In the reply, the referee's comments are in *italics*, our response is in normal text, and quotes from the manuscript are in blue.

In this manuscript, the authors model the age field in a 70x70 km region centered around Kunlun Station (Dome A). The modeling is based on the finite-elements code Elmer/Ice. It takes into account the anisotropy of the ice material due to its fabric, the mechanical behavior of the ice and the temperature field. An important assumption is that the ice sheet is in steady-state, so only a steady-state velocity field is computed. Various hypotheses are tested regarding the geothermal flux and the fabric. The model is compared to age observations at Kunlun station obtained by tracing radar layers to the dated Vostok ice core. It is found that the best agreement is obtained with a geothermal flux of 60 mW/m^2 and a fabric evolving from isotropic at surface to a girdle fabric at depth=2/3 of ice thickness. From there, the model extrapolates the basal age to the range 650-830 kyr BP at the base of the ice sheet at Kunlun station that is too young to record the Mid-Pleistocene Transition (MPT). The model is also compared to horizontal surface velocity measurements, but it is found that it is difficult to discriminate between the different geothermal and fabric assumptions. The surface vertical velocity model is also compared to surface accumulation measurements, which allows to eliminate values of geothermal flux higher than 60 mW/m^2. Finally, some locations for old ice recording the MPT are proposed, 1-2 km maximum far from the Kunlun station, on the flanks of a bedrock valley.

Generally, I enjoyed reading this manuscript which is clearly written. The modelling experiments presented are an advance with respect to the state-of-art ice flow and age modeling around Dome A, despite some rough assumptions. However, I have some major concerns explained below:

- there is no discussion on the Raymond effect, which occurs at domes with a non-linear rheology and which has an important influence on the age-depth profile. The Raymond arches should be present in their modeling experiments. In reality, the Raymond arches are probably not easily observable in the radar age observations, since the dome has probably moved during the past (a movement of only a few kilometers is sufficient to dilute the Raymond effect spatially). This is a clear limitation of the steady-state assumption when modeling the age of the ice in the vicinity of a dome. A discussion on this effect is mandatory.

Reply: Elmer-ice does in fact include all the physics that explains the Raymond effect. But a Raymond effect is not seen on the observed radar profiles.

The modeled Raymond effect is also quite obscure. Fig. R1 shows the modelled age against normalized depth on a transect perpendicular to the ridge (see the red straight line on the left plot). There are two rises in Fig. R1B, at about x=1015 and at x=1035. However, the depths at x<1015 should be much deeper according to Fig. 4 where the model overestimates ages at depths compared with the radar observation of 153.3 ka isochrone in triangle 3. The x=1035 feature might be a weak Raymond bump.

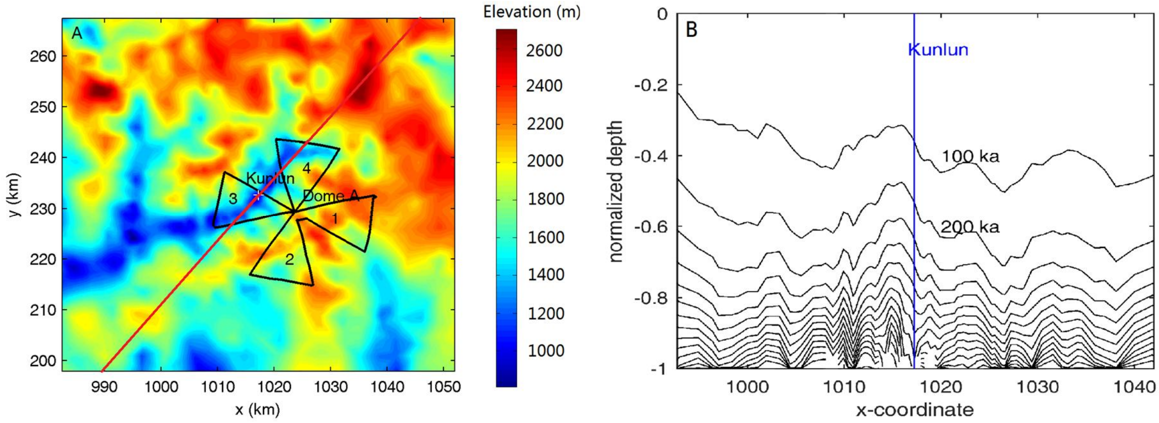

Fig R1. A) Bedrock elevation in the 70×70 km^2 region. The black lines are the route of the polarimetric radar in respect of the 153 ka isochrone plotted in Fig. 4; the common point of the four triangles is Dome A; the white cross is Kunlun station. B) the simulated age/normalized depth plot along the route marked in red in A). The isochrones contour interval is 100 ka.

