Note: Reviewer's comments are in italics. Changes to manuscript text are in blue.

Reply to reviewers:

"Glaciological characteristics in the Dome Fuji region and new assessment for 1.5Ma old ice"

Reviewer #1

Main points

#1

The title and conclusion claim that this study is a new assessment for 1.5 Ma old ice. The 1.5 Ma is a target of the Oldest-Ice project, but the study does not demonstrate that ice as old as 1.5 Ma could be retrieved in the area. The fact that the basal ice may not be at the pressure melting point for the present day conditions is not a sufficient condition to retrieve ice older that is 1.5Ma old; this could be affected by basal disturbances, past melting conditions etc... Van Liefferinge and Pattyn (2013) speak of "suitable sites for the preservation of million year old ice". At this stage it is too early to say that it could be up to 1.5 Ma. This will have to be refined by further studies aiming are providing potential ages for the basal ice. In this prospect it would be useful here to recall the age of the ice at the bottom of the Dome Fuji ice core.

Reply

That is a valid point. All mentions of 1.5Ma has been changed to "oldest ice".

The following lines have been added to include mention of the Dome Fuji ice core:

"Ice cores retrieved from Dome Fuji extend 330ka and 720 ka back in time (Watanabe et al., 2003, Kawamura et al., 2017). The second deep ice-coring project reached a depth of 3028 m where the ice is an estimated 720ka and close to melting point (Kawamura et al., 2017). However, in the region around the ice core site (Fig. 1), the subglacial topography has so far been undersampled."

#2

The new thickness map: Kriging naturally comes with an estimate of the uncertainty. This estimate is lost when merging the new map with bedmap2. It seems that this merge is needed because they exclude the Soviet data and thus have no data outside of the new thickness data area. It seems that there is a high spatial resolution of the new thickness data, so that providing the grid with the new data and the uncertainty estimate (eventually masked to give data only at grid points where the closest distance is less than 20km) might be more useful for further investigation than this merged map where the uncertainty information has been lost. It is not clear if the gridded data really include the old German and Japanese data, as the raw individual points are compared to the gridded product (page 4, lines 9-12)?

Reply

The new data are merged with bedmap2 only in areas where we have no new information. Thus, the uncertainty estimate from the kriging routine is still valid within the new thickness data area. We have addressed this by including the calculated standard deviation from the kriging routine in Fig. 2. To clarify which lines are included in the gridded product, Fig. 2 now also includes a map of the radarlines. In other words, we have modified figure 2 so that it now includes A) a map of all the radarlines included in the final ice thickness product, B) the OIR ice thickness map, C) the difference between the OIR ice thickness and Bedmap2 and D) the standard deviation from the kriging routine.

We thank the reviewer for the suggestions on how to improve the readability and information in these sections. The section about results and uncertainties have been rewritten and now includes mention of standard deviation from the kriging and has a clearer outline of the uncertainty analysis. It now reads as follows:

"2.2 Results and Uncertainties

The resulting ice thickness is displayed in Fig. 2A and in the following we refer to this dataset as the OIR (ice thickness) data although it is based on data from several surveys (cf. the radarlines shown in Fig. 2A). The denser data coverage from the GEA and OIR surveys reveals a landscape with ice thicknesses varying between 2000 m and 4000 m with an average ice thickness of 3021 m. Immediately south of the Dome Fuji is an area with shallow ice thicknesses while the ice further to the south and to the southeast and is significantly thicker. A complex terrain with a patchwork of thick and thin ice has now become visible north and west of Dome Fuji. Since the surface topography in this part of Antarctica is relatively flat, ice thicknesses are good indicators of bed topography, thus thick ice indicates valleys while shallower ice indicates mountains or highlands. The OIR dataset shows a system of valleys surrounded by high plateaus.

The difference between the OIR and the Bedmap2 datasets is shown in Fig. 2C. The largest differences appear to the west of Dome Fuji between 30˚W and 35˚W, and 77˚S. In the immediate vicinity of the station, differences are smaller due to the high-resolution data from Japanese ground-based surveys that were included in the Bedmap2 and the OIR compilations. The difference between the new ice thickness map and Bedmap2 is upwards of 800 m in some areas, with a mean difference of 20 m, a mean absolute difference of 136 m, and a standard deviation of 177 m. This difference is undoubtedly due to the geolocation uncertainty of the Soviet data included in Bedmap2.

We examine the uncertainties of our result by comparing the gridded ice thickness map with point measurements from the individual radarlines, and through crossover analysis of the radarlines. In the latter analysis, we consider all points within 50 m of each other to be crossover points following Fretwell et al. (2013). For the GEA-OIR radarlines, 2453 points were found to be crossover points. The mean difference in ice thickness between the radarlines is -13 m with a standard deviation of 79m. For 18% of the crossover points the difference exceeded 100 m. We ascribe this difference to geometrical effects of flightline orientation since we observe that radarlines intersecting each other at oblique angles have a larger thickness difference than those that are almost parallel.

