Reply to "Comment on Sensitivity of glaciation in the arid subtropical Andes to changes in temperature, precipitation, and solar radiation by " by

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Short Communication

Reply to “Comment on Sensitivity of glaciation in the arid subtropical Andes to changes in temperature, precipitation, and solar radiation by Vargo et al. (2018)” by Martini and Astini (2018)

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The subtropical Andes (18–30 S) is an interesting area to investigate the relationship between glaciers and climate as there are no modern glaciers, and dated glacial deposits show asynchronous timing of maximum glaciation between three sub-regions (Zech et al. 2008; Blard et al. 2009; Smith et al. 2009; Blard et al. 2013; Ward et al. 2015, 2017; Zech et al. 2017). These regions, which have distinct climates, include the Altiplano, the hyper-arid western cordillera, and the more humid eastern cordillera. Better understanding the climatic drivers of glaciation across these three regions is important for constraining the changes in climate required for the regions to have previously sustained glaciers.

With the aim of investigating differences in large-scale climatic drivers of glaciation between the three regions, not simulating ELAs at specific locations, we calculated the response of equilibrium line altitudes (ELAs) to idealized changes in temperature, precipitation, and shortwave radiation (Vargo et al. 2018). We used a surface energy and mass balance model (SEMB) (Rupper and Roe 2008) driven with NCEP/NCAR reanalysis data (Kalnay et al. 1996). NCEP/NCAR data was originally used because the precipitation is more accurate compared with general circulation models (GCMs), and it included all of the climate variables required for input into the SEMB model. Results showed that glaciation of the hyper-arid western cordillera is the most sensitive of the three regions to changes in precipitation, and that glaciation of the eastern cordillera is the least sensitive to the same changes in climate (Vargo et al. 2018). These results indicate that past glaciation of the western cordillera likely occurred when precipitation was higher than modern, while past glaciation of the eastern cordillera could have been driven largely by lower temperatures.

Martini and Astini (2018) point out that NCEP/NCAR overestimates precipitation, and therefore question the ELA sensitivities for the eastern cordillera presented in Vargo et al. (2018). They note that the coarse resolution of NCEP/NCAR precipitation (1.9) leads to overestimated precipitation particularly in the eastern cordillera, where there is a high precipitation gradient. They go on to argue to that overestimated NCEP/NCAR precipitation invalidates calculated ELA sensitivities for the eastern cordillera, which should be similar to those calculated in the western cordillera (Martini and Astini, 2018).

However, while NCEP/NCAR overestimates precipitation in the subtropical Andes, it does capture the spatial pattern for precipitation across the three regions, with lowest precipitation in the western cordillera and higher precipitation in the eastern cordillera (Table 1). We see similar spatial patterns in higher-resolution precipitation datasets, including WorldClim version2 (1 km and 10 km; WC2) (Fick and Hijmans 2017) and CRU TS v4.01 (10 km) (Harris et al. 2014) (Table 1). All three datasets show that precipitation is lower in the western cordillera compared with the eastern cordillera, suggesting that ELAs in the western cordillera will still be more sensitive to changes in precipitation than ELAs in the eastern cordillera.

Furthermore, the first eigenvector calculated for each of the different precipitation datasets show similar spatial patterns. These were calculated using monthly NCEP/NCAR precipitation (1948–1977), monthly CRU precipitation (1951–2000), and monthly average WC2 precipitation (calculated for 1970–2000). For NCEP/NCAR precipitation, the first eigenvector shows higher values in the eastern cordillera, and lower values in the western cordillera (Fig. 1a), which is also seen for CRU precipitation (Fig. 1b) and WC2 precipitation (Fig. 1c). Of the three regions, the first eigenvector calculated for the Altiplano is the least consistent between NCEP/NCAR and the other two datasets, although it shows the same trend of higher values in the northeast, and decreasing towards the southwest of the sub-region (Fig. 1).

To show the validity of our original results, that ELAs in the western cordillera are still more sensitive to precipitation, we re-run idealized ELA sensitivity experiments using the same SEMB model and NCEP/NCAR data, but with the higher-resolution precipitation datasets. We first use the WC2 precipitation linearly interpolated to a

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Table 1
Mean precipitation ± the standard deviation, as well as minimum and maximum precipitation at elevations over 3750 m, for NCEP/NCAR (NN), WorldClim version 2 (WC2) at the original 1 km resolution, WC2 linearly interpolated to 10 km, and CRU TS v4.01 (CRU) precipitation datasets, across the three regions.

