Reply to reviewer #2

In general the manuscript is quite interesting and the contribution of a global glacier model coupled with a global hydrologic hydrologic model certainly has the potential to be an important and significant contribution to our field.

We appreciate this affirmation of the relevance of our study.

I do have a few but important major comments that relate to both the model coupling and verification of the process representation.

(1) It would be useful to speak more about the coupling approach and its compatibility with BMI (L110-113). In particular, this sentence needs to be expanded on: "Communication with hydrological models is independent of the model language through GRPC4BMI (van den Oord et al., 2019) and BMI (Hutton et al., 2020). Additionally, the ESMValTool (Eyring et al., 2016) implementation in eWaterCycle allows for smooth preprocessing and high compatibility of forcing data."

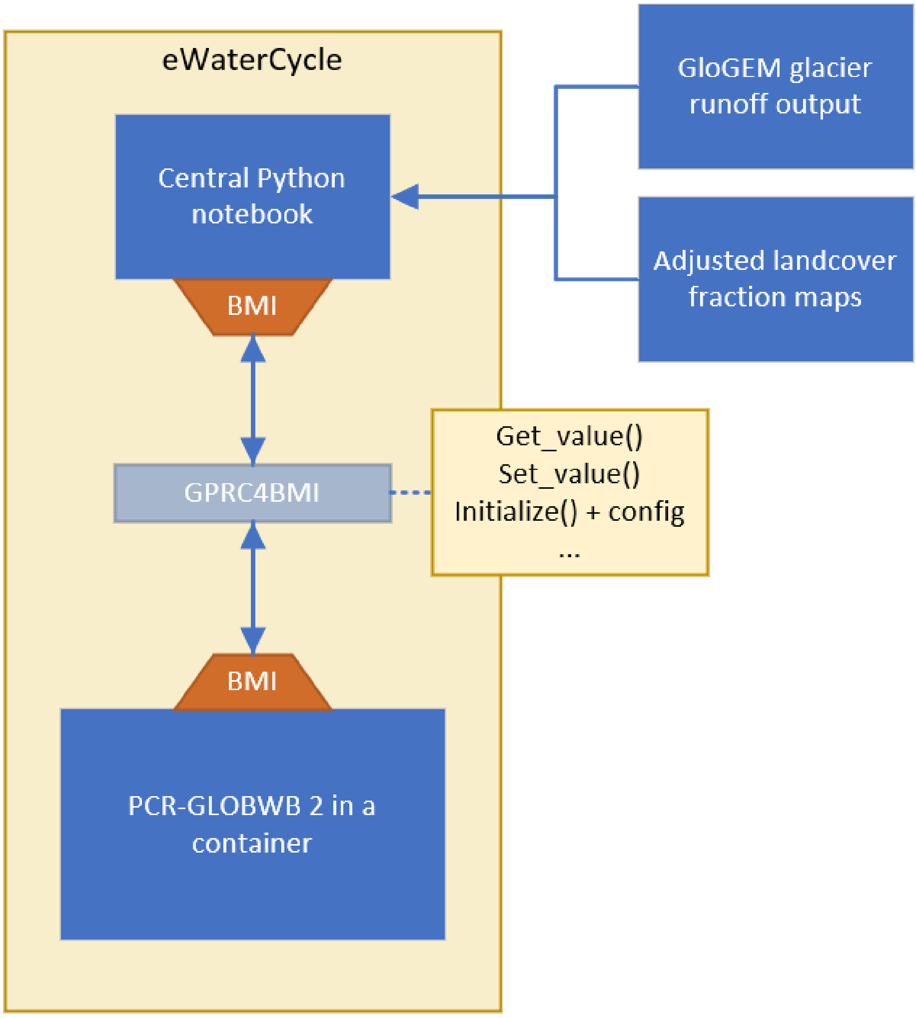
Firstly, please spell out BMI in its first use. In the US in particular, BMI is rapidly becoming the standard for model coupling. It should be noted as to how the coupling approach here is compliant with the BMI standard or can be adapted to BMI.

If the code is not usable with the BMI standard, please add detail to the text so that a user understands that (at least from what is implied by the above sentence) they can use something other than a Jupyter Notebook (Python, for example) to couple the models - because of the language-independent nature of the coupling used by the different modeling components.

