Review of GMD Manuscript # gmd-2015-19
"SPHY v2.0: Spatial Processes in HYdrology"
by W. Terink, A. F. Lutz, G. W. H. Simons, W. W. Immerzeel, and P. Droogers.

Summary

This paper introduces and describes the SPHY v2.0 model, which aims to integrate several hydrologic processes including evapotranspiration (ET), canopy storage, snow and glacier melt, soil storage, and runoff routing throughout rivers and lakes. The model is described by the authors as a 'spatially distributed leaky bucket type' (p. 1691, L10), and it is essentially a water balance model running at daily time steps. The authors also present a few example applications using the SPHY model, including (i) soil-moisture simulation for irrigation management, (ii) simulation of historical and future hydrologic processes in snow and glacier-dominated catchments, and (iii) streamflow forecasting in mountainous regions. Finally, some potential areas for future improvement are described, with emphasis on ET, depression storage, representation of lakes/reservoirs, runoff routing, cryosphere processes and the development of a graphical user interface.

In general, I found this manuscript interesting, technically sound, and well organized. I also think that the model is described with enough detail to allow any reader to put the equations in an Excel spreadsheet or a Matlab script and simulate fluxes and storages of water. Nevertheless, I think this paper needs substantial revisions in order to clarify the novelty of this modeling framework, demonstrate the ability of SPHY to faithfully simulate the spatial distribution of hydrologic processes, and also provide further interpretation of the results presented in section 3. I also suggest the authors to carefully review grammar and spelling throughout the entire manuscript. I have provided some editorial suggestions at the end of this review, but I may have missed some.

Major comments

1. My main concern is the tone used by the authors to introduce their model. They state that:
   - "Compared to other hydrological models, that typically focus on the simulation of streamflow only, the SPHY model has several advantages…" (p.1688, L9-10).
   - "Traditionally, hydrologists have put a strong emphasis on streamflow analysis and forecasting, while ignoring other hydrological processes" (p.1690, L3-4; p.1724, L22-24 and p.1725, L3-4).
   - "…there is a clear need for a hydrological model that combines the strengths of existing modelling approaches…" (p.1690, L19-20).

   Although I agree that the lack of detailed observational datasets is a big constraint in hydrologic modeling (which partially explains why analysis tend to focus on streamflow), sentences like these seem to point that the hydrologic and land surface communities have made no efforts to improve our understanding on the spatial representation of fluxes of water and energy over the past decades, which is clearly not the case (e.g. Abbott et al. 1986; Wigmosta et al. 1994; VanderKwaak and Loague 2001; Ivanov et al. 2004; Maxwell and Miller 2005; Rigon et al. 2006; Pomeroy et al. 2007; Qu and Duffy 2007; Niu et al. 2011; Lawrence et al. 2011; Essery et al. 2013; Clark et al. 2015a,b). Even more, there are many more examples in the literature presenting models with similar or deeper level of granularity in hydrologic process representation if compared

with SPHY v2.0 (e.g. Leavesley et al. 1983; Liang et al. 1994; Chen et al. 1996; Bandaragoda et al. 2004; Oleson et al. 2010).
Based on this, I recommend: (i) re-wording or deleting sentences similar to the examples presented above; (ii) acknowledge past efforts aimed to improve hydrologic process representations (please see references included at the end of this review), and (iii) clearly state what makes SPHY v2.0 different from other modeling frameworks (i.e. any particular process included, data sets used, computing time, etc.). I find the last point particularly critical since, in my opinion, the manuscript as it stands does not highlight any novel contributions to the hydrologic modeling literature.

2. The title of the paper ("Spatial Processes in HYdrology") prepares the reader for detailed results on the spatial representation of processes (e.g. ET, soil moisture, runoff, snowpack) with SPHY v2.0. However, such analysis is only provided for the snow and glacier-dominated case study basins in section 3.2. I think the manuscript would greatly benefit from the inclusion of at least one additional figure showing maps with any particular state/flux for the case studies in sections 3.1 and 3.3.

3. Section 3: I think that the case studies included here are quite interesting, but very little explanation of the results is provided. For instance:
    - P.1717 L7-18 (section 3.1): Are the authors presenting the results for only one field out of 380 (Figure 4)? If that is the case, was a similar performance observed in the rest of the fields? What parameters should be calibrated to improve simulated soil moisture?
    - P.1719 L1-9 (section 3.2): What is the time step used to compute the metrics displayed in Figure 5? What are the calibration and validation periods? Can the authors speculate about the reasons for bias results? Additionally, the case study description prepares the reader for climate change impact results, but these are never provided.
    - P.1720 L16-29 (section 3.3): How were model simulations forced to issue streamflow forecasts? Did the authors use outputs from a weather model, or assumed specific meteorological forcings?

    I recommend going through this section carefully and provide answers to these questions, together with further interpretation of the results presented in the manuscript.

