Dear reviewer,

We would like to thank you for thoroughly reviewing our manuscript entitled: "SPHY v2.0: Spatial Processes in Hydrology". After reading your comments we have made substantial revisions to the manuscript, and replied to all your comments and we believe the manuscript has improved considerably. Please find our reply to each comment in *italic* font below.

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.

We totally agree with the main concern of the reviewer regarding the tone that is used to introduce the SPHY model. First of all, it is not our intention to criticize other models for their level of granularity in hydrological processes compared to the SPHY model, because we think that some other models (Leavesley et al. 1983; Liang et al. 1994; Chen et al. 1996; Bandaragoda et al. 2004; Oleson et al. 2010) have a similar or even deeper level of detail compared to the SPHY model.

Secondly, the hydrologic and land surface communities have indeed made substantial efforts to improve our understanding of the spatial representation of fluxes of water and energy. These efforts have led to the development of well-known hydrological models, such as e.g. VIC (Liang et al., 1994;1995), SWAT (Neitsch et al., 2009), TOPKAPI-ETH (Finger et al., 2011; Ragettli and Pellicciotti, 2012; Ragettli et al., 2013; 2014), LISFLOOD (Van der Knijff et al., 2010), SWIM (Krysanova et al., 1998;2000;2015), HYPE (Lindström et al., 2010), mHM (Samaniego et al., 2010), PCR-GLOBWB (Van Beek and Bierkens, 2008; Bierkens and Van Beek, 2009; Wada et al., 2010; Sperna Weiland et al., 2010), MIKE-SHE (Refshaard, 1995; Oogathoo et al., 2008; Deb and Shukla, 2011) and GEOtop (Rigon et al, 2006, Endrizzi et al, 2013, Endrizzi et al., 2011), amongst others. All these models are different with respect to i) the number and detail of hydrological processes that are included, ii) their field and iii) scale of application, and iv) the way they are implemented. Whereas for example the SWIM and

HYPE model both include all major hydrological processes, they are typically developed for large-scale (large river basins to continental) applications and therefore contain less detail as fully distributed models such as GEOtop and TOPKAPI-ETH that typically focus on the catchment and river basin scale. Models like MIKE-SHE and LISFLOOD have the advantage of being flexible in terms of the spatial and temporal resolution, but their disadvantages are that they do not include glacier processes and that they are not open-source and therefore not available to the larger community.

In summary, all these models, including the SPHY model, have their pros and cons in terms of processes included, field of application, scale of application, and implementation. To have a better overview of the pros and cons of SPHY, and how these compare to those of other well-known models, we've modified the text on the pages 1688-1691, and inserted the text and table as shown below. Besides this, we've deleted or rephrased sentences that criticize other models and we've acknowledged past hydrologic model developments as suggested.

Inserted text and table:

"

Over the past decades the land surface and hydrologic communities have made substantial progress in understanding the spatial presentation of fluxes of water and energy (Abbott et al., 1986; Wigmosta et al., 1994; VanderKwaak and Loague, 2001; Rigon et al., 2006). Their efforts have led to the development of well-known hydrological models, such as e.g. VIC (Liang et al., 1994, 1996), SWAT (Neitsch et al., 2009), TOPKAPI-ETH (Finger et al., 2011; Ragettli and Pellicciotti, 2012; Ragettli et al., 2013, 2014), LISFLOOD (Van Der Knijff et al., 2010), SWIM (Krysanova et al., 2015, 2000, 1998), HYPE (Lindström et al., 2010), mHM (Samaniego et al., 2010), PCR-GLOBWB (van Beek and Bierkens, 2008; Bierkens and van Beek, 2009; Wada et al., 2010; SpernaWeiland et al., 2010), MIKE-SHE (Refshaard and Storm, 1995; Oogathoo et al., 2008; Deb and Shukla, 2011) and GEOtop (Rigon et al., 2006; Endrizzi et al., 2013, 2011), amongst others. The number of existing hydrological models is probably in the tens of thousands (Droogers and Bouma, 2014). Some existing model- overviews cover a substantial amount of models: IRRISOFT (Irrisoft, 2014): 114, USGS (USGS, 2014): 110, EPA (EPA, 2014): 211, USACE (HEC, 2014): 18.
All these hydrological models are different with respect to i) the number and detail of hydrological processes that are integrated, ii) their field and iii) scale of application, and iv) the way they are implemented. Whereas for example the SWIM (Krysanova et al., 2015, 2000, 1998) and the HYPE model (Lindström et al., 2010) both include all major hydrological processes, they are typically developed for large-scale (large river basins to continental) applications and therefore contain less detail as fully distributed models such as e.g. GEOtop (Rigon et al., 2006; Endrizzi et al., 2013, 2011) and TOPKAPI-ETH (Finger et al., 2011; Ragettli and Pellicciotti, 2012; Ragettli et al., 2013, 2014) that typically focus on the catchment and river basin scale. Models like e.g. MIKE-SHE (Refshaard and Storm, 1995; Oogathoo et al., 2008; Deb and Shukla, 2011) and LISFLOOD (Van Der Knijff et al., 2010) have the advantage of being flexible in terms of the spatial and temporal resolution, but their disadvantages are that they do not include glacier processes and that they are not open-source and therefore not available to the larger community.
It is clear that all these models have their pros and cons in terms of i) processes integrated, ii) field of application, iii) scale of application, and iv) implementation. Table 2 shows the pros and cons of some well-known hydrological models, including the Spatial Processes in HYdrology (SPHY) model. Over the last couple of years we have developed the SPHY model, and improved its usefulness by applying the model in various research projects. SPHY has been developed with the explicit aim to simulate terrestrial hydrology under various physiographical and hydro-climatic conditions by integrating key components from existing and well-tested models: HydroS (Droogers and Immerzeel, 2010), SWAT (Neitsch et al., 2009), PCR-GLOBWB (van Beek and Bierkens, 2008; Bierkens and van Beek, 2009; Wada et al., 2010; Sperna Weiland et al., 2010), SWAP (van Dam et al., 1997) and HimSim (Immerzeel et al., 2011). Based on Tab. 2 it is clear that SPHY i) integrates most hydrologic processes, including

