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Vegetation dynamics and land-cover change along a precipitation gradient in the tropical semi-arid high Andes

M. Otto*, Ch. Höpfner, F. Maussion, D. Scherer

*Corresponding author: marco.otto@klima.tu-berlin.de

CLIMATOLOGY DEPARTMENT OF ECOLOGY

1. Introduction

Besides other factors like land use, soil, groundwater or temperature, precipitation is strongly influencing vegetation and land cover (LC). Various studies showed strong linear relations between annual precipitation and Normalized Differenced Vegetation Index (NDVI) within semi-arid climates of monomodal annual precipitation [1]. The NDVI is also known to represent soil moister content and aboveground Net Primary Production (NNP) [2]. Quantifying inter- and intra-annual precipitation variability and its influence on vegetation and LC is thus important for a deeper understanding of ecosystem variability. It also forms the basis for predicting vegetation productivity and LC changes from time series data of precipitation.

Our study investigates these effects in a selected region of the tropical high Andes [Fig. 1]. Satellite-based remote sensing data offer a cost-effective possibility for retrieving information on vegetation dynamics and LC change. Data from the NDVI product MOD13Q1 (version 5) of the Moderate Resolution Imaging Spectrometer (MODIS) and the gridded 3h precipitation product (3B42 V6) from the Tropical Rain Measurement Mission (TRMM) were used in this study covering the period from 2000 to 2010. NDVI data have a spatial resolution of 250 m and a temporal resolution of 16 days, while TRMM data are available on a 0.25 degree geographic grid at three-hourly intervals.

First we applied a simple LC classification scheme [Tab. 1] using known thresholds derived from NDVI based phenologic metrics [3] over ten hydrological years (Sep-Aug) [Fig. 2]. Then areas were delineated in which no LC change was detected (i.e., stable LC classes). These areas were then aggregated as spatial NDVI means for each of the TRMM pixels along a precipitation gradient. In a second step precipitation of the actual season [Fig. 3 – Fig. 5] and prior season [Fig. 6] were stepwise aggregated to precipitation sums of 16 days to two years and linear correlated with the NDVI means and annual LC –area [Fig. 7]. Snow cover data at different altitudes within a selected river basin was linear correlated with NDVI means of stable and unstable LC-types as well as lake level data [Fig. 8]. Based on our results we propose a concept of vegetation productivity and land cover change related to precipitation and water retention capacity within a water scarce landscape of the Andes [Fig. 9].

