論 文 の 内 容 の 要 旨

論文題目

Study on Air-Sea Interaction over East Asia Using a Regional Atmosphere-Ocean Coupled Model

（領域結合モデルを用いた東アジアにおける大気海洋相互作用に関する研究）

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The coarse resolution of current state-of-the-art global climate models (GCMs) limits their applications on regional scales as the finer scale information and local climate conditions cannot be resolved at the scale of GCM. Recently, the coupled regional climate models (RCMs) have become useful tools for simulation of regional-scale climate change process and impact studies due to the higher-resolution model forcings and inclusion of air-sea interactions. In this dissertation, a fully atmosphere-ocean coupled regional climate model RSM-ROMS is used, which consists of the atmosphere component, Regional Spectral Model (RSM) and the ocean component, Regional Ocean Modeling System (ROMS). The primary aim is to provide a more general and comprehensive assessments and understandings of the RSM-ROMS.

Chapter 2 aims to remove the systematic cold sea surface temperature (SST) biases over Subtropical Western North Pacific in RSM-ROMS. The long-standing cooler SST bias over Northwest Pacific is found to be pronounced in most Coupled Model Intercomparison Project Phase 5 (CMIP5) GCMs and some coupled RCMs, which limits the model skills in simulating the historical climate and making projection of future climate. Additionally, flux adjustment has been a big issue and so that investigated more in coupled GCMs with the aim to reduce the substantial model errors, but not so much in coupled RCMs. A set of experiments are carried out using RSM-ROMS by employing the flux adjustment and increasing the horizontal resolution from 25 km to 10 km, combinedly and separately, to explore their effects on the simulation of atmospheric and oceanic climate during the warmer season (May-August) in 2006. Both approaches exhibit apparent advantages in the SST simulation. The largest reduction (around 1.09 °C) in cold SST bias can be achieved when the two methods are combined. Among all surface heat flux components, the latent heat flux exhibits the most prominent improvement, which is associated with the improved simulations of the near-surface wind speed and air-sea humidity difference. Flux adjustment appears to exert large positive impacts on the simulation of most atmospheric variables and some oceanic variables in the upper ocean layer. Noted that very small differences are detected in the ocean currents when the flux adjustment is adopted. Increasing spatial resolution can improve the climate simulation in most aspects, especially in the simulation of ocean dynamic and thermodynamic process, no matter whether the flux adjustment scheme is activated or not. Fine grid experiment better captures the observed mean Kuroshio Current path South of Japan due to the better representation of mesoscale eddy activities while the coarse grid run produces the erroneous path. Noted that both approaches cannot guarantee the improved performances in all aspects, and their effects are time and space dependent.

In another aspect, air–sea interaction on the intraseasonal timescales is essential for weather prediction and climate simulation. The advantages of air-sea coupling in the East Asia climate have been well revealed in the previous studies. However, it is still unclear whether RSM-ROMS has the ability to reproduce the realistic feedbacks in the climate system. Thus, chapter 3 aims to confirm the fidelity of this fully coupled RCM in simulating the features of intraseasonal air-sea interaction over East Asia. The intraseasonal (10-60-day) variability over East Asia during 1999-2008 is examined using the coupled model RSM-ROMS and uncoupled model RSM at a resolution of 25 km. Compared with the uncoupled run, the coupled model is more skillful in simulating the intensity of intraseasonal rainfall. In particular, the features (e.g., propagation direction) of eastward propagating boreal winter intraseasonal oscillation and associated MJO events are well captured in the coupled run in spite of slightly weaker amplitude while the uncoupled model misrepresents this phenomenon in the entire tropical regions. The coupled model better reproduces the observed spatial and temporal characteristics (e.g., quadrature phase relationship, amplitude) of intraseasonal SST-precipitation relationship, especially over Western Pacific. However, the uncoupled model forced by prescribed SST tends to produce in-phase variation due to the spurious SST forcing. Additional experiment confirms that the inferior representation in the uncoupled run is due to lack of coupling rather than the atmospheric bias which is unrelated to coupling. The improved simulated positive surface shortwave radiation-SST feedback in the coupled run is potentially attributed to the improved simulation of negative SST-cloud feedback. The temporal coupling feedbacks between the atmosphere and ocean surface can be captured by the coupled model although there are slight differences in the phase lag of time compared with observation.

Chapter 4 aims to clarify the main process responsible for the SST variation by quantifying the relative contribution of atmospheric process to the SST tendency in RSM-ROMS. The atmospheric process (i.e., net surface heat flux) has a leading contribution to the SST variation in RSM-ROMS. However, the coupled model tends to overestimate the contribution of net heat flux in most oceanic region due to the simulated shallower mixed layer depth. The shortwave radiation and latent heat flux are two primary contributing components. Overall, the coupled model RSM-ROMS has substantial advantages in the local air-sea interaction simulation.

Some deficiencies still remain in RSM-ROMS, such as the lower intraseasonal SST variation and shallower mixed layer depth. Chapter 5 focuses on exploring how well the higher horizontal or ocean vertical resolution improves the mean climate and intraseasonal variability. The thicker thickness (around 10 meters) of uppermost layer in the ocean submodel is insufficient to resolve the vertical variation near the ocean surface, which possibly restricts the model capabilities in simulating the realistic upper ocean heat budget for RSM-ROMS. Thus, in order to explore the impacts of higher vertical resolution, two experiments are conducted with 30 layers (around 10 meters) and 50 layers (around 0.5 meters) for the settings of ocean layers (thickness of uppermost layer), respectively. The results show that increasing vertical resolution effectively enhances the lower intraseasonal SST variation over the Kuroshio-Oyashio Current region due to the lower thermal inertia caused by thinner uppermost layer thickness. The shallower mixed layer depth over Western Pacific and Indian Ocean deepens with the magnitude of approximately 10 meters by increasing the vertical resolution. Following the improved simulation of mixed layer depth, the contribution of atmospheric process to SST variation is more realistically presented, with the originally overestimated contribution percentage reduced at a magnitude up to 20%. However, increasing vertical resolution cannot improve or even slightly degrade the simulation of salinity in the maritime continent and coastal regions where there is huge input of grand rivers, indicative of the necessity to introduce the river routing scheme. In another aspect, two experiments are performed over tropical regions with 25 km and 10 km resolution, respectively. Better overall representation of ocean thermodynamics is obtained in tropical regions with an increase of horizontal resolution from 25 km to 10 km. Most importantly, higher horizontal resolution produces more realistic features (e.g., amplitude and direction) of MJO-related convection propagation with higher pattern correlation coefficient.

In general, increasing the horizontal and ocean vertical resolution lead to subtle but significant changes in the mean climate (especially ocean thermodynamics) and intraseasonal variability. It should be mentioned that the effects of modifying model resolution are straightforward and model dependent. The finer-resolution simulations are not always superior, implying that the model physical and dynamical configuration at this resolution might not be optimal. Moreover, compared with observation, the coupled simulations still remain deficient such as weaker intensity of MJO-related convection propagation and shallower mixed layer depth. The RSM-ROMS might exhibit better performance than reported here using improved physics schemes (e.g., mixing, radiation, convection and cloud schemes) in the individual submodels.

To conclude, the benefits of air-sea coupling, increasing horizontal and ocean vertical resolution in RSM-ROMS have been well demonstrated in this thesis. It is verified that RSM-ROMS is an effective and powerful tool to simulate the natural climate system and conduct impact assessments. It not only greatly compensates the previous studies but also facilitates further development of the higher resolution version of RSM-ROMS.