Response to Interactive comment on “Aerosol–radiation–cloud interactions in a regional coupled model: the effects of convective parameterisation and resolution” by S. Archer-Nicholls et al.

Anonymous Referee #2

Received and published: 27 November 2015

We thank the referee for their helpful critique of our paper. We appreciate that you found the paper to be well written and documented, agree that there was more scientific value that we could extract from the studies we made and have sought to address the areas of concern.

General/major comments

The authors state that the purpose of the study is to “critically evaluate how regional aerosol-radiation-cloud interactions are captured in WRF-Chem, . . .” (p. 27454, l. 1-9, see also p. 27463, l. 5). Although I realize that comparison with observations has been presented in a companion paper, the present study does not include any comparison with observations, and it is therefore difficult to know which of the experiments are more realistic. In particular, I think the value of what we learn from running with and without convective parameterization at the “grey zone” scales (i.e., <10 km) is limited when there is no idea of which is better. Evaluation against observations of clouds or precipitation, if available, would make this sensitivity experiment of with/without convective parameterization much more useful. At present, I do not agree that the paper is an evaluation paper, it is more a description of what happens when running with different setups.

Both referees have commented on our use of “evaluate” – to address this we have replaced the term with “investigate” instead.

Although I can understand the authors’ statement that “The shorter case-studies at high-resolution were prioritized over a longer, low-resolution setup for the purpose and scope of the current investigation“ (p. 27472, l. 1-3), the fact that the model region is tiny and the simulated time periods are few and very short, makes it difficult to generalize the results and make broader conclusions. Adding comparison to observations could possibly make up for this, as it may give some idea of which model setup is better.

The authors caution that the calculations of radiative balance should not be seen as robust calculations of radiative forcing (p. 27474, l. 10-11). However, I am not convinced that the method is good enough for drawing conclusions such as on p. 27466, l. 10-11 and p. 27467, l. 18-22 for simulations over such short time and for such a small region. A forcing imposed, e.g., by a reflecting compound such as sulfate, would rapidly lead to a decrease in surface temperature, which again would lead to reduced LW radiation from the Earth's surface, and hence contribute to maintain radiative balance. Supplement Table 4 shows that the near-surface temperature is affected by inclusion of an aerosol layer. In a long global climate model run this is solved by running with fixed sea-surface temperatures. A better, but more complex method would be to include double radiation calls, such as the method of Ghan et al. (2012), to quantify the direct, semi-direct, and indirect aerosol effects. Please justify the method used to calculate the radiative balance.

The authors were unaware of the Ghan et al., paper prior to receiving this review. We thank the reviewer for drawing attention to this article. The methodology described helps deconvolve the different forcings (direct, semi- and indirect) and we have implemented modifications to the WRF-Chem code to repeat the double radiation calls and re-run several of the scenarios over the three case-studies. We repeated the Ghan et al., analysis to generate estimates of direct, semi and indirect effects over the case studies, over the two domains and with and without the convective parameterization on the 5km domain. This has resulted in the development of the figures 3, 4, and 5 included at the end of this document, which will be inserted into the manuscript replacing the radiative balance figures 7, 9 and 10 as we believe this new analysis is easier to interpret. Details on how we carried out the calculations will be included in the appendix.

Our results from this new analysis are entirely consistent with our previous conclusions – namely that, for the case studies considered here, indirect effects are small relative to the dominant semi-direct effects. The semi-direct effect itself is highly sensitive to the convective parameterization and horizontal resolution of domain in question. However, being able to quantify the different effects substantially improves the quality of the study. The newly calculated numbers have also been inserted into to the abstract and conclusion.

