Dear reviewer 2

We highly appreciate the new review of this manuscript. We noted that the manuscript could increase its quality later of reading your comments.

Following, we point to every comment with their answer indicating the changes done.

Thank you for your valuable time in this review.

Ivo Fustos and co-authors.

RC2: Abstract still needs significant improvements. In particular some caution should be added to the last two sentences

A: We modified the original abstract to a improived version

Original version

> Rainfall-Induced Landslide Early Warning Systems (RILEWS) are critical tools for reducing and mitigating economic and social damages related to landslides. Despite this utility, the Southern Andes do not have an operational-scale RILEWS yet. In this contribution, we present a pre-operational RILEWS based on the Weather and Research Forecast (WRF) model and geomorphological features coupled to logistic models in the Southern Andes. The models have been forced using simulations of precipitation. We correct the precipitation derived from WRF using 12 weather stations through a bias correction approach. The models were trained using 57 well-characterized Rainfall-Induced Landslides (RIL) and validated by ROC analysis. We show that WRF does not represent the spatial variability of the precipitation. Therefore, accurate precipitation needs a bias correction in the study zone. Accurate precipitation simulations allow RILEWS with high predicting capacity (area under the curve, AUC of 0.80) using daily precipitation data and

slope. We conclude that our proposal is suitable at an operational level. The proposed RILEWS will become a support in the mitigation of RIL events related to climate change.

New version

Rainfall-Induced Landslides (RIL) are an issue in the Southern Andes nowadays. RIL affected the population losing lives and critical infrastructure. Rainfall-Induced Landslide Early Warning Systems (RILEWS) can reduce and mitigate economic and social damages related to RIL events. The Southern Andes do not have an operational-scale RILEWS yet. In this contribution, we present a pre-operational RILEWS based on the Weather and Research Forecast (WRF) model and geomorphological features coupled to logistic models in the Southern Andes. The models have been forced using precipitation simulations. We correct the precipitation derived from WRF using 12 weather stations through a bias correction approach. The models were trained using 57 well-characterized Rainfall-Induced Landslides (RIL) and validated by ROC analysis. We show that WRF has strong limitations in the representativity of the precipitation variability. Therefore, accurate precipitation needs a bias correction in the study zone. Accurate bias-corrected precipitation simulation allows high predicting capacity (area under the curve, AUC of 0.80). Our proposal is suitable at an operational level under determined conditions. Moreover, a reliable RIL database and operational weather networks that allow real-time correction of the mesoscale model in the implemented zone are needed. Our model RILEWS could become a support to decision-makers during extreme-precipitation events related to climate change in the south of the Andes and similar climatic zones.

RC2: L10:First mention that landslides is a issue in Andes.

A: Done. Thanks for your suggestion

RC2: L21:"… is suitable...”. Downplay a bit this sentences.

A: We agree. Now we replace the sentences.

Original sentences:

We conclude that our proposal is suitable at an operational level. The proposed RILEWS will become a support in the mitigation of RIL events related to climate change.

Modifed sentences:

We conclude that our proposal could be suitable at an operational level under determined conditions. A reliable RIL database and operational weather networks that allow real-time correction of the mesoscale model in the implemented zone are needed. The RILEWS could become a support to decision-makers during extreme-precipitation events related to climate change in the south of the Andes.

RC2: L52 “The object of the present...”

A: We modified to The objective of the present...

RC2: L62: “A prolonged increase of RIL...”, respect to which baseline?

A: Our apologies. Now, we include the temporal baseline and reference.

