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Hydrology and Earth System Sciences
Discussions

Interactive comment on “Scenario approach for the seasonal forecast of Kharif flows from Upper Indus Basin” *by* Muhammad Fraz Ismail and Wolfgang Bogacki

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Dear Referee No. 1

We thank you very much for your valuable comments. These will definitely improve our paper. We have tried to answer your main remarks by splitting them into separate comments, which as we hope give a correct interpretation of your major points.

COMMENT: The authors do not review different methods that have been proposed or are in operational use for developing seasonal forecasts. I would expect some discussion on statistical methods as opposed to methods that use numerical weather

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prediction models. At the minimum the Ensemble Streamflow Prediction (ESP) approach, which has been widely used for seasonal water resources predictions should be considered.

RESPONSE: We agree to your comment. We have focussed on the enhancement of SRM+G (mainly inclusion of glacier melt and splitting of the UIB into sub-catchments) in comparison to the other operational forecast models used in Pakistan and not so much on the scenario approach that we have applied. In fact, this approach is quite similar to the NWS Extended Streamflow Prediction / Ensemble Streamflow Prediction (ESP) approach. However it is rather aimed at arriving at a point forecast than to explicitly generate a probabilistic forecast. We will include a discussion on this topic in a revised version.

COMMENT: I could not identify in the results and discussion section the resulting ensembles or evaluation of the results of the scenarios selected. In assessing the skill of the forecasts I think the authors could significantly extend the current discussion and results presented. (. . .) A more elaborate verification of forecasts would be insightful.

RESPONSE: As stated in our response to a similar comment by Referee No. 2, we have focussed on the error in predicted flow volume, as this is the common metric in discussions with the involved authorities. We will substitute Table 4 of the paper by a more detailed comparison of yearly forecast results from all three models as given in the attached Table 01. Furthermore, as suggested by both referees, the forecast skills will be evaluated against reference (climatological) forecasts by quantitative metrics and respective diagrams used in probabilistic forecast verification.

COMMENT: It is not that clear in the manuscript how these [model parameters] have been derived during the calibration. Was this done as a pure calibration exercise, or was some physical basis used to estimate parameter values?

RESPONSE: Apart from the degree-day factors (see next comment) the model parameters have been derived mainly as described in the SRM user manual (Martinec et al.,

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2011). Some were slightly adjusted by manual fitting. We may show a synopsis of the model parameters as given in attached Table 02 and explain briefly how each of them was derived.

COMMENT: What is interesting is the linear relationship, with [degree-day] factors increasing during the season. I would like some more discussion on how realistic this is. Is there a physical reason that these melt-factors increase to such an extent, or is this the result of the calibration procedure?

RESPONSE: Many researcher have addressed the temporal and spatial variability of degree-day factors, e.g. Hock (2003), van den Broeke et al. (2010), and others. However, the complex interactions between atmospheric and surface characteristics affecting the degree-day factor is still not very well understood (He et al., 2014). One mechanism obviously is the accumulation of energy from solar radiation as well as from air temperature during the ‘ripening’ of the snowpack that is different with altitude. The authors have shown and discussed the temporal increase in a paper by Ismail et al. (2015). We may give a more detailed explanation in a revised version.

COMMENT: While RFE is chosen as an input, which given the scarcity of data is to my mind a reasonable choice, it is not so clear if there is an under-prediction of precipitation input. Comparison to the few ground stations may not help as these are, again as the authors note, likely underestimating the precipitation.

RESPONSE: We fully agree that, as others also have noted, ground stations due to their location at the valley floors tend to underestimate the actual precipitation. We therefore have referred in section 2.5 to a paper by Reggiani and Rientjnes (2015) who have compared a number of different studies with own calculations and estimate the mean annual precipitation in UIB to 675 ±100 mm/a, which is higher than in most of the other studies. The RFE basin-wide annual mean for the period 2003 – 2015 is 701 mm/a, which corresponds to the ERA-Interim (681 mm/a) and NCEP/NCAR (705 mm/a) reanalysis means calculated by Reggiani and Rientjnes. Taking into account the much lower values of other precipitation (reanalysis) products as well as of most of the UIB water balance studies, we feel that the RFE product is more likely over- rather than under-estimating the actual precipitation.

