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The International Bathymetric Chart of the Southern Ocean Version 2

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1 The International Bathymetric Chart of the Southern Ocean Version

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56

57 **Abstract**

58 The Southern Ocean surrounding Antarctica is a region that is key to a range of climatic and
59 oceanographic processes with worldwide effects, and is characterised by high biological
60 productivity and biodiversity. Since 2013, the International Bathymetric Chart of the
61 Southern Ocean (IBCSO) has represented the most comprehensive compilation of
62 bathymetry for the Southern Ocean south of 60°S. Recently, the IBCSO Project has combined
63 its efforts with the Nippon Foundation – GEBCO Seabed 2030 Project supporting the goal of
64 mapping the world’s oceans by 2030. New datasets initiated a second version of IBCSO
65 (IBCSO v2). This version extends to 50°S (covering approximately 2.4 times the area of
66 seafloor of the previous version) including the gateways of the Antarctic Circumpolar Current
67 and the Antarctic circumpolar frontal systems. Due to increased (multibeam) data coverage,
68 IBCSO v2 significantly improves the overall representation of the Southern Ocean seafloor
69 and resolves many submarine landforms in more detail. This makes IBCSO v2 the most
70 authoritative seafloor map of the area south of 50°S.

71

72 **Background & Summary**

73 The Southern Ocean is a major component of the coupled ocean-atmosphere climate system
74 and references therein¹ including the Antarctic Circumpolar Current (ACC). It is furthermore
75 the most important ocean region for the uptake of anthropogenic CO₂ and heat from the
76 atmosphere e.g. ^{2,3}, and cold and dense bottom waters form on the shelves surrounding
77 Antarctica e.g. ^{4,5}. Interactions of the Southern Ocean with Antarctic glaciers and ice shelves
78 are the main drivers of present, past, and future Antarctic ice sheet mass balance ⁶ and thus
79 global sea-level change. Biologically, the Southern Ocean is a high-productivity area ⁷ with
80 high biodiversity ⁸. The Southern Ocean is also one of the most remote and harshest areas of
81 the world with extensive sea-ice cover and year-round severe weather conditions. Despite its
82 remoteness and hostility, human activities are increasingly extending into this distant part of
83 the world, examples including research, fisheries, and tourism. Precise bathymetric
84 information as e.g. provided by the International Bathymetric Chart of the Southern Ocean
85 (IBCSO) and the Digital Bathymetric Model of the Drake Passage (DBM-BATDRAKE) ⁹ are
86 paramount to better understand the Southern Ocean and its processes as well as for human
87 activities and conservation and management measures ¹⁰. IBCSO aims to provide the most
88 comprehensive compilation of bathymetric data for this region.

89 IBCSO was initiated in 2006 with the first version published by Arndt et al. in 2013 ¹¹. It is the
90 southern equivalent of the International Bathymetric Chart of the Arctic Ocean (IBCAO),
91 which was originally produced in 2000 and recently released its fourth version ^{12,13}. Both
92 initiatives are regional mapping projects of the General Bathymetric Chart of the Oceans
93 (GEBCO). GEBCO is a project under the auspices of the International Hydrographic
94 Organization (IHO) and the Intergovernmental Oceanographic Commission (IOC) with the
95 goal to produce the authoritative map of the world’s oceans. Furthermore, IBCSO has
96 combined its efforts with and is supported by the Nippon Foundation – GEBCO Seabed 2030
97 Project launched in 2017 by the Nippon Foundation of Japan and GEBCO ¹⁴. The IBCSO
98 Project is also an integral part of the Antarctic research community and an expert group of
99 the Scientific Committee on Antarctic Research (SCAR).

100 Initially, IBCSO was limited to the Antarctic Treaty area covering the area south of 60°S with a
101 resolution of 500 m × 500 m in a Polar Stereographic projection ¹¹. Following the release of
102 Version 1, the user community expressed the wish for an IBCSO reaching to 50°S to cover the
103 entire ACC and the Antarctic circumpolar frontal systems. This request, the growing demand

104 for bathymetric information of the Southern Ocean, and the availability of numerous new
105 bathymetric datasets collected since the first version of IBCSO were the motivations to
106 produce a new version of IBCSO.

107 Here we present IBCSO Version 2 (IBCSO v2) (Fig. 1) covering the area south of 50°S. The
108 resolution is 500 m × 500 m in IBCSO Polar Stereographic projection (EPSG: 9354, see also
109 the usage notes). It covers over 77 Million km² of seafloor (approximately 2.4 times the area
110 of seafloor covered by IBCSO v1). Highlights include improved bathymetries for the
111 important oceanographic gateway of the ACC, the Drake Passage (now entirely included in
112 IBCSO v2), and the Tasmanian Gateway (Fig. 1). The IBCSO v2 Digital Bathymetric Model
113 (DBM) is available in two topography versions: one with ice surface elevation on the
114 Antarctic continent and one with bedrock elevation, including sub-ice topography.
115 Furthermore, we provide a Type Identifier (TID) grid that indicates the type of data that
116 composes each grid cell. The TID codes adhere to GEBCO standards (Table 1). In addition, a
117 unique Regional Identifier (RID) grid links each data cell to the corresponding metadata
118 information and thus the DBM's cell value origin. All grids, a metadata table, and a print
119 version of the IBCSO v2 map are publicly available for download from the PANGAEA data
120 repository¹⁵.

121

122 **Methods**

123 The increase in coverage from IBCSO v1 to IBCSO v2 resulted in a substantial increase in the
124 amount of data processing necessary at all levels from data submission to product
125 generation. To cope with this higher computing workload, we have created a full
126 computational environment surrounding the main processing pipeline (SEAHORSE) (Fig. 2) of
127 the IBCSO v2 DBM. This environment includes a database management system linked to
128 SEAHORSE. To reduce run times, SEAHORSE is running dedicated code in a high-performance
129 computing environment using parallel computing.

