A multi-level ocean mixed layer model resolving the diurnal cycle and its coupling application

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Introduction

The air-sea interaction is one of the most important processes in the climate system. Exchanges of momentum, heat, and mass between the atmosphere and ocean directly influence the ocean's upper mixed layer. The temperature and salinity of the upper mixed layer are often represented in ocean models by constant profiles representing the first several meters. However, in a snapshot view, the upper layer is constructed by overlaying several sub-layers developed at different temporal scales, including the diurnal, synoptic, and seasonal cycles. It is known that reasonable simulation the sea surface temperature (SST) diurnal cycle helps reproduce seasonal variation [*Chen et al.*, 1994; *Li et al.*, 2001; *Clayson and Chen*, 2002; *Bernie et al.*, 2005; *Mosedale et al.*, 2005; *Vitart et al.*, 2007]. Despite this, many coupled atmosphere-ocean models still exchange variables only once every several hours, which may poorly simulate the SST diurnal cycle. Even current models with higher coupling frequency still contain large biases in SSTs and hence also in surface fluxes, cloud and surface radiation. Even now, ocean mixed layer models with Realistic SST diurnal cycles are not extensively used in coupled climate models. Thus, the SST diurnal cycle's effect on climate has not been studied effectively [*Noh et al.*, 2011].

The model improvements and experiments

A multi-level upper ocean model (OML) was developed to more realistically resolve these interactions. The model is based on the one-dimension turbulence kinetic energy closure developed by Noh et al. [2011], and incorporates new numerical techniques and improved schemes for model physics.

Improvements

- A surface momentum flux penetration scheme to better depict velocity shear in the diurnal mixed layer;
- A solar penetration scheme in penetrating visible and near-infrared bands of solar radiation into the mixed-layer ocean;
- A scheme to resolve the cool-skin and warm-layer effects on sea skin temperature;
- A vertical grid stretch scheme to achieve higher near-surface resolution with fewer vertical levels;
- A trapezoidal time integration scheme for flexible time steps;
- A relaxation term of the previous daily mean difference between observed and modeled SST.

Experiments

- The control experiment (CTL) uses the model as originally presented by Noh et al. [2011]. The subsequent sensitivity experiments employ the modified model that consecutively incorporates *incremental* improvements of the momentum penetration (EXP1), the solar radiation penetration (EXP2), the cool-skin temperature (EXP3), and finally the numerical algorithm combining the daily SST nudging, the vertical grid stretch with N_z = 30, and the semi-implicit time integration with β = 0.4 and Δt=60s (EXP4). In experiments CTL and EXP2-3, the model adopts the original configuration with 150 levels, β = 0.5 and Δt=60s. CTL, EXP1 and EXP2 were driven by the IMET data. The final model, was independently evaluated on its ability to simulate U.S. coastal conditions in the extratropics in the case of NDBC data.
- The coupling experiments (WRF model coupled with ocean mixed layer model, i.e. OML, mentioned above) are set up in the region of the North West Pacific with 0.5 degree and 36 levels. The WRF model in control experiment (EXP5) is forced by OISST. The couple experiment (EXP6) employs OML model as the lower boundary, and updating SST within each time step, which cool water pumping was parameterized in the ocean mixed layer model. The simulating period is from 2 July,2015 to 22 July,2015, and two typhoons pass through.

Results and discussions

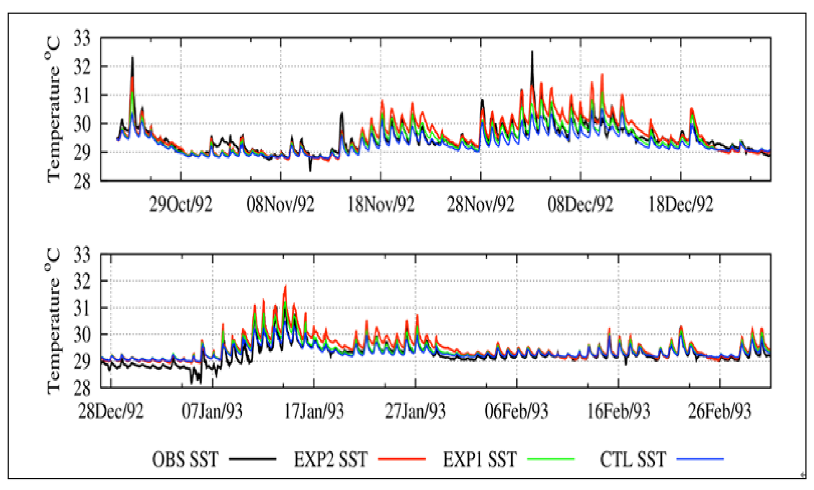

Figure 1 .Time series of hourly SST observed (*black*), SST as modeled in the control experiments (CTL, *blue*), the momentum penetration (EXP1, *green*), and the momentum plus solar radiation penetration (EXP2, *red*)