COMMENT: . . . the hydrographs the authors present in figures 7&8 do not clearly show the contribution of the different sources of runoff that are considered in the model; direct runoff from precipitation; snowmelt; and glacier melt. (. . .) Although the model itself is not conservative, and does not include a base-flow component such as subsurface flow, the authors could evaluate the water balance across the fourteen-year period they have selected.

RESPONSE: It is not possible to split the calculated daily discharge into the different sources of runoff, as due to SRM's recession flow approach (eq. 1 in the paper) only a small part (about 10%) contributes directly to the daily discharge while the larger part origins from recession flow Qn. In this respect the model is not mass-conservative. Annual water balances give an average contribution of 26%, 53%, and 21% from rain, snowmelt, and glacier melt respectively, which coincides well with figures given by Immerzeel et al. (2010) or Charles (2016).

COMMENT: Overall the presentation of the results and discussion is weak. Results of some of the methods described are not presented, such as the results of the ensemble scenario approach. Also, the hydrographs presented at the two gauging stations are for 2008, and seem not to represent real forecasts, but rather simulations. (. . .) Forecasts have been developed for 2015 and 2016, but the results of these are not really presented, other than stating the estimated error.

RESPONSE: As stated before, we will substitute Table 4 of the paper by a yearly comparison of forecast results with all three models as given in the attached Table 01. Regarding SRM+G, figures for the years 2003 – 2014 are from hindcasts using the developed forecasting procedures, while 2015 and 2016 are genuine forecasts. Fig. 7 & 8 indeed show the results of a model simulation aimed to validate the forecasting

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parameter sets and rules (= historical trace). In addition we shall give e.g. a plume diagram showing the traces of all members of the forecast ensemble.

COMMENT: Finally, the manuscript lacks clear conclusions or take-home messages, as well as an outlook to scientific challenges that have been identified.

RESPONSE: The authors think that they gave some conclusions, e.g. on improving the UIB SRM+G model (inclusion of glacier melt, splitting of the catchment), as well as an outlook on further fields of research, e.g. selection of scenarios respectively weighting of ensemble members according to climate signals. Nevertheless we appreciate the comment as it is indicating, that this is not communicated clearly and we will give a separate and extended chapter 'Conclusions' in a revised version.

COMMENT: The Figures included are not clear and would need to be improved. Figure 3 is to a large extent redundant, and with the division of the basin easily displayed on Figure 1. The figures that include the hydrographs are also not easy to read.

RESPONSE: We have included the splitting of UIB (Figure 3) in the catchment map as suggested (see attached Figure 1) and have simplified the hydrographs.

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van den Broeke, M., C. Bus, J. Ettema, and P. Smeets (2010). Temperature thresholds for degree-day modelling of Greenland ice sheet melt rates. In Geophys. Res. Lett. 37 (18),

Please also note the supplement to this comment:
https://www.hydrol-earth-syst-sci-discuss.net/hess-2017-182/hess-2017-182-AC2-supplement.pdf