130 On submission, the quality and integrity of datasets is assessed visually and autonomously
131 using designated Python scripts in order to identify major errors (e.g. inverted coordinates,
132 wrong projections, outliers). After these initial checks, weights (Table 2) are assigned to
133 datasets for later processing. Weights are based on the type of data (Table 1) as well as the
134 quality and age of the data¹⁵. Multibeam datasets have generally high weights (≥ 15)
135 compared to e.g. singlebeam data (weights ≤ 10) in order to supersede during data
136 processing. Then, the data are transferred as ASCII XYZ files to SEAHORSE for the production
137 of the IBCSO DBM.

138

139 *SEAHORSE processing workflow*

140 SEAHORSE consists of four distinct stages (Stage A-D, Fig. 2), each containing a number of
141 individual steps. All stages can be run independent from each other. Outputs include
142 extensive reports for quality assurance (QA) and continuous feedback to the IBCSO metadata
143 database (i.e. properties of the data sets derived from processing). SEAHORSE harmonises
144 submitted datasets (harmonisation – Stage A), subdivides them into smaller spatial chunks of
145 data (tiling – Stage B), calculates weighted blockmedians within these chunks (weighted
146 statistics – Stage C) and computes a composite of all data (containing data of all quality).
147 Furthermore, a subset that contains only high-quality data (weights ≥ 15) is computed for
148 subsequent gap-filling to produce the final grid product (product creation – Stage D).

149

150 **Stage A: harmonisation**

151 The initial Stage A (Fig. 2) harmonises incoming datasets line by line and adds the
152 harmonised version of the input data to the IBCSO file database. The harmonisation arranges
153 arbitrarily ordered datasets into standardised XYZ files (consisting of an X, Y, and Z column)
154 with each line representing a single geographic location and depth sounding. A next step
155 identifies and removes potential errors in the data, such as erroneous depths (values

156 exceeding known maximum depths in the study area) and implausible coordinate values (e.g.
157 ship-borne bathymetry with locations on land). Output files from Stage A contain X, Y and Z
158 values rounded to 1-metre accuracy, with duplicates removed, and separated by a
159 standardised column separator. They are stored in a harmonised file database using the
160 dataset identifier and the associated weight as filenames (Table 2).

161

162 **Stage B: tiling**

163 Stage B (Fig. 2) subdivides the harmonised file database into smaller spatial regions, pooling
164 data from different sources. For this purpose, we subdivide the area south of 50°S into 100
165 km × 100 km tiles (in EPSG:9354 projection). Subsequently, a spatial join of all datasets with
166 the defined tiles allows the assignment of each data point to a distinct tile. Points that do not
167 fall into any tile are skipped and reported to QA. The result is a tile database with a single file
168 for each tile. The tiles are further used to identify the origin of outliers and erroneous data
169 visible in the final product. Erroneous data are removed from the harmonised database
170 during iterative cleaning routines using the software suite Qimera® until all obvious artefacts
171 disappear and a satisfactory quality is achieved.

172

173 **Stage C: weighted statistics**

174 In Stage C (Fig. 2), a weighted blockmedian is calculated for each 500 m × 500 m cell using
175 the Generic Mapping Tools 6.1.1 (GMT) *blockmedian* module¹⁶. Five statistic descriptors are
176 calculated: minimum, 25% quartile, 50% quartile (median), 75% quartile, and maximum of
177 the weighted data in each cell. In a subsequent step, the median data points are augmented
178 with additional information from the metadata, i.e. TID and RID. The outputs of this stage
179 are single files per tile containing XYZ values, the summary statistics (min, q25, q75, and
180 max), and categorical values (TID, RID, and the contributing organisation) for each line.

181

182 **Stage D: product creation**

183 In the final Stage D (Fig. 2), all files from Stage C are combined and subsets of geographic
184 points are created (XYZ files) depending on the type of data. Based on the TID, the data are
185 filtered to extract only high-quality data (weights ≥15, Table 2) from the database. The
186 complete dataset and the extracted high-quality dataset are gridded using a modified
187 processing sequence that has been initially introduced for the IBCAO Project by Jakobsson, et
188 al.¹² and later adapted for IBCSO v1¹¹, and the Southwest Indian Ocean Bathymetric
189 Compilation¹⁷. For IBCSO v2, this approach has been further developed. At first, all
190 irregularly spaced geographic points are gridded using “*continuous curvature spline in*
191 *tension*” from the GMT’s *surface* module¹⁶ with a tension factor of 0.35 (first used in IBCSO
192 v1) to create a 2 km × 2 km background grid. Comparisons of outputs show that this tension
193 factor is appropriate for the SEAHORSE workflow. This grid is subsequently filtered in the
194 spatial domain using GMT *grdfilter* with an isotropic cosine arch convolution filter (width
195 6000 m). The output is resampled to 500 m × 500 m resolution using a bicubic interpolation
196 (GMT *grdsample*). The high-quality data are gridded to a separate 500 m × 500 m resolution
197 grid using GMT *nearneighbor* to preserve the high-quality direct measurements in the final
198 product.

199 Background and high-quality grid are combined using the bending algorithm from Arndt, et
200 al.¹¹ that follows the remove-restore concept described in Hell and Jakobsson¹⁸ and
201 Jakobsson, et al.¹². The algorithm is implemented using the programming language Python
202 and its scientific ecosystem, e.g. SciPy¹⁹, NumPy²⁰, PyGMT²¹, and Dask <https://dask.org/> as
203 an interface for GMT¹⁶. Based on experiences from previous compilations, we choose a
204 transition zone covering 20% high-quality and 80% background data grid along the
205 intersection edges for the bending (Fig. 3). An extended high-quality grid is calculated by
206 convolving both grids to infill (i.e. extrapolate) the transition zone for the sparse high-quality
207 grid. This is required to calculate the depth values (z_c) in equation (1) for the transition zone

208 using a combination of the extended high-quality and background grids where z_h and z_b are
209 depth values of the high-quality and the background grid, respectively,
210

$$211 \quad (1) \quad z_c = \frac{z_b * d_i^2 + z_h * d_o^2}{d_i^2 + d_o^2}$$

212
213 with weighted distances of the transition zone grid cells to the inner (d_i) and outer (d_o)
214 edges of the transition zones, using a hyperbolic weighting function ($1/d^2$). Depth values in
215 the transition zone are progressively more affected by the closer (e.g. high-quality) input
216 grid. Finally, the high-quality and background grids are merged by replacing cell values in the
217 background grid with values from the high-quality grid before inserting the transition zone
218 cell values calculated via equation (1). This approach successfully minimises undesired edge
219 effects caused by the combination of grids of different resolutions and potential depth
220 offsets. The quality of the resulting composite grid is visually evaluated using the Open
221 Source Geographic Information System QGIS.

