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Biogeosciences Discussions



# *Interactive comment on* "Sensitivity and predictive uncertainty of the ACASA model at a spruce forest site" *by* K. Staudt et al.

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We would like to thank the anonymous referee #2 for the time and effort taken to review our manuscript. We will reply to the comments one by one, quoting the comments for convenience.

General Comments:

"The paper deals with a sensitivity and uncertainty estimation study of the ACASA model using the Generalized Uncertainty Estimation (GLUE) method. The ACASA model uses a third order turbulence closure scheme to concern higher moments of micro-turbulent exchange which are temporary relevant inside forest canopies. This approach is state-of-the-art, and so I recommend in principle to publish this paper.

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But some questions and “problems of understanding” should be clarified before a final publication of this paper (listed in the special comments below)."

"1. The authors discussed in the introduction the advantages of higher-order closure turbulence schemes in contrast to first order closure schemes based on K approach and flux gradient relationships. They substantiate this thesis by older citations. Referring to several new comparative papers (e.g., Pinard and Wilson, JAM, 2000) I must contradict this general statement. The advantage or disadvantage of the different closure schemes depends strongly on the quality of input data and the aim of turbulence simulations. The theoretical advantage of higher-order closure schemes (to simulate counter gradient fluxes, for example) is “given away” in practical applications, when, for example, time-averaged turbulent fluxes at a special forest site should be reproduced (as presented in the paper). In that case the large natural variability of crucial model input parameters, as for example drag coefficient (cd) and plant area densitity (pai), which are essential to parameterise the additional plant-specific source term in the basic equation of motion (cd*pai*u2, see, e.g., Meyers and Paw U, BLM, 1986, p. 301 or Wilson and Shaw, JAM, 1977, p. 1200), leads to uncertainties of simulated results. In the present paper the typical spectra of variability of pai in a forest is not adequately represented by the 5 measured profiles (Fig. 1). Furthermore, I miss any information about the quantity and variability of cd. These parameters were also not included in the GLUE method which was the main method applied by the authors. So, there exists an inadequacy between the complexity of the turbulence modelling and the quality of data input. Finally, it is difficult to discuss the results of uncertainties satisfyingly if the natural variability of essential model input parameters is not represented realistically."

The general aim of this investigation was to learn about model sensitivity to input parameters, to identify the most significant parameters of the model and to detect weaknesses in process representations within ACASA. In this paper the ACASA model was used ’as is’ and the GLUE methodology was applied to study the sensitivity of the fluxes to input parameter values and to assess the uncertainty for the model surface



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energy flux estimates. We have made two other investigations on the performance of the ACASA model which are more relevant to the discussion of the reviewer concerning the advantages and disadvantages of the type of model closure. One investigation compares model results on different levels in and above the canopy with eddy-covariance and sap flux measurements and also comprises the comparison to another SVAT-model which does not include a higher-order turbulence scheme (Staudt et al., 2010). A second investigation is in preparation about the comparison of profiles of first-, second- and third-order moments. A concatenation of these three papers would extend this paper in an undue way, because the first paper focuses more on plant physiological aspects and the second on turbulence aspects. We understand the present paper as a basis for these two papers. Therefore, it was not our aim in the current paper to establish completely the merits of applying a higher order closure schema, or to compare different schemata as well as the K-approach. A higher order closure model was chosen because of the strong influences of coherent structures up to 100% at night and about 20% on average on the energy exchange (Thomas and Foken, 2007a, b). Earlier investigations with a first order non local transilient schema (Berger et al., 2004; Inclan et al., 1996) have already demonstrated the benefit of non-local or non-K-approaches. In the revised manuscript, we will make the general aim of the paper more clear.

Furthermore, we will include the papers by Pinard and Wilson (2001) and Zeng and Takahashi (2000) in the literature overview in the introduction. Zeng and Takahashi (2000) presented the ability of a first-order closure model that also accounts for non-local transport within the canopy to predict profiles of wind speed and momentum stress within the canopy. Pinard and Wilson (2001) showed that a first-order closure model arrived at similar simulations of the fundamental wind properties within a canopy as a second-order closure model and questioned the theoretical superiority of a second-order model due to uncertainties of the drag coefficient in model applications.

