RESPONSES TO REVIEWERS' COMMENTS

We are grateful to the reviewers and associate editor for their detailed and insightful comments. In light of the suggestions, we have made efforts to significantly revise the manuscript. The suggestions and comments have substantially contributed towards improving the paper. More details are as follows:

Interactive comment on "Modeling the Potential Impacts of Climate Change on the Hydrology of Selected Forested Wetlands in the Southeastern United States" by Jie Zhu et al.

Anonymous Referee #2

Received and published: 17 May 2017

GENERAL COMMENTS: The discussion paper uses an empirical approach to determine hydrological effects on climate change for 5 wetland types in the southeastern U.S. The paper generally has scientific significance in that it tries to address uncertainties associated with climate change, and the overall structure of the paper is clear and concise. However, the paper lacks rigorous evaluation of the model and results. The general model structure appears flawed (see comments below), and model results are seemingly taken at face value. For example, the authors do not address a major source of uncertainty associated with climate change: water use efficiency (WUE). Climate change is associated with increases in CO2, not just temperature, and increased CO2 is known to increase WUE, which would have major implications for the results presented here. There was also little consideration given to changes in water availability for vegetation, which drives actual ET. Additionally, the graphics and tables were lacking in quality and readability, and should be revised. There were many typographical and grammatical errors. Overall, this paper needs major revisions.

RESPONSE: We are very thankful for the reviewer's detailed reviews about the uncertainty associated with our modeling results related to other factors of future climate change, e.g. the increased WUE because of the increased CO_2, and the changes in water availability for vegetation. This work focuses on the wetland groundwater variability due to climate drivers' change such as precipitation and air temperature. We did not specifically consider the effects of increased CO_2 on vegetation growth and productivity which may further affect wetland hydrology in the study due to the following reasons.

First, some of the GCM models used here already contain a dynamics vegetation model (e.g., Yu et al., 2016); thus, vegetation responses to increased CO_2 have been considered in these GCMs. Second, previous results suggest that precipitation and surface air temperature are the two first order climate variables to drive wetland groundwater (Liljedahl et al., 2011). Third, quantitative analysis about the wetland evaporation/evapotranspiration comparison found that transpiration from canopy provided few contributions to evapotranspiration (Li et al., 2009).

We thank the reviewer to get our attention and will study the aspect in our future work although this is out of the scope of work of the present study. According to the comment, we added recommendations for future work in line 200-203 (in the revised manuscript, similarly hereinafter). The related references were added in the revised version.

"Li, Y. J., Zhou, L., Xu, Z. Z., and Zhou, G. S.: Comparison of water vapour, heat and energy exchanges over agricultural and wetland ecosystems, Hydrological Processes, 23, 2069-2080, 2009. (Line 571-573)

Liljedahl, A. K., Hinzman, L. D., Harazono, Y., Zona, D., Tweedie, C. E., Hollister, R. D., Engstrom, R., and Oechel, W. C.: Nonlinear controls on evapotranspiration in arctic coastal wetlands, Biogeosciences, 8, 3375-3389, 2011. (Line 574-576)

Yu, M., G. Wang, and H. Chen, Quantifying the impacts of land surface schemes and dynamic vegetation on the model dependency of projected changes in surface energy and water budgets, J. Adv. Model. Earth Syst., 8, 370–386, 2016. (Line 699-701)"

We have also improved the methodology (line 131-134, line 141-144, line 148-156, line 161-175, line 195-198, line 223-232, etc.), results (line 248-249, line 249-250, line 260-270, line 312-314, line 315-323, etc.), and discussion (line 326-332, line 439-440, etc.), re-plotted the graphs (line 725, line 730, line 740, line 745, line 755, and line 760) using high resolution and re-done the tables (line 700 and line 710) to improve the quality and readability as suggested.

SCIENTIFIC COMMENTS:

For the reviewer's convenience during re-review, we numbered his/her comments and included our corresponding responses, below.

Point #1

COMMENT: Line 78-79: Why is Greenberg et al. (2015) referenced here without discussing how it "satisfactorily" used an empirical model? All you say is that they used one.

RESPONSE: We much appreciate the reviewer's careful review. We further discussed the references in line 75-77 as follows:
"Greenberg et al. (2015) developed an empirical model and demonstrated its utility for climate-change planning by successfully forecasting the weekly hydrologic regimes (2012-2060) and examining the indirect impacts of climate change on biological diversity."

Point #2

COMMENT: Line 158-159: It is not clear what the rationale is for using lagged water table as an independent variable? It seems clear that the most recent water table value will be highly correlated to the water table now. Is this just using autocorrelation as a covariate? Consider revision.

RESPONSE: The lagged water table was actually considered as a covariate. The rationale to use the lagged water table was to account for its contribution to the current water table, in addition to the role of current climate and water availability, based on the considerations as follows:

(i) This study adopted the well-established methodology of dynamic panel model widely used in statistics and econometrics. The dynamic panel modeling includes the first lag dependent variable coupled with the explanatory variables (e.g. P, PET, in this study). The model structure with a given lag effect were successfully used in the previous studies for hydroregime prediction (Greenberg et al., 2015, Webb et al., 2003), urban water demand prediction (Almendarez-Hernández et al., 2016; Arbués et al., 2004; Arbues et al., 2010, Lyman, 1992), and energy-food-water interaction modelling (Liu et al., 2017; Ozturk, 2015). Lyman's (1992) and Ozturk (2015) confirmed the adjustments significance of minimizing heterogeneity in the traditional Ordinary Least Squares assumptions by including the first lagged dependent variable. Webb et al. (2003) improved the sensitivity and explanatory power of the hourly based water-air temperature regression models by incorporating a lagged response of water temperature. In a wetland hydrology and climate change study, Greenberg et al. (2015) successfully forecasting the hydroregimes of multiple wetlands by modeling the water table depth using water level of the prior week and precipitation as predictors of current water table.