222 In the following gap-filling step, areas without direct measurements are filled with predicted
223 bathymetry (for IBCSO v2 this is SRTM15+ v2.2²²). The composite and predicted bathymetry
224 grids are combined using the above-described bending algorithm with a transition zone of 10
225 km (or 20 grid cells for 500 m resolution) that exclusively comprises grid cells from the
226 predicted bathymetry grid to avoid altering high-quality data cells representing direct depth
227 measurements. Pre-bending, the predicted bathymetry grid is adjusted to the IBCSO
228 database to minimise artefacts caused by varying depths by calculating an offset factor
229 between both grids on a cell-by-cell basis. A 1000 m × 1000 m blockmedian is computed with
230 the GMT *blockmedian* module to suppress small-scale artefacts in the grid. The factor values
231 are re-gridded and filtered using GMT *surface* and *grdfilter* with a cosine arch filter (2000 m x
232 2000 m) via PyGMT before the resulting grid is resampled to 500 m x 500 m using GMT
233 *grdsample*. Then, this factor grid is used to adjust the predicted bathymetry grid by
234 multiplying both grids. Areas are masked out, if the adjusted predicted bathymetry differs
235 significantly from the surface grid (e.g. continental shelf areas and around islands). There,
236 the background surface spline grid is used instead. This approach successfully prevents
237 artefacts caused by differences in data resolution and accuracy.

238 In the final step, ice-surface and ocean mask grids are dynamically generated from the
239 datasets created in previous processing steps (Fig. 2). The ice-surface mask is derived from
240 the BedMachine²³ surface elevation grid. The ocean mask is calculated from the gap-filled
241 composite grid considering the ice-surface mask and RID grid (excluding all values above 0
242 m). It is used to assure that all ocean cells are modelled below sea level and all topographic
243 cells are modelled above sea level. Grid cells that failed this logical test are set to the value -1
244 for ocean cells and to the value 1 for topographic cells. The ice-surface mask is used to create
245 IBCSO v2 with ice surface elevation from BedMachine²³.

246

247 **Data Records**

248 IBCSO v2 is available for download from the PANGAEA data repository¹⁵. It comprises a
249 variety of datasets (Table 1) ranging from digitised contours and lead line soundings to high-
250 resolution multibeam data. If possible, the use of gridded compilations was avoided and
251 source datasets were used instead to achieve the most consistent interpolation and prevent
252 an overestimation of the covered area (Fig. 3). Therefore, each dataset mostly refers to a
253 single expedition with its unique RID value¹⁵.

254

255 *Bathymetry*

256 High-resolution multibeam datasets make up the basis of the compilation with a total of 464
257 datasets. In addition, 766 singlebeam datasets provide measured bathymetric information
258 (Table 1, Fig. 3). The datasets were received in various formats and were standardised as

259 ASCII XYZ data with associated metadata information when available (e.g. data contributor,
260 source survey, year of survey). However, many datasets lack detailed information regarding
261 their origins making it difficult to assess their quality. Furthermore, the spatial distribution of
262 data shows a high degree of heterogeneity. For example, Drake Passage and the Ross Sea
263 areas display high multibeam data coverage while along East Antarctica mostly singlebeam
264 data exist (Fig. 3).

265 IBCSO v2 uses SRTM15+ v2.2²² as the predicted bathymetry. It, however, contains numerous
266 artefacts especially in areas of sea-ice cover and on the continental shelves. To avoid the
267 incorporation of those artefacts, after interrogation of the available high-resolution
268 multibeam data, critical areas are masked out for the infill with predicted bathymetry.

269

270 *Sub-ice shelf bathymetry*

271 Sub-ice shelf bathymetry in IBCSO v2 is constrained by direct measurements (e.g. from
272 seismic campaigns), and in the absence of direct measurements by bathymetry estimations
273 from gravity inversions, interpolation, and artificial steering lines. Seismic measurements
274 from 21 datasets conducted since the 1950s are included (Supplementary Table 1).

275 We only include bathymetry inferred from gravity inversion that rely on airborne gravity
276 measurements and only in areas that are further away than 5 km from direct measurements
277 in the IBCSO v2 database. In addition, we do not use bathymetry inferred from gravity
278 inversions in areas where the models produce unrealistically shallow topography. Such areas
279 have been identified either by a large discrepancy between the depths modelled by the
280 gravity inversion and depths determined by seismic measurement, or by very small water
281 column thicknesses (less than 100 m) in the sub-ice shelf continuation of narrow, deeply
282 incised subglacial troughs beyond the grounding-line. Such areas with steep topography with
283 abrupt elevation changes are usually poorly resolved by gravity inversions due to the long
284 wavelength and are therefore typically inadequately modelled^{24,25}. This mainly occurs at the
285 western Ross Ice Shelf close to the Transantarctic Mountains. Supplementary Table 2
286 summarises the gravity inversions that are incorporated directly or as part of the
287 BedMachine Antarctica dataset²³.

288 For the Amery Ice Shelf cavity, we use the bathymetric model created by Galton-Fenzi, et al.
289²⁶. This model also uses seismic point data and an interpolation guided by tidal modelling for
290 the deepest, most inland section of the ice shelf which is difficult to survey due to crevasses.
291 For the remaining ice shelf areas, i.e. where neither direct measurements nor good quality
292 gravity inversions exist, we have investigated the adjacent bathymetry and subglacial
293 bedrock measurements for glacially incised troughs. Where such troughs are located, we
294 introduce artificial steering lines to guide our interpolation to model a continuation of these
295 troughs. For the remaining areas, we use the seafloor depths as provided in the bed layer of
296 BedMachine²³.