2. Vegetation & Precipitation – Methods & Data

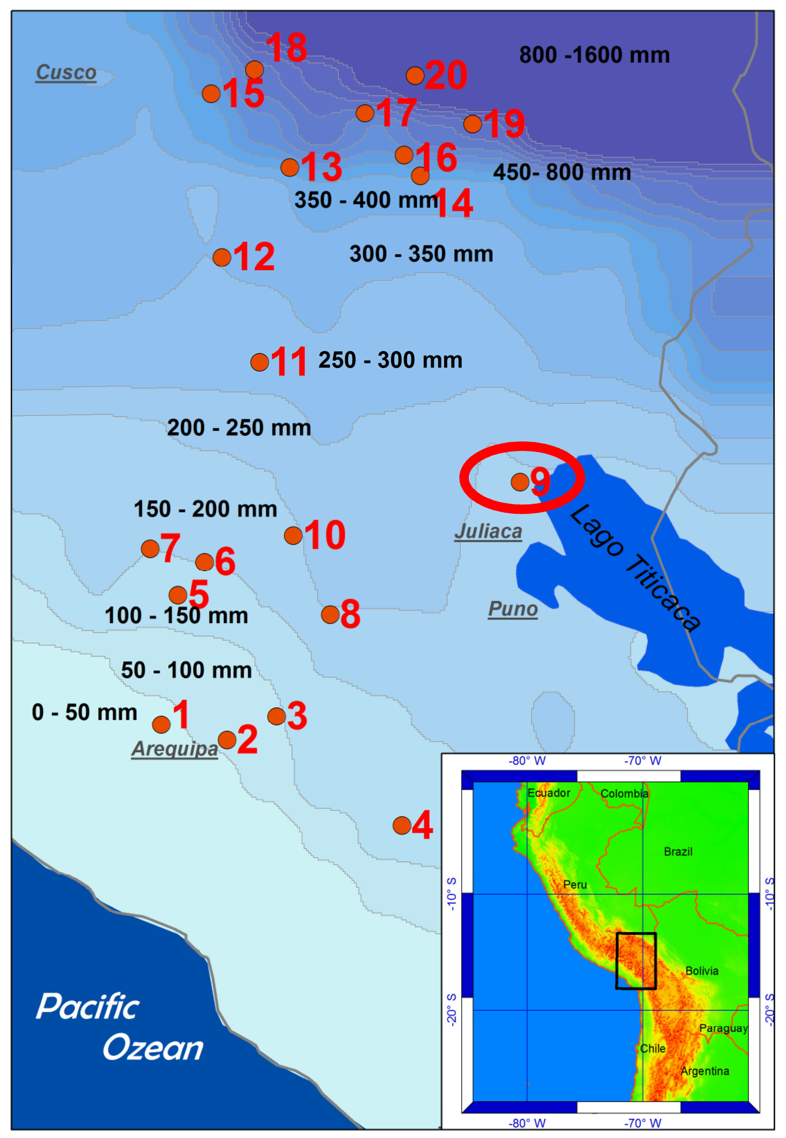

Fig .1: Study region and selected sites along a precipitation gradient northeast of Lago Titicaca in the tropical Andes. Red circled test site (9) within sub-basin of Lago Titicaca (17000 km²)

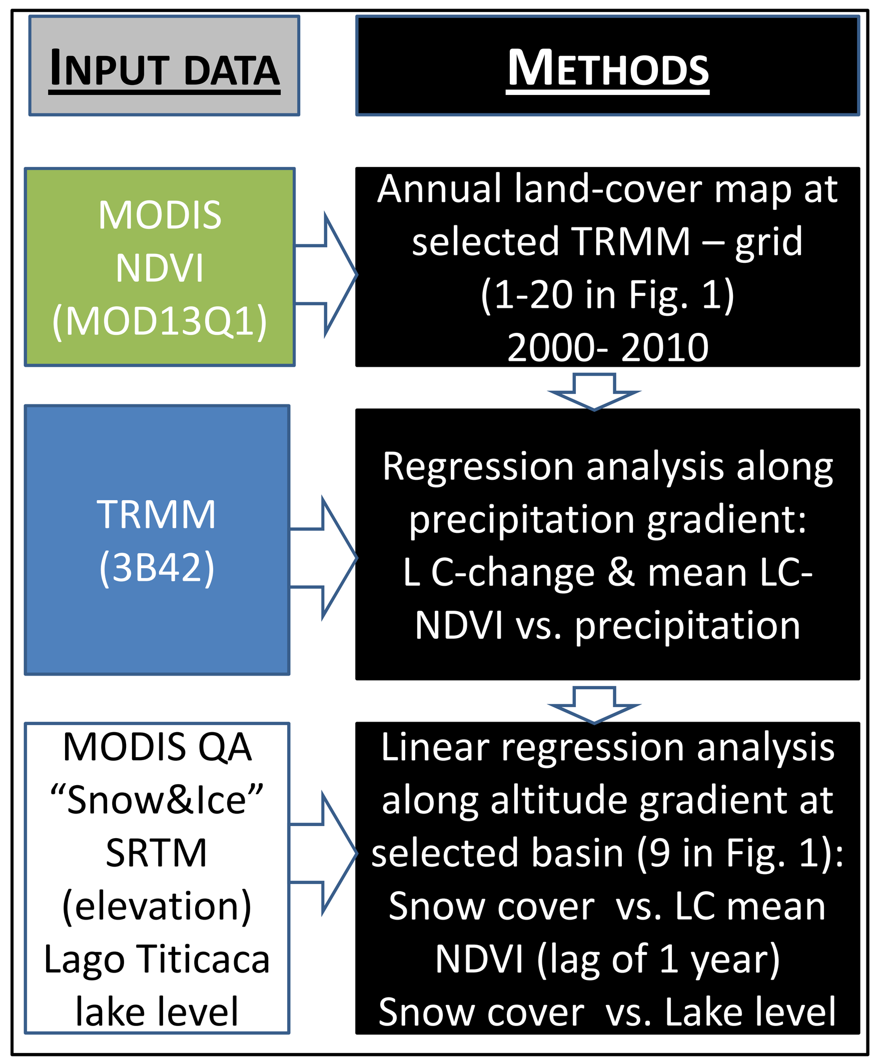

Fig .2: Data and Methods applied.

