

Interactive comment on “A coupled atmosphere and multi-layer land surface model for improving heavy rainfall simulation” by M. Haggag et al.

M. Haggag et al.

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As authors, we would like to thank the anonymous reviewers for their constructive comments on the manuscript to provide valuable and exciting discussion of our paper. Their meaningful comments will be useful to improve the manuscript allowing us to further clarify the aims of our paper. The comments provided a basis for making some revisions to the manuscript. We are currently working on these revisions, and will submit a revised manuscript within the coming 1 or 2 months. Below we explain the general changes we will make to the manuscript with our correspondence to the specific comments raised by the reviewers that will be integrated in the revised version of the paper.

The general comment raised by the reviewers requires additional analysis regarding the different models initialization and the inclusion of other meteorological observa-

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tions rather than precipitation to present stronger evidences to convince the readers of the paper's contents. The authors believe that such modifications are requiring neither profound shift in the main aim nor major changes to the structure of the paper. A more detailed discussion of the difference in physics between the different LSM incorporated in this paper will be added in section 2.2. A new sub-section that present the models initialization will be added under Section 5. The additional analysis with other meteorological observation will be merged in the current discussion of soil temperature and soil moisture results.

Anonymous Referee no. 2 Specific comments:

1) Title

After both reviewers suggested a different title of the paper to reflect that two existing models are coupled and applied to a case study in the paper, the authors have already decided to select an alternative title to be used in the revised version of the manuscript; however, the title is not yet decided.

2) Page 1075: Model setup. How was soil moisture initialized in the model?

An appropriate initialization of soil moisture in coupled regional/mesoscale models is restricted by the fact that there are no routine soil moisture observations. Recent observations based on aircraft and satellite data can help regarding to this issue (Taylor and Ellis, 2006, Taylor et al., 2007), however it is still important to use a reliable observations to examine the quality and accuracy of such remote sensing procedures. Because of the scarcity of routine soil moisture observations, the initialization of the LSM mostly depend on soil moisture fields obtained from analysis/forecasts from other models. In this manuscript, the lower boundary condition represented in the land surface's heat/moisture fluxes are coming from three different land surface parameterizations. In the following, the soil moisture initialization procedures for each of the LSMs implemented in this manuscript will be described:

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a. First, NOAH LSM (MM5-NOAH): NOAH LSM is capable of predicting soil moisture and temperature in four layers (10, 30, 60 and 100 cm thick). In the current MM5-NOAH, the initial soil moisture/temperature can be obtained from several global forecast/analysis systems, because a similar LSM is used in these systems and the soil moisture fields are compatible to the MM5-NOAH with regard to its dynamic range (e.g. JRA-25 from Japan Meteorological Agency, Onogi et al., 2007; ERA-15 and ERA-40 from ECMWF, Uppala et al., 2005; NCEP-NCAR and NCEP's Final Analyses from National Center for Atmospheric Research, Kalnay et al., 1996). In the current MM5-NOAH, the initial soil moisture is obtained from NCEP Final Analysis (FNL) corresponding to 00 UTC of 20 July, 2006. The reanalysis volumetric soil moisture and soil temperature fields are available for four soil layers, 0-10, 10-40, 40-100, and 100-200 cm, and are used directly without any interpolation to the four soil layers in the MM5-NOAH.

b. Second, the simple LSM (Blackadar, 1976) with five soil layers used in the control run (MM5-CTRL). This model calculates the soil temperature in 1, 2, 4, 8, and 16 cm thick layers with a fixed substrate below based on the vertical diffusion of heat. It resolves the diurnal temperature variation in the soil. The initial conditions for the soil temperature have been interpolated from NCEP-FNL data available at 1 x1 degree resolution corresponding to 00 UTC of 20 July, 2006.

c. Third, SOLVEG LSM fully coupled to MM5 model (MM5-CPL). The soil sub-model in SOLVEG had seven layers with boundary depths of 2, 5, 10, 20, 50, 100, and 200 cm, respectively. As explained in the manuscript in Page1073 L21-25 and explained in Figure 1, MM5 sends the initialization states to SOLVEG including initial soil moisture (SM), and bottom soil temperature (TB). As for the case of NOAH LSM, the initial soil moisture and the bottom temperature are obtained from NCEP Final Analysis (FNL). In the soil sub-model of SOLVEG, the bottom layer's (100-200 cm) temperature is kept constant throughout the computation, and the initial soil temperature profile at each grid location is made by interpolation between the surface soil temperature (NCEP-FNL air

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temperature near the soil surface) and the bottom soil temperature. SOLVEG's initial soil moisture at each grid location had a homogeneous distribution of NCEP-FNL first 10-cm depth soil layer's moisture.