(ii) The statistical model structure has physical meaning and can be viewed from the perspective of water balance. A lagged effect of water table was supported by the water balances and the water table dynamics of wetlands. It is due to the fact that wetland groundwater has memories which can be carried beyond the next season as to influence the water balance in the coming years (Miguez-Macho and Fan 2012). Firstly, the water balance of the five selected wetlands can be written as $\mathrm{WT_t} - \mathrm{WT_{t-1}} = \alpha + \beta(\mathrm{P_t} - \mathrm{ET_t}) + \varepsilon_t$. It indicates the causality balances between water tables changes (left side terms of the above equation i.e., $\mathrm{WT_t}$ –$\mathrm{WT_{t-1}}$) and its water availability changes (right side terms of the above equation). The item of $\mathrm{WT_{t-1}}$ depending on the time scale can be considered as the memory effect of water tables. By moving the memory item ($\mathrm{WT_{t-1}}$) to the right side, the different statistical coefficient of $\mathrm{WT_{t-1}}$ can reflect the different memory characters/effects in the five selected wetlands. Based on these reasons, we believe the model structure that includes a lagged water table in this study can offer more information concerning not only water tables changes due to changes in climate variables, but also the different memory effects of different wetlands in this region.

(iii) All the information is not contained in the antecedent water table conditions of wetlands. The lagged water table only offers the basis for the current condition, however, the forcings (e.g. climate and water availability in this study) alters the water table depth. In another word, the water table depth would always decrease/increase along with a given initial discharge/recharge condition for the wetland. But, a wetland actually alternatively discharges or recharges for the flatness, thus water tables fluctuated with the forcings. Therefore, both the forcings and the lagged water table would determine the water tables for a wetland. What's more, when using the water table at LP site with forcings from FL-WET site, the statistics show that in spite of the same antecedent condition, the R^2 becomes poorer to 0.54 from 0.83.

(iv) From the perspective of the proved wide-sense stationary first-order autoregressive process of water tables in the five selected wetlands, the variance will not change with the autoregressive process introduced into the statistic model. For an autoregressive process given by: $\mathrm{Y_t} = \alpha + \beta \mathrm{Y_{t-1}} + \varepsilon_t$, where ε_t is a white noise process with zero mean and constant variance σ_{ε}^2. The first-order autoregressive process is wide-sense stationary when and only when $|\beta|<1$, because it is the output of a stable filter with a white noise input (Mills, 1990). In the wetlands analyzed in the study, the coefficient of WT_{t-1} are<1 (Table 4), indicating a wide-sense stationary autoregressive process of water table. Thus the variance of the process does not change with simulation over time, and the intertemporal effect ($\beta^n \varepsilon_1$) of shocks diminishes toward zero in the limit.

(ⅴ) From the perspective of the independence of the explanatory variables, introduce of antecedent water table does not violate the independence requirements among the explanatory variables. Independence between the explanatory variables was satisfied since correlation coefficient between P-PET and WT_{t-1} was very poor (<2.7) for the five selected wetlands in the study.

According to the comment, the justification was further concisely added in line 161-175 in the revised manuscript to make it clearer for readers. Also, the related new references were added to the revised manuscript as follows:

"Almendarez-Hernández, M., Avilés Polanco, G., Hernández Trejo, V., Ortega-Rubio, A., and Beltrán Morales, L.: Residential Water Demand in a Mexican Biosphere Reserve: Evidence of the Effects of Perceived Price, Water, 8, 428, 2016. (Line 467-469)

Arbués, F., Barberán, R., and Villanúa, I.: Price impact on urban residential water demand: A dynamic panel data approach, Water Resour Res, 40, 2004. (Line 475-476)

Arbues, F., Garcia-Valinas, M. A., and Villanua, I.: Urban Water Demand for Service and Industrial Use: The Case of Zaragoza, Water Resour Manag, 24, 4033-4048, 2010. (Line 477-478)

Liu, G., Yang, Z., Tang, Y., and Ulgiati, S.: Spatial correlation model of economy-energy-pollution interactions: The role of river water as a link between production sites and urban areas, Renewable and Sustainable Energy Reviews, 69, 1018-1028, 2017. (Line 574-576)

Lyman, R. A.: Peak and off-peak residential water demand, Water Resour Res, 28, 2159-2167, 1992. (Line 586)

Mills, Terence C. Time Series Techniques for Economists. Cambridge University Press, 1990. (Line 600)

Ozturk, I.: Sustainability in the food-energy-water nexus: Evidence from BRICS (Brazil, the Russian Federation, India, China, and South Africa) countries, Energy, 93, 999-1010, 2015. (Line 627-628)

Webb, B., Clack, P., and Walling, D.: Water–air temperature relationships in a Devon river system and the role of flow, Hydrological processes, 17, 3069-3084, 2003. " (Line 688-689)

Point #3

COMMENT: Line 160: It seems like an autocorrelation covariance structure should be used given the time-series nature of the data.

RESPONSE: We view that "an autocorrelation covariance structure" here as "covariance structure of autocorrelation". For an autoregressive process given by: $Y_t = \alpha + \beta Y_{t-1} + \varepsilon_t$, where ε_t is a white noise process with zero mean and constant variance σ_ε^2. The autocovariance is $B_n = E(X_{t+n}X_t) - \mu^2 = \frac{\sigma_\varepsilon^2}{1-\beta^2}\beta^{|n|}$, where μ is the model mean, and n is the time step (Mills, 1990). In this study, autoregressive process is wide-sense stationary ($|\beta|<1$), thus $\frac{\sigma_\varepsilon^2}{1-\beta^2}\beta^{|n|}$ diminishes toward zero in the limit in the general model form (Line 180). Besides, the autocorrelation nature for the given data time-series was first tested to select the final variables. The autocorrelation of water tables with lag time of 0 day, 15 days, 30 days, 45 days, and 60 days were tested, as well as their correlations with the other explanatory variables. Consequently, in the final model (line 246), only the 15-day (one time step) lagged water table was chose as an explanatory variable for the best statistical results. Thus only a constant variance σ_ε^2 exists in the final selected wide-sense stationary first order autoregressive process.

Point #4

COMMENT: Line 176: Water loss is also controlled by net groundwater flow, but more importantly by vegetation access to water and vegetation water use efficiency (WUE), which are not accounted for in the model. And because we know that WUE is strongly influenced by CO2 concentrations, this appears to be a major deficiency in the model.

RESPONSE: Please see our replies to the General Comment (page 1-2). We agree with reviewer on the hydrological processes identified. However, given the empirical nature of our model, these factors are not explicitly considered. We have also added some discussion regarding the potential uncertainty originating from discounting the effects of increase in CO_2 on WUE in the revised version (see lines 200-203):

"The change in atmospheric CO_2 is likely to affect water use by trees through altering plant water use efficiency (WUE) (Brummer et al., 2012), but this process was not considered in this study. In addition, lateral water loss/gain from net groundwater flow was not simulated explicitly."