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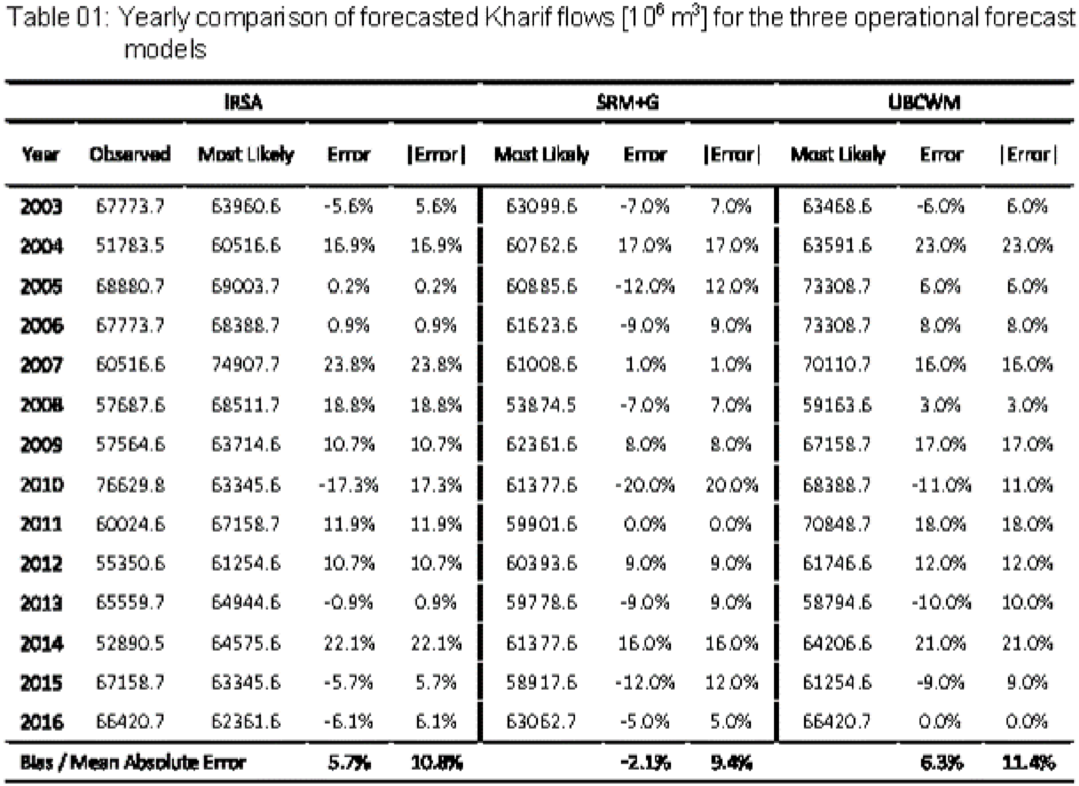

Table 01: Yearly comparison of forecasted Kharif flows [10^6 m^3] for the three operational forecast models

	IRSA				SRM+G			UBCWM		
Year	**Observed**	**Most Likely**	**Error**	**|Error|**	**Most Likely**	**Error**	**|Error|**	**Most Likely**	**Error**	**|Error|**
2003	67773.7	63960.6	-5.6%	5.6%	63099.6	-7.0%	7.0%	63468.6	-6.0%	6.0%
2004	51783.5	60516.6	16.9%	16.9%	60762.6	17.0%	17.0%	63591.6	23.0%	23.0%
2005	68880.7	69003.7	0.2%	0.2%	60885.6	-12.0%	12.0%	73308.7	6.0%	6.0%
2006	67773.7	68388.7	0.9%	0.9%	61623.6	-9.0%	9.0%	73308.7	8.0%	8.0%
2007	60516.6	74907.7	23.8%	23.8%	61008.6	1.0%	1.0%	70110.7	16.0%	16.0%
2008	57687.6	68511.7	18.8%	18.8%	53874.5	-7.0%	7.0%	59163.6	3.0%	3.0%
2009	57564.6	63714.6	10.7%	10.7%	62361.6	8.0%	8.0%	67158.7	17.0%	17.0%
2010	76629.8	63345.6	-17.3%	17.3%	61377.6	-20.0%	20.0%	68388.7	-11.0%	11.0%
2011	60024.6	67158.7	11.9%	11.9%	59901.6	0.0%	0.0%	70848.7	18.0%	18.0%
2012	55350.6	61254.6	10.7%	10.7%	60393.6	9.0%	9.0%	61746.6	12.0%	12.0%
2013	65559.7	64944.6	-0.9%	0.9%	59778.6	-9.0%	9.0%	58794.6	-10.0%	10.0%
2014	52890.5	64575.6	22.1%	22.1%	61377.6	16.0%	16.0%	64206.6	21.0%	21.0%
2015	67158.7	63345.6	-5.7%	5.7%	58917.6	-12.0%	12.0%	61254.6	-9.0%	9.0%
2016	66420.7	62361.6	-6.1%	6.1%	63062.7	-5.0%	5.0%	66420.7	0.0%	0.0%
Bias / Mean Absolute Error			**5.7%**	**10.8%**		**-2.1%**	**9.4%**		**6.3%**	**11.4%**

Fig. 1.