glacier processes, ii) has the flexibility to study a wide range of applications, including climate and land use change impacts, irrigation planning, and droughts, iii) can be used for catchment- and river basin scale applications as well as farm- and country-level applications, and has a flexible spatial resolution, and iv) can easily be implemented. Implementation of SPHY is relatively easy because it i) is open-source, ii) in- and output maps can directly be used in GIS, iii) is setup modular in order to switch on/off relevant/irrelevant processes and thus decreases model run-time and data requirements, iv) needs only daily precipitation and temperature data as climate forcing, v) can be forced with remote sensing data, and vi) uses a configuration file that allows the user to change model parameters and choose the model output that needs to be reported.
The objective of this publication is to introduce and present the SPHY model, its development background, and demonstrate some typical applications. The model executable and source code are in the public domain (open access) and can be obtained from our website free of charge (www.sphy.nl)."

Table 2. Pros (+) and cons (-) of some well-known hydrological models, including the SPHY model. A categorization is made between i) processes that are integrated, ii) field of application, iii) scale of application, and iv) implementation.

	SPHY	TOPKAPI-ETH	SWAT	VIC	LIS-FLOOD	SWIM	HYPE	mHM	MIKE-SHE	PCRGLOB-WB	GEO-top
Processes integrated											
Rainfall-runoff	+	+	+	+	+	+	+	+	+	+	+
Evapotranspiration	+	+	+	+	+	+	+	+	+	+	+
Dynamic vegetation growth	+	-	+	+	+	+	+	NA	+	+	-
Unsaturated zone	+	+	+	+	+	+	+	+	+	+	+
Groundwater	+	-	+	+	+	+	+	+	+	+	+
Glaciers	+	+	-	-	-	+	+	-	-	-	+
Snow	+	+	+	+	+	+	+	+	+	+	+
Routing	+	+	+	+	+	+	+	+	+	+	+
Lakes incorporated in routing scheme	+	-	+	+	+	+	+	NA	+	+	-
Reservoir management	-	-	+	-	-	+	+	NA	-	+	-
Field of application											
Climate change impacts	+	+	+	+	+	+	+	+	+	+	+
Land use change impacts	+	+	+	+	+	+	+	+	+	+	+
Irrigation planning	+	-	+	+	-	+	+	-	+	-	+
Floods	-	-	-	-	*3	-	-	-	+	+	+
Droughts	+	+	+	+	+	+	+	+	+	+	+
Water supply and demand	-	-	+	-	-	-	-	NA	-	-	-
Scale of application											
Catchment-scale	+	+	+	+	-	-	-	-	+	-	+
River basin scale	+	+	+	+	+	+	+	+	+	-	-
Mesoscale river basins	+	-	+	+	+	+	+	+	+	+	-
Global-scale	-	-	-	+	-	-	+	-	-	+	-
Farm-level	+	-	-	-	-	-	-	-	-	-	-
Country-level	+	-	-	-	-	-	-	-	-	-	-
Fully distributed	+	+	-	+	+	-	-	+	+	+	+
Sub-grid variability	+	-	-	+	-	-	-	+	-	+	+
Felxible spatial resolution	+	+	-	+	+	-	-	+	+	+	+
Hourly resolution	-	+	+	-	+	-	-	+	+	-	+
Sub-daily resolution	-	-	-	+	+	-	-	NA	+	-	-
Daily resolution	+	+	+	+	+	+	+	NA	+	+	-
Implementation											
Open-source	+	-	+	+	-	-	+	-	-	-	+
Forcing with remote sensing	+	+	-	+	+	-	-	NA	-	-	+
GIS compatibility	+	+	+	-	+	+	-	+	+	+	+
Modular setup	+	-	-	+	+	+	+	+	+	-	-
Computational efficient	+	+	+	-	+	+	+	+	-	+	+
Climate forcing requirements	+	+	-	*2	-	-	+	+	-	-	-
Flexible output reporing options	+	+	-	+	+	+	+	NA	+	-	+
Graphical user-interface in GIS	*1	-	+	-	-	+	-	-	+	-	-

*1 Currently in development.
*2 More climate variables are required if model is run in energy balance mode.
*3 Only if run in combination with LISFLOOD-FP.
NA Information not available.

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.

One of the strengths of SPHY is indeed to provide detailed results of the spatial representation of processes, such as e.g. ET, snow store, soil moisture, etc. We agree with the reviewer that the *manuscript would benefit from the inclusion of additional figures for the case studies in sections 3.1 and 3.3.*

Regarding Section 3.1 we have inserted the following text and figure:

"In irrigation management applications like these, a model should be capable of simulating the moisture stress experienced by the crop due to insufficient soil moisture contents, which manifests itself by an evapotranspiration deficit (potential ET – actual ET > 0). Figure 4 shows the spatial distribution of ET deficit, as simulated by the SPHY model for the entire farm on April 3rd, 2014. When SPHY is run in an operational setting, this spatial information can be included in a decision support system that aids the farmer in irrigation planning for the coming days."

