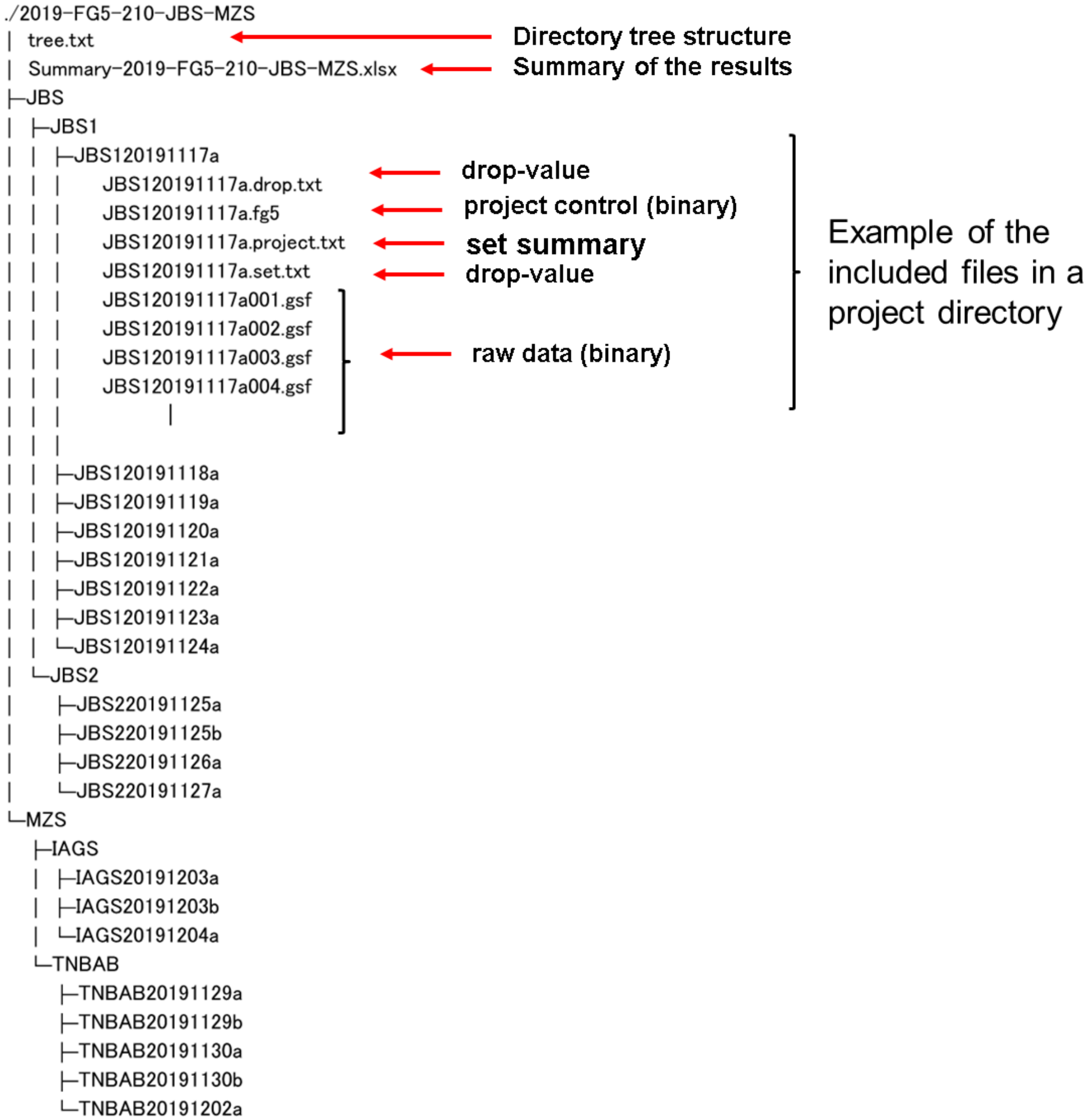


Fig. 3. Directory tree structure of the provided database.
The file names in the JBS120191117a project directory are shown here. The complete directory tree with all of the file names is stored in the "tree.txt" file.

9. Tables

Table 1. Summary of the absolute gravity measurements at Jang Bogo Station (JBS).

