**Supplementary Material:**

**Geospatial simulations of airborne ice-penetrating radar surveying reveal elevation under-measurement bias for ice sheet bed topography**

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**Table S1** Probability and descriptive statistics of deviation magnitude and sign for all simulations. To use means as correction factors add to input elevation if negative and subtract if positive.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Probability** (*scale m*) | | | | | | | |  | **Descriptive statistics** | | | | |
|  |  | *-100* | *-10* | *-1* | *-0.1* | *0.1* | *1* | *10* | *100* |  | **mean (m)** | **std (m)** | **sum (m)** | **skew** | **kurt** |
| **Interior** |  |  |
| **MP** | **Elevation province** |  |
| MP all | low | 0.000 | 0.101 | 0.349 | 0.117 | 0.105 | 0.216 | 0.110 | 0.001 |  | -0.031 | 11.424 | -10110 | 1.432 | 15.399 |
| high | 0.000 | 0.201 | 0.370 | 0.063 | 0.054 | 0.209 | 0.103 | 0.000 |  | -3.384 | 15.380 | -1120948 | -0.884 | 11.947 |
| all | 0.000 | 0.151 | 0.360 | 0.090 | 0.079 | 0.213 | 0.106 | 0.000 |  | -1.708 | 13.652 | -1131095 | -0.318 | 14.008 |
| ING | low | 0.000 | 0.083 | 0.385 | 0.101 | 0.088 | 0.258 | 0.086 | 0.000 |  | -0.328 | 9.524 | -18598 | 0.337 | 13.169 |
| high | 0.000 | 0.013 | 0.436 | 0.108 | 0.093 | 0.314 | 0.037 | 0.000 |  | 0.078 | 4.891 | 6807 | 0.978 | 11.042 |
| all | 0.000 | 0.094 | 0.416 | 0.105 | 0.091 | 0.292 | 0.056 | 0.000 |  | -0.082 | 7.086 | -11828 | 0.460 | 18.397 |
| KG | low | 0.000 | 0.103 | 0.304 | 0.173 | 0.148 | 0.186 | 0.087 | 0.000 |  | -0.800 | 9.494 | -62265 | 0.210 | 12.738 |
| high | 0.000 | 0.204 | 0.381 | 0.071 | 0.061 | 0.197 | 0.085 | 0.000 |  | -3.168 | 10.578 | -299329 | -0.719 | 14.941 |
| all | 0.000 | 0.158 | 0.346 | 0.117 | 0.100 | 0.192 | 0.086 | 0.000 |  | -2.099 | 10.171 | -361594 | -0.403 | 14.256 |
| PEA | low | 0.000 | 0.073 | 0.380 | 0.136 | 0.130 | 0.205 | 0.076 | 0.001 |  | -0.408 | 9.337 | -42669 | 3.273 | 39.201 |
| high | 0.000 | 0.188 | 0.480 | 0.040 | 0.032 | 0.170 | 0.089 | 0.001 |  | -3.144 | 13.019 | -219947 | 0.787 | 16.301 |
| all | 0.000 | 0.119 | 0.420 | 0.098 | 0.091 | 0.191 | 0.081 | 0.001 |  | -1.505 | 11.045 | -262616 | 1.580 | 24.875 |
| EGA | low | 0.000 | 0.144 | 0.332 | 0.058 | 0.052 | 0.230 | 0.185 | 0.000 |  | 1.234 | 15.367 | 113382 | 1.039 | 7.792 |
| high | 0.002 | 0.416 | 0.190 | 0.022 | 0.020 | 0.141 | 0.209 | 0.000 |  | -7.699 | 25.474 | -609310 | -0.375 | 4.687 |