The related new reference was added to the revised manuscript as follows:

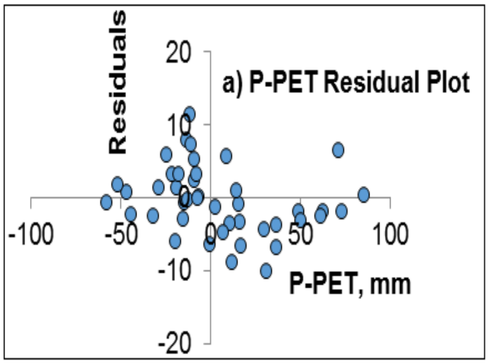
"Brummer, C., Black, T. A., Jassal, R. S., Grant, N. J., Spittlehouse, D. L., Chen, B., Nesic, Z., Amiro, B. D., Arain, M. A., Barr, A. G., Bourque, C. P. A., Coursolle, C., Dunn, A. L., Flanagan, L. B., Humphreys, E. R., Lafleur, P. M., Margolis, H. A., McCaughey, J. H., and Wofsy, S. C.: How climate and vegetation type influence evapotranspiration and water use efficiency in Canadian forest, peatland and grassland ecosystems, Agricultural and Forest Meteorology, 153, 14-30, 2012." (Line 490-494)

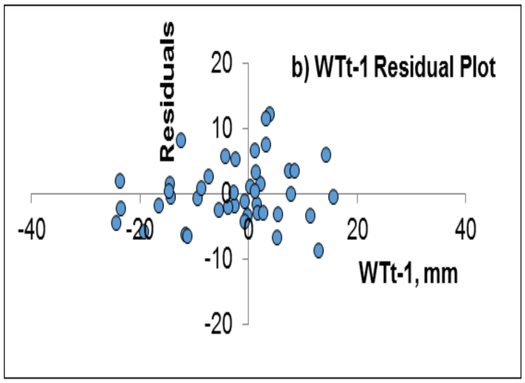
Point #5

COMMENT: Line 186-195: Did you also test for assumptions of normality of residuals and homoscedasticity of residuals? If you did not take into account autocorrelation of covariance it is likely that these assumptions may be violated.

RESPONSE: The normality and the homoscedasticity for both the five sites were tested before the models were applied to the prediction. The residual plots of the five specific models showed that errors are homoscedastic, and both the residuals and the normal probability plot showed the normality of the residuals in the five selected wetlands. With introducing the autoregressive variable, the Durbin's h also indicated the autocorrelation disturbance process. We also added the clarification to the revised version in line 248-249:

"The residual plots and the normal probability plot of residuals showed the normality and homoscedasticity of residuals of the five specific models." The related figures of AR site were shown as an example as follows:





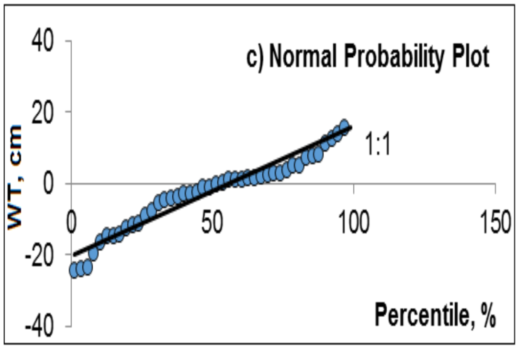


Figure 1 Residuals and normal probability plots of AR site, a) P-PET residual plot, b) WTt-1 residual plot, c) normal probability plot. The residuals and standard residuals of the observed Y (water table) have a mean of zero (6×10^{-16}， 1×10^{-16}， respectively).

Point #6

COMMENT: Lines 196-199: What did you find with Durbin's h? Did it support autocorrelation or not?

RESPONSE: The Durbin's h tests for the models showed that all the five wetlands regression models support the autocorrelation, by comparing the lower and upper critical value from the Durbin-Watson Table. The results of DW test were added to the Table 4 in line 711 in the revised manuscript. We also added the statement to the revised manuscript in line 249-250 as follows:
"Durbin's h statistic showed that the five wetlands regressions support the autocorrelation disturbance process."

Point #7

COMMENT: Line 234-236: Are these estimates for changes to PET based purely on temperature changes? This seems important to note.

RESPONSE: Yes, PET is estimated based on air temperature only in addition to day length following Sun et al., (2002). The associated note was added in line 195-198 as follows:
"PET is mainly controlled by net radiation, air temperature, wind speed, air humidity (Hargreaves and Samani, 1982). Due to data availability, here we used the air temperature-based Hamon equation to calculate PET (Hamon, 1963) using widely

available temperature data. This Hamon’s PET method has been widely used worldwide to estimate potential water uses, especially in this region (Sun et al., 2002)”

The new reference was added to the revised manuscript as follows:

“Hargreaves, G. H. and Samani, Z. A.: Estimating potential evapotranspiration, Journal of the Irrigation and Drainage Division, 108, 225-230, 1982.” (Line545-546)

Point #8

COMMENT: Line 270-271: This sentence is the opposite of what is suggested by the figure and is confusing to interpret.

RESPONSE: The sentence was revised in line 312-314 as follows;
“In contrast to wetlands of LP, FL–UP, and SC, the wetlands AR and FL–WET show a lower probability (40 % for FL–WET, 49 % for AR) being ineffective to store surface water as a wetland in the baseline, but still significantly increasing to 62 % and 93%, respectively.”
We also updated the table order in line 312 from (Table 4, Fig. 6) to (Table 6, Fig. 6).

Point #9

COMMENT: Lines 272-279: This section is very difficult to understand, especially trying to reconcile with figures. Suggest re-writing.

RESPONSE: The section has been re-written (Line 315-323) as follows:

“While LP, FL–UP and SC were all predicted to be ineffective to store surface water (water table < 0 cm) over the study period, the soil saturation status (water table depth still within 30 cm) were different (Table 6). Site LP and FL–UP would completely dry up from baseline to2099 based on the RCP 8.5 scenario. Wetland SC, which was saturated 100% of the time during baseline period, would also suffer significant dryness with saturation time period decreasing to 57 % in 2099. The wetland SC would, therefore, be at high risk of being unsaturated. The wetland FL-WET, however, would be the most sensitive one among the five with the most change of probability being ineffective to store surface water (increasing from 40% to 93% from the baseline period to 2099) and being saturated (decreasing from 100% to 63%). Notably, the wetland AR would be the only wetland that would remain 100% saturated under all scenarios including RCP 8.5 scenario (Table 6, Fig. 6)."