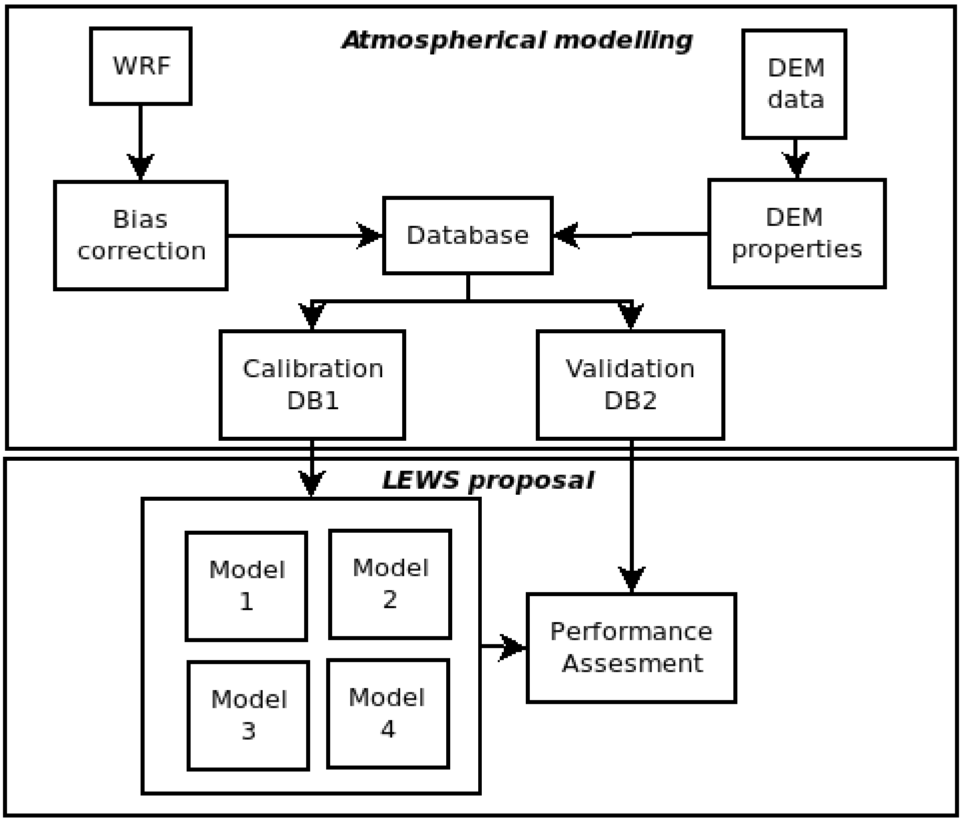
Modified text:

> A prolonged increase of RIL events in this area took place during the period 2012-2019, generated by extreme precipitation events (Espinoza et al., 2019)