Their study also points out that the drag coefficient cd and the PAI are crucial model parameters. Thus, these two parameters were also already included in the GLUE analysis presented here. Within the ACASA model, the drag coefficient cd is named drx (15th parameter in Table 2) and the variability of this parameter was chosen to cover the range found in literature for tall vegetation (references see Table 2). In our study, it was shown that the drag coefficient is an influential parameter for the sensible heat flux (Table 4) but not for the other fluxes (see page 4241, line 20-21). The LAI of the stand (first parameter in table 2) is also an essential parameter for the ACASA model that was varied in a range derived from spatial PAI measurements performed at our site. To avoid changes to the ACASA input routines, the measured PAI was converted to LAI and SAI using allometric relations from unpublished forest inventory data gathered during IOP-1 and IOP-2 and the relations between SAI and LAI used in ACASA. The ACASA model then re-calculates SAI from the LAI input, with PAI the sum of SAI and LAI. The LAI appeared to be an influential parameter for all studied fluxes (Table 4). Only the normalized LAI profile that needs to be provided for the 100 layer canopy used in the radiation calculations was held constant, as explained on page 4232, line 18, but not the total LAI of the stand. We will clarify this issue in our revised manuscript.

"2. A prominent disadvantage of models using higher-order closure turbulence schemes is the limitation of vertical model extension. Authors of early papers suppose a limit of about 100 meters, and the ACASA model has a vertical boundary (as typical for SVAT) of few multiples of vegetation height. This concept is working well as long as the SVAT is part (sub-model) of a meso- or large scale meteorological model (as, e.g., coupling of ACASA with MM5, Pyles et al., JAM, 2003). In this case there is an aerodynamic coupling to the complete atmospheric boundary layer and to the free atmosphere. In the presented paper the ACASA model is working “stand-alone” to reproduce turbulent fluxes at an experimental site. Because of the strong vertical limitation of ACASA a realistic aerodynamic coupling to the complete boundary layer, which is essential at a forest site (see, e.g., Pinty et al., Agformet 61 (1992) or Martin, Agformet 49 (1989)), cannot be reproduced. Because the measurements of turbulent fluxes include the effects of aerodynamic coupling, a methodical problem occurs when measurements and simulations are compared. Finally it was not clear what is the reason for the uncertainties: the variability of the 24 input parameters of ACASA, the insufficient inclusion of crucial input parameters of turbulence modelling (cd and pai) – or the insufficient description of aerodynamic coupling."

We used meteorological input data measured within the surface-layer to run the model. These meteorological input data, averaged over 30 minutes for each time step, already include the effects of aerodynamic coupling in a manner similar to that of the eddy-covariance measurements that were used for model evaluation. Therefore, the effects of aerodynamic coupling are included in the meteorological data used to force the model, effectively 'imitating' the proper methodology of coupling that would ordinarily occur in a meso-scale model. This method is not perfect, but the validity of using any surface-layer model that is steady-state in nature, regardless of closure order, is subject to the assumptions necessary for Reynolds-averaging. This includes acknowledging a temporal footprint of ∼30 minutes. Furthermore the stage of the atmospheric boundary layer was controlled by Sodar-RASS measurements. Thus, we believe that the reasons for the uncertainties do not result from the insufficient description of aerodynamic coupling. In addition, as described in the answer to comment 1, the crucial model parameters cd and pai were already included in this study.

"3. Regarding to more actual references I suggest a comparison of the ACASA simulations with simulations using a K approach (models with first order turbulence closure). In contrast to the remarks from the authors in this paper, models using a K approach do not must be worse “per se” in relation to models using higher order closure principles. This is especially the case when time-averaged fluxes are simulated for comparison with measurements above the canopy (e.g., half-hour means - as in the paper presented, see also Zeng and Takahashi, Agformet, 2000 or Pinard and Wilson, JAM, 2000). In this layer the flux-gradient relationship (FGRS) is valid in most cases, and the advantage of models using higher order closure schemes - to simulate fluxes against

FGRS – becomes less important."

"Referring to the remarks made in 1. to 3. a clear specification of advantages and disadvantages of the closure scheme used in ACASA, with focus to the model application in this paper, is recommended."

The analysis of the ACASA model 'as is' and its ability to simulate above-canopy fluxes for our site was the aim of the current paper. Thus, we did not intend to verify the higher order closure schema or to compare different models with different closure schemata. We would like to refer the reviewer to the study by Staudt et al. (2010) on evapotranspiration profiles within the canopy as modeled by ACASA compared to within-canopy eddy-covariance and sap flux measurements that also comprises a comparison to a second model (STANDFLUX) which does not include a higher-order closure turbulence scheme. Furthermore, because more sophisticated models are used for the energy exchange of forest sites, it would be a pleasure for us to support a model comparison project with the available data set of both EGER IOPs.