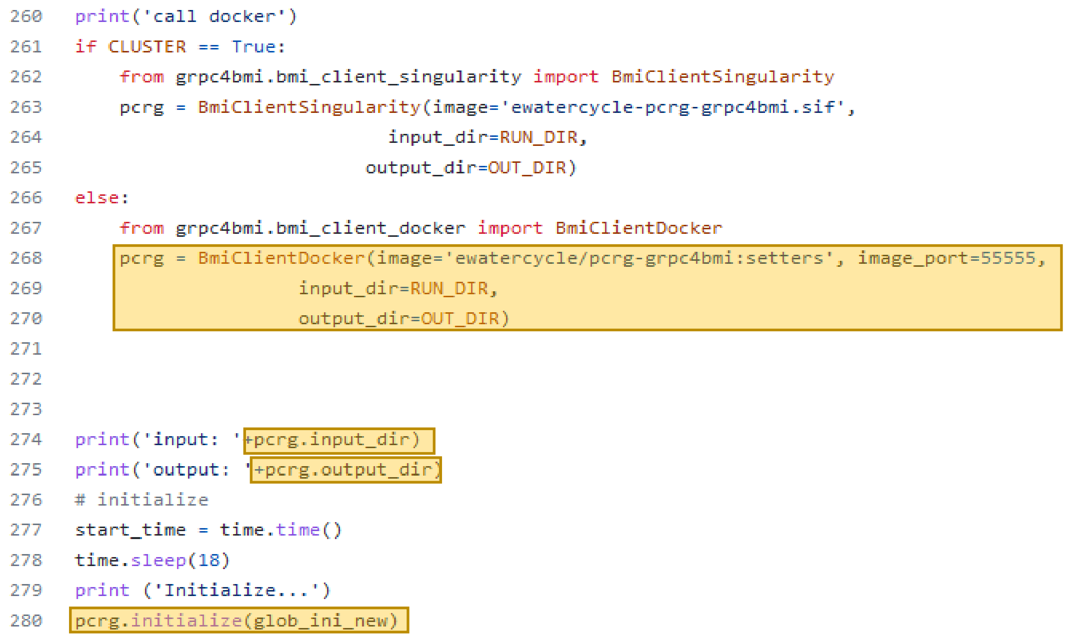
Hopefully, this is the case, as it is certainly an important advancement beyond the potential scientific improvements offered with respect to the process representation.

We agree with the reviewer that we should further elaborate on what BMI is, how we use it for model coupling, and which parts of the coupling are done with or without the BMI interface. In section 2.3 (L110-113), we only discuss the use of BMI on the eWaterCycle platform itself, but not whether the coupling is also established using BMI. Below we explain this in detail and suggest changes to the manuscript.

