General comments

The authors want to tank the three anonymous reviewers because of their useful suggestions and comments to the paper.
As requested by the reviewer n.1 we modified the abstract and Introduction and Conclusions to better engage the reader and to better specify the importance of develop and test these radiation model components.
As requested by the reviewer n.3, and suggested by the reviewer n.2 and n.1, we decided to cut the subsection concerning the data analysis. Data analysis is not a goal of the discussed paper and the possibility of enlarging this section can in fact confuse the reader.
As requested by all the reviewers we added a new section about the raster mode of simulation. We computed solar radiation raster maps and we presented the results for four hours during a day for the Piave river basin that was the catchment with the more complex topography.

Below, please find a detailed answer to reviewers questions.

REVIEWER 1

We thank the reviewer for the appreciation of the paper and for the comments. Comments 1 to 8, as well as comments 10, 12,13, 15-22, 24, 26, 28, 29 were referred about typos, the spelling, or minor notes. The authors accepted and applied the reviewer's suggestions to the revised manuscript.

Comment n.9

In the sentences: 'the solar radiation measurement over a flat homogeneous landscape are well correlated' and 'the correlation between solar radiation measurement decrease', what is being correlated? You are referring to one single variable. I believe you mean that modeled and measured are correlated. Please rewrite this piece. Also correct the grammar to 'measurement decreaseS' or 'solar radiation measurement IS'.

Answer n.9

The section 4.2 was included in the paper for showing the fact that complex topography played a more important role in the application of the Piave river basin than in the applications on Little Washita and Fort Cobb. It had not the aim of presenting a statistical method used to analyze the model results.

Because two reviewers commented it and suggested to reduce or exclude the section from the paper, the authors decided remove the section.

We hope that the new section about a raster application of the model on the Piave river basin could better illustrate the interplay of complex topography and radiation than the original section.

Comment n.11

'It does not require any calibration, once the four parameters in table 1 are assigned according to literature values.' This is somehow an awkward statement. Sure that by using the values in Table 1 you can estimate realistic radiances, which does not mean that if you calibrate those the results would not be better. But this is the case with almost any model calibration. Please consider rephrasing.

Answer n.11

We tried to rephrase as follows:

Old sentence: "It does not require any calibration, once the four parameters in Table 1 are assigned according to literature values"

New sentence: "In this paper we chose to assign the four parameters in Table 1 according to literature values. However, because the model is an OMS3 component, its parameters could indeed be also calibrated by using one of the OMS3 NewAge-JGrass calibration algorithms (LUCA, Hay et al., 2006 and Particle Swarm, Kennedy and Eberhart, 1995.)"

Comment n.14

What have been the criteria to select the subset used for validation?

Answer n.14

The criteria we used in selecting the verification stations was based on the idea to consider stations with different topographical features in terms of elevation, aspect, slope since these highly affects the solar radiation in a given point. This is also the rational behind the use of three areas with different topographical and climates

features.

Comment n.23
The graphical quality of the flow charts in Figure 1, 3 and 4 needs to be substantially improved. Please increase the size of the font as well.
Answer n.23
The figures' quality and the font were improved. Moreover the layout was modified in order to better visualize the words in the figures.

Comment n.25
Table 2, 3 and 4 should be combined. There is no reason to keep them separate; the name of the 3 catchments can be added in a row in the table.
Answer n.25
The authors prefer to keep the three tables separated. We want to avoid a very long table and keep different plots and tables for each river basin.

Comment n.27
Same for Table 5, 6 and 8. They can also be combined.
Answer n.27
The authors prefer to keep the three tables separated. We want to avoid a very long table and keep different plots and tables for each river basin.

