Future Projection of Drought in the Indochina Region Based on the Optimal Ensemble Subset of CMIP5 Models

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1. Introduction

Droughts in the Indochina Region (ICR) have been recorded to affect large number of people and cost large amount of economic loss. Under global warming, more severe drought is expected to hit the region, which requires more detailed analysis on future drought in the region. Thus, the contribution to the future projection of drought in this region is greatly important and in need for effective planning to adapt to climate change. Future climate projection relies on climate model simulations which contain uncertainty. Multimodel ensemble is one way to reduce uncertainty in climate simulation. Thus, evaluating climate model and exploring better way of multimodel ensemble are required for more credible future climate projection, or drought projection in ICR. This study explores the future changes of surface air temperature, precipitation, and drought characteristics in ICR using multimodel ensemble of the Couple Model Intercomparison Project Phase 5 (CMIP5). This thesis is comprised of four parts. First, the variability of precipitation over ICR is analyzed. Second, a framework for climate model evaluation and optimal ensemble selection is proposed. Third, bias correction procedure appropriate for multimodel ensembles is examined for drought analysis. Finally, future surface air temperature, precipitation, and drought characteristics are analyzed using the bias-corrected optimal ensemble subset.

2. Datasets

The station data to assess gridded precipitation data in this study are obtained from Global Surface Summary of the Day (GSOD) of the United States National Climate Data Center (NCDC) and station observations of Department of Meteorology of Ministry of Water Resource and Meteorology (MOWRAM), Cambodia. Five gridded precipitation datasets are obtained, and they include Global Precipitation Climatology Centre (GPCC), Asian Precipitation-Highly Resolved

Observational Data Integration Towards Evaluation of Water Resources (APHRODITE), Global Precipitation Climatology Project (GPCP), Tropical Rainfall Measurement Mission (TRMM 3B42), and NOAA CPC Morphing Technique (CMORPH). After assessment of these gridded datasets, two gridded precipitation datasets, namely APHRODITE and GPCC are employed to characterize the precipitation and evaluate climate models in ICR. The Japanese 55-year Reanalysis dataset (JRA55) is employed for the atmospheric circulation analysis, and its surface air temperature data are used to represent the observed surface air temperature. For Sea Surface Temperature (SST), the dataset of the Hadley Centre Sea Ice and Sea Surface Temperature (HadISST) is used. The outputs of total 43 General Circulation Models (GCMs) of CMIP5 are obtained from Meteorological Research Institute (MRI) of Japan Meteorological Agency (JMA), and this data can be also downloaded from https://cmip.llnl.gov/cmip5/data_portal.html.

3. Characterizations of Monthly Precipitation in the Indochina Region

Space-time variability and interannual variations of precipitation in ICR are analyzed in this study (published as Chhin et al. (2017) and Chhin et al. (2018)). Empirical Orthogonal Function (EOF) analysis for full time series of monthly precipitation in ICR shows that the monotonic pattern of its first mode is influenced from monsoon circulation, whereas the north-south seesaw pattern of its second mode is strongly connected with El Niño Southern Oscillation (ENSO). Long time-lagged correlations of several climate indices related to interannual variation in the tropical Pacific Ocean, such as, Southern Oscillation Index, Nino3.4, Nino4, and El Niño Modoki Index, are found to be statistically significant with precipitation anomalies in southern Myanmar only for pre- and post-monsoon months (April and October, respectively). This long time-lagged correlations are also confirmed by the wide distributions of significant time-lagged regression projected to SST and horizontal wind at 850 hPa level for pre- and post-monsoon months. The composite analysis of extremes and EOF analysis on precipitation variation for the pre- and post-monsoon months over the whole ICR show a good simultaneous association of precipitation in southern Myanmar with a large-scale precipitation structure in ICR. The analysis of moisture flux over large domain shows that the regressed variability of its convergence with precipitation anomaly in southern Myanmar is statistically significant over wide area from Bay of Bengal to southern ICR and South China Sea for both pre- and post-monsoon months.

4. Model Evaluation and the Optimal Ensemble Selection in the Indochina Region

A framework of climate model evaluation and ensemble selection which can be customized toward a specific impact assessment perspective under climate change (e.g., agriculture, flood control, or else) by weighting the performance metrics is proposed in this study (published as Chhin and Yoden (2018a)). The model evaluation and ensemble selection in ICR are performed on precipitation of 43 GCMs of CMIP5. Three criteria are applied to combine a set of diagnostics for creating a single performance index, namely, summation of rank (SR), Euclidean distance of the cluster analysis (CA), and that of EOF analysis. These indices are then used to objectively select optimal ensemble subsets by applying culling method. The model evaluation and multimodel ensemble selection in ICR as a study area are performed on monthly precipitation for two cases: a metric nonweighted case applying equal weights for all 36 metrics, and a metric weighted case focusing on the evaluation for agricultural drought monitoring, as an example, with and without model independence and skill weights introduced by Sanderson et al. (2015). The optimal ensemble subsets selected using this framework show significant improvement in terms of the distribution of monthly precipitation data compared to those of the best single model or the full model ensemble during in-sample period (historical simulation, 1951-2005). The optimal ensemble subsets of CA and EOF criteria are improved more than those of the SR criterion. The performance of the optimal ensemble subsets is also confirmed in out-of-sample period (future simulation under the Representative Concentration Pathways (RCP) 8.5 scenario, 1971-2100) by implementing model-as-truth experiments as done by Herger et al. (2018). A simple and user-friendly decision graph of all model members for the ensemble selection is developed, and its usefulness is demonstrated.