297

298 *Sub-ice sheet topography, ice surface topography, and island topography*

299 Sub-ice sheet topography is entirely derived from the bed layer of BedMachine²³.
300 BedMachine in these areas builds on ice-thickness measurements from airborne radio-echo
301 sounding and a mass-conservation approach that uses ice sheet dynamics to interpolate
302 between measurements²³.

303 The topography is derived from various datasets (Fig. 3). Their selection depends on the
304 geographical region and the quality of the different datasets in these regions. For the
305 Antarctic mainland, we use the surface layer of the BedMachine dataset²³ derived from the
306 “Reference Elevation Model of Antarctica” (REMA) that has a spatial resolution of 8 m²⁷.
307 Despite this higher resolution, we use the BedMachine topography information in
308 continental ice-covered areas of Antarctica to ensure consistency with the ice thicknesses
309 reported within BedMachine. For some coastal, ice-free areas of East Antarctica and for

310 some small islands that are not resolved in BedMachine, we have directly added elevation
311 information from the REMA dataset ²⁷.
312 For many Antarctic islands, REMA, and thus also BedMachine, yields no (e.g. South Orkney
313 Islands, Balleny Islands) or incomplete (e.g. King George Island) topographic information. For
314 these islands, most sub-Antarctic islands, and for South America we use elevation data from
315 the ALOS Global Digital Surface Model Version 3.2 of the Japan Aerospace Exploration
316 Agency ²⁸. For a few islands, including some smaller reefs, and for a few parts of larger
317 islands, the ALOS model does not provide elevation information. These areas are modelled
318 using elevation data from other models, for example reefs at South Georgia from a
319 compilation by Fretwell, et al. ²⁹ and parts of the South Sandwich Islands from a compilation
320 by Leat, et al. ³⁰. In the cases where no elevation models are available but the location of the
321 island is constrained by satellite imagery, we create artificial elevation data to constrain our
322 model to a reasonable elevation.

323

324 **Technical Validation**

325 SEAHORSE produces detailed reports for each individual stage. These reports are used to get
326 estimates on runtimes per step and the size of data processed in each stage. In addition, we
327 create a wide range of auxiliary data used for internal quality management and data review.
328 For estimating the variation of data from different surveys within a grid cell, we use the
329 interquartile range (the absolute distance between the 25% and 75% quartile) of
330 blockmedian window data to produce bathymetric charts analogous to the main workflow.
331 These we use to derive a map of depth-ranges (Z_{range}) in equation (2).

332

$$333 \quad (2) \quad Z_{range} = |(Q_{75} - Q_{25})|$$

334

335 Under the assumption that depth values per grid cell are normal distributed with zero
336 skewness, this is the most intuitive measure of variability that we can derive. While this is
337 not a perfect way to measure the uncertainty in a given grid cell, we regard this as the most
338 practical way to get an estimate of the expected range of depth values for every given grid
339 cell (Fig. 4).

340 Overall variability increases with the number of datasets in a grid cell. The interquartile range
341 of depth values at any given cell falls mostly between 0 m and 100 m. High values occur
342 along the regular supply routes for Antarctic stations and within areas of high scientific
343 interest where many datasets overlap. These areas have been visited across multiple
344 generations of technical proficiency. On the other hand, areas with low variability indicate
345 areas with little survey effort or areas that have produced similar data across multiple data
346 sources. This can be expected for measurements e.g. in shallower waters. However,
347 variability does not immediately quantify the reliability of the reported depth value. We can
348 conclude that our blockmedian approach is robust against outliers in the 25th and 75th
349 quartiles. Only areas where both low coverage and high variation in measured data coincide
350 have a detrimental effect on the final depth value in a grid cell.

351 The RID grid (Fig. 1b) gives a first impression, where the IBCSO v2 grid is constrained by
352 actual data. Data coverage per tile (Fig. 5) provides an additional indication of how many grid
353 cell values per tile originated from measured data. This coverage map highlights distinct
354 distribution patterns. Exceptionally high coverages, up to 100%, occur e.g. in the Drake
355 Passage (upper left sector Fig. 5), whereas vast areas with only little data coverage are
356 especially prominent offshore East Antarctica. Depths in regions of high coverage can be
357 considered reliable, regardless of an apparent increase in the interquartile range. These
358 areas are located along more frequently used ship routes and have been surveyed using
359 more accurate recent multibeam systems. In areas with low data coverages (Fig. 5), the
360 inclusion of the SRTM15+ predicted bathymetry grid yields a more comprehensive and
361 representative DBM of the seafloor.

362 The overall increase in multibeam data coverage (Fig. 3b) resulted in a clear improvement of
363 the grid. The differences between IBCSO v2 and the reference grids IBCSO v1 (Table 3) and
364 SRTM 15+ were assessed to quantify the impact of the new data contributions (and updates
365 of external data, such as the predicted bathymetry grid and high-resolution topographic
366 data). When comparing grids, we applied the ocean mask from Stage D to use the same
367 extent. Then, the arithmetic difference between each cell of IBCSO v2 and its corresponding
368 grid cell from the reference grid (discarding all empty cell pairs) were calculated. Due to the
369 amount of data, moving averages (with window sizes of 100 and 500) were plotted of the
370 depth difference for each grid cell (Fig. 6a & b). The plot is created with ggplot2³¹ in R
371 version 3.6.1 <https://www.r-project.org/>. Difference between IBCSO v2 and IBCSO v1 (Fig.
372 6a) are noticeable throughout all depth ranges. The comparison with SRTM15+ (Fig. 6b) also
373 shows noticeable differences for water depths in particular between -4500 m and -2000 m.
374 For more detailed comparisons between IBCSO v2 and the reference grids IBCSO v1 and
375 SRTM15+, we target six areas of interest for closer inspection (Fig. 1c, 7). Since IBCSO v1
376 does not provide information on uncertainty, we cannot use any measure of uncertainty for
377 this comparison. Instead, we opt for a discrepancy metric (discrepancy λ , equation (3))
378 defined as the difference grid between IBCSO v2 and IBCSO v1 or SRTM15+ (δ , equation (4))
379 divided by the mean of IBCSO v2 and IBCSO v1 or SRTM15+ (μ , equation (5)):

380

381 (3) $\lambda = \frac{\delta}{\mu}$

382 (4) $\delta = Z_{IBCSO\ v2} - Z_{Reference}$

383 (5) $\mu = \frac{(Z_{IBCSO\ v2} + Z_{Reference})}{2}$

384

385 This results in values centred on zero, with positive numbers indicating IBCSO v2 depths
386 being deeper than the reference grid and negative numbers being shallower.