We acknowledge that the limited domain size and duration of the study makes drawing general conclusions problematic. We now emphasise that the behaviour observed in this study is only indicative of the current case-studies, and caution should be used before generalizing our findings to other regions and events. The conclusions highlighted in the above comment (at 27466, l. 10-11 and p. 27467, l. 18-22 respectively) have had their language softened accordingly:

"For the limited case-studies considered in this paper, SW↓ Sfc is lower in the FE scenario, but the net forcing is less consistent and of smaller magnitude. The general reduction in cloud cover in the FE scenario adds a semi-direct warming effect which acts counter to the direct cooling of the aerosol, largely cancelling out any net impact."

"Overall, we find that net RB is more sensitive to whether or not a convective parameterisation is used than it is to the presence of aerosol or the horizontal resolution in the current case studies. The diurnally averaged reduction in RB of

approximately 20Wm−2 between scenarios with and without convective parameterisation (Table S2 in the Supplement) is largely due a result of the reduction in nighttime clouds in the runs without convective parameterization"

We believe the developments enabling double radiation calls for this further analysis are a valuable tool for analysing impacts of aerosol. We would be interested in feeding these code developments back to be released in future WRF-Chem versions so it may be used in further studies.

While the introduction and model description sections are well referenced, the results section contains very little comparison and reference to other work (with the exception of Zhang et al., 2008). Several papers deal with the impact of biomass burning aerosols on meteorology and radiative forcing so this could easily be added. What about other regions, either of Amazonia, or in other biomass burning regions such as central and southern Africa, or Indonesia? Have similar or different results been found there? E.g., the result that fire aerosols stabilize the atmosphere and inhibits convection and cloud formation (p. 27465, l. 20-22) has also been found before, e.g., recently in tropical Africa (Tosca et al., 2015), and could be mentioned.

We acknowledge this issue and have added the following passage to the end of section 4.2:

"Similar effects have been found by other modeling studies investigating the impact of BBA over continental regions. For example, Zhang et al. (2008) found a peak negative clear-sky forcing of −8 W m−2 over the highest AOD region in the Amazon, but with reductions in cloud cover resulting in localised surface forcings as high as ≈ 22 W m−2 when changes to clouds were included. Tosca et al. (2013) found a global reduction in surface radiation of −1.3 Wm−2, but a local reduction of −9.1 Wm−2 over South America, reducing surface temperature and precipitation. Kolusu et al., (2015), also show reduced all-sky forcing magnitude compared to clear-sky, show a decrease in precipitation due to BBA over the same SAMBBA period using the Met Office Unified Model (MetUM). Similarly in Africa, BBA has been shown to inhibit convection and cloud formation (Sakaeda et al., 2011, Tosca et al., 2015)."

The paper does not include any estimation of uncertainties in the results (except in the Supplement), but a statement that many of the results are not statistically significant (p. 27471, l. 23-25). In my view, it would still be useful to include some estimation of uncertainties. Including statistical significance based on a Student's t-test or similar could be useful when interpreting the results, and give the reader an idea of which results are robust and which are not.

Need to follow up with Dave's suggestion of statistically significant difference in distribution of key variables – need to work out which variables will be most interesting for this… While the authors agree that an estimation of the statistical uncertainties of results would be useful, the small size of domain and short runtimes, necessitated due to the high cost of running the model, make doing so *challenging. From review of the literature, the authors found no standard way to calculate uncertainty for small domains. A common technique is to carry out a student-t test on every grid point on a difference plot, and only show those results with p values greater than 0.95. Using this method for the short runs in our study results in no significant grid-points – we would need to run for much longer periods to have a chance of passing a significance test. Note this does not necessarily mean the results are not important or of consequence, just that we cannot be sure of their robustness and so should avoid drawing general conclusions.*