Points	Lat (deg N)	Lon (deg E)	H (m)	Date (2019)	dg/dz (μGal /cm)	Number of accepted drops	Precision (μGal)	gravity at 130 cm (μGal)		gravity at 0 cm (μGal)	
JBSAG1	-74.62340	164.22547	18.3	Nov. 18-25	-2.249	19101	0.38	982855925.6	± 1.9	982856218.0	± 4.3
JBSAG2	-74.62342	164.22553	19.4	Nov. 25-28	-2.997	14398	0.32	982855650.2	± 1.9	982856039.8	± 4.3

Table 2. Summary of the absolute gravity measurements at t Mario Zucchelli Station (MZS).

Points	Lat (deg N)	Lon (deg E)	H (m)	Date (2019)	dg/dz (μGal /cm)	Number of accepted drops	Precision (μGal)	gravity at 130 cm (μGal)		gravity at 0 cm (μGal)	
TNB AB	-74.6948	164.1129	30	Nov. 29-Dec. 2	-3.120	12812	0.24	982865562.8	± 1.8	982865968.4	± 4.3
IAGS	-74.6929	164.1018	54.3	Dec. 3-5	-3.570	12304	0.32	982854849.6	± 1.8	982855313.7	± 4.3

Author contributions

Y.F. and J.O. worked on the observations at JBS and MZS. K.O. was the principal investigator of the project and managed the observations. C-K.L. and A.C. were the responding scientists of JBS and MZS, respectively, and managed and supported the observations. Y.F. wrote most of the MS, and others reviewed and agreed it.

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Data Citations

Fukuda, Y., Okuno, J., Doi, K., Lee, C., and Capra, A. Absolute gravity measurement data at Jang Bogo Station and Mario Zucchelli Station in 2019. 1.00, Japan, Arctic Data archive System (ADS), 2021. https://doi.org/10.17592/001.2021081001.