Point #10

COMMENT: Lines 283-285: Where are the R2 values coming from? Are these ratios of R2 to other sites? Clarification needed.

RESPONSE: The R^2 values are the coefficient of determination of the regressions model results. The clarification was added in the revised version in line 326-332 as follows: "the relatively lower R^2 values of AR (0.81) compared with that of LP (0.83), are likely due to lateral water movement in AR due to coastal influence (Johnston et al., 2005), which cannot be ignored but is generally hard to simulate. The R^2 values of FL-WET and SC sites (0.78 and 0.72, respectively) were lower than that of the North Carolina sites (AR and LP).It was likely due to the higher sensitivity of the wetland type (FL-WET site as a depression wetland, SC site as a Carolina bay, Table 1) to the warming and strongly changing precipitation. The lowest R^2 values lies in the FL-UP site (0.69) mainly for the uncertain contribution of the artificial managed drainage system."

Point #11

COMMENT: Line 288: Did you statistically test that the model coefficients were similar? They do not seem too similar to me…

RESPONSE: We much appreciate the reviewer's careful review. The sentence was deleted in the revised version.

Point #12

COMMENT: Where is the discussion of how the model did not perform well? The model appears to be much flashier and tends to overpredict relative to observed data? RMSE or some other metric would be useful as a comparison.

RESPONSE: We have addressed reviewer's concerns by adding RMSE values. The discussion was added in line 260-270 and line 439-440 as follows:

"Compared to observation years, the average water table was over-predicted by 1.4 cm for LP (-106.25 cm for observation, -104.85 cm for prediction, with root mean square error (RMSE) of 4.92 cm, similarly hereinafter), 1.97 cm for FL-WET (19.02 cm, 19.97 cm, with RMSE of 9.23 cm), and 1.3 cm for SC (-19.1 cm, -17.8 cm, with RMSE of 5.16 cm). Also, it was under-predicted at 2.11 cm for FL-UP (-48.97 cm, -51.08 cm, with RMSE of 5.9 cm), and 0.38 cm for AR (-4.19 cm, -4.57 cm, with RMSE of 3.71 cm).

The under/over prediction may be explained by the different model capability for the different characters of the wetlands types (Cypress Ponds/Swamps, Carolina Bays, Pine Flatwoods, and Wet Pine, and natural Bottomland Hardwoods ecosystems). For example, for the FL-WET Cypress Ponds/Swamps, the water tables were relatively over-predicted during the normal period while the observations and the predictions matched better during the extreme dry year in 1993. It may be because of the higher water table sensitivity to the forcings and the sharper water table changes in a short term (two weeks) in FL-WET as a depression wetland. It also explained the good capability of the empirical models in the annual-scale water table averages, even in the sensitive FL-WET site. Overall, …" (line 260-270).

"Besides, limited observation data availability can contribute to model deficiency and uncertainty as well." (Line 439-440).

TECHNICAL CORRECTIONS:

Point #1

COMMENT: Line 56: "… and more powerful hurricanes landfall." Word choice here is awkward.

RESPONSE: In line 54-55, the phrase was revised to "more frequent and intense Atlantic hurricanes".

Point #2

COMMENT: Line 58: “process-based study” should be “process-based studies”.

RESPONSE: The phrase was revised to “process-based studies” in line 56 in the updated version.

Point #3

COMMENT: Line 70: add “and” before “…their potential uses…”

RESPONSE: The “and” was accordingly added in line 67.

Point #4

COMMENT: Line 73-75: This sentence needs revision for clarity and grammar.

RESPONSE: The sentence was revised in line 70-71 as follows:
“In contrary, when applied over multiple sites, statistical models have advantages of both high efficiency and acceptable performance.”

Point #5

COMMENT: Line 75: “Performance such type of models…” a word is missing.

RESPONSE: The sentence was revised as “Especially, performance of such empirical models…” in line 71-72.

Point #6

COMMENT: Line 84: change “increased” to “subsequent increases”.

RESPONSE: The word was changed accordingly in line 82.

Point #7

COMMENT: Line 88: There is an extra “s” after the parentheses.

RESPONSE: The extra “s” was deleted in the revised version in line 88.

Point #8

COMMENT: Line 289: change “higher” to “lower”.

RESPONSE: The word was accordingly changed to “lower” in line 335.

Point #9

COMMENT: Line 387: Missing a word in “Climate change from single has been used…” and “wetalnd” is misspelled.

RESPONSE: The sentence was revised as “Climate data from single GCMs (Greenberg et al., 2015; Wang et al., 2015) has been used in wetland hydrological response, …” in line 4235-436.

Point #10

COMMENT: Line 625: Table 1 should have consistent formatting for each of the data in columns for ease of comparison. Consider a more generic description of soils instead of series names.

RESPONSE: The Table 1 was reformatted and revised in line 700, and a more generic description of soils instead of series names were used for the sites. The climate data from different time series including the most of the observation years is to better reflect different climate background during model development.

Point #11

<u>COMMENT</u>: Line 670: Figure 3(d) what is meant by the orange dots?

<u>RESPONSE:</u> Figure 3 (line 740, as follows) was updated in the revised version with mistake fixed and the site names put in the figure panel itself. We also improved the quality of Figure 1 (line 725, as follows) and Figure 2 (line 730, as follows).