Comment n.30
Figures 5, 6 and 7 are substantially better in quality, but please add a scale to the maps and improve the captions, they need to be much more descriptive (also correct ', (Italy).').
Answer n.30
We added the scale in figures 5, 6 and 7 and we improved the captions adding for all the river basins: "Triangles represent the verification set (V-set) and circles represent the calibration set (C-set). The comparison between measured and modeled incoming solar radiation is represented in term of scatter plots"

Comment n.31
- 'the global shortwave solar radiation showing...'. Two things about this sentence: (a) remove 'global', it gives the impression your domain is global (do you mean 'overall'?), (b) I believe you are looking at solar radiation not just the (large) fraction of solar radiation that can be considered as 'shortwave'. If you want to use 'shortwave' as a synonym to 'solar' then avoid using the term 'solar shortwave'.
Answer n.31
The authors agree with the second part (b) of the suggestion given by the reviewer. We prefer to maintain the term "global", since it is usually accepted among who talks about radiation, as summation of direct and a diffuse component incoming solar radiation. We accept the suggestion (b) and, as proposed by the reviewer, and we substituted the term "solar shortwave" with "shortwave".
Old sentence: "In all the cases the model was able to simulate the global shortwave

solar radiation showing relatively good goodness of fit indices"
New sentence: "In all the cases the model was able to simulate the global shortwave radiation showing relatively good goodness of fit indices"

Comment n.32
Avoid the use of the apostrophe in 'components' structure'; better just use the 'structure of the components'. Same for 'components's framework'.
Answer n.32
The authors agree with the suggestion given by the reviewer but the modification of the sentence is quite different respect the one suggested by the reviewer. The goal is to describe the new possibilities offered by a modular system based on components such as JGrass-NewAge. This is in contrast with the old programming paradigm which brings to "monolithic" models. JGrass-NewAGE offers the possibility to link different components and execute the chain of model but also substitute just one component of the model chain while preserving the others.
Old sentence: "About the possibilities open by the components' structure of JGrass-NewAGE"
New sentence: "About the possibilities open by the components based JGrass-NewAGE system"

Comment n.33
The Discussion of the Figures is very limited please extend and try to link the different pieces. Avoid the use of two-sentence paragraphs.
Answer n.33
We expanded the comments to the Figures and detailed the relative captions.

Comment n.34
Please check if the words 'visualisable' and 'identificative' exist in English. They do not sound very correct to me...
Answer n.34
The authors agree with the suggestion given by the reviewer. We modified the sentence:
Old sentence: "immediately visualisable in a GIS"
New sentence: "immediately displayed in a GIS"
Moreover we substitute the word "identificative" with "identification".

Comment n.35
'The goal of this paper was to present a set of hydrological components'. If this was the goal, you did not succeed. This is not the goal. 'Hydrological components' by definition are very related to water. Precipitation for instance could be considered as a component of hydrology. Please rephrase.
Answer n.35
The authors agree with the suggestion given by the reviewer. We modified the sentence as following:
Old sentence: "The goal of this paper was to present a set of hydrological components"
New sentence: "The goal of this paper was to present a new set of components for

shortwave radiation modeling under generic sky condition”

Comment n.36

As I said at the beginning this piece needs to be more engaging.

Answer n.36

As we told in the general comments, we modify the section in order to satisfy the readers according to the reviewer suggestions.

REVIEWER 2

We thank the reviewer for the appreciation of the paper and for the comments. Comments 2 and 6 referred about typos, the spelling, or minor notes. The authors accepted and applied all of these suggestions of the reviewer.

Comment n.1:

p. 4356 – Abstract: "The first component, NewAGE-SwRB, accounts for slope, aspect, shadow and the topographical information of the sites, and use suitable parameterization for obtaining the cloudless irradiance."

- it not clear what kind of topographical information in addition to slope, aspect and shadow has been used in this study

Answer n.1:

The elevation is the only topographical information we missed in the list. It is used in (eq. 5): correction factor for increased transmittance with elevation. We accepted the reviewer suggestion and we modified the sentence:

Old sentence: "The first component, NewAGE-SwRB, accounts for slope, aspect, shadow and the topographical information of the sites, and use suitable parameterization for obtaining the cloudless irradiance."

New sentence: "The first component, NewAGE-SwRB, accounts for elevation slope, aspect, shadow of the sites, and use suitable parameterization for obtaining the cloudless irradiance"

Comment n.3:

p. 4359 "Therefore in the following is assumed that the solar constant, I_{sc} has been spatially corrected to account for the geometry and the position of the landscape underneath, to give a "corrected" solar constant, $\hat{I}_{sc}$."

- please explain what you mean by "corrected" solar constant based on geometry and position of the landscape underneath. Include any reference if available.