Minor comments

4. P.1688 L27: I recommend adding a couple of references after 'future' (Wagener et al. 2010; Lall 2014).

5. P.1690 L20-22: The authors mention the need for modular frameworks to decide what processes should be included. This very important, since there is a large body of literature suggesting that hydrologic model structure should be specific to catchment properties (i.e. hydroclimate, topography, geology, land cover, etc.), following the concept of uniqueness of place (see Keith Beven's papers). I recommend to make this point explicitly and cite recent contributions on flexible modeling frameworks (e.g. Pomeroy et al. 2007; Clark et al. 2008; Niu et al. 2011; Essery et al. 2013; Clark et al. 2015a,b).

6. In the first paragraph of section 2.1, the authors describe SPHY as 'spatially distributed leaky bucket type', although it is implied throughout the paper that this is a 'process-

based' model. It should be noted that, in the literature, bucket-style models (also referred to as 'conceptual') are distinguished from process-based or 'physically-motivated' models in terms of scope and complexity, and it seems that SPHY is closer to the conceptual modeling philosophy. I recommend the authors to clarify what type of model they are introducing (see discussion in section 4.2, Clark et al. 2015a).

7. Section 2.1: This manuscript would greatly benefit from the inclusion of a table describing all the parameters (i.e. adjustable coefficients in model equations) in the SPHY V2.0 model. Some points to include are: acronym, description, units and type (i.e. 'free' if the parameter value can be determined only through calibration and 'observable if the parameter can be measured).

8. P.1691 L24: It should be pointed that the soil column structure is similar to VIC (Liang et al. 1994, 1996).

9. P.1692 L23-26: It seems that the authors mean 'static data' and 'meteorological forcings' when referring to 'state variables' and 'dynamic variables', respectively. Please note that the term 'state variable' is typically used to refer to storages of water or energy in hydrologic models (or simply to any storage within a system).

10. P.1694 L25: does TD denote for DAILY temperature range? Please clarify.

11. P.1695 L6: What does 'short of water' mean?

12. Section 2.4.1: Should this section be entitled 'Maximum canopy storage'? Looks like the main goal here is to compute this variable (equation 7). If yes, please correct.

13. Section 2.4.2: In p.1698 L21, the authors state that the coefficient Kp 'can easily be altered in the model code'. Is this coefficient hard-coded? Note that, if Kp is a parameter, it should NOT be treated as a physical constant, and therefore should not be embedded in the model source code (I suggest the authors see the discussion in Mendoza et al. 2015).

14. In sections 2.5.2 and 2.5.3, SSW is described as 'the amount of refrozen melt water' or 'melt of water that can refreeze' (implying that it is NOT refrozen). Please be consistent when describing this variable.

15. Section 2.7.1: Why isn't there lateral flow (LF2,t) from layer 2 in equation (29)? If it is assumed that capillary rise can only occur from layer 2 to layer 1, it should be clearly stated in the text.

16. Section 2.7.2: Does pF denote for binding capacity? After reading several times this section, the physical meaning of pF is completely unclear for this reviewer. I suggest elaborating the text to clarify.

17. Section 2.7.3: There are too many lines of text at the beginning of this section just to say that Hortonian runoff is irrelevant for the time scale used in the SPHY model. I suggest condensing this text.

18. Section 2.7.5: Is the lag time for percolation computed using EXACTLY the same equation than for lag time in lateral flow? Please clarify, and justify the choice whatever is the case.

19. Section 2.7.7: From the integration of equation (45), looks like the variable time (t) is missing from the exponential function in equation (46). Please check the math.

20. Section 2.8: should it be more appropriate to entitle this section simply as ‘Routing’? (Including: 2.8.1 Runoff routing, and 2.8.2. Lake/reservoir routing).

21. P.1712 L4: The authors introduce the variable rain runoff (RRo). Is this the sum of surface runoff (RO) and lateral flow (LF)? Please clarify.

22. P.1713 L1: It should be mentioned (if this is the case) that the use of very small time steps is intended to provide numerically stable solutions.

23. Section 2.8.1: It is completely unclear for this reviewer what the accuflux function is doing. Please clarify.

24. P.1718 L23-25: Given the large uncertainties in future climatic conditions and modeling decisions, I do not think that any hydrologic model application can be described as ‘successful’ in the context of hydrologic change estimates. I suggest the authors to clarify what they mean with ‘success’.

25. P.1719 L11-13: For this reviewer, it is not clear the connection made by the authors between ‘harsh’ environments, statistical models and ‘physical information’. Although hydroclimatic variability in Chile is tremendous, statistical forecasting approaches are operationally used in areas where climatic conditions are not necessarily ‘harsh’ (e.g. Mendoza et al. 2014). Furthermore, there is a large body of literature (e.g. Piechota and Chiew 1998; Grantz et al. 2005; Regonda et al. 2006; Bracken et al. 2010) showing that statistical models can provide skillful seasonal forecasts using large scale climate variables and in-situ meteorological data – which can also be considered ‘physical information’.

26. Section 3.3: In the last paragraph, the authors speculate that a large source of uncertainty in hydrologic modeling results is related with forcing uncertainty at high altitudinal areas in Chile. Other studies have also reported this problem (e.g. Vicuña et al. 2010; McPhee et al. 2010; Mendoza et al. 2012; Ragettli and Pellicciotti 2012; Ragettli et al. 2014 and many others), and therefore should be referred to in this section.