Supplemental figures

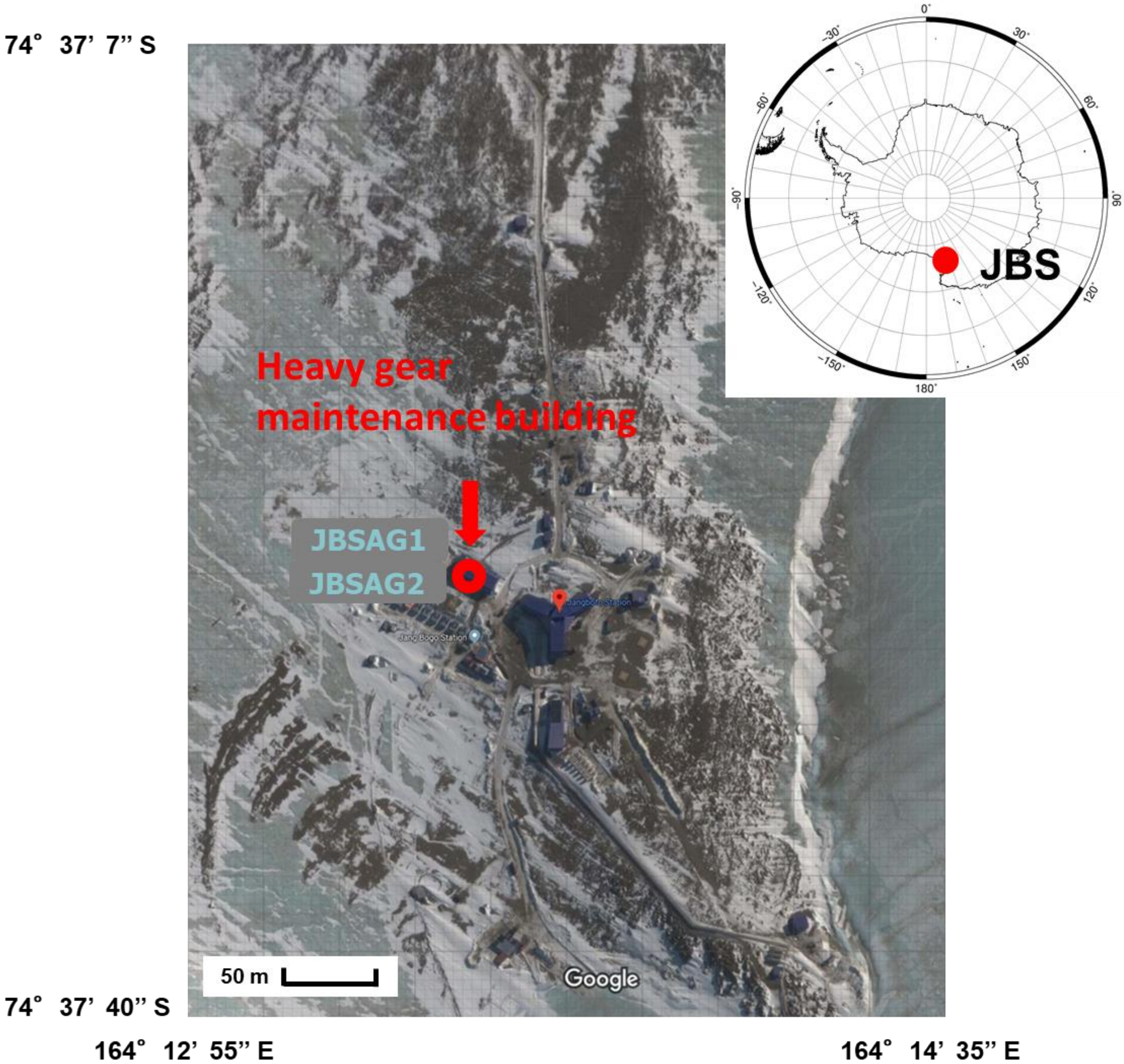

Fig. S1. Locations of the gravity reference points at Jang Bogo Station (JBS).

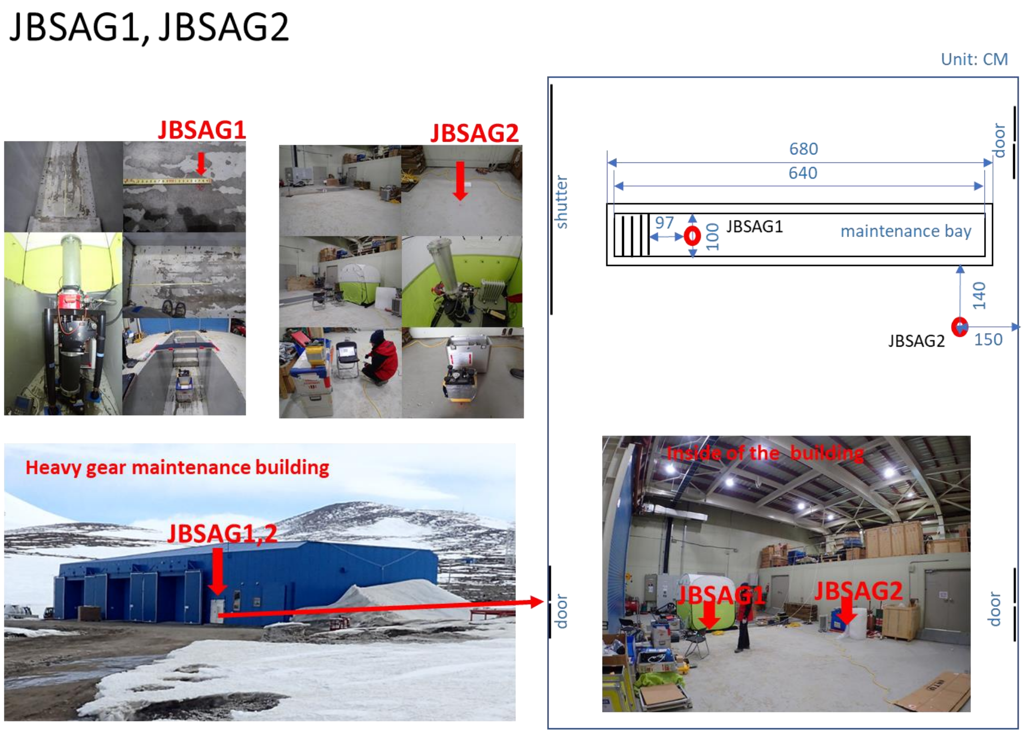

Fig. S2. Detailed location of the gravity reference points at Jang Bogo Station (JBS), JBSAG1 (74.62340° S, 164.22547° E) and JBSAG2 (74.62342° S, 164.22553° E). (from Fukuda *et al.*[2]).

