

Review for Regional modeling of vegetation and long term runoff for Mesoamerica by P. Imbach, L. Molina, B. Locatelli, O. Roupsard, P. Ciais, L. Corrales, and G. Mahé

Response to reviewer #2:

The integral reviews are included in this response. Answers to the questions made by the reviewer are marked in italic text. Changes to the manuscript, revised and new paragraphs are indicated by a bold font

Review: "This paper makes a useful contribution to regional modelling of water balance components such as (evapo)transpiration and runoff, as well as important vegetation parameters such as leaf area index or stomatal conductance based on climate input for Mesoamerica at a resolution of 1km. It is generally clear and well written and the diagrams are clear and relevant. I am convinced of the relevance of this topic and applicability of results to further studies and therefore strongly support the publication of this paper. However, I do have some general questions and more detailed ones further below. In general it would be helpful if the model was described in more detail."

Response 1: The model is described in full detail by Neilson (1995) with all equations in Appendix 1. We did not include the equations because we believed that the presentation of a simplified model version would raise more questions than it would bring information. Nevertheless we deepened model explanation and revised the whole Section 2.2, P806 L6 – P807 L4, to look as follows:

"MAPSS simulates potential vegetation cover and leaf area given light and water constraints. The water balance of one year is calculated in monthly time steps based on the vegetation leaf area and stomatal conductance for canopy transpiration and soil hydrology (Neilson, 1995). The modeled year represents a multi-year average climate parameters (see periods for each variable in Table 1). Canopy interception and evaporation of precipitation are a function of the number of rain events and leaf area index (LAI) and are linearly related to monthly precipitation. Summer and winter frequency of events is estimated depending on a potential evapotranspiration threshold in order to distinguish frontal and convective storms. Water reaching the soil layer is divided into fast runoff and infiltration. The latter is regulated by saturated and unsaturated percolation processes according to Darcy's Law (Hillel, 1982). As much as three times per month, water balance is compared to soil capacity and excess of water leads to infiltration and percolation. The soil is divided in three layers with grasses having access to water from the top layer, woody vegetation (including trees and shrubs) from the top and intermediate layers, and the deepest layer is used for base-flow and has no roots. Before percolation, transpiration by grasses and woody plants occurs. The ratio of actual to potential evapotranspiration (PET) increases exponentially with LAI. PET is calculated using climate and an aerodynamic turbulent transfer model (Marks, 1990). Stomatal conductance decreases with decreasing soil water potential and with increasing PET. Actual transpiration is calculated for each life form, constrained by PET and based on canopy conductance. Canopy conductance is the product of the life form stomatal conductance and canopy leaf area (based on LAI). Stomatal conductance depends on soil water content and PET.

The calculation of LAI involves competition for both water and light between woody and herbaceous vegetation. Water is used by each life form proportional to their LAI values. Woody and grasses competition is based on an inverse linear relationship, in which LAI

of trees increases and that of grasses decreases up to a threshold where grasses are eliminated and the canopy is closed. The final equilibrium LAI is calculated iteratively for grasses and woody vegetation, so that life forms consumes most of the available water in a single month of the growing period and never drops below the wilting point. MAPSS assumes the annual soil and aquifers water storage term (Δs) in Eq. (1) is close to zero, which is mostly true on an annual basis or in catchments characterized by a high superficial runoff to infiltration ratio:

$$R = P - E - I - \Delta s \quad (1)$$

Where, R is runoff, P is precipitation, E is evapotranspiration, I is interception and Δs is the water storage in soils and aquifers.

Vegetation physiognomy is hierarchically classified with rules based on life forms LAI (grasses, shrubs and trees), leaf form (broadleaf or microphyllous) and phenology (evergreen or deciduous) of woody vegetation and thermal zones (tundra, taiga, boreal, temperate, subtropical and tropical).

A detailed model description, in which we based this section, including model equations and default parameters, is given by Neilson (1995)."

Review: "Most importantly, I am concerned about the modelling period, which was chosen. Did I understand correctly that longterm monthly averages are simulated? And that a validation is carried out with longterm averages of then different periods? (The language is not very precise here)."

Response 2: Climate input data are long term averages (see in Table 1 the period averaged for each variable), therefore output variables (i.e. runoff and evapotranspiration) represent long term averages. Validation was carried out with long term averages both for runoff and leaf area index. The average period for leaf area index is stated in Table 1. The runoff average period is different for each catchment and does not necessarily exactly match the period of the climate input data although it overlaps most of it. In order to account for this problem we included the catchment selection criterion of having at least a 15 year average runoff (LTSA dataset). This criterion allowed us to account for a potential validation bias due to mismatches in the periods averaged for input and validation data by assuming that a 15 year average would remove annual and inter-annual differences. A sentence was added at the end of the first paragraph in P810 L3: "The runoff data was collected for a time period overlapping the time period of climate data (see data description in Table 1) and any bias due to a mismatch between time periods of input and validation data was discarded. In addition, no significant trends in mean precipitation have been observed in Central America between 1960 and 2005 (Aguilar et al., 2005)."