Answer n.3:

The authors decided to delete the sentence: " Therefore in the following is assumed that the solar constant, I_{sc} has been spatially corrected to account for the geometry and the position of the landscape underneath, to give a "corrected" solar constant, $\hat{I}_{sc}$. The word "corrected" was referred to the correction due to the eccentricity of the earth's orbit and it was computed as proposed in Spencer (1971). In order to make the notation lighter the authors decided to only use the symbol I_{sc} to indicate the solar constant and to modify the formula 1 substituting $\hat{I}_{sc}$ with I_{sc}.

The correction due to the eccentricity of the earth's orbit is specified when the term E_0 is described ("is a correction factor related to the Earth's orbit eccentricity computed according to Spencer (1971)").

Comment n.4:

p. 4360 "– s is the shadows index that accounts for the sun or shadow of the point under analysis, and is modelled according to Corripio (2003):"

- please be specific how shadows are calculated without information on the surrounding terrain geometry. Isn't this a reason for poorer results in the Piave river basin study area?

Answer n.4:

The shadow is computed by using the surrounding terrain information. In particular, as specified in (Corripio, 2003-a and Corripio, 2003-b) for each simulation time step the shadow map is computed for each pixel depending on the solar vector value. This map contains binary values: 0 for shaded cell, 1 for in-sun cells. Information on the shadow function are available on http://www.uibk.ac.at/geographie/personal/corripio/ or at http://abouthydrology.blogspot.it/2012/12/solar-radiation-physics-and-geometry.html by one of the authors.

The authors accept the suggestions of the reviewer and modified the sentence as following:

Old sentence: "ψ [-] is the shadows index that accounts for the sun or shadow of the point under analysis, and is modeled according to Corripio, 2003"

New sentence: "ψ [-] is the shadows index that accounts for the sun or shadow of the point under analysis, and is modeled according to Corripio, 2003. The algorithm computes a binary map (with value 0 is the pixel is in the sun or 1 if the pixel is in the shadow) taking into account the topographic information and the solar position."

Comment n.5:

p. 4364 "eq. (22) and (23) equation which also define kd, the ratio between the diffuse shortwave irradiance and the shortwave total irradiance."

- Please correct the sentence and be specific how this equation defines the kd coefficient

Answer n.5:

The authors accept the suggestion. We modified the sentence:

Old sentence: "equation which also define kd the ratio between the diffuse shortwave irradiance and the shortwave total irradiance. Therefore, at stations:"

The new sentence is: "eq. (22) and (23). Eq.(23)" defines the diffuse sky fraction coefficient kd, (Liu and Jordan, 1960 and Helbig, 2010), as the ratio between the diffuse sky radiation and the and the measured global radiation under generic sky condition

Comment n.7:

p. 4374 "The outputs provided by the model composition shown are independent of both the simulation time step and of the spatial resolution the user wants to use. This means that they can be integrated in both semi-distributed hydrological model and for fully distributed hydrological model (once these models follow the conditions required by OMS3)."

- Please explain how your system can be integrated with a fully distributed hydrological model when it calculates values for specific points (as demonstrated in case studies). Do you use any grid-based calculations?

Answer n.7:

The authors decided to accept the suggestion of the reviewer adding a raster mode simulation and modifying the sentence as the following:

Old sentence: “The outputs provided by the model composition shown are independent of both the simulation time step and of the spatial resolution the user want to use. This means that they can be integrated in both semi-distributed hydrological model and for fully distributed hydrological model (once these models follow the conditions required by OMS3).“
New sentence:” “The outputs provided by the model composition shown are independent of both the simulation time step and of the spatial resolution the user want to use. This means that they can be integrated in both semi-distributed hydrological model and for fully distributed hydrological model (once these models follow the conditions required by OMS3). The paper presented both the vector and the raster mode applications and showed the flexibility of the model able to be linked both to semi-distributed and to fully distributed hydrological models.
The model can be executed in two different modes: a vector mode, in which it computes the output just in some points and a raster mode, in which it computes the output in all the pixel of a geo-registered grid. In both the case the model take in account of the surrounding terrain information because it needs the digital elevation model of the study area. In order to show also the raster mode a new test case has been added which shows hourly solar radiation maps in the Piave river basin.

Abstract: we added the sentence “Moreover, a raster mode test is performed in order to show the capability of the system in providing raster maps of solar radiation.”