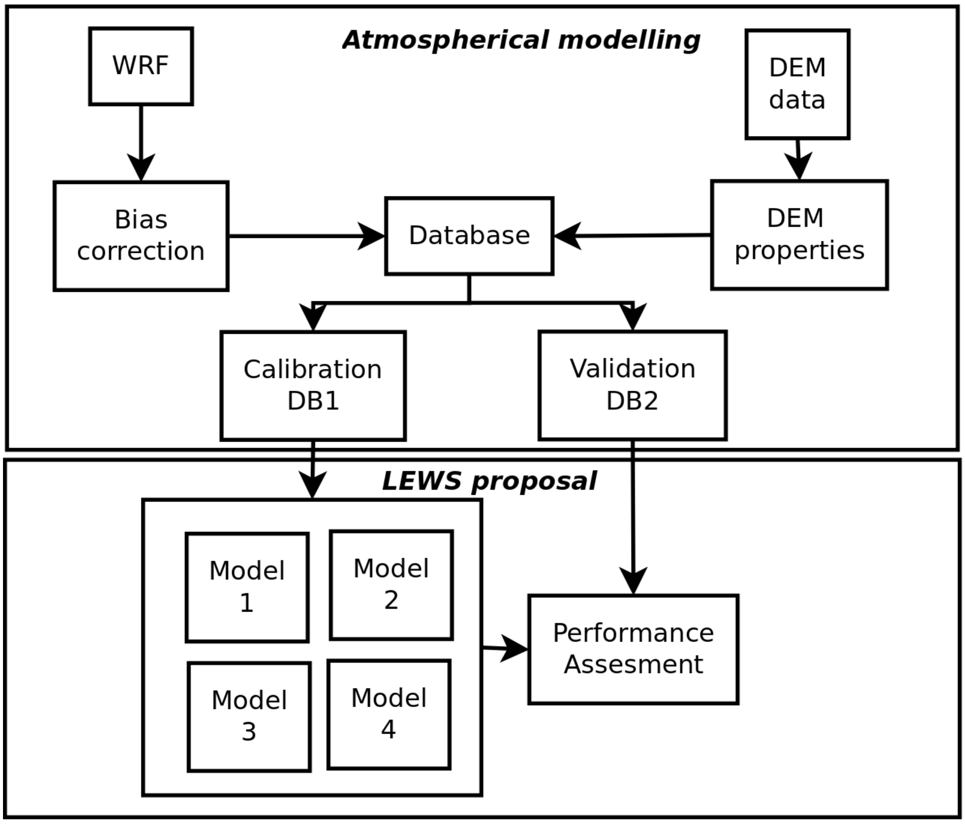
RC2: L100: Figure 2: Improve arrow

A: We agree. Now we modified the figure

Original figure



Modified Figure



RC2: L112: "... compared with 12 meteorological stations...". How were these 12 stations selected?- Are there other rain gauges available?

> A: Only 12 stations were available in the study from 2014 to 2015, mandatory for bias correction of Meteolab codes (see additional information relative to techniques in RC2: 3.1). Moreover, additional stations had been installed with incomplete records recently (2016-2018). The additional stations were installed in the central valley, far from the slopes that show landslides (do not generate relevant information). Therefore, these stations were discarded. In future, we plan to increase the spatial coverage of the RILEWS by integrating new stations provided by the national meteorology authority, national water authority and additional national institutes if they agree to provide data.

RC2: L124: "We used slope values derived from SRTM data.". Mention resolution

> A: We agree. Now, we modified the text
>
> Original text:
>
> > We used slope values derived from SRTM data
>
> Modified text

We used slope values derived from SRTM data with a spatial resolution of 30m

RC2: L133: “PDF generation issue?”, equation 1

A: Thanks by your careful observation. We rebuild the PDF removing the error.

RC2: 3.1. The bias correction methods should be described in more detail. Just Table 1 in not sufficiently explanatory (what is perfect “prog”?)

A: We agree. Thanks for this point. Now, we introduce a better description and justification of the use of these methods. Moreover, we replace perfect prog by perfect prognosis to be consistent with the literature.

Original text:

Biases associated with local effects of the parametrisation selected in WRF were corrected by MeteoLab (Wilcke, 2013) using three different methods (Table 1).

Modified text

Biases associated with local effects of the parametrisation selected in WRF were corrected by MeteoLab (Wilcke, 2013) using three different methods (Table 1). The first approach corresponds to the PP_M4A method with a perfect prognosis approach (San-Martin et al., 2017). The perfect prognosis establishes statistical relationships between the variables at large and local scales. The physical processes on intermediate scales could be ignored (Maraun et al., 2010). The second approach, corresponding to the ISI_MIP method, corrects at different time scales using the monthly mean and followed by correction of the daily variability about the monthly mean. The ISI-MIP method requires a long time series of data, requiring weather stations with low gap data. The last method corresponds to BC_QPQM which focuses on extreme value correction and its effects on the bias correction on the temporal change signal. The methodology requires weather stations without gap data in the time series. In some cases, outliers take place showing problems to correct these situations.

RC2: (Marjanovi? et al., 2018) -> Fix citation

A: Fixed, now is cited as Marjanovi et al., 2018. Thanks for your careful observation.