However, it is still possible to show uncertainty related to domain averaged values. To do this, we have followed a similar methodology to Kolosu et al. (2016). The standard error (SE) is traditionally calculated by dividing the standard deviation by the square root of the number of data points. This method implicitly assumes all data points are independent, which is not the case for the grid points of a model run, where most variables show strong spatial and temporal autocorrelation. Assuming independence results in an erroneously small SE, and therefore too high a significance. We therefore apply a correction factor k (Bence 1995):

$$SE = \frac{SD}{\sqrt{N}}k \qquad 1.$$

where;

$$k = \frac{\sqrt{1+\rho}}{\sqrt{1-\rho}} \qquad 2.$$

and ρ is the autocorrelation factor, varying from -1 (perfect anti-correlation) to 1 (perfect correlation). For all the variables we applied this method to ρ was positive, so the correction acted to increase the SE relative to if we assumed all points were independent. We estimate spatial autocorrelation using the Moran's-I for neighbouring points. While the authors believe this method is valid for averages over the 5km domain, caution is advised over the 1km. The 1km domain region is small, and the region of the 5km domain it covers is not representative of the whole domain. As it is very sensitive to boundary conditions from the 5km domain, chaotic variation in cloud fields can create anomalous strong signals in the 1km domain. The 1km domain would need to be made larger and run for longer to filter out these systematic errors.

For presenting precipitation results, we have shown histograms of the data. In order to compare with TRMM data, the model fields were averaged over 25km boxes (~0.25 degrees) prior to analysis. Significant differences between model scenarios were identified using the Kolmogorov-Smirmov test. An example of this analysis is presented in response to the comment on P. 27466, l. 22-26.

P. 27459, l. 28 – p. 27460, l. 2: Do the authors have an idea of how big of an impact this has on the results presented for the 5 km domain?

We tried to investigate this in the study. To test it directly would require two versions of the same convective parameterisation, one with aerosol interactions and one without. As this was not available at the time of study, we ran simulations with and without convective parameterisation and at higher resolution – the sensitivity study presented in the paper. Making these changes caused such a large difference to the cloud fields in the study, indirect effects from aerosol-cloud *interactions were buried underneath the resultant noise. This finding is one of the main conclusions of the study. The new double-radiation call analysis further supports this statement and we emphasise this point more strongly in the abstract and conclusions section. The low magnitude of indirect effects found makes the authors believe that no, the inclusion of cloud-aerosol interactions in the model would not have a large impact to the simulations (in the case studies considered here).*

P. 27466, l. 22-26: I am not sure this assumption and statement can be made without any observations showing that the results are more realistic in the 1 km domain.

Figures of precipitation from the 5km and 1km domain, from the FE and FE_nocu scenarios, during the time of peak precipitation (20:00-21:00 UTC) on 18 September 2012 are included below, with equivalent figure (or close as can be managed) from the TRMM 3B42 satellite product. The small size of the domain and coarse resolution of the TRMM product (0.25 degrees) makes direct comparison difficult. However, it is clear from the TRMM product that precipitation occurs in intense, tight convective cells. In the 5km domain with convective parameterisation, this structure is not well represented, instead there is large areal coverage of light precipitation. In the 1km domain, and in the nocu scenarios, these tight convective cells are seen in the model output, with corresponding lower domain cloud-coverage. The total precipitation in the FE_nocu scenario is substantially reduced.

These figures will be included in the paper in the section on impact of convective parameterisation, along with the following discussion:

"Peak precipitation rates (which occur between 20:00 – 21:00 UTC) in the afternoon of 18 September for the FE and FE_nocu scenarios, with similar figure from the TRMM 3B42 product, are shown in Figure 1. Although the TRMM product is coarse (with a resolution of 0.25 degrees), precipitation can, nonetheless, be seen to occur in small convective cells. In the FE scenario, precipitation less intense and covers a larger area, whereas in the 1km domain and FE_nocu scenario, precipitation follows a more cellular structure with a greater portion of the domain receiving no precipitation. The FE scenario correspondingly has a larger portion of the domain covered by cloud at any one time. However, total precipitation over both domains is greater in the FE scenario than the FE_nocu scenario."