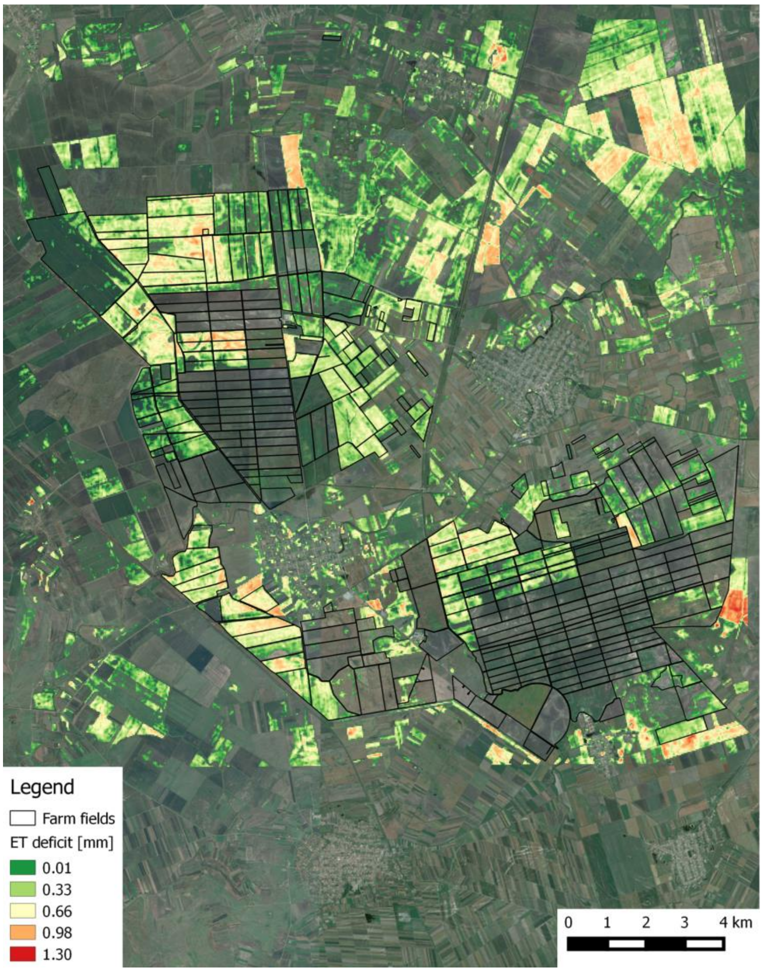

Figure 4: Spatial distribution of evapotranspiration (ET) deficit, as simulated by the SPHY model for a Romanian farm on April 3rd, 2014. Transparency means no ET difict.

Regarding Section 3.3 we have inserted the following text and figure on page 1719 after the sentence: "These images were ……the forecasting period.":

"Figure 10 shows the snow store as simulated by the SPHY model during the snow melting season in the Laja Basin. These maps clearly show the capability of SPHY to simulate the spatial variation of snow storage, with more snow on the higher elevations, and a decrease in snow store throughout the melting season."

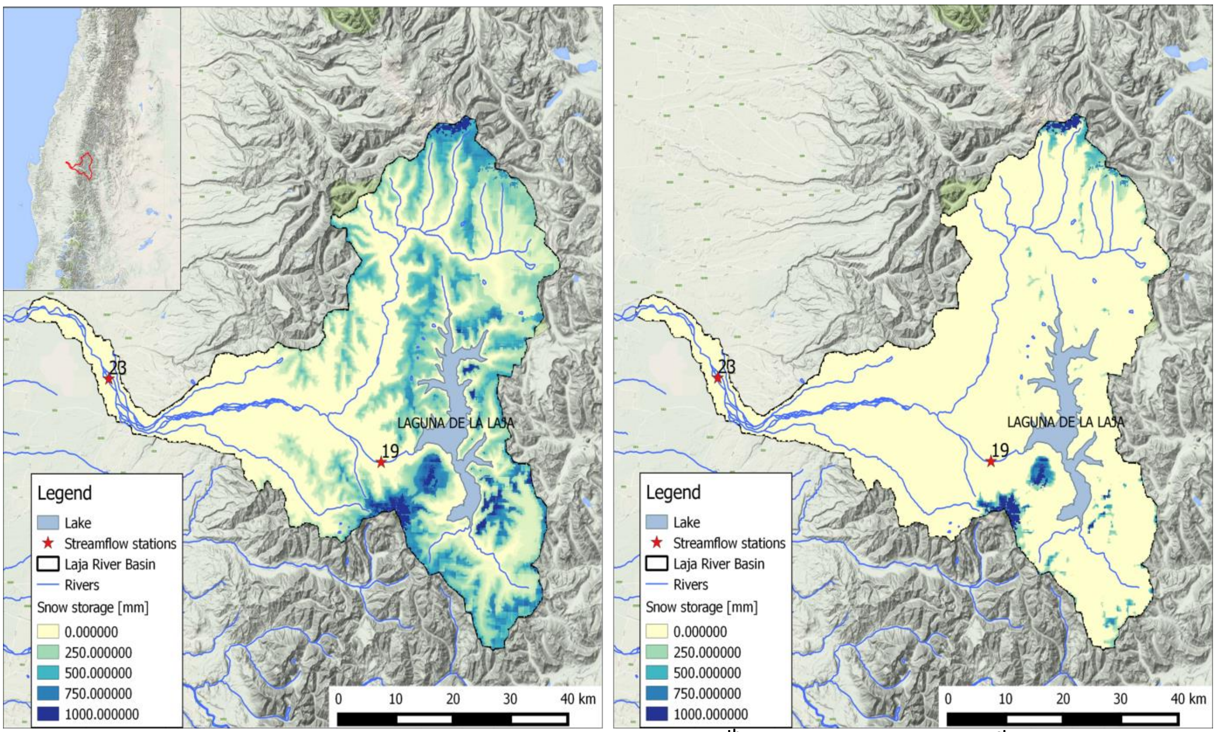

Figure 10: Snow storage [mm] as simulated by the SPHY model on the 12th of August (left) and the 1st of October (right) during the snow melting season of 2013 in the Laja River Basin.

