

## Author response to referee reports in manuscript wcd-2020-5:

### “The sensitivity of atmospheric blocking to changes in upstream latent heating – numerical experiments”

by Daniel Steinfeld, Maxi Boettcher, Richard Forbes, and Stephan Pfahl

We would like to thank both reviewers, Oscar Martinez-Alvarado and Florian Pantillon, for their second review and the detailed feedback to the manuscript. We have revised the manuscript accordingly (see below – our response in blue).

## 1 Second review by Florian Pantillon

### General comment

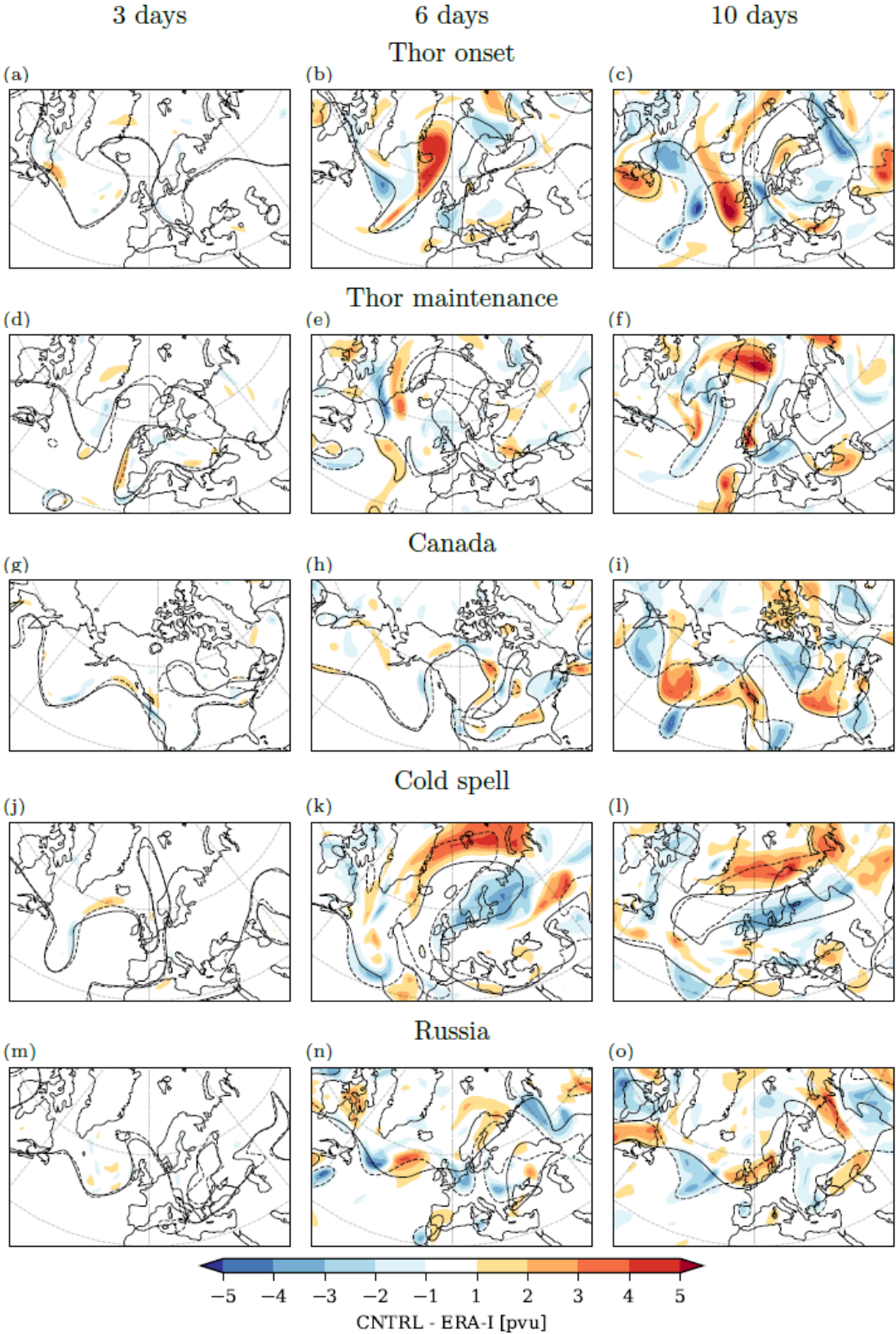
I fully understand that the predictability of blocking situations is beyond the scope of the paper. The authors justify that “the reference simulations capture large-scale blocking conditions”, which is true, but how close are these to the actual large-scale blocking conditions? If the model completely diverged from reality—which does not appear to be the case here—there would be no point at investigating real case studies. In their response figure AR1 the authors show that the control simulation is very close to the analysis after 3 days, which is good and strengthens the results, and deviates after 6 days, which is okay but deserves some discussion. This must be mentioned at least, and showed in any case, otherwise it may be interpreted as trying to hide some findings. As I suggested in my previous review, the analysis could be included by adding panels (or simply the 2-pvu contour) in Figs. 3–4 and S1–3 (or alternatively 7–8) and/or intensity and spatial extent in Figs. 2 and 10.