Tab .1: Land cover classification scheme

Bio-physical characteristics	land cover (LC)	land use (LU)	LC-Type** (seasonal NDVI metrics)
No or very low PV* (very sparsely vegetated)	Bare ground, desert, permanent sow	very dense populated areas, open pit-mining	vlPV - seasonal maximum NDVI below 0.2
low PV* (sparsely vegetated)	Semi-desert, open shruplands	temporal rangelands	lPV -Seasonal mean NDVI below 0.25
constant PV* (dense evergreen vegetation)	perennial wetlands	all season rangeland fodder crops e.g. alfalfa	cPV -seasonal onset NDVI and end of season NDVI greater then 0.4, mean NDVI greater 0.45
high range PV*	temporal wetlands	temporal rangeland Irrigated crops	hrPV Seasonal NDVI range greater 0.4
low range PV*	grasslands	temporal rangeland agriculture (fallow)	lrPV Seasonal NDVI range less 0.4

*Productive Vegetation in terms of NDVI related to ANPP
**hierarchically order of binary decision tree classifier [3]

3. Vegetation productivity and land-cover along the precipitation gradient

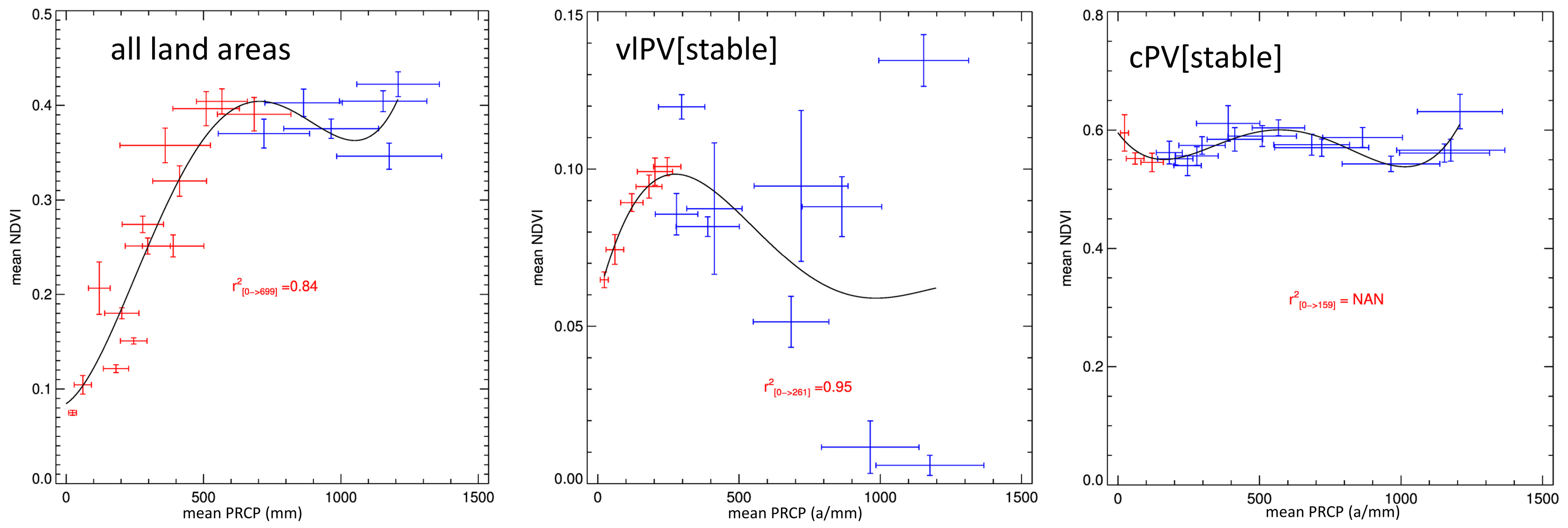

Fig. 3: Polynomial fit of mean precipitation vs. mean NDVI (2000-2010) of selected sites (Fig. 1) along the precipitation gradient - red coloured sites indicate strong linear correlation (r^2=0.84 -> 700 mm)

Fig. 4: Same as in Fig. 3 but for stable vlPV, red coloured sites are within arid climate indicating strong linear correlation (r^2=0.84) up to 260 mm typical to xeric ecosystems (desert at western slopes of the Andes).