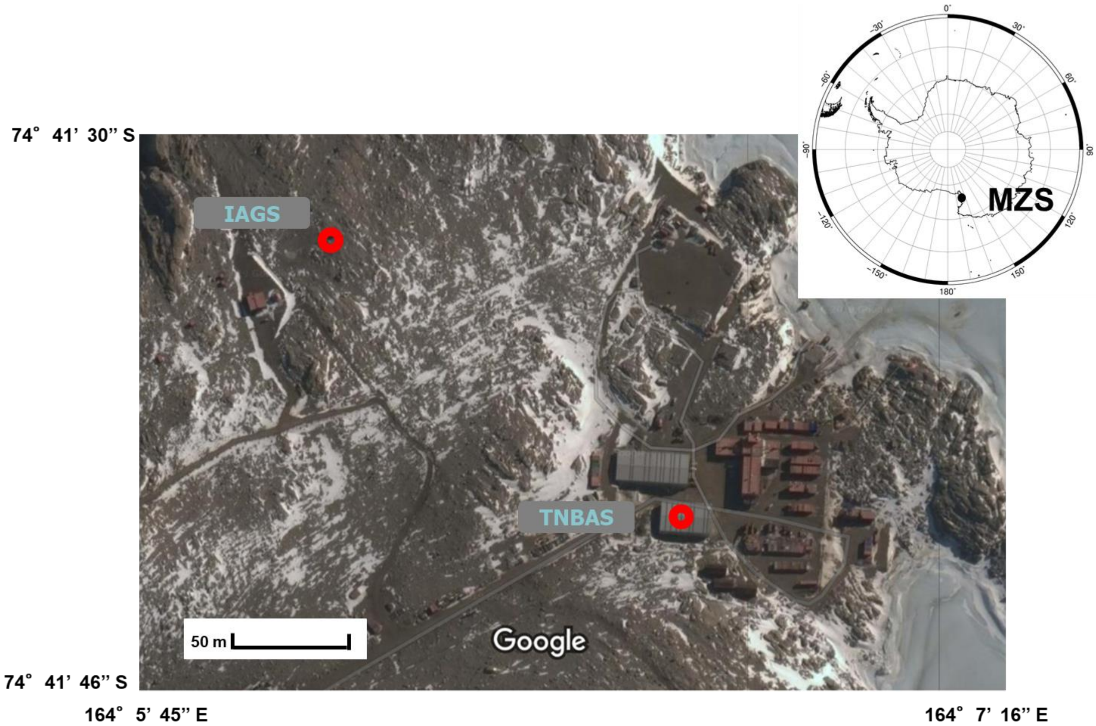

Fig. S3. Locations of the gravity reference points at Mario Zucchelli Station (MZS).