"4. Finally I miss clear statements to the uncertainties of measurements. One of the main problems in comparison of ACASA results and turbulence measurements is due to the fact that neither the ACASA model using third order turbulence closure scheme nor measurements using eddy covariance techniques can reproduce the complete turbulence spectra. So it could be assumed that one part of uncertainties is caused by the lack of information from the turbulence spectra. Of course, this problem is well known regarding to the measurements - but it should be discussed more detailed in the conclusions."

As uncertainty analysis for turbulent fluxes measured with the eddy-covariance technique we used the widely applied data quality analysis by Foken and Wichura (1996) in the version of Foken et al. (2004). This method gives the opportunity to determine for each time series (independent from another instrument or the conditions on another day) the data quality or in combination with the instrument type (Foken and Oncley,

1995) a quantitative accuracy (Mauder et al., 2006). We have combined our separated formulations on pages 4228 and 4243 to make this clearer. Thus, the accuracy of the eddy-covariance data measured with our sonic anemometer (USA 1 Metek GmbH, type B) after applying the quality scheme after Foken et al. (2004) and only considering flux data with a quality flag of 6 and better is 10% to 15% for the sensible heat flux and 15% to 20% for the latent heat flux and the NEE depending on the quality flag (Mauder et al., 2006). This accuracy was added to Figure 7 and Figure 8 (see below). We will include these measurement uncertainties in the discussion of parameter induced model uncertainty.

"5. To reproduce the complete variability of turbulent fluxes at the experimental site Waldstein-Weidenbrunnen a longer measurement period for analyse is recommended. Otherwise, the reason the restriction to one short period should be explained."

The limiting factor is the number of model runs for the GLUE methodology. The number should be very large and therefore the number of days must be reduced to have an acceptable CPU time (calculations were done on a single Linux computational node at the University of California, Davis). Furthermore during both EGER IOPs more data for comparison were available than during other time periods, when only the usual instrumentation of the FLUXNET station DE-Bay was available. ACASA model simulations were compared to data from the FLUXNET station for the whole year of 2003 within a Diploma thesis (Schäfer, 2010), which showed a good agreement in all seasons except during the extreme heat of August. A publication of these results is in preparation.

Special comments

"p. 4244, 25: Please specify the favoured direction of uncertainty. In most cases there is an underestimation of fluxes because of the loss of a part of turbulence spectra during the turbulence measurements."

The high frequency loss of energy of the eddy-covariance measurements was carefully corrected according to a method by Moore (1986). For more details see Mauder and

Foken (2004, 2006) and Mauder et al. (2008). Therefore the direction of uncertainties is not related to the high frequency loss of the eddy-covariance measurements.

"p. 4246, 10: What CPU time did you need for all simulations?"

The ACASA model was run using a single Linux computational node at the University of California, Davis. 20000 model runs for a five day period needed a CPU time of about one week.

"p. 4250...: Please add more actual references referring to the applications of models at forest sites using different turbulence closure schemes."

See response to comment 1

"p. 4270: Fig. 7 and 8: The uncertainties of measurements should be added."

See updated figures below.

Full figure captions:

Figure 7. Predictive uncertainty bounds (5th and 95th quantile) and observed values (black dots) for the sensible heat flux (H, a), the latent heat flux (LE, b) and the net ecosystem exchange (NEE, c) for the coefficient of efficiency (IOP 1, dotted lines: individual best 10%, solid lines: combined). Vertical lines display the error after Mauder et al. (2006) depending on the quality flag. For sensible heat fluxes, the error is 10% for quality classes 1-3 and 15% for quality classes 4-6. For latent heat fluxes and the NEE, the error is 15% for quality classes 1-3 and 20% for quality classes 4-6 according to Foken et al. (2004).

Figure 8. Predictive uncertainty bounds (5th and 95th quantile) and observed values (black dots) for the sensible heat flux (H, a), the latent heat flux (LE, b) and the net ecosystem exchange (NEE, c) for the coefficient of efficiency (IOP 2, dotted lines: individual best 10%, solid lines: combined). Vertical lines display the error after Mauder et al. (2006) depending on the quality flag. For sensible heat fluxes, the error is 10%



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for quality classes 1-3 and 15% for quality classes 4-6. For latent heat fluxes and the NEE, the error is 15% for quality classes 1-3 and 20% for quality classes 4-6 according to Foken et al. (2004).