Turning to the gridded ice thickness map, the mean difference between the GEA-OIR point measurements along the radarlines and the gridded map and is 1.5 m (cf. Fig. 3), indicating that the gridded ice thickness is slightly underestimating the ice thickness on this spatial scale. The standard deviation is 117 m. The mean difference between the gridded ice thickness and the individual data points from the older German survey is -11 m and the standard deviation is 162 m. For the Japanese surveys the mean difference and standard deviation is -16 m and 187 m, respectively. The overall high value for the standard deviation is an inevitable result of the smoothing introduced by the kriging interpolation scheme. Indeed, the negative mean difference between the high-resolution ground-based survey data and the gridded map indicates that the gridded data tend to overestimate the ice thickness in some areas, most likely because subglacial valleys are made broader by the kriging. This is a direct result of the smoothing introduced by the kriging scheme. This is also evident from the standard deviation in the grid points calculated by the kriging scheme (Fig. 2D). The standard deviation lies typically between 110-120 m close to the data points and increases with distance. Towards the margin of data coverage area the values exceed 200 m. We note that 110–120 m is still smaller than the difference between the OIR data and Bedmap2.

The decision to exclude the Soviet data was partly based on results from a crossover analysis. Comparison between the Soviet radarlines and the OIR and GEA surveys shows that only slightly more than 100 points is within 50m of each other. For these points, the mean difference in ice thickness between the points is -5 m with a standard deviation of 193 m. This larger standard deviation is likely due the poorly resolved bed rock and the large navigational uncertainty in the Soviet radarlines. Considerable differences were also found between Soviet data and ground-based JARE surveys (Fujita, pers. comm., 2016)

We performed a similar crossover analysis of the surface elevation measured in the GEA-OIR surveys. Here, we find a mean difference of less than 1 m with a standard deviation of 2.5 m. Thus, the uncertainties in the surface reflection measurements are negligible compared to uncertainties in the bed picking. Based on this we assign an average uncertainty of 150~m to the OIR ice thickness although we note that uncertainties increase with distance from data point are likely larger along the edge of the survey grid."

#3

New Prediction of Oldest Ice Locations: because they use a 1D thermokinematic model, all others parameters being identical to Van Liefferinge and Pattyn (2013),the solution depends only on the local ice thickness and not on the topography, i.e. the thickness gradient. So for oldest ice locations, we should have differences between the old and the new studies only if areas are significantly thicker or shallower; which seems not to be the case here; there is only a better description of the topography and there is no large areas with significant differences with bedmap2. So it seems not surprising that there is a good agreement between the old and new map. Moreover, I am a bit concerned by the validity of the 1D assumption when the model is run with a horizontal spatial resolution (here 500m) much lower than the ice thickness. A more in-depth discussion on the limits of this approximation to study potential local variations is required and avoid the risk of over-interpreting the results.

We agree that that the difference between the results from Van Liefferinge and Pattyn (2013) and the results presented here only reflect the new information about ice thickness. This is a result of the 1D model and its assumptions. We disagree that there are no areas that are significantly thicker or shallower. As presented in Fig. 3 we are able to exclude several areas as candidates for oldest ice sites. The area west of Dome Fuji (that has been considered to be an area of interest for some time) has been reduced in size, while the southernmost candidate site has changed position shifting almost 100km towards the east.

In response to the comments from other reviewers, we now present the model results on a 1km for our domain and on a 500m grid for the area around Dome F. We note that comparisons between results from 500m, 1km and 2km grids show small differences.

Additionally, we add the following to Section 3:

"[…] where *w* is the vertical velocity, and $\kappa = K/(\rho\ c)$, where *K* is the thermal conductivity, ρ is the density and *c* the heat capacity of ice. This approach neglects several processes that may influence the resulting geothermal heat flux, including changes over time in ice thickness or flow regime and horizontal advection.

This is in particular problematic for areas that have experienced higher velocities than what is currently observed. For our study domain, ice thicknesses are thought to have varied between 50m and 250m (Pollard and DeConto, 2009) and are thus unlikely to have experienced substantial changes in flow regime."

And

"In our study, all above-mentioned parameters with the exception of ice thicknesses are identical to the fields used in Van Liefferinge and Pattyn (2013) but regridded to 1km and 500m resolution using nearest neighbour interpolation. Thus, the difference in ice thickness between Bedmap2 and the OIR data is the main cause for the difference in results. As all the input parameters are smoothly varying on these spatial scales, we also expect a smooth minimum geothermal heat flux map especially as used geothermal heat flux datasets have a sparse special resolution around 100km. This implies that while the large-scale pattern is robust, detailed interpretation of features that are on a scale smaller than a few kilometres is not realistic."