Accumulation (m)	Altiplano	W. Cordillera	*E. Cordillera*
Mean NN	0.702 ± 0.446	0.223 ± 0.037	1.420 ± 0.059
Max NN	1.312	0.242	1.447
Min NN	0.138	0.152	1.294
Mean WC2 (1 km)	0.250 ± 0.097	0.080 ± 0.015	0.247 ± 0.047
Max WC2 (1 km)	0.567	0.178	0.393
Min WC2 (1 km)	0.082	0.040	0.163
Mean WC2 (10 km)	0.256 ± 0.010	0.080 ± 0.015	0.248 ± 0.051
Max WC2 (10 km)	0.568	0.173	0.367
Min WC2 (10 km)	0.102	0.046	0.166
Mean CRU	0.195 ± 0.093	0.161 ± 0.046	0.446 ± 0.075
Max CRU	0.474	0.266	0.697
Min CRU	0.032	0.086	0.327

10 km grid, for computational efficiently. However, WC2 precipitation is calculated using precipitation interpolated between climate stations, for which station density is extremely low in the arid subtropical Andes (Fick and Hijmans 2017). We therefore also use CRU TS v4.01 precipitation (Harris et al. 2014), which was used to drive the same glacier model in Sagredo et al. (2014). Fig. 2 shows ELA response to changes in precipitation, and resulting ELA sensitivity to precipitation, for each of the three regions calculated using the different precipitation datasets. ELA sensitivities calculated using NCEP/NCAR precipitation (solid lines) are the same as presented in Vargo et al. (2018). These results show that for all three precipitation datasets, ELA response to changes in precipitation is higher for the western cordillera (Fig. 2b) compared to the eastern cordillera (Fig. 2c). ELA sensitivity to precipitation is therefore also higher in the western cordillera (Fig. 2e) compared with the eastern cordillera (Fig. 2f). We note that NCEP/NCAR precipitation is calculated for 1948–1977, WC2 precipitation is calculated for 1970–2000, and CRU precipitation is calculated for 1951–2000, and the offset timing that average precipitation is calculated over may introduce additional uncertainties when comparing the three datasets.

While these results show that western cordillera ELAs still more sensitive to precipitation than eastern cordillera ELAs, there are differences in ELA sensitivity calculated with NCEP/NCAR precipitation compared with the higher-resolution precipitation datasets (WC2 and CRU). ELA sensitivities for the western and eastern cordilleras (Fig. 2e, f) are lower when calculated with WC2 and CRU precipitation compared with those calculated from NCEP/NCAR precipitation. However, ELA sensitivities in the Altiplano are higher when calculated with WC2 and CRU precipitation compared with the NCEP/NCAR precipitation (Fig. 2d). While the magnitudes of ELA sensitivity varies across the three precipitation datasets used, the trends in changing ELA sensitivity with changing precipitation is similar. For both the Altiplano and western cordillera, all three precipitation datasets show that ELA sensitivity decreases as precipitation is increased (Fig. 2d, e). In the eastern cordillera, besides an initial decrease in sensitivity calculated from WC2 precipitation, ELA sensitivity stays about constant for changes in precipitation for all three datasets (Fig. 2f).

In summary, the results of sensitivity experiments run with three different precipitation datasets all show that ELAs in the hyper-arid western cordillera are more sensitive to changes in precipitation compared with the eastern cordillera. These results agree with previous works suggesting that glaciation of the western cordillera required higher precipitation than modern, while glaciation of the eastern cordillera could have been driven by lower temperatures or increases in precipitation (Klein et al. 1999; Ammann et al. 2001; Kull et al. 2008). ELAs simulated with the higher-resolution WC2 and CRU precipitation datasets show higher sensitivities in the Altiplano and lower sensitivities in the eastern and western cordilleras compared with original sensitivities calculated with NCEP/NCAR precipitation (Vargo et al. 2018). These results show that ELA sensitivity is dependant on the climate data used to drive the glacier model. However, as NCEP/NCAR does generally capture the spatial pattern of precipitation in the subtropical Andes, it is still useful for investigating large-scale glacial sensitivity. This work highlights the need for more climate observations in the subtropical Andes, as well as better representation of precipitation in reanalysis data and GCMs for the region.

