Reply to comments of referee #2

We thank the referee for his/her comment on our manuscript. In the following paragraphs, we provided detailed answers to all his/her comments. We repeat the specific comments of the referee before our answers (bold font).

In their manuscript, Ringeval et al. describe a wetland parameterisation for the ORCHIDEE LSM, based on the TOPMODEL approach and a new parameterisation of frozen soil water. They present model validation results for streamflow and inundated area.

The manuscript generally is well written, with the exception of the model description section, and the model extension presented is a valuable contribution, since the extent of saturated soils is an important factor for determining Methane emissions, an area where the current generation of GCMs generally is lacking.

The new parameterisation actually degrades model performance with respect to streamflow, and the determined grid cell fractions of saturated soil are far from perfect, but the authors present these shortcomings openly. Since very few approaches for determining wetland extent are published yet, the manuscript still is a valuable contribution.

I therefore recommend acceptance with revisions.

Major comments: The model description clearly is lacking. From the manuscript, it is impossible for the reader to understand, how TOPMODEL and the normal ORCHIDEE hydrology interact. The authors refer to a previous publication describing some aspects of TOPMODEL in ORCHIDEE, but even when referring to this it is very difficult for the reader to understand how model hydrology and TOPMODEL interact.

In addition, important model outputs are not documented at all. An equation for Fmax is missing completely, and how the topographic index enters the model is completely unclear. Wmax and Wmin are used in the text, but never explained. Fwet is also unclear.

Section 2.3 therefore needs to be rewritten completely so the readers can actually understand what the new scheme does. A few more equations would certainly improve the manuscript.

2.1) We agree with this comment, also underlined by the referee 1. We rewritten the entire section 2.3 in the revised version of manuscript. The new version, given also in the reply 1.1 of referee #1 comments, is pasted below in blue.

Pages 692; lines 4 to Page 693; line 2 of the current version of the manuscript are replaced in the revised version by (in blue):

We follow the approach of [Decharme et al., 2006; Habets and Saulnier, 2001] for the ISBA model and [Gedney and Cox, 2003] for the MOSES model to describe a subgrid soil moisture distribution into ORCHIDEE using TOPMODEL concepts [Beven and Kirkby, 1979]. Following [Decharme and Douville, 2007] we also incorporate the bias correction of [Saulnier and Datin, 2004]. This defines the ORCHIDEE-TOP version, which we apply globally and evaluate in this study (Fig. 1) and which allows us to compute at each time-step the fraction of each grid-cell which reaches ω_{max}, further noted F_{max}.

TOPMODEL was initially developed at river catchment scale. It attempts to combine the distributed effects of channel network topology and dynamic contributing areas for runoff generation [Beven and Kirkby, 1979; Sivapalan at al. 1987]. This formalism takes into account topographic heterogeneities explicitly based on the spatial distribution of a topographic index λ_i (m), defined at the pixel scale as follows:

$$\lambda_i = \ln(a_i / \tan\beta_i) \quad (2)$$

where a_i (m) is the drainage area per unit of contour of a local pixel, i, and $\tan\beta_i$, the local topographic slope, approximates the local hydraulic gradient where β_i is the local surface slope. If a given pixel in a catchment has a large drainage area and a low local slope, its topographic index will be large and thus, its ability to be saturated will be high.

TOPMODEL gives a relationship between the mean water deficit in a catchment (D_t), the local deficit of a given pixel ($d_{i,t}$) into the considered catchment and the topographic index:

$$D_t - d_{i,t} = -M\,(\lambda_m - \lambda_i) \quad (3)$$

where M (m) is a parameter describing the exponential decrease of the soil transmissivity with local deficit and λ_m is the mean topographic index over the catchment. For a given mean deficit over the catchment (D_t), a threshold topographic index λ_{th} can be diagnosed in such a way that all pixels with a local topographic index $\lambda_i > \lambda_{th}$ have no local deficit ($d_{i,t} = 0$).

