Bed topography of Princess Elizabeth Land in East Antarctica 1

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20 Abstract

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22 We present a topographic digital elevation model (DEM) for Princess Elizabeth Land (PEL), East 23 Antarctica – the last remaining region in Antarctica to be surveyed by airborne radio-echo sounding 24 (RES) techniques. The DEM covers an area of ~900,000 km² and was established from new RES data 25 collected by the ICECAP-2 consortium, led by the Polar Research Institute of China, from four 26 campaigns since 2015. Previously, the region (along with Recovery basin elsewhere in East Antarctica) 27 was characterised by an inversion using low resolution satellite gravity data across a large (>200 km 28 wide) data-free zone to generate the Bedmap2 topographic product. We use the mass conservation 29 (MC) method to produce an ice thickness grid across faster-flowing (>30 m yr⁻¹) regions of the ice sheet 30 and streamline diffusion in slower-flowing areas. The resulting ice thickness model is integrated with 31 an ice surface model to build the bed DEM. With the revised bed DEM, we are able to model the flow 32 of subglacial water and assess where the hydraulic pressure, and hydrological routing, is most sensitive 33 to small ice-surface gradient changes. Together with BedMachine Antarctica, and Bedmap2, this new 34 PEL bed DEM completes the first order measurement of subglacial continental Antarctica - an 35 international mission that began around 70 years ago. The ice thickness and bed elevation DEMs of 36 PEL (resolved horizontally at 500 m relative to ice surface elevations obtained from a combination of 37 European Remote Sensing Satellite 1 radar (ERS-1) and Ice, Cloud and Land Elevation Satellite (ICESat) 38 laser satellite altimetry datasets) are accessible from https://doi.org/10.5281/zenodo.3666088 (Cui et 39 al., 2020).

40 1. Introduction

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42 Radio-echo sounding (RES) is commonly used to measure ice thickness, and to understand subglacial topography and basal ice-sheet conditions (Dowdeswell and Evans, 2004; Bingham and Siegert, 2007). 43 44 A series of airborne geophysical explorations were conducted across East Antarctica in the 1970s by 45 the Scott Polar Resear (n) stitute (SPRI) (Robin et al., 1977; Dean et al., 2008; Turchetti et al., 2008; 46 Naylor et al., 2008), which led to the first compilation 'folio' maps of subglacial bed topography, ice-47 sheet surface elevation and ice thickness of Antarctica (Drewry and Meldrum, 1978; Drewry et al., 48 1980; Jankowski and Drewry, 1981; Drewry, 1983). Since then, multiple efforts have been made to 49 collect and compile RES data in order to expand the RES database across the continent (Lythe et al., 2001; Fretwell et al. 2013). Russian Diciologists conducted the first geophysical exploration of the 50 coast of Princess Elizabeth Land (PEL) between 1971-2016, providing basic ice thickness, bed 51 52 topography and magnetic field data (Popov and Kiselev, 2018; Popov, 2020). To date, virtually no RES 53 data have been acquired upstream of ~300 km from the grounding line of PEL. Hence, this region has 54 been described as one of the so-called 'poles of ignorance' (Fretwell et al., 2013) and its representation 55 in recent bed DEMs is as a zone of flat topography, reflecting the absence of RES data (Morlighem et 56 al., 2020). Indeed other data gaps (Recovery system, Diez et al., 2019; and South Pole, Jordan et al, 57 2018) have been filled recently, leaving PEL has the last remaining site to be surveyed systematically. 58