We add a discussion on this effect in Uncertainties section as follows:

The special ice flow conditions at ice divides often leads to the presence of Raymond arches (Raymond, 1983), where older ice is at shallower depth than it is several ice thicknesses away from the divide. These features are visible as uplifted radar internal reflections in profiles across the divide. The strongest Raymond arches show up in high-accumulation coastal domes where the bed is cold and flat and the ice column is closer to isothermal (e.g. Hindmarsh et al., 2011). However, bed topography is complex at Dome A and Raymond arches are not seen in the observed radar profiles. Furthermore, our ice dynamics package, Elmer-ice, includes all the physics needed to produce the Raymond effect, but we also detect no such feature in transects across the flow divide. We explain this by the Raymond arch being obscured by a combination of rugged basal topography and thermal structure. The strong thermal gradient in the ice sheet tends to reduce the Raymond effect: the tendency of the non-Newtonian rheology to produce a stiff layer near the bed where strain rates are low is counteracted by the tendency of warm temperatures to produce softer ice at depth. The viscosity of the basal ice under the dome is softer than the viscosity of the super cold ice near the surface, but it is still much stiffer than the basal ice away from the dome, causing the old ice to be up-warped somewhat under the ridge. Moreover, the high basal melt rates of 2-3 mm a^{-1} at Kunlun station draws down ice and obscure the Raymond effect.

- Why is the age model compared to the radar age observations only at Kunlun? The comparison could be done anywhere where there are radar data.

Reply: There are only dated isochrones along the 2 radar lines that connect Dome A with Vostok. We show the lines now in the new Fig. 1A. The rest of the AGAP, polarimetric and Chinare radar data we use in the paper is not tied to the Vostok ice core and hence no age-depth models exist along those radar lines. The most relevant use of the results is at the location of the deep ice core site, which is the focus the simulation using the ice fabric taken from there.

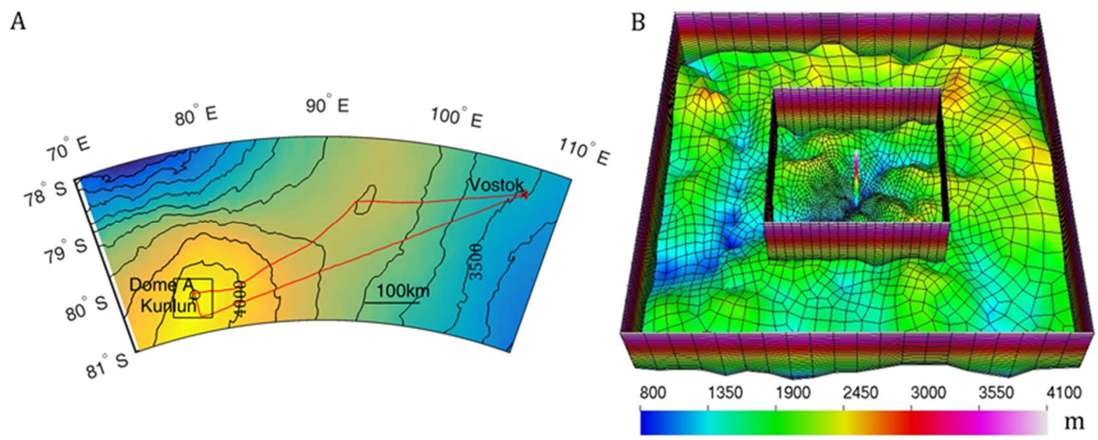

Fig. 1 (A) The locations of Dome A (black circle), Kunlun (black +), Vostok (black ×) and the 70×70 km^2 study region (black box). The background is surface elevation with 100 m contour interval. The two radar lines that connect the Vostock drill site to Dome Aare shown in red. (B) The 70×70 km^2 finite element mesh in the vicinity of Dome A projected on a polar stereographic map with standard parallel at 71°S and central meridian at 0°E. The background is bedrock elevation. The boundaries of the inner region and the whole region are shown, with the inner 30×30 km^2 region centred on Kunlun station has 300 m resolution, and the outer region 3 km resolutions. There are 21 terrain-following vertical layers with thinner layers near the base. The bar in the center denotes the drilling site at Kunlun station.