Regarding the reviewer's inquiry about impacts of the choice of initialization for the results, in this paper the authors did not engage with sensitivity analysis to check the influence of uncertainty in the initial soil moisture and its impacts on the spatial and temporal variations in latent and sensible heat fluxes. The existing literature of NOAH and SOLVEG LSMs had already dealt with the sensitivity analysis of soil moisture initialization on models performance. Nagai (2002) performed a sensitivity analysis to evaluate the performance of SOLVEG LSM setting on the surface fluxes. He found that the influence of the uncertainty in the initial soil moisture mainly affected the sensible and latent heat fluxes, but without significance as a whole. Chen and Dudhia (2001 a) demonstrated the sensitivity of the coupled MM5 to NOAH LSM to the initial soil moisture fields. They also showed that partitioning of surface radiation forcing into latent and sensible heat fluxes are significantly influenced by the initial soil moisture fields, especially in arid and semi-arid climatic regions. As for the last part of the reviewer's comment, it is shown in detail in the above discussion that no spin-up performed for to reach initial soil fields for the different models setting. In fact, within this paper, the authors did not think about spin-up as a mean to obtain reliable soil moisture initialization fields because of the scarcity of meteorological observations on regional scale needed to drive a LSM in offline mode to simulate long-term evolution of soil moisture. However for future studies, the spin-up procedure can be performed by using the output of global forecast/analysis systems data to run any LSM in an offline mode to looping repeatedly through a single year until a desired level of equilibrium in soil moisture is achieved.

3) Page 1077, Line 14. Does this feedback really exist? Higher ground temperatures do heat up the surface layer air (only if this is higher than the surface temp!), but this also leads to a heat transport from the soil to the atmosphere (and thus cooling of the

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surface). This suggests a link with radiation differences between the model runs, which result in surface temperature differences.

The reviewer commented our statement in the manuscript P1077L14 that states "SOLVEG has tendency to produce higher ground temperature than the slab land surface model or the NOAH LSM. The higher ground temperature heats up the surface layer air, and the higher air temperature causes further rise in ground temperature". However, there are no technical errors in the statement based on reviewer response; the authors agree with the reviewer that this point was not investigated in enough detail through the manuscript. In P1077L3-14, SOLVEG tendency to produce higher ground temperature was explained by SOLVEG's advanced radiation and stomatal resistance schemes. The treatment of the radiation processes and canopy resistance differ profoundly among the different models used in this study. The radiation scheme of SOLVEG calculates the radiation transmission in the canopy by separately treating the four solar radiation components (visible and near-infrared bands in direct and diffuse components). By this scheme, the observed albedo can be better simulated which is necessary for the energy balance at the ground surface, (Nagai, 2003). This scheme enables the utilization of stomatal resistance schemes based on the leaf photosynthesis. The stomatal resistance scheme is not only used to determine the stomatal resistance but also to calculate CO₂ exchange between vegetation and the atmosphere. In NOAH LSM, a simpler radiation schemes is implemented in which the solar and long-wave radiation fluxes are dealt with as isotropic downward and upward fluxes without spectral dependency of radiation assumed. The Jarvis type scheme is implemented in NOAH LSM to calculate the stomatal resistance from the solar radiation flux following Deardorff (1978). No doubt that the radiation transmission in canopy is more realistically parameterized in SOLVEG rather than NOAH. The study by DePury and Farquhar (1997) showed the importance of the separate treatment of direct and diffuse components of visible solar radiation flux for the photosynthesis and energy balance calculation. The effectiveness of photosynthesis based schemes compared to a Jarvis-type scheme is discussed by Niyogi and Raman (1997). The changes of the radiation

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and stomatal resistance schemes affect the latent and sensible heat fluxes that are reflected in different ground temperature pattern among the different models.