59 In the absence of bed data, glaciologists have had to rely on satellite imagery, inversion from poor 60 resolution satellite gravity observations, and ice-flow modelling to infer the subglacial landscape and 61 its interaction with the ice above (Fretwell et al., 2013; Jamieson et al., 2016). For example, 62 combination of three satellite-derived mosaics, and some initial exploratory RES data, have been used to hypothesise the subglacial features of PEL (Jamieson et al., 2016). That study utilised the first RES 63 64 data collected as part of the collaborative effort between the US–UK–Australian ICECAP (Internation 65 Collaborative Exploration of Central East Antarctica through Airborne geophysical Profiling), which was conducted between 5th December 2010 to 20th January 2013 (Blankenship et al., 2017). Jamieson <mark>66</mark> 67 et al. (2016) reveal presence of a potentially large (>100 km long) subglacial lake (white box; Figure 1) and an expected canyon morphology across the PEL sector (Jamieson et al., 2016). Previously, a study 68 69 by Dongchen et al. (2004) adopted the interferometric synthetic-aperture radar (InSAR) satellite technology to generate an 'experimental' subglacial bed elevation model across the Grove Mountains 70 (Figure 1 While the result contains a level of 'detail', it has an obvious limitation in that the bed 71 72 elevation was based solely on the satellite data and without direct measurement of the subglacial 73 landscape. Another study used an inversion technique to generate a 'synthetic' glacier thickness of 74 the PEL region from satellite gravity data, as part of the Bedmap2 compilation (Fretwell et al., 2013). 75 A gualitative inspection of the Bedmap2 bed elevation product reveals the bed of PEL to be 76 anomalously flat -a consequence of its use of satellite gravity data in a low resolution inversion for 77 bed elevation across a data-free region. Hence, the bed topography in PEL is the poorest-defined of 78 any region in Antarctica – and indeed of any land surface on Earth.

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80 Here, we present the first detailed ice thickness DEM for PEL, based on new RES measurements 81 collected by the ICECAP2 programme led by the Polar Research Institute of China (PRIC) since 2015. 82 We integrated the DEM with ice surface elevation measurements to produce a bed DEM. We briefly 83 discuss the differences between the new bed DEM and its representation in Bedmap2, and the impact 84 of the new DEM on calculations of the flow of subglacial water. The bed DEM is relative to ice surface 85 elevations from a combination of European Remote Sensing Satellite 1 radar (ERS-1) and Ice, Cloud 86 and Land Elevation Satellite (ICESat) laser satellite altimetry datasets (Bamber et al., 2009). The ice 87 thickness DEM can be easily integrated with updated surface DEMs in future (Helm et al., 2014; Howat 88 et al., 2019) and, in particular, the upcoming Bedmap3 product.

- 89 2. Study Area
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91 The PEL sector of East Antarctica is bounded on the west by the Amery Ice Shelf, and on the east by 92 Wilhelm II Land (Figure 1a). The region covered by the new DEM we present here extends ~1,300 km 93 from East to West and ~800 km from North to South. In comparison with Bedmap2, the new DEM 94 benefits from recently acquired airborne geophysical data collected by the ICECAP2 for ramme over 95 four austral summer seasons from 2015 to 2019 (Figure 1b). We use the Differential Interferometry

- 96 Synthetic Aperture Radar (DInSAR) grounding line (Rignot et al., 2011) to delimit the ice-shelf facing
- 97 margin of the ice sheet.

98 3. Data and Methods

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During the first ICECAP2 season (2015/16), a survey acquiring exploratory 'fan-shaped' radial profiles, to maximize range and data return on each flight, was completed across the broadly unknown region of PEL. These flight lines extend from the coastal Progress Station to the interior ice-sheet divide at Ridge B (Figure 1a). In the second and third seasons (2016/17 and 2017/18), a survey 'grid' was completed, targeting enhanced resolution over a proposed subglacial lake and a series of basal canyons (see Jamieson et al., 2016). In the fourth season (2018/19), a few additional transects were completed to fill the largest data gaps within aircraft range.