387 When comparing IBCSO v2 with v1, areas with significant bathymetric changes over a
388 relatively short distance e.g. the shelf break around Antarctica (Fig. 7a,c), the South Scotia
389 Ridge (Fig. 7b) or slopes around islands (Fig. 7d) display more pronounced discrepancies. The
390 change in data coverage and quality is obvious when looking at the area seaward of Totten
391 Glacier (Fig. 7c) where a multibeam dataset acquired in 2017 by the Australian research
392 vessel RV Investigator improves the morphology of the shelf break and resolves a network of
393 submarine channels at the slope. Similar improvement is visible at the South Scotia Ridge
394 where incised slopes facing towards the Powell Basin have been mapped in high-resolution
395 by the RV Polarstern³² in 2019 resulting in a larger discrepancy. The benefit of incorporating
396 actual source data rather than gridded compilations is seen in Fig. 7d. In IBCSO v1, the slopes
397 around the Balleny Islands are based on a data compilation with a resolution of 1000 m.
398 However, for IBCSO v2 we were able to receive the source data in full multibeam resolution
399 resulting in a much more detailed DBM for this area compared to IBCSO v1.

400 Improvements can also be observed when comparing IBCSO v2 with the predicted
401 bathymetry grid (SRTM15+ v2.2, Fig. 7). The Williams Ridge and the adjacent Labuan Basin at
402 the Kerguelen Plateau were mapped by the RV Investigator and RV Sonne in 2020. These
403 additional data substantially improved the bathymetry for this region (Fig. 7e). Distinct
404 improvements are also visible when examining the region around the South Sandwich
405 Islands and Trough (Fig. 7f). Although not covered by IBCSO v1, the comparison with the
406 SRTM15+ grid highlights an increased grid quality caused by large seafloor areas now
407 constrained by multibeam measurements. This effect is especially obvious at the slopes of
408 the South Sandwich Islands. Overall, the IBCSO v2 grid contains a multiplicity of additional
409 datasets gathered since the release of IBCSO v1 also including extended areas previously not
410 covered.

411

Usage Notes

The IBCSO DBM is provided in GeoTIFF and netCDF-4 file formats with coordinates and depth stored as 16-bit integers and a pixel node registration. These formats can be imported into all major GIS packages (e.g. QGIS, ArcGIS). All grids are available in geographic coordinates (WGS84, EPSG:4326) and in projected Cartesian coordinates defined in the IBCSO Polar Stereographic projection registered with the EPSG Geodetic Parameter Dataset using the code EPSG:9354 (https://epsg.org/crs_9354/WGS-84-IBCSO-Polar-Stereographic.html). The projection's true scale is set at 65°S and coordinates in X and Y directions are given in meters. The horizontal datum is WGS84 whereas the vertical datum is approximately Mean Sea Level. Due to limited acquisition parameter information, there are uncertainties associated with the vertical datum information, especially for older data. The grid cell value of the DBM is given in meters with negative values representing depths below sea level and positive values corresponding to topographic elevation. For the RID and TID grids, the cell values represent a unique dataset and type identifier value respectively. An overview of the TID codes is given in Table 1, whereas a list of all incorporated datasets is provided at the PANGAEA data repository¹⁵.

When using the native IBCSO projection, it is important to consider the following: The EPSG code was registered in March 2020 and first included in EPSG v9.8.11 database published on the 30th April 2020 that was again included in the PROJ 7.1.0 database (from 1st July 2020). However, QGIS versions prior to release 3.20.0 (from 19th June 2021) are using older PROJ database versions that do not include the IBCSO projection (EPSG:9354). Similar limitations may also apply to other GIS software packages (e.g. ArcGIS) depending on the version of their libraries. In this case, we recommend creating a temporary user-defined CRS from the specifications provided at the PANGAEA data repository¹⁵.

Code Availability

The GMT and GDAL routines used in the SEAHORSE workflow are Open Source and can be accessed on their respective webpages (<https://www.generic-mapping-tools.org/> and <https://gdal.org/>). All relevant code related to the main SEAHORSE workflow are available at https://github.com/SeaBed2030/IBCSO_v2_Dorschel_et_al_2022. Data for the technical validation are hosted on figshare³³. Since the SEAHORSE workflow was customised to fit the existing architecture of AWI's high performance cluster, most of the code is specific and requires severe adjustments when moved to a different environment.

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535

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554

555 Competing Interests

556 The authors declare that they have no competing interests.

557

558 Author Contributions

559 Boris Dorschel: Lead the compilation work, writing parts of the Data Descriptor. Laura
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561 Data Descriptor. Sacha Viquerat: Developed SEAHORSE, writing parts of the Data Descriptor,
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599 Contributed source data, quality control. Jan Erik Arndt: Under ice shelf topography,
600 bathymetry-topography integration, writing parts of the Data Descriptor.

601

602 **Table Captions**

603 Table 1: Type identifier (TID) table with codes adhering to the standards of the General
604 Bathymetric Chart of the Ocean (GEBCO), short data type name, description,
605 weight (see also Table 2), and number of linked datasets featured in IBCSO v2.

