

Interactive comment on “Extension of the Representative Elementary Watershed approach by incorporating energy balance equations” by F. Tian et al.

F. Tian et al.

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Answers to the comments by the Referee, Varado

We would like to thank the Referee, N. Varado for his valuable comments on our manuscript, which will improve the paper greatly.

General comments

As pointed out by the Referee, it is true that the differences between our extension and the original formulation by Reggiani et al. (1998), and the main objectives are not highlighted in the manuscript, the mathematical methods are perhaps over-developed, some key statements such as “new sub-regions can easily be added” are not clearly

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expressed, and some sentences are apt to be misled due to the language problem. In the revised manuscript, the following major revisions are made:

1. Some sections such as Sect.1, Sect.2, Sect.3, and Appendices are rewritten and/or re-organized.

(1) In Sect.1, the scientific and societal significance of studies on hydrology of cold regions is discussed in a new paragraph by following the advice of anonymous Referee #3.

(2) In Sect.2, the Eq.(1) to Eq.(11) developed by Reggiani et al. (1998) are removed for conciseness in the revised manuscript by following the Referee's comment.

(3) Also in Sect.2, the paragraphs discussing the restriction of REW defined by Reggiani et al. (1998) are moved to this section from Sect.3 in the original manuscript.

(4) In Sect.3, the paragraphs discussing the limitation of original definition of REW are moved to Sect.2. Following the Referee's comment, Sect.3 is re-organized as follows: After introducing revised definition of REW, the spatial discretization of eight defined sub-regions is specified. We then discuss how to represent various hydrological processes in the revised definition such as evaporation/transpiration, surface and subsurface runoff generation, and then give the detail description of each sub-region. In Sect.3, special attention is focusing on the difference between our extension and the original definition by Reggiani et al. (1998).

(5) In Appendix A, some of formulation procedures are removed or simplified in order to shorten the length but not at any cost of interpretation. For example, the proof of Lemma1 and Lemma2 is removed, and the formulation procedures for temporal and spatial derivation terms, convective and non-convective terms, and the general form of energy conservation equation are largely simplified.

(6) In Sect.7 (the conclusion section), the differences and the main objectives are emphasized, and the key points of our work are highlighted. The improved extensibility of

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our REW definition and formulation is summarized including introduction of new sub-regions and phases, introduction of new assumptions or reduction of the existing ones, and consideration of the subsurface heterogeneity. The partition problem of saturation excess flow and infiltration excess flow is discussed, and the possible methods for developing new geometric and constitutive relationships are also investigated.

2. Some arguments, statements, and words are revised.

(1) Partition of saturation excess flow and infiltration excess flow: as pointed out by the Referees, Varado and the anonymous Referee #3, such partition really has the major advantage to inform on the saturated fraction of the REW surface. The “abandon” argument in the original manuscript is not suitable. In the revised manuscript, we emphasize that runoff generation can be modeled physically even without such partition, and that different types of runoff generation including saturation excess flow and infiltration excess flow have the underlying unified mechanism (Rui, 2004). The fact that hillslope is divided into two different overland flow zones does help to represent various flow processes conveniently, but still cannot represent evaporation/transpiration occurring from various kinds of land cover such as water, vegetation, bare soil, snow, and glacier. Hillslopes, which are the primary regions for runoff generation as well as water dissipation, must be treated with by its flow nature and evaporation/transpiration nature simultaneously. Therefore, the original hillslope division scheme containing saturated overland flow zone and concentrated overland flow zone, which is intended to account for various flow processes, is inadequate for hydrological modeling physically. In the revised definition of REW, the hillslope is divided into various kinds of land covers which presently include bare soil zone, vegetated zone, snow covered zone, and glacier covered zone.

(2) The differences between our extension and Reggiani et al.'s (1998) energy balance equations: as pointed out by the Referees, the improvement of the representation of evaporation and transpiration is not highlighted (see the comments of the Referee, Varado), and the energy balance equations developed by Reggiani et al. (1998) is not

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explicitly indicated and evaluated (see the comments of anonymous Referee #3) in the original manuscript. In the revised version, we call the hydrological processes such as evaporation/transpiration, melting, freezing, and thawing as energy related processes because they are intensively coupled with energy supply and transfer processes. The Reggiani et al.'s (1998) formulation cannot represent evaporation/transpiration in a physically reasonable way (Reggiani et al., 1999), and cannot represent melting, freezing, and thawing processes at all which occur in the immense cold regions, although the energy balance equations are indeed included in their formulation. We highlight these points in Sect.1, Sect.2, Sect.3, and Sect.7, respectively.

(3) Evaporation within the soil: The Referees question the statements about evaporation within the soil pores appeared at the beginning of Sect.3 in the original manuscript. Perhaps our idea is not correctly expressed. In our extension of REW approach, evaporation/transpiration can occur from each sub-region in the surface layer, and no evaporation is considered from subsurface sub-regions. Such assumption would be applicable in most regions including cold regions and “hot” regions. However, water can indeed vaporized within the soil pores in the unsaturated zone. In the dry desert it can even become the dominating processes together with condense process of vapor in the atmosphere. Generally, however, in common areas such vaporization of water within the soil pores is small compared with evaporation/transpiration occurring from land surface and can, therefore, be omitted. In the revised manuscript, the related sentences are rewritten.