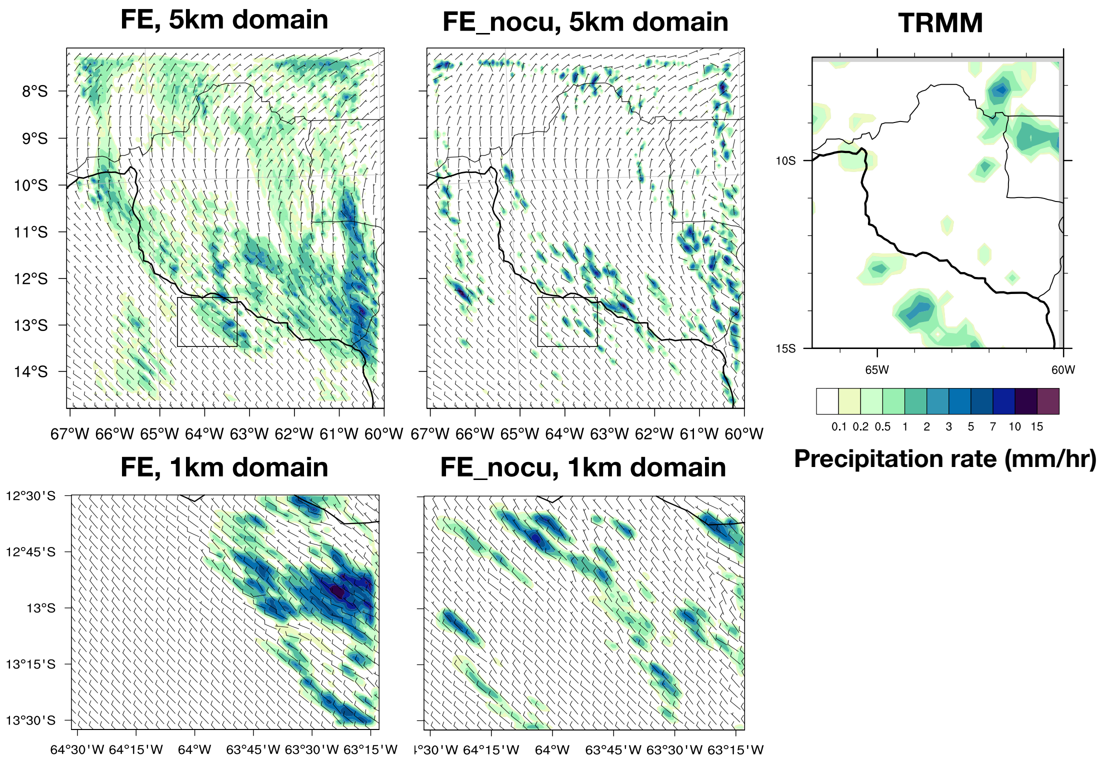

Figure 1. Precipitation rates between 20:00 and 21:00UTC on 18 September, 2012 across 5km (top) and 1km (bottom) domains from FE (left) and FE_nocu scenarios. Precipitation rate from TRMM 3B42 product between 18:00 and 21:00 on 18 September 2012.

We have also presented the precipitation as a bar-chart in Figure 2, which shows how the distribution of precipitation frequency changes between scenarios. For this comparison, the model data was averaged over a 25km grid to be of roughly the same resolution as the TRMM data. In the FE scenario, most grid cells contain at least some precipitation, whereas the TRMM dataset shows most cells with no precipitation. The scenario with no convective parameterization follows a closer distribution to the TRMM dataset, with more cells receiving little to no precipitation and a greater portion of total precipitation from a few cells with high precipitation. The average precipitation over the whole domain on 18 September is 2.30mm, 1.43mm and 1.49mm for the FE, FE_nocu and TRMM datasets respectively. Thus the nocu case preforms better for both precipitation distribution and total magnitude over the region for this case study.