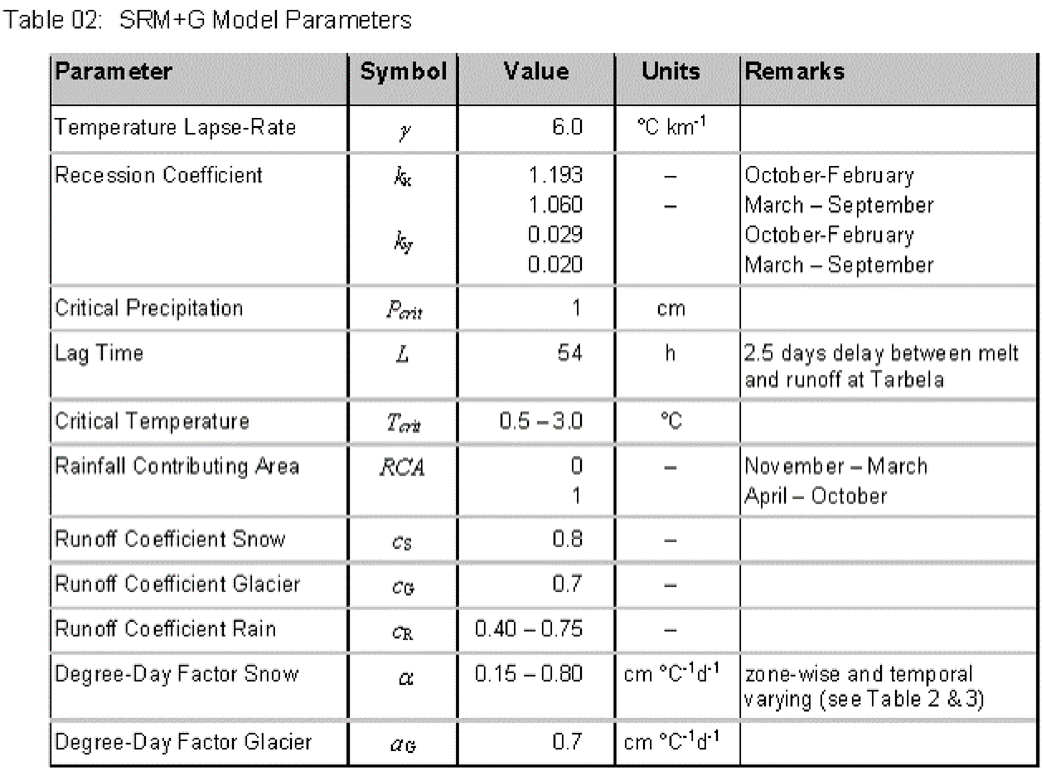

Table 02: SRM+G Model Parameters

Parameter	Symbol	Value	Units	Remarks
Temperature Lapse-Rate	γ	6.0	°C km^{-1}	
Recession Coefficient	k_x	1.193 1.060	– –	October-February March – September
	k_y	0.029 0.020		October-February March – September
Critical Precipitation	P_{crit}	1	cm	
Lag Time	L	54	h	2.5 days delay between melt and runoff at Tarbela
Critical Temperature	T_{crit}	0.5 – 3.0	°C	
Rainfall Contributing Area	RCA	0 1	–	November – March April – October
Runoff Coefficient Snow	c_S	0.8	–	
Runoff Coefficient Glacier	c_G	0.7	–	
Runoff Coefficient Rain	c_R	0.40 – 0.75	–	
Degree-Day Factor Snow	α	0.15 – 0.80	cm °C^{-1}d^{-1}	zone-wise and temporal varying (see Table 2 & 3)
Degree-Day Factor Glacier	α_G	0.7	cm °C^{-1}d^{-1}	

Fig. 2.