| all | 0.001 | 0.270 | 0.266 | 0.041 | 0.037 | 0.189 | 0.196 | 0.001 |  | -2.899 | 21.141 | -495928 | -0.382 | 6.458 |
| Average all PGAS |  | 0.000 | 0.155 | 0.361 | 0.089 | 0.079 | 0.214 | 0.106 | 0.000 |  | -1.735 | 12.260 | -188658 | 0.565 | 15.321 |
| **MO** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| MO all | low | 0.000 | 0.131 | 0.325 | 0.101 | 0.101 | 0.215 | 0.127 | 0.000 |  | -0.397 | 12.074 | -131149 | 0.713 | 13.312 |
| high | 0.000 | 0.226 | 0.330 | 0.064 | 0.056 | 0.209 | 0.114 | 0.000 |  | -3.630 | 15.912 | -1201329 | -0.771 | 8.943 |
| all | 0.000 | 0.179 | 0.328 | 0.083 | 0.078 | 0.212 | 0.121 | 0.000 |  | -2.015 | 14.218 | -1332505 | -0.413 | 10.902 |
| ING | low | 0.000 | 0.109 | 0.374 | 0.099 | 0.086 | 0.242 | 0.090 | 0.000 |  | -0.674 | 10.065 | -37646 | 0.722 | 10.473 |
| high | 0.000 | 0.014 | 0.407 | 0.129 | 0.115 | 0.311 | 0.026 | 0.000 |  | -0.022 | 4.424 | -1976 | 0.478 | 8.755 |
| all | 0.000 | 0.051 | 0.394 | 0.117 | 0.103 | 0.284 | 0.051 | 0.000 |  | -0.275 | 7.161 | -39622 | 0.741 | 16.439 |
| KG | low | 0.000 | 0.147 | 0.225 | 0.140 | 0.143 | 0.202 | 0.144 | 0.000 |  | -0.163 | 12.549 | -12688 | -0.083 | 7.739 |
| high | 0.000 | 0.285 | 0.283 | 0.055 | 0.046 | 0.192 | 0.185 | 0.000 |  | -3.988 | 14.913 | -377319 | -0.472 | 5.209 |
| all | 0.000 | 0.223 | 0.257 | 0.093 | 0.090 | 0.196 | 0.141 | 0.000 |  | -2.263 | 14.026 | -390006 | -0.405 | 6.133 |
| PEA | low | 0.000 | 0.104 | 0.359 | 0.115 | 0.124 | 0.203 | 0.094 | 0.001 |  | -0.763 | 10.361 | -79903 | 1.559 | 29.107 |
| high | 0.000 | 0.219 | 0.455 | 0.043 | 0.034 | 0.167 | 0.083 | 0.000 |  | -4.459 | 14.234 | -309984 | -0.638 | 14.834 |
| all | 0.000 | 0.150 | 0.397 | 0.086 | 0.088 | 0.189 | 0.089 | 0.000 |  | -2.238 | 12.192 | -389913 | 0.029 | 20.842 |
| EGA | low | 0.000 | 0.162 | 0.342 | 0.054 | 0.047 | 0.221 | 0.174 | 0.000 |  | -0.010 | 14.357 | -927 | 0.702 | 9.562 |
| high | 0.001 | 0.400 | 0.191 | 0.022 | 0.021 | 0.152 | 0.213 | 0.000 |  | -6.512 | 23.990 | -509770 | -0.305 | 4.468 |
| all | 0.001 | 0.271 | 0.273 | 0.039 | 0.035 | 0.189 | 0.192 | 0.000 |  | -2.996 | 19.654 | -510697 | -0.343 | 6.472 |
| Average PGAS |  | 0.000 | 0.178 | 0.330 | 0.083 | 0.078 | 0.212 | 0.123 | 0.000 |  | -2.030 | 13.160 | -221704 | 0.165 | 11.669 |
| **Marginal** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **MP** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| MP all | low | 0.000 | 0.044 | 0.403 | 0.154 | 0.138 | 0.217 | 0.046 | 0.000 |  | -0.570 | 6.698 | -187333 | 1.734 | 24.938 |
