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Interactive comment on "The effect of obliquity on temperature in subduction zones: insights from 3D numerical modeling" *by* Alexis Plunder et al.

Anonymous Referee #2

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Review:

The study presented here investigates possible temperature variations at the subduction interface due the subduction obliquity. The motivation comes from geological data (Western and Central Turkey) and present-day configuration of the global subduction system, that large slab segments are subducting at an angle relative to their upper plate. The authors perform 3-D thermo-kinematic numerical models, in which they vary: a) the curvature (convex, concave, sinusoidal), b) amplitude of curvature (sinA), c) and parameters beta and gamma, that control the shape of the curvature. Two additional simulations were performed on a subset (reference model, convex geometry) to investigate the effect of the subduction rate.

The focus of the study is thus calculating the flow in the mantle wedge and the temperature variations at the subduction interface (how temperature profiles vary laterally). Results show that the effect of the trench curvature (obliquity) on the geotherm is considerable. Variations in obliquity can lead to temperature variations as large as 200degC along strike. The results are then discussed in relation to geological data from the Western and Central Turkey, and could potentially be applied to other present-day/paleo-oblique subduction zones.

The manuscript at this point has a well defined structure, with clear and well documented results and conclusions. Some exceptions include insufficient figure captions, labels that need to be improved, and few paragraphs that need rephrasing/more details.

I recommend the manuscript to be published in Solid Earth with major modifications, and I identify below 5 major points to be addressed, followed by other minor points. My comments primarily aim at clarifying some aspects of the model and results, and thus making the manuscript a more complete piece of work.

Major points:

1. Model details.

a) Time stepping and temperature advection. Temperature advection (i.e. Page 8, Line 5) was suggested in a couple of locations as an important mechanism. However, it is not explained what temperature advection is (for the general audience), or how you solve for it (from Eq. 3).

A few questions to help here: When was steady-state (Abstract, Line 8) reached in simulations? How long did the models run? Did you solve just once for Stokes and T equation (1 time step)? How large was the time step? This is not clear. What about transient evolution of temperature and feedback to the system (i.e. flow of hot material that facilitates subduction)?

b) Model dimensions. What are the physical dimensions of the model? What is the physical resolution of the domain? Box dimensions are indicated in Fig 2a, but please include more information in the main text.

c) Inflow/outflow boundary conditions (i.e. Page 6, Line 10). Could you explain better the in/out flow condition at 100 km depth? Did you choose this particular BC to allow for corner flow in the mantle wedge? If so, please indicate in text.

2. Subduction curvature and obliquity. Confusing interchange of “curvature” and “obliquity”. For example, Page 1, Line 10: One sentence uses “trench curvature”, and the next “obliquity”. Authors should make it clearer how obliquity and curvature are linked to each other.

Global subduction zone. Page 2, Line 32, Figure 1: Measured subduction curvature depends on the trench length considered (i.e. Schellart et al 2007). When you make the statement “majority of subduction zones have concave,... or convex”, do you consider the length? What is the maximum curvature/obliquity (i.e. theta_max) for the present-day natural system?

3. Systematic study. First, all simulations (convex, concave, s-shaped) should be clearly listed as in Table 2, with corresponding varied parameters. Then, comparing the model results as in Table 2 across the entire simulation spectrum (v, vy_max, dT_max) could provide more information on the general behaviour of the system. For example, that the largest dT are obtained for s-shaped simulations, what are the max/min bounds for dT for each geometry, or how subduction rate affects dT. I consider valuable information could be derived from an extended Table 2.

4. The study needs more link to former studies on the topic. For example, Page 2, Line 16, Lines 24-25: Ji and Yoshioka (2015), Yoshioka and Murakami (2007) also investigated the relationship between slab geometry (convex, concave) and obliquity, and the thermal regime of the plate interface in 3D models. It deserves more explanations (what did they find, what is different in your model etc.) than just a mention. A comparison between their and your results should also be included in the manuscript.

5. The limitations of the model need to be discussed into more details (i.e. Page 10, Lines 24-27). What are the factors that could modify your results (max dT ~200C)? i.e. revision of field data (different P-depth interpretation), model improvements (non-linear rheology for mantle), geometry, subduction parameters (age, velocity, subduction angle) etc. What about dynamic models (steady-state vs transient state of temperature)?

Minor points:

Page 1.

Line 1: The geotherm in subduction zones. Line 4: proposed/observed instead of supposed. Line 7: Please revise the sentence: some commas missing and remove “only”. Line 8: the results in terms of: (i) mantle flow..., and (ii) temperature... Line 12: heat that is advected by velocity causes such temperature variations (linked to the magnitude of the trench parallel component of velocity). Line 17: are primarily. Lines 19-23: Sentence too long, please rephrase. Line 24: “with” instead of “whereby”.

Page 2.

Line 2: trench perpendicular flow (poloidal). Line 11 (paragraph): Explain what is temperature advection and why it is important/of interest here?. Line 13: trench curvature vs obliquity - should be explained what they are/stay consistent. Line 22: setup.

Page 3.