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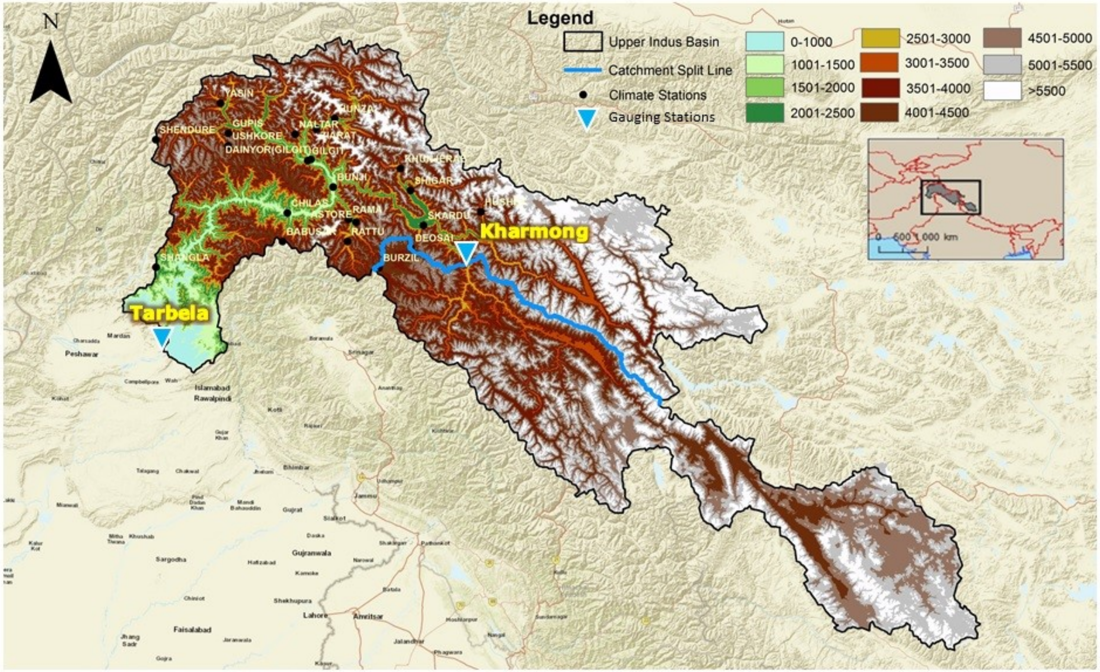

Background Map Source: ESRI Open Street Map

Fig. 3.