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108 Field data acquisition was achieved using the "Snow Eagle 601" aerogeophysical platform; a BT-67 airplane operated by the Polar Research Institute of China for the Chinese National Antarctic 109 110 Research Expedition (CHINARE) program (Figure 2a and b). The suite of instruments configured on the 111 airplane include a phase coherent RES system, functionally similar to the High Capability Airborne Radar Sounder developed by the University of Texas Institute for Geophysics (UTIG), which has been 112 used on many ICECAP surveys (i.e. Young et al., 2011; Greenbaum et al., 2015). HiCARS is a phase <u>113</u> coherent RES system, operating at a central frequency of 60 MHz and a peak power of 8 kW, making 114 it capable of penetrating deep (>3 km) ice in Antarctica. After applying coherent integration and pulse 115 compression at a bandwidth of 15 MHz, which gave an along-track spatial sampling rate and a vertical 116 resolution of ~20 m and ~5.6 m, respectively. Further details on the parameters and introduction of 117 118 the CHINARE IPR can be found in Cui et al. (2018). A JAVAD GPS receiver and its four antennas are 119 mounted at the aircraft centre of gravity (CG), tail and both wings. GPS data from antenna at the 120 aircraft CG were used for RES data interpretation.

121 4. Data Processing

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123 Ice thickness measurements were derived from two RES data products from which the ice-bed 124 interface was traced and digitized: (a) 2D focused SAR processed data applied to RES data from the first two seasons; and (b) unfocused 'field' RES data from the third and fourth seasons. Raw RES data 125 126 were first separated to differentiate PST (Project/Set/Transect) during the field data processing. Pulse 127 compression, filtering, 10-traces coherent stacking and 5-traces incoherent stacking were then applied 128 to generate a field RES data product. The field RES data can be used for quality control and is also good 129 enough for initial ice-bed interface measurements, from which a-first-order ice thicknesses and bed 130 elevation DEM can be calculated. To achieve better-quality RES images, two-dimensional focused SAR processing was applied to data from the first two seasons (Peters et al., 2007). The ice-bed interface 131

- was picked in a semi-automatic manner using a picking program used previously by the ICECAP <u>132</u> program on data from the Aurora and Wilkes subglacial basins (Blankenship et al., 2016; Blankenship 133 134 et al., 2017). Ice thicknesses are calculated from multiplying two-way travel time by the velocity of electromagnetic waves in ice (i.e. 0.168 m ns⁻¹) (Cui et al., 2018). Firn corrections were not applied 135 The precise point positioning (PPP) method was used in the GPS processing to improve positioning 136 accuracy since the flight distance is too far from the GPS base station for post airborne GPS data 137 138 processing. Processed GPS data are interpolated and fitted to the radar traces according to time 139 stamps generated by the integrated airborne system. Aircraft to ice-surface range was calculated by 140 multiplying the two-way travel time of the radar reflections of the ice surface by its velocity in air (0.3 141 m ns⁻¹). Figure 2c shows examples of the two-ways RES images from the data collected in 2017/18.
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143 4.1 Quantifying ice thickness, bed topography and subglacial hydrology pathway

To derive the ice thickness map based on the PEL radar measurements, we employed a variety of techniques depending on the ice speed following the approach described in Morlighem et al. (2020). In fast flowing regions (i.e. velocity >30 m yr⁻¹), we relied on mass conservation (MC; Figure 3), constrained by the PEL RES data and additional RES data that were available as part of BedMachine Antarctica (Morlighem et al., 2020). In the slower moving regions inland, we relied on a streamline diffusion interpolation to fill between data points (Figure 3).

150 For the purpose of comparing the bed DEM with Bedmap2, the 1 km ice-surface elevation DEM 151 from Bamber et al. (2009) was used. Prior to the subtraction process, the ice thickness was resampled 152 using the 'Nearest Neighbour' function in ArcGIS to a 1 km spacing and referenced to the polar 153 stereographic projection (Snyder, 1987). The PEL ice thickness model was then subtracted from the 154 Bamber et al. (2009) ice surface elevation DEM to produce a 1 km bed DEM (Figure 4b). The Bedmap2 155 bed DEM was transformed from the g104c geoid vertical reference to the WGS 1984 vertical reference 156 frame (Figure 4c). A difference map was then computed by subtracting the Bedmap2 bed DEM from 157 the ICECAP2 bed DEM (Figure 4d). Crossover analyses show RMS errors of 24.2 m (2015/16), 39.2 m 158 (2016/17), 10.4 m (2017/18), 7.5 m (2018/19) and 35.4 m (for the full dataset).