RC2: Terminology prone-landslide event is not adequate. Perhaps use “likely” instead of “prone”, but reorganize the words

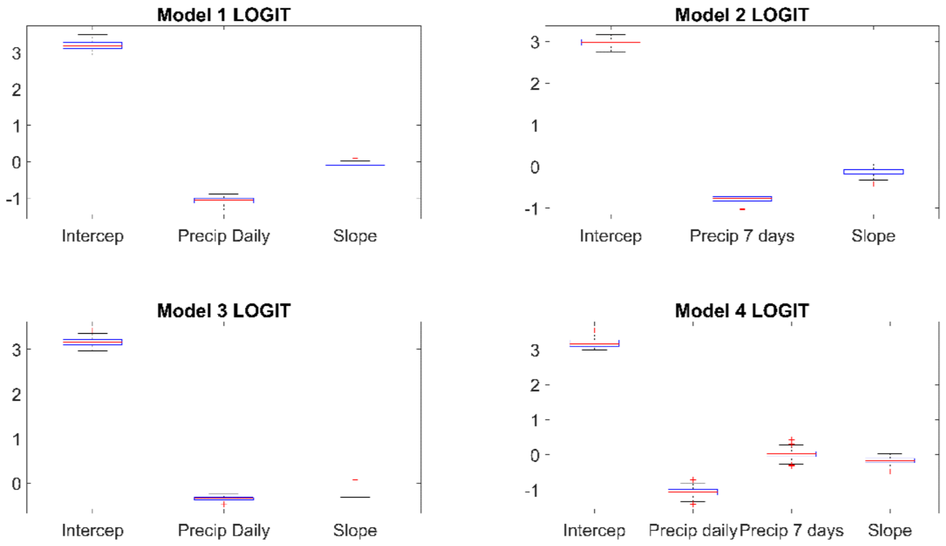
A: We agree. We replaced “prone” with likely and reorganized the words depending on the case. Thanks you

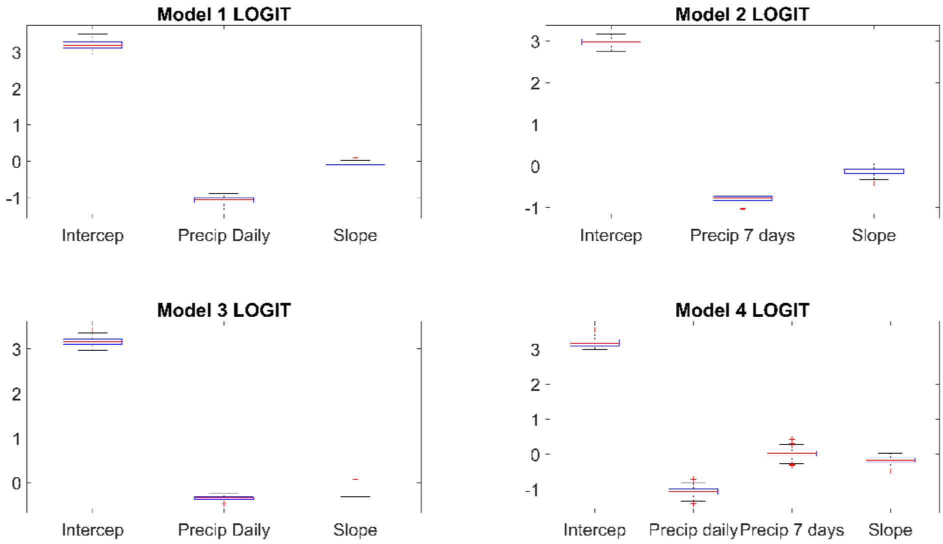
RC2: Spearman -> Spearman correlation coefficient or Linear correlation coefficient

A: Thanks for your detailed observations. We modified from Spearman to Spearman correlation coefficient to allow the readers a correct reading of the manuscript.

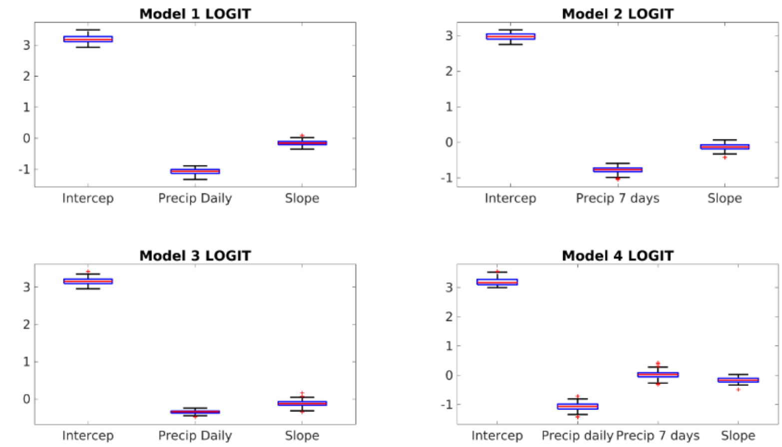
RC2: Figures should be improved. It is not a matter of resolution. For instance Fig. 5 and 6 shows box-plots that are very difficult to see;