3)
Section 3: I think that the case studies included here are quite interesting, but very little explanation of the results is provided. I recommend going through this section carefully and provide answers to these questions, together with further interpretation of the results presented in the manuscript.

Although we agree that more detail and explanation of the results could benefit the manuscript, our goal here is not to provide full details of the three applications shown, because each of these applications could be a publication on their own, which in fact the application focusing on snow and glacier-fed river basins is (Lutz et al., 2014). As stated by reviewer 2, the manuscript is already rather long, and including more details and explanation would make the manuscript even longer. Therefore, our goal here is to provide the reader with some typical example applications for which the SPHY model is a suitable model to be used, and not go into full details for each of these applications. However, we have answered the reviewer's questions related to each of these applications below.

- 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?

We are indeed presenting the simulated and measured soil moisture content of one field, containing one soil moisture sensor. The use of one soil moisture sensor was mentioned on page 1716 line 28, and page 1717 lines 1-2. Because it was a demonstration project it was infeasible to install, monitor, and calibrate the model for each individual farm field. Therefore, only four other soil moisture sensors were installed in four other fields. Unfortunately, due to the wrong installation of these sensors, the time-series of these sensors contained many errors and missing data, and were therefore not suitable to compare with the model. It may not have been directly clear from the manuscript, but the SPHY model was not fully calibrated for this demonstration study. For this study only an initial calibration was performed to improve soil moisture simulations, tuning only the crop coefficient (Kc) in order to increase/decrease the evaporative demand for water. Soil moisture simulations could be further *improved by conducting a full model calibration, adjusting the soil physical parameters $K_{sat,1}$, $SW_{1,fc}$, $SW_{1,pF3}$, and $SW_{1,pF4.2}$. To state this more clear in the manuscript, we have inserted the text as shown below:*

"Since this study was a demonstration project, only an initial model calibration was performed. The model was in this case most sensitive for the crop coefficient (Kc), affecting the evaporative demand for water. As can be seen in Fig. 5, the temporal patterns as measured by the soil moisture sensor are well simulated by the SPHY model. Based on daily soil moisture values, a Nash-Sutcliffe (Nash and Sutcliffe, 1970) model efficiency coefficient of 0.6 was found, indicating that the quality of prediction of the SPHY model is "good" (Foglia et al., 2009). Soil moisture simulations could be further improved by conducting a full model calibration, adjusting the soil physical parameters $K_{sat,1}$, $SW_{1,fc}$, $SW_{1,pF3}$, and $SW_{1,pF4.2}$."

- 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.

The metrics in Figure 5 are calculated at monthly time step. This is now mentioned in the figure caption. Calibration and validation was done for the same period (1998-2007), but different station locations were used for the validation, than for the calibration of the model, to ensure an independent validation. We included a table with all station locations that were used in the study and mentioning the metrics and which stations were used for calibration and which stations were used for an independent validation. Also we mention in the table caption that the calibration and validation period is the same.
We added a paragraph citing possible explanations for the observed biases from the original publication. Climate change impact results are not presented here to keep the manuscript length within appropriate limits. However, these are thoroughly discussed in the cited publications.

In order to clarify these matters, we have inserted the following text on page 1719, line 7 after 2050…:

"Table 4 lists the calibration and validation results. Based on the validation results, we concluded that the model performs satisfactory given the large scale, complexity and heterogeneity of the modeled region and data scarcity (Lutz et al., 2014). We use one parameter set for the entire domain, which inherently means some stations perform better than others. In the particular case of the upper Indus, another possible explanation could be uncertainty in air temperature forcing in the highest parts of the upper Indus basin (locations Dainyor bridge, Besham Qila and Tarbela inflow in Tab. 4), since especially in this area, the used forcing datasets are based on very sparse observations."

Updated caption:

"Figure 5. Average monthly observed and SPHY-simulated flow (1998–2007) for the Chatara major discharge measurement location in the Ganges basin (Lutz et al., 2014). Metrics are calculated based on monthly time steps."

Table 4: Station locations used for calibration and validation of the SPHY model in HICAP (Lutz et al., 2014). Three stations were used for calibration for 1998-2007. Five stations were used for an independent validation for the same period. The Nash-Sutcliffe efficiency (NS) and bias metrics were calculated at a monthly time step.

Location	**NS [-]**	**Bias [%]**	**Validation/Calibration**
Dainyor bridge	0.39	58.2	Validation

Besham Qila	0.66	24.7	Validation
Tarbela Inflow	0.63	34.6	Calibration
Marala Inflow	0.65	12.0	Validation
Pachuwarghat	0.90	-1.6	Validation
Rabuwa Bazar	0.65	-22.5	Validation
Turkeghat	0.87	-5.4	Calibration
Chatara	0.87	7.9	Calibration

- 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?