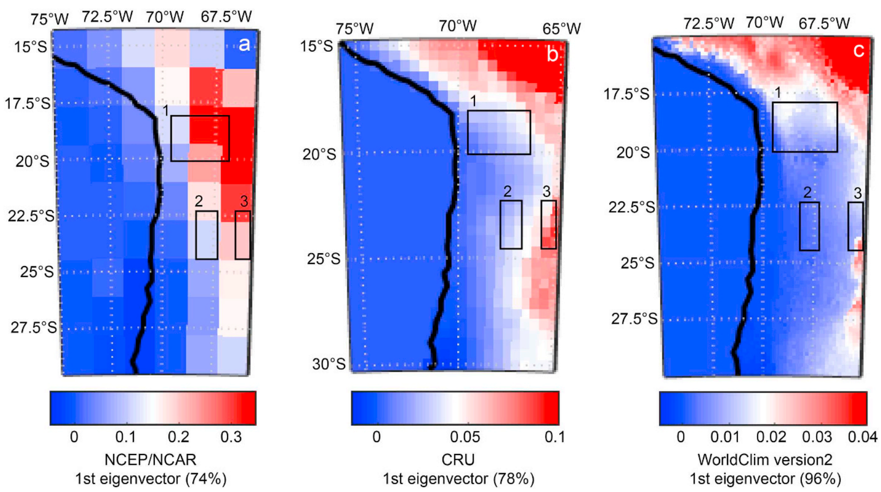

Fig. 1. First eigenvectors calculated for (a) NCEP/NCAR, (b) CRU, and (c) WorldClim version2 precipitation with the percent indicating the fraction of variance explained by each mode. The three sub-regions, the Altiplano (1), western cordillera (2), and eastern cordillera (3), are shown in boxes.

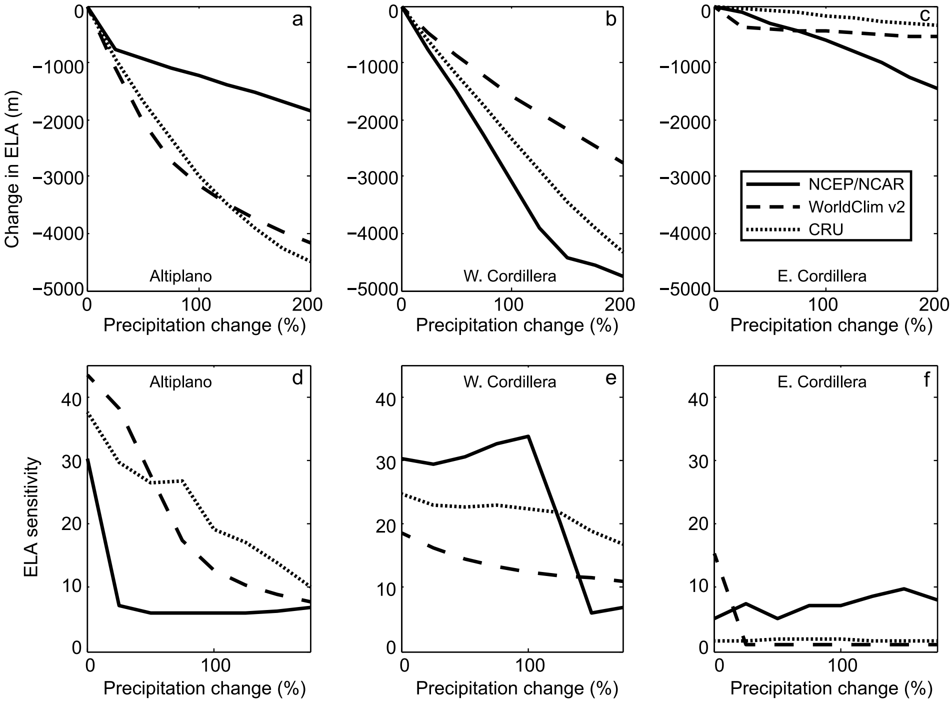

Fig. 2. ELA changes from increasing NCEP/NCAR (solid line), WorldClim version2 (dashed line), and CRU (dotted line) precipitation (with respect to modern values) for the Altiplano (a), western cordillera (b), and eastern cordillera (c), and resulting ELA sensitivity to precipitation in the Altiplano (d), western cordillera (e), and eastern cordillera (f). ELA sensitivity is defined as the absolute value of the derivative of ELA change with respect to changes in % of precipitation.