Then, a fraction of the catchment, noted F_{max}, defined by the pixels with no water deficit can be estimated from the partial integration of the spatial distribution of the topographic index in the catchment, noted δ:

$$F_{max} = \int_{\lambda_{th}}^{\lambda_{max}} \delta(\lambda_i)\,.\,d\lambda_i \quad (4)$$

The coupling between TOPMODEL and ORCHIDEE assumes that the relationship between local soil moisture, mean deficit and topography holds within each grid-cell at the LSM resolution [Gedney and Cox, 2003]. It requires the estimation of the grid-cell mean deficit from variables computed by ORCHIDEE. Following [Decharme et al., 2006], we consider that the grid-cell average deficit (D_t) and the soil moisture computed by ORCHIDEE (ω_{soil}) are proportional for each time-step, so that the grid-cell average deficit D_t can be simply expressed as:

$$D\,t = ((\omega_{max} - \omega_{min}) - \omega_{soil}).h_{soil} \quad (5)$$

Here, h_{soil} is the ORCHIDEE soil depth and D_t is computed as a deficit with respect to the maximum soil water content ω_{max}. As a result, F_{max} corresponds to the subgrid fraction at ω_{max}, and it varies at each time-step, being inversely proportional to the grid-cell mean deficit D_t deduced from the soil water content ω_{soil} computed for each time-step by ORCHIDEE.

Following [Decharme and Douville, 2007], we also incorporate the bias correction of [Saulnier and Datin, 2004]. This correction leads to more complex relationships than given here by equations (3) and (4) for the sake of simplicity. All details can be found in [Decharme et al., 2006].

Wmax and Wmin were already explained on Page 690, Line 5. We modified slightly the corresponding lines to be clearer.
Better explanations about how Fwet is computed are also given in the revised version of the manuscript. The new lines corresponding to this section are given in the reply 1.2 of referee #1 comments and are copied below.

Pages 697 Lines 4-5 and 9-16 of the current version of the manuscript are replaced in the revised version by (in blue):

In the aim to simulate wetland extents that are compatible with P10, we introduce a global parameterization in order to deduce calibrated wetland fractions (Fwet) from the fractions at maximum

soil water content (F_{max}).
[…]
We performed a shift of the topographic index distribution by modifying the topographic index in all grid-cells:

$$\lambda'=\lambda+c \qquad (7)$$

where c is a global constant. This leads to modify the sub-grid topographic index distribution, called hereafter δ'. In the idealized case in which the equations of the Section 2.3 are given, i.e. without the bias correction of [Saulnier and Datin, 2004], the wetland fraction, F_{wet}, would be computed similarly to the Equation (4):

$$F_{wet} = \int_{\lambda_{th}}^{\lambda_{max}} \delta'(\lambda_i) \, . \, d\lambda_i \qquad (8)$$

c has been optimized to obtain an annual global F_{wet} close to the global annual P10 +29%, i.e. P10 + the estimate of drained wetland extent since the pre-industrial period [Sterling and Ducharne, 2008] This leads to a global "pristine" wetland fraction about ~3.2%. With c (unit in ln(m); see [Ducharne, 2009]), the yearly global F_{wet} is equal to 3.4% while the mean annual F_{max} fraction over 1993-2004 is 9.7%.

Minor comments:

- Page 690, line 23, and page 702, line 19: A Figure "S1" is referenced, which doesn't exist. You mean Fig. A1? **corrected**
- Citations: There are numerous instances, where the brackets of citations are used in a non-optimal way. The first paragraph of Section 2.3, for example, contains numerous cases where publications are cited (authors, year), though authors (year) would be more appropriate. Please check and correct.

From the "Examples for Reference Sorting" in http://www.geoscientific-model-development.net/submission/manuscript_preparation.html , it seems that short citations in the text can be displayed as "[…] Smith (2009) […]", or "[…] (Smith, 2009) […]".

- Page 696, lines 1-5: The limitation through the non-consideration of anthropogenically modified river basins: would that apply to all basins? Some basins? Where is it really important?

Effect of dams could be particularly large in the Ob (see Page 699, Line 5) and the irrigation could play a particularly strong effect in the Mississippi (see Page 700, line 3). We added it it in the revised version.

- Page 697, lines 9-16: Do you use a constant c for all grid cells? Since Sterling and Ducharne published a map of drained wetland areas, it might also be a spatially varying c. This issue, and especially the reasons for the choice you made, should be discussed.

c is used to deduce Fwet from Fsat. This section has been improved in the revised version of the manuscript (please see below).
The opportunity to optimize c at regional scale (which allows both to match in a better way the data and to account for variability in the wetland drained area between the different world regions) has been added in the discussion in the revised version.

- Page 701, line 16: "Yearly" should be replaced by "annual". Same goes for Fig. 5 **corrected**
- Page 703, line 25: Spurious "max". **removed**

- Page 704, line 12: Reference in the text is Fig. 8, should be Fig. 7 **corrected**
- Page 708, line 28: "wetlands extents" should be "wetland extents". There’s other instances of incorrect plural "wetlands" in the text, for example "wetlands diversity" on page 713, line 24. **corrected**

for copy-editing: please add “Melton et al., in prep”, on page 688, Line 7