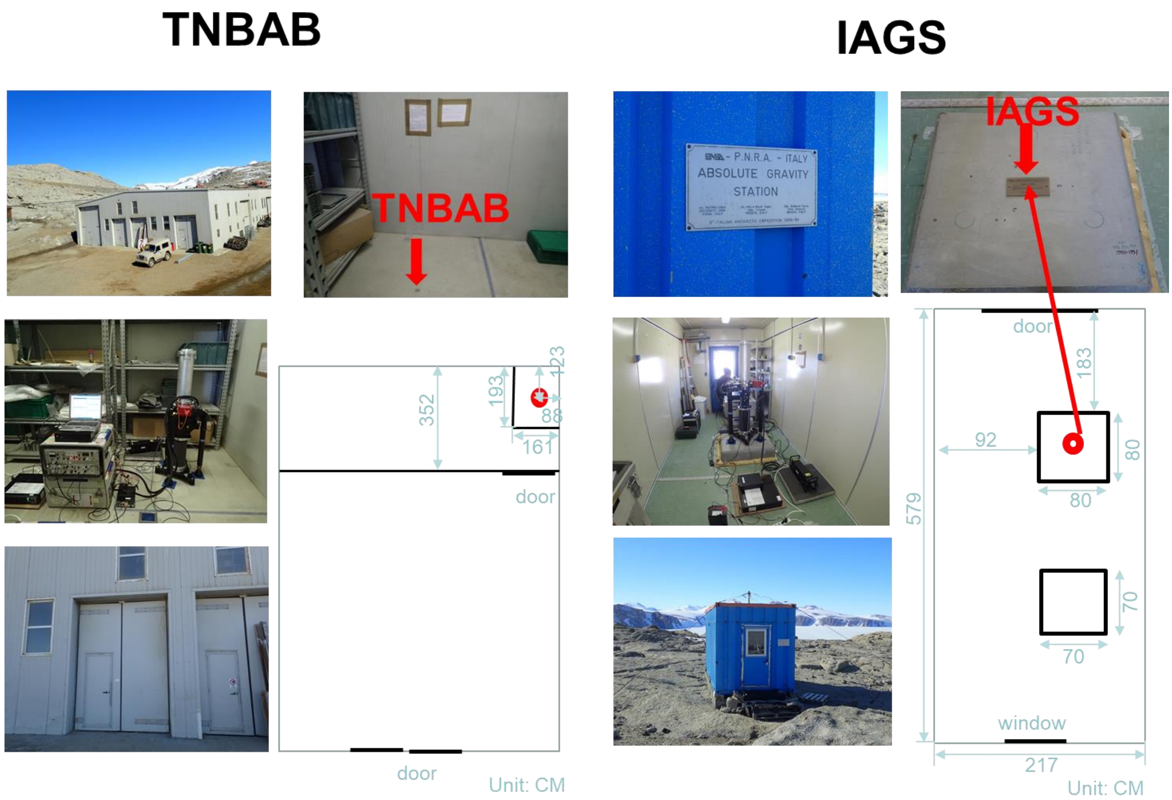

Fig. S4. Detailed locations of the gravity reference points at Mario Zucchelli Station (MZS), TNBAB (74.6948° S, 164.1129° E) and IAGS (74.6829° S, 164.1018° E).

Source Data Filename: JBS120191117a																														
g Acquisition Version: 3.080600																														
g Processing Version: 9.120423																														
Set	Drp	Time	DOY	Year	Gravity	Sigma	Error	Tide	Load	Baro	Polar	Transfer	Refxo	Tilt	Diffraction	SelfAttract	SysResp	Temp	Ion	Spring	Laser	Pres	Chan5	Chan6	Chan7¥	Chan8	Chan9	Chan10	Laser Lock	Accept
1	1	20:29:15	321	2019	982856220.7	19.008	0.613	-64.36	-0.947	-5.201	-2.133	289.266	-0.002	0	0	0	N/A	-0.002	0.016	-0.01	-0.256	994.71	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	2	20:29:25	321	2019	982856215.3	19.707	0.633	-64.33	-0.945	-5.208	-2.133	289.266	-0.002	0	0	0	N/A	-0.002	0.016	-0.01	-0.261	994.69	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	3	20:29:35	321	2019	982856220.1	18.759	0.604	-64.31	-0.944	-5.183	-2.133	289.266	-0.002	0	0	0	N/A	-0.009	0.016	-0.011	-0.259	994.77	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	4	20:29:45	321	2019	982856217.4	19.315	0.621	-64.29	-0.942	-5.195	-2.133	289.266	-0.002	0	0	0	N/A	-0.004	0.016	-0.011	-0.249	994.73	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	5	20:29:55	321	2019	982856217.2	17.58	0.567	-64.27	-0.94	-5.183	-2.133	289.266	-0.002	0	0	0	N/A	-0.003	0.016	-0.011	-0.256	994.77	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	6	20:30:05	321	2019	982856215.3	18.632	0.601	-64.25	-0.938	-5.181	-2.133	289.266	-0.002	0	0	0	N/A	-0.001	0.016	-0.011	-0.263	994.78	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	7	20:30:15	321	2019	982856225.4	18.672	0.602	-64.22	-0.936	-5.191	-2.133	289.266	-0.002	0	0	0	N/A	-0.008	0.016	-0.011	-0.263	994.75	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	8	20:30:25	321	2019	982856220.2	18.008	0.58	-64.2	-0.934	-5.199	-2.133	289.266	-0.002	0	0	0	N/A	-0.005	0.016	-0.011	-0.259	994.72	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	9	20:30:35	321	2019	982856220.8	19.137	0.617	-64.18	-0.932	-5.185	-2.133	289.266	-0.002	0	0	0	N/A	-0.007	0.016	-0.011	-0.263	994.77	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	10	20:30:45	321	2019	982856211.6	19.057	0.614	-64.16	-0.93	-5.201	-2.133	289.266	-0.002	0	0	0	N/A	-0.007	0.016	-0.011	-0.262	994.71	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	11	20:30:55	321	2019	982856213	18.583	0.599	-64.13	-0.929	-5.203	-2.133	289.266	-0.002	0	0	0	N/A	-0.009	0.016	-0.011	-0.256	994.71	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	12	20:31:05	321	2019	982856216.9	19.254	0.621	-64.11	-0.927	-5.193	-2.133	289.266	-0.002	0	0	0	N/A	-0.008	0.016	-0.011	-0.259	994.74	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	13	20:31:15	321	2019	982856216.9	20.177	0.651	-64.09	-0.925	-5.199	-2.133	289.266	-0.002	0	0	0	N/A	-0.008	0.016	-0.011	-0.26	994.72	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	14	20:31:25	321	2019	982856217.3	19.283	0.622	-64.07	-0.923	-5.189	-2.133	289.266	-0.002	0	0	0	N/A	-0.008	0.016	-0.012	-0.265	994.75	N/A	N/A	N/A	N/A	N/A	N/A	E	0
1	15	20:31:35	321	2019	982856222.4	18.806	0.606	-64.05	-0.921	-5.189	-2.133	289.266	-0.002	0	0	0	N/A	-0.006	0.016	-0.012	-0.262	994.75	N/A	N/A	N/A	N/A	N/A	N/A	E	0