27. Section 4: I think future implementations should include the possibility of simulation time steps smaller than 1 day.

28. P.1725 L25: The authors refer to ET simulations for the irrigation application, but these results were not reported.

29. Figure 2: This is a very nice figure, but the text is too small. I recommend increasing its size.

Suggested minor edits

30. P.1688 L10-13: Awkward sentence. Please check grammar.
31. P.1688 L18: ‘and range from’ -> ‘including’, and delete ‘to’ in subsequent lines.
32. P.1689 L17: delete ‘ultimate’.
33. P.1689 L18: ‘for difficult to include sub-processes’ reads awkward. Please check grammar.
34. P.1689 L26: ‘model-overviews’ -> ‘model reviews’.
35. P.1690 L12: ‘relevant’ -> ‘understood’.
36. P.1691 L23: ‘model concepts’ -> ‘modeling concepts’.
37. P.1692 L1: Delete ‘any’.
38. P.1692 L16-18: Awkward sentence.
39. P.1693 L2: ‘data on streamflows’ -> ‘streamflow data’.
40. P.1693 L4: ‘snow coverage’ -> ‘snow covered area (SCA)’.
41. P.1693 L10: ‘on daily base’ -> ‘on a daily basis’.
42. P.1694 L2-3: ‘For routing two modules are available’ -> ‘Two modules are available for runoff routing’.
43. P.1694 L19: ‘method’ -> ‘methods’.
44. P.1695 L2: delete ‘evaporation equivalents’.
45. P.1695 L20-21: I suggest deleting ‘not very realistic to use a single constant Kc throughout the entire simulation period. It is therefore’.
46. P.1696 L4-6: Awkward sentence.
47. P.1696 L11: There is no need to spell out NDVI again.
48. P.1698 L4: ‘First of all’ -> ‘First,’
49. P.1699 L7: Delete ‘on’.
50. P.1701 L2-3: Suggest ‘…which is the total water equivalent of snow melt [mm] that…’
51. P.1703 L19: This sentence reads like a ‘tongue twister’. I suggest re-wording.
52. P.1705 L1: ‘e.g.’ -> ‘- for instance -’.
53. P.1705 L12: ‘As was’ -> ‘As it was’.
54. P.1705 L15: ‘as soons as’ -> ‘as soon as’.
55. P.1705 L23: ‘that is’ -> ‘that are’.
56. P.1705 L24: ‘a evapotranspiration’ -> ‘an evapotranspiration’.
57. P.1706 L22: Incomplete sentence at the end of paragraph.
58. P.1707 L16-19: I suggest writing ‘Therefore, the drainable volume… needs to be calculated first’.
59. P.1708 L13-14: I suggest writing ‘if the catchment of interest has a time of concentration greater than 1 day’.
60. P.1710 L8: ‘instantaneous’ -> ‘instantaneously’’.
61. P.1710 L15: ‘on day t and t-1’ -> ‘on days t and t-1’.
62. P.1712 L12: ‘latereral’ -> ‘lateral’.
63. P.1712 L24: ‘which is’ -> ‘which are’.
64. P.1713 L1: ‘require’ -> ‘requires’.
65. P.1713 L10: ‘would be used’ -> ‘is used’.
66. P.1713 L22: ‘involves the solving of complex…’ -> ‘involves solving complex…’
67. P.1713 L24: ‘approacing’ -> ‘approaching’.
68. P.1714 L10-11: Awkward sentence.
69. P.1715 L21-25: ‘ranging from’ -> ‘including’, and delete ‘to’ in subsequent lines.
70. P.1718 L10-11: ‘for such an approach’ -> ‘for such goals’ (SPHY is a modeling approach per se).
71. P.1718 L21: delete ‘and’.
72. P.1719 L15: ‘the coming’ -> ‘upcoming’.

73. P.1719 L16 and L19: the authors use ‘INTOGENER’ and ‘INTOGNER’ interchangeably. Which one is correct?
74. P.1719 L20: delete ‘that were’.
75. P.1719 L21: ‘map-series of snow cover’ -> ‘time series of snow cover maps’.
76. P.1720 L8: delete ‘(Nash and Sutcliffe, 1970)’ (no need to reference twice).
77. P.1721 L8: ‘being’ -> ‘including’.
78. P.1721 L22: ‘dynamically’ -> ‘dynamical’.
79. P.1722 L17: delete ‘SPHY’.
80. P.1723 L15: ‘emperical’ -> ‘empirical’.
81. P.1723 L16: ‘dischargen’ -> ‘discharge’.
82. P.1724 L7: ‘respresentation’ -> ‘representation’.
83. P.1724 L13: delete ‘even’.
84. P.1725 L5: ‘easy’ -> ’easily’.
85. P.1725 L20: ‘decision makers’ -> ’decision-making’.
86. P.1726 L5: ‘minimzed’ -> ’minimized’.

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