Fig. 5: Same as in Fig. 3 but for stable cPV, indicating no correlation along precipitation gradient due to their hydric characteristics (e.g. wetlands [4]).

4. Rain fall & Vegetation productivity (sub-basin)

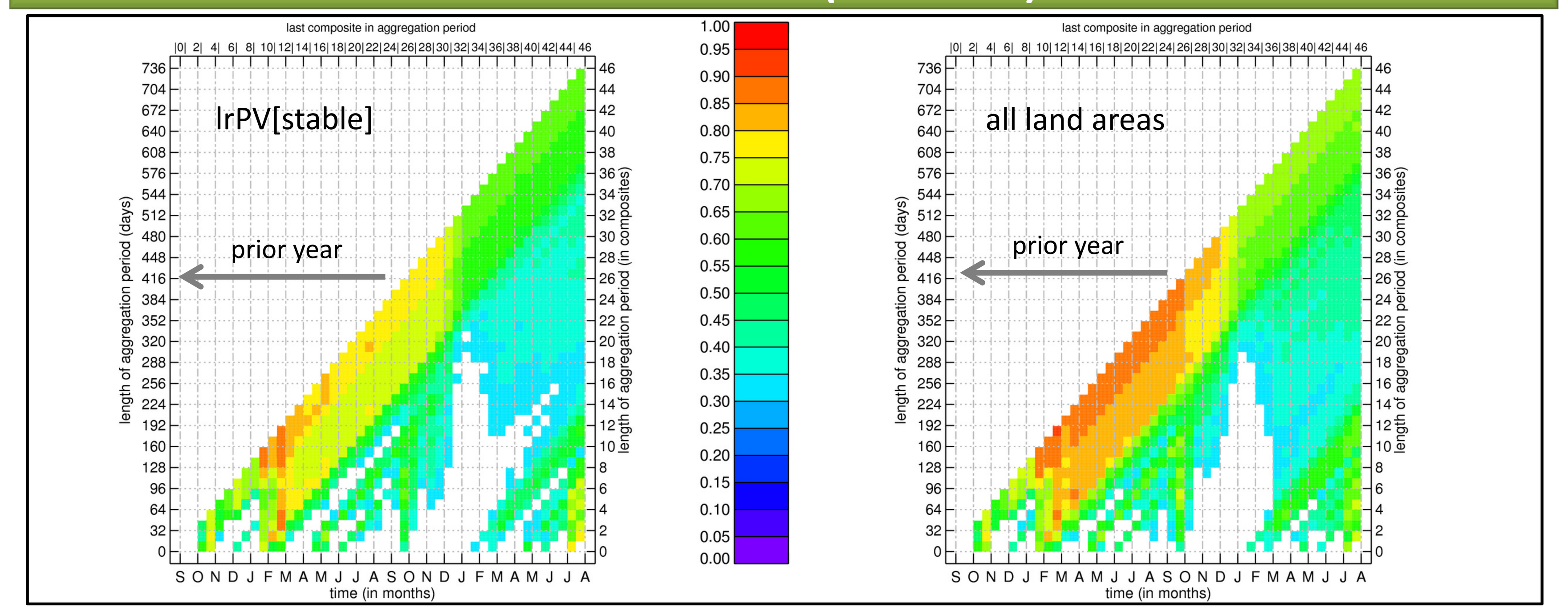

Fig. 6: Matrix of significant (p=0.1, DF=8) correlation coefficients of stepwise aggregated precipitation and annual mean NDVI starting at prior year. Left: stable lrPV strongest correlations (r2= 0.8) to precipitation of prior raining season (Oct-May). Right: mean NDVI off all land areas within study area 9 is correlated strongly with total precipitation of the prior year (above r^2=0.85) indicating annual land cover changes (mean NDVI was used as threshold for land cover classification [Tab. 1]).