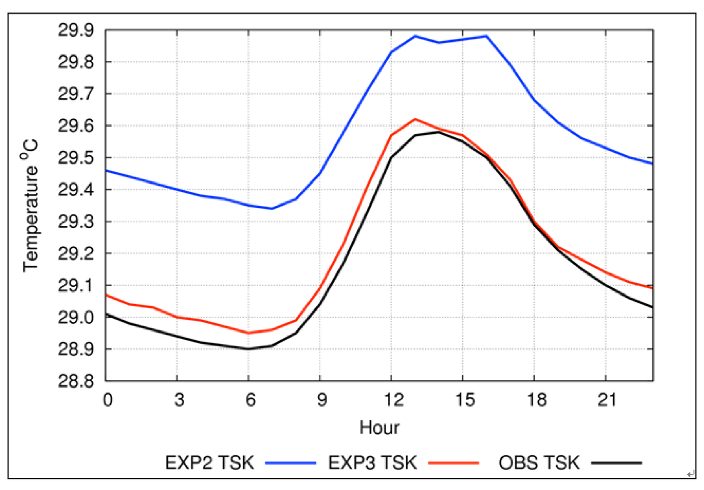

Figure 2.The average diurnal cycle of skin SST comparison observed (black) and simulated in the control experiments (EXP2, blue) and the cool-skin effect (EXP3, red)

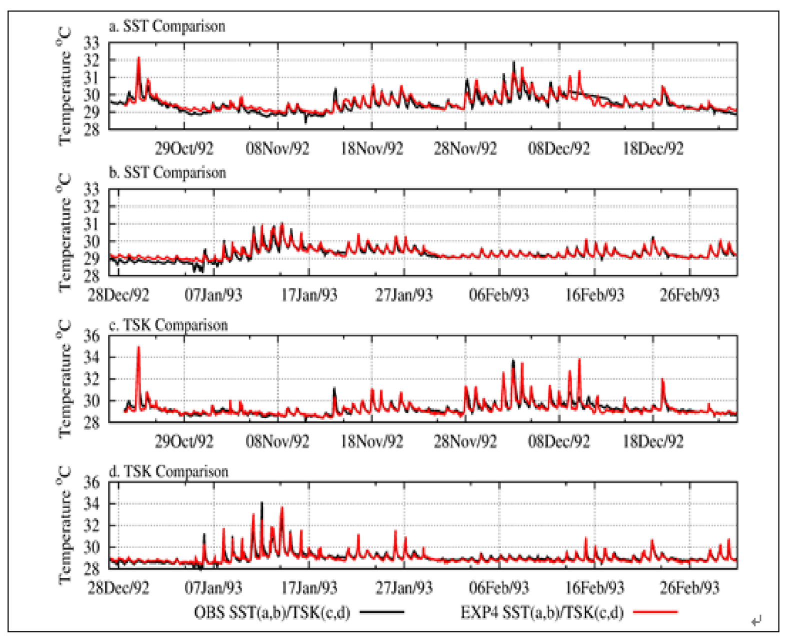

Figure 3. Time series of hourly observed SST and skin SST (black line) compared with the model experiment SST and skin SST (label EXP4, red line).

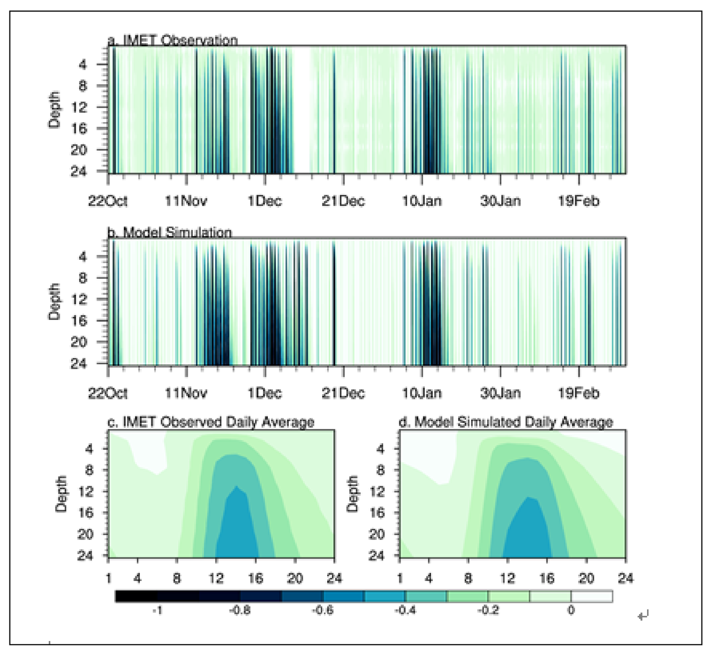

Figure 4. Temperature slice (variation from SST) comparison between EXP3(b,d) and IMET observations (a,c) in the whole simulation period (a,b) and the daily average (c,d).