Modelling subglacial water flow for both DEMs utilized the ice-surface elevation from a combination of European Remote Sensing Satellite 1 radar (ERS-1) and Ice, Cloud and Land Elevation Satellite (ICESat) laser satellite altimetry datasets (Bamber et al., 2009). Subglacial hydrology pathways for both the Bedmap2 and our bed DEMs (Figure 4e) were determined by assuming the pressure equilibrium between ice overburden and basal water (Shreve, 1972) represented by the following equation:

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$$\varphi = g(\rho_w y + \rho_i h) \tag{1}$$

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168 where φ is the theoretical hydropotential surface (Figures 4f and 4g), y is the bed elevation, h is the 169 ice thickness, ρ_w and ρ_i are the density of water (1000 kg m⁻³) and ice (920 kg m⁻³) respectively, 170 assuming ice to be homogenous, and g is the acceleration due to gravity (9.81 ms⁻²). Hydrological 171 sinks were filled in the hydropotential surface to produce realistic hydrology pathways, and flow 172 direction was applied by assigning a direction from eight adjacent cells (i.e. D8 approach) to determine 173 the steepest downslope neighbouring cell (Jenson and Domingue, 1988).

174 **5. Results**

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176 5.1 Subglacial morphology of Princess Elizabeth Land

178 The new RES data allow us to form an appreciation of the subglacial topography of PEL (Figure 4a and 179 b). While its hypsometry (Figure 5) reveals an area-elevation distribution that is mainly concentrated around 0 to 500 m (>15% frequency, Figure 5a) with a mean elevation of 347.29 m, the DEM reveals 180 a newly-discovered broad, low-lying subglacial basin (>400 m below sea leve \mathcal{D} igure 4b). This is the 181 most distinct new topographic feature uncovered by the new data. The data also resolve higher 182 ground across the northwest grid of the PEL DEM (i.e. American Highland, Figure 5a). A deep (i.e. ~500 183 m below sea level) subglacial trough can be observed near to Zhaojun Di area, coinciding with the 184 185 location of fast ice flow towards the Amery Ice Shelf (Figure 1a). Mountains beneath Ridge B (Figure 186 1a) can be observed in enhanced resolution from the new data (Figure 5b) with an average elevation 187 of ~1500 m above sea level. The bed topography closer to the grounding line (i.e. Wilhelm II Land) and 188 at the central grid areas are characterized as having a lower bed elevation (below sea level, Figure 5b), 189 consistent with the recent BedMachine Antarctica product (Morlighem et al., 2020). Subglacial 190 troughs with depth less than ~500 m can also be observed in Wilhelm II Land.

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192 5.2 Comparison with Bedmap2

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194 The 1 km bed elevation model of the PEL sector of East Antarctica, the corresponding Bedmap2 DEM 195 and a map displaying difference between the two are shown in Figure 4b,c,d. The new DEM reveals substantial changes relative to Bedmap2 bed product especially across the central upstream region of 196 PEL. For example, the P bed DEM shows noticeable disagreement from Bedmap2 across the 197 Australian Antarc ierritory extending from the central grid of the DEM (i.e. Korotkevicha Plateau 198 and King Leopold and Queen Astrid Coast) to the Mason 2 ks at the northern grid, with differences 199 200 typically ranging between -100 and -300 m. However, the bed elevation is higher in the new bed DEM compared with Bedmap2 across Wilhelm II Land with a mean of ~90 m. Because the new bed DEM is 201 202 higher in some places compared with Bedmap2, and lower in others, the mean difference for the 203 entire PEL study area is only -41 m.