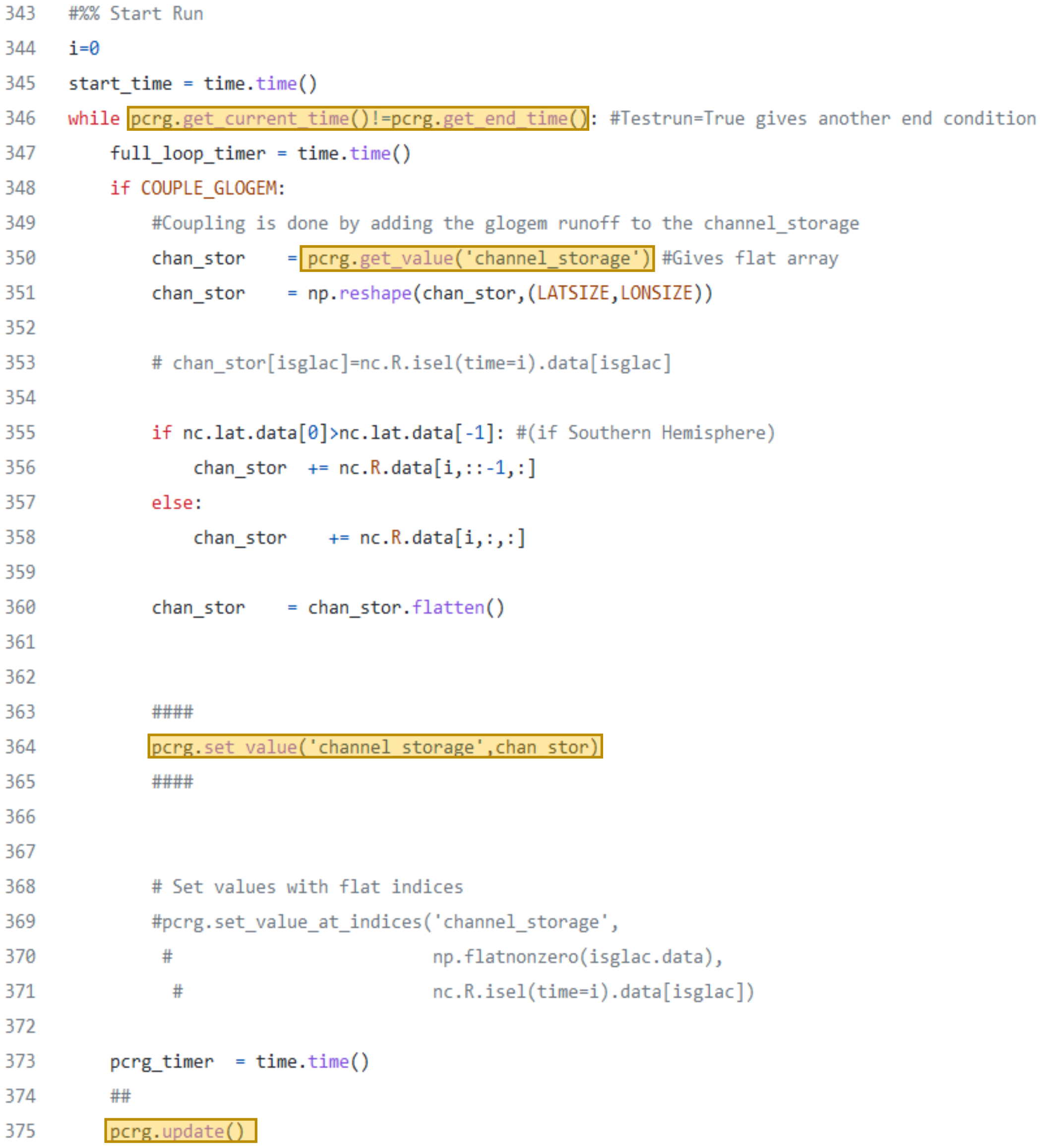
As discussed in section 3.1 (L141-L154), the numerical implementation of the coupling consists of two steps: the addition of the glacier runoff calculated from the Global Glacier Evolution Model (GloGEM) and the removal of the PCR-GLOBWB 2 glacier runoff. As for the first step, the *channel_storage* variable in PCR-GLOBWB 2 can be adjusted using BMI, and thus the GloGEM glacier runoff is added to PCR-GLOWB 2 using the get_value() and set_value() BMI functions. This communication is established using the existing eWaterCycle architecture: BMI calls from the central python notebook (client) are conveyed and translated to the BMI implementation in PCR-GLOBWB 2 (server) using GRPC4BMI, and vice versa. Concerning the second step, the adjusted landcover fraction maps (which exclude all glacierized area) can be handed over to the model using a class in the eWaterCycle package that creates the model configuration file, which is then passed to the model via the BMI initialize function. This communication therefore also takes place through a standard model interface and not at the model itself. The creation of the adjusted landcover fraction maps needs to be done manually however. The flowchart below illustrates this numerical implementation of the coupling, and the code snippets show how the BMI and eWaterCycle functions (in yellow) are used for the coupling of GloGEM (Github link).



```python
if ADJUST_LANDCOVER!=False:
    if ADJUST_LANDCOVER=='GRASSLANDS':
        FRAC_PREFIX = 'grassf'
    elif ADJUST_LANDCOVER=='PROPORTIONAL':
        FRAC_PREFIX = 'propf'
    else:
        print('Wrong input ADJUST_LANDCOVER')
    parameter_set.config['landSurfaceOptions']['noLandCoverFractionCorrection']='True'
    parameter_set.config['forestOptions']['fracVegCover']    ='glaciers_landcov/'+FRAC_PREFIX+'_tall.map'
    parameter_set.config['grasslandOptions']['fracVegCover']='glaciers_landcov/'+FRAC_PREFIX+'_short.map'
    parameter_set.config['irrPaddyOptions']['fracVegCover'] ='glaciers_landcov/'+FRAC_PREFIX+'_pad.map'
    parameter_set.config['irrNonPaddyOptions']['fracVegCover']='glaciers_landcov/'+FRAC_PREFIX+'_nonpad.map'
elif ADJUST_LANDCOVER==False:
    parameter_set.config['landSurfaceOptions']['noLandCoverFractionCorrection']='False'
    parameter_set.config['forestOptions']['fracVegCover']    ='global_05min/landSurface/landCover/naturalTall/vegf_tall.map'
    parameter_set.config['grasslandOptions']['fracVegCover']='global_05min/landSurface/landCover/naturalShort/vegf_short.map'
    parameter_set.config['irrPaddyOptions']['fracVegCover'] ='global_05min/landSurface/landCover/irrPaddy/fractionPaddy.map'
    parameter_set.config['irrNonPaddyOptions']['fracVegCover']='global_05min/landSurface/landCover/irrNonPaddy/fractionNonPaddy.map'
else:
    print('Wrong input ADJUST_LANDCOVER')

parameter_set.save_config(glob_ini_new)
```



```
print('call docker')
if CLUSTER == True:
    from grpc4bmi.bmi_client_singularity import BmiClientSingularity
    pcrg = BmiClientSingularity(image='ewatercycle-pcrg-grpc4bmi.sif',
                            input_dir=RUN_DIR,
                          output_dir=OUT_DIR)
else:
    from grpc4bmi.bmi_client_docker import BmiClientDocker
    pcrg = BmiClientDocker(image='ewatercycle/pcrg-grpc4bmi:setters', image_port=55555,
                    input_dir=RUN_DIR,
                    output_dir=OUT_DIR)



print('input: '+pcrg.input_dir)
print('output: '+pcrg.output_dir)
# initialize
start_time = time.time()
time.sleep(18)
print ('Initialize...')
pcrg.initialize(glob_ini_new)
```



```
#%% Start Run
i=0
start_time = time.time()
while pcrg.get_current_time()!=pcrg.get_end_time(): #Testrun=True gives another end condition
    full_loop_timer = time.time()
    if COUPLE_GLOGEM:
        #Coupling is done by adding the glogem runoff to the channel_storage
        chan_stor    = pcrg.get_value('channel_storage') #Gives flat array
        chan_stor    = np.reshape(chan_stor,(LATSIZE,LONSIZE))

        # chan_stor[isglac]=nc.R.isel(time=i).data[isglac]

        if nc.lat.data[0]>nc.lat.data[-1]: #(if Southern Hemisphere)
            chan_stor  += nc.R.data[i,::-1,:]
        else:
            chan_stor    += nc.R.data[i,:,:]

        chan_stor    = chan_stor.flatten()


        ####
        pcrg.set_value('channel_storage',chan_stor)
        ####



        # Set values with flat indices
        #pcrg.set_value_at_indices('channel_storage',
         #                         np.flatnonzero(isglac.data),
          #                        nc.R.isel(time=i).data[isglac])

    pcrg_timer  = time.time()
    ##
    pcrg.update()
```