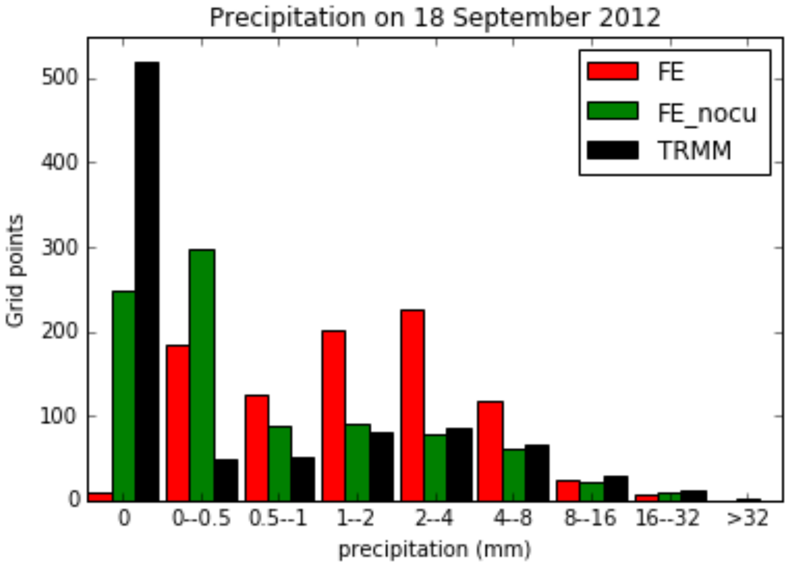

Figure 2. Bar-chart of precipitation on each grid cell over the 5km domain from FE, FE_nocu scenarios and TRMM 3B42 product.

P. 27470, l. 26-28: Again, how can this conclusion be made without comparison to observations?

We believe that our reply to the referee's previous question answers this question too.

Minor comments/corrections:

P. 27454, l. 1: This -> The

Changed accordingly.

P. 27459, l. 11: caries -> carries

Changed.

P. 27462, l. 17-28: The aerosol loadings are mentioned several times, but this is not shown in Fig. 2. Perhaps add reference to Fig. 3 in this paragraph?

Added reference to Fig 3 at end of line 20:

"Extensive fire emissions and minimal precipitation over the region between 10 and 14 September result in high modelled aerosol loadings (see Fig 3.)"

P. 27469, l. 27: subsistence -> subsidence

Changed

P. 27471, l. 20-21: This is an interesting finding and could be made more clear in the abstract?

The authors thank the reviewer for drawing more attention to this. We agree this is an interesting finding, and have emphasized it in the abstract accordingly.

P. 27472, l. 19: Remove "to the" after "includes".

Changed.

P. 27487, l. 3: Scenrios -> Scenarios

Changed

P. 27489, l. 2: averaged -> accumulated

Changed

References:

Bence, J. R.: Analysis of short time series: correcting for autocorrelation, Ecology, 76, 628–639, doi:10.2307/1941218, 1995.

Ghan, S. J., Liu, X., Easter, R. C., Zaveri, R., Rasch, P. J., Yoon, J. H., and Eaton, B.: Toward a Minimal Representation of Aerosols in Climate Models: Comparative Decomposition of Aerosol Direct, Semidirect, and Indirect Radiative Forcing, J. Clim., 25, 19, 6461-6476, 10.1175/jcli-d-11-00650.1, 2012.

Kolusu, S. R., Marsham, J. H., Mulcahy, J., Johnson, B., Dunning, C., Bush, M., & Spracklen, D. V. (2015). Impacts of Amazonia biomass burning aerosols assessed from short-range weather forecasts. *Atmospheric Chemistry and Physics*, *15*(21), 12251–12266. http://doi.org/10.5194/acp-15-12251-2015

Tosca, M. G., Diner, D. J., Garay, M. J., and Kalashnikova, O. V.: Human-caused fires limit convection in tropical Africa: First temporal observations and attribution, Geophys. Res. Lett., 42, 15, 6492-6501, 10.1002/2015gl065063, 2015.

