

**AUTHORS' RESPONSES TO REVIEWERS' OBSERVATIONS ON THE MANUSCRIPT
“Pertinent spatio-temporal scale of observation to understand sediment yield control factors in the Andean region: the case of the Santa River (Peru)” TO HESS.**

The authors thank the reviewers for their perceptive and constructive remarks on our manuscript. In the following Authors' responses, Reviewer comments are in *italics* and Authors' responses are in **bold**.

Anonymous Referee #1

Point 1: *“The structure of the manuscript can be improved. In the current version...but is a (fuzzy and very general) overview of the link between erosion and slope gradients.”*

We accept this criticism. The revised version of the manuscript has been reorganized with a clearer distinction between data and results (see the revised manuscript attached). Above all, in the revised version, we have tried to emphasize the logic of the manuscript, with more explanation of the scientific goals in the Introduction and Discussion.

Point 2: *“Parts of the conclusions are not supported by the data and analyses. Finally, the authors conclude that the difference in SSY between two large basins is mainly linked to dispersed mining developed on a specific lithological formation. There are no data or analyses that support this idea.”*

We think that Reviewer 1 did not catch the main scientific point of the original text, which was not clear enough about the relevant issue that we tried to develop. Actually, the main point of the manuscript is to show that: (i) sediment production differences between watersheds in the western Andes may not be “climatically controlled”; (ii) lithology, combined with slope spatial distribution and mining activities are eligible factors for explaining these differences; and (iii) any study about sediment production in the western Andes cannot be done without a map of possible erosive factors at relevant resolutions and daily time-series. In other words, small heterogeneities in erosive factors may have great impact on erosion products.

Our argument about lithology, slope and anthropic factors did not convince Reviewer 1. We partly agree that this argument is based on clues and not on evidence, but quantitative indisputable evidence about any of these factors seldom exists in the literature. Besides, analysis of time-series of long-term sediment yields (e.g., Walling, 2006) and combination of lithology and human activity maps to understand sediment yield rates has always been debatable. This is mainly because of the difficulty of quantifying clearly, at the basin scale, the erodibility of lithology and the total impact of human activities.

We analyzed all the information available from the two watersheds (Santa and Tablachaca basins): (i) slope distribution, (ii) precipitation, (iii) water and sediment discharges, (iv) lithology, (v) land-use and mining locations. We supplemented the precipitation database with TRMM data (Figure 4 in the revised manuscript and section 3.1). We found only quantitative differences between the two watersheds in the spatial distribution of lithological domains, which also influence mining activities and have different slope frequencies. This is certainly not a demonstration of fact; nonetheless, our observations are serious clues for suspecting that the combination of these factors is responsible for the huge difference in sediment production between the watersheds.

In the revised version of the manuscript, we present the spatial distribution of sediment concentration during one field campaign during a rainfall period (Feb-March 2009). These “ground truth” data are listed in Table 2 and located in Figure 2 of the revised manuscript. They show two orders of magnitude in concentration variability depending on the location of the samples (from 0.1-24.5 g.L⁻¹). This demonstrates that

the main sediment sources are located in specific areas that correspond to intensive mining activities and specific lithologies.

Thus, with this study we demonstrate points (i) and (iii), which are valuable and original results to help understand factors driving production of sediment yield. These two points should be integrated into future studies interpreting Andean sediment yield production. Considering our original results, at the regional scale, and specifically for the Andes, we can explain why, for example, a graph of sediment yield production vs. runoff does not show any useful trends (see Figure 11 in the revised manuscript). One cannot easily understand annual sediment yield production factors using fitting models (citation) without exploring these factors at high spatio-temporal resolutions.

Point 3: *"In the introduction, the authors state that 'numerous studies address ... When you want to compare the results of these studies, this has to be done correctly by discussing their complexity and their Impact.'"*

We accept the criticism; our statements about these references may have been too direct and needed to be more precise. In the revised manuscript, we have totally rewritten the introduction. We hope this new text is clearer and more convincing.

