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Reply to comment

Reply to comment on Prada *et al.* 2012. 'Cloud water interception in the high altitude tree heath forest (*Erica arborea* L.) of Paul da Serra Massif (Madeira, Portugal)'. *Hydrological Processes* 26: 202–212

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The authors of 'Comment on Cloud water interception in the high-altitude tree heath forest (*Erica arborea* L.) of Paul da Serra Massif (Madeira, Portugal)' (2012), hereafter RR, criticize 'Cloud water interception in the high-altitude tree heath forest (*Erica arborea* L.) of Paul da Serra Massif (Madeira, Portugal)' (2012), hereafter P12. We welcome those critiques and think they are important as a complement to our work. However, some of them are repetitive and appear to result from a misunderstanding of P12. As such, we would like to defend our work from the arguments presented against it.

1. RR say that the data used by P12 was the same as the data used in Prada *et al.* (2009, 2010), and this is not acknowledged. If the authors had thoroughly read the paper, they would have seen that in the last paragraph of the introduction section, P12 clearly states that the data set is the same from that of Prada *et al.* (2009), corrected in Prada *et al.* (2010). The difference is that it was used for a different purpose, as stated in the objectives. The objective of P12 was not to quantify cloud water, which was already published (Prada *et al.*, 2009), but to analyse its relationship with climatic variables, such as precipitation, humidity and wind speed. Further references to this fact can be read throughout the paper.
2. RR argue that, when compared with other places in the world, fog precipitation (cloud water interception) in Madeira's high-altitude tree heath forest is abnormally high. In Table I, we compare the information obtained in the different studies referred by RR (Kämmer, 1974; Regalado and Ritter, 2010; Ritter and Regalado, 2010) and P12, plus another recent one about Madeira's humid laurissilva (Figueira *et al.*, 2012). The first part of P12 was made in a windward first-line (first row of individual plants along a windward exposed edge of a vegetation patch) old-growth heath tree that is fully exposed to fog and wind and, obviously, does not represent the entire forest. This can clearly be seen in the second part of P12, in which it is shown that cloud water interception diminishes to the interior of a high-altitude tree heath forest stand, in the same manner as by Kämmer (1974) in Tenerife. In this way, the mean cloud water input in the whole forest is considerably lower than the one registered in the first line (Table I). For example, inside a continuous stand of Madeira's temperate laurissilva, cloud water was found to represent 9.6% of annual throughfall (Figueira *et al.*, 2012) and inside a secondary tree heath forest, 13% of annual throughfall (Prada *et al.*, 2009). These are very similar to the results (11% of throughfall) obtained in *Garajonay Park* (Regalado and Ritter, 2010; Ritter and Regalado, 2010). We believe that in a high-altitude tree heath forest stand, cloud water represents a larger fraction of the water that reaches the forest floor, but further investigation must be performed to confirm this. Different climate between islands, especially rainfall regime, must also be accounted for. Usually, in the high altitudes of Madeira Island, rain (orographic or frontal) is accompanied by fog (the cloud touches the ground). Cloud water interception also occurs during rain events and is common before their onset (Figueira *et al.*, 2012). Madeira Island has higher mean rainfall values than any of the Canary Islands, and *Bica da Cana*, in particular, is much wetter than any other

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Table I. Comparison between sites and studies