References

Berger, M., Dlugi, R., and Foken, T.: Modelling the vegetation atmospheric exchange with a transilient model, in: Biogeochemistry of Forested Catchments in a Changing Enivironment, A German Gase Study. Ecological Studies, edited by: Matzner, E., Springer, Berlin, Heidelberg, 177-190, 2004.

Foken, T., and Oncley, S. P.: Results of the workshop 'Instrumental and methodical problems of land surface flux measurements', Bull. Amer. Meteorol. Soc., 76, 1191-1193, 1995.

Foken, T., and Wichura, B.: Tools for quality assessment of surface-based flux measurements, Agric. Forest. Meteorol., 78, 83-105, 1996.

Foken, T., Göckede, M., Mauder, M., Mahrt, L., Amiro, B. D., and Munger, J. W.: Post-field data quality control, in: Handbook of Micrometeorology: A Guide for Surface Flux Measurement and Analysis, edited by: Lee, X., Massman, W. J., and Law, B., Kluwer, Dordrecht, 181-208, 2004.

Inclan, M. G., Forkel, R., Dlugi, R., and Stull, R. B.: Application of transilient turbulent theory to study interactions between the atmospheric boundary layer and forest canopies, Boundary-Layer Meteorol., 79, 315-344, 1996.

Mauder, M., and Foken, T.: Documentation and instruction manual of the eddy covariance software package TK2, Arbeitsergebn., Univ. Bayreuth, Abt. Mikrometeorol., ISSN 1614-89166, 26, 42 pp., 2004.

Mauder, M., and Foken, T.: Impact of post-field data processing on eddy covariance flux estimates and energy balance closure, Meteorol. Z., 15, 597-609, 2006.

Mauder, M., Foken, T., Clement, R., Elbers, J., Eugster, W., Grünwald, T., Heusinkveld, B., and Kolle, O.: Quality control of CarboEurope flux data - Part 2: Inter-comparison of eddy-covariance software, Biogeosci., 5, 451-462, 2008.

Mauder, M., Liebethal, C., Göckede, M., Leps, J.-P., Beyrich, F., and Foken, T.: Processing and quality control of flux data during LITFASS-2003, Boundary-Layer Meteorol., 121, 67-88, 2006.

Moore, C. J.: Frequency response corrections for eddy correlation systems, Boundary-Layer Meteorol., 37, 17-35, 1986.

Pinard, J. D. and Wilson, J. D.: First- and second-order closure models for wind in a plant canopy, J. App. Meteorol., 40, 1762–1768, 2001.

Schäfer, A.: Modellierung des Kohlenstoff- und Energieaustausches am Waldstein/Weidenbrunnen im Jahr 2003, Diploma Thesis, University of Bayreuth, 141 pp., 2010. available from the Department of Micrometeorology, University of Bayreuth, on request.

Staudt, K., Serafimovich, A., Siebicke, L., Pyles, R. D., and Falge, E.: Vertical structure of evapotranspiration at a forest site (a case study), Agric. Forest. Meteorol., under revision, 2010. available from the Department of Micrometeorology, University of Bayreuth, on request.

Thomas, C., and Foken, T.: Organised motion in a tall spruce canopy: Temporal scales, structure spacing and terrain effects, Boundary-Layer Meteorol., 122, 123-147, 2007a.

Thomas, C., and Foken, T.: Flux contribution of coherent structures and its implications for the exchange of energy and matter in a tall spruce canopy, Boundary-Layer Meteorol., 123, 317-337, 2007b.

Zeng, P., Takahashi, H.: A first-order closure model for the wind flow within and above vegetation canopies. Agric. For. Meteorol., 103, 301–313, 2000.