Point 4: *"The authors state that 'the analyses of worldwide data present a large statistical dispersion, and cannot be used to design an easy-use universal or physical model'. ... See also Syvitski and Milliman (2007), Restrepo and Syvitski (2006), Kettner et al. (2010)."*

Models proposed by Syvitski et al (2003), Restrepo and Syvitski (2006), Syvitski and Milliman (2007) and Kettner et al (2010) (cited by Reviewer 1) are empirical "fitting" models trying to connect mean values of water discharge and temperature and fixed values of basin geomorphic characteristics, such as drainage area and topographic amplitude, with two or four parameters to calibrate dam, lithologic or anthropic impacts. Such models give a broad estimate of what the sediment yield should be for a specific watershed within a factor of two for 75% of the rivers described in their database. They do not, however, give real insights into erosive processes but only into empirical relationships with varying degrees of statistical significance.

To test the suitability of such an empirical model, we applied one described in Syvitski et al (2003) with the equations 10 and 14. Annual precipitation rates are calculated from TRMM data, and temperatures come from two meteorology stations (Cabana and Yungay at Figure 1) and the NOAA Merged Land-Ocean Surface Temperature Analysis dataset free available (<http://www.esrl.noaa.gov/psd>).

The calibration parameter values are those proposed in the article for tropical regions (Table 2, Table 4, Table 5 and Table 6).

Results are presented in Figure attached at the end (Figure A). It shows that for both watersheds, the inter-annual variability of sediment-yield production is not accurately predicted, but at the decade time scale, the average sediment yield may be predicted well for the Tablachaca watershed. To capture the inter-annual variability of both watersheds, the parameters should be time-dependent. In other words, discrepancies between these models and our data is inherent in the type of variables used, which cannot encompass daily variability in water discharge and heterogeneity in lithology, mines, etc., which are only represented with fixed regional values in the model.

For example, the use of a drainage-area functions as a proxy for water input and as a control factor for erosion rate has been statistically explored and remains controversial. One of the most recent studies (Vanmaercke et al. 2011 - cited by Reviewer 1) concludes: *"Furthermore, calculated SY-A relationships explained little of the observed variation, are region-specific and scale-dependent"*.

We do not believe that the models cited by Reviewer 1 have a "good fit" for observations and specifically for sediment yields of Peruvian Andean watersheds because, first, they do not correctly represent the influence of daily discharge

variability on sediment export balance, and second, because lithology and anthropic impacts on sediment yield at the regional scale cannot be summarized with a single coefficient of an empirical relation for a region with expanding mining activities. Our study demonstrates this, showing a good example of two adjacent watersheds with similar topography, climate and hydrological contexts (i.e., daily discharge variability), at similar scales, but with sediment erosion rates clearly opposite from those predicted by global models such as those cited by Reviewer 1.

Point 5: *“Recent studies have analyzed the relation between ENSO ... Have a look at Tote et al. (2011), Romero et al (2007), Tarras-Wahlberg and Lane (2003).”*

We are grateful to Reviewer 1 for the references. The references have been included and commented on in the revised manuscript. The question about ENSO impact on sediment-yield production of western Andean watersheds need a more complete study integrating different catchments along the coast of Peru (regional scale).

Point 6: *“The authors make use of stratigraphic maps to discuss the link between lithology ... central granodiorite-tonalite batholith that is all overlain by clastic sediments deposited during the glacial retreat.”*

We agree totally with this comment. Following the recommendation of Reviewer 1, we have rewritten the lithology description in the revised manuscript according to standard lithology characteristics (see Table 3 and section 2.2 and 3.3 in the revised manuscript). The lithological map has been refined with stratigraphic characteristics (see formation code 1a and 1b and 2a and 2b).

Point 7: *“As one of the aims of the study is to analyse the influence of ENSO on P, Q and SSY ... This would allow you to do a quantitative analysis between P, Q and SOI values.”*

We understand this comment about the relevance of the rainfall data presented in the manuscript and agree that a rainfall database with only two stations may have low representativeness given the size of the watershed. One figure has been added to the revised manuscript to supplement description of the rainfall context (Fig. 5). Based on TRMM rainfall data, these figures show the representativeness of the two rainfall stations for the entire study area (section 2.5 in the revised manuscript).