5. Snow cover & Vegetation productivity (sub-basin)

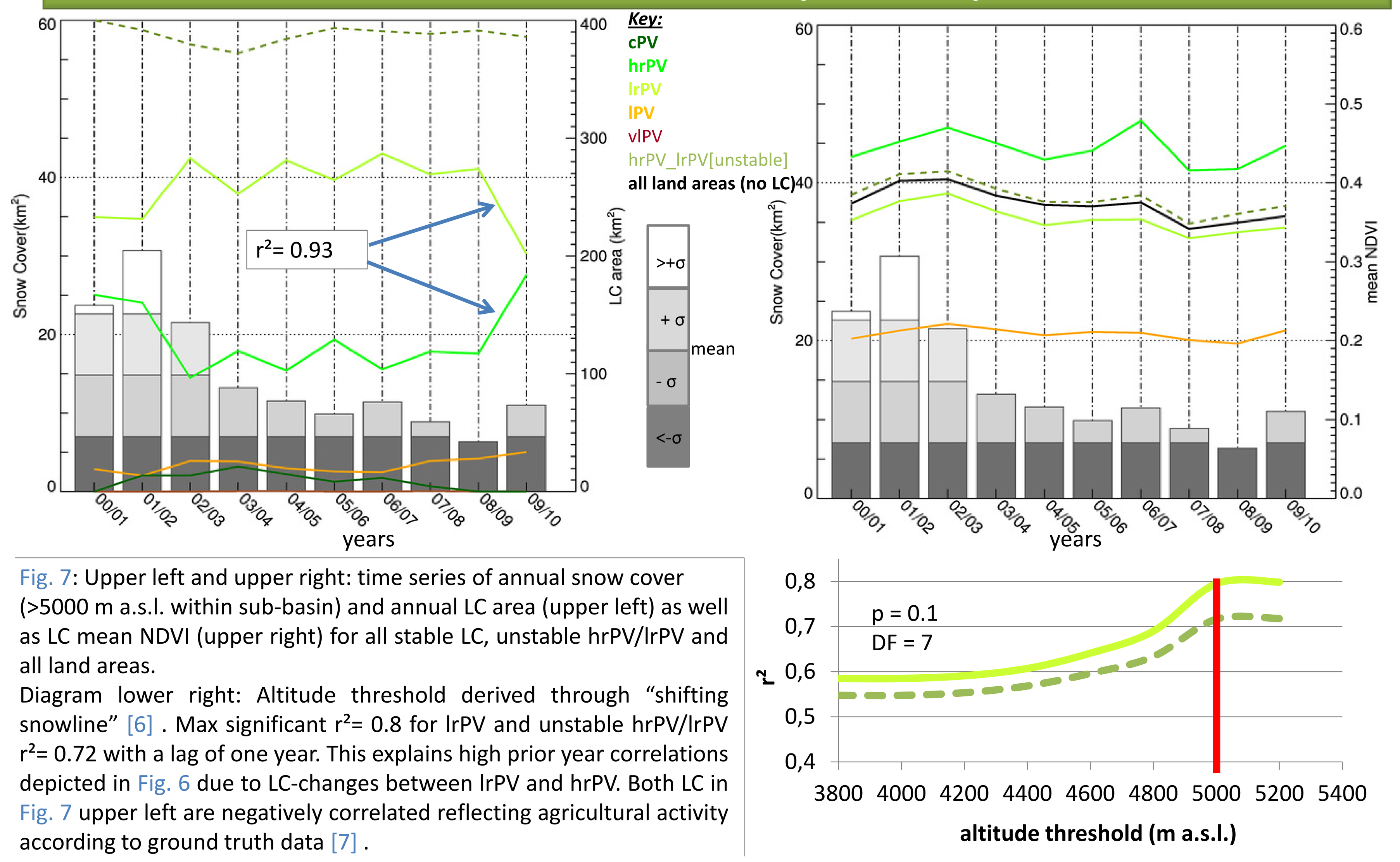

Fig. 7: Upper left and upper right: time series of annual snow cover (>5000 m a.s.l. within sub-basin) and annual LC area (upper left) as well as LC mean NDVI (upper right) for all stable hrPV/lrPV, unstable hrPV/lrPV and all land areas.
Diagram lower right: Altitude threshold derived through "shifting snowline" [6] . Max significant r^2= 0.8 for lrPV and unstable hrPV/lrPV r^2= 0.72 with a lag of one year. This explains high prior year correlations depicted in Fig. 6 due to LC-changes between lrPV and hrPV. Both LC in Fig. 7 upper left are negatively correlated reflecting agricultural activity according to ground truth data [7] .