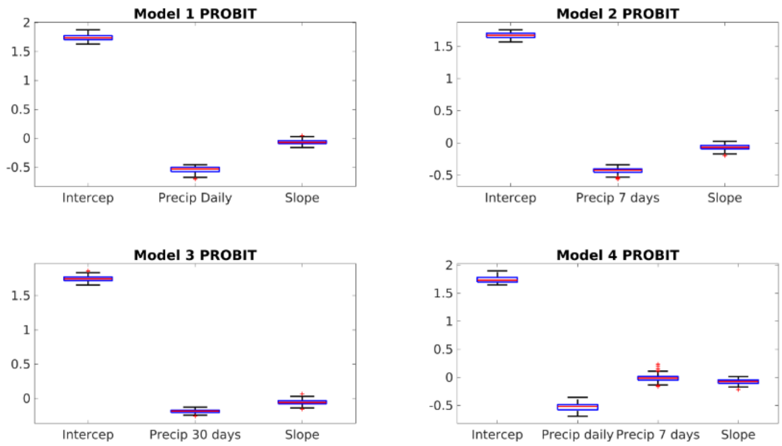
Original plots





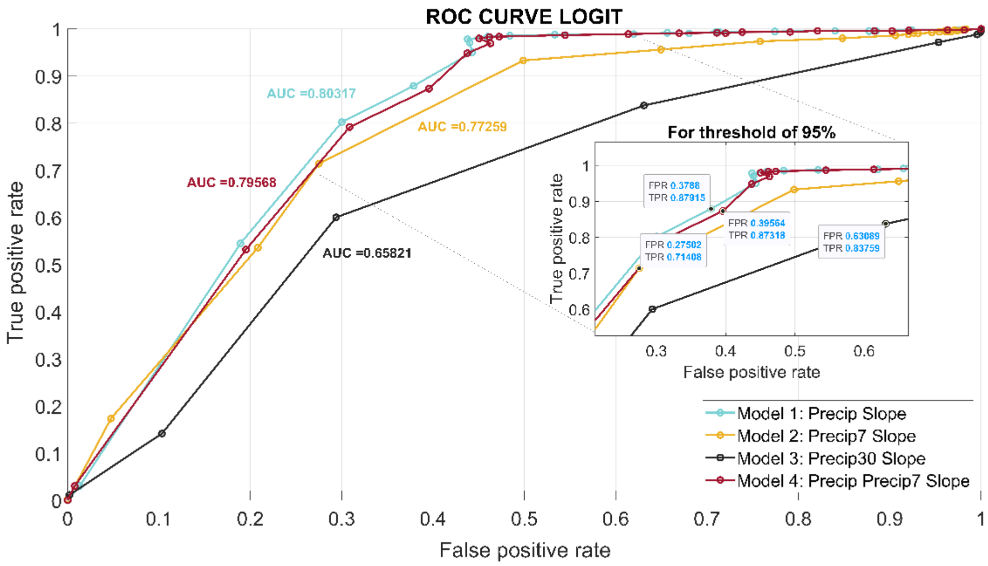
Modified plots. Moreover, We include in figures in eps format.