- if I understood correctly, to compare the modeled vertical velocity with the accumulation observations, the authors use an average accumulation which is calculated as a weighted average of glacial and interglacial accumulations. This is too rough an hypothesis. The authors should use the EPICA Dome C record to calculate a ratio between the present-day accu and the 800 kyr average accu. This way, the comparison with the modeled vertical velocity would be more relevant- in a similar way, the authors should use a 800 kyr average value of the surface temperature based on the Dome C temperature variations (assuming the variations are the same at Dome A), rather than simply the present-day value at Dome A.

Reply: Yes, this is true for accumulation and we modify the text thus:

The average accumulation during the past 800 ka is 17.7 mm i.e. a^{-1} using the EPICA Dome C record (Bazin et al, 2013), which is very close to what the three best fit simulations achieve (Fig. 3B; Table 1).

However, we do not think it is better to use the 800 ka average value of the surface temperature based on the Dome C temperature variations than simply the present-day value at Dome A, because the important thing for the ice dynamics is how the viscosity of the ice would change over time and that is not a linear function of temperature.

In our simulations published in Sun et al. (2014), we tried both the present-day temperature (-58.5 °C) and that in glacial period (-68.5 °C). The cold temperatures produce very poor fits that must be rejected. We explain in the text

The present-day surface temperature is −58.5°C, while it is likely about 10°C warmer than that during the Last Glacial Maximum (LGM) over the East Antarctic plateau (Ritz et al., 2001). The viscosity of the ice would change over time and that is not a linear function of temperature. Sun et al. (2014) found that none of the simulations using a surface temperature of -68.5°C matched well with the dated radar isochrones at Kunlun station, and we confirm that with the extended set of dated isochrones extending to 2/3 ice depth. While glacial period temperatures were likely warmer on average than -68.5°C they were certainly colder than present day. Sun et al. (2014) explain the poor fits for cold surface temperature simulations as being due to key role of warm interglacials in determining the vertical velocity profile of the ice because of the exponential Arrhenius dependence on temperature of the ice viscosity (Eqn (8)), along with much higher accumulation rates during interglacials. Therefore we prescribe surface temperature to be the present value of -58.5°C in this study.

- there is a mistake at the beginning of section 4.1. At steady-state, surface vertical velocity should be equal to surface accumulation rate, not surface accumulation rate plus basal melting. This should be corrected.

Reply: Yes. We agree with the referee. We made a mistake here. At steady-state, surface vertical velocity equals surface accumulation rate, while vertical velocity at the bottom equals the basal melting rate. We correct it in the revision.

At steady-state, surface vertical velocity equals surface accumulation rate. The average accumulation during the past 800 ka is 17.7 mm i.e.a^{-1} using the EPICA Dome C record (Bazin et al, 2013), which is very close to what the three best fit simulations achieve (Fig. 3B; Table 1).

- Because of these rough assumptions in the modeling, a perspective paragraph listing what could be improved in a future modeling study would be welcome.

Clear suggestions for improving the model include: Non-steady state dynamics; Basal hydrology allowing for water flow and refreezing

Reply: In the revision, we add a substantial section of Uncertainties listing what could be improved in a future modeling study.

Our approach here is relatively sophisticated in terms of ice models presently in use, but there are several limitations that almost certainly mean that details of the simulation will be wrong. We make the key assumption that the ice sheet is in steady-state, and the surface geometry is fixed, which means the surface accumulate rates balances the vertical velocity and it is also fixed in time. However, the basal thermal condition is sensitive to the ice thickness although other simulations of the whole Antarctic ice sheet suggest that elevation changes at Dome A have been less than 50 m over glacial cycles (Ritz et al., 2001; Saito and Abe-Ouchi, 2010.) Transient simulations with varying geometry and surface accumulation rate in the past 800 ka would improve the model result.