Minor points

In all Figures in stereo-polar projection have the longitude the labelled "W". It should be "E"?

Yes, thanks for pointing that out!

In Fig. 1: make the symbols bigger for Dome Fuji station and OIR camp.

Symbols have been made bigger in Fig. 1 and 2.

Fig.2 : It could be interesting to show some surface elevation contours.

Surface elevation contours have been added to the new figures 1 and 2.

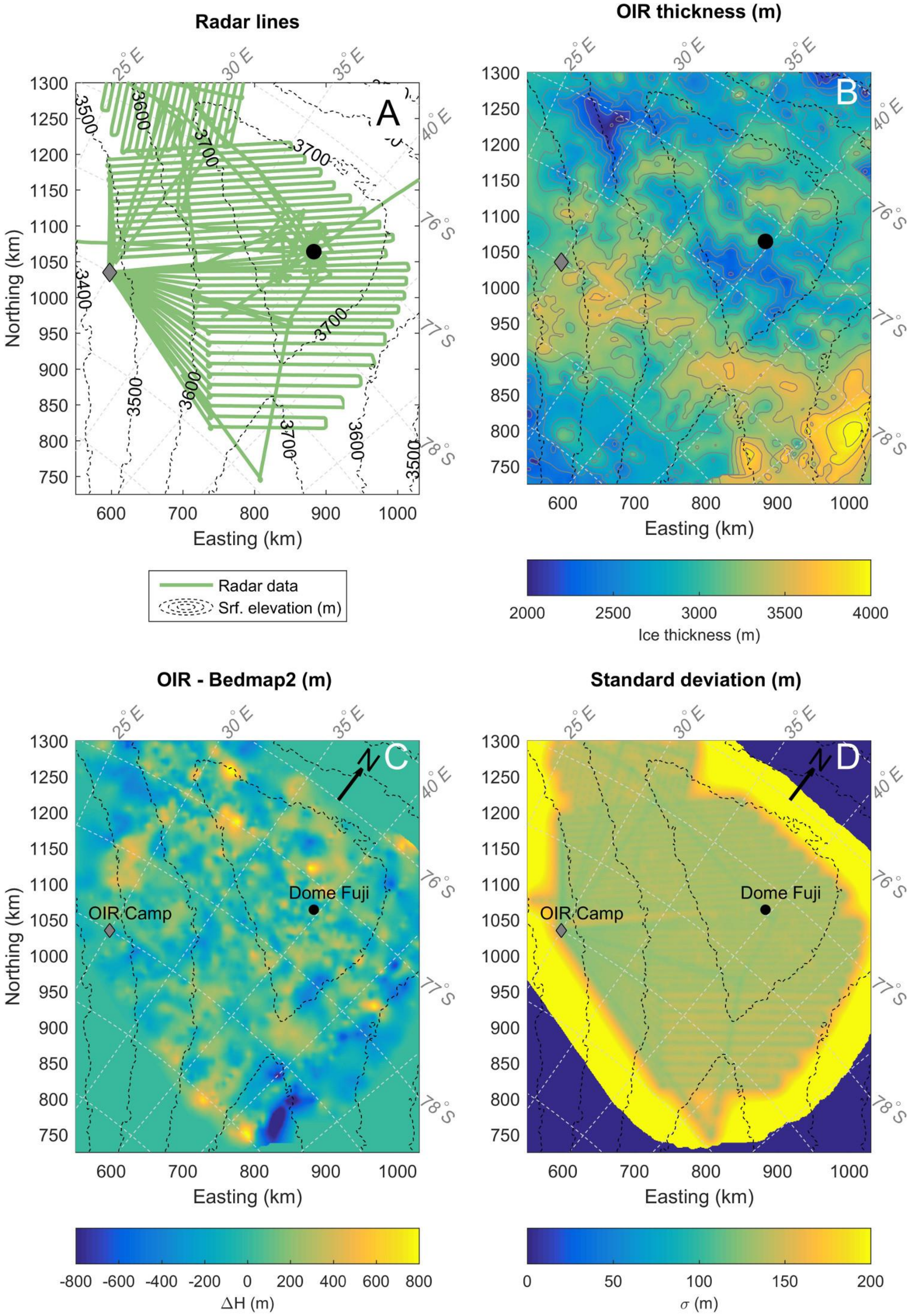
Fig.3 : The color scale shows the full range from 0; but in the figure, a threshold has been applied to show only values > 5 mW/m2?

The colour scale and its range have been changed for clarity.

Page 9, line 9; "(white arrow, Fig. 5)". There is no white arrow in Fig. 5.