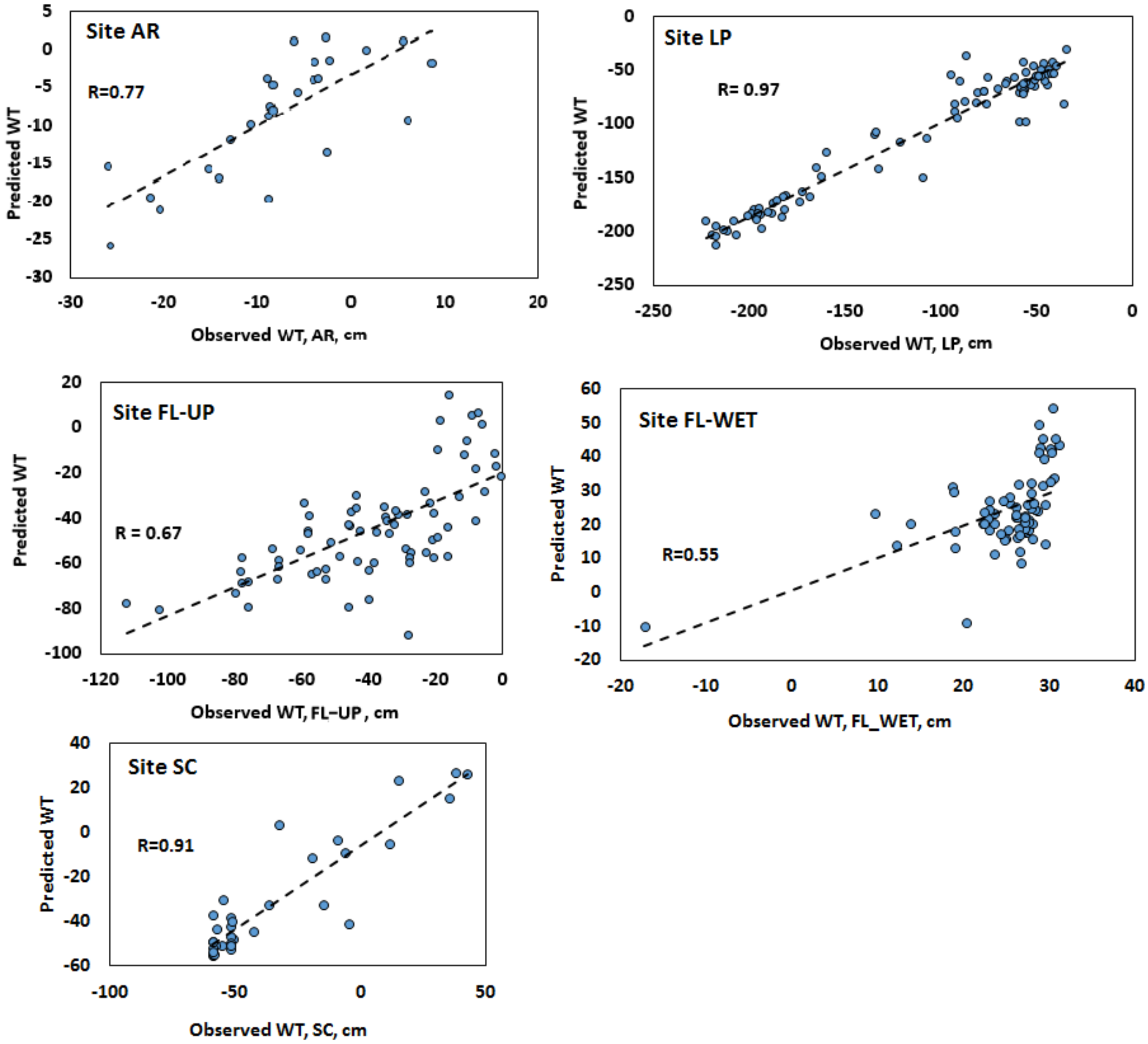


Fig. 3 Scatter plots of the observed and predicted mean water table in five wetlands in the Southeastern United States (unit: cm), Dashed lines are 1:1 line.

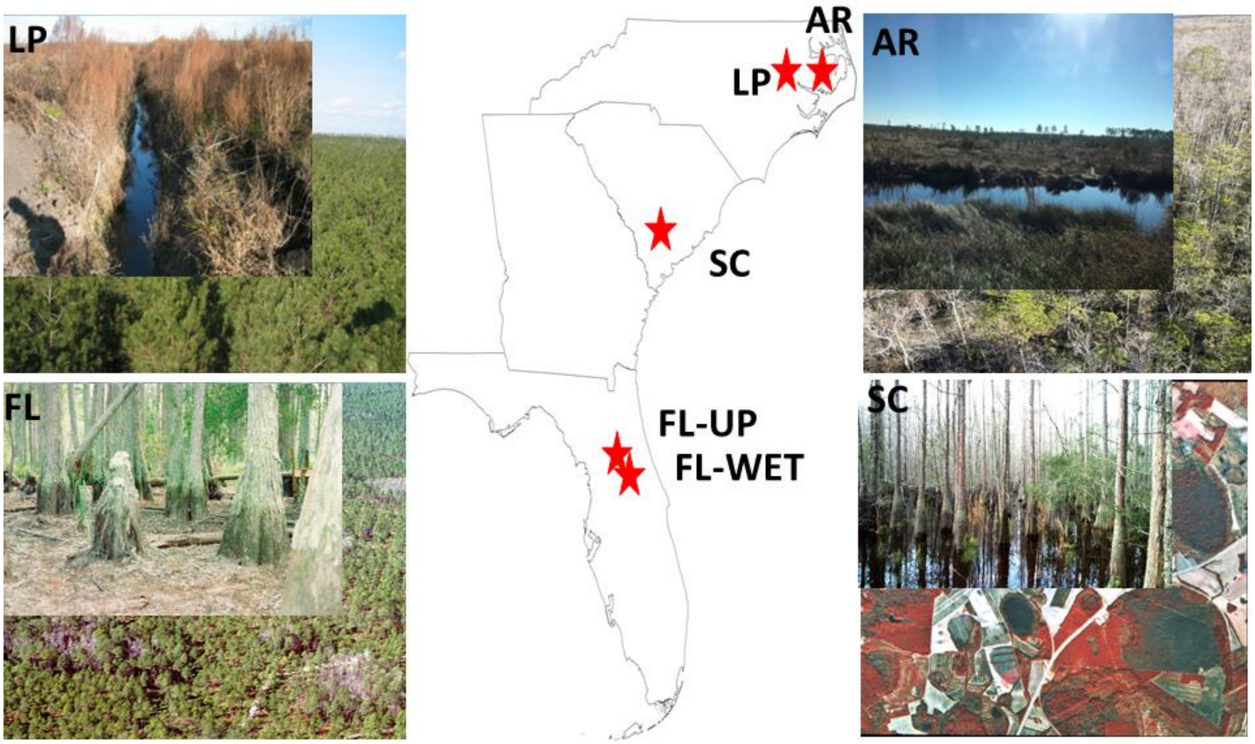


Fig. 1 Study area, where the star symbol marks the study site location. Wetland AR: wetland of Alligator River National Wildlife Refuge in North Carolina; wetland LP: wetland of loblolly pine plantation in North Carolina; wetland SC: wetland in South Carolina; wetlands in Florida: wetland FL–UP (upland in Florida) and FL–WET.