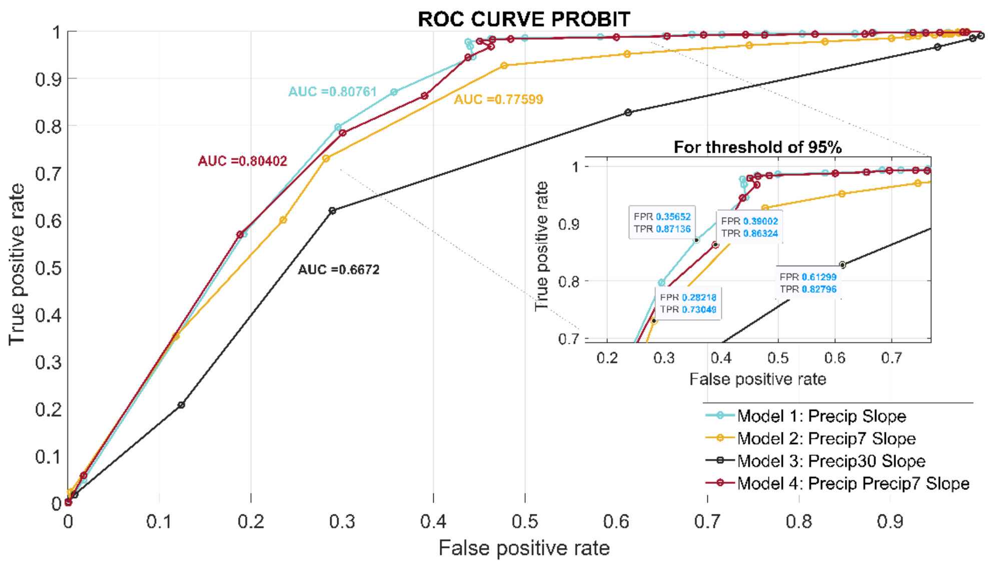




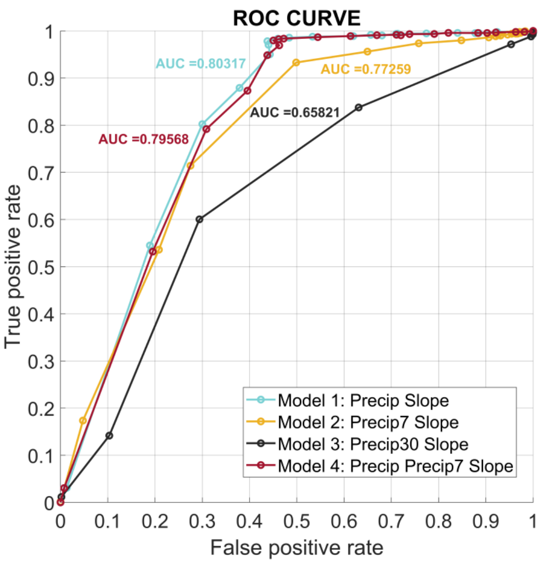
RC2: fig 7 and 8 (ROC curves): the plot area should be square (equal scaling of x- and y-axis), the data visualized though labels (data cursor), should be transferred in a table – in this way there will not be the need for the secondary plot (zoom in). The ROC curves turn back near the peak. This should be fixed by ordering correctly the data.

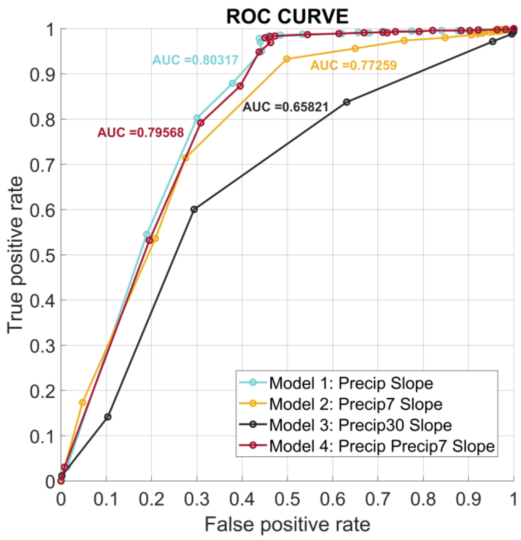
Original plots





Modified plots. The values of TPR and FPR were integrated into tables with reported estimators.





RC2: L 126: “The actual (-> current) database is not suitable…”. Please rephrase: since you are using the database for deriving a predictor for landslide occurrence, it is quite inappropriate to say that in a certain sense you cannot do so.