Review: "On the one hand I am curious about the gain of this study, if longterm averages are modelled. Shouldn't the aim be to model time series? And if timeseries are indeed modelled, how is this done with the longterm average climate input that is used?"

Response 3: Time series are not modeled nor validated, only long term average runoff. Climate input data is not available as time series at high resolution. Furthermore, the model simulates climax vegetation and water balance as a static biogeography model and therefore cannot account for inter-annual variability.

Review: “And secondly, if longterm averages are constructed from different decades, i.e. modelling period (climate input) and validation period (longterm runoff) do not match, how well does the validation work considering decadal climate/runoff variabilities? “

Response 4: Modelling period (climate data) and validation period (runoff data) mostly overlap (see previous point). See changes made in response 2 on input and validation data.

*Table 1 was updated with a comment on the runoff period used for validation. We added, to the runoff series length column in Table 1, a footnote stating: “**Information on time period was available for 79 catchments (LTSA) and ranged from 1950 to 2008 with a value concentration between 1965 and 1991.**”*

Review: “What is the advantage of using potential vegetation, wouldn't it be more useful to consider actual vegetation, which is available at 1km spatial resolution from remotely sensed data? Especially since on agricultural areas, infiltration and surface runoff behaviour differs from that on potential natural vegetation? Further, irrigation additionally modifies the local water balance. Also urban areas have a very different runoff regime at that resolution due to sealed areas. Shouldn't this be taken into account? Compare P806 L2 “anthropogenic influence has reduced natural vegetation to 58% of the area”. “

Response 5: Ideally, yes. MAPSS approach allowed us to have results relevant for both hydrology and vegetation at a regional scale with rather simple input data that was available for a data scarce region. The model is “concerned with the constraints on vegetation “carrying capacity” and potential type, rather than constraints on growth rates or productivity during succession” (Neilson, 1995) using a process based approach applicable at regional scale which is important for future studies on the impacts of climate change. Other models/approaches could provide deeper knowledge into either the hydrology of the region (i.e. forcing current land use categories or a catchment or distributed hydrological model) or its vegetation (i.e. vegetation dynamics or carbon dynamics) but MAPSS provided a good balance between these two components.

The lack of time series for input climate data or detailed land cover dynamics meant that an attempt at modelling long term runoff considering agricultural classes could have faced similar gaps that the ones currently found with MAPSS. For example, land cover would have had to be assumed constant over the modelling period and no differences between annual and perennial agricultural types could have been made (the data is not available). Agroforestry systems and perennial crops covering large areas of the region (i.e. shaded coffee or cocoa) have a hydrological behavior that is probably closer to that of forests than of intensive annual agriculture (i.e. Gomez et al., in preparation for this journal). Finally, remote sensing global data on land cover do not distinguish agricultural types in the region nor have field validation in the region. This issue was particularly relevant for the selection of LAI validation areas from the remote sensing sources presented in this paper (see section 2.3.6 Performance of vegetation and LAI modeling). The land cover map used here is the only one available with validation field work performed in the region along with a much coarser one based on NOAA-AVHRR data for 1998 (with practically the same date).

*To further clarify this point we modified the end of the sentence in P804 L5-7 to look as follows: “**This model, called MAPSS (Mapped Atmosphere Plant Soil System), has been validated at the continental scale for the United States (Neilson, 1995; Bishop et al., 1998) and provided a good trade-off between the accuracy of the outputs (vegetation and hydrology) and the amount of input data.**”*

Review: “In the following I have more detailed questions that arouse when reading the paper. I tried to indicate page and line number when possible, abbreviated P and L, where ff means including the lines after, F= figure. P804 L10 – apparently the model is useful if detailed land use maps are missing as it relies on soil data. How good is the soil data in regions where there is no land use data? Maybe this sentence could be re-written?”

Response 6: Input soil data is texture, depth and rock content that is assumed to remain constant over several years and not affected by land cover, therefore the advantage of not needing time series of land use or land use maps that have different agricultural classes (i.e. annual and perennial crops). Soil data is based on a global soils map (although a dataset of higher resolution soil maps was also tested, see Figure 8 and section 2.3.2 on Sensitivity tests). The sentence, P804 L7, was changed for: “(i) potential vegetation cover can be simulated based solely on climate and soils (texture, depth and rock content) data. Land use does not need to be forced into the model, which is of considerable advantage in areas where detailed land use maps are missing,”

Review: “Which vegetation classes are exactly differentiated – the same as described in Neilson, 1995, i.e. grass and woody vegetation, which can be trees or shrubs, evergreen or deciduous, and needleleaved or broadleaved? Are shrubs part of the tree class? Are the rooting depth assumptions the same in one class (i.e. wood vs. grass)? (see P806 L14)”

Response 7: See response 1 on changes in model description.

Review: “P804 L11 (iv) evapotranspiration modeled through ecophysiological modelling; in how far is soil evaporation included? Please give equations for these processes. Is there any lateral transport of water in the model? the Model needs to be explained in more detail (i.e. include equations)”

Response 8: See response 1 on changes in model description.