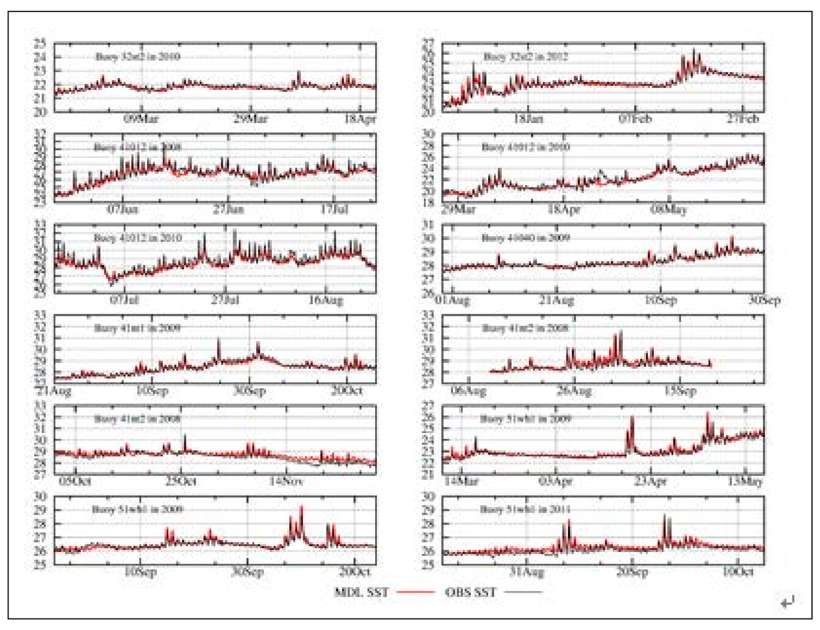

Figure 5. Time series of hourly SST variations at the select NDBC buoys, observed (OBS, *black*) and modeled (MDL, *red*).