5. Bias Correction Procedure for the Optimal Ensemble Subset

Nonstationary cumulative-distribution-function-matching (CNCDFm) method introduced by Miao et al. (2016) is applied to correct the monthly precipitation data of multimodel ensemble, and the performance of the method is evaluated for a test field of ICR. The performances of the bias correction procedures through two routes (ensemble first and bias correction later, or bias correction on each model first and ensemble later) are compared (Chhin and Yoden, 2018b). The performance of the bias correction procedures is examined for both training period (first half) and evaluation period (second half), after dividing the historical simulation period into two equal lengths. The bias-corrected ensemble subsets that are corrected through the route of ensemble first and bias correction later exhibit higher skill score of probability density function, albeit not much improvement in terms of mean quartile bias. For drought analysis, the optimal ensemble subset that is corrected through the route of ensemble first and bias correction later is adopted for its better performance.

6. Future Projection of Drought in the Indochina Region under a Climate Change Scenario

The bias-corrected optimal ensemble subset projects a larger increase of surface temperature than the bias-corrected full model ensemble, with 0.8°C difference in the late 21st century under RCP8.5 scenario. Based on the bias-corrected optimal ensemble subset, mean temperature in ICR is projected to increase around 1.1°C in near future (2011-2040), 2.5°C in mid future (2041-2070), and 4.3°C in far future (2071-2100). Mean precipitation decreases in dry season (DJF and MAM), increases in wet season (JJA and SON), and the largest increase occurs in SON, whereas the largest decrease occurs in MAM over the whole region under warming climate. Three-month standardized precipitation evapotranspiration index (SPEI-3) projects larger changes of drought characteristics than those of the 3-month standardized precipitation index (SPI-3), especially quite large increases of drought duration and severity. Based on SPEI-3, the potential increase of severe drought hazard is expected in ICR in far future period under RCP8.5 scenario. The most drought-prone areas are detected over Thailand and Cambodia from which the drought characteristics are projected to expand to cover most parts of ICR in mid and far future. The potentially dry condition in ICR is clearly depicted based on SPEI-3.

7. General Discussion

The framework proposed in Chapter 4 (Chhin and Yoden, 2018a) can be generalized by including more metrics of multiple variables and large number of models. The generalization of this framework will increase the applicability of this framework for wider use. First, this framework could be developed into a user-interface software or user-interaction website for model output users (or stakeholders of climate model output). Second, this framework can possibly be used to predict equilibrium climate sensitivity (ECS) employing the concept of emergent constraint that relates a currently observable variable to climate-model-simulated ECS. The relationship (e.g., correlation) between the current observed variables and the climate-model-simulated ECS can be objectively generated weights for performance metrics, which can be incorporated with this framework. Moreover, to the best of the author's knowledge, the application of the newly proposed independence and skill weighting scheme by Sanderson et al. (2015) to the regional scale in the tropical region is the first attempt at the time of this work. The bias correction procedure for the optimal ensemble subsets in this study (ensemble first and bias correction later) is different from several previous studies (bias correction on each model first and ensemble later), and the better performance of the bias correction through this route (ensemble first and bias correction later) for drought analysis is demonstrated. To the best of the author's knowledge, there is no published article applied SPEI to analyze future drought characteristics in ICR at the time of this work. The similar decreasing trend of SPEI obtained in this study is also noted for U.S. Great Plains under RCP8.5 scenario (Feng et al., 2016, Figure 2).

8. General Conclusions

Interannual variations of precipitation in ICR are analyzed, after the assessments of five gridded precipitation datasets based on station observations. A framework for climate model evaluation and optimal ensemble selection is proposed, and its performance is demonstrated using the precipitation data and outputs of 43 CMIP5 models. The framework can be customized toward a specific impact assessment perspective by weighting the performance metrics. Improvement of the optimal ensemble subsets selected by this framework is demonstrated for in-sample period, and also for out-of-sample period under RCP8.5 climate change scenario by implementing model-as-truth experiments. Bias correction procedure appropriate for multimodel ensembles is also examined for drought analysis. SPEI-3 projects larger changes of drought characteristics than those of SPI-3, especially quite large increases of drought duration and severity. Based on SPEI-3, the potential increase of severe drought hazard is expected in ICR in far future period under RCP8.5 scenario. The most drought-prone areas are detected over Thailand and Cambodia from which the drought characteristics are projected to expand to cover most parts of ICR in mid and far future.

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