Fig. S5. Contents of an example drop-value (drop.txt) file.

Source Data Filename: JBS120191117a																				
g Acquisition Version: 3.080600																				
g Processing Version: 9.120423																				
Set	Time	DOY	Year	Gravity	Sigma	Error	Uncert	Tide	Load	Baro	Polar	Transfer	Refxo	Tilt	Diffraction	SelfAttract	Temp	Pres	Accept	Reject
1	20:37:25	321	2019	982856218.4	4.443	0.447	4.288	-63.26	-0.853	-5.184	-2.133	289.6	-0.002	0	0	0	-0.011	994.77	99	1
2	21:07:30	321	2019	982856218.4	5.564	0.556	4.3	-58.96	-0.48	-5.191	-2.133	289.6	-0.002	0	0	0	-0.016	994.75	100	0
3	21:37:30	321	2019	982856219.2	6.083	0.608	4.307	-54.29	-0.063	-5.193	-2.133	289.6	-0.002	0	0	0	-0.017	994.74	100	0
4	22:07:30	321	2019	982856218.1	7.31	0.731	4.326	-49.3	0.398	-5.179	-2.133	289.6	-0.002	0	0	0	-0.016	994.79	100	0
5	22:37:30	321	2019	982856217.2	7.185	0.719	4.325	-44.05	0.894	-5.139	-2.133	289.6	-0.002	0	0	0	-0.017	994.92	100	0
6	23:07:30	321	2019	982856217.2	7.804	0.78	4.337	-38.63	1.418	-5.12	-2.133	289.6	-0.002	0	0	0	-0.017	994.98	100	0
7	23:37:30	321	2019	982856216.7	8.065	0.806	4.343	-33.13	1.955	-5.096	-2.133	289.6	-0.002	0	0	0	-0.017	995.07	100	0
8	0:07:28	322	2019	982856216.8	8.268	0.831	4.351	-27.69	2.49	-5.081	-2.133	289.6	-0.002	0	0	0	-0.017	995.11	99	1
9	0:37:30	322	2019	982856216	8.394	0.839	4.356	-22.39	3.006	-5.093	-2.133	289.6	-0.002	0	0	0	-0.018	995.07	100	0
10	1:07:30	322	2019	982856216.6	7.888	0.789	4.35	-17.39	3.482	-5.079	-2.133	289.6	-0.002	0	0	0	-0.02	995.12	100	0
11	1:37:31	322	2019	982856216.8	8.218	0.826	4.36	-12.79	3.899	-5.108	-2.133	289.6	-0.002	0	0	0	-0.021	995.02	99	1
12	2:07:30	322	2019	982856217	7.377	0.738	4.347	-8.724	4.239	-5.076	-2.133	289.6	-0.002	0	0	0	-0.021	995.13	100	0
13	2:37:30	322	2019	982856215.5	7.934	0.793	4.36	-5.296	4.485	-5.072	-2.133	289.6	-0.002	0	0	0	-0.021	995.14	100	0
14	3:07:30	322	2019	982856216.9	6.676	0.668	4.34	-2.602	4.624	-5.068	-2.133	289.6	-0.002	0	0	0	-0.02	995.16	100	0
15	3:37:30	322	2019	982856217.2	7.591	0.759	4.355	-0.719	4.647	-5.056	-2.133	289.6	-0.002	0	0	0	-0.022	995.2	100	0

Fig. S6. Contents of an example set summary (set.txt) file.