4) Page 1081, Line 14. Can slightly higher soil temperature really impact the upper model layers? The heat capacity of the soil is limited, so any heat transport to the atmosphere will in turn lead to a decrease in surface temperature. Differences in soil temperature can only be sustained by differences in air temperature or radiation, non of which is investigated in the paper.

This comment and the previous one are almost dealing with the same problem of the mechanism of the higher ground temperature computed by the SOLVEG in the MM5-CPL compared with the ground temperature in MM5-NOAH and MM5-CTRL. The authors agree with the reviewer this point needs more analysis and clarification to be placed in the manuscript. As for the time this was not done in a complete manners, the authors will engage with this point in the revised version of the manuscript.

5) Page 1083, Line 22. It is not shown that the MOST profound differences are in the rainfall, but only that the differences in rainfall are profound.

The authors agree with the reviewer's statement that only the differences in rainfall are profound. The analysis of the simulation results depended principally on the difference of rainfall results among different model configurations (MM5 with the slab LSM, MM5 with the NOAH LSM, and MM5 with SOLVEG LSM). This is because authors believe that rainfall depends strongly on the atmospheric motion, moisture content, and physical processes, and the quality of a model's rainfall simulation can be used as an indicator of the overall model health (P1076L6-10). Moreover, the availability of dense network of rainfall observations on the study area supported the analysis to be focused on rainfall results.

6) Page 1068, line 2: "represent better"

Correction: "better represent"

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7) Page 1068, line 5: Earth

Correction:

8) Page 1068, line 18/19: "This paper clearly shows"

Correction: "This paper shows"

9) Page 1069, Line 20: It is not the parameters that are exchanged, but rather the fluxes.

Correction: Page 1069, Line 20 should be "in two-way coupling, models exchange the relevant moisture and heat fluxes".

10) Page 1070, Line 4: TOPMODEL is a concept or framework rather than a complete hydrological model. The correct reference is to Beven and Kirkby, 1979.

Correction: We fully agree with the reviewer that the TOPMODEL (Beven and Kirkby 1979) is a framework and approach for the formulation of the subsurface hydrologic behavior and the spatial variability in soil moisture. In the introduction section Page 1070, Line 3, the correction will be "Seuffert et al. (2002) coupled the LM model (Doms and Schattler, 1999) and the land surface hydrologic model known as the the "TOPMODEL"-Based Land Surface Atmosphere Transfer Scheme (TOPLATS; Famiglietti et al. 1992; Peters-Lidard et al. 1997) in a two way-coupling to study the Influence of hydrologic modeling on the predicted local weather".

11) Page 1073, Line 21: again states, or fluxes, rather than parameters.

Correction: The authors are apologizing for such kind of repeated inappropriate choice of terms within the manuscript; probably some of the English is a little awkward, because of the nativeness of the main author. Page 1073, Line 21-22 should be "At the first time step, MM5 sends the initialization states to SOLVEG". The manuscript will be proof-read again by the authors and probably by native English speakers before the submission of the final revised manuscript.

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12) Page 1077, Line 7: "SOLEVEG"

Correction: "SOLVEG"

13)Page 1078, Line 19: "On the contrary to"

Correction: "In contrast to... "

14) Page 1082, Line 23: "state of the art"

Correction: "state-of-the-art"

15) Figures: The color bars are very small; sometimes i had to look twice to see that in fact they were not missing!

These authors agree with the reviewer that some figures are not clear enough, especially the colors bars in Figure 3 and Figure 5. Such figures will be edited for more visibility and clearness in the revised version of the manuscript.

Anonymous Referee no. 3 Specific comments

1) The title

Refer to the correspondence of the comment (1) by the anonymous reviewer no. 2.

2) Contour labels on Figures 6 and 7 are too small, axis scale and title fonts on figures 2, 3 and 5 are too small, and color bar on Figure 3 is too small.

These authors agree with the reviewer that some figures are not clear enough, especially the colors bars in Figure 3 and Figure 5, the axis scale and title fonts on figures 2, 3. Such figures will be edited for more visibility and clearness in the revised version of the manuscript.