6. Snow cover & lake level changes (sub-basin)

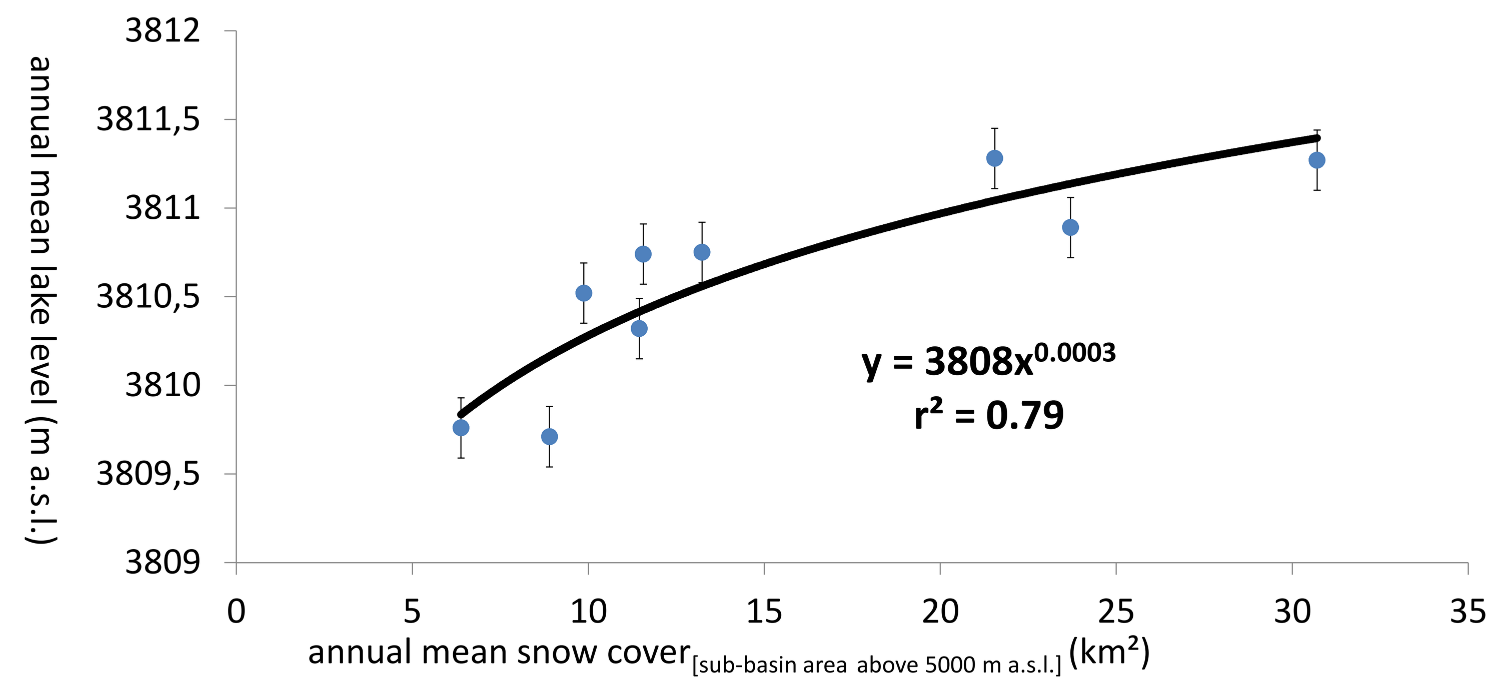

Fig. 8: Relationship between annual mean snow cover and annual mean lake level of Lago Titicaca (RMS = 0.17 m [5]).