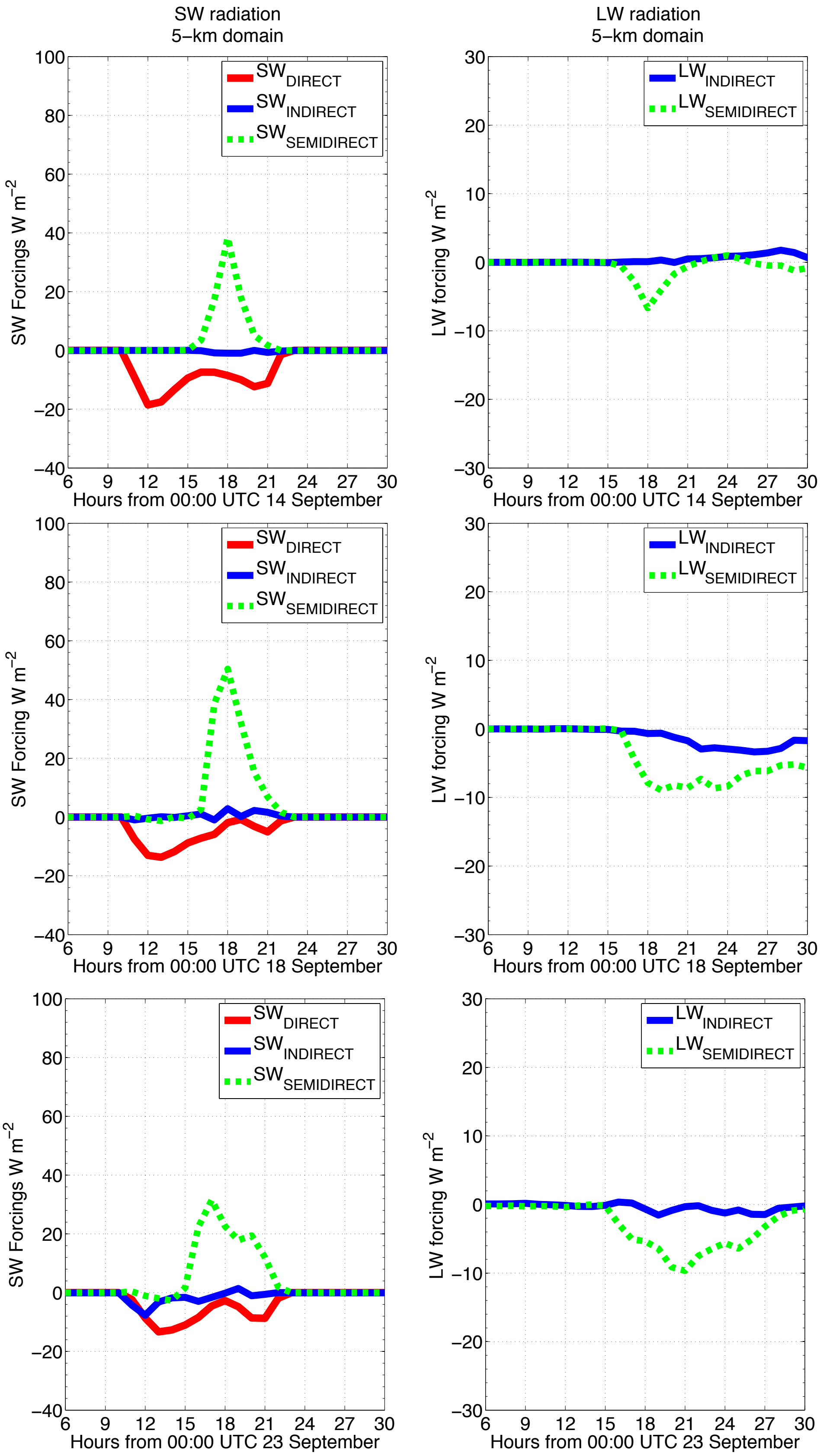

Figure 3.Estimates of short-wave (left) and longwave (right) direct, indirect and semi-direct effects over 5km domain for scenarios using convective parameterisation on 5km domain on 14 (top), 18 (middle) and 23 (bottom) September.