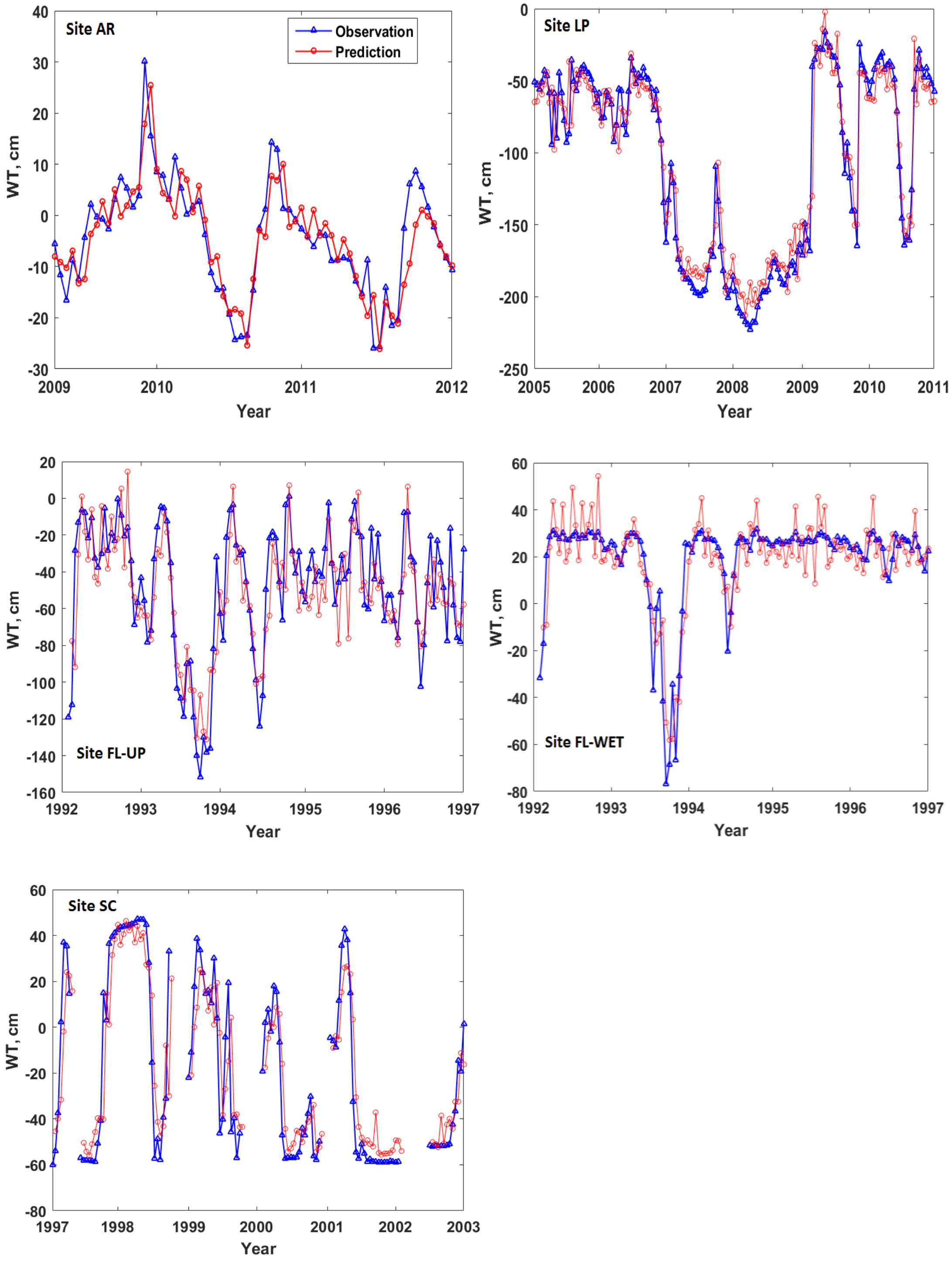


Fig. 2 Comparison of observed and simulated15-day water table in five wetlands in the Southeastern United States, WT is water table.

Point #12

<u>COMMENT</u>: Line 680 and 685: Figures 4 and 5 are begging to have significance letters attributed to each boxplot.

<u>RESPONSE:</u> We much appreciate the reviewer's careful review. The Figures 4 and 5 were revised in line 745 (as follows) and 755 with significance letters, site names in the panel itself, and the quality was improved as well.