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We also present five terrain profiles for both DEMs (Figure 6), which collectively cover most of the 205 PEL sector (Figure Lb). The purpose is to capture as much of the subglacial morphology as possible 206 207 and assess the accuracy of the DEMs in their characterization of these subglacial features. In general, 208 and as one would expect, the ICECAP2 bed DEM shows reasonable agreement with the RES transects 209 in all profiles compared with Bedmap2 bed DEM. Consistencies between the ICECAP2 DEM and the 210 bed elevation from RES data picks can be seen upstream of the PEL DEM grid (i.e. Mason Peaks and 211 Zhaojun Di) with a correlation coefficient of 0.54 (RE:15%) and 0.94 (RE:16%) for Profile A and B, respectively. This is higher relative to Bedmap2 DEM which is 0.45 (RE:25%) for Profile A and 0.86 212 (RE:24%) for Profile B. A significant improvement is noted in the new DEM with correlation coefficient 213 214 of 0.79 (RE:21%), compared with 0.50 (RE:30%) for Bedmap2, across the American Highland in Profile 215 C (Figure 6). A slightly lower correlation coefficient than Profile C is quantified for the new DEM, at 216 0.78 (RE:38%), but it is still higher than in Bedmap2 at 0.60 (RE:42%) for Profile D. Similarly, the correlation coefficient between both DEMs near to the Wilhelm II Land (Figure 6; Profile E–E') is higher 217 in the new DEM at 0.91 (RE:34%) than Bedmap2 at 0.57 (RE:42%). 218

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220 5.3 Subglacial hydrology and lakes

Understanding subglacial water flow in Antarctica is crucial for assessing its potential influence on icesheet flow and dynamics (Stearns et al., 2008). The main flow network for most parts remains broadly unchanged irrespective of the bed DEM used, highlighting the dominance of ice surface slopes on defining subglacial water pathways (Wright et al., 2008; Le Brocq et al., 2009; Horgan et al., 2013). Nevertheless, there are a few clear differences in the subglacial hydrological pathways, particularly across the central region of the grid where the bed differences are greatest.

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Essentially, there are five main subglacial water networks observed, where the hydrological 229 230 pathway is related to geomorphology (Figure 4e). One subglacial water pathway (red region, Figure 231 4e), can be seen feeding into a subglacial trough (Figure 4b, 4c and 5b), coinciding with the location of fast ice flow (Figure 1a). A number of subglacial lakes exist at the southwest grid of the DEM close to 232 233 Lake Vostok, the largest subglacial lake in East Antarctica first detected in 1974 (Figure 1a; Robin et 234 al., 1977; Kapitsa et al., 1996; Studinger et al., 2004; Siegert et al., 2011; Siegert, 2017), which may 235 provide water to this network. It should be noted that Lake Vostok lies just outside the PEL DEM. There 236 are seven previously recognised subglacial lakes located at the southwestern region of the DEM which 237 are named Sovetskaya, 90°E, SPRI-47, SPRI-54/59, SPRI-60, C25SAE1 and C25SAE2 (Figure 1a; Wright 238 and Siegert, 2012), indicating the presence of stored water beneath the ice-sheet interior of PEL. In 239 addition, subglacial lakes named Komsomolskoe and R15Ea_4 are located at the southern grid of the 240 DEM (Figure 1a; Wright and Siegert, 2012).

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242 Another subglacial water network (yellow region, Figure 4e) can be seen beside the American <u>243</u> Highlands, where a newly discovered subglacial lake has been proposed. A study by Jamieson et al. (2016) suggested an extensive and elongated smooth-surface feature (white box; Figure 1), elucidated 💭 <mark>244</mark> as a subglacial lake based on the similar characteristics of the ice surface with subglacial lakes <u>245</u> 246 identified previously using the same satellite dataset (Bell et al., 2006; Bell et al., 2007). The feature 247 covered an area of ~ 1250 km², which would be the second largest by length after Lake Vostok (Kapitsa 248 et al., 1996) and the fourth largest by area in Antarctica after Lakes Vostok, 90°E and Sovetskaya (Bell 249 et al., 2006). The ice thickness above the subglacial lake is shown to be ~600 m greater in the PEL DEM 250 relative to Bedmap2 (Figure 4b, 4c and 4d), but even this may lead to an under appreciation of the 251 real bed topography owing to the unknown thickness of the water layer. A series of shorter and 252 distinct subglacial water pathways (orange region, Figure 4e) can be seen flowing towards the 253 grounding line (i.e. Progress Station and Ranvik Glacier). Two separated subglacial water networks 254 (blue and green regions, Figure 4e) are observed across the Wilhelm II Land, coinciding with the 255 location of subglacial troughs (Figure 4b, 4c and 5b) and the ice surface features noted from satellite 256 images (Jamieson et al., 2016).