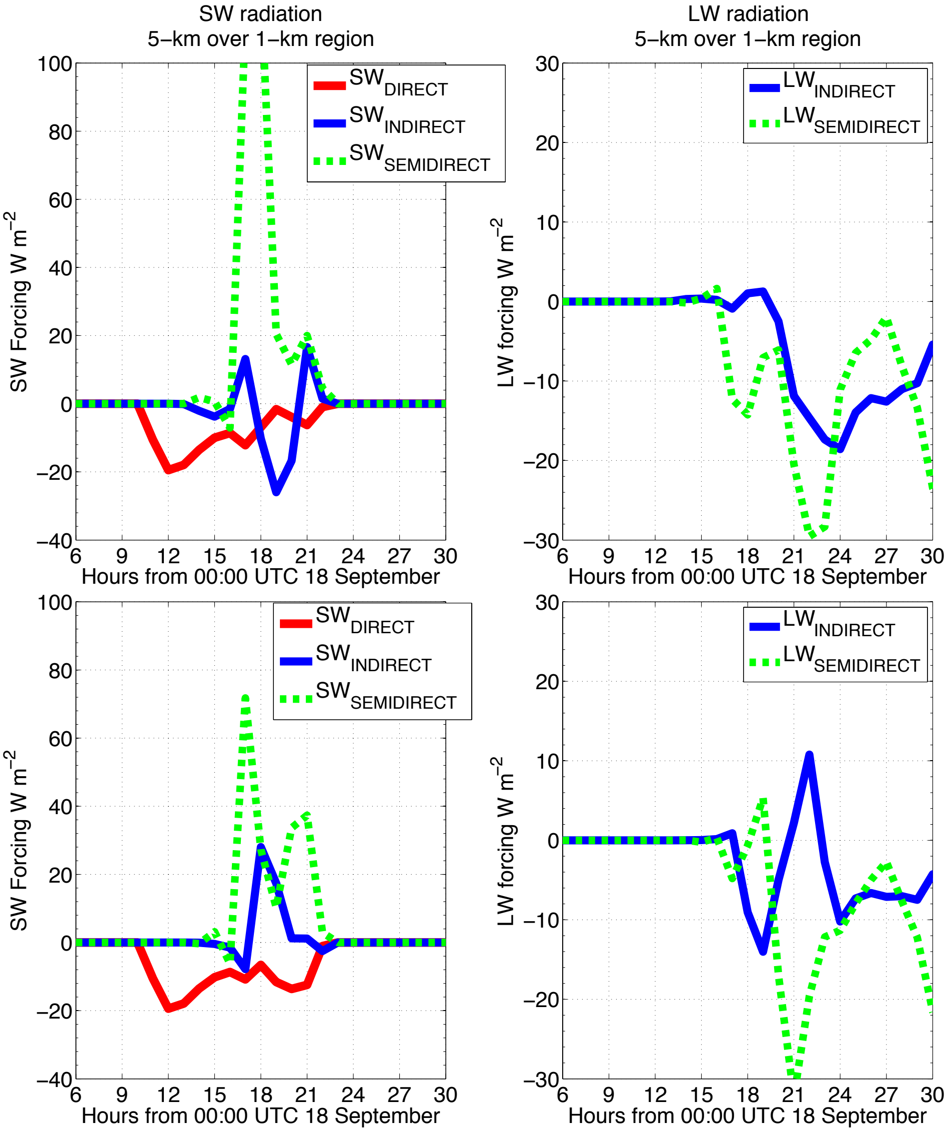

Figure 4. Estimates of direct, indirect and semi-direct effects on 18 September, 2012 from the 5km domain over the 1km domain region (top) and in the 1km domain (bottom).