The SPHY model was forced using meteorological forecasts from the European Centre for Medium-range Weather Forecasts (ECMWF) HRES (High Resolution) Model (Andersson, 2013) (http://old.ecmwf.int/products/catalogue/I.html), and the Seasonal Forecasting System (SEAS) (Andersson, 2013) (http://old.ecmwf.int/products/catalogue/V.html). The HRES model, with a spatial resolution of 0.125 degrees, was used to provide short-term streamflow forecasts, 7 days ahead. To provide streamflow forecasts up to the end of the melting season, forcing from SEAS was used, which has a spatial resolution of 0.75 degrees. The following text has been inserted in the manuscript to make this clear to the reader:

"To forecast streamflow during the snow melting season, the SPHY model was forced with gridded temperature and precipitation data from the European Centre for Medium-range Weather Forecasts (ECMWF) HRES (High-Resolution) Model (Andersson, 2013), and the Seasonal Forecasting System (SEAS) (Andersson, 2013). The HRES model provided short-term (7-day) meteorological forecasts on a spatial resolution of 0.125°, whereas the SEAS model provided daily forecasts on a spatial resolution of 0.75°, 7 months ahead, and was used to forecast streamflow up till the end of the melting season."

Minor comments

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

These references have been added as suggested.

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).

We agree that the processes included in the modelling framework are dependent on the catchment properties. It is therefore required that the user knows which characteristics and processes are relevant for their catchment of interest. If this is known, then the irrelevant processes (modules) can be turned off. Instead of mentioning this point explicitly in the introduction, we've modified the text on page 1693 where the modules are discussed in detail, and we've inserted the text as shown below.

Inserted text:

"It should be noted, however, that the hydrologic model structure should be specific to the catchment's characteristics (Pomeroy et al., 2007; Clark et al., 2008; Niu et al., 2011; Essery et al., 2013; Clark et al., 2015a, b). It is therefore essential that the user knows which catchment characteristics and processes should be included in their modeling framework."

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).

We agree that it may not be directly clear what type of model the SPHY model is. Especially the following sentence may cause some confusion: "The main terrestrial hydrological processes are described in a ***physically*** *consistent way……… over time and space." To clarify: SPHY is a spatial distributed leaky bucket (conceptual) type of model. In order to make this statement clear, we have changed the sentence in section 2.1 to:*

"The main terrestrial hydrological processes are described in a ***conceptual*** *way so that changes in storages and fluxes can be assessed adequately over time and space."*

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).

We agree that the manuscript would greatly benefit from the inclusion of a table describing the adjustable model parameters. Therefore, we have included the table as shown below in Appendix A of the revised manuscript. Instead of using the acronym 'free' or 'observable' for parameter type, we renamed the fourth column of this table to 'observable', because in our opinion all parameters are observable, whereas one parameter may be very easy to observe and another may be very difficult to observe and is therefore often used as a calibration parameter. With + we indicated whether the parameter is easy (+++), moderate (++), or very difficult to observe.

Table A1. Overview of SPHY model parameters. The last column indicates if this parameter is easy (+++), moderate (++), or difficult (+) to observe.

Acronym	Description	Units	Observable
Kc	Crop coefficient	-	++
Kc_{max}	Maximum crop coefficient	-	++
Kc_{min}	Minimum crop coefficient	-	++
$NDVI_{max}$	Maximum NDVI	-	+++
$NDVI_{min}$	Minimum NDVI	-	+++
$FPAR_{max}$	Maximum Fraction of Absorbed Photosynthetically Active Radiation	-	++
$FPAR_{min}$	Minimum Fraction of Absorbed Photosynthetically Active Radiation	-	++
T_{crit}	Temperature threshold for precipitation to fall as snow	$^{\circ}\mathrm{C}$	+
DDF_s	Degree Day Factor for snow	$\mathrm{mm}\ ^{\circ}\mathrm{C}^{-1}\mathrm{d}^{-1}$	+
SSC	Water storage capacity of snowpack	$\mathrm{mm\ mm}^{-1}$	+
$GlacF$	Glacier fraction of grid-cell	-	+++
DDF_{CI}	Degree Day Factor for debris free glaciers	$\mathrm{mm}\ ^{\circ}\mathrm{C}^{-1}\mathrm{d}^{-1}$	+
DDF_{DC}	Degree Day Factor for debris covered glaciers	$\mathrm{mm}\ ^{\circ}\mathrm{C}^{-1}\mathrm{d}^{-1}$	+
F_{CI}	Fraction of GlacF that is debris free	-	+++
F_{DC}	Fraction of GlacF that is covered with debris	-	+++
$GlacROF$	Fraction of glacier melt that becomes glacier runoff	-	+
$SW_{1,sat}$	Saturated soil water content of first soil layer	mm	+++
$SW_{1,fc}$	Field capacity of first soil layer	mm	+++
$SW_{1,pF3}$	Wilting point of first soil layer	mm	+++
$SW_{1,pF4.2}$	Permanent wilting point of first soil layer	mm	+++
$K_{sat,1}$	Saturated hydraulic conductivity of first soil layer	$\mathrm{mm\ d}^{-1}$	+++
$SW_{2,sat}$	Saturated soil water content of second soil layer	mm	+++
$SW_{2,fc}$	Field capacity of second soil layer	mm	+++
$K_{sat,2}$	Saturated hydraulic conductivity of second soil layer	$\mathrm{mm\ d}^{-1}$	+++
$SW_{3,sat}$	Saturated soil water content of groundwater layer	mm	+
slp	Slope of grid-cell	$\mathrm{m\ m}^{-1}$	+++
δ_{gw}	Groundwater recharge delay time	d	+
α_{gw}	Baseflow recession coefficient	d^{-1}	++
BF_{tresh}	Threshold for baseflow to occur	mm	+
kx	Flow recession coefficient	-	+

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

We have inserted the following sentence:

"The soil column structure is similar to VIC (Liang et al., 1994, 1996) with two upper soil stores and a third groundwater store."