Island	**Madeira**		**La Gomera**	**Tenerife**		
Authors	Prada *et al.* , 2012	Figueira *et al.* , 2012	Ritter and Regalado, 2010	Kämmer, 1974		
Location	Bica da Cana (Madeira)	Folhadal (Madeira)	Garajonay (La Gomera, Canary Islands)	Anaga (Tenerife, Canary Islands)		Northern side of Tenerife (Canary Islands)
Type of forest	High altitude tree heath forest	Humid temperate laurissilva	Wax myrtle – tree heath shrubland (fayal-brezal)	Humid evergreen laurel forest		Mixed pine woodland and cold evergreen laurel forest
Time period	01 Oct. 1997 – 30 Sep. 1999 (730 days)	01 Oct. 2008 – 30 Sep. 2009 (1 year)	05 Oct. 2006 – 22 May 2007 (230 days)	Apr. 1971 – Mar. 1972 (1 year)	Apr. 1971 – Mar. 1972 (1 year)	26 Mar. 1971 – 22 Sep. 1971 (181 days)
Conditions	First-line of forest stand	Inside forest stand	Inside forest stand	Inside forest stand	Inside forest stand	First-line of forest stand
Dominant species	Tree heather (*Erica arborea*)	Stink-laurel (*Ocotea foetens*), *Clethra arborea* , Laurel (*Laurus novocanariensis*)	Tree heather (*Erica arborea*)	Laurel (*Laurus novocanariensis*), Wax-myrtle (*Myrica faya*)	Laurel (*Laurus novocanariensis*), Wax-myrtle (*Myrica faya*)	Pine (*Pinus canariensis*), laurel (*Laurus novocanariensis*), Wax-myrtle (*Myrica faya*)
Other tree species	-	*Vaccinium padifolium, Picconia excelsa, Heberdenia excelsa, Ilex perado*	*Myrica faya* , *Laurus novocanariensis* (*L. azorica*)	*Ilex canariensis, Persea indica*	*Ilex canariensis, Persea indica*	*Ilex canariensis; Persea indica*
Dominant leave shape	Needle-leaves	Broad-leaves	Mix of needle and broad-leaves	Broad-leaves	Broad-leaves	Mix of needle and broad-leaves
Dominant tree structure	Tree-like structure, broad canopy	Tree-like structure, broad canopy	Thin and shrub-like structure	Tree-like structure, broad canopy	Tree-like structure, broad canopy	Tree-like structure, broad canopy
Macrobioclimate	Temperate[b]	Temperate[b]	Mediterranean[a]	Mediterranean[a]	Mediterranean[a]	Mediterranean[a]
Thermotype	Superior mesotemperate[b]	Inferior mesotemperate[b]	Superior mesomediterranean[a]	Superior thermomediterranean[a]	Inferior mesomediterranean[a]	Superior mesomediterranean[a]
Ombrotype	Ultrahyperhumid[b]	Inferior hyperhumid[b]	Sub-humid[a]	Sub-humid to Humid[a]	Sub-humid to Humid[a]	Sub-humid to Humid[a]
Altitude (m a.s.l.)	1580	1025	1300	915	960	1447
Latitude	≈ 32º 45’N	≈ 32º 45’N	≈ 28º 08’N	≈ 28º 25’N	≈ 28º 25’N	≈ 28º 32’N
Area inclination	Low inclination (5º)	Medium inclination (15º)	High inclination (40º)	-	High inclination (25-35º)	Low inclination (1-2º)
Local annual precipitation	≈ 3000 mm	≈ 2500 mm	≈ 900 mm	≈ 1000 mm	≈ 1000 mm	≈ 1000 mm
Precipitation (study period total/ projected year total)	4488 mm / 2244mm	2484 mm	610 mm / 968 mm	888 mm	883 mm	288 mm / 580 mm
Throughfall (study period total/ projected year total)	12362 mm / 6181 mm	2087 mm	399 mm / 633 mm	1074 mm	1063 mm	1008 mm / 2033 mm
Cloud water interception or fog precipitation (study period total/ projected year total)	8338 mm / 4169 mm	200 mm	34 mm / 54 mm	186 mm	279 mm	720 mm /1451 mm
Cloud water (or fog water) vs. Precipitation proportion	1.9:1	0.08:1	0.06:1	0.2:1	0.3:1	2.5:1
Cloud water (or fog water) input in throughfall	67.50%	9.60%	8.5% (11% in a subset of this experiment - Regalado and Ritter, 2010a)	17.30%	24.20%	71.40%

[a] Climatic and vegetation data compiled from del-Arco *et al.* (2006, 2009, 2010).

[b] Climatic and vegetation data compiled from Capelo *et al.* (2004) and Mesquita *et al.* (2004).