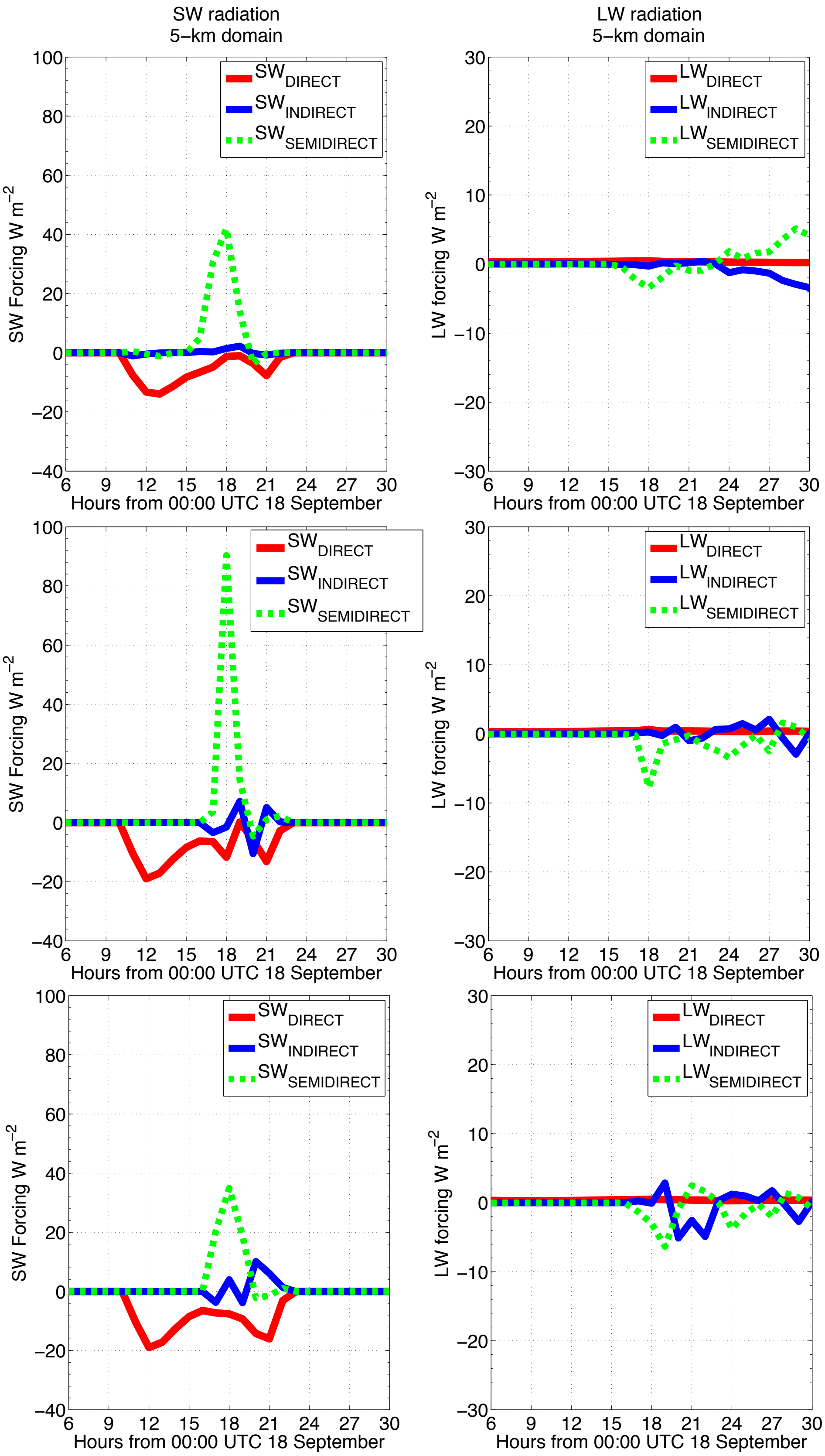

Figure 5. Estimates of direct, indirect and semidirect effect from scenarios with no convective parameterisation on the 5km domain on 18 September 2012. Over whole of 5km domain (top), 1km region of the 5km domain (middle) and 1km domain (bottom).