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).

In this section we refer to "static data" as suggested by the reviewer, but regarding "dynamic variables" we do not refer to "meteorological forcings" only. Although the main dynamic variables are meteorological forcing data, such as precipitation and temperature, SPHY can also be forced with other data, such as remotely sensed NDVI (see page 1692 line 27-29). Therefore, we have changed the sentences:

"As input SPHY requires data on state variables as well as dynamic variables. For the state variables the most relevant are: Digital Elevation Model (DEM), land use type, glacier cover, lakes/reservoirs

and soil characteristics. The main dynamic variables are climate data such as precipitation, temperature, and reference evapotranspiration."

Into:

"As input SPHY requires static data as well as dynamic data. For the static data the most relevant are: Digital Elevation Model (DEM), land use type, glacier cover, lakes/reservoirs and soil characteristics. The main dynamic data consists of climate data, such as precipitation, temperature, and reference evapotranspiration."

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

Yes, TD does denote the daily temperature range. The word DAILY has been inserted.

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

"Short of water" is related to the amount of water that is required by a crop to transpire at its potential rate. If a crop is short of water, then the crop experiences stress and reduces its potential transpiration to an actual transpiration rate. To make it more clearly, we have modified this sentence to:

"According to Allen et al. (1998), the ET_r is the evapotranspiration rate from a reference surface with access to sufficient water to allow evapotranspiration at the potential rate."

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.

The main goal of this section is indeed to calculate the maximum canopy storage. Therefore we have modified the title of this section to "Maximum canopy storage".

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).

The Kp coefficient is hard-coded and therefore NOT a parameter. To prevent misinterpretation we've removed the following sentence:
"If desired this value can easily be altered in the model code."

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.

We agree that the use of the words refreeze and refrozen can cause some confusion. To clarify: SSW_t is the amount of melt water stored in the snowpack that can freeze in the next time-step, whereas SSW_{t-1} is the amount of melt water that has frozen in the previous time-step. In order to make this clearer in the manuscript, we have changed "refreeze" to "freeze", and "refrozen" to "frozen".

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.

We think our description may have confused the reviewer, because the reviewer first mentions lateral flow, and then refers to capillary rise. In order to make things clear: capillary rise can only occur from the second to the first soil layer, which is clearly stated in the text.

If the user runs the SPHY model using the groundwater module, then lateral flow only occurs from layer 1, which is clear from equations 28 and 29. If the user runs the model without the groundwater module, for example when he/she is only interested in soil moisture simulations in locations where the groundwater table is very deep and doesn't affect moisture conditions in the first soil layer, then lateral flow also occurs from the second soil layer. This is in our opinion well explained in lines 23-24 on page 1704, lines 1-9 on page 1705, and in equation 31.

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.

The pF-curve relates the moisture content of the soil with its binding capacity. This relation is unique for each soil type. The binding capacity is a suction force (H) and is therefore often expressed in cm negative water column. The pF-value is simply a conversion of the suction force (H), and is calculated using equation 33. More information regarding pF-curves can be found in:

Ehlers, W., Goss, M. 2003. Water Dynamics in Plant Production. CABI Publishing, Cambridge, USA.

To make this clearer in the manuscript, we have elaborated the text in Section 2.7.2 and inserted the text as shown below:

"This critical value can be determined using the soil water retention curve (pF-curve), which relates the moisture content of the soil with its binding capacity. This relation is unique for each soil type. The binding capacity is a suction force (H) and is therefore often expressed in cm negative water column. The pF-value is simply a conversion of the suction force (H), and is calculated as:

$$pF = \log_{10}(-H)$$

"

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.

As suggested by the reviewer the text in Section 2.7.3 has been condensed to:

"Since the SPHY model runs on a daily time-step, the model does not account for sub-daily variability in rainfall intensities. Therefore, the Hortonian runoff process (Beven 2004, Corradini et al., 1998), which refers to infiltration excess overland flow, is considered less important. For this reason SPHY uses the saturation excess overland flow process, known as Hewlettian runoff (Hewlett, 1961), to calculate surface runoff."

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.

The lag time for percolation is indeed computed using exactly the same equation as for the lag time in lateral flow. The lag time is calculated using the same equation (41), because the speed in which water can move through the soil is mainly dependent on the saturated hydraulic conductivity (Ksat). In the original manuscript it was already mentioned that it is calculated using the exact same equation (lines 1-3 page 1710). We have inserted the text as shown below to justify why the exact same equation was used:

"Since the speed in which water can move through the soil is mainly dependent on the saturated hydraulic conductivity (K_{sat}), the travel time for percolation is calculated the same way as the travel time for lateral flow (Eq. 41)."

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.

Because the model is running on a daily time step, t always equals 1. Therefore, it has been removed from the equation to show the equation in a more compact form.

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).

This has been modified has suggested by the reviewer.

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.

Rain runoff (RRo) is indeed the sum of surface runoff (RO) and lateral flow (LF). Although this was stated on page 1712 lines 7-8 as "Rainfall runoff is the sum of surface runoff (RO, Sect. 2.7.3) and lateral flow from the first soil layer (LF_1, Sect. 2.7.4)", it may not be clear that "rainfall runoff" is the same as "rain runoff". Therefore we have changed "Rain runoff" into "Rainfall runoff", and moved this sentence directly after the description of the different components.

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.

To solve the St. Venant equations (not used in the SPHY model) the use of very small time-steps is indeed required to provide numerical stability. Therefore, the following sentence has been added to the manuscript:

"The use of very small time steps in the St. Venant equations is required to provide numerical stability."