257 6. Data availability

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The ICECAP2 ice thickness and bed elevation models of the PEL sector are available in 500 m horizontal resolutions at <u>https://doi.org/10.5281/zenodo.3666088</u> (Cui et al., 2020). The airborne radio-echo sounder ice thickness measurements used to generate the products, recorded <u>here</u> in commaseparated values (CSV) format is accessible from https://doi.org/10.5281/zenodo.3815064. The 1 km

ice-sheet surface elevation DEM derived using a combination of ERS-1 surface radar and ICESat laser 263 altimetry is downloadable from the National Snow and Ice Data Center (NSIDC) website at 264 265 https://nsidc.org/data/docs/daac/nsidc0422_antarctic_1km_dem/. If the users wish to modify the bed DEM, our model can be easily integrated with the updated surface elevation models (Helm et al., 266 267 2014; Howat et al., 2019). Auxiliary details for the MEaSUREs InSAR ice velocity map of Antarctica can be found at https://doi:10.5067/MEASURES/CRYOSPHERE/nsidc-0484.001. The satellite images for 268 269 MODIS Mosaic of Antarctica 2008-2009 and RADARSAT (25m) are obtainable from 270 https://doi.org/10.7265/N5KP8037 and https://research.bpcrc.osu.edu/rsl/radarsat/data/, 271 respectively. A summary of the data used in this paper and their availability is provided in the Table 1.

272 7. Summary

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We have compiled the first airborne RES dataset for PEL; acquired by ICECAP2 and led by PRIC. From 274 275 the data, using a combination of interpolation and modelling techniques, we have generated a bed 276 DEM which is gridded to 1 km resolution for direct comparison with Bedmap2, and at a higher 277 resolution of 500 m for ice sheet modelling. The DEM has a total area of ~899,730 km². Considerable 278 variabilities between the new DEM and Bedmap2 are observed, particularly at the central grid of the 279 DEM where a broad subglacial basin occurs, and across the Wilhelm II Land toward the margin. The 280 PEL DEM completes the first-order data coverage of subglacial Antarctica – a feat spanning around 70 281 years of international collaboration.

282 283

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297

298 Competing Interests

- 299 The authors report no competing interests for this paper.
- 300

301 Author contributions

302 This paper was research and written by the ICECAP2 partnership, in which all authors are members.

303 Specific responsibilities are as follows. XB, JSG, JG, LL, LEL, FH, WW, LJ and JRL undertook fieldwork

and data acquisition. JSG and DAY undertook data processing. MM and HJ undertook data

- 305 interpolation. All authors comments and edited drafts of this paper. The paper was written by MJS
- and HJ. ICECAP2 is led by SB, JLR, DDB and MJS.

- **Table 1:** Data files and locations.