place in the Canaries. Mean annual rainfall in *Bica da Cana* is approximately 3000 mm, whereas in Tenerife and La Gomera, it reaches a maximum of approximately 1000 mm (Table I). Looking at the ratio between rainfall and cloud water interception, RR will find that Kämmer (1974) also found unusually high volumes of fog water in a first-line laurel forest in Tenerife (2.5 : 1 *vs* 1.9 : 1 – Table I). The fog water percentage in total throughfall was even larger than in Madeira's high altitude tree heath forest (71% *vs* 67% – Table I). Following this, we do not consider that P12 values in a first-line tree are as extraordinary as claimed by RR. Focus should be put on the fraction of cloud water represented in throughfall and not on total cloud water, as this measure, in our view, better accounts for differences between sites. Nevertheless, RR point out something that we also subscribe. It seems that, even though cloud water interception volumes are higher during wetter periods, it represents a larger proportion of the water that enters the ecosystem during drier ones, like in summer. The results for temperate laurissilva in the work of Prada *et al.* (2009) show that during winter, cloud water interception is 11% of the registered water under the vegetation, whereas in summer, it is 33%, even though it has a lower total. The same pattern is also referred in the work of Figueira *et al.* (2012). We consider the measured cloud water values in the high-altitude tree heath forest to be very high. Prada *et al.* (2009, 2010) offered arguments to make such observation plausible, as we also do again in this reply. On the other hand, the arguments presented by RR (also in Regalado and Ritter, 2010) against those values were intended to falsify the observation. Even though P12 values are among the highest already published, that does not mean that they are invalid. The truth is that until further experiments are performed, neither our arguments can undoubtedly prove such values nor RR arguments can undoubtedly disprove them. For the interested reader, detailed information about this issue can be read in the work of Prada *et al.* (2009, 2010) and Regalado and Ritter (2010).

3. As for the 'roving gauge technique', we acknowledge that our experiment did not follow such a refined systematic methodology as that described in the very interesting paper from Ritter and Regalado (2010). P12's work was not specifically designed to address the differences between fixed and moving gauges, as Regalado and Ritter (2010) have, and that was not its objective. Its purpose was to make a preliminary assessment of fog precipitation in *Bica da Cana* before the installation of the fixed gauges. The roving gauge measurements were made after field observations, which large quantities of water poured from the trees during heavy fog events without rainfall. It was decided to make a preliminary assessment of fog precipitation before installing recordable rain gauges. That is why the time frame of the roving gauge experiments did not coincide with the quantification time frame. The methodology consisted of dividing the area under the tree heath in eight sectors of approximately 8 m^2 each and randomly putting the three gauges inside a sector for an hour. Then the gauges were removed and placed in the contiguous sector, in a clockwise direction. But for the reasons already explained in the work of Prada *et al.* (2009, 2010), P12 considered it to be representative of the conditions under that heath. But if high volumes of fog precipitation were registered during March 1996, why would not similar conditions occur again during the latter period?
4. Two gauges are a limited number for giving a precise measurement. RR make a good explanation on why this is a problem in their comment and in the work of Ritter and Regalado (2010). However, P12 did not recalculate the total volumes that were already published, a fact acknowledged throughout the text. P12 just wanted to observe how cloud interception relates with climatic factors.
5. Like all methodologies, the throughfall–rainfall comparison method has its problems. It tends to underestimate cloud water interception because of losses by evaporation, canopy storage and stemflow unaccountability. Other issues are also possible (Bruijnzeel, 2001 and Holder, 2003, 2004), but mathematical modelling is also prone to its own problems. All mathematical models are, necessarily, simplifications of reality that do not take into account all the variables associated with a particular phenomenon. Otherwise, they would be so specific that it would only be possible to apply them to a very specific case. We think that both methodologies have their advantages and problems and should be used to complement each other, not rule each other out.
6. The term Macaronesia is used to refer to the loose set of the North-Atlantic archipelagos of the Azores, Madeira, Cape Verde and Canary Islands. All these archipelagos have very different climates between themselves and between the islands that compose each of them. Even in the same island, one may encounter very different climates, according to altitude and wind exposure. So, it is very difficult to compare different islands just because they are from Macaronesia. A thorough explanation on this issue is given in a previous response to RR (Prada *et al.*, 2010). Examples from Madeira Island are *Funchal* (50 m a.s.l.) that has a mean annual rainfall of approximately 600 mm and *Bica da Cana* (1560 m a.s.l.), just 20 km to the northwest, that has about 3000 mm. In Tenerife, maximum mean annual rainfall is 1000 mm in the northern slope of *La Esperanza* Ridge, between 1000 and 1500 m a.s.l., and 900 mm in *Anaga* (del-Arco *et al.*, 2006) and approximately 900 mm/year in La Gomera's *Garajonay Park* (del-Arco *et al.*, 2009 – Table I).
7. RR continue to assume that vegetation is the same between islands. Although there are obvious similarities between them, there are also some fundamental differences, especially in the composition of the different plant communities. Laurissilva is used as a generic term to a forest that is dominated by species from the Lauraceae family, such as *Laurus novocanariensis* or