Applications section: “The model is applied in two different modes: vector mode, providing the radiation results in a number of points defined by the user, and raster mode, providing the radiation maps of the analyzed area. Below we described the basins used for the verification, comment their data, illustrate the procedure of verification and finally present the raster mode application.”

Raster mode application on Piave river basin section: “In order to show the capability of the system in providing solar radiation maps, a raster mode simulation was set up for the Piave river basin. Differently from the previous vector mode applications, the model results are computed for each point of the Piave river basin.
In order to perform this application, was necessary interpolate the air temperature and relative humidity measurement data for each pixel of the basins by using the detrended Kriging technique (component).
The simulation time step was hourly and the simulation period was one day: from 01/01/2010 to 01/02/2010.”

Discussion section: Finally, figure (8) presents the raster mode application of the model. Maps of incoming solar radiation are presented for four hours during the daytime. The effect of the complex topographic feature of the Piave river basin is evident in the radiation maps. Their patterns change during the daytime according to the solar position, the surrounding terrain and the shadow.

Comment n.8:
p. 4382, Table 2-4
Aspect () please explain why you have included in the tables Aspect values of the meteo stations. Solar radiation is usually measured for horizontal surfaces. If your

sites have aspects then they have also slope values (if you need them to calculate solar radiation for tilted surfaces)

Answer n.8:

The aspect value refers to the pixel to which the station belongs. The authors choose to include this information also because is usual in literature (Tovar et al. (1995); Long and Ackerman (1995))

REVIEWER 3

We thank the reviewer for the detailed comments, and the overall appreciation of the paper. Comments 3, 4, 13-15 and 17-21 referred about typos, the spelling, or minor notes that were accepted and applied following the suggestions of the reviewer.

Comment n.1

section 4.2 together with figures 3 and 4 should be removed or largely reduced to a comment about possible future work, unless results are obtained and presented using the methods described in this section.

Answer n1

The section 4.2 was included in the paper for showing the fact that complex topography played a more important rule in the application of the Piave river basin than in the applications on Little Washita and Fort Cobb. It had not the aim of presenting a statistical method used to analyze the model results.

Because two reviewers commented it and suggested to reduce or exclude the section from the paper, the authors decided remove the section.

The new section about a raster application of the model on the Piave river basin instead allows the authors to present the effect of the complex topography.

Comment n.2

There are several references to the hydrological application of these components, however, no effort has been made to test this application. This is fine, but then, the reference to hydrology should just appear on the Introduction, as a possible application, and it should be removed from the abstract, conclusions and discussion because it is not part of the work presented.

Answer n.2

The references to the hydrological application are justified many reasons. First of all the components presented in this paper are part of the whole hydrological system NewAge-JGrass. Secondly, as part of the system the component was applied in related work:

- In Formetta et al., 2011 the radiation is computed by using the component presented in this paper. The results was used in sequence for the estimation of evapotranspiration and finally for the computation of discharge.
- In Formetta et al., 2013 the snow model uses an energetic index computed by using the radiation tools presented this paper.
- All the applications presented in the Ph.D. thesis Formetta, 2013 use the components presented in this paper for estimating radiation and the results are used as input for other components estimating evapotranspiration, snow water equivalent, and discharge.

Because of this reasons the authors decided to maintain the references to the hydrological applications of the component presented in this paper. Presenting hydrological applications related to the water (discharge, soil moisture) is not an aim of this paper but it is necessary to make the reader aware that the presented components are part of a bigger system to which they can be linked.

Comment n.5

P4359L15-20. Specify how Isc is spatially corrected and rephrase why this correction

is needed.

Answer n.5

This comment was also presented by the reviewer n.1. As answered in that case, the authors decided to delete the sentence: " Therefore in the following is assumed that the solar constant, I_{sc} has been spatially corrected to account for the geometry and the position of the landscape underneath, to give a "corrected" solar constant, $\hat{I}_{sc}$". The word "corrected" referred to the correction due to the eccentricity of the earth's orbit and it was computed as proposed in Spencer (1971). In order to make the notation lighter the authors decided to use only the symbol I_{sc} to indicate the solar constant and to modify the formula 1 substituting $\hat{I}_{sc}$ with I_{sc}.