Products	Files	Location	DOI/URL	
Bed elevation	500m bed	Zenodo Data Repository	https://doi.org/10.5281/zenodo.3666	
DEM	elevation DEM	Cui et al. (2020)	088	
Ice thickness DEM	500m ice	Zenodo Data Repository	https://doi.org/10.5281/zenodo.3666	
	thickness DEM	Cui et al. (2020)	088	
	Polar Research			
Airborne ice	Institute of China	Zenodo Data Repository	https://doi.org/10.5281/zenodo.3815	
thickness data	ice thickness data	Cui et al., (2020)	064	
	in CSV format			
1 km ice sheet	ERS-1 radar and	National Snow and Ico	https://nsidc.org/data/docs/daac/nsid	
	ICESat laser	Data Center (NSIDC)		
	satellite altimetry			
Ice velocity map	MFaSUREs InSAR-	National Snow and Ice	https://doi:10.5067/MEASURES/CRYO	
of Central	hased ice velocity	Data Center (NSIDC)	SPHERE/nside-0484 001	
Antarctica	based lee velocity			
Ice sheet surface satellite imagery	MODIS Mosaic of			
	Antarctica	National Snow and Ice	https://doi.org/10.7265/N5KP8037	
	(2008 – 2009)	Data Center (NSIDC)	11(1ps.//doi.org/10./203/10307803/	
	(MOA2009)			
	RADARSAT (25m)	Byrd Polar and Climate	https://research.bpcrc.osu.edu/rsl/rad	
	satellite imagery	Research Center	arsat/data/	

315 (a)





Figure 1. Map of (a) ice flow velocity version 2 (Rignot et al., 2017b); (b) the Aerogeophysical flight lines surveyed by PRIC in four seasons which are 2015/16 (orange), 2016/17 (green), 2017/18 (red) and 2018/19 (blue) across the PEL sector; the inset denotes location of the study region in East Antarctica. Both images are overlain by MODIS Mosaic of Antarctica 2008–2009 (Haran et al., 2014); and (c) MODIS Mosaic of Antarctica 2008–2009 satellite image (Haran et al., 2014). The black line denotes the grid boundary for PEL bed elevation model. White box indicates a location of a previously discovered smooth-surface elongated and extensive feature interpreted as a potential subglacial lake (Jamieson et al., 2016). The Differential Interferometry Synthetic Aperture Radar (DInSAR) grounding line (yellow line) are also shown (Rignot et al., 2017a).







Figure 2. (a) Snow Eagle 601 airplane operated by the Polar Research Institute of China for the Chinese
National Antarctic Research Expedition (CHINARE) program; (b) The interior image of the airplane
showing the airborne radio-echo sounder equipment; and (c) Two-dimensional radio-echo sounding
radargram collected in 2017/18 revealing the quality of internal layers, bed topography and subglacial
lake water.

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- Figure 3. Map shows interpolation techniques used to infer ice thickness DEM across PEL, reference
- Elevation Model of Antarctica, International Bathymetric Chart of the Southern Ocean (REMA IBCSO,
- green), mass conservation (brown), interpolation (yellow) and streamline diffusion (blue).

357 (a)

750	2250
750 m	2500
1000	2750
1250	3000
1500	3250
1750	3500





(b)

PEL Bed elevation	400
	600
-600 m	800
-400	1000
-200	1200
0	1400
200	1100





367 (e)

PEL subglacial water flow

---- Bedmap2 subglacial water flow





Figure 4. Map of (a) 500m PEL ice thickness DEM derived using mass conservation; (b) 1km PEL bed DEM for the PEL sector; Profile A–A', B–B', C–C', D–D' and E–E' are overlain in (b); (c) 1km Bedmap2 bed elevation model (Fretwell et al., 2013), the red box indicates a location of a previously discovered smooth-surface elongated and extensive feature interpreted as a potential subglacial lake (Jamieson et al., 2016); (d) 1km Difference map between the PEL and Bedmap2 DEMs; (e) Subglacial water pathway calculated with PEL (blue) and Bedmap2 (r Ded DEMs; (f) PEL hydropotential surface; and (g) Bedmap2 hydropotential surface.

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386 (a)



Figure 5. (a) Hypsometry (area-elevation distribution) derived from the PEL bed elevation model; and
 (b) Bed elevation model determined for the PEL sector, East Antarctica, the red box indicates a location
 of a previously discovered smooth-surface elongated and extensive feature interpreted as a potential
 subglacial lake (Jamieson et al., 2016). The graph and map have the same elevation-related colour

(a)







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