We used a spatially constant geothermal heat flux. Although geothermal flux may over kilometer scales, it seems unlikely in East Antarctica. For example, Carson et al., (2014) suggest heat flow may vary by a factor of >150% over 10–100 km length scales in East Antarctica. Passalacqua et al., (2017) explored variation in heat flux around Dome C using data from radar surveys, and prescribe uniform geothermal heat flux over 10 km scales. Schroeder et al (2014) similarly infer geothermal heat flux variability from radar surveys over Thwaites glacier in West Antarctica, which is proximal to the Mount Takahe volcano that was active during the Quaternary, finding heat fluxes could double over ranges of about 20 km. We do not expect any recent magmatic activity in the Gamburtsev Mountains, and the situation of Dome C is probably a reasonable analogue. However there is simply no data to constrain heat flux around Dome A, and hence modelled thermal structure, ice viscosity and age-depth profile. Liefferinge and Pattyn (2013) explored the uncertainty in existing geothermal heat flux data sets and their effect on basal temperature with a spatial resolution of 5 km. The basal temperature was calculated using the steady-state thermodynamic equation in which ice flow velocity is calculated from the shallow-ice approximation. The mean geothermal heat flux of the three existing datasets at Dome A is about 45 mWm^{-2}, with root mean square error of about 20 mWm^{-2}. Their modelled basal temperature at Dome A is about -10°C corrected for the dependence on pressure with a root mean square error of about 6°C. Due to the coarse resolution (5 km) used in the whole Antarctic simulations of Liefferinge and Pattyn (2013), the modelled basal temperature does not have obvious spatial variation across the Dome A region at scales of hundreds kilometers.

The Gamburtsev Mountain is characterized by large spatial variability in bedrock topography, which means that a full-Stokes model that considers the all the stress components is better able to capture the ice dynamics than does the shallow-ice approximation (e.g., Zhao et al., 2013). In our study, large variations in basal temperature are simulated using a full-stokes model run at around 500 m resolution. The basal thermal state is then very sensitive to geothermal heat flux (Sun et al., 2014), which we explored using 45, 50, 55 and 60 mWm^{-2}, and which spans the broad range suggested by Liefferinge and Pattyn (2013).

We also use a spatially constant fabric across all our model domain, with transitions between fabrics at two fixed depths taken from those measured at Kunlun station by Wang et al., (2017). As discussed in Section 4.2, this leads to lower confidence in the age of the basal ice in the region south of Kunlun than to the north. This further means that we have more confidence in finding very old ice in the slightly further away northern region of Fig. 6 than to the south of Kunlun.

Our results suggest spatial variability in basal melting, and this may introduce basal accretion in places (Bell et al., 2011), though there is no radar evidence of any basal accretion features in the vicinity, the model could be improved by adding basal hydrology. Basal melting may also introduce sliding at the ice/bed interface, which we explicitly excluded in the model, however, comparison with observed horizontal velocities suggests that this is not an issue. Indeed extraction of sliding rates from inverse modeling using observed velocities would be extremely difficult at Dome A given the very low speeds making satellite interferometry impossible, and the sparse network of GPS locations.

I also have some minor points below:

- l.51: "Hou et al., 2007" -> missing space

Reply: Done.

- l.102: "special" -> "spatial"

Reply: Done.

- Fig.1A is difficult to ready. I would use a square region in a classical projection.

Reply: OK. The other referee also said Fig.1 A is not informative. So we change it to show important feature such as the radar profiles connecting Kunlun and Vostok.

- l.165: "is gas constant" -> "is the gas constant"

Reply: Done.

- l. 173: "the components of..." -> missing space

Reply: Done.

- l. 242: why not using an intermediate value of the surface temperature between the present-day and the LGM? (Cf. comment above).

Reply: Sun et al. (2014) used surface temperatures both in present-day value (-58.5 °C) and that in glacial period (-68.5 °C). It is clear that -68.5 °C (the full glacial temperatures) cannot produce a good match to the internal reflection horizons and vertical velocities.