The correction due to the eccentricity of the earth's orbit is specified when the term E_0 is described ("is a correction factor related to the Earth's orbit eccentricity computed according to Spencer (1971)")

Comment n.6

Ambient temperature and relative humidity are reported as inputs of the model, but they do not appear in any of the equations or elsewhere in the text so please specify in which of the referenced models and/or how are they used.

Answer n.6

Air temperature and relative humidity are used in the computation of the precipitable water w[cm] that appears in equation 12. w is computed according Prata(1996) as specified in the paper. The author decided to include in the text the fact that w depends on the air temperature and relative humidity of the point in which radiation is computed:

Old sentence: " where w [cm] is precipitable water in cm calculated according to Prata, 1996."

New sentence: "where w [cm] is precipitable water in cm calculated according to Prata, 1996. In this formula w depends on the atmospheric conditions of the point in which radiation is estimated and in particular w is a function of air temperature and relative humidity."

Comment n.7

P4363L20-21. Rephrase the unclear sentence "To account for the presence of clouds, some models found in the literature were denominated decomposition models." and include here the pertinent references.

Answer n.7

The authors agree with the reviewer's suggestion. The sentence was modified:

Old sentence: "To account for the presence of clouds, some models found in the literature were denominated decomposition models"

New sentence: "To account for the presence of clouds, three decomposition models were implemented: Erbs et al. (1982), Reindl et al.(1990)" and Boland et al. (2001)"

Comment n.8

How does the model handle the event of shadowed sites? In this case the clear sky direct irradiance will be zero and (cs)i will not be well defined. This will affect the

interpolation at non-shaded sites.

Answer n.8

If in a certain hour of the day the point of the measuring station is in shadow, the direct irradiance will be zero. In this case when the Decomposition model component runs, it excludes from the computation domain this point and it use just the point in which the direct irradiance is higher than zero.

Comment n.9

Three decomposition models are described for the DEC-MOD's component, namely Erbs et al. (1982); Reindl et al. (1990) and Boland et al. (2001). However only the first two are used in the validation process. In addition and according to P4369L9-11 Reindl model is applied to the sites "Little Washita and Fort Cobb catchments", and Erbs model to site "Piave river basin". But section 3.4.3 states that Reindl model is used for site "Piave river basin". Why are not all the models used in all the sites? This way their performance could be better assessed on complex topography. The reader and potential user of the proposed implementations could also benefit from a recommendation on the use of one of them.

Answer n.9

The decomposition models are based on site-specific coefficients. In the paper it is reported for each model the zone in which they can be applied. Erbs' model was applied with USA data whit latitudes between 31 and 42 degrees North; Reindl's model was applied by using data measured in USA and Europe (latitude between 28--60 degrees N); Boland's model was applied by using data from Victoria, Australia. Because of this reason we decided to apply the Reindl's model for the Italian river basin and the Erbs model for the USA river basins, and avoid to use Boland's parameterization (which, however, we offer to the users)

The reviewer suggestion of estimating the sensitivity of the decomposition models is highly appreciated and the authors will take care of this suggestion for future works.

Moreover, the authors correct the sentence in which the use of the decomposition model for each river basin is defined as follows:

Old sentence: "For the simulations of this paper, the Reindl model was used in the case of Piave river basin and Erbs model was used for Little Washita and Fort Cobb catchments."

New sentence: "For the simulations of this paper, the Reindl model was used in the case of Piave river basin and the Erbs model was used for Little Washita and Fort Cobb catchments. This choice was based on the fact that the Erbs model was estimated by using USA measurement and Reindl model was estimated by using European measurements. The Boland's parameterisation is not used but just offered to possible Australian users."

Comment n.10

Section 3.1 states that the 5 minutes data was summed /accumulated /summarized to an hourly step. Do you mean averaged? Please use the same term for the three sites and expand the description of this process.

Answer n.10

The authors accept the reviewer's suggestion and decided to use the word "cumulated" in the three cases.

The operation was to sum the 5 minutes available measurement in order to obtain an

hourly time series starting from the 5 minutes time series.

Comment n.11

How was the selection process for the validation data sets?

Answer n.11

The criteria we used in selecting the verification stations was based on the idea to consider stations with different topographical features in terms of elevation, aspect, slope that highly condition the solar radiation in a given point. The fact that we present the model verification for three river basins with different topographical features and climates makes, in our view, the verification more robust.