23)

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

The accuflux function simply calculates for each cell the accumulated specific runoff from its upstream cells, including the specific runoff generated within the cell itself. The accuflux is a PCRaster built-in function, and only requires the flow direction network, and the cell specific runoff.

If for example there are 10 cells upstream of cell Y, and each of these cells have the same specific runoff of for example 2 m^3/s, then the accuflux function results in an accumulated flow of: 10 x 2 + 2 = 22 m^3/s in cell Y.

The following sentence has been added to the manuscript to make this point more clear:

"This can easily be obtained by using the accuflux PCRaster built-in function, which calculates for each cell the accumulated specific runoff from its upstream cells, including the specific runoff generated within the cell itself."

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'.

"Successfully" in the context of the SPHY application in Central Asia (ADB 2012, Lutz et al., 2012a; 2012b) means that the model has been setup, calibrated against measured streamflow, and used to project the outflow from upstream basins by forcing the model with an ensemble of 5 GCMs. To prevent the misinterpretation of "successfully", we have removed the word "successfully", resulting in the following sentence:

"In Central Asia, SPHY was applied in a study (ADB 2012; Lutz et al., 2012a, b) that focused on the impacts of climate change on water resources in the Amu Darya and Syr Darya river basins."

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'.

With "harsh environments" we refer to difficult to access areas because of the high altitudes and extreme low temperatures. Therefore, "harsh environments" is better replaced with "harsh conditions". These "harsh conditions" lead to the fact that it will be difficult to install instrumentation and obtain real-time physical data from these instruments. A combination of data retrieved from both in-situ sensors and Earth Observation (EO) satellites in these data-scarce environments under harsh conditions has therefore the potential to improve the forecasting capability of hydrological models.

We agree that operational statistical forecasting approaches can provide skillful seasonal forecasts using large scale climate variables and in-situ meteorological data. The objective of this case study was to demonstrate the capability of SPHY to be used in operational mode to forecast seasonal streamflow, and we are therefore NOT saying that the SPHY model outperforms all statistical *forecasting approaches. To address these matters, we have modified the text of "In harsh environments…….. management organizations." (Page 1719, lines 11-18) to:*

"In data-scarce environments and inaccessible mountainous terrain, like in the Chilean Andes, it is often difficult to install instrumentation and retrieve real-time physical data from these instruments. This real-time data can be useful to capture the hydro climatic variability in this region, and improve the forecasting capability of hydrological models. Although statistical models can provide skillful seasonal forecasts, using large scale climate variables and in-situ data (Piechota and Chiew 1998; Grantz et al. 2005; Regonda et al. 2006; Bracken et al. 2010), a particular hydropower company in Chile was mainly interested in the potential use of an integrated system, using measurements derived from both Earth Observation (EO) satellites and in-situ sensors, to force a hydrological model to forecast seasonal streamflow during the snow melting season. The objective of the INTOGENER project was therefore to demonstrate the operational forecasting capability of the SPHY model in data-scarce environments with large hydro climatic variability."

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.

We have inserted these references as suggested by the reviewer.

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

We agree that future implementations include the possibility to use time steps smaller than 1 day. Therefore, we have included the following text in Section 4:

"Currently, the SPHY model can only run at a daily time step. The implementation of hourly model time steps is foreseen for future SPHY versions, which allows other processes, like e.g. Hortonian runoff (Beven 200;, Corradini et al., 1998) to be included as well. Using hourly instead of daily climate forcings will improve other processes as well, such as snow and glacier melt."

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

We agree that these results were not reported. However, a new figure (Figure 4) showing the evapotranspiration deficit has been included in the revised version of the manuscript. This figure was included as a response to major comment nr. 2).

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

We agree that the text may be too small. Therefore we have increased its font size, as suggested by the reviewer.

Minor edits

30)
P.1688 L10-13: Awkward sentence. Please check grammar.

This sentence does not exist anymore because the abstract has been revised substantially.

31)
P.1688 L18: 'and range from' -> 'including', and delete 'to' in subsequent lines.

This has been corrected as suggested.

32)
P.1689 L17: delete 'ultimate'.

This has been deleted.

33)
P.1689 L18: 'for difficult to include sub-processes' reads awkward. Please check grammar.

This sentence has been rephrased into:

"The strength of hydrological models is that they can provide output on high temporal and spatial resolutions, and for hydrological processes that are difficult to observe on the large scale that they are generally applied on (Bastiaanssen et al., 2007)."

34)
P.1689 L26: 'model-overviews' -> 'model reviews'.

This has been corrected as suggested.

35)
P.1690 L12: 'relevant' -> 'understood'.

This section has been completely revised as part of major comment 1. This sentence does not exist anymore in the revised manuscript.

36)
P.1691 L23: 'model concepts' -> 'modeling concepts'.

This has been corrected as suggested.

37)
P.1692 L1: Delete 'any'.

This has been deleted as suggested.

38)
P.1692 L16-18: Awkward sentence.

This sentence has been rephrased to:

"This accumulated amount is the amount of water in the cell itself plus the amount of water in upstream cells of the cell, and is calculated using the flow direction network."

39)
P.1693 L2: 'data on streamflows' -> 'streamflow data'.

This has been corrected as suggested.

40)
P.1693 L4: 'snow coverage' -> 'snow covered area (SCA)'.

This has been corrected as suggested.

41)
P.1693 L10: 'on daily base' -> 'on a daily basis'.

This has been corrected as suggested.

42)
P.1694 L2-3: 'For routing two modules are available' -> 'Two modules are available for runoff routing'.

This has been corrected as suggested.