Table II. Depletion equations for each of the events (first and last plot not used)

Plot	23-03-2008 (ml)	05-07-2008 (ml)	26-09-2008 (ml)
51–100	200	109	189.5
111–150	130	68	121
151–200	142	49.5	99
201–250	114	35	99
251–300	108.5	33.5	91
301–350	84.5	34.5	77
Depletion equation	$y = -56.5\ln(x) + 191.8$ $R^2 = 0.89$	$y = -43.5\ln(x) + 102.6$ $R^2 = 0.95$	$y = -58.1\ln(x) + 176.4$ $R^2 = 0.92$

Ocotea foetens. In Madeira, five different types of laurissilva occur, each one with different structure, dominant species, spatial distribution and edafic positioning. The high-altitude tree heath forest is not a laurissilva, and broad-leaved trees are absent. When RR refer a high-altitude tree heath forest in La Gomera, they are most probably talking about a 'fayal-brezal', a community that is dominated by tree heaths (*Erica arborea*) but where broad-leaved trees such as *Myrica faya*, *Laurus novocanariensis* and *Ilex canariensis* are also common (Table I). Instead, the madeiran tree heath forest is exclusively composed by *Erica arborea* (at tree-shrub level), a needle-leaved that, when compared with a broad-leaved, is more efficient in intercepting cloud water. Further description on the studied site and distinction from the Canary Islands vegetation, especially La Gomera, are available in the work of P12, as well as in Capelo *et al.* (2004); del-Arco *et al.* (2009) and Prada *et al.* (2010).

8. As for the relationship between monthly throughfall and gross precipitation, there is a strong reason for it to be nonlinear. The deviation from linearity is not consequence of errors in the estimation of either of these variables because they are not estimated but observed values. Anyway, despite the presence of two obvious outliers (that we kept in our data set, as they provide evidence that other factors, besides precipitation, influence throughfall), the plot of the residuals against the predicted values for the linear relationship shows that a quadratic term was missing. This is not observed in the residuals plot for the quadratic relationship. Also, the determination coefficient (R^2) is greater than the obtained for the linear relationship. If RR wanted to contest the quadratic relationship, they should focus on the growth variation of throughfall as a function of gross precipitation. In fact, the growth variation of this variable is very different between the two models. The quadratic relationship admits that the growth of throughfall, beyond a certain value, is a much smaller variation than that of the linear relationship. The latter assumes that the growth variation is constant for any value of gross precipitation, something that is not observed in our data. Also, the large observed dispersion shows that throughfall is affected not only by precipitation but also by another factor, in this case, cloud water.
9. As for the correlations between cloud water and the other variables, this is not a general purpose model but only the correlation between the 2-year average and the climate normals. That is why there is no need to put error bars in the data (as it would also prove very difficult to do with only two values for each month). Of course, these correlations should be taken with care. They are not intended to model cloud water interception but just to correlate these events. Further data would have been necessary to model cloud water interception in that first-line tree heath, a work that we are currently performing. About the multicorrelation between cloud water interception and climate factors, we have to consider that some of these may be strongly related to each other (e.g. relative humidity and fog days, or temperature and relative humidity). So, we are currently working on the continuous collection of cloud water interception data for a future application of a principal component analysis to select one or two components to use in a multicorrelation analysis.
10. Lastly, about the logarithmic decrease observed in the forest stand, RR are right. The logarithmic decrease is only supported if the plots located at the rim of the stand are removed, thus showing that the conditions present at the borders of a forest stand are very different from what happens in the interior. That is why one should not compare the first line with an entire forest. We publish new equations for the depletion rate observed during the three events, without the first and the last plot (Table II). We also would like to stress what was already said by P12, that further, more refined measurements should be made to obtain a general depletion equation. As for the fact that the equations can render a negative value, we do not see a problem with it. Inside the plot interval in which the experiment was performed, they could not render a negative value. If the stand was larger and further measurements were made, the depletion equation would be much different than this one, probably pointing to an asymptote of positive value. In our opinion, because of various reasons already explained by P12, the interception of cloud water would stabilize (not completely disappear). That is why, in the work of P12, it is acknowledged that those equations only account for those individual episodes and do not constitute a model. Further measurements, with a higher degree of detail, will be necessary to model this depletion.

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