Review: “P805 L11 mean annual surface temperature cannot have small fluctuations over the year, please rewrite sentence “

Response 9: P805 L11 was changes for: “Compared to temperate latitudes mean monthly surface temperature has less seasonal variation in the tropics.”

Review: “Better distinguish actual and potential evapotranspiration, sometimes it is not clear which one you are talking about.

Response 10: See response 1 on changes in model description.

What exactly is the time step of the model/ which years / period is modelled? Average climate input have different base years? How well do averaging-periods match for runoff and climate? Is a monthly time step suitable for modelling transpiration and soil hydrology if it is based on the modelling of stomatal conductance? Wouldn't a higher resolution in time be necessary?

Response 11: See previous changes presented in response 1 on model upscaling from stomatal to canopy conductance and clarifications made regarding validation and input data periods. Working with a higher time resolution was not possible due to lack of high resolution

time series of climate or validation data (we are currently assessing the possibility of building such databases).

What is the gain to model stomatal conductance in comparison to using a simple rainfall-runoff relationship if average monthly values are desired? P806 L8ff”

Response 12: Section 3.2 and Figure 10 show the advantage of not using simple rainfall-runoff relationships. Furthermore, modelling vegetation also sets the basis for analyzing the impacts of climate change on vegetation as well as the hydrological component (a publication on this is being prepared). To further clarify this point we modified the end of the sentence in P804 L5-7 as stated in response 5 on the reasons for choosing MAPSS.

Review: “P806 L10 “interception is a function of the number of rain events and lai” - doesn’t the timing of rain events make a difference here, e.g. rain events evenly spread over the months vs. all rain days in a row? Is this considered in the model? What is the effect of this error?”

Response 13: See response 1 on changes in model description. There is an indirect consideration since the model accounts for different types of rains (frontal and convective storms) but data is not available to measure this source of error. The model has many other variables that could be validated in the field but for which data is not available at the regional scale.

Review: “P808 L18 maybe the calibration method section could be moved to follow the sensitivity test section, as it is mentioned there.”

Response 14: The suggestion has been made. Section “2.3.2 Sensitivity tests” has been moved after section “2.3.4 Model calibration and validation”.

Review: “P809 L9 Only 135 catchments of 466 are used for calibration and validation? Is any conclusion drawn to the other catchments? Is calibration transferred to catchments without records? If so, how?”

Response 15: The assumption here is that the catchments used account for the whole range of climate conditions in the region and therefore the validation presented allows extrapolating the model output variables for the whole region. The catchments not used for calibration/validation do not meet the specified criteria for LTSA and TSA and therefore are not suitable for calibration/validation nor are they all the region catchments. In order to avoid confusion in P809 L9 we changed the sentence to: “(out of a total of 466 with available runoff data)”.

Review 16: “P802 L17 / P812 L14 How well can modelled potential vegetation be validated with remotely sensed actual vegetation? And P813 L4 how many pixels had to be excluded because the maps don’t concur?”

Response 17: We made the following modification in P813 L2-4 for clarification: “Comparisons were made only in pixels (17% of the area) where each land cover map matched the ecosystem type on the Central America Ecosystem map (WB and CCAD, 2001) over pristine ecosystem classes (i.e. excluding agricultural areas).”

Review: “P814 L10ff please specify calibration, validation and modelling periods. How about a map of catchments?”

Response 18: See changes made for P810 L3. Table 1 was updated with a comment on the runoff period used for validation. We added this information in Table 1, see response 4. Figure 1 was updated with catchment location.

Review: "P815 L17 how about using equation 1 from the paper instead?"

Response 19: It was not possible to use Formula 1 ($R = P - E - I - \Delta s$) since we only have the R and P components for each catchment, therefore we had to simplify the test.

Review: "P819 L20 does this database consist of longterm averages? Is it available for other groups?"

Response 20: Yes, if the paper is published it will be available from our website. We cannot provide a link yet.

Review: "F4 – would percentage deviation give a better picture?"

Response 21: We believe is better understood in absolute values (we evaluated the possibility of using percentages). Although differences are high in terms of percentage, they are within normal absolute values found in LAI comparison studies both from field studies and remotely sensed data (i.e. a 100% difference could have an absolute value of 0.5 in dry areas which is within an acceptable level of variation).

Review: "F7 – where are these catchments located?"

Response 22: Figure 1 was updated with catchment location.

Review: "F9 – is this pixel based runoff? It might be helpful to include catchment boundaries?"

*Response 23: Yes. P807 L6 was updated with: **"We implemented MAPSS at the resolution of the temperature forcing data (1km²) unless otherwise stated. In cases where input data had a coarser resolution (i.e. wind speed data) it was re-sampled to 1km² (see Table 1 for data description)."** Figure 1 was updated with catchment location.*

*We added a new paragraph to the acknowledgments section after P820 L25 with the following: **"The authors would like to thank Ron Neilson, Ray Drapek and John Wells from the USDA Forest Service, Pacific Northwest Research Station in Corvallis, Oregon, USA. They provided essential support for this work, by providing the model code and advice in its implementation and usage."***