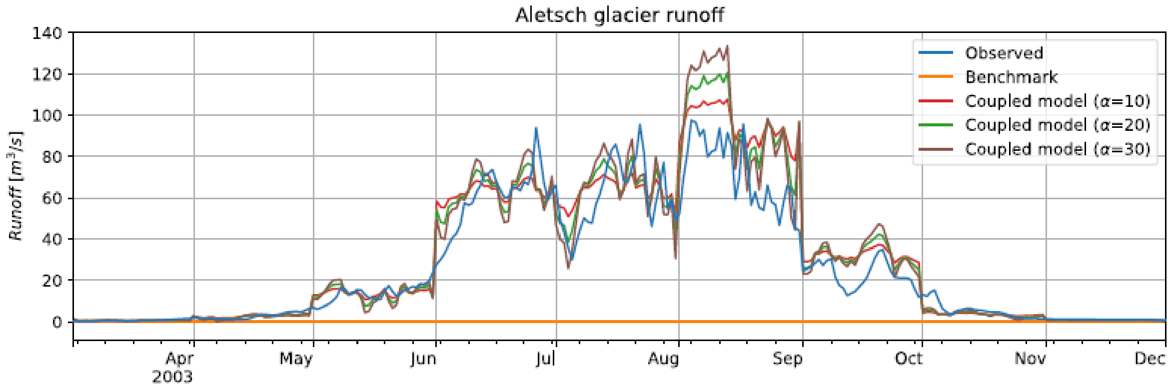
In conclusion, both the addition of the GloGEM runoff and the removal of the PCR-GLOBWB 2 runoff are established using a BMI. Only the creation of the adjusted landcover maps needs to be performed manually. We will make two adjustments to the manuscript to incorporate the reviewer's feedback:

- Swap BMI and GRPC4BMI and spell out BMI in L110, which thus becomes: "Communication with hydrological models is independent of the model language through the Basic Model Interface (BMI) (Hutton et al., 2020) and GRPC4BMI (van den Oord et al., 2019)."
- Adding a new paragraph after L154: "The numerical implementation of the coupling is largely done using standard BMI functionality. As mentioned in section 2.3, the eWaterCycle platform uses BMI for communication with the hydrological models and therefore also allows for requesting and modifying model variables using the *get_value()* and *set_value()* BMI functions. In this case, these functions are used to add the GloGEM glacier runoff to PCR-GLOBWB 2 but other combinations of glacier and hydrological models could be coupled using the same interface. While the adjusted landcover fraction maps need to be created manually, they are passed to the model via the model's configuration file in the BMI *initialize()* function.