43)
P.1694 L19: 'method' -> 'methods'.

Based on comment 26 of the other reviewer, this paragraph has been condensed resulting in the deletion of this sentence.

44)
P.1695 L2: delete 'evaporation equivalents'.

This sentence has been rephrased to:

"The constant 0.408 is required to convert the units to mm, and Ra can be obtained from tables (Allen et al., 1998) or equations using the day of the year and the latitude of the area of interest."

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'.

This has been deleted as suggested.

46)
P.1696 L4-6: Awkward sentence.

This sentence has been rephrased to:

"This approach shows the flexibility of SPHY to use remote sensing data (e.g. NDVI) as input to improve model accuracy."

47)
P.1696 L11: There is no need to spell out NDVI again.

This has been corrected as suggested.
48)
P.1698 L4: ‘First of all’ -> ‘First,’

This has been corrected as suggested.

49)
P.1699 L7: Delete ‘on’.

This has been deleted.

50)
P.1701 L2-3: Suggest ‘…which is the total water equivalent of snow melt [mm] that…’

This has been corrected as suggested.

51)
P.1703 L19: This sentence reads like a ‘tongue twister’. I suggest re-wording.

This sentence has been rephrased to:

“The percolated glacier water is added to the water that percolates from the soil layers of the non-glacierized part of the grid cell (Sect. 2.7.1 and Sect. 2.7.6), which eventually recharges the groundwater.”

52)
P.1705 L1: ‘e.g.’ -> ‘- for instance -’.

This has been corrected as suggested.

53)
P.1705 L12: ‘As was’ -> ‘As it was’.

This has been corrected as suggested.

54)
P.1705 L15: ‘as soons as’ -> ‘as soon as’.

This has been corrected as suggested.

55)
P.1705 L23: ‘that is’ -> ‘that are’.

This has been corrected as suggested.

56)
P.1705 L24: ‘a evapotranspiration’ -> ‘an evapotranspiration’.

This has been corrected as suggested.

57)
P.1706 L22: Incomplete sentence at the end of paragraph.

The correct sentence is:

"$ETred_{dry}$ is eventually used in Eq. (32) to calculate the ET_a."

58)
P.1707 L16-19: I suggest writing 'Therefore, the drainable volume… needs to be calculated first'.

This has been corrected as suggested.

59)
P.1708 L13-14: I suggest writing 'if the catchment of interest has a time of concentration greater than 1 day'.

This has been corrected as suggested.

60)
P.1710 L8: 'instantaneous' -> 'instantaneously''.

This has been corrected as suggested.

61)
P.1710 L15: 'on day t and t-1' -> 'on days t and t-1'.

This has been corrected as suggested.

62)
P.1712 L12: 'latereral' -> 'lateral'.

This has been corrected as suggested.

63)
P.1712 L24: 'which is' -> 'which are'.

This has been corrected as suggested.

64)
P.1713 L1: 'require' -> 'requires'.

This has been corrected as suggested.

65)
P.1713 L10: 'would be used' -> 'is used'.

This has been corrected as suggested.

66)
P.1713 L22: 'involves the solving of complex…' -> 'involves solving complex…'

This has been corrected as suggested.

67)
P.1713 L24: ‘approacing’ -> ‘approaching’.
This has been corrected as suggested.

68)
P.1714 L10-11: Awkward sentence.

This sentence has been rephrased to:

“To use this routing scheme, SPHY requires a nominal map with the lake cells having a unique ID, and the non-lake cells having a value of zero.”

69)
P.1715 L21-25: ‘ranging from’ -> ‘including’, and delete ‘to’ in subsequent lines.

This has been corrected as suggested.

70)
P.1718 L10-11: ‘for such an approach’ -> ‘for such goals’ (SPHY is a modeling approach per se).

This has been corrected as suggested.

71)
P.1718 L21: delete ‘and’.

This has been deleted as suggested.

72)
P.1719 L15: ‘the coming’ -> ‘upcoming

This sentence has been deleted as a result of the reviewer’s minor comment nr. 25.

73)
P.1719 L16 and L19: the authors use ‘INTOGENER’ and ‘INTOGNER’ interchangeably. Which one is correct?

INTOGENER is the correct one to be used here. This has been corrected accordingly.

74)
P.1719 L20: delete ‘that were’.

This sentence has been deleted as a result of the reviewer’s minor comment nr. 25.

75)
P.1719 L21: ‘map-series of snow cover’ -> ‘time series of snow cover maps’.

This has been corrected as suggested.

76)
P.1720 L8: delete ‘(Nash and Sutcliffe, 1970)’ (no need to reference twice).

This has been deleted as suggested.

77)
P.1721 L8: ‘being’ -> ‘including

This has been corrected as suggested.

78)
P.1721 L22: ‘dynamically’ -> ‘dynamical’.

This has been corrected as suggested.

79)
P.1722 L17: delete ‘SPHY

This has been deleted as suggested.

80)
P.1723 L15: ‘emperical’ -> ‘empirical’.

This has been corrected as suggested.

81)
P.1723 L16: ‘dischargen’ -> ‘discharge’.

This has been corrected as suggested.

82)
P.1724 L7: ‘respresentation’ -> ‘representation’.

This has been corrected as suggested.

83)
P.1724 L13: delete ‘even

This has been corrected as suggested.

84)
P.1725 L5: ‘easy’ -> ’easily’.

This has sentence has been deleted as part of major comment 1.

85)
P.1725 L20: ‘decision makers’ -> ’decision-making’.

This has been corrected as suggested.

86)
P.1726 L5: ‘minimzed’ -> ’minimized’.

This has been corrected as suggested.