(4) Some key words such as “fundamental” and “isolated” as pointed out by the Referee are not suitable and have been revised.

3. The discussion and references about the derivation of additional constitutive relationship are added.

Both the Referees and the authors are aware of the urgent need of the constitutive relationship and its difficulties. To publish the results about the constitutive relationships

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related with the extension of REW approach, we need not only the formulas related with the constitutive relationships but also the numerical model, detailed experimental data, and calibration and validation of the model. In the corresponding author's dissertation just finished in June 2006 (Tian, 2006), the procedures and formulas developed by Lee et al. (2005) and the Monte Carlo simulation method have been applied to obtain the constitutive relationships required by the extended REW theory excluding energy related processes. The application to the Chabagou Watershed typically with semi-arid climate (i.e., not a cold region) shows that the proposed constitutive relationships can represent the essential characteristics of the corresponding hydrological processes. In spite of the accomplished work, it will still take additional long time to modify and apply them for cold regions which are often poor gauged. In the revised manuscript, the possible methods and the references to pursue the closure relationships are added.

4. Appendix B is added to demonstrate how to include a new sub-region in the modified REW system.

The improved extensibility of REW theory is one of the major points in our manuscript. It is, however, not clearly and fully expressed as pointed out by the Referee. To demonstrate how to include a new sub-region into the existing REW system, the new appendix is added.

The authors' answers to the specific comments are listed below:

Comment 1

As pointed out by the Referee, the title of the original manuscript couldn't express the major contribution clearly, which is revised to "Extension of the Representative Elementary Watershed approach for cold regions via explicit treatment of energy related processes" by considering the Referee's advice.

Comment 2

The complementary relationships between the two ways proposed to solve the scale

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incompatibility problem are highlighted in the revised manuscript, and the error reference to Beven (1989, 2000) is removed according to the Referee's comment.

Comment 3

The statements on the function of evaporation/transpiration and special hydrological processes related with cold regions including melting, freezing, and thawing are not clearly separated in the original manuscript, as pointed out by the Referee. In the revised version, we highlight that the combined processes of evaporation and transpiration are major components of the hydrological cycle (Ward and Robinson, 1990) and should be an elementary component of hydrological models. As for melting from snowpack and glaciers, it is often a crucial component of the hydrological cycle in cold regions which cover nearly half of global land area (Yang Z. et al., 2000; Fassnacht, 2000) at least in some parts of the year. Besides, soil freezing and thawing have significant influences on the local and global water and energy cycle (Hu et al., 2006).

Comment 4, 26

The possible approaches for investigation of constitutive relationships required by the extended balance equations are discussed in the Conclusion Section in the revised manuscript in brief. See the answers in general comment 3.

Comment 5

The Eq.(1) to (11) are not necessary for interpretation of the author's arguments, as pointed out by the Referee. They are removed for conciseness from the manuscript by following the comment of the Referee.

Comment 6

The organization of Section 3 is reformulated. See the answers in general comment 1.

Comment 7, 16

The original manuscript doesn't clarify our ideas. The transpiration is the phase transi-

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tion process in the vegetated zone, and the evaporation is the phase transition process in other surface zones. We assume that the evaporation within the soil pores small and could be omitted. Such assumption should be generally applicable for cold regions as well as “hot” regions. The original sentences are revised and re-organized in Sect.3. See the answers in general comment 2 (3).

Comment 8

The separation of saturated overland flow from concentrated overland flow is useful in hydrological modeling, it can indeed provide important information such as saturated fraction of REW. What we want to express is that the runoff generation could be modeled physically even without such separation, as in most current physically-based hydrological models such as SHE (Abbott et al., 1986a, b) and GBHM (Yang D. et al., 2000, 2002a, 2002b). The related sentences are revised. See the answers in general comment 2 (1).

Comment 9

To our mind, the size of REW in hydrological practices is not small enough so that it will get more exact results if the sub-REW-scale runoff routing is considered in the model.

Comment 10

The surface and subsurface layers were already separated in Reggiani's definition of REW, as pointed out by the Referee. The statement is revised and the differences between our extension and the original formulation are highlighted.

Comment 11

The word 'fundamental' is not suitable as pointed out by the Referee. We have revised the statements. See the answers in the general comment 2 (4).

Comment 12, 25

We add a new appendix in the revised manuscript to demonstrate how to add a new

sub-region into the existing REW system. See the answers in general comment 4.

Comment 13

The paragraph about the subsurface heterogeneity and subsurface flow is rewritten according to the Referee's comment.

Comment 14

The definition of the saturated zone and the unsaturated zone is derived from Reggiani, which is highlighted in the revised manuscript. The reader can refer to the Reggiani et al. (1998) for detail.

Comment 15

To our mind, gas is one of the important phases contained in the unsaturated zone. To keep the problem physically, gas is needed in REW definition.