Comment n.12

Eq 1 defines the direct component as Rsw, also in the comment before the equation, and also in table 8 R is defined as "direct" But in most of the paper S is used for the direct component and R for the global shortwave radiation (sum of direct and diffuse). Please fix.

Answer n.12

The authors accept the reviewer's comment and decided to use $S\downarrow$ for the incident cloudless solar radiation, $S\downarrow^{*}$ for the incident all-sky solar radiation and $R_{sw}\downarrow$ for the global shortwave radiation (sum of direct and diffuse).

Comment n.16

Please review all the references to equations in the text, most of them seem to be off (e.g. P4365L9 Eq. (22) should be Eq. (28); P4370L5 "...Eq(21) and (22):" should be 33 and 34).

Answer n.17

The authors accept the reviewer's comments in part and modify the mistakes. In our opinion P4365L9 Eq. (22) is correct: $S\downarrow^{*}$ and $d\downarrow^{*}$ depend on, among the other things, k_d coefficient and kd depend, in turn, on k_t coefficient through the decomposition models. The "...Eq(21) and (22) references were wrong and were corrected in the revised paper.

Comment n.23

Figs. 3 and 4 could be removed.

Answer n.23

The authors prefer to keep in the paper the two figure because they are important part of the discussion section. Moreover they give the idea of the component-based capability of the model: exchanging few components of the system different model solution could be easily executed.

Comment n.24

Figs. 5-7. Expand the captions. Add Latitude/Longitude grids, scale, and north arrow to the maps.

Answer n.24

The authors agree with the reviewer's comment. We added the scale in figures 5, 6 and 7, we added the north arrow and we improved the captions adding for all the river basins: "Triangles represent the verification set (V-set) and circles represent the calibration set (C-set). The comparison between measured and modeled incoming solar radiation is represented in term of scatter plots"
We did not add the Latitude/Longitude grids because to perform the graphs we used the GIS uDig-JGrass integrated in the NewAge-JGrass system according to the framework OMS v3.0. Until now, the option of exporting maps with the lat/long box is not implemented in the version 1.3.1. We prefer to use our tools because it is an important part of the system and we are going to introduce them in the next version. The scale-bar, legend, and north arrow are options implemented in the current version of the GIS and were used according to reviewer's suggestion.

Comment n.25

Specify in the legend what do the triangle and circle stand for, according to figures 6 and 7 it seems to be a distinction between the C-set and the V-set but this does not stand for figure 5. Add the total area covered to the description of the three sites. Remove the ".0" from station ids in figure 6.

Answer n.25

The authors agree with the reviewer's comment. Figure 5 was corrected and in the new version of the paper there is the distinction between the C-set and the V-set for all the figures.

Comment n.26

A map of Direct and Diffuse radiation, or maybe simply a map of global radiation must be added to demonstrate the results of the method, and a description and analysis of the map will throw some light about the goodness of the methodology when applied to complex topography in addition to the utilized statistics.

Answer n.26

The authors agree with the reviewer's comment. The model application in raster mode is presented in a new section in the revised paper. Comments to the map are presented in the Results section.

Reference

Corripio, J. G.: 2003-a*, Modelling the energy balance of high altitude glacierised basins in the Central Andes*. University of Edinburgh, 2003.

Corripio, J. G.: 2003-b, Vectorial algebra algorithms for calculating terrain parameters from DEMs and the position of the sun for solar radiation modelling in mountainous terrain, *International Journal of Geographical Information Science* 17(1), 1–2

Long, C. and Ackerman, T.: Surface measurements of solar irradiance: A study of the spatial correlation between simultaneous measurements at separated sites, Journal of Applied Meteorology, 34, 1995.

Liu, Benjamin YH, and Richard C. Jordan. "The interrelationship and characteristic distribution of direct, diffuse and total solar radiation." *Solar Energy* 4.3 (1960): 1-19.

Helbig, N., et al. "Explicit validation of a surface shortwave radiation balance model over snow‐covered complex terrain." *Journal of Geophysical Research: Atmospheres (1984–2012)* 115.D18 (2010).

Tovar, J., Olmo, F., and Alados-Arboledas, L.: Local-Scale Variability of Solar Radiation in a Mountainous Region., Journal of Applied Meteorology, 34, 2316–2328, 1995