606

607 Table 2: Numerical weights assigned to each source dataset based on data type, age, and
608 quality.

609

610 Table 3: Descriptive summary of metadata and the database of IBCSO v2. Seafloor area (km²)
611 is calculated based on WGS84 ellipsoid using the QGIS plugin Cruise Tools
612 (<https://github.com/simondreutter/cruisetools>). Data type coverages correspond
613 to percentage of filled ocean cells in IBCSO v2 grid resolution (500 m x 500 m).

614

615 **Figure Captions**

616 Figure 1: (a) Shaded relief of IBCSO v2 with ice surface topography. (b) Regional Identifier
617 (RID) grid showing unique datasets (multicolours), topographic data (white),
618 interpolated transition zone (black) and predicted bathymetry (dark grey). (c)
619 Locations of example areas shown in Fig. 7.

620
621 Figure 2: Schematic overview of the SEAHORSE processing workflow comprising the Stages
622 A-D.

623
624 Figure 3: (a) Map showing the data type identifier (TID) of source data used for IBCSO v2.
625 Various data types representing isolated soundings (TID: 10, 12, 13, 14) are
626 grouped together and displayed as "singlebeam". Data type "other" includes all TID
627 greater than 14 (e.g. 71: unknown source) whereas "multibeam" only represents
628 actual multibeam datasets (TID: 11). White dashed line represents the
629 northernmost IBCSO v1 extent (60°S latitude).
630 (b) Comparison of percent seafloor coverages by different data types for IBCSO v1
631 and v2 south of 60°S as well as current status of IBCSO v2 (south of 50°S).

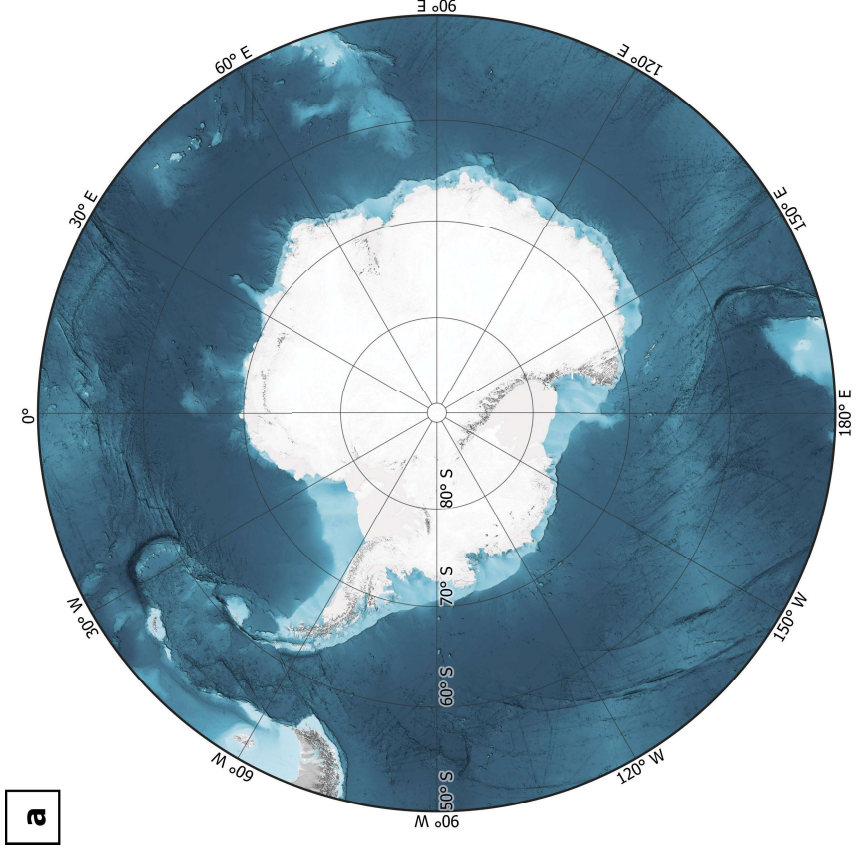
632
633 Figure 4: Map showing the interquartile range for the final depth values of the grid.
634 Estimation based on grids created from the 25% quartile and the 75% quartile of
635 data as reported by GMT blockmedian.

636
637 Figure 5: Overall data coverage of IBCSO v2 indicated by coverage per tile (100 km x 100 km).
638 (a) Data coverage of only high-quality multibeam datasets (weights ≥ 15 , multibeam
639 data, see Table 1) with tiles featuring only low-quality data (weights < 15) masked
640 out in grey. (b) Data coverage based on all datasets.

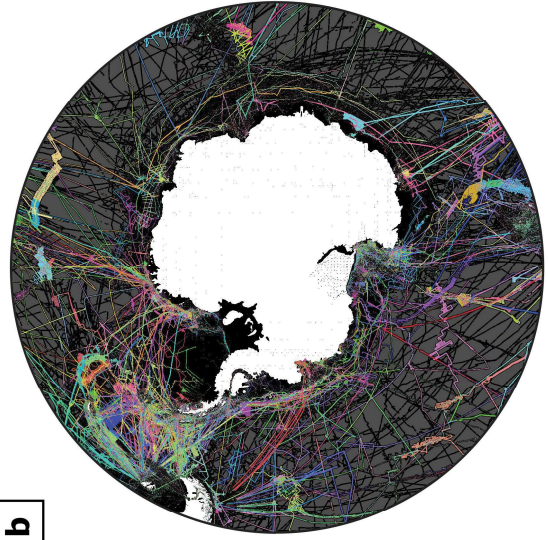
641
642 Figure 6: Cell by cell difference between IBCSO v2 depths (x-axis) and reference grid depth
643 differences (on y-axis). (a) IBCSO v1 as reference grid; (b) SRTM 15+ as reference
644 grid. Blue lines indicate moving average with step size 100, orange lines indicate
645 moving averages with step size 500. Grids were masked to contain only ocean cells
646 and extents were adjusted in order to ascertain identical extents when comparing
647 IBCSO v2 and the reference grid.