7. Concept of precipitation & runoff related to vegetation productivity

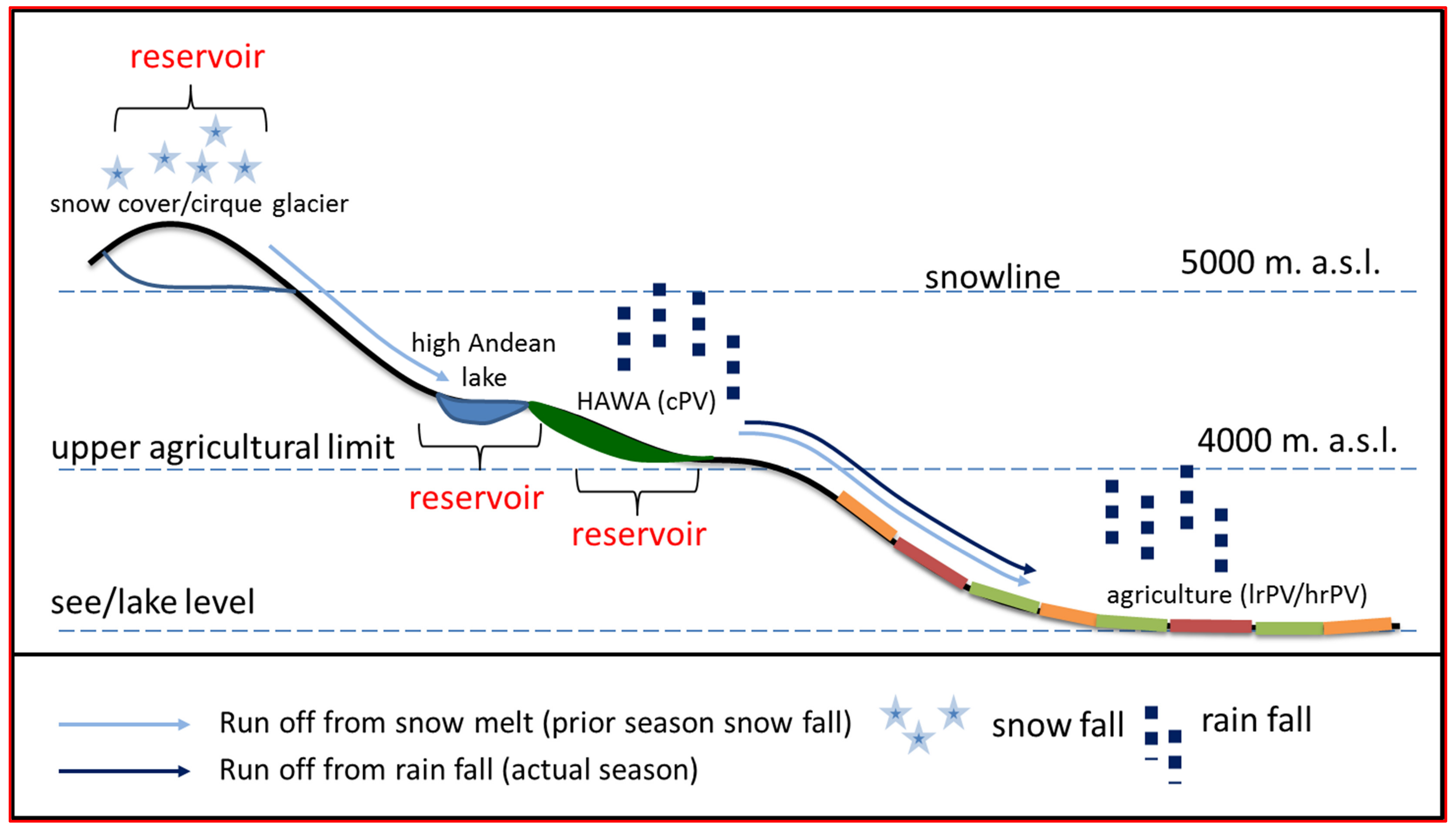

Fig. 9: Concept of how productive vegetation (agriculture lrPV/hrPV) is linked to snow fall (cirque glacier [8]) generating run off into high Andean lakes in connection with wetlands (HAWA [4]) forming a cascade of three potential reservoirs.

8. Conclusions

1. Strong linear relationship between precipitation and vegetation dynamic up to 700 mm along the precipitation gradient [see section 3].
2. Vegetation productivity of xeric ecosystems (deserts) towards western slopes of the Andes indicated highest dependency on precipitation [see section 3].
3. **Prediction of vegetation productivity (mean NDVI) one year in advance for areas of low range productive vegetation [see section 4].**
4. **Annual land cover changes of high and low range productive areas are strongly negatively correlated to each other but their all together land cover area remained stable (no trend) [see section 5].**
5. **A very small fraction of the investigated basin covered by snow or ice (less then 0.5%) explains 80% of the variability in vegetation productivity of agricultural areas [see section 5].**
6. **Vegetation productivity of both LC-Types depend on snow cover above the snow line generated in prior years [see section 5].**
7. Annual lake level changes were linked to snow cover [see section 6].

Our results indicate a strong dependence of vegetation dynamic and land-cover change on precipitation within a region receiving extremely small rainfall amounts at intensive evaporation rates. However land use within our study area seems to be still well adopted to periods of low precipitation. At the same time it remains unclear how future climate variability will affect vegetation productivity. Therefore the proposed concept [Fig. 9] based on our finding will foster future investigations still required.

References

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