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# The ENSO Effects on Tropical Clouds and Top-of-Atmosphere Cloud Radiative Effects in CMIP5 Models

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This study evaluates and investigates El Niño-Southern Oscillation (ENSO) effects on tropical clouds and top-of-atmosphere (TOA) cloud radiative effects (CREs) in seven Coupled Model Intercomparison Project Phase5 (CMIP5) models. Satellite-based observations and International Satellite Cloud Climatology Project (ISCCP) satellite simulator output from the CMIP5 Atmospheric Model Intercomparison Project (AMIP) simulations are used. The CMIP5 model simulations of the relative roles of changes in cloud amount, cloud top pressure (CTP) and optical thickness ($\tau$) on TOA CRE anomalies during ENSO are assessed using a series of offline Fu-Liou radiative transfer calculations, including derivation of cloud radiative kernels.
The results show that the CMIP5 models do a considerably better job in simulating tropical TOA CREs than clouds. The better simulations of TOA CREs are often a result of compensating errors between different cloud processes. In the tropical Indo-Pacific, most of the CMIP5 models have the climatological biases of producing considerably less total cloud amount with notably higher cloud top, and all the models produce clouds that are optically much thicker than the observed. During ENSO, most of the CMIP5 models considerably underestimate TOA CREs and cloud changes in the western tropical Pacific. In the central tropical Pacific, while the multi-model mean is comparable to the observations in TOA CRE anomalies and cloud fraction changes, it overestimates the cloud top pressure (CTP) changes by 50%; there are also substantial inter-model variations. On the relative roles of cloud property changes for the TOA CRE anomalies during ENSO, the CMIP5 multi-model mean agrees with the observations on the dominance of proportional cloud fraction change for the shortwave TOA CRE anomalies, and the comparable contributions of changes in cloud fraction and CTP for the longwave TOA CRE anomalies. The comparison between the models and the observations in TOA CRE anomalies from individual cloud properties shows that, the notable model underestimation of TOA CRE anomalies over the western tropical Pacific are mainly due to the model biases in CTP and $\tau$ for shortwave, and CTP for longwave. By comparison, the model biases in proportional cloud fraction changes contribute little to the TOA CRE biases, because of the compensating errors between model underestimating TOA CRE changes from high thin clouds and overestimating TOA CRE changes from medium and thick high clouds.