> A: The aim of the sentence was to establish that the dataset could be used in our study, but will be complicated to take into account a dense catalogue of RIL to thresholds (as the cited author). We removed the sentence to avoid confusion for the readers. Thanks for your suggestion.

RC2: Conclusions should evidence also the general findings which can be deemed valid in other parts of the globe

A: We agree. We appreciate the comment that increases the impact of our contribution. Now we modified the section.

Original text:

This work evaluated the implementation of a RILEWS based on a logistic model and forced by geomorphological and atmospheric conditions in the Southern Andes. For the first time in the Southern Andes, we showed how the WRF model can be integrated into RILEWS operating systems without the need to use ensembles, by use of bias correction processes. This opens the door to the implementation of precipitation-based prediction models without costly computer iterations by ensembles of models (Yáñez-Morroni et al., 2018; Schumacher et al., 2020). New studies of LEWS in the Southern Andes should be directed towards increasing the RIL database currently available. In future we suggest evaluating alternatives to strengthen better quality RIL database generation in this segment of South America, completing the existing database from the records of the Chilean National Geological and Mining Service (Sernageomin). This could help to strengthen future RILEWS in the Southern Andes, improving their performance in terms of sensitivity and specificity. Logistic models proved their capacity to predict RIL events with AUC varying between 0.65 and 0.80, indicating their ability to represent RIL occurrence correctly. Despite the high relative sensitivity of M3, the models which presented high sensitivity and specificity were those which included precipitations on a daily scale (models 1, 2 and 4). Using the precipitation of the previous 7 days could improve this approach to representing soil moisture. There is no network of moisture sensors in the area, so Model 4 should be incorporated as it allows this factor to be represented. Finally, we propose to use models M1 and M4 in conjunction.

Modified text:

This work evaluated the implementation of a RILEWS based on a logistic model and forced by geomorphological and atmospheric conditions in the Southern Andes. For the first time in the Southern Andes, we showed how the WRF model can be integrated into RILEWS operating systems without the need to use ensembles, by use of bias correction processes. Our findings suggest that the bias correction is a useful alternative to numerical ensembles that increases the computational cost at operative scale. This opens the door to the implementation of precipitation-based prediction models without costly computer iterations by ensembles of models (Yáñez-Morroni et al., 2018; Schumacher et al., 2020). A WRF-corrected model could be used at operational scale in different countries in the measure that a weather network exists.

The logistic approach proposed in this study allow to implement rapidly a RILEWS using a limited landslide catalogue in different countries into the future. Our results and previous New studies indicate that of RILEWS in the Southern Andes should be directed towards increasing the RIL database currently available. In future we suggest evaluating alternatives to strengthen better quality RIL database generation in this segment of South America, completing the existing database from the records of the Chilean National Geological and Mining Service (Sernageomin). This could help to strengthen future RILEWS in the Southern Andes, improving their performance in terms of sensitivity and specificity. Logistic models proved their capacity to predict RIL events with AUC varying between 0.65 and 0.80, indicating their ability to represent RIL occurrence correctly. Despite the high relative sensitivity of M3, the models which presented high sensitivity and specificity were those which included precipitations on a daily scale (models 1, 2 and 4). Using the precipitation of the previous 7 days could improve this approach to representing soil moisture. There is no network of moisture sensors in the area, so Model 4 should be incorporated as it allows this factor to be represented. Finally, we propose to use models M1 and M4 in conjunction.

Our proposed RILEWS was developed under limited and scarce atmospheric data. We expect that national emergency authorities integrate this proposal into their routinary activities disseminating the landslide warning information to the stakeholders. The continual improvement will allow increasing the performance and correct alert under different precipitation scenarios. The real-time implementation will allow testing the precipitation representation, assessing the accurate precipitation estimation. We conclude that our RILEWS could become a promising methodology for implementation in similar climatic zones in different countries/latitudes. In future, worldwide scale products such as the Global Landslide database could support future implementation of RILEWS at a regional scale using corrected precipitation products such as the WRF model or satellite precipitation products.