Point 8: *“The study lacks a quantitative analyses of the factors that control Q, SY and SSY... Hence it is difficult to follow the interpretation and the conclusions made by the authors as they are not supported by numerical analyses.”*

The answer to this comment was partly developed in our responses to points 2 and 3 above. With our database, it is rather difficult to generate spatial correlations with data from one confluence of two main watersheds. However, fuzzy lithological and anthropic impact on sediment yield is not easily identified with statistics on water discharge, temperature or geomorphic data alone. This study highlights the interesting issue of the pertinent scale at which to build datasets to obtain convincing arguments about the controlling factors of sediment yield. Our methodology is not based on statistical fitting models but rather on cross-correlations between slope frequencies within lithological domains, land uses and mine locations.

A suspended sediment concentration distribution map used during two water-sampling campaign in the field has been added to the revised manuscript (Figure 2, see point 2 above). This quantitative information (albeit not statistical but still meaningful) reinforces our interpretations of the huge differences in sediment production between the Santa and Tablachaca watersheds.

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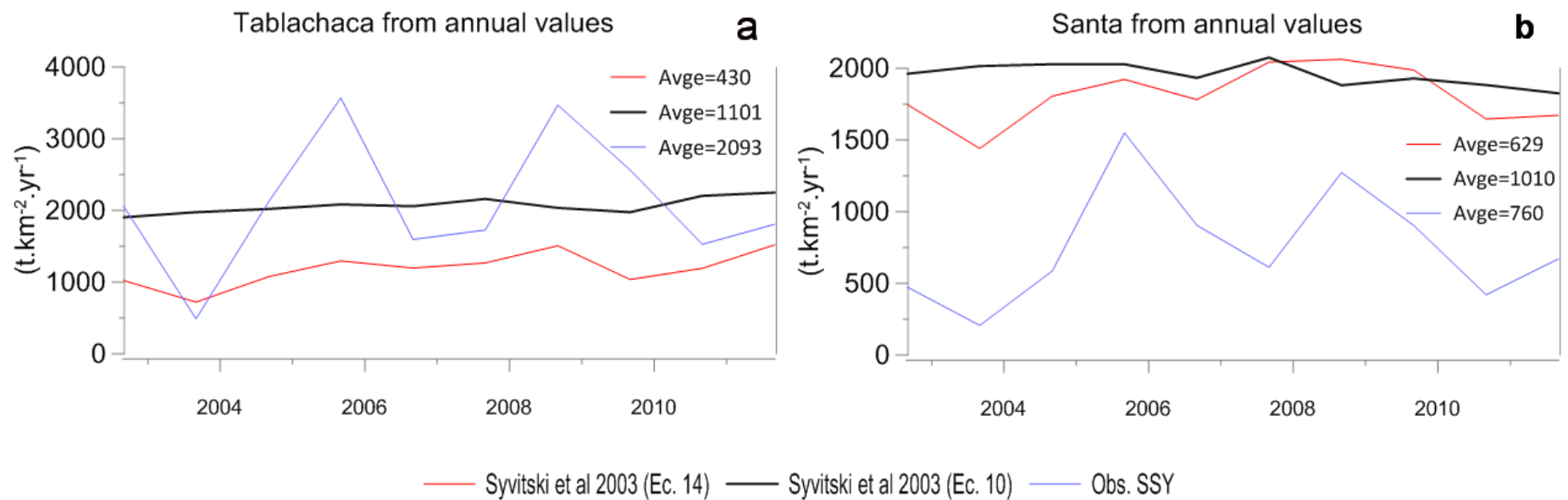


FIGURA. Observed specific sediment yield (SSY) (blue). SSY predicted from observed water discharge and catchment temperature (red) (Eq. 14 in Syvitski et al., 2003) and SSY predicted from catchment temperature alone (black) (Eq. 10 in Syvitski et al., 2003).