648
649 Figure 7: Comparison between IBCSO v1 and IBCSO v2 for: (a) Cosmonauts Sea, (b) South
650 Scotia Ridge, (c) seaward of Totten Glacier and (d) Balleny Islands. Plots indicate
651 (from left to right) IBCSO v1 chart, IBCSO v2 chart and calculated discrepancy
652 between IBCSO v1 and IBCSO v2. Comparison between SRTM15+ and IBCSO v2 for:
653 (e) Williams Ridge (Kerguelen Plateau) and (f) South Sandwich Through and Islands.
654 Plots indicate (from left to right) SRTM15+ chart, IBCSO v2 chart and calculated
655 discrepancy between SRTM15+ and IBCSO v2. Grids for comparison are masked to
656 contain only ocean cells. Columns IBCSO v1 and IBCSO v2 show the seabed as
657 depth-scaled colour layer shaded by multiplication with a slope-inclination layer
658 and a synthetic light source (hillshade) with 10× vertical exaggeration.

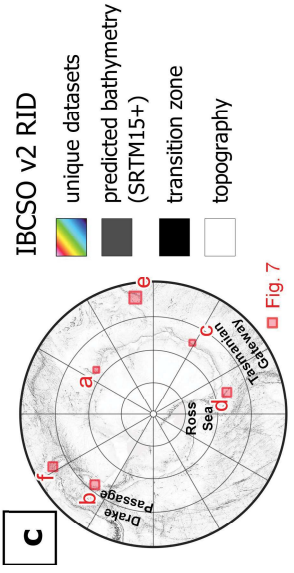
659



a



b



c

pre-processing

Stage A

Stage B

Stage C

Stage D

data cleaning

harmonisation

tiling

weighted statistics

product creation

data coverages
(points, polygons)

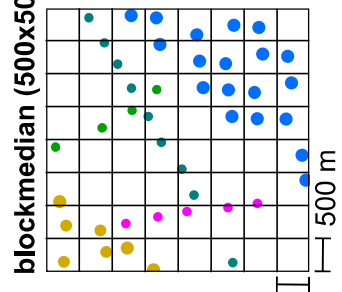
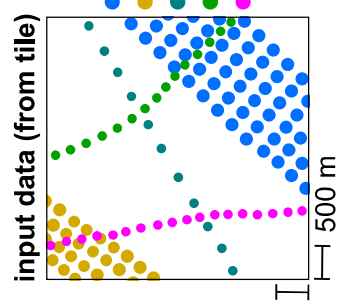
harmonised
database

tile
database

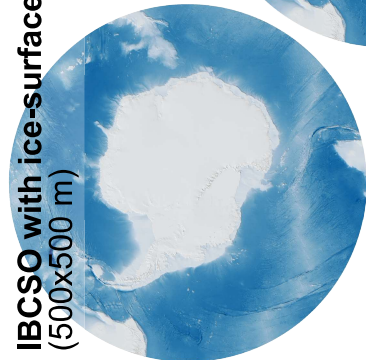
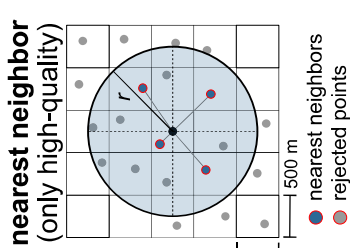
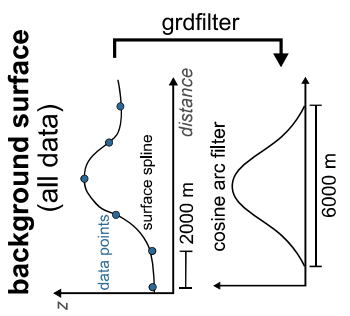
append sampled
auxiliary data
(i.e. BedMachine)

..... cleaning iterations

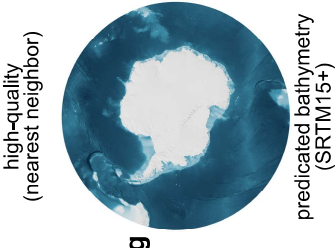
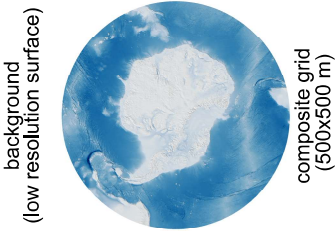
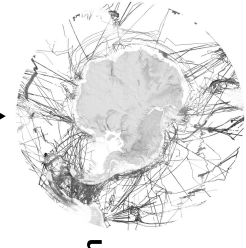
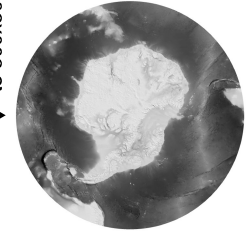
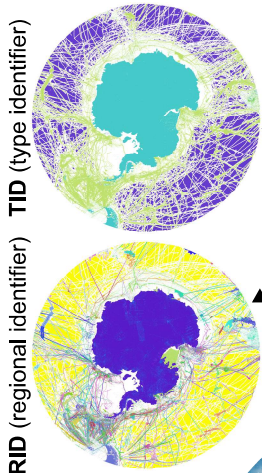
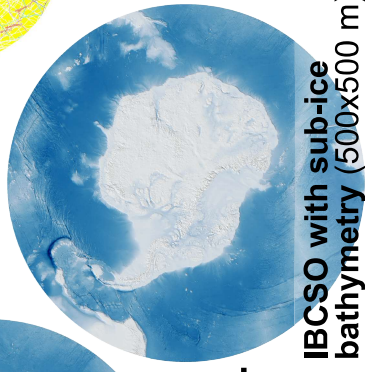
Computation of weighted blockmedian