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References

Ammann, C., Jenny, B., Kammer, K., Messerli, B., 2001. Late Quaternary glacier response to humidity changes in the arid Andes of Chile (18–29 S). Palaeogeogr. Palaeoclimatol. Palaeoecol. 172, 313–326.

Blard, P.H., Lavé, J., Farley, K., Fornari, M., Jiménez, N., Ramirez, V., 2009. Late local glacial maximum in the Central Altiplano triggered by cold and locally-wet conditions during the paleolake Tauca episode (17–15 ka, Heinrich 1). Quat. Sci. Rev. 28, 3414–3427.

Blard, P.H., Lavé, J., Sylvestre, F., Placzek, C., Claude, C., Galy, V., Condom, T., Tibari, B., 2013. Cosmogenic 3 he production rate in the high tropical Andes (3800 m, 20 S): implications for the local last glacial maximum. Earth Planet. Sci. Lett. 377, 260–275.

Fick, S.E., Hijmans, R.J., 2017. Worldclim 2: new 1-km spatial resolution climate surfaces for global land areas. Int. J. Climatol. 37, 4302–4315.

Harris, I., Jones, P., Osborn, T., Lister, D., 2014. Updated high-resolution grids of monthly climatic observations – the CRU TS3.10 Dataset. Int. J. Climatol. 34, 623–642.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., et al., 1996. The NCEP/NCAR 40-year reanalysis project. Bull. Am. Meteorol. Soc. 77, 437–471.

Klein, A.G., Seltzer, G.O., Isacks, B.L., 1999. Modern and last local glacial maximum snowlines in the Central Andes of Peru, Bolivia, and Northern Chile. Quat. Sci. Rev. 18, 63–84.

Kull, C., Imhof, S., Grosjean, M., Zech, R., Veit, H., 2008. Late Pleistocene glaciation in the Central Andes: temperature versus humidity control- a case study from the eastern Bolivian Andes (17 S) and regional synthesis. Glob. Planet. Chang. 60, 148–164.

Martini, M.A., Astini, R.A., 2018. Comment on "Sensitivity of glaciation in the arid subtropical Andes to changes in temperature, precipitation, and solar radiation" by Vargo et al. (2018). Glob. Planet. Change. https://ac.els-cdn.com/S0921818118302716/1-s2.0-S0921818118302716-main.pdf?_tid=8ffa4907-1413-42a2-864d-131a13ee219c&acdnat=1539205905_65d12780b3322f6da94fa2b313e94683.

Rupper, S., Roe, G., 2008. Glacier changes and regional climate: a mass and energy balance approach. J. Clim. 21, 5384–5401.

Sagredo, E.A., Rupper, S., Lowell, T.V., 2014. Sensitivities of the equilibrium line altitude to temperature and precipitation changes along the Andes. Quat. Res. 81, 355–366.

Smith, C.A., Lowell, T.V., Caffee, M.W., 2009. Lateglacial and Holocene cosmogenic surface exposure age glacial chronology and geomorphological evidence for the presence of cold-based glaciers at Nevado Sajama, Bolivia. J. Quat. Sci. 24, 360–372.

Vargo, L., Galewsky, J., Rupper, S., Ward, D., 2018. Sensitivity of glaciation in the arid subtropical Andes to changes in temperature, precipitation, and solar radiation. Glob. Planet. Chang. 163, 86–96.

Ward, D.J., Cesta, J.M., Galewsky, J., Sagredo, E., 2015. Late Pleistocene glaciations of the arid subtropical Andes and new results from the Chajnantor Plateau, northern Chile. Quat. Sci. Rev. 128, 98–116.

Ward, D., Thornton, R., Cesta, J., 2017. Across the Arid Diagonal: deglaciation of the western Andean Cordillera in Southwest Bolivia and northern Chile. Cuadernos de Investigación Geográfica. https://doi.org/10.18172/cig.3209.

Zech, R., May, J.H., Kull, C., Ilgner, J., Kubik, P.W., Veit, H., 2008. Timing of the late Quaternary glaciation in the Andes from 15 to 40 S. J. Quat. Sci. 23, 635–647.

Zech, J., Terrizzano, C., Garca-Morabito, E., Veit, H., Zech, R., 2017. Timing and extent of late pleistocene glaciation in the arid Central Andes of Argentina and Chile (22-41 S). Cuadernos Invest. Geográfica 43.