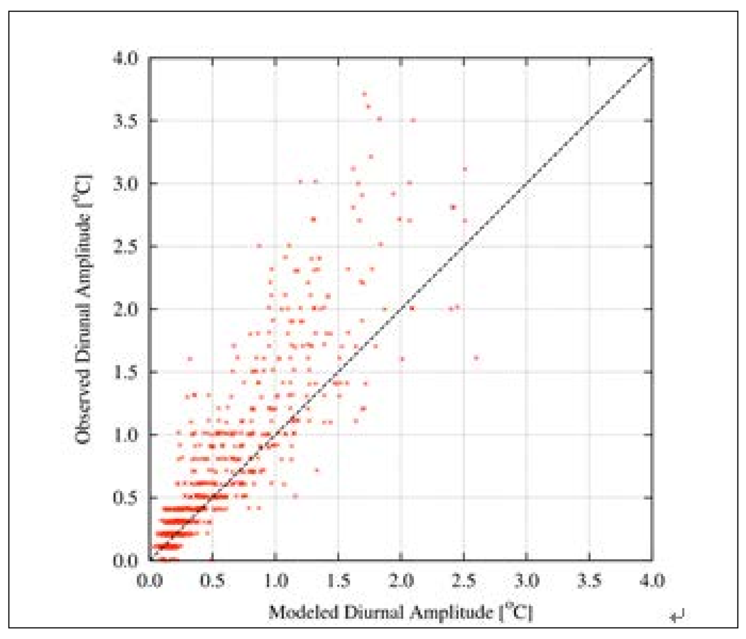

Figure 6. SST diurnal amplitude comparison between model and observation

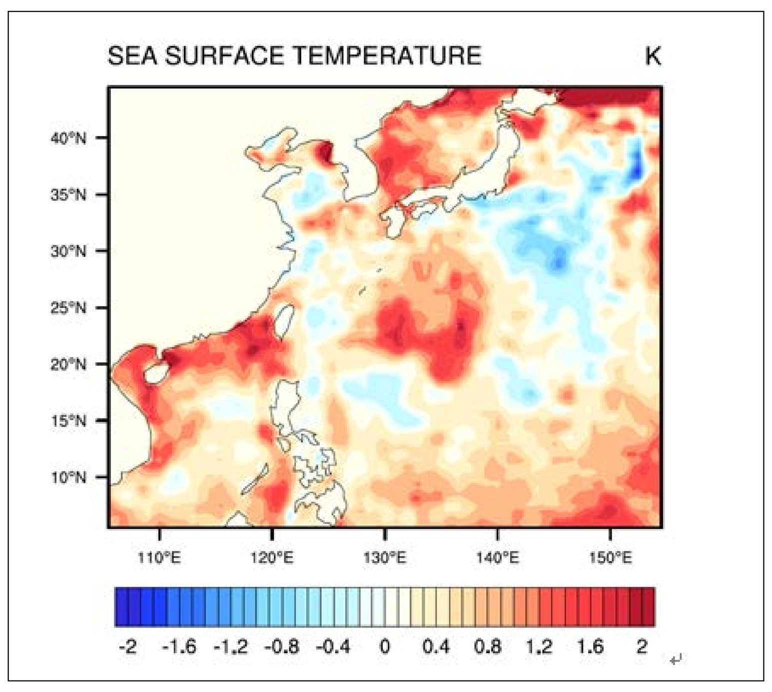

Figure 7. The difference of SST(EXP5-EXR6) integral average

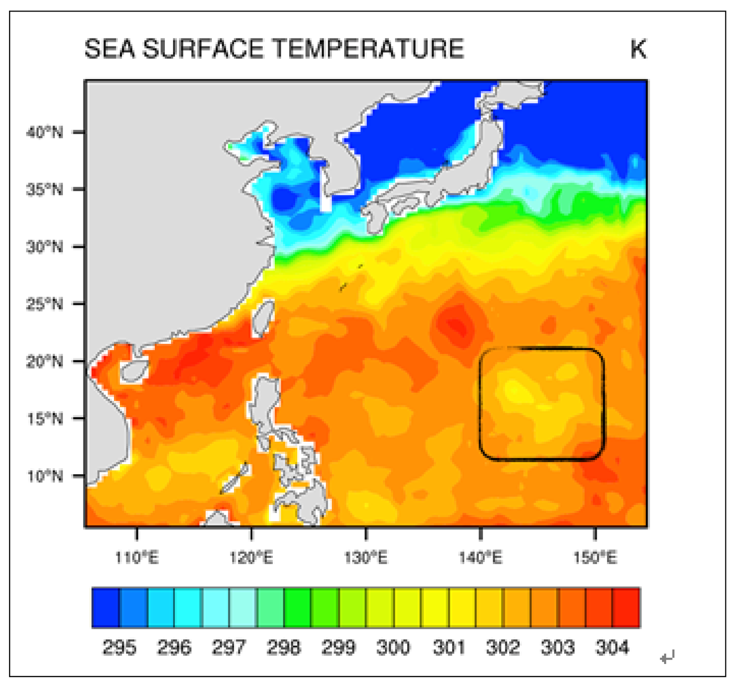

Figure 8. SST cooling simulation in the typhoon center

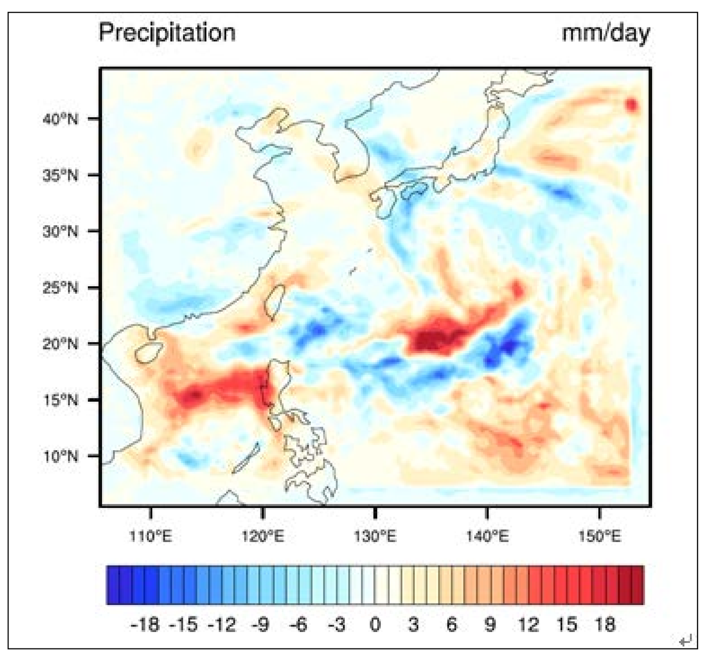

Figure 9. The difference of SST(EXP5-EXR6) mean precipitation

Summary and conclusion

- According the numerical experiments based on the TOGA-COARE IMET mooring buoy data and the validation by the U.S. coastal buoy observations, the results indicate that the new upper ocean mixed layer model improves the simulation of the diurnal cycle of SST and sea skin temperature in both phase and amplitude.
- After coupled the OML with regional atmospheric model WRF (the weather research and forecast model), the preliminary impact of SST diurnal cycle on regional weather/climate was studied with numerical experiments. That show that the SST diurnal cycle should be considered appropriately in the coupled model.