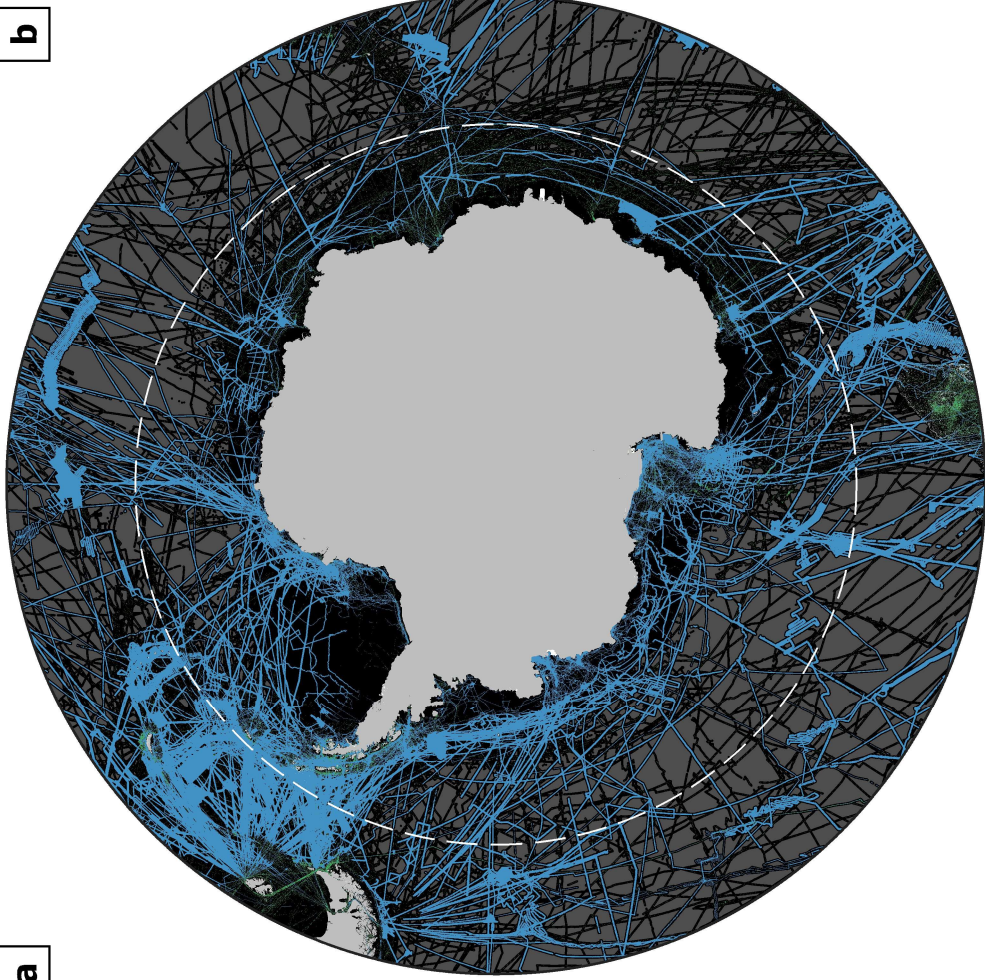


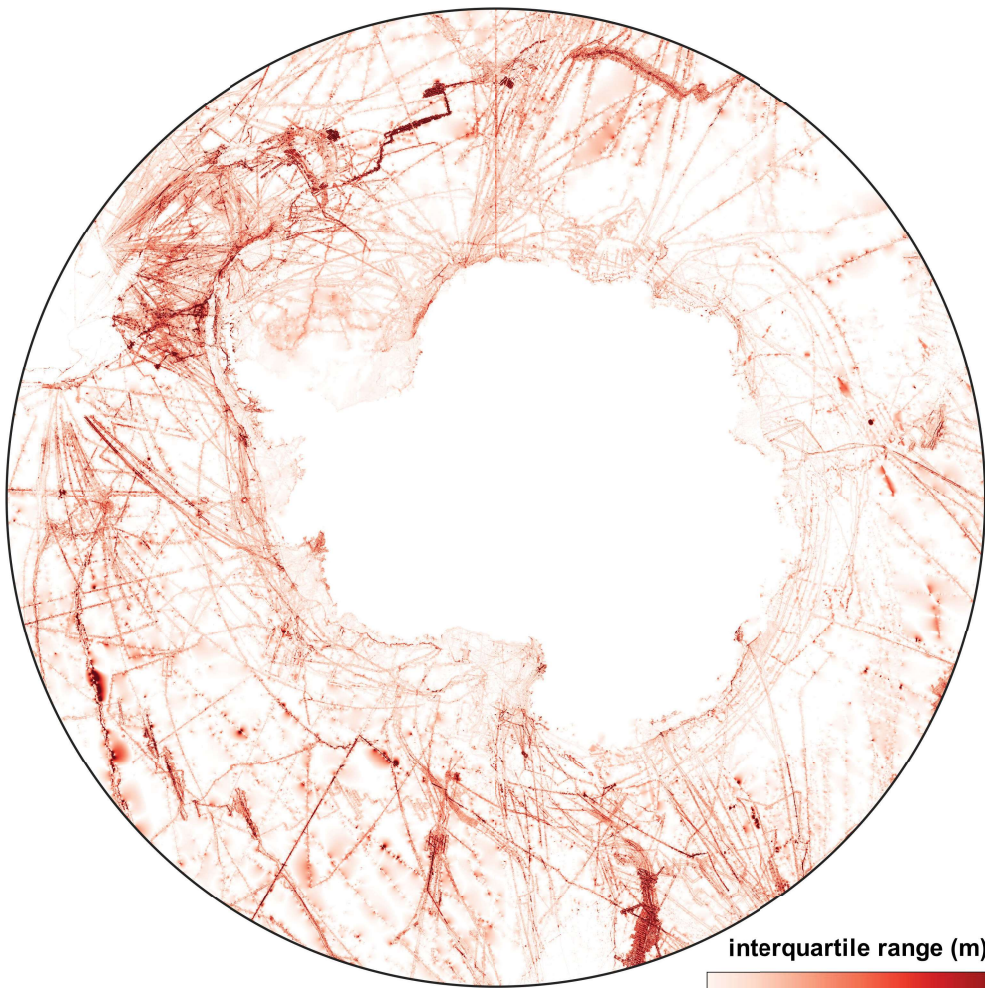
Gridding of tiled data



BedMachine ice-surface







interquartile range (m)
0 50 100 150 200