Comment 17

The area of snow covered zone can be modeled in our formulation, see Eq.(54) in the original manuscript or Eq.(43) in the revised manuscript for detail.

Comment 18

The statement about the invariant of glacier is removed because the Referee's comment is reasonable.

Comment 19

The geometric, kinetic, and thermodynamic properties of hierarchical continua, including REW level, sub-region level, and phase level continua, are necessary and already defined in Reggiani et al.'s (1998) formulation. What we did is to provide them in a more rigorous, systematic, and consistent manner.

Comment 20

The definitions of the time-averaged REW-scale quantities are derived from Reggiani et al. (1998), which is clearly stated in the revised manuscript.

Comment 21

The symbols listed in Table 6 are already rigorously defined in the previous sections. To our mind, the summary of these interfaces is necessary for the following formulation.

Comment 22

As pointed out by the Referee, the equations are applicable at the spatial scale of the REW, not at the whole watershed scale. We correct the sentence in the revised manuscript by following the Referee's comment.

Comment 23

In the revised manuscript, the way that surface and subsurface flow are represented in the extensible REW approach is described in Sect.3 after the introduction to the new definition of REW, and is also discussed in the balance equation of mass for water phase of saturated zone, unsaturated zone, bare soil zone, vegetated zone, snow covered zone, and glacier covered zone in Sect.6. We finally give the brief summary in the conclusion section.

Comment 24

About the partition of saturation excess flow and infiltration excess flow, we have made major changes in the revised manuscript. See the answers in the general comment 2 (1) and in the specific comment 8.

Other comments, concerning spelling and style were taken into account in the revised manuscript.

References

Abbott, M. B., Bathurst, J. C., Cunge, J. A., O'Connell, P. E., and Rasmussen, J.: An

introduction to the European Hydrological System - Systeme Hydrologique European, SHE, 1: History and philosophy of a physically based, distributed modeling system, J. Hydrol., 87, 45-59, 1986a.

Abbott, M. B., Bathurst, J. C., Cunge, J. A., O'Connell, P. E., and Rasmussen, J.: An introduction to the European Hydrological System - Systeme Hydrologique European, SHE, 2: Structure of a physically based, distributed modeling system, J. Hydrol., 87, 61-77, 1986b.

Beven, K. J.: Changing ideas in hydrology-the case of physically-based models, J. Hydrol., 105, 157-172, 1989.

Beven, K. J.: Towards an alternative blueprint for a physically based digitally simulated hydrologic response modelling system, Hydrol. Process., 16, 189-206, 2002.

Fassnacht, S. R.: Distributed snowpack simulation using weather radar with an hydrologic-land surface scheme model (dissertation), University of Waterloo, Canada, 2000.

Lee, H., Sivapalan, M. and Zehe, E.: Representative Elementary Watershed (REW) approach, a new blueprint for distributed hydrologic modelling at the catchment scale: the development of closure relations, in: Predicting Ungauged Streamflows in the Mackenzie River Basin: Today's Techniques and Tomorrow's Solutions, edited by Spence, C., Pomeroy, J. W., and Pietroniro, A., Canadian Water Resources Association (CWRA), Ottawa, Canada: 165-218, 2005b.

Hu, H., Ye, B., Zhou, Y., Tian, F.: A Land Surface Model Incorporated with Soil Freeze/Thaw and Its Application in GAME/Tibet, Science in China Ser. D, 2006 (in press).

Reggiani, P., Sivapalan, M., and Hassanizadeh, S. M.: A unifying framework for watershed thermodynamics: balance equations for mass, momentum, energy and entropy,

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and the second law of thermodynamics. Adv. Water Resour., 22(4), 367-398, 1998.

Reggiani, P., Hassanizadeh, S. M. and Sivapalan, M.: A unifying framework for watershed thermodynamics: constitutive relationships, Adv. Water Resour., 23, 15-39, 1999.

Rui X. F.: Principles of Hydrology, China Water Power Press, Beijing, China, 143-152, 2004.

Tian, F. Q.: Study on thermodynamic watershed hydrological modeling (THModel) (dissertation), Tsinghua University, China, 2006.

Ward, R. C. and Robinson, M.: Principles of Hydrology, McGraw-Hill, London, 1990.

Yang, D., Herath, S., and Musiake, K.: Comparison of different distributed hydrological models for characterization of catchment spatial variability, Hydrol. Process., 14, 403-416, 2000.

Yang, D., Herath, S., and Musiake, K.: Hillslope-based hydrological model using catchment area and width functions, Hydrol. Sci. J., 47(1), 49-65, 2002a.

Yang, D., Oki, T., Herath, S., and Musiake, S.: A geomorphology-based hydrological model and its applications, in: Mathematical Models of Small Watershed Hydrology and Applications, edited by: Singh, V. P., Frevert, D. K., Water Resources Publications, Littleton, Colorado, Chapter 9, p. 259-300, 2002b.

Yang, Z., Liu, X. R., Zeng, Q. Z., and Chen, Z. T.: Hydrology in Cold Regions of China, Science Press, Beijing, 2000.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 3, 427, 2006.

HESSD

3, S697–S707, 2006

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