**Reply** We followed this recommendation and included a new Figure S4 with a brief discussion comparing the control simulations to ERA-Interim in the supplement. A reference to the supplement has been added in the manuscript: “Although a 10-day forecast simulation does not perfectly match observations/analysis (cf. supplemental Fig. S4), especially during blocking situations with increased forecast uncertainty (e.g., Tibaldi and Molteni, 1990; Pelly and Hoskins, 2003; Matsueda, 2009), such differences do not affect the conclusions obtained from the sensitivity experiments, since we compare simulations with LH (CNTRL) to simulations without LH (NOLH).”

### Supplement 2: Synoptic comparison between CNTRL and ERA-Interim

The following Figure S4 compares upper-level PV between the control simulation (CNTRL) and ERA-Interim (ERA-I, Dee et al., 2011) for the cases Thor onset, Thor maintenance, Canada, Cold spell and Russia. After 3 days of model simulation (left panels in Fig. S4), the initial ridge amplification is very well represented in all cases with only minor differences in the upper-level PV compared to ERA-I. 6 days into the model simulation during the mature phase (middle panels in Fig. S4), the intensity and spatial extent of the mature block are generally well represented in the CNTRL simulations. However, positive and negative upper-level PV differences between CNTRL and ERA-I are found near the flanks of the blocking anticyclones, indicating a shift in location of the negative PV anomalies. 10 days into the model simulation (right panels in Fig. S4), both the CNTRL simulations and ERA-I show the decay phase of the blocks, but up- and downstream ridges and troughs are strongly displaced with marked differences in the upper-level PV pattern. Nevertheless, the forecast evolution of the blocks in the CNTRL simulations is similar enough to ERA-Interim over the time of interest (onset and mature phases) and captures an intense blocking anticyclone. It

thus allows studying the impact of LH on the flow amplification in the IFS sensitivity experiments.



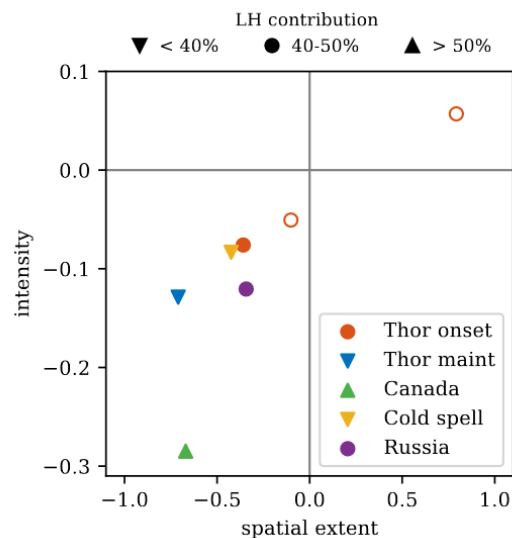
**Figure S4.** Difference (CNTRL - ERA-I) in upper-level PV (shaded in pvu) and upper-level 2 pvu contour (solid for CNTRL, dashed for ERA-I) after (left panels) 3 days, (middle panels) 6 days and (right panels) 10 days of model simulation.

## Specific comments

1. l. 34 “concepts”: studies?  
**Reply** We replaced “concepts” with “studies”.
2. The l. 83–99 specify the boxes are fixed during each run  
**Reply** We changed the sentence to “In order to isolate the effect of this LH, a 3-dimensional box is placed over the main heating region, which is kept fixed during each NOLH simulation, and LH is only modified in this box.”
3. l. 105–107 this is not convincing...  
**Reply** See our reply to general comment.
4. l. 116–117 emphasize this terminology is used for all variable throughout the paper  
**Reply** Thank you. We added: “The term “upper-level” is used hereafter to describe the vertically averaged flow between 500 and 150 hPa.”
5. l. 229–232 avoid referring to Fig. 1b as it does not show the features mentioned here)  
**Reply** We removed the reference to Fig. 1b.
6. l. l. 352 day 2 or 3?  
**Reply** Thanks for pointing out the mistake. Figure 6a shows 2 pvu contours on 3 October 2016 (day 3).
7. l. 356 “underestimated”: weaker?  
**Reply** We replaced “underestimated” with “weaker”.
8. l. 366–368 “demonstrates” is too strong, as uncertainty can arise from low-level moisture in the initial conditions, phasing between lower and upper-level flows, etc.  
**Reply** We replaced “demonstrates” with “suggests”: “This strong sensitivity of block development to changes in upstream latent heating further suggests that forecast uncertainty during blocking can arise from diabatic heating from parametrized processes (e.g., Grams et al., 2018; Maddison et al., 2019).”
9. l. 438–547 (4.2.2) Fig. 9 is (1) very similar to Fig. 7, (2) only once referred to, and (3) implies returning to day 3 after discussing day 6 in Fig. 8. I thus recommend merging Fig. 9 with Fig. 7 (or alternatively with Figs. 3–4 and S1–S3) by simply adding a contour of strong PV advection by the divergent wind (see e.g. Fig. 7 in <https://doi.org/10.1002/qj.2419>) and merging contents of 4.2.2 with 4.2.1.  
**Reply** Thanks for your suggestion. We favor keeping 4.2.2 as a separate section. Adding PV advection by the divergent wind to Fig. 7, this and the corresponding discussion would become too complex and we think that the current version is easier to read.
10. l. 501–503 The definition of intensity and spatial extent indices is unclear: relative or normalized differences? Better express as percentage?  
**Reply** Thanks for spotting this mistake. Figure 11 shows the “normalized” differences:  
$$\frac{NOLH - CNTRL}{CNTRL}$$
11. Figure 1 “2 days lead time”: rather 42h in (a) and 36h in (b)?  
**Reply** Thanks for the careful reading. We changed this.