(2) In the results and conclusions (and abstract), (see L341 as an example), the statement is made that "The coupled model produces higher runoff across all basins." However, there is not a follow-on statement discussing whether this results in better hydrological modeling of the process in that it matches observations. This type of assessment should be more clearly stated in these sections. Simply producing more runoff through this new model coupling does not necessarily mean the modeling results are better or the process representation is more correct. Using an evidence-based approach with a comparison to observations, and showing how this is an improvement over other modeling approaches is preferred. Otherwise, the manuscript's hydrologic contribution is reduced and more emphasis is placed on the model coupling/software engineering contribution. I would be interested to understand the authors' response to this comment.

If we understand this comment correctly, the reviewer here points to an identifiability problem in our study: when only relying on downstream runoff observations, it is difficult to tell whether (I) the actual glacier representation is improved and glacier runoff underestimation is prevented, or whether (ii) the GloGEM runoff simply compensates for other deficits at the basin level but is an actual overestimation of the glacier runoff on itself. The reviewer is correct in pointing this out, we acknowledge the existence of this problem and the fact that we did not elaborate on it sufficiently.

The best (and perhaps only) way to solve this problem would be to have access to isolated observations of each glacier's runoff, but this is clearly unfeasible considering the thousands of glaciers involved in this study. We did use the observations of one glacier's runoff (Greater Aletsch glacier, with a volume of ca. 15 km^3 the largest of the European Alps) to manually calibrate the temporal downscaling parameter. The results are shown in section two of the supplementary material, and they clearly indicate that at least for this particular glacier PCR-GLOBWB 2 heavily underestimates the glacier runoff with a constant value of zero.



An additional aspect of this study that helps to solve the identifiability problem is the fact that GloGEM has been calibrated on and validated against glacier mass balance observations of different sources (Gardner2013, WGMS 2021). This means that at least on a monthly timescale, the GloGEM glacier runoff is unlikely to be heavily overestimated.

The identifiability problem can be further reduced by taking the runoff observations as close as possible to the glaciers to limit the influence of other runoff generation mechanisms. Therefore, the discharge stations chosen in this study were chosen as upstream as possible while still including all glacier runoff (L118-124). However, we did limit ourselves to a single discharge station per basin, even when other upstream discharge stations were available. Including these would have led to a further reduction of the identifiability problem and a more thorough evaluation of our results. This would be something to consider in future studies.

The final point that we believe provides most of the solution to the identifiability problem is the evidence of the glacier runoff underestimation of PCR-GLOBWB 2. We showed that snow towers are present in a majority of the basins (L252-261), that PCR-GLOBWB 2 does not include the additional glacier runoff from glacier mass loss (L74-76, 262-265), and that these two factors are responsible for a large portion of the difference between the benchmark and the coupled model (figure 5).

To try to take away the doubts that the reviewer had and that other readers might have, we will add a paragraph and adjust the final paragraph in section 5.2 as follows:

“A major limitation of using runoff observations at the basin outlet is that they are not a direct measure of glacier runoff, and therefore we can not fully exclude the possibility that GloGEM overestimates the glacier runoff and simply compensates for other deficits of PCR-GLOBWB 2 at the basin level to reach the higher RRD-scores. While we chose the discharge stations as close to the glacier sink as possible, we excluded in many cases other upstream discharge stations from our analysis. Future studies are encouraged to consider multiple discharge stations per basin to limit this identifiability problem. Nonetheless, several aspects of our study point against the abovementioned possibility. Firstly, since GloGEM has been calibrated and validated with glacier mass balance observations (Gardner et al., 2013) it is unlikely that GloGEM heavily underestimates glacier runoff, at least on a monthly scale. Secondly, an indication that the PCR-GLOBWB 2 underestimation stems from glacierized areas is given by the observation at the Aletsch glacier (see section 2 of the Supplement), where PCR-GLOBWB 2 simulates zero runoff over multiple years. Finally, in section 5.1 we provide evidence that the difference in glacier parameterization between PCR-GLOBWB 2 and GloGEM is responsible for a large part of the difference in runoff.

In conclusion, strongly glacier-influenced basins produce at the same time higher and more significant RRD scores, and we have shown this to be mostly attributable to the difference in glacier representation. The coupling of GloGEM is therefore likely to prevent significant underestimation of glacier runoff in PCR-GLOBWB 2. While in this study the coupling does not lead to better results for weakly glacier-influenced basins, it is probable that the glacier parameterization has in fact improved the resulting runoff in these basins, at least close to the headwaters, but that this is not visible in the results.”