3) Page 1069, line 20: states, not parameters Refer to the correspondence of the comment (9) by the anonymous reviewer no. 2.

4) Page 1072, line 13: Why is MM5 used rather than WRF?

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The models combination introduced in this study are representing the atmosphere land surface interaction part of a comprehensive Atmosphere-Ocean-Land-Surface-Hydrology coupled model known as ASIA ENVIRONMENTAL SIMULATOR (AES). Haggag and Yamashita (2008) defined AES as a coupled system of computer simulation for meteorology, physical oceanography, land surface, vegetation, hydrology, coastal dynamics, and urban environment. For the time being, PSU/NCAR-MM5 model (Dudhia, 1993) is used as the atmospheric circulation model in AES because of its extensive prior validation and wide range of users worldwide. Weather Research and Forecasting model (WRF) has an advanced research core version (Skamarock et al. 2005) that is designed as the next generation model after the PSU/NCAR-MM5. One of the big differences between WRF and MM5 is that the dynamical core of WRF uses high-order accurate discretization schemes for time and space: third-order Runge-Kutta scheme for the time integration, and second to sixth-order schemes for the advection terms. Another is that new microphysics schemes are developed and incorporated into WRF. Nowadays, many current MM5 users are shifting to use WRF for simulation of atmospheric circulation. In the near future the AES will be improved such that WRF will be used as the atmospheric circulation model following the worldwide trend in shifting to WRF, and to make use of WRF's potential advantages compared with MM5.

5) Page 1072, line 19: Noah is also multi-layered

NOAH is one of the land surface models that represent soil as multilayer and deal with canopy as one layer (Deardorff 1978; Sellers et al. 1986; Dickinson et al. 1993). The objectives of these models are mainly in the improvement of bottom boundary condition of the atmospheric models by accurately evaluating the ground-surface impact on the atmosphere. While multilayer representation is used for the soil, considering the importance of influences due to soil moisture and heat capacity, rather simple representation is preferred for the vegetation, considering the computational constraint and the difficulty of specifying model parameters of vegetation in practical use.

SOLVEG is designed to simulate processes in the atmosphere-soil-vegetation system in a more realistic way than do other land surface models by using multilayer expression for the atmosphere, soil, and vegetation and avoiding uncertain parameterizations as far as possible. SOLVEG consists of multilayer submodels for the atmosphere, soil, and vegetation and radiation transmission schemes in the canopy layer. SOLVEG is intended for studies to understand the ground-surface processes and to design better parameterizations for the ground-surface (soil-canopy) boundary conditions of atmospheric models.

6) Page 1074, line 3-5: This sentence is confusing, and unnecessary. The authors agree with the reviewer that this sentence is unnecessary, but about being confusing, this is not clear to the authors. As both authors and reviewer agree that this sentence is unnecessary, it will be omitted in the revised version of the manuscript without affecting the meaning.

7) Page 1074, line 20: From Figure 1, these are not "arbitrary" time intervals.

The numerical stability condition in MM5 requires the maximum step not to exceed 3 times the maximum grid distance. Since we used a grid distance of 27 km, the maximum time step should be less than 81 sec. In all of the numerical experiment we used a time step of 60 sec for MM5 computation (same as shown in Figure 1). The time step of SOLVEG calculation is usually smaller than that of MM5, and several time steps are carried out for SOLVEG calculation during a single time step of MM5 calculation. For SOLVEG calculation we used a time step of 20 sec (same as in Figure 1) such that during one time step of MM5, SOLVEG execute 3 time steps. The time steps shown in Figure 1 are the exact time steps used in the numerical experiments.

8) Page 1075, line 7: What time/date was the model initialized? Are the soil layers the same in the models and initial conditions data? Can a map be provided of initial conditions, e.g. in Figures 3 and 4?

The computations were initialized at 00 UTC of 20 July in 2006 for a simulation time of

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6 days the ended at 23 UTC of 26 July in 2006. Regarding the soil layers setting and the initialization of different model, Refer to the correspondence of the comment (2) by the anonymous reviewer no. 2 in which a detailed discussion about model initialization can be found.