12. Figure 11 use different symbols or annotate reduced and enhanced LH.

**Reply** Thanks for the suggestion. We changed the markers to better indicate the LH contribution for each case.



**Figure 11.** Normalized difference in peak spatial extent and peak intensity of the NOLH blocks compared to the CTRL blocks. Values close to zero indicate weak sensitivity. Markers indicate the LH contribution in the CTRL simulations (see Table 1). Red open circles for Thor onset simulations with reduced LH ( $\alpha = 0.5$ ) and enhanced LH ( $\alpha = 1.5$ ).

## 2 Second review by Oscar Martinez-Alvarado

### Specific comments

13. Throughout the text (L2, L50, L77): This comment is more on semantics than atmospheric dynamics. While I agree with the objectives of the article to find a causal relationship between LH and blocking development, I would recommend changing the expression 'causal effect' for 'effect'. The modifier would only be required if there was an alternative type of effects, which I'm struggling to find.

**Reply** Thank you very much for the comment. We replaced 'causal effect' with 'effect'.

14. L80-81: L508-509: I'd rephrase the last part 'for which  $\alpha = 1.5$  shows a stronger sensitivity...'. This gives the impression that sensitivity is a property of each LH setting. In my view, sensitivity is a measure of the changes in the target given changes in a parameter, LH in this case. My interpretation of these results would be that the sensitivity of blocking in the onset case is not linear with respect to changes in LH (as the curve joining the red dots must go through the origin). This is very interesting as it shows that changes in LH have an even greater effect on spatial extent rather than intensity as LH increases. It leaves the question of what happens in between the points shown open.

**Reply** That's right. The sentence was adjusted accordingly: "In addition, the Thor onset simulations with reduced LH ( $\alpha = 0.5$ ) and enhanced LH ( $\alpha = 1.5$ ) are shown as open red circles, highlighting that the sensitivity of blocking in the Thor onset case is not linear with respect to changes in LH. It shows that an increase in LH has an even

greater effect on spatial extent than on intensity, as blocking area increases by a value of 0.7 (by a factor 3) for  $\alpha = 1.5$ .”

## Minor changes and typos

15. L90: Change ‘diabatic PV modification at the tropopause’ to ‘the presence of diabatically modified PV at the tropopause’.  
[Reply](#) We changed this.
16. L131: It is enough to say that the quantities are area-weighted. Therefore, you can delete ‘with the cosine of latitude’. In fact the weighting function will depend on the data grid.  
[Reply](#) We deleted this part.
17. L225: Change ‘following Scherrer et al...’ to ‘the index described by Scherrer et al...’.  
[Reply](#) We changed this.
18. L243: Change ‘They...’ to ‘These trajectories...’  
[Reply](#) We changed this.
19. L245-246: About the sentence starting with ‘Both cloud microphysics...’, as it is written I understand from that both schemes together contribute 5 K heating in total, whereas I think what you mean is that each scheme contributes about 5 K heating.  
[Reply](#) Thanks for pointing this out. We adjusted this sentence: “Each scheme (cloud microphysics and convection) contributes about 5 K to the total diabatic heating along these ascending trajectories (not shown), ...”
20. L253: I’d recommend changing ‘underpins’ for ‘underlines’ or ‘highlights’. To me ‘underpins’ would imply that the importance of LH requires the trajectory behaviour described.  
[Reply](#) We changed this.
21. L376: Perhaps ‘While’ would be more appropriate than ‘Whereas’, as there is no contrast between items here.  
[Reply](#) We changed this.
22. L399: Add ‘The’ before ‘largest differences’.  
[Reply](#) Done
23. L441: I think it should read ‘i.e.’.  
[Reply](#) Thanks for spotting the mistake.
24. L510: Delete ‘thus’.  
[Reply](#) Done.
25. Figure 11: It would be good to add a quantitative indication of the LH contribution represented by the circles. Perhaps you could add a couple of reference circles?  
[Reply](#) See reply 12 to comment for referee 1.