Line 6: with increasing. Line 10: proxies to record them [lateral variations in temperature]. Line 14: Melt-inclusion data suggest that temperature variations occur along strike and vary through <time>. This invites for some discussion about time-dependent (dynamic) variations in slab geometry. Line 16-18: Please explain what’s the difference between eclogite and garnet-amphibolite facies (i.e. high/low P,T) for the general audience. Line 18: Yamato and Brun (2016) have shown that peak pressures recorded in subducted rocks might not reflect their maximum burial depths. This suggests that the assumption of transforming pressure into depth might not be the best practice. Could you comment on this aspect? How would that change the temperature variation estimated in line 19 (i.e. >300C) and how would that relate to your modeling results? Line 27: Please explain in a few words what is supra-subduction, as compared to subduction for the general audience.

Page 4.

Lines 3-7: Please rephrase this sentence. It is too long. Line 10: Nice transition/motivation to the next section. Line 15: measurements. Paragraph 22-33: This paragraph provides some background on previous studies investigating the effect of geometry (obliquity) on subduction dynamics. However, more should be included on studies that look at development of trench curvature (i.e. Schellart et al - convex/concave due to slab width, or sinusoidal when there is both trench advance and retreat), because these studies are more relevant to the present investigation.

Page 5.

Line 8: Why no analytical solution in 3D? Perhaps because of its too complex nature (i.e. take into account poloidal and toroidal components and other complex features)? Also, a lot of work was restricted to 2D in previous decades because of computer limitations at that time. In principle, 2D is a first order approximation, which yielded some important results, but with some limitations. The authors could explain why the transition from 2D to 3D studies (i.e. trench obliquity is an inherent 3D feature). Line 9: setup. Line 23: parameter values . . .Table 1. Line 24: Decoupled energy equation: what about dislocation+diffusion creep, with P,T dependence for mantle viscosity? How would that affect temperature advection on the interface? Line 32 (throughout manuscript): Need to be consistent with units, especially for the time unit (yr): Ma, My, Myr, cm/yr etc. Model Setup: Should indicate before line 30, that that the model setup and boundary conditions are tuned for the Anatolian case study explained in Section 2.

Page 6.

Line 7: than. Line 16: use. Line 15-19: Any computational libraries that need to be cited here? Line 20: How deformed are the Q1Q1 elements to conform with the geometry? Is that affecting the accuracy of the solution?

Page 7.

Line 9: multiple typos. Why use these particular boundary conditions? Is mass conserved? The inflow/outflow bc are not clearly explained (i.e. flow comes in horizontally from the top right boundary and flows out at the bottom boundary, conserving the mass. . . Line 24: sentence is not clear. Line 28, Figure 3: Why does the magnitude of vy_max decrease with depth? Is it a consequence of the model setup?

Page 8.

Line 4 (end): Reference to Figure 4 is incorrect, as that observation was derived from Figure 3. Line 6: becomes. Figure 4: insufficiently explained in the text/caption. What are the pink/light blue lines in figure 4a? It also seems in Figure 4b, that path 3 is the warmest (compared to 1,2,4) - which corresponds to location theta_max? Line 14: What was the subduction rate for the reference model (sin20_1) compared to these values? Line 15-16: Why an increase in subduction velocity produces such a polarity change in the temperature variation? This is not explained why that happens/results are not shown. The paragraph is not clear that it refers to the pink/light blue lines in Fig 4. Also, please clarify the differences between the reference model and these additional experiments. Line 20: also called inflection points.

Page 9.

Line 3: 100 or 110C (as in the Fig5c)? Line 6: centre (purple contours), flow brings colder material from the surface to the centre of the slab. Concave models: I feel their model description is incomplete. The warmest part of the slab is in the center. How warm relative to the edges? What about vy_max? Line 16: max theta is in the inflection point. Line 20: sentence not clear. Lines 21-22: typos. Line 23: Why is the temperature field asymmetric in Figure 6b, slice at 75 km depth, as compared to a,c? Line 26, Figure 6: T variation for ATAN05_20 (fig 6b) is indicated 75C, not 200C as suggested in the text./ If you mean ATAN10_20, the T variation in fig 6c is indicated 110C, even if it looks around 200C. Please revise figure 6 and paragraph.

Page 10.

Line 9: In which way the results in this paper agree well with previous work? Line 16: Theta remains constant in the simulations here. Should make it clear and potentially discuss implications for variable Theta (age, velocity, subduction angle) Lines 24-27: The limitations should be extended a bit more. For example, how would power-law T,p dependent rheology of the mantle expect to influence the T variations? Are the T variations calculated here lower bound estimates? Line 25: typo.

Page 11.

Lines 11-12: What are the limitations/improvements of the numerical model that could produce a larger T variation as observed in Anatolia?

Figures and Tables.

Figure 1: Please add some labels/names of the major subduction zones used to illustrate in the text (i.e. Aleutians, remnants of W-C Turkey). b) The name abbreviations in the figure are not clear. Please either explain in caption or in figure.

Figure 3: Labels for Fig 3g,h,i are missing (as indicated in the text on Page 8, line 2)

Figure 4: Incomplete figure caption/figure legend. Labels are missing (a,b). What do the paths,vbc,"middle/edge" represent? Some sentences in the caption could help explain the figure better.

Figure 5: Please indicate simulation labels (i.e. sin20_1) in Fig 5a-b. c) The colours for the maximum temperature paths are misleading. If they are all taken at the inflection point (yellow in the sketch), they should all be yellow (like the purple curves). Similarly

for the concave model.

Figure 6: Vy direction arrows as in Figure 5a,b would be useful.

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