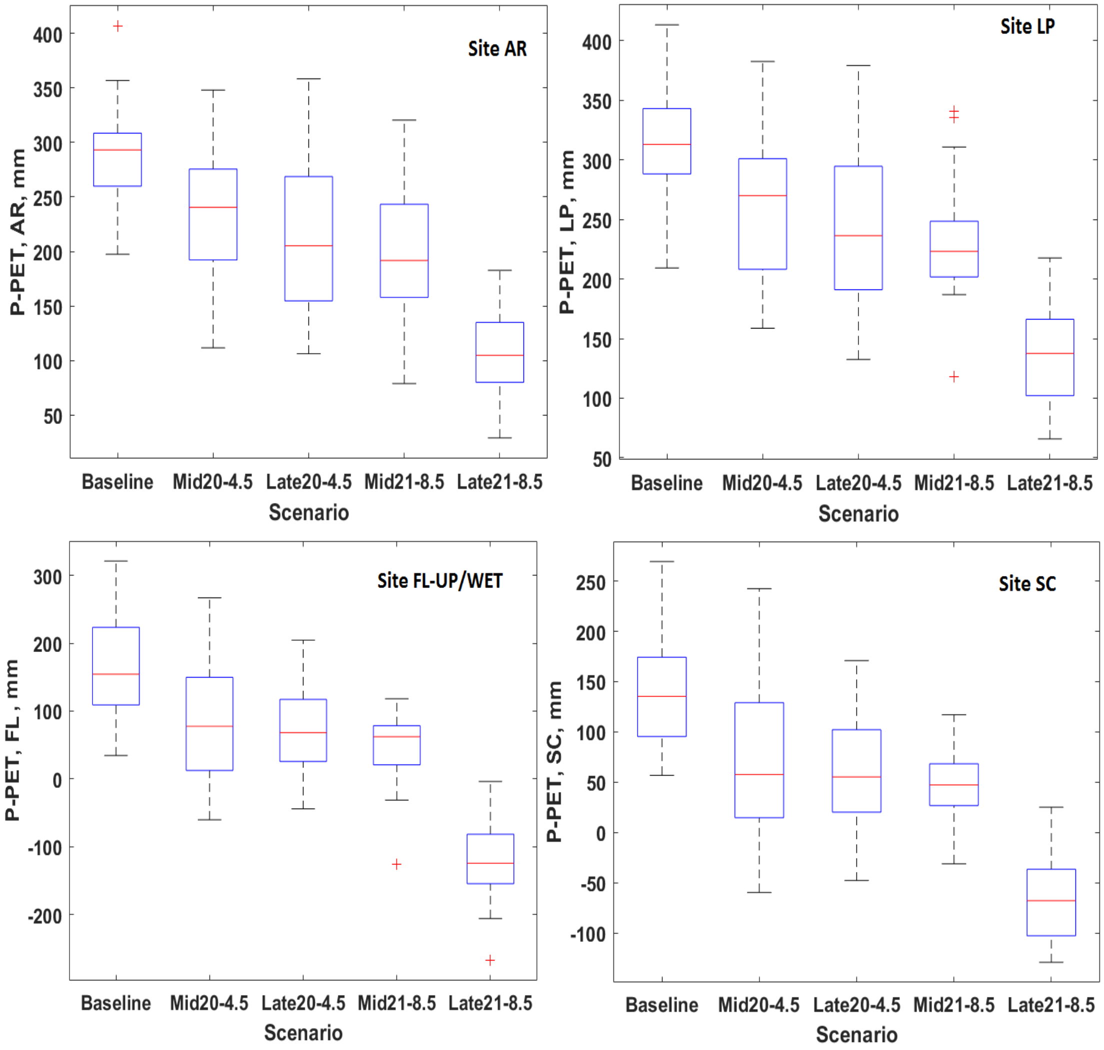


Fig. 4 Total annual precipitation minus potential evapotranspiration of 20 GCMs in five wetlands in the Southeastern United States (unit: mm).

Note: Bseline:1980–1999, historical baseline period;

Mid 20-4.5:2040–2059, RCP 4.5; Late 20-4.5:2080–2099, RCP 4.5;
Mid 21-8.5:2040–2059, RCP 8.5, Late 21-8.5:2080–2099, RCP 8.5;