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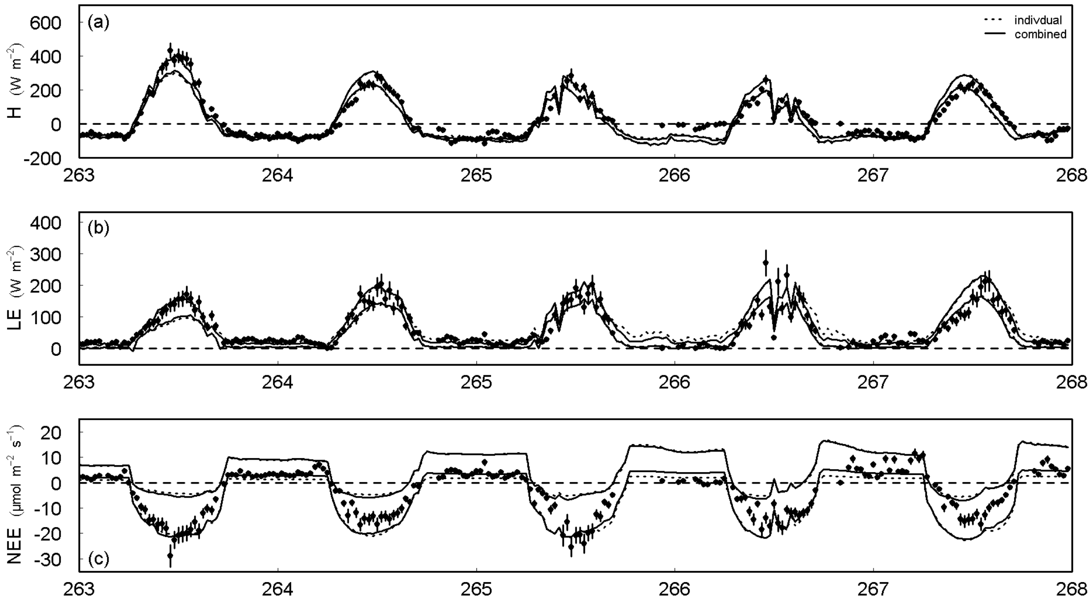


**Fig. 1.** Predictive uncertainty bounds (5th and 95th quantile) and observed values (black dots) for the sensible heat flux (H, a), the latent heat flux (LE, b) and the net ecosystem exchange (NEE, c) (IOP-1)

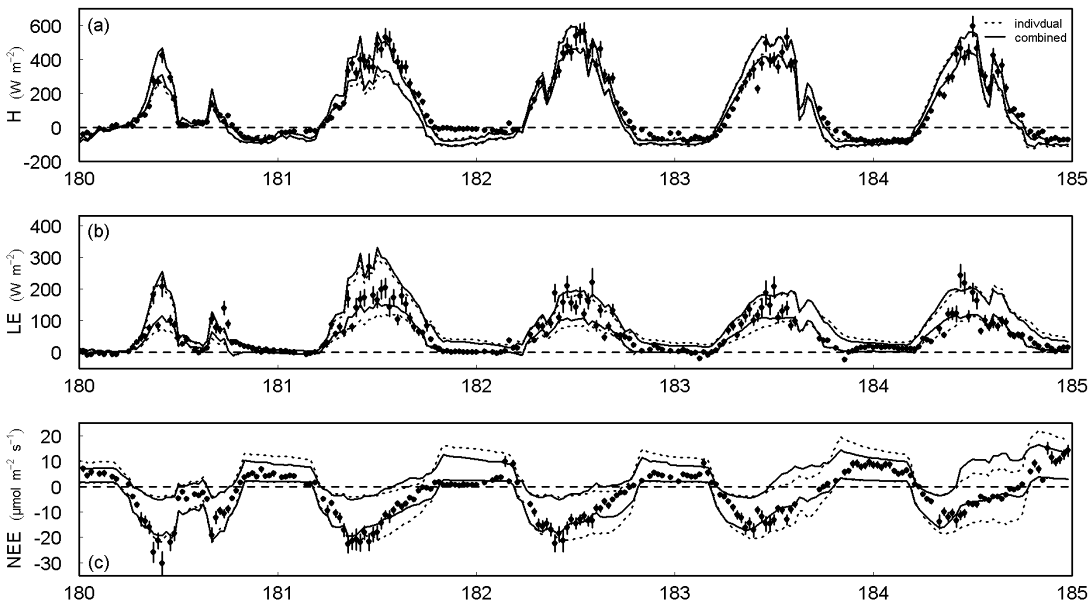


**Fig. 2.** Predictive uncertainty bounds (5th and 95th quantile) and observed values (black dots) for the sensible heat flux (H, a), the latent heat flux (LE, b) and the net ecosystem exchange (NEE, c) (IOP-2)