- l245: the no sliding assumption is quite rough. There is probably sliding where there is melting.

Reply: It is possible there is sliding. Although surface speeds in our study region is very small (a mean speed of ~11±2.5 cm a^{-1}), and well matched to the model results we find from ice deformation without basal sliding (Fig. 7), hence basal sliding must be a small fraction of the total velocity, and not affect the results we show. Attempting an inversion from observation velocities would introduce very large errors because the speeds are below the error margin from satellite measurements and thus only available from the very sparse GPS network shown in Fig. 7. We mention this both in Section 3.4:

We run the model with a no-slip condition at the bed. We could expect that sliding might occur where there is melting at the bottom. However, surface speeds in our study region is very small (a mean speed of ~11±2.5 cm a^{-1}, Yang et al., 2014) and well matched to the model results we show later from ice deformation without basal sliding (Section 4.4) hence basal sliding must be a small fraction of the total velocity, and not affect the results we show.

And in the discussion:

Our results suggest spatial variability in basal melting, and this may introduce basal accretion in places (Bell et al., 2011), though there is no radar evidence of any basal accretion features in the vicinity, the model could be improved by adding basal hydrology. Basal melting may also introduce sliding at the ice/bed interface, which we explicitly excluded in the model, however, comparison with observed horizontal velocities suggests that this is not an issue. Indeed extraction of sliding rates from inverse modeling using observed velocities would be extremely difficult at Dome A given the very low speeds making satellite interferometry impossible, and the sparse network of GPS locations.

- l. 261: quite a big assumption here also, since the geothermal flux might change at a kilometer scale.

Reply: Actually we note that other studies in Antarctica expect no large variations over 10 km scales. But in principle this is a problem, and we discussion in the Uncertainties:

We used a spatially constant geothermal heat flux. Although geothermal flux may over kilometer scales, it seems unlikely in East Antarctica. For example, Carson et al. (2014) suggest heat flow may vary by a factor of >150% over 10–100 km length scales in East Antarctica. Passalacqua et al. (2017) explored variation in heat flux around Dome C using data from radar surveys, and prescribe uniform geothermal heat flux over 10 km scales. Schroeder et al (2014) similarly infer geothermal heat flux variability from radar surveys over Thwaites glacier in West Antarctica, which is proximal to the Mount Takahe volcano that was active during the Quaternary, finding heat fluxes could double over ranges of about 20 km. We do not expect any recent magmatic activity in the Gamburtsev Mountains, and the situation of Dome C is probably a reasonable analogue. However there is simply no data to constrain heat flux around Dome A, and hence modelled thermal structure, ice viscosity and age-depth profile. Liefferinge and Pattyn (2013) explored the uncertainty in existing geothermal heat flux data sets and their effect on basal temperature with a spatial resolution of 5 km. The basal temperature was calculated using the steady-state thermodynamic equation in which ice flow velocity is calculated from the shallow-ice approximation. The mean geothermal heat flux of the three existing datasets at Dome A is about 45 mWm^{-2}, with root mean square error of about 20 mWm^{-2}. The modelled basal temperature at Dome A is about -10°C corrected for the dependence on pressure with a root mean square error of about 6°C. Due to the coarse resolution (5 km) used in the whole Antarctic simulations of Liefferinge and Pattyn (2013), the modelled basal temperature does not have obvious spatial variation across the Dome A region at scales of hundreds kilometers.

The Gamburtsev Mountain is characterized by large spatial variability in bedrock topography, which means that a full-Stokes model that considers the all the stress components is better able to capture the ice dynamics than does the shallow-ice approximation (e.g., Zhao et al., 2013). In our study, large variations in basal temperature are simulated using a full-stokes model run at around 500 m resolution. The basal thermal state is then very sensitive to geothermal heat flux (Sun et al., 2014), which we explored using 45, 50, 55 and 60 mWm^{-2}, and which spans the broad range suggested by Liefferinge and Pattyn (2013).

- l. 326: the reference is Ruth et al., not Urs et al. (Urs is the first name).

Reply: Done. Thanks for that info!

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