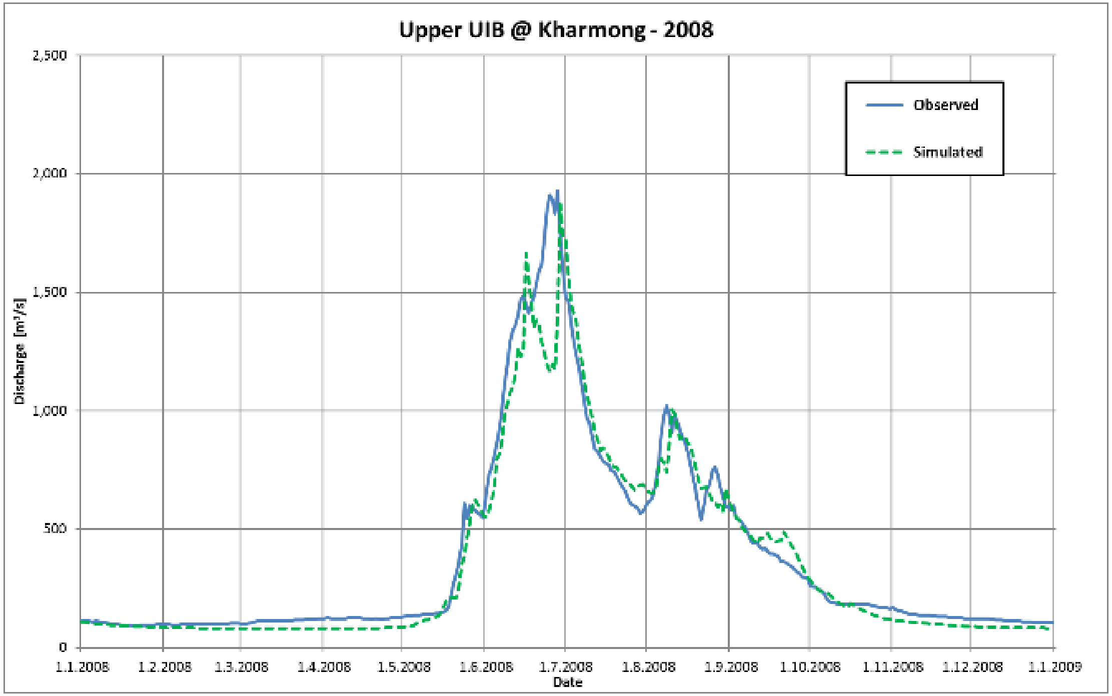

Fig. 4.

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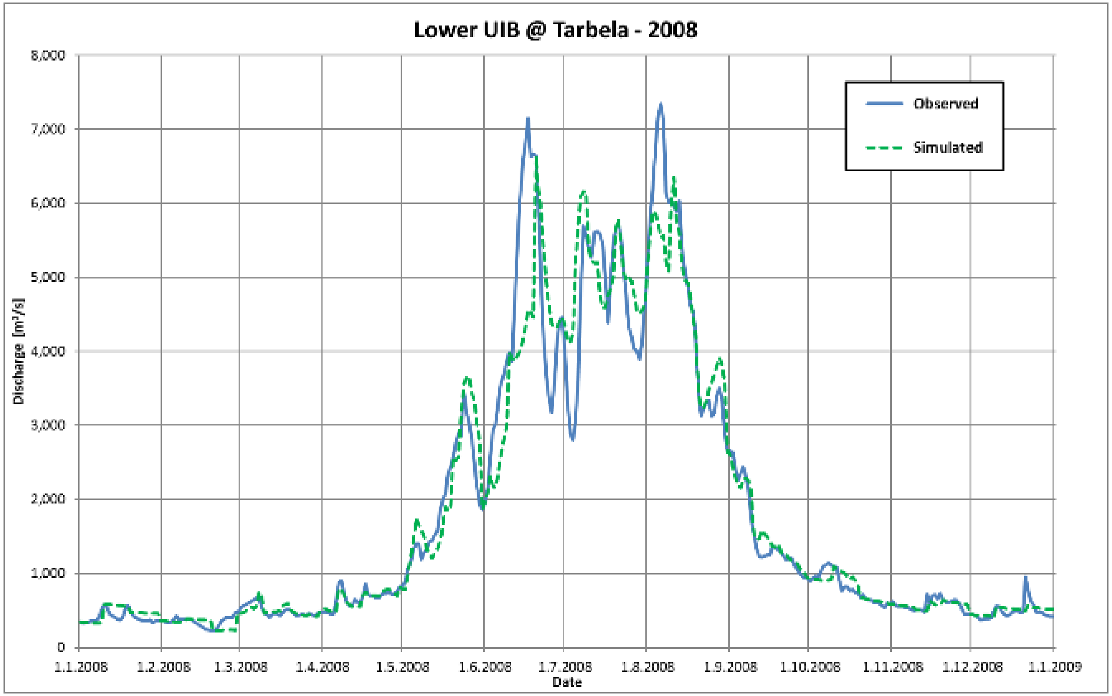

Fig. 5.

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