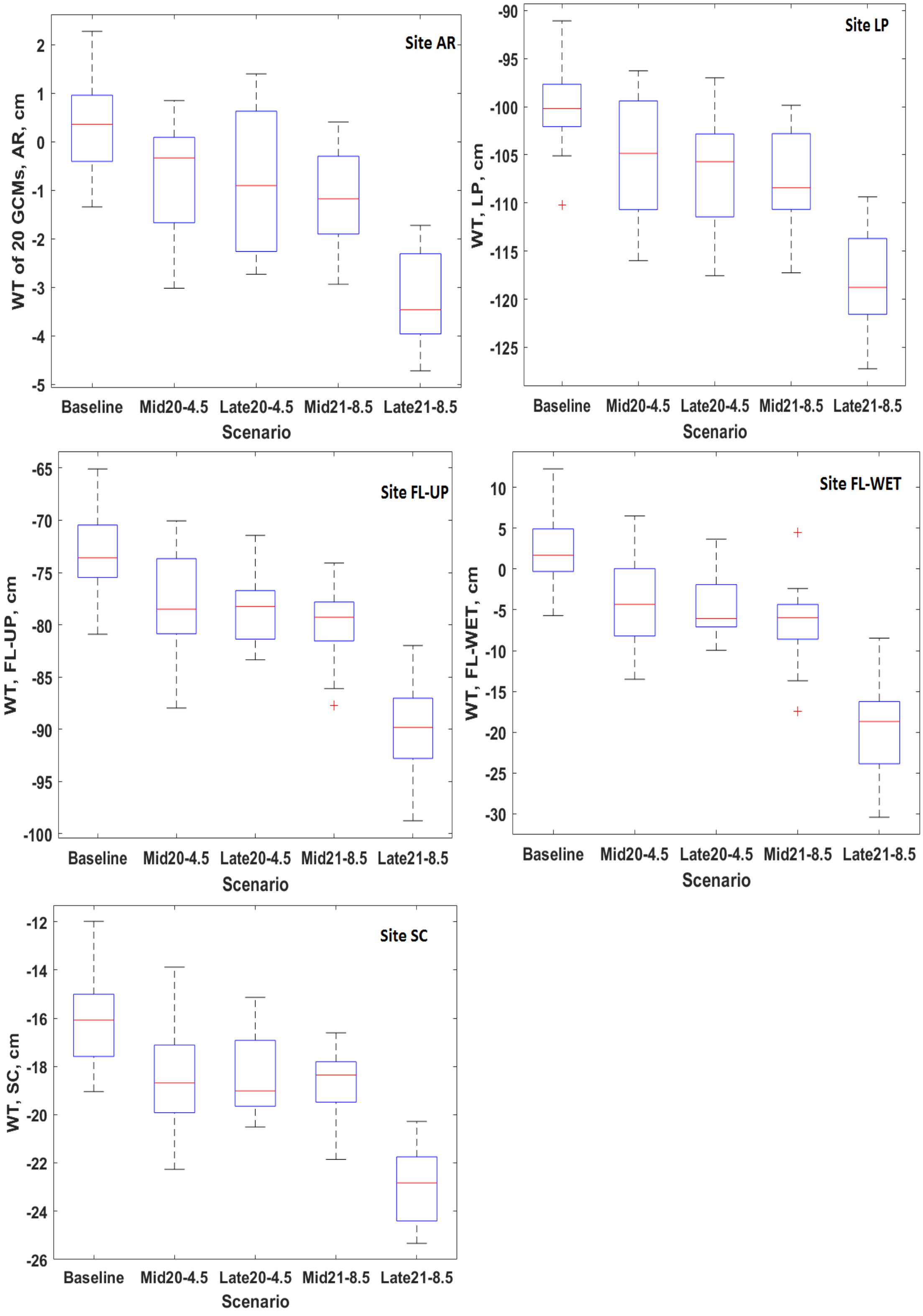


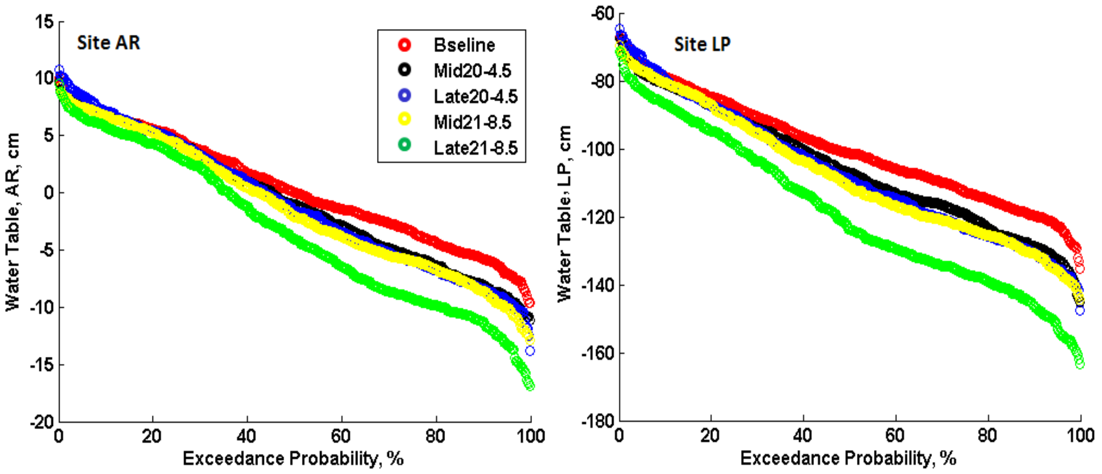
Fig. 5 Mean predicted annual water table of 20 GCMs in five wetlands in the Southeastern United States (unit: cm).

Note: Bseline:1980–1999, historical baseline period; Mid 20-4.5:2040–2059, RCP 4.5; Late 20-4.5:2080–2099, RCP 4.5; Mid 21-8.5:2040–2059, RCP 8.5, Late 21-8.5:2080–2099, RCP 8.5;

Point #13

COMMENT: Line 685: Figure 6 – These axes should be flipped for ease of interpretation. Also fix the legend so it doesn't look like it was drawn by hand. Consider changing the x-axis label and putting the site name in the figure panel itself.

RESPONSE: We much appreciate the reviewer's careful review. The Figure 6 was revised with fixing the axes, legend, label, and site names. Also, the figure quality was improved in the revised version in line 760 as follows.



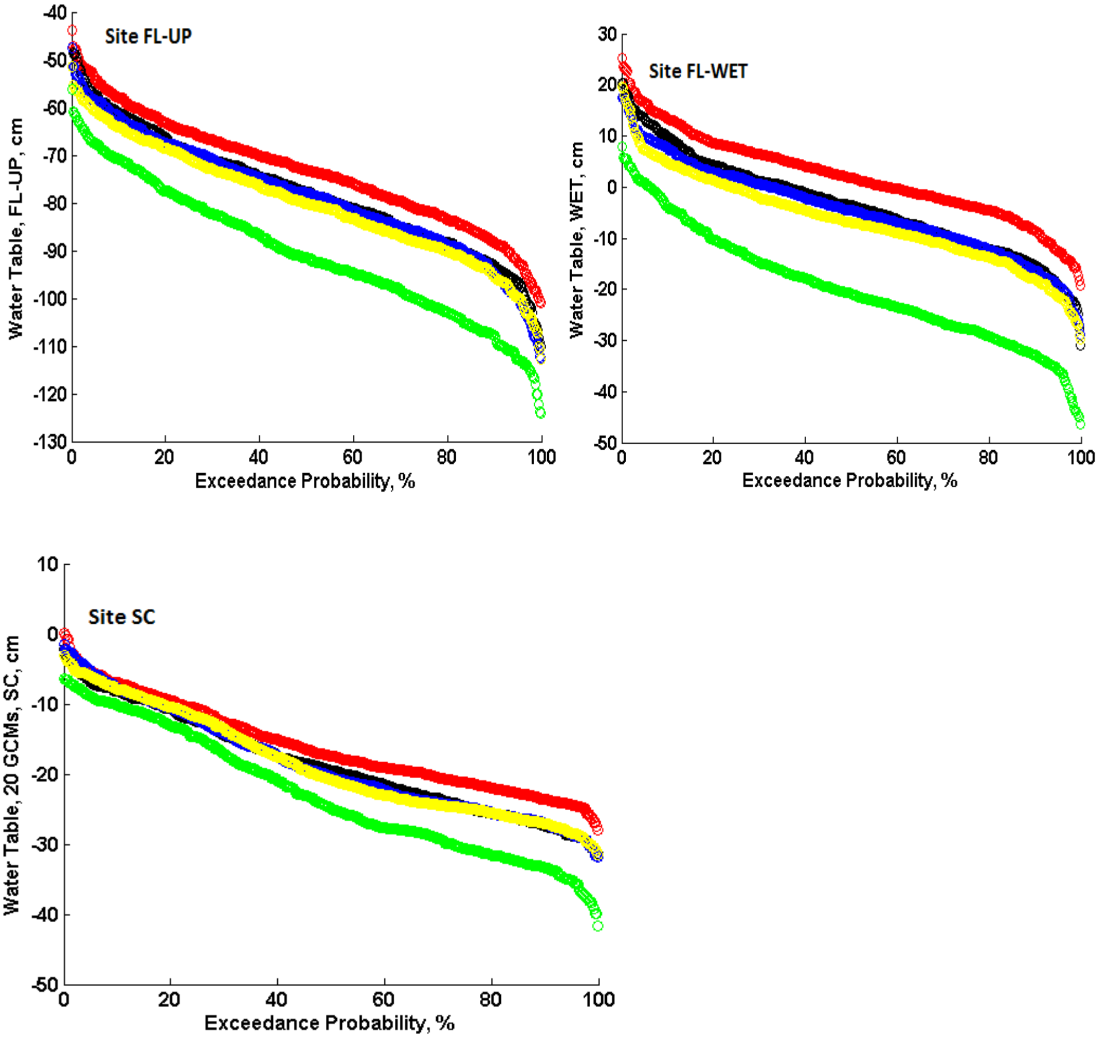


Fig. 6 Exceedance probability of the mean predicted water table in the growing season of 20 GCMs in five wetlands in the Southeastern United States (unit: cm).

Note: Bseline:1980–1999, historical baseline period;

Mid 20-4.5:2040–2059, RCP 4.5; Late 20-4.5:2080–2099, RCP 4.5;

Mid 21-8.5:2040–2059, RCP 8.5, Late 21-8.5:2080–2099, RCP 8.5;