| high | 0.000 | 0.103 | 0.398 | 0.151 | 0.087 | 0.219 | 0.042 | 0.000 |  | -2.343 | 9.661 | -781650 | -1.971 | 20.923 |
| all | 0.000 | 0.073 | 0.423 | 0.130 | 0.112 | 0.218 | 0.044 | 0.000 |  | -1.463 | 8.371 | -968983 | -1.196 | 24.671 |
| ING | low | 0.000 | 0.036 | 0.368 | 0.157 | 0.142 | 0.260 | 0.036 | 0.000 |  | -0.360 | 5.713 | -20387 | -0.002 | 16.155 |
| high | 0.000 | 0.005 | 0.374 | 0.179 | 0.150 | 0.283 | 0.010 | 0.000 |  | -0.040 | 3.344 | -3540 | 1.031 | 22.332 |
| all | 0.000 | 0.017 | 0.372 | 0.170 | 0.147 | 0.274 | 0.020 | 0.000 |  | -0.166 | 4.431 | -23927 | 0.211 | 21.974 |
| KG | low | 0.000 | 0.033 | 0.371 | 0.203 | 0.186 | 0.183 | 0.025 | 0.000 |  | -0.859 | 5.102 | -66863 | -0.129 | 14.803 |
| high | 0.000 | 0.048 | 0.514 | 0.118 | 0.095 | 0.206 | 0.019 | 0.000 |  | -1.750 | 5.162 | -165402 | -0.180 | 6.527 |
| all | 0.000 | 0.041 | 0.449 | 0.156 | 0.136 | 0.195 | 0.022 | 0.000 |  | -1.348 | 5.154 | -232265 | -0.159 | 10.074 |
| PEA | low | 0.000 | 0.030 | 0.400 | 0.173 | 0.153 | 0.208 | 0.036 | 0.000 |  | -0.503 | 6.528 | -52510 | 3.404 | 51.823 |
| high | 0.000 | 0.073 | 0.551 | 0.074 | 0.055 | 0.202 | 0.045 | 0.000 |  | -1.648 | 8.235 | -115485 | 1.237 | 22.391 |
| all | 0.000 | 0.048 | 0.461 | 0.133 | 0.114 | 0.206 | 0.040 | 0.000 |  | -0.963 | 7.283 | -167995 | 2.131 | 34.840 |
| EGA | low | 0.000 | 0.072 | 0.455 | 0.087 | 0.075 | 0.229 | 0.081 | 0.000 |  | -0.531 | 8.455 | -47533 | 1.342 | 10.644 |
| high | 0.001 | 0.297 | 0.341 | 0.041 | 0.038 | 0.182 | 0.101 | 0.000 |  | -6.095 | 16.117 | -496391 | -1.225 | 8.059 |
| all | 0.000 | 0.179 | 0.401 | 0.065 | 0.057 | 0.207 | 0.091 | 0.000 |  | -3.180 | 12.994 | -543924 | -1.278 | 11.516 |
| Average PGAS |  | 0.000 | 0.073 | 0.421 | 0.130 | 0.112 | 0.220 | 0.044 | 0.000 |  | -1.454 | 7.376 | -161352 | 0.532 | 19.262 |
| **MO** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| MO all | low | 0.000 | 0.061 | 0.399 | 0.144 | 0.127 | 0.223 | 0.047 | 0.000 |  | -0.877 | 6.966 | -287580 | 0.181 | 46.132 |
| high | 0.000 | 0.131 | 0.401 | 0.109 | 0.090 | 0.225 | 0.044 | 0.000 |  | -2.746 | 10.216 | -915616 | -2.791 | 37.137 |
| all | 0.000 | 0.096 | 0.400 | 0.127 | 0.108 | 0.224 | 0.045 | 0.000 |  | -1.819 | 8.806 | -1203223 | -2.267 | 43.876 |
| ING | low | 0.000 | 0.041 | 0.393 | 0.158 | 0.126 | 0.248 | 0.034 | 0.000 |  | -0.514 | 5.856 | -28689 | 0.522 | 13.255 |
| high | 0.000 | 0.004 | 0.330 | 0.214 | 0.170 | 0.276 | 0.006 | 0.000 |  | 0.004 | 3.005 | 332 | 0.229 | 16.461 |
| all | 0.000 | 0.018 | 0.354 | 0.192 | 0.153 | 0.265 | 0.017 | 0.000 |  | -0.196 | 4.343 | -28357 | 0.428 | 19.144 |
| KG | low | 0.000 | 0.070 | 0.313 | 0.187 | 0.174 | 0.209 | 0.048 | 0.000 |  | -0.812 | 7.074 | -63141 | -2.515 | 119.517 |
| high | 0.000 | 0.127 | 0.420 | 0.097 | 0.084 | 0.228 | 0.045 | 0.000 |  | -2.336 | 8.008 | -221057 | -3.556 | 151.389 |
| all | 0.000 | 0.101 | 0.372 | 0.137 | 0.125 | 0.219 | 0.046 | 0.000 |  | -1.649 | 7.638 | -284198 | -3.186 | 140.495 |
| PEA | low | 0.000 | 0.050 | 0.402 | 0.156 | 0.142 | 0.211 | 0.038 | 0.000 |  | -0.891 | 6.771 | -93145 | 1.611 | 40.036 |
| high | 0.000 | 0.102 | 0.543 | 0.074 | 0.056 | 0.190 | 0.036 | 0.000 |  | -2.534 | 8.365 | -176514 | -0.375 | 19.759 |
| all | 0.000 | 0.070 | 0.459 | 0.123 | 0.171 | 0.140 | 0.037 | 0.000 |  | -1.548 | 7.493 | -269686 | 0.436 | 28.732 |
| EGA | low | 0.000 | 0.079 | 0.473 | 0.085 | 0.067 | 0.233 | 0.063 | 0.000 |  | -1.142 | 7.682 | -102581 | 0.803 | 8.706 |
| high | 0.002 | 0.304 | 0.332 | 0.039 | 0.036 | 0.196 | 0.091 | 0.000 |  | -6.458 | 16.248 | -520658 | -1.683 | 10.477 |
| all | 0.001 | 0.185 | 0.406 | 0.063 | 0.052 | 0.215 | 0.076 | 0.000 |  | -3.657 | 12.768 | -623238 | -1.941 | 15.378 |
| Average PGAS |  | 0.000 | 0.096 | 0.400 | 0.127 | 0.113 | 0.219 | 0.045 | 0.000 |  | -1.811 | 7.937 | -200911 | -0.769 | 48.612 |

**Table S2** Deviation in valley characteristics from DEM values.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **DEM Valley CSA (m2)** | | **Interior** | | | | | | | **Marginal** | | | | | | |
| n | prominence difference (m) | | width difference (m) | | CSA difference (m2) | | n | prominence difference (m) | | width difference (m) | | CSA difference (m2) | |
| μ | σ | μ | σ | μ | σ | μ | σ | μ | σ | μ | σ |
| CSA < 105 | ING | 39 | 7.21 | 44.48 | 397.63 | 1,302.06 | 53,777.31 | 128,522.78 | 48 | -1.96 | 9.00 | -14.38 | 248.43 | 9,733.43 | 20,593.68 |
| KG | 31 | 15.82 | 71.57 | 557.05 | 1,786.87 | 88,456.78 | 300,186.20 | 31 | 10.10 | 70.00 | 316.15 | 1,507.28 | 69,333.41 | 271,658.22 |
| PEA | 23 | 17.38 | 120.63 | 496.65 | 2,280.80 | 116,382.23 | 486,604.61 | 27 | 14.16 | 103.81 | 407.92 | 2,063.85 | 92,343.72 | 446,374.12 |
| EGA | 3 | -44.12 | 70.35 | 12.66 | 12.11 | 4,568.44 | 9,107.58 | 5 | -40.68 | 48.28 | -2.83 | 10.77 | -2,060.62 | 11,754.36 |
| 105 < CSA < 106 | ING | 100 | 0.58 | 53.65 | 385.06 | 1,545.02 | 85,304.70 | 321,061.12 | 103 | -1.29 | 12.67 | 167.28 | 664.32 | 43,803.12 | 183,364.06 |
| KG | 561 | -3.80 | 28.91 | 14.79 | 533.45 | 3,323.36 | 189,941.31 | 609 | -1.89 | 16.87 | 38.67 | 419.94 | 12,616.93 | 165,032.25 |
| PEA | 216 | 3.36 | 65.39 | 114.88 | 863.50 | 34,495.43 | 232,043.88 | 222 | -1.95 | 22.06 | 23.59 | 314.77 | 18,130.43 | 204,283.73 |
| EGA | 226 | -20.35 | 52.22 | 65.58 | 504.13 | 71,121.63 | 528,855.16 | 269 | -10.30 | 41.53 | 29.02 | 340.83 | 33,803.27 | 401,347.61 |
| 106 < CSA | ING | 38 | -7.03 | 42.77 | -644.20 | 2,297.25 | -158,969.00 | 489,504.45 | 39 | 1.85 | 2.59 | -53.26 | 423.93 | -20,726.86 | 196,666.71 |
| KG | 104 | -14.93 | 61.78 | -439.94 | 1,379.84 | -162,893.35 | 438,707.10 | 109 | -10.39 | 45.65 | -315.51 | 1,310.33 | -129,155.19 | 466,563.92 |
| PEA | 140 | -22.90 | 104.50 | -458.05 | 2,137.40 | -138,713.85 | 448,948.67 | 141 | -6.65 | 47.02 | -91.91 | 457.92 | -58,721.02 | 308,265.43 |
| EGA | 508 | -32.68 | 26.95 | -13.18 | 554.24 | -29,149.47 | 679,635.16 | 542 | -17.32 | 26.32 | -26.97 | 294.78 | -39,679.15 | 400,610.60 |
| **Total** | **ING** | 177 | **0.41** | **49.53** | **166.86** | **1,731.79** | **25,914.83** | **348,538.31** | **190** | **-0.82** | **10.49** | **76.12** | **547.47** | **21,950.41** | **163,405.47** |
| **KG** | 696 | **-4.59** | **38.67** | **-29.00** | **831.52** | **-17,721.76** | **255,923.73** | **749** | **-2.63** | **27.29** | **-1.39** | **708.68** | **-5,667.38** | **243,424.23** |
| **PEA** | 379 | **-5.49** | **86.51** | **-73.59** | **1,581.66** | **-24,517.50** | **355,740.79** | **390** | **-2.53** | **42.64** | **8.44** | **656.74** | **-4,516.48** | **270,620.26** |
| **EGA** | 737 | **-28.94** | **37.16** | **11.07** | **539.09** | **1,735.77** | **637,044.68** | **816** | **-15.15** | **32.46** | **-8.37** | **310.76** | **-15,224.66** | **400,867.22** |
|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | **All** | 1989 | **-13.34** | **53.10** | **-5.22** | **1,046.09** | **-7,923.72** | **456,270.66** | **2145** | **2.85** | **1.03** | **4.61** | **563.15** | **-6,647.57** | **312,251.43** |

**Table S3** Coefficients for interior valley geometry correctionwhere valley cross-section profiles surveyed in areas with ice thickness exceeding 2000 m.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *x* | *m* | *c* | *RMSE* | *R2* |
| RES Valley cross-section CSA | 1.02 | -2.08E+04 | 3.10E+05 | 0.98 |
| RES Valley cross-section depth | 1.04 | +1.62 | 52.2 | 0.95 |
| RES Valley cross-section width | 1.07 | -168 | 1024 | 0.89 |