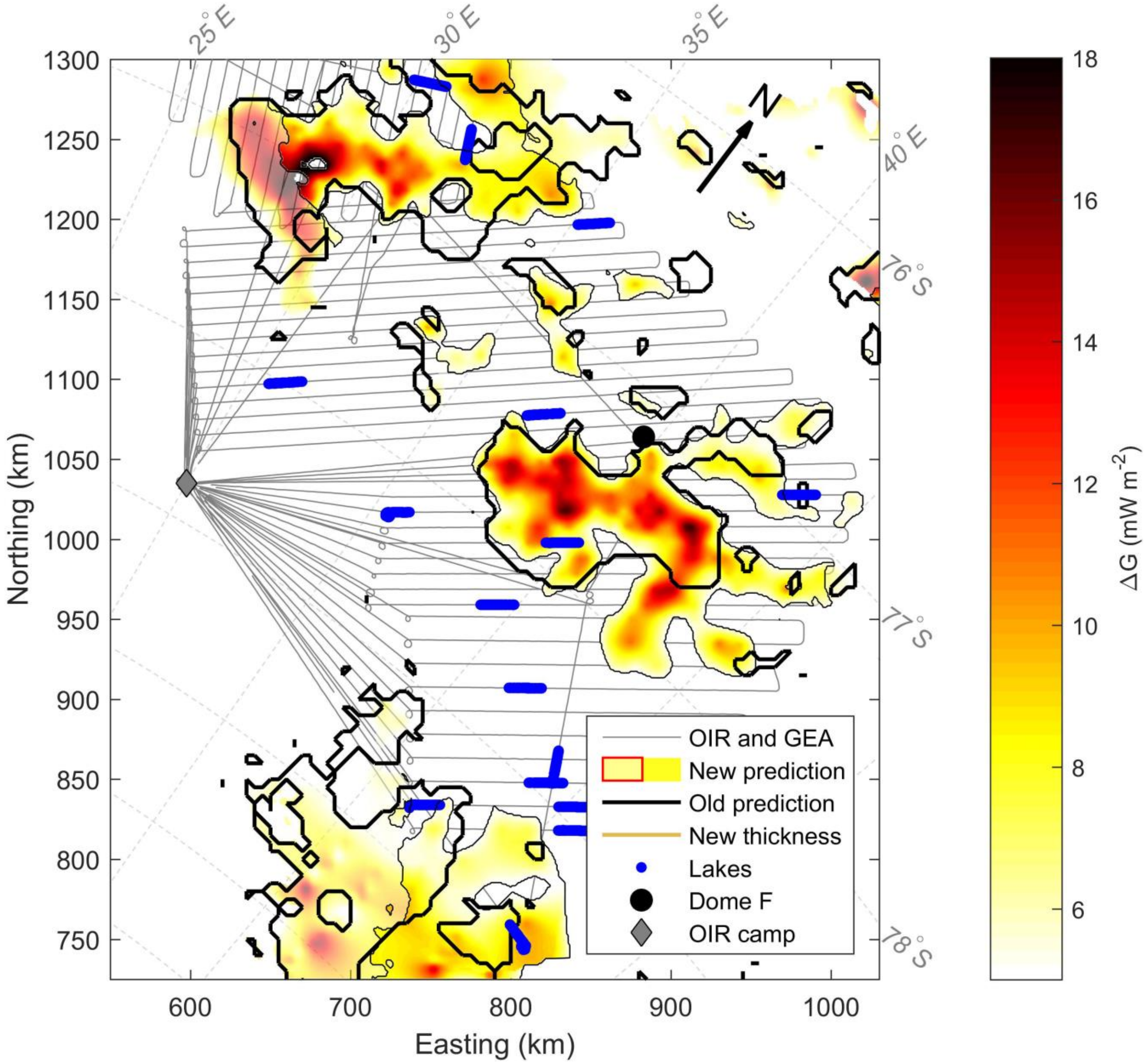
Has been changed to a blue box.

New figure 2



Radar lines
OIR thickness (m)
OIR - Bedmap2 (m)
Standard deviation (m)
A
B
C
D
Northing (km)
Easting (km)
Radar data
Srf. elevation (m)
Ice thickness (m)
ΔH (m)
σ (m)
OIR Camp
Dome Fuji
N
25° E
30° E
35° E
40° E
76° S
77° S
78° S
3400
3500
3600
3700

New figure 3



25° E
30° E
35° E
40° E
76° S
77° S
78° S
N
1300
1250
1200
1150
1100
1050
1000
950
900
850
800
750
Northing (km)
600
700
800
900
1000
Easting (km)
OIR and GEA
New prediction
Old prediction
New thickness
Lakes
Dome F
OIR camp
18
16
14
12
10
8
6
ΔG (mW m-2)