As for the reviewer's inquiry about whether can a map of initial conditions be provided, e.g. in Figures 3 and 4? For the time being the current manuscript does not provide adequate discussion and analysis of the different models initialization and its effects on models performance. Following the recommendation of the reviewers, this point will be investigated and added to the revised version of the manuscript.

9) Page 1075, lines 9-14: This belongs in Section 4

The authors agree with the reviewer's opinion that this paragraph describing briefly the model initialization is best suited in section 4 that deals with a description of the different numerical experiments. In fact, P1075L7-14 should belong to section 4; this will be managed in the revised version of the manuscript.

10) Page 1075, line 11: Rainfall observations from ...

Rainfall observation from JMA's Automated Meteorological Data Acquisition System (AMeDAS) stations are used in the model validation. JMA is an abbreviation of Japan Meteorological Agency, P1075L9. AMeDAS is an abbreviation of Automated Meteorological Data Acquisition System that is a high-resolution surface observation network developed by JMA and used for gathering regional weather data. The system consists of about 1,300 stations with automatic observation equipment. These stations, of which more than 1,100 are unmanned, are located at an average interval of 17 km throughout Japan, (<http://en.wikipedia.org/wiki/AMeDAS>).

11) Page 1076, line 18-19: "By comparing the results of each case, the ground temperatures reveal patterns similar to the soil moistures". This is not obvious from Figures 3 and 4.

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The authors mean that there is an inverse relationship between soil temperature and soil moisture that can be noticed from Figures 3 and 4. Figure 4 shows one-day soil moisture of MM5-NOAH and MM5-CPL in 22 July. At the noon time, the southern part of Kyushu Island had higher soil moisture distribution compared to the northern part of the Island. From Figure 3 at the noon time of July 22, we can notice the vice versa in the soil temperature distribution, the southern part had lower temperature compared to the northern part of the Island. If soil moisture distribution figures in other days were given, this inverse relation with the soil temperature would be clearer.

12) Page 1076, line 22-24: "This pattern of ground temperature can be seen as footprint of the produced rainfall by each model and its corresponding soil moisture variability". This is not obvious to me.

This comment is a continuation of the previous comment. From the results shown in the manuscript, the soil moisture and soil temperature distribution are highly affected by the rainfall. Figure 7 shows that in 20 July, heavy rainfall band (200-600 mm) bounded between (32.5 deg. N to 33.5 deg. N) is reproduced by the MM5-CTRL and MM5-NOAH with higher intensities in MM5-NOAH, this heavy rainfall band can be seen neither in the AMeDAS observations nor in MM5-CPL. This resulted in lower soil temperature and higher soil moisture to be calculated at the north of Kyushu Island in the case of MM5-NOAH compared to MM5-CPL. In 22 July, heavy rainfall (200-500 mm) is observed in the location of (130.5 deg. E, 32 deg. N). MM5-CPL captured this event, while it cannot be reproduced by MM5-CTRL or MM5-NOAH. This resulted in lower soil temperature and higher soil moisture to be calculated at the south of Kyushu Island in the case of MM5-CPL compared to MM5-NOAH. Based on this discussion the authors stated that the distribution pattern of ground temperature can be seen as footprint of the produced rainfall by each model and its corresponding soil moisture variability.

13) Page 1077, line 7: SOLVEG Correction: "SOLVEG"

14) Page 1078, line 9: "The plots show ... ". Please give figure numbers,

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Correction: "Figure 4 shows".

15) Page 1079, line 23: "goal" or "aim" rather than target?

Correction: I would prefer to use "goal" instead of "target".

16) Page 1082, lines 18 and 19. Where are these numbers in Table 2?

Table 2 summarizes the different statistical measures of the cumulative observed and computed rainfall for the different model configurations from 00 UTC of 20 July to 23 UTC of 26 July in 2006. The ranges of the correlation coefficient (r) stated in P1082L-18-19 are representing the values of r calculated for each single-day cumulative rainfall, and for the 6-days cumulative rainfall. The lower boundary of each range is reflecting a single-day correlation coefficient that is not given in Table 2, while the upper boundary of the range is reflecting the 6-days correlation coefficient that is given in Table 2. For example, P1082L19-20 shows that the correlation coefficient in the case of MM5-CPL and JMA-GPV ranges from 0.65 to 0.95, the 0.65 is a single-day correlation coefficient that is not shown in Table 2, while 0.95 is the 6-days correlation coefficient between JMA-GPV computed rainfall and the observed rainfall that is given in Table 2.

17) Page 1081, line 26: Provide some references for past studies ...

Several studies have suggested that mesoscale models run at high resolution can realistically predict precipitation structures over complex terrain. Example of previous studies include (e.g. Chang et al., 2008; Colle et al., 1999; Das, 2002; Hart et al., 2005; Leung and Qian, 2003; Riphagen et al., 2002... etc). The text in P1081L26 will be edited to include examples of previous studies that support the statement.

18) Section 5.4 belongs on page 1080, around line 15 as it demonstrates that MM5_CPL performs best in terms of reproducing the precipitation.

The authors agree with the reviewer that section 5.4 should be merged in section 5.3 before line 15. Section 5.4 presents a statistical summary that shows the superiority of MM5-CPL compared to other models configurations. This should be pasted after

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rainfall results comparison given in section 5.3, and before starting the discussion of the mechanisms for the improvement achieved by using MM5-CPL.

19) Page 1083, lines 11 and 12: "Improved simulation" implies that the quantity has been compared to observations ...

The reviewer commented the sentence in P1083L11-12 that states "The improved simulation of soil moisture fields in conjunction with improved simulation of the surface temperature leads to better computation of energy fluxes, and precipitation". It is shown in the manuscript that the computed rainfall from MM5-CPL reflects the observed rainfall much better compared to other model configurations. The authors believe that rainfall depends strongly on the atmospheric motion, moisture content, and physical processes, and the quality of a model's rainfall simulation can be used as an indicator of the overall model health (P1076L6-10). However, no observation rather than rainfall were used in the analysis, improvement in rainfall results reflect improvement in other meteorological fields. In the revised version of the manuscript, other observed parameters (e.g. air temperature and pressure) will be used to provide evidences on the reliability of the model computations.

20) Table 2: What observations are used as OBS here?

"OBS" here refers to the rainfall observations from Japan Meteorological Agency Automated Meteorological Data Acquisition System (AMeDAS) stations. A total of 165 meteorological stations are employed for the validation of the computed rainfall from the different model configurations, P1075L13. A map showing the station locations is shown in Figure 2a.

At the end of our response to the reviewers' comments, we will try to answer an important question that has been raised by the anonymous reviewer no. 2 that is what the readers can learn from this study besides that different model setups give different results. The models combination introduced in this study are representing the atmosphere land surface interaction part of a comprehensive Atmosphere-Ocean-Land-

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Surface-Hydrology coupled model known as ASIA ENVIRONMENTAL SIMULATOR (AES). Haggag and Yamashita (2008) defined AES as a coupled system of computer simulation for meteorology, physical oceanography, land surface, vegetation, hydrology, coastal dynamics, and urban environment (. Our main objective of AES is to make it as an effective environmental assessment tool for the integrated sustainable development plans in Asia and Africa. All the models included in AES to represent the different components of the earth environment have been used and validated extensively in the literature, but in isolation from other environmental processes. Our proposed scheme is to model the earth environment in unison to better represent the different feedbacks among the earth environment components and their ultimate influence on the properties of the whole system. In this paper, we want the reader to realize that we are neither developing a new atmospheric circulation model nor a new land surface model from scratch. But we can make use of the available state-of-the-art tools in different fields to build an integrated earth environment modeling system by introducing the feedbacks among the different environment components. The coupling scheme between MM5 and SOLVEG is just an example of what can be done to include many other processes in this proposed modeling system.

Finally, we thank the reviewers for contributing to the discussion of our paper. The reviewers' comments greatly added to the clarity of this manuscript. However, we apologize for any lack of clearness in the first version of the manuscript. After this deep revision, we hope that the reviewers and the editor in charge will find the revised manuscript of interest and value for the readers' community.

References

Apology: Because the maximum length for an author comment is limited to 15 pages, there